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The effect of waste stabilization pond seepage on groundwater quality of shallow aquifers in eastern North Dakota

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THE EFFECT OF WASTE STABILIZATION POND SEEPAGE ON GROUNDWATER QUALITY OF SHALLOW AQUIFERS IN EASTERN NORTH DAKOTA

by
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Bachelor of Science, Northern Illinois University, 1979

A Thesis

Submitted to the Graduate Faculty

of the

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in partial fulfillment of the requirements

for the degree of

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This thesis submitted by David J. Brown in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

Alan E. Kehew

(Chairman)

John R. Reid

This thesis meets the standards for appearance and conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

Dean of the Graduate School

Permission

Title: THE EFFECT OF WASTE STABILIZATION POND SEEPAGE ON GROUNDWATER QUALITY OF SHALLOW AQUIFERS IN EASTERN NORTH DAKOTA

Department: GEOLOGY

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Signature David J. Brown

Date April 14, 1983

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ABSTRACT

The use of stabilization ponds to dispose of municipal wastes has become popular with many North Dakota cities. When managed properly they are an efficient and economical method of waste disposal and may not adversely affect groundwater quality. In order to achieve efficient treatment, the ponds must be built in sediment that has permeability low enough to inhibit excessive percolation of wastewater into the subsurface. Some North Dakota cities have not met this basic requirement in the construction of their ponds. As a result, insufficiently treated pond liquids are allowed to reach the water table, potentially contaminating groundwater supplies. Three such sites located over important aquifers near Grand Forks were chosen for this study: McVille, Larimore, and Fordville, North Dakota.

Monitoring wells were constructed peripheral to and downgradient from the sites beginning in May, 1980. The wells served two purposes: to determine the flow system by recording water levels periodically, and to obtain water samples for subsequent chemical and biological analyses by the Department of Health in Bismarck.

In general, concentrations of constituents such as calcium, magnesium, total dissolved solids, chloride, ammonium, and iron increase immediately downgradient from the ponds, indicating that groundwater is adversely affected by wastewater percolation. In

some cases, the elevated values exceed maximum pollution standards set by the U.S. Environmental Protection Agency.

The behavior of the contaminant plumes are complex and dependent on redox conditions both in the pond bottom sediments and the groundwater. Contaminants originate from three sources at the McVille site: continuous percolation of anaerobic wastewater from cell I, aerobic cell II discharges, and aerobic leachate from a dump at the site. Groundwater quality is severely degraded at that site. Groundwater at the Larimore site is generally of better quality; however, several constituents are excessive. The transfer of pond liquids from one cell to another at Larimore has a significant effect on groundwater quality at that site. Groundwater quality at Fordville is least influenced by the pond, although a few constituents are present at high levels.

Seepage from the waste stabilization ponds studied does not presently affect municipal water supplies of the cities that use them. However, because of severe groundwater contamination immediately downgradient from the McVille site, it is recommended that an impermeable clay liner be installed in the McVille ponds. Evidence of groundwater degradation adjacent to the study sites indicates that construction of wells near the sites should be prohibited.

INTRODUCTION

General Statement

Many communities in North Dakota use unlined waste stabilization ponds to dispose of municipal sewage. Current State Health Department standards for these ponds requires natural sediment, or a compacted clay liner, with permeability low enough that seepage from the pond is less than 1/8 inch (0.3 cm) per day (Kehew and others, 1980). Retention of pond liquids insures proper treatment of the sewage by accompanying biological and chemical processes.

Construction of ponds in low permeability sediment involves excavation and compaction of that sediment. In areas of high permeability sediments, sediment must be hauled to the site and compacted to form a low permeability liner in the pond.

In the past, some ponds were built in high permeability sediments without the construction of compacted clay liners. These ponds function, in effect, as rapid infiltration basins instead of waste stabilization ponds. Many communities prefer to leave such ponds in their present state unless it is proved that the ponds are contaminating present or potential sources of groundwater supply.

The purpose of this project, then, is to study the hydrogeologic setting of three unlined ponds, located over important shallow aquifers, and to evaluate the effects of waste stabilization pond seepage on groundwater quality.

Objectives

The four specific objectives of the project were to:

1. Determine the geologic setting of the pond sites, including information on the type, distribution, and physical properties of surficial sediments and those sediments comprising the aquifers beneath the impoundments.
2. Determine the hydrogeologic conditions at the sites, including the direction and rate of movement of groundwater and the background chemical quality of the aquifer.
3. Determine the changes, if any, in chemical composition of groundwater in the aquifer caused by seepage of wastewater from the ponds.
4. Make recommendations to the North Dakota State Department of Health concerning regulation of unlined municipal waste stabilization ponds.

Waste Stabilization Processes

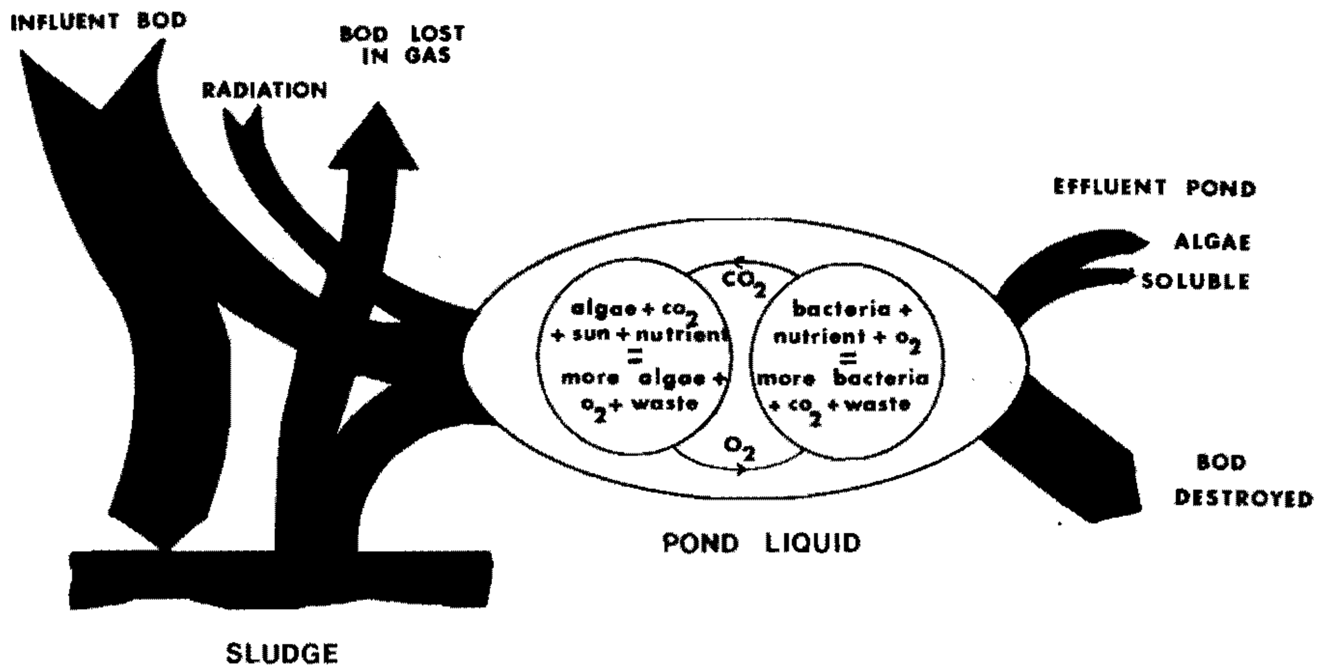
Typical municipal wastewater has solid and liquid organic matter and significant quantities of aerobic bacteria (Caldwell, 1946). The primary function of a waste stabilization pond is to destroy both the oxygen demand of the organic constituents and the potentially pathogenic bacteria that are present in the influent sewage.

Most waste stabilization ponds utilized by small communities in North Dakota, the type discussed in this study, have been termed facultative ponds because only organisms having the faculty to withstand alternating aerobic and anaerobic conditions exist in the pond (Marais, 1970). In this type of pond, the pond liquids are predominantly aerobic with most of the oxygen being produced by algal photosynthesis. In addition, an anaerobic sludge layer forms on the pond bottom by settling of solids through the liquid (Marais, 1970).

Both the aerobic and anaerobic portions of a waste stabilization pond break down wastewater constituents to more desirable end products. In the upper part of the pond, influent sewage is mixed with oxygen-bearing water. This upper portion of the pond receives solar radiation, which sustains the growth of algae. Algae also require carbon dioxide for respiration. One source of this gas is anaerobic fermentation of the sludge layer on the pond bottom (Neel and Hopkins, 1956). Through photosynthesis, algae grow by combining light energy, water, and carbon dioxide into primitive sugars. The waste product of algae, oxygen, can be utilized by aerobic bacteria, which are largely responsible for the breakdown of organic matter in the influent sewage (Van Heuvelen and Svore, 1954). These aerobic bacteria are present in the liquid portion of the pond, whereas anaerobic bacteria, including sulfate-reducing bacteria, are in the bottom sludge layer (Neel and Hopkins, 1956). Bacteria liberate nutrients and carbon dioxide needed for algal growth, and the cycle continues. These processes are depicted in Figure 1.

A critical but commonly neglected component of proper waste stabilization in ponds is the bottom sludge layer (Marais, 1970). In addition to producing carbon dioxide and other gases through fermentation, it seals the pond bottom and decreases percolation of untreated wastewater into the subsurface. The sludge layer physically traps and prevents large particles from entering groundwater below the pond. Also, some wastewater contaminants may be adsorbed onto particles in the sludge layer. Chemical reduction of various wastewater consti-

Figure 1. Diagram illustrating processes operating in waste stabilization ponds (modified from Marais, 1970, p. 18).


INFLUENT BOD
RADIATION
BOD LOST IN GAS
algae + co_2 + sun + nutrient = more algae + o_2 + waste
CO_2
O_2
bacteria + nutrient + o_2 = more bacteria + co_2 + waste
EFFLUENT POND
ALGAE
SOLUBLE
BOD DESTROYED
POND LIQUID
SLUDGE

tuents occurs within the anoxic sludge layer. This process alters groundwater chemistry directly below the pond site.

Many factors, both controllable and uncontrollable, dictate how effectively the waste stabilization process will operate within the pond. Controllable factors include water depth, pond surface area, mode of sewage inflow, and loading (Towne and others, 1957); experience in North Dakota suggests that three foot (0.9 m) to five foot (1.5 m) pond depths in ponds of one acre (0.40 hectares) per 100 people are most efficient (Van Heuvelen and Svore, 1954). Guidelines for pond design have been established and are discussed in E. A. Hickok and Associates (1978).

Uncontrollable factors that affect stabilization pond operation include such meteorological conditions as wind velocity, solar radiation and temperature. Because mixing of pond water with the atmosphere aerates the pond and destroys any thermal stratification within the water, windy conditions are usually associated with better wastewater treatment (Marais, 1970). Algal photosynthesis, crucial to proper pond performance, is enhanced by sunlight and warmth. Hence, sunny and hot weather is ideal for proper wastewater treatment (Towne and others, 1957).

Chemical Components of Wastewater

The chemical and biological constituents in wastewater differ markedly from those in groundwater. If a waste stabilization pond is leaking sewage into groundwater, anomalously high concentrations of wastewater constituents will be detected in monitoring wells downgradient from the pond. This section will discuss the parameters most useful in determining whether contamination of groundwater by sewage has occurred. Table 1 lists specified limits for these constituents for public water supplies (condensed from Freeze and Cherry, 1979, p. 386).

Total Hardness

Total hardness is commonly recognized by the increased quantity of soap required to produce lather. Hard water tends to form scale on boilers, water heaters and pipes. Caused predominantly by compounds of calcium and magnesium, total hardness is calculated as 2.5 (Ca^{2+}) + 4.1 (Mg^{2+}), where hardness and the concentrations in parentheses are expressed in milligrams per liter (mg/L) (Freeze and Cherry, 1979, p. 387). Therefore, groundwater with elevated concentrations of calcium and/or magnesium has high total hardness as well.

Total Dissolved Solids (TDS)

TDS (in milligrams per liter), a measure of mineralization of water, is approximately 65 percent of the specific conductance (capacity to conduct an electrical current, in micromhos per centimetre, Downey, 1971). A waste stabilization pond contributes dissolved mineral constituents as well as some organic matter to groundwater. Therefore, TDS concentrations should increase in groundwater downgradient from a leaking waste stabilization pond. Excessive dissolved solids restrict the use of water for domestic and stock purposes, irrigation, and some manufacturing processes.

TABLE 1

DRINKING WATER STANDARDS

Constituent		Recommended Concentration Limit (mg/L)
Total Hardness		80 - 100
Total Dissolved Solids (TDS)		500
Nitrate (N)	(NO_3^-)	10
Chloride	(Cl^-)	250
Sulfate	(SO_4^{2-})	250
Sodium	(Na^+)	20*
Iron	(Fe)	0.3
Manganese	(Mn^{2+})	0.05
		Maximum Permissible Concentration (mg/L)
Arsenic	(As)	0.05
Barium	(Ba)	1.0
Cadmium	(Cd)	0.01
Chromium	(Cr)	0.05
Copper	(Cu)	1.0
Lead	(Pb)	0.05
Selenium	(Se)	0.01
Zinc	(Zn)	5.0
		Maximum Permissible Colonies
Total Coliforms		1 per 100 ml
Fecal Coliforms		0 per 100 ml

Source: U.S. Environmental Protection Agency, 1975

*Limit for people with low salt diets.

Ammonia

Ammonia (NH_3) and ammonium (NH_4^+) are two forms of nitrogen that can occur in groundwater. These forms can be introduced into the groundwater through land application of nitrogenous fertilizers, by natural ammonification of organic nitrogen in decomposed plant material, or by disposal of sewage on or beneath the land surface. Below a pH value of 9, the ammonium ion (NH_4^+) is the dominant nitrogen species (Preul and Schroepfer, 1968).

Nitrate (NO_3^-)

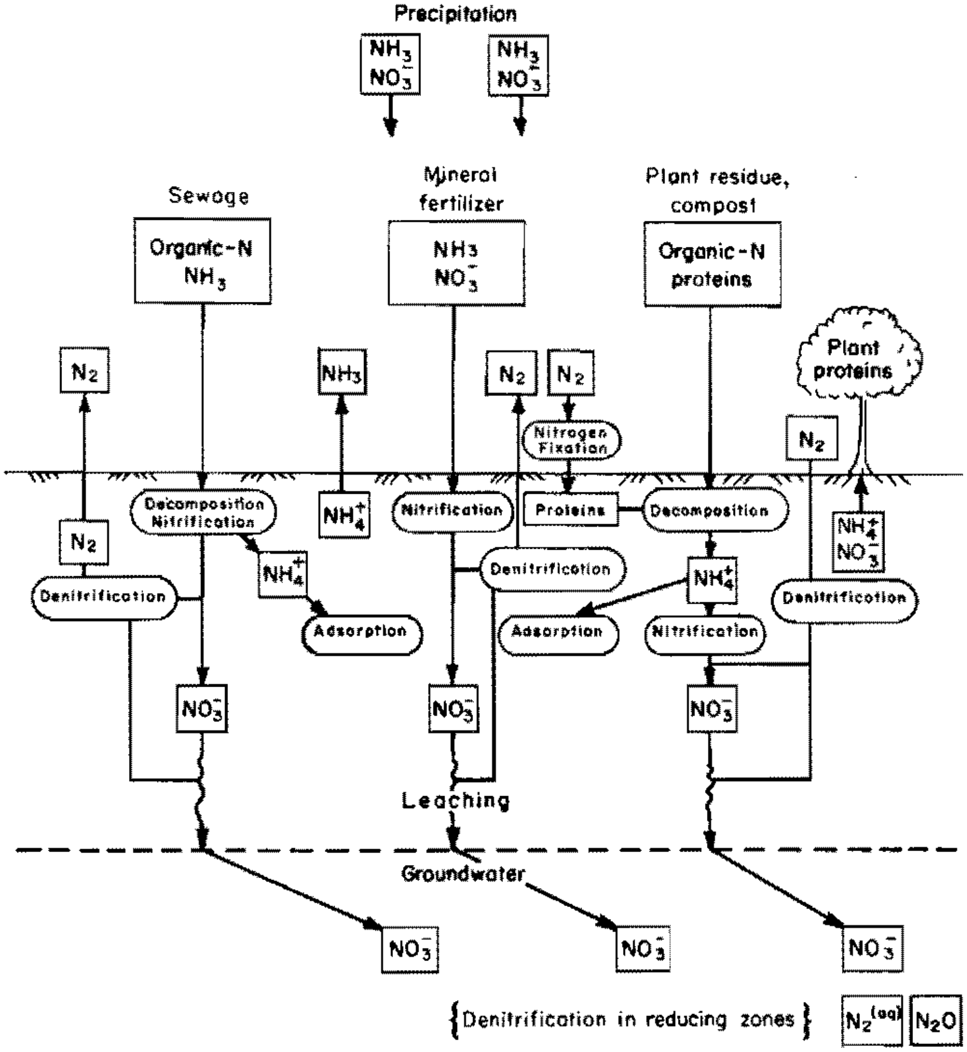
Nitrate can be introduced into groundwater directly through fertilizer application onto crops and by the process of nitrification, where ammonia or ammonium is oxidized to nitrate either above or below the water table. In oxidizing groundwater, nitrate is the most stable form of nitrogen and is very mobile; no transformation or retardation occurs as long as oxidizing conditions prevail (Freeze and Cherry, 1979, p. 413). Figure 2 illustrates the sources and pathways of nitrogen in the subsurface environment.

Nitrates are among the most serious health threats of any contaminants discussed in this report. When water containing greater than 10 mg/L nitrate (expressed as N) is ingested by infants or fetuses, methemoglobinemia (blue baby disease) may result (Culp and Culp, 1974, p. 19).

Chloride (Cl^-)

Chloride is an excellent indicator of groundwater contamination

Figure 2. Sources and pathways of nitrogen in the subsurface environment (from Freeze and Cherry, 1979, p. 414).


Precipitation
NH_3 NO_3^-
NH_3 NO_3^-
Sewage
Organic-N NH_3
Mineral fertilizer
NH_3 NO_3^-
Plant residue, compost
Organic-N proteins
Plant proteins
N_2
NH_3
N_2
N_2
Nitrogen Fixation
N_2
Decomposition Nitrification
NH_4^+
Nitrification
Proteins
Decomposition
NH_4^+ NO_3^-
N_2
Denitrification
NH_4^+
Denitrification
NH_4^+
Denitrification
Adsorption
Adsorption
Nitrification
NO_3^-
NO_3^-
NO_3^-
Leaching
Groundwater
NO_3^-
NO_3^-
NO_3^-
{Denitrification in reducing zones}
$N_2^{(aq)}$
N_2O

because of its low concentrations in natural groundwater in the study areas and also because of its mobility in groundwater. Excessive concentrations of chloride can impart a salty taste to water and increase its laxative properties (Culp and Culp, 1974, p. 17).

Sulfate (SO_4^{2-})

The chemical species of sulfur in groundwater is dependent on local redox conditions. When estimating or predicting oxidation-reduction reactions in aqueous solutions, the relative proton activity ($pH = -\log [H^+]$) and relative electron activity ($pE = -\log [e^-]$) are used. Large positive values of pE (low electron activity) represent strongly oxidizing conditions while small or negative values (high electron activity) correspond to strongly reducing conditions (Stumm and Morgan, 1970, p. 304). Oxidizing groundwater normally contains the sulfate ion (SO_4^{2-}), while waters with low redox potential contain sulfur in the form of HS^- or hydrogen sulfide (H_2S) gas.

The stable form of sulfur in aerobic wastewater is the sulfate ion (SO_4^{2-}). As the wastewater percolates through the anaerobic sludge layer, sulfate is reduced by bacteria to hydrogen sulfide gas, which is usually outgassed from the system; sometimes, it remains in solution. Therefore, concentrations of sulfate are typically low in groundwater immediately downgradient from a waste stabilization pond having a sludge layer. Excessive amounts of sulfate affect the taste of water and increase its laxative properties (Culp and Culp, 1974, p. 17).

Iron (Fe)

Local redox conditions in groundwater determine the stable form of iron. Ferric iron (Fe^{3+}) is stable in oxidizing groundwater, while ferrous iron (Fe^{2+}) is stable in reducing groundwater. Because ferrous iron is much more soluble than ferric iron, high total iron readings reflect a greater concentration of ferrous iron. Total iron concentrations commonly increase downgradient from waste stabilization ponds because reducing conditions promote soluble ferrous iron (Fe^{2+}) as the dominant iron form.

Iron in water is not toxic at most natural concentrations. However, concentrations of iron above the standard can affect the taste of water and cause brown staining of laundry and plumbing fixtures (Culp and Culp, 1974, p. 18).

Sodium (Na^+)

Sodium, a major constituent in sewage, is not always abundant in groundwater. Therefore, elevated concentrations of sodium may occur downgradient from leaking waste stabilization ponds.

People with low salt diets may be adversely affected by drinking water high in sodium. Also, excessive concentrations of sodium cause foaming, which accelerates scale formation and corrosion in boilers (Miller, 1978, p. 126).

Manganese (Mn^{2+})

Manganese-containing minerals, almost ubiquitous in usual groundwater systems, are attacked by reducing groundwaters, causing Mn to become soluble as Mn^{2+}. Absence of Mn^{2+} in groundwater cannot be used as an indication of absence of Mn-bearing minerals; rather, it is an indication that water in the aquifer contains dissolved oxygen, causing the Mn to be relatively insoluble (Stumm and Morgan, 1970, p. 545). Manganese in oxidizing waters occurs as coatings $(MnO_2)_{(s)}$ on aquifer sand grains.

Manganese is present in limited concentrations in wastewater; excessive amounts of manganese in water may affect its taste and also may stain the water (Culp and Culp, 1974, p. 18).

Trace Elements

Trace elements in natural or contaminated groundwaters almost always occur at concentrations below 1 mg/L. Such concentrations occur because of adsorption of trace elements on clay minerals or on hydrous oxides of manganese and iron. Also, they tend to form complexed species by combining with more common inorganic anions such as SO_4^{2-}, Cl^-, HCO_3^-, and NO_3^- (Freeze and Cherry, 1979, p. 416). The formation of complexes is influenced by redox conditions, which change the oxidation state of either the trace element or the anion with which it forms complexes (Freeze and Cherry, 1979, p. 417). Several trace elements mentioned in this thesis, such as arsenic and chromium, can be toxic when present in excessive concentrations.

Coliform Bacteria

The ubiquity of coliform bacteria in sewage makes these organisms possible indicators of groundwater contamination by waste pond seepage. These potentially pathogenic organisms inhabit the intestinal tract of warm blooded animals. Water is an unfavorable environment, though, and they eventually die. The presence of coliform bacteria, then, suggests recent pollution of groundwater (Culp and Culp, 1974, p. 13).

Previous Work

During the Surface Impoundment Assessment, funded by the EPA, 363 municipal waste stabilization sites containing a total of 746 impoundments in North Dakota were identified and a general assessment of their pollution potential was made. Sixty-seven percent of these impoundments were evaluated as having high or moderate pollution potential (Kehew and others, 1980). Many of these sites are near wells and surface water bodies but the amount of groundwater degradation resulting from pond seepage is unknown because of a lack of monitoring systems at the sites. The State Department of Health, the regulatory agency for surface impoundments, is obligated to determine if communities using seeping ponds must upgrade their facilities for greater groundwater protection. Because the cost of such projects is large it is essential to obtain accurate documentation of the effects of long-term seepage on groundwater quality.

The use of waste stabilization ponds became popular in the Dakotas in the late 1940's because of their cost advantages over more conventional methods such as secondary sewage treatment plants. The effluent produced by the waste pond was usually of similar quality to treatment plant effluent (Towne and others, 1957).

The first designed waste stabilization pond in North Dakota was installed in 1948 at Maddock (Van Heuvelen and Svore, 1954). The pond design was based on a pond at nearby Fessenden, N.D. The Fessenden site, put into operation in 1928 and used for 20 years, was merely a dammed pothole into which the sewage was discharged (Van Heuvelen and Svore, 1954). The State Department of Health concluded that effluent water from the Maddock, N.D. waste pond was of better quality than water present in many shallow, sluggish streams of the state. Based on Biological Oxygen Demand (BOD) values, the pond reduced sewage strength by 65% in the winter months and 95% in the summer months. From these data, Van Heuvelen and Svore (1954) concluded that this method of sewage disposal was satisfactory for communities in the state.

In 1955, the State Health Departments of North and South Dakota conducted field investigations on waste stabilization ponds at Maddock and Wishek, North Dakota and Lemmon, Kadoka, and Wall, South Dakota (Towne and others, 1957). The purpose was to obtain knowledge of the factors involved in the stabilization of sewage in ponds and to develop design and operation criteria. They concluded that the efficiency of treatment at the five study sites was high during all times of the year and they recommended their use in the Missouri River Basin.

Preul (1968) made field observations over a three year period of ten waste stabilization ponds built in sandy sediment. Contaminants of concern in this study included ammonia nitrogen, nitrate nitrogen, phosphate, and alkyl benzene sulfonate (ABS). The conclusions of the study were that algae consume nitrate nitrogen and phosphates in the ponds and thus these two contaminants are not present in sufficient concentrations in downgradient groundwater to be a serious health threat. Significant ABS levels in groundwaters were detected as far as 200 feet (60.97 m) from the waste stabilization ponds, however.

In addition to field studies, laboratory investigations have also been important in defining which sediment properties attenuate contaminant constituents. Preul and Schroepfer (1968), for example, conducted laboratory investigations of the factors that affect nitrogen in wastewater as it flows through different sediment types. The tests were conducted on representative samples of clay, silt and sand. Wastewater samples were prepared to various concentrations and mixed with different sediment types. A battery of tests was run on the sediment-solution mixtures to determine the adsorptive characteristics of the sediments, the effect of the potassium ion on ammonium adsorption, time dependency of ammonium adsorption onto soil particles, and the amount of nitrate nitrogen adsorption onto the sediment. The results indicate that ammonium nitrogen is adsorbed onto sediment particles, inhibiting their movement. Nitrate nitrogen movement was not found to be inhibited by any mechanism and the presence of the potassium ion had a limiting affect on ammonium adsorption (Preul and Schroepfer, 1968).

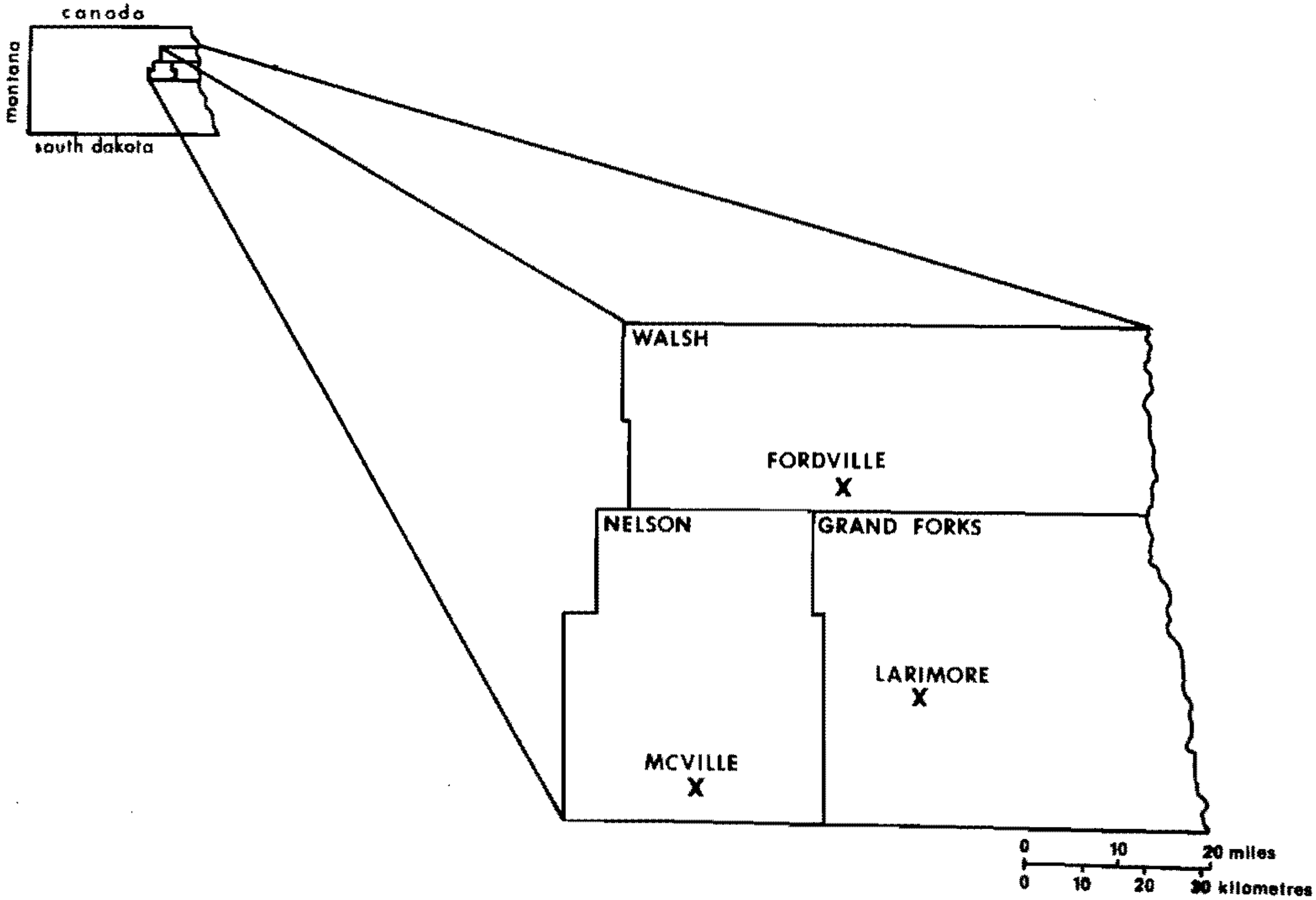
More recently, extensive research has been conducted on seeping ponds in South Dakota. Bleeker and Dornbush (1980) suggested that, in some cases, even seeping waste stabilization ponds should be considered a satisfactory means of municipal sewage disposal. In those cases, groundwater degradation generally was not serious and percolation often resulted in the improvement of wastewater to a quality better than surface discharges. The physical, chemical, and biological treatment capabilities of the sediment are the principal factors that attenuate wastewater contaminants. In addition, Dornbush (1979) summarized work done by South Dakota State University graduate students on land treatment of wastewater by the utilization of infiltration-percolation techniques. It was concluded that a moderate-rate infiltration system constructed in silty clay sediment with a high water table can serve as a practical treatment alternative for secondary effluents, such as stabilization pond effluent.

A study of five waste stabilization pond sites in Minnesota by E. A. Hickok and Associates (1978) produced contrasting results. At the sites constructed in low permeability glacial till, no significant increases of nitrogen, phosphorous or fecal coliforms were recorded. However, soluble salts such as chloride were much higher in groundwater downgradient from the ponds. At other sites, significant increases in fecal coliforms and hardness, in addition to soluble salts, were recorded in the downgradient direction. At one of the study sites, groundwater quality approximately 75 feet (22.9 m) downgradient from the pond was equivalent to raw sewage, indicating minimal attenuation of pond liquids percolating into groundwater.

Location of Study Sites

Figure 3 shows the location of the three study sites in northeastern North Dakota. All three sites were selected because of their

Figure 3. Map showing locations of the study sites.


canada
montana
south dakota
WALSH
FORDVILLE
X
NELSON
GRAND FORKS
LARIMORE
X
MCVILLE
X
0
10
20 miles
0
10
20
30 kilometres

location over important aquifers and their close proximity to the University of North Dakota.

McVille is a city of 626 people (1982 census) in south-central Nelson County and has been slowly increasing in population over the last two decades. Larimore, in west-central Grand Forks County, has 1,524 people (1982 census) and has experienced a modest population increase during the past 20 years. Fordville is a city of 326 people (1982 census) in south-central Walsh County and has been gradually declining in population during the last few decades.

All three cities have agricultural-based economies and none has any major industry. Therefore, it is assumed that wastes entering the ponds are primarily municipal sewage and wastewater.

Regional Geologic Setting

Cenozoic deposits in the study area include the Coleharbor Formation of Pleistocene age and the overlying Holocene Oahe Formation. These deposits occur at the surface throughout most of the tri-county area. The Coleharbor Formation is named for well-exposed sections of glacial sediment along the shores of Lake Sakakawea near Coleharbor in McLean County, North Dakota (Bluemle, 1973). The thickness of the Coleharbor Formation ranges from zero to 455 feet (138.72 m) in the three-county area (Hansen and Kume, 1970). The Coleharbor and Oahe Formations are polygenetic; wide variations of sediment type are commonly encountered within a short distance. Therefore, the sediment types encountered at the three study sites will be discussed separately in later sections.

METHODS

Field

Instrumentation

Determination of the effects of wastewater pond seepage on groundwater quality requires a dense network of wells in all directions from the pond site. Ideally, nested piezometers should be installed; differences in groundwater quality between the piezometers of the nest provides information on the vertical distribution of the contaminant plume within the aquifer. Comparisons of water quality data from piezometers downgradient from and lateral to the site with data from upgradient piezometers indicate areal extent and magnitude of groundwater degradation peripheral to and downgradient from the ponds.

Piezometers are preferred over other types of wells for a study of this type because they have a small screened interval and are sealed above the screen, prohibiting: a) the influx of groundwater from other aquifers or other portions of the same aquifer into the well, and b) infiltration of surface water down the annulus of the well and into the screened interval. Unfortunately, piezometer installation at the three sites was prevented by the existence of saturated sandy sediment below the surface. This sediment collapsed into the well hole and prohibited the installation of a seal above the screened interval of the well. Because of this problem, the monitoring wells were driven into the aquifer. Auger cuttings then were replaced into the hole and packed to the greatest density possible. The packing of backfilled sediment is believed to be at least that of the natural sediment. In addition, the top several inches of the hole were filled with cement. For these reasons it is concluded that surface water contamination of well water is not a problem at the study sites.

"Upgradient" monitoring wells at the Larimore and Fordville sites do not approximate background chemistry of groundwater because they are within the influence of a groundwater mound created by the stabilization ponds. Therefore, farm wells were sampled in an attempt to determine background concentrations of constituents in uncontaminated groundwater.

During the fall of 1980, instrumentation began at the McVille, Larimore, and Fordville sites. Six monitoring wells were installed at McVille and four wells were installed at Larimore and Fordville. In the summer of 1981, three additional monitoring wells at Larimore and two more wells at McVille and Fordville were installed. Instrumentation was completed in the summer of 1982, when six additional monitoring wells were installed at McVille.

The monitoring wells were constructed in the field by cementing a five-foot (1.52 m) section of slotted, two-inch (5.08 cm) diameter PVC pipe onto the appropriate length of unslotted two-inch diameter PVC pipe. Holes for the monitoring wells were drilled using a truck-mounted auger made available by the North Dakota Geological Survey. Well installation consisted of: 1) augering a hole to the desired depth; 2) dropping the PVC pipe, screened interval first, into the hole and pushing it into the hole as far as possible (this was necessary in holes where sandy sediment had caved back into the borehole); 3) pounding the remainder of the pipe into the hole to the desired depth; 4) backfilling around the pipe with auger cuttings and 5) covering the above-ground section of PVC pipe with a metal sleeve and cementing the sleeve into the ground. A metal cap was then locked onto the sleeve. The locked cap and sleeve was designed to inhibit vandalism and prevent contamination of well water. Despite this precaution, several wells were damaged by vandals during the study.

It should be noted that installation of monitoring wells at the Larimore and Fordville sites was limited to the embankments because crops surrounded these sites. At the McVille site, where the surrounding land is not being farmed, downgradient monitoring wells were installed up to 1,100 feet (335.3 m) from the north edge of the waste stabilization pond. Hence, better well control was realized at McVille than at the other two sites. Specifications on all monitoring wells are listed in Table 2.

Sediment Description

During monitoring well installation, auger cuttings were collected and described. Sediment texture, color, and depth were noted. Other information, such as approximate position of the water table and presence of a sewage smell of the sediment, were also recorded. The samples were then placed into labeled bags and returned to the laboratory for further analyses.

Mapping

During the summer of 1981, each site was surveyed using plane table and alidade. From these data, topographic base maps of the sites were constructed. Positions of the monitoring wells were included on the base maps and their specific elevations were recorded. By convention, the tops of the embankments surrounding the waste ponds were assumed to be 100 feet (30.5 m) above the arbitrary subsurface datum.

Water Level Readings

In order to determine hydraulic head configurations, directions of groundwater flow, and the effects of precipitation and/or pond wastewater percolation on water table elevations, monthly water level readings were taken at the study sites from May, 1981 to June, 1982, with the exception of the months of December, 1981 and February, 1982, when snow cover prevented access to the wells. Water levels were measured with a battery powered water-level tape. Hydraulic head values are reported as the elevation of the water levels above an arbitrary subsurface datum. Because the aquifers beneath the sites are assumed to be unconfined, water levels in the wells represent the position of the water table at those wells.

Hydraulic Conductivity Estimates

One method for determining the hydraulic conductivity of underlying sediment was the single-well response (slug) test (Hvorslev, 1951). In this test, a solid cylinder (slug) was dropped rapidly to the bottom of a 2-inch (5.08 cm) diameter monitoring well, raising the water level exactly 1 metre. The rate of recovery of the hydraulic head to its original elevation is proportional to the hydraulic conductivity.

Sampling Procedure

Water sampling was done in a specially equipped van provided by the University of North Dakota Engineering Experiment Station. Samples were collected during August and October, 1981 and April and July, 1982. All wells were sampled with the exception of Fordville no. 1 in April, 1982; apparently the well was blocked with ice at the time. Also, Fordville well no. 6 was not sampled in July, 1982 because of an insufficient amount of water in the well.

To be certain that the water samples were representative of groundwater surrounding the wells, approximately 2 well volumes of water were bailed from all wells prior to sampling with a 6-foot (1.83 m) PVC bailer.

To prevent sample contamination, the bailer was thoroughly rinsed with distilled water prior to sampling. Before taking samples for bacteria analyses, a small bailer was sterilized with a dilute bleach solution and rinsed several times with distilled water. Immediately after sample extraction, pH was determined with a Hach model 1975 pH meter; conductivity (micromhos/cm) was determined with a Beckman model RC-16C conductivity bridge and the temperature (Celsius) was recorded. Also, dissolved oxygen (mg/L) of well water was determined by the YSI model 57 Dissolved Oxygen meter with immersible probe. Samples were filtered through 142 mm. diameter, 8 micron pre-filters and then through 142 mm. diameter, 0.45 micron filters.

One-quart (0.95 l) samples were collected for major ion analyses; 100 milliliter samples were collected for phosphate, nitrate, total and fecal coliform, and trace metal analyses. After collection, the samples were placed in styrofoam coolers, covered with ice, and shipped to the North Dakota State Department of Health laboratories in Bismarck for analysis.

Laboratory

Sediment Characterization

Samples that appeared to be dominantly very fine sand-size (4.0ϕ or 1/16 mm.) or coarser were dry-sieved using a RoTap machine and U.S. standard sieves. Stacks of sieves at 0.5ϕ intervals were used. When silt- and clay-size particles amounted to less than 5% of the samples (by weight), no attempt was made to separate those size fractions.

The hydrometer method was subsequently used to determine sand, silt and clay percentages of dominantly silty or clayey samples. This procedure is described by Perkins (1978).

A textural analysis computer program, written by Dr. R. D. LeFever of the University of North Dakota Department of Geology, produced statistical data and frequency and cumulative distribution curves. Input data needed for the program were the grain-size distributions obtained from the dry-sieve technique mentioned above.

The other technique to determine the hydraulic conductivity of sediments at the three sites utilized grain-size parameters obtained from cumulative distribution curves (Masch and Denny, 1966). One restriction with this procedure is that it can be used only for dominantly sandy sediment; one of the assumptions made in the method is that the particles are not cohesive. Thus, this technique was not used for silty and/or clayey samples.

Contaminant Contour Mapping

Chemical data were plotted on base maps of the sites to illustrate changes in groundwater quality. Because well control was better at McVille, isopleth lines (lines of equal concentration) of each parameter were superimposed on the base map of that site using data from the July, 1982 sampling period.

McVILLE WASTE POND SITE

Results and Discussion

Site Description

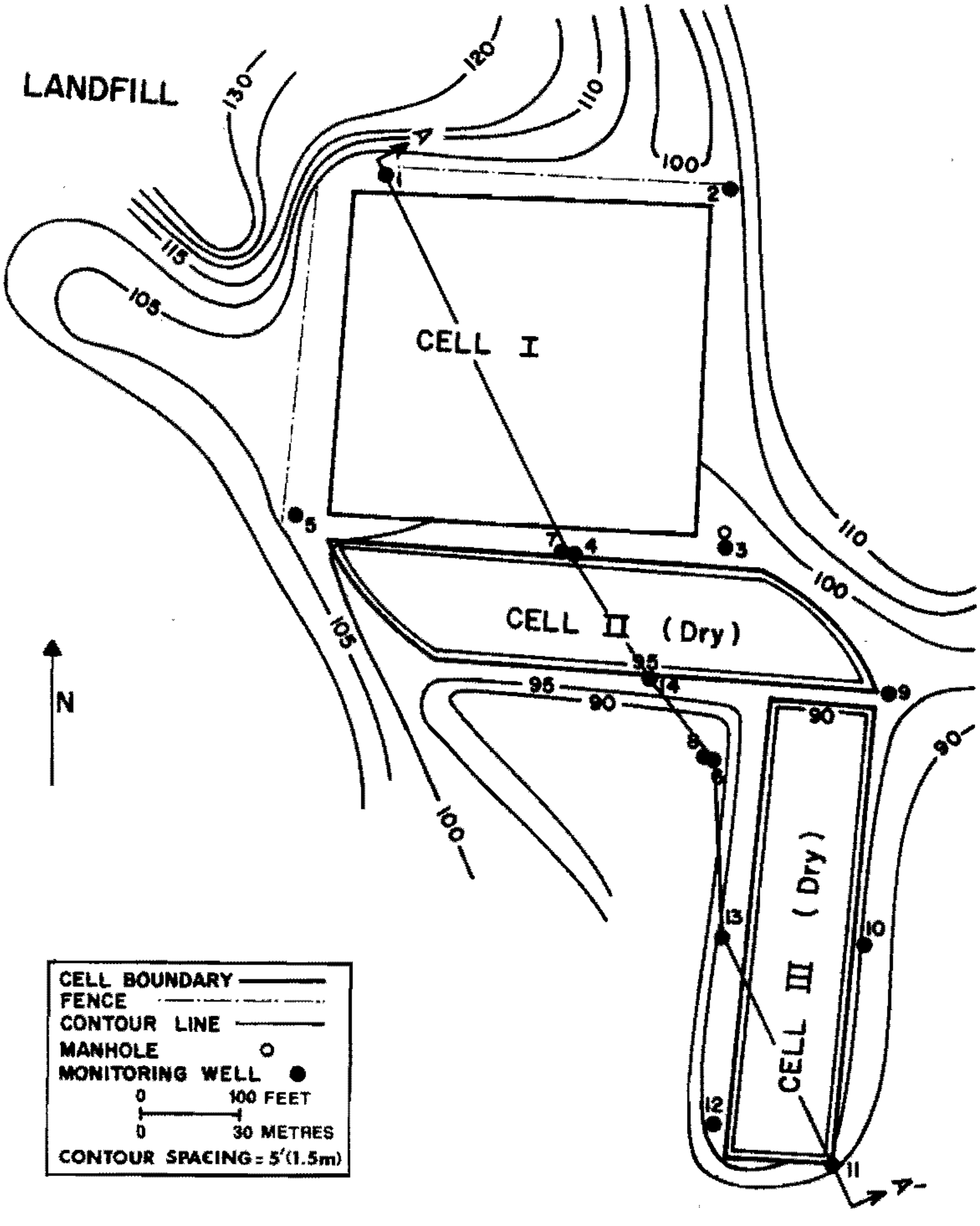
Three cells are available for use at McVille. However, only cell I (Figure 4) is used consistently. Wastes are discharged from cell I into cell II approximately twice a year for a period of less than a week. It is believed that cell III has never been used since the ponds were built in 1974. The area of cell I is approximately 2.50 acres (1.0 hectare); at a depth of 3 feet (0.91 m), it holds about 2.46×10^6 gallons (9.31×10^3 m^3) of wastewater.

Of considerable interest to the study is the dump located near the northwest corner of cell I (Figure 4). The dump is approximately ten years old.

Geologic Setting

The Pleistocene Coleharbor Formation is the most extensive surface formation in Nelson County. It is composed of three different facies: 1) till, 2) sand and gravel, and 3) silt and clay. At the McVille site, the sand and gravel facies occurs at the surface and is interpreted to be outwash transported to the area from eastern Nelson County by Wisconsinan meltwater streams (Bluemle, 1973). Test drilling near McVille by the North Dakota State Water Commission revealed a trench, filled with sand and gravel, incised into the Pierre Formation. The McVille site overlies the axis of this buried

Figure 4. Topographic map of the McVille, N.D. site. Geologic cross-section along A-A' is presented in Figure 5.


LANDFILL
130
120
110
115
105
100
A
A-
1
2
3
4
5
6
7
8
9
10
11
12
13
14
CELL I
CELL II (Dry)
CELL III (Dry)
95
90
105
100
N
CELL BOUNDARY
FENCE
CONTOUR LINE
MANHOLE ○
MONITORING WELL ●
0 100 FEET
0 30 METRES
CONTOUR SPACING = 5'(1.5m)

river valley; the sand and gravel is greater than 200 feet (60.9 m) thick there and thins rapidly away from the trench axis. Coarse-grained sediment within the buried valley comprises the McVille aquifer. Samples recovered from drilling for this study were fine- to medium-grained sand with numerous shale fragments (Figure 5, Appendix II-A).

Hydrogeologic Setting

The McVille waste stabilization ponds are in the buried fluvial sands comprising the McVille aquifer. The aquifer extends from T.152N., R.61W. to T.149N., R.58W. (Figure 6) and has the greatest potential for development of any aquifer in Nelson County, with an estimated storage capacity of 200,000 acre-feet (2.47×10^8 m^3) of water (Downey, 1973). In Nelson County, the aquifer is 31 miles (49.9 km) long and ranges in width from a quarter of a mile (0.4 km) to about half a mile (0.8 km). Figure 7 is a cross-section of the aquifer near the city of McVille. The aquifer is the source of water for that city; two wells pump approximately 70,000 gallons (2.65×10^2 m^3) of water a day from it (Downey, 1973).

Figure 8 illustrates the position of the water table beneath the McVille site on July 27, 1982. Along the north edge of cell I, the water table was approximately 85 feet (25.91 m) above the arbitrary datum, while south of cell III the water table was only 79 feet (24.1 m) above the subsurface datum. Thus, groundwater flows north to south under the study site towards its discharge area, the Sheyenne River. Using this contour map, the water table gradient was calculated to be 0.06 inches per foot (0.5 cm per meter). Similar

Figure 5. Geologic cross-section of the McVille site. See Figure 4 for location of cross-section.

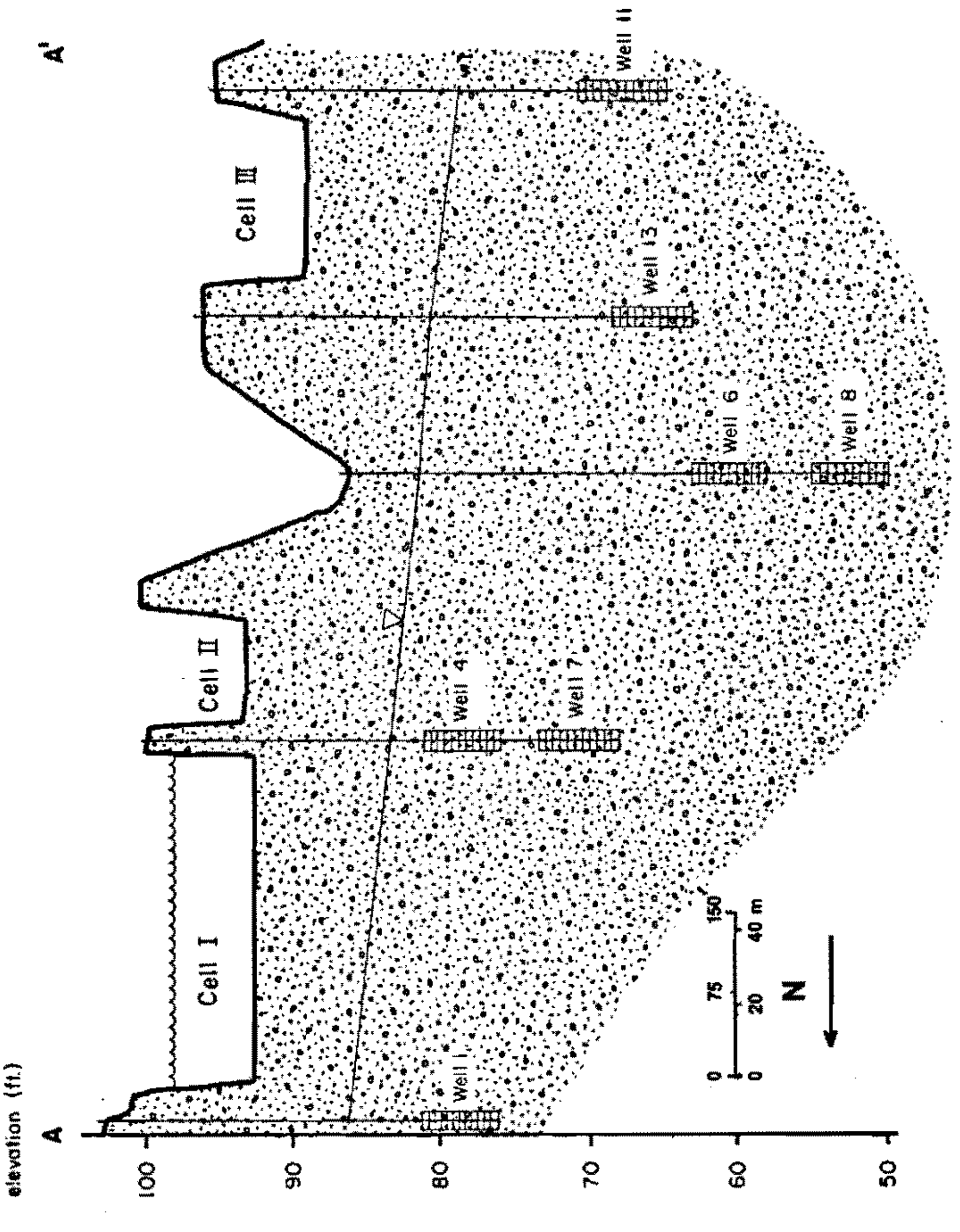

elevation (ft.)
100
90
80
70
60
50
A
A'
Cell I
Cell II
Cell III
Well 1
Well 4
Well 7
Well 6
Well 8
Well 13
Well 11
0
75
150
0
20
40 m
N

Figure 6. Location and trend of the McVille aquifer in Nelson County. Geologic cross-section along B-B' is presented in Figure 7.

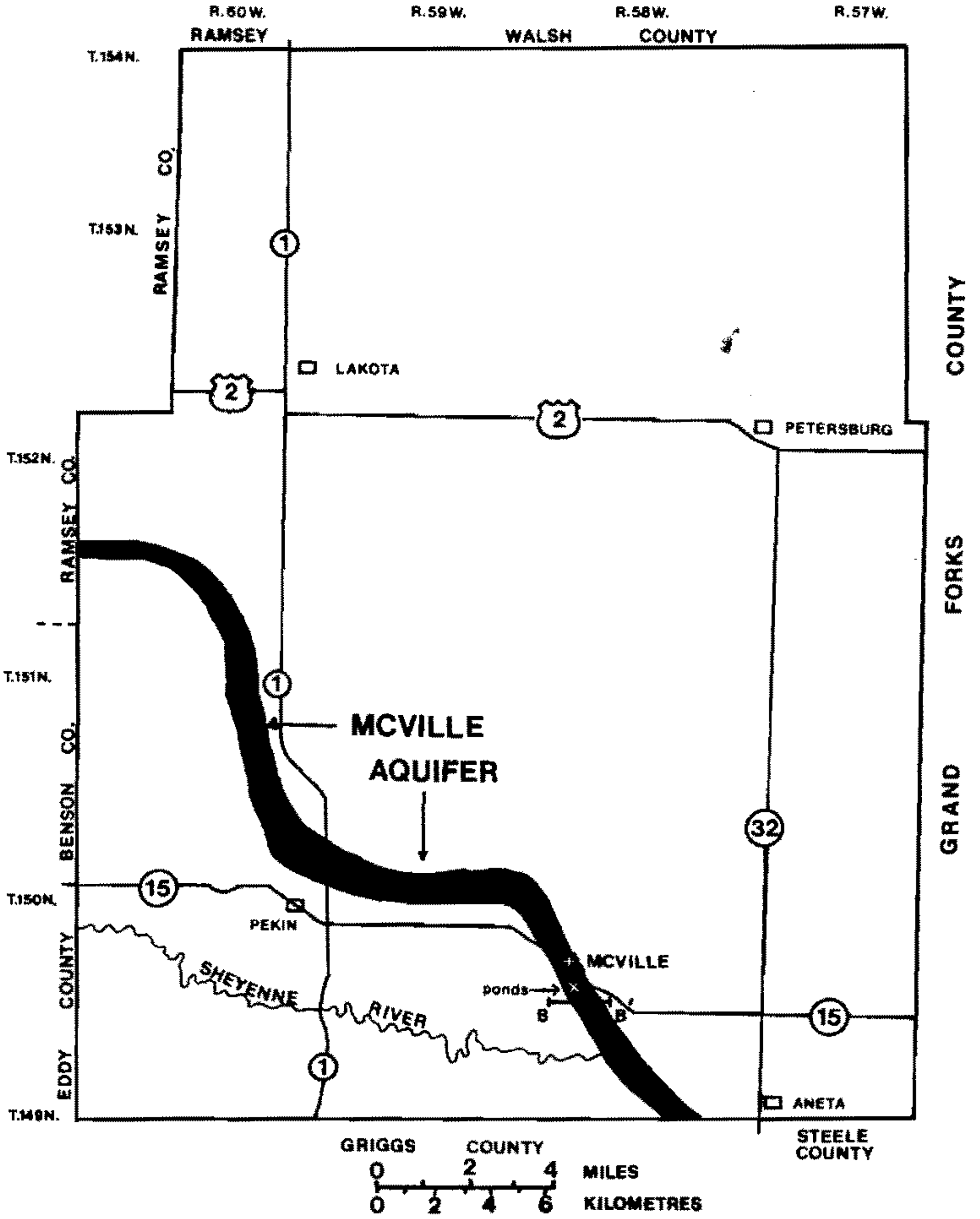
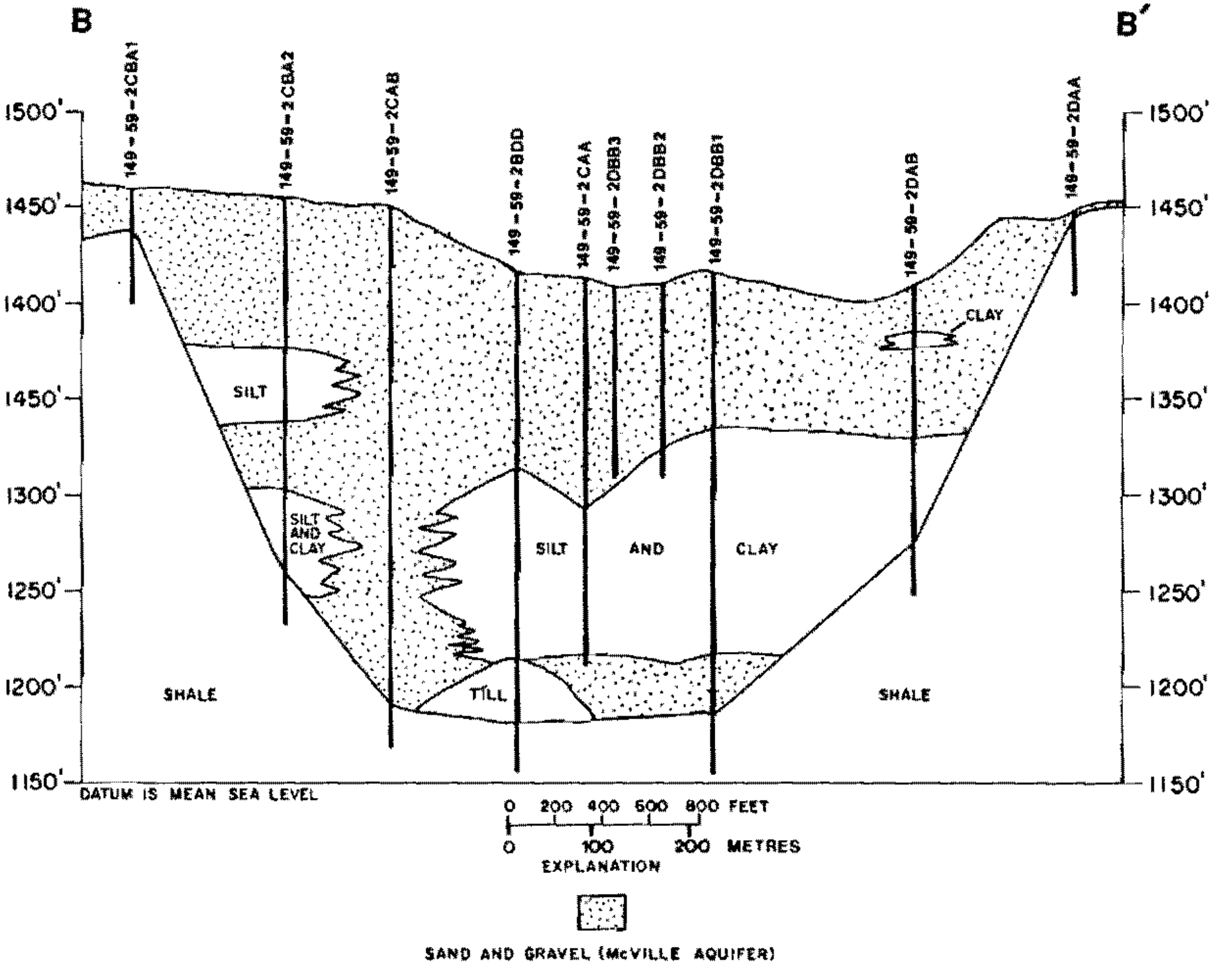
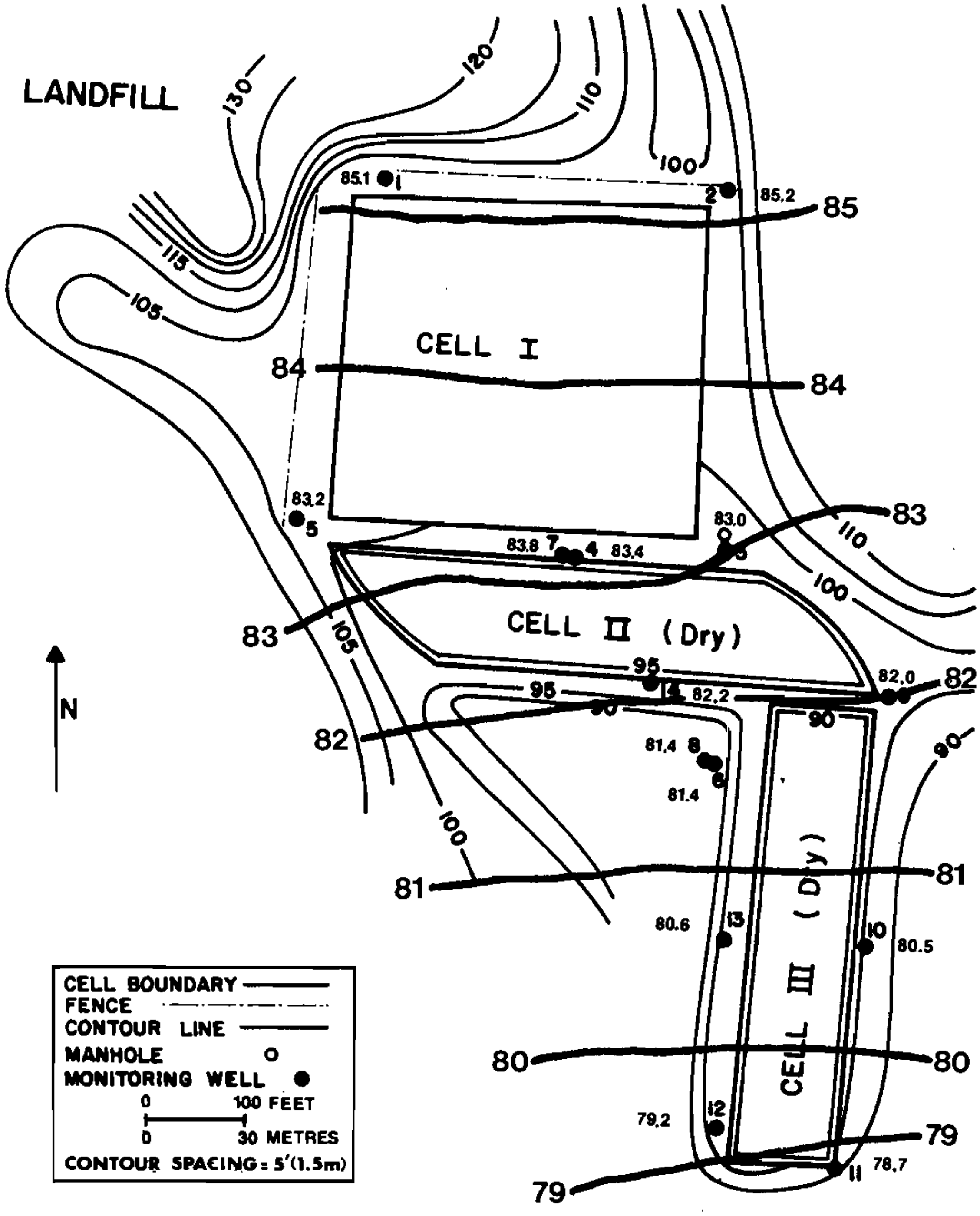

R.60W.
R.59W.
R.58W.
R.57W.
RAMSEY
WALSH COUNTY
T.154N.
T.153N.
RAMSEY CO.
1
LAKOTA
2
PETERSBURG
T.152N.
RAMSEY CO.
T.151N.
BENSON CO.
MCVILLE AQUIFER
32
T.150N.
15
PEKIN
MCVILLE
ponds
B
B
SHEYENNE RIVER
EDDY COUNTY
T.149N.
ANETA
GRIGGS COUNTY
STEELE COUNTY
0 2 4 MILES
0 2 4 6 KILOMETRES
GRAND FORKS COUNTY

Figure 7. Cross-section of the McVille aquifer near the city of McVille. See Figure 6 for location of cross-section. From Downey, 1973.



B
B′
149-59-2CBA1
149-59-2CBA2
149-59-2CAB
149-59-2BDD
149-59-2CAA
149-59-2DBB3
149-59-2DBB2
149-59-2DBB1
149-59-2DAB
149-59-2DAA
1500′
1450′
1400′
1450′
1300′
1250′
1200′
1150′
1500′
1450′
1400′
1350′
1300′
1250′
1200′
1150′
SILT
SILT AND CLAY
SILT AND CLAY
CLAY
TILL
SHALE
SHALE
DATUM IS MEAN SEA LEVEL
0 200 400 600 800 FEET
0 100 200 METRES
EXPLANATION
SAND AND GRAVEL (McVILLE AQUIFER)

Figure 8. Water table contours (heaviest lines), in feet above an arbitrary datum, superimposed on a topographic map of the McVille site, July 27, 1982.


LANDFILL
130
120
110
100
115
105
85.1
1
2
85.2
85
CELL I
84
84
83.2
5
83.8
7
4
83.4
83.0
3
83
110
100
83
CELL II (Dry)
105
95
95
14
82.2
90
82.0
82
82
90
90
81.4
8
9
81.4
N
100
81
81
80.6
13
10
80.5
CELL III (Dry)
80
80
79.2
12
79
79
11
78.7
CELL BOUNDARY
FENCE
CONTOUR LINE
MANHOLE ○
MONITORING WELL ●
0 100 FEET
0 30 METRES
CONTOUR SPACING: 5'(1.5m)

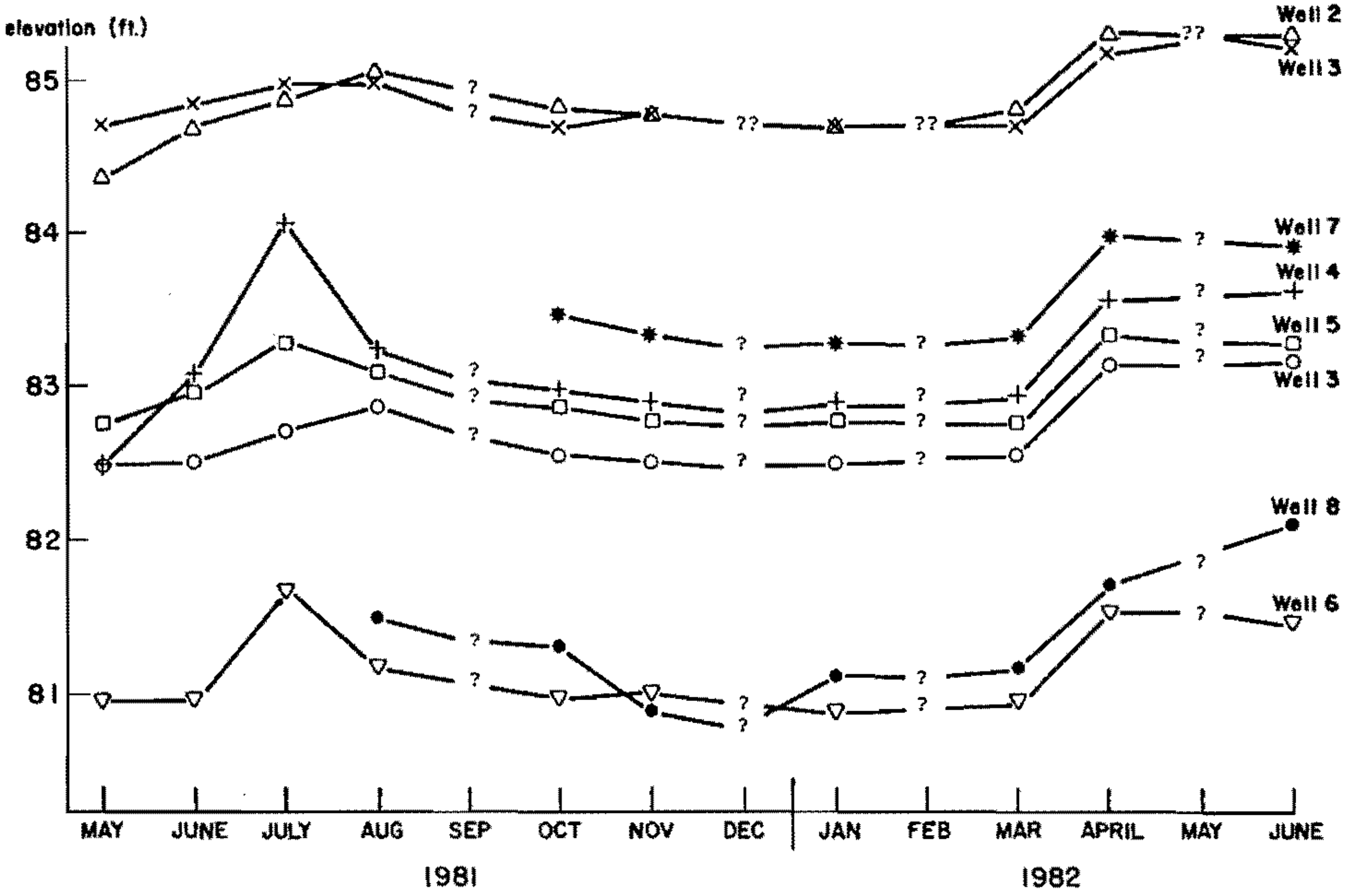
gradients were determined using water level data from other months. Water level readings for the entire study period are listed in Table 3.

During the study period, seasonal variations in the water table were minor at the McVille site (Figure 9). However, an unusual rise in water levels in wells 4, 5, and 6 in relation to the other wells occurred in July, 1981. This is explained by the transfer of wastewater from cell I to cell II that occurred at that time. Wastewater is discharged into cell II during peak sewage production in summer through a pipe/gate assembly approximately 50 feet (15.2 m) east of well 5 (Figure 8). The distinct rise in water levels in wells 4, 5, and 6, therefore, is assumed to be a response to localized recharge by the transfer procedure. Wells 7 and 8 were not installed at that time; but they, too, would have shown elevated water levels in July, 1981.

The velocity of groundwater flow is dependent on the hydraulic gradient, porosity, and hydraulic conductivity of sediments through which it moves. The hydraulic conductivity of the sediment under the McVille site was estimated from grain-size distribution curves using the statistical method of Masch and Denny (1966) and by using the result of a single-well response (slug) test (Hvorslev, 1951).

The Masch and Denny method of determining hydraulic conductivity was performed on samples recovered during the drilling of McVille wells 7 and 8. Little difference exists between cumulative grain-size distribution curves of the samples. All hydraulic conductivity values derived from those curves, with one exception (Table 5), are of the same order (10^{-5} m/s).

Figure 9. Water table fluctuations at the McVille site. Wells 9 - 14 were constructed in July, 1982.


elevation (ft.)
85
84
83
82
81
Well 2
Well 3
Well 7
Well 4
Well 5
Well 3
Well 8
Well 6
MAY
JUNE
JULY
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APRIL
MAY
JUNE
1981
1982

In November, 1981, a single-well response (slug) test was performed on McVille well 8. Using the equation:

$$K = \frac{R^2 \ln \frac{L}{R}}{2\ LT_o} ,$$

where K = hydraulic conductivity (cm/s)
R = radius of pipe (cm)
L = length of pipe (cm)
and T_o = basic time lag (seconds, measured graphically, see Appendix VI)

a hydraulic conductivity of 3.49×10^{-5} m/s was determined. This is in general agreement with values obtained from the Masch and Denny method.

The average linear velocity of the groundwater at this site was calculated using the formula:

$$\overline{V} = \frac{K}{n} \cdot \left(\frac{dh}{dl}\right) ,$$

where $\overline{V}$ = average linear velocity (m/s)
K = hydraulic conductivity of sediment (m/s)
n = sediment porosity (assumed to be 0.3 for sand; Freeze and Cherry, 1979, p. 37).
and $\left(\frac{dh}{dl}\right)$ = gradient of water table surface (m/m)

A value of 6.92×10^{-7} m/s was obtained using the above equation. At this velocity, groundwater travel time from well 1 to 11 is 15.4 years. Because the velocity used in the calculation is an average, some parcels of water travelling along circuitous routes will take much longer while other parcels taking shorter paths will arrive in less time.

Background Chemical Quality of Groundwater

In general, water from the McVille aquifer is a calcium-bicarbonate type of good quality. The TDS concentration is typically less than 300 mg/L (Downey, 1973). In an applicability study of local groundwaters for irrigation purposes, two McVille aquifer water samples were classified as having low alkali hazard and a moderate to high salinity hazard (Downey, 1973). The high salinity of the water makes it of marginal quality for irrigation purposes; however, high salinity waters have been used successfully for some crops where drainage and soil properties permit (Downey, 1973).

A farm well and monitoring wells upgradient from the McVille waste stabilization ponds were sampled to ascertain the background chemical quality of groundwater in the vicinity of the ponds. Data from upgradient control wells are compared with data from other wells at the site in the following section. In general, McVille aquifer water has less than 1 mg/L total iron and nitrate, less than 10 mg/L ammonium and chloride, and less than 100 mg/L calcium, magnesium, sodium, and sulfate (Downey, 1971, p. 451). All chemical and bacterial data from the McVille site are listed in Appendix VII.

Chemical Quality of Groundwater Samples

Total Hardness, Calcium (Ca^{2+}), Magnesium (Mg^{2+})

The lowest readings of total hardness, calcium, and magnesium occur at well 2, upgradient form cell I, and the lateral farm well. Highest values occur at upgradient well 1, lateral well 5, and downgradient wells 10, 11, and 12 (Figures 10, 11, 12).

The farm well, located about 1/4 mile (0.4 km) west of the pond site, had a July, 1982 total hardness reading of only 235 mg/L; not coincidentally, calcium and magnesium also were lowest in the farm well (Figures 10, 11, 12). This well and well 2 reflect background concentrations of these parameters for the McVille aquifer.

Well 1, approximately 5 feet (1.5 m) downgradient from the base of the dump, had a July, 1982 total hardness reading of 358 mg/L, nearly 100 mg/L higher than well 2. Well 5 had a July, 1982 total hardness concentration of 422 mg/L (Figure 10) and a mean value of 566 mg/L throughout the study period. The contrast of hardness, calcium, and magnesium values of wells 1 and 5 with those of wells 2 and 3 (Figures 10, 11, 12) suggest that leachates from the dump are reaching the groundwater. Although well 5 is farther from the dump than well 1, its position more directly downgradient from the dump causes it to receive greater amounts of calcium and magnesium ions which, collectively, elevate total hardness in groundwater. Alternatively, a hardness halo may have formed downgradient from the dump in the vicinity of well 5. The formation of a hardness halo is the result of exchange between cations from surface sources and aquifer particles with cations adsorbed on interstitial clay particles in the aquifer. The dump is a likely source of cations such as ammonium; as these components travel downgradient, they become adsorbed onto clay particles. Simultaneously, calcium and magnesium ions are

Figure 10. Total hardness concentrations (mg/L) in groundwater at the McVille site. July 27, 1982. Wells 7 and 8 are relatively deep; the values are in parentheses and not contoured.

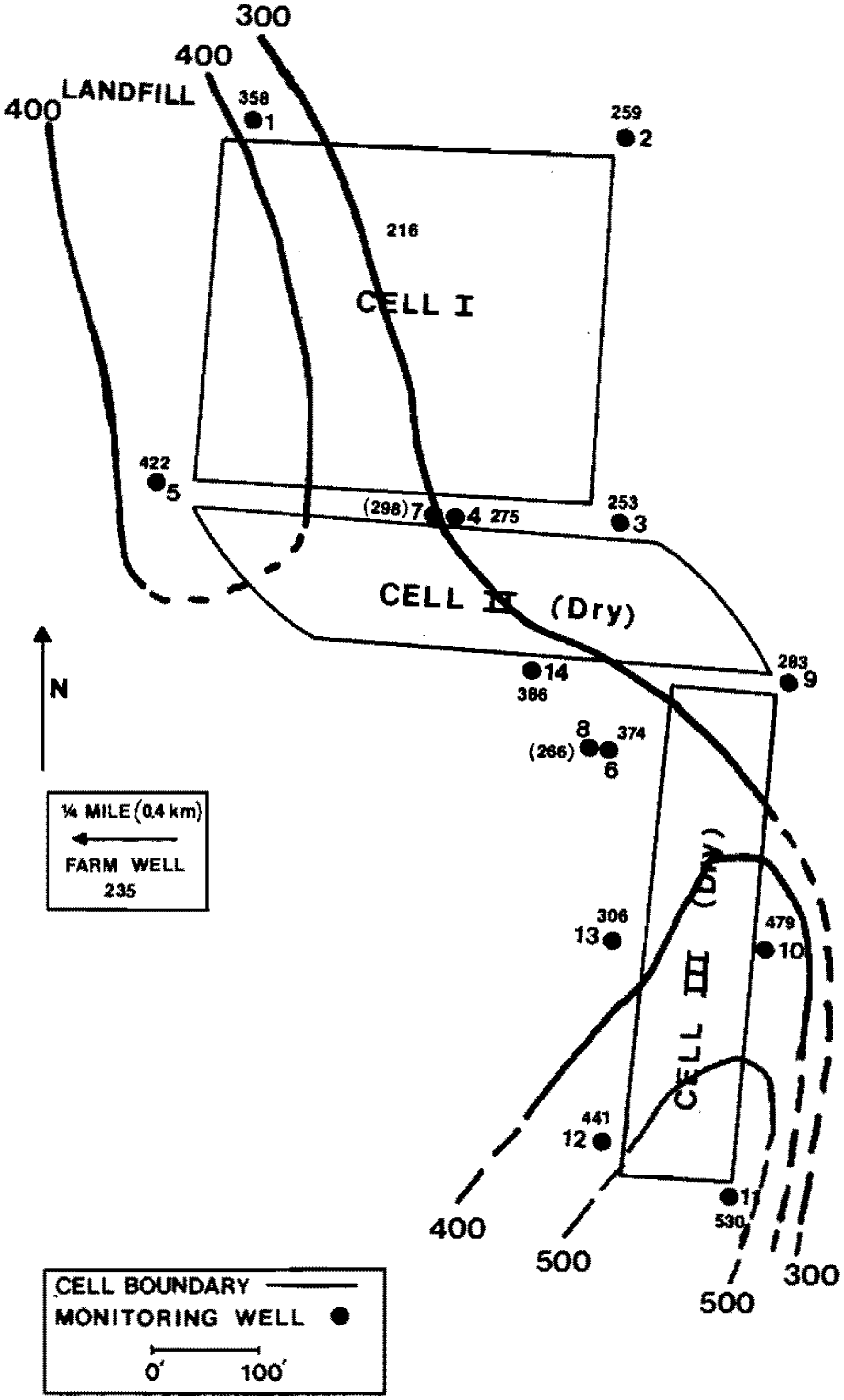

300
400
400
LANDFILL
358
1
259
2
216
CELL I
422
5
(298) 7
4 275
253
3
CELL II (Dry)
N
283
9
14
386
8
(266)
374
6
¼ MILE (0.4 km)
FARM WELL
235
CELL III (Dry)
306
13
479
10
441
12
11
530
400
500
500
300
CELL BOUNDARY
MONITORING WELL ●
0'
100'

Figure 11. Calcium concentrations (mg/L) in groundwater at the McVille site. July 27, 1982. Wells 7 and 8 are relatively deep; the values are in parentheses and not contoured.

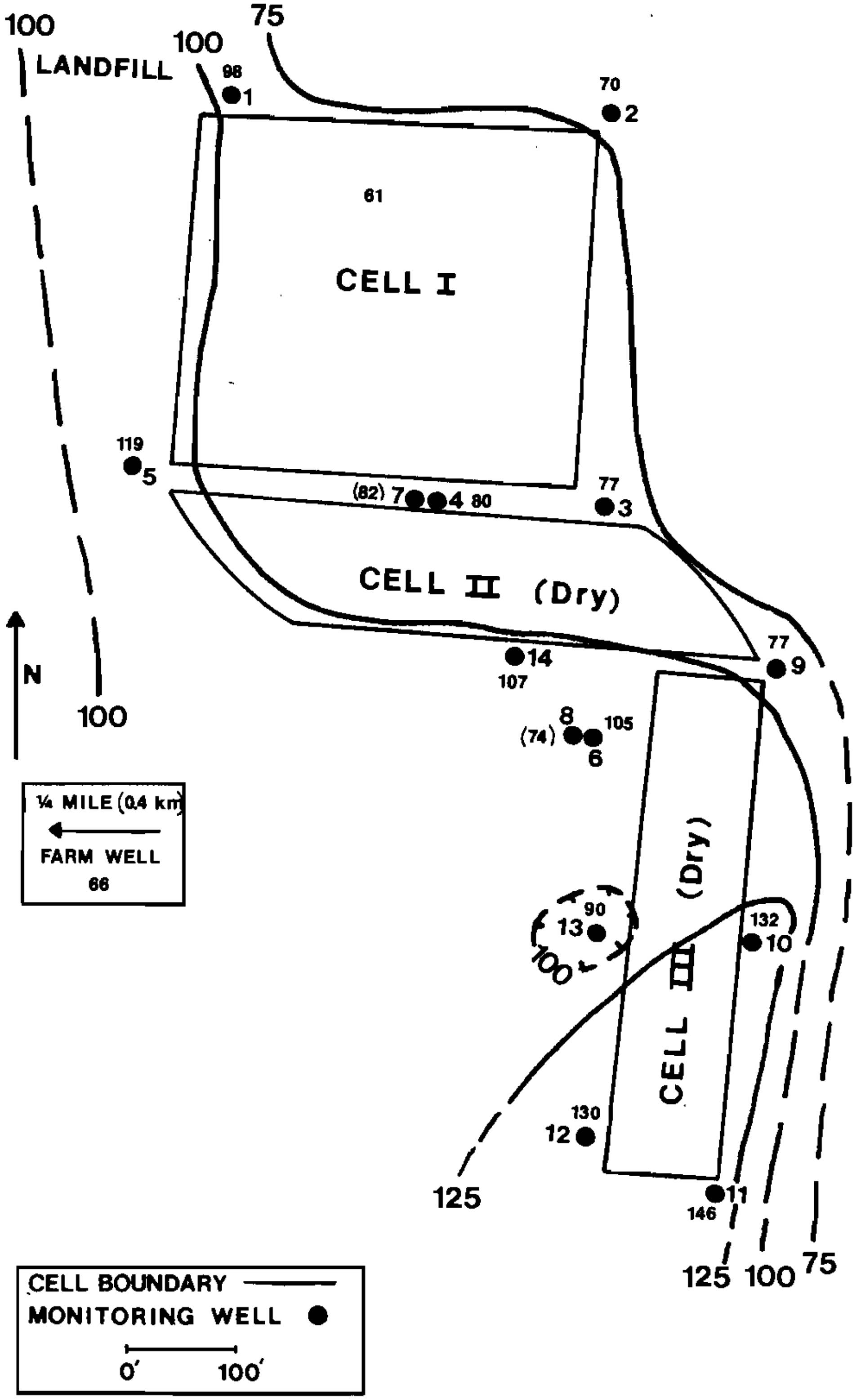
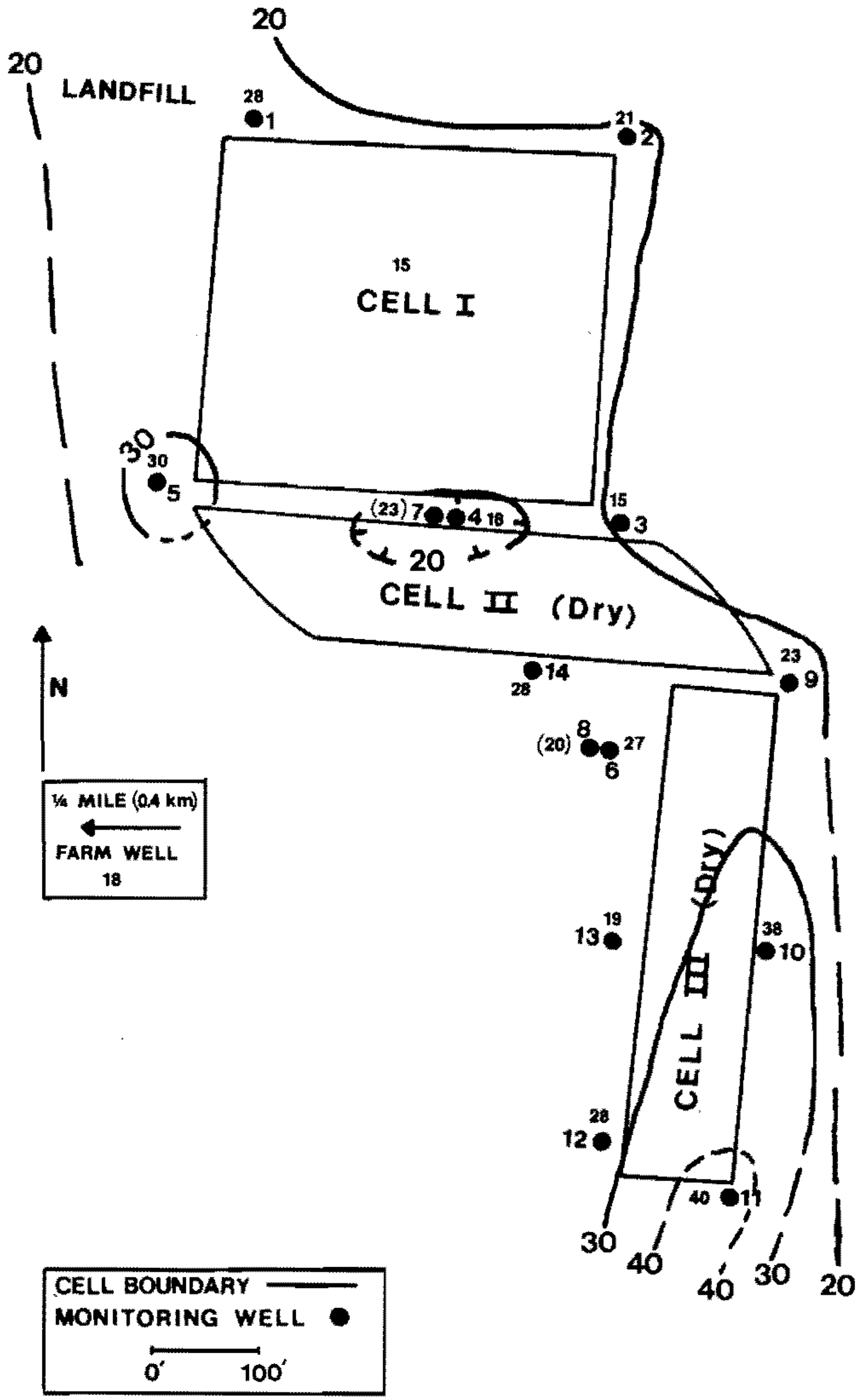

100
LANDFILL
100
75
98
1
70
2
61
CELL I
119
5
(82) 7
4 80
77
3
CELL II (Dry)
77
9
14
107
N
100
8
(74)
105
6
¼ MILE (0.4 km)
FARM WELL
66
(Dry)
90
13
100
132
10
CELL III
130
12
125
11
146
125 100 75
CELL BOUNDARY
MONITORING WELL ●
0′ 100′

Figure 12. Magnesium concentrations (mg/L) in groundwater at the McVille site. July 27, 1982. Wells 7 and 8 are relatively deep; the values are in parentheses and not contoured.


20
20
LANDFILL
28
1
21
2
15
CELL I
30
30
5
(23) 7
4 18
20
15
3
CELL II (Dry)
23
9
N
14
28
8
(20)
27
6
¼ MILE (0.4 km)
FARM WELL
18
CELL III (Dry)
19
13
38
10
28
12
40
11
30
40
40
30
20
CELL BOUNDARY
MONITORING WELL ●
0′
100′

released into solution, causing concentrations of those parameters to increase downgradient from the dump.

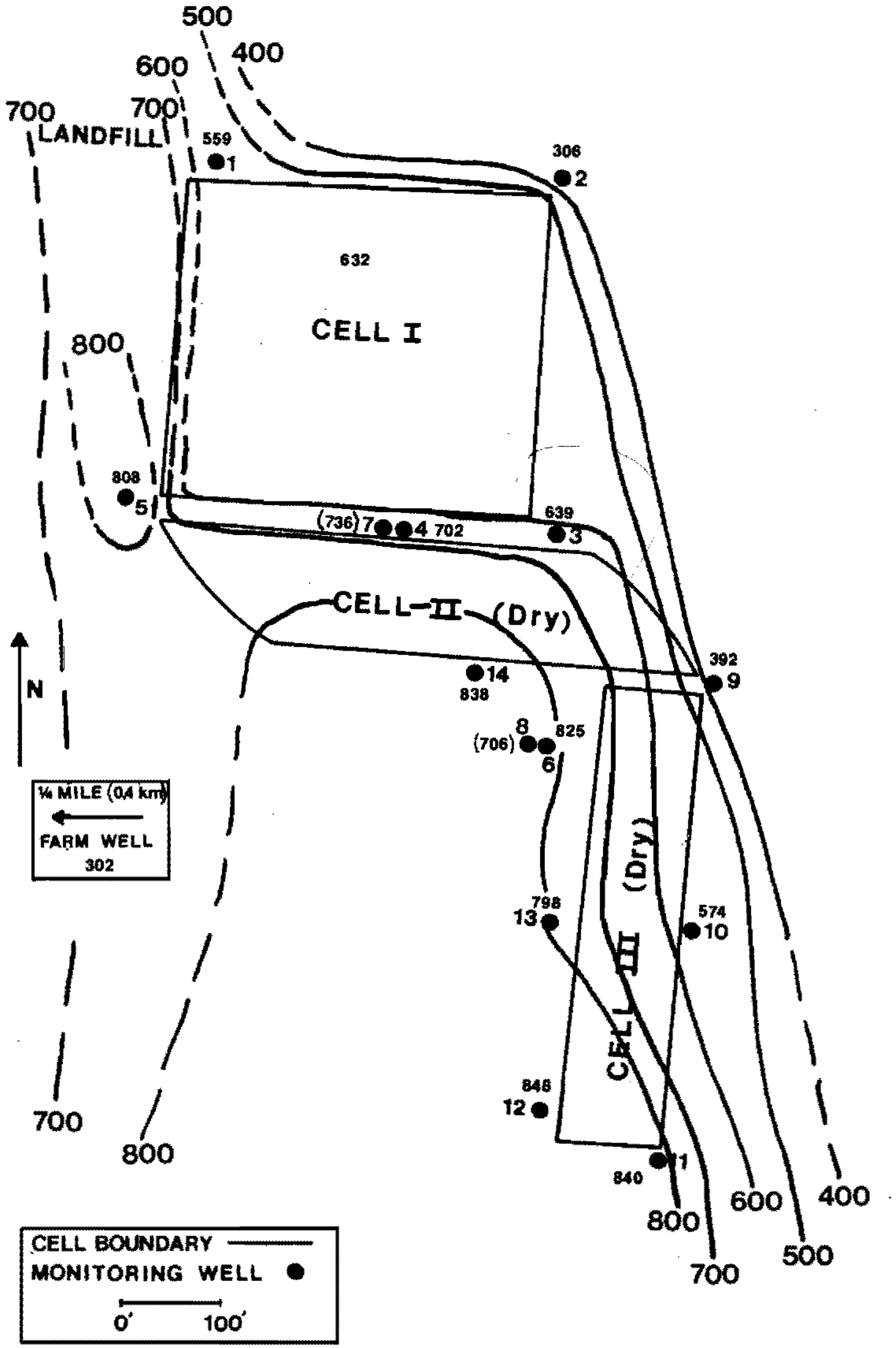
Wells immediately downgradient from cell I have intermediate concentrations of total hardness, calcium, and magnesium. Wells 10, 11, 12, and 13, however, have the highest concentrations of those parameters (Figures 10, 11, 12). The elevated values at these downgradient wells are probably not the result of waste dump leachates reaching groundwater because wells between the dump and those wells are not high in total hardness. Instead, a hardness halo may have formed in the vicinity of those wells. Ammonium ions in wastewater percolating from cell I are adsorbed on aquifer particles. Concurrently, calcium and magnesium ions are released into solution, forming the hardness halo downgradient from cell I (Figure 10).

Because the McVille aquifer is incised in the sodic Pierre shale, montmorillonitic clays in the aquifer are likely to be sodic as well. Therefore, calcium and magnesium ions can be attenuated by sodium-rich clays in the aquifer by adsorption. If this is occurring, it is taking place downgradient from the McVille site. Dilution also will attenuate these constituents.

Total Dissolved Solids (TDS)

Background TDS values of approximately 300 mg/L occur at well 2 and the farm well (Appendix VII). The TDS distribution pattern (Figure 13) indicates that both the dump and the sewage ponds are contributing dissolved solids to the groundwater. TDS values are considerably higher at well 1 (559 mg/L), just downgradient from the dump, than at

Figure 13. Total dissolved solids concentrations (mg/L) in groundwater at the McVille site. July 27, 1982. Wells 7 and 8 are relatively deep; the values are in parentheses and not contoured.


500
400
600
700
700
LANDFILL
559
1
306
2
632
CELL I
800
808
5
(736) 7
4 702
639
3
CELL-II-(Dry)
392
9
14
838
8
(706)
825
6
N
¼ MILE (0.4 km)
FARM WELL
302
(Dry)
CELL III
798
13
574
10
848
12
840
1
700
800
800
600
400
700
500
CELL BOUNDARY
MONITORING WELL ●
0'
100'

well 2 (306 mg/L, Figure 13). The high TDS levels at well 5, lateral to the pond, also suggest a source at the dump.

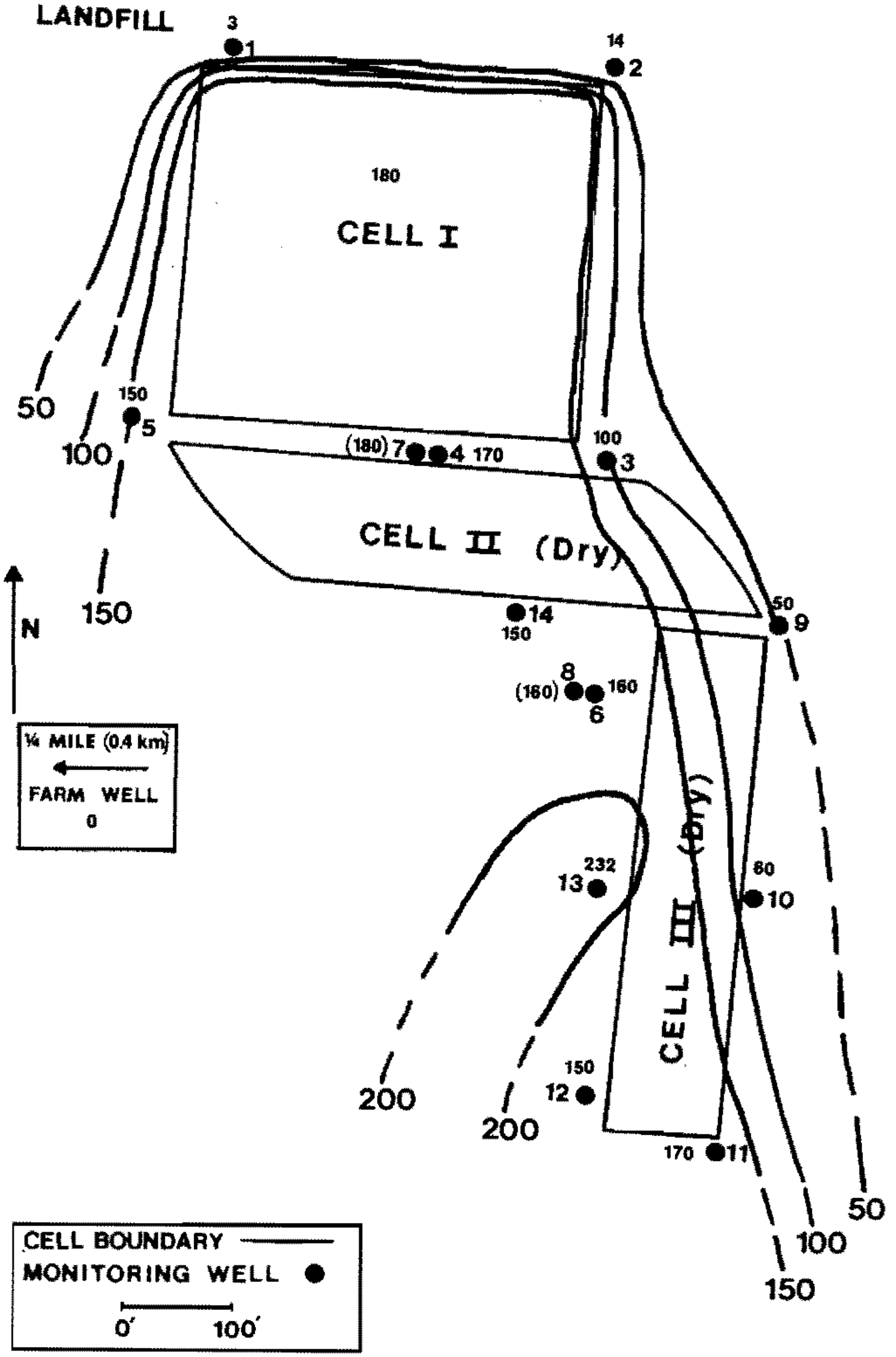
Many of the wells downgradient from cells I and II have TDS concentrations in excess of 800 mg/L, more than a two-fold increase from background readings. The contoured data of the site from July, 1982 (Figure 13) indicate a plume of water with high TDS concentrations extending downgradient from cell I. It is not known how far the plume extends south of the site. Dilution with ambient groundwater beyond the study site will eventually reduce TDS concentrations to background levels.

Chloride (Cl^-)

Groundwater from the McVille aquifer in the McVille area has generally less than 10 mg/L chloride (Downey, 1971, p. 451). The high chloride concentration in wastewater makes it an excellent indicator of groundwater contamination by sewage pond seepage from the McVille site. Attenuation of chloride occurs by dispersion, where uncontaminated groundwater mixes with the contaminant plume and lowers chloride concentrations downgradient, eventually to background values. The July, 1982, background readings from the farm well and well 2 were 0 mg/L and 14 mg/L, respectively (Figure 14), and mean values are 3 mg/L and 4 mg/L, respectively.

High chloride readings occur downgradient from cell I; some wells have chloride concentrations two orders of magnitude greater than those in the control wells (Figure 14). Wells 9 and 10, however, have lower concentrations than other downgradient wells. Because the

Figure 14. Chloride concentrations (mg/L) in groundwater at the McVille site. July 27, 1982. Wells 7 and 8 are relatively deep; the values are in parentheses and not contoured.


LANDFILL
3
1
14
2
180
CELL I
150
5
50
100
(180) 7
4 170
100
3
CELL II (Dry)
150
N
50
9
14
150
8
(160)
160
6
¼ MILE (0.4 km)
FARM WELL
0
CELL III (Dry)
232
13
60
10
150
12
200
200
170
11
50
100
150
CELL BOUNDARY
MONITORING WELL ●
0'
100'

highly mobile chloride ion is not affected by redox conditions nor are they adsorbed onto negatively charged clays, the low chloride values at wells 9 and 10 suggest that those wells lie on the edge of the chloride plume.

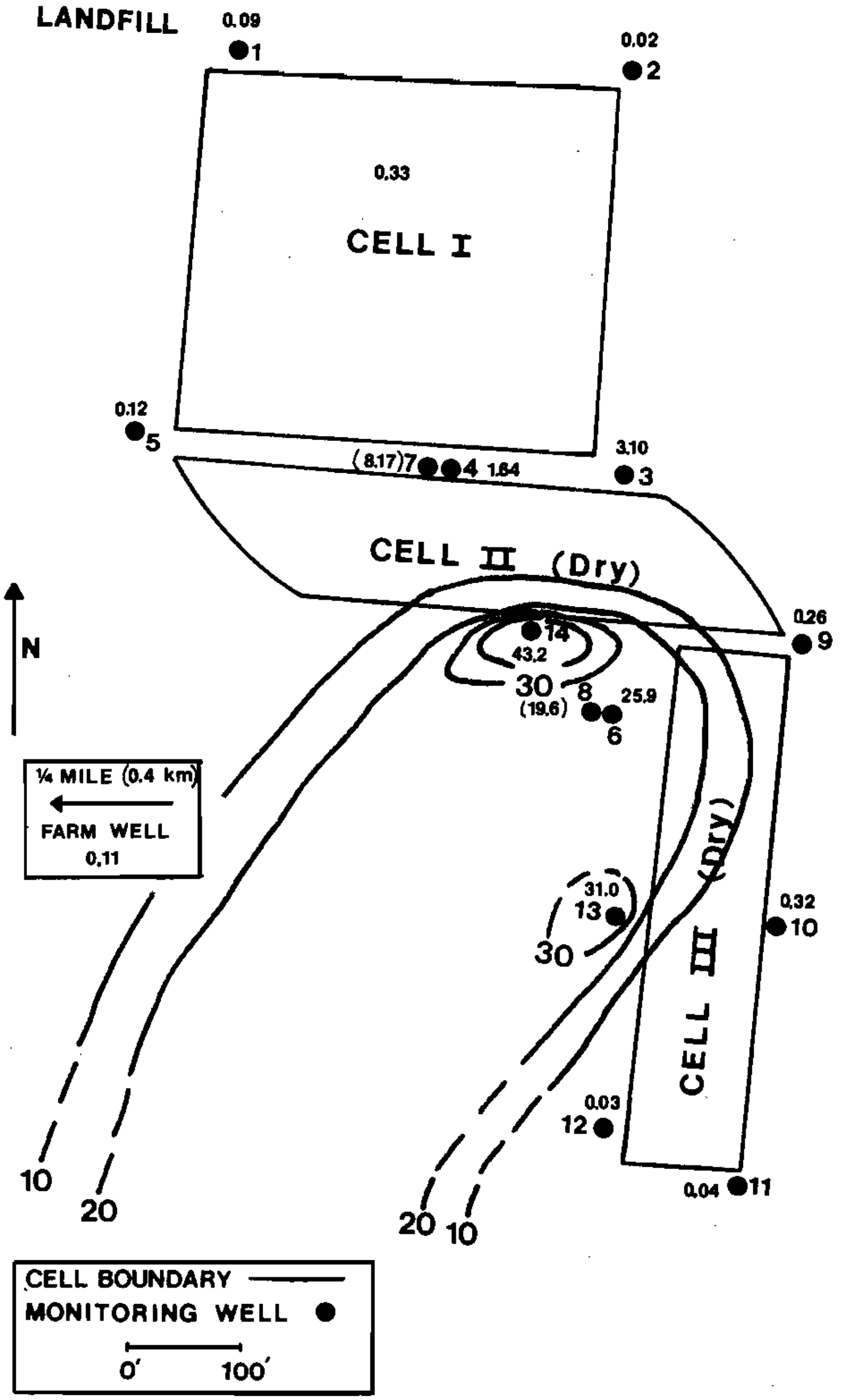
The chloride concentration at well 13 is particularly high (232 mg/L, Figure 14). Chloride concentrations at well 6, 200 feet (60.9 m) upgradient from well 13, and well 12, 200 feet (60.9 m) downgradient, are 160 and 150 mg/L, respectively. This concentration distribution suggests a discrete body of high-chloride groundwater in the vicinity of well 13. This high chloride reading may represent a slug of wastewater discharged from cell I into cell II. Cell II, having no sludge layer, would not retard infiltration of the wastewater into the subsurface. Because the slug has not advanced very far downgradient, it would still have fairly distinct boundaries within a larger, lower concentration chloride plume extending downgradient from cell I (Figure 14).

Ammonia (NH_3) and ammonium ion (NH_4^+)

Groundwater and wastewaters sampled at the McVille site had pH values less than 9. Below this value, the ammonium ion (NH_4^+) is the dominant nitrogen species (Preul and Schroepfer, 1968). Therefore, despite the fact that the Health Department reported "ammonia" values, ammonium was actually being detected.

The July, 1982 ammonium reading of McVille wastewater (0.33 mg/L, Figure 15) is probably not indicative of actual ammonium concentrations in the pond, as all previous values exceeded 6 mg/L (Appendix VII).

Figure 15. Ammonium concentrations (mg/L) in groundwater at the McVille site. July 27, 1982. Wells 7 and 8 are relatively deep; the values are in parentheses and not contoured.


LANDFILL
0.09
1
0.02
2
0.33
CELL I
0.12
5
(8.17)7
4 1.84
3.10
3
CELL II (Dry)
N
0.26
9
14
43.2
30
8
(19.6)
25.9
6
¼ MILE (0.4 km)
FARM WELL
0.11
(Dry)
31.0
13
30
0.32
10
CELL III
0.03
12
10
20
0.04
11
20
10
CELL BOUNDARY
MONITORING WELL ●
0'
100'

Disregarding the last ammonium reading, it is normally a good indicator of sewage percolation and contamination of groundwater.

Not all downgradient wells have high ammonium readings. In July, 1982, for example (Figure 15), wells 9, 10, 11, and 12 had background readings. Conversely, wells 6, 8, 13, and 14 had very high ammonium concentrations while wells 3, 4, and 7 had intermediate values.

Several factors determine the concentrations of ammonium at the McVille site: first, the bottom sludge layer of cell I, and second, the periodic transfer of wastewater from cell I into cell II.

The positively charged ammonium ions in wastewater may be adsorbed onto fine-grained particles in the sludge layer as they percolate from the pond; hence, partial attenuation is possible within the pond itself. The ammonium concentration of wastewater which moves through the sludge layer can be estimated by the ammonium concentration of wells 3, 4, and 7.

It is possible that the high ammonium ion readings in wells 6, 8, 13, and 14 are the result of occasional cell II discharges. Because the bottom of cell II contains no sludge layer, it offers less resistance to wastewater infiltration and has less adsorptive capacity. Hence, ammonium ions entering cell II infiltrate more rapidly to the groundwater.

The large reduction of ammonium values over a small distance (wells 10, 11, and 12 compared to well 13, for example) suggests strong attenuation of ammonium by adsorption between well 13 and wells

10, 11, and 12. The low nitrate concentrations in wells 10, 11, and 12 (Figure 16) indicate that nitrification of ammonium in the aquifer is not occurring.

Nitrate (NO_3^-)

High levels of nitrate were recorded at wells 1, 2, 5, and 9 at the McVille site in July, 1982 (Figure 16). The McVille sewage pond is not the source of nitrate in the groundwater, however. While aerobic conditions in the pond promote nitrification of ammonia to nitrate by the reaction:

$$(1) \quad 2O_2 + NH_4^+ \longrightarrow NO_3^- + 2H^+ + H_2O \quad ,$$

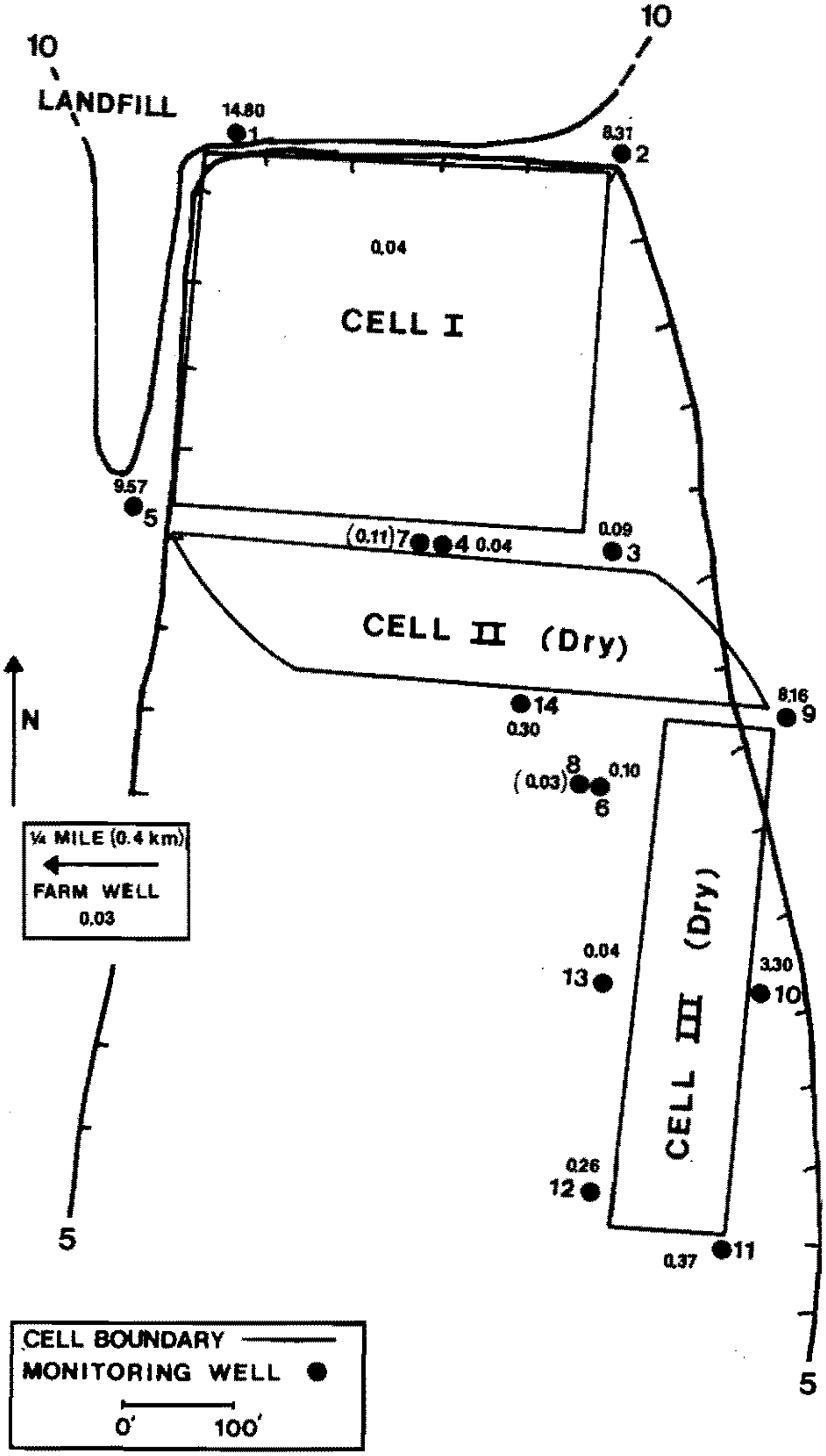
bacteria in the pond consume and denitrify that nitrate as soon as it is formed by the reaction:

$$(2) \quad 5CH_2O + 4NO_3^- \longrightarrow 2\,N_{2(g)} + 5HCO_3^- + H^+ + 2H_2O \ .$$

Gaseous nitrogen is then outgassed from the system (Freeze and Cherry, 1979, p. 118). Thus, nitrates normally remain an insignificant constituent in wastewater. The nitrates in the wells adjacent to the McVille ponds must have originated from a source other than the ponds.

Groundwaters with high levels of dissolved oxygen tend to oxidize (nitrify) the ammonium ion (reaction 1). Wells 1, 2, and 5 at McVille consistently had the highest dissolved oxygen readings of all wells at the site. Oxidizing conditions upgradient from the pond apparently nitrified the ammonium derived from animal wastes (Kehew, 1982), and converted it to nitrate. The distribution of nitrate at the McVille

Figure 16. Nitrate concentrations (mg/L) in groundwater at the McVille site. July 27, 1982. Wells 7 and 8 are relatively deep; the values are in parentheses and not contoured.


10
10
LANDFILL
14.80
1
8.31
2
0.04
CELL I
9.57
5
(0.11) 7
4 0.04
0.09
3
CELL II (Dry)
N
8.16
9
14
0.30
8
(0.03)
0.10
6
¼ MILE (0.4 km)
FARM WELL
0.03
CELL III (Dry)
0.04
13
3.30
10
0.26
12
0.37
11
5
5
CELL BOUNDARY
MONITORING WELL ●
0'
100'

site indicates that wastewater percolating from cell I either dilutes the nitrate or promotes denitrification of the existing nitrate. Because no mechanism promoting low pE conditions exists below the dump, such as a sludge layer, nitrate is not reduced there. Well 5 water therefore reflects the lack of denitrifying conditions below the dump (Figure 16). Because nitrates are very mobile and are not adsorbed by clay particles, dispersion must be the dominant attenuation mechanism.

Total Iron (Fe) and Sulfate (SO_4^{2-})

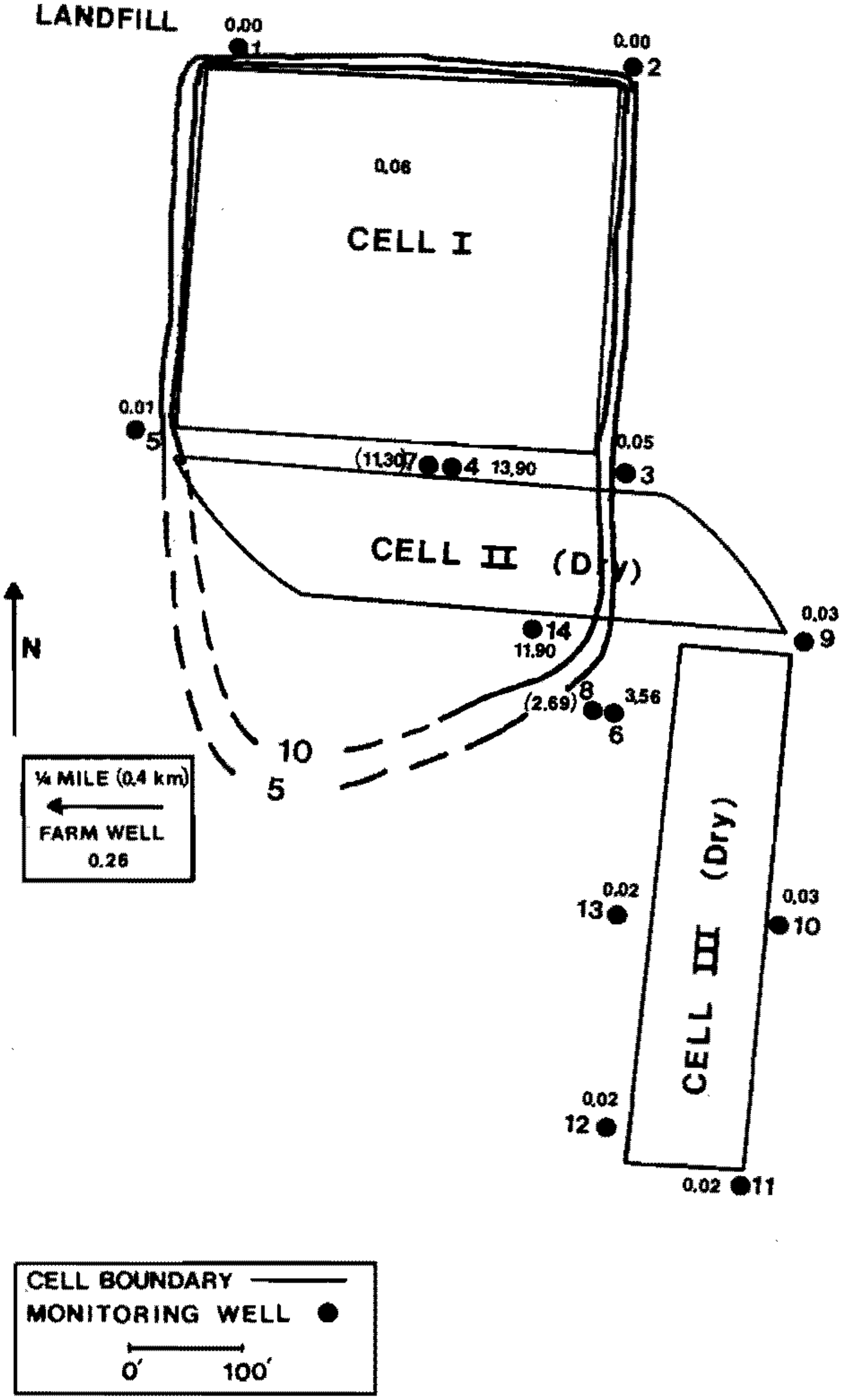
Local groundwater redox conditions control the chemical form of iron and sulfate in groundwater. Total iron and sulfate concentrations at the McVille site are shown in Figures 17 and 18, respectively. Oxidizing conditions (high pE) upgradient from the pond site promote the reaction:

$$(3)\quad O_2 + 4Fe^{2+} + 4H^+ \longrightarrow 4Fe^{3+} + 2H_2O\ .$$

The product, ferric iron (Fe^{3+}), is relatively insoluble and combines with dissolved oxygen in groundwater to form $Fe_2O_{3(s)}$ or $Fe(OH)_{3(s)}$ (Freeze and Cherry, 1979, p. 124). Because most iron has combined to form solid iron oxides, total iron readings are low. Because wells 1, 2, and 5 have high levels of dissolved oxygen, dissolved iron concentrations are low near those wells (Figure 17).

Lower pE conditions in sewage pond bottoms and in groundwater downgradient from leaking ponds lead to the presence of ferrous iron (Fe^{2+}) as the dominant species of dissolved iron. The reduced

Figure 17. Iron concentrations (mg/L) in groundwater at the McVille site. July 27, 1982. Wells 7 and 8 are relatively deep; the values are in parentheses and not contoured.


LANDFILL
0.00
1
0.00
2
0.06
CELL I
0.01
5
(11.30)7
4
13.90
0.05
3
CELL II (Dry)
N
14
11.90
0.03
9
8
(2.69)
3.56
6
10
5
¼ MILE (0.4 km)
FARM WELL
0.26
0.02
13
0.03
10
CELL III (Dry)
0.02
12
0.02
11
CELL BOUNDARY
MONITORING WELL ●
0′
100′

ferrous form is much more soluble than ferric iron. Consequently, total iron readings increase downgradient from the McVille pond; wells 4, 7, and 14 (Figure 17) contain water with high total iron. The source of the iron is not the pond, however, as total iron readings of wastewater samples averaged only 0.06 mg/L. It is likely that ferrous iron ions (Fe^{2+}) from iron oxide coatings on aquifer sand grains are made soluble as reducing pond waters flow through the sand and convert ferric iron to the more soluble ferrous form.

As the wastewater plume travels downgradient, it mixes with uncontaminated groundwater having higher amounts of dissolved oxygen. The higher pE causes the oxidation of Fe^{2+} to Fe^{3+} and the subsequent precipitation of iron oxide (Fe_2O_3) on aquifer particles. This process is indicated by attenuation of the high total iron plume between well 14 and wells 6 and 8 (Figure 17).

Sulfate concentrations are inversely related to iron concentrations. Sulfates are most abundant in wells 1 and 5 and at considerable distances downgradient from the pond (wells 11 and 12). Lowest sulfate concentrations occur immediately downgradient from the pond (wells 3, 4, and 7, Figure 18).

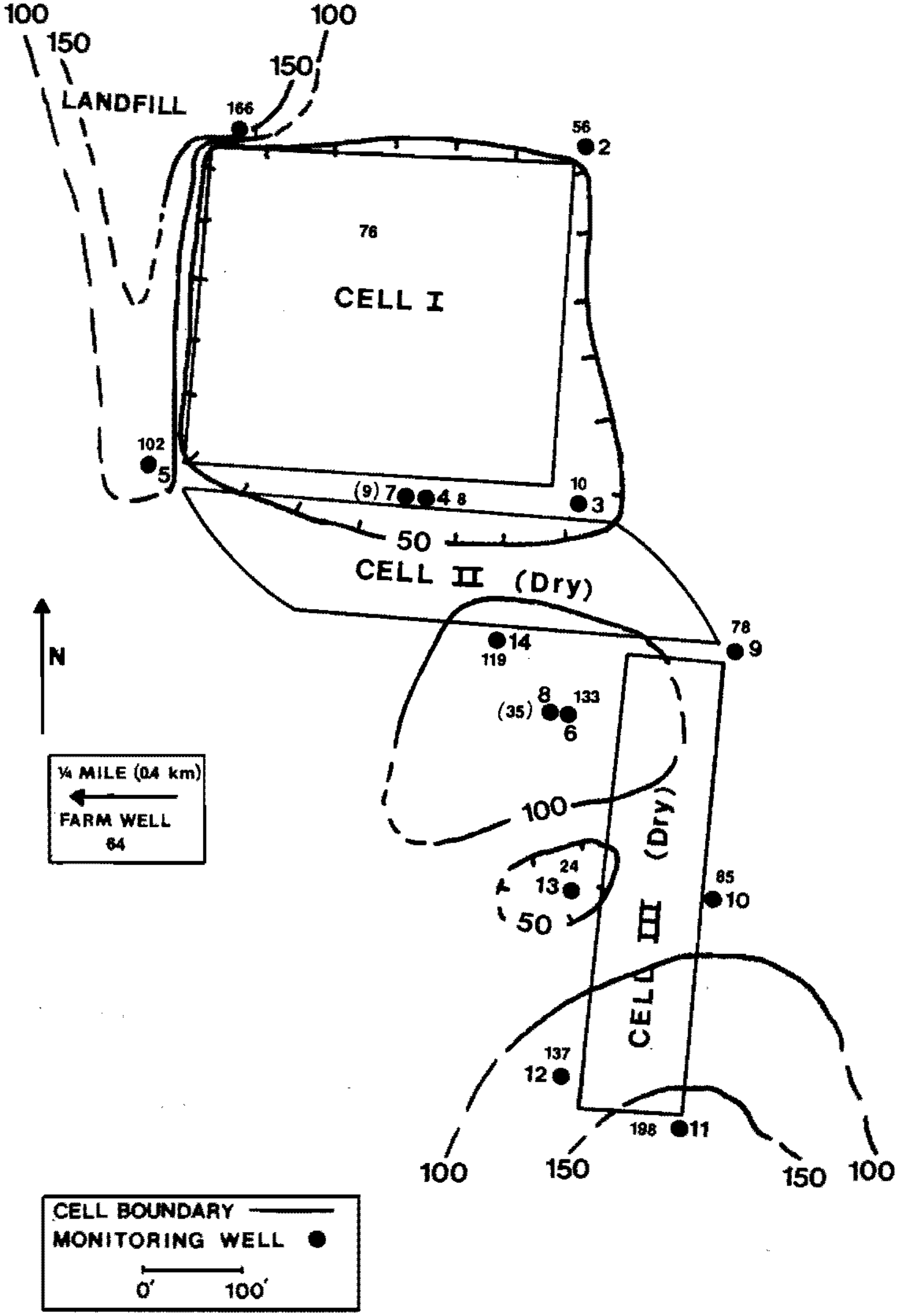
Sulfates are produced in oxidizing groundwaters by the reaction:

$$(4) \quad 2O_2 + HS^- \longrightarrow SO_4^{2-} + H^+ .$$

Wells 1 and 5 have more sulfate than other wells because of high dissolved oxygen and sulfate content in groundwater near the dump.

Sulfates, abundant in the wastewater of cell I, are reduced to sulfides by the reaction:

Figure 18. Sulfate concentrations (mg/L) in groundwater at the McVille site. July 27, 1982. Wells 7 and 8 are relatively deep; the values are in parentheses and not contoured.


100
150
100
150
LANDFILL
166
56
2
76
CELL I
102
5
(9) 7
4
8
10
3
50
CELL II (Dry)
N
78
9
14
119
8
133
(35)
6
¼ MILE (0.4 km)
FARM WELL
64
100
24
13
50
85
10
CELL III (Dry)
137
12
198
11
100
150
150
100
CELL BOUNDARY
MONITORING WELL
0'
100'

$$(5)\quad 2CH_2O + SO_4^{2-} \longrightarrow HS^- + 2HCO_3^- + H^+ .$$

This reaction is catalyzed within the bottom sludge layer by anaerobic bacteria (Neel and Hopkins, 1956). Sulfate-depleted water then percolates into the groundwater; wells 3, 4, and 7 produce water samples of that type. Bicarbonate (HCO_3^-), a product of sulfate reduction (reaction 5), is present in higher concentrations in those wells than in wastewater (Appendix VII). Iron and nitrate reduction may also account for bicarbonate concentration increases in wells 3, 4, and 7.

Increasing concentrations of sulfates farther downgradient from cell I could be the result of a re-oxidation of hydrogen sulfide that has been produced in the sludge layer. The re-oxidation, if it occurs, is biologically catalyzed. An alternative postulate is that the intermittent discharges into cell II are contributing sulfates to the groundwater. Cell II infiltration would be high in sulfate because of the lack of a reducing sludge layer. Well 6 has sulfate concentrations nearly as high as well 1, and well 11 has an even greater concentration of sulfate (Figure 18). Dispersion with uncontaminated groundwater downgradient from the site may eventually reduce the sulfate concentrations slightly.

Other Cations

Sodium and manganese concentrations increase downgradient from cell I. Sodium concentrations in wells 3, 4, 5, and 7, for example, are more than ten times greater than the background reading of

15 mg/L in well 2 (Figure 19). Elevated manganese (Mn^{2+}) concentrations, the result of reduction of manganese oxide solids in the sludge layer, occur in downgradient wells 4, 6, 7, and 8; they are two orders of magnitude greater than background values (Figure 20). Manganese concentrations decrease gradually downgradient as a result of precipitation and/or dispersion, whereas sodium is probably attenuated by dispersion only. The exact attenuation mechanisms have not been determined.

Trace Elements

Because laboratory tests for trace elements were expensive, only one upgradient and one downgradient well were analyzed for such elements for each sampling period at McVille. Because some of the McVille wastewater originated at locations such as service stations, trace elements in the wastewater were expected. Samples collected downgradient from cell I were almost always lower in trace elements than upgradient samples (Appendix VII). The anaerobic conditions in the pond sludge layer promote the presence of insoluble sulfide minerals that can limit trace element concentrations (Freeze and Cherry, 1979, p. 418). In addition, the mobility of the trace elements can be restricted by adsorption processes within the sludge layer. Coatings on sand grains, such as hydrous oxides of iron, $Fe(OH)_{3(s)}$, and manganese, $MnO_{2(s)}$, can control the fixation of Co, Ni, Cu, and Zn (Freeze and Cherry, 1979, p. 418). If trace elements occur in McVille wastewater, as is likely, one or more of the previously mentioned attenuation mechanisms prohibit them from contaminating the

Figure 19. Sodium concentrations (mg/L) in groundwater at the McVille site. July 27, 1982. Wells 7 and 8 are relatively deep; the values are in parentheses and not contoured.

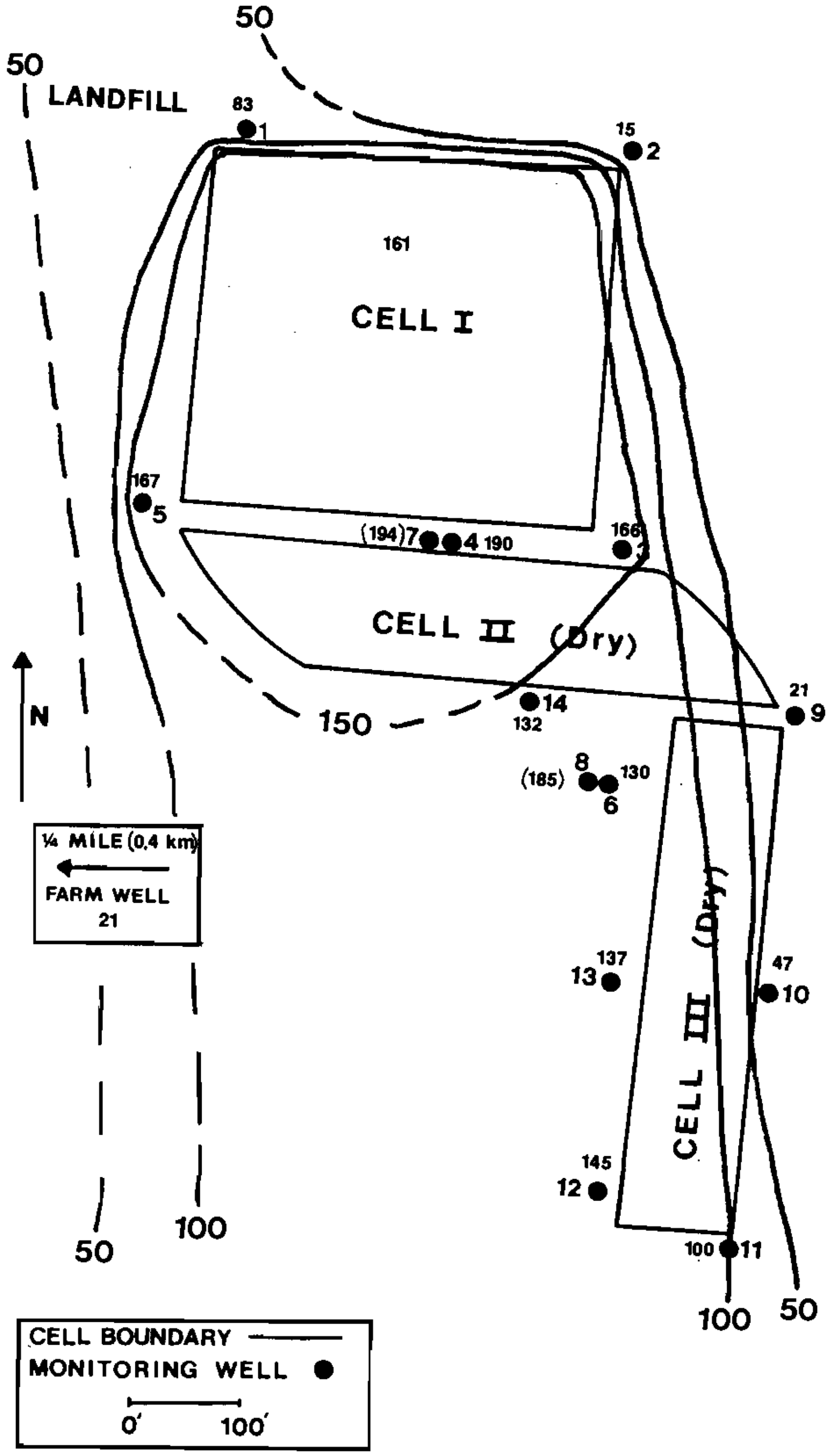
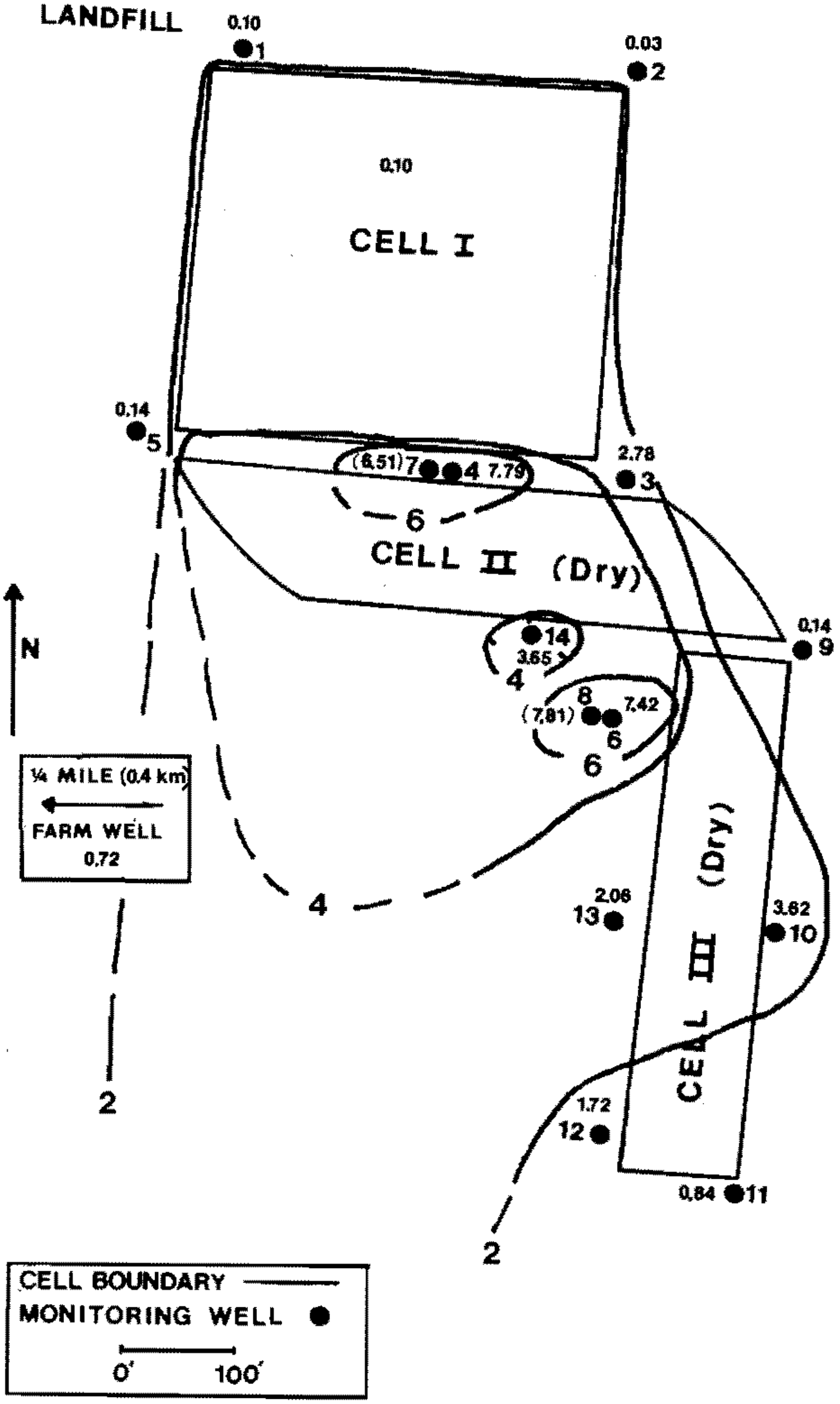

50
50
LANDFILL
83
1
15
2
161
CELL I
167
5
(194)7
4 190
166
CELL II (Dry)
150
14
132
21
9
N
8
(185)
130
6
¼ MILE (0.4 km)
FARM WELL
21
137
13
47
10
CELL III (Dry)
145
12
100
11
50
100
100
50
CELL BOUNDARY
MONITORING WELL
0'
100'

Figure 20. Manganese concentrations (mg/L) in groundwater at the McVille site. July 27, 1982. Wells 7 and 8 are relatively deep; the values are in parentheses and not contoured.


LANDFILL
0.10
1
0.03
2
0.10
CELL I
0.14
5
2.78
3
(6.51) 7
4 7.79
6
CELL II (Dry)
0.14
9
14
3.65
4
8
(7.81)
7.42
6
6
N
¼ MILE (0.4 km)
FARM WELL
0.72
4
2
2.06
13
(Dry)
CELL III
3.62
10
1.72
12
0.84
11
2
CELL BOUNDARY
MONITORING WELL ●
0'
100'

groundwater.

Total and Fecal Coliform Bacteria

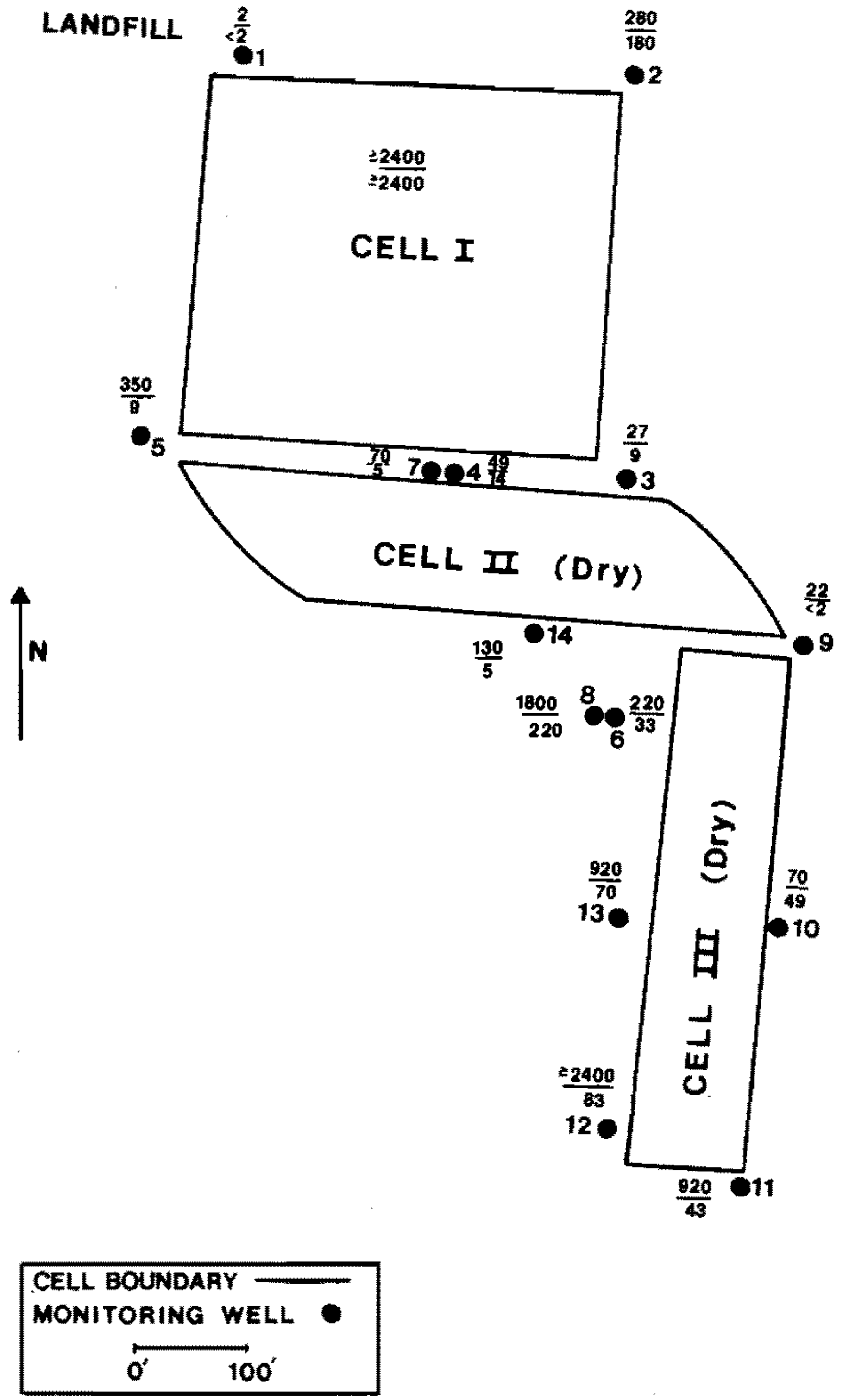
Bacteriological analyses from the October, 1981 and April, 1982 sampling periods were probably not accurate because insufficient rinsing of bleach from the sampling bailer effectively killed most of the bacteria in the water sample. Results probably more representative of actual conditions were obtained later in the project because of improved sampling techniques. The sampling bailer was disinfected with a dilute bleach solution and then triple-rinsed with distilled water to remove the bleach.

Bacteria data from the July and September, 1982 sampling periods indicate infiltration and travel of bacteria in groundwater. The 2400 colonies per 100 ml sample in the wastewater was equalled in well 12, over 600 feet (183 m) downgradient from cell I (Figure 21). In addition, wells 4, 5, 6, 7, 8, 10, 11, 13, and 14 had in excess of 10 total coliforms per 100 ml (Figure 21). Because bacteria do not survive very long in water, it appears that groundwater velocity is much faster than that predicted by single-well response tests.

Summary - McVille

The concentrations of most parameters strongly indicate a contaminant plume elongated downgradient from the McVille site. The plume likely has three sources: 1) continuous percolation of wastewater from cell I; 2) rapid infiltration from intermittent cell II wastewater discharges; and 3) continuous leachate migration from the

Figure 21. Total and fecal coliform bacteria (colonies per 100 ml) in groundwater at the McVille site. Total coliform counts are the numerator values. July 27, 1982.


LANDFILL
2
<2
1
280
180
2
≥2400
≥2400
CELL I
350
9
5
70
5
7
4
49
14
27
9
3
CELL II (Dry)
N
22
<2
9
14
130
5
1800
220
8
6
220
33
CELL III (Dry)
920
70
13
70
49
10
≥2400
83
12
920
43
11
CELL BOUNDARY
MONITORING WELL ●
0′
100′

waste dump located just upgradient from cell I.

Total hardness, calcium, magnesium, TDS, chloride, iron, sodium, manganese and coliforms are present in higher concentrations downgradient from cell I than in upgradient wells. These trends indicate groundwater contamination from cell I wastewater percolation. Data that suggest the influence of the cell II discharges, on the other hand, are elevated TDS, chloride, ammonium, sulfate, manganese, and bacteria readings. For example, wells 6, 8, and 14, downgradient from cell II, have high ammonium and sulfate concentrations, whereas wells 4 and 7, upgradient from cell II, have much lower ammonium and sulfate concentrations (Figures 15 and 18). The influence of the dump is indicated by increased concentrations of total hardness, calcium, magnesium, TDS and nitrate in wells 1 and 5 (Figures 10, 11, 12, 13, and 16).

The concentrations of many of the constituents are less than the maximum limits set for drinking water by the U.S. EPA. However, a few are excessive. The limit for TDS, for example, is 500 mg/L (Table 1) but only two wells at McVille had concentrations less than that value. In fact, many were greater than 800 mg/L (Figure 13).

Limits have not been established for ammonium. However, because it can be oxidized to nitrate, concentrations above 10 mg/L are not desirable. At the McVille site, four downgradient wells contained excessive levels of ammonium. The highest value was more than 43 mg/L (Figure 15).

Well 1 contained excessive nitrate levels, and wells 2, 5, and 9 were of marginal quality with respect to nitrate (Figure 16). Water containing nitrates at these concentrations can cause methemoglobinemia in infants or to developing fetuses that ingest it for a long time.

Iron is present in excessive concentrations in three downgradient wells; however, excessive iron is undesirable only because it colors the water and affects the taste.

Only McVille well 2 showed a manganese concentration below the limit of 0.05 mg/L. Some downgradient wells contain water two orders of magnitude above the limit for manganese. These concentrations constitute a health hazard if they persist in the vicinity of domestic wells downgradient from the site.

Because excessive bacterial colonies in drinking water are potentially pathogenic, coliform counts are among the parameters of most concern in this study. The limit for total and fecal coliforms are 1 and 0 colonies per 100 ml sample, respectively. Almost all McVille wells exceeded the total coliform limit and a few had excessive fecal coliform colonies.

In summary, a contaminant plume, derived from different sources at the site, has reached the water table below the site. Flow is evident by the elevated concentrations of many of the study parameters downgradient from the pond. Some constituents in the plume are attenuated within the study area by adsorption, precipitation, and/or dispersion. These attenuation mechanisms may effectively reduce contaminant parameters to acceptable drinking water levels by the time the plume reaches wells or discharge points downgradient. However, lack of well control beyond the study area precludes any definite conclusions regarding contaminant attenuation.

LARIMORE WASTE POND SITE

Results and Discussion

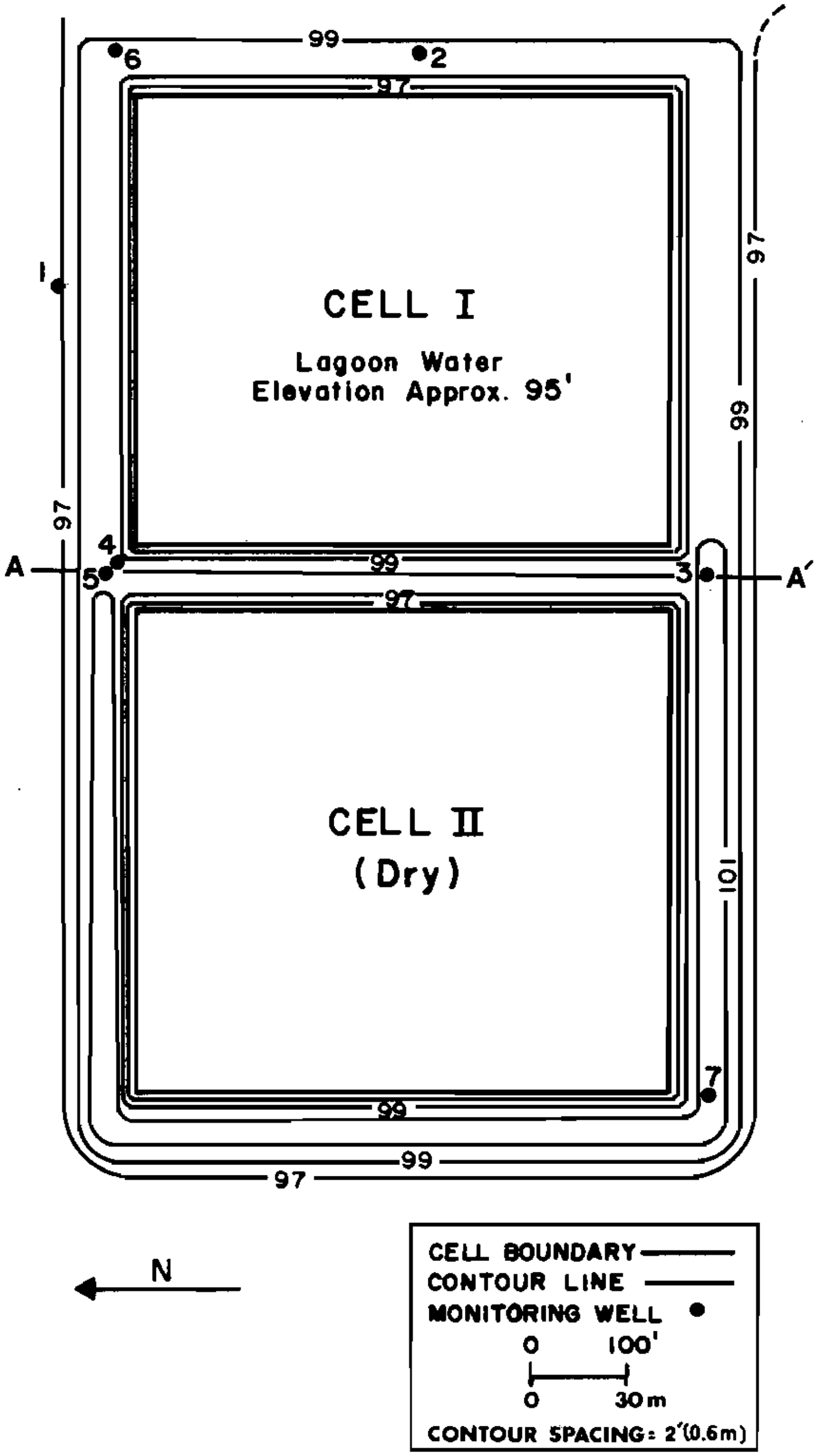
Site Description

The waste stabilization pond serving Larimore, Grand Forks County, is approximately 1 mile (1.6 km) northeast of the city limits. The pond was originally constructed in 1953 as a single cell of 10 acres (4.0 hectares). Because sufficient pond depths could not be maintained, an earthen dike was built across the middle of the pond, forming two cells (Figure 22), each having an area of nearly 5 acres (2.0 hectares). With an estimated water depth of 2 feet (0.61 m), the volume of each cell is approximately 3.7×10^6 gallons (1.4×10^4 m^3). The east cell (cell I) was used during most of the study period except in the summer of 1982 when cell I liquids were emptied into cell II to facilitate the removal of weeds from cell I.

Geologic Setting

The most extensive surficial deposit in Grand Forks County is Late Wisconsinan glacial drift. In the Larimore vicinity, the drift, approximately 250 feet (76.2 m) thick, is composed of three till units from several glaciations (Hansen and Kume, 1970), and is overlain by glaciolacustrine clay and silt. These units, in turn, are overlain by cross-stratified sand and gravel. The sand and gravel, overlain locally by Pleistocene and Holocene eolian sand and silt, is interpreted as a delta (the Elk Valley delta) deposited in Lake Agassiz

Figure 22. Topographic map of the Larimore, N.D. site. Geologic cross-section along A-A' is presented in Figure 23.


CELL I
Lagoon Water
Elevation Approx. 95'
CELL II
(Dry)
99
97
101
1
2
3
4
5
6
7
A
A′
N
CELL BOUNDARY
CONTOUR LINE
MONITORING WELL ●
0 100'
0 30 m
CONTOUR SPACING: 2'(0.6m)

near the margin of an ice lobe during the Edinburg glacial phase (Hansen and Kume, 1970). The sandy eolian sediment at the surface is greater than 25 feet (7.6 m) thick at Larimore. Samples recovered from drilling at the Larimore site were therefore predominantly these silty sands (Figure 23, Appendix II-B).

Hydrogeologic Setting

The Larimore waste stabilization ponds are in the eolian sands and silts that overlie the Elk Valley aquifer. The aquifer extends from T.154N., R.56W. to T.149N., R.53W. (Figure 24) and is one of the most important sources of water in eastern North Dakota; the estimated transient storage of water in the aquifer is 1 million acre-feet (1.2×10^9 m^3) in Grand Forks County (Kelly and Paulson, 1970). The aquifer is 38 miles (61.1 km) long and ranges in width from 3 miles (4.8 km) to 12 miles (19.3 km) (Figure 24). At Larimore, the aquifer is 20 feet (6.1 m) to 30 feet (9.1 m) thick. In 1970, the city of Larimore pumped 150,000 gallons (5.7×10^2 m^3) of water a day from the Elk Valley aquifer for municipal use (Kelly and Paulson, 1970).

Figure 25 illustrates the position of the water table beneath the Larimore site on November 21, 1981. Regional groundwater flow is from south to north toward the South Branch of the Turtle River. However, a groundwater mound under cell I, caused by excessive recharge from pond seepage, results in a local hydraulic gradient reversal south of the site (Figure 25). Based on water table contours at the site (Figure 25), hydraulic gradient estimates range from 0.02 inches per foot (0.17 centimetres per metre) under cell II to 0.24 inches per

Figure 23. Geologic cross-section of the Larimore site. See Figure 22 for location of cross-section.

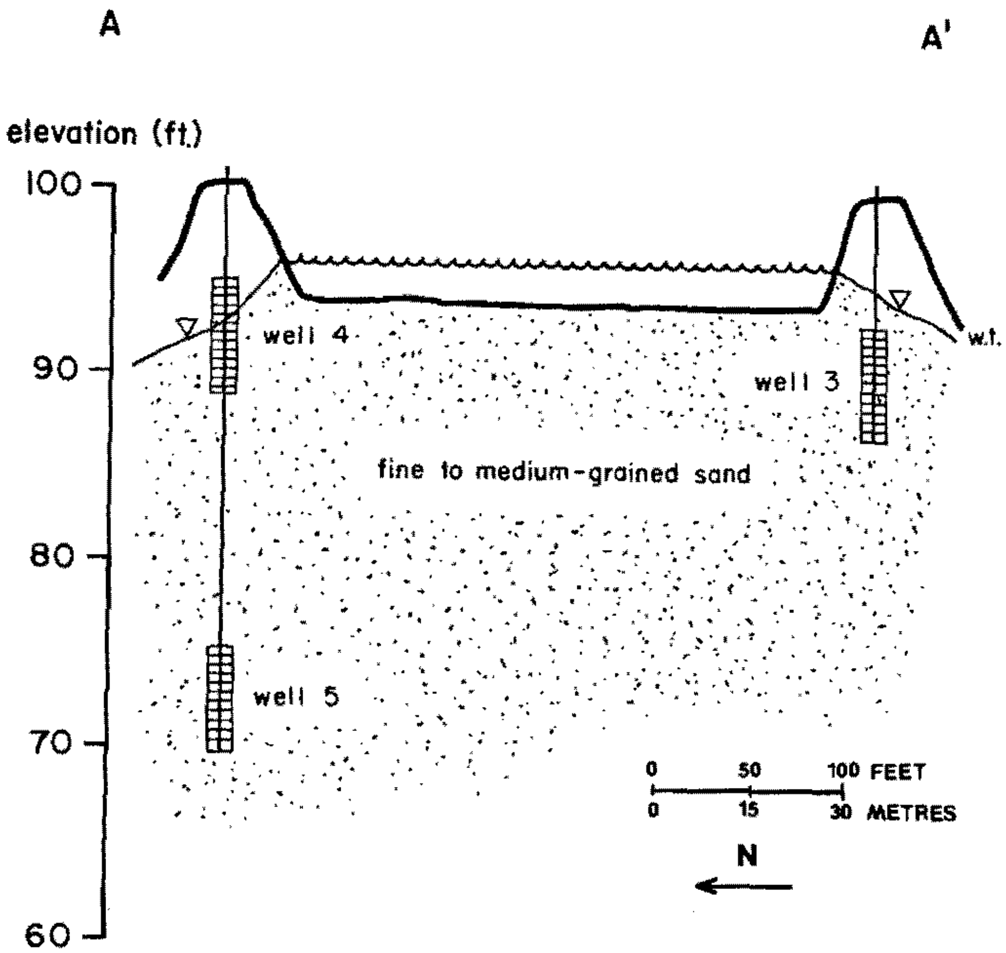

A
A'
elevation (ft.)
100
90
80
70
60
well 4
well 3
well 5
w.t.
fine to medium-grained sand
0
50
100 FEET
0
15
30 METRES
N

Figure 24. Location of the Elk Valley aquifer in Grand Forks County.

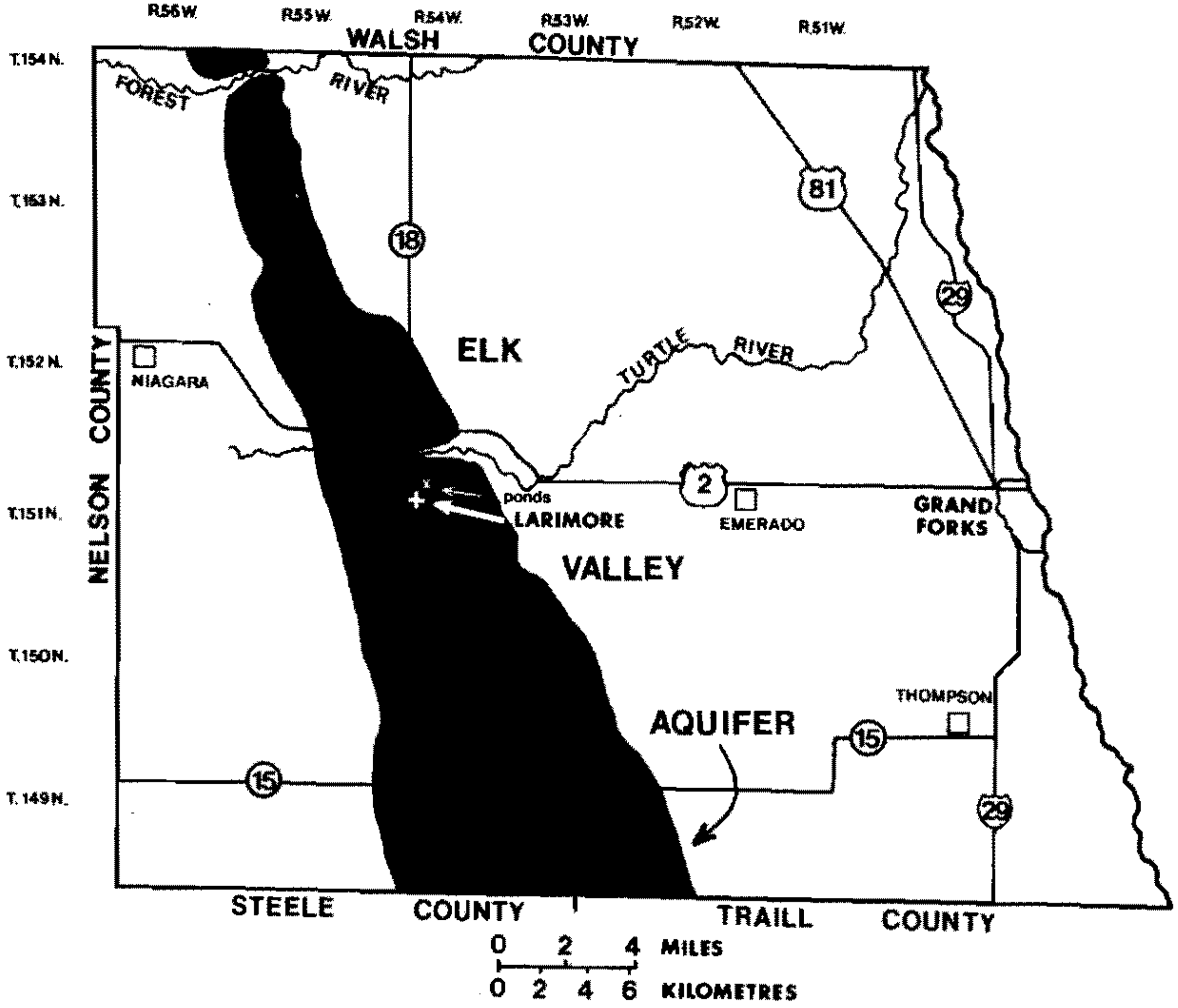
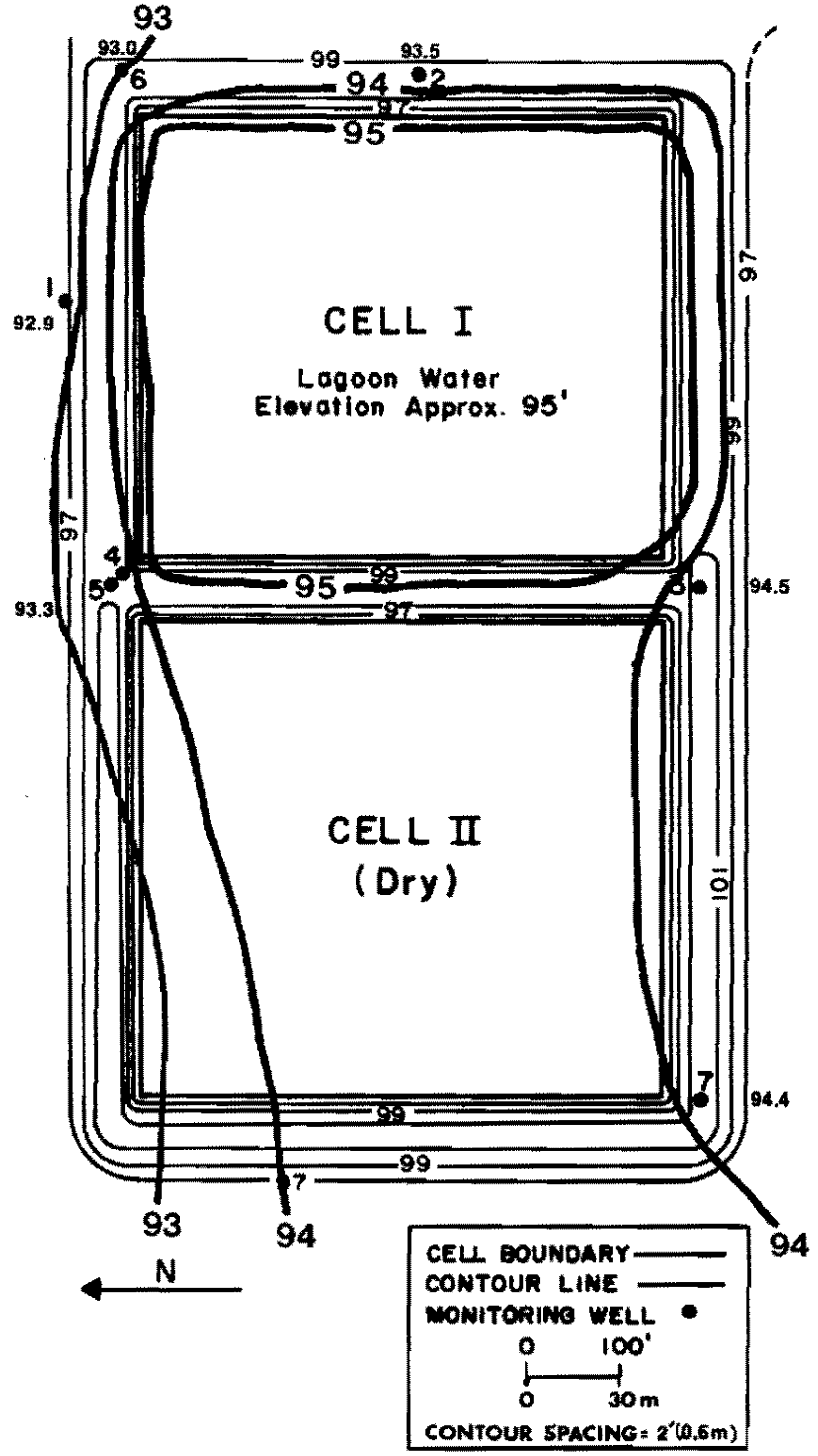

R56W.
R55W.
R54W.
R53W.
R52W.
R51W.
WALSH COUNTY
T.154N.
T.153N.
T.152N.
T.151N.
T.150N.
T.149N.
FOREST RIVER
18
81
29
ELK
TURTLE RIVER
NIAGARA
NELSON COUNTY
2
ponds
LARIMORE
EMERADO
GRAND FORKS
VALLEY
THOMPSON
AQUIFER
15
15
29
STEELE COUNTY
TRAILL COUNTY
0 2 4 MILES
0 2 4 6 KILOMETRES

Figure 25. Water table contours (heaviest lines), in feet above an arbitrary datum, superimposed on a topographic map of the Larimore site, November 21, 1981.


93
93.0
6
99
93.5
94
2
97
95
1
92.9
97
CELL I
Lagoon Water
Elevation Approx. 95'
99
97
4
5
93.3
95
99
97
3
94.5
CELL II
(Dry)
101
7
94.4
99
99
97
93
94
94
N
CELL BOUNDARY
CONTOUR LINE
MONITORING WELL ●
0 100'
0 30 m
CONTOUR SPACING= 2'(0.6m)

foot (2.0 cm/m) along the edge of the groundwater mound under cell I. All water level readings at the Larimore site are listed in Table 3.

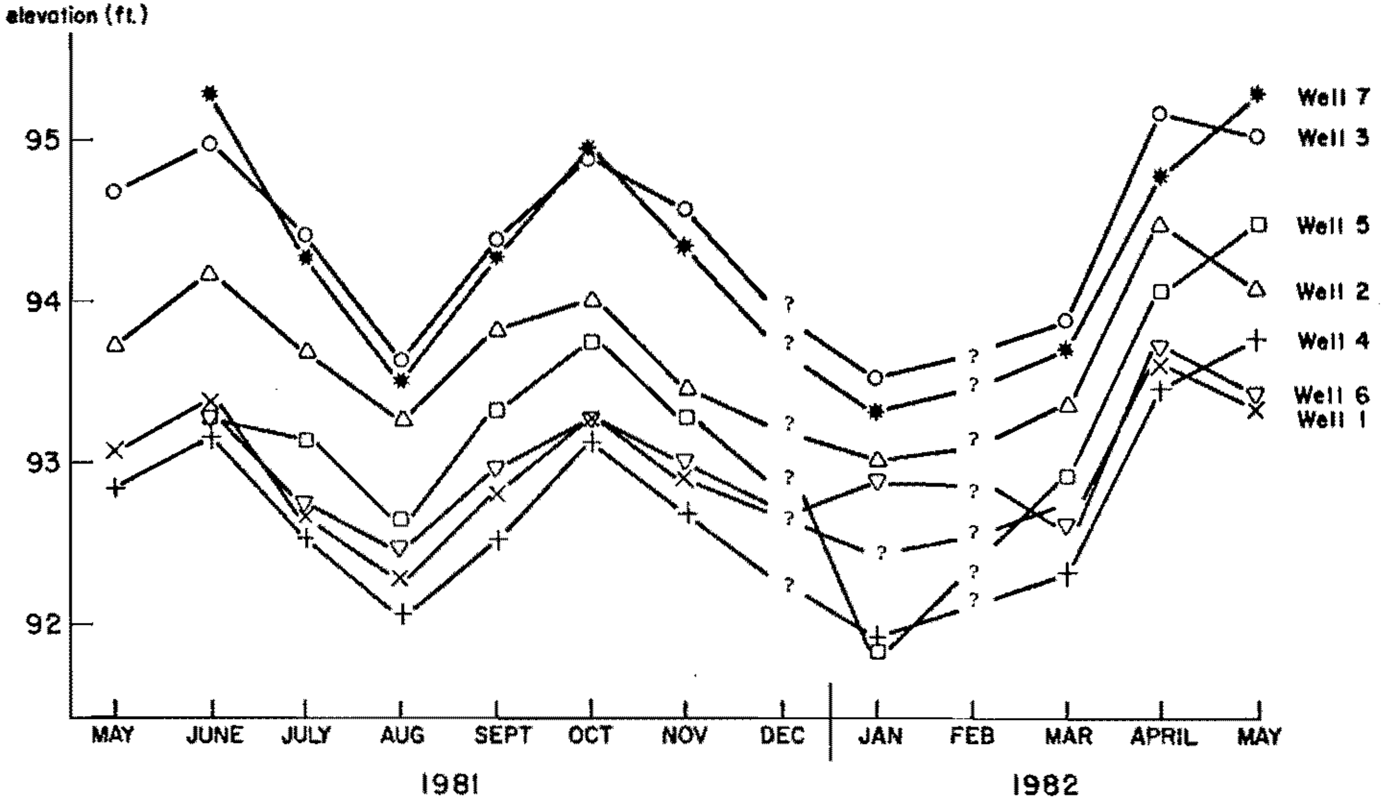
Large variations in the water table occurred during the study period at the Larimore site (Figure 26). Typically, reductions in water table elevation occurred in summer and winter, while the water table rose in fall and spring in response to precipitation and snowmelt.

A hydraulic conductivity value of 1.9×10^{-4} m/s was estimated for sediment underlying the Larimore site using the Masch and Denny (1966) method on samples recovered during drilling of well 4. In addition, a single-well response (slug) test was performed on well 1 and a hydraulic conductivity value of 1.6×10^{-6} m/s was determined. The discrepancy between the two values is either the result of heterogeneity of the subsurface material or error inherent in the laboratory method of hydraulic conductivity estimation.

Background Chemical Quality of Groundwater

Water from the Elk Valley aquifer generally is a calcium-bicarbonate type of good quality and is classified as having medium to high salinity and a low alkali hazard (Kelly and Paulson, 1970). Concentrations of most chemical constituents are extremely variable in the aquifer (Kelly and Paulson, 1970); this probably is the result of shallow aquifer depths, variability of material in the unsaturated zone, and contamination from surface sources. TDS concentrations, for example, range from several hundred to over 1,000 mg/L (Kelly and Paulson, 1970).

Figure 26. Water table fluctuations at the Larimore site.


elevation (ft.)
95
94
93
92
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
APRIL
MAY
1981
1982
Well 7
Well 3
Well 5
Well 2
Well 4
Well 6
Well 1

A farm well and several monitoring wells upgradient from the Larimore waste stabilization site were sampled to determine chemical and bacterial quality of natural groundwaters in the vicinity of the ponds. These values were compared with data from other wells at the site. Because of the switch of pond liquids from cell I to cell II prior to the summer, 1982 sampling period, mean concentrations of constituents from the first three sampling periods were analyzed separately from the summer, 1982 data.

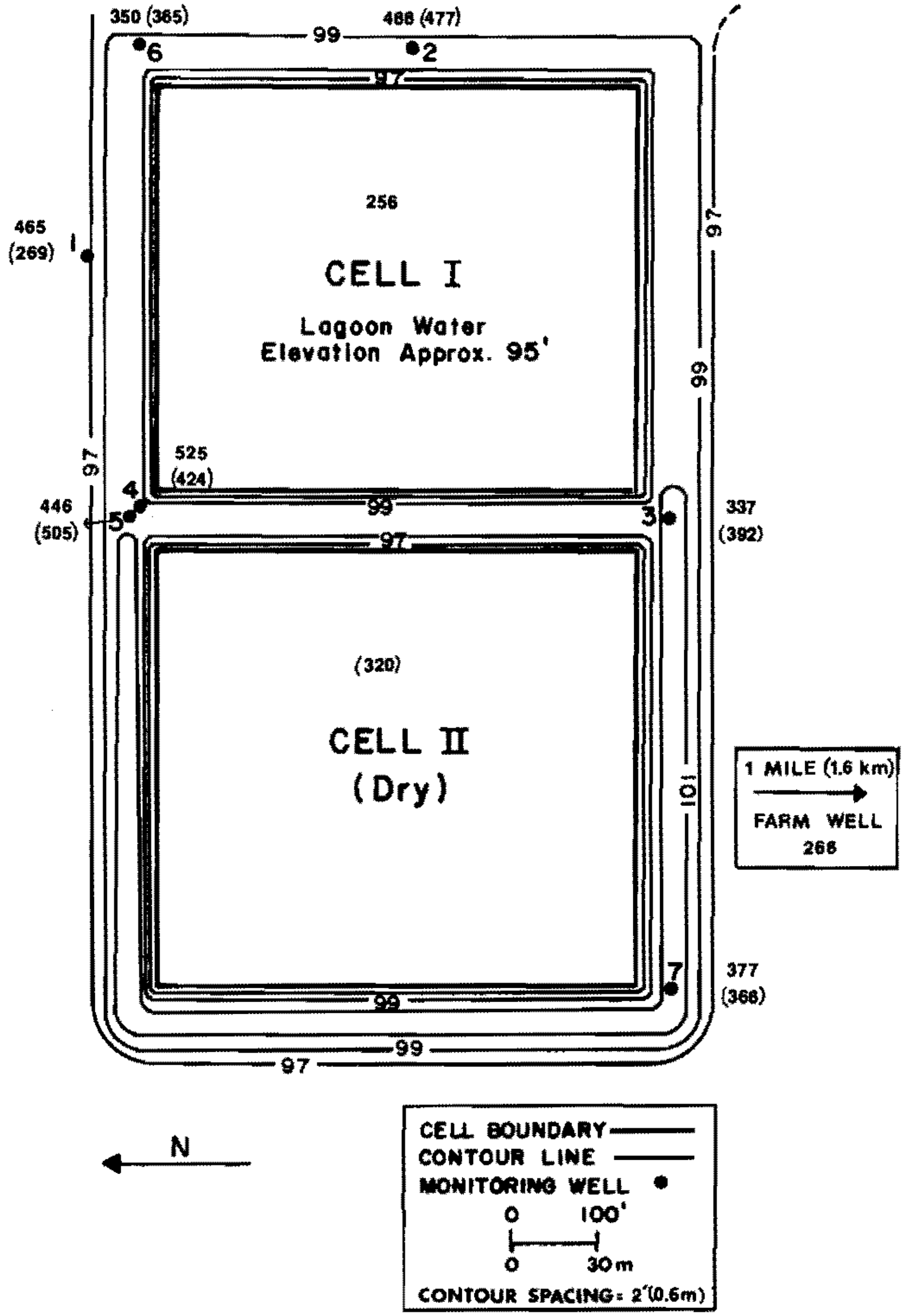
Chemical Quality of Groundwater Samples

Total Hardness

A background total hardness value of 268 mg/L was recorded in the farm well, 1 mile (1.6 km) upgradient from the site. The lowest total hardness values were recorded in wells 3, 6, and 7 (Figure 27). Well 7, 600 feet (182.9) lateral to cell I and upgradient from cell II, had water only slightly harder than natural water from the aquifer. Wells 3 and 6 had even softer water; although less than 50 feet (15.2 m) from cell I, they may be barely within the influence of the groundwater mound.

Elevated total hardness values occur in wells 1, 2, 4, and 5, all within the groundwater mound below cell I. Well 4 had a mean hardness concentration of 525 mg/L, the highest at the site and a two-fold increase over the background readings (Figure 27).

Figure 27. Mean total hardness concentrations (mg/L) from August, 1981 to April, 1982 in groundwater at the Larimore site. Summer, 1982 value in parentheses. Farm well value is from a single reading.


350 (365)
6
99
488 (477)
2
97
256
CELL I
Lagoon Water
Elevation Approx. 95'
465
(269)
1
97
99
97
525
(424)
4
446
(505)
5
99
3
337
(392)
97
(320)
CELL II
(Dry)
101
1 MILE (1.6 km)
FARM WELL
266
7
377
(366)
99
99
97
N
CELL BOUNDARY
CONTOUR LINE
MONITORING WELL ●
0
100'
0
30 m
CONTOUR SPACING= 2'(0.6m)

Total Dissolved Solids (TDS)

Total dissolved solids readings equivalent to background values were recorded in the farm well (303 mg/L) and in wells 3 and 7 (391 mg/L and 442 mg/L, respectively, Figure 28). However, TDS concentrations increased markedly in other wells peripheral to the Larimore ponds. Wells 1, 2, 4, 5, and 6 had average TDS concentrations ranging from 736 mg/L in well 5 to 976 mg/L in well 4 (Figure 28), representing a two- to three-fold increase over background TDS concentrations.

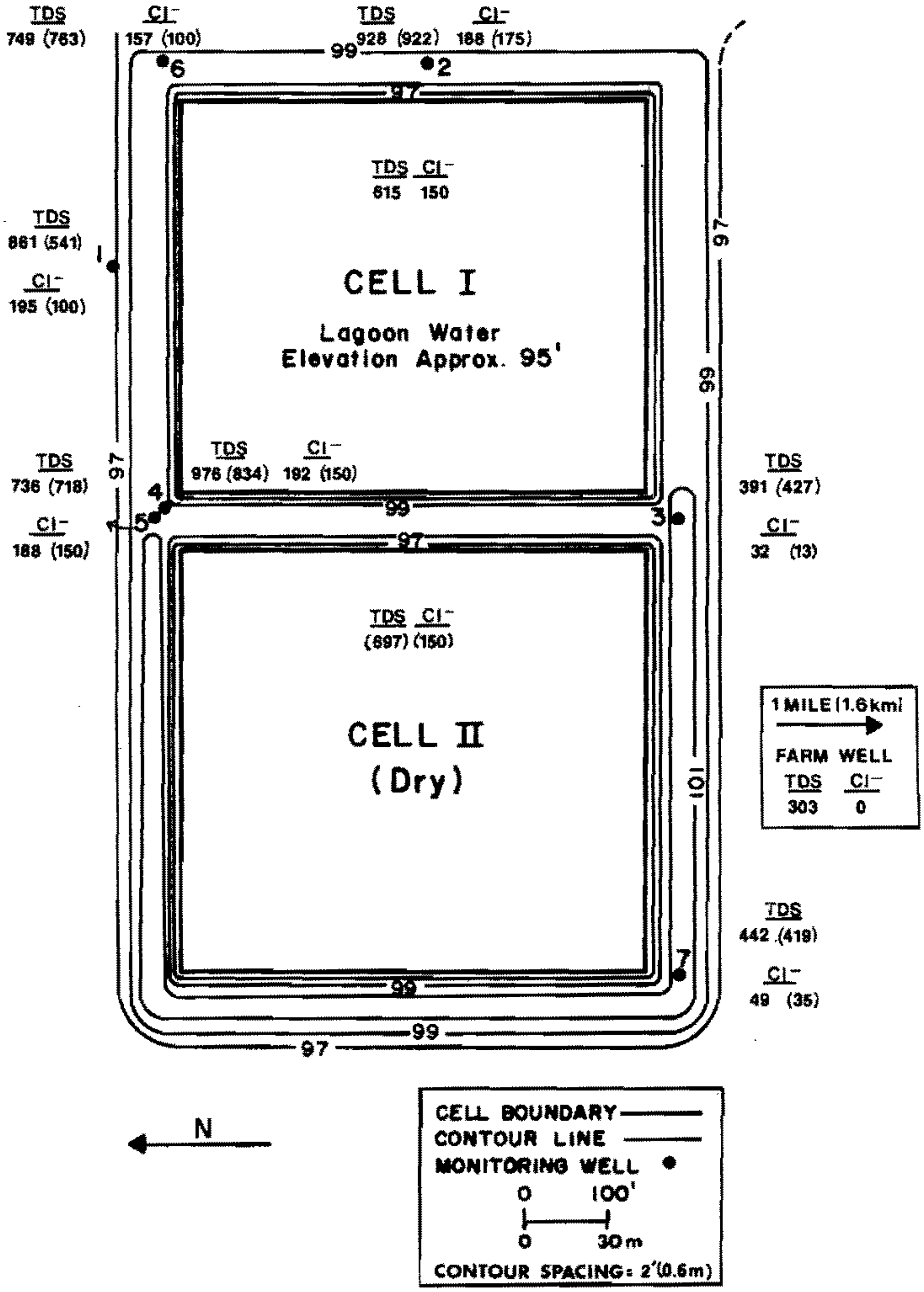
Wells having high TDS concentrations during the first three sampling periods had lower TDS concentrations during the summer, 1982 sampling period. For example, well 1 had an average TDS value of 861 mg/L prior to the summer of 1982 and a reading of 541 mg/L during that summer (Figure 28).

Chloride

Typical chloride concentrations in the Elk Valley aquifer generally are less than 10 mg/L. For example, the farm well showed no chloride. Wells 3 and 7 had slightly higher chloride concentrations; well 3 had an average of 32 mg/L chloride while well 7 had an average chloride reading of 49 mg/L (Figure 28). These values suggest the presence of a permanent or intermittent groundwater mound, causing a gradient reversal in the vicinity of these "upgradient" wells.

Chloride values increased markedly in wells 1, 2, 4, 5, and 6, similar to TDS. The mean chloride concentrations in these wells

Figure 28. Mean total dissolved solids (TDS) and chloride (Cl^-) concentrations (mg/L) from August, 1981 to April, 1982 in groundwater at the Larimore site. Summer, 1982 values in parentheses. Farm well value is from a single reading.


TDS
749 (763)
Cl⁻
157 (100)
TDS
928 (922)
Cl⁻
188 (175)
99
6
2
97
TDS Cl⁻
615 150
CELL I
Lagoon Water
Elevation Approx. 95'
TDS
861 (541)
1
Cl⁻
195 (100)
97
99
TDS
736 (718)
97
TDS
976 (834)
Cl⁻
192 (150)
4
5
Cl⁻
188 (150)
99
97
3
TDS
391 (427)
Cl⁻
32 (13)
TDS Cl⁻
(697) (150)
CELL II
(Dry)
101
1 MILE (1.6km)
FARM WELL
TDS Cl⁻
303 0
TDS
442 (419)
7
Cl⁻
49 (35)
99
99
97
N
CELL BOUNDARY
CONTOUR LINE
MONITORING WELL ●
0 100'
0 30m
CONTOUR SPACING: 2'(0.6m)

ranged from 157 mg/L in well 6 to 195 mg/L in well 1 (Figure 28), representing a three- to four-fold increase from upgradient chloride values in the farm well.

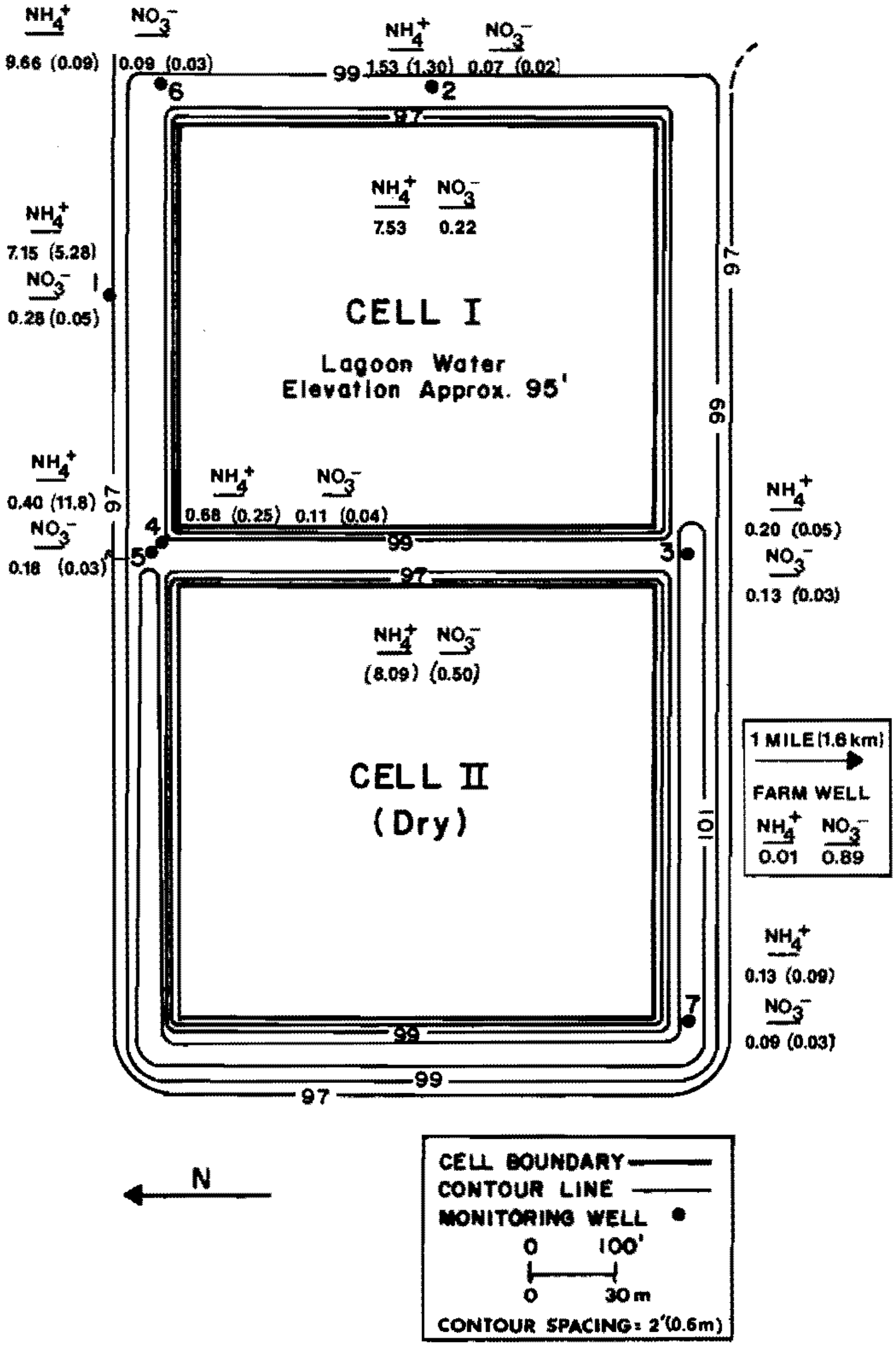
Chloride values in wells peripheral to cell I decreased after pond liquids were transferred to cell II. The greatest decrease was in well 1; chloride concentrations were reduced by one-half in that well following the summer, 1982 transfer.

Ammonium

Because the pH values of Larimore wastewater and groundwater are below 9, the ammonium ion is the dominant nitrogen species at the site. Because wastewater in the Larimore waste stabilization pond had an average ammonium concentration of 7.5 mg/L and the farm well had an ammonium concentration of less than 1 mg/L (Figure 29), the presence of ammonium in downgradient groundwater indicates contamination by wastewater. In fact, wells 1 and 6 had ammonium concentrations similar to that of wastewater; average ammonium concentrations in those wells were 7.1 mg/L and 9.7 mg/L, respectively (Figure 29). Well 2 had an average ammonium reading of 1.5 mg/L, suggesting that it is within the groundwater mound beneath cell I.

The ammonium distributions at this site are unlike those at McVille. At that site, ammonium was attenuated in all wells immediately downgradient from cell I except for well 7 (Figure 15); at Larimore, ammonium concentrations in wells 1 and 6 were similar to that of wastewater. Apparently, adsorption of the ammonium ion is not occurring within the Larimore pond. Either a sludge layer capable of attenuating

Figure 29. Mean ammonium (NH_4^+) and nitrate (NO_3^-) concentrations (mg/L) in groundwater from August, 1981 to April, 1982 at the Larimore site. Summer, 1982 values in parentheses. Farm well value is from a single reading.


NH_4^+ NO_3^-
9.66 (0.09) 0.09 (0.03)
NH_4^+ NO_3^-
1.53 (1.30) 0.07 (0.02)
99
6
2
97
NH_4^+ NO_3^-
7.53 0.22
CELL I
Lagoon Water
Elevation Approx. 95'
NH_4^+
7.15 (5.28)
NO_3^-
0.28 (0.05)
1
97
99
NH_4^+
0.40 (11.8)
NO_3^-
0.18 (0.03)
97
NH_4^+ NO_3^-
0.68 (0.25) 0.11 (0.04)
4
5
99
3
NH_4^+
0.20 (0.05)
NO_3^-
0.13 (0.03)
97
NH_4^+ NO_3^-
(8.09) (0.50)
CELL II
(Dry)
101
1 MILE (1.6 km)
FARM WELL
NH_4^+ NO_3^-
0.01 0.89
NH_4^+
0.13 (0.09)
NO_3^-
0.09 (0.03)
7
99
99
97
N
CELL BOUNDARY
CONTOUR LINE
MONITORING WELL ●
0 100'
0 30 m
CONTOUR SPACING: 2'(0.6m)

ammonium has not yet formed in this pond, or the adsorptive capacity of the sludge layer has been exceeded. Abundant weeds in cell I suggest water depths of less than 2 feet (0.6 m), a depth that would inhibit the formation of a sludge layer because of aeration by wind. Without a sludge layer, less adsorption of ammonium would occur.

Summer, 1982 ammonium readings in wells 1, 2, 4, and 6 were lower than in previous sampling periods. For example, well 6 decreased by two orders of magnitude and well 4 ammonium decreased by one-half (Figure 29). It is expected that ammonium would easily migrate from cell II because that cell has no sludge layer. Some adsorption could occur on aquifer particles, however. Unfortunately, no monitoring wells were constructed downgradient from cell II because it was assumed that only cell I would be used.

Nitrate

Nitrate was present in concentrations less than 1 mg/L in all wells and in the wastewater at Larimore. The highest nitrate reading was at the upgradient farm well; however, it had only 0.9 mg/L nitrate (Figure 29). Dissolved oxygen, necessary for nitrification, was in concentrations greater than 1 mg/L in wells 3 and 7, but nitrate was not formed because of low ammonium levels in those wells. The transfer of wastewater to cell II in the summer of 1982 caused nitrate levels to decrease in all wells peripheral to cell I (Figure 29).

Total Iron and Sulfate

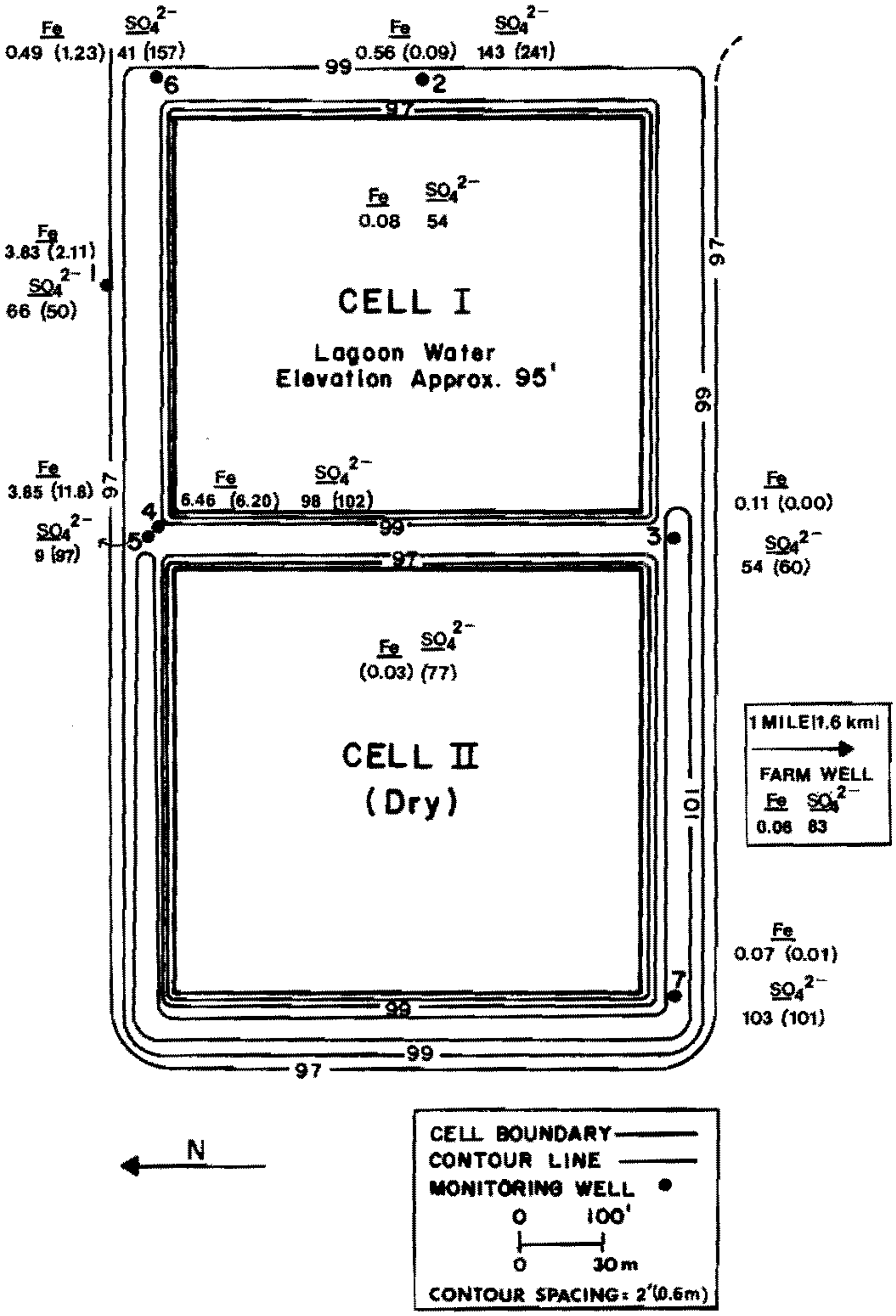
Iron was present in minor amounts in Larimore wastewater. However, iron increased slightly in wells 2 and 6 and was considerably elevated in wells 1, 4, and 5 (Figure 30). The highest total iron reading, in well 4, was 6.5 mg/L, two orders of magnitude above background iron readings (0.06 mg/L, Figure 30).

Lower pE conditions within the groundwater mound under the pond led to the presence of ferrous iron (Fe^{2+}) as the dominant species of dissolved iron. Ferrous iron is probably derived from iron oxide coatings on aquifer sand grains and is released into solution by wastewater reduction, raising total iron readings in wells screened within the groundwater mound.

Sulfate concentration distributions, also dependent on redox conditions, were variable at the Larimore site. Highest amounts of sulfate were in well 2 (143 mg/L average value, Figure 30), suggesting either reduction of sulfate to sulfide on the pond bottom by bacteria (leading to offgassing of H_2S) or precipitation of sulfide minerals.

Some anomalies do occur at the site. For example, well 4 had a mean sulfate value ten times that of well 5, located only a few feet away. The screened interval of well 5 is more than 16 feet (4.9 m) deeper than that of well 4; conditions at this depth are more reducing than in well 4, suppressing sulfate formation. The lower sulfate concentration in well 5 also is the result of predominantly lateral movement of the contaminant plume in the upper part of the saturated zone. While the contaminant plume likely is more dense than natural groundwater, the density contrast is probably minimal. Therefore, the plume does not sink to the level of the screened interval of well

Figure 30. Mean iron (Fe) and sulfate (SO_4^{2-}) concentrations (mg/L) in groundwater from August, 1981 to April, 1982 at the Larimore site. Summer, 1982 values in parentheses. Farm well value is from a single reading.


Fe
0.49 (1.23)
SO$_4^{2-}$
41 (157)
Fe
0.56 (0.09)
SO$_4^{2-}$
143 (241)
99
6
2
97
Fe
0.08
SO$_4^{2-}$
54
Fe
3.83 (2.11)
SO$_4^{2-}$
66 (50)
1
CELL I
Lagoon Water
Elevation Approx. 95'
97
99
Fe
3.85 (11.8)
97
SO$_4^{2-}$
9 (97)
4
5
Fe
6.46 (6.20)
SO$_4^{2-}$
98 (102)
99
Fe
0.11 (0.00)
SO$_4^{2-}$
54 (60)
3
97
Fe
(0.03)
SO$_4^{2-}$
(77)
CELL II
(Dry)
101
1 MILE (1.6 km)
FARM WELL
Fe
0.06
SO$_4^{2-}$
83
Fe
0.07 (0.01)
SO$_4^{2-}$
103 (101)
7
99
99
97
N
CELL BOUNDARY
CONTOUR LINE
MONITORING WELL ●
0
100'
0
30 m
CONTOUR SPACING: 2' (0.6m)

5 within that small lateral distance.

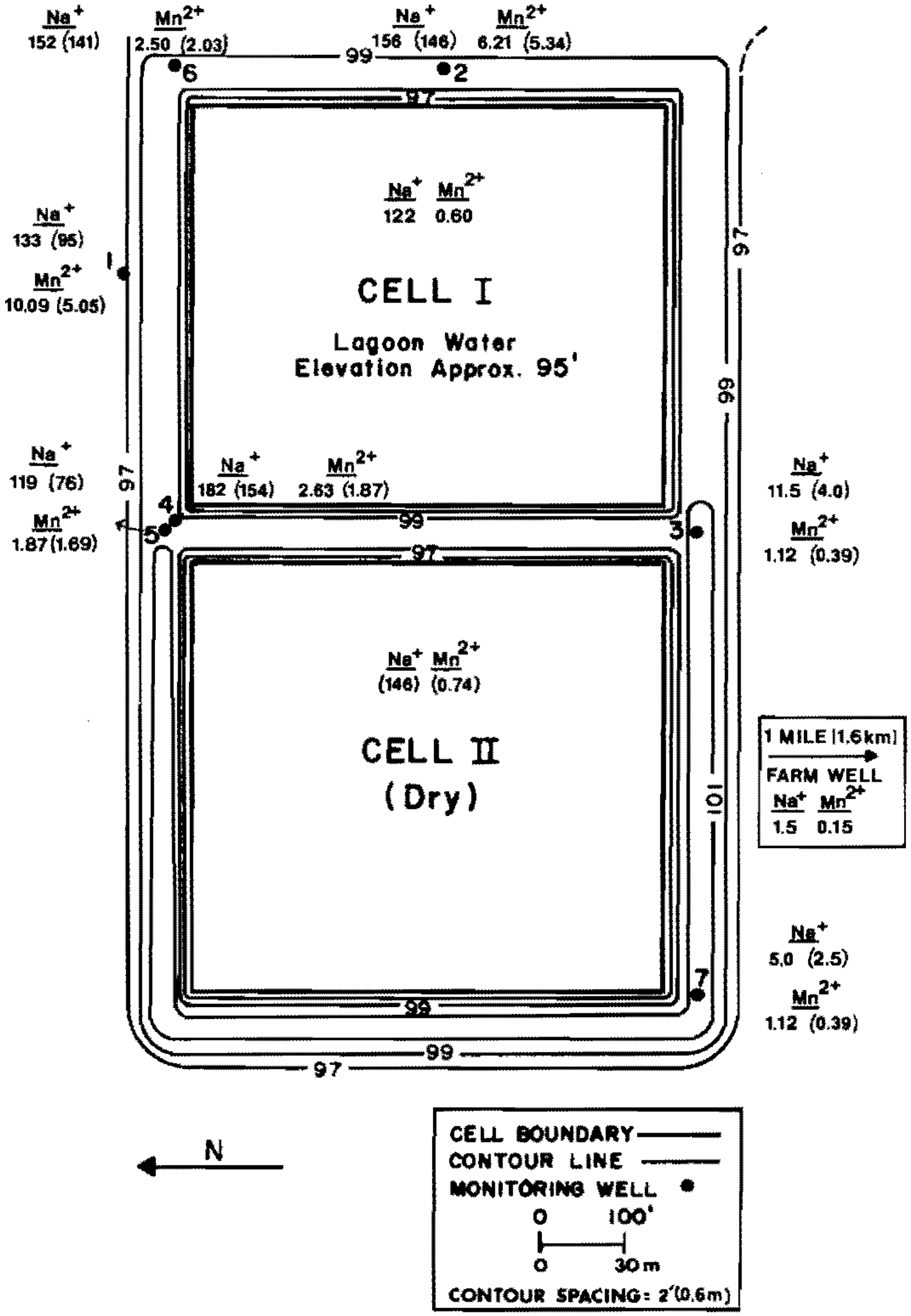
The transfer of pond liquids from cell I to cell II caused sulfates to increase in all wells near cell I except in well 1. The greatest increases occurred in wells 5 and 6 (Figure 30). For example, the summer 1982 sulfate value of well 5 was an order of magnitude higher than the previous mean sulfate value for that well. It is hypothesized that when liquids were in cell II, the bottom of cell I became subaerially exposed, causing oxidation of reduced sulfur forms present in the thin, poorly developed sludge layer. Sulfate was produced, which later was leached to the water table by rainfall and as a result, sulfate levels rose in nearby wells.

Other Cations

Sodium, a major constituent in Larimore wastewater, occurred in wells 1, 2, 4, 5, and 6 at levels an order of magnitude higher than in well 3 and two orders of magnitude above the upgradient farm well value of 1.5 mg/L (Figure 31). These sodium concentrations indicate contaminant movement within the groundwater mound below cell I.

Background manganese concentrations at Larimore were approximately 1 mg/L or less (Figure 31) but concentrations of manganese in wells around cell I were at least twice that value. Well 1 contained the highest amount of manganese (10.09 mg/L), a ten-fold increase over the background level. Because the solubility of Mn^{2+} increases with decreasing pE (Stumm and Morgan, 1970, p. 331), minimal amounts of manganese occurs in the aerobic wastewater but is made soluble as wastewater percolates through the reducing (low pE) bottom layer of

Figure 31. Mean sodium (Na^+) and manganese (Mn^{2+}) concentrations (mg/L) in groundwater from August, 1981 to April, 1982 at the Larimore site. Summer, 1982 values in parentheses. Farm well value is from a single reading.


Na+ 152 (141)
Mn2+ 2.50 (2.03)
Na+ 156 (146)
Mn2+ 6.21 (5.34)
99
6
2
97
Na+ Mn2+ 122 0.60
CELL I
Lagoon Water Elevation Approx. 95'
Na+ 133 (95)
Mn2+ 10.09 (5.05)
1
97
99
Na+ 119 (76)
Mn2+ 1.87 (1.69)
97
Na+ 182 (154)
Mn2+ 2.63 (1.87)
4
5
99
3
Na+ 11.5 (4.0)
Mn2+ 1.12 (0.39)
97
Na+ Mn2+ (146) (0.74)
CELL II
(Dry)
1 MILE (1.6km)
FARM WELL
Na+ Mn2+ 1.5 0.15
101
Na+ 5.0 (2.5)
Mn2+ 1.12 (0.39)
7
99
99
97
N
CELL BOUNDARY
CONTOUR LINE
MONITORING WELL ●
0 100'
0 30m
CONTOUR SPACING: 2'(0.6m)

the pond. Reducing conditions in the groundwater mound below the pond allow soluble manganese to persist in the vicinity of peripheral wells.

Both sodium and manganese concentrations decreased in all wells around cell I after pond liquids were transferred to cell II (Figure 31). Corresponding increases in well 7 were not observed, however. Because the transfer procedure involved only a portion of cell I wastewater for a period of less than 3 months, it is unlikely that a well-developed groundwater mound developed under cell II. As a result, the hydraulic gradient was not reversed in the direction of well 7, and contaminants therefore did not migrate toward that well.

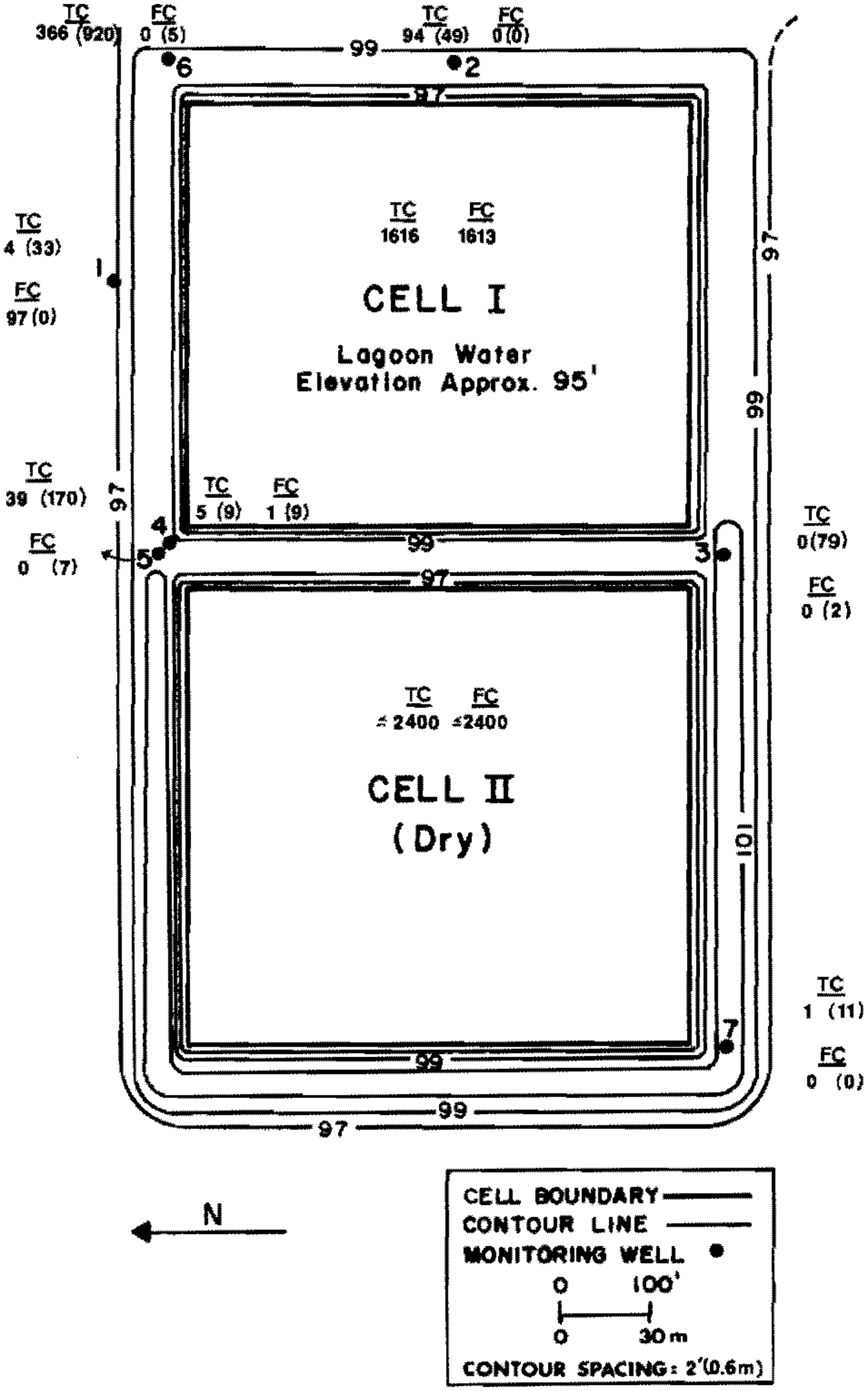
Trace Elements

Concentrations of most trace elements were generally lower in well 1, "downgradient" from cell I than in well 3, on the "upgradient" side of the groundwater mound. Although not analyzed for trace elements, their presence is probable in Larimore wastewater. Trace elements in Larimore wastewater are being attenuated by dilution, chemical precipitation, and/or adsorption within the pond and sludge layer.

Total and Fecal Coliform Bacteria

Coliform bacteria counts in wells at the Larimore site were extremely variable. As expected, both total and fecal coliform counts were highest in the wastewater (Figure 32, Appendix VII). No distinct trends in bacteria counts were evident in wells peripheral

Figure 32. Mean total coliform (TC) and fecal coliform (FC) bacteria (colonies per 100 ml) in groundwater from August, 1981 to April, 1982 at the Larimore site. Summer, 1982 values in parentheses.


TC
366 (920)
FC
0 (5)
99
TC
94 (49)
FC
0 (0)
6
2
97
TC
1616
FC
1613
CELL I
Lagoon Water
Elevation Approx. 95'
TC
4 (33)
1
FC
97 (0)
97
99
TC
39 (170)
97
TC
5 (9)
FC
1 (9)
4
5
FC
0 (7)
99
3
TC
0(79)
FC
0 (2)
97
TC
≤2400
FC
≤2400
CELL II
(Dry)
101
TC
1 (11)
7
FC
0 (0)
99
99
97
N
CELL BOUNDARY
CONTOUR LINE
MONITORING WELL ●
0 100'
0 30 m
CONTOUR SPACING: 2'(0.6m)

to cell I. For example, well 1, within the groundwater mound, averaged only 4 total coliforms (per 100 ml sample) during the first three sampling periods, and only 33 counts in the summer of 1982. Well 6, on the other hand, showed much higher coliform counts (Figure 32).

While bacteria counts around cell I were inconsistent, the fact that they greatly exceed the bacteria counts of well 7 suggest that the bacteria originate from cell I and are migrating into groundwater below the Larimore waste stabilization pond.

Summary - Larimore

Chemical and bacterial trends demonstrate contamination of groundwater by wastewater percolation from the Larimore waste stabilization pond. Elevated concentrations of most parameters occurred in wells peripheral to cell I during the summer and fall of 1981 and spring of 1982 sampling periods, when pond liquids percolated from that cell. High permeability sediment under the site prohibit maintenance of pond depths sufficient for the development of a sludge layer capable of attenuating ammonium. However, low pE conditions probably still prevail at the pond bottom, and iron and sulfate are chemically reduced in mounded groundwater beneath the pond, causing increased levels of iron and decreased levels of sulfate. Other parameters, such as total hardness, TDS, chloride, and sodium are also abundant in wells peripheral to cell I.

The transfer of wastes to cell II should cause contaminant concentrations to decrease in wells adjacent to cell I. Indeed, except for sulfate, the summer 1982 readings were quite low compared to previous values. Sulfate readings increased because of subaerial exposure of the bottom of cell I and resultant oxidation of reduced sulfur forms, such as $FeS_{2(s)}$, to form sulfate. Later, precipitation could have leached sulfate to the water table, but because a groundwater mound was absent, groundwater flow rates were slow and sulfate had not yet moved from under the site. The other contaminants, such as TDS, chloride, and sodium, not affected by redox conditions, were merely attenuated by dilution. As a result, concentrations of those parameters gradually decreased near cell I while wastewater was in cell II.

Despite the fact that wastewater constituents reached the water table, water quality standards in most cases were not exceeded. The exceptions were: a) the manganese limit of 0.05 mg/L (Table 1) which was exceeded in all Larimore wells (including the farm well); b) nearly 10 mg/L ammonium, potentially hazardous levels if nitrified, which occurred in wells 1 and 6; and c) total coliform levels, which were excessive in all Larimore wells.

Additional wells downgradient from cells I and II would have provided valuable information on contaminant percolation and travel in the subsurface at the site. Because the surrounding land is farmed, this was not feasible. However, several factors suggest that domestic well water downgradient from the site is potable: a) the nearest farm home is at least 1 mile (1.6 km) downgradient from the pond; b) no home is located between the pond site and the local groundwater discharge area; and c) water quality is generally acceptable adjacent to the site.

FORDVILLE WASTE POND SITE

Results and Discussion

Site Description

The waste stabilization pond at Fordville, located approximately 3/4 mile (1.2 km) southwest of the city limits, was built in 1955 as a single cell of 4 acres (1.6 hectares). Later, an earthen dike was constructed to form a pair of 2 acre (0.8 hectare) cells (Figure 33). At an estimated water depth of 3 feet (0.9 m), each cell has a volume of 1.8 x 10^6 gallons (6.9 x 10^3 m^3). The east cell (cell I) was used exclusively throughout the study period.

Geologic Setting

The sand and gravel facies of the Pleistocene Coleharbor Formation occurs at or near the surface in the Fordville area. The sand and gravel was deposited during the Late Wisconsinan Edinburg glacial phase, when the retreating Red River Valley lobe stabilized at a position approximately 1 mile (1.6 km) east of Fordville (Bluemle, 1973). While the ice margin paused at this position the Edinburg end moraine was formed. A proglacial lake formed west of the moraine, and ice marginal streams flowing south into the lake deposited the sand and gravel. These coarse-grained, cross-bedded deposits comprise the Fordville aquifer. Samples recovered from drilling at the Fordville site were coarse sand and gravel overlain by clay and silt (Figure 34,

Figure 33. Topographic map of the Fordville, N.D. site. Geologic cross-section along A-A' is presented in Figure 34.

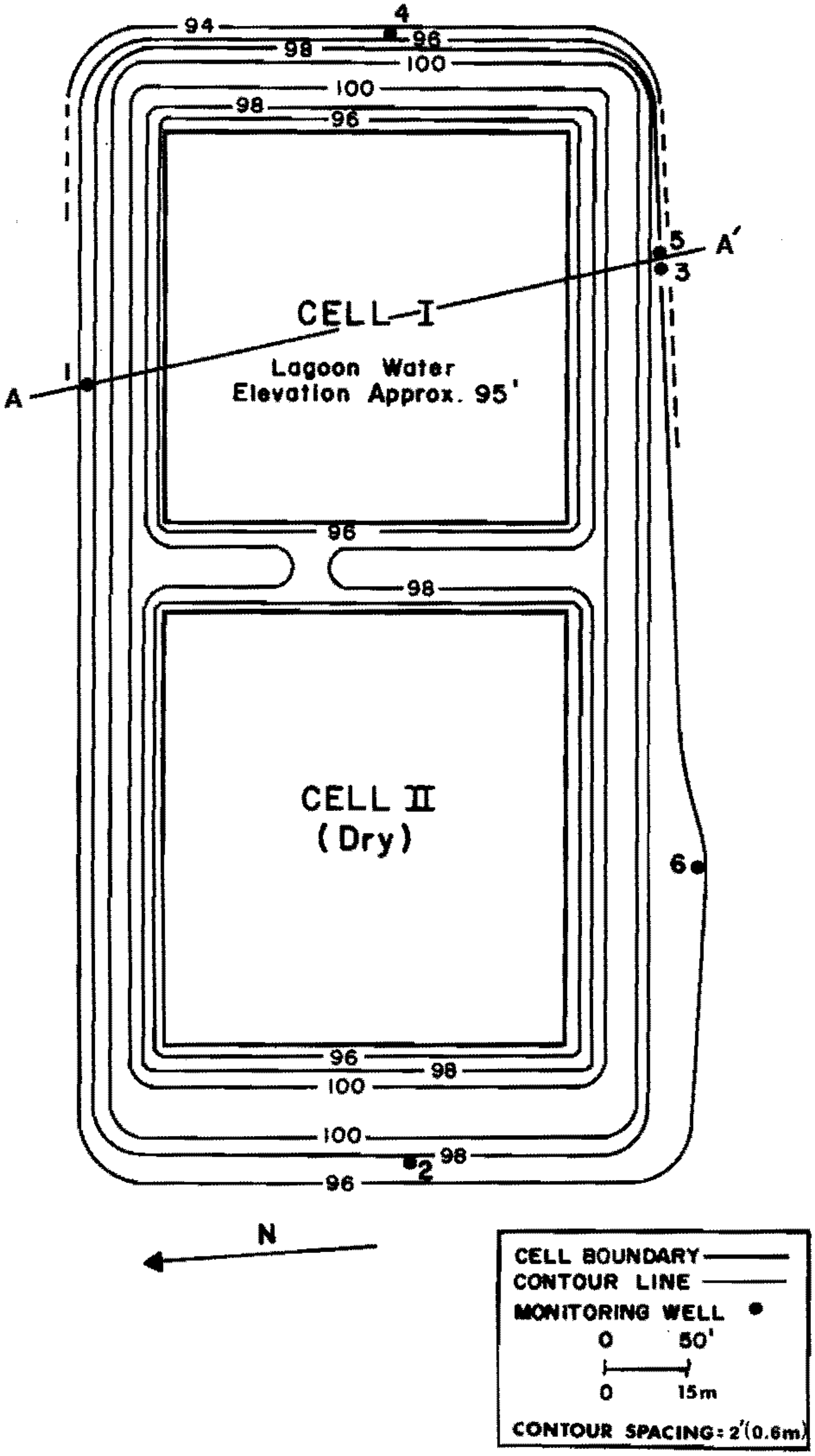
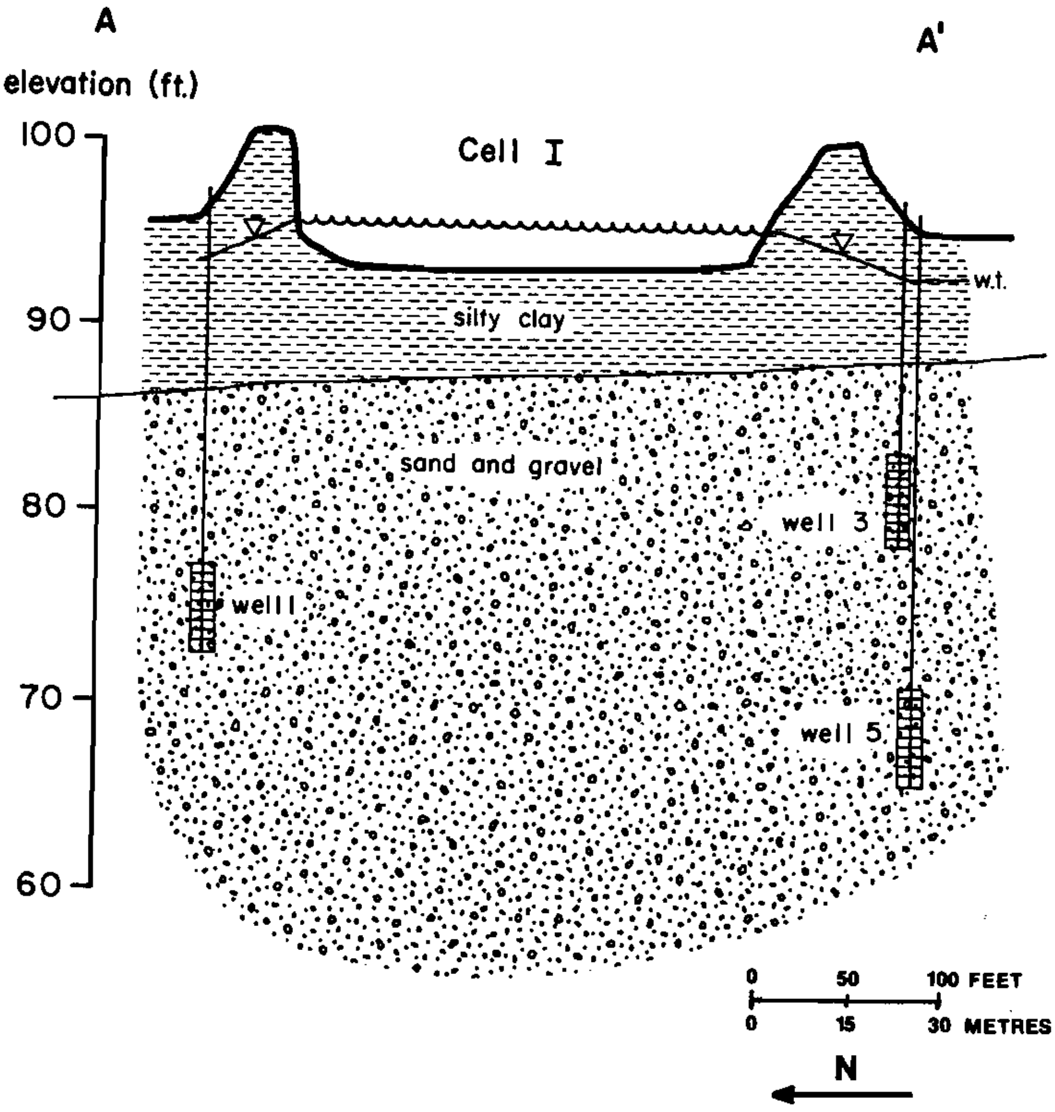

94
96
98
100
4
CELL I
Lagoon Water
Elevation Approx. 95'
CELL II
(Dry)
A
A'
5
3
6
2
N
CELL BOUNDARY
CONTOUR LINE
MONITORING WELL ●
0 50'
0 15m
CONTOUR SPACING: 2'(0.6m)

Figure 34. Geologic cross-section of the Fordville site. See Figure 33 for location of cross-section.


A
A'
elevation (ft.)
100
90
80
70
60
Cell I
w.t.
silty clay
sand and gravel
well 1
well 3
well 5
0
50
100 FEET
0
15
30 METRES
N

Appendix II-C). The finer material, the Holocene Oahe Formation, is dominantly Forest River alluvium (Bluemle, 1973).

Hydrogeologic Setting

The Fordville waste stabilization ponds were excavated in the alluvium overlying the sand and gravel of the Fordville aquifer. The aquifer extends from T.156N., R.56W., to south of the city of Fordville (Figure 35). In Walsh County, the aquifer is 3 miles (4.8 km) to 4 miles (6.4 km) wide and is approximately 6 miles (9.6 km) long. The aquifer beneath Fordville is approximately 25 feet (7.6 m) thick.

The Fordville aquifer is the most important aquifer in Walsh County; it has an estimated storage capacity of 63,000 acre-feet (7.8×10^7 m^3) of water (Downey, 1973). The city of Fordville utilizes the Fordville aquifer as the municipal water source.

The position of the water table beneath the Fordville site on November 21, 1981 is illustrated in Figure 36. Groundwater flows from north to south under the site toward its discharge area, the Middle Branch of the Forest River. A groundwater mound under cell I causes a local hydraulic gradient reversal to the north of the site (Figure 36). Based on water levels in monitoring wells (Figure 36), the hydraulic gradient ranged from 0.04 inches per foot (0.33 cm/m) below cell II to 0.96 inches per foot (8.0 cm/m) along the edge of the groundwater mound under cell I.

Figure 37 illustrates the extreme fluctuation of Fordville water levels. Fractures, common in unconsolidated fine-grained deposits, may have developed in the alluvium overlying the aquifer. Such

Figure 35. Location of the Fordville aquifer in Walsh County.

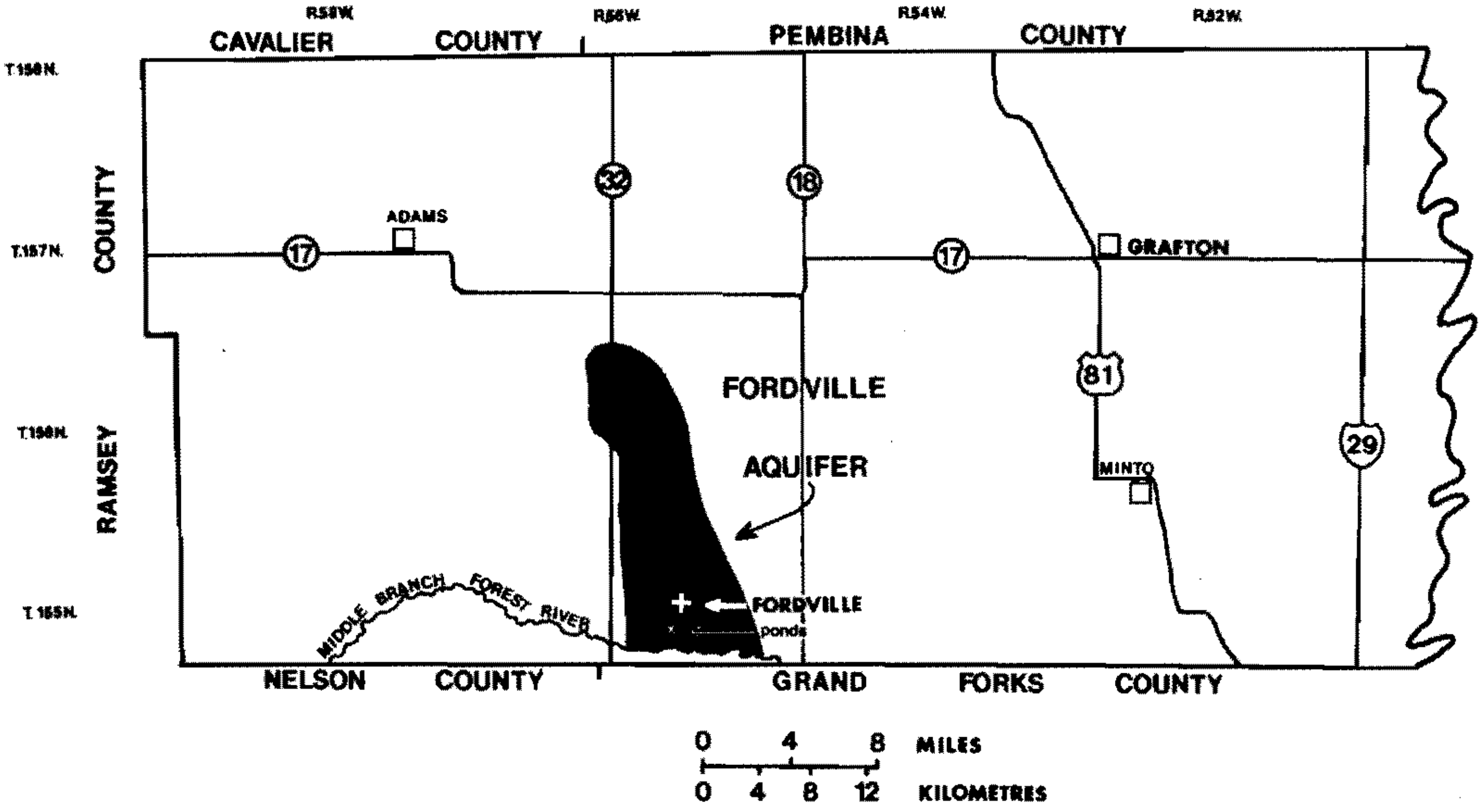
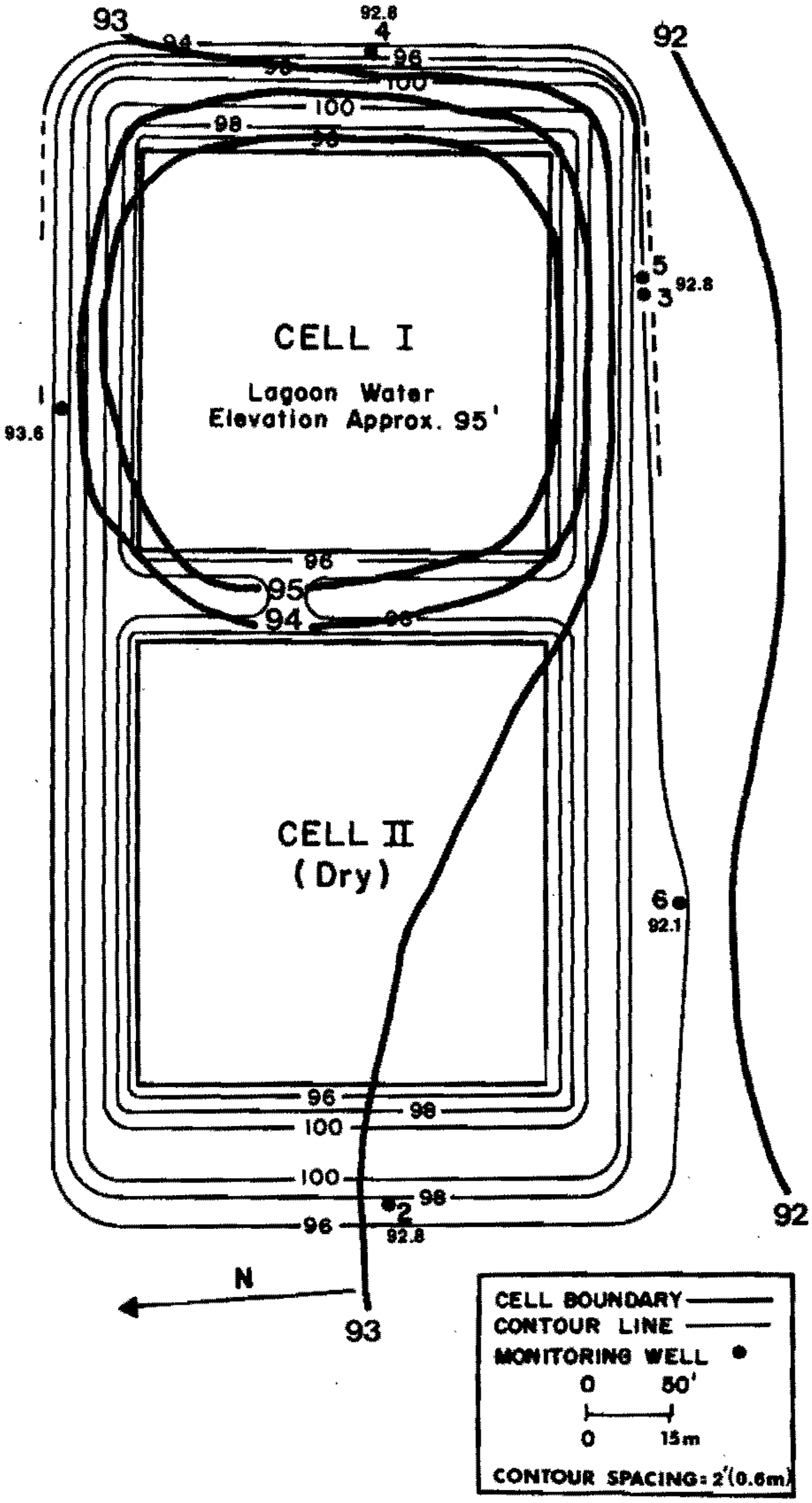
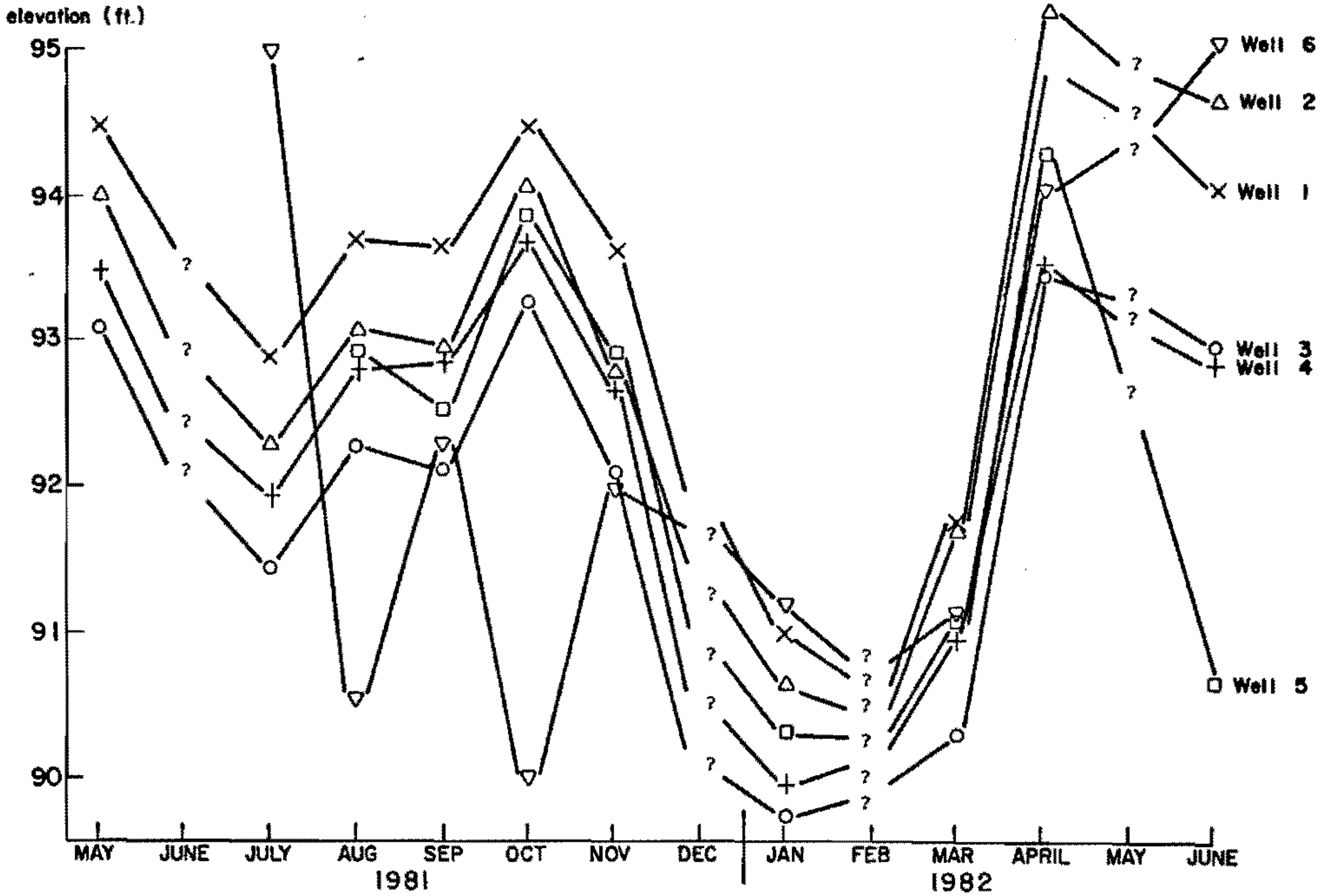

R.58W.
R.56W.
R.54W.
R.52W.
CAVALIER COUNTY
PEMBINA COUNTY
T.158N.
T.157N.
T.156N.
T.155N.
RAMSEY COUNTY
32
18
17
ADAMS
17
GRAFTON
81
FORDVILLE AQUIFER
29
MINTO
FORDVILLE
ponds
MIDDLE BRANCH FOREST RIVER
NELSON COUNTY
GRAND FORKS COUNTY
0 4 8 MILES
0 4 8 12 KILOMETRES

Figure 36. Water table contours (heaviest lines), in feet above an arbitrary datum, superimposed on a topographic map of the Fordville site, November 21, 1981.

Figure 37. Water table fluctuations at the Fordville site.


93
94
92.8
4
96
98
100
92
100
98
98
5
3
92.8
CELL I
Lagoon Water
Elevation Approx. 95'
1
93.6
96
95
94
96
CELL II
(Dry)
6
92.1
96
98
100
100
98
2
96
92.8
92
N
93
CELL BOUNDARY
CONTOUR LINE
MONITORING WELL ●
0 50'
0 15m
CONTOUR SPACING: 2'(0.6m)


elevation (ft.)
95
94
93
92
91
90
MAY
JUNE
JULY
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APRIL
MAY
JUNE
1981
1982
Well 6
Well 2
Well 1
Well 3
Well 4
Well 5
?

fractures provide open pathways for infiltrating water; thus, precipitation reaches the water table more quickly than if it had moved only through intergranular voids. Such variability in water levels did not occur at McVille and Larimore, underlain by coarse-grained material with only intergranular porosity. Water levels in well 6 were erratic compared to other wells; either the screened interval of that well was damaged during installation or the screen was clogged with fine-grained sediment, obstructing water flow into the well.

Sediment collected at the Fordville site was too fine-grained to use the Masch and Denny (1966) method of hydraulic conductivity determination. Single-well response tests were performed on wells 1, 2, and 3, however, and hydraulic conductivity values of 4.8×10^{-7} m/s, 8.7×10^{-6} m/s, and 3.0×10^{-6} m/s, respectively, were determined for those wells. Using a mean value, the average linear velocity of groundwater at the Fordville site is 4.5×10^{-8} m/s. Obviously, much higher flow rates occur within the groundwater mound.

Background Chemical Quality of Groundwater

Water from the Fordville aquifer is a calcium-sodium type of relatively good quality. Typical TDS values range from 315 mg/l to 525 mg/L (Downey, 1973). A domestic well 1/2 mile (0.8 km) upgradient from the site was sampled in an attempt to ascertain background concentrations of constituents in the groundwater. Water quality from that well was poor (Appendix VII), apparently the result of septic tank contamination. For example, the concentration of nitrate in the well was 118.0 mg/L, over ten times the limit set for that constituent by the EPA (Table 1). Therefore, published data (Downey, 1971) was used to determine background quality of Fordville aquifer water.

Chemical Quality of Groundwater Samples

Total Hardness

Wells 1, 3, 4, and 5, within the influence of the groundwater mound under cell I, had generally uniform concentrations of calcium and magnesium ions (Appendix VII); as a result, similar hardness values were recorded in those wells (Figure 38). Hardness readings similar to background values (250-350 mg/L) occurred in wells 2 and 6 (Figure 38), suggesting that those wells are beyond the influence of the groundwater mound under cell I.

Total Dissolved Solids (TDS)

Water with the greatest amount of dissolved solids came from well 3 (Figure 39). In addition, TDS values in wells 1, 2, and 5 (315 - 525 mg/L, Figure 39) also exceeded background levels. The wastewater pond is certainly contributing dissolved mineral matter to groundwater below the site.

Chloride

Chloride concentrations, typically less than 5 mg/L in the aquifer, ranged from 23 mg/L in well 4 to 191 mg/L in well 3 (Figure 39), representing five- to forty-fold increases over background levels. Cell I wastewater, containing an average 106 mg/L chloride, is undoubtedly the cause of elevated readings in those wells.

Figure 38. Mean total hardness concentrations (mg/L) in groundwater at the Fordville site.

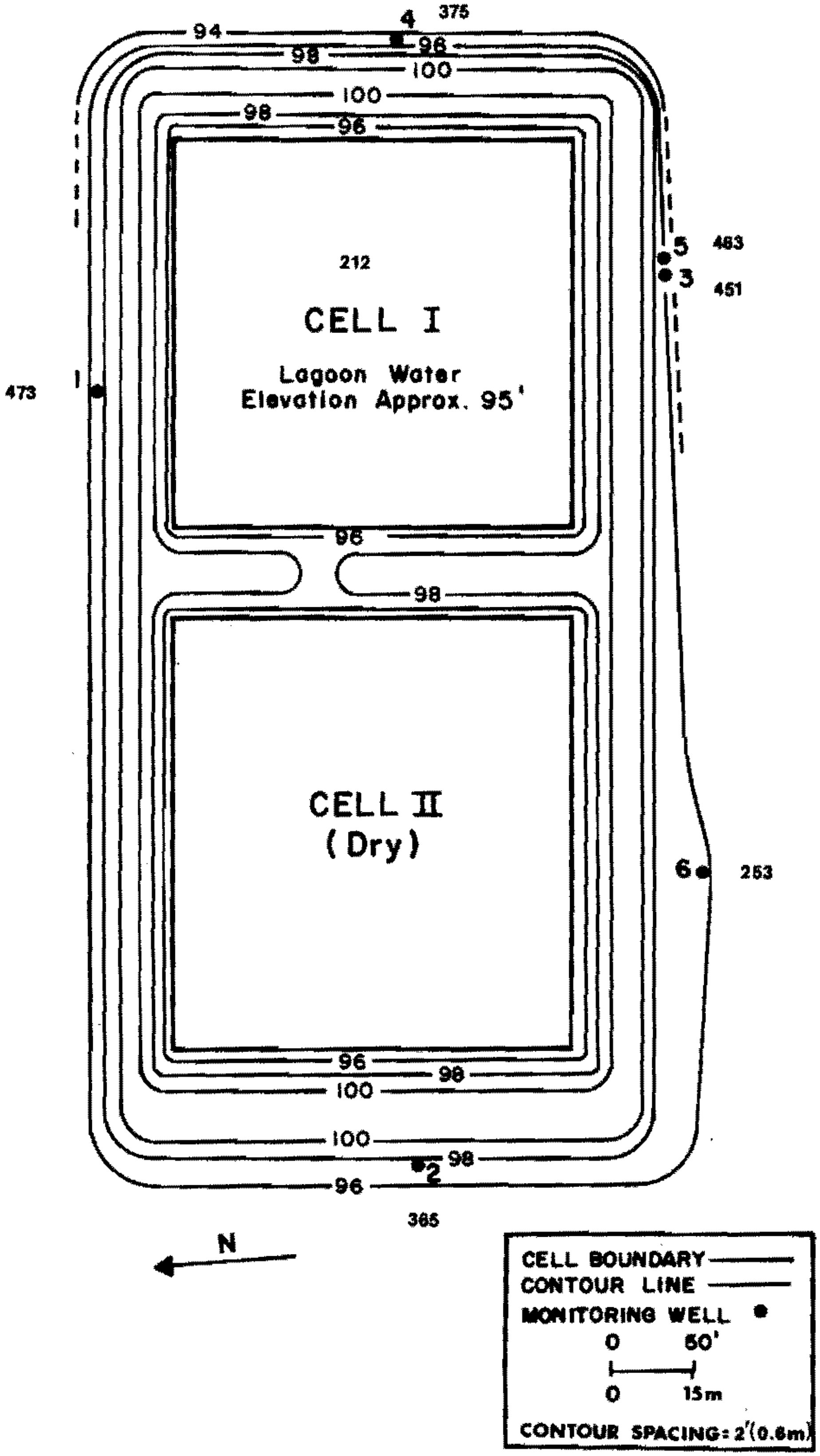
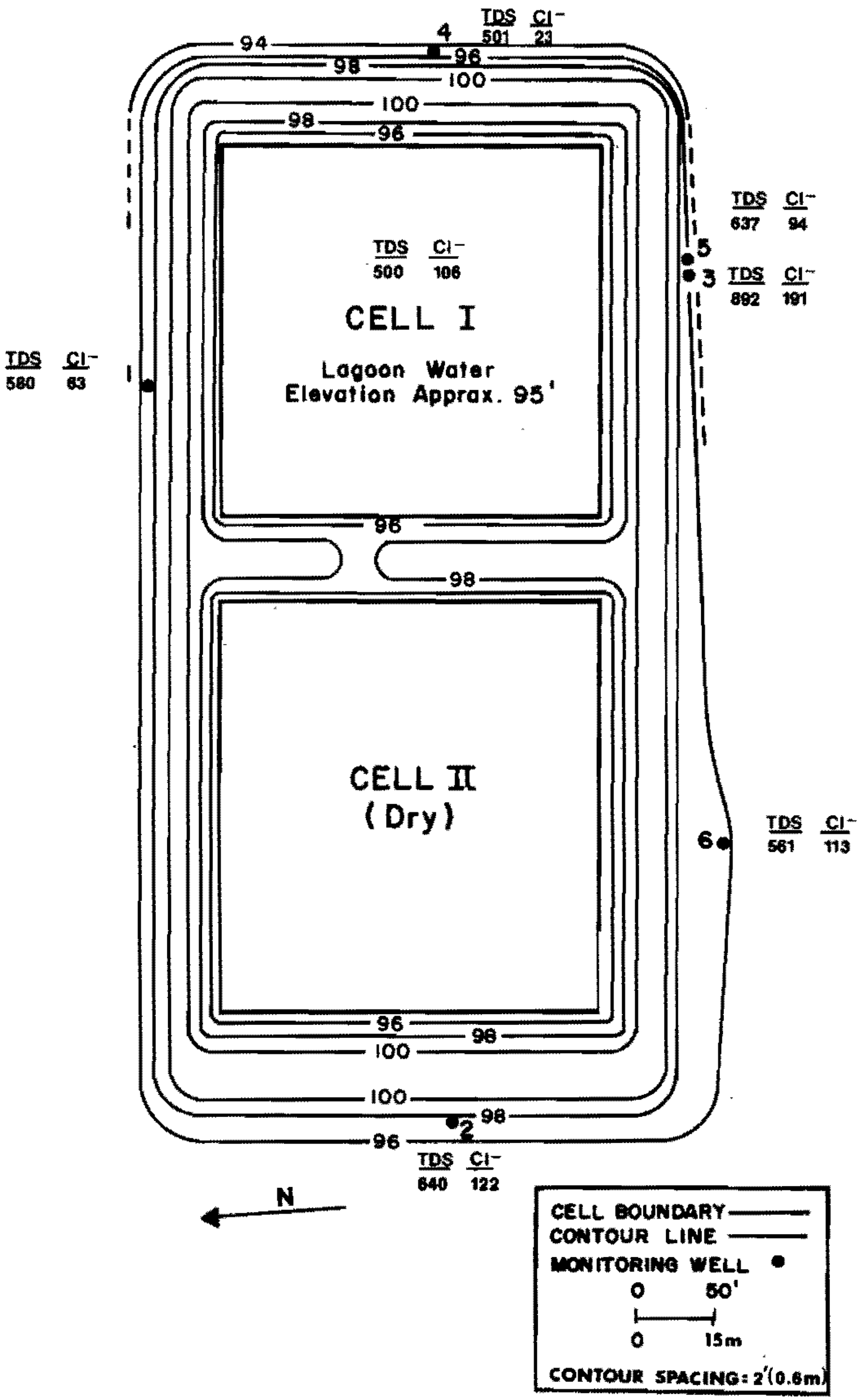

4
375
94
98
96
100
100
98
96
212
CELL I
Lagoon Water
Elevation Approx. 95'
5
463
3
451
1
473
96
98
CELL II
(Dry)
6
253
96
98
100
100
98
2
96
365
N
CELL BOUNDARY
CONTOUR LINE
MONITORING WELL ●
0
50'
0
15m
CONTOUR SPACING: 2'(0.6m)

Figure 39. Mean total dissolved solids (TDS) and chloride (Cl^-) concentrations (mg/L) in groundwater at the Fordville site.


TDS Cl⁻
501 23
4
94
96
98
100
100
98
96
TDS Cl⁻
637 94
5
3
TDS Cl⁻
892 191
TDS Cl⁻
500 106
CELL I
Lagoon Water
Elevation Approx. 95'
TDS Cl⁻
580 63
1
96
98
CELL II
(Dry)
6
TDS Cl⁻
561 113
96
98
100
100
98
2
96
TDS Cl⁻
640 122
N
CELL BOUNDARY
CONTOUR LINE
MONITORING WELL ●
0 50'
0 15m
CONTOUR SPACING: 2'(0.6m)

Chloride values in well 5 were one-half those in well 3, located only a few feet away. Because well 3 has a shallower screened interval than well 5, it probably received contaminated water that tends to move along the top of the aquifer.

Chloride was abundant in wells 2 and 6, over 200 feet (61.0 m) from cell I. Either the groundwater mound extends that distance west of cell I or cell II has been used in the past and has degraded groundwater near those wells.

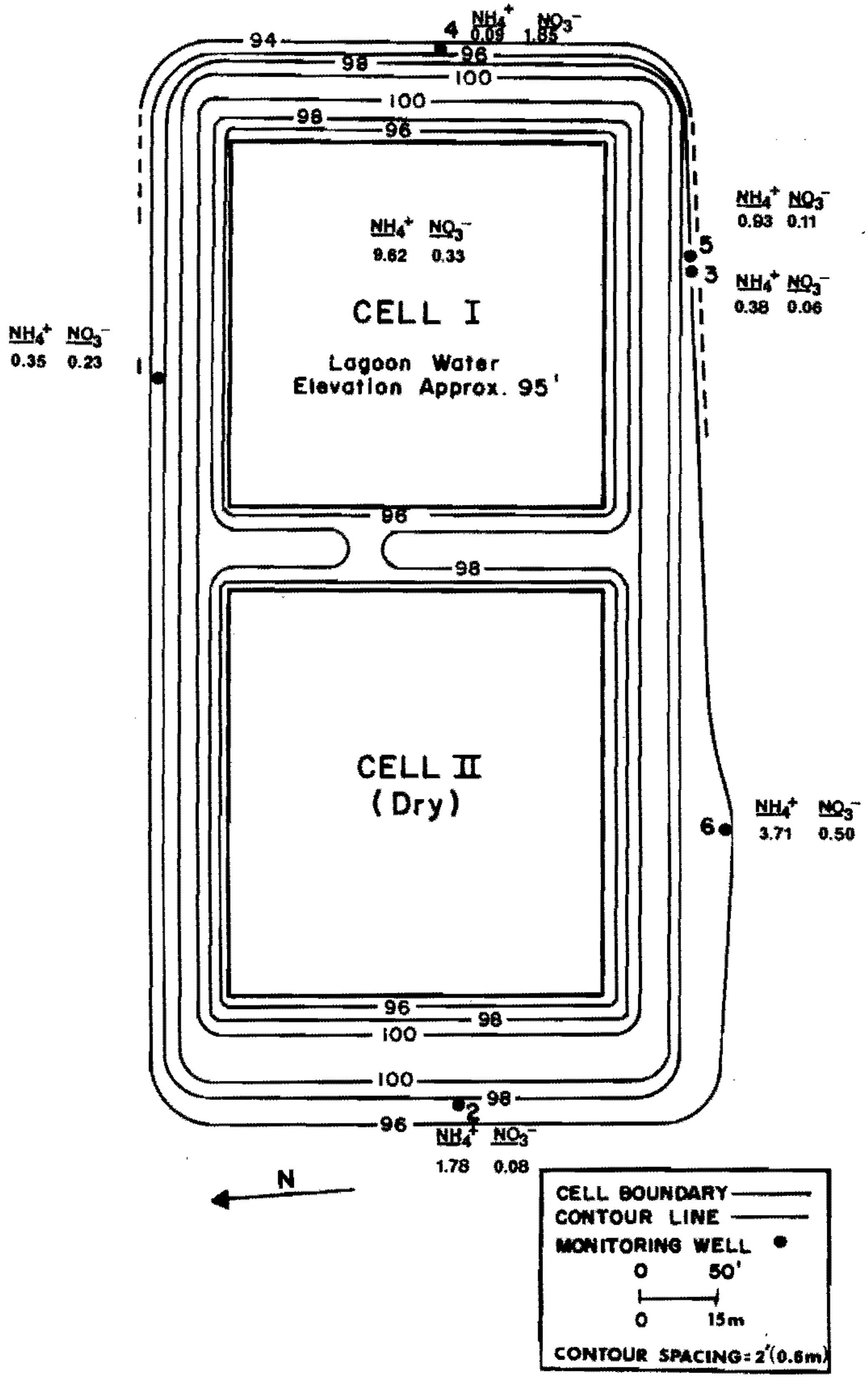
Ammonium

Ammonium, the dominant nitrogen form in groundwater at the site, was highest in the wastewater (9.62 mg/L, Figure 40). All wells at the site had less than 1 mg/L ammonium except for wells 2 and 6 (1.78 mg/L and 3.71 mg/L, respectively, Figure 40). The Fordville maintenance worker "could not recall" cell II ever being used; however, ammonium and other constituents concentrations in wells 2 and 6 suggest a cell II wastewater source rather than fertilizers or some natural source. If cell II ever was used, it probably was for a short time, thus prohibiting the formation of a sludge layer on the bottom of the cell. Hence, attenuation of ammonium by adsorption would not occur, as is the case in cell I. As a result, ammonium reached the groundwater around cell II, attenuated only by dilution.

Nitrate

Nitrates were not significant in wastewater nor groundwater at the Fordville site. All average nitrate concentrations were 1 mg/L

Figure 40. Mean ammonium (NH_4^+) and nitrate (NO_3^-) concentrations (mg/L) in groundwater at the Fordville site.


4
NH₄⁺ NO₃⁻
0.09 1.85
94
98
96
100
100
98
96
NH₄⁺ NO₃⁻
9.62 0.33
CELL I
Lagoon Water
Elevation Approx. 95'
NH₄⁺ NO₃⁻
0.93 0.11
5
3
NH₄⁺ NO₃⁻
0.38 0.06
NH₄⁺ NO₃⁻
0.35 0.23
1
96
98
CELL II
(Dry)
6
NH₄⁺ NO₃⁻
3.71 0.50
96
98
100
100
98
2
96
NH₄⁺ NO₃⁻
1.78 0.08
N
CELL BOUNDARY
CONTOUR LINE
MONITORING WELL ●
0 50'
0 15m
CONTOUR SPACING: 2'(0.6m)

or less, except for the reading of 1.85 mg/L in well 4 (Figure 40). Apparently, any nitrates produced in the pond are being assimilated by aerobic bacteria in the pond.

Total Iron and Sulfate

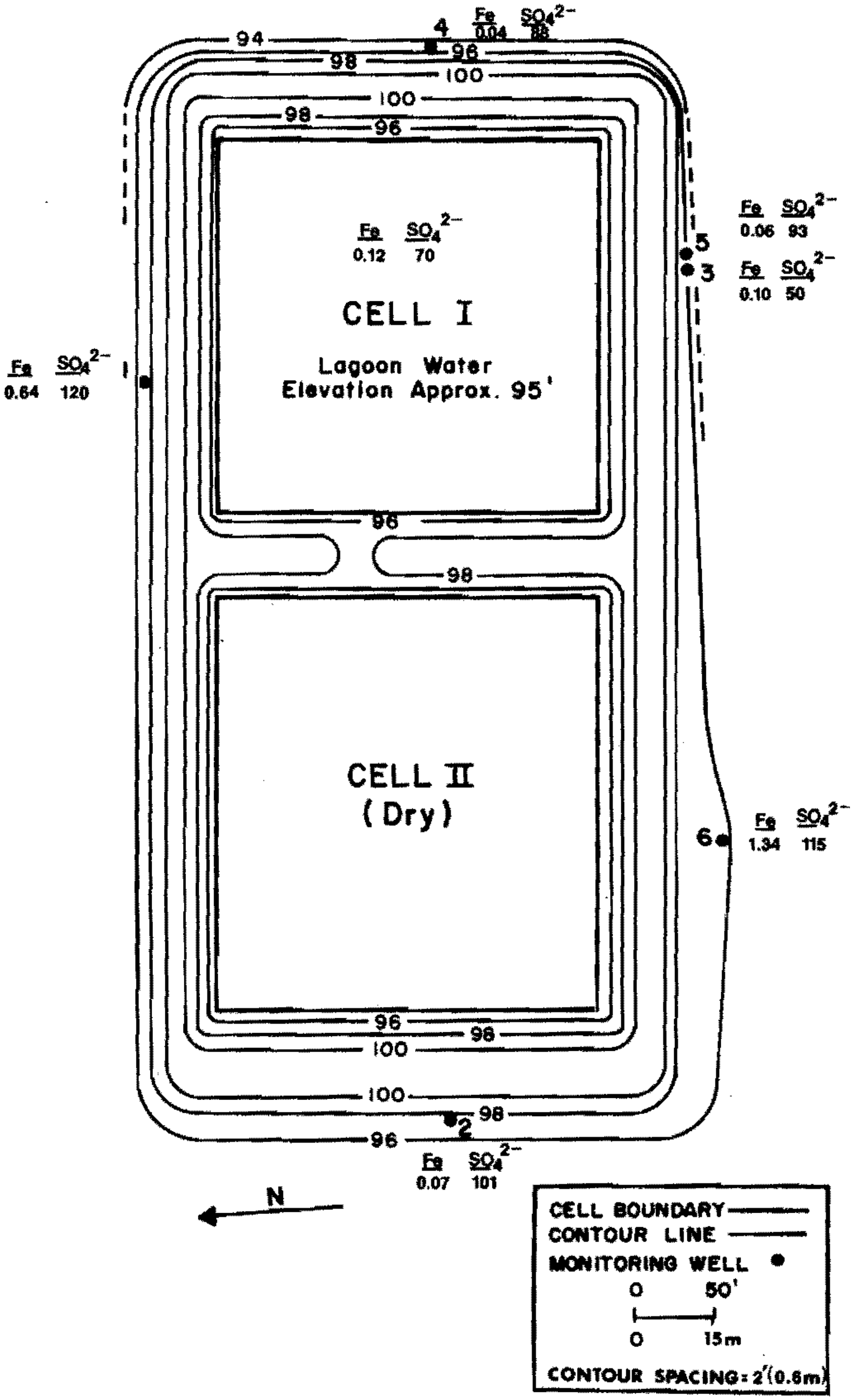
Iron and sulfate readings at this site did not show the variation that they had at the other two sites. Total iron actually decreased in many wells around the cells with the exception of the 1.3 mg/L mean value of well 6 (Figure 41). The clay layer separating the pond bottom from the aquifer retards percolation of wastewater from the pond; apparently, the reducing wastewater is inhibited from coming into contact with iron oxide coatings on aquifer sand grains. Therefore, soluble ferrous iron is not released into solution and total iron readings remain low. Reaction of sulfate with ferrous iron on the pond bottom, precipitating iron pyrite is also a viable mechanism to explain the low total iron readings in groundwater near the cells.

Sulfate concentrations in wells peripheral to cell I were similar to that of wastewater (Figure 41). Sulfates in well 3 decreased in abundance, suggesting some sulfate reduction in pond-bottom waters and migration of low-sulfate water to the groundwater mound under cell I. Higher sulfate readings in wells 2 and 6 suggest oxidation of reduced sulfur forms that remain from a time when cell II contained wastewater.

Manganese

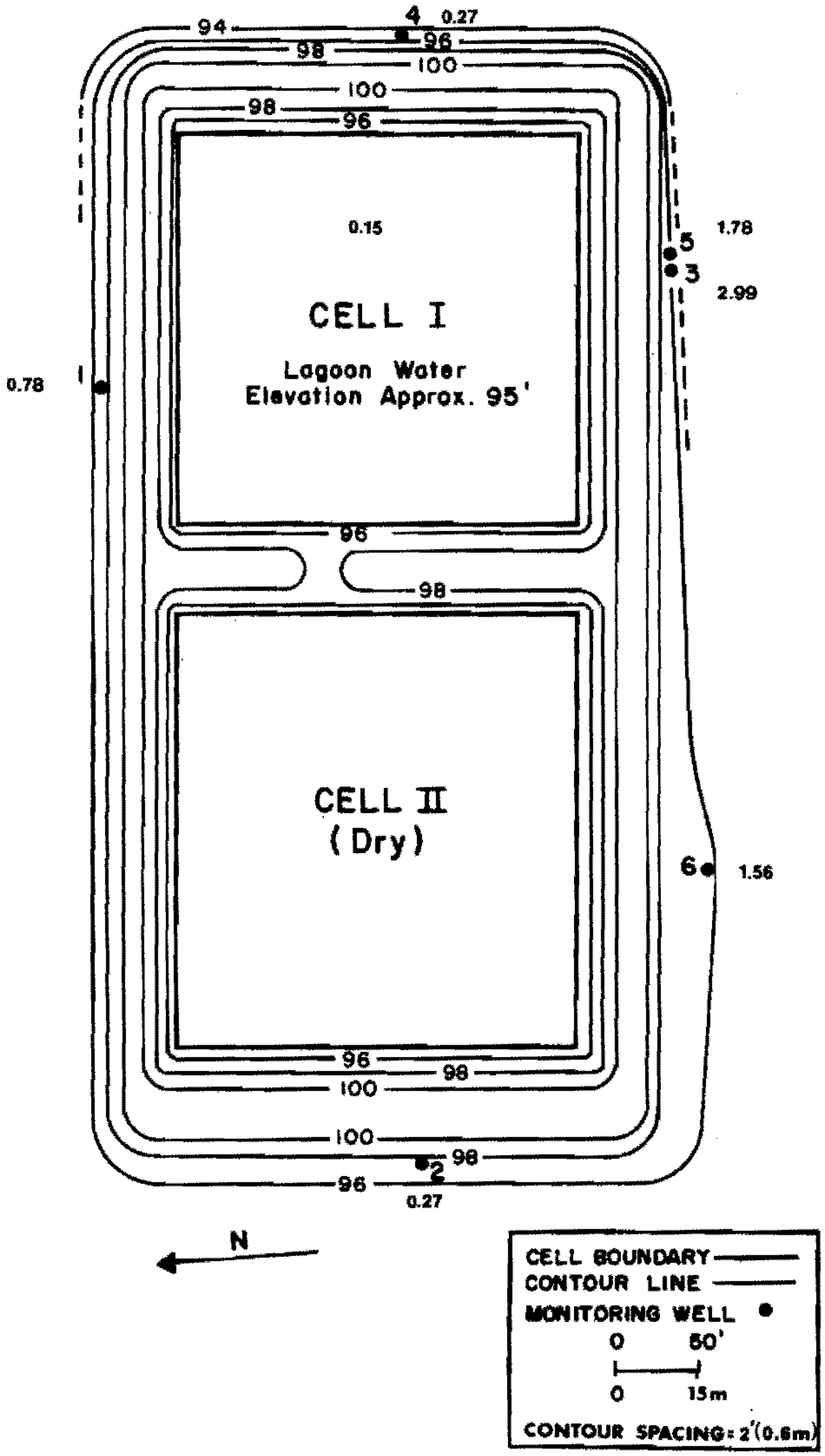
The average manganese concentration in Fordville wastewater was 0.15 mg/L (Figure 42). Concentrations of manganese increased in all

Figure 41. Mean iron (Fe) and sulfate ($SO4^{2-}$) concentrations (mg/L) in groundwater at the Fordville site.



4
Fe 0.04
SO$_4^{2-}$ 88
94
96
98
100
CELL I
Fe 0.12
SO$_4^{2-}$ 70
Lagoon Water Elevation Approx. 95'
Fe 0.64
SO$_4^{2-}$ 120
5
Fe 0.06
SO$_4^{2-}$ 93
3
Fe 0.10
SO$_4^{2-}$ 50
CELL II (Dry)
6
Fe 1.34
SO$_4^{2-}$ 115
2
Fe 0.07
SO$_4^{2-}$ 101
N
CELL BOUNDARY
CONTOUR LINE
MONITORING WELL ●
0 50'
0 15m
CONTOUR SPACING: 2'(0.6m)

Figure 42. Mean manganese (Mn^{2+}) concentrations (mg/L) in groundwater at the Fordville site.


4
0.27
94
96
98
100
100
98
96
0.15
1.78
5
3
2.99
CELL I
Lagoon Water
Elevation Approx. 95'
0.78
1
96
98
CELL II
(Dry)
6
1.56
96
98
100
100
98
2
96
0.27
N
CELL BOUNDARY
CONTOUR LINE
MONITORING WELL ●
0
50'
0
15m
CONTOUR SPACING=2'(0.6m)

wells at the site; the readings in wells 3, 5, and 6 were three times that of natural groundwater. These elevated concentrations are the result of increasing manganese solubility in the low pE environment of the pond bottom.

Trace Elements

Trace elements concentrations were greater in wells on the upgradient side of the groundwater mound than on the opposite side of the mound. If it is assumed that trace elements exist in Fordville wastewater, it is difficult to explain why they preferentially occur in one area of the groundwater mound than in any other. The trace elements may be from an unknown source upgradient from the site.

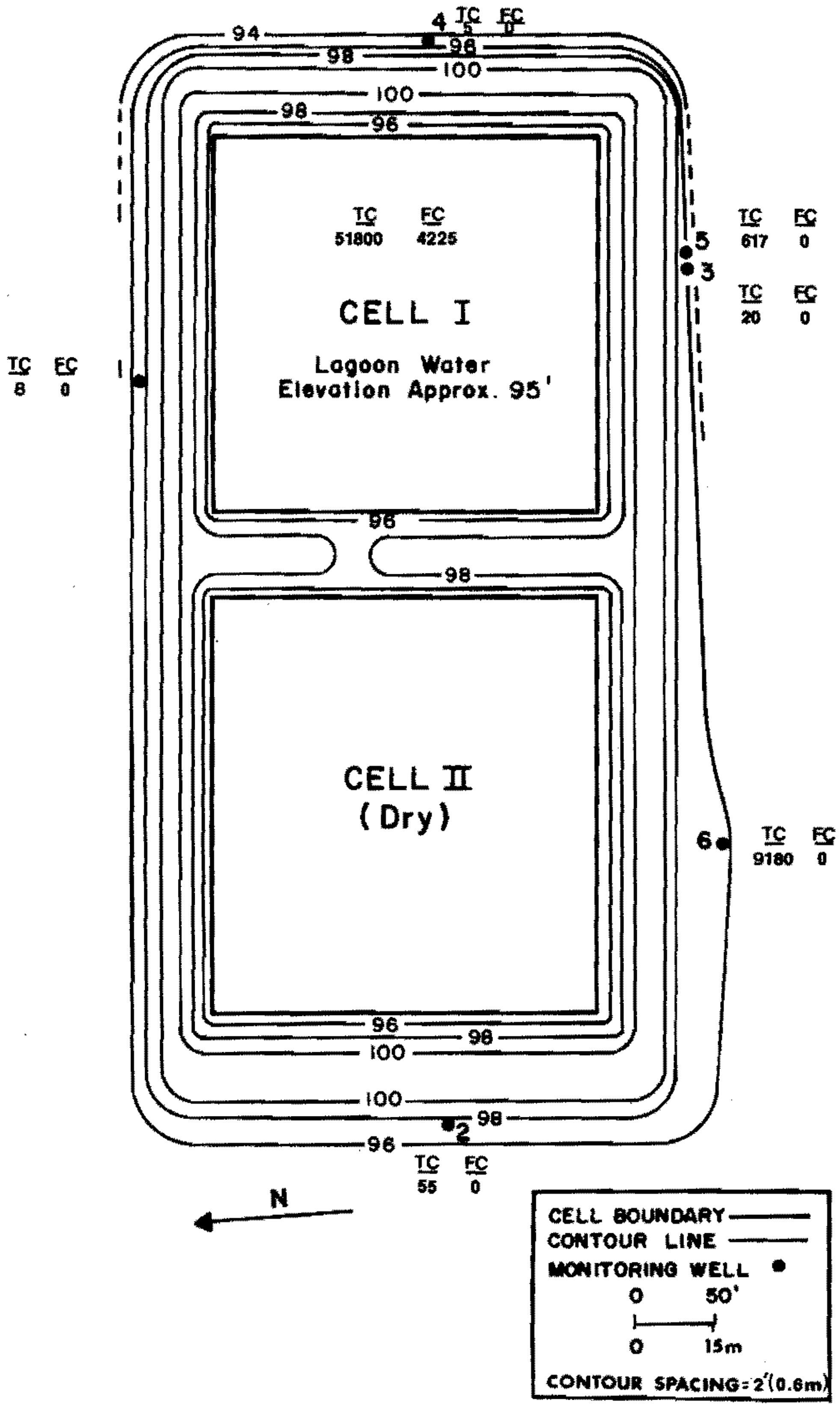
The trace element concentrations in well 1 at the Fordville site were the highest of any of the study sites. For example, barium and selenium at Fordville were three times above the levels at the other sites. Most trace element levels from the October 1981 sampling period were well above maximum limits set for those parameters (Appendix VII).

Total and Fecal Coliform Bacteria

Except for wastewater, no Fordville well sample contained fecal coliform bacteria (Figure 43); however, some total coliform bacteria were detected. The highest counts from the first three sampling periods were recorded in wells 5 and 6.

Sampling techniques were much improved for the summer, 1982 sampling period; total coliform bacteria counts were generally higher

Figure 43. Mean total coliform (TC) and fecal coliform (FC) bacteria (colonies per 100 ml) in groundwater at the Fordville site.


4 TC 5 FC 0
94
98
96
100
100
98
96
TC 51800 FC 4225
CELL I
Lagoon Water Elevation Approx. 95'
5 TC 617 FC 0
3 TC 20 FC 0
1 TC 8 FC 0
96
98
CELL II (Dry)
6 TC 9180 FC 0
96
98
100
100
98
2
96
TC 55 FC 0
N
CELL BOUNDARY
CONTOUR LINE
MONITORING WELL ●
0 50'
0 15m
CONTOUR SPACING=2'(0.6m)

in all wells. Wells 1 and 5 were lowest in coliform bacteria, whereas well 3 had the highest counts (Figure 43), suggesting bacteria migration to the water table mound below the site.

Summary - Fordville

Contamination of groundwater near the Fordville waste stabilization ponds appears to be less severe than at the other two sites. However, contaminant concentrations in Fordville wells still exceed background levels of those constituents. Because the upgradient domestic well probably was contaminated by septic tank effluent and "upgradient" well 1 was within the influence of a groundwater mound under cell I, they did not reflect background concentrations of groundwater constituents. Therefore, published data were consulted to ascertain those values.

Certain constituents in wells peripheral to cell I, such as total hardness, TDS, chloride, and manganese, were present in concentrations exceeding background levels. In addition, wells 2 and 6, lateral to cell I, had high levels of chloride, ammonium, manganese, and total coliform bacteria. Fertilizers may be contributing some of these constituents to groundwater; more likely, though, is the probability that cell II has been used in the past and has contributed contaminants to the groundwater. Subsequent removal of the contaminants did not occur because of slow groundwater velocities caused by the low hydraulic gradient below cell II and presence of a low-permeability silty-clay layer. As a result, contaminant concentrations remain elevated around cell II.

Many contaminant concentrations were considerably higher in well 3 than in well 5, located only a few feet away. For example, TDS, iron, manganese, and chloride were all much higher in well 3 than in well 5. Well 5 is screened approximately 13 feet (4.2 m) beneath well 3; perhaps it receives unaffected groundwater from below the contaminant plume, while well 3 contains poorer quality water from within the plume.

Contaminant concentrations in Fordville wells were generally within the limits set for those constituents. The only exceptions were total hardness concentrations in wells 3 and 5 and total coliform levels in all Fordville site wells. Typical Fordville aquifer water commonly has greater than 250 mg/L total hardness (Downey, 1971), so hardness readings at the site were not grossly excessive.

Although groundwater quality is affected adjacent to the site, concentrations of contaminants generally are not excessive. Because the nearest downgradient domestic well is at least 3/4 mile (1.2 km) from the site and on the other side of the local discharge area, the Forest River, it is not likely to be affected by Fordville waste stabilization pond seepage.

CONCLUSIONS

The McVille, Larimore, and Fordville waste stabilization ponds overlie important aquifers of Pleistocene age glaciofluvial sediment. Hydraulic gradients at the sites were calculated as less than 0.06 inches per foot (0.17 centimetres per metre), but groundwater mounds under the Larimore and Fordville ponds result in steeper hydraulic gradients. Because of highly permeable sandy sediment and a deep water table under the McVille site, a groundwater mound did not form at that site.

Groundwater quality at the three study sites has been adversely affected by wastewater pond percolation. Based on concentrations of wastewater constituents, groundwater near the McVille site is most severely contaminated. Several constituent concentrations downgradient from that site are two or three orders of magnitude above background concentrations. The influence of the Larimore and Fordville ponds is less pronounced than at McVille; nonetheless, many contaminant concentrations increase in monitoring wells adjacent to those sites. Lack of wells farther downgradient from the Larimore and Fordville sites made it impossible to determine the extent of the contaminant plume.

The following conclusions can be made about the study sites:

McVille

1. Most contaminant concentrations increase markedly downgradient from the site, including total hardness, total dissolved solids, chloride, ammonium, total iron, sodium, and bacteria.

2. Three sources contribute contaminants to the groundwater: 1) slow, continuous percolation from cell I; 2) rapid infiltration of wastewater from cell II; and 3) leachate migration from the dump.

3. Redox conditions control the chemical form of many constituents in groundwater at McVille; leachate migration and cell II infiltration generally are more aerobic than percolation from cell I, which has an anaerobic bottom sludge layer typical of such ponds.

4. Potential attenuation mechanisms at the site are: a) dilution with ambient groundwater; b) chemical adsorption of wastewater constituents onto sludge layer particles and/or aquifer particles; c) mechanical filtering of wastewater constituents within the sludge layer; d) precipitation of wastewater constituents with groundwater ions to form insoluble compounds; and e) biologically-catalyzed reduction or oxidation of wastewater constituents.

5. Numerous contaminants are present in McVille groundwater in concentrations exceeding drinking water standards, indicating contaminant influx rates greater than the attenuation capacities of sludge and aquifer particles.

Larimore

1. Many constituents are present in elevated concentrations in wells adjacent to cell I, including total dissolved solids, chloride, ammonium, total iron, and manganese.

2. Contaminant sources were cell I from August, 1981 to April, 1982 and cell II during the summer of 1982. Groundwater quality in wells surrounding cell I improved markedly when pond liquids were transferred to cell II.

3. The influence of redox conditions on chemical species and attenuation processes are similar to that at McVille, except for possibly less efficient pond-bottom attenuation at Larimore because of a poorly developed sludge layer.

4. Water quality standards are met for most constituents, with the exception of manganese and bacteria.

5. Surrounding farmland prohibited construction of wells beyond the pond site; however, it is believed that downgradient domestic wells are not affected by wastewater percolation from the pond.

Fordville

1. Some contaminant percolation to groundwater occurs at the Fordville site; TDS, chloride, and manganese concentrations are elevated in wells peripheral to the site.

2. Because the Fordville pond is excavated in clayey silts and the water table is naturally shallow, a well-developed groundwater mound has formed under the pond. This results in a local hydraulic gradient reversal to the north and a steepening of the gradient south of the site. Contamination of monitoring wells by wastewater constituents is the result.

3. The fine-grained sediment under the Fordville site tends to retain wastewater for long time periods. Therefore, contaminated groundwater is suspected downgradient from Fordville cell II, even though that cell was not used during the study period. A well-developed groundwater mound does not form under cell II if the transfer lasts only a few weeks, as is the usual practice. The resultant low hydraulic gradient causes contaminants to remain near cell II.

4. With the exception of total hardness and bacteria, contaminant concentration limits are being met.

5. Because of the distance of downgradient domestic wells and generally acceptable water quality near the site, it is believed that domestic wells are not affected by Fordville waste pond percolation.

RECOMMENDATIONS

To determine the suitability of potential waste stabilization pond sites, a detailed knowledge of the geology at those sites is critical. Although examination of geologic maps of each area provides a general idea of where sites should be located, exploratory drilling and characterization of the sediment at candidate sites is essential to further narrow the choices. The hydrogeologic setting, including determination of depth of the water table, rate and direction of groundwater flow, and proximity of surface water bodies must also be understood. Only after the hydrogeologic suitability of the sites has been evaluated should factors such as distance from town and the potential aesthetic impacts be considered.

For proper waste stabilization processes to occur within the pond, seepage of less than 1/8 inch (0.3 cm) a day from the pond must be maintained. Therefore, it is imperative that the ponds be excavated in low permeability, fine-grained sediments. In eastern and central North Dakota, clay-rich till and glaciolacustrine deposits are favorable settings. In the western part of the state, Tertiary deposits with high percentages of clay-size particles are generally suitable. However, all sites should be carefully evaluated because of the potential presence of fractured fine-grained sediment with increased permeability. In areas not underlain by low permeability sediment, a low permeability liner of clay or bentonite should be installed in the cell(s).

Seepage from the McVille, Larimore, and Fordville waste stabilization ponds degrade groundwater quality near those sites. Because the sites are downgradient from the cities that use them, contaminants from the ponds travel away from the heavily populated areas of those cities. Nonetheless, groundwater quality is so seriously affected at the McVille site that an impermeable clay liner should be installed in cells I and II to prevent migration of contaminants beyond the site boundary. Groundwater contamination is less serious at the Larimore and Fordville sites; these ponds will cause little damage if left in their present state. Construction of wells in the immediate vicinity of the McVille, Larimore, and Fordville waste stabilization ponds should be prohibited.

APPENDICES

APPENDIX I

MONITORING WELL CONSTRUCTION DATA

TABLE 2

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

MONITORING WELL CONSTRUCTION DATA, Continued

Well Number	Surface Elevation	Elevation of Top of Pipe	Elevation of Top of Screen	Elevation of Bottom of Screen
		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
		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

APPENDIX II

LITHOLOGIC LOGS OF MONITORING WELL HOLES

APPENDIX II-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, 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.
27-43 Sand, fine- to coarse-grained, gravelly, brown, wet.

Well 10

0-16 Sand; fine- to medium-grained, gravelly, yellowish-brown to brown.
16-43 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.
27-38 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 II-B, LARIMORE

Well 1

0-2 Silt; black.
2-5 Sand; fine- to medium-grained, grayish-brown.
5-7 Clay; silty, brown.
7-13 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 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 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 II-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; silty, tan.
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.
3-8 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 III

WATER LEVEL DATA

TABLE 3

WATER LEVEL DATA

Elevations given in feet above an arbitrary datum of zero feet

A. McVILLE

Well	Surface Elevation	5/27/81	6/22	7/16	8/26	10/14	11/29	1/31/82	3/28	4/25	6/08	7/27
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

WATER LEVEL DATA, Continued

B. LARIMORE

Well	Surface Elevation	5/27/81	6/24	7/15	8/30	9/20	10/14	11/21	1/31/82	3/28	4/21	6/22	8/10
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

C. FORDVILLE

		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

APPENDIX IV

GRAIN-SIZE ANALYSES

GRAIN-SIZE ANALYSES

The hydrometer method was used to determine sand, silt, and clay percentages of dominantly silty or clayey samples. This method, discussed in detail by Perkins (1978), is based on the depth to which a standard Buoyoucos hydrometer (a weighted glass tube, graduated in grams per liter) will sink when immersed in a sediment-water mixture. The principle of this method is that a fluid with a high percentage of floating clay-size particles is buoyant and will cause the immersed hydrometer to remain at a high level in the fluid. Conversely, the hydrometer will sink farther into a liquid lacking clay-size particles.

The sediment solution is prepared by combining 35 grams of sediment with 1.25×10^{-4} m^3 of Calgon $(Na\ PO_4)_6$ stock solution. After the sample has soaked for 24 hours, the disaggregated sample and solution is mixed in a blender for one minute and then washed with distilled water into a 10^{-3} m^3 graduate cylinder. The cylinder is then filled to the 10^{-3} m^3 mark with distilled water. Next, the solution is mixed with a plunger to assure that all clay-size particles are in suspension. After mixing, the time is recorded. At the end of a specified time (Perkins, 1978, p. 48), the hydrometer is inserted into the sample suspension and the amount of clay (gm/L) recorded directly from the hydrometer reading.

The solution is then wet-sieved using a number 230 U.S. Standard sieve (0.0625 mm) to remove silt and clay, leaving only sand and gravel. The remaining sediment is oven-dried and then sieved in a RoTap machine using U.S. Standard sieves at 0.5 ϕ intervals to determine sand and gravel percentages of the sample. The silt percentage is determined by subtracting the weights of clay, sand, and gravel from the original sample weight. Results of the procedure are listed in Table 4. Sample numbers in the table refer to well numbers at the sites.

TABLE 4

TEXTURAL CHARACTERISTICS OF STUDY SAMPLES

Sample Number	Depth (ft)	Percentage (by weight)		
		Sand	Silt	Clay
Fordville 1a	2-7	2	73	25
Fordville 1b	10-15	21	68	11
Fordville 2	2-7	38	56	6
Fordville 3a	7-12	28	64	8
Fordville 3b	12-17	23	68	9
Fordville 5a	0-3	4	75	21
Fordville 5b	3-8	21	67	12
Fordville 5c	8-13	23	65	12
Fordville 5d	13-18	25	68	7
Fordville 6	18-23	23	66	11
Larimore 1	5-6	28	63	9
Larimore 2	6-7	28	61	11
Larimore 4	2-7	97	3	3
Larimore 6	13-18	19	69	12
McVille 7a	8-13	96	4	4
McVille 7b	13-18	95	5	5
McVille 7c	28-33	95	5	5
McVille 8a	0-3	95	5	5
McVille 8b	8-13	95	5	5
McVille 8c	18-23	95	5	5

APPENDIX V

HYDRAULIC CONDUCTIVITY ESTIMATES USING GRAIN-SIZE ANALYSES

HYDRAULIC CONDUCTIVITY ESTIMATES USING GRAIN-SIZE ANALYSES

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

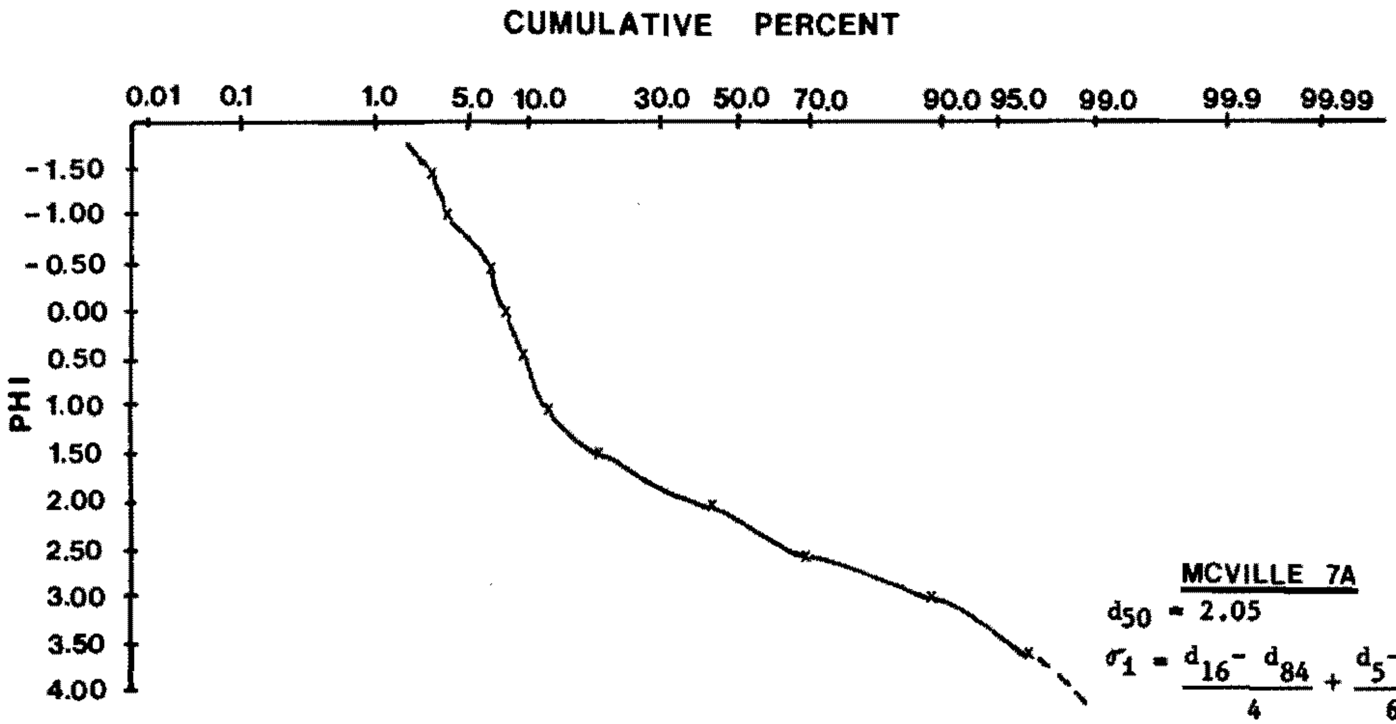
$$\sigma_i = \frac{d_{16} - d_{84}}{4} + \frac{d_5 - d_{95}}{6.6} \quad ,$$

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}. Data, grain-size distribution curves, and results of the procedure are given in Table 5. Sample numbers in the table refer to well numbers at the sites.

TABLE 5

HYDRAULIC CONDUCTIVITY ESTIMATES

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	1.52	7.08×10^{-5}
McVille 7c	28-33	1.345	1.65	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	2-7	0.483	1.90	1.89×10^{-4}



MCVILLE 7A

$d_{50} = 2.05$

$$\sigma_1 = \frac{d_{16} - d_{84}}{4} + \frac{d_5 - d_{95}}{6.6}$$

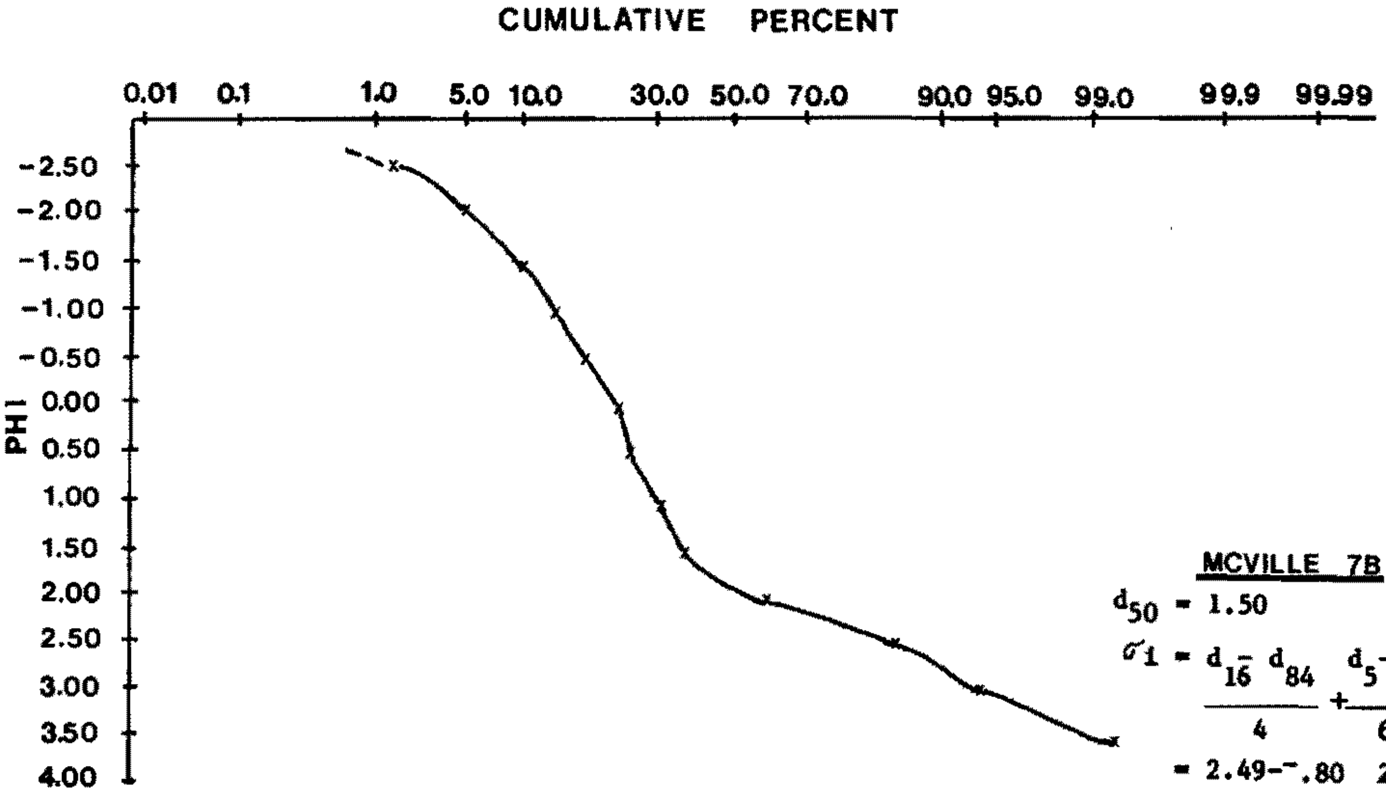
$$= \frac{2.70-1.20}{4} + \frac{3.25 - -.70}{6.6}$$

$$= 0.973$$

From Masch and Denny (1966);

$K = 200$ gal/day-ft^2

$= 9.44 \times 10^{-5}$ m/s



MCVILLE 7B

$d_{50} = 1.50$

$$\sigma_1 = \frac{d_{16} - d_{84}}{4} + \frac{d_5 - d_{95}}{6.6}$$

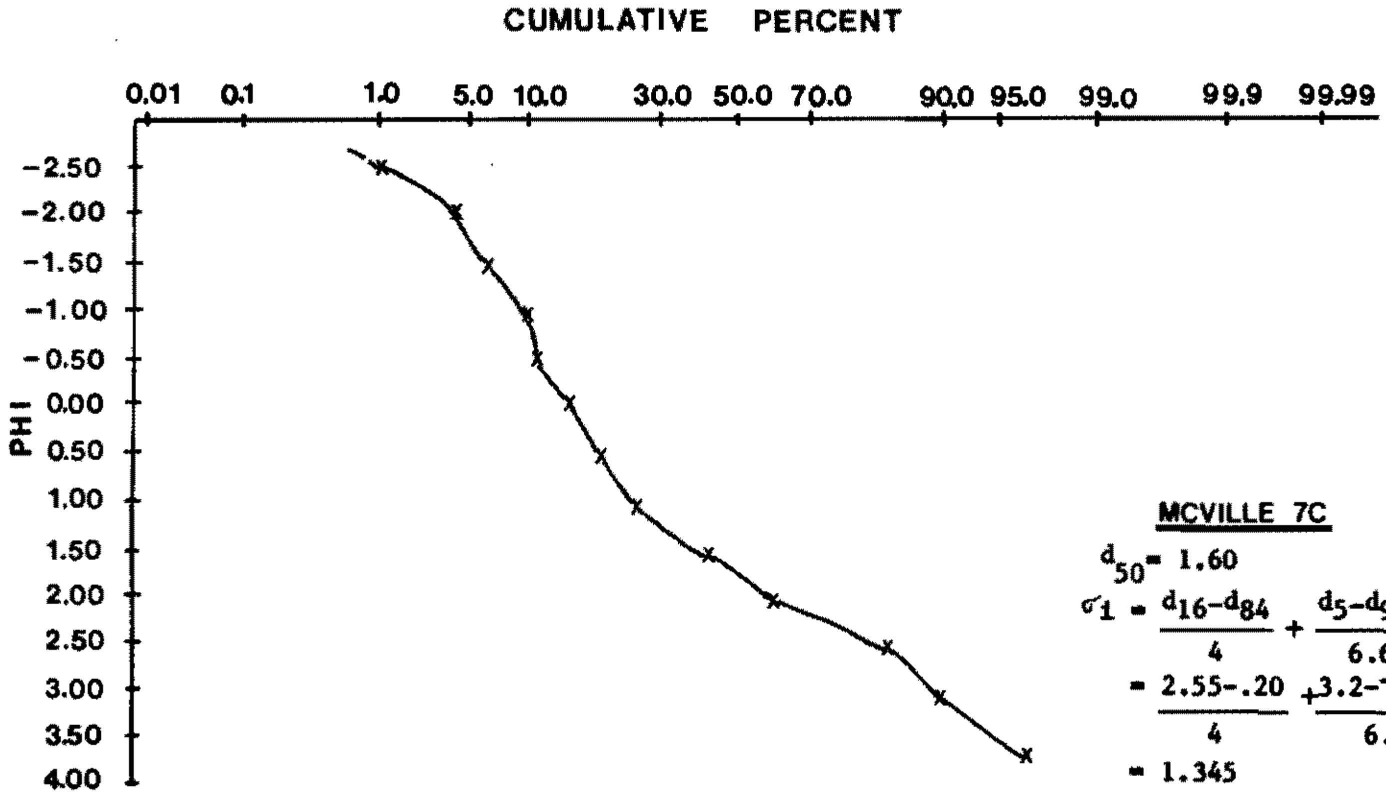
$$= \frac{2.49 - -.80}{4} + \frac{2.7 - -2.0}{6.6}$$

$$= 1.535$$

From Masch and Denny (1966);

$K = 150$ gal/day-ft^2

$= 7.08 \times 10^{-5}$ m/s



MCVILLE 7C

$d_{50} = 1.60$

$$\sigma_1 = \frac{d_{16}-d_{84}}{4} + \frac{d_5-d_{95}}{6.6}$$

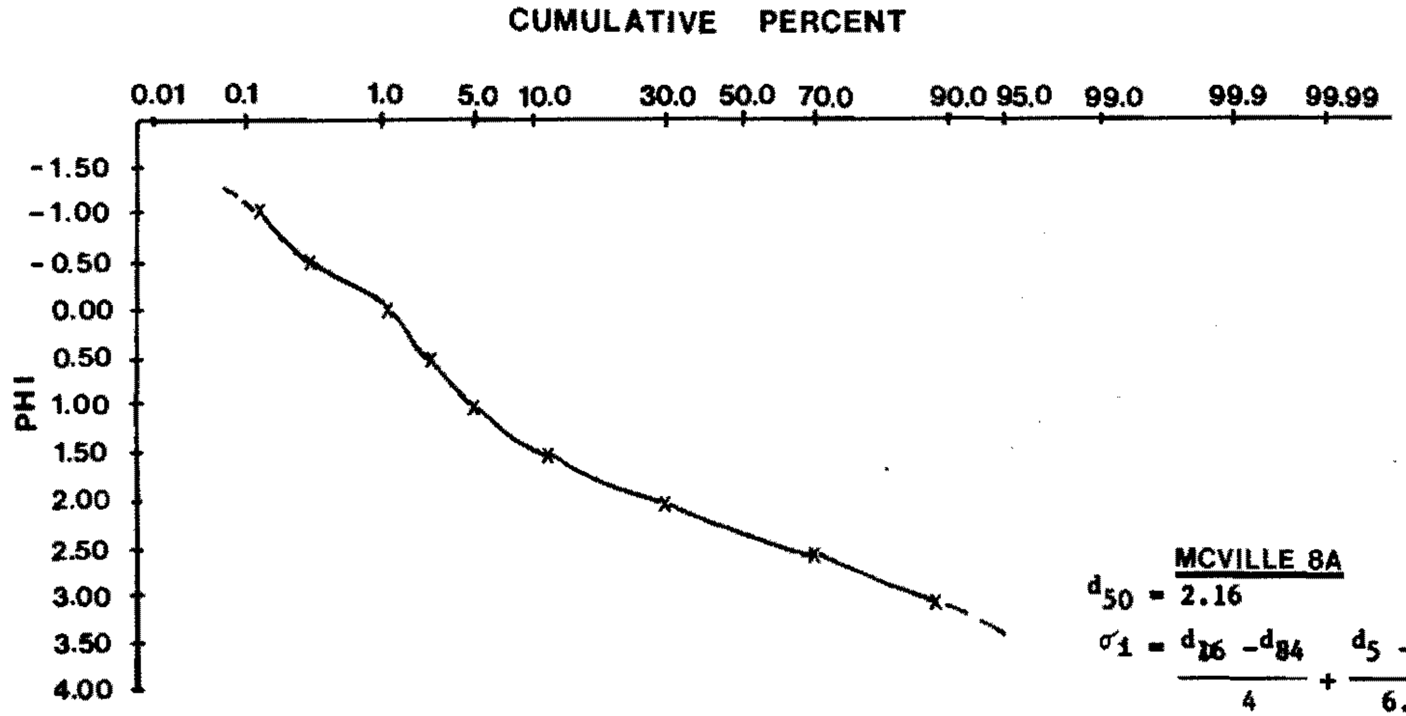
$$= \frac{2.55-.20}{4} + \frac{3.2-{}^{-}1.8}{6.6}$$

$$= 1.345$$

From Masch and Denny (1966);

K= 170 gal/day-ft^2

= 8.02 x 10^{-5} m/s



MCVILLE 8A

$d_{50} = 2.16$

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

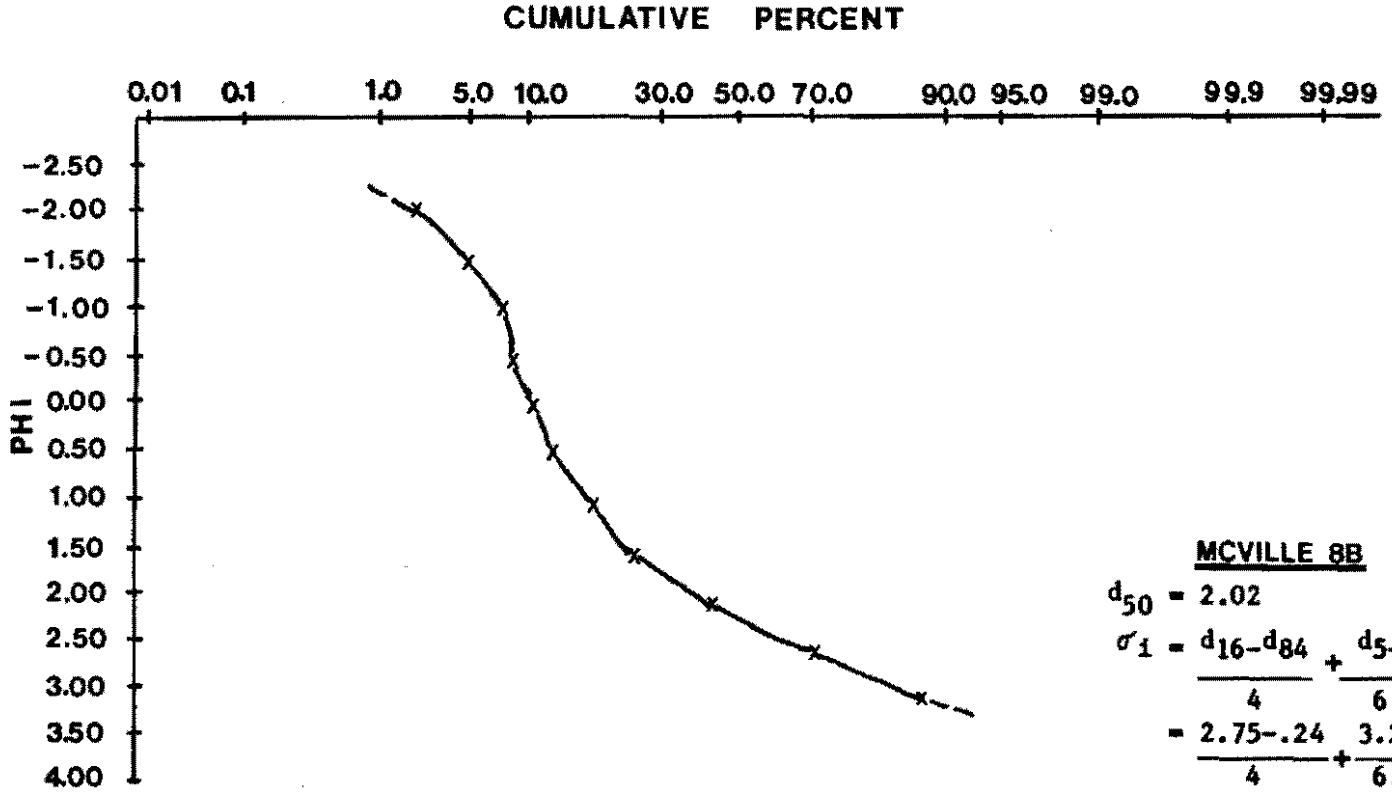
$$= \frac{2.77-1.45}{4} + \frac{3.20-.77}{6.6}$$

$$= 0.698$$

From Masch and Denny(1966);

$K = 250$ gal/day-ft^2

$= 1.18 \times 10^{-4}$ m/s



MCVILLE 8B

$d_{50} = 2.02$

$$\sigma_1 = \frac{d_{16}-d_{84}}{4} + \frac{d_5-d_{95}}{6.6}$$

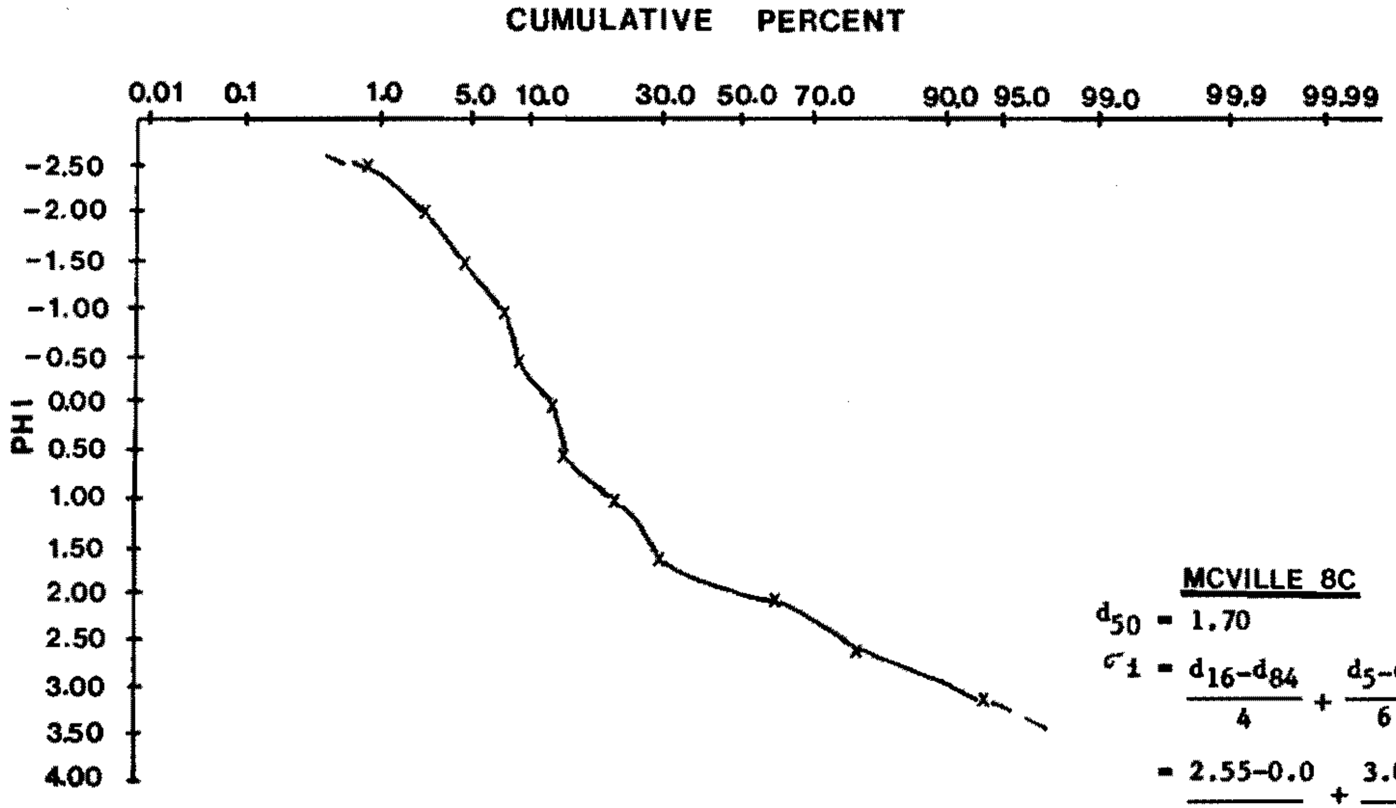
$$= \frac{2.75-.24}{4} + \frac{3.2-{}^{-}1.5}{6.6}$$

$$= 1.34$$

From Masch and Denny (1966);

$K = 170$ gal/day-ft^2

$= 8.02 \times 10^{-5}$ m/s



MCVILLE 8C

$d_{50} = 1.70$

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

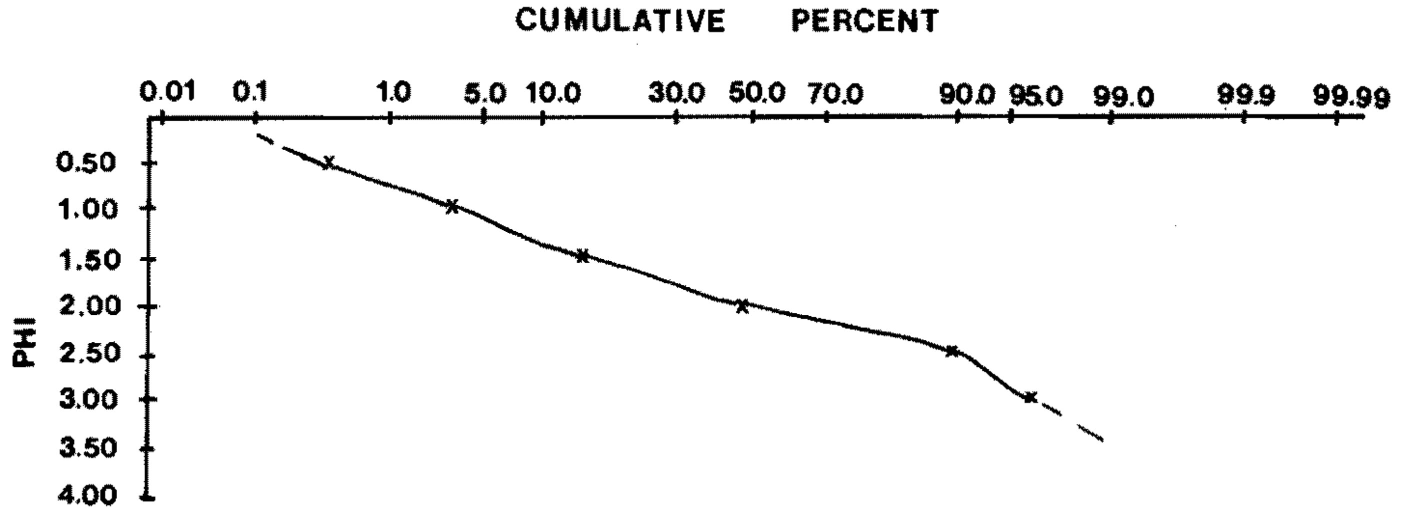
$$= \frac{2.55-0.0}{4} + \frac{3.0-{}^{-}1.5}{6.6}$$

$$= 1.319$$

From Masch and Denny (1966);

$K = 190$ gal/day-ft^2

$= 8.97 \times 10^{-5}$ m/s



LARIMORE 4A

$d_{50} = 1.90$

$$\sigma_1 = \frac{d_{16}-d_{84}}{4} + \frac{d_5 - d_{95}}{6.6}$$

$$= \frac{2.25-1.38}{4} + \frac{2.75-1.0}{6.6}$$

$$= 0.4827$$

From Masch and Denny (1966);

$K = 400$ gal/day-ft^2

$= 1.89 \times 10^{-4}$ m/s

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 study wells. In this test, a metal slug is dropped into the well, raising the water level exactly one metre. The water level is monitored as it declines to its original position. The data are plotted as the unrecovered head difference versus time on semi-logarithmic paper (Hvorslev, 1951, Freeze and Cherry, 1979) to determine the basic time lag (T_o), which is used with well dimensions to calculate hydraulic conductivity using the formula:

$$K = \frac{R^2 \ln (L/R)}{2 L T_o} \text{ , where:}$$

K = hydraulic conductivity (cm/s)

L = length of well screen (cm)

R = radius of well screen (cm), and

T_o = basic time lag (seconds).

Hydraulic conductivity estimates for the study wells are listed in Table 6.

TABLE 6

HYDRAULIC CONDUCTIVITY ESTIMATES

Well	Hydraulic Conductivity (m/s)
McVille 3	4.20×10^{-5}
McVille 6	3.10×10^{-6}
McVille 8	3.49×10^{-5}
Fordville 1	4.84×10^{-7}
Fordville 2	8.72×10^{-6}
Fordville 3	3.06×10^{-6}
Larimore 1	1.56×10^{-6}

APPENDIX VII

WATER QUALITY DATA

TABLE 7

McVILLE - WELL 1

Parameter	10/2/80	8/26/81	10/24/81
Water Level (Ft)	83.28	84.97	84.71
pH	6.6	7.2	6.8
Field Conductivity (umhos/cm)	1250.	-	-
Lab Conductivity (umhos/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	228.	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 (ug/L)	-	13.	29.6
Barium (ug/L)	-	350.	470.
Cadmium (ug/L)	-	1.0	1.9
Chromium (ug/L)	-	14.4	24.9
Copper (ug/L)	-	102.	12.0
Lead (ug/L)	-	22.	35.3
Selenium (ug/L)	-	0.2	0.4
Zinc (ug/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 (umhos/cm)	-	1100.
Lab Conductivity (umhos/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 (ug/L)	91.8	-
Barium (ug/L)	1750.	-
Cadmium (ug/L)	41.1	-
Chromium (ug/L)	112.	-
Copper (ug/L)	270.	-
Lead (ug/L)	140.	-
Selenium (ug/L)	1.1	-
Zinc (ug/L)	362.	-

TABLE 8

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 (umhos/cm)	610.	-	-
Lab Conductivity (umhos/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 (ug/L)	-	-	-
Barium (ug/L)	-	-	-
Cadmium (ug/L)	-	-	-
Chromium (ug/L)	-	-	-
Copper (ug/L)	-	-	-
Lead (ug/L)	-	-	-
Selenium (ug/L)	-	-	-
Zinc (ug/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 (umhos/cm)	-	650.
Lab Conductivity (umhos/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 (ug/L)	-	-
Barium (ug/L)	-	-
Cadmium (ug/L)	-	-
Chromium (ug/L)	-	-
Copper (ug/L)	-	-
Lead (ug/L)	-	-
Selenium (ug/L)	-	-
Zinc (ug/L)	-	-

TABLE 9

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 (umhos/cm)	1800.	-	-
Lab Conductivity (umhos/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	-	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 (ug/L)	-	-	-
Barium (ug/L)	-	-	-
Cadmium (ug/L)	-	-	-
Chromium (ug/L)	-	-	-
Copper (ug/L)	-	-	-
Lead (ug/L)	-	-	-
Selenium (ug/L)	-	-	-
Zinc (ug/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 (umhos/cm)	-	1400.
Lab Conductivity (umhos/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 (ug/L)	-	-
Barium (ug/L)	-	-
Cadmium (ug/L)	-	-
Chromium (ug/L)	-	-
Copper (ug/L)	-	-
Lead (ug/L)	-	-
Selenium (ug/L)	-	-
Zinc (ug/L)	-	-

TABLE 10

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 (umhos/cm)	1800.	-	-
Lab Conductivity (umhos/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 (ug/L)	-	-	22.6
Barium (ug/L)	-	-	70.
Cadmium (ug/L)	-	-	1.3
Chromium (ug/L)	-	-	6.9
Copper (ug/L)	-	-	90.
Lead (ug/L)	-	-	12.1
Selenium (ug/L)	-	-	0.2
Zinc (ug/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 (umhos/cm)	-	1700.
Lab Conductivity (umhos/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 (ug/L)	19.0	-
Barium (ug/L)	230.	-
Cadmium (ug/L)	2.1	-
Chromium (ug/L)	7.2	-
Copper (ug/L)	161.	-
Lead (ug/L)	25.9	-
Selenium (ug/L)	0.4	-
Zinc (ug/L)	47.	-

TABLE 11

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 (umhos/cm)	1900.	-	-
Lab Conductivity (umhos/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 (ug/L)	-	-	-
Barium (ug/L)	-	-	-
Cadmium (ug/L)	-	-	-
Chromium (ug/L)	-	-	-
Cooper (ug/L)	-	-	-
Lead (ug/L)	-	-	-
Selenium (ug/L)	-	-	-
Zinc (ug/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 (umhos/cm)	-	1500.
Lab Conductivity (umhos/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 (ug/L)	-	-
Barium (ug/L)	-	-
Cadmium (ug/L)	-	-
Chromium (ug/L)	-	-
Copper (ug/L)	-	-
Lead (ug/L)	-	-
Selenium (ug/L)	-	-
Zinc (ug/L)	-	-

TABLE 12

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 (umhos/cm)	2000.	-	-
Lab Conductivity (umhos/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 (ug/L)	-	-	-
Barium (ug/L)	-	-	-
Cadmium (ug/L)	-	-	-
Chromium (ug/L)	-	-	-
Copper (ug/L)	-	-	-
Lead (ug/L)	-	-	-
Selenium (ug/L)	-	-	-
Zinc (ug/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 (umhos/cm)	-	1980.
Lab Conductivity (umhos/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 (ug/L)	-	-
Barium (ug/L)	-	-
Cadmium (ug/L)	-	-
Chromium (ug/L)	-	-
Copper (ug/L)	-	-
Lead (ug/L)	-	-
Selenium (ug/L)	-	-
Zinc (ug/L)	-	-

TABLE 13

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 (umhos/cm)	-	-	-	1750.
Lab Conductivity (umhos/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 (ug/L)	-	-	-	-
Barium (ug/L)	-	-	-	-
Cadmium (ug/L)	-	-	-	-
Chromium (ug/L)	-	-	-	-
Copper (ug/L)	-	-	-	-
Lead (ug/L)	-	-	-	-
Selenium (ug/L)	-	-	-	-
Zinc (ug/L)	-	-	-	-

TABLE 14

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 (umhos/cm)	-	-	-	-
Lab Conductivity (umhos/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 (ug/L)	-	-	-	-
Barium (ug/L)	-	-	-	-
Cadmium (ug/L)	-	-	-	-
Chromium (ug/L)	-	-	-	-
Copper (ug/L)	-	-	-	-
Lead (ug/L)	-	-	-	-
Selenium (ug/L)	-	-	-	-
Zinc (ug/L)	-	-	-	-

TABLE 15

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 (umhos/cm)	600.	1400.	1600.
Lab Conductivity (umhos/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 (ug/L)	-	-	-
Barium (ug/L)	-	-	-
Cadmium (ug/L)	-	-	-
Chromium (ug/L)	-	-	-
Copper (ug/L)	-	-	-
Lead (ug/L)	-	-	-
Selenium (ug/L)	-	-	-
Zinc (ug/L)	-	-	-

TABLE 16

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 (umhos/cm)	1800.	2000.	1800.
Lab Conductivity (umhos/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)	0.0	1.4	1.2
Total Coliform (colonies/100 ml)	≥2400.	920.	130.
Fecal Coliform (colonies/100 ml)	63.	70.	5.
Arsenic (ug/L)	-	-	-
Barium	-	-	-
Cadmium (ug/L)	-	-	-
Chromium (ug/L)	-	-	-
Copper (ug/L)	-	-	-
Lead (ug/L)	-	-	-
Selenium (ug/L)	-	-	-
Zinc (ug/L)	-	-	-

TABLE 17

McVILLE - LAGOON

Parameter	10/12/80	8/26/81	10/25/81
Water Level (Ft)	-	-	-
pH	7.5	8.2	8.2
Field Conductivity (umhos/cm)	650.	-	-
Lab Conductivity (umhos/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 (ug/L)	-	-	-
Barium (ug/L)	-	-	-
Cadmium (ug/L)	-	-	-
Chromium (ug/L)	-	-	-
Copper (ug/L)	-	-	-
Lead (ug/L)	-	-	-
Selenium (ug/L)	-	-	-
Zinc (ug/L)	-	-	-

McVILLE - LAGOON (Continued)

Parameter	4/25/82	7/27/82
Water Level (Ft)	-	-
pH	7.2	8.1
Field Conductivity (umhos/cm)	-	1500.
Lab Conductivity (umhos/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 (ug/L)	-	-
Barium (ug/L)	-	-
Cadmium (ug/L)	-	-
Chromium (ug/L)	-	-
Copper (ug/L)	-	-
Lead (ug/L)	-	-
Selenium (ug/L)	-	-
Zinc (ug/L)	-	-

TABLE 18

McVILLE - FARM WELL

Parameter	10/12/80	4/25/82	7/27/82
Water Level (Ft)	-	-	-
pH	7.0	6.8	-
Field Conductivity (umhos/cm)	1800.	-	-
Lab Conductivity (umhos/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 (ug/L)	-	-	-
Barium (ug/L)	-	-	-
Cadmium (ug/L)	-	-	-
Chromium (ug/L)	-	-	-
Copper (ug/L)	-	-	-
Lead (ug/L)	-	-	-
Selenium (ug/L)	-	-	-
Zinc (ug/L)	-	-	-

TABLE 19

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 (umhos/cm)	-	-	-	1270.
Lab Conductivity (umhos/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 (ug/L)	61	58.8	93.1	-
Barium (ug/L)	870.	410.	500.	-
Cadmium (ug/L)	4.5	2.8	1.7	-
Chromium (ug/L)	17.5	2.6	7.8	-
Copper (ug/L)	23.0	4.3	19.1	-
Lead (ug/L)	14.0	4.7	5.7	-
Selenium (ug/L)	0.0	0.1	0.3	-
Zinc (ug/L)	181.	78.	27.	-

TABLE 20
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 (umhos/cm)	-	-	-	1860.
Lab Conductivity (umhos/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 (ug/L)	-	-	-	-
Barium (ug/L)	-	-	-	-
Cadmium (ug/L)	-	-	-	-
Chromium (ug/L)	-	-	-	-
Copper (ug/L)	-	-	-	-
Lead (ug/L)	-	-	-	-
Selenium (ug/L)	-	-	-	-
Zinc (ug/L)	-	-	-	-

TABLE 21
LARIMORE - WELL 3

Parameter	8/2/81	10/21/81	4/21/81	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 (umhos/cm)	-	-	-	690.
Lab Conductivity (umhos/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.	13.
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 (ug/L)	45.	-	16.3	-
Barium (ug/L)	1260.	-	250.	-
Cadmium (ug/L)	175.	-	1.3	-
Chromium (ug/L)	24.2	-	21.0	-
Copper (ug/L)	98.0	-	30.5	-
Lead (ug/L)	64.	-	19.2	-
Selenium (ug/L)	0.0	-	6.0	-
Zinc (ug/L)	238.	-	48.	-

TABLE 22

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 (umhos/cm)	-	-	-	1370.
Lab Conductivity (umhos/cm)	1510.	1510.	1810.	1554.
Dissolved Oxygen (mg/L)	0.5	1.0	3.0	0.6
Total Dissolved Solids	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 (ug/L)	-	-	-	-
Barium (ug/L)	-	-	-	-
Cadmium (ug/L)	-	-	-	-
Chromium (ug/L)	-	-	-	-
Copper (ug/L)	-	-	-	-
Lead (ug/L)	-	-	-	-
Selenium (ug/L)	-	-	-	-
Zinc (ug/L)	-	-	-	-

TABLE 23
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 (umhos/cm)	-	-	-	1290.
Lab Conductivity (umhos/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 (ug/L)	-	-	-	-
Barium (ug/L)	-	-	-	-
Cadmium (ug/L)	-	-	-	-
Chromium (ug/L)	-	-	-	-
Copper (ug/L)	-	-	-	-
Lead (ug/L)	-	-	-	-
Selenium (ug/L)	-	-	-	-
Zinc (ug/L)	-	-	-	-

TABLE 24

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 (umhos/cm)	-	-	-	1450.
Lab Conductivity (umhos/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 (ug/L)	-	-	-	-
Barium (ug/L)	-	-	-	-
Cadmium (ug/L)	-	-	-	-
Chromium (ug/L)	-	-	-	-
Copper (ug/L)	-	-	-	-
Lead (ug/L)	-	-	-	-
Selenium (ug/L)	-	-	-	-
Zinc (ug/L)	-	-	-	-

TABLE 25

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 (umhos/cm)	-	-	-	840.
Lab Conductivity (umhos/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 (ug/L)	-	6.6	-	-
Barium (ug/L)	-	130.	-	-
Cadmium (ug/L)	-	2.7	-	-
Chromium (ug/L)	-	5.0	-	-
Copper (ug/L)	-	70.0	-	-
Lead (ug/L)	-	11.1	-	-
Selenium (ug/L)	-	0.3	-	-
Zinc (ug/L)	-	53.	-	-

TABLE 26

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 (umhos/cm)	-	-	-	1440.
Lab Conductivity (umhos/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 (ug/L)	-	-	-	-
Barium (ug/L)	-	-	-	-
Cadmium (ug/L)	-	-	-	-
Chromium (ug/L)	-	-	-	-
Copper (ug/L)	-	-	-	-
Lead (ug/L)	-	-	-	-
Selenium (ug/L)	-	-	-	-
Zinc (ug/L)	-	-	-	-

TABLE 27

LARIMORE - FARM WELL

Parameter	4/21/82
Water Level (Ft)	-
pH	6.8
Field Conductivity (umhos/cm)	-
Lab Conductivity (umhos/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 (ug/L)	-
Barium (ug/L)	-
Cadmium (ug/L)	-
Chromium (ug/L)	-
Copper (ug/L)	-
Lead (ug/L)	-
Selenium (ug/L)	-
Zinc (ug/L)	-

TABLE 28

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 (umhos/cm)	-	-	-	1400.
Lab Conductivity (umhos/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 (ug/L)	1.0	165.	-	-
Barium (ug/L)	1940.	73.00	-	-
Cadmium (ug/L)	29.8	12.2	-	-
Chromium (ug/L)	1.0	149.	-	-
Copper (ug/L)	4.1	490.	-	-
Lead (ug/L)	0.0	182.	-	-
Selenium (ug/L)	5.0	13.3	-	-
Zinc (ug/L)	578.	1290.	-	-

TABLE 29
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 (umhos/cm)	-	-	-	1090.
Lab Conductivity (umhos/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 (ug/L)	-	-	69.3	-
Barium (ug/L)	-	-	390.	-
Cadmium (ug/L)	-	-	1.0	-
Chromium (ug/L)	-	-	98.1	-
Copper (ug/L)	-	-	87.0	-
Lead (ug/L)	-	-	30.2	-
Selenium (ug/L)	-	-	1.9	-
Zinc (ug/L)	-	-	126.	-

TABLE 30

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 (umhos/cm)	-	-	-	1630.
Lab Conductivity (umhos/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	35.0
Sodium (mg/L)	124.	112.	122.	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 (ug/L)	8.0	0.0	2.9	-
Barium (ug/L)	620.	420.	330.	-
Cadmium (ug/L)	1.6	1.0	0.6	-
Chromium (ug/L)	20.5	3.2	6.3	-
Copper (ug/L)	29.0	9.6	36.0	-
Lead (ug/L)	12.0	5.8	9.5	-
Selenium (ug/L)	1.0	0.1	0.2	-
Zinc (ug/L)	61.0	29.0	28.0	-

TABLE 31

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 (umhos/cm)	-	-	-	960.
Lab Conductivity (umhos/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 (ug/L)	-	-	-	-
Barium (ug/L)	-	-	-	-
Cadmium (ug/L)	-	-	-	-
Chromium (ug/L)	-	-	-	-
Copper (ug/L)	-	-	-	-
Lead (ug/L)	-	-	-	-
Selenium (ug/L)	-	-	-	-
Zinc (ug/L)	-	-	-	-

TABLE 32

FORDVILLE - WELL 5

Parameter	8/4/81	10/25/81	4/20/81	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 (umhos/cm)	-	-	-	1060.
Lab Conductivity (umhos/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 (ug/L)	-	-	-	-
Barium (ug/L)	-	-	-	-
Cadmium (ug/L)	-	-	-	-
Chromium (ug/L)	-	-	-	-
Copper (ug/L)	-	-	-	-
Lead (ug/L)	-	-	-	-
Selenium (ug/L)	-	-	-	-
Zinc (ug/L)	-	-	-	-

TABLE 33

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 (umhos/cm)	-	-	-	-
Lab Conductivity (umhos/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 (ug/L)	-	-	-	-
Barium (ug/L)	-	-	-	-
Cadmium (ug/L)	-	-	-	-
Chromium (ug/L)	-	-	-	-
Copper (ug/L)	-	-	-	-
Lead (ug/L)	-	-	-	-
Selenium (ug/L)	-	-	-	-
Zinc (ug/L)	-	-	-	-

TABLE 34

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 (umhos/cm)	-	-	-	975.
Lab Conductivity (umhos/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 (ug/L)	-	-	-	-
Barium (ug/L)	-	-	-	-
Cadmium (ug/L)	-	-	-	-
Chromium (ug/L)	-	-	-	-
Copper (ug/L)	-	-	-	-
Lead (ug/L)	-	-	-	-
Selenium (ug/L)	-	-	-	-
Zinc (ug/L)	-	-	-	-

TABLE 35

FORDVILLE - HOME WELL

Parameter	8/4/81	10/25/81	4/20/82	8/17/82
Water Level (Ft)	-	-	-	-
pH	-	-	6.6	-
Field Conductivity (umhos/cm)	-	-	-	-
Lab Conductivity (umhos/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 (ug/L)	-	-	-	-
Barium (ug/L)	-	-	-	-
Cadmium (ug/L)	-	-	-	-
Chromium (ug/L)	-	-	-	-
Copper (ug/L)	-	-	-	-
Lead (ug/L)	-	-	-	-
Selenium (ug/L)	-	-	-	-
Zinc (ug/L)	-	-	-	-

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