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FOREWORD

This study was partially funded by the North Dakota Water Resources Research Institute, and this report constitutes the research project technical completion report for OWRT Project No. A-072-NDAK.

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ILLUSTRATIONS

EXECUTIVE SUMMARY

A number of unlined municipal waste stabilization lagoons in North Dakota lose water by seepage in excess of state regulations. Many of these lagoons are constructed in permeable soils overlying important shallow aquifers. The purpose of this project is to evaluate the effect of the seepage on groundwater quality in the vicinity of the lagoons.

Of six lagoons selected for study, three were chosen for more detailed instrumentation and monitoring, and three were treated as reconnaissance investigations. All six lagoons which are located over shallow, unconfined aquifers with high water tables, are unlined and are known to lose large amounts of water by seepage through the bottoms of the impoundments. Two of the lagoons maintain no standing wastewater because of rapid infiltration.

Monitoring wells were installed around the lagoons for the purpose of determining groundwater flow systems beneath the lagoons and for taking periodic water samples for analysis. Water levels in the wells were measured monthly and samples were taken quarterly for chemical, biological, and isotope analyses. The geological settings of the sites were studied by taking sediment samples from holes drilled for installation of monitoring wells.

The results of the water analyses indicate varying degrees of groundwater contamination at all sites.* The McVille site is the most significant site because land use in the area permitted the installation of downgradient wells for several hundred feet away from the lagoon. Farming and other land-use constraints limited installation of monitoring wells at the other sites to the embankments of the lagoons. The McVille site also appears to have the most severe groundwater contamination of the lagoons studied.

The seepage of wastewater into the groundwater flow systems results in a plume of contaminated water elongated in the direction of groundwater flow. Concentrations of various chemical constituents in the plume vary horizontally and vertically. At McVille, the plume extends beyond the farthest monitoring wells, located 700 feet (210 m) from the lagoon. Chemical parameters that indicate contamination in the vicinity of the farthest monitoring wells include chloride, sodium, total dissolved solids (TDS), calcium, magnesium, and bicarbonate. The distance of travel of individual chemical contaminants depends on the biochemical attenuation mechanisms which control the movement of that particular constituent in soil and groundwater systems. In addition, coliform organisms appear to be migrating several hundred feet in groundwater at the McVille site.

Conditions in the lagoon itself play an important part in the quality of water reaching the groundwater flow system. If several feet of standing water are maintained, anaerobic conditions predominate in the lower part of the lagoon and the sludge layer at the base of the lagoon. Water which passes through the sludge layer is therefore highly reducing. Nitrogen remains in the reduced ammonium form and sulfate concentrations are very low due to sulfate reduction. These characteristics persist in the groundwater flow system for some distance. Iron concentrations increase downgradient as a result of reduction of ferric iron present in the aquifer as iron oxide coatings on mineral grains. The more soluble ferrous iron then increases iron concentrations in groundwater.

Chemical concentrations change along the flow path because of a variety of attenuation mechanisms. Ammonium is strongly adsorbed by soils and can only migrate through materials which are saturated with respect to ammonium adsorption. Ammonium has moved several hundred feet in the groundwater flow system at McVille, indicating that the adsorption and exchange capacity of the soil for ammonium has been exceeded. Sandy soils, such as the soils at the study areas, have low exchange capacities. Ammonium levels decrease to very low values within a narrow zone several hundred feet from the McVille lagoon.

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*In this report the word contamination is used for any addition of solutes into groundwater by human activities whether or not the water is degraded to the point where it is a health hazard or is objectionable for consumption for some other reason.

Adsorption is the probable attenuating mechanism because nitrate levels do not increase beyond that point.

The management of a waste stabilization lagoon may have a significant effect on the groundwater quality generated by wastewater seepage. At McVille, the wastewater is maintained in a single cell throughout the year with the exception of brief, periodic discharges into an adjacent cell. The groundwater downgradient from the cell used for intermittent discharges is much poorer in quality than the groundwater immediately downgradient from the continuously used cell. The difference in water quality is probably the result of the beneficial effect of the sludge layer on the bottom of the primary cell. The sludge layer affects seepage in several ways. First, the sludge layer decreases the permeability of the soils by clogging the soil pores with sludge particles, thus retarding the rate of seepage into the soil. Secondly, the sludge layer interacts chemically with the wastewater through a variety of mechanisms which tend to improve the quality of the wastewater. The intermittent discharges of wastewater into the adjacent cell infiltrate rapidly into the soil without the beneficial effect of the sludge layer. The high degree of groundwater contamination at McVille may be a direct result of this practice.

The degree of groundwater contamination at the other sites is less than at the McVille lagoon, even though concentration limits for drinking water are exceeded for certain parameters in several cases. The results of this study indicate that potential health hazards exist if wells are located near unlined sewage lagoons in unsuitable geological settings. These lagoons should be lined so that proper biochemical treatment mechanisms can operate in the impoundments.

ABSTRACT

Groundwater quality changes were investigated around six unlined municipal waste stabilization lagoons in North Dakota. The lagoons chosen were constructed in permeable sediments directly over shallow, unconfined aquifers. Groundwater contamination at all sites is characterized by a plume of water with low redox potential and high dissolved-solids content extending downgradient from the impoundments. At McVille, the site with the most severe contamination, untreated wastewater is maintained in one cell throughout the year except when short intermittent discharges of wastewater are made into an adjacent cell. Groundwater quality is much poorer downgradient from the intermittently used cell relative to groundwater just downgradient from the primary cell. Seepage water quality is apparently better when adequate holding time is maintained in a cell with a basal sludge layer. Water downgradient from the intermittently used cell has a very high ammonium concentration, which is subsequently decreased by adsorption. Evidence suggests that coliform organisms can move several hundred feet away from the lagoons in groundwater under favorable conditions. Contamination at the other sites was not as severe as at McVille, although levels of some parameters exceed concentration limits for drinking water in the vicinity of the lagoons. Lagoons in geological settings similar to the study area should be lined, particularly if wells are nearby.

INTRODUCTION

Purpose and Objectives

A recent survey of surface impoundments in North Dakota identified 363 municipal waste stabilization lagoon sites (Kehew et al., 1980). The survey, the Surface Impoundment Assessment (SIA) of the U.S. Environmental Protection Agency, utilized a rating system to evaluate the groundwater contamination potential of lagoons based on the hydrogeologic setting of the site. Evaluation was made using existing data sources such as topographic and geologic maps. Sixty-seven percent of the municipal waste stabilization lagoon sites were rated as having moderate to high pollution potential.

The purpose of this study was to conduct field evaluations of groundwater contamination at some of the lagoons which have the most unfavorable hydrogeological settings. These conditions include the presence of high water tables and unconfined aquifers directly beneath the sites. In addition, the lagoons selected were known to have excessive seepage. Some of the lagoons, in fact, contain no standing wastewater as a result of rapid seepage through the bottoms of the impoundments. None of the sites studied was lined for seepage control.

Six municipal lagoons were selected for study (fig. 1). Three sites, McVille, Larimore, and Fordville, were chosen for relatively detailed study because of their proximity to the University of North Dakota in Grand Forks. The other three sites, Lidgerwood, Esmond, and Underwood, were studied less intensively than sites in the first group.

The specific objectives of the study are:

1. To determine the geologic setting of the lagoon sites including information on the type, distribution, and lithologic properties of the sediments comprising the aquifers beneath the impoundments;
2. To determine the nature of the groundwater flow systems including the direction and rate of movement of groundwater and the background chemical quality of the aquifers;
3. To determine the changes in chemical composition of groundwater in the aquifers caused by seepage of wastewater from the lagoons; and
4. To make recommendations to the State Health Department concerning regulation of unlined municipal waste stabilization lagoons.

Methods

After sites were selected, monitoring wells were installed around each impoundment. The monitoring wells were installed in holes drilled by a truck-mounted power auger. Sediment samples were taken during drilling for lithologic description and lab testing. Wells were constructed of two-inch (5.1 cm), schedule 40 PVC pipe with five-foot (1.5 m) PVC screened sections at their bases. Problems were encountered during well installation because of collapse of the unconsolidated sediments below the water table into the bore hole when the auger was removed. Therefore, conical, PVC tips were added to the bases of the wells and, after removal of the auger, wells were manually driven into the collapsed sediment to the desired depth. The wells were completed by backfilling the well annulus with cuttings from the auger hole and then pouring a concrete seal around the top of the hole. Metal covers with locking tops were pushed into the concrete to prevent vandalism. Despite this precaution, several of the wells and locks were damaged by vandals during the course of the study.

The lagoon sites were surveyed by plane table and alidade to determine relative elevations of the wells and to construct topographic maps of the sites. An initial station, usually a point on top of a lagoon embankment, was assigned an elevation of 100 feet (30 m) above an arbitrary datum level of zero feet. The elevations of all other points were determined relative to the initial station.

In the lab, grain-size analysis and X-ray diffraction were done on selected samples to determine lithology of the materials and to supplement visual classification of the sediments. Hydraulic conductivity was estimated from grain-size distribution curves by the method of Masch and Denny (1966).

Soil-water samplers were also installed at the detailed study sites in

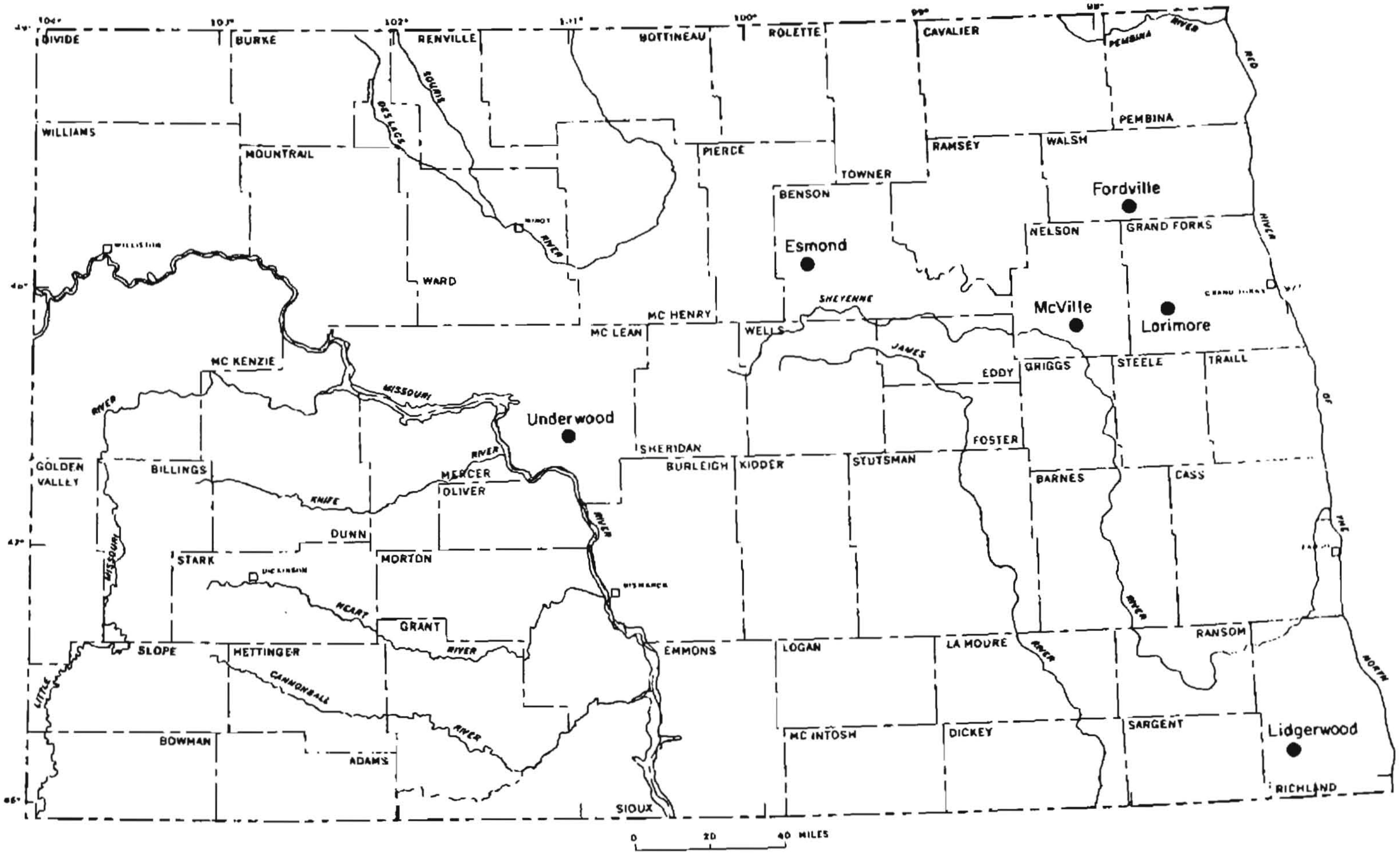

Figure 1. Map of North Dakota showing location of study sites.

an attempt to sample soil moisture from the unsaturated zone. The soil-water samplers consist of 25-inch (.64 m) plastic tubes with porous ceramic cups at their bases. The bore-hole sections containing the ceramic cup were filled with silica flour to prevent clogging. Bentonite plugs were then emplaced above the silica flour. Access tubes extend to land surface for applying a vacuum to draw the sample into the cup and for applying pressure to remove the water sample from the sampler. Unfortunately, the soil-water samplers did not function properly and no samples were obtained during the course of the study.

Groundwater flow conditions were investigated by taking water-level measurements in the monitoring wells and by single-well response tests. Water levels were measured monthly at the detailed sites and less frequently at the other sites. Single-well response tests, used to measure hydraulic conductivity, were conducted and analyzed using the method of Hvorslev (1951).

Groundwater samples were collected from all wells, excluding the Underwood site, at approximate quarterly intervals for one year. The Underwood site was sampled twice. In addition, new wells installed at the McVille site near the end of the study were sampled only once. Prior to sampling, wells were bailed with a PVC bailer to remove approximately two well volumes of water and then allowed to recover. Samples for chemical analysis were then taken using a small bailer that was rinsed with distilled water between wells. Immediately after sample recovery, measurements of pH, temperature, and electrical conductivity were made. The samples were then filtered through a .45 micron filter and poured into bottles for transportation to the lab. Samples for trace element analysis were preserved with nitric acid, and samples for nutrient analysis were preserved with sulfuric acid. Samples for other parameters were unpreserved. After treatment, sample bottles were labeled and placed in plastic ice chests filled with ice and shipped by bus to the State Health Department laboratory in Bismarck, North Dakota, for analysis. Samples were received by the lab the morning after the day in which the sampling was done. The chemical results are given in appendix IV.

Samples for bacteriological analysis were also taken. These samples were taken with the small bailer after it had been disinfected with a dilute chlorine solution and triple-rinsed with distilled water. Chlorine levels in the rinse water were below the level of detection after the third rinse. The bacteriological samples were also cooled and sent to the State Health Department laboratory in Bismarck. Analyses were made for total and fecal coliform counts.

Groundwater samples at the McVille site were taken for nitrogen isotope analysis. Sample preparation of the nitrogen isotope samples was done using a modification of the method of Bremner and Keeney (1965). Analyses were made at the Department of Biology at Washington University in St. Louis, Missouri.

Acknowledgments

Many people and agencies contributed to the success of this project. Major funding was received from the North Dakota Water Resources Research Institute under OWRT Project No. A-072-NDAK. The North Dakota Geological Survey contributed drilling equipment and water sampling equipment to the project. The North Dakota State Health Department conducted laboratory analyses at a reduced cost. Although many individuals at the Health Department lab participated in the analytical work, Dr. James Pearson provided special assistance in the bacteriological portion of the project, and Ms. Lydia Fewless was particularly helpful in organizing and supervising the chemical analytical work. Nitrogen isotope analyses were done at no cost by the Biology Department at Washington University in St. Louis under the supervision of Drs. Georgia Shearer and Barbara Bryan. Clerical work, drafting, and accounting for this project were done by the Engineering Experiment Station at the University of North Dakota. The Engineering Experiment Station lab prepared the nitrogen isotope samples.

Grateful thanks are extended to the people and agencies listed above and also to those employees of the above agencies who are not mentioned by name, but who also worked on some

phase of this project.

FUNCTION OF WASTE STABILIZATION LAGOONS

The waste stabilization lagoon is an inexpensive method for wastewater treatment and disposal used in small towns in rural areas where sufficient land near the town is available. Waste stabilization lagoons have been used in the United States since the 1920's (Caldwell, 1946) and in North Dakota since 1948, although a natural depression near Fessenden was used as a sewage lagoon for a twenty-year period starting in 1928 (Van Heuvelen and Svore, 1954).

Study of the operation and performance of waste stabilization lagoons has been in progress for many years (Caldwell, 1946). Lagoons in North Dakota are considered to be facultative in performance; that is, they treat wastewater by a combination of aerobic and anaerobic processes. The aerobic portions of the lagoons depend on the relationship between algae and aerobic bacteria to decompose waste. Algae utilize carbon dioxide, nutrients from the waste water such as nitrogen, phosphorous, and potassium, and sunlight to grow in the lagoons. As carbon dioxide is taken up by algae, the pH of the lagoon water rises. Oxygen given off by the algae maintains aerobic conditions in the upper part of the lagoon and is used by bacteria to convert organic carbon to carbon dioxide. The carbon dioxide, in turn, sustains the growth of the algae. Lagoons that maintain a depth of several feet also achieve anaerobic treatment of waste within a layer of sludge deposited on the floor of the lagoon. In the sludge layer, organic matter is converted to methane and carbon dioxide. A considerable improvement in wastewater treatment has been observed in lagoons with sludge layers in comparison to those ponds without sludge layers (Parker et al., 1950). The sludge layer also has the function of decreasing seepage rates by clogging soil pores on the lagoon bottoms (Chang et al., 1974).

In North Dakota, lagoons are designed to have a capacity of about 1¼ acre (.5 hectares) per 100 people. This size provides for a holding period of at least 180 days, a period of time necessary to store wastes through the winter months when lagoons freeze over and aerobic treatment does not occur. Discharges to surface drainages are permitted, although the ponds lose some of their wastewater by seepage and evaporation. No treatment prior to discharge into the lagoon is the common practice in lagoons in North Dakota.

Reduction in concentration of various waste components in lagoons is high if sufficient retention time is achieved. Studies of lagoons in North and South Dakota (Towne et al., 1957) report reductions in coliform bacteria generally greater than 90 percent by comparing lagoon influent with surface effluent during each season of the year. Treatment of organic waste matter, measured as Biochemical Oxygen Demand (BOD) also reaches high levels of reduction in lagoons. Decreases in nutrient concentrations in lagoons are achieved by algae and bacteria intake. Decreases have been noted in all nitrogen forms, phosphorous, and potassium (Fitzgerald and Rohlich, 1958).

Most studies of wastewater treatment in lagoons have focused on water discharging to surface drainages. Aside from description of anaerobic wastewater treatment in the sludge layer (Parker et al., 1950), there is a lack of information on the quality of water directly below the sludge layer, which is lost from the lagoon as seepage. Water from monitoring wells near the point of seepage gives the best indication; however, these results reflect treatment of the wastewater by soil below the sludge layer. In this report, the term soil is used for all unconsolidated subsurface materials.

GROUNDWATER CONTAMINANTS FROM WASTE STABILIZATION LAGOONS

Nitrogen

Relationship to Health

Nitrogen forms are common contaminants of aqueous systems and are present at high levels in municipal waste stabilization lagoons. Nitrogen is an essential component of all living matter but, when present at high concentrations in drinking water, some forms of nitrogen can be harmful to humans and livestock. One of the most serious medical problems associated with nitrogen is methemoglobinemia, a

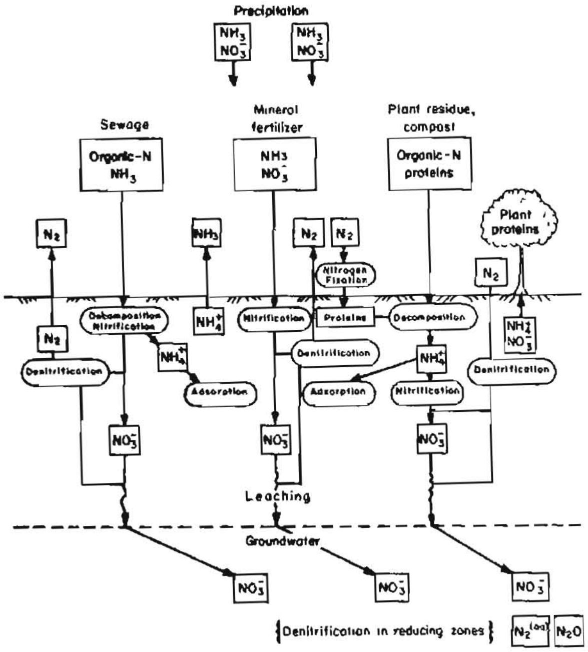

Figure 2. Nitrogen pathways in the environment from Freeze and Cherry (1979).

disease affecting infants less than one year of age. Methemoglobinemia is the conversion of hemoglobin, the blood's oxygen carrier, to methemoglobin, an oxidized form unable to carry oxygen (Shuval and Gruener, 1977). The process involves oxidation of ferrous iron (Fe^{2+}) to ferric iron (Fe^{3+}) and the bacteriological reduction of nitrate (NO_3^-) to nitrite (NO_2^-). The United States drinking water standard for nitrate is 45 mg/l NO_3^- (10 mg/l as N). Other health problems caused by nitrogen are less clearly documented. Nitrosamines, which can be produced in the stomachs of mammals from nitrate and nitrite, are carcinogenic in lab animals (Shuval and Gruener, 1977).

Nitrogen in the Environment

The components of the nitrogen system, and their pathways both above and below ground surface, are shown in figure 2. The major natural input of nitrogen to the subsurface environment is the fixation of nitrogen from the atmosphere, which contains 79 percent nitrogen (N_2) by volume. The fixation of nitrogen is a biological process accomplished by several genera of blue-green algae and many species of bacteria (Horne, 1977). On land, plants such as the legumes (peas) and certain non-legumes (alder), are involved in nitrogen fixation by forming symbiotic relationships with nitrogen-fixing bacteria. Upon the death of these plants, organic nitrogen is supplied to the soil.

During decomposition of soil organic matter, organic nitrogen is mineralized to other nitrogen forms (Kolenbrander, 1977). The initial product of mineralization, in most soils, is ammonium (NH_4^+). Ammonium is usually held by adsorption in soils. In the form of ammonium, nitrogen can be utilized by crops. Additional conversions, however, occur with the aid of soil bacteria, transforming ammonium into nitrate (nitrification). Nitrate can also be utilized by plants or converted to nitrogen gas (N_2) by soil bacteria and lost to the atmosphere. An important consequence of nitrification is the mobility of the nitrate anion. At common soil pH levels, anions are not adsorbed on clay particles and are therefore subject to downward leaching to the water table. Nitrate that reaches the water table is also highly mobile in groundwater flow systems, where decrease in nitrate concentration levels occurs mainly by dispersion (dilution). If redox conditions within the groundwater flow system become more reducing, reduction of nitrate to dissolved nitrogen (N_2) and nitrous oxide (N_2O) occurs. In addition, reduction of nitrate to ammonium is also possible in groundwater (Freeze and Cherry, 1979).

Nitrogen as a Contaminant

The natural nitrogen cycle is modified by the introduction of nitrogen into the subsurface in the form of fertilizers and sewage wastes. Nitrogen in mineral fertilizers is applied in the forms of ammonium and nitrate. Application of ammonium beyond crop needs can result in nitrification and subsequent leaching to groundwater. Nitrification is desirable from a farming standpoint because yields are higher if crops receive nitrate than if they receive ammonium only (Kolenbrander, 1977).

Nitrogen contamination from waste disposal includes human, animal, industrial, and agricultural sources. The emphasis in this report is placed on human-waste disposal. Nitrogen from human wastes can enter the subsurface from infiltration and seepage of effluent from sewage treatment plants, septic tanks, waste stabilization lagoons, outhouses, and leaking sewers.

Raw wastewater contains nitrogen mainly in the forms of organic nitrogen, ammonia (NH_3), and ammonium (NH_4^+). Of the inorganic forms ammonium and ammonia, ammonium is predominant up to a pH of 9 (Preul and Schroepfer, 1968) even though analyses commonly report the concentration as ammonia. Concentrations of nitrogen in all forms in wastewater generally range from 18 to 28 mg/l N (Schmidt, 1971). Organic nitrogen is converted to inorganic ammonium during decomposition. Nitrate and nitrite concentrations in raw wastewater are generally negligible. In a lagoon, nitrate concentrations are maintained at a low level because nitrate is used as a nutrient by algae in the pond (Preul, 1968). Nitrate concentrations may be higher seasonally, during periods of low photosynthetic activity. Therefore, initial seepage of wastewater into the soil from lagoons, septic tanks, and sewage-treatment-plant effluent, is likely to contain nitrogen mainly in the form of ammonium.

Once in the soil environment, oxidation of ammonium to nitrate (nitrification) is probable if oxidizing conditions prevail. The nitrate produced can then be leached directly to groundwater. High nitrate levels have commonly been observed in the vicinity of septic tanks, sewage treatment plants, and leaking sewers (Schmidt, 1971). The travel of ammonium in soils, however, is a function of the ability of the soil to adsorb ammonium during cation exchange reactions, as well as the redox conditions. Ammonium adsorption isotherms were determined for various soils by Preul and Schroepfer (1968). Sandy soils had the lowest adsorption. Another effect noted by Preul and Schroepfer was the decrease in ammonium adsorption as the amount of other cations in the solution was increased. Attenuation of ammonium by ion exchange would therefore be less from wastewaters whose original source was an aquifer containing hard water than from wastewater low in cations. Column leaching tests under both saturated and unsaturated conditions were also performed by Preul and Schroepfer (1968). Under anaerobic saturated conditions, ion exchange reactions in which ammonium was adsorbed were the primary inhibitors of ammonium movement. Adsorption acts only until all available cation exchange sites on soil particles are occupied. After that point has been reached, ammonium is free to move through the soil. In the unsaturated experiments, rapid nitrification of ammonium resulted (Preul and Schroepfer, 1968). The unsaturated tests are analogous to septic tank leaching fields.

Bacteria

Relationship to Health

Waterborne disease is a serious and persistent problem in the United States. From 1971-1977, there were a total of 192 outbreaks of waterborne disease in the United States, affecting a total of 36,757 people (Craun, 1979). Of this number, 12 percent of the outbreaks were chemical poisonings. The remaining 88 percent of the outbreaks are assumed to be biological contamination, although an etiologic agent was not determined for 57 percent of the cases. These unknown diseases were classified as acute gastrointestinal illness, a category which includes the effects of a variety of bacteria and viruses (Craun, 1979). The identified biological outbreaks included Giardiasis, Shigellosis, Hepatitis A, Salmonellosis, Typhoid, and Enterotoxigenic E. coli.

About half of the outbreaks were caused by the consumption of untreated or inadequately treated groundwater. Most of the cases studied involved water from wells near a source of sewage disposal. Sewage lagoons with excessive seepage provide a concentrated source of these pathogenic organisms and therefore cannot be considered safe disposal systems until the fate of bacteria and viruses in soil and groundwater systems is known.

Movement of Bacteria in Soil and Groundwater

Early studies dealing with soil and groundwater contamination from various types of wastewater disposal were reviewed by Romero (1970). Studies were basically of two types: monitoring of groundwater around disposal sites such as privies, latrines, and septic tanks; and application of wastewater to the soil surface in infiltration ponds while monitoring bacteria levels in soil and groundwater beneath the impoundments.

The results of studies dealing with groundwater contamination from pit privies and latrines dug in areas of shallow groundwater in relatively coarse-grained materials indicate significant reductions or total removal of bacteria within distances generally within 50 to 100 feet (15 to 30 m) downgradient from the source (Romero, 1970). Attenuation of the bacteria was attributed to various "soil defense" mechanisms including physical straining and inability of the organisms to survive in the groundwater environment.

Studies of treated or untreated wastewater infiltration (Romero, 1970; Gerba et al., 1975) show extremely variable results. Several studies indicate the removal of most or all bacteria during 5 to 15 feet (1.5 to 4.5 m) of vertical percolation through soil. Other investigations, however, demonstrate the possibility for long distances of travel, even though significant reductions in bacterial density may occur. For example, a California study summarized by Romero (1970) documented the travel of several types of bacteria from tertiary-treated wastewater in infiltration beds to an interceptor trench 1,500 feet (457 m) downgradient. The sediment consisted of coarse alluvium in an old river channel.

Groundwater investigations of sewage lagoons have not generally focused on bacteriological contamination. Fecal coliform bacteria were measured in a Minnesota lagoon study (E. A. Hickok and Associates, 1978). Positive counts were observed in wells at most of the sites. Results in the study were questioned in the report, however, because sampling equipment was not disinfected between wells.

Gerba et al. (1975) reviewed work on the mechanisms involved in the travel and retardation of bacteria in soil and groundwater. In soil, survival of bacteria is increased by high moisture content, high water-holding capacity, low temperature, high pH, and high organic matter content. Bacteria are adversely affected by sunlight and soil microflora. In groundwater, limited data suggest bacteria survival times on the order of several months (Gerba et al., 1975). Longer survival times (several years) under favorable conditions have been suggested by other studies (Romero, 1970).

Krone et al. (1958) conducted intensive studies on the mechanisms of bacteria movement through simulated subsurface environments. Two mechanisms influence the movement of bacteria through saturated soils (Krone et al., 1958). Initially, a mechanical straining occurs as bacteria begin to pass through the soil pores. Eventually, saturation of straining sites is reached along a flow path. Accumulation of bacteria on straining sites facilitates further removal of organisms until a condition of mechanical instability is reached. At this point bacteria and clusters of bacteria cascade rapidly forward along the flow path (Krone et al., 1958). In a portion of the porous medium saturated with respect to straining, sedimentation (the second removal mechanism) is operative. Sedimentation follows Stokes' Law and operates only in low density fluids.

Together, straining and sedimentation retard the movement of bacteria until natural die-off occurs. The movement of bacteria at any specific site is a complex process involving the composition of the wastewater, particle-size distribution of the soil, and subsurface geochemical conditions above and below the water table.

PREVIOUS STUDIES OF WASTE STABILIZATION LAGOON SEEPAGE

Several investigations of groundwater quality have been made to determine the effect of municipal waste stabilization lagoons. Disposal of raw sewage in a lagoon excavated in sand and gravel near Kearney, Nebraska, led to detection of detergents in irrigation wells as far as ½ mile (1 km) from the lagoon (Neel and Hopkins, 1956). Contamination by other components derived from the lagoon, except for chloride, was determined not to be significant.

Two important studies of waste stabilization lagoon seepage have been conducted in Minnesota. Preul (1968) studied ten lagoons in the vicinity of Minneapolis, Minnesota. All lagoons in the study had an unsaturated zone between the base of the lagoon and the water table. The primary nitrogen form detected in groundwater downgradient from the lagoons was ammonium (Preul, 1968), indicating that aeration in the unsaturated zone beneath the ponds was not sufficient to cause nitrification of the ammonium from the lagoons. Ammonium in groundwater reached approximate background concentrations by a distance of 200 feet (61 m) downgradient. Travel of high concentrations of ammonium is possible only by surpassing the adsorptive capacity of the aquifer materials. As seepage from the lagoon continues, the ammonium front will advance slowly by exceeding the adsorptive capacity of the soils. Nitrate levels in groundwater were very low near the lagoons studied by Preul (1968). The groundwater contaminant plumes spreading downgradient from the lagoons were sufficiently anaerobic to prevent nitrification of the ammonium. The lack of nitrification in the unsaturated zone beneath the ponds is in contrast to conditions beneath septic tank drain fields, where nitrification of seepage occurs within several feet of its source (Preul, 1968).

Another study of Minnesota lagoons (E. A. Hickok and Associates, 1978), examined lagoons constructed in fine-grained and coarse-grained soils. Lagoons in the fine-grained soils showed very little nitrogen contamination of groundwater because of the high ammonium adsorptive capacity of the soils. Two of the lagoons constructed in sand, however, caused severe ammonium contamination downgradient from the pond. In addition, at the Royalton Pond, downgradient nitrification of the ammonium occurred, leading to high nitrate concentrations within several hundred feet of the lagoon.

Lagoon studies in South Dakota were reviewed by Bleeker and Dornbush (1980), and, in addition, results of new studies were presented. The report concludes that groundwater contaminated by waste stabilization lagoons is not degraded below drinking water standards. Levels of ammonium and nitrate in samples collected from seepage into drainage ditches and drain tiles adjacent to the lagoons were not considered to be representative of groundwater quality beneath the lagoons because of the short distance of travel of the water. Bleeker and Dornbush (1980) recommend that lagoons with excessive leakage be retained as acceptable treatment facilities.

Prior to this study only two North Dakota waste stabilization lagoons have been investigated (North Central Consultants, Ltd., 1979a,b) to determine groundwater quality. Nitrate levels were generally low with the exception of one sampling period at the Esmond, North Dakota lagoon (North Central Consultants Ltd., 1979a), in which they reached nearly 100 mg/l at one well. This was not considered to be a serious problem. Ammonium levels were not measured in the studies.

McVILLE WASTE STABILIZATION LAGOON

Introduction

The most detailed investigation in the project was conducted at McVille, a town of 626 people in Nelson County (fig. 1). Of the three waste cells at the site, cell I, with an area of approximately three acres (1.2 hectares), is the only cell which permanently retains wastewater (fig. 3). Cell II, with an approximate area of one acre (.4 hectares) receives wastewater from cell I for short periods of time several times per year. Cell III, also approximately one acre (.4 hectares) in area, is not used. The occasional use of cell II may have an extremely important effect on the groundwater quality around the lagoon.

The McVille lagoon site was more suitable for groundwater monitoring than the other sites studied because monitoring wells could be installed downgradient from the operating wastewater cell. This was not possible at the other sites because of land use adjacent to the lagoons. Because of the importance of the McVille site, fourteen wells were installed. Eight wells were installed in the fall of 1980 and summer of 1981, and six more wells were added in 1982. Only one sampling period was possible for these last six wells. The large amount of data at the McVille site requires more discussion of this site than the other sites in the study.

Hydrogeologic Setting

The McVille lagoon site lies above one of the most productive aquifers in eastern North Dakota, the McVille Aquifer. The McVille Aquifer is a buried channel aquifer consisting of fluvial sand and gravel sediments deposited in a deep valley cut into bedrock of the Pierre Formation. Some portions of the aquifer are buried beneath till and other sediments deposited during and after a glacial advance which overrode the valley containing the aquifer. In the vicinity of McVille, however, sand and gravel are exposed at the surface and the aquifer is unconfined. Just south of the lagoon site, the aquifer contains as much as 260 feet (79 m) of sand and gravel (fig. 4) (Downey, 1973). Flow is southward in this part of the aquifer leading to discharge areas in the Sheyenne Valley, about 2 miles (3.2 km) south of the study area. The water table lies 20 to 30 feet (6 to 9 m) below land surface.

The material encountered during drilling for monitoring well installation is relatively uniform medium- to coarse-grained sand. Single-well response tests in monitoring wells yielded a mean hydraulic conductivity value of 1.3×10^{-4} ft/s (4.0×10^{-5} m/s) (app. VI). Some wells recovered too rapidly to obtain water level data, so this value should be considered to be lower than the true mean. The mean value of hydraulic conductivity derived from grain-size distribution curves is 9.2×10^{-5} ft/s (2.8×10^{-5} m/s) (app. V). The transmissivity of the aquifer is estimated to range from 2,100 ft^2/day to 9,400 ft^2/day (195 m^2/day to 873 m^2/day) (Downey, 1973).

Hydrogeologic conditions at the lagoon site are illustrated in figures 5 and 6. Although a slight water table mound may exist beneath the impoundment, the elevation of this mound must be minor. Wastewater seeping through the base of cell I must therefore move through a significant unsaturated thickness to reach the water table (fig. 5). The direction of flow at the site is southward (fig. 6) with an approximate gradient estimated from the water table contours as 6×10^{-3}. The average linear flow velocity of groundwater at the site is .07 ft/day (.02 m/day). This value is calculated from Darcy's Law by using the above gradient, a hydraulic conductivity of 3.3×10^{-5} ft/s (10^{-5} m/s), and a porosity of .3.

Groundwater fluctuations at the site are not high (fig. 7) relative to the other study sites, indicating a higher hydraulic conductivity and specific yield at the McVille site than at the other lagoon sites studied.

The general water quality in the aquifer is good. The water is calcium bicarbonate to sodium bicarbonate or sodium sulfate type (Downey, 1973). The range in total dissolved solids (TDS) for the aquifer was 285 mg/l to 2,400 mg/l (Downey, 1973).

Results

Figures 8 through 19 show the

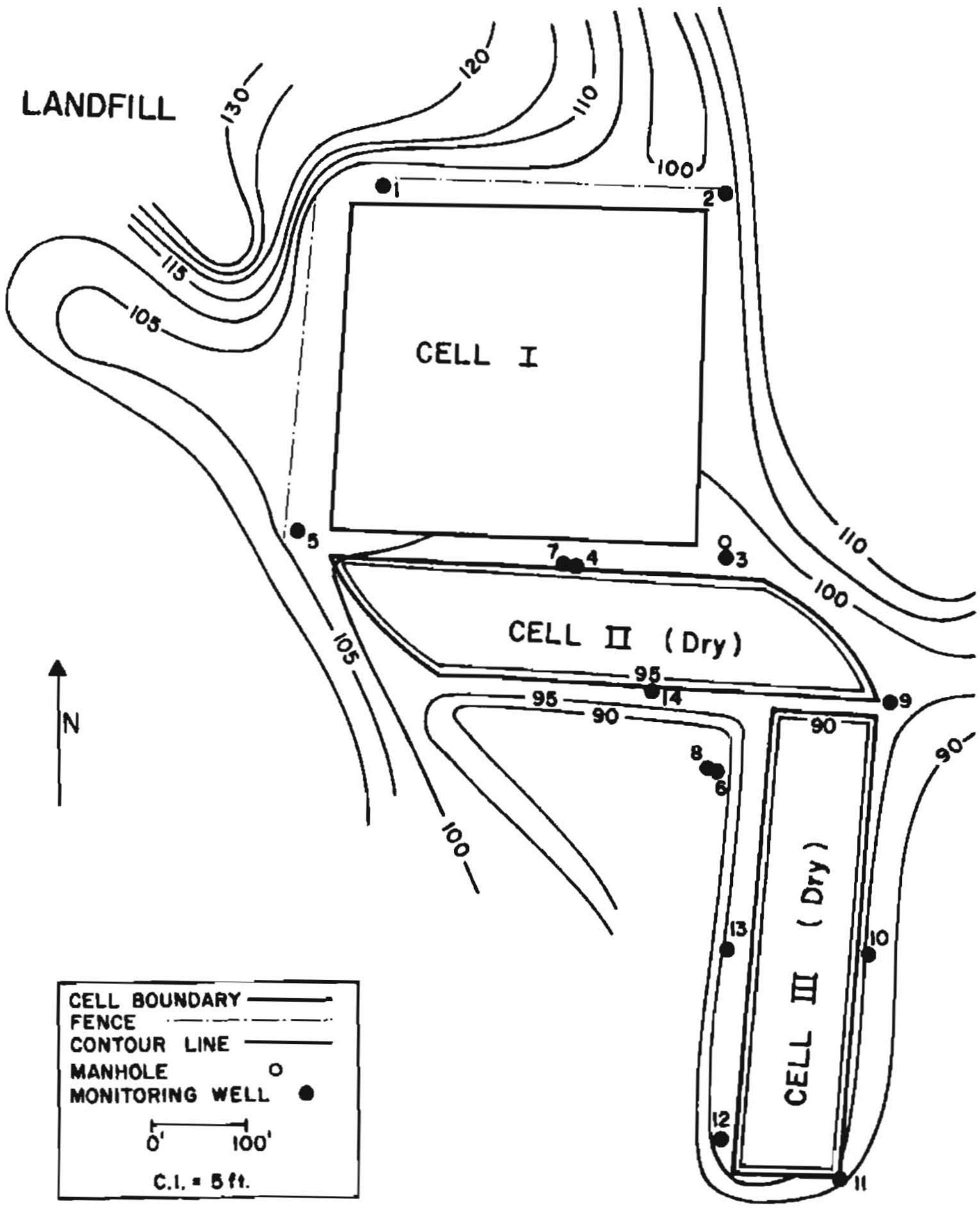

Figure 3. Topography and location of monitoring wells at the McVille site.

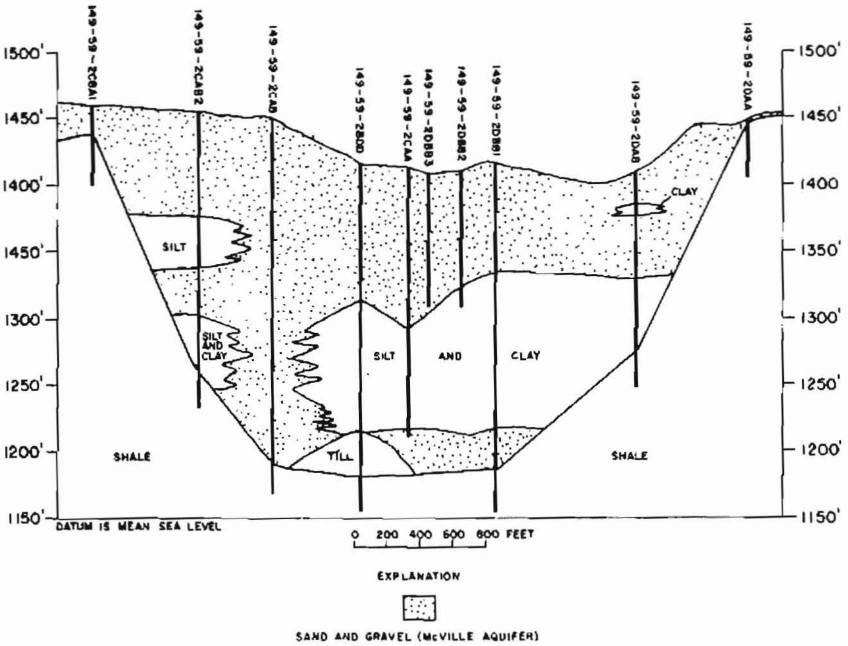

Figure 4. Cross section of McVille Aquifer located about 1 mile (1.6 km) south of McVille. Section from west (left) to east (right). From Downey, 1973.

distribution of various chemical parameters at the lagoon site for the summer, 1982 sampling period, which was the only sampling period to include data from all fourteen wells because wells 9 through 14 were installed just prior to this sampling period. Variation in most parameters in wells sampled four times was not great (app. IV); therefore the values obtained for the six wells sampled only once are assumed to be representative.

A factor which influences the water chemistry at the McVille site is the presence of an inactive landfill bordering the northeast corner of the lagoon (fig. 3). The landfill most directly affects the chemical quality of well 1.

Contamination of groundwater from the lagoon affects all downgradient wells at the site. The general form of the contaminant plume is best illustrated by the distribution of TDS (fig. 8) and chloride (fig. 9). The plume is the result of steady seepage from cell I and intermittent rapid seepage from cell II. The intermittent discharge of wastewater into cell II is lost very rapidly by seepage because of the lack of a sludge layer at the base of the cell. Sludge layers formed in wastewater lagoons decrease the hydraulic conductivity of underlying sediments by clogging of soil pores with colloidal materials and by growth of slime-forming microorganisms (Chang et al., 1974). This self-sealing process is reversible upon drying of the soil. Therefore, intermittent wastewater discharge into cell II at the McVille site results in very rapid infiltration unhindered by self-sealing mechanisms. The intermittent discharges into cell II may result in pulses of contaminant movement through the groundwater flow system.

The analysis of samples from a farm well located approximately 1,000 feet (300 m) east of the lagoon is shown on each diagram. This well is screened in the lower part of the buried channel aquifer and is assumed to represent background aquifer quality unaffected by the lagoon. The upgradient shallow wells at the site can be compared to this farm well. Well 1 indicates contamination from the

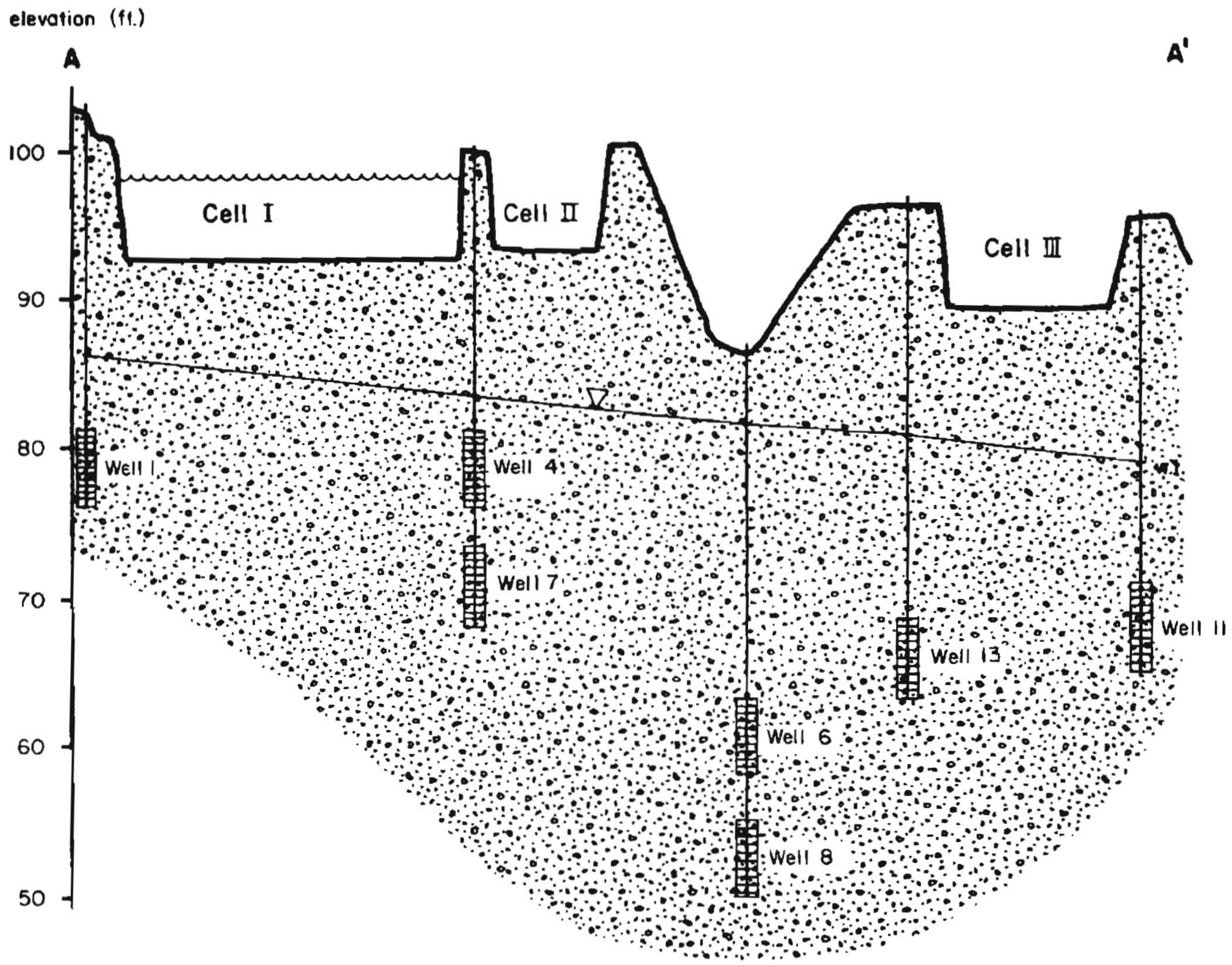

Figure 5. Cross section of McVille Lagoon site. Location of section shown on figure 6. Screened section shown at base of each well.

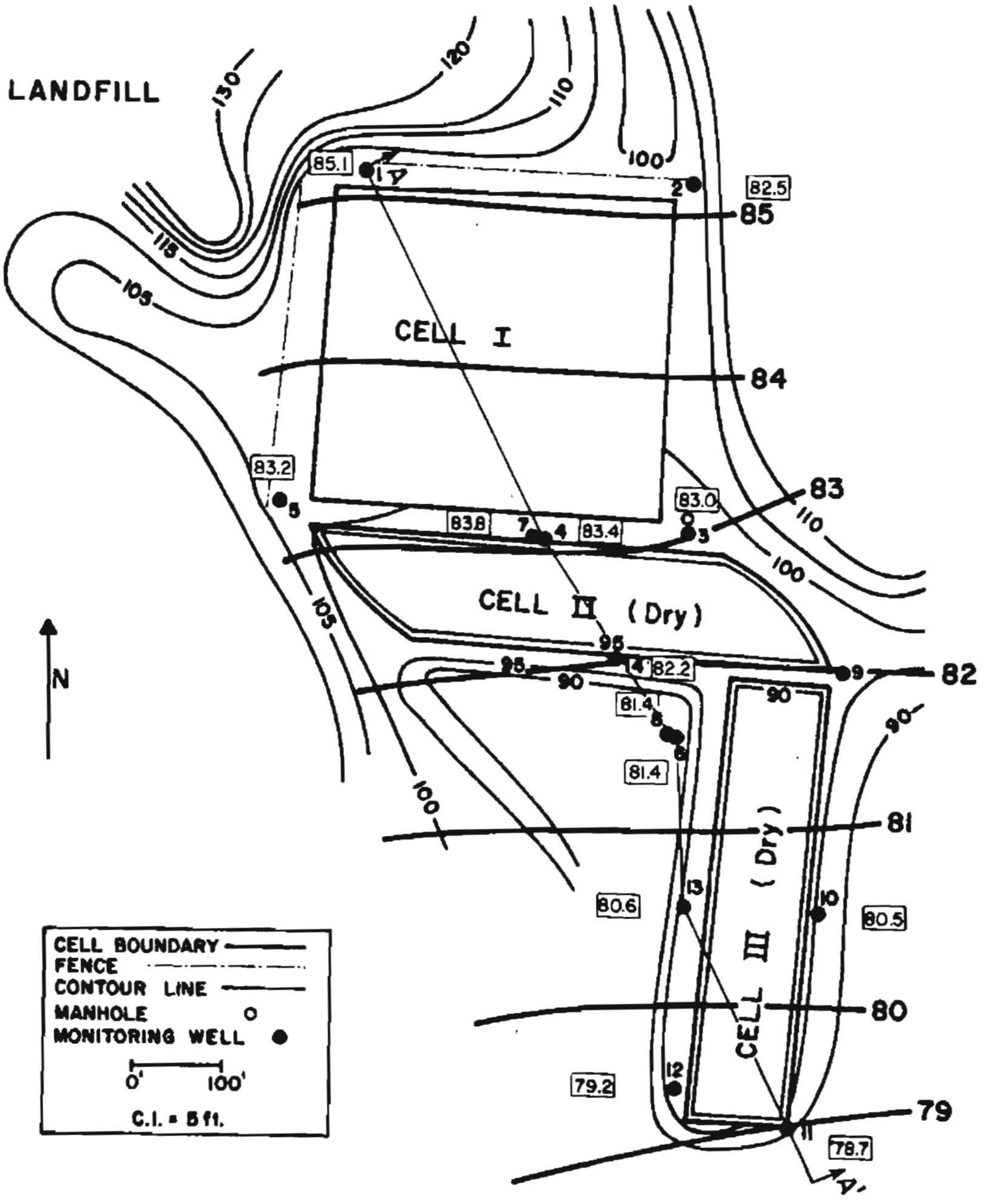

Figure 6. Contours showing water table elevation (heaviest lines) at McVille site on July 27, 1982. Water table elevations (in boxes) based on arbitrary datum at 0 feet. Line A-A': Location of cross section shown in figure 5.

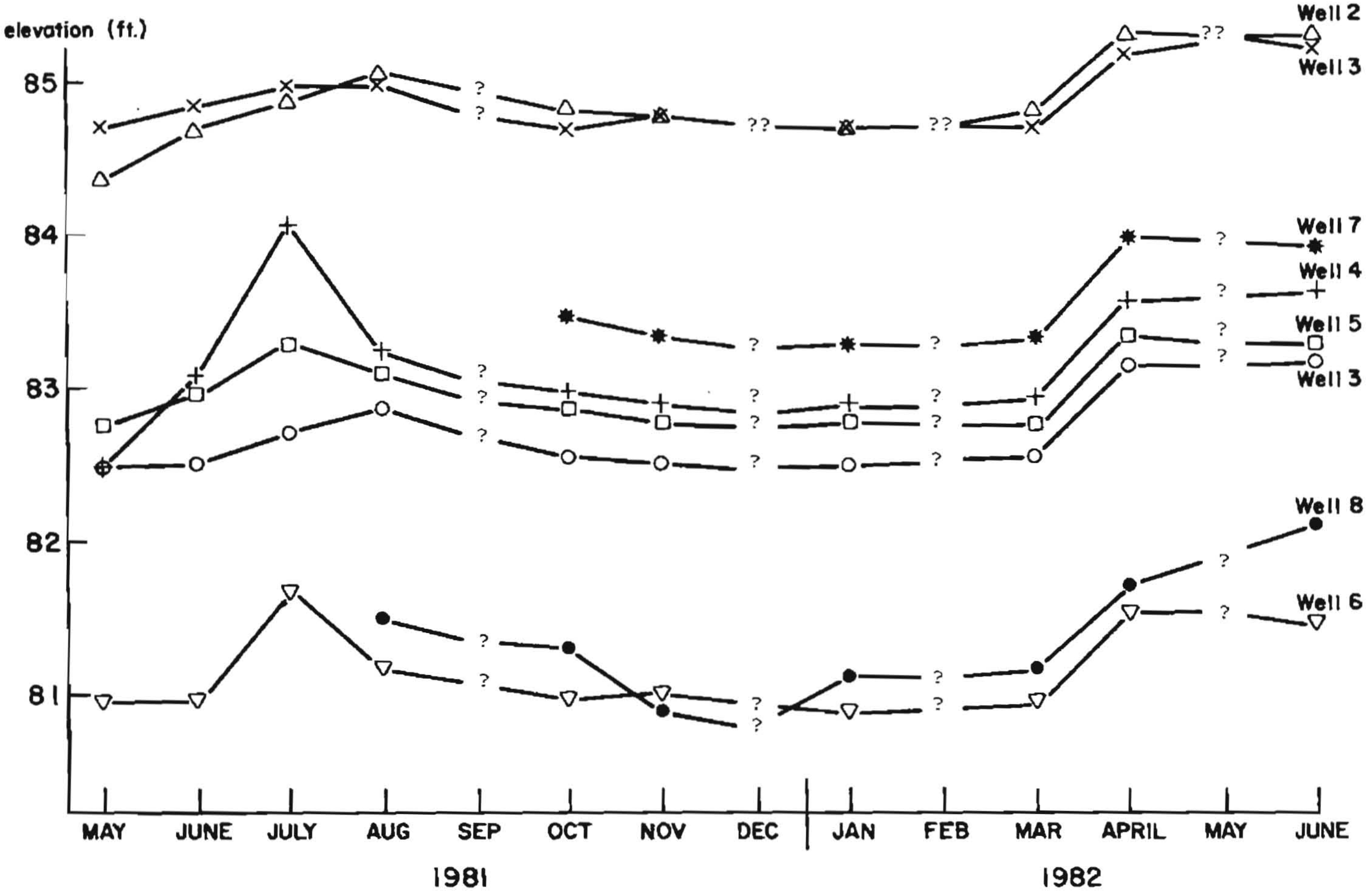

Figure 7. Water level fluctuations at McVille site during study period. Question marks indicate times at which measurements were not made.

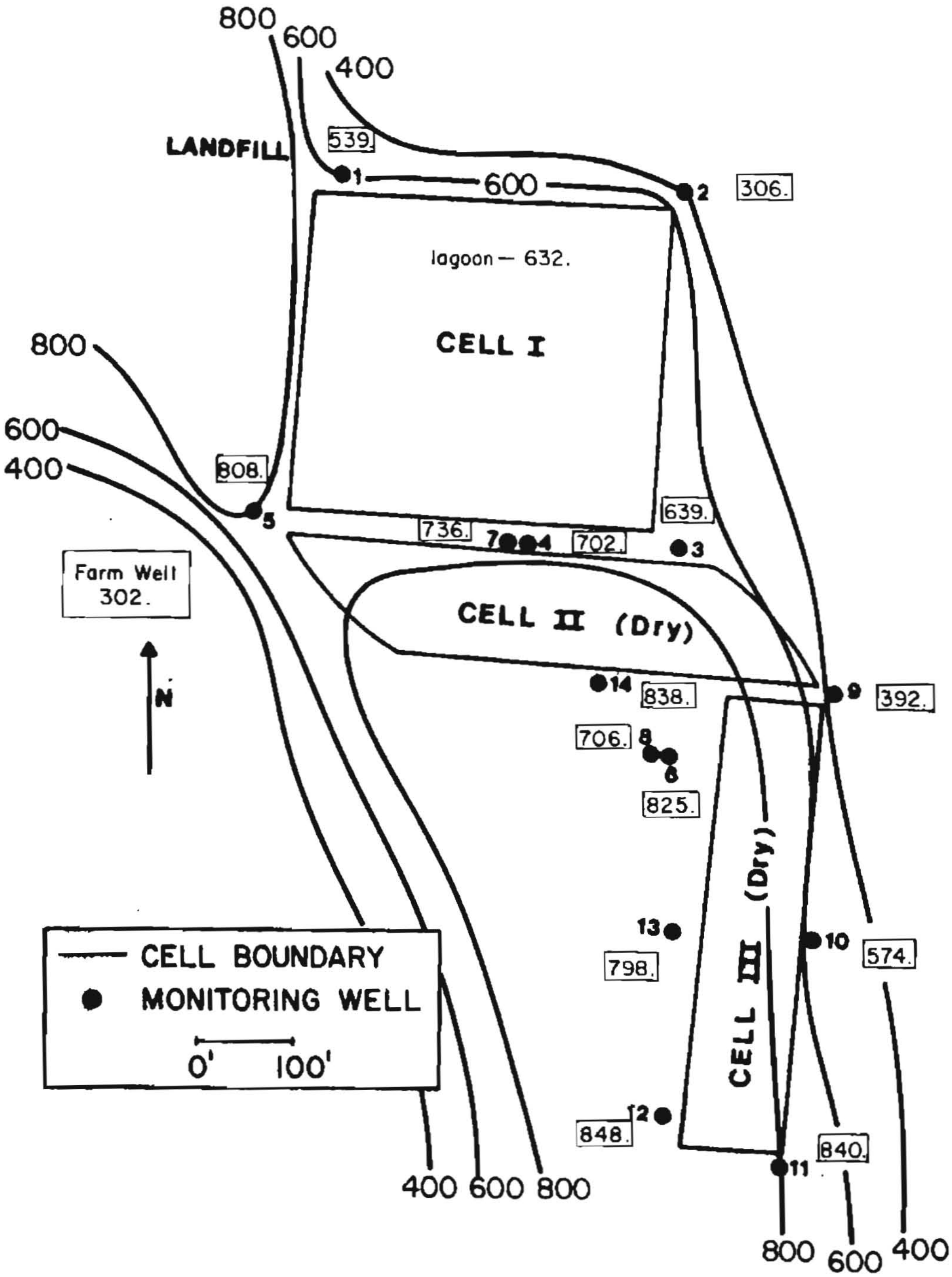

Figure 8. Total dissolved solids content (TDS) in groundwater at McVille site on July 27, 1982. Measured values in boxes. Contour interval 200 mg/l. At sites with well nests, concentration value of shallow well is used for contouring.

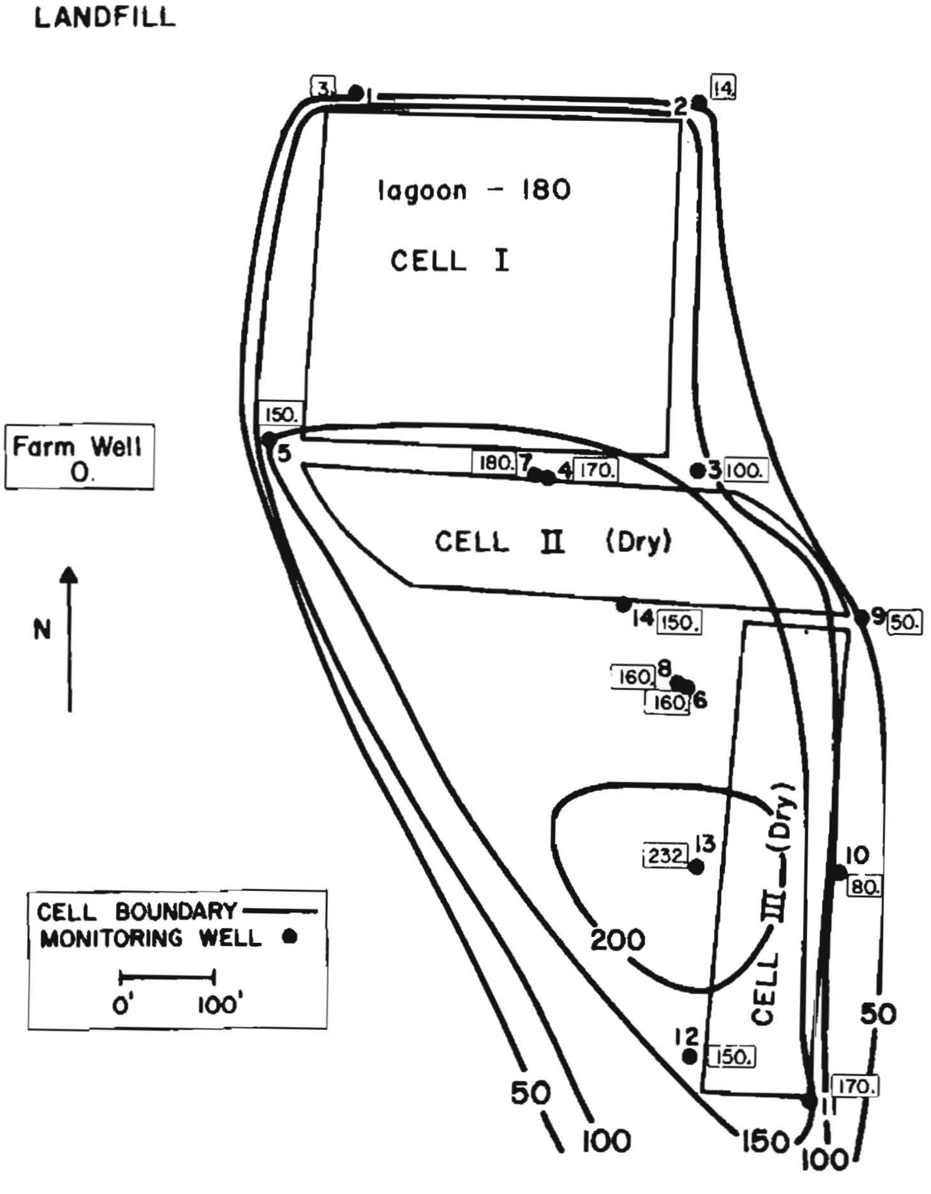

Figure 9. Chloride concentration in groundwater at McVille on July 27, 1982. Measured values in boxes. Contour interval 50 mg/l.

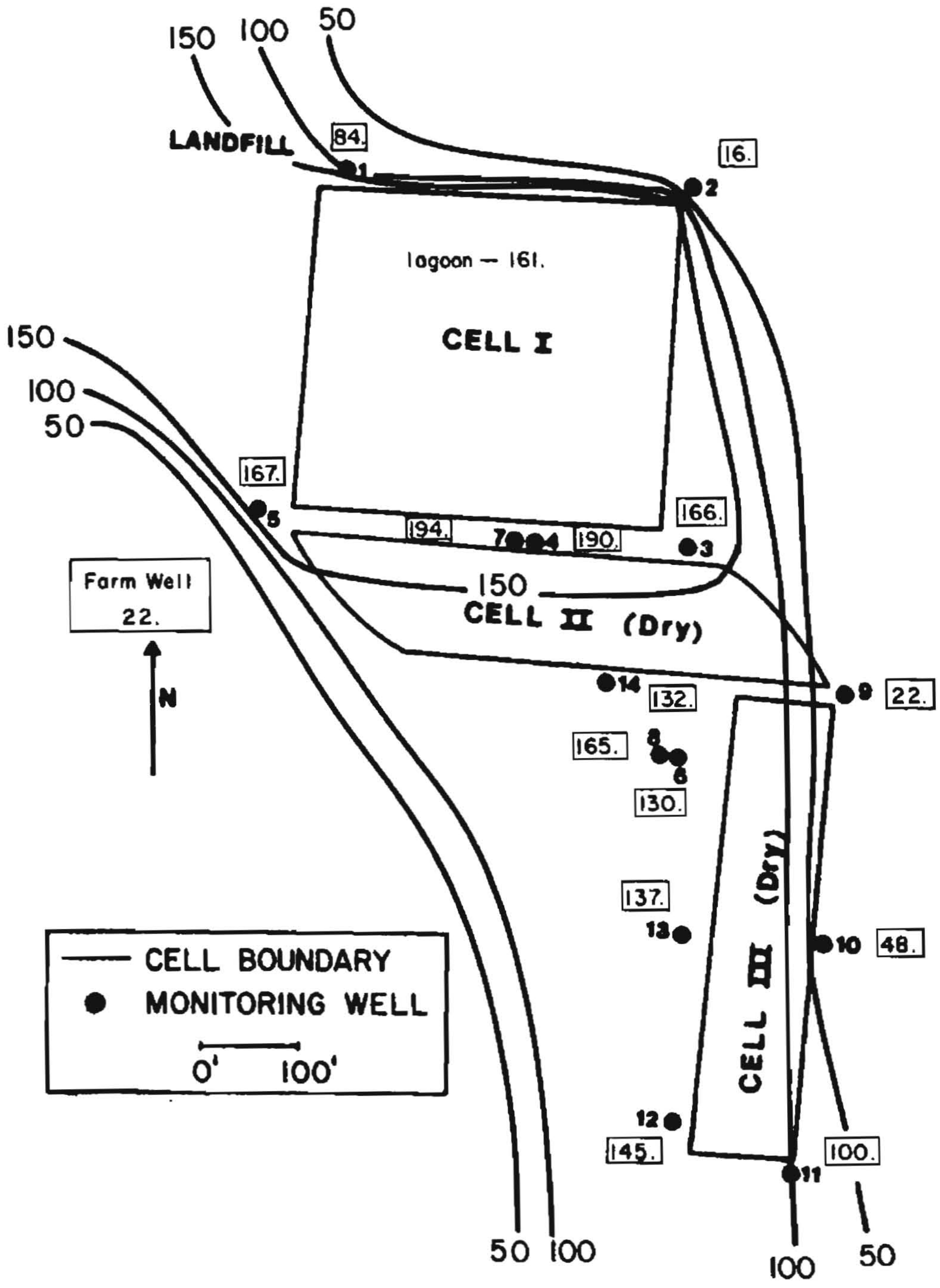

Figure 10. Sodium concentration in groundwater at McVille site on July 27, 1982. Measured values in boxes. Contour interval 50 mg/l. At sites with well nests, concentration value of shallow well is used for contouring.

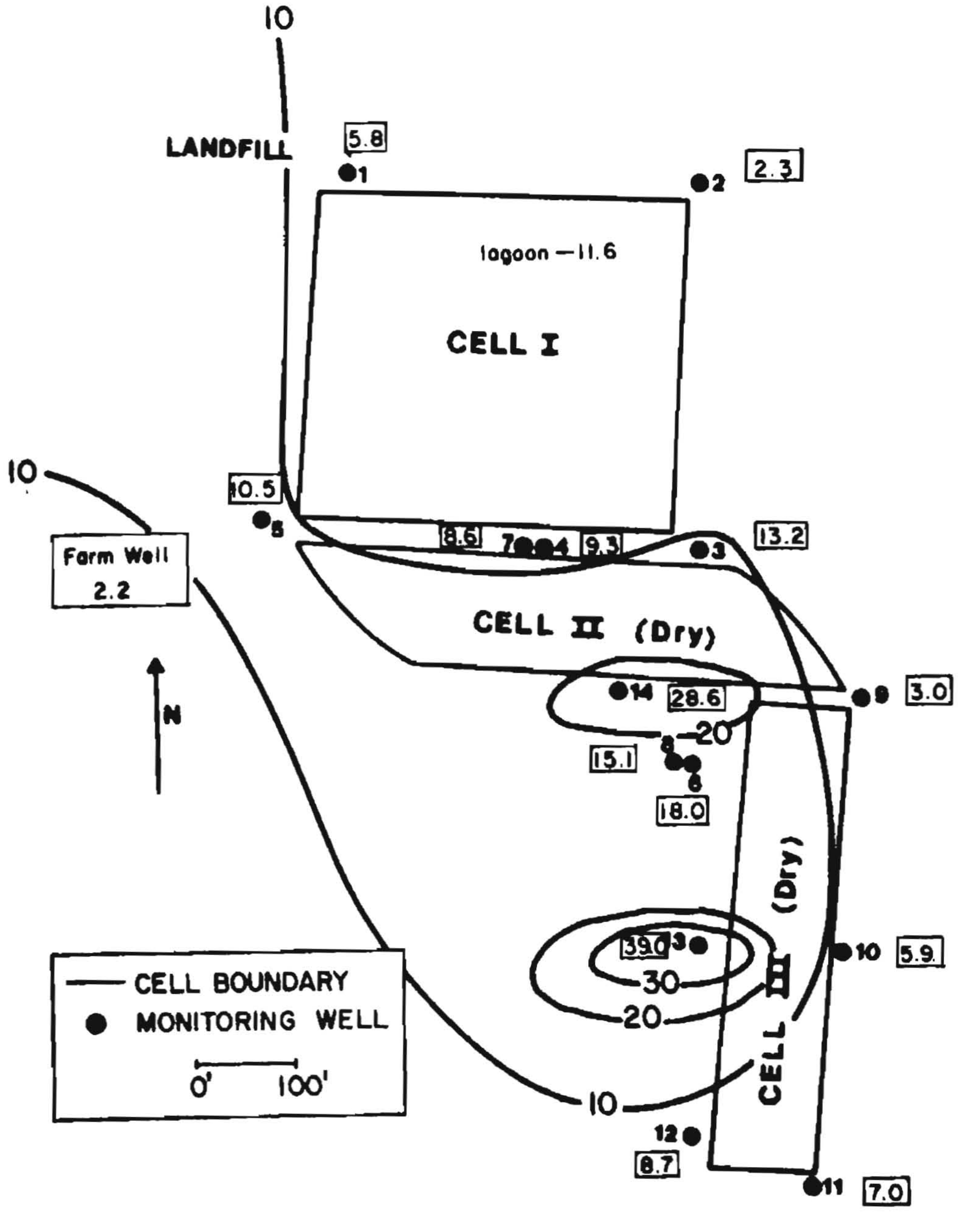

Figure 11. Potassium concentration in groundwater at McVille site on July 27, 1982. Measured values in boxes. Contour interval 10 mg/l.

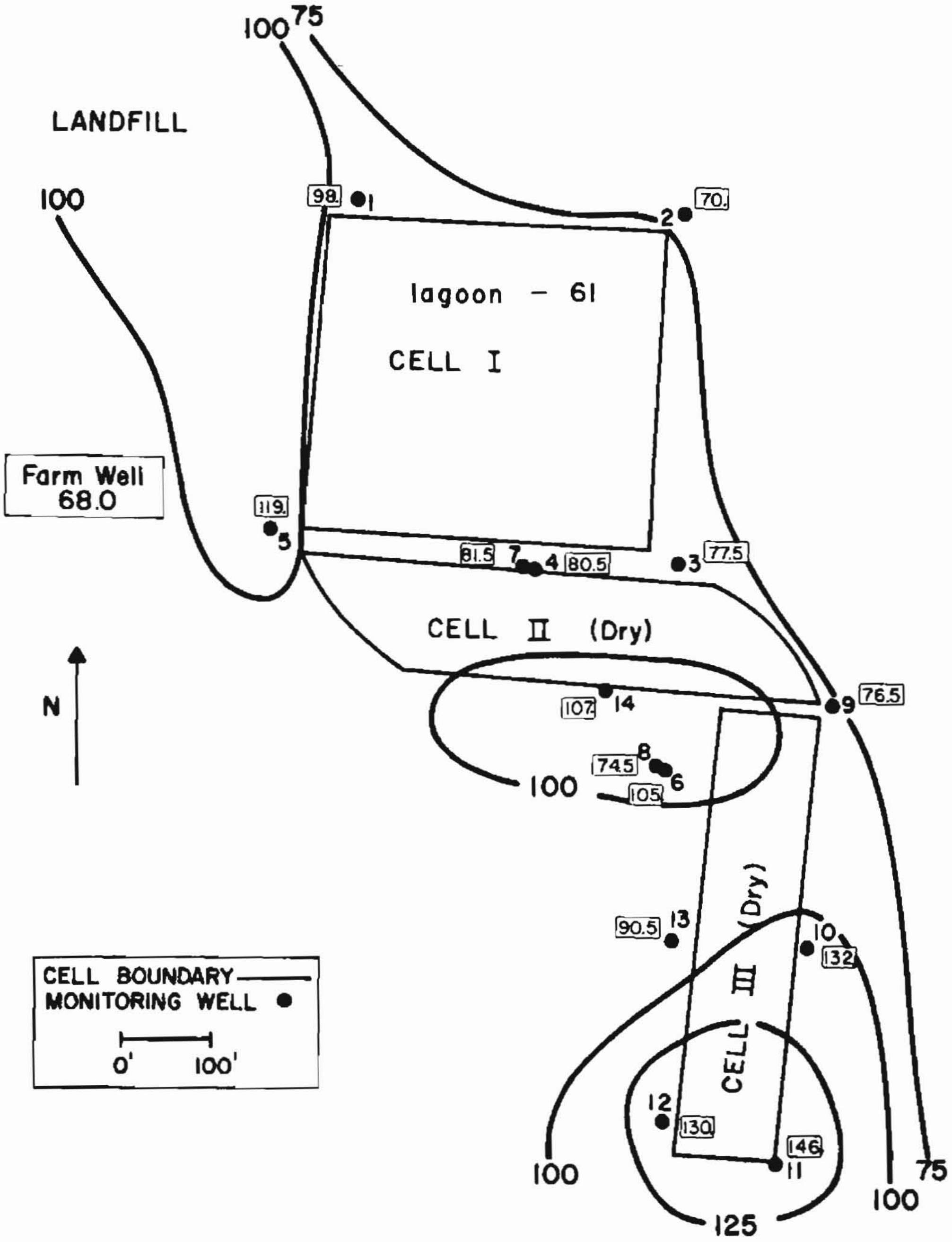

Figure 12. Calcium concentration in groundwater at McVille site on July 27, 1982. Measured values in boxes. Contour interval 25 mg/l. At sites with well nests, concentration value of shallow well is used for contouring.

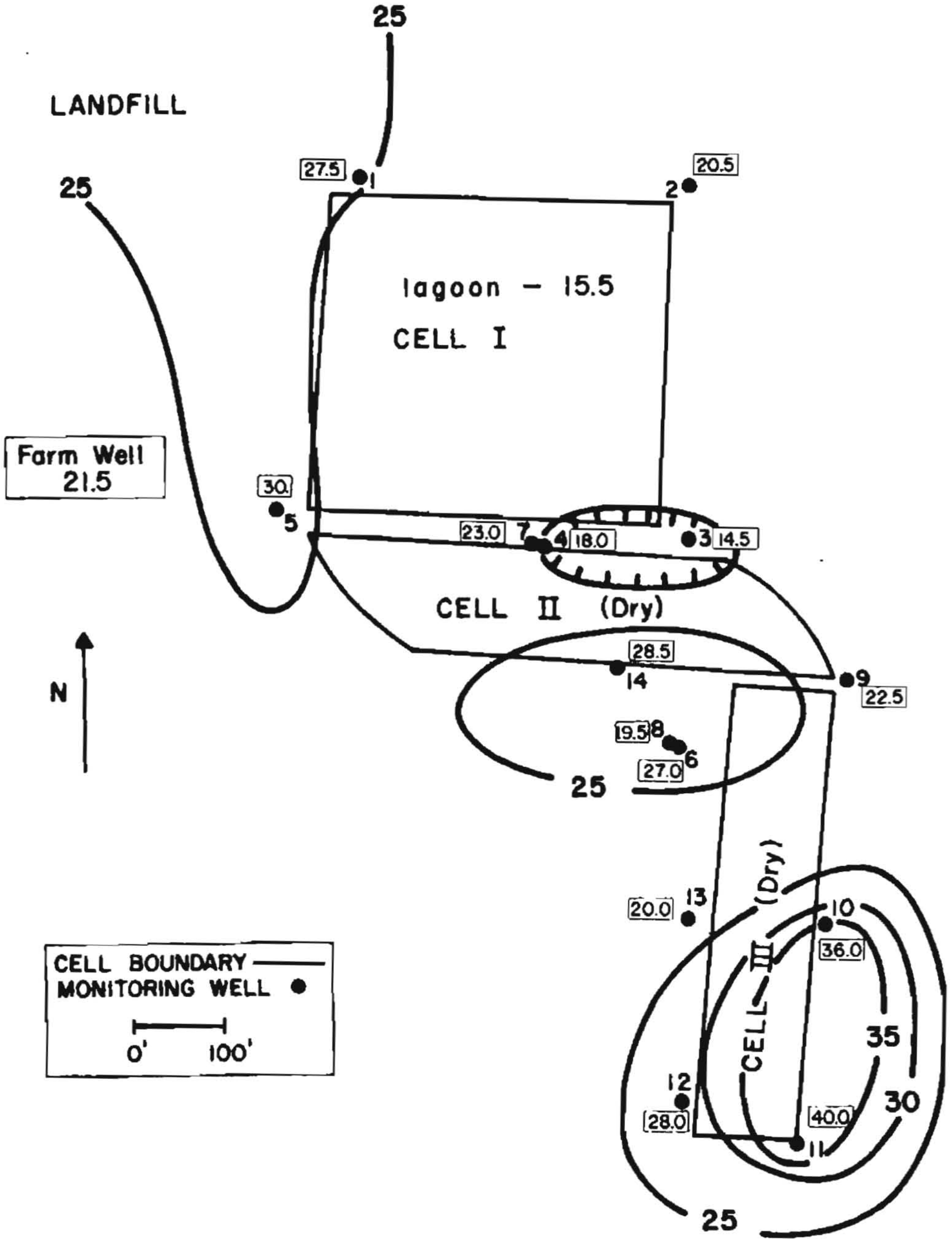

Figure 13. Magnesium concentration in groundwater at McVille site on July 27, 1982. Measured values in boxes. Contour interval 5 mg/l. At sites with well nests, concentration value of shallow well is used for contouring.

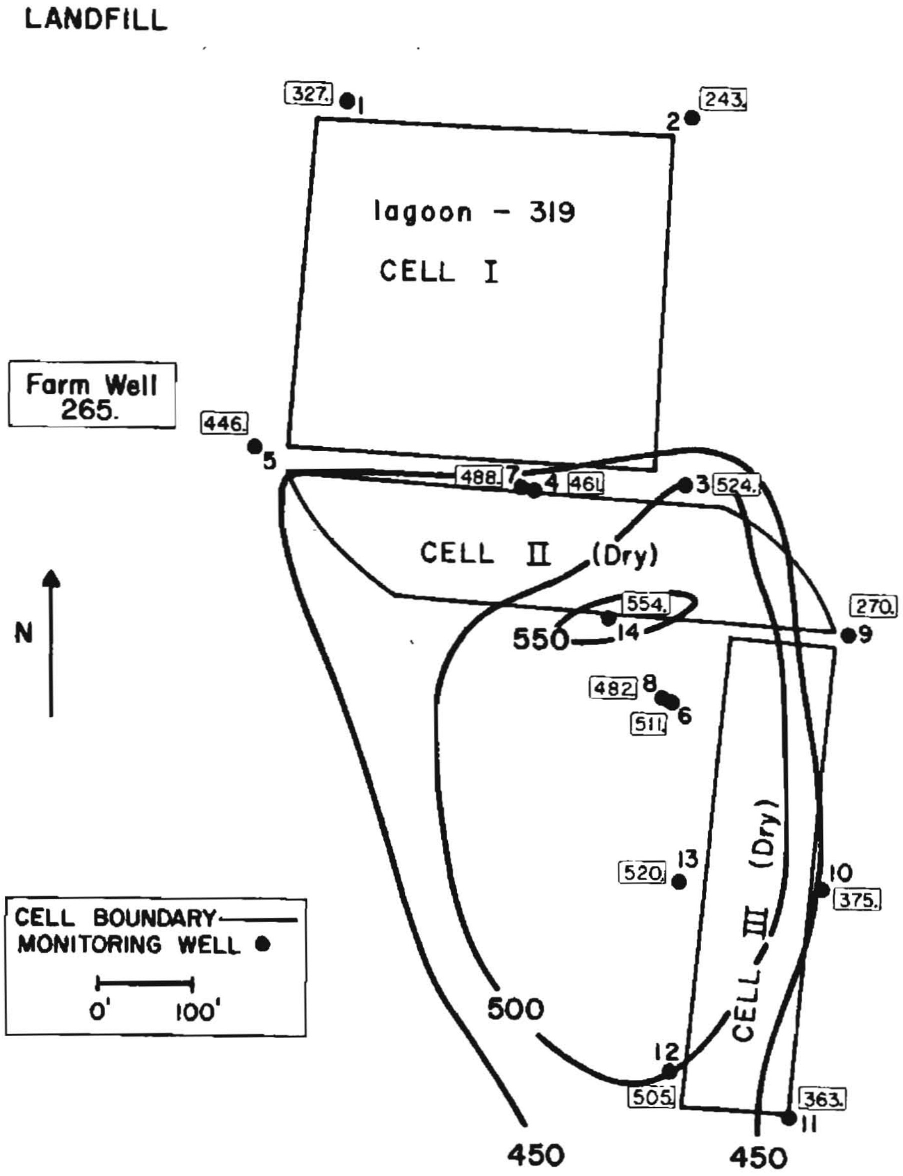

Figure 14. Bicarbonate concentration in groundwater at McVille site on July 27, 1982. Measured values in boxes. Contour interval 50 mg/l. At sites with well nests, concentration value of shallow well is used for contouring.

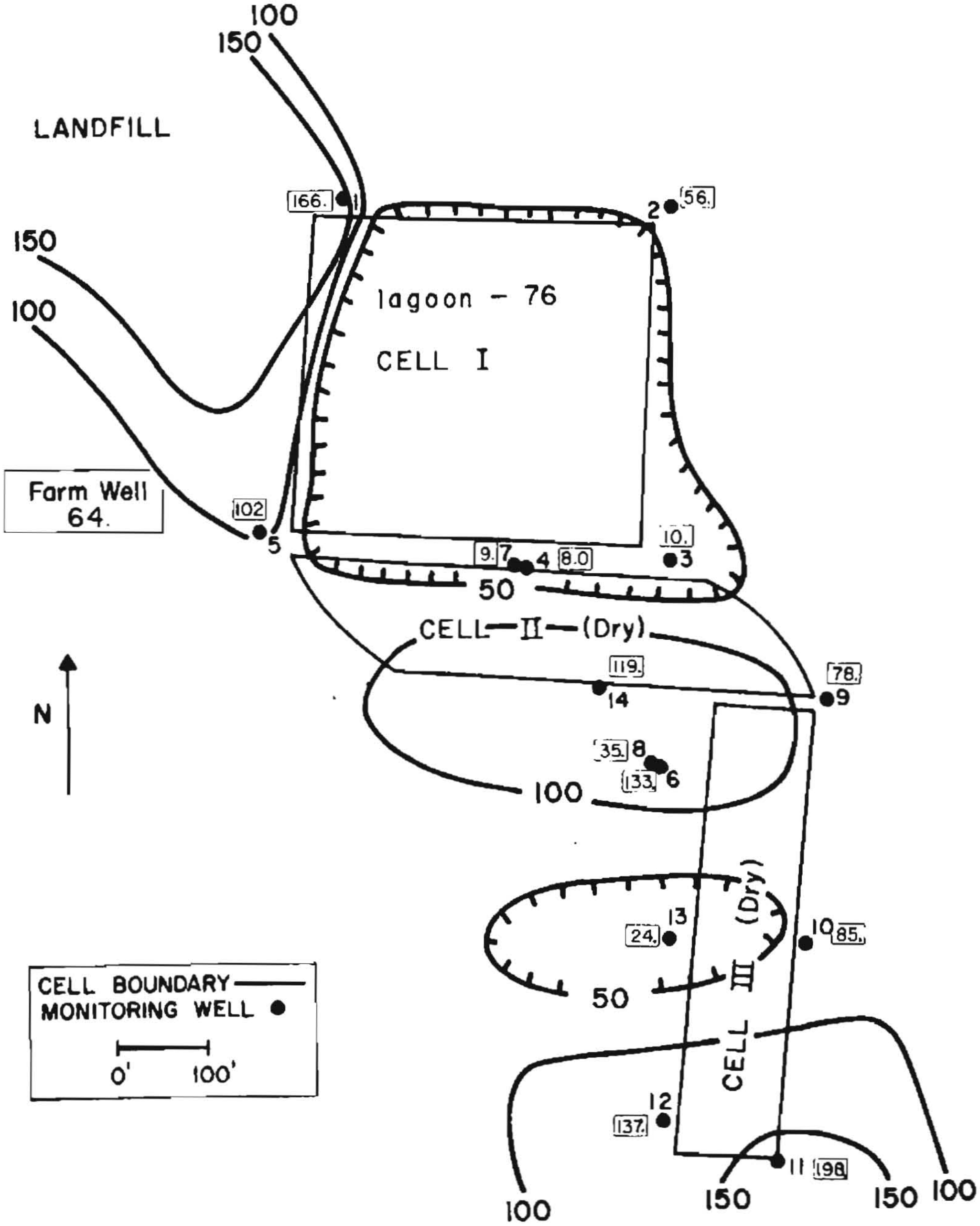

Figure 15. Sulfate concentration in groundwater at McVille site on July 27, 1982. Measured values in boxes. Contour interval 50 mg/l. At sites with well nests, concentration value of shallow well is used for contouring.

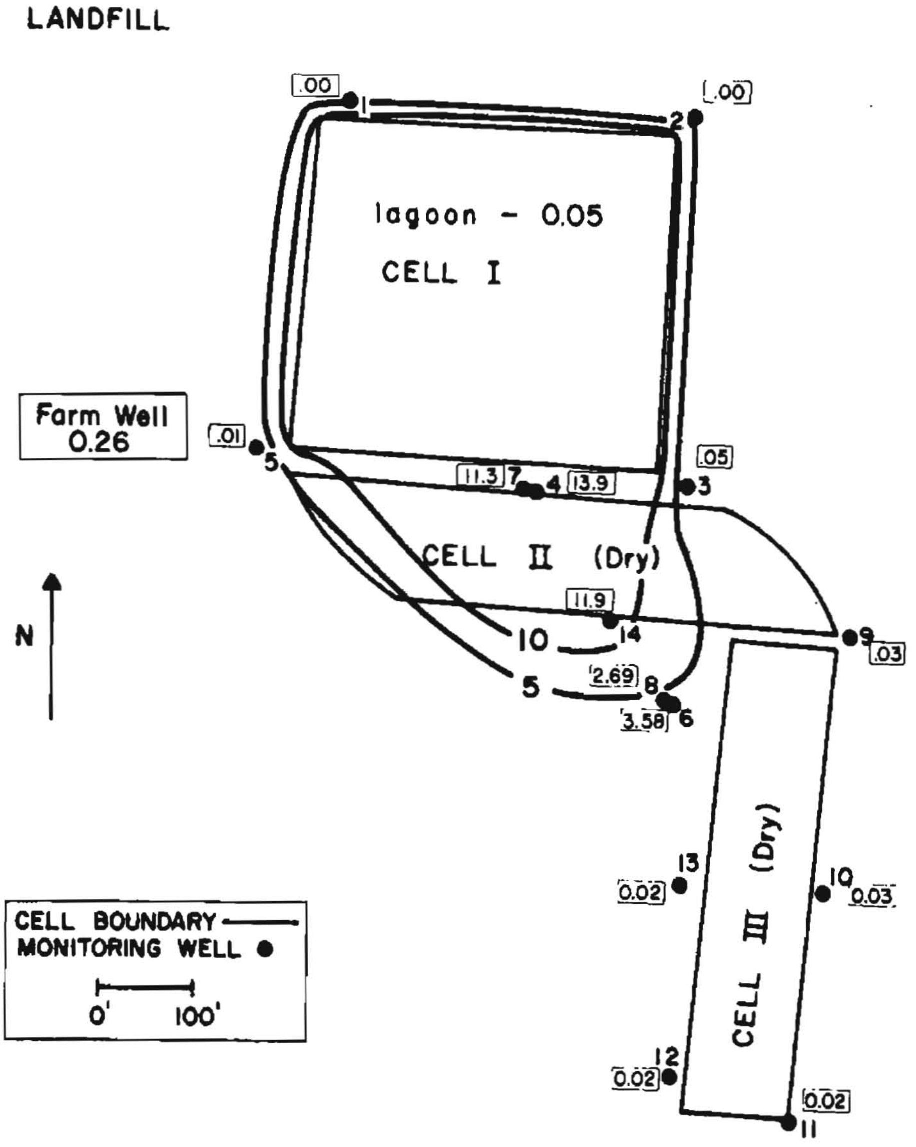

Figure 16. Iron concentration in groundwater at McVille site. Wells 1 through 8 show data from August 26, 1981. Wells 9 through 14 show data from July 27, 1982. Measured values in boxes. Contour interval 5 mg/l.

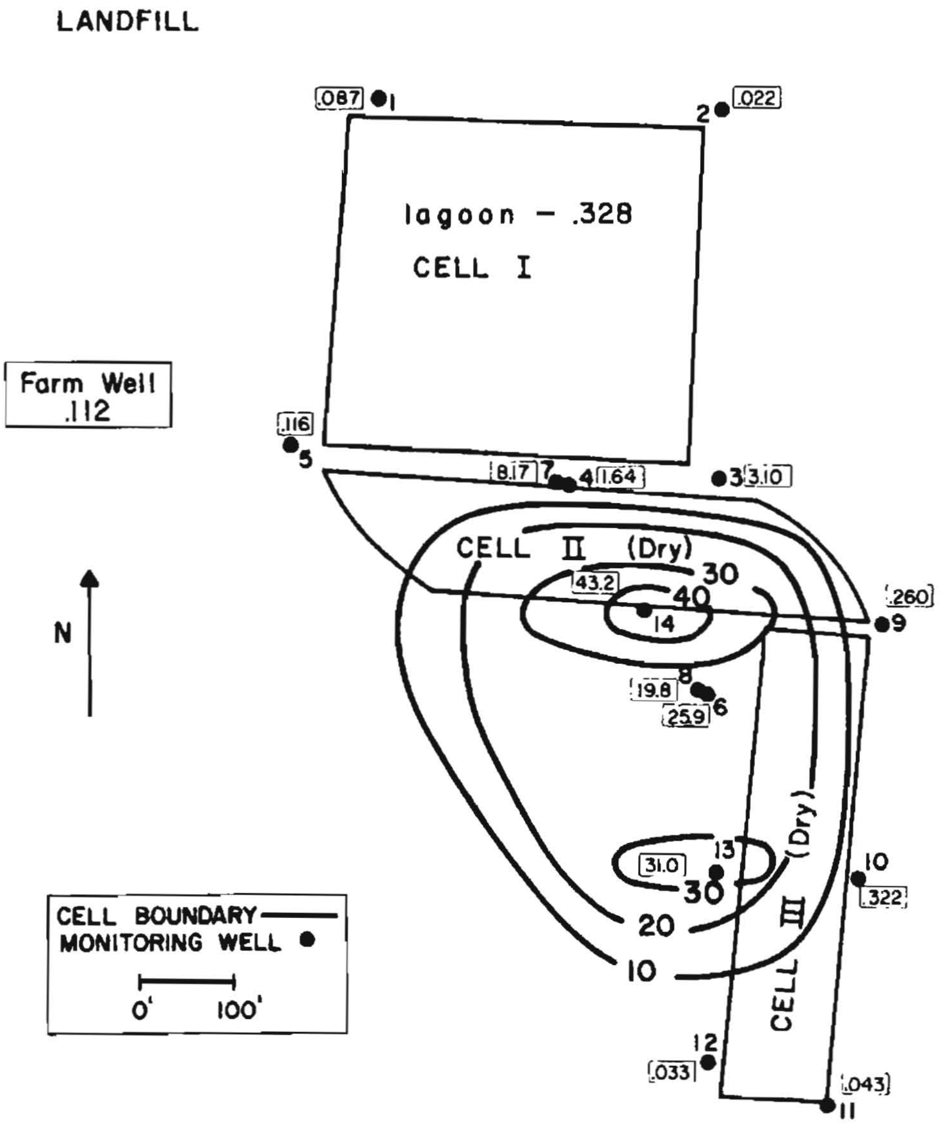

Figure 17. Ammonium concentration in groundwater at McVille site on July 27, 1982. Measured values in boxes. Contour interval 10 mg/l. At sites with well nests, concentration value of shallow well is used for contouring.

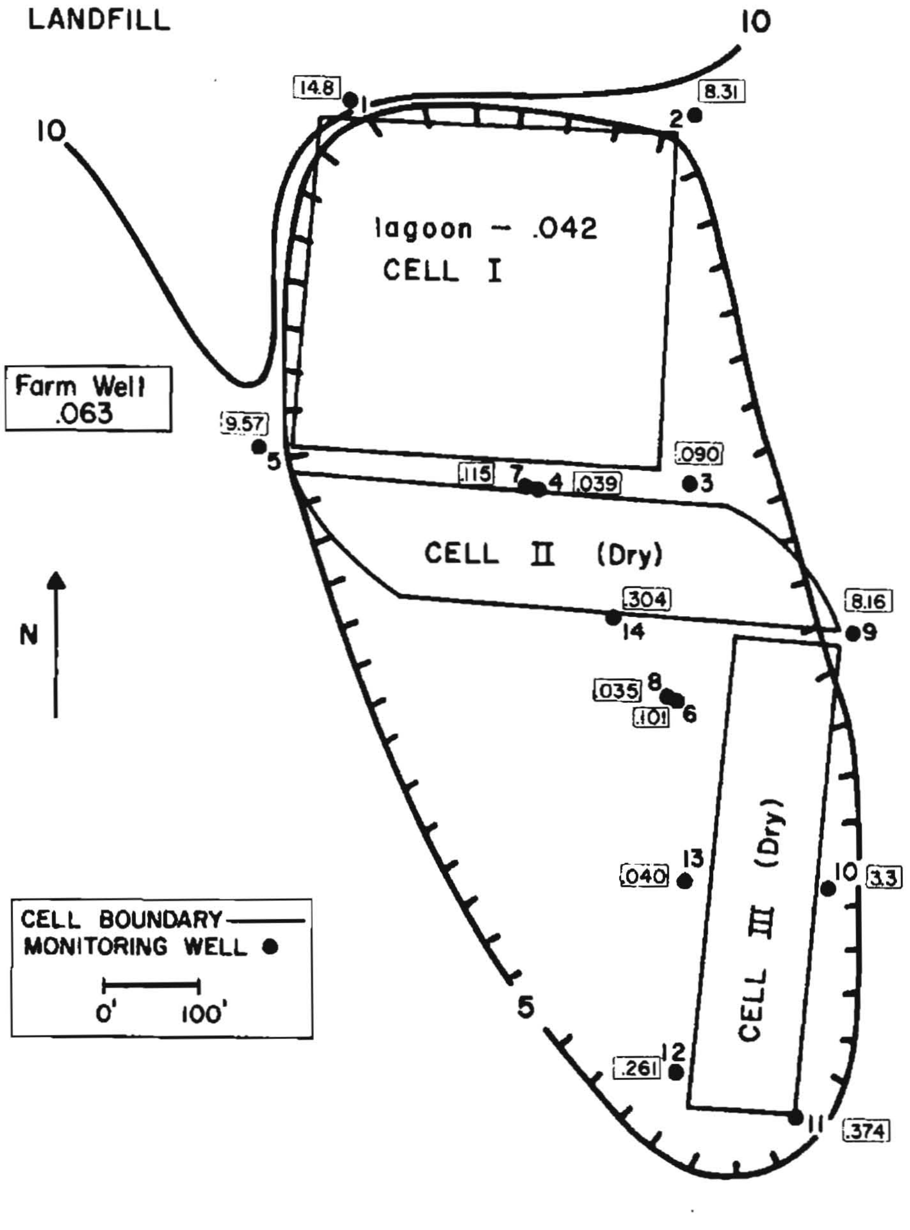

Figure 18. Nitrate concentration in groundwater at McVille site on July 27, 1982. Measured values in boxes. Contour interval 5 mg/l.

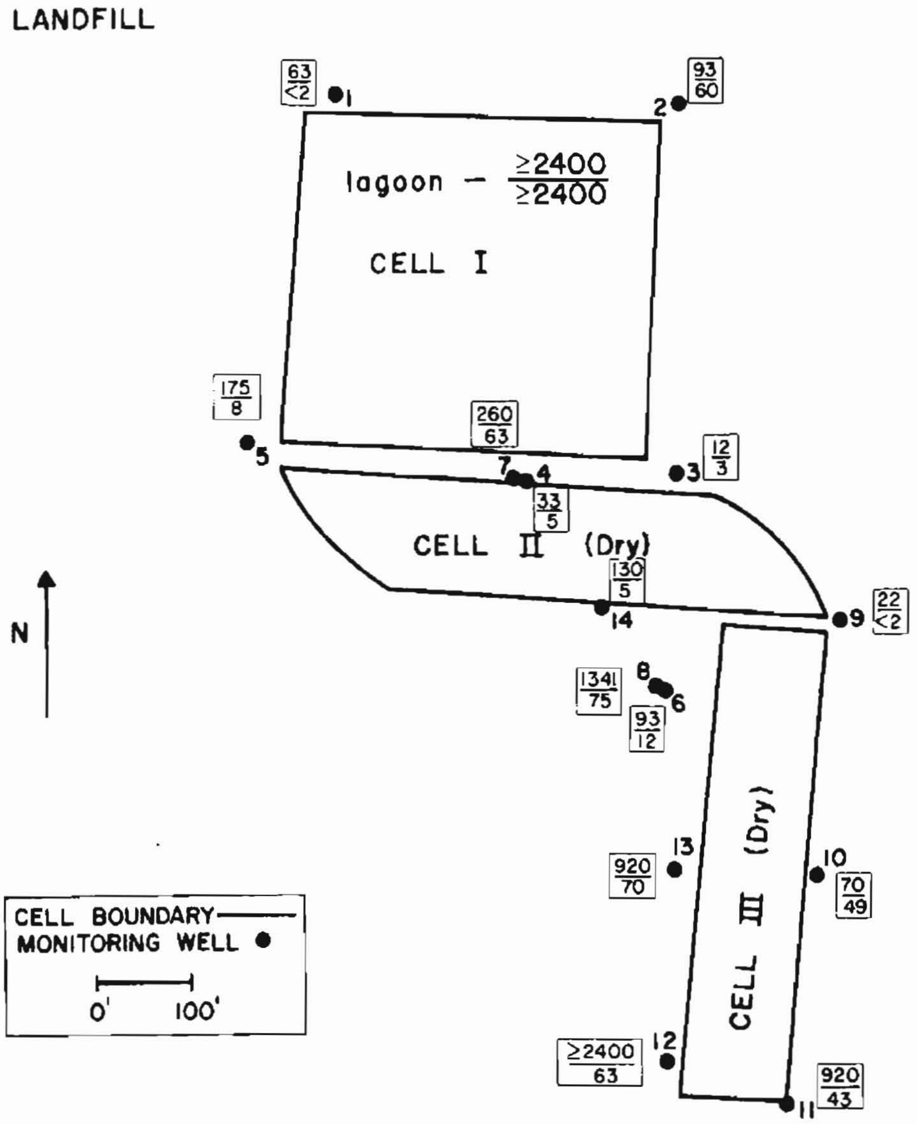

Figure 19. Bacteria counts in groundwater at McVille site. Upper number in box is total coliform count and lower number is fecal coliform count. Wells 1-8 are mean values for three sampling periods. Wells 9-14 are values for July 27, 1982. Values expressed as colonies per 100 ml.

landfill to the northeast. Well 2 is very close to background levels for most parameters.

The geochemical interactions between the wastewater, soil, and groundwater are revealed by the distribution of other chemical parameters at the site. Interpretation must include recognition of the two seepage mechanisms in operation: slow, constant seepage from cell I through an anaerobic sludge layer, and intermittent, rapid seepage under aerobic conditions through the bottom of cell II. A discharge of wastewater into cell II occurred several weeks prior to the July 27, 1982 sampling date.

The sodium and potassium concentrations are shown in figures 10 and 11. Both cations form plumes similar in shape to the TDS and chloride plumes. The highest concentration of sodium lies just downgradient from cell I while maximum potassium concentrations are centered downgradient of cell II. Cation concentrations are controlled by cation exchange reactions with clay minerals and other colloidal materials. Sodium and potassium are among the more weakly adsorbed cations so that some attenuation of their concentrations in groundwater by adsorption and ion exchange will occur, but retardation relative to other cations is not great.

Calcium and magnesium concentrations are shown in figures 12 and 13. These parameters have similar distribution patterns with distinct areas of high concentration beneath the southern end of cell III. Other less pronounced high areas are just downgradient of cell II and in well 5. The calcium and magnesium contents of the wastewater entering the lagoon are probably somewhat higher than the value measured for the lagoon water, but lower than the concentrations in groundwater beneath cell III. The relatively high levels at wells 1 and 5 are probably the result of leachate from the landfill. Concentrations increase from wells 4 and 7 to the vicinity of wells 6 and 8 and from well 13 to the very high concentration area around wells 10, 11, and 12. These trends can be explained by the hardness halo effect (Griffin et al., 1976), whereby calcium and magnesium concentrations increase downgradient as calcium and magnesium ions are displaced from clay mineral exchange sites by cation exchange with other cations present in the contaminated wastewater. The distribution of bicarbonate (fig. 14) supports the hardness halo concept because wells 10 and 11, which are very high in calcium and magnesium, are relatively low in bicarbonate. This indicates that the additional calcium and magnesium is not coming from dissolution of carbonate minerals in the aquifer.

The chemical concentration of several parameters of well 13 suggest that this well lies within a slug of contaminated water moving through the flow system at the time of measurement. This slug could have resulted from an intermittent discharge into cell II. The concentration of parameters in well 13 and other wells downgradient from cell II provide an interesting comparison to concentrations in wells 4 and 7, which are just downgradient from cell I. The water in wells 4 and 7 has infiltrated downward through the sludge layer in cell I and the unsaturated zone beneath cell I, and then moved laterally in the groundwater flow system to wells 4 and 7. The intermittent discharges in cell II, however, infiltrate directly and rapidly through the unsaturated zone to the water table and then move downgradient in the groundwater flow system.

Redox conditions in groundwater around the McVille site are indicated by the distribution of some of the chemical species measured. Sulfate (fig. 15), one such indicator species, has a complex distribution around the lagoon. Background levels of sulfate in the aquifer are indicated by concentrations in the farm well and well 2. Higher levels are present in the lagoon wastewater. The high values measured in wells 1 and 5 probably result from the landfill northeast of the lagoon and suggest oxidizing conditions in the landfill leachate relative to seepage from cell I of the lagoon. Oxidizing conditions are maintained in the upper part of the lagoon during most of the year, but reducing conditions characterize the lower part of the lagoon and the sludge layer. Sulfate in the wastewater could therefore be reduced to sulfide as the wastewater passes through this reducing zone. The very low concentrations of sulfate in wells 3, 4, and 7 suggest that reduction of sulfate is occurring.

The wells downgradient from cell II show a complicated sulfate distribution. Two of the wells immediately downgradient from cell II, wells 14 and 6, are high in sulfate. Well 8, a slightly deeper well adjacent to well 6, is relatively low in sulfate. The high sulfate levels in the wells just downgradient from cell II could be derived from intermittent discharges of wastewater into cell II from cell I prior to infiltration through the sludge layer. The explanation for the low sulfate in well 13 is not known. This well is very similar to raw wastewater in many aspects. It is possible that it may be a slug of water resulting from infiltration from cell II after a transfer from cell I, at a time when highly oxidizing conditions were not present in cell I. The water beneath the downgradient portion of the lagoon site may actually consist of a sequence of slugs originating from cell II. Consequently, the variability in chemical composition may be quite high. The specific source of high sulfate concentrations in wells 11 and 12 at the south end of the site cannot be explained with currently available data. These concentrations are higher than the sulfate level in the lagoon and in the landfill leachate at the time of measurement. However, the variability in sulfate concentrations in some wells at the site is quite high. Well 5, for example, had a maximum sulfate concentration of 244 mg/l.

Iron (fig. 16) is another indicator of redox conditions. Iron is generally present at low concentrations in oxidizing groundwater and in lagoon wastewater. When wastewater reaches the aquifer, its redox potential has been decreased during infiltration through the sludge layer. The increase in dissolved iron in wells downgradient from cell I can be explained by an increasing solubility of iron oxide coatings on aquifer particles as Fe^{+3} is reduced to Fe^{+2}. The solubility of Fe^{+2} in aqueous solutions is substantially higher than Fe^{+3}. Therefore, the high iron concentrations in wells 4, 6, 7, 8, and 14 is interpreted as being primarily the result of reducing groundwater reaching the aquifer by seepage through cell I. The high iron concentrations downgradient from cell II (fig. 16), which suggest reducing conditions, seem to conflict with the relatively high sulfate concentrations (fig. 15), which suggest oxidizing conditions. The simultaneous presence of Fe^{+2} and sulfate in solution is not necessarily unlikely because the reduction of ferric to ferrous iron occurs at a slightly higher redox potential than the reduction of sulfate to sulfide (Freeze and Cherry, 1979). Therefore, the redox potential just downgradient from cell II, while still in the reducing range, may be low enough to allow the presence of ferrous iron, but not low enough to cause the reduction of sulfate to sulfide. Intermittent seepage from cell II may cause significant variation in redox conditions and, therefore, large variations in dissolved species in the vicinity of wells 6, 8, and 14.

Nitrogen contamination of groundwater is one of the most important aspects of lagoon seepage. Nitrogen distribution at the McVille site can be best discussed by considering together the two main nitrogen species, ammonium (fig. 17) and nitrate (fig. 18). The concentrations of these two species are inversely proportional, ammonium indicating reducing conditions and nitrate indicating oxidizing conditions. Raw wastewater contains high ammonium and organic nitrogen concentrations. Lagoon samples were generally relatively high in ammonium. Oxidizing conditions and dilution by rain, however, can reduce ammonium concentrations in the upper portions of the lagoon, where the lagoon sample was taken from. Organic nitrogen is converted to ammonium in the sludge layer of the lagoon. In soils, ammonium is adsorbed on colloidal surfaces with unsaturated exchange sites. The ammonium distribution at McVille shows a distinct contrast between the downgradient wells closest to cell I, the operational cell (wells 3, 4, and 7), and the downgradient wells farther from cell I (wells 14, 6, 8, and 13). The former wells have moderate ammonium concentrations while the latter group has very high concentrations. This is the opposite distribution that would be expected if seepage occurred only from cell I. These data suggest, instead, that the intermittent discharges of wastewater into cell II are the source of the ammonium levels in wells 14, 6, 8, and 13. A decrease in ammonium concentration must occur in the sludge layer of cell I either by adsorption onto organic colloidal material or by consumption by microorganisms. The wastewater moving through the sludge layer is then of only moderate ammonium concentration, as shown in wells 3, 4, and 7. Wastewater which is drawn from cell I into cell II does not receive the decrease in ammonium concentration because there is no sludge layer in cell II. High ammonium concentrations extend downgradient to well 13 (31 mg/l). Wells farther downgradient than well 13 (wells 11 and 12), have very low ammonium concentrations. Wells 11 and 12 also have very low nitrate concentrations, suggesting that ammonium is adsorbed beyond well 13. Under this hypothesis, high ammonium concentrations are maintained in wells 14, 8, 6, and 13 because of anaerobic conditions and saturation of cation exchange sites with ammonium from previous discharges into cell II. Beyond the point in the flow system where the ammonium adsorptive capacity of the soil is exceeded, rapid adsorption occurs. The high calcium and magnesium concentrations in the vicinity of wells 10, 11, and 12 supports the hypothesis of significant cation exchange in the area of postulated ammonium adsorption.

High nitrate values (fig. 18) are limited to wells generally out of the influence of lagoon seepage. Wells 1, 2, 5, and 9 had consistently high nitrate values throughout the study. The concentrations were more variable than most parameters at the site. Wells 1 and 5 had the highest nitrate values reaching concentrations of 30 mg/l at various sampling periods. The most probable source for these levels is the landfill, which is directly upgradient from wells 1 and 5. Wells 2 and 9 had somewhat lower values, reaching a maximum of 14.8 mg/l in well 2. Other chemical parameters at well 2 indicate very little influence of wastewater seepage. The nitrate levels, therefore, are probably the result of contamination from some other source of nitrogen. The lack of nitrate in the downgradient wells indicates that denitrification occurs as the groundwater passes beneath the lagoon. In addition, some of the nitrate could possibly be reduced to ammonium contributing to the very high ammonium concentrations in several of the downgradient wells.

An attempt to determine the source of the nitrogen in the upgradient wells was made by obtaining nitrogen isotope analyses on samples from all the wells. The samples were prepared by the method of Bremner and Keeney (1965). Nitrogen in samples with high nitrate was converted to ammonium and then analyzed to determine the isotope ratio $^{15}N/^{14}N$ in the sample. Isotope ratios differ in nitrogen derived from inorganic fertilizer, natural soil sources, and animal wastes (Kreitler, 1975). ^{15}N abundance is reported as $\delta\ ^{15}N$ where

$$\delta\ ^{15}N = \left[\frac{^{15}N/\ ^{14}N\ (\text{sample})}{^{15}N/\ ^{14}N\ (\text{standard})} - 1 \right] \times 1000$$

The standard is atmospheric N_2. The standard error for replicate measurements of the same gas sample is approximately 0.05 $\delta\ ^{15}N$ units. The results of the analyses are given in table I, which shows the total amount of ammonium and nitrate in each sample (expressed as N) and the $\delta\ ^{15}N$ values for each sample. The high $\delta\ ^{15}N$ values measured for all samples fall into the range expected for nitrogen of animal waste origin (Kreitler, 1975). Therefore, the high nitrate values obtained in wells 1, 2, and 5 are from an animal waste source. The very low concentration of chloride in wells 1 and 2 rules out nitrification of ammonium from the lagoon as a source of the nitrate. The source of this nitrate may be a plume of nitrate derived from septic tanks or leaking sewers in the town of McVille, located about 1 km upgradient from the lagoon, which moves downgradient near the top of the aquifer.

One potential danger of high ammonium levels in groundwater from the lagoon is that conversion of ammonium to nitrate (nitrification) will occur. This conversion was noted in a previous study (E. A. Hickok and Associates, 1978). At the McVille site, however, nitrification of ammonium does not appear to be occurring.

Phosphorous is undesirable in groundwater because of its function as a nutrient. If groundwater high in phosphorous reaches a surface water discharge point such as a lake or stream, growth of aquatic plants such as algae would be promoted, thus leading to eutrophication of the water body. Dissolved phosphorous was present at high levels in only one well, well 4. Well 4 contained dissolved phosphorous levels ranging from .9 to 4.4 mg/l. Well 4 is the closest downgradient well to water in the impoundment and therefore it is encountered early along the flow path by wastewater moving from the base of the impoundment. Phosphorous is strongly adsorbed by soils and the high dis-

TABLE I

TOTAL NITROGEN VALUES (EXPRESSED AS N) AND δ^{15}N VALUES FROM SAMPLES FROM THE McVILLE SITE

Well Number	N (mg/l)	δ^{15}N
1	22.2	10.84
2	12.8	7.24
3	7.1	10.43
4	4.3	7.23
5	56.1	8.97
6	28.1	10.28
7	9.8	9.29
8	21.5	10.44
9	10.5	9.99
10	5.9	30.44
11	3.2	29.26
12	2.0	-
13	35.6	10.75
14	48.9	9.83
Lagoon	8.2	20.02

solved phosphorous concentration in well 4 indicates that the adsorptive capacity of the sediment around the screen of well 4 has been exceeded. The lack of high phosphorous levels in other wells, including well 7 screened directly below well 4, suggests that well 4 represents the approximate front of the zone of phosphorous movement.

Fluoride is added to municipal water supplies because of its beneficial effect on dental health. At high concentrations, however, flouride is detrimental to health. Effects include objectionable dental fluorosis at concentrations of about 5 mg/l. The drinking water standard for fluoride is 2.4 mg/l. A municipal sewage lagoon, because it serves as a waste site for the municipal water system, can therefore be a source of fluoride contamination for groundwater in lagoons with excessive seepage. At the McVille lagoon, fluoride contamination of downgradient wells is evident. Background levels of fluoride, estimated from wells 1, 2, and the farm well, range from 0.1 to 0.2 mg/l. Downgradient wells show significantly higher fluoride contents. Wells 4 and 7 had fluoride contents of approximately 5 mg/l during the study period. These levels are somewhat difficult to explain because the fluoride concentration in the lagoon ranged from 1.9 mg/l to 2.6 mg/l during the study period. The fluoride concentration in the McVille city water supply was approximately 1 mg/l when analyzed in 1980. Downgradient wells 3, 6, 8, 11, 13, and 14 typically have fluoride concentrations between 1 and 2 mg/l.

Trace element analyses were done twice on samples from wells 1 and 4 (app. IV). Well 1, located upgradient from the lagoon, but downgradient from the landfill, had higher concentrations of all trace elements than well 4, located directly downgradient of the lagoon. The high levels of trace elements may therefore be caused by the landfill. On April 25, 1982, drinking water limits were exceeded for arsenic, barium, cadmium, chromium, and lead in well 1. The concentrations of all trace elements were below drinking water limits in well 4. Conclusions concerning the effect of the lagoon on trace elements in groundwater are difficult to make because of the small amount of data collected. Background levels in the aquifer are not known as well as the spatial and temporal distribution of trace elements in groundwater around the lagoon. Data collected from McVille and other sites suggest that trace element concentrations in groundwater show large variations. More work is needed to determine the geochemical controls causing these variations.

Total coliform and fecal coliform counts (fig. 19) are difficult to interpret. Positive total coliform counts were obtained in all wells. The absolute values shown are not considered to be significant because contamination during drilling and sampling cannot be ruled out. Coliforms that are introduced into a well from surface sources may survive and multiply under these conditions.

The distribution of total coliforms during the entire study (app. IV) does indicate higher coliform counts in the downgradient wells. Positive coliform counts were rare in wells 1 and 2, but common in the downgradient wells. These data suggest that the lagoon is responsible for some of the coliforms, even though actual numbers should not be considered significant.

Fecal coliforms are harder to explain by contamination from surface sources. Fecal coliforms were never detected in well 1, and in well 2 on only one occasion. The chloride concentration in well 2 at that time was at its highest recorded value during the study (14 mg/l), suggesting that a reversal of gradient had occurred and some seepage had reached well 2. In contrast to the upgradient wells, one or more of the downgradient wells had fecal coliforms present in all sampling periods. The wells installed for the last sampling period, wells 9, 10, 11, 12, 13, and 14 all had fecal coliforms present with the exception of well 9 (fig. 19). Well 9, which contains water with near background concentrations for most constituents, is located on the eastern edge of the contaminant plume. These results indicate travel of fecal coliforms for distances of hundreds of feet in groundwater. Uncertainty concerning the reliability of the sampling techniques used must relegate these results to a preliminary status. Additional and more detailed investigation of microbiological contamination from this lagoon is highly recommended.

Discussion

Instrumentation at the McVille lagoon site provides an excellent illustration of the complex chemical changes in groundwater resulting from wastewater seepage. Seepage from the impoundments forms an elongated plume of contaminated groundwater extending more than 700 feet (215 m) beyond cell I in the direction of groundwater flow. At this distance, chloride concentration in well 11, the farthest downgradient monitoring well, is equal to the chloride content measured in the lagoon water. Contaminant movement considerably beyond this distance is indicated. The depth of the plume is unknown; the deepest well, screened 30 feet (9 m) below the water table, is significantly degraded.

The contaminant plume maintains the reducing conditions and elevated dissolved solids content of municipal wastewater, although the redox potential increases along the flow path. The distance of contaminant movement and the degree of contamination may be greatly affected by the intermittent discharge of wastewater into cell II. This procedure bypasses the beneficial effects of the sludge layer located at the bottom of cell I. This effect can be illustrated by comparing the water chemistry of wells 4 and 7 to wells 14, 6, 8, and 13.

Wells 4 and 7 form a nest on the downgradient embankment of cell I. These wells are the nearest measuring points for seepage entering groundwater from cell I. The water is very reducing, with very low sulfate contents and high iron contents. Sulfate in the wastewater is reduced to sulfide which is either precipitated prior to reaching the water table or converted to hydrogen sulfide. Hydrogen sulfide could be lost to the atmosphere or carried in dissolved form in groundwater. By contrast, the shallow wells downgradient of cell II, with the exception of well 13, are high in sulfate. Well 13 is anomalous in that it is more contaminated than any of the wells closer to the lagoon. One possible explanation is that it represents an isolated slug of contaminated water moving through the flow system. Continued monitoring would be necessary to confirm or reject this hypothesis. Ammonium concentrations are the best indicators of the effects of intermittent discharges into cell II. Wells 4 and 7 show considerable attenuation of ammonium from cell I, probably in the sludge layer. The ammonium concentrations in these wells have never exceeded 10 mg/l during the study. On the other hand, wells 14, 8, 6, and 13 have ammonium concentrations ranging between 20 and 40 mg/l. These levels could originate only from a different source than cell I if wells 4 and 7 are representative of cell I seepage. The high ammonium concentrations in wells 14, 8, 6, and 13 decrease to negligible amounts in the distance between wells 13 and 12. The probable mechanism for this attenuation is adsorption. Nitrification is ruled out because of low nitrate contents in wells 12, 11, and 10. Adsorption and cation exchange is also suggested by the elevated calcium and magnesium concentrations in wells 10, 11, and 12. These concentrations are considerably higher than background levels for the aquifer or wastewater concentrations in the lagoon.

A leachate plume emanating from an inactive landfill northwest of the site can be detected in wells 1 and 5. This plume has a high dissolved solids content, but it can be distinguished from the lagoon contamination by the presence of oxidized species. The landfill leachate is high in sulfate and nitrate, in contrast to the lagoon seepage, which is high in ammonium and low in nitrate and sulfate.

The biological contaminants of the lagoon seepage may pose one of the most serious groundwater contamination hazards. Although cross contamination of wells is a possibility, the overall distribution of total and fecal coliform organisms suggests that these indicator bacteria are moving significant distances away from the site in the groundwater flow system. Further, more detailed work is needed on this aspect of the problem.

LARIMORE WASTE STABILIZATION LAGOON

Introduction

The Larimore waste stabilization lagoon (fig. 1) serves a town population of 1,524 (1980 census). The lagoon (fig. 20), built in 1953, consists of two cells, each with an area of

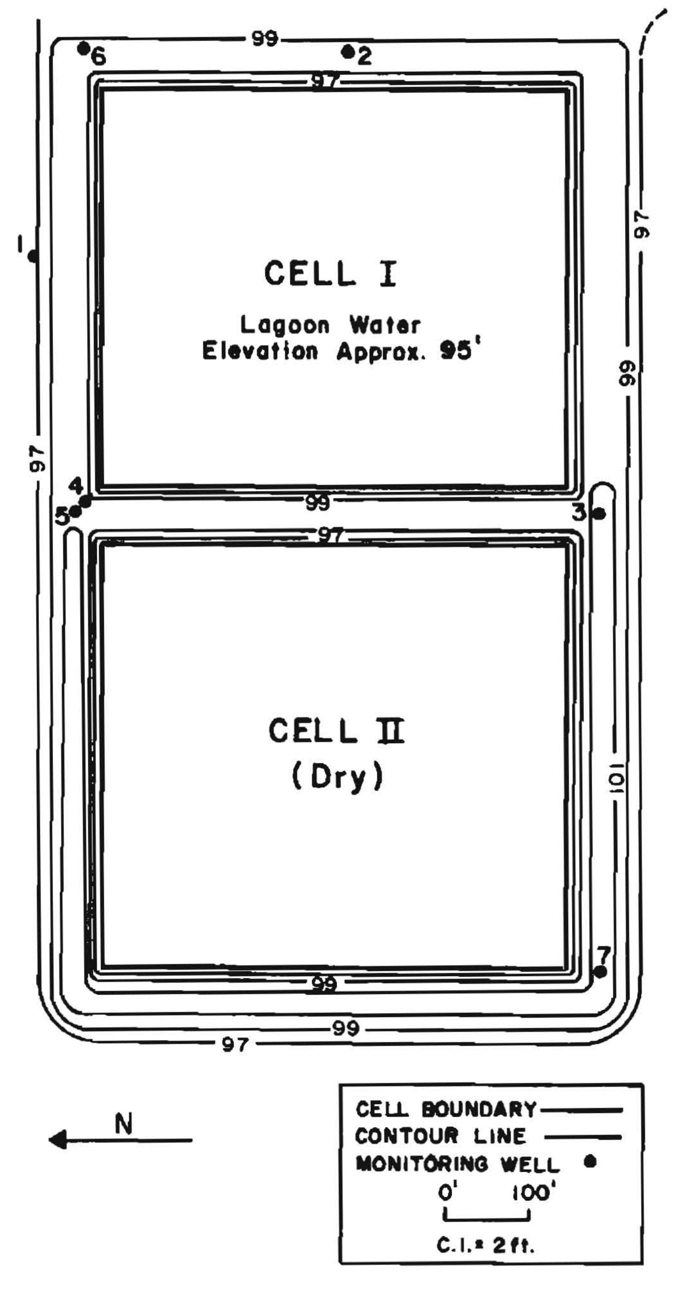

Figure 20. Topography and location of monitoring wells at Larimore site.

5 acres (2 hectares). Normally, only one cell is utilized for wastewater. Throughout most of the study period, cell I contained wastewater and cell II was unused. Water was transferred from cell I to cell II prior to the last sampling period in July of 1982. Periodic transfers between the cells are common. During the study period, wastewater in cell I maintained a depth of less than 2 feet (.6 m) because of seepage losses through the bottom of the cell. This shallow depth of water results in the growth of tall wetland vegetation near the edges of the lagoon.

Seven monitoring wells were installed at the Larimore site (fig. 20). Instrumentation was limited to the embankments because cropland extends up to the edges of the embankments on all sides of the lagoon.

Hydrogeologic Setting

The Larimore lagoon lies within permeable sediments that contain an unconfined aquifer of large areal extent. The sediments grade progressively from coarse sand and gravel deposited in an ice-marginal outwash river channel about 3 miles (5 km) wide in northern Grand Forks County to fine sand and silt deposited where the ice-marginal stream discharged into glacial Lake Agassiz and formed a delta about 12 miles (20 km) wide (Kelley and Paulson, 1970). Typical grain sizes in the vicinity of the Larimore lagoon fall into the fine to medium size range. Holocene wind action has modified the delta surface around Larimore into an area of stabilized sand dunes.

The fluvial-deltaic sediments contain an important unconfined aquifer, the Elk Valley Aquifer, which extends from near land surface to a depth of about 50 feet (15 m) in the Larimore area. Yields of 50 to 250 gal/min (3 to 16 l/s) can be expected in this area (Kelley and Paulson, 1970). The water table in the Elk Valley Aquifer is generally less than 10 feet (3 m) below land surface and water quality is good. TDS ranges from 337 to 1,300 mg/l and the water is of calcium bicarbonate type (Kelley and Paulson, 1970).

Samples from borings at the site consist of well-sorted, fine- to medium-grained sand to silty sand to sandy silt. Silt ranges from about 3 to 50 percent. Clay percentages ranges from 0 to 3 percent. The hydraulic conductivity value estimated from one grain-size distribution curve is 6.2 x 10^{-4} ft/s (1.9 x 10^{-4} m/s).

Groundwater movement at the Larimore site is from south to north, toward the south branch of the Turtle River (fig. 21). The water table lies only about 6 feet (2 m) below land surface at the lagoon (fig. 22). High seasonal fluctuations (fig. 23) indicate low specific yield of the deposits.

The water level in cell I constitutes the water table (fig. 22). This indicates that wastewater in the lagoon causes a groundwater mound. The presence of a mound indicates radial flow of wastewater outward from the lagoon in all directions for a short distance. Calculation of the hydraulic gradient and groundwater flow velocity is not attempted because of the effect of the groundwater mound on the water levels of wells around the lagoon and because of the lack of monitoring wells away from the influence of the groundwater mound. In the vicinity of the lagoon, seepage is controlled by the lateral outflow of groundwater from the mound rather than vertical seepage through the bottom of the cell.

Results

In the analysis of the effect of lagoon seepage on groundwater quality at the Larimore and other sites, contour maps of chemical parameters will not be used because land-use constraints limited the placement of monitoring wells to the immediate vicinity of the cells. The chemical results are best illustrated by comparing the quality of water in upgradient wells with water quality in downgradient wells (table II).

Wells 3 and 7 are considered to be upgradient of the lagoon, although significant levels of chloride and other parameters indicate that these wells are influenced by seepage because of groundwater mounding beneath the lagoon cell. The chloride concentration in a well about ½ mile (1 km) upgradient from the lagoon was 0.0 (app. IV). Slight contamination in well 7, prior to the last sampling period, is probably due to the residual effects of previous wastewater transfers from cell I to cell II.

Downgradient increases in TDS by an approximate factor of 2, in chloride by a factor of 3 to 6, in sodium by a

TABLE II

COMPARISON OF UPGRADIENT AND DOWNGRADIENT WELLS AT LARIMORE SITE

Mean concentrations ($\bar{X}$) and standard deviations ($\bar{S}$) are shown for each well (n=3). Summer 1982 data shown at bottom for comparison.

Upgradient

	Well 3		Well 7	
	$\bar{X}$	$\bar{S}$	$\bar{X}$	$\bar{S}$
TDS	391.0	29.4	442.3	35.9
Amm	.2	.1	.1	.1
Na	11.5	4.9	5.3	1.0
Cl	31.7	37.5	49.1	35.6
SO_4	54.3	9.2	103.0	5.3
Fe	.1	.1	.07	.01

Downgradient

	Well 1		Well 4		Well 6	
	$\bar{X}$	$\bar{S}$	$\bar{X}$	$\bar{S}$	$\bar{X}$	$\bar{S}$
TDS	861.	56.4	976.	98.8	749.	35.6
Amm	7.2	0.4	0.7	0.4	9.7	1.6
Na	133.0	13.0	181.7	26.1	152.3	22.4
Cl	195.0	18.0	191.7	14.4	156.6	50.2
SO_4	66.3	23.1	97.6	64.1	41.3	49.3
Fe	3.8	3.4	6.5	5.4	.5	.4

Summer 1982 Results

	Well 3	Well 7	Well 1	Well 4	Well 6
TDS	427.	419.	541.	834.	793.
Amm	.054	.088	5.28	.253	.09
Na	4.0	2.5	95.	154.	141.
Cl	13.0	35.0	100.	150.	100.
SO_4	60.	101.	50.	102.	157.
Fe	0.00	0.01	2.11	6.2	1.23

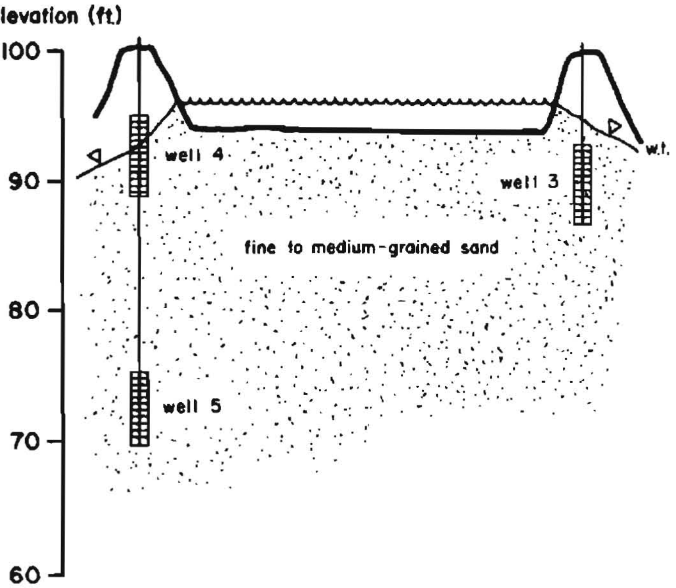

Figure 21. Cross section of Larimore site. Location of section shown in figure 22. Screened section shown at base of each well.

factor of 13 to 16, and in ammonium by a factor of 2 to 48 indicate the general level of contamination at the site. The reducing tendency of the downgradient groundwater is indicated by sulfate and iron contents. Sulfate decreases significantly from the lagoon water (app. IV) to several of the downgradient wells (table II). The iron contents increase greatly downgradient, reflecting reduction of ferric iron and dissolution of aquifer-grain, iron-oxide coatings.

Nitrate values never exceed 1 mg/l in any of the monitoring wells. Although the relatively high ammonium levels in some of the wells could be converted to nitrate downgradient, the nitrate concentrations probably still would not exceed drinking water standards because the maximum ammonium concentration recorded was 11.8 mg/l (app. IV).

Dissolved phosphorous concentrations were occasionally high in wells 6 and 1. The maximum concentration was 2.03 mg/l in well 6 on April 21, 1982. The lagoon concentration at that time was 2.88 mg/l. The presence of high dissolved phosphorous concentrations in wells just downgradient from the site suggests that the adsorptive capacity of the materials close to the lagoon has been exceeded. Phosphorous is free to move downgradient to the point where adsorption capacity is not exceeded.

Bacteria counts at the site were generally low. Positive total coliform counts were not uncommon but contamination during sampling cannot be ruled out for these values. The highest fecal coliform value was 290 colonies per 100 ml, obtained from well 1. This value was exceptionally high for this site; the detection of fecal coliforms in any of the wells was rare.

Trace element concentrations were measured in one upgradient well and one downgradient well on each sampling period. Results for arsenic showed a consistent increase in the downgradient direction. Values occasionally exceeded drinking water standards, attaining a maximum concentration of 93.1 ug/l in well 1 (app.

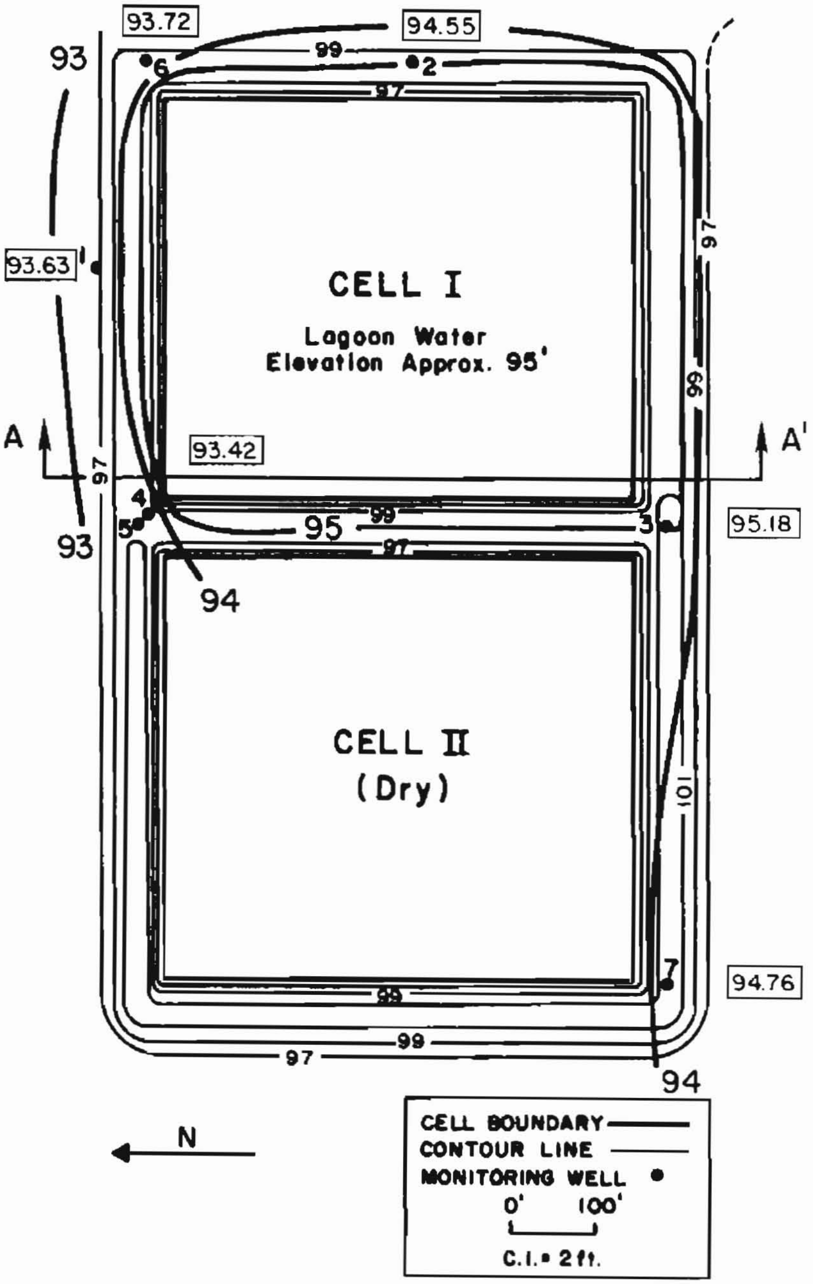

Figure 22. Contours showing water table elevation (heaviest lines) at Larimore site on April 21, 1982. Water table elevations in boxes based on arbitrary datum at 0 feet. Line A-A': Location of cross section shown in figure 21.

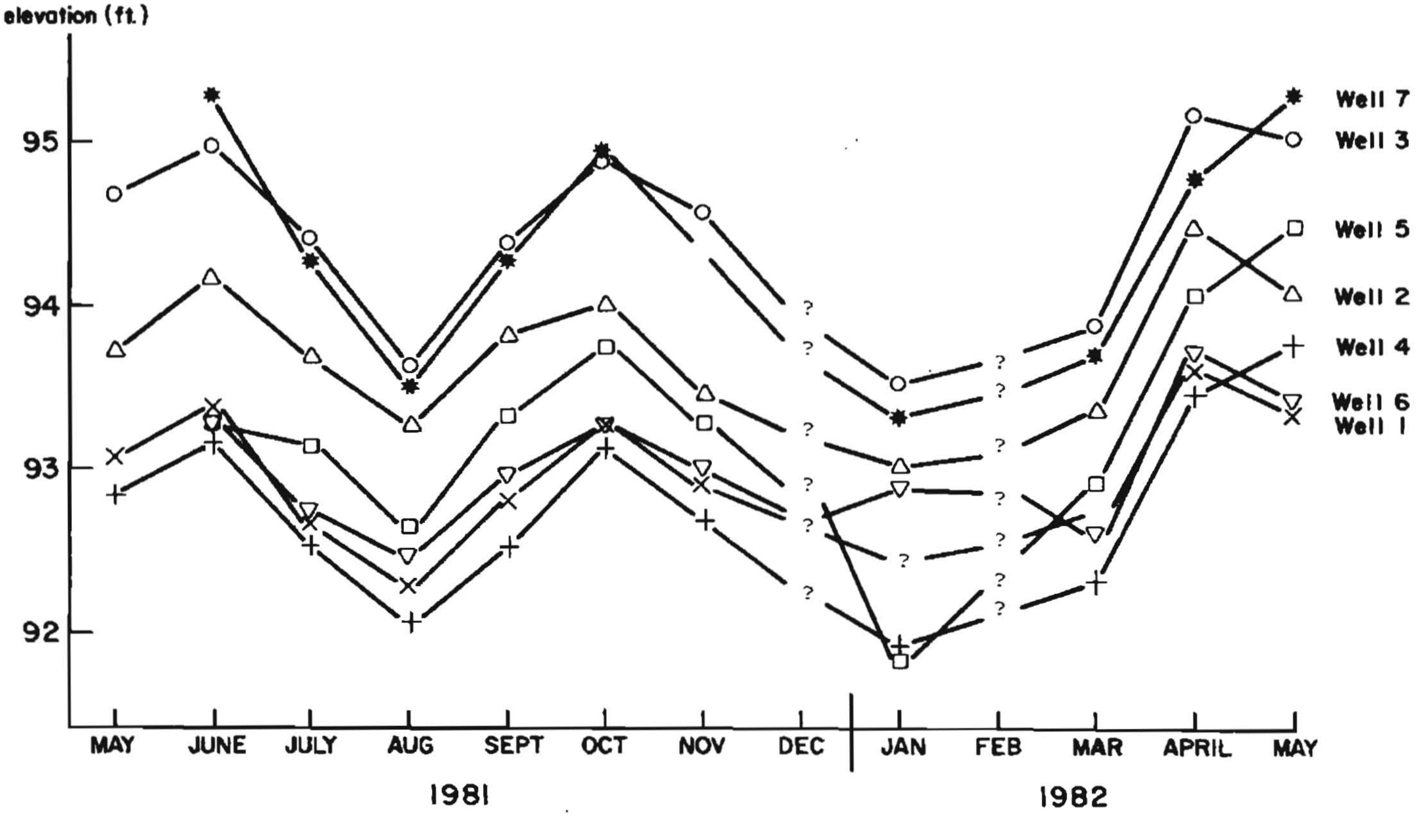

Figure 23. Water table fluctuations at Larimore site during study period. Question marks indicate times at which measurements were not made.

IV). The increase in arsenic concentration can be explained by a mechanism similar to the downgradient increase in iron concentrations. Aquifer materials subjected to the passage of reducing groundwater release arsenic contained in precipitated grain coatings by chemical reduction of the arsenic species and increased solubility of the arsenic-bearing compounds (Matisoff et al., 1982). A group of elements including chromium, copper, lead, selenium, and zinc is characterized by decreasing concentrations between the upgradient and downgradient wells. The decrease is probably the result of decreasing redox potential causing decreased solubility of compounds containing these elements. Additional trace element analyses are necessary before firm conclusions can be drawn concerning the relative concentrations of these constituents.

Wastewater was transferred from cell I to cell II just prior to the summer 1982 sampling period. Predictable changes occur in some of the chemical parameters in the wells around cell I. Table I shows the chemical parameters for the summer, 1982 sampling period for comparison with the mean concentrations from the other sampling periods. Concentrations of TDS, chloride, ammonium, and sodium for summer 1982, are generally below the means for wells 1, 4, and 6. Sulfate concentrations are higher than the means for wells 4 and 6. These changes indicate an improvement in groundwater quality in the vicinity of cell I following the transferral of wastewater to cell II.

Discussion

The Larimore lagoon is characterized by seepage so rapid that a sufficient wastewater depth cannot be maintained in the cell. Groundwater degradation, although present, is not particularly severe. While certain chemical parameters are greatly increased, most of the potentially hazardous or undesirable contaminants do not reach high levels. Exceptions to the previous generalization include phosphorous and arsenic. Ammonium concentrations approach undesirable levels in some wells. A high fecal coliform value was obtained in one sample. These parameters indicate that the lagoon is not functioning properly because of the excessive leakage.

Without downgradient wells located farther from the lagoon, little can be said about the changes in water quality as the contaminated groundwater moves along its flow path. It seems likely, however, that contaminants introduced into the groundwater flow system from the lagoon are decreased to acceptable levels within several hundred feet of the lagoon. Confirmation of this hypothesis will require more detailed monitoring at the site.

FORDVILLE WASTE STABILIZATION LAGOON

Introduction

Fordville, a town of 326 people (1980 census), is located in south-central Walsh County (fig. 1). The waste stabilization lagoon serving Fordville was built in the fall of 1955. Originally, the lagoon consisted of one cell with an area of 4 acres (1.6 hectares). Later, the single cell was divided into two cells by construction of an embankment across the center of the impoundment (fig. 24). Cell I was used primarily for wastewater disposal during the study period. Cell II may be used occasionally for wastewater, although it contained tall wetland vegetation on its bottom during the course of the study.

Seven monitoring wells were installed at the site (fig. 24). Land-use constraints limited these wells to the embankments of the lagoon. It was not possible to construct downgradient wells.

Hydrogeologic Setting

The Fordville lagoon is located on a terrace adjacent to the Forest River in an area where its valley is cut into a large deposit of coarse-grained glaciofluvial sediment (Bluemle, 1973). Much of this sediment was deposited by streams flowing between ice lobes in the Red River Valley and the Pembina escarpment to the west. The surficial deposits at the site consist of 6 to 8 feet (1.8 to 2.4 m) of silty and clayey Holocene overbank sediment (fig. 25). These fine-grained sediments are directly underlain by saturated sand and gravel, which becomes quite coarse grained in places.

The coarse-grained glaciofluvial sediments comprise an important unconfined aquifer, the Fordville Aquifer

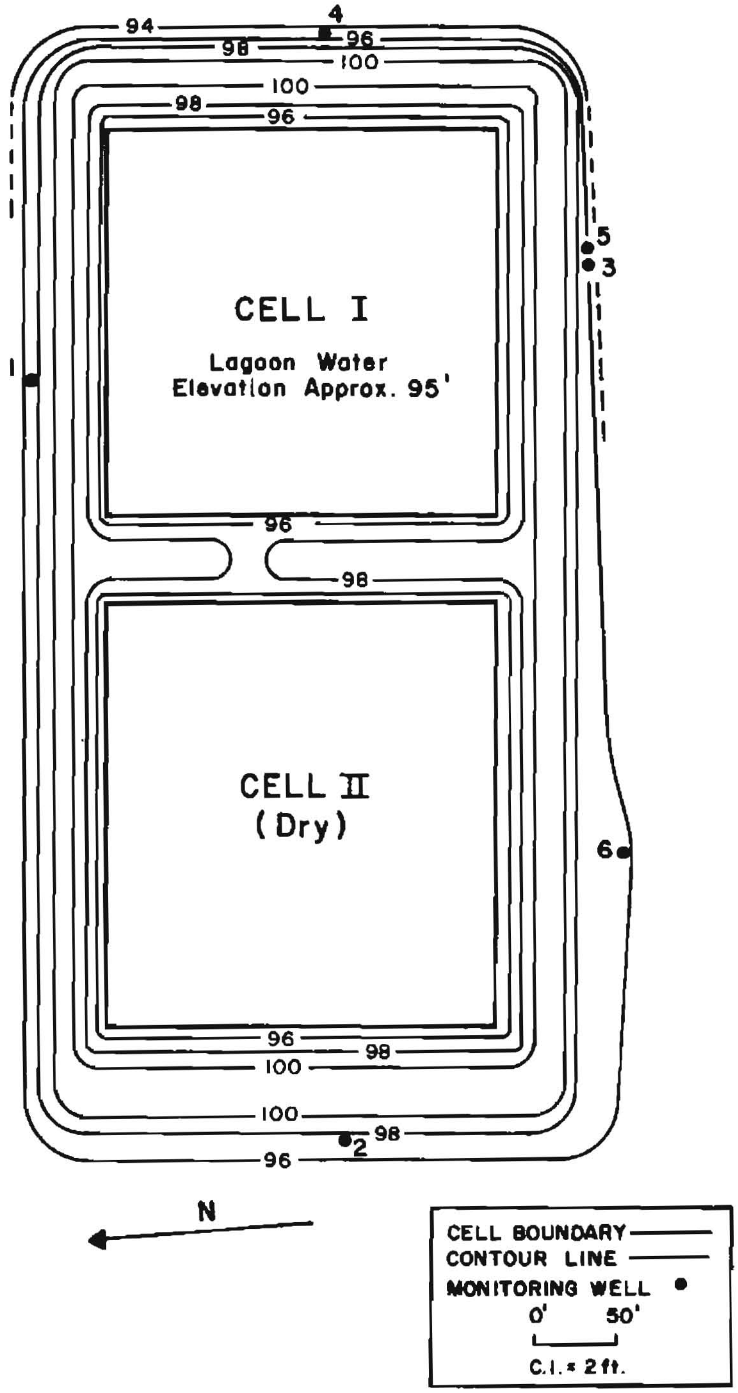

Figure 24. Topography and location of monitoring wells at the Fordville site.

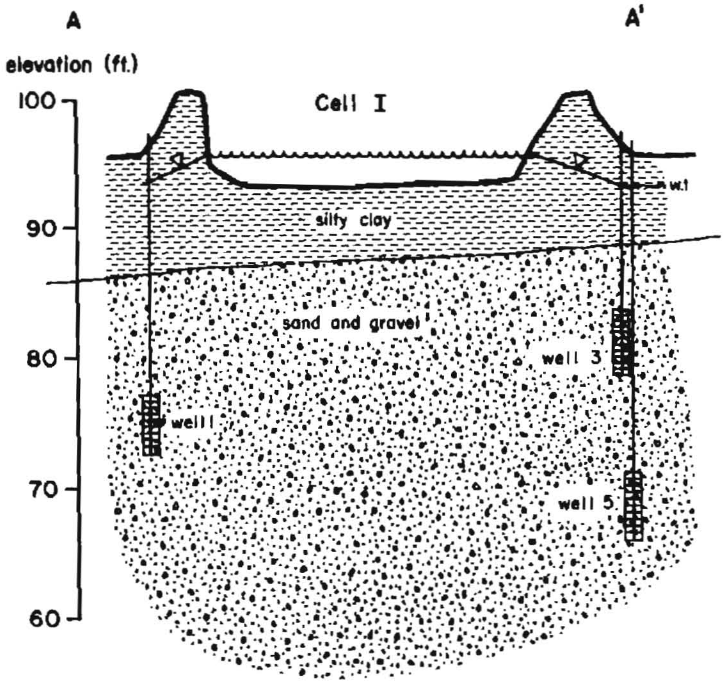

Figure 25. Cross section of Fordville site. Location of section shown in figure 26. Screened section shown at the base of each well.

(Downey, 1973), that has a surface area of about 33 square miles (85 km^2) and an average thickness of 20 feet (6 m). The water table is shallow throughout the aquifer and ranges from 3 to 10 feet (1 to 3 m) at the lagoon site (fig. 26). The water table in this vicinity may be elevated because of seepage from the lagoon. Water table fluctuations are large (fig. 27) and correspond closely to precipitation. The transmissivity of the aquifer ranged from 5,830 to 8,860 ft^2/day (542 to 823 m^2/day) at an aquifer test site near the area of its greatest saturated thickness (Downey, 1973). Two slug tests done in monitoring wells at the lagoon yielded values of 1.0×10^{-5} ft/s (3.1×10^{-6} m/s) and 1.6×10^{-6} ft/s (4.8×10^{-7} m/s). The direction of groundwater flow at the site is toward the south where the Forest River channel is located. The gradient at the site is probably affected by the groundwater mound and therefore is not representative of the aquifer. Consequently, the groundwater flow velocity cannot be accurately determined with the monitoring wells installed.

Groundwater in the Fordville aquifer is of calcium sodium bicarbonate type. The quality is generally good with a TDS range of 315 to 595 mg/l (Downey, 1973).

Results

The chemical results at the Fordville lagoon are the most inconsistent obtained at any study site. All wells show some evidence of contamination (app. IV), probably as a result of the groundwater mound beneath the site. Somewhat surprising were the levels of contamination at wells 2 and 6, located around the cell which did not contain wastewater. These results suggest the periodic use of the cell for overflows or transfers of wastewater. The periodic use of cell II would result in a situation similar to McVille in which a beneficial sludge layer exists at the base of the continuously filled cell,

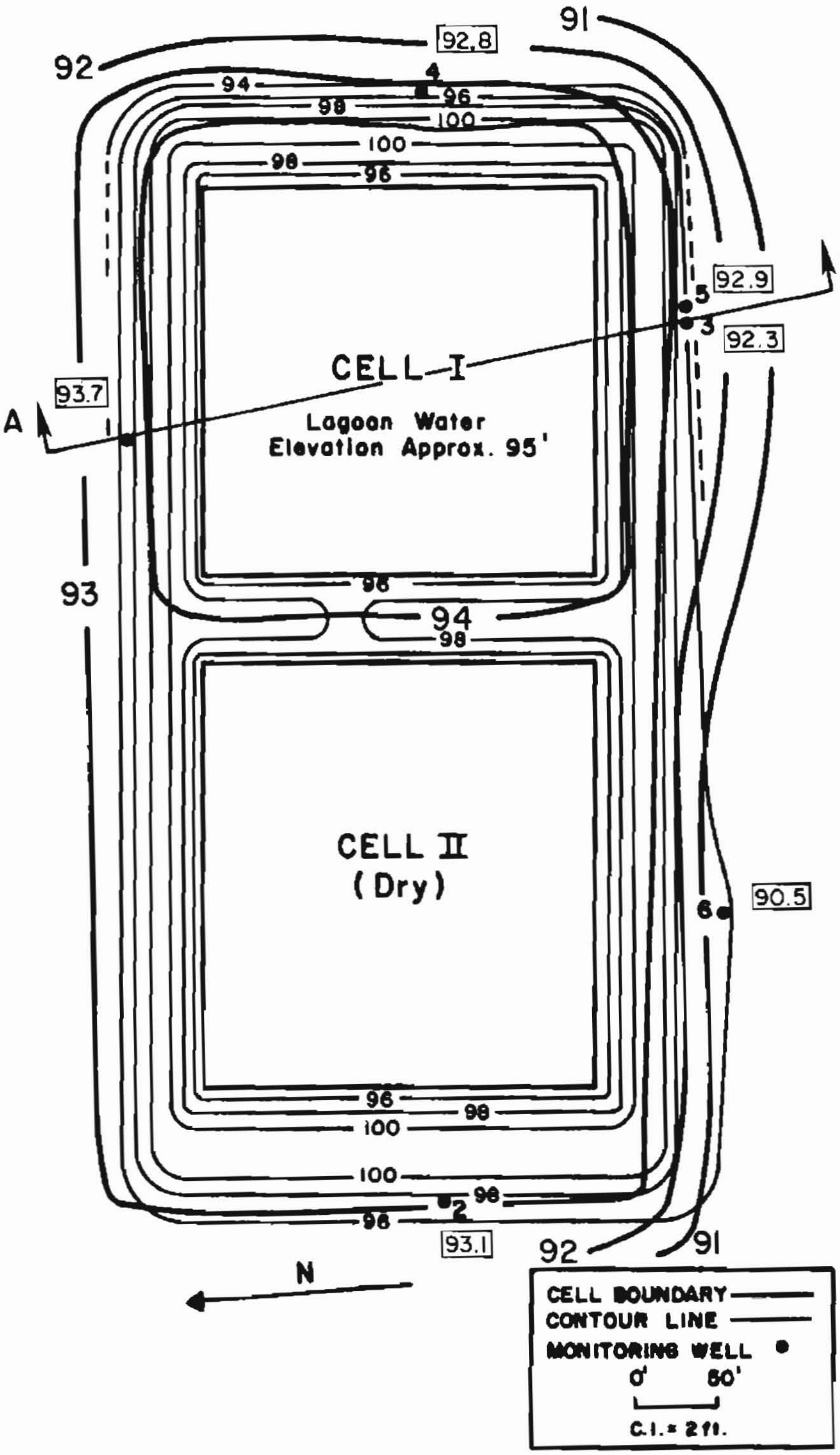

Figure 26. Contours showing water table elevation (heaviest lines) at the Fordville site on August 4, 1981. Water table elevations (in boxes) based on arbitrary datum at 0 feet. A-A': Location of cross section shown in figure 25.

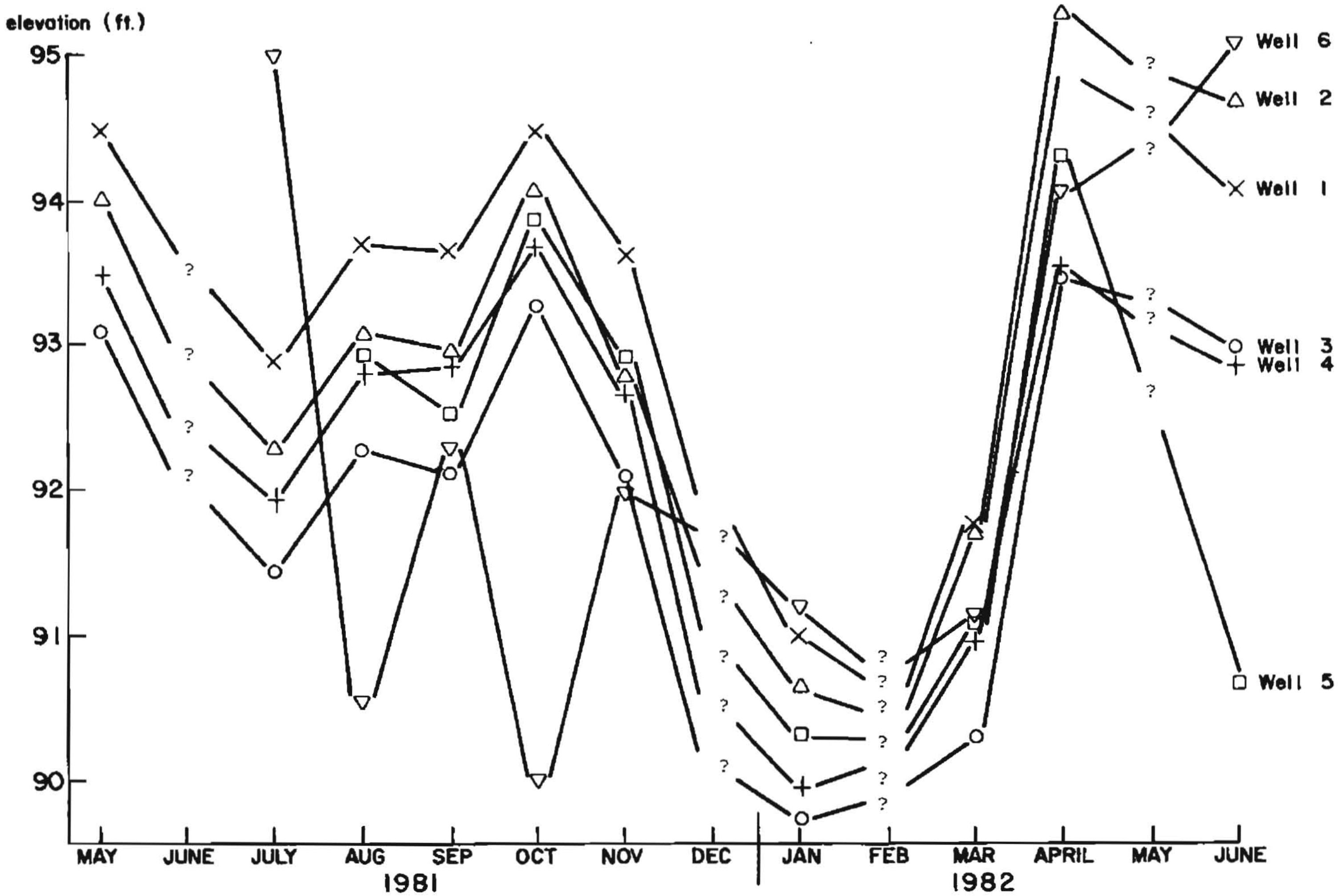

Figure 27. Water table fluctuations at Fordville site during study period. Question marks indicate times at which measurements were not made.

while the infrequently used cell cannot develop and maintain a sludge layer.

A domestic well upgradient from the lagoon sampled for use as a control well for the monitoring wells was unacceptable for this purpose because it was contaminated (app. IV). When sampled, the farm well contained nitrate at a concentration of 118 mg/l (as N), an extremely high concentration. Moderate concentrations of other contaminant indicators at the domestic well, such as chloride, suggest contamination by a sewage source, such as a septic tank, cesspool, or leaking sewer line.

Table III shows mean concentrations of certain parameters from well 1, located upgradient of cell I (fig. 26); well 3, located downgradient from cell I; and well 6, located downgradient from the unused cell II. Wells 1 and 3 show a definite downgradient increase in TDS, chloride, and sodium and a downgradient decrease in sulfate. These are expected results from the seepage of reducing wastewater into the groundwater flow system. Other parameters that also indicate reducing groundwater are not present in well 3. Iron and ammonium, for example, do not show predicted increases in well 3. The lack of ammonium in well 3 can perhaps be explained by adsorption on the sludge layer on the bottom of cell I. Well 5 (fig. 27), a deeper well adjacent to well 3, shows less contaminated values than well 3 for most parameters. This suggests that the contaminant plume moves in the upper part of the aquifer near the water table.

The levels of contamination in wells 2 (app. IV) and 6 (table III) are higher than expected, considering the lack of wastewater in cell II. Both wells have moderately high chloride levels. Well 6 had the highest ammonium concentration at the site. These results probably reflect the periodic use of cell II for wastewater disposal. The lack of a sludge layer probably permits the movement of ammonium into the groundwater with less attenuation than in cell I. In addition, the high sulfate and low iron concentrations in wells 2 and 6 (app. IV) indicate the lack of reducing conditions achieved in a temporarily filled lagoon.

Positive bacteria counts were infrequent at Fordville. The high total coliform count measured in well 5 on one occasion (app. IV) probably indicates contamination during sampling. The surficial layer of fine-grained sediments (fig. 25) at the Fordville lagoon probably contributes to the attenuation of bacterial movement in groundwater at this site.

Trace constituents at the site are inconsistent. For example, arsenic increases in the downgradient direction in one sampling period, but shows the opposite trend in the subsequent sampling period. The concentration of arsenic in well 1 increases from 1 ug/l on the first sampling period to 165 ug/l, a value higher than the drinking water standard by a factor of three, on the second sampling period. Almost all the other trace elements increase in well 1 in the same manner. In well 3, however, the opposite trend occurs; the concentrations decrease from the first to the second sample. The cause for these drastic fluctuations is not known, but perhaps it is related to the large fluctuations in the water table at Fordville. These fluctuations could cause changes in the redox conditions and thereby affect solubility of precipitated solids containing the trace elements.

Discussion

The Fordville study site demonstrates the beneficial effect of the surficial layer of fine-grained sediment on the quality of the seepage which reaches the underlying aquifer. Nitrogen and bacterial contaminants are attenuated, particularly in cell I, the cell which is continuously used. The lagoon has, in effect, a natural clay liner separating the wastewater from the sand and gravel aquifer. Although the clay layer does allow the movement of some contaminants such as chloride and sodium, the most harmful contaminants appear to be greatly reduced in concentration. Ammonium contamination is increased, however, if the cell is used only periodically and remains dry during the intervening time intervals.

ESMOND WASTE STABILIZATION LAGOON

Introduction

Esmond, a town of 285 people (1980 census) is located in western Benson County (fig. 1). The waste stabilization lagoon, constructed in

TABLE III

COMPARISON OF UPGRADIENT AND DOWNGRADIENT WELLS AT FORDVILLE SITE

Well 1 (n = 3)

	$\bar{X}$	$\bar{S}$
TDS	580.	10.8
Cl	63.	32.
SO_4	120.	30.
Na	24.	4.

Well 3 (n = 4)

	$\bar{X}$	$\bar{S}$
TDS	893.	173.
Cl	190.	24.
SO_4	50.	12.
Na	120.	5.

Well 6 (n = 3)

	$\bar{X}$	$\bar{S}$
TDS	560.	123.
Cl	110.	59.
SO_4	115.	34.
Na	103.	21.
NH_3	3.7	1.3

1956, occupies 14.3 acres (5.7 hectares). A dike across the center of the lagoon, added in 1966, reduced the primary cell to 10 acres (4 hectares) (fig. 28). The Esmond lagoon has never functioned according to design because of the high seepage rate through the bottom of the impoundment. Wastewater occupies only a small area near the center of the cell (fig. 28). Throughout the life of the lagoon, discharge has never been required because of the high seepage (North Central Consultants Ltd., 1979a). A previous study of the lagoon (North Central Consultants Ltd., 1979a) recommended leaving the lagoon in its present state. The site would then be considered to be a rapid infiltration facility, an accepted method of wastewater treatment.

Hydrogeologic Setting

The town of Esmond, including the lagoon site, is located on till deposits mapped as the Heimdal end moraine (Carlson and Freers, 1975). These deposits, composed of low to moderate relief collapsed superglacial sediment, mark an ice-marginal position of a late Wisconsinan glacial advance. Near the western boundary of Esmond and about one-half mile (1 km) west of the lagoon site, coarse-grained glaciofluvial deposits (outwash) extend westward beyond the limit of the ice-marginal (till) deposits. The outwash sediments constitute the Esmond Aquifer (Randich, 1977). The aquifer contains water of calcium bicarbonate type to sodium bicarbonate type with an average dissolved-solids content of 444 mg/l (Randich, 1977). The sodium bicarbonate water may be derived from the underlying Fox Hills Formation.

The geological setting of the lagoon is shown in figure 29. Twelve to 15 feet (3.7 to 4.6 m) of till at the surface overlie 20 to 25 feet (6.0 to 7.6 m) of sand and gravel. Bedrock of the Fox Hills Formation lies about 40 feet (12 m) below the surface. The water table fluctuates within the upper portion of the sand. Samples obtained during drilling (app. I) indicate that the outwash material is a gravelly sand to sandy gravel. Using the method of Masch and Denny (1966), hydraulic conductivity estimated from grain-size distribution ranges from 1.7 x 10^{-4} ft/s (5.2 x 10^{-5} m/s) to 3.5 x 10^{-4} ft/s (1.1 x 10^{-4} m/s).

Water level measurements in the monitoring wells installed indicate groundwater flow to the southwest (fig. 30). Although water table contours are shown as straight lines on figure 30, mounding of the water table beneath the area of wastewater seepage is likely. This is schematically illustrated on the subsurface cross section (fig. 29). The contours shown are water levels measured on July 28, 1982. The gradient, and even direction of groundwater flow, could vary seasonally with variations in recharge and other factors. The average linear flow velocity of groundwater beneath the site can be estimated as .7 ft/day (.2 m/day) using Darcy's Law, assuming values of 2.5 x 10^{-4} ft/s (7.6 x 10^{-5} m/s) for hydraulic conductivity, .01 for gradient, and .3 for porosity.

Results

Samples from the four wells installed at the lagoon were analyzed three times. The analyses confirm the southwesterly groundwater flow direction suggested by water-table elevations. Samples from monitoring well 4 are as much as two to three times higher in dissolved solids as the other wells. Elevated levels of sodium, bicarbonate, and chloride in well 4 demonstrate the effect of lagoon seepage on downgradient groundwater quality. Well 3 appears to have background quality water; that is, well 3 does not receive wastewater seepage. Nested wells 1 and 2 are intermediate in quality between well 4 and well 3. Well 1, which is screened at the base of the sand and gravel aquifer (fig. 29), has consistently higher concentrations of sodium, potassium, and chloride than well 2, which is screened just below the water table. The difference in water quality between the two wells in the nest may indicate the influence of water recharging the outwash aquifer from the Fox Hills Formation below. The water in the vicinity of wells 1 and 2 may be under some influence of wastewater seepage because of its higher concentration of some parameters relative to well 3. Wells 1 and 2 are closer to the point of wastewater seepage and may receive some contaminants under the influence of dispersion and a gradient toward the wells resulting from groundwater mounding at the point of wastewater seepage.

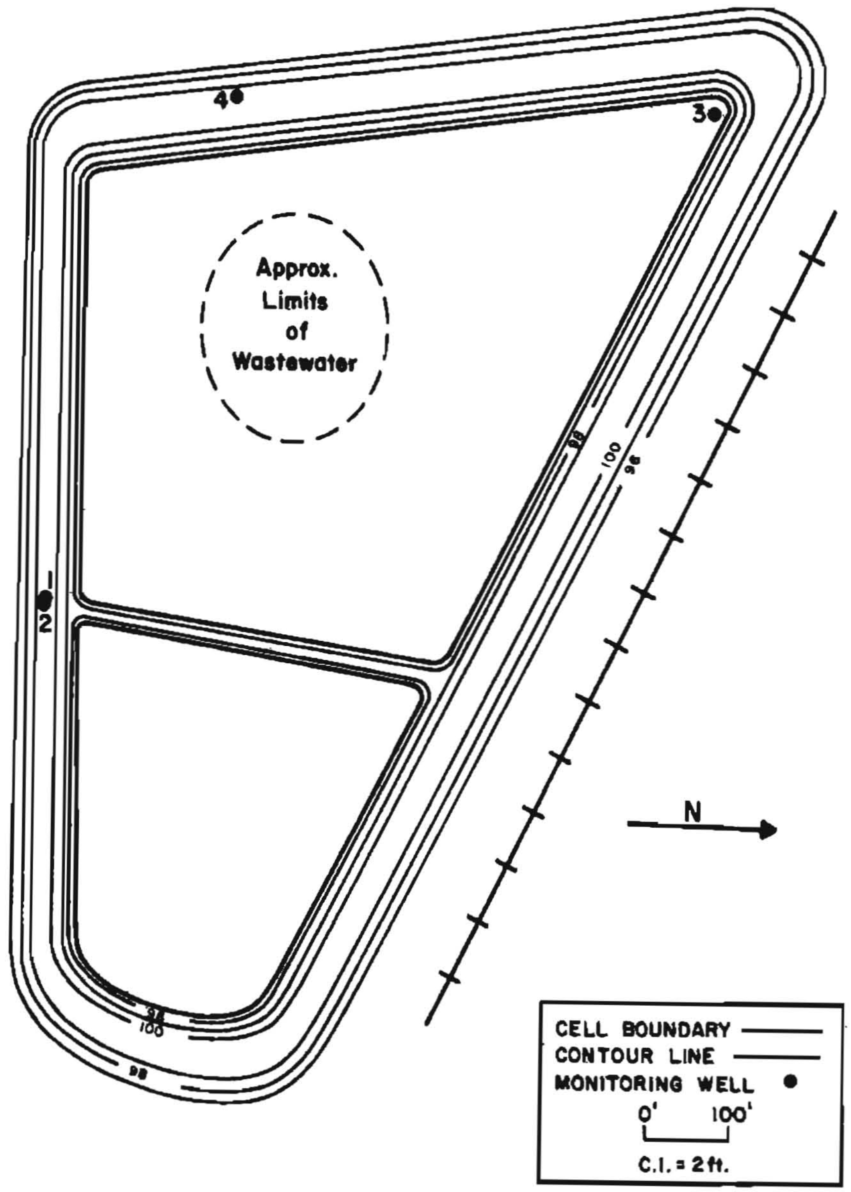

Figure 28. Topography and location of monitoring wells at Esmond site.

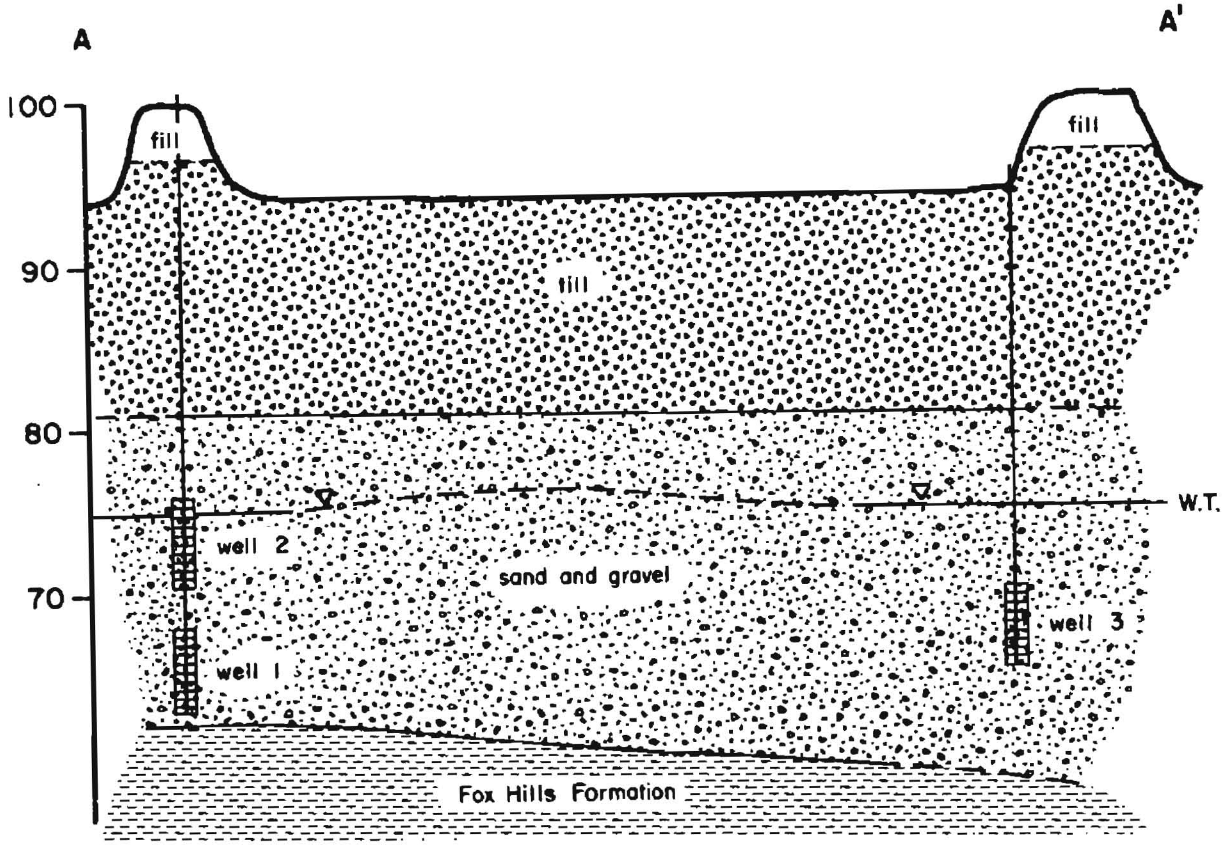

Figure 29. Cross section of Esmond site. Location of section shown on figure 30. Screened section shown at the base of each well.

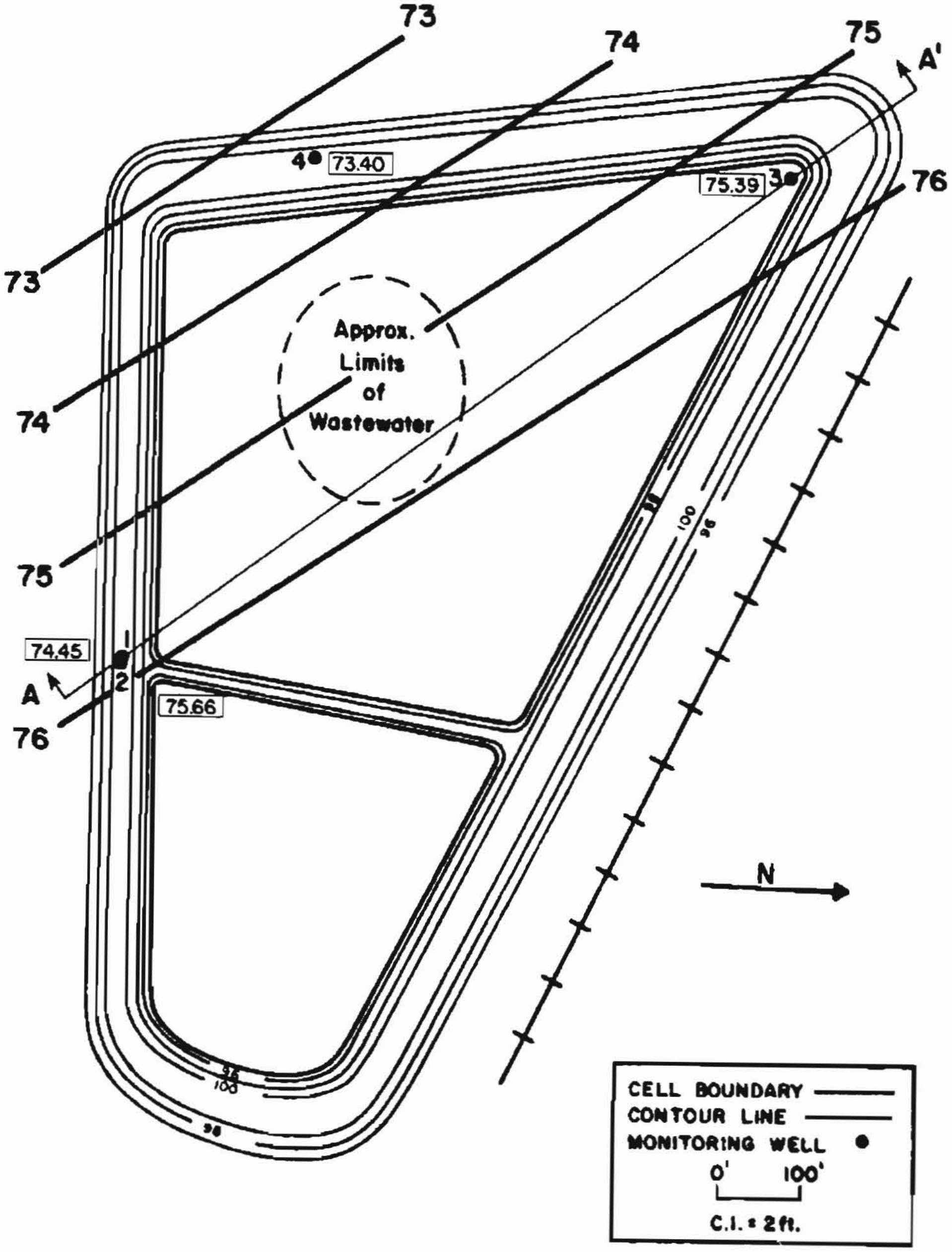

Figure 30. Contours showing water table elevation (heaviest lines) at the Esmond site on July 28, 1982. Water table elevations (in boxes) based on arbitrary datum at 0 feet. A-A': Location of section shown in figure 29.

Nitrogen levels were higher than background in wells 2 and 4 in several of the sampling periods. Well 4 had fairly high ammonium (2.37 mg/l) and nitrate (2.88 mg/l) values on October 28, 1981. The ammonium is probably derived from wastewater while the source of the nitrate is not known but could represent nitrification of wastewater ammonium. The highest nitrate levels at the site were obtained from well 2 on two sampling periods (3.60 mg/l and 3.62 mg/l). These levels could be the result of fertilization in the cropland immediately adjacent to the field.

The Esmond site was also studied prior to this study (North Central Consultants Ltd., 1979a). Three wells were installed, two of which were within the impoundment near the wastewater zone. The third well was located 25 feet (7.6 m) south of the impoundment near wells 1 and 2 of this project. The two wells within the impoundment were higher in most anions and cations than well 4. These concentrations are expected because of the proximity of the wells to the wastewater source. Fecal coliform analyses were positive for both wells and nitrates were very high in at least one sampling period. Values of 39.7 mg/l and 91.7 mg/l were reported although it is not stated whether the values are reported as N or as NO_3 (North Central Consultants Ltd., 1979a). The third well, south of wells 1 and 2 also contained fecal coliforms and very high nitrates. In light of the chemical results reported from wells 1 and 2 of this study, the source of the nitrates in the third well from the earlier study is probably something other than the lagoon. Fertilization is the most probable explanation. The source of the fecal coliforms is more difficult to explain.

Discussion

The results of the Esmond study do not indicate severe groundwater degradation. Well 4, the closest downgradient well is within drinking water standards for the parameters measured. More monitoring wells would be necessary for a detailed analysis of this site. Bacteriological contamination could be significant, but was not attempted in this study.

The most significant result of the Esmond site is the amount of seepage occurring through the surficial till. Till is normally characterized by a very low primary hydraulic conductivity. The amount of seepage occurring at the Esmond lagoon indicates that the till must have a higher effective hydraulic conductivity, probably resulting from fractures. Fractures in fine-grained materials can increase the effective permeability several orders of magnitude higher than the matrix permeability. The continued seepage over the 26-year age of the lagoon, as indicated by the failure of the impoundment to retain water, demonstrates the high degree of fracturing that must be present.

LIDGERWOOD WASTE STABILIZATION LAGOON

Introduction

One 16.5 acre (6.6 hectares) cell serves as the sewage lagoon for Lidgerwood, a town of 971 people in Richland County (fig. 1). The impoundment, completed in the 1950s, has never retained water. An area in the north-central part of the cell (figs. 31 and 32) contains shallow wastewater seasonally, and is surrounded by wetland vegetation. Like the Esmond lagoon, the Lidgerwood facility was recommended for continued operation in its present state as a rapid infiltration lagoon (North Central Consultants Ltd., 1979b).

Hydrogeologic Setting

The Lidgerwood lagoon lies above the shallow, unconfined Milnor Channel Aquifer (Baker and Paulson, 1967). The Milnor Channel Aquifer is a glaciofluvial deposit occupying a shallow valley which probably functioned as an ice-marginal stream during the Pleistocene. Aquifer hydraulic conductivity was estimated as 5.6×10^{-4} ft/s (1.7×10^{-4} m/s) by Baker and Paulson (1967), while the samples taken in test holes during this project yielded a mean hydraulic conductivity of 2.6×10^{-4} ft/s (7.9×10^{-5} m/s) using the method of Masch and Denny (1966). The thickness of the aquifer ranges between 8 and 66 feet (2.4 and 20 m).

Regional flow in the aquifer follows the generally northwest to southeast topographic gradient in Milnor Channel. Southeast was the expected

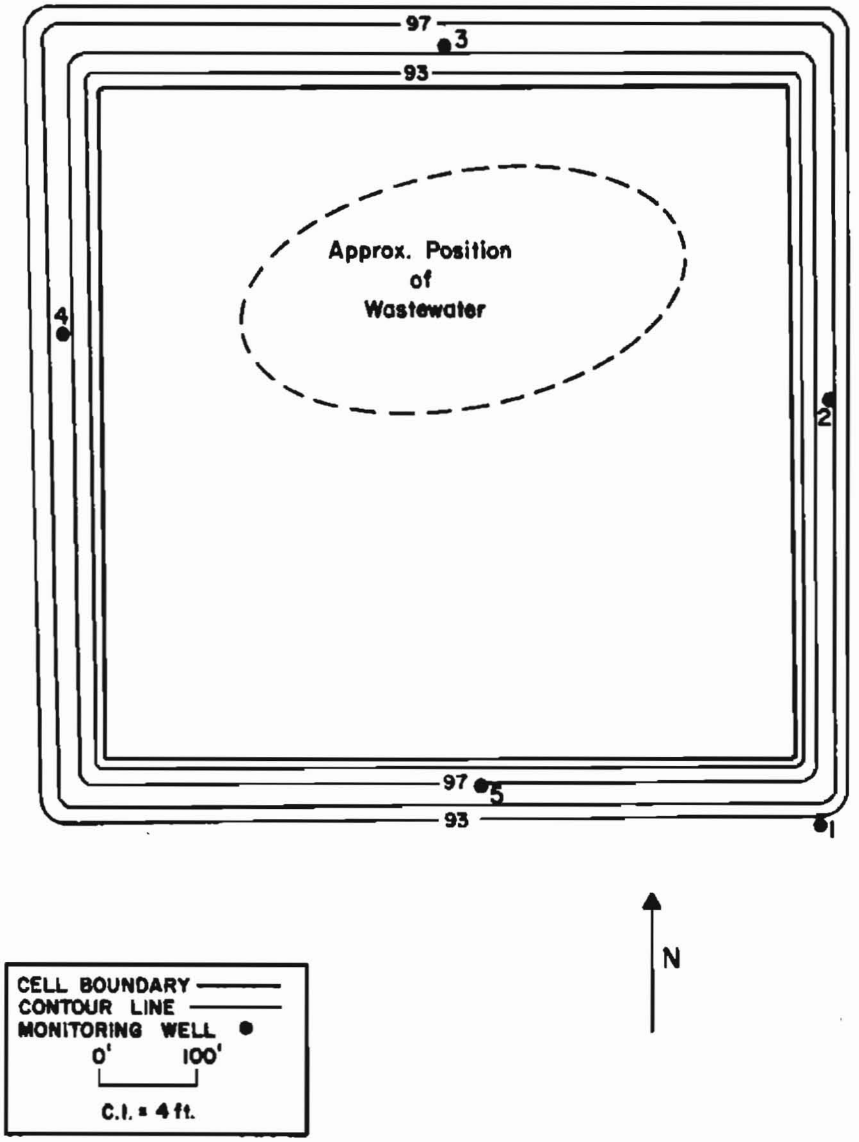

Figure 31. Topography and location of monitoring wells at Lidgerwood site.

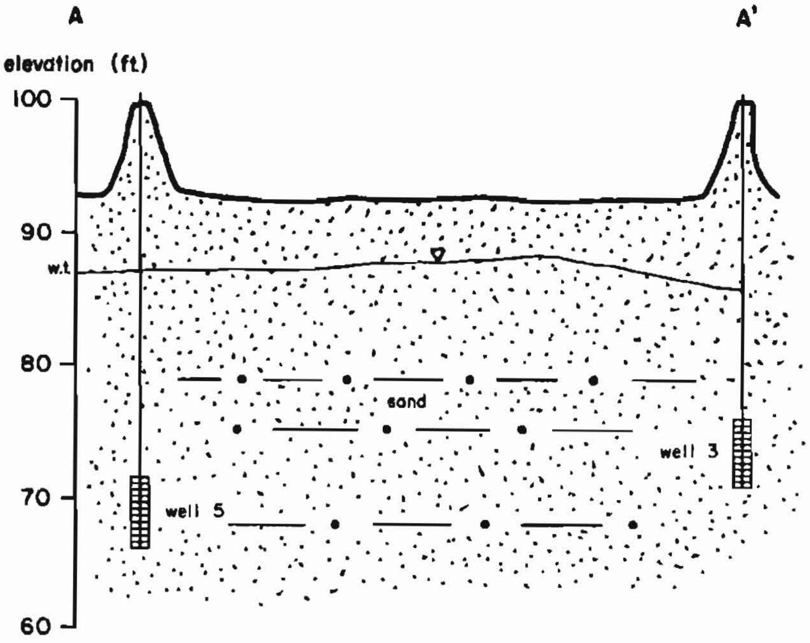

Figure 32. Cross section of Lidgerwood site. Location of section shown in figure 33. Screened section shown at the base of each well.

groundwater flow direction at the Lidgerwood lagoon also, particularly since Swan Lake, a potential discharge point, lies approximately 600 feet (182 m) southeast of the lagoon. Actual groundwater flow at the site, as determined from water-level measurements (fig. 33) occurs under a very low gradient to the northwest. The discrepancy between actual and expected groundwater flow direction at the site may be the result of drawdown from the Lidgerwood municipal wells, located approximately 1,500 feet (366 m) southwest of the impoundment. These wells, which pump approximately 55,000 gpd (208 m^3/day), may have caused a reversal in the local groundwater gradient. An irrigation well approximately 1,000 feet (305 m) may also influence the hydraulic gradient at the lagoon. Chemical results support a predominantly westward movement of seepage from the lagoon.

Results

Chemical analyses from the Lidgerwood wells (app. IV) suggests that lagoon seepage affects all wells. Well 4, on the west embankment of the lagoon, has the highest levels of all major ions. A TDS value of 2,030 mg/l and a chloride concentration of 426 mg/l for the spring, 1982 sampling period can be compared to TDS and chloride values of 1,070 mg/l and 10 mg/l, respectively, from a nearby domestic well (app. IV). The remaining wells around the impoundment have dissolved-solids contents ranging between 800 and 1,200 mg/l. Chloride contents range between 27 and 150 mg/l, indicating influence of wastewater seepage. Well 5 is consistently low in TDS and chloride content, suggesting that it receives the least amount of contaminated groundwater.

Other cations and anions, with the exception of sulfate, attain their highest concentration in well 4. The sulfate concentration may be lowered in well 4 by sulfate reduction. Dissolved oxygen contents in well 4 are the lowest at the site.

Nitrogen parameters were not high in any sampling period. Ammonium values above 1.0 mg/l were measured

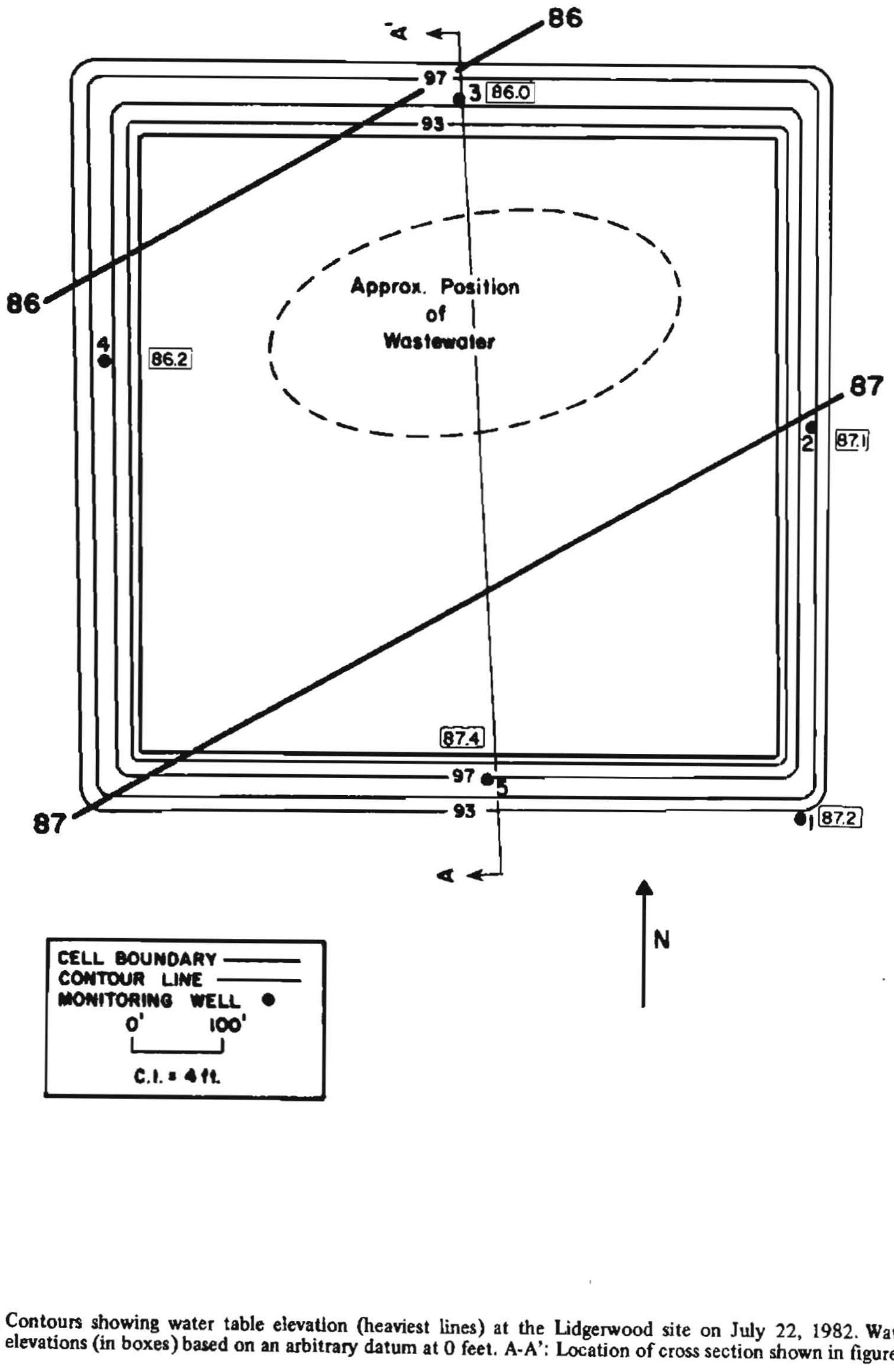

Figure 33. Contours showing water table elevation (heaviest lines) at the Lidgerwood site on July 22, 1982. Water table elevations (in boxes) based on an arbitrary datum at 0 feet. A-A': Location of cross section shown in figure 32.

on several occasions, but no values approached the drinking water standard for nitrate of 10 mg/l (N). Therefore, potential nitrification of the ammonium should not be a problem.

Wells installed at the Lidgerwood site are somewhat farther below the water table than wells at other sites. The wells screened just below the water table of other sites often have maximum concentrations of contaminants resulting from nearly horizontal flow in the aquifer. It is possible, however, that the wells installed at Lidgerwood are not measuring the highest levels of contaminants present in the groundwater.

A significant groundwater problem in the Lidgerwood area is high arsenic concentrations. This problem may be the result of inadequate disposal of arsenic compounds used as pesticides in the 1930s. Alternatively, the arsenic concentrations may be a natural phenomenon. Arsenic levels were measured in this study because of this situation. Three wells sampled, including a nearby domestic well, exceed the drinking water standard of 50 ug/l (app. IV), and several other wells were close to the drinking water standard. A maximum value of 216 ug/l was obtained from well 4. The next highest value of 184 ug/l was measured in well 1, a well which is not highly contaminated by seepage from the lagoon.

Arsenic concentrations in the lagoon water were below drinking water standards in both samples. The lagoon, therefore, may not be the source of the arsenic in the monitoring wells. The arsenic concentration in almost all wells decreased drastically from the spring, 1982 to the summer, 1982 samples. The reason for these fluctuations is not known. The data collected in this study is not sufficient to explain the spatial and temporal variations in arsenic around the lagoon. A more thorough and comprehensive geochemical study must be made to solve this problem.

Discussion

The Lidgerwood lagoon has operated as a rapid infiltration pond for about 30 years. During that time, self-sealing of the impoundment has not occurred. Biological treatment of wastewater cannot occur if standing water is not maintained in the impoundment. Contamination of groundwater is occurring in all directions in the immediate vicinity of the impoundment, probably because of groundwater mounding. A gradient reversal, which may be the result of pumping from the city well, has caused maximum contaminant movement toward the west. The groundwater gradient may revert back to its presumed original southeasterly direction during periods of low pumping from the city wells. Although no harmful levels of nitrogen were found in groundwater in the wells installed, these wells may be screened too far below the water table to intersect maximum contamination. In order to fully assess contamination of this site, additional wells should be installed at various depths and bacteriological sampling should be done.

UNDERWOOD WASTE STABILIZATION LAGOON

Introduction

The Underwood lagoon has two cells (fig. 34) of which the larger one, with an approximate area of 9 acres (3.6 hectares), is sufficient for disposal of the wastewater produced by the town. The smaller cell II is not needed for wastewater disposal. The lagoon is constructed near the head of a south-trending intermittent drainage. Underwood has a population of 1,329 (1980 census). The lagoon, one of the oldest in North Dakota, was built in the 1950s.

Hydrogeologic Setting

The regional hydrogeology of the Underwood area is discussed by Groenewold et al. (1979). Beds of the Sentinel Butte and Bullion Creek Formations are overlain by glacial sediments of the Coleharbor Group. At the lagoon site, glacial sediment is lacking and the lagoon is directly underlain by the Underwood sand, a thick sand within the Sentinel Butte Formation. Along the axis of the stream valley into which the lagoon was constructed, the Underwood sand is overlain by several feet of fine-grained, organic-rich alluvium (fig. 35).

The sewage lagoon and the city of Underwood lie near the center of a large upland recharge area underlain

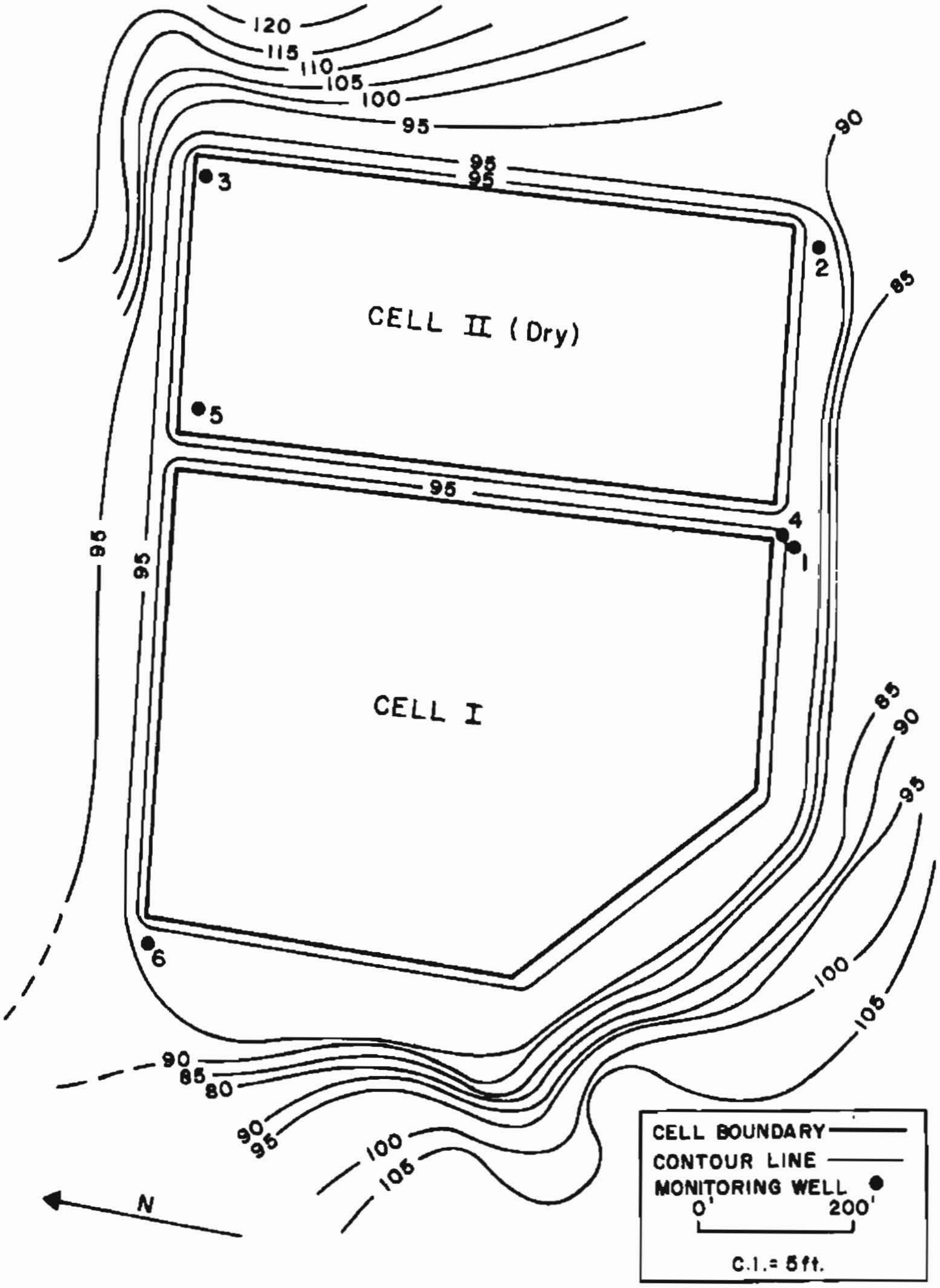

Figure 34. Topography and location of monitoring wells at Underwood site.

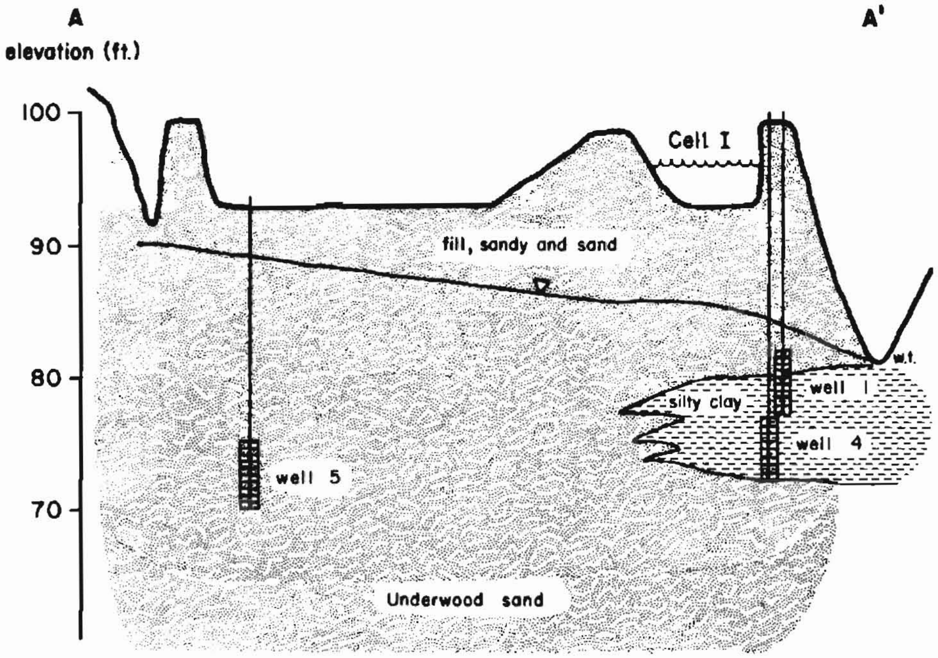

Figure 35. Cross section of Underwood site. Location of section shown in figure 36. Screened section shown at the base of each well.

by the Underwood sand, which contains an aquifer mostly under unconfined conditions (Groenewold et al., 1979). Groundwater flow in the Underwood sand is radially outward toward topographically lower discharge points as well as downward to underlying lignite aquifers. The lagoon apparently lies just south of a groundwater divide because water levels at the site (fig. 36) indicate southward gradients. Hydraulic conductivity of the Underwood sand and other similar lithologic units has a mean value of 7.9 x 10^{-6} ft/s (2.4 x 10^{-4} cm/s) (Groenewold et al., 1979).

Groundwater quality within the Underwood sand is generally good. TDS values generally range between 500 and 2,000 mg/l (Groenewold et al., 1979). Wells previously installed near the lagoon have high chloride levels. A well 59 feet (18 m) deep, completed in the Underwood sand, had a chloride level of 137.1 mg/l in one sampling period (Groenewold et al., 1979).

The location of monitoring wells at the Underwood site is shown in figure 34. Cell I contains wastewater at all times but cell II is completely dry. All wells except wells 1 and 4 are completed in the Underwood sand. Wells 1 and 4 are screened in fine-grained, organic-rich sediment deposited in the intermittent stream valley into which the lagoon is built. Water-level elevations in the monitoring wells (fig. 36), indicate southward flow of groundwater beneath the lagoon. This flow direction conforms to the topographic gradient to the south. In addition to southward lateral flow, downward vertical flow is probably also occurring. Hydrogeological relationships in the Underwood area indicate that the area between Underwood and the lagoon serves as a major recharge area for underlying aquifers (Groenewold et al., 1979). Additional evidence for downward components of flow includes high chloride concentrations in deep piezometers adjacent to the lagoon (Groenewold et al., 1979). The southward component of flow at the lagoon indicates that the lagoon lies to the south of the center of the recharge area

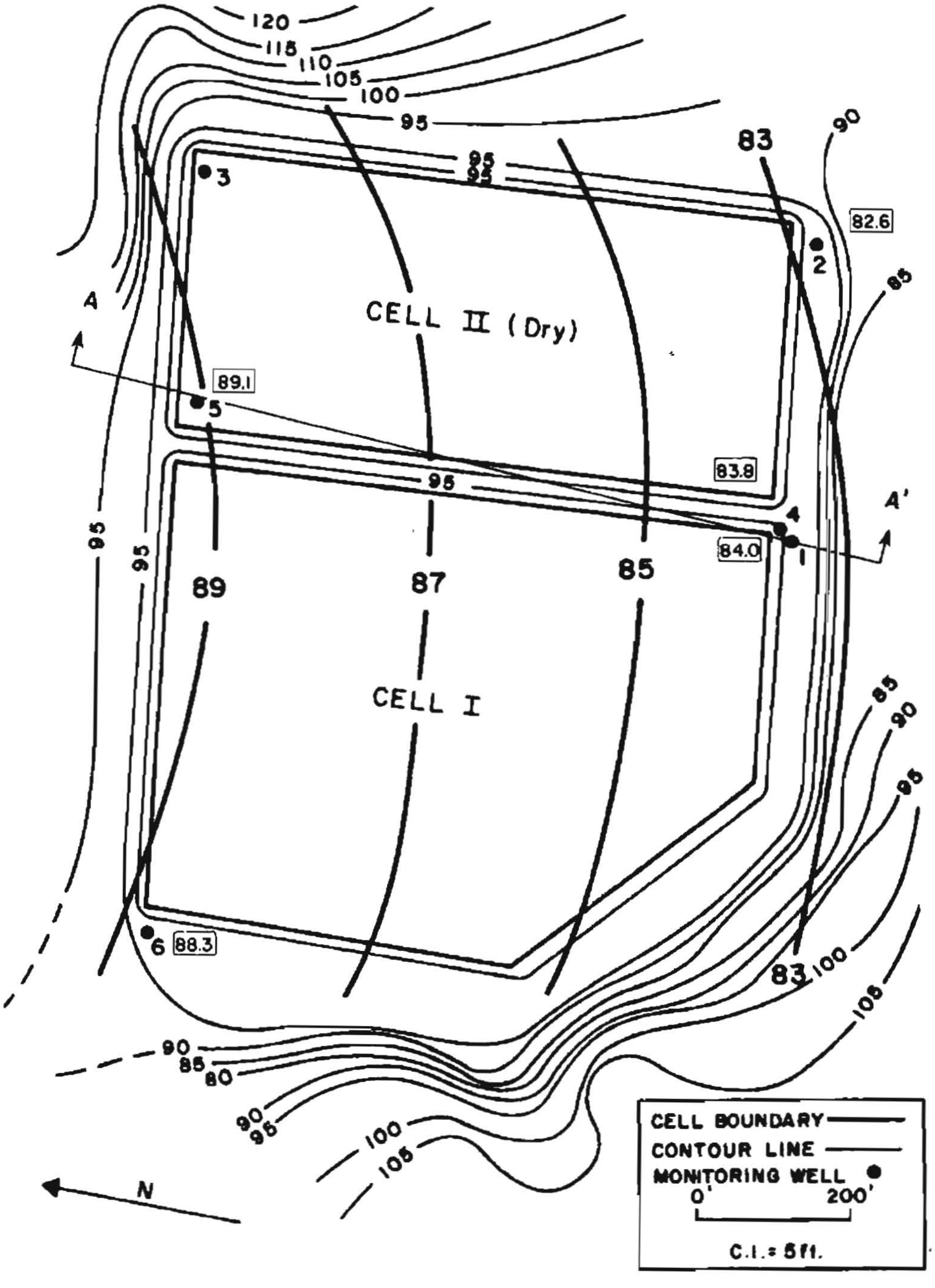

Figure 36. Contours showing water table elevation (heaviest lines) at the Underwood site on August 11, 1982. Water table elevations (in boxes) based on an arbitrary datum at 0 feet. A-A': Location of cross section shown in figure 35.

mentioned above.

Single-well response tests conducted in wells 2, 3, and 5, screened within the Underwood sand, yielded a mean hydraulic conductivity value of 2.5 x 10^{-6} ft/s (7.6 x 10^{-7} m/s). A mean value of 9.2 x 10^{-7} ft/s (2.8 x 10^{-7} m/s) was obtained from single-well response tests in wells 1 and 4, completed in the fine-grained alluvium overlying the sand.

Results

The results of chemical analyses at the Underwood lagoon (app. IV) indicate that all the monitoring wells are affected by seepage of wastewater to some degree. Wells 1 and 4 have the highest levels of TDS, chloride, sodium, potassium, and bicarbonate at the site, a finding consistent with the southward gradient (fig. 36). Chloride levels were above normally expected values for the Underwood sand in the other wells as well. Apparently, mounding of the water table beneath the site occurs, perhaps only seasonally, producing gradients radially outward from the area of primary seepage from cell I. Well 6 in particular, on the upgradient side of the lagoon, has chloride, TDS, and sodium levels as high, or in some cases higher, than wells 1 and 4. This can be explained by a steep topographic slope downward from the lagoon embankments to the west and northwest of well 6. The water table must slope downward in this direction as well, causing a gradient reversal near the northwest corner of the lagoon and a high degree of groundwater contamination in the vicinity of well 6.

Anaerobic conditions in the wastewater seepage to wells 1 and 4 are indicated by mean sulfate concentrations of 4 mg/l in these wells. Sulfate reduction lowers the sulfate concentration from a mean value of 93 mg/l in the wastewater in cell I. Very high ammonium concentrations are present in wells 1 [mean value: 25 mg/l (N)] and 4 [mean value: 35 mg/l (N)]. High levels of ammonium or nitrate were not detected in any of the other wells.

Discussion

The Underwood lagoon was the only site investigated which involved pre-Pleistocene materials. The Underwood sand has a somewhat lower hydraulic conductivity than the materials at most of the other sites studied. Despite lower hydraulic conductivity, significant seepage has occurred from the lagoon. Biological sealing of the impoundment has not been sufficient over the 30-year life of the lagoon to require utilization of cell II. In addition, high levels of ammonium characterize the groundwater beneath the downgradient end of the lagoon. The extent of the ammonium movement is not known, but the adsorptive capacity of the soil for ammonium has been exceeded in the vicinity of wells 1 and 4. Downward movement of the contaminants is also apparent in the high chloride concentrations reported in wells as deep as 59 feet (18 m) in the vicinity of the lagoon (Groenewold et al., 1979). This downward movement is a consequence of the location of the lagoon in a groundwater recharge area. The contaminated groundwater can be expected to travel downward to aquifers underlying the Underwood sand, although harmful contaminants such as nitrogen forms may be attenuated by adsorption and other mechanisms. The predominant southward hydraulic gradient at the site should prevent contamination from the lagoon from reaching the city wells located north of the lagoon.

CONCLUSIONS AND RECOMMENDATIONS

This study describes the levels of groundwater contamination around unlined municipal waste stabilization lagoons constructed in geological settings which would be considered as being poorly suited for any type of waste disposal. The common hydrogeological conditions at the sites include unconfined, shallow aquifers directly beneath the impoundments. The water tables are shallow and the aquifers are all sources of high quality water presently used for domestic and municipal water supplies. The degree of contamination caused by these "worst-case" situations should be an important factor when considering whether to require the installation of liners in such unlined impoundments.

All the impoundments studied lose significant amounts of water as seepage through their sides and bottoms and therefore utilize less impoundment capacity than is available at the site.

Two of the sites contain essentially no standing wastewater in the impoundment. All the inflow is lost to seepage immediately and the impoundments contain marshy zones around the inlet pipe. Both of these impoundments are nearly 30 years old. The self-sealing mechanisms reported for waste stabilization lagoons are not functioning at these sites. The other four sites all maintain some depth of standing wastewater in at least one cell. Wastewater storage is sometimes rotated from cell to cell by the operators; alternatively some operators use the unfilled cells for seasonal or periodic discharges in times of high inflow to the primary cell.

Studies in the literature on the design and function of waste stabilization lagoons stress the importance of sufficient holding time for proper biochemical waste treatment. Because of the rapid seepage in the lagoons we studied, adequate storage time is not achieved. The water lost to seepage moves rapidly downward to the water table and then laterally in the direction of groundwater flow. Groundwater mounds are probably present in all the sites studied with the possible exception of McVille. The size of the mounds is inversely proportional to the permeability of the soils at the site.

Groundwater contamination is obvious around all impoundments studied. Because of the groundwater mounds, upgradient wells adjacent to the impoundments are somewhat affected by seepage. The main result of the seepage, however, is a plume of contaminated groundwater which extends downgradient from the site. The distal extent of the plume could not be determined at any of the sites because of land-use constraints, but at McVille, wells located more than 700 feet (210 m) downgradient from the impoundment show significant evidence of contamination. At the other sites, wells were installed only on and adjacent to the embankments of the impoundments.

Indicators of contamination at all sites include TDS, sodium, calcium, magnesium, potassium, bicarbonate, and chloride. Chloride is particularly useful for recognition of seepage because of its very low natural concentrations in the aquifer and because of its mobility in the subsurface. The other chemical characteristics of the contaminant plumes vary from site to site depending on a number of factors. One of the most important factors is the depth of standing water in the impoundment. The depth is assumed to be partially controlled by the presence of a sludge layer at the base of the lagoon. Sludge layers decrease the permeability of the soils and participate in treatment reactions with the wastewater. If a cell maintains a water depth of greater than several feet, it can be assumed that facultative processes are in operation; that is, the lower portion of the cell is anaerobic and chemically reducing. The seepage which reaches groundwater below such lagoons maintains these reducing conditions. Redox potentials are low enough to reduce sulfate to sulfide and limit sulfate concentrations to negligible values. Nitrogen occurs almost entirely in the ammonium form. Another consequence of seepage of reducing water is the interaction between it and aquifer materials. Iron concentrations, which are very low in the lagoon wastewater, increase drastically downgradient from the lagoons. This can be explained by the reduction of ferric-oxide mineral coatings to ferrous compounds, which are more soluble in aqueous solutions. Arsenic species behave in a similar manner and the limited trace-element data collected suggest that this mechanism may be operating in at least one of the sites. Some of the trace metals are less soluble at lower redox potential, forming insoluble sulfide compounds. Some of the data suggest downgradient decreases in these constituents. At other sites, trace-metal data show large fluctuations which are more difficult to explain.

Despite the contribution of highly reducing wastewater to the groundwater flow system, lagoons with self-sealing characteristics provide effective treatment to the seepage. Seepage through the sludge layer appears to retard the movement of some of the most undesirable contaminants from reaching groundwater in high concentrations. These waters usually contain ammonium in concentrations less than 10 mg/l. This limits the amount of nitrate that could be produced farther downgradient in the flow system by nitrification. Ammonium may also be adsorbed onto soil particles before it can be nitrified. The sludge layer may also retard the migration of biological contaminants by reducing the rate of seepage.

The operating practice of periodically discharging wastewater into adjacent empty cells may contribute to greatly increased groundwater degradation. This wastewater is short-circuited to the groundwater flow system without the beneficial effects of slower seepage through the sludge layer. The intermittent discharge hypothesis is invoked to explain the spatial patterns of contamination at the McVille site. The groundwater quality downgradient from cell II (the intermittent cell) is much worse than the quality of water downgradient from cell I (the primary cell).

Once contaminants from the lagoons reach the groundwater flow systems, a variety of attenuation mechanisms begin to reduce their concentrations. Anions such as chloride, sulfate, and bicarbonate travel long distances in groundwater and are attenuated mainly by dispersion. High chloride levels in the most distant downgradient wells at McVille indicate the potential of these ions for migration from the sites. Nested monitoring wells indicate that contaminants do move downward in the aquifer under the influence of a hydraulic gradient component or by dispersion; however, the concentrations indicate that lateral migration near the top of the saturated zone is the most active form of movement. Contaminants in cationic form are mainly attenuated by adsorption and exchange reactions. Movement of sodium, potassium, and ammonium seems to be controlled by these mechanisms. Adsorption of ammonium is postulated because nitrate concentrations do not increase downgradient from the zone of ammonium retardation. Exchange, rather than total adsorption, is indicated by the large increases of calcium and magnesium in solution downgradient from the center of the sodium, potassium, and ammonium plumes. Phosphorous species are strongly adsorbed by soils. Dissolved phosphorous levels are high only very close to the impoundments. At some sites, high phosphorous concentrations are not observed in any wells. Constituents such as phosphorous and ammonium can move only if the adsorption capacity for that ion has been exceeded. This means that the rate of movement of these ions is substantially retarded relative to anions such as chloride. Because adsorption capacity is finite, however, these contaminants will move, but at a slower rate than others. The sandy soils in which the study sites are located have low adsorption and exchange capacities and therefore represent minimum attenuation for undesirable cations. Lagoons constructed in clayey soils or built with clay liners would demonstrate much greater removal of wastewater cations.

Microbiological contaminants are perhaps the greatest potential threat to groundwater quality from unlined sewage lagoons. Uncertainties regarding sampling techniques preclude definite conclusions from this study. High counts of total and fecal coliform bacteria were measured in wells at most of the sites. The distribution of the bacteria suggest that the trends, if not the absolute values, are real. The results from McVille suggest the potential for long distances of movement. Other microbiological contaminants, such as viruses, may also be mobile in these aquifers.

Based on the results of this study, it is recommended that unlined lagoons in geological settings similar to the lagoons investigated be supplied with clay liners. Unlined lagoons with high seepage rates are not functioning in the manner for which they are designed. Efficient biochemical treatment cannot be achieved unless adequate wastewater residence time is allowed. This study demonstrates the potential for movement of undesirable contaminants for distances of hundreds of feet from an unlined lagoon in sandy soil. Water quality in productive shallow aquifers should be protected for future use. Even though the lagoons studied may not be presently affecting wells, this potential exists for other similar lagoons and for these lagoons if land development around them should occur.

The microbiological contamination of groundwater from waste stabilization lagoons should receive further study. The development of better sampling techniques by geologists and microbiologists could lead to an accurate evaluation of microbiological contamination. Water samples should be analyzed for more parameters than total and fecal coliform numbers.

Intermittent discharges of water into empty cells where rapid infiltration can occur should not be permitted. Groundwater degradation is maximized in these instances and the resulting groundwater quality may be considerably lower than achieved by slower seepage through a sludge layer.

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APPENDICES

APPENDIX I

LITHOLOGIC LOGS OF MONITORING WELL HOLES

APPENDIX I-A, McVILLE

Well 1	
0-25	Sand; fine- to coarse-grained, gravelly, yellowish-brown to brown.
25-27	Sand; wet, poor sample recovery.

Well 2	
0-22	Sand; fine- to coarse-grained, gravelly, yellowish-brown to brown.
22-30	Sand; coarse-grained, brown, moist.
30-32	Clay; sandy, pebbly, grayish-green.

Well 3	
0-27	Sand; fine- to coarse-grained, gravelly, yellowish-brown to brown.
27-32	Sand; coarse-grained, brown, wet.

Well 4	
0-10	Sand; fine- to coarse-grained, gravelly, yellowish-brown to brown.
10-17	Sand; medium- to coarse-grained, gravelly, brown to greenish-gray, sewage odor.
17-30	Sand; medium-grained, dark-gray to dark-grayish-green, sewage odor decreased.
30-32	Sand; medium-grained, clayey.

Well 5	
0-22	Sand; fine- to medium-grained, yellowish-brown to brown.
22-32	Sand; medium-grained, wet.

Well 6	
0-7	Sand; fine- to medium-grained, brown.
7-32	Sand; fine- to medium-grained, gravelly, brown, wet.

Well 7	
0-10	Sand; medium-grained, brown.
10-18	Sand; fine-grained, dark-grayish-brown.
18-33	Sand; medium- to coarse-grained, pebbly, brown.

Well 8	
0-8	Sand; fine- to medium-grained, brown.
8-18	Sand; medium-grained, pebbly, grayish-brown.
18-34	Sand; medium- to coarse-grained, pebbly, brown.

Well 9	
0-27	Sand; fine- to medium-grained, gravelly, yellowish-brown to brown.
27-42.5	Sand; fine- to coarse-grained, gravelly, brown, wet.

Well 10	
0-16	Sand; fine- to medium-grained, gravelly, yellowish-brown to brown.
16-42.5	Sand; fine- to coarse-grained, gravelly, brown to brownish-gray, wet.

Well 11	
0-27	Sand; fine- to coarse-grained, gravelly, yellowish-brown to brown.
27-37.5	Sand; fine- to coarse-grained, clayey, brown to brownish-gray, wet.

Well 12	
0-25	Sand; fine- to medium-grained; light-brown.
25-42	Sand; medium- to coarse-grained, brown, wet.

Well 13	
0-15	Sand; fine- to medium-grained; brown.
15-23	Sand; medium-grained, brown.
23-42	Sand; coarse-grained, gravelly, dark-brown, wet.

Well 14

0-20	Sand; fine- to medium-grained, light-brown.
20-30	Sand; medium- to coarse-grained, brown, moist.
30-37	Sand; coarse-grained, gray to brown, wet.

APPENDIX I-B, LARIMORE

Well 1

0-2	Silt; black.
2-5	Sand; fine- to medium-grained, grayish-brown.
5-7	Clay; silty, brown.
7-13.2	Sand; medium-grained, brown, wet.

Well 2

0-2	Silt; grayish-black.
2-5	Sand; fine- to medium-grained, grayish-brown.
5-7	Clay; silty, brown.
7-13.1	Sand; medium-grained, grayish-brown, wet.

Well 3

0-2	Silt; grayish-black.
2-5	Sand; fine- to medium-grained, grayish-brown.
5-7	Sand; medium-grained, light-brown.
7-13.3	Sand; medium-grained, brown, wet.

Well 4

0-2	Silt; black.
2-5	Sand; fine- to medium-grained, grayish-brown.
5-7	Sand; medium-grained, light-brown.
7-12	Sand; medium- to coarse-grained, wet.

Well 5

0-3	Silt; black.
3-6	Sand; fine- to medium-grained, grayish-brown.
6-8	Sand; medium-grained, light-brown.
8-12	Sand; medium-grained, brown, wet.

Well 6

0-3	Silt; black.
3-6	Sand; fine- to medium-grained, grayish-brown.
6-8	Sand; medium-grained, light-brown.
8-24	Sand; medium-grained, occasional silty clay lenses, brown, wet.

Well 7

0-3	Silt; black.
3-6	Sand; fine- to medium-grained, grayish-brown.
6-8	Sand; medium-grained, light-brown.
8-23	Sand; medium-grained, light-brown to brown, wet.

APPENDIX I-C, FORDVILLE

Well 1

0-2	Silt; black.
2-7	Clay; silty, brown.
7-10	Clay; silty, gray.
10-24	Sand; medium- to coarse-grained, gravelly.

Well 2

0-2	Silt; black.
2-5	Clay; silty, brown.
5-6	Clay; silty, tan.

6-9	Sand; sandy, gravelly.
9-24	Gravel; sandy, brown.

Well 3	
0-2	Silt; black.
2-5	Clay; silty, brown.
5-6	Clay; silty, light-brown.
6-18	Sand; medium- to coarse-grained, gravelly.

Well 4	
0-2	Silt; black.
2-6	Clay; silty, brown.
6-12	Sand; medium- to coarse-grained.
12-13	Sand; very coarse grained.
13-14	Sand; gravelly.

Well 5	
0-3	Silt; black.
3-13	Clay; brown.
8-13	Clay; brown, occasional pebbles.
13-30	Sand; coarse-grained, pebbly.

Well 6	
0-3	Silt; black.
3-13	Clay; brown.
13-18	Sand; gravelly.
18-22	Gravel; sandy.

APPENDIX I-D, ESMOND

Well 1	
0-3	Till; sandy, pebbly, brown.
3-20	Till; pebbly, cobbly, brown.
20-38	Sand; gravelly, brown.
38-45	Shale; Fox Hills Formation.

Well 2

Same as #1.

Well 3	
0-3	Topsoil.
3-13	Till; pebbly, olive-brown.
13-33	Sand; medium- to coarse-grained, gravelly, brown.

Well 4	
0-3	Topsoil.
3-18	Till; pebbly, olive-brown.
18-40	Sand; gravelly, brown.
40-43	Clay; Fox Hills Formation.

APPENDIX I-E, LIDGERWOOD

Well 1	
0-3	Topsoil; dark-brown to grayish-brown.
3-43	Sand; fine- to coarse-grained, poorly sorted to well-sorted, light-brown to brown.

Well 2	
0-8	Fill; black.
8-13	Sand; fine- to coarse-grained, light-brown to brown.

Well 3	
0-8	Fill.
8-38	Sand; fine- to coarse-grained, gravelly from 28 to 38 feet, light-brown.

Well 4	
0-8	Fill.
8-38	Sand; fine- to coarse-grained, light-brown.

Well 5	
0-8	Fill.
8-43	Sand; fine- to coarse-grained, gravelly from 13 to 18 feet, coarser from 28 to 43 feet, light-brown.

APPENDIX I-F, UNDERWOOD

Well 1	
0-9	Sand; yellowish-brown (fill?).
9-15	Sand; yellowish-brown, moist (fill?).
15-18	Clay; sandy, gray.
18-23	Silt; clayey, organic-rich, sewage odor.

Well 2	
0-8	Sand; medium-grained, yellowish-brown (fill?).
8-13	Sand; silty, light-brown (fill?).
13-18	Silt; clayey, organic-rich, black.
18-28	Silt; clayey, dark-brown, wet.
28-33	Poor sample recovery.
33-38	Silt; clayey, dark-brown.

Well 3	
0-3	Sand; fine- to medium-grained, light-brown.
3-13	Sand; as above, moist.
13-23	Sand; poor sample recovery, wet.

Well 4	
0-8	Sand; yellowish-brown (fill?).
8-18	Sand; as above, moist (fill?).
18-23	Silt; sandy, organic-rich, black, sewage odor, wet.
23-28	Poor sample recovery, boulders at bottom, hard drilling.

Well 5	
0-3	Sand; fine- to medium-grained, well-sorted.
3-8	Sand; as above, moist.
8-13	Sand; as above, wet.
13-38	Sand; poor sample recovery, wet.

Well 6	
0-8	Sand; light-brown (fill?).
8-13	Sand; silty, organic-rich, black, sewage odor.
13-18	Sand; silty, dark-brown, wet.
18-23	Sand; poor sample recovery.

APPENDIX II

MONITORING WELL CONSTRUCTION DATA

MONITORING WELL CONSTRUCTION DATA

Elevations measured in feet above an arbitrary datum located at an elevation of 0 feet.

Well Number	Surface Elevation	Elevation of Top of Pipe	Elevation of Top of Screen	Elevation of Bottom of Screen
		A. McVILLE		
1	102.73	104.39	80.87	75.87
2	104.20	106.03	83.01	78.01
3	99.63	101.19	77.75	72.75
4	100.00	101.54	79.92	74.92
5	102.99	104.57	82.91	77.91
6	87.19	88.86	63.85	58.85
7	100.00	101.42	72.08	67.08
8	87.19	88.52	58.27	53.27
9	101.62	102.04	75.29	70.29
10	97.61	98.44	70.86	65.86
11	97.21	95.72	71.04	66.04
12	101.16	102.41	70.00	65.00
13	99.08	97.51	71.08	66.08
14	102.77	99.68	73.77	68.77
		B. LARIMORE		
1	96.15	97.73	87.98	82.98
2	99.45	101.11	91.35	86.35
3	101.27	102.85	93.02	88.02
4	100.00	101.79	93.40	88.40
5	100.00	101.50	76.80	71.80
6	100.85	102.35	82.35	77.35
7	101.75	103.75	83.75	78.75

APPENDIX II--Continued

Well Number	Surface Elevation	Elevation of Top of Pipe	Elevation of Top of Screen	Elevation of Bottom of Screen
		C. FORDVILLE		
1	96.48	98.15	77.31	72.31
2	97.10	98.27	85.02	80.02
3	95.78	96.53	83.36	78.36
4	94.66	96.58	86.66	81.16
5	95.78	97.11	70.70	65.70
6	96.50	98.67	78.67	73.67
		D. ESMOND		
1	99.90	100.73	67.79	62.69
2	100.06	100.98	75.46	[illegible].46
3	93.90	94.40	69.86	64.86
4	100.10	100.43	67.60	62.60
		E. LIDGERWOOD		
1	92.73	94.06	69.06	64.06
2	99.77	101.19	73.60	68.60
3	100.00	101.25	76.42	71.42
4	99.93	100.75	74.51	69.51
5	99.93	101.26	71.26	66.26
		F. UNDERWOOD		
1	99.62	101.62	81.62	76.62
2	99.04	101.12	66.71	61.71
3	90.84	92.17	67.01	62.01
4	100.37	101.37	77.70	72.70
5	91.76	93.09	74.76	69.76
6	98.89	100.22	80.89	75.89

APPENDIX III

WATER LEVEL DATA

WATER LEVEL DATA

Elevations given in feet above an arbitrary datum of zero feet.

A. McVILLE

Well	Surface Elevation	5/27/81	6/22/81	7/16/82	8/26/81	10/14/81	11/29/81	1/31/82	3/28/82	4/25/82	6/08/82	7/27/82
1	102.73	84.71	84.81	84.94	84.97	84.78	84.78	84.71	84.71	85.17	85.20	85.10
2	104.20	84.38	84.71	84.84	85.04	84.81	84.78	84.71	84.78	85.33	85.33	85.23
3	99.63	82.49	82.56	82.69	82.82	82.56	82.49	82.46	82.56	83.12	83.15	82.95
4	100.00	82.49	83.04	84.06	83.21	82.98	82.88	82.84	82.91	83.54	83.60	83.40
5	102.99	82.76	82.89	83.25	83.09	82.82	82.79	82.79	82.79	82.32	83.25	83.24
6	87.19	80.99	80.99	81.64	81.19	80.99	81.02	80.89	80.92	81.55	81.45	81.35
7	100.00	-	-	-	83.09	83.45	83.35	83.28	83.35	83.94	83.87	83.77
8	87.19	-	-	-	81.44	81.24	80.88	81.14	81.17	81.70	82.06	81.60
9	101.62	-	-	-	-	-	-	-	-	-	-	81.95
10	97.61	-	-	-	-	-	-	-	-	-	-	80.46
11	97.21	-	-	-	-	-	-	-	-	-	-	78.73
12	101.16	-	-	-	-	-	-	-	-	-	-	79.24
13	99.08	-	-	-	-	-	-	-	-	-	-	80.55
14	102.77	-	-	-	-	-	-	-	-	-	-	82.24

B. LARIMORE

Well	Surface Elevation	5/27/81	6/24/81	7/15/81	8/30/81	9/20/81	10/14/81	11/21/81	1/31/82	3/28/82	4/21/82	6/22/82	8/10/82
1	96.15	93.14	93.37	92.68	92.25	92.81	93.24	92.91	-	-	93.63	93.34	92.23
2	99.45	93.73	94.19	93.67	93.24	93.73	94.03	93.47	93.04	93.37	94.55	94.06	93.01
3	101.27	94.65	94.98	94.39	93.57	94.39	94.88	94.55	93.50	93.83	95.18	95.01	93.85
4	99.37	92.80	93.19	92.57	92.01	92.50	93.16	92.70	91.88	92.30	93.42	93.78	92.46
5	100.35	-	93.29	93.16	92.60	93.32	93.75	93.29	91.81	92.83	94.08	94.44	93.05
6	100.85	-	93.26	92.74	92.48	92.94	93.23	93.00	92.90	92.61	93.72	93.36	92.45
7	101.75	-	95.32	94.24	93.52	94.34	94.83	94.37	93.25	93.68	94.76	95.32	94.25

APPENDIX III--Continued

C. FORDVILLE

Well	Surface Elevation	5/27/81	7/17/81	8/30/81	9/27/81	10/14/81	11/21/81	1/31/82	3/28/82	4/20/82	6/16/82
1	96.48	94.53	92.89	93.71	93.65	94.50	93.61	90.98	91.74	-	94.07
2	97.10	94.01	92.33	93.09	92.99	94.11	92.79	-	91.71	95.32	94.66
3	95.78	93.09	91.41	92.27	92.10	93.12	92.10	-	90.30	93.45	92.99
4	94.66	93.46	91.92	92.81	92.81	93.46	92.78	89.96	90.97	93.53	92.81
5	95.78	-	88.02	92.91	92.55	93.85	92.83	-	91.03	94.26	90.62
6	96.50	-	95.00	90.54	92.34	90.01	92.05	91.19	91.09	94.14	95.06

D. ESMOND

Well	Surface Elevation	10/26/81	4/19/82	7/28/82
1	99.90	74.33	75.01	74.45
2	100.06	75.17	75.23	75.66
3	93.90	74.23	74.82	75.39
4	100.10	73.01	72.98	73.40

APPENDIX III--Continued

E. LIDGERWOOD

Well	Surface Elevation	10/18/81	4/28/82	7/22/82
1	92.73	87.90	89.80	87.24
2	99.77	87.80	89.48	87.05
3	100.00	87.44	89.24	85.96
4	99.93	87.23	88.77	86.15
5	99.93	88.17	90.56	87.38

F. UNDERWOOD

Well	Surface Elevation	4/18/82	8/11/82
1	99.62	85.64	84.00
2	99.04	87.21	82.62
3	90.84	-	-
4	100.37	85.49	83.82
5	91.76	-	89.12
6	98.89	88.74	88.31

APPENDIX IV

CHEMICAL DATA

McVILLE - WELL 1

Parameter	10/2/80	8/26/81	10/25/81
Water Level (ft)	83.28	84.97	84.71
pH	6.6	7.2	6.8
Field Conductivity (μmhos/cm)	1250.	-	-
Lab Conductivity (μmhos/cm)	1044.	874.	1160.
Dissolved Oxygen (mg/l)	3.3	5.5	7.0
Total Dissolved Solids (mg/l)	559.	549.	725.
Total Alkalinity (mg/l)	288.	262.	303.
Total Hardness (mg/l)	374.	354.	437.
Ammonia (N) (mg/l)	-	0.476	0.132
Nitrate (N) (mg/l)	12.6	27.8	31.0
Dissolved Phosphorous (mg/l)	-	0.256	0.217
Calcium (mg/l)	105.	96.5	117.
Magnesium (mg/l)	27.0	27.5	35.0
Sodium (mg/l)	88.0	90.0	109.
Potassium (mg/l)	5.70	5.55	6.10
Bicarbonate (mg/l)	352.	321.	370.
Chloride (mg/l)	39.	35.	48.
Sulfate (mg/l)	107.	109.	196.
Iron (mg/l)	0.02	0.00	0.03
Manganese (mg/l)	0.020	0.290	0.050
Carbonate (mg/l)	0.0	0.0	0.0
Fluoride (mg/l)	0.2	0.2	0.1
Total Coliform (colonies/100 ml)	-	-	110.
Fecal Coliform (colonies/100 ml)	-	-	2.
Arsenic (μg/l)	-	13.	29.6
Barium (μg/l)	-	350.	470.
Cadmium (μg/l)	-	1.0	1.9
Chromium (μg/l)	-	14.4	24.9
Copper (μg/l)	-	102.	12.0
Lead (μg/l)	-	22.	35.3
Selenium (μg/l)	-	0.2	0.4
Zinc (μg/l)	-	119.	143

McVILLE - WELL 1 (Continued)

Parameter	4/25/82	7/27/82
Water Level (ft)	85.17	85.10
pH	7.0	6.4
Field Conductivity (μmhos/cm)	-	1100.
Lab Conductivity (μmhos/cm)	738.	1003.
Dissolved Oxygen (mg/l)	8.7	6.0
Total Dissolved Solids (mg/l)	418.	559.
Total Alkalinity (mg/l)	248.	267.
Total Hardness (mg/l)	241.	358.
Ammonia (N) (mg/l)	0.210	0.087
Nitrate (N) (mg/l)	12.3	14.8
Dissolved Phosphorous (mg/l)	0.107	0.084
Calcium (mg/l)	65.5	98.0
Magnesium (mg/l)	19.0	27.5
Sodium (mg/l)	69.5	83.5
Potassium (mg/l)	4.35	6.40
Bicarbonate (mg/l)	303.	327.
Chloride (mg/l)	15.0	3.00
Sulfate (mg/l)	83.	166.
Iron (mg/l)	0.06	-
Manganese (mg/l)	0.030	-
Carbonate (mg/l)	0.	0.
Fluoride (mg/l)	0.1	-
Total Coliform (colonies/100 ml)	2.	-
Fecal Coliform (colonies/100 ml)	2.	-
Arsenic (μg/l)	91.8	-
Barium (μg/l)	1750.	-
Cadmium (μg/l)	41.1	-
Chromium (μg/l)	112.	-
Copper (μg/l)	270.	-
Lead (μg/l)	140.	-
Selenium (μg/l)	1.1	-
Zinc (μg/l)	362.	-

McVILLE - WELL 2

Parameter	10/2/80	8/26/81	10/25/81
Water Level (ft)	83.01	85.04	84.81
pH	6.5	7.5	6.9
Field Conductivity (μmhos/cm)	610.	-	-
Lab Conductivity (μmhos/cm)	597.	515.	541.
Dissolved Oxygen (mg/l)	3.0	4.5	4.4
Total Dissolved Solids (mg/l)	308.	307.	308.
Total Alkalinity (mg/l)	203.	199.	205.
Total Hardness (mg/l)	284.	285.	275.
Ammonia (N) (mg/l)	-	0.153	0.098
Nitrate (N) (mg/l)	14.8	14.2	13.1
Dissolved Phosphorous (mg/l)	-	0.101	0.068
Calcium (mg/l)	76.0	76.5	72.5
Magnesium (mg/l)	27.0	23.5	23.0
Sodium (mg/l)	88.0	18.0	15.5
Potassium (mg/l)	5.70	2.20	2.05
Bicarbonate (mg/l)	352.	244.	251.
Chloride (mg/l)	39.	0.0	3.0
Sulfate (mg/l)	107.	53.	57.
Iron (mg/l)	0.02	0.00	0.00
Manganese (mg/l)	0.010	0.060	0.020
Carbonate (mg/l)	0.0	0.0	0.0
Fluoride (mg/l)	0.2	0.2	0.2
Total Coliform (colonies/100 ml)	-	-	2.
Fecal Coliform (colonies/100 ml)	-	-	2.
Arsenic (μg/l)	-	-	-
Barium (μg/l)	-	-	-
Cadmium (μg/l)	-	-	-
Chromium (μg/l)	-	-	-
Copper (μg/l)	-	-	-
Lead (μg/l)	-	-	-
Selenium (μg/l)	-	-	-
Zinc (μg/l)	-	-	-

McVILLE - WELL 2 (Continued)

Parameter	4/25/82	7/27/82
Water Level (ft)	85.33	85.23
pH	6.9	6.8
Field Conductivity (μmhos/cm)	-	650.
Lab Conductivity (μmhos/cm)	541.	564.
Dissolved Oxygen (mg/l)	6.5	3.8
Total Dissolved Solids (mg/l)	291.	306.
Total Alkalinity (mg/l)	205.	199.
Total Hardness (mg/l)	256.	259.
Ammonia (N) (mg/l)	0.069	0.022
Nitrate (N) (mg/l)	10.0	8.31
Dissolved Phosphorous (mg/l)	0.052	0.049
Calcium (mg/l)	68.0	70.0
Magnesium (mg/l)	21.0	20.5
Sodium (mg/l)	15.0	15.5
Potassium (mg/l)	2.05	2.30
Bicarbonate (mg/l)	251.	243.
Chloride (mg/l)	2.5	1.0
Sulfate (mg/l)	49.	56.
Iron (mg/l)	0.05	-
Manganese (mg/l)	0.020	-
Carbonate (mg/l)	0.0	0.0
Fluoride (mg/l)	0.2	-
Total Coliform (colonies/100 ml)	2.	280.
Fecal Coliform (colonies/100 ml)	2.	180.
Arsenic (μg/l)	-	-
Barium (μg/l)	-	-
Cadmium (μg/l)	-	-
Chromium (μg/l)	-	-
Copper (μg/l)	-	-
Lead (μg/l)	-	-
Selenium (μg/l)	-	-
Zinc (μg/l)	-	-

McVILLE - WELL 3

Parameter	10/2/80	8/26/81	10/25/81
Water Level (ft)	80.97	82.82	82.56
pH	6.8	7.4	6.9
Field Conductivity (μmhos/cm)	1800.	-	-
Lab Conductivity (μmhos/cm)	1316.	1220.	1130.
Dissolved Oxygen (mg/l)	0.0	0.7	2.0
Total Dissolved Solids (mg/l)	715.	729.	666.
Total Alkalinity (mg/l)	368.	455.	357.
Total Hardness (mg/l)	312.	296.	213.
Ammonia (N) (mg/l)	-	2.52	4.52
Nitrate (N) (mg/l)	0.475	0.433	0.455
Dissolved Phosphorous (mg/l)	-	0.187	0.270
Calcium (mg/l)	97.0	90.5	65.0
Magnesium (mg/l)	17.0	17.0	12.5
Sodium (mg/l)	175.	199.	167.
Potassium (mg/l)	13.5	15.1	17.3
Bicarbonate (mg/l)	450.	556.	437.
Chloride (mg/l)	170.	125.	175.
Sulfate (mg/l)	20.	9.	13.
Iron (mg/l)	0.04	0.05	0.03
Manganese (mg/l)	2.28	3.28	2.68
Carbonate (mg/l)	0.0	0.0	0.0
Fluoride (mg/l)	2.1	1.8	2.2
Total Coliform (colonies/100 ml)	-	-	2.
Fecal Coliform (colonies/100 ml)	-	-	2.
Arsenic (μg/l)	-	-	-
Barium (μg/l)	-	-	-
Cadmium (μg/l)	-	-	-
Chromium (μg/l)	-	-	-
Copper (μg/l)	-	-	-
Lead (μg/l)	-	-	-
Selenium (μg/l)	-	-	-
Zinc (μg/l)	-	-	-

McVILLE - WELL 3 (Continued)

Parameter	4/25/82	7/27/82
Water Level (ft)	83.12	82.95
pH	6.9	6.6
Field Conductivity (μmhos/cm)	-	1400.
Lab Conductivity (μmhos/cm)	1373.	1202.
Dissolved Oxygen (mg/l)	3.2	1.6
Total Dissolved Solids (mg/l)	784.	639.
Total Alkalinity (mg/l)	422.	429.
Total Hardness (mg/l)	329.	253.
Ammonia (N) (mg/l)	1.79	3.10
Nitrate (N) (mg/l)	4.46	0.090
Dissolved Phosphorous (mg/l)	0.091	0.090
Calcium (mg/l)	100.	77.5
Magnesium (mg/l)	19.0	14.5
Sodium (mg/l)	175.	166.
Potassium (mg/l)	13.6	13.5
Bicarbonate (mg/l)	516.	524.
Chloride (mg/l)	100.	100.
Sulfate (mg/l)	117.	10.
Iron (mg/l)	0.05	-
Manganese (mg/l)	2.90	-
Carbonate (mg/l)	0.0	0.0
Fluoride (mg/l)	2.1	-
Total Coliform (colonies/100 ml)	8.	27.
Fecal Coliform (colonies/100 ml)	2.	9.
Arsenic (μg/l)	-	-
Barium (μg/l)	-	-
Cadmium (μg/l)	-	-
Chromium (μg/l)	-	-
Copper (μg/l)	-	-
Lead (μg/l)	-	-
Selenium (μg/l)	-	-
Zinc (μg/l)	-	-

McVILLE - WELL 4

Parameter	10/12/80	8/26/81	10/25/81
Water Level (ft)	81.37	83.21	82.98
pH	6.6	6.9	6.6
Field Conductivity (μmhos/cm)	1800.	-	-
Lab Conductivity (μmhos/cm)	1206.	1090.	1160.
Dissolved Oxygen (mg/l)	0.0	0.4	1.0
Total Dissolved Solids (mg/l)	671.	643.	655.
Total Alkalinity (mg/l)	386.	378.	378.
Total Hardness (mg/l)	258.	261.	242.
Ammonia (N) (mg/l)	-	3.37	3.25
Nitrate (N) (mg/l)	0.259	0.106	1.55
Dissolved Phosphorous (mg/l)	-	2.64	1.63
Calcium (mg/l)	71.5	74.0	67.5
Magnesium (mg/l)	19.5	18.5	18.0
Sodium (mg/l)	181.	177.	172.
Potassium (mg/l)	7.00	6.75	7.35
Bicarbonate (mg/l)	472.	462.	462.
Chloride (mg/l)	145.	130.	150.
Sulfate (mg/l)	15.	9.	11.
Iron (mg/l)	11.0	13.9	13.5
Manganese (mg/l)	6.90	7.24	8.69
Carbonate (mg/l)	0.00	0.00	0.00
Fluoride (mg/l)	4.1	5.1	5.0
Total Coliform (colonies/100 ml)	-	-	2.
Fecal Coliform (colonies/100 ml)	-	-	2.
Arsenic (μg/l)	-	-	22.6
Barium (μg/l)	-	-	70.
Cadmium (μg/l)	-	-	1.3
Chromium (μg/l)	-	-	6.9
Copper (μg/l)	-	-	90.
Lead (μg/l)	-	-	12.1
Selenium (μg/l)	-	-	0.2
Zinc (μg/l)	-	-	48.

McVILLE - WELL 4 (Continued)

Parameter	4/25/82	7/27/82
Water Level (ft)	83.54	83.40
pH	6.6	6.4
Field Conductivity (μmhos/cm)	-	1700.
Lab Conductivity (μmhos/cm)	1279.	1358.
Dissolved Oxygen (mg/l)	2.0	0.3
Total Dissolved Solids (mg/l)	691.	702.
Total Alkalinity (mg/l)	381.	377.
Total Hardness (mg/l)	278.	275.
Ammonia (N) (mg/l)	2.18	1.64
Nitrate (N) (mg/l)	0.083	0.039
Dissolved Phosphorous (mg/l)	0.891	4.37
Calcium (mg/l)	78.5	80.5
Magnesium (mg/l)	20.0	18.0
Sodium (mg/l)	170.	190.
Potassium (mg/l)	7.95	9.3
Bicarbonate (mg/l)	466.	461.
Chloride (mg/l)	150.	170.
Sulfate (mg/l)	35.	8.
Iron (mg/l)	12.9	-
Manganese (mg/l)	8.33	-
Carbonate (mg/l)	0.0	0.0
Fluoride (mg/l)	4.0	-
Total Coliform (colonies/100 ml)	49.	49.
Fecal Coliform (colonies/100 ml)	2.	14.
Arsenic (μg/l)	19.0	-
Barium (μg/l)	230.	-
Cadmium (μg/l)	2.1	-
Chromium (μg/l)	7.2	-
Copper (μg/l)	161.	-
Lead (μg/l)	25.9	-
Selenium (μg/l)	0.4	-
Zinc (μg/l)	47.	-

McVILLE - WELL 5

Parameter	10/12/80	8/26/81	10/25/81
Water Level (ft)	81.47	83.09	82.82
pH	6.5	7.1	6.6
Field Conductivity (μmhos/cm)	1900.	-	-
Lab Conductivity (μmhos/cm)	1368.	1390.	1660.
Dissolved Oxygen (mg/l)	2.0	2.0	3.0
Total Dissolved Solids (mg/l)	771.	860.	1040.
Total Alkalinity (mg/l)	375.	345.	391.
Total Hardness (mg/l)	676.	530.	710.
Ammonia (N) (mg/l)	-	0.346	0.232
Nitrate (N) (mg/l)	22.9	27.1	29.8
Dissolved Phosphorous (mg/l)	-	0.256	0.306
Calcium (mg/l)	190.	149.	197.
Magnesium (mg/l)	49.0	38.5	53.0
Sodium (mg/l)	64.0	155.	124.
Potassium (mg/l)	6.95	10.7	8.75
Bicarbonate (mg/l)	549.	422.	478.
Chloride (mg/l)	85.	125.	150.
Sulfate (mg/l)	127.	147.	244.
Iron (mg/l)	0.06	0.01	0.28
Manganese (mg/l)	0.140	0.150	0.030
Carbonate (mg/l)	0.0	0.0	0.0
Fluoride (mg/l)	0.2	0.1	0.1
Total Coliform (colonies/100 ml)	-	-	5.
Fecal Coliform (colonies/100 ml)	-	-	2.
Arsenic (μg/l)	-	-	-
Barium (μg/l)	-	-	-
Cadmium (μg/l)	-	-	-
Chromium (μg/l)	-	-	-
Copper (μg/l)	-	-	-
Lead (μg/l)	-	-	-
Selenium (μg/l)	-	-	-
Zinc (μg/l)	-	-	-

McVILLE - WELL 5 (Continued)

Parameter	4/25/82	7/27/82
Water Level (ft)	83.32	83.24
pH	6.8	6.7
Field Conductivity (μmhos/cm)	-	1500.
Lab Conductivity (μmhos/cm)	1602.	1537.
Dissolved Oxygen (mg/l)	3.4	1.4
Total Dissolved Solids (mg/l)	901.	808.
Total Alkalinity (mg/l)	373.	365.
Total Hardness (mg/l)	491.	422.
Ammonia (N) (mg/l)	0.150	0.116
Nitrate (N) (mg/l)	22.3	9.57
Dissolved Phosphorous (mg/l)	0.143	0.078
Calcium (mg/l)	137.	119.
Magnesium (mg/l)	36.0	30.0
Sodium (mg/l)	165.	167.
Potassium (mg/l)	10.9	10.5
Bicarbonate (mg/l)	456.	446.
Chloride (mg/l)	150.	150.
Sulfate (mg/l)	155.	102.
Iron (mg/l)	0.37	-
Manganese (mg/l)	0.250	-
Carbonate (mg/l)	0.0	0.0
Fluoride (mg/l)	0.2	-
Total Coliform (colonies/100 ml)	170.	350.
Fecal Coliform (colonies/100 ml)	14.	9.
Arsenic (μg/l)	-	-
Barium (μg/l)	-	-
Cadmium (μg/l)	-	-
Chromium (μg/l)	-	-
Copper (μg/l)	-	-
Lead (μg/l)	-	-
Selenium (μg/l)	-	-
Zinc (μg/l)	-	-

McVILLE - WELL 6

Parameter	10/12/80	8/26/81	10/25/81
Water Level (ft)	79.38	81.19	80.99
pH	6.9	7.3	6.8
Field Conductivity (μmhos/cm)	2000.	-	-
Lab Conductivity (μmhos/cm)	1535.	1340.	1430.
Dissolved Oxygen (mg/l)	0.4	0.4	2.0
Total Dissolved Solids (mg/l)	758.	720.	773.
Total Alkalinity (mg/l)	393.	361.	383.
Total Hardness (mg/l)	450.	396.	397.
Ammonia (N) (mg/l)	-	31.5	30.2
Nitrate (N) (mg/l)	0.721	0.444	1.65
Dissolved Phosphorous (mg/l)	-	0.084	0.066
Calcium (mg/l)	130.	112.	110.
Magnesium (mg/l)	30.5	28.0	29.5
Sodium (mg/l)	96.0	115.	114.
Potassium (mg/l)	19.9	18.8	16.6
Bicarbonate (mg/l)	481.	442.	468.
Chloride (mg/l)	138.	130.	175.
Sulfate (mg/l)	106.	97.	95.
Iron (mg/l)	0.34	3.58	1.23
Manganese (mg/l)	9.20	7.93	6.83
Carbonate (mg/l)	0.0	0.0	0.0
Fluoride (mg/l)	1.0	1.2	1.1
Total Coliform (colonies/100 ml)	-	-	11.
Fecal Coliform (colonies/100 ml)	-	-	2.
Arsenic (μg/l)	-	-	-
Barium (μg/l)	-	-	-
Cadmium (μg/l)	-	-	-
Chromium (μg/l)	-	-	-
Copper (μg/l)	-	-	-
Lead (μg/l)	-	-	-
Selenium (μg/l)	-	-	-
Zinc (μg/l)	-	-	-

McVILLE - WELL 6 (Continued)

Parameter	4/25/82	7/27/82
Water Level (ft)	81.55	81.35
pH	6.9	6.8
Field Conductivity (μmhos/cm)	-	1980.
Lab Conductivity (μmhos/cm)	1383.	1505.
Dissolved Oxygen (mg/l)	3.3	0.8
Total Dissolved Solids (mg/l)	716.	825.
Total Alkalinity (mg/l)	398.	418.
Total Hardness (mg/l)	344.	374.
Ammonia (N) (mg/l)	20.5	25.9
Nitrate (N) (mg/l)	0.083	0.101
Dissolved Phosphorous (mg/l)	0.023	0.023
Calcium (mg/l)	96.0	105.
Magnesium (mg/l)	25.5	27.0
Sodium (mg/l)	117.	130.
Potassium (mg/l)	15.9	18.0
Bicarbonate (mg/l)	486.	511.
Chloride (mg/l)	125.	160.
Sulfate (mg/l)	98.	133.
Iron (mg/l)	2.55	0.14
Manganese (mg/l)	5.72	6.53
Carbonate (mg/l)	0.0	0.0
Fluoride (mg/l)	1.1	1.2
Total Coliform (colonies/100 ml)	49.	220.
Fecal Coliform (colonies/100 ml)	4.	33.
Arsenic (μg/l)	-	-
Barium (μg/l)	-	-
Cadmium (μg/l)	-	-
Chromium (μg/l)	-	-
Copper (μg/l)	-	-
Lead (μg/l)	-	-
Selenium (μg/l)	-	-
Zinc (μg/l)	-	-

McVILLE - WELL 7

Parameter	8/26/81	10/25/81	4/25/82	7/27/82
Water Level (ft)	83.09	83.45	83.94	83.77
pH	7.1	6.8	6.7	6.6
Field Conductivity (μmhos/cm)	-	-	-	1750.
Lab Conductivity (μmhos/cm)	1260.	1240.	1342.	1449.
Dissolved Oxygen (mg/l)	0.3	0.7	1.2	1.2
Total Dissolved Solids (mg/l)	735.	683.	707.	736.
Total Alkalinity (mg/l)	440.	443.	414.	399.
Total Hardness (mg/l)	322.	290.	282.	298.
Ammonia (N) (mg/l)	5.60	4.90	4.58	8.17
Nitrate (N) (mg/l)	0.188	0.061	0.593	0.115
Dissolved Phosphorous (mg/l)	0.828	0.216	0.101	0.053
Calcium (mg/l)	90.5	80.	77.5	81.5
Magnesium (mg/l)	23.5	22.0	21.5	23.0
Sodium (mg/l)	194.	172.	179.	194.
Potassium (mg/l)	-	7.05	7.95	8.55
Bicarbonate (mg/l)	538.	542.	506.	488.
Chloride (mg/l)	140.	125.	150.	180.
Sulfate (mg/l)	15.	9.	21.	9.
Iron (mg/l)	11.3	1.84	4.51	-
Manganese (mg/l)	7.76	6.06	4.51	-
Carbonate (mg/l)	0.0	0.0	0.0	0.0
Fluoride (mg/l)	4.6	5.0	5.0	-
Total Coliform (colonies/100 ml)	-	540.	170.	70.
Fecal Coliform (colonies/100 ml)	-	170.	14.	5.
Arsenic (μg/l)	-	-	-	-
Barium (μg/l)	-	-	-	-
Cadmium (μg/l)	-	-	-	-
Chromium (μg/l)	-	-	-	-
Copper (μg/l)	-	-	-	-
Lead (μg/l)	-	-	-	-
Selenium (μg/l)	-	-	-	-
Zinc (μg/l)	-	-	-	-

McVILLE - WELL 8

Parameter	8/26/81	10/25/81	4/25/82	7/27/82
Water Level (ft)	81.44	81.24	81.70	81.60
pH	7.3	6.8	6.9	6.7
Field Conductivity (μmhos/cm)	-	-	-	-
Lab Conductivity (μmhos/cm)	1330.	1430.	1425.	1438.
Dissolved Oxygen (mg/l)	0.3	1.8	1.9	0.5
Total Dissolved Solids (mg/l)	724.	796.	755.	706.
Total Alkalinity (mg/l)	393.	425.	470.	394.
Total Hardness (mg/l)	358.	387.	308.	266.
Ammonia (N) (mg/l)	25.2	26.9	17.6	19.6
Nitrate (N) (mg/l)	0.150	0.190	0.496	0.035
Dissolved Phosphorous (mg/l)	0.087	0.057	0.013	0.032
Calcium (mg/l)	101.	110.	86.5	74.5
Magnesium (mg/l)	25.5	27.0	22.5	19.5
Sodium (mg/l)	140.	138.	155.	165.
Potassium (mg/l)	18.6	16.1	16.8	15.1
Bicarbonate (mg/l)	481.	520.	575.	482.
Chloride (mg/l)	125.	200.	150.	160.
Sulfate (mg/l)	76.	49.	41.	35.
Iron (mg/l)	2.69	0.78	10.0	4.46
Manganese (mg/l)	11.0	9.13	3.30	1.72
Carbonate (mg/l)	0.0	0.0	0.0	0.0
Fluoride (mg/l)	1.7	1.7	2.0	2.0
Total Coliform (colonies/100 ml)	-	2400.	23.	1600.
Fecal Coliform (colonies/100 ml)	-	5.	2.	220.
Arsenic (μg/l)	-	-	-	-
Barium (μg/l)	-	-	-	-
Cadmium (μg/l)	-	-	-	-
Chromium (μg/l)	-	-	-	-
Copper (μg/l)	-	-	-	-
Lead (μg/l)	-	-	-	-
Selenium (μg/l)	-	-	-	-
Zinc (μg/l)	-	-	-	-

McVILLE - NEW WELLS SAMPLED ONLY ONCE (7/27/82)

Parameter	Well 9	Well 10	Well 11
Water Level (ft)	81.95	80.46	78.73
pH	6.6	6.6	6.7
Field Conductivity (μmhos/cm)	600.	1400.	1600.
Lab Conductivity (μmhos/cm)	637.	1162.	1455.
Dissolved Oxygen (mg/l)	1.5	1.7	1.5
Total Dissolved Solids (mg/l)	392.	574.	840.
Total Alkalinity (mg/l)	221.	307.	297.
Total Hardness (mg/l)	283.	479.	530.
Ammonia (N) (mg/l)	0.260	0.322	0.043
Nitrate (N) (mg/l)	8.16	3.30	0.374
Dissolved Phosphorous (mg/l)	0.028	0.044	0.047
Calcium (mg/l)	76.5	132.	146.
Magnesium (mg/l)	22.5	36.0	40.0
Sodium (mg/l)	21.5	47.5	100.
Potassium (mg/l)	3.00	5.90	7.00
Bicarbonate (mg/l)	270.	375.	363.
Chloride (mg/l)	50.0	80.0	170.
Sulfate (mg/l)	78.	85.	198.
Iron (mg/l)	0.03	0.03	0.02
Manganese (mg/l)	0.140	3.62	0.840
Carbonate (mg/l)	0.0	0.0	0.0
Fluoride (mg/l)	0.2	0.5	1.5
Total Coliform (colonies/100 ml)	22.	70.	920.
Fecal Coliform (colonies/100 ml)	2.	49.	43.
Arsenic (μg/l)	-	-	-
Barium (μg/l)	-	-	-
Cadmium (μg/l)	-	-	-
Chromium (μg/l)	-	-	-
Copper (μg/l)	-	-	-
Lead (μg/l)	-	-	-
Selenium (μg/l)	-	-	-
Zinc (μg/l)	-	-	-

MCVILLE - NEW WELLS SAMPLED ONLY ONCE (7/27/82)

Parameter	Well 12	Well 13	Well 14
Water Level (ft)	79.24	80.55	82.24
pH	6.8	6.8	6.5
Field Conductivity (μmhos/cm)	1800.	2000.	1800.
Lab Conductivity (μmhos/cm)	1444.	1566.	1738.
Dissolved Oxygen (mg/l)	1.5	1.5	0.4
Total Dissolved Solids (mg/l)	848.	798.	838.
Total Alkalinity (mg/l)	413.	426.	453.
Total Hardness (mg/l)	441.	306.	386.
Ammonia (N) (mg/l)	0.033	31.0	43.2
Nitrate (N) (mg/l)	0.261	0.044	0.304
Dissolved Phosphorous (mg/l)	0.056	0.045	0.023
Calcium (mg/l)	130.	90.5	107.
Magnesium (mg/l)	28.0	19.5	28.5
Sodium (mg/l)	145.	137.	132.
Potassium (mg/l)	8.70	39.0	28.6
Bicarbonate (mg/l)	505.	520.	554.
Chloride (mg/l)	150.	232.	150.
Sulfate (mg/l)	137.	24.	119.
Iron (mg/l)	0.02	0.02	11.9
Manganese (mg/l)	1.72	2.06	3.65
Carbonate (mg/l)	0.0	0.0	0.0
Fluoride (mg/l)	0.1	1.4	1.2
Total Coliform (colonies/100 ml)	2400.	920.	130.
Fecal Coliform (colonies/100 ml)	63.	70.	5.
Arsenic (μg/l)	-	-	-
Barium (μg/l)	-	-	-
Cadmium (μg/l)	-	-	-
Chromium (μg/l)	-	-	-
Copper (μg/l)	-	-	-
Lead (μg/l)	-	-	-
Selenium (μg/l)	-	-	-
Zinc (μg/l)	-	-	-

McVILLE - LAGOON

Parameter	10/12/80	8/26/81	10/25/81
Water Level (ft)	-	-	-
pH	7.5	8.2	8.2
Field Conductivity (μmhos/cm)	650.	-	-
Lab Conductivity (μmhos/cm)	1403.	1120.	1220.
Dissolved Oxygen (mg/l)	-	7.0	-
Total Dissolved Solids (mg/l)	743.	-	713.
Total Alkalinity (mg/l)	309.	282.	303.
Total Hardness (mg/l)	269.	253.	244.
Ammonia (N) (mg/l)	-	6.20	8.21
Nitrate (N) (mg/l)	0.518	0.034	0.252
Dissolved Phosphorous (mg/l)	-	3.69	4.52
Calcium (mg/l)	78.0	69.5	67.5
Magnesium (mg/l)	18.0	19.5	18.5
Sodium (mg/l)	205.	176.	179.
Potassium (mg/l)	12.6	11.4	10.2
Bicarbonate (mg/l)	331.	345.	370.
Chloride (mg/l)	155.	125.	175.
Sulfate (mg/l)	88.	83.	81.
Iron (mg/l)	0.04	0.05	0.02
Manganese (mg/l)	0.220	0.380	0.050
Carbonate (mg/l)	23.	0.0	0.0
Fluoride (mg/l)	2.6	2.5	2.6
Total Coliform (colonies/100 ml)	-	-	2400.
Fecal Coliform (colonies/100 ml)	-	-	2400.
Arsenic (μg/l)	-	-	-
Barium (μg/l)	-	-	-
Cadmium (μg/l)	-	-	-
Chromium (μg/l)	-	-	-
Copper (μg/l)	-	-	-
Lead (μg/l)	-	-	-
Selenium (μg/l)	-	-	-
Zinc (μg/l)	-	-	-

McVILLE - LAGOON (Continued)

Parameter	4/25/82	7/27/82
Water Level (ft)	-	-
pH	7.2	8.1
Field Conductivity (μmhos/cm) -	1500.	
Lab Conductivity (μmhos/cm)	937.	1234.
Dissolved Oxygen (mg/l)	2.0	-
Total Dissolved Solids (mg/l)	473.	632.
Total Alkalinity (mg/l)	245.	261.
Total Hardness (mg/l)	166.	216.
Ammonia (N) (mg/l)	13.4	0.328
Nitrate (N) (mg/l)	0.034	0.042
Dissolved Phosphorous (mg/l)	3.96	3.09
Calcium (mg/l)	47.0	61.0
Magnesium (mg/l)	12.0	15.5
Sodium (mg/l)	112.	161.
Potassium (mg/l)	8.30	11.6
Bicarbonate (mg/l)	300.	319.
Chloride (mg/l)	100.	150.
Sulfate (mg/l)	46.	76.
Iron (mg/l)	0.13	0.05
Manganese (mg/l)	0.190	0.100
Carbonate (mg/l)	0.0	0.0
Fluoride (mg/l)	1.9	2.4
Total Coliform (colonies/100 ml)	2400.	-
Fecal Coliform (colonies/100 ml)	2400.	2400.
Arsenic (μg/l)	-	-
Barium (μg/l)	-	-
Cadmium (μg/l)	-	-
Chromium (μg/l)	-	-
Copper (μg/l)	-	-
Lead (μg/l)	-	-
Selenium (μg/l)	-	-
Zinc (μg/l)	-	-

McVILLE - FARM WELL

Parameter	10/12/80	4/25/82	7/27/82
Water Level (ft)	-	-	-
pH	7.0	6.8	-
Field Conductivity (µmhos/cm)	1800.	-	-
Lab Conductivity (µmhos/cm)	529.	472.	533.
Dissolved Oxygen (mg/l)	13.0	-	-
Total Dissolved Solids (mg/l)	302.	237.	302.
Total Alkalinity (mg/l)	220.	207.	217.
Total Hardness (mg/l)	244.	217.	235.
Ammonia (N) (mg/l)	-	0.127	0.112
Nitrate (N) (mg/l)	0.191	0.063	0.032
Dissolved Phosphorous (mg/l)	-	0.020	0.044
Calcium (mg/l)	70.5	61.5	68.0
Magnesium (mg/l)	16.5	15.5	16.0
Sodium (mg/l)	17.5	19.0	21.5
Potassium (mg/l)	1.75	2.20	2.15
Bicarbonate (mg/l)	269.	253.	265.
Chloride (mg/l)	3.0	5.00	0.00
Sulfate (mg/l)	61.	10.0	64.
Iron (mg/l)	1.12	0.55	0.26
Manganese (mg/l)	0.810	0.670	0.720
Carbonate (mg/l)	0.0	0.0	0.0
Fluoride (mg/l)	0.1	0.2	0.2
Total Coliform (colonies/100 ml)	-	-	-
Fecal Coliform (colonies/100 ml)	-	-	-
Arsenic (µg/l)	-	-	-
Barium (µg/l)	-	-	-
Cadmium (µg/l)	-	-	-
Chromium (µg/l)	-	-	-
Copper (µg/l)	-	-	-
Lead (µg/l)	-	-	-
Selenium (µg/l)	-	-	-
Zinc (µg/l)	-	-	-

LARIMORE - WELL 1

Parameter	8/2/81	10/21/81	4/21/82	8/10/82
Water Level (ft)	92.68	93.24	93.63	92.23
pH	7.0	6.7	6.5	6.7
Field Conductivity (μmhos/cm)	-	-	-	1270.
Lab Conductivity (μmhos/cm)	1320.	1330.	1617.	1052.
Dissolved Oxygen (mg/l)	0.3	0.8	2.0	0.7
Total Dissolved Solids (mg/l)	809.	853.	921.	541.
Total Alkalinity (mg/l)	449.	502.	504.	324.
Total Hardness (mg/l)	399.	455.	541.	269.
Ammonia (N) (mg/l)	6.75	7.39	7.32	5.28
Nitrate (N) (mg/l)	0.052	0.255	0.532	0.047
Dissolved Phosphorous (mg/l)	0.076	0.059	0.520	1.34
Calcium (mg/l)	104.	120.	144.	71.5
Magnesium (mg/l)	34.0	37.5	44.0	22.0
Sodium (mg/l)	125.	126.	148.	95.0
Potassium (mg/l)	13.0	12.2	13.0	8.00
Bicarbonate (mg/l)	549.	614.	616.	395.
Chloride (mg/l)	210.	200.	175.	100.
Sulfate (mg/l)	52.	54.	93.	50.
Iron (mg/l)	0.68	3.36	7.44	2.11
Manganese (mg/l)	10.1	9.99	10.2	5.05
Carbonate (mg/l)	0.0	0.0	0.0	0.0
Fluoride (mg/l)	0.6	0.5	0.5	0.6
Total Coliform (colonies/100 ml)	-	12.	2.	33.
Fecal Coliform (colonies/100 ml)	290.	2.	2.	2.
Arsenic (μg/l)	61.	58.8	93.1	-
Barium (μg/l)	870.	410.	500.	-
Cadmium (μg/l)	4.5	2.8	1.7	-
Chromium (μg/l)	17.5	2.6	7.8	-
Copper (μg/l)	23.0	4.3	19.1	-
Lead (μg/l)	14.0	4.7	5.7	-
Selenium (μg/l)	0.0	0.1	0.3	-
Zinc (μg/l)	181.	78.	27.	-

LARIMORE - WELL 2

Parameter	8/2/81	10/21/81	4/21/82	8/10/82
Water Level (ft)	93.67	94.03	94.55	93.01
pH	7.3	6.7	6.8	6.7
Field Conductivity (μmhos/cm)	-	-	-	1860.
Lab Conductivity (μmhos/cm)	1470.	1330.	1589.	1628.
Dissolved Oxygen (mg/l)	0.4	1.6	3.0	1.6
Total Dissolved Solids (mg/l)	908.	797.	938.	922.
Total Alkalinity (mg/l)	366.	316.	418.	309.
Total Hardness (mg/l)	465.	435.	498.	477.
Ammonia (N) (mg/l)	1.35	1.67	1.57	1.30
Nitrate (N) (mg/l)	0.110	0.077	0.030	0.024
Dissolved Phosphorous (mg/l)	0.074	0.089	0.107	0.032
Calcium (mg/l)	129.	121.	137.	132.
Magnesium (mg/l)	34.5	32.0	37.5	36.0
Sodium (mg/l)	143.	144.	182.	146.
Potassium (mg/l)	9.20	7.80	7.8	5.95
Bicarbonate (mg/l)	447.	387.	511.	377.
Chloride (mg/l)	240.	150.	175.	175.
Sulfate (mg/l)	132.	151.	146.	241.
Iron (mg/l)	0.62	0.64	0.42	0.09
Manganese (mg/l)	6.39	5.93	6.31	5.34
Carbonate (mg/l)	0.0	0.0	0.0	0.0
Fluoride (mg/l)	0.8	0.8	0.7	0.8
Total Coliform (colonies/100 ml)	10.	280.	2.	49.
Fecal Coliform (colonies/100 ml)	10.	2.	2.	2.
Arsenic (μg/l)	-	-	-	-
Barium (μg/l)	-	-	-	-
Cadmium (μg/l)	-	-	-	-
Chromium (μg/l)	-	-	-	-
Copper (μg/l)	-	-	-	-
Lead (μg/l)	-	-	-	-
Selenium (μg/l)	-	-	-	-
Zinc (μg/l)	-	-	-	-

LARIMORE - WELL 3

Parameter	8/2/81	10/21/81	4/21/82	8/10/82
Water Level (ft)	94.37	94.88	95.18	93.85
pH	7.5	6.9	6.8	6.7
Field Conductivity (μmhos/cm)	-	-	-	690.
Lab Conductivity (μmhos/cm)	623.	597.	616.	773.
Dissolved Oxygen (mg/l)	1.2	3.6	5.2	4.7
Total Dissolved Solids (mg/l)	425.	374.	374.	427.
Total Alkalinity (mg/l)	281.	307.	288.	356.
Total Hardness (mg/l)	325.	352.	334.	392.
Ammonia (N) (mg/l)	0.264	0.281	0.066	0.054
Nitrate (N) (mg/l)	0.204	0.162	0.024	0.035
Dissolved Phosphorous (mg/l)	0.076	0.063	0.064	0.016
Calcium (mg/l)	85.0	90.	84.5	99.0
Magnesium (mg/l)	27.5	31.0	30.0	35.0
Sodium (mg/l)	17.0	7.50	10.0	4.00
Potassium (mg/l)	7.5	2.10	1.80	2.00
Bicarbonate (mg/l)	344.	375.	352.	434.
Chloride (mg/l)	75.	10.	10.0	13.0
Sulfate (mg/l)	49.	49.	65.	60.
Iron (mg/l)	0.23	0.06	0.04	0.00
Manganese (mg/l)	2.09	0.910	0.360	0.390
Carbonate (mg/l)	0.0	0.0	0.0	0.0
Fluoride (mg/l)	0.7	0.6	0.5	0.6
Total Coliform (colonies/100 ml)	10.	2.	2.	79.
Fecal Coliform (colonies/100 ml)	10.	2.	2.	2.
Arsenic (μg/l)	45.	-	16.3	-
Barium (μg/l)	1260.	-	250.	-
Cadmium (μg/l)	175.	-	1.3	-
Chromium (μg/l)	24.2	-	21.0	-
Copper (μg/l)	98.0	-	30.5	-
Lead (μg/l)	64.	-	19.2	-
Selenium (μg/l)	0.0	-	6.0	-
Zinc (μg/l)	238.	-	48.	-

LARIMORE - WELL 4

Parameter	8/2/81	10/21/81	4/21/82	8/10/82
Water Level (ft)	92.57	93.16	93.42	92.46
pH	7.4	6.6	6.7	6.8
Field Conductivity (μmhos/cm)	-	-	-	1370.
Lab Conductivity (μmhos/cm)	1510.	1510.	1810.	1554.
Dissolved Oxygen (mg/l)	0.5	1.0	3.0	0.6
Total Dissolved Solids (mg/l)	914.	924.	1090.	834.
Total Alkalinity (mg/l)	459.	589.	543.	459.
Total Hardness (mg/l)	487.	490.	597.	424.
Ammonia (N) (mg/l)	1.13	0.674	0.245	0.253
Nitrate (N) (mg/l)	0.234	0.055	0.051	0.042
Dissolved Phosphorous (mg/l)	0.054	0.038	0.008	0.009
Calcium (mg/l)	108.	115.	143.	102.
Magnesium (mg/l)	52.5	49.0	58.0	41.0
Sodium (mg/l)	153.	188.	204.	154.
Potassium (mg/l)	15.1	12.9	9.20	8.20
Bicarbonate (mg/l)	561.	720.	664.	560.
Chloride (mg/l)	200.	175.	200.	150.
Sulfate (mg/l)	108.	29.	156.	102.
Iron (mg/l)	4.65	2.23	12.5	6.20
Manganese (mg/l)	2.14	2.76	2.99	1.87
Carbonate (mg/l)	0.0	0.0	0.0	0.0
Fluoride (mg/l)	1.1	0.9	0.5	0.7
Total Coliform (colonies/100 ml)	10.	17.	8.	9.
Fecal Coliform (colonies/100 ml)	10.	2.	2.	9.
Arsenic (μg/l)	-	-	-	-
Barium (μg/l)	-	-	-	-
Cadmium (μg/l)	-	-	-	-
Chromium (μg/l)	-	-	-	-
Copper (μg/l)	-	-	-	-
Lead (μg/l)	-	-	-	-
Selenium (μg/l)	-	-	-	-
Zinc (μg/l)	-	-	-	-

LARIMORE - WELL 5

Parameter	8/2/81	10/21/81	4/21/82	8/10/82
Water Level (ft)	93.16	93.75	94.08	93.05
pH	6.9	6.6	6.6	6.6
Field Conductivity (μmhos/cm)	-	-	-	1290.
Lab Conductivity (μmhos/cm)	1260.	1370.	1227.	1410.
Dissolved Oxygen (mg/l)	0.4	1.4	2.0	.5
Total Dissolved Solids (mg/l)	748.	811.	649.	718.
Total Alkalinity (mg/l)	376.	509.	367.	344.
Total Hardness (mg/l)	470.	528.	341.	505.
Ammonia (N) (mg/l)	0.436	0.398	0.369	11.8
Nitrate (N) (mg/l)	0.128	0.373	0.037	0.028
Dissolved Phosphorous (mg/l)	0.063	0.043	0.075	0.014
Calcium (mg/l)	128.	149.	97.0	142.
Magnesium (mg/l)	36.5	37.5	24.0	36.5
Sodium (mg/l)	11.0	122.	144.	76.5
Potassium (mg/l)	6.9	11.0	10.7	8.95
Bicarbonate (mg/l)	460.	622.	449.	420.
Chloride (mg/l)	240.	175.	150.	150.
Sulfate (mg/l)	14.	10.	3.	97.
Iron (mg/l)	3.15	4.91	3.48	11.6
Manganese (mg/l)	2.34	2.13	1.19	1.69
Carbonate (mg/l)	0.0	0.0	0.0	0.0
Fluoride (mg/l)	0.4	0.3	0.4	0.3
Total Coliform (colonies/100 ml)	110.	8.	2.	170.
Fecal Coliform (colonies/100 ml)	10.	2.	2.	7.
Arsenic (μg/l)	-	-	-	-
Barium (μg/l)	-	-	-	-
Cadmium (μg/l)	-	-	-	-
Chromium (μg/l)	-	-	-	-
Copper (μg/l)	-	-	-	-
Lead (μg/l)	-	-	-	-
Selenium (μg/l)	-	-	-	-
Zinc (μg/l)	-	-	-	-

LARIMORE - WELL 6

Parameter	8/2/81	10/21/81	4/21/82	8/10/82
Water Level (ft)	92.74	93.23	93.72	92.45
pH	7.1	6.9	6.7	6.7
Field Conductivity (μmhos/cm)	-	-	-	1450.
Lab Conductivity (μmhos/cm)	1300.	1230.	1311.	1466.
Dissolved Oxygen (mg/l)	0.3	0.6	2.2	1.2
Total Dissolved Solids (mg/l)	789.	721.	737.	793.
Total Alkalinity (mg/l)	352.	509.	434.	416.
Total Hardness (mg/l)	360.	372.	319.	365.
Ammonia (N) (mg/l)	8.08	9.59	11.3	0.09
Nitrate (N) (mg/l)	0.158	0.083	0.032	0.028
Dissolved Phosphorous (mg/l)	0.841	1.16	2.03	1.22
Calcium (mg/l)	106.	110.	96.5	112.
Magnesium (mg/l)	23.0	23.5	19.0	21.0
Sodium (mg/l)	142.	137.	178.	141.
Potassium (mg/l)	12.1	10.5	13.7	12.7
Bicarbonate (mg/l)	431.	622.	531.	507.
Chloride (mg/l)	195.	125.	150.	100.
Sulfate (mg/l)	98.	8.	18.	157.
Iron (mg/l)	0.92	0.15	0.39	1.23
Manganese (mg/l)	23.0	2.20	1.88	2.03
Carbonate (mg/l)	0.0	0.0	0.0	0.0
Fluoride (mg/l)	0.6	0.5	0.5	0.4
Total Coliform (colonies/100 ml)	1100.	2.	2.	920.
Fecal Coliform (colonies/100 ml)	10.	2.	2.	5.
Arsenic (μg/l)	-	-	-	-
Barium (μg/l)	-	-	-	-
Cadmium (μg/l)	-	-	-	-
Chromium (μg/l)	-	-	-	-
Copper (μg/l)	-	-	-	-
Lead (μg/l)	-	-	-	-
Selenium (μg/l)	-	-	-	-
Zinc (μg/l)	-	-	-	-

LARIMORE - WELL 7

Parameter	8/2/81	10/21/81	4/21/82	8/10/82
Water Level (ft)	94.24	94.83	94.76	94.25
pH	7.6	6.8	6.9	6.7
Field Conductivity (μmhos/cm)	-	-	-	840.
Lab Conductivity (μmhos/cm)	673.	648.	701.	746.
Dissolved Oxygen (mg/l)	0.3	2.4	2.7	1.6
Total Dissolved Solids (mg/l)	483.	415.	429.	419.
Total Alkalinity (mg/l)	246.	253.	249.	249.
Total Hardness (mg/l)	371.	382.	377.	368.
Ammonia (N) (mg/l)	0.240	0.096	0.053	0.088
Nitrate (N) (mg/l)	0.203	0.047	0.029	0.035
Dissolved Phosphorous (mg/l)	0.134	0.157	0.095	0.039
Calcium (mg/l)	102.	106.	104.	101.
Magnesium (mg/l)	28.0	28.5	28.5	28.0
Sodium (mg/l)	6.50	4.50	5.00	2.50
Potassium (mg/l)	2.70	1.95	2.40	2.05
Bicarbonate (mg/l)	301.	309.	305.	304.
Chloride (mg/l)	90.	25.	32.5	35.0
Sulfate (mg/l)	105.	97.	107.	101.
Iron (mg/l)	0.08	0.06	0.08	0.01
Manganese (mg/l)	2.58	1.66	0.650	1.78
Carbonate (mg/l)	0.0	0.0	0.0	0.0
Fluoride (mg/l)	0.4	0.4	0.4	0.01
Total Coliform (colonies/100 ml)	100.	2.	-	11.
Fecal Coliform (colonies/100 ml)	10.	2.	-	2.
Arsenic (μg/l)	-	6.6	-	-
Barium (μg/l)	-	130.	-	-
Cadmium (μg/l)	-	2.7	-	-
Chromium (μg/l)	-	5.0	-	-
Copper (μg/l)	-	70.0	-	-
Lead (μg/l)	-	11.1	-	-
Selenium (μg/l)	-	0.3	-	-
Zinc (μg/l)	-	53.	-	-

LARIMORE - LAGOON

Parameter	8/2/81	10/21/81	4/21/82	8/10/82
Water Level (ft)	-	-	-	-
pH	9.0	8.5	6.9	7.8
Field Conductivity (μmhos/cm)	-	-	-	1440.
Lab Conductivity (μmhos/cm)	1017.	1230.	837.	-
Dissolved Oxygen (mg/l)	14.5	-	2.6	-
Total Dissolved Solids (mg/l)	585.	729.	449.	697.
Total Alkalinity (mg/l)	97.	333.	243.	332.
Total Hardness (mg/l)	140.	357.	209.	320.
Ammonia (N) (mg/l)	0.150	9.39	12.5	8.09
Nitrate (N) (mg/l)	0.102	0.251	0.046	0.500
Dissolved Phosphorous (mg/l)	0.195	2.75	2.88	1.72
Calcium (mg/l)	40.5	102.	60.0	89.5
Magnesium (mg/l)	9.50	25.0	14.5	23.9
Sodium (mg/l)	147.	25.0	77.5	146.
Potassium (mg/l)	9.80	141.	8.40	11.0
Bicarbonate (mg/l)	-	407.	297.	405.
Chloride (mg/l)	215.	150.	85.0	150.
Sulfate (mg/l)	104.	99.	57.	77.
Iron (mg/l)	0.11	0.05	0.08	0.03
Manganese (mg/l)	0.04	0.820	0.930	0.740
Carbonate (mg/l)	58.	0.0	0.0	0.0
Fluoride (mg/l)	0.5	0.7	0.6	0.9
Total Coliform (colonies/100 ml)	-	-	2400.	2400.
Fecal Coliform (colonies/100 ml)	40.	-	2400.	2400.
Arsenic (μg/l)	-	-	-	-
Barium (μg/l)	-	-	-	-
Cadmium (μg/l)	-	-	-	-
Chromium (μg/l)	-	-	-	-
Copper (μg/l)	-	-	-	-
Lead (μg/l)	-	-	-	-
Selenium (μg/l)	-	-	-	-
Zinc (μg/l)	-	-	-	-

LARIMORE - FARM WELL

Parameter	4/21/82
Water Level (ft)	-
pH	6.8
Field Conductivity (μmhos/cm)	-
Lab Conductivity (μmhos/cm)	497.
Dissolved Oxygen (mg/l)	-
Total Dissolved Solids (mg/l)	303.
Total Alkalinity (mg/l)	201.
Total Hardness (mg/l)	268.
Ammonia (N) (mg/l)	0.014
Nitrate (N) (mg/l)	0.891
Dissolved Phosphorous (mg/l)	0.020
Calcium (mg/l)	75.5
Magnesium (mg/l)	19.5
Sodium (mg/l)	1.50
Potassium (mg/l)	2.15
Bicarbonate (mg/l)	246.
Chloride (mg/l)	0.00
Sulfate (mg/l)	83.
Iron (mg/l)	0.06
Manganese (mg/l)	0.150
Carbonate (mg/l)	0.0
Fluoride (mg/l)	0.4
Total Coliform (colonies/100 ml)	-
Fecal Coliform (colonies/100 ml)	-
Arsenic (μg/l)	-
Barium (μg/l)	-
Cadmium (μg/l)	-
Chromium (μg/l)	-
Copper (μg/l)	-
Lead (μg/l)	-
Selenium (μg/l)	-
Zinc (μg/l)	-

FORDVILLE - WELL 1

Parameter	8/4/81	10/25/81	4/20/82	8/17/82
Water Level (ft)	93.71	94.50	-	94.03
pH	7.6	6.9	-	6.5
Field Conductivity (μmhos/cm)	-	-	-	1400.
Lab Conductivity (μmhos/cm)	907.	889.	-	1067.
Dissolved Oxygen (mg/l)	0.7	1.8	-	1.6
Total Dissolved Solids (mg/l)	583.	568.	-	589.
Total Alkalinity (mg/l)	316.	375.	-	346.
Total Hardness (mg/l)	476.	468.	-	476.
Ammonia (N) (mg/l)	0.264	0.717	-	0.076
Nitrate (N) (mg/l)	0.285	0.263	-	0.145
Dissolved Phosphorous (mg/l)	0.131	0.490	-	0.122
Calcium (mg/l)	118.	110.	-	118.
Magnesium (mg/l)	44.0	47.0	-	44.0
Sodium (mg/l)	29.0	20.5	-	23.0
Potassium (mg/l)	4.80	3.20	-	3.15
Bicarbonate (mg/l)	386.	459.	-	422.
Chloride (mg/l)	45.	45.	-	100.
Sulfate (mg/l)	152.	116.	-	93.
Iron (mg/l)	0.98	0.06	-	0.87
Manganese (mg/l)	1.25	0.260	-	0.836
Carbonate (mg/l)	0.0	0.0	-	0.0
Fluoride (mg/l)	0.4	0.2	-	0.3
Total Coliform (colonies/100 ml)	10.	21.	-	13.
Fecal Coliform (colonies/100 ml)	10.	2.	-	2.
Arsenic (μg/l)	1.0	165.	-	-
Barium (μg/l)	1940.	7300.	-	-
Cadmium (μg/l)	29.8	12.2	-	-
Chromium (μg/l)	1.0	149.	-	-
Copper (μg/l)	4.1	490.	-	-
Lead (μg/l)	0.0	182.	-	-
Selenium (μg/l)	5.0	13.3	-	-
Zinc (μg/l)	578.	1290.	-	-

FORDVILLE - WELL 2

Parameter	8/4/81	10/25/81	4/20/82	8/17/82
Water Level (ft)	93.09	94.11	95.32	94.10
pH	7.2	6.9	6.6	6.6
Field Conductivity (µmhos/cm)	-	-	-	1090.
Lab Conductivity (µmhos/cm)	1043.	959.	1044.	1060.
Dissolved Oxygen (mg/l)	1.0	2.0	2.0	2.9
Total Dissolved Solids (mg/l)	587.	570.	557.	848.
Total Alkalinity (mg/l)	200.	204.	246.	277.
Total Hardness (mg/l)	402.	374.	394.	292.
Ammonia (N) (mg/l)	1.50	1.24	1.11	3.29
Nitrate (N) (mg/l)	0.088	0.034	0.146	0.040
Dissolved Phosphorous (mg/l)	0.117	0.112	0.271	0.066
Calcium (mg/l)	102.	94.5	101.	73.5
Magnesium (mg/l)	35.5	33.5	34.5	26.5
Sodium (mg/l)	6.20	59.0	65.5	77.0
Potassium (mg/l)	7.80	7.25	7.70	9.25
Bicarbonate (mg/l)	245.	250.	301.	338.
Chloride (mg/l)	125.	150.	100.	113.
Sulfate (mg/l)	133.	103.	100.	70.
Iron (mg/l)	0.15	0.01	0.06	0.05
Manganese (mg/l)	4.12	3.72	2.02	1.96
Carbonate (mg/l)	0.0	0.0	0.0	0.0
Fluoride (mg/l)	0.3	0.2	0.2	0.2
Total Coliform (colonies/100 ml)	10.	2.	2.	220.
Fecal Coliform (colonies/100 ml)	10.	2.	2.	2.
Arsenic (µg/l)	-	-	69.3	-
Barium (µg/l)	-	-	390.	-
Cadmium (µg/l)	-	-	1.0	-
Chromium (µg/l)	-	-	98.1	-
Copper (µg/l)	-	-	87.0	-
Lead (µg/l)	-	-	30.2	-
Selenium (µg/l)	-	-	1.9	-
Zinc (µg/l)	-	-	126.	-

FORDVILLE - WELL 3

Parameter	8/4/81	10/25/81	4/20/82	8/17/82
Water Level (ft)	92.27	93.12	93.45	92.72
pH	7.1	6.9	6.7	6.4
Field Conductivity (µmhos/cm)	-	-	-	1630.
Lab Conductivity (µmhos/cm)	1510.	1390.	1420.	1435.
Dissolved Oxygen (mg/l)	0.6	1.2	3.0	1.4
Total Dissolved Solids (mg/l)	850.	779.	793.	1148.
Total Alkalinity (mg/l)	399.	433.	448.	428.
Total Hardness (mg/l)	538.	503.	497.	267.
Ammonia (N) (mg/l)	0.386	0.487	0.312	0.322
Nitrate (N) (mg/l)	0.100	0.044	0.055	0.041
Dissolved Phosphorous (mg/l)	0.099	0.124	0.045	0.032
Calcium (mg/l)	136.	124.	125.	107.
Magnesium (mg/l)	48.0	47.0	45.0	35.
Sodium (mg/l)	124.	112.	122.0	121.
Potassium (mg/l)	10.2	9.20	11.3	9.55
Bicarbonate (mg/l)	488.	529.	548.	522.
Chloride (mg/l)	225.	175.	175.	188.
Sulfate (mg/l)	66.	51.	44.	38.
Iron (mg/l)	0.07	0.17	0.16	0.01
Manganese (mg/l)	2.88	3.28	3.12	2.67
Carbonate (mg/l)	0.0	0.0	0.0	0.0
Fluoride (mg/l)	0.2	0.1	0.1	0.2
Total Coliform (colonies/100 ml)	100.	2.	2.	79.
Fecal Coliform (colonies/100 ml)	100.	2.	2.	2.
Arsenic (µg/l)	8.0	0.0	2.9	-
Barium (µg/l)	620.	420.	330.	-
Cadmium (µg/l)	1.6	1.0	0.6	-
Chromium (µg/l)	20.5	3.2	6.3	-
Copper (µg/l)	29.0	9.6	36.0	-
Lead (µg/l)	12.0	5.8	9.5	-
Selenium (µg/l)	1.0	0.1	0.2	-
Zinc (µg/l)	61.0	29.	28.	-

FORDVILLE - WELL 4

Parameter	8/4/81	10/25/81	4/20/82	8/17/82
Water Level (ft)	92.81	93.46	93.53	92.61
pH	7.3	6.7	6.8	6.3
Field Conductivity (μmhos/cm)	-	-	-	960.
Lab Conductivity (μmhos/cm)	690.	655.	687.	943.
Dissolved Oxygen (mg/l)	1.0	1.4	3.4	2.4
Total Dissolved Solids (mg/l)	428.	406.	418.	754.
Total Alkalinity (mg/l)	280.	280.	298.	337.
Total Hardness (mg/l)	366.	349.	356.	431.
Ammonia (N) (mg/l)	0.185	0.098	0.046	0.024
Nitrate (N) (mg/l)	2.03	2.87	0.341	2.17
Dissolved Phosphorous (mg/l)	0.124	0.063	0.065	0.051
Calcium (mg/l)	90.5	88.0	89.0	111.
Magnesium (mg/l)	34.0	31.5	32.5	37.5
Sodium (mg/l)	22.0	16.0	14.5	19.0
Potassium (mg/l)	3.25	2.15	2.25	2.50
Bicarbonate (mg/l)	342.	342.	364.	411.
Chloride (mg/l)	18.	20.	15.0	40.0
Sulfate (mg/l)	91.	78.	86.0	99.
Iron (mg/l)	0.06	0.02	0.02	0.08
Manganese (mg/l)	0.840	0.100	0.070	0.086
Carbonate (mg/l)	0.0	0.0	0.0	0.0
Fluoride (mg/l)	0.2	0.1	0.1	0.2
Total Coliform (colonies/100 ml)	10.	5.	11.	5.
Fecal Coliform (colonies/100 ml)	10.	2.	2.	2.
Arsenic (μg/l)	-	-	-	-
Barium (μg/l)	-	-	-	-
Cadmium (μg/l)	-	-	-	-
Chromium (μg/l)	-	-	-	-
Copper (μg/l)	-	-	-	-
Lead (μg/l)	-	-	-	-
Selenium (μg/l)	-	-	-	-
Zinc (μg/l)	-	-	-	-

FORDVILLE - WELL 5

Parameter	8/4/81	10/25/81	4/20/82	8/17/82
Water Level (ft)	92.91	93.85	94.26	93.47
pH	7.4	6.9	6.6	6.3
Field Conductivity (µmhos/cm)	-	-	-	1060.
Lab Conductivity (µmhos/cm)	1091.	886.0	925.	1142.
Dissolved Oxygen (mg/l)	0.6	0.4	3.0	3.1
Total Dissolved Solids (mg/l)	609.	516.	509.	914.
Total Alkalinity (mg/l)	316.	276.	266.	294.
Total Hardness (mg/l)	461.	446.	441.	505.
Ammonia (N) (mg/l)	2.68	0.493	0.209	0.326
Nitrate (N) (mg/l)	0.183	0.059	0.146	0.044
Dissolved Phosphorous (mg/l)	0.141	0.066	0.042	0.034
Calcium (mg/l)	111.	114.	115.	134.
Magnesium (mg/l)	44.5	39.0	37.5	41.5
Sodium (mg/l)	56.5	22.0	20.5	17.0
Potassium (mg/l)	8.25	5.00	5.90	4.65
Bicarbonate (mg/l)	386.	337.	325.	359.
Chloride (mg/l)	100.	75.	75.0	125.
Sulfate (mg/l)	98.	95.	95.0	86.
Iron (mg/l)	0.08	0.02	0.03	0.13
Manganese (mg/l)	2.62	1.73	1.37	1.41
Carbonate (mg/l)	0.0	0.0	0.0	0.0
Fluoride (mg/l)	0.2	0.1	0.2	0.2
Total Coliform (colonies/100 ml)	10.	2400.	2.	70.
Fecal Coliform (colonies/100 ml)	10.	2.	2.	2.
Arsenic (µg/l)	-	-	-	-
Barium (µg/l)	-	-	-	-
Cadmium (µg/l)	-	-	-	-
Chromium (µg/l)	-	-	-	-
Copper (µg/l)	-	-	-	-
Lead (µg/l)	-	-	-	-
Selenium (µg/l)	-	-	-	-
Zinc (µg/l)	-	-	-	-

FORDVILLE - WELL 5

Parameter	8/4/81	10/25/81	4/20/82	8/17/82
Water Level (ft)	-	-	-	-
pH	-	-	6.6	-
Field Conductivity (μmhos/cm)	-	-	-	-
Lab Conductivity (μmhos/cm)	-	-	651.	-
Dissolved Oxygen (mg/l)	-	-	-	-
Total Dissolved Solids (mg/l)	-	-	727.	-
Total Alkalinity (mg/l)	-	-	317.	-
Total Hardness (mg/l)	-	-	794.	-
Ammonia (N) (mg/l)	-	-	6.00	-
Nitrate (N) (mg/l)	-	-	118.	-
Dissolved Phosphorous (mg/l)	-	-	0.047	-
Calcium (mg/l)	-	-	208.	-
Magnesium (mg/l)	-	-	66.5	-
Sodium (mg/l)	-	-	15.5	-
Potassium (mg/l)	-	-	26.7	-
Bicarbonate (mg/l)	-	-	388.	-
Chloride (mg/l)	-	-	50.0	-
Sulfate (mg/l)	-	-	51.	-
Iron (mg/l)	-	-	0.04	-
Manganese (mg/l)	-	-	0.040	-
Carbonate (mg/l)	-	-	0.0	-
Fluoride (mg/l)	-	-	0.1	-
Total Coliform (colonies/100 ml)	-	-	-	-
Fecal Coliform (colonies/100 ml)	-	-	-	-
Arsenic (μg/l)	-	-	-	-
Barium (μg/l)	-	-	-	-
Cadmium (μg/l)	-	-	-	-
Chromium (μg/l)	-	-	-	-
Copper (μg/l)	-	-	-	-
Lead (μg/l)	-	-	-	-
Selenium (μg/l)	-	-	-	-
Zinc (μg/l)	-	-	-	-

FORDVILLE - WELL 6

Parameter	8/4/81	10/25/81	4/20/82	8/17/82
Water Level (ft)	90.54	90.01	94.14	94.86
pH	7.8	7.1	6.8	-
Field Conductivity (μmhos/cm)	-	-	-	-
Lab Conductivity (μmhos/cm)	1072.	856.	809.	-
Dissolved Oxygen (mg/l)	0.5	0.3	9.0	5.9
Total Dissolved Solids (mg/l)	700.	514.	468.	-
Total Alkalinity (mg/l)	209.	234.	225.	-
Total Hardness (mg/l)	306.	237.	215.	-
Ammonia (N) (mg/l)	3.86	4.95	2.33	-
Nitrate (N) (mg/l)	0.198	0.098	1.21	-
Dissolved Phosphorous (mg/l)	0.155	0.420	0.048	-
Calcium (mg/l)	66.5	51.5	47.5	-
Magnesium (mg/l)	34.0	26.5	23.5	-
Sodium (mg/l)	126.	94.5	87.5	-
Potassium (mg/l)	17.4	9.05	9.15	-
Bicarbonate (mg/l)	256.	286.	275.	-
Chloride (mg/l)	175.	95.	70.0	-
Sulfate (mg/l)	154.	97.	94.	-
Iron (mg/l)	3.83	0.05	0.14	-
Manganese (mg/l)	1.58	1.65	1.45	-
Carbonate (mg/l)	0.0	0.0	0.0	-
Fluoride (mg/l)	0.4	0.2	0.3	-
Total Coliform (colonies/100 ml)	27,000.	540.	2.	-
Fecal Coliform (colonies/100 ml)	10.	2.	2.	-
Arsenic (μg/l)	-	-	-	-
Barium (μg/l)	-	-	-	-
Cadmium (μg/l)	-	-	-	-
Chromium (μg/l)	-	-	-	-
Copper (μg/l)	-	-	-	-
Lead (μg/l)	-	-	-	-
Selenium (μg/l)	-	-	-	-
Zinc (μg/l)	-	-	-	-

FORDVILLE - LAGOON

Parameter	8/4/81	10/25/81	4/20/82	8/17/82
Water Level (ft)	-	-	-	-
pH	9.1	7.9	6.8	8.5
Field Conductivity (μmhos/cm)	-	-	-	975.
Lab Conductivity (μmhos/cm)	979.	1040.	1749.	950.
Dissolved Oxygen (mg/l)	20.0	-	6.0	-
Total Dissolved Solids (mg/l)	567.	604.	322.	508.
Total Alkalinity (mg/l)	221.	312.	200.	222.
Total Hardness (mg/l)	226.	261.	138.	222.
Ammonia (N) (mg/l)	4.33	13.6	17.4	3.14
Nitrate (N) (mg/l)	0.188	0.698	0.025	0.393
Dissolved Phosphorous (mg/l)	0.682	3.66	3.19	0.814
Calcium (mg/l)	53.5	65.0	35.0	52.5
Magnesium (mg/l)	22.5	24.0	12.5	22.0
Sodium (mg/l)	126.	114.	53.0	99.0
Potassium (mg/l)	12.9	11.1	8.00	11.0
Bicarbonate (mg/l)	150.	382.	245.	165.
Chloride (mg/l)	125.	125.	60.0	113.
Sulfate (mg/l)	95.	76.	33.	77.
Iron (mg/l)	0.40	0.01	0.08	0.00
Manganese (mg/l)	0.170	0.120	0.260	0.063
Carbonate (mg/l)	59.	0.0	0.0	52.
Fluoride (mg/l)	0.2	0.1	0.1	0.2
Total Coliform (colonies/100 ml)	200,000.	2400.	2400.	2400.
Fecal Coliform (colonies/100 ml)	9700.	2400.	2400.	2400.
Arsenic (μg/l)	-	-	-	-
Barium (μg/l)	-	-	-	-
Cadmium (μg/l)	-	-	-	-
Chromium (μg/l)	-	-	-	-
Copper (μg/l)	-	-	-	-
Lead (μg/l)	-	-	-	-
Selenium (μg/l)	-	-	-	-
Zinc (μg/l)	-	-	-	-

ESMOND - WELL 1

Parameter	10/26/81	4/19/82	7/28/82
Water Level (ft)	74.33	75.01	74.45
pH	6.6	6.7	6.9
Field Conductivity (μmhos/cm)	-	-	1300.
Lab Conductivity (μmhos/cm)	958.	931.	1105.
Dissolved Oxygen (mg/l)	1.6	3.6	0.8
Total Dissolved Solids (mg/l)	766.	601.	670.
Total Alkalinity (mg/l)	422.	402.	454.
Total Hardness (mg/l)	412.	375.	426.
Ammonia (N) (mg/l)	0.345	0.049	0.038
Nitrate (N) (mg/l)	0.058	0.895	0.261
Dissolved Phosphorous (mg/l)	0.051	0.051	0.029
Calcium (mg/l)	102.	93.5	109.
Magnesium (mg/l)	38.	34.5	37.5
Sodium (mg/l)	77.5	80.0	84.0
Potassium (mg/l)	6.75	7.70	8.15
Bicarbonate (mg/l)	516.	491.	555.
Chloride (mg/l)	33.	25.0	26.0
Sulfate (mg/l)	-	118.	132.
Iron (mg/l)	0.00	0.05	0.02
Manganese (mg/l)	0.03	0.08	0.11
Carbonate (mg/l)	-	-	-
Fluoride (mg/l)	-	-	-
Total Coliform (colonies/100 ml)	-	-	-
Fecal Coliform (colonies/100 ml)	-	-	-
Arsenic (μg/l)	-	-	-
Barium (μg/l)	-	-	-
Cadmium (μg/l)	-	-	-
Chromium (μg/l)	-	-	-
Copper (μg/l)	-	-	-
Lead (μg/l)	-	-	-
Selenium (μg/l)	-	-	-
Zinc (μg/l)	-	-	-

ESMOND - WELL 2

Parameter	10/26/81	4/19/82	7/28/82
Water Level (ft)	75.17	75.23	75.66
pH	6.7	6.8	6.8
Field Conductivity (µmhos/cm)	-	-	1150.
Lab Conductivity (µmhos/cm)	848.	835.	950.
Dissolved Oxygen (mg/l)	6.0	6.0	6.8
Total Dissolved Solids (mg/l)	678.	518.	537.
Total Alkalinity (mg/l)	422.	416.	382.
Total Hardness (mg/l)	441.	446.	469.
Ammonia (N) (mg/l)	0.823	0.392	0.048
Nitrate (N) (mg/l)	0.688	3.60	3.62
Dissolved Phosphorous (mg/l)	0.151	0.038	0.027
Calcium (mg/l)	107.	108.	116.
Magnesium (mg/l)	42.	42.5	43.5
Sodium (mg/l)	31.5	24.5	27.5
Potassium (mg/l)	4.5	4.9	4.95
Bicarbonate (mg/l)	516.	508.	467.
Chloride (mg/l)	13.	12.5	8.00
Sulfate (mg/l)	-	72.	104.
Iron (mg/l)	0.03	0.06	0.04
Manganese (mg/l)	0.19	0.07	0.20
Carbonate (mg/l)	-	-	-
Fluoride (mg/l)	-	-	-
Total Coliform (colonies/100 ml)	-	-	-
Fecal Coliform (colonies/100 ml)	-	-	-
Arsenic (µg/l)	-	-	-
Barium (µg/l)	-	-	-
Cadmium (µg/l)	-	-	-
Chromium (µg/l)	-	-	-
Copper (µg/l)	-	-	-
Lead (µg/l)	-	-	-
Selenium (µg/l)	-	-	-
Zinc (µg/l)	-	-	-

ESMOND - WELL 3

Parameter	10/26/81	4/19/82	7/28/82
Water Level (ft)	74.23	74.82	75.39
pH	6.8	6.7	6.7
Field Conductivity (μmhos/cm)	-	-	435.
Lab Conductivity (μmhos/cm)	609.	570.	650.
Dissolved Oxygen (mg/l)	2.0	4.6	2.8
Total Dissolved Solids (mg/l)	487.	343.	357.
Total Alkalinity (mg/l)	309.	282.	303.
Total Hardness (mg/l)	290.	259.	283.
Ammonia (N) (mg/l)	0.386	0.076	0.049
Nitrate (N) (mg/l)	0.496	0.656	1.57
Dissolved Phosphorous (mg/l)	0.055	0.013	0.021
Calcium (mg/l)	67.5	61.0	69.
Magnesium (mg/l)	29.5	26.0	27.0
Sodium (mg/l)	28.0	29.0	27.5
Potassium (mg/l)	4.60	5.35	5.50
Bicarbonate (mg/l)	378.	345.	370.
Chloride (mg/l)	13.	7.50	4.00
Sulfate (mg/l)	-	44.	41.
Iron (mg/l)	0.04	0.05	0.01
Manganese (mg/l)	1.93	1.67	1.13
Carbonate (mg/l)	-	-	-
Fluoride (mg/l)	-	-	-
Total Coliform (colonies/100 ml)	-	-	-
Fecal Coliform (colonies/100 ml)	-	-	-
Arsenic (μg/l)	-	-	-
Barium (μg/l)	-	-	-
Cadmium (μg/l)	-	-	-
Chromium (μg/l)	-	-	-
Copper (μg/l)	-	-	-
Lead (μg/l)	-	-	-
Selenium (μg/l)	-	-	-
Zinc (μg/l)	-	-	-

ESMOND - WELL 4

Parameter	10/26/81	4/19/82	7/28/82
Water Level (ft)	73.01	72.98	73.40
pH	6.8	6.7	6.8
Field Conductivity (μmhos/cm)	-	-	1650.
Lab Conductivity (μmhos/cm)	1410.	1404.	1542.
Dissolved Oxygen (mg/l)	1.6	4.6	1.9
Total Dissolved Solids (mg/l)	1120.	919.	908.
Total Alkalinity (mg/l)	741.	754.	777.
Total Hardness (mg/l)	373.	333.	340.
Ammonia (N) (mg/l)	2.37	0.115	0.038
Nitrate (N) (mg/l)	2.88	2.19	1.05
Dissolved Phosphorous (mg/l)	0.054	0.043	0.031
Calcium (mg/l)	90.0	80.0	84.5
Magnesium (mg/l)	36.0	32.5	31.5
Sodium (mg/l)	233.	250.	239.
Potassium (mg/l)	8.85	10.8	10.5
Bicarbonate (mg/l)	905.	921.	949.
Chloride (mg/l)	50.	47.5	46.0
Sulfate (mg/l)	-	42.	28.
Iron (mg/l)	0.13	0.06	0.02
Manganese (mg/l)	1.07	0.78	0.79
Carbonate (mg/l)	-	-	-
Fluoride (mg/l)	-	-	-
Total Coliform (colonies/100 ml)	-	-	-
Fecal Coliform (colonies/100 ml)	-	-	-
Arsenic (μg/l)	-	-	-
Barium (μg/l)	-	-	-
Cadmium (μg/l)	-	-	-
Chromium (μg/l)	-	-	-
Copper (μg/l)	-	-	-
Lead (μg/l)	-	-	-
Selenium (μg/l)	-	-	-
Zinc (μg/l)	-	-	-

ESMOND - LAGOON

Parameter	10/26/81	4/19/82	7/28/82
Water Level (ft)	-	-	-
pH	7.5	7.8	7.7
Field Conductivity (μmhos/cm)	-	-	1400.
Lab Conductivity (μmhos/cm)	1480.	760.	1178.
Dissolved Oxygen (mg/l)	-	-	7.2
Total Dissolved Solids (mg/l)	889.	441.	635.
Total Alkalinity (mg/l)	727.	354.	464.
Total Hardness (mg/l)	70.	43.	107.
Ammonia (N) (mg/l)	35.5	17.2	16.5
Nitrate (N) (mg/l)	0.114	0.222	1.19
Dissolved Phosphorous (mg/l)	4.84	3.77	3.87
Calcium (mg/l)	18.0	11.5	29.0
Magnesium (mg/l)	6.0	3.50	8.50
Sodium (mg/l)	287.	147.	211.
Potassium (mg/l)	17.5	14.9	16.1
Bicarbonate (mg/l)	888.	433.	567.
Chloride (mg/l)	50.	17.5	29.0
Sulfate (mg/l)	73.	34.	61.
Iron (mg/l)	0.11	0.17	0.11
Manganese (mg/l)	0.07	0.05	0.18
Carbonate (mg/l)	-	-	-
Fluoride (mg/l)	-	-	-
Total Coliform (colonies/100 ml)	-	-	-
Fecal Coliform (colonies/100 ml)	-	-	-
Arsenic (μg/l)	-	-	-
Barium (μg/l)	-	-	-
Cadmium (μg/l)	-	-	-
Chromium (μg/l)	-	-	-
Copper (μg/l)	-	-	-
Lead (μg/l)	-	-	-
Selenium (μg/l)	-	-	-
Zinc (μg/l)	-	-	-

LIDGERWOOD - WELL 1

Parameter	10/18/81	4/28/82	7/22/82
Water Level (ft)	87.90	89.80	87.24
pH	6.8	6.7	7.1
Field Conductivity (µmhos/cm)	-	-	-
Lab Conductivity (µmhos/cm)	1640.	1622.	1742.
Dissolved Oxygen (mg/l)	1.0	1.8	1.2
Total Dissolved Solids (mg/l)	1180.	1140.	-
Total Alkalinity (mg/l)	501.	479.	-
Total Hardness (mg/l)	477.	446.	-
Ammonia (N) (mg/l)	1.20	1.43	0.930
Nitrate (N) (mg/l)	0.156	0.053	0.476
Dissolved Phosphorous (mg/l)	0.112	0.031	0.035
Calcium (mg/l)	118.	122.	125.
Magnesium (mg/l)	44.0	34.0	31.5
Sodium (mg/l)	235.	225.	211.
Potassium (mg/l)	22.3	16.6	16.4
Bicarbonate (mg/l)	612.	586.	559.
Chloride (mg/l)	100.	40.	25.0
Sulfate (mg/l)	360.	415.	435.
Iron (mg/l)	0.05	0.21	0.11
Manganese (mg/l)	0.66	1.75	1.77
Carbonate (mg/l)	-	-	-
Fluoride (mg/l)	-	-	-
Total Coliform (colonies/100 ml)	-	-	-
Fecal Coliform (colonies/100 ml)	-	-	-
Arsenic (µg/l)	-	184.	25.1
Barium (µg/l)	-	-	-
Cadmium (µg/l)	-	-	-
Chromium (µg/l)	-	-	-
Copper (µg/l)	-	-	-
Lead (µg/l)	-	-	-
Selenium (µg/l)	-	-	-
Zinc (µg/l)	-	-	-

LIDGERWOOD - WELL 2

Parameter	10/18/81	4/28/82	7/22/82
Water Level (ft)	87.80	89.48	87.05
pH	6.8	6.7	7.0
Field Conductivity (μmhos/cm)	-	-	-
Lab Conductivity (μmhos/cm)	1470.	1643.	1791.
Dissolved Oxygen (mg/l)	1.4	1.8	.7
Total Dissolved Solids (mg/l)	1000.	1020.	-
Total Alkalinity (mg/l)	398.	413.	-
Total Hardness (mg/l)	442.	432.	-
Ammonia (N) (mg/l)	0.474	0.273	0.188
Nitrate (N) (mg/l)	0.184	0.005	0.065
Dissolved Phosphorous (mg/l)	.113	.021	0.032
Calcium (mg/l)	112.	107.	111.
Magnesium (mg/l)	39.5	40.	40.0
Sodium (mg/l)	213.	226.	202.
Potassium (mg/l)	10.3	10.3	9.85
Bicarbonate (mg/l)	487.	505.	487.
Chloride (mg/l)	150.	150.	111.
Sulfate (mg/l)	240.	246.	243.
Iron (mg/l)	0.05	0.45	0.14
Manganese (mg/l)	0.66	0.90	0.830
Carbonate (mg/l)	-	-	-
Fluoride (mg/l)	-	-	-
Total Coliform (colonies/100 ml)	-	-	-
Fecal Coliform (colonies/100 ml)	-	-	-
Arsenic (μg/l)	-	39.3	9.7
Barium (μg/l)	-	-	-
Cadmium (μg/l)	-	-	-
Chromium (μg/l)	-	-	-
Copper (μg/l)	-	-	-
Lead (μg/l)	-	-	-
Selenium (μg/l)	-	-	-
Zinc (μg/l)	-	-	-

LIDGERWOOD - WELL 3

Parameter	10/18/81	4/28/82	7/22/82
Water Level (ft)	87.44	89.24	85.96
pH	6.9	6.8	7.0
Field Conductivity (μmhos/cm)	-	-	-
Lab Conductivity (μmhos/cm)	1260.	1498.	1827.
Dissolved Oxygen (mg/l)	1.2	1.4	1.0
Total Dissolved Solids (mg/l)	832.	889.	-
Total Alkalinity (mg/l)	382.	382.	-
Total Hardness (mg/l)	364.	359.	-
Ammonia (N) (mg/l)	0.280	0.119	0.120
Nitrate (N) (mg/l)	0.121	0.033	0.029
Dissolved Phosphorous (mg/l)	.088	0.016	0.021
Calcium (mg/l)	92.5	88.5	98.0
Magnesium (mg/l)	32.5	33.5	35.5
Sodium (mg/l)	189.	216.	222.
Potassium (mg/l)	6.70	7.35	7.35
Bicarbonate (mg/l)	467.	467.	466.
Chloride (mg/l)	150.	175.	260.
Sulfate (mg/l)	131.	139.	140.
Iron (mg/l)	0.03	0.09	0.20
Manganese (mg/l)	0.84	0.60	0.590
Carbonate (mg/l)	-	-	-
Fluoride (mg/l)	-	-	-
Total Coliform (colonies/100 ml)	-	-	-
Fecal Coliform (colonies/100 ml)	-	-	-
Arsenic (μg/l)	-	9.8	4.7
Barium (μg/l)	-	-	-
Cadmium (μg/l)	-	-	-
Chromium (μg/l)	-	-	-
Copper (μg/l)	-	-	-
Lead (μg/l)	-	-	-
Selenium (μg/l)	-	-	-
Zinc (μg/l)	-	-	-

LIDGERWOOD - WELL 4

Parameter	10/18/81	4/28/82	7/22/82
Water Level (ft)	87.23	88.77	86.15
pH	6.6	6.5	7.1
Field Conductivity (μmhos/cm)	-	-	-
Lab Conductivity (μmhos/cm)	3000.	3338.	3678.
Dissolved Oxygen (mg/l)	1.1	1.0	0.5
Total Dissolved Solids (mg/l)	2030.	2030.	-
Total Alkalinity (mg/l)	592.	720.	-
Total Hardness (mg/l)	822.	777.	-
Ammonia (N) (mg/l)	1.27	1.18	0.940
Nitrate (N) (mg/l)	0.150	0.057	0.027
Dissolved Phosphorous (mg/l)	.086	.011	0.025
Calcium (mg/l)	199.	183.	194.
Magnesium (mg/l)	79.0	77.5	67.5
Sodium (mg/l)	436.	463.	488.
Potassium (mg/l)	21.2	24.4	23.4
Bicarbonate (mg/l)	723.	880.	792.
Chloride (mg/l)	625.	550.	590.
Sulfate (mg/l)	321.	298.	411.
Iron (mg/l)	0.12	0.58	3.86
Manganese (mg/l)	1.36	0.75	1.32
Carbonate (mg/l)	-	-	-
Fluoride (mg/l)	-	-	-
Total Coliform (colonies/100 ml)	-	-	-
Fecal Coliform (colonies/100 ml)	-	-	-
Arsenic (μg/l)	-	216.	41.6
Barium (μg/l)	-	-	-
Cadmium (μg/l)	-	-	-
Chromium (μg/l)	-	-	-
Copper (μg/l)	-	-	-
Lead (μg/l)	-	-	-
Selenium (μg/l)	-	-	-
Zinc (μg/l)	-	-	-

LIDGERWOOD - WELL 5

Parameter	10/18/81	4/28/82	7/22/82
Water Level (ft)	88.17	90.56	87.38
pH	6.6	6.7	7.2
Field Conductivity (μmhos/cm)	-	-	-
Lab Conductivity (μmhos/cm)	1550.	1570.	1708.
Dissolved Oxygen (mg/l)	3.4	2.6	1.4
Total Dissolved Solids (mg/l)	1170.	1130.	-
Total Alkalinity (mg/l)	468.	466.	-
Total Hardness (mg/l)	487.	451.	-
Ammonia (N) (mg/l)	0.839	0.869	0.800
Nitrate (N) (mg/l)	0.106	0.082	0.066
Dissolved Phosphorous (mg/l)	.088	.038	0.023
Calcium (mg/l)	132.	128.	126.
Magnesium (mg/l)	38.0	32.0	30.0
Sodium (mg/l)	236.	230.	209.
Potassium (mg/l)	13.5	14.1	13.9
Bicarbonate (mg/l)	572.	569.	560.
Chloride (mg/l)	60.	27.5	26.0
Sulfate (mg/l)	410.	426.	437.
Iron (mg/l)	0.09	0.21	0.10
Manganese (mg/l)	2.54	1.77	1.71
Carbonate (mg/l)	-	-	-
Fluoride (mg/l)	-	-	-
Total Coliform (colonies/100 ml)	-	-	-
Fecal Coliform (colonies/100 ml)	-	-	-
Arsenic (μg/l)	-	11.7	12.9
Barium (μg/l)	-	-	-
Cadmium (μg/l)	-	-	-
Chromium (μg/l)	-	-	-
Copper (μg/l)	-	-	-
Lead (μg/l)	-	-	-
Selenium (μg/l)	-	-	-
Zinc (μg/l)	-	-	-

LIDGERWOOD - LAGOON

Parameter	10/18/81	4/28/82	7/22/82
Water Level (ft)	-	-	-
pH	-	8.2	-
Field Conductivity (µmhos/cm)	-	-	-
Lab Conductivity (µmhos/cm)	-	2288.	3194.
Dissolved Oxygen (mg/l)	-	-	-
Total Dissolved Solids (mg/l)	-	1400.	-
Total Alkalinity (mg/l)	-	390.	-
Total Hardness (mg/l)	-	396.	-
Ammonia (N) (mg/l)	-	6.91	18.2
Nitrate (N) (mg/l)	-	0.125	0.131
Dissolved Phosphorous (mg/l)	-	1.76	3.25
Calcium (mg/l)	-	110.	127.
Magnesium (mg/l)	-	29.5	32.5
Sodium (mg/l)	-	371.	462.
Potassium (mg/l)	-	25.7	28.7
Bicarbonate (mg/l)	-	440.	657.
Chloride (mg/l)	-	350.	550.
Sulfate (mg/l)	-	281.	340.
Iron (mg/l)	0.06	0.06	0.32
Manganese (mg/l)	0.04	0.50	0.640
Carbonate (mg/l)	-	-	-
Fluoride (mg/l)	-	-	-
Total Coliform (colonies/100 ml)	-	-	-
Fecal Coliform (colonies/100 ml)	-	-	-
Arsenic (µg/l)	-	35.5	40.5
Barium (µg/l)	-	-	-
Cadmium (µg/l)	-	-	-
Chromium (µg/l)	-	-	-
Copper (µg/l)	-	-	-
Lead (µg/l)	-	-	-
Selenium (µg/l)	-	-	-
Zinc (µg/l)	-	-	-

LIDGERWOOD - FARM WELL

Parameter	10/18/81	4/28/82	7/22/82
Water Level (ft)	-	-	-
pH	-	6.8	-
Field Conductivity (μmhos/cm)	-	-	-
Lab Conductivity (μmhos/cm)	-	1466.	1639.
Dissolved Oxygen (mg/l)	-	-	-
Total Dissolved Solids (mg/l)	-	1070.	-
Total Alkalinity (mg/l)	-	429.	-
Total Hardness (mg/l)	-	475.	-
Ammonia (N) (mg/l)	-	1.12	1.08
Nitrate (N) (mg/l)	-	0.042	0.126
Dissolved Phosphorous (mg/l)	-	.026	0.097
Calcium (mg/l)	-	135.	134.
Magnesium (mg/l)	-	33.5	32.0
Sodium (mg/l)	-	193.	179.
Potassium (mg/l)	-	17.0	17.0
Bicarbonate (mg/l)	-	525.	531.
Chloride (mg/l)	-	10.	12.0
Sulfate (mg/l)	-	424.	442.
Iron (mg/l)	-	0.40	0.35
Manganese (mg/l)	-	0.56	0.570
Carbonate (mg/l)	-	-	-
Fluoride (mg/l)	-	-	-
Total Coliform (colonies/100 ml)	-	-	-
Fecal Coliform (colonies/100 ml)	-	-	-
Arsenic (μg/l)	-	54.6	91.4
Barium (μg/l)	-	-	-
Cadmium (μg/l)	-	-	-
Chromium (μg/l)	-	-	-
Copper (μg/l)	-	-	-
Lead (μg/l)	-	-	-
Selenium (μg/l)	-	-	-
Zinc (μg/l)	-	-	-

UNDERWOOD - WELL 1

Parameter	4/18/82	8/11/82
Water Level (ft)	85.64	84.00
pH	6.7	6.8
Field Conductivity (μmhos/cm)	-	1250.
Lab Conductivity (μmhos/cm)	1501.	1575.
Dissolved Oxygen (mg/l)	3.0	4.5
Total Dissolved Solids (mg/l)	811.	743.
Total Alkalinity (mg/l)	622.	609.
Total Hardness (mg/l)	388.	363.
Ammonia (N) (mg/l)	25.5	24.5
Nitrate (N) (mg/l)	0.231	0.066
Dissolved Phosphorous (mg/l)	0.056	0.033
Calcium (mg/l)	79.5	71.0
Magnesium (mg/l)	46.0	45.0
Sodium (mg/l)	144.	142.
Potassium (mg/l)	16.2	13.8
Bicarbonate (mg/l)	760.	741.
Chloride (mg/l)	150.	100.
Sulfate (mg/l)	1.0	6.0
Iron (mg/l)	2.17	0.23
Manganese (mg/l)	1.17	1.54
Carbonate (mg/l)	-	-
Fluoride (mg/l)	-	-
Total Coliform (colonies/100 ml)	-	-
Fecal Coliform (colonies/100 ml)	-	-
Arsenic (μg/l)	-	-
Barium (μg/l)	-	-
Cadmium (μg/l)	-	-
Chromium (μg/l)	-	-
Copper (μg/l)	-	-
Lead (μg/l)	-	-
Selenium (μg/l)	-	-
Zinc (μg/l)	-	-

UNDERWOOD - WELL 2

Parameter	4/18/82	8/11/82
Water Level (ft)	87.21	82.62
pH	6.9	6.8
Field Conductivity (μmhos/cm)	-	1300.
Lab Conductivity (μmhos/cm)	1080.	1328.
Dissolved Oxygen (mg/l)	1.0	1.5
Total Dissolved Solids (mg/l)	638.	645.
Total Alkalinity (mg/l)	421.	494.
Total Hardness (mg/l)	556.	644.
Ammonia (N) (mg/l)	0.289	0.257
Nitrate (N) (mg/l)	0.147	0.044
Dissolved Phosphorous (mg/l)	0.014	0.010
Calcium (mg/l)	136.	148.
Magnesium (mg/l)	52.5	66.5
Sodium (mg/l)	17.5	13.0
Potassium (mg/l)	3.50	2.85
Bicarbonate (mg/l)	515.	603.
Chloride (mg/l)	75.0	75.0
Sulfate (mg/l)	100.	43.
Iron (mg/l)	0.28	0.23
Manganese (mg/l)	1.84	1.44
Carbonate (mg/l)	-	-
Fluoride (mg/l)	-	-
Total Coliform (colonies/100 ml)	-	-
Fecal Coliform (colonies/100 ml)	-	-
Arsenic (μg/l)	-	-
Barium (μg/l)	-	-
Cadmium (μg/l)	-	-
Chromium (μg/l)	-	-
Copper (μg/l)	-	-
Lead (μg/l)	-	-
Selenium (μg/l)	-	-
Zinc (μg/l)	-	-

UNDERWOOD - WELL 3

Parameter	4/18/82	8/11/82
Water Level (ft)	-	-
pH	-	-
Field Conductivity (μmhos/cm)	-	-
Lab Conductivity (μmhos/cm)	-	-
Dissolved Oxygen (mg/l)	-	-
Total Dissolved Solids (mg/l)	-	-
Total Alkalinity (mg/l)	-	-
Total Hardness (mg/l)	-	-
Ammonia (N) (mg/l)	-	-
Nitrate (N) (mg/l)	-	-
Dissolved Phosphorous (mg/l)	-	-
Calcium (mg/l)	-	-
Magnesium (mg/l)	-	-
Sodium (mg/l)	-	-
Potassium (mg/l)	-	-
Bicarbonate (mg/l)	-	-
Chloride (mg/l)	-	-
Sulfate (mg/l)	-	-
Iron (mg/l)	-	-
Manganese (mg/l)	-	-
Carbonate (mg/l)	-	-
Fluoride (mg/l)	-	-
Total Coliform (colonies/100 ml)	-	-
Fecal Coliform (colonies/100 ml)	-	-
Arsenic (μg/l)	-	-
Barium (μg/l)	-	-
Cadmium (μg/l)	-	-
Chromium (μg/l)	-	-
Copper (μg/l)	-	-
Lead (μg/l)	-	-
Selenium (μg/l)	-	-
Zinc (μg/l)	-	-

UNDERWOOD - WELL 4

Parameter	4/18/82	8/11/82
Water Level (ft)	85.49	83.82
pH	6.7	6.8
Field Conductivity (μmhos/cm)	-	2100.
Lab Conductivity (μmhos/cm)	1739.	1855.
Dissolved Oxygen (mg/l)	2.8	2.4
Total Dissolved Solids (mg/l)	940.	903.
Total Alkalinity (mg/l)	802.	798.
Total Hardness (mg/l)	491.	503.
Ammonia (N) (mg/l)	33.6	35.6
Nitrate (N) (mg/l)	0.201	0.038
Dissolved Phosphorous (mg/l)	0.036	0.039
Calcium (mg/l)	109.	110.
Magnesium (mg/l)	53.0	55.0
Sodium (mg/l)	141.	136.
Potassium (mg/l)	21.6	19.3
Bicarbonate (mg/l)	980.	974.
Chloride (mg/l)	125.	100.
Sulfate (mg/l)	7.	2.
Iron (mg/l)	2.21	3.92
Manganese (mg/l)	2.19	1.94
Carbonate (mg/l)	-	-
Fluoride (mg/l)	-	-
Total Coliform (colonies/100 ml)	-	-
Fecal Coliform (colonies/100 ml)	-	-
Arsenic (μg/l)	-	-
Barium (μg/l)	-	-
Cadmium (μg/l)	-	-
Chromium (μg/l)	-	-
Copper (μg/l)	-	-
Lead (μg/l)	-	-
Selenium (μg/l)	-	-
Zinc (μg/l)	-	-

UNDERWOOD - WELL 5

Parameter	4/18/82	8/11/82
Water Level (ft)	-	89.12
pH	-	6.8
Field Conductivity (μmhos/cm)	-	1380.
Lab Conductivity (μmhos/cm)	-	1406.
Dissolved Oxygen (mg/l)	-	1.0
Total Dissolved Solids (mg/l)	-	712.
Total Alkalinity (mg/l)	-	566.
Total Hardness (mg/l)	-	509.
Ammonia (N) (mg/l)	-	0.480
Nitrate (N) (mg/l)	-	0.085
Dissolved Phosphorous (mg/l)	-	0.059
Calcium (mg/l)	-	118.
Magnesium (mg/l)	-	52.0
Sodium (mg/l)	-	94.0
Potassium (mg/l)	-	6.05
Bicarbonate (mg/l)	-	691.
Chloride (mg/l)	-	50.0
Sulfate (mg/l)	-	51.
Iron (mg/l)	-	0.07
Manganese (mg/l)	-	1.60
Carbonate (mg/l)	-	-
Fluoride (mg/l)	-	-
Total Coliform (colonies/100 ml)	-	-
Fecal Coliform (colonies/100 ml)	-	-
Arsenic (μg/l)	-	-
Barium (μg/l)	-	-
Cadmium (μg/l)	-	-
Chromium (μg/l)	-	-
Copper (μg/l)	-	-
Lead (μg/l)	-	-
Selenium (μg/l)	-	-
Zinc (μg/l)	-	-

UNDERWOOD - WELL 6

Parameter	4/18/82	8/11/82
Water Level (ft)	88.74	88.31
pH	6.8	6.7
Field Conductivity (μmhos/cm)	-	1770.
Lab Conductivity (μmhos/cm)	1493.	1601.
Dissolved Oxygen (mg/l)	3.0	1.7
Total Dissolved Solids (mg/l)	844.	803.
Total Alkalinity (mg/l)	692.	660.
Total Hardness (mg/l)	501.	496.
Ammonia (N) (mg/l)	0.627	0.544
Nitrate (N) (mg/l)	0.303	0.053
Dissolved Phosphorous (mg/l)	0.004	0.028
Calcium (mg/l)	75.5	72.5
Magnesium (mg/l)	76.0	76.5
Sodium (mg/l)	155.	144.
Potassium (mg/l)	4.45	4.10
Bicarbonate (mg/l)	845.	805.
Chloride (mg/l)	100.	100.
Sulfate (mg/l)	17.	9.
Iron (mg/l)	0.02	0.02
Manganese (mg/l)	1.76	1.95
Carbonate (mg/l)	-	-
Fluoride (mg/l)	-	-
Total Coliform (colonies/100 ml)	-	-
Fecal Coliform (colonies/100 ml)	-	-
Arsenic (μg/l)	-	-
Barium (μg/l)	-	-
Cadmium (μg/l)	-	-
Chromium (μg/l)	-	-
Copper (μg/l)	-	-
Lead (μg/l)	-	-
Selenium (μg/l)	-	-
Zinc (μg/l)	-	-

UNDERWOOD - LAGOON

Parameter	4/18/82	8/11/82
Water Level (ft)	-	-
pH	7.1	8.3
Field Conductivity (μmhos/cm)	-	950.
Lab Conductivity (μmhos/cm)	577.	1166.
Dissolved Oxygen (mg/l)	4.0	-
Total Dissolved Solids (mg/l)	302.	655.
Total Alkalinity (mg/l)	194.	346.
Total Hardness (mg/l)	142.	344.
Ammonia (N) (mg/l)	-	0.292
Nitrate (N) (mg/l)	0.127	0.030
Dissolved Phosphorous (mg/l)	2.18	1.58
Calcium (mg/l)	33.0	68.5
Magnesium (mg/l)	14.5	42.0
Sodium (mg/l)	47.0	110.0
Potassium (mg/l)	6.90	11.2
Bicarbonate (mg/l)	238.	375.
Chloride (mg/l)	40.0	141.
Sulfate (mg/l)	0.04	0.01
Iron (mg/l)	0.08	0.07
Manganese (mg/l)	-	-
Carbonate (mg/l)	-	-
Fluoride (mg/l)	-	-
Total Coliform (colonies/100 ml)	-	-
Fecal Coliform (colonies/100 ml)	-	-
Arsenic (μg/l)	-	-
Barium (μg/l)	-	-
Cadmium (μg/l)	-	-
Chromium (μg/l)	-	-
Copper (μg/l)	-	-
Lead (μg/l)	-	-
Selenium (μg/l)	-	-
Zinc (μg/l)	-	-

APPENDIX V

HYDRAULIC CONDUCTIVITY ESTIMATES FROM GRAIN-SIZE ANALYSES

HYDRAULIC CONDUCTIVITY ESTIMATES

Hydraulic conductivity values were estimated from grain-size distribution using the method of Masch and Denny (1966). Grain-size data are plotted as cumulative percent vs. grain-size diameter in ϕ units, where: $\phi = \log_2 d$, and d is the grain-size diameter in millimeters. The method involves graphic determination of the inclusive standard deviation σ_i by the formula

$$\sigma_i = \frac{d_{16} - d_{84}}{4} + \frac{d_5 - d_{95}}{6.6},$$

where d_{16}, for example, is the diameter of which 16 percent (by weight) of the sample is finer. Hydraulic conductivity is determined from a graph in Masch and Denny (1966) using σ_i and d_{50}. Results of the procedure for selected samples are given in the table below. Data and grain-size distribution curves are given in Brown (1983). Sample numbers in the table refer to well numbers at the various sites.

Sample Number	Depth (ft)	σ_i (ϕ)	d_{50}(mm)	Hydraulic Conductivity (m/s)
McVille 7A	8-13	0.973	2.05	9.44×10^{-5}
McVille 7B	13-18	1.535	1.50	7.08×10^{-5}
McVille 7C	28-33	1.345	1.60	8.02×10^{-5}
McVille 8A	0-3	0.698	2.16	1.18×10^{-4}
McVille 8B	8-13	1.340	2.02	8.02×10^{-5}
McVille 8C	18-23	1.319	1.70	8.97×10^{-5}
Larimore 4	2.5-7.5	.4827	1.90	1.89×10^{-4}
Esmond 1C	23-28	1.57	0.51	8.97×10^{-5}
Esmond 1D	33-38	1.75	0.92	5.19×10^{-5}
Esmond 4C	28-33	1.47	-0.17	1.08×10^{-4}
Lidgerwood 3A	8-13	0.79	2.28	8.5×10^{-5}
Lidgerwood 3B	13-18	0.45	2.72	8.26×10^{-5}
Lidgerwood 3C	28-33	1.49	1.56	7.08×10^{-5}
Underwood 4A	8-13	.55	2.49	8.5×10^{-5}

APPENDIX VI

HYDRAULIC CONDUCTIVITY ESTIMATES FROM SINGLE-WELL RESPONSE TESTS

HYDRAULIC CONDUCTIVITY ESTIMATES FROM SINGLE-WELL RESPONSE TESTS

Single-well response (slug) tests were conducted on some of the wells installed. The test consists of dropping a metal slug, which is proportioned to raise the water level in a two-inch diameter well by one metre, into the well. Water levels are monitored as the water level declines to its original valve. A recovery test can be conducted by pulling the slug out and monitoring the rise in water level to equilibrium. The data are plotted as the unrecovered head difference vs. time on semilogarithmic paper (Hvorslev 1951, Freeze and Cherry, 1979), in order to determine the basic time lag (T_o). Basic time lag is used with the dimensions of the well to calculate hydraulic conductivity by the formula

$$K = \frac{R2 \ln(L/R)}{2 L T_o}$$

where, K = hydraulic conductivity in cm/s

L = the length of the well screen in cm

R = the radius of the well screen in cm, and

T_o = the basic time lag in seconds.

The results of the test are given in the table below.

Well	Hydraulic Conductivity (m/s)
McVille 3	4.2×10^{-5}
McVille 6	3.1×10^{-5}
McVille 6 (recovery)	4.7×10^{-5}
Fordville 2	4.9×10^{-7}
Fordville 3	8.7×10^{-6}
Underwood 1	2.6×10^{-7}
Underwood 2	1.5×10^{-7}
Underwood 3	8.3×10^{-7}
Underwood 4	2.9×10^{-7}
Underwood 5	1.3×10^{-6}