The Infiltration of a Lagoon Effluent for Final Waste Treatment

William B. Sherman

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THE INFILTRATION OF A LAGOON

EFFLUENT FOR FINAL WASTE TREATMENT

BY

WILLIAM B. SHERMAN

A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science, Major in
Engineering, South Dakota
State University

1975

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THE INFILTRATION OF A LAGOON

EFFLUENT FOR FINAL WASTE TREATMENT

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.

Thesis Adviser

Date

Head, Civil Engineering
Department

Date
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INTRODUCTION

Waste treatment is a means of maintaining or recovering one of man's most precious and abused natural resources—fresh water (1-765). All wastewater is eventually returned to the land or waters of the earth. Man faces the dilemma of deciding which of the contaminants of wastewater must be removed to protect the remaining fresh water sources (2-4). It has been stated that history has been written by man's need for fresh water (1-765). If this statement is true, the future of mankind depends upon his ability to protect and conserve the waters of the world.

The deterioration of water resources has been caused, at least partially, by priorities that placed economic well-being at the top of the list and environmental quality near the bottom (3). With the advent of Public Law 92-500 and stringent regulation of wastewater discharges, this priority list is apparently being readjusted.

In the state of South Dakota, many stabilization ponds exist. Few of these ponds are capable of producing effluents of consistently high quality. As the standards become more stringent, even fewer treatment facilities will be able to meet the requirements placed upon them. More advanced waste treatment of some form will be necessary.

In general, most advanced forms of waste treatment are expensive to institute and operate. South Dakota is not a state of great wealth or numerous population centers which makes most forms of advanced
treatment not only difficult to implement but also difficult to justify economically. South Dakota does, however, have a relative abundance of land at reasonable prices. Depending upon the soil type, land application of lagoon effluent may be a moderately priced method of consistently producing waste discharges of the required quality.

The study and literature herein described was instituted for the purpose of examining the application of the stabilization pond effluent at Madison, South Dakota, to a soil type present in that area. The literature emphasizes the importance of investigating the soil and water at each location because of variations witnessed in nearly every land application system that has been studied.

With much assistance from officials of Madison, South Dakota, a lysimeter study was performed at the Madison lagoon by passing stabilization pond effluent through local soil, collecting the resultant water to measure the rate of infiltration and analyzing the resultant water quality. In this way the following objectives were to be met:

1. To determine the feasibility of operating an infiltration-percolation basin in the Madison area based on limitations posed by infiltration rate.
2. To evaluate the water quality resulting from such a basin.
3. To determine if the water quality standards could be met by treatment with such a basin.
Several investigations have been conducted at South Dakota State University concerning the effects of the passage of treated sewage through soil (4, 5, 6, 7). These studies have contained extensive literature reviews on the topic of land application of wastes. Therefore, this literature review will be undertaken primarily to update previous reviews and to emphasize some of the major principles involved in the successful operation of soil filtration systems.

With increasing concern over the deterioration of surface waters, an incredible amount of research has been conducted in the area of land application of wastewater. With the advent of Public Law 92-500 and its goal "that the discharge of pollutants into the navigable waters be eliminated by 1985" (8), land application has been so emphasized that it could become one of the few legal methods of economical wastewater disposal allowed in this country (3).

Land application of wastewater can be accomplished through several methods, including crop irrigation, overland flow, and infiltration. Spray irrigation and flood irrigation are the principal methods of applying wastes to crops. Plants make use of both the water and nutrients present in the water when crop irrigation is used. This method has been used extensively in water-short areas. In overland flow systems waste is generally applied to the land by spraying and it then travels over land through grass fields or forested areas. This system has been used
to treat several industrial wastes. Over 50 percent of the applied wastewater is usually allowed to run off, thus returning a substantial quantity of water directly to surface waters. The design of infiltration systems, including septic tank, drain fields, and infiltration percolation basins, do not generally allow any runoff. The infiltrated water may be collected or allowed to percolate through the soil to the groundwater (9). The emphasis of this investigation will be placed on infiltration-percolation basins.

Although land disposal has not been extensively researched until the last ten-to-twenty years, it is not a new method of treating wastes. Thomas reports that in Prussia an irrigation system for waste disposal was instituted in 1559 and operated for over 300 years (9). In France as early as 1875 the Seine Pollution Commission expressed concern over the degradation of the Seine (3):

To prevent the pollution of the Seine by waters of the intercepting severs, the most economical, practical, and efficacious means consists of using them in irrigation of sufficiently permeable soil.

In the past, land treatment has been emphasized simply as a method of disposal, whereas in more recent research, emphasis has been placed on the use of soil as a treatment device that could ultimately allow reuse of the water. Early designs were based simply on the ability of the soil to hydraulically accept the quantities of waste applied. Investigations have today allowed us to recognize that the plant-soil complex will produce desirable quality changes as the water passes
through the soil if proper design loadings based on the soil and waste characteristics are used. Some of the benefits that may be derived from applying wastewater to the soil include (10):

1. Safe and satisfactory disposal of wastes that may otherwise result in increased stream pollution.

2. Conservation of high quality waters by reuse of infiltrated waters when and where possible.

3. Provision of valuable nutrients to croplands if used for crop irrigation.

Numerous investigators have reported that chemical, bacterial, and viral quality improvements have resulted when conventional wastewater treatment plant effluents were passed through the soil (11). Studies have further shown that those quality improvements are due primarily to filtration, biological degradation and adsorption that occurs as the water passes through the soil pores (12).

Thousands of highly efficient systems are today using soil as the final disposal medium for wastes and are achieving excellent results (3). One study conducted in 1972 located 316 municipalities in 13 western states using their city wastewater for crop irrigation. Another 225 infiltration and groundwater recharge systems were in operation in a total of 32 states. Industrial wastes were being applied to the land in 44 states by 1300 industries (9). It is obvious by this count in the United States alone that soil filtration is presently an important
method of wastewater purification. In light of future requirements under Public Law 92-500 and groundwater shortages in some populated areas, the importance of soil infiltration for treatment and groundwater recharge is not likely to subside.

There are three basic steps involved in determining the ability of a given soil to assimilate wastewater. First, one must examine the wastewater to determine the chemical and physical quality and the required removals of pollutants. Second, the soil must be characterized as to type and composition. Finally, the water and soil must be combined in order to examine the actual chemical interactions that occur and the resultant water quality (12). The results of these steps may be used to determine a satisfactory soil for use in a proposed soil filtration system. Obviously the soil chosen must provide treatment plus a reasonable infiltration rate.

Infiltration Rates and Clogging

Several important points must be recognized when considering land application as a method of waste treatment. One consideration of primary importance is whether the infiltration rates obtained will be high enough to allow economical operation of a soil filtration system. Tremendous physical and chemical diversity is found in differing soil types which results in varying abilities of different soils to accept and purify polluted waters (13).
Infiltration rates reported in the literature have varied from 0.09 to 200 feet per day (11). The rate at which water will pass through soil is based upon many factors including soil permeability, permeability of the surface layer, moisture content of the underlying beds, basin slope, depth of water in the basin, water temperature, quantity of suspended solids present and other undefined factors (11, 14, 15). It may be possible in open basin design to slightly alter the infiltration rate by surface preparations or partial dewatering of the underlying beds, but basically the rate is still a function of the geological conditions prevailing in the area (11).

The natural infiltration rate of the soil can be decreased by several factors when the soil is being flooded by polluted waters (11, 15). If initially the groundwater table is high in the area of an infiltration basin and inflow is great, the groundwater mound may rise to the bottom of the basin. This groundwater mound will decrease the infiltration area available, thus decreasing the rate. Soil clogging may also reduce the natural percolation rate. There are three ways in which clogging usually occurs: physical clogging of the soil pores with particles, biological clogging by algae or other microbial action, or chemical clogging due to soil-water reactions (11, 15).

Relative to physical clogging, the important variables appear to be the distribution of suspended particle size with respect to the soil pore size and the concentration of material in suspension (11, 16).
The rapid rate of physical clogging that occurs when high suspended solids concentrations are present has been attributed in part to the highly organic nature of the suspended material which can be readily compacted, thus increasing the clogging effect (15).

Numerous studies have attributed clogging to biological activities. Biological clogging has usually been found to occur when anaerobic conditions prevail in the soil. Investigations have indicated in some cases that infiltration rates have been decreased because of the gas production associated with denitrification in anaerobic soils (15). The nitrogen gas is entrapped in the soil pores, thus interfering with the water flow (17). Another source of biological clogging may be microbial polysaccharides. These polysaccharides and the bacteria that produce them are commonly found in trickling filters and have been found in soil infiltration systems (18). As anaerobic conditions develop during infiltration, the degradation of the polysaccharides is inhibited and they build up, which eventually clogs the soil (11, 18, 19).

Chemical clogging is rare unless the water contains a high sodium concentration. Interaction between dissolved salts in the water and the soil results in decreased pore diameters, thus resulting in decreased soil permeability (15). If sodium is present in high concentrations and is applied to soils with high clay content, deflocculation
of the clay may occur, leaving the soil tightly compacted and nearly impermeable (20).

Physical and biological clogging have, for the most part, been found to be surface sealing phenomena (11, 15, 19). This phenomena may be indicated by an increase in water tensions below the surface layer as clogging occurs and a decrease in water content of the upper soil layers as inundation continues (14, 16). Chemical clogging may be found to occur at different depths, depending upon soil and water characteristics (15).

Soil clogging must be controlled and high infiltration rates must be maintained if one is to successfully use soil percolation over extended periods of time (15). Care must be taken when designing and operating any infiltration system to avoid as much clogging as is practicable.

In Peoria, Illinois, a permanent loss of infiltration rate resulted when a very coarse surface layer was used and small particles were allowed to penetrate deep into the lower soil profile (11, 15). This points to the fact that a coarse-to-fine soil profile is not the most desirable. For infiltration with low quality water, the finest material should be at the surface. In this way, if particles do penetrate the surface layer, more than likely, they will pass through the lower, coarse layers. In this situation the clogging is limited to the upper soil layers which
generally can be replaced or otherwise restored to renew the infiltration rate (14).

In one study it was found that where sandy soil overlies sand and gravel, suspended solids concentrations above 50 milligrams per liter (mg/l) will produce a need for occasional cleaning or removal of a thin surface layer (14). Another study, using a similar soil configuration indicated that no significant build-up of organic matter occurred deeper than four inches into the soil (21). These findings indicate that physical and biological reductions in the infiltration rate may be treated by occasionally skimming a thin layer from the surface of the infiltration basin. Waters with suspended solids concentrations of less than 10 mg/l have shown little tendency to inhibit infiltration even after months of continual inundation, thus precluding surface skimming (15, 16).

As described previously, clogging is generally a surface sealing phenomenon. If the basin is allowed to dry after significant reductions in the infiltration rate have occurred, the accumulated silt and algae deposits on the soil surface dry and crack. The infiltration rate will then be restored. The restored rate has been found to be nearly as high as the original rate, unless chemical or some other form of deep clogging has occurred (11, 15). This intermittent flooding or dosing of a basin is also beneficial in that it prevents the production of mosquitoes and midges in the quiescent water (22).
One study using water with large quantities of algae found that the mat formed by the algae and other suspended material on the soil surface became buoyant and floated to the surface, resulting in a continued high rate of infiltration. It was believed that the buoyancy was the result of oxygen produced by the algae in the sealing mat (15). These findings have not been substantiated by other studies which indicate that algae tend to continue sealing until infiltration has nearly ceased.

The determination of the optimum schedule for dosing infiltration basins may best be determined by experimentation at each site. At the Flushing Meadows Project near Phoenix, Arizona, alternate inundation and drying periods of two to three weeks have maintained the infiltration rates and hydraulic conductivity of the aquifer relatively constant since 1967 (14). Another study reported that primary effluent applied for two hours each day to fine sand did not clog the sand during a year of experimentation (23). It has been suggested that long-term declines in infiltration rates can be avoided if regular "dry-ups", occasional long "dry-ups", and occasional cleaning of the basins are practiced (14).

Other possible methods of slowing the decline of infiltration rate have been suggested. Two that have been researched include the use of a thin gravel layer at the soil surface and the cultivation of the basin. Investigations into relative rates have found that the highest filtration rates were produced by vegetated surfaces, followed by bare soil, and finally by soil covered with a gravel layer (14).
As previously discussed, the gravel at the surface may contribute to permanent reductions in infiltration rates. Another problem with the gravel layer is that the rate recovery that results when the soil is allowed to dry occurs much more slowly than it does with finer grained soil surfaces (11, 15). This has been attributed to a mulching effect created by the gravel, resulting in a reduced rate of decomposition of the clogging materials (14).

Vegetated basins usually exhibit rates greater than non-vegetated basins and often make use of grasses because of their ability to withstand extended periods of flooding. The higher rates were attributed to the removal of suspended material from the water by grass filtration and also to the passage of water into the soil by way of channels caused by roots in the root zone (14). Paddy rice was also found effective in sustaining high infiltration rates. In this case it was concluded that the soil remained aerobic for much longer periods because of oxygen released from the roots of the rice (11, 18). It is possible that vegetation in large basins could be harvested and sold thus defraying a portion of the operating expenses (14).

It must also be considered that over the whole year the total infiltration would probably not be appreciably affected by vegetation or the lack of it. It is reasonable because greater depths and longer inundation periods may generally be used in bare soil basins especially in the spring while the vegetation is developing a mature stand.
Therefore, for ease of operation and high, long-term infiltration rates, deep, non-vegetated basins would probably be the best basin design.

Removals of Microorganisms

A great deal of study has been undertaken to determine the suitability of using wastewater for irrigation of agricultural land. These studies have dealt in many cases with the likelihood of pathogenic organisms contaminating the crops or the groundwater. In general, the investigations have shown that there is little chance that pathogenic organisms can penetrate truck crops, which are often eaten raw (10). The literature also suggests that it is not likely that pathogens will enter the groundwater if the waste percolates through at least two feet of soil (10, 24, 25).

Both pathogenic bacteria and viruses are present in human wastes (1). The removal of these organisms is difficult and is, at best, poorly accomplished by conventional waste treatment (24). To determine the likelihood of pathogenic microorganisms, fecal coliform organisms serve as an indicator (26). Large numbers of fecal coliforms are present in the feces of warm blooded animals, and it is relatively easy to test for their presence in water (1). If the purpose of infiltrating a given wastewater is groundwater recharge or if portions of the water may be reused, the removal of pathogenic organisms is of prime importance.

Bacteria are generally removed by the straining effect of the soil and natural die off. As the inundation time increases, the fecal
coliiform density at a given level may be expected to decrease. This reduction in coliform density is due to fine straining resulting from surface clogging, and to competition with other organisms present in the upper soil layers (27). If bacteria are not strained from the water at the surface, they are rapidly adsorbed by most soils and die off because they compete poorly with the organisms present in the soil and water (28).

Results from the Flushing Meadows Project indicate nearly complete removal of fecal coliforms in the first two feet of sandy soil (27). Another study using sand as the filtering medium found 99 percent removals of fecal coliforms within two feet of the surface. When the same water was applied to a silt loam soil, 100 percent removals of the indicator bacteria were noted in the top eight inches of soil (28). These results seem to indicate that bacteria are readily removed from water by soil percolation in relatively short distances.

Viruses, unfortunately, are not as easily removed as bacteria. They are much smaller than bacteria and can survive in water that is nearly free of nutrients. Viruses do not multiply in water since they must be within other living cells for replication to take place (24). Over 100 different viruses are known to be excreted with the feces of man and there is little doubt that more exist that are as yet unknown (10, 25). Due to these factors the detection of virus particles is expensive and requires significant amounts of technical expertise (24).
Virus removal in soils may be due to cation exchange or physical adsorption. Surface straining is very unlikely to remove significant numbers of viruses due to their minute size (24). Nearly all reported removals have been attributed to physical adsorption and only in soils with high cation exchange capacities have significant removals been credited to cation exchange (25, 29).

Soils with high clay contents have been found to remove viruses more rapidly than soils lower in clay presumably because of the greater overall surface area available for adsorption and the high cation exchange capacity generally exhibited by clay soil (29). Agricultural-type soils have exhibited over 99 percent removals when virus laden water passed through 15 to 20 inches of soil (25). Although virus removals are good, studies generally indicate that prolonged inundation with water containing high virus concentrations will eventually result in a breakthrough of organisms (29).

Between 1938 and 1960, 555 outbreaks involving 137,304 cases of water-borne disease were reported in the United States alone. All were attributed to the contamination of public or private water supplies by waste (24, 25). Several of the outbreaks were due to well contamination by septic tank drain fields. The movement of the infecting organisms was found to be anywhere from a few to several hundred feet. Intensive investigation of these outbreaks resulted in the discovery that in nearly every case the contaminated water did not pass through the soil
but rather through cracks present in fractured rock that connected the drain field and water supply (11, 24, 25, 28). This may serve as an illustration of the care that is necessary when selecting the site for any land disposal system.

**Nutrient Removals**

Nitrogen, phosphorus and carbon are the primary nutrients required by plants and microorganisms for growth and metabolism. Excesses of these nutrients added to surface waters by waste treatment plant effluents have resulted in serious degradation of many lakes and streams (2).

Land application of wastes has been shown extremely effective at removing the carbon from the waste, a large portion of which results when suspended solids are removed (23, 27). The conventional treatment methods for the removal of nitrogen and phosphorus have been somewhat expensive. Land application may be less expensive but nitrogen removals are not always easily attained.

Ideally, the removal of nitrogen and phosphorus could be obtained by the application of nutrient laden water to crops at optimum dosages for crop production. The result would be the removal of nitrogen and phosphorus by plants and a true recycling of the nutrients (23). This recycling of nutrients has been tried at Pennsylvania State University; Melbourne, Australia; Muskegon, Michigan and many other places with varying degrees of success (9). Other studies have shown that nutrients
can be removed in the soil without crops (27, 30). Whether the removals are to come about by recycling the nutrients or otherwise, it is important to the preservation of our surface waters that the removals occur.

**Nitrogen.** As mentioned, nitrogen can be removed effectively by using the nitrogen-containing water to irrigate crops. The major disadvantage of this method is that wastewater application rates must be low if significant removals are to be obtained (30). Due to the required low rates, large areas may be necessary for proper application that can be cost prohibitive if alternate solutions are possible.

Obviously the most desirable nitrogen removal mechanism is one that changes the nitrogen into a relatively stable form. This done, one no longer needs to concern himself with serious groundwater contamination or eutrophication. One possible method of accomplishing this is by denitrification (30).

Denitrification in the soil is a complex process requiring the existence of some restrictive conditions. Most of the nitrogen in treated sewage is still in the ammonia form (31). If the sewage is added to the soil, the ammonia is adsorbed by the soil particles. If aerobic conditions exist or if the flooding is stopped and aerobic conditions reoccur, the ammonia may be converted to the nitrate form by nitrification. When the soil is again inundated, the nitrate is leached away and ammonia is once again adsorbed from the sewage. Once anaerobic conditions return, nitrates passing through the soil can be
denitrified, and nitrogen gas is released to the atmosphere, thus a portion of the nitrogen initially present in the waste is removed (27, 30, 32).

Overall nitrogen removals of 30 percent have been accomplished when long inundation periods have been used (27, 32). When flooding is begun, about the first 10 percent of the renovated water will contain a high nitrate concentration because of the leaching of nitrates through the soil. The high nitrate water is called the nitrate peak (9, 27, 30, 32). If the nitrate peak can be collected and passed through the soil after anaerobic conditions have been re-established, significant removals of nitrogen can be obtained (30, 32). Nitrogen removals of over 67 percent can be maintained in sandy soil if the nitrate peak is recycled (32).

Long inundation periods have been found most effective in removing nitrogen by denitrification. Short, two-to-four day inundation periods followed by drying periods of the same length have not been found to accomplish much denitrification. During these short periods some ammonia may be nitrified but anaerobic conditions are either short or non-existent, and nearly all the nitrate leaches through the soil which may cause serious problems should it reach the groundwater (30). If two-to-three week wet periods followed by dry periods also of two-to-three weeks are used, essentially all the ammonia is converted to nitrate and leached, forming the nitrate peak. During inundation, anaerobic
conditions occur allowing denitrification of nitrates (27, 32). Thus, long wet and dry periods provide much more effective nitrogen removals especially if the nitrate peak is recycled.

Three major difficulties exist when attempting to establish a denitrifying system with secondary effluent. These include (30):

1. The oxidation of the ammonium ion to nitrate,

2. The passage of nitrates through an anaerobic zone after nitrification,

3. The provision of an adequate energy source in the anaerobic zone to support denitrifying organisms.

Nitrification, as already mentioned, can generally be accomplished by intermittent flooding (30). Problems can occur, however, if too much ammonia is adsorbed in the soil. When the soil dries, only a limited amount of oxygen can enter the soil, thus limiting the quantity of ammonia that can be nitrified. If more ammonia is continually added to the soil, an ammonia build-up will occur, resulting in less adsorption of ammonia and higher ammonia concentrations in the renovated water. To prevent ammonia from building up in the soil, an optimum flooding and drying sequence must be determined experimentally. A build-up can be reversed by shortening the inundation periods, thus allowing more oxygen to enter the soil relative to the amount of ammonia being adsorbed (27).

Another limit to denitrification is that only nitrates passing through an anaerobic zone will be nitrified. Since large quantities of
nitrates are leached from the soil before anaerobic conditions are established in the soil, it appears that significant amounts of nitrogen will be removed only if the high nitrate water is recirculated (27).

The third problem is due in part to the fact that most of the carbon present in the waste is removed during primary and secondary treatment processes because there is simply not enough carbon in the water by the time it reaches anaerobic soil (30). Denitrifying organisms require approximately one milligram of organic carbon per milligram of denitrified nitrogen (27). Most of the organic carbon in the waste is oxidized by aerobic bacteria long before the anaerobic soil zone is reached. Thus, the organic carbon content of the waste to be applied to the soil may limit the amount of denitrification possible in the soil.

Several methods of stimulating denitrification have been practiced successfully. According to reports, the addition of soluble carbon, such as glucose, to the waste prior to infiltration and the recycling of the nitrate peak have served as the most effective stimulants of denitrification. Removals of 80 to 90 percent have been witnessed when soluble carbon was added and 75 to 80 percent of the total nitrogen has been removed when nitrate peaks have been recycled. Vegetation, however, may also increase denitrification in the root zone. Organic carbon is added to the soil by the roots of live plants and is also added by decaying roots and plant residue. One study reports that by reducing the
infiltration rate by 50 percent, removals of up to 80 percent have been obtained (27).

It is known that algae remove significant quantities of nitrogen from water. If the waste to be applied to the land is drawn from a stabilization pond, algae are usually present in abundance. Strumm and Morgan reported that the bulk of nutrients from wastes can be removed by algae in stabilization ponds provided that the algae can be removed (33). This author could find little research on the topic but land application does provide an efficient and economical method of removing the algae. Such a study would lend itself well to an M.S. thesis and could provide valuable information on nitrogen removal from stabilization pond effluents.

**Phosphorus.** Basically there are only two forms of phosphorus that are of interest to the sanitary engineer. These are the inorganic orthophosphates and polyphosphates (31). Most of the phosphates in waste treatment plant effluents are orthophosphates which are the most available nutrient form (27). The polyphosphates gradually hydrolyze in aqueous solution to the orthophosphate form (31). Phosphorus is generally considered the limiting nutrient that contributes to algal blooms in surface waters (33).

Phosphorous retention in soil is attributed to precipitation of insoluble complexes from solution or to adsorption by the soil (34).
The reactive surfaces of iron, aluminum, and calcium in the soils adsorb and precipitate soluble phosphates (35).

At Santee, California, 62 pounds per day of phosphorus was found in the waste treatment plant effluent while only 1.4 pounds per day of phosphorus was found in the renovated water (11). At the Flushing Meadows project, removals are still stable after five years of operation and the application of approximately 43,000 pounds of phosphorus per acre.

Studies have shown that most of the plant-available phosphorus is removed from the water within the top centimeter of the soil. After the thin surface layer, the phosphorous concentration in the soil solution rapidly decreases with depth. As the quantity of phosphorus in the applied water is increased, the layer of greatest phosphorous concentration in the soil tends to increase in thickness (35).

Apparently the movement of phosphorus through the soil may be described as a progressive adsorption by successive soil layers. If the phosphorous content of the soil exceeds equilibrium, phosphorus will leach downward until the equilibrium is not exceeded. It has been noted that phosphorous concentrations many times the normal concentration found in wastewater do not generally cause the equilibrium to be exceeded (36).

Slower infiltration rates have been found to allow more phosphorous removal and the removals occur closer to the surface. This increased phosphorus removal is simply due to the longer contact time between the water and soil (36). In sandy soil, removals are generally lower than
those in fine-grained soils but tend to increase with the distance the water travels through the soil (27).

When considering all of the possibilities presented by soil for the treatment of polluted waters, care must be taken to avoid past errors. Surface waters have been abused by exceeding their natural assimilative capacities until, in some cases, the stream or lake is nearly useless except to carry waste. A similar error must be avoided when dealing with the soil as the treatment media. Even though research has been extensive in the area of land application of wastewaters, continued efforts to further our knowledge of the capacity of the soil to purify used water are necessary (12).
This study was conducted at the Madison, South Dakota, waste stabilization pond. The city of Madison has been and remains extremely interested in upgrading the degree of treatment given their wastewater. The desire of the city officials to produce a high quality effluent is based partially on the need to meet state and federal regulations regarding the quality of the effluent and receiving waters and is also due to concern over the deterioration of the water quality of Lake Madison. The stabilization pond effluent enters Park Creek which flows into Lake Madison less than two miles downstream of the outfall.

The city operates a single-stage, trickling-filter wastewater treatment plant followed by a stabilization pond. The plant was designed to treat 1.25 million gallons per day (MGD) and presently treats approximately 0.65 MGD. The stabilization pond is fed by a force main approximately one-half mile in length. The lagoon covers about 23 acres and is maintained between two and one-half and three feet in depth. The detention time in the pond is sixty-to-ninety days.\(^1\) Figure 1 shows the location of pertinent points in the lagoon area.

The majority of the equipment used in the study was constructed for use by Tiltrum (7) in a prior investigation. The apparatus used in the study included:

\(^1\)Personal conversation with Dale Carlson
Figure 1. Location map of points pertinent to the investigation.
1. Two 55 gallon barrels filled with compacted soil
2. A distribution box
3. A funnel and hose to provide influent
4. Outlet hoses
5. Catch pails for collection of sample bottle overflow
6. Sample containers

The barrels served as the lysimeters. In Tiltrum's study the barrels were different colors which, as was pointed out, may have accounted to some degree for inconsistencies in his results. To avoid this possible source of error the two barrels were painted yellow.

The distribution box was placed directly between the barrels at an elevation that supplied the desired water level in the barrels. The distribution box served two main purposes, the primary one being to divide the flow, diverted from the lagoon, to the barrels and to an influent sampling point. The box also provided continuous, uniform inundation of the barrels without creating turbulence at the soil surface. Such turbulence could have had an effect on the rate of clogging at the soil surface by disturbing the solids from the influent that clogged the pores in the soil.

The funnel and hose apparatus provided an excellent and simple method of diverting a small quantity of lagoon effluent to the lysimeters. The funnel was mounted at the lagoon overflow weir so as to catch a small quantity of the overflow and direct it into a hose. The hose itself was
about 100 feet long. It was connected at one end to the funnel, passed through the lagoon outfall, and was connected at the lower end to the distribution box.

The remaining equipment was used for sampling purposes. The sample bottles were empty nine-pound acid bottles which, during filling, were placed in the catch pails. The catch pails were dug into the ground directly below the lysimeter outlet hoses. Any effluent that overflowed the sample bottles was caught by the pails, thus an accurate measurement of effluent volume could be obtained for infiltration rate calculations. Two of the outlet hoses were short hoses attached to the side of the lysimeters about an inch from the bottom edge of each barrel. These hoses provided the lysimeter effluent samples. Another hose was attached to the distribution box and provided influent samples and wasted excess influent to Park Creek. Figures 2 and 3 show the position of the barrels and the arrangement of the sampling equipment.

In early July of 1974, after discussion with William Heyer, Madison City Engineer; Arnold Baltzer, Madison Sewer and Water Commissioner; and Dale Carlson, Madison wastewater treatment plant operator, the project was authorized by the city commission. Assistance was pledged by Mr. Carlson, and on July 17th the preliminary work began.

The first step in the set-up procedure was to provide the lysimeter site with influent flow. The funnel was attached to the overflow weir, and the hose passed through the outfall line to the lysimeters. Before
Figure 2. General view of the investigation site
Figure 3. Position of sampling apparatus with respect to the lysimeters
exactly locating the lysimeters, the quantity of flow at several elevations at the site was checked to provide assurance that enough water would be available to allow continuous inundation of the barrels. The proper elevation of the barrels was decided on, based upon exaggerated infiltration rates, and the barrels were located accordingly.

Next, the type of soil to fill the lysimeters had to be selected. For this task, the Soil Survey of Lake County South Dakota (37) compiled by the United States Department of Agriculture was consulted. Upon examining the soil maps of the area surrounding the lagoon, a Dempster series silt loam was chosen to fill the barrels. The choice was based upon availability of the soil and the fact that the areas where this soil is located are generally flat or gently rolling, thus suitable for possible future infiltration basins. The soil maps indicated that there were very few large areas of any given type of soil adjacent to the lagoon but that some areas of primarily Dempster soil did exist nearby.

It was concluded prior to the outset of the investigation that duplicate barrels were not necessary. For this reason the soil to fill the barrels was chosen from two horizons of Dempster series soil. The root zone or approximately the top six inches of soil was discarded. Soil was taken from the horizons six-to-eighteen inches deep for use in one barrel and eighteen-to-thirty-six inches deep for the other barrel.

The soil from the six-to-eighteen inch horizon was placed in the southern-most barrel. This soil may be characterized as dark
grayish-brown silt loam of weak, fine, granular structure. It may be found to be hard when dry and slightly sticky when wet.

The other soil was placed in the northern barrel. This horizon was more coarse grained, brown to pale brown, and some small patches of clay were evident. It could be expected to be hard when dry and slightly sticky when wet. The soil structure was generally weak and medium to very coarse (37).

Prior to placing the soil in the barrels, a coarse screen supported by wooden slats was placed in each barrel. These screens supported approximately four-to-six inches of coarse sand and gravel. The screen arrangement provided an open area which enhanced the effluent flow to the outlet, and the sand and gravel layer prevented the fine soil particles from being washed out with the effluent.

The soils were then added to the respective barrels in approximately three inch lifts. Each lift was uniformly compacted as advised by Johnson (6) to avert possible short-circuiting of the water along the periphery of the barrel. The surface of each lift was loosened by scratching to prevent a possible impermeable boundary layer in the barrel. Each barrel was filled in this manner to approximately one and one-half inches from the barrel rim, resulting in a soil column of about 24 inches.

Once the barrels were filled with soil, the next step was to start water flowing through the barrels. It is known that air entrapped in the soil pores tends to interfere with infiltration. It is not likely
that this entrapped air would have been pushed down through the soil and out the sampling hoses had the barrels been inundated from the top (17). Based on this knowledge the soil was saturated by connecting the influent hose to the lysimeter outlet at the bottom of the barrel and filling the lysimeter from the bottom. It was believed that this would drive most of the entrapped air upward through the soil to escape to the atmosphere.

Upon completing the saturation of the barrels, the hoses were attached and the influent was applied to the soil columns. The barrels were allowed to operate for two days to assure that the water being sampled had percolated through most of the column.

The first samples were collected August 8, 1974. Initially the sampling schedule was arranged so that morning and evening samples could be collected and then transported to the Sanitary Engineering Laboratory at South Dakota State University for analysis. This arrangement allowed the investigator to receive two samples for analysis with each trip between Brookings and Madison. The operators of the Madison sewage treatment plant assisted in the placing and pick-up of the sample bottles.

The samples collected from the lysimeters consisted of the entire flow during each sampling period, while the influent samples were simply grab samples taken from the distribution box waste line. It was concluded that grab samples of the lagoon effluent would satisfactorily
represent the lysimeter influent quality. This assumption was based on
the knowledge that the lagoon effluent would be of a generally consistent
quality over the short time periods involved in this study. The dates
upon which samples were taken and the times of sampling are shown in
the appendix with the data.

After the tenth sample, the infiltration rate was so low as to pre-
clude sampling twice per day. Each sample obtained was analyzed in the
laboratory, and infiltration rates were calculated from the measurements
of the total volume of wastewater that had passed through the barrels.

Bacteriological samples were collected six times during the study,
and the analyses were performed by the investigator in a microbiology
laboratory with the assistance of Dr. Paul Middaugh. The bacteriologi-
cal samples were collected on the dates indicated by the data in the
appendix.
DESCRIPTION OF THE ANALYSES

The analyses performed on the samples were only those consistent with the objectives of the investigation. Those tests, therefore, should have made it possible to:

1. Determine the feasibility of operating an infiltration-percolation basin in the Madison area—based on required economical infiltration rates.

2. Evaluate the water quality resulting from such a basin.

3. Determine if the standards could be met by the use of such an infiltration-percolation basin.

To meet the first of these objectives, it was necessary to perform sodium, hardness, and suspended solids (SS) tests. The sodium and hardness tests are used to calculate the sodium adsorption ratio (SAR) which indicates the potential of a water to cause chemical soil clogging. The SS concentration can help predict the likelihood of physical clogging.

The method used to determine the sodium concentration was flame photometry. A Coleman Model 21 flame photometer was used in the testing. High concentrations of sodium generally occur in wastewater when sodium exchange water softening is practiced extensively (31), as is the case in Madison, South Dakota.

Hardness was determined in two parts. The total hardness and calcium hardness were both tested in order to calculate the SAR. Both
total and calcium hardness were determined using the EDTA titrametric method which was modified by using prepared chemical additives produced by the Hach Chemical Company. This method assumes the presence of only calcium and magnesium as the hardness-causing ions, which in most instances is reasonable. Other possible hardness-causing ions such as iron, strontium and manganese may be present but generally in only very limited quantities (31-349). Thus calcium hardness was determined by one test and magnesium hardness was assumed to make up that portion of the total hardness not accounted for by the calcium.

The SAR which may be calculated using the tests described above, is used basically to classify irrigation waters. When a given water exhibits a high SAR, it is generally considered to be of poor quality for irrigation because it has a tendency to break down the granular soil structure, causing the soil to become nearly impermeable (20-109). Thus, one may immediately understand the importance of the sodium and hardness tests in meeting the final objective.

The quantity of SS present in the influent also affects the infiltration rate through a soil. In his studies, Rice found that the SS concentration may be the single most important factor in the rate at which soil clogging will occur (15). The method used in this study to determine the SS concentration is the method described as the determination of nonfilterable residue by the glass fiber filter (26). Standard procedures were followed, but determination of the volatile portion of
the solids was not considered valuable to the investigation and was therefore excluded.

Eight tests were conducted in order to meet the second objective: Biochemical oxygen demand (BOD), SS, total residue, specific conduc-
tance, fecal coliforms, nitrates, total Kjeldahl nitrogen (TKN) and phos-
phorus.

The BOD test is used in nearly all cases when a check is being made on the efficiency of a wastewater treatment system (26). The test re-
sults indicate the quantity of oxygen that would be required by bacteria in order to stabilize the organics present when a given waste is dis-
charged into a body of water in which aerobic conditions exist (31-394). The test was conducted using the five-day procedure outlined in Standard Methods (26). Since the samples were treated sewage, no seeding of the dilution water was necessary.

The SS content, on top of being an important indicator of probable soil clogging, is also used extensively to determine waste strength and the efficiency of treatment units (31-441). The test procedures, as previously described, can be found in Standard Methods (26).

The total residue test was also conducted by the standard pro-
cedure of evaporating the water portion of the sample. Actually, this test is of little value in determining the effect an effluent will have on a receiving stream (26), but may be useful in this study as an in-
dication of the total solids removed or added by the soil.
The specific conductance of a solution may be described as the conductivity of one cubic centimeter of the solution (31-184). In other words, it is a measure of the ability of a solution to carry an electric current (26). The test results are related to the concentration of ions present in the water sample and are often used to give a quick estimate of the concentration of dissolved solids in the water. For this reason the conductivity is generally used in order to classify a water according to its salinity hazard. The specific conductance is one measure of the irrigation suitability of a water and may be used in conjunction with the SAR to determine whether or not the water will be detrimental to either the soil or the crops to which it will be applied (20). The method used to evaluate specific conductance may be found in Standard Methods (26). The apparatus used included a Wheatstone bridge developed by Industrial Instruments Incorporated and a Model 3401 conductivity cell manufactured by the Yellow Springs Instrument Company.

The test for fecal coliforms was run intermittently throughout the investigation. Fecal coliforms are found in the intestines of warm-blooded animals and are therefore used as indicator organisms to determine the likelihood of the contamination of water with pathogenic microorganisms (1-746). The samples for this test were collected separately in small sample bottles that had been sterilized by being placed in an autoclave for 15 minutes at 121°C. The test method used, as
described in *Standard Methods*, was the multiple-tube fermentation technique, using EC broth as the growth medium (26).

The nitrate, TKN, and phosphorous tests were all made using a Technicon Auto Analyzer. The procedures for performing those tests are not found in *Standard Methods*; however, they are accepted for use by the United States Environmental Protection Agency (EPA) and are described in the EPA publication entitled *Manual of Methods for Chemical Analysis of Water and Wastes* (38).

The determination of nitrates by the auto analyzer also includes any nitrite which may be present in the water (38-207). It has been found that nitrite concentrations in most waters are insignificant compared to the nitrate concentration (31-432). Nitrate determinations have historically been one of the most difficult determinations to perform accurately (31-430). This is unfortunate since nitrate concentrations can be dangerous when the water that is being applied to the land might reach groundwater. Nitrate in drinking water is a cause of methemoglobinemia in infants (31-433). Nitrate concentrations are also of importance from the standpoint of surface water eutrophication. Nitrate is the form of nitrogen that is readily available for plant use; thus it may stimulate algal blooms and other aquatic plant growth, resulting in accelerated eutrophication.

Total Kjeldahl nitrogen includes ammonia and organic nitrogen but not nitrate or nitrite (26). The automated selenium method of TKN
determination was used. The organic nitrogen in the sample is digested under highly acidic conditions, thus converting the organically bound nitrogen to ammonia. The sample is further treated, and the total quantity of ammonia is determined colorimetrically (38-190).

By running nitrate-nitrite and TKN analyses, all of the nitrogen present in the water can be measured. Under aerobic conditions organic nitrogen and ammonia may be degraded and oxidized by bacteria, thus providing more nitrate for plant use and exerting an oxygen demand on the receiving stream. Ammonia may also be used directly by some plants in the production of protein. It appears then that the tests that were performed should yield information concerning readily available nutrients, potential nutrients, and potential nitrogenous oxygen demand.

All of those factors can combine to cause serious problems in receiving waters (31-421). Excessive algal blooms may result in highly turbid waters which will absorb more sunlight, causing an increase in water temperature, and at the same time nitrification may be depleting the dissolved oxygen (DO) level. The result may be a shift in fish species to less desirable types, and the recreational value of the stream or lake may be destroyed (39-207).

The level of phosphorus present in the samples was determined by the total inorganic phosphate test. Included in the results from this analysis are the polyphosphate and orthophosphate compounds. Orthophosphate is the phosphorous form most readily available for use by
plants and other biological organisms. It is often added to agricultural land to supply crops with sufficient phosphorus for optimum growth (26). Polyphosphate is not as readily available as a nutrient but it does gradually hydrolyze in aqueous solution to orthophosphate (31-468). Organically bound phosphorus, which was not measured by this test, is usually only of minor concern in wastes (31-466).

During the analysis, polyphosphates are converted to orthophosphates by sulfuric acid hydrolysis. The sample is then treated chemically to form a dye complex, the intensity of which is proportional to the orthophosphate concentration in the sample. The intensity of the dye complex is measured colorimetrically, resulting in the total inorganic phosphate concentration (38-256).

Domestic sewage is relatively rich in phosphorous compounds. Some of the phosphorus in wastewater is derived from the breakdown of human wastes, but far more is added in the form of polyphosphates from synthetic detergents. A small portion of the phosphorus present may be used by microbes during the stabilization of the organic matter present in the waste. Most of it, however, remains in the waste, and passes through the treatment plant and into the receiving stream (31-467). Once in the receiving stream it serves as a nutrient for algae and, in excess, promotes undesirable algal blooms (26).

Several of the tests used to meet the second objective are also needed to meet the third objective. The Madison National Pollutant
Discharge Elimination System (NPDES) permit delineates limits for BOD, SS, and fecal coliforms. Ammonia standards can be found in the South Dakota Surface Water Quality Standards (40). It seems likely that criteria will be forthcoming with respect to phosphorus and nitrates. These tests have all been described in connection with the second objective, so they will not be further detailed here.
PRESENTATION AND DISCUSSION OF RESULTS

Fifteen samples of the lysimeter influent and the two effluents were analyzed, and infiltration rates were obtained at the time of sampling. For the purpose of this discussion the stabilization pond effluent will be designated as influent since the lagoon was the source of lysimeter input. North effluent and south effluent shall represent the lysimeter effluents from the barrels located immediately north and south of the distribution box.

The results, along with a discussion relating the quality of the influent to that of the lysimeter effluents, are presented in light of the objectives of the study. The infiltration data and quality analyses are included.

Infiltration Rates

Infiltration usually proceeds according to the typical infiltration curve described by McGauhey and Krone (41-35) and illustrated in Figure 4. In this investigation the infiltration curves obtained did not closely parallel the typical curve. Phase II of the typical curve, in which the infiltration rate increases due to the dissolving of gases entrapped in the soil did not appear in this study as may be seen in Figure 5. There appears to be two possible reasons for the lack of the appearance of phase II in the plot of the data. Perhaps the most likely suggestion is that as the barrels were filled from the bottom, the air in
Figure 4. Typical infiltration curve in three phases resulting from prolonged water spreading.
Figure 5. Infiltration curves resulting from lysimeter study
the soil pores was nearly all driven out of the soil and into the atmosphere. It is possible, however, since the rate measurements were taken only at the time of sampling, that phase II was present to some degree, but was not evident because so few samples were taken as it occurred.

As Figure 5 indicates, different infiltration rates resulted in the two soils that were used. The south barrel containing the fine loamy soil had an average rate of 1.08 gallons per day per square foot (gpd/ft²), while the north barrel which contained a more sandy soil had an average rate of 1.77 gpd/ft². These average rates correspond to 1.75 inches per day (in/day) and 2.87 in/day.

Figure 5 indicates that during the study the infiltration rate reached equilibrium after inundation. This equilibrium rate corresponds to the end of phase III of the typical infiltration curve. In the north barrel the equilibrium rate occurred about four weeks after initial flooding. The rate that resulted was approximately 1.2 gpd/ft² or 1.9 in/day. The south barrel, which contained the finer soil only took about three weeks to reach an equilibrium of .9 gpd/ft² or 1.45 in/day. Apparently clogging occurred more quickly and to a greater extent in the finer soil than it did in the more coarse soil. This is consistent with reports in the literature (11, 16).

It is difficult to say whether or not these infiltration rates accurately represent the rates that would be obtained using in-place
soil overlaid by one inch of water. It does not seem likely that the compaction of the soil in the barrels accurately resembles the natural compaction of undisturbed soil. That is not to say that the infiltration rates obtained are useless. They do indicate that the coarse soil from the lower horizon will probably allow greater infiltration than the finer soil.

During early work with a pilot infiltration-percolation basin in Brookings, South Dakota, it has been found that infiltration rates through in-place soil are much greater than those observed by Tiltrum (7) during his lysimeter study at the Brookings lagoon. The soil used by Tiltrum was representative of the soil present in the pilot basins. These preliminary results indicate that on a larger scale, using undisturbed soil, the rates could be expected to be greater than indicated by a lysimeter study.

The infiltration rate varies directly with the head applied (17). That is to say, the greater the water depth over the soil, the greater the infiltration rate should be. During the lysimeter study in Madison, only about one inch of water covered the soil surface. An actual infiltration basin would be operated at a depth of at least one foot and probably more. As the literature indicates, because of surface clogging the soil surface limits infiltration; consequently, changing the water depth above the soil should change the infiltration rate. If the depth of water above the soil was one foot instead of one inch, a more
reasonable rate of one-to-two feet per day could result. Thus, as stated in the literature (6), for ease of operation and high, long-term infiltration rates, deep, nonvegetated basins may be most effective.

If a wastewater flow of 0.65 million gallons occurred every day in Madison and an infiltration-percolation basin could be operated 365 days a year at an average infiltration rate of 1.5 gpd/ft² or 2.43 in/day, an infiltrative area of about ten acres would be required to treat the Madison waste. If, on the other hand, the same conditions existed and an average rate of 7.48 gpd/ft² or 12 in/day could be maintained, approximately two acres of infiltrative area would be required. The waste flow in Madison is unlikely to be 0.65 MGD year-round and possibly winter operation of an infiltration basin would be difficult. If the city could make use of the storage capacity already available in the present lagoon, an operating schedule, taking winter storage and inconsistent flows into account, could probably be set up.

Quality

The results of individual analyses will not be given here, but they may be found in the appendix. Table 1, which follows, presents an average of the results obtained in the laboratory analyses.
Table 1. Average Quality Results of the Lysimeter Study

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Influent Concentration (mg/l)</th>
<th>North Effluent Concentration (mg/l)</th>
<th>South Effluent Concentration (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biochemical Oxygen Demand</td>
<td>9.5</td>
<td>3.1</td>
<td>2.6</td>
</tr>
<tr>
<td>Suspended Solids</td>
<td>52.5</td>
<td>3.6</td>
<td>2.8</td>
</tr>
<tr>
<td>Fecal Coliforms as MPN/100ml</td>
<td>838</td>
<td>2.3</td>
<td>2.0</td>
</tr>
<tr>
<td>Total Kjeldahl Nitrogen as N</td>
<td>7.1</td>
<td>2.4</td>
<td>3.1</td>
</tr>
<tr>
<td>Nitrites as N</td>
<td>0.13</td>
<td>0.03</td>
<td>0.08</td>
</tr>
<tr>
<td>Phosphorus as P</td>
<td>2.1</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Sodium</td>
<td>366</td>
<td>295</td>
<td>228</td>
</tr>
<tr>
<td>Total Residue</td>
<td>1663</td>
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<td>2905</td>
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<tr>
<td>Specific Conductance*</td>
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<td>3040</td>
</tr>
<tr>
<td>Total Hardness as CaCO₃</td>
<td>596</td>
<td>714</td>
<td>1184</td>
</tr>
<tr>
<td>Calcium Hardness as CaCO₃</td>
<td>546</td>
<td>599</td>
<td>873</td>
</tr>
</tbody>
</table>

*Reported in µmhos/cm

Biochemical Oxygen Demand

There was a considerable reduction in the BOD of the lagoon effluent when it was passed through the soil. The reductions of 67 percent for the north barrel and 73 percent for the south barrel do not appear exceptionally high, but considering the low BOD of the influent, they are satisfactory. It appears as though the removals in the south barrel may have been slightly higher than those in the north. The more coarse soil present in the north barrel might possibly have allowed slightly more oxygen demanding material to pass through.

As the time of inundation continued, the removals became more consistent and improved slightly. It is possible that higher results
in the early testing were due to a lack of expertise on the part of the analyst or that as the soil clogged, finer straining occurred and slightly more oxygen-demanding material was removed.

In other studies (7, 27) similar effluent BOD's have resulted even when the BOD of the influent was higher. This information may be valuable in that the BOD of the Madison lagoon effluent cannot always be expected to be as low as it was during this study. Future growth of Madison and the natural decrease in efficiency during the winter months could result in a considerably higher BOD from the lagoon than the 9.5 mg/l average witnessed during this investigation.

The NPDES permit for Madison calls for an average of less than 30 mg/l of BOD in any consecutive 30-day period. This limit is to be achieved by July 1, 1977. Throughout the study the maximum BOD found in the lagoon effluent was 15 mg/l. This is well within the limit. In the future, however, it can be expected that the allowable BOD will be lowered to a level that will require more complete treatment of the Madison waste flow.

**Suspended Solids**

Throughout the investigation the removals of suspended solids were consistently high. The only exceptions occurred when solids were sloughed from inside a rubber hose that was initially used to collect the effluent from the south barrel. Upon replacing the rubber hose with a plastic hose, the sloughing stopped and did not recur. Excluding
the samples in which sloughing was evident, the north barrel removed 93 percent of the SS while the south removed 95 percent. The solids in the influent appeared to be primarily algae and aquatic macroorganisms while the effluents were essentially free of visible solids.

Once again the more coarse soil seemed to allow slightly more material to pass through the soil pores. It seems likely that most of the solids in the effluent samples resulted from a washout of fine material in the soils.

The Madison NPDES permit places a ceiling on the SS allowed in the discharge at an average of 30 mg/l over 30 consecutive days. This limit was only met on two occasions by the influent. The lysimeter effluents, with the exception of one instance where the sloughing from the rubber hose was extreme, were well below 30 mg/l. The averages of 3.6 and 2.8 mg/l for the north and south barrels, meet the present standards, and, as with the BOD, meet the expected 10 mg/l standards that are likely to be instituted for Madison in the near future.

The literature indicates that waters low in suspended solids will not appreciably affect the infiltration rate (11), and with less than 10 mg/l, high rates can be sustained over long time periods (6). In this case the SS concentration in the influent was too high to allow unrestricted infiltration but, as this study shows, still low enough to allow inundation periods that were long enough to assure some degree of economy with effective treatment.
Fecal Coliforms

The fecal coliforms in the lagoon effluent varied greatly during the study period. The minimum result was a most probable number (MPN) of 11 organisms per 100 milliliters (MPN/100ml), and the maximum result was an MPN greater than 1609 organisms per 100 ml. The computed average was 838 MPN/100ml.

The initial bacteriological samples were taken shortly after the soil was saturated from the bottom. The coliform counts in these first samples of effluent were quite high. This may be explained by the fact that when the barrel was filled from the bottom, coliforms became lodged in the lower soil pores. After downward flow began in the barrels, these lodged coliform organisms may have been slowly washed out with the effluent. The coliform counts obtained during later samples were used to compute the average and are believed to accurately represent the removals that may be expected with the system.

Both barrels exhibited removals of well over 99 percent. This reduction is consistent with those found in the literature (7, 27, 28) and is not surprising considering the relatively fine-grained nature of both soils used (28).

An MPN limit of 200 organisms per 100 ml for any 30 consecutive days is specified by the Madison discharge permit. During discussion with the operators of the Madison waste treatment plant, it was reported that this limit is generally met; but, as shown by the data obtained
during the study, there are times when it is greatly surpassed. The data indicates that effluents well within the limit may be obtained regardless of whether low or relatively high numbers of fecal coliforms are present in the influent of the infiltration system.

**Total Kjeldahl Nitrogen**

Ammonia and organic nitrogen are both measured by this test. Unless industrial wastes high in organic nitrogen are present, the organic portion is of little sanitary significance (31). Madison has a waste that probably has a considerable quantity of organic nitrogen contributed to it by an industry that processes eggs. Egg-processing waste contains large amounts of organic nitrogen but, in general, it is in a form easily degradable by conventional waste treatment. Organic nitrogen degrades to ammonia, so it is likely that most of the nitrogen measured as TKN is in the ammonia form except for the organic nitrogen present in the influent as algae.

The TKN removals obtained by the soil system were fairly consistent throughout the experiment. The influent TKN concentrations ranged from about 4 to 11.4 mg/l with an average of 7.1 mg/l. The removals realized by the north barrel were 66 percent, and the south barrel produced 56 percent removals. Ammonia removal is accomplished generally by adsorption within the soil (27, 30, 32). Tiltrum obtained higher removals, which may have been due to the finer texture of the soil used for his study and the higher adsorptive capacity.
It could be assumed that the TKN in the lysimeter effluents was exclusively ammonia. Since almost no SS were evident in the effluents, very little organic material was likely to have been present, thus, little organic nitrogen. The flow in Park Creek during the summer of 1974 was essentially composed of the effluent from the stabilization pond. Therefore, if the effluent did not meet the standards, neither did the creek. The South Dakota Surface Water Quality Standards (40) do not define any beneficial uses for Park Creek, but if the creek is considered a tributary of Skunk Creek, with warm water marginal fish-life propagation as a beneficial use, the ammonia limit is 1.5 mg/l. Based on the TKN results, this limit was not met by either the lysimeter influent or effluents.

If nitrification followed by denitrification could be accomplished with intermittent flooding, it is possible that ammonia could be removed by land application to the level required (27, 30, 32). In this study the soil probably became anaerobic soon after inundation, after which nitrification could not occur. To achieve and maintain the required 1.5 mg/l ammonia level, closely-monitored operation would be necessary.

Nitrate

The nitrate concentrations present in the lysimeter influent were quite low due to the removal of nitrate by biological organisms in the stabilization pond. These low nitrate concentrations in the influent suggest that even if the nitrates present did leach through the soil,
very little serious groundwater degradation would be likely to occur. If they pass through anaerobic conditions, however, denitrification may occur (27, 32).

During this study, 74 percent of the nitrate was removed from the north barrel, and 62 percent from the south barrel. The removals did not seem to be consistent throughout the investigation. Anaerobic conditions probably occurred shortly after inundation and may account for the removals that did occur during the investigation.

About halfway through the study, two uncharacteristically high nitrate values in the north barrel indicate that a possible mix-up of samples occurred. If this was the case, excellent removals by the north barrel were achieved throughout the study. Toward the end of the study, the south barrel seemed to show deteriorating removals. The nitrates appeared to be leaching through the soil more readily as inundation continued.

**Phosphorus**

In many cases, phosphorus is considered the limiting nutrient for biological production in water. Conventional treatment plants do not effectively remove phosphorus; thus effluents often contain quantities in excess of those desired for natural rates of biological activity.

Phosphorus may be effectively removed from water by adsorption or precipitation when the water is passed through soil (34, 35). During this study the phosphorous concentration in the lysimeter influent
ranged from 1.2 to 3.0 mg/l with an average of 2.06 mg/l measured as phosphorous. The removal efficiencies achieved by both soils were over 94 percent. These removals are substantiated by removals of over 97 percent reported at Santee, California (11) and studies of seeping lagoons in South Dakota (4, 5). The removals throughout the study were consistent in each barrel and also between the barrels, supporting the findings that phosphorous removals do not rapidly decline with time (27).

**Sodium and Hardness, Specific Conductance and Total Residue**

As discussed previously, the sodium and hardness tests were conducted for the purpose of calculating the sodium adsorption ratio (SAR). According to the U.S. Salinity Laboratory, the best method of expressing the sodium hazard of irrigation water is the SAR (20). Using the average sodium and total hardness results of 366 mg/l and 686 mg/l (as CaCO₃), respectively, the milliequivalents of each constituent was calculated. The total hardness was used in lieu of the individual calcium (Ca) and magnesium (Mg) concentrations. This was possible since both Ca and Mg are expressed as CaCO₃ by the total hardness test. From this total, milliequivalents per liter for both Ca and Mg could be directly calculated. The resultant SAR of the lysimeter influent was 6.

This alone does not indicate whether the influent water is suitable for land application. Any given SAR will represent a greater hazard to the soil as the salinity of the water increases (20). High salinity of
a water, generally measured by specific conductance or total residue, presents a threat to the irrigated plants. A high SAR, on the other hand, threatens the infiltration capacity of the soil. These are two of the primary criteria used to judge irrigation waters (20).

The conductivity of the influent averaged 2944 micromhos per centimeter, and the total residue averaged 2014 mg/l. A diagram presented by the USDA uses SAR and specific conductance to classify waters for irrigation suitability. This diagram places the lagoon effluent in a classification of very high salinity hazard and medium sodium hazard.

It is suggested that water of this type can be applied to coarse textured or organic soils as long as permeability is high. It is likely that such water can only be used to irrigate vegetation that is highly resistant to salinity (20).

The results of the sodium test indicate that both soils removed large quantities of sodium early in the flooding period. The north barrel seemed to reach equilibrium about one week after initial flooding, while the south barrel removed considerable sodium for nearly three weeks. The averages, therefore, indicate removals of about 19 percent by the north barrel and 38 percent by the south. These removals probably resulted from cation exchange with calcium and magnesium ions in the soil (20).

Upon examining the hardness results, it appears that in the north barrel only part of the sodium removal can be accounted for by exchange
with the hardness causing ions. An increase of only 4 percent was noted in the north barrel during inundation. During the time that the sodium was being removed in the north barrel, the hardness was essentially the same in the influent and effluent.

The south barrel shows an average increase of 73 percent in total hardness, which is more than enough to account for the possible exchange with sodium. That is not to say that all of the sodium entering the south barrel exchanged with either calcium or magnesium in the soil, but it is likely that this occurred to some extent.

For the most part, the hardness in the north barrel effluent closely paralleled the influent, but rather large increases occurred in the south barrel. These increases in hardness in the water passing through the south barrel probably explain to some extent the increases in total residue and specific conductance. Increases of 14 and 3 percent were noted, respectively. The north barrel, on the other hand, displayed slight decreases of 2.5 and 4 percent, respectively. The more coarse soil in the north barrel appeared to exhibit a rapid washout of fine soil particles. The fines present in the south barrel seem to have washed out more slowly. This difference in wash-out time may have occurred partially because the more coarse soil had fewer fine particles to wash out or because the soil pores were larger in the coarse soil, allowing the fine material to pass through the coarse soil pores more rapidly.
CONCLUSIONS AND RECOMMENDATIONS

This study was conducted for the city of Madison, South Dakota, for the purpose of examining land application as a possible means of improving the quality of the present municipal stabilization pond effluent. The conclusions reached here are based on information derived from the study and from a literature review of the subject.

Conclusions

The soil used in the study was one of only a few in the Madison area which were reported to have high permeability. The final decision to use Dempster series soil was based on the location of suitable areas of the soil near the municipal lagoon.

The infiltration rates through the compacted soil in the lysimeters were not extremely high. It was found that the soil from the lower horizon (18-36 inches deep) produced a higher average infiltration rate and held a higher equilibrium rate without an appreciable decrease in effluent quality. Thus, it appears that removing the upper layers of soil would probably produce a more acceptable rate of infiltration.

If the lower soil horizon were used for an infiltration basin, the required infiltrative area to treat the Madison waste flow would be approximately 8.5 acres if the lysimeter rates approximate those possible through undisturbed soil. About 14 acres would be required if the upper soil horizon was left intact.
The assumption that the infiltration rates through the lysimeter approximates those through in-place soil may be a serious error. An incomplete study at the Brookings lagoon has reported significantly higher initial infiltration rates than those reported in a lysimeter study. This may be due in part to a significant difference in the natural compaction of the in-place soil as opposed to the artificial compaction of the lysimeter soil. The depth of water applied above the soil surface may offer another explanation. Theoretically, the greater the head applied, the greater the infiltration rate. A significant rate increase should be noted if the one inch of head applied during this lysimeter study was increased to 12 or 18 inches. This would result in a decreased area requirement and an increased economy.

The quality improvements exhibited in BOD, SS, and fecal coliforms were such that both present standards and those expected in the future may be easily met. The study indicated that desirable improvements in these parameters could be obtained with either of the soils used. Other investigations have indicated that with proper maintenance of the basins, removals of the magnitude obtained could be expected to continue far into the future. Indications are that the removals shown with a lysimeter should closely parallel those expected using undisturbed soil.

Nitrogen was not removed as well as had been hoped. The literature indicates that it is difficult to obtain consistently satisfactory removals of ammonia and nitrates with a soil percolation system.
Experimention with dosing and vegetation has shown that nitrogen can be more effectively removed than it was with the continuous inundation used in this study.

Phosphorous removal was very good throughout the study. Other research has yielded similar results and has indicated that removals are not seriously affected by time.

The SAR of the lagoon water indicates that it should be applied to coarse textured or organic soils with good permeability. The Dempster soil is characterized as coarse to medium structure with moderate organic content and high permeability, especially in the lower horizons. Thus, it would not appear that the SAR would greatly affect the permeability of the soil, but more exacting analyses should be conducted.

The salinity of the lysimeter influent was very high. It precludes the application of this water to vegetation that is not considered very resistant to salinity.

**Recommendations**

As this study indicates, at the present time the city of Madison is unable to consistently meet the effluent quality required by the discharge permit applicable to the city. More stringent limits may be forthcoming. If these limitations are to be met as scheduled, consideration must soon be given to the methods available for meeting the regulations. Land application is one of several methods that should be considered.
A pilot study utilizing small cells could yield information valuable for planning a full-scale land application system. Such a pilot study should be located near the stabilization pond in soils representative of those that could be used for a full-scale system. Since Tiltrum's lysimeter study, such a pilot plant has been constructed in Brookings, South Dakota and by the end of this coming summer should have greatly enhanced the information obtained in Tiltrum's study.

General design considerations may be obtained from several sources. An article by Bouwer, Lance, and Riggs (27) contains some valuable design considerations and information about the Brookings pilot study can be obtained from the Civil Engineering Department at South Dakota State University, Brookings, South Dakota, 57006. Also an M.S. thesis by Peter S. Johnson (6) contains an extensive review of design considerations. Other recent reports (42, 43) have extensively surveyed the literature and existing land application facilities and provide some of the most complete information available concerning the application of wastewater to the soil. The Soil Survey of Lake County South Dakota may be consulted to locate areas of proper soil type for such a pilot study. The survey, compiled by the USDA, should be readily available from county agriculture representatives or can be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402.
Land disposal has not yet been fully investigated, and without continued large-scale studies no advancement seems likely. It has been said (10):

Nothing would be done at all if a man waited until he could do it so well that no one could find fault with it.

Such is the case with land treatment of wastes. Research must be continued on a larger scale to better define the limitations inherent in soil systems and to assure the recognition of long-term effects at the earliest possible date.
LITERATURE CITED


33. Strumm, W., and Morgan, J. J., "Stream Pollution by Algal Nutrients", Transactions, Twelfth Annual Conference of Sanitary


### APPENDIX. RESULTS OF LABORATORY ANALYSES

<table>
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<tr>
<th>Date</th>
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<th>Fecal Coliforms (MPN/100ml)</th>
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*Unreliable data due to sloughing of solids into the sample bottle*
## APPENDIX (Cont.). RESULTS OF LABORATORY ANALYSES

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### Parameter

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