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Evaluation of the interaction between seepage from a municipal waste stabilization lagoon, McVille, North Dakota, and a shallow unconfined aquifer

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EVALUATION OF THE INTERACTION BETWEEN SEEPAGE FROM A MUNICIPAL WASTE STABILIZATION LAGOON, MCVILLE, NORTH DAKOTA, AND A SHALLOW UNCONFINED AQUIFER

by
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Bachelor of Science, University of Minnesota, Duluth, 1984

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Master of Science

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This thesis submitted by Paul R. Bulger in partial fulfillment of the requirements for the Degree of Geology from the University of North Dakota has been read by the Faculty Advisory Committee under whom the work has been done, and is hereby approved.

Alan E. Kehew
(Chairperson)

Don L. Halvorson

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: EVALUATION OF THE INTERACTION BETWEEN SEEPAGE FROM A MUNICIPAL SEWAGE LAGOON, MCVILLE, NORTH DAKOTA, AND A SHALLOW UNCONFINED AQUIFER

Department: GEOLOGY AND GEOLOGICAL ENGINEERING

Degree: MASTER OF SCIENCE

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Signature Paul R. Bulger

Date April 23, 1987

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ABSTRACT

The McVille, North Dakota, Municipal Waste Stabilization Lagoon is situated above the McVille Aquifer, an unconfined glaciofluvial aquifer capable of significant water yields. The site contains a 3-D network of 29 monitoring wells. Standing waste-water is maintained in the clay-lined, primary-operating cell. Operating practices at the site entail periodic discharges of waste-water from the lined cell to an unlined cell, a procedure which results in rapid infiltration.

The shape and extent of the groundwater contaminant plume caused by the waste-stabilization process is best delineated by the distribution of chloride. Background wells contain less than 10 mg/L chloride. The area up to 60 m downgradient of the lined cell contains chloride levels at the waste water mean concentration of 256 mg/L. Further downgradient, the chloride levels decrease gradually to 130 mg/L, at a distance of 220 m from the lined cell. Contoured concentrations of total dissolved solids and electrical conductivity display a similar subelliptical plume shape. These three parameters are essentially nonreactive and appear to be attenuated by hydrodynamic dispersion.

Water-table elevations, redox potential and water chemistry, which were determined before and after discharge of waste water into the unlined cell, did not demonstrate a distinct effect resulting from this event. A slight rise

in the water table elevations was detected 3 days after the discharge.

The most important hydrogeochemical interactions are a result of redox processes controlled by anaerobic bacteria. The infiltrating waste-water contains high dissolved organic carbon (DOC) concentrations. Oxidation of DOC in the aquifer results in lowering of the redox potential. Sulfate concentrations decrease beneath and shortly downgradient of the lined cell, as sulfate is reduced to sulfide. Elevated Fe and Mn levels immediately downgradient of the lined and unlined cells indicate reduction and dissolution of solid phases. Arsenic concentrations increase in this same area, where adsorbed ions are liberated as the iron phase dissolves. The abrupt downgradient decrease in Fe, Mn and As suggests reprecipitation or adsorption of these elements. Field measured redox potentials delineate the extent of a plume of reducing water, along with the afore-mentioned inorganic constituents. The measured pe gradually increases, approaching background levels at the extreme downgradient edge of the site.

High ammonium values, up to four times the level within the waste-water, are present within the plume of reducing groundwater. High nitrate waters are contributed upgradient of the lagoon. Beneath and downgradient of the lagoon, the dissimilatory reduction of nitrate by anoxic bacteria forms ammonium. Ammonium is attentuated by adsorption and ion exchange for Ca and Mg.

INTRODUCTION

General Statement

In the northern latitudes of the United States, surficial sediments and near-surface aquifers are predominantly composed of Pleistocene glacial materials. The majority of this sediment can be classified into several groups: till (pebble to boulder-size clasts in a sand to clay-size matrix), glacial-lacustrine, and relatively coarse grained glaciofluvial sediments. Other less abundant glacial sediment types occur but generally are localized in distribution.

In the last 30 to 40 years, surface and near-surface disposal of solid and liquid wastes have replaced incineration as the predominant means of disposal (Cartwright, 1984, p. 67). In the last 15 years, use of fewer larger disposal sites has been favored over use of numerous small disposal sites, resulting in higher concentrations of contaminants in the subsurface (Cartwright, 1984, p.67). Near-surface geological materials commonly have the capability of storing and treating small waste disposal sites in an environmentally sound manner, through dispersion and attenuation of the contaminants (ASTM, 1981, p. 56). These materials vary widely in their capacity to stabilize waste. In general, sediments composed of predominantly fine-grained material, namely those having large components of silt and clay, are more suitable for waste disposal. Sediments of this texture, which frequently include till, have a greater attenuation capacity and a lower hydraulic conductivity than more coarse-grained sediment composed of sand and gravel. However, till may be fractured, providing macropores for rapid fluid transport.

Glaciofluvial deposits are highly variable in size, morpohology, and lateral and vertical continuity. These coarse-grained deposits often contain aquifers suitable for municipal water needs for small towns and rural areas. Disposal of waste in these coarse-grained deposits is generally not recommended because of their suitability for water supply, along with their vulnerability to contamination.

Precautionary foresight and adequate field testing of potential sites enhances the use of near-surface geological materials for both waste disposal and water resource needs. Determination of stratigraphic and hydrogeologic relationships prior to approval of a waste disposal site can help to avoid geologically unfavorable choices. Guidelines, for safe waste disposal, which would vary depending on the given region, and include sediment type, toxicity of waste, depth to the water table, permeability and attenuation capacity, have not been established. This is primarily due to a lack of understanding as to how a given environment will respond to various types of solid or liquid waste disposal. The variability of the interaction between the above factors hampers the establishment of rigid guidelines for waste disposal until a better understanding is achieved.

In the last several decades, detailed laboratory and field investigations which characterize the behavior, ability to attenuate contaminants and other properties of different sediment types have been areas of intense research. However, while information has been gained, a more thorough understanding of natural environments has also raised pertinent questions. These questions have pointed out areas of man's lack of comprehension, for instance, the influence of microorganisms in the subsurface. A more thorough understanding of the hydrogeochemical interactions between contaminants and subsurface materials at low concentrations and cool temperatures is needed to reliably predict the risk of near-surface waste disposal. At present, asessment of potential risk is not possible. More interdisciplinary research correlating lab and field results is necessary to improve our knowledge.

Objectives

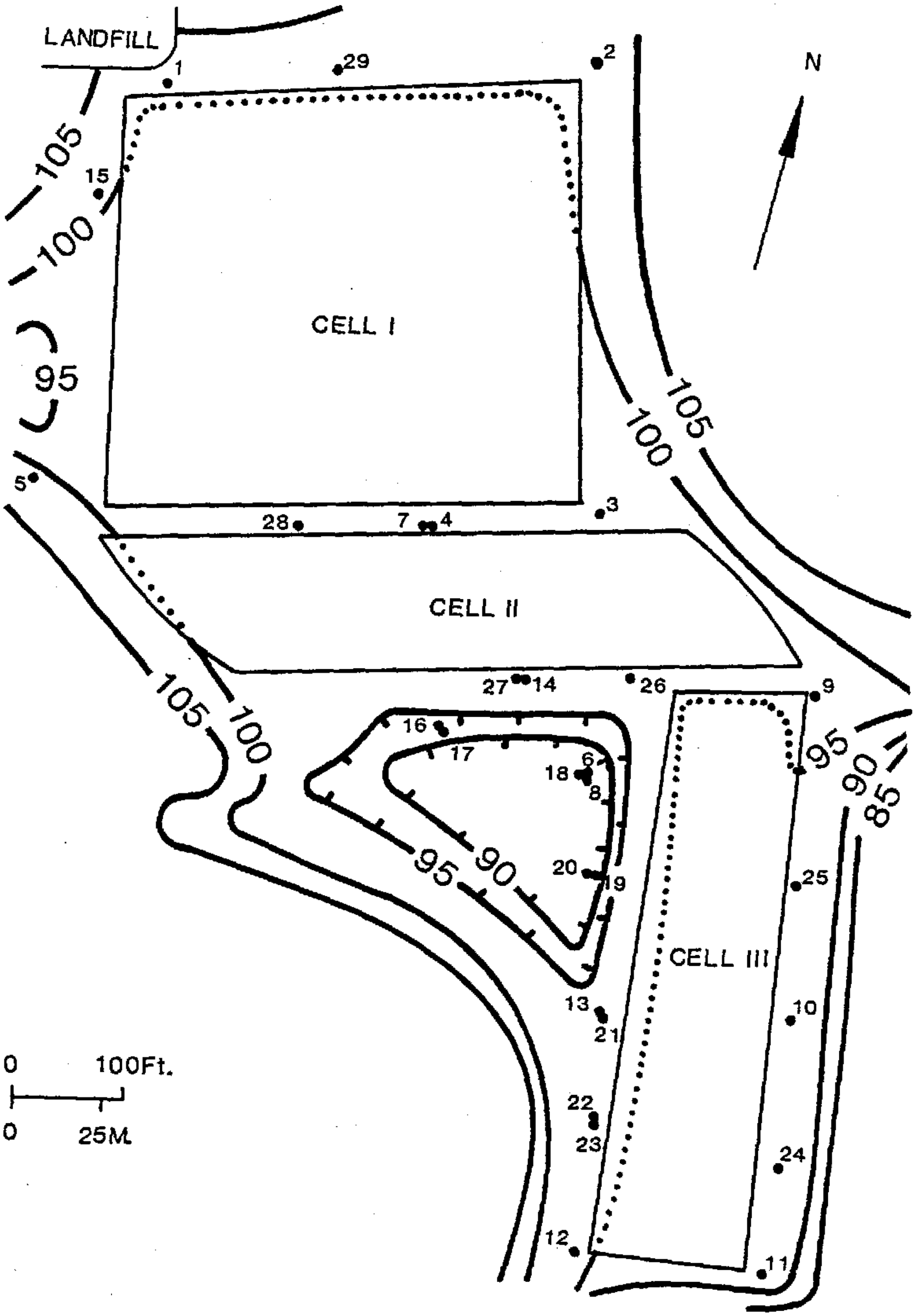
Municipal waste stabilization lagoons are considered to be a major national concern as sources of groundwater contamination (US EPA, 1984, p. 13). A previous study (Kehew et al., 1983) monitored the groundwater contamination from six municipal lagoons in North Dakota. The six sites were selected because of excessive seepage into shallow, unconfined aquifers, as determined by lack of standing waste water, and alteration of water chemistry. Of those sites, the McVille, ND, lagoon was monitored the most thoroughly and proved to be most suitable for further detailed hydrogeochemical evaluation because:

(1) significant seepage of unstabilized waste water occurs,
(2) monitoring wells could be installed downgradient of the lagoon,
(3) both lined and unlined cells are used, and
(4) rapid transport of contaminants takes place within the aquifer.

The general objective of this project was to obtain a detailed understanding of the interaction between wastewater seepage and the aquifer at this site. Previous groundwater monitoring instrumentation at McVille was inadequate to determine geochemical processes occurring in the contaminant plume.

The McVille municipal sewage lagoon consists of three containment cells, bordered to the northwest by an abandoned landfill (Fig. 1). Fifteen monitoring wells were added to fourteen previously existing wells. In addition to parameters measured in the previous study, two addtional chemical parameters were measured in order to achieve a more complete chemical data base. These parameters included redox potential (pe) and dissolved organic carbon (DOC).

Figure 1. Surface topographic contours above an arbitrary datum. Also gives location and numbering system for monitoring wells. Contour interval is 5 feet.


LANDFILL
N
CELL I
CELL II
CELL III
105
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0 25M.

The specific objectives of this study were:

1. Characterization of the hydrogeologic setting of the site, including: depth and fluctuations of the water table, estimation of rate of flow, and visual classification of auger cuttings to detect grain size variation between monitoring wells.

2. Determination of the chemistry of the waste-water and groundwater based on concentrations of major cations, major anions, pH, conductivity, redox potential and trace elements.

3. Evaluation of the hydrogeochemical interaction between waste stabilization pond leachate and groundwater, particularly to determine the distribution of the above listed constituents in the plume(s), the effects of discharge into an unlined cell, the relative contaminant contribution due to the waste stabilization process and the landfill, and the chemical environment and specific reactions taking place to identify attenuation mechanisms which result in plume evolution.

4. Recommendation of effective waste disposal practices and suggestions for areas of possible future research.

The "site" refers to the entire area seen in figure 1. The "lagoon" refers to Cell I, and contaminant will refer to any solute introduced to the aquifer due to the landfill or waste stabilization process.

WASTE STABILIZATION LAGOONS

Design and Function

Waste stabilization lagoons are relatively inexpensive, essentially self-operating systems for treating municipal waste-water. Sewage is discharged into surficial ponds and treated using natural biochemical processes. Biochemical oxidation-reduction (redox) reactions in lagoons are catalyzed by enzymes (Viessman and Hammer, 1985, p.440). Organic matter in waste-water is stabilized during redox reactions controlled by microorganisms. Bacteria, the predominant microorganisms in stabilization ponds, metabolize waste-water, with the aid of enzymes, for synthesis (cell growth) and energy. The chief use of energy is for synthesis; thus, synthesis and the production of energy are coupled processes that cannot be separated (Viessman and Hammer, 1985 p. 441).

In North Dakota, lagoons are maintained at depths of two to three metres, resulting in a layered system which is termed facultative. The upper portion of the lagoon receives sunlight and is aerated (aerobic), whereas the bottom waters are anaerobic. Sediment accumulates on the lagoon bottom, forming an anaerobic sludge layer. Other variables affecting stabilization pond performance are: surface area, population served, temperature, and loading of sewage (measured as biochemical oxygen demand, BOD).

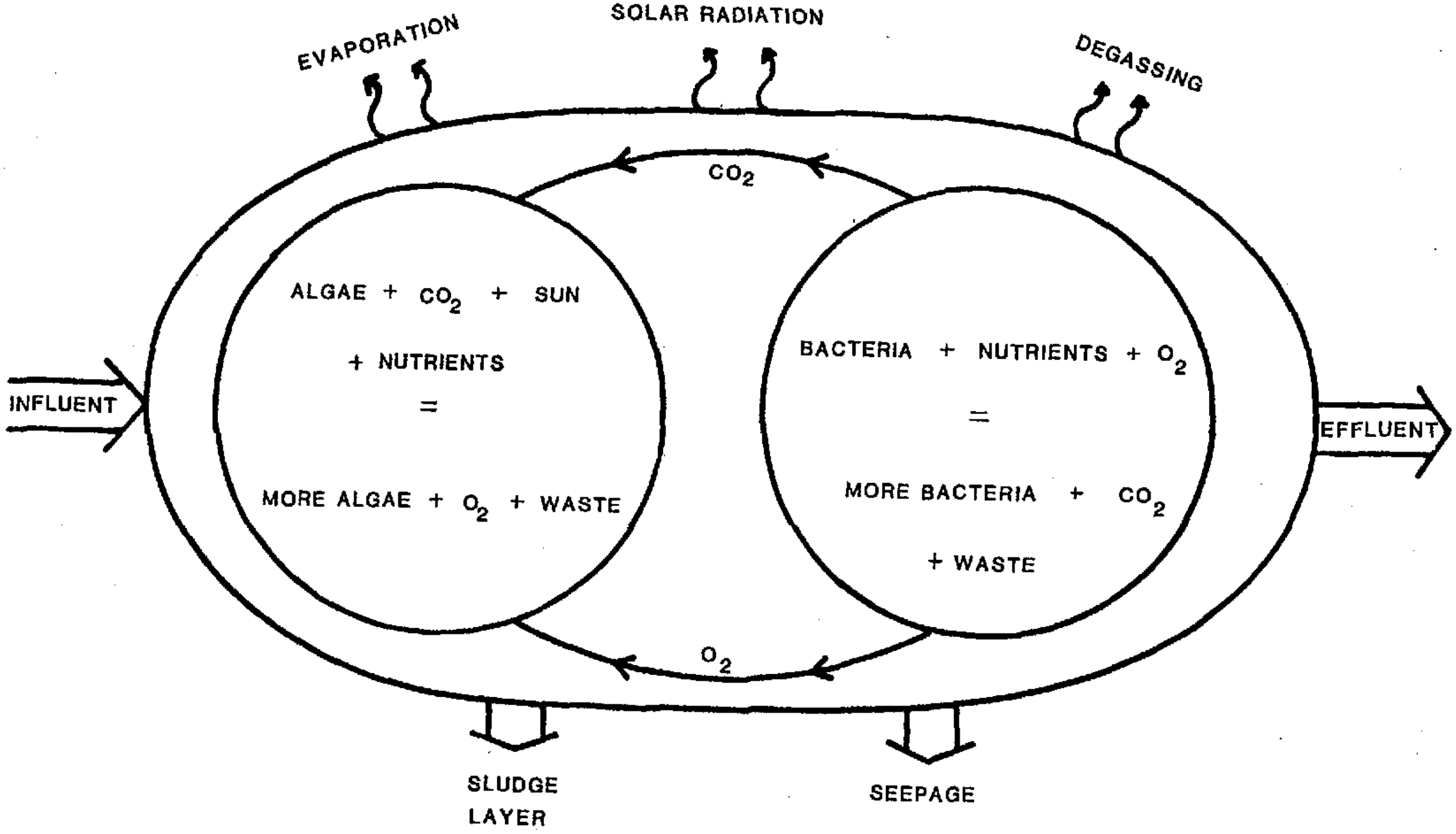
In the aerobic environment, waste organics, inorganic nutrients and oxygen are metabolized by bacteria, resulting in more bacteria, nutrients and carbon dioxide. The carbon dioxide and nutrients promote growth of algae during photosynthesis, thus producing oxygen. Oxygen in turn is used by bacteria resulting in a symbiotic relationship (Fig. 2). The organic carbon is used for bacterial cell synthesis, with byproducts degassing to the atmosphere.

Waste-water is stabilized in the anaerobic environment of a lagoon through a process termed digestion. Anaerobic and facultative bacteria metabolize organic matter, producing carbon dioxide and methane (Viessman and Hammer, 1985 p. 455; Parker et al., 1950, p.768). Hydrogen sulfide is also a product of decomposition. The anaerobic growth reactions (metabolism) are commonly limited by a lack of anions (carbon, boron, sulfide and nitrogen) capable of binding with hydrogen. In aerobic environments, oxygen is plentiful enough to act as the hydrogen acceptor. Because of a lack of anions to bind with hydrogen, in anaerobic environments the reactions are incomplete. This results in a low energy yield for the amount of substrate reacting (Viessman and Hammer, 1985, p. 441).

The rate at which compounds are degraded and bacteria die off varies with aerobic and anaerobic conditions (Bouwer, 1984, p. 23); thus, waste-water purification is best achieved by encountering both environments.

Chang et al.(1974), cites the potential of the anaerobic sludge layer to reduce permeability and operate as a self-sealing mechanism. However, work by Hickock and

Figure 2. Processes occurring during aerobic decomposition of waste-water in a stabilization lagoon.


EVAPORATION
SOLAR RADIATION
DEGASSING
CO_2
ALGAE + CO_2 + SUN
+ NUTRIENTS
=
MORE ALGAE + O_2 + WASTE
BACTERIA + NUTRIENTS + O_2
=
MORE BACTERIA + CO_2
+ WASTE
INFLUENT
EFFLUENT
O_2
SLUDGE
LAYER
SEEPAGE

Associates (1978) determined that a sludge layer increased impermeability of the cell bottom for coarser grained sediments, but not for finer grained sediments. The sludge layer did aid in stabilizing sewage by increasing the ion exchange capacity (sorption) of cell bottom materials.

Sewage Quality Criteria

Stabilization of waste-water is typically measured using the following chemical and biochemical parameters: BOD, nutrients (P, N, K), detergents, bacteria and turbidity.

Biochemical oxygen demand (BOD), expressed in mg/L, measures the amount of oxygen used to stabilize waste-water through biochemical processes (Viessman and Hammer, 1985 p.244). A standard five-day lab test determines the amount of biodegradable organic material or strength of the waste-water. Bacteria consume the oxygen and the quantity of oxygen remaining after five days is measured. A higher oxygen content indicates the need for more bacteria to stabilize the waste. BOD reductions of greater than 80 percent are desired prior to effluent discharge. This criterion is commonly achieved in stabilization ponds. BOD was not monitored during this study.

Reduction of bacterial content is related to BOD. Oxidation ponds are capable of removing 99 percent of the original bacterial content of sewage (Fitzgerald and Rohlich, 1958 p.1216). The mechanism of bacterial reduction is not clear. Possible mechanisms include: settling, termination of bacteria due to toxic substances liberated by algae, and filtration by the substrate (Fitzgerald and Rohlich, 1958, p. 1216). Enumeration and identification of bacteria was not attempted during this study due to difficulties in avoiding contamination during sampling.

Nutrient removal from waste-water is desirable to decrease the concentration of dissolved solids in the effluent. P, N and K are significant components of organic matter and thus also of sewage. These elements are also used by plants and bacteria, and incorporated into vegetation in a lagoon. Nutrient removal from sewage occurs, although the percentage varies for each element and for different lagoons (Fitzgerald and Rohlich, 1958, p. 1216). Nutrient concentrations of waste-water are further lowered through adsorption processes. Elevated concentrations of these parameters in groundwater near lagoons indicates that the waste-water concentration of nutrients exceeds biological demand (Preul, 1968;LeBlanc, 1984) or is due to very rapid seepage rates.

Detergents in groundwater are an indication of contamination from sewage disposal (Preul, 1968, p. 659). Previous to 1965, Alkyl Benzene Sulfonate (ABS) was a significant component of detergents. This compound is resistant to biodegradation and a recommended drinking-water limit has been established (Preul, 1968, p. 659).

Since 1965, a more biodegradable compound has been used in detergents (Linear Alkyl Sulfonates, LAS). LaBlanc (1984, p. 20- 22) measured detergents in groundwater from a sewage plume. The highest concentrations, located 910 to 3048 metres from the disposal site, were attributed to pre-1965 disposal of the conservative ABS compound. LAS is more capable of biodegradation, although this may proceed slowly in groundwater at ten degrees Celcius (LeBlanc, 1984, p. 22). Detergent concentration was not monitored during this study; however, dissolved organic carbon (DOC) can be partially attributed to the presence of detergents (Ceazan et al., 1984, p.133).

Turbidity is a measure of the interference of the passage of light through water due to insoluble particulates (Viessman and Hammer, 1985, p.229). Turbidity, considered to be a contaminant, is measured in turbidity units relative to a standard. Turbidity is undesirable because it inhibits disinfection by sheltering microorganisms and in additon, turbidity often indicates inadequate treatment (Viessman and Hammer, 1985, p. 230). Turbidity in sewage is interpreted to be the result of plankton content (Neel, 1956, p.1333).

Previous Work

Investigations conducted by Brown (1983, p. 15-18) and Kehew et al., (1983, p.8-9) summarize previous studies of waste stabilization lagoons in North Dakota. The reader is referred to these references for a more detailed summary.

Brown (1983) discusses the historical use of lagoons in the Dakotas, beginning with the installation of the first engineered impoundment in 1948. Studies on the operation and effectiveness of waste-stabilization lagoons concluded that the degree of waste-water treatment provided by these facilities was adequate for communities in the Dakotas (Brown, 1983, p. 16).

Kehew et al., (1983) and Brown (1983), also cite important research concerning the effects of seepage from waste-stabilization lagoons on groundwater. The results of these studies indicate a wide variation in severity of groundwater degradation and the chemical quality of contaminated groundwater. Nitrogen in the form of ammonia was detected in groundwater (Preul, 1968;Hickok and Associates, 1978). Ammonia and phosphorous transport is impeded by adsorption in fine-grained sediments (Preul, 1968; Hickok and Associates, 1978). Fine-grained sediments beneath lagoon systems characteristically developed highly soluble salt (Na^+, Ca^{2+}, Mg^{2+}, Cl^-) concentrations, up to 20 times the waste-water level (Hickok and Associates, 1978). In contrast, in more coarse-grained sediments, increases in fecal coliforms, nitrogen, and phosphorous were detected. Soluble salts did not become concentrated in groundwater within coarse-grained materials. Detergents were transported 61 meters (Preul, 1968). However, Bleeker and Dornbush (1980) concluded that even lagoons with excessive infiltration rates provided adequate waste-water treatment through the physical, chemical, and biological processes in sediments.

Given that the chemical composition of waste-water and mode of contamination (excessive seepage) was similar in all of these studies, the resulting contamination is dependant upon the site specific hydrogeology. Primarily, but not exclusively, the particle size and mineralogy of aquifer materials controls the extent and distribution of contaminants in groundwater.

Previous research on groundwater contamination at the McVille, North Dakota, site (Kehew et al., 1983; Brown, 1983) indicated that a contaminant plume extended 215 m downgradient from the primary operating cell. Reducing conditions are characteristic of most of the plume volume. This influenced the distribution of many of the constituents. A plume of organic-rich reducing water, in addition to biological contamination from coliforms, suggests that biochemical processes have a dominant influence. Kehew et al., (1983) also discuss other processes resulting in chemical changes in the seepage plume.

Aulenbach and Tofflemire (1975) investigated the effects of discharging secondarily treated sewage effluent onto natural sand beds in New York. The study indicated a depletion of dissolved oxygen (DO) downgradient of the sand beds, yet the groundwater remained aerobic (greater than 1.0 mg/L DO). However, nitrate concentrations in downgradient wells did not indicate nitrification of Kjeldahl (organic plus ammonia) nitrogen. Sewage-tainted groundwater discharged near a brook 600 m from the sand beds.

A study by LeBlanc (1984) at Cape Cod, Massachusetts also indicated significantly contaminated groundwater. Secondarily treated domestic sewage has been discharged onto sand beds at this site since 1936. The discharged sewage percolates downward to an unconfined sand and gravel aquifer. Monitoring of 11 physical and chemical parameters delineated a contaminant plume extending 3700 m downgradient from the sand beds. The study identified the geochemical processes affecting each of the 11 parameters along the flow path in the plume. Boron, chloride, and sodium are diluted due to hydrodynamic dispersion. Nitrogen is in the form of ammonia where DO is depleted, and in the nitrate form where DO is present.

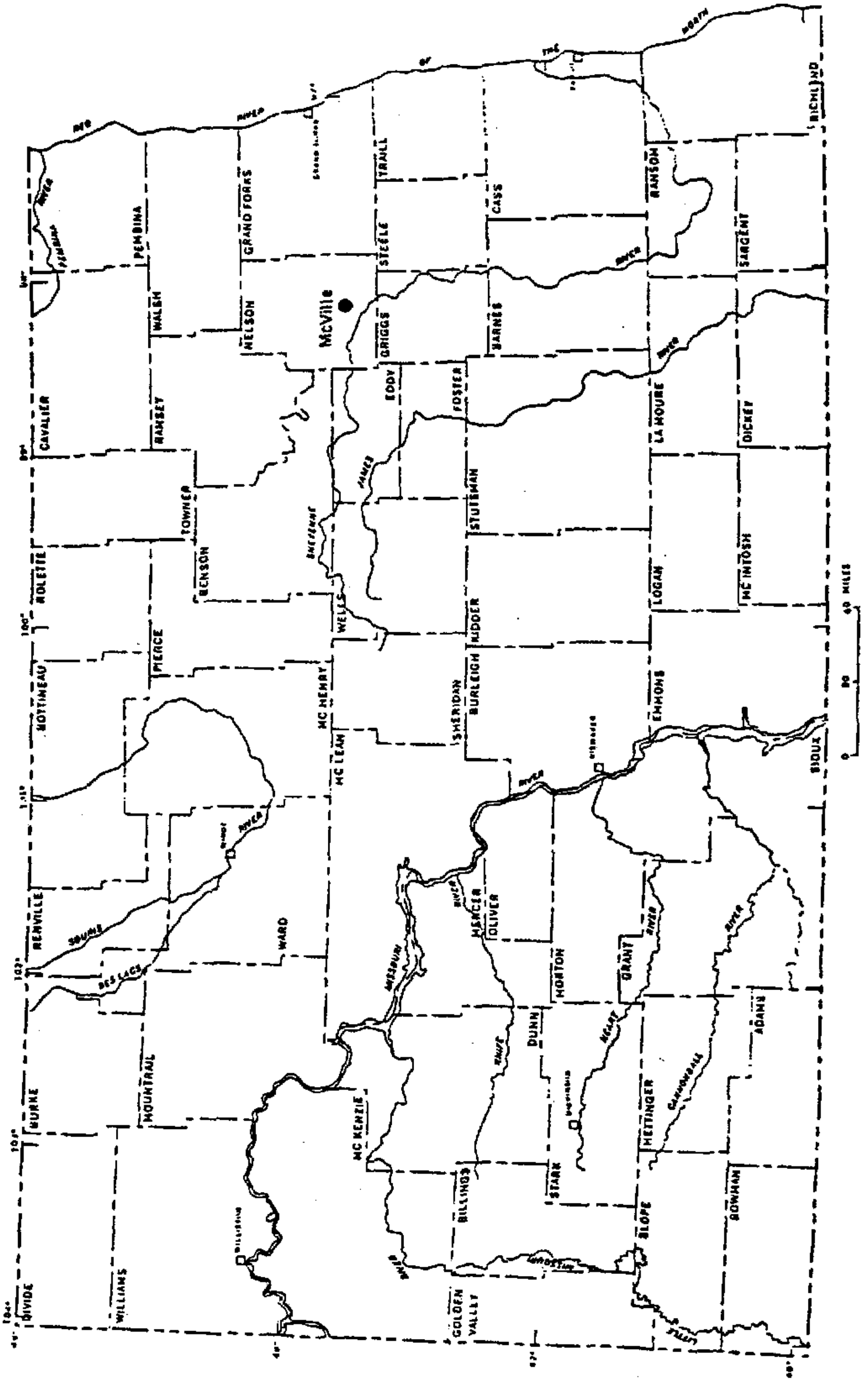
The Cape Cod (LeBlanc, 1984) and McVille (Kehew et al., 1983; Brown, 1983) studies, in addition to other studies of contaminant plumes, indicate the complexity of contaminant-plume evolution and potential for contamination from sewage. A variety of physical, chemical, and biological processes are involved and yet inadequately understood. Realization of this complexity has led to interdisciplinary research by teams of scientists. An example of this is further study at Cape Cod conducted by geohydrologists, chemists, and microbiologists (USGS, 1984). This investigation included calibration of a digital solute-transport model, description of inorganic and organic chemical distributions, and description of the microbiological processes that control the fate of some solutes. The study verifies the occurance of a significant bacterial population due to sewage contamination. It further verifies the chemical transformation of the sewage plume due to various attenuation mechanisms.

Operations of the McVille Waste Stabilization Lagoon

The McVille Sewage Lagoon was built in the early 1960's to serve an agricultural community of 620 people and process predominantly non-industrial sewage (Kehew et al., 1983, p. 9)(Fig. 3). The site consists of three containment cells, bordered to the northwest by an abandoned landfill (Fig. 1). Contours display a topographic low in the center of the site, which is part of the drainage system leading into the Sheyenne River Valley, and elevations increasing along the western border.

Site operations maintain standing waste-water in the clay-lined primary operating cell, Cell I, at all times throughout the year. When this cell is near capacity, three to four times annually, a portion of its contents are drained into an unlined cell, Cell II. Lack of a liner at the base of Cell II results in rapid infiltration of partially treated sewage to the water table. Steady seepage from Cell I also contributes partially treated

Figure 3. Map of North Dakota showing location of the study site.


McVille
DIVIDE
WILLIAMS
BURKE
MOUNTRAIL
RENVILLE
WARD
BOTTINEAU
MC HENRY
MC LEAN
ROLETTE
PIERCE
TOWNER
BENSON
CAVALIER
RAMSEY
PEMBINA
WALSH
NELSON
GRAND FORKS
EDDY
WELLS
SHERIDAN
FOSTER
GRIGGS
STEELE
TRAILL
CASS
BARNES
STUTSMAN
KIDDER
BURLEIGH
EMMONS
LOGAN
LA MOURE
RANSOM
RICHLAND
SARGENT
DICKEY
MC INTOSH
SIOUX
GRANT
MORTON
OLIVER
MERCER
DUNN
STARK
HETTINGER
ADAMS
BOWMAN
SLOPE
BILLINGS
GOLDEN VALLEY
MC KENZIE
RED RIVER OF THE NORTH
PEMBINA RIVER
SOURIS RIVER
DES LACS
MISSOURI
JAMES
SHEYENNE
RIVER
KNIFE
HEART
CANNONBALL
LITTLE
0
20
40 MILES
97°
98°
99°
100°
101°
102°
103°
104°
49°
48°
47°
46°

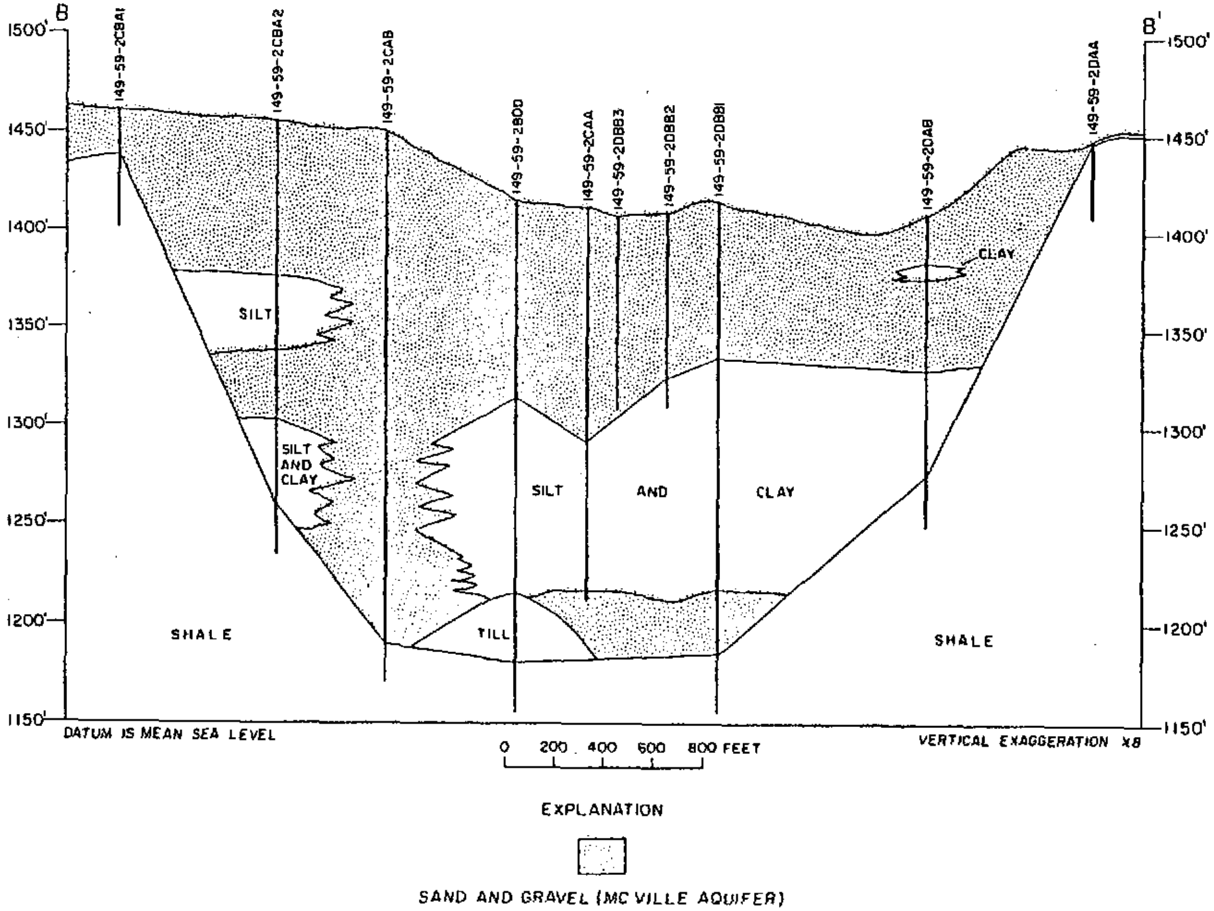
sewage to the water table. To date, Cell III has not been used for waste water treatment.

HYDROGEOLOGICAL SETTING

The near-surface sediment in Nelson County, North Dakota is composed of the Quaternary Coleharbor Formation and the Holocene Oahe Formation. The Coleharbor Formation is of glacial origin and can be separated into three facies: (1) till, (2) glacial outwash sand and gravel, and (3) lacustrine silt and clay (Bluemle, 1973, p. 13). The Oahe Formation, overlying the Coleharbor, is comprised of three facies: clay, sand and silt, and gravel. The Oahe sediments formed as slough deposits, alluvium, aeolian deposits, and colluvium (Bluemle, 1973).

The waste-stabilization site was constructed above the McVille Aquifer. This feature is a buried valley, incised into the Cretaceous Pierre Shale bedrock before the last glacial advance and filled with glaciofluvial sand and gravel (Fig. 4)(Downey, 1973, p. 32). The buried valley, which is 50 to 90 metres deep and 400 to 800 metres wide, generally shows no surface expression. The McVille Aquifer is unconfined, with the depth to the water table ranging from 2 to 7 m below the ground surface at the study site. Recharge to the aquifer is from precipitation, with flow toward the south, until it discharges into the Sheyenne River. Brown (1983), calculated a groundwater velocity of 0.016 m/d in the aquifer near McVille. Testing of the aquifer estimated transmissivity to range from 640 to 2865 m/d, with yield capable of up to 1893 L/min. Chemically, the aquifer is of sodium bicarbonate and calcium

Figure 4. Generalized geologic cross section through the McVille Aquifer south of McVille, Nelson County.


B
B'
1500'
1450'
1400'
1350'
1300'
1250'
1200'
1150'
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
SILT
SILT AND CLAY
SILT AND CLAY
CLAY
TILL
SHALE
SHALE
DATUM IS MEAN SEA LEVEL
0 200 400 600 800 FEET
VERTICAL EXAGGERATION x8
EXPLANATION
SAND AND GRAVEL (MC VILLE AQUIFER)

bicarbonate type in the region near McVille (Downey, 1973, p.34). Groundwater from the McVille Aquifer provides the municipal supply for the town of McVille and has potential as a source of irrigation water.

METHODOLOGY

Field

Fifteen monitoring wells (numbers 15 to 29) were installed during June of 1985 (Fig. 1). These wells were added to 14 existing wells installed between 1981 and 1983 (Kehew et al., 1983,p.9;Brown, 1983, p.22). New well locations were selected in order to fill in spatial gaps in the monitoring network, increase vertical control, and to better determine the relative contributions of the landfill and Cells I and II.

Monitoring wells consist of 5.08-cm PVC pipe cemented onto 5.08-cm PVC pre-slotted 1.2 or 1.5-meter screen lengths. Conical tips were cemented onto the base of each well to aid in installation.

Well holes were augered to the desired depth using the North Dakota Geological Survey truck-mounted power auger. The monitoring well was inserted into the augered hole by hand, then driven through the collapsed, unconsolidated sand in the lower portions of the hole using the hydraulic auger.

Augered cuttings were then backfilled into the annulus of the well hole, with the top 0.6-meters of the hole backfilled with concrete. Metal locking covers were installed over the pipe and into the concrete to prevent vandalism and tampering with the monitoring wells.

Water samples from all the wells at the site were taken four times during the summer of 1985. The discharge from Cell I to Cell II was sampled once from the pipe connecting the two cells beneath an embankment. Water samples were obtained using a battery operated Johnson-Keck submersible pump and a hand bailer when necessary. Prior to sample collection a minimum of two well volumes was removed. A total of six bottles was filled at each well during sampling: a plastic 0.97-liter bottle for major cations and anions; four plastic 242-millilitre bottles for trace metals (preserved with nitric acid), phosphates (preserved with sulfuric acid), nitrates and ammonium (preserved with sulfuric acid); and a glass 242-mL bottle for dissolved organic carbon (DOC). The samples were kept on ice in styrofoam coolers in order to minimize post-collection chemical changes before analysis and shipped by Greyhound Bus to the North Dakota State Department of Health Laboratory in Bismarck. DOC analysis was conducted by the U. S. Geological Survey in Denver.

Specific conductance and pH were measured in the field immediately upon sampling. Unfortunately, the meters did not operate consistently and results obtained for most days may be unreliable.

Water-table levels were measured at least once monthly using an electrical water-level tape borrowed from the North Dakota Geological Survey.

Redox potential was measured in the field using an airtight redox cell obtained from the North Dakota State Department of Health. The redox cell was constructed of

PVC pipe into which a platinum electrode and a reference electrode filled with Orion solution (90-00-01) could be inserted (Wood, 1976). The electrodes were connected to a pH meter which measured in millivolts and calibrated to a reference Zobell Solution (potassium-iron-cyanide) to approximately 210 millivolts at ambient groundwater temperature (Wood,1976). The electrodes were then inserted into the airtight redox cell, through which groundwater was pumped directly from the vicinity of the well screen, preventing contact of the solution with the atmosphere. Readings were taken every five minutes until the millivolt readings stabilized, a period of approximately 30 minutes.

Well location and elevations were surveyed using a plane table and alidade. From this data a topographic base map was constructed. The well elevations were surveyed relative to an arbitrarily chosen datum of 100 feet (30.5 meters).

Lab and Office

Concentrations of chemical parameters were contoured on base maps and cross-sections to display hydrogeochemical relationships relative to the contaminant source. Qualitative redox levels were determined using pe-pH diagrams.

The hydrogeologic setting at the McVille site, which consists of unidirectional flow in a relatively uniform aquifer, is ideal for the simulation of contaminant transport. Contaminant transport modeling was attempted for chloride using a package of solute transport programs entitled Solute (Beljin, 1985). These programs are written in Basic for an IBM Personal Computer. The programs selected for use were WMPLUME and PLUME3D, two dimensional (2D) and three dimensional (3D) programs, respectively. The theoretical approach for these programs is an analytical solution of solute transport based on the advection-dispersion equation for uniform flow, including options for retardation and decay. Assumptions which were not always appropriate for the McVille hydrogeologic setting were written into the programs. The programs were written to simulate continuous injection from injection wells. Of the available programs, WMPLUME and PLUME3D best approximated the field setting. Programs were not modified to more accurately simulate the contaminant input.

Groundwater chemistry samples were evaluated using the chemical equilibrium computer program WATEQF (Plummer et al., 1976), written in FORTRAN. In WATEQF the thermodynamic speciation of inorganic ions and complex solutes is determined from the input water analysis. The solution is modeled from concentrations of species to determine whether it is saturated with respect to pertinant phases and minerals.

Ionic concentrations for one sample at a time were input in mg/L. Other chemically related parameters are: temperature, pH, specific conductance, field Eh, and density.

Following definition of the variables, the van't Hoff equation is used to calibrate the equilbrium constant (K) for the measured temperature. Molality of species and the ratio of cations to anions are computed. Next, the Deybe-Huckle constants are corrected using the measured temperature. The activity coefficients of species are calculated for common elements, followed by the speciation of ions. The program next determines molar ratios, log activity ratios, and the ion activity products (IAP). Saturation with respect to a given mineral is evaluated using:

$$\log (IAP/KT),$$

where K is the equilbrium constant and T is the temperature. If this ratio is greater than zero the solution is considered to be saturated for that mineral. Conversely, if the ratio is less than zero, the solution is undersaturated with respect to that phase.

Statistical tests were conducted to attain a more rigid verification of the spatial distribution of certain solutes, and thereby ascertain a hydrogeochemical relationship. The multiple regression computer program, MULTR, obtained from Dr. Richard LeFever (personal communication), is modified from Davis (1973, p. 415-417).

Selected parameters were input to determine the correlation coefficient and goodness-of-fit. The correlation coefficient (r) is computed using (Davis, 1973),

$$r_{jk} = \frac{COV_{jk}}{s_j s_k} = \frac{\dfrac{n\sum_{i=1}^{n} X_{ij}X_{ik} - \sum_{i=1}^{n} X_{ij}\sum_{j=1}^{n} X_{ik}}{n(n - 1)}}{\sqrt{\dfrac{n\sum_{j=1}^{n} X_j^2 - (\sum_{j=1}^{n} X_j)^2}{n(n - 1)}} \cdot \sqrt{\dfrac{n\sum_{k=1}^{n} X_k^2 - (\sum_{k=1}^{n} X_k)^2}{n(n - 1)}}}$$

where:

COV_{jk} = covariance of parameter j and k

s_j and s_k = standard deviation of parameter j and k

n = number of samples

X = the observation.

The goodness-of-fit is determined using,

$$R^2 = \frac{SS_R}{SS_T} = \frac{\sum_{i=1}^{n} (\hat{Y} - \bar{Y}_i)^2}{\sum_{i=1}^{n} (Y_i - \bar{Y})^2}$$

where:

SS_R = sum of squares due to regression

SS_T = total sum of squares

n = number of samples

$\bar{Y}$ = mean of the regressed variables

$\hat{Y}_i$ = regressed variable

Y_i = the estimated value of Y_i at different values of X_i, as determined from the equation for a line,

$$Y_i = b_0 + b_1 x_i.$$

Here,

b_0 = the y-intercept
b_1 = the slope.

The mean concentrations from all wells, in addition to data from Cells I and II, were used for regression analysis. Tests involving distance downgradient, refers to the downgradient distance of the well from the south edge of Cell I. The distance was determined from the grid used in the contaminant transport simulation. Wells upgradient of the southern edge of Cell I were not included during these tests.

RESULTS

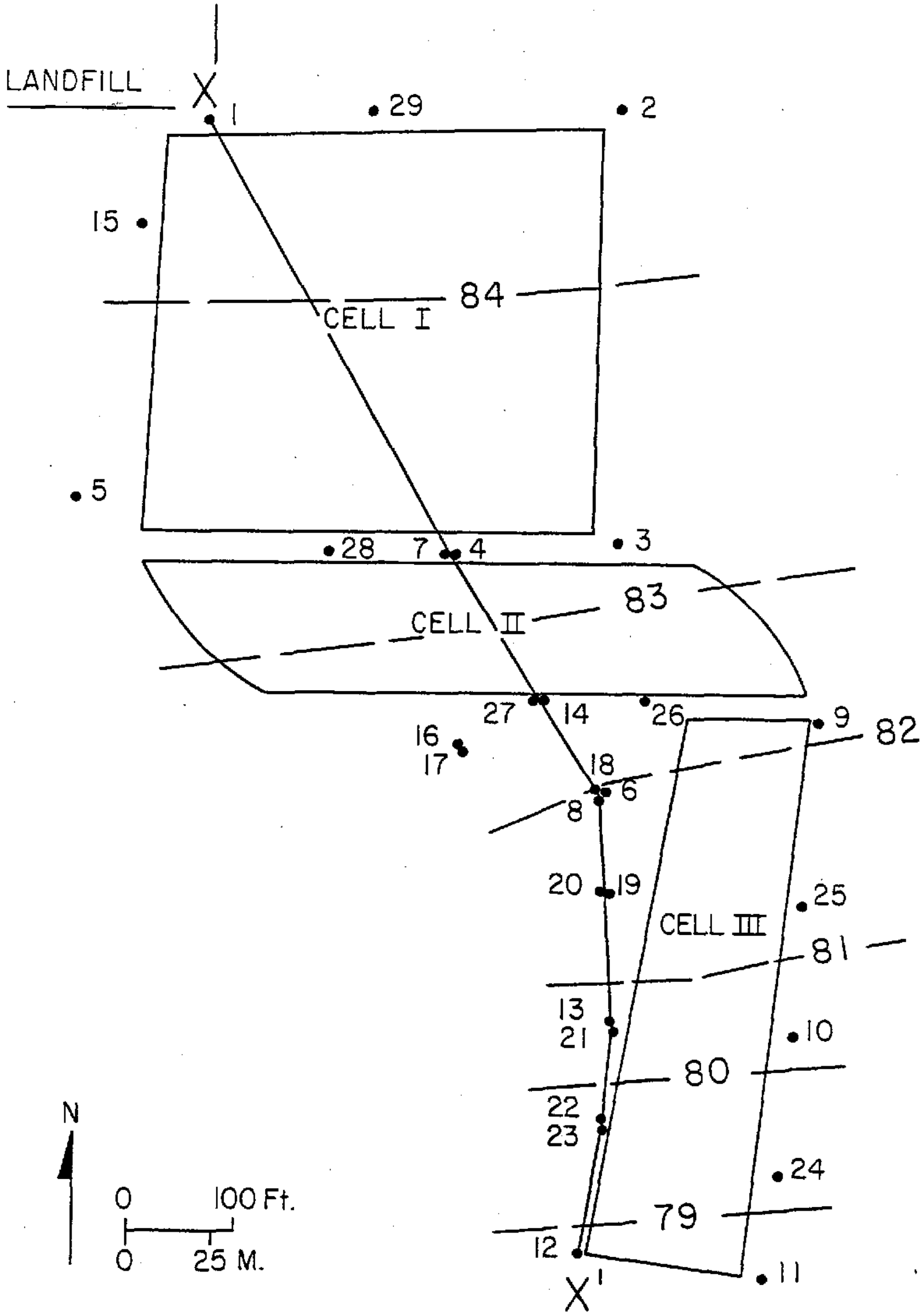
Hydrogeology

Grain-size analysis of cuttings from wells seven and eight conducted by Brown (1983, p.32) indicated that the glaciofluvial sediment consists of fine-to-medium grained sand with abundant shale fragments. Grain-size analysis was not conducted during this study primarily for two reasons: (1) examination of well hole cuttings indicated material similar to that described during the 1983 study, and (2) accurate stratigraphic characterization cannot be obtained using cuttings from augered well holes in this type of material due to mixing of sediment from different horizons prior to sample collection. Hydrologically, the majority of the aquifer beneath the site appears to be homogeneous on a macroscopic scale, although local heterogeneities are probable based on the mode of deposition.

Mean-water table elevations contoured on a base map show a hydraulic gradient of 0.0056 to the south, indicating the primary direction of water flow (Fig. 5). Depth to the water table ranges from 2 to 6.5 metres below the ground surface (appendix II).

Using a hydraulic conductivity of 10-5 m/s and a porosity of 0.3 (Kehew et al., 1983, p.9), groundwater flow has an approximated Darcy velocity of 0.016 m/day. Water table elevations displayed very little fluctuation during the summer of 1985 (Appendix II). A minor, but significant

Figure 5. Water table elevation contours (ft) based on an arbitrary datum. Data contoured was mean of measured water table elevations. Line X-X' indicates location of cross section in figures 20 and 21.


LANDFILL
X
X'
CELL I
CELL II
CELL III
84
83
82
81
80
79
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
N
0
100 Ft.
0
25 M.

rise in the water table was measured in the wells near Cell II three days after discharge into Cell II. Recharge to the water table is seasonal, with recharge due to snow melt and heavy rains, and a balance between evapotranspiration and precipitation during summer (Groenewold et al., 1982, p. 38). Water-table elevation data show a slight water-table mound beneath Cell I.

Rapid Infiltration Test

Previous work at the McVille site identified variations in the distribution of certain species in groundwater beneath Cells I and II (Kehew et al., 1983). These differences were partially attributed to the operating practice of discharging reduced waste-water from the base of Cell I into unlined Cell II. As a consequence of discharge into Cell II, the waste-water was assumed to be instantaneously aerated, thus altering the distribution of constituents, particularly those constituents controlled by redox reactions.

An objective of the present study was to determine the physical and chemical effects of the practice of periodic discharge into an unlined cell. In order to evaluate the effects of this discharge, selected parameters were measured before and after the discharge from Cell I to Cell II on July 5th. Groundwater samples for chemical analysis were taken June 19th and 20th, prior to discharge, and July 9th, 10th and 11th after the discharge. Redox measurements on the groundwater in wells surrounding Cell II, and wells

10, 13, and 23, were conducted before (July 3rd and 5th) and after the discharge (July 8th and 9th). Water levels were measured June 28th and July 8th.

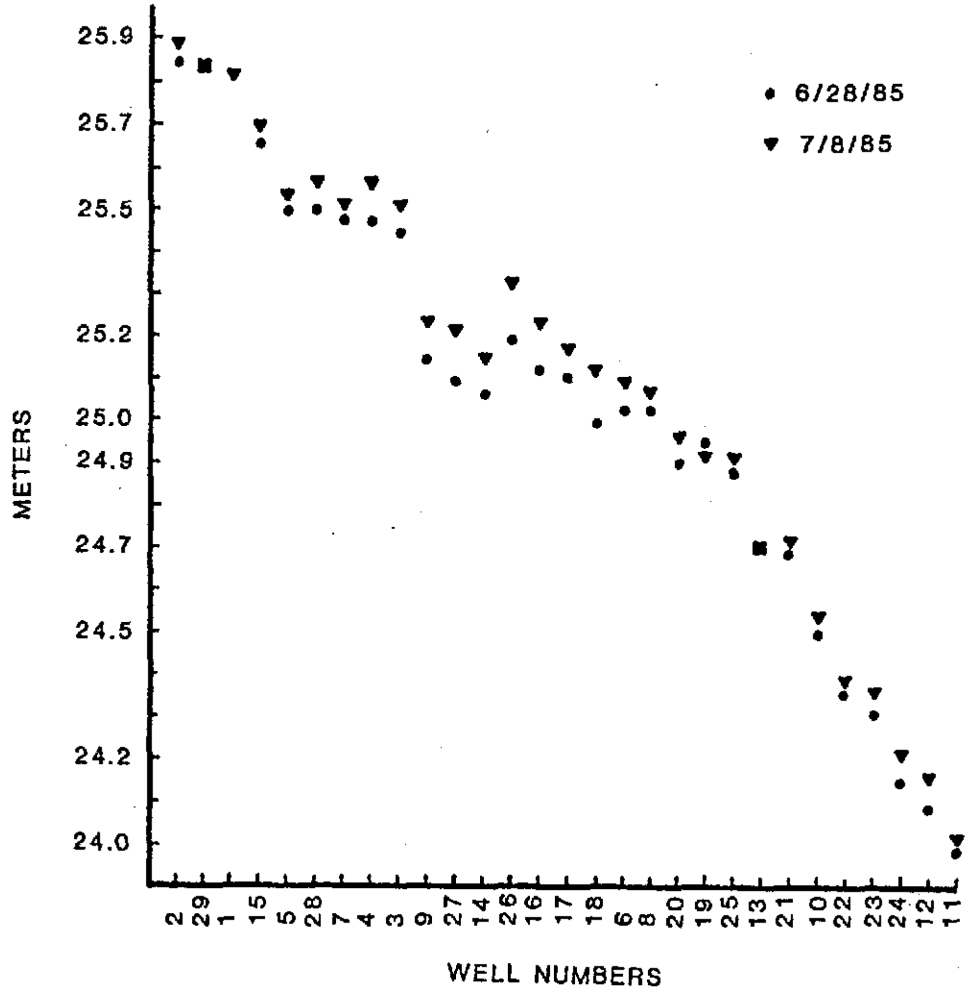
All of the waste-water discharged into Cell II infiltrated to the subsurface within two days, except the undetermined amount lost to evaporation. A minor, but consistent, rise in water-table elevations between June 28th and July 8th was measured throughout the site (Fig. 6). The largest rise in elevations occurred in wells surrounding Cell II. The shallow wells demonstrated a greater rise in water table than the deep wells. Chemical analyses and redox measurements did not indicate any significant variation due to this event (appendices III and IV).

General Inorganic Parameters, Trace Elements and Organic Constituents

Interpretation of site hydrogeochemistry can be simplified by grouping the wells into four catagories which display similar hydrogeochemical behavior. These categories are as follows:

1. Background concentrations of the aquifer indicated by wells 2 and 9.
2. Wells upgradient of Cell I which are directly influenced by the landfill. Wells 5, 15, 1 and 29.
3. Wells bordering Cell II which are most influenced by contamination from waste-water seepage. Wells 28, 4, 7, 3, 26, 14, 27, 16, 17, 6, 8, and 18.

Figure 6. Water table elevations in monitoring wells showing the effects of discharge to Cell II. Discharge from Cell I to Cell II was on July 5th, 1985.



● 6/28/85
▼ 7/8/85
METERS
25.9
25.7
25.5
25.2
25.0
24.9
24.7
24.5
24.2
24.0
2
29
1
15
5
28
7
4
3
9
27
14
26
16
17
18
6
8
20
19
25
13
21
10
22
23
24
12
11
WELL NUMBERS

4. Downgradient wells in the vicinity of Cell III. Wells 19, 20, 13, 21, 22, 23, 12, 11, 24, 10, and 25.

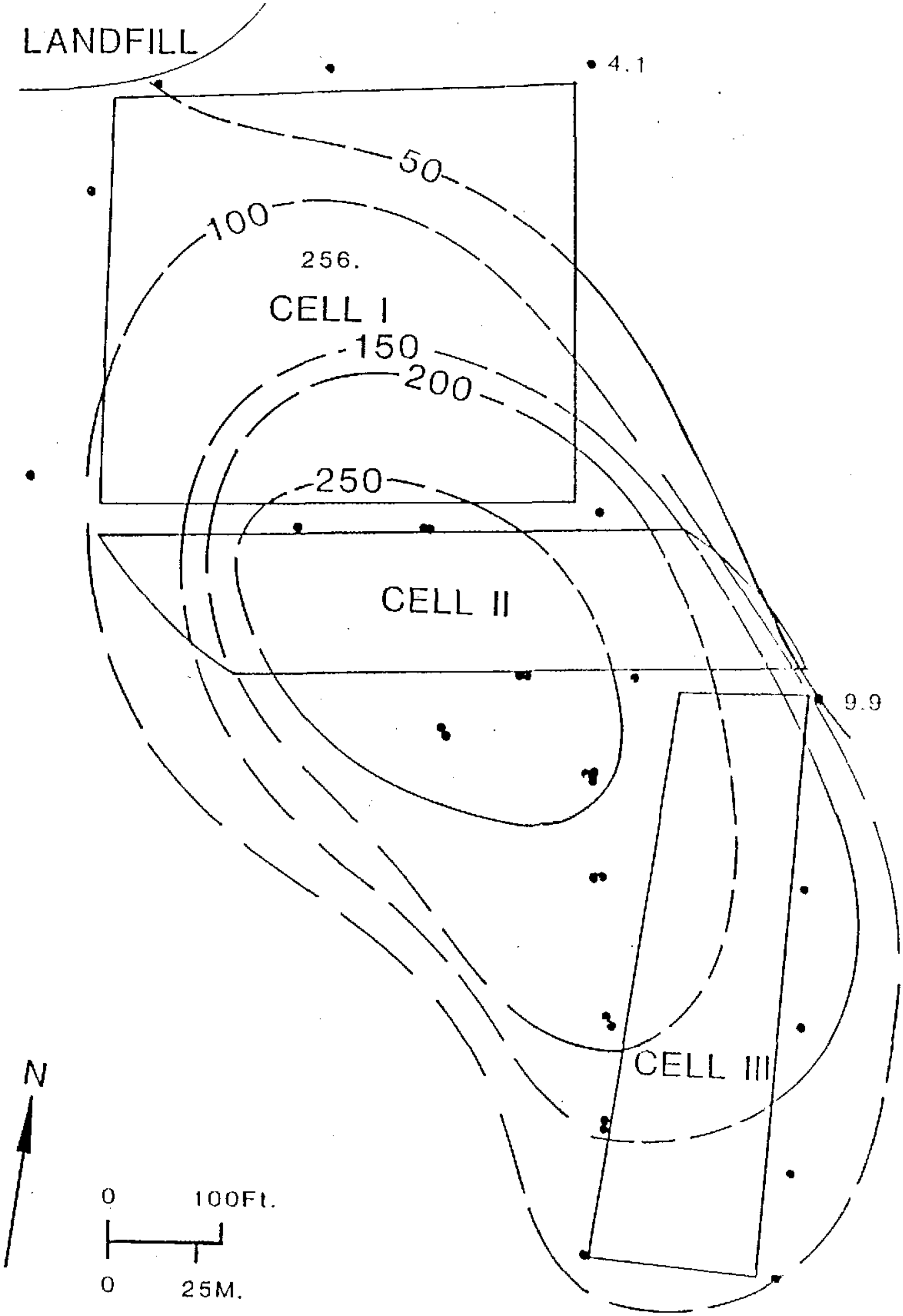
Accurate pH measurement was inhibited during the majority of this study due to problems calibrating the pH meter; consequently, results may be unreliable (appendix III). Results obtained that did seem to be reliable agree reasonably well with field measurements taken during the 1983 study at McVille (Kehew et al., 1983). pH levels fall within a fairly narrow range of 6.0 to 8.0. No systematic variation in pH is present at the site relative to the contaminant sources, with the exception that lagoon pH is consistently greater than 8.0. The alkaline waste-water is buffered by the aquifer materials, to the range mentioned above. The buffering mechanisms could include formation of iron and other metal hydroxides in the area of group 4 wells, or reaction of hydroxide with organic carbon (CO_2) forming bicarbonate, according to the reaction,

$$OH^- + CO_2 = HCO_3^-$$

Chloride ion concentrations provide a good indication of the shape and extent of contamination from the sewage lagoon. Because of a high chloride concentration in the sewage, yet low background concentrations and low concentrations derived from the landfill, elevated chloride levels can be directly attributed to waste-water seepage (Fig. 7).

The highest levels of chloride are in the waste-water

Figure 7. Mean chloride concentration (mg/L) in groundwater. Individual wells and shallow nested wells. Contour interval is 50 mg/L.


LANDFILL
4.1
50
100
256.
CELL I
150
200
250
CELL II
9.9
CELL III
N
0
100Ft.
0
25M.

and group 3 wells. Roughly 60 metres downgradient from Cell II, chloride levels are still at the lagoon concentration. Downgradient of this area (group 4), chloride concentrations decrease gradually, reaching approximately half that of the waste-water at the wells farthest downgradient.

The total dissolved solids (TDS) concentrations and electrical conductivity can be used to distinguish the relative contributions of the landfill and the lagoon. Both contaminant sources produce high concentrations, but the wells of group 3 are distinctly higher than the wells of group 2. Major ions (Na^+, Mg^{2+}, Ca^{2+}, Cl^-, HCO_3^-, and SO_4^{2-}) make up 90 percent of the TDS concentration (Freeze and Cherry, 1979, p.84). Specific conductance is a measure of the ability of a solution to conduct electricity as a function of the amount of ionic constituents. Conductivity, measured in umhos/cm, gives a general indication of the TDS content. Both solid waste and sewage-disposal methods are noted for resulting in elevated TDS and conductivity in groundwater (Cartwright, 1984, p.68). Figures 8 and 9 indicate high TDS and conductivity levels in wells associated with the landfill (group 2), with even higher values in the waste-water itself. The highest levels for these parameters are located in wells surrounding Cell II. These levels are approximately three times greater than background concentrations and slightly higher than in the waste-water. Downgradient of Cell II,

Figure 8. Mean total dissolved solids (TDS) concentration (mg/L) in groundwater. Individual plus shallow nested wells. Contour interval is 200 mg/L.

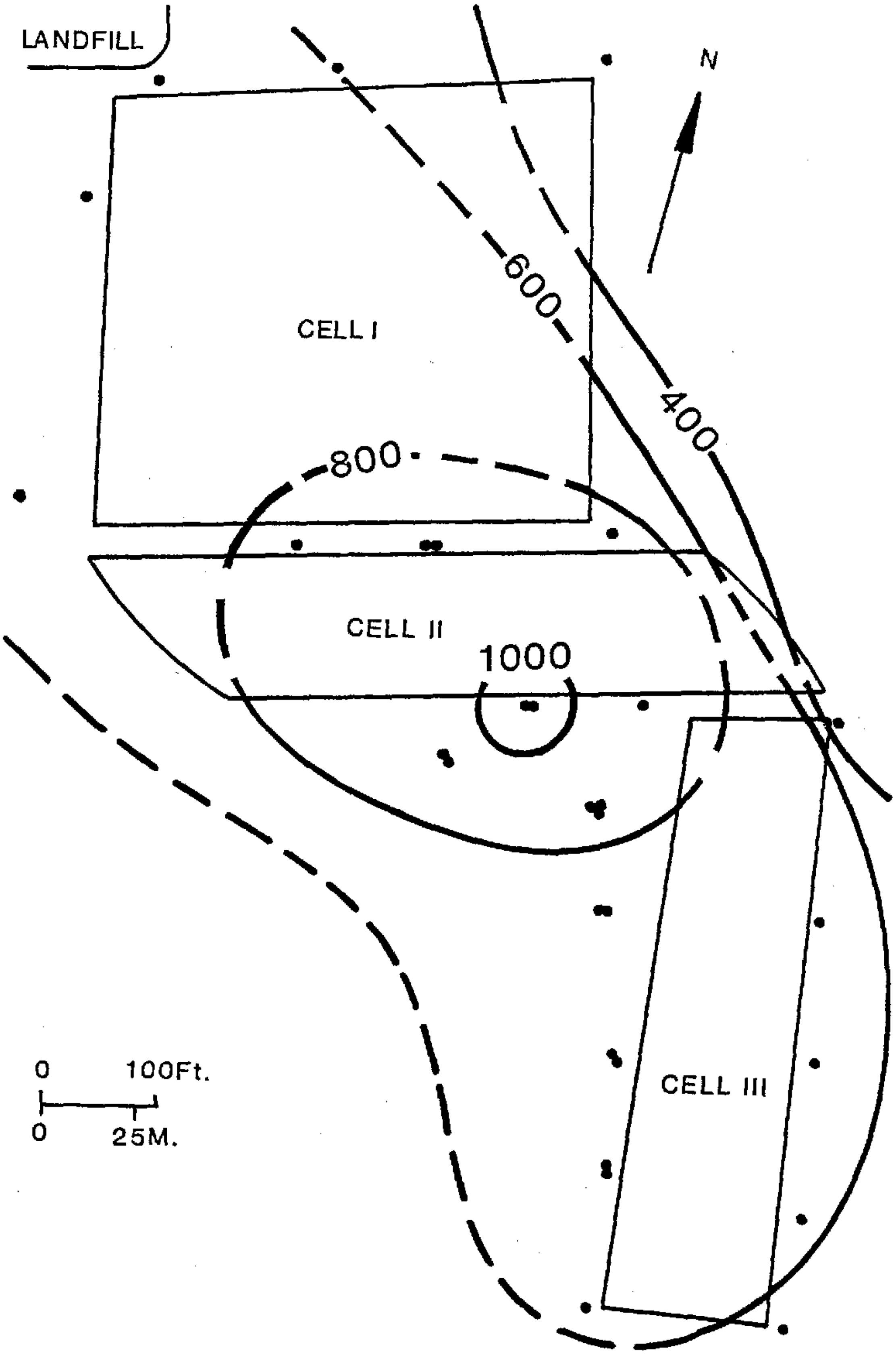
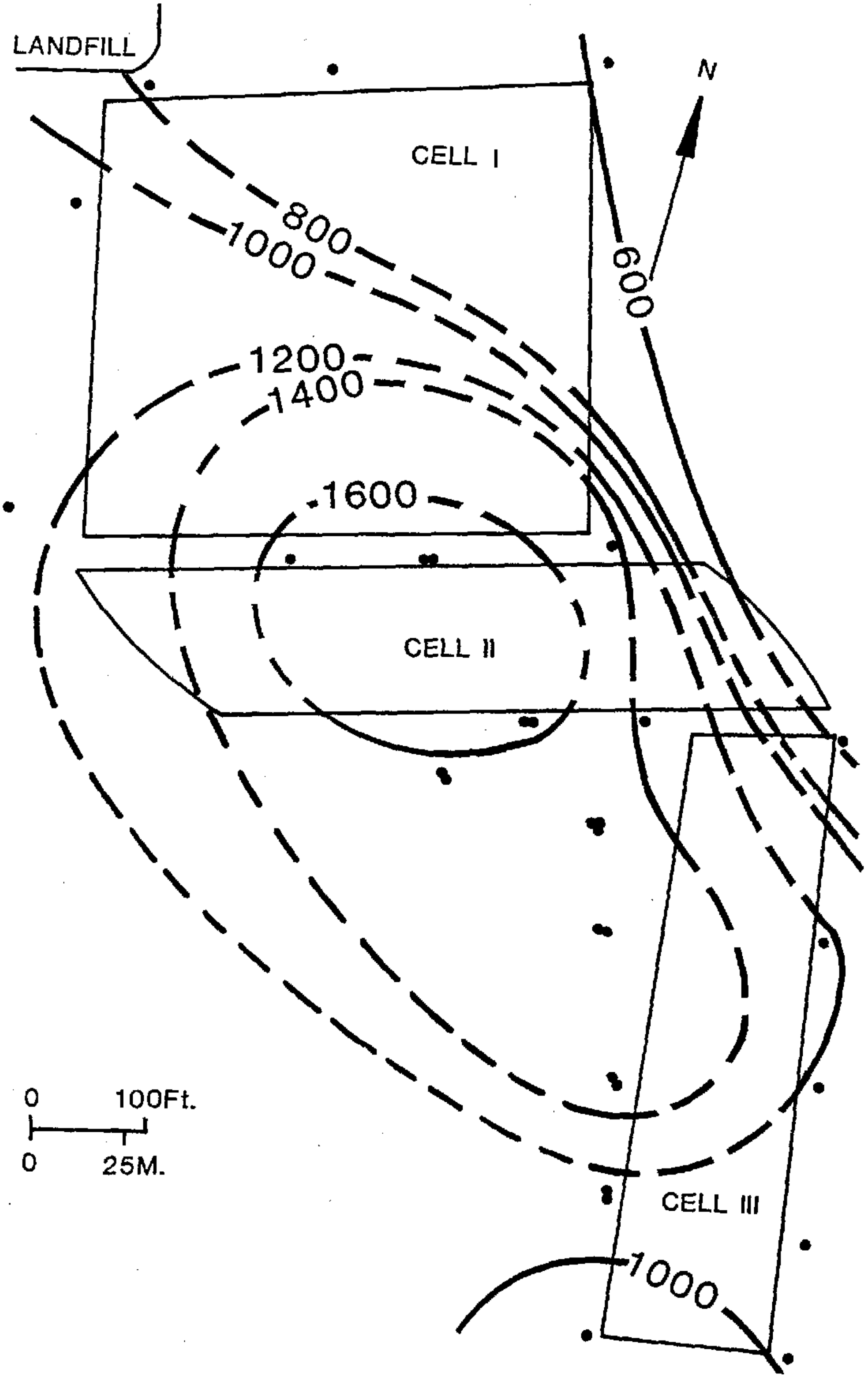

LANDFILL
N
CELL I
600
400
800
CELL II
1000
CELL III
0
100Ft.
0
25M.

Figure 9. Mean lab electrical conductivity (umhos/cm) in groundwater. Individual plus shallow nested wells. Contour interval is 200 umhos/cm.


LANDFILL
N
CELL I
800
1000
600
1200
1400
1600
CELL II
CELL III
1000
0 100Ft.
0 25M.

TDS and conductivity values decrease steadily toward the southernmost wells, yet remain at least two times greater than background levels.

Phosphate in sewage occurs primarily in the form of orthophosphate (PO_4^{3-}). Orthophosphate concentration is a function of pH and is also the stable form of dissolved phosphate in natural waters (LeBlanc, 1984, p. 16). Comparison of total phosphate, dissolved phosphate and dissolved orthophosphate data indicates that the majority of measured phosphate is in the dissolved orthophosphate form (appendix III). Phosphate is a vital nutrient for vegetation. At the McVille site, the highest orthophosphate levels are within the lagoon (Fig. 10). In well 4, orthophosphate is at the same concentration as the waste-water, whereas in wells 7 and 28 orthophosphate levels are roughly half that of the waste-water content. Farther downgradient the orthophosphate levels approximate those found upgradient of the lagoon. This phosphate concentration is maintained throughout the downgradient half of the site.

Calcium and magnesium cations behave similarly in an aqueous environment. Concentrations of these species are predominantly controlled by dissolution of carbonates, sulfates, silicates and clay minerals, and cation exchange. The distribution of calcium and magnesium levels at the McVille site is similar. Waste-water and background levels of these cations are very similar (Fig. 11 and 12). Wells

Figure 10. Mean dissolved orthophosphate concentration (mg/L) in groundwater. All wells are contoured. Contour interval is 1 mg/L.

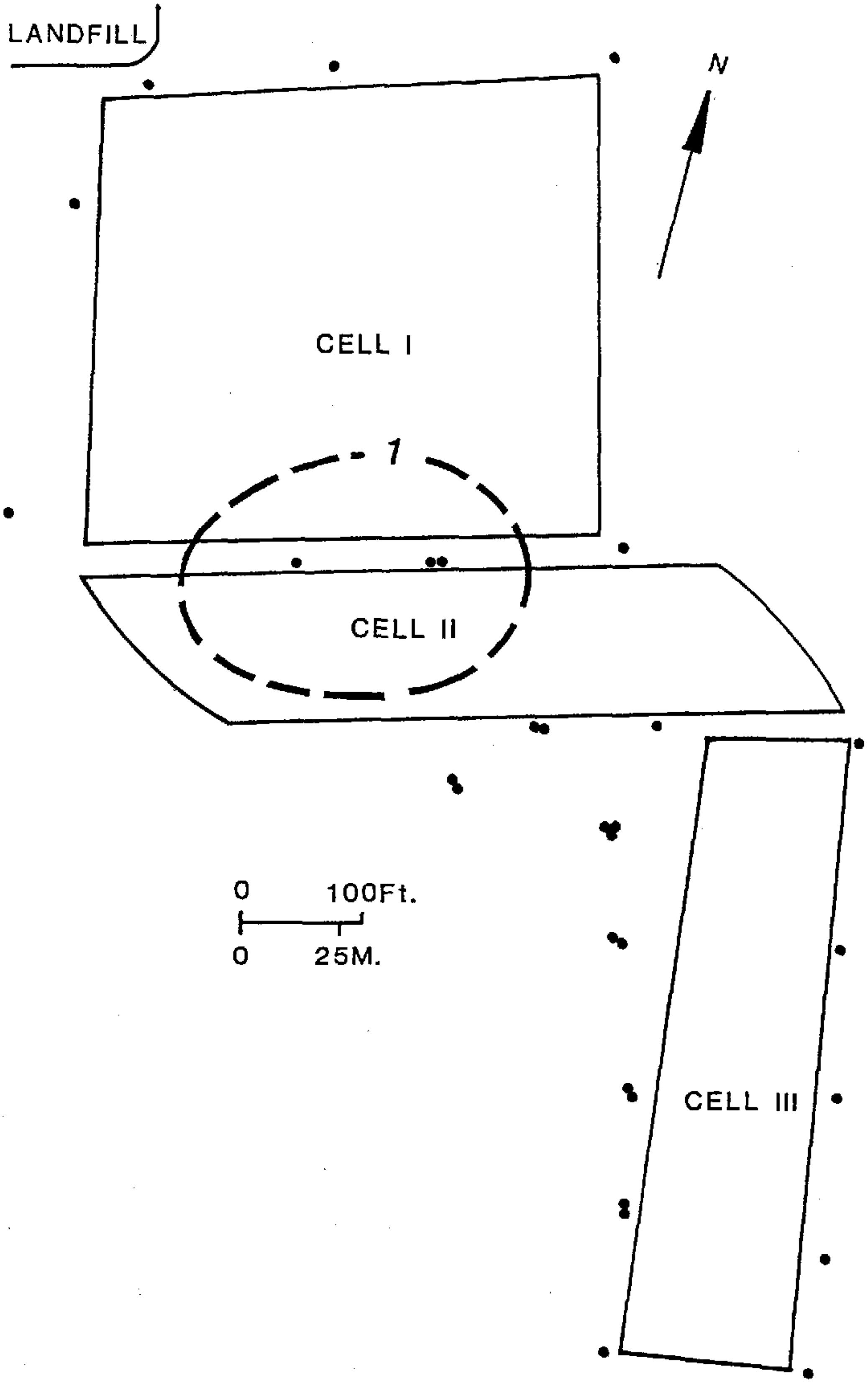

LANDFILL
N
CELL I
1
CELL II
0 100Ft.
0 25M.
CELL III

Figure 11. Mean calcium concentration (mg/L) in groundwater. Individual plus shallow nested wells. Contour interval is 20 mg/L.

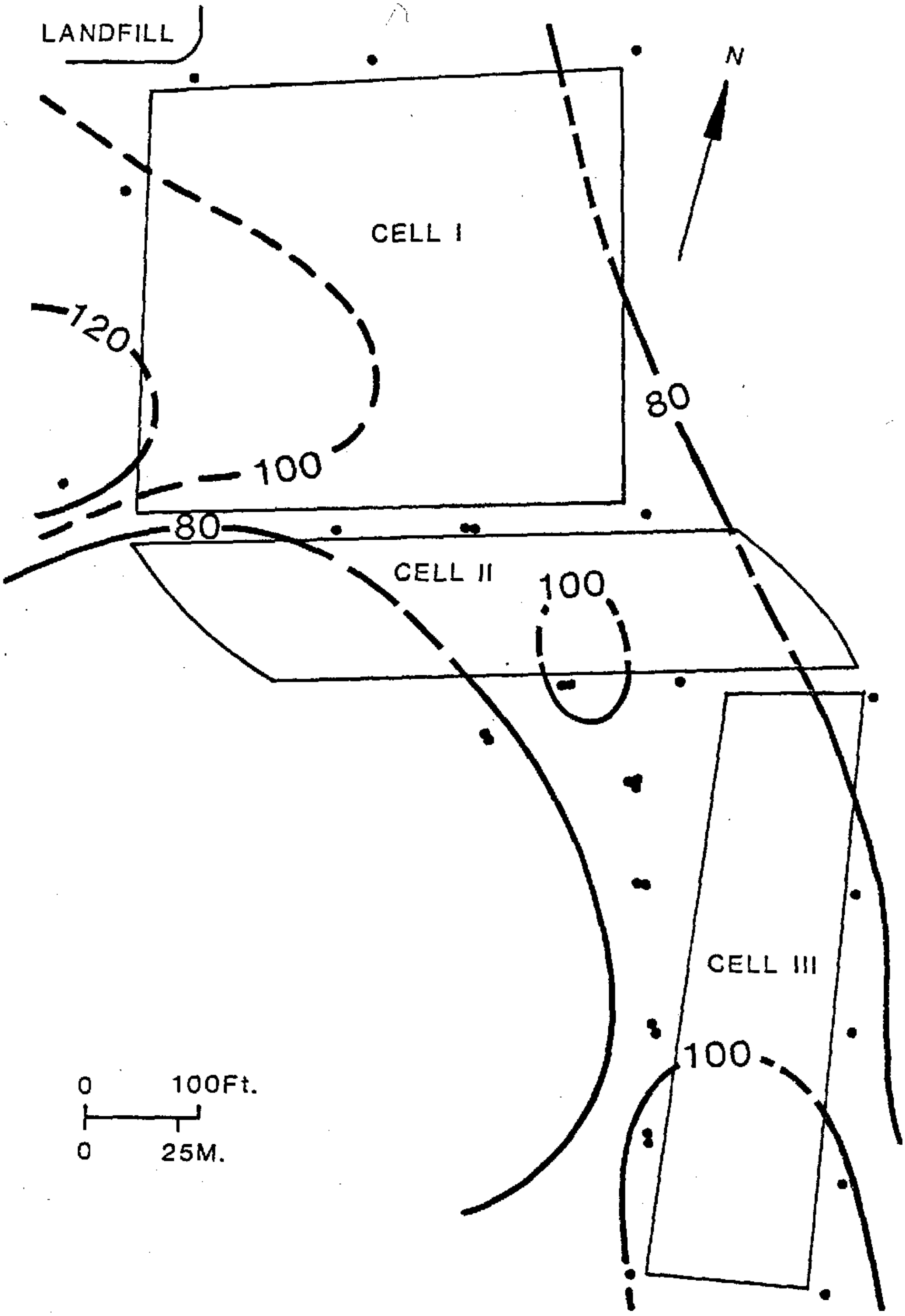
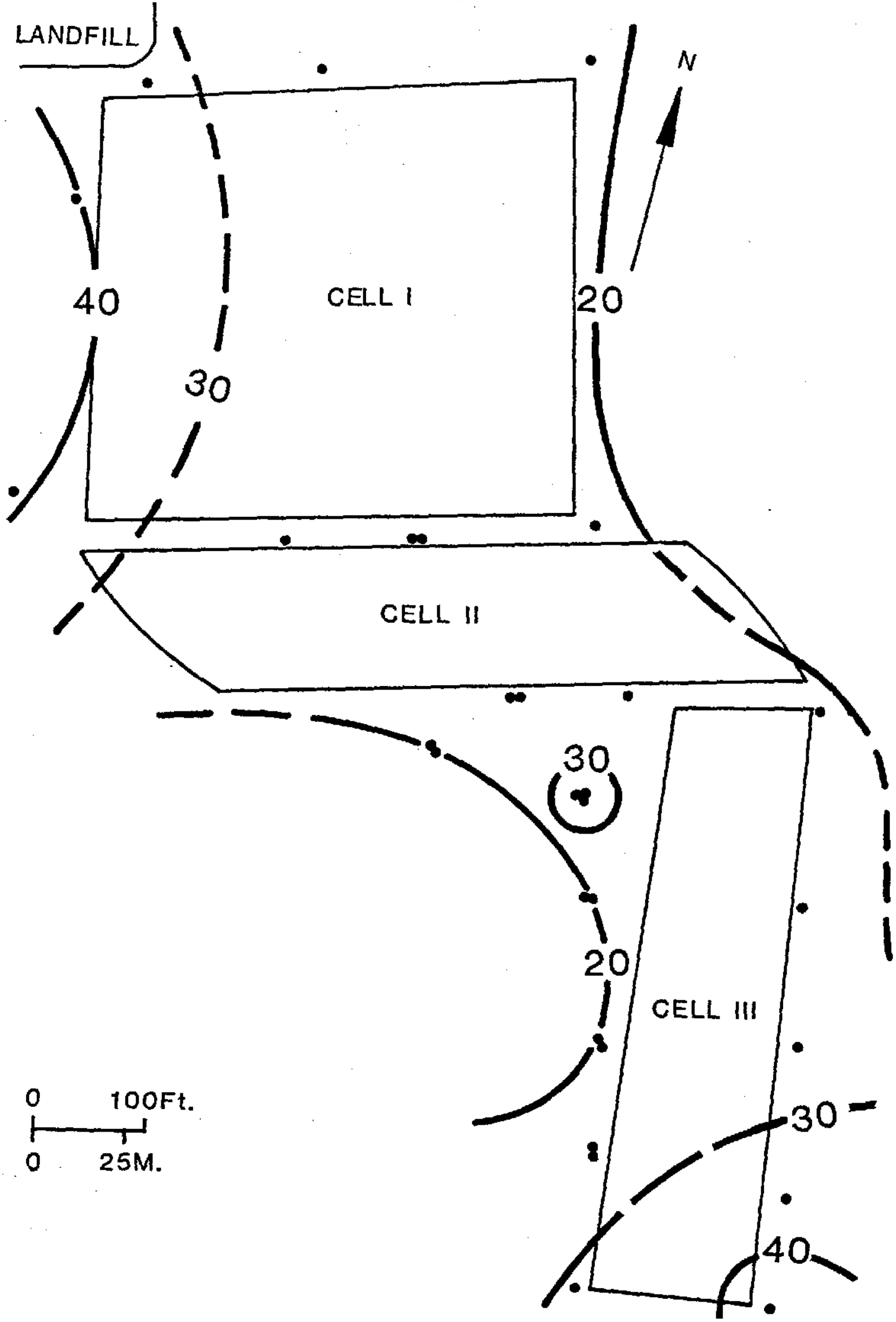

LANDFILL
N
CELL I
120
100
80
80
CELL II
100
CELL III
100
0
100Ft.
0
25M.

Figure 12. Mean magnesium concentration (mg/L) in groundwater. Individual plus deep nested wells. Contour interval is 10 mg/L.


LANDFILL
N
40
CELL I
20
30
CELL II
30
20
CELL III
0 100Ft.
0 25M.
30
40

influenced by landfill leachate contain calcium and magnesium concentrations one and a half to two times greater than the waste-water concentrations. The area just downgradient of Cells I and II contains variable calcium and magnesium levels, but, generally, levels are in the same range as the landfill leachate. Between wells 6 and 8, and wells 13 and 21, calcium and magnesium concentrations decrease slightly. Downgradient of wells 13 and 21 these cations increase again to the levels found in the area just downgradient of Cells I and II.

The potassium and sodium cations can be controlled by cation exchange, but generally are weakly attenuated by this mechanism (Freeze and Cherry, 1979, p. 133). Thus, these monovalent cations are hydrogeochemically similar and display similar distributions at the McVille site. Background concentrations of sodium and potassium are very low relative to the levels produced by contamination (Fig. 13 and 14). Within the waste-water the sodium and potassium concentrations are 10 to 20 times greater than background and two to five times greater than the landfill contribution. Immediately downgradient of Cell I, these monovalent cations are at the same level or slightly lower than the concentration within the lagoon. Immediately downgradient of Cell II, sodium concentrations are slightly greater than those immediately upgradient of Cell II. Further downgradient, sodium levels generally decrease with distance, and are variable with depth. Wells along the

Figure 13. Mean potassium concentration (mg/L) in groundwater. Individual plus shallow nested wells. Contour interval is 4 mg/L.

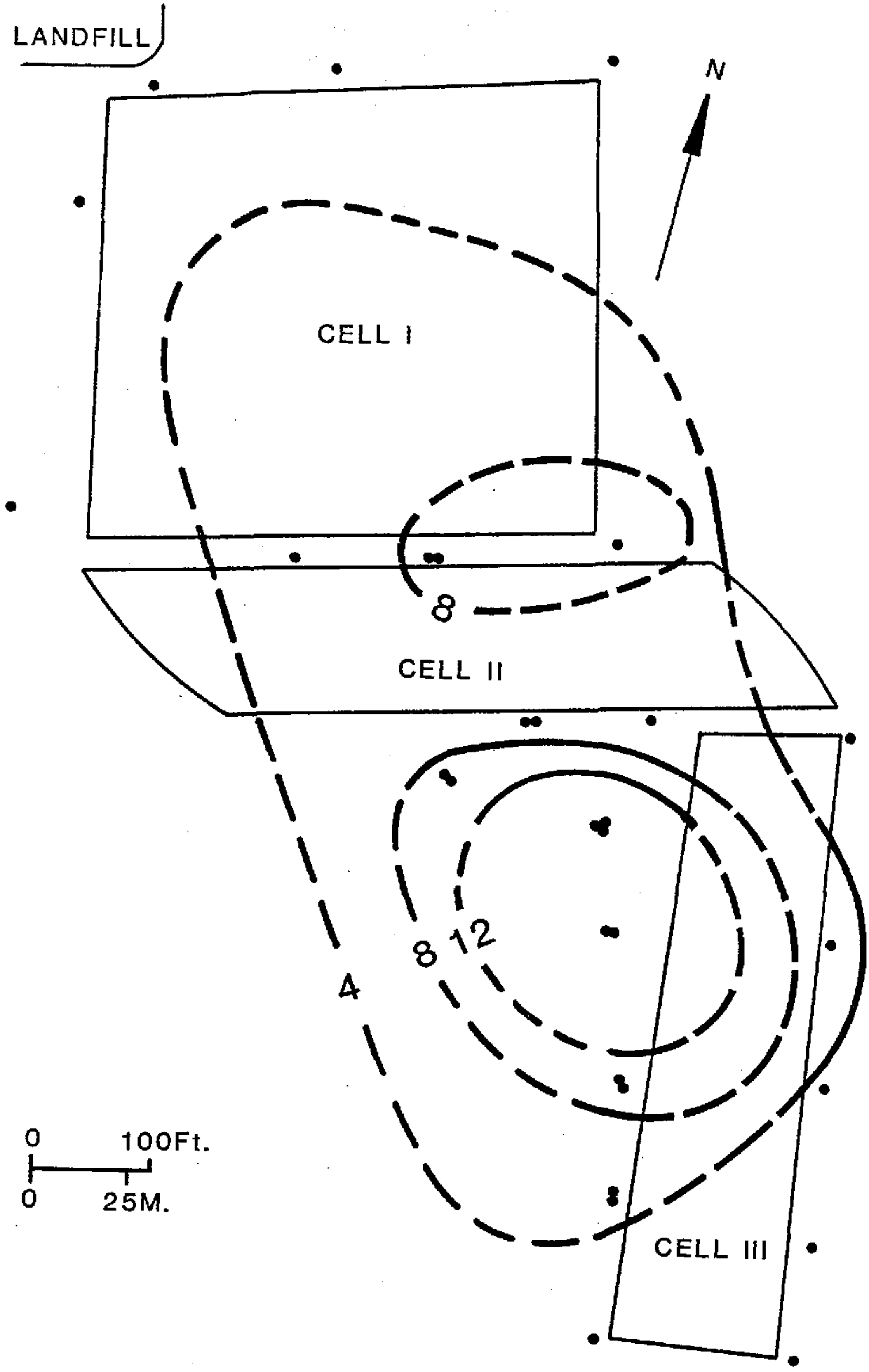
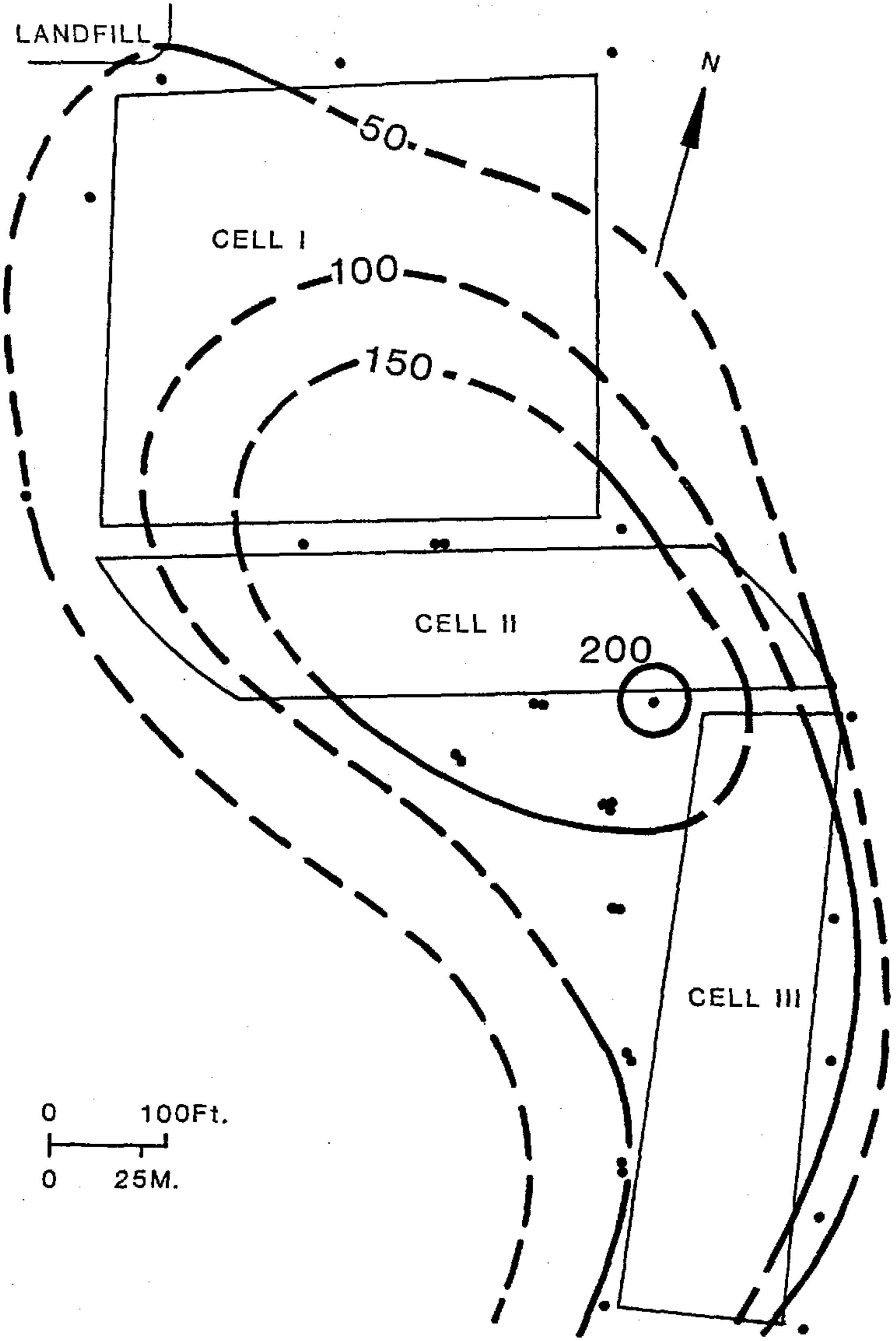

LANDFILL
N
CELL I
8
CELL II
8
12
4
0
100Ft.
0
25M.
CELL III

Figure 14. Mean sodium concentration (mg/L) in groundwater. Individual plus shallow nested wells. Contour interval is 50 mg/L.


LANDFILL
N
50
100
150
200
CELL I
CELL II
CELL III
0 100Ft.
0 25M.

eastern border of Cell III are low in sodium content.

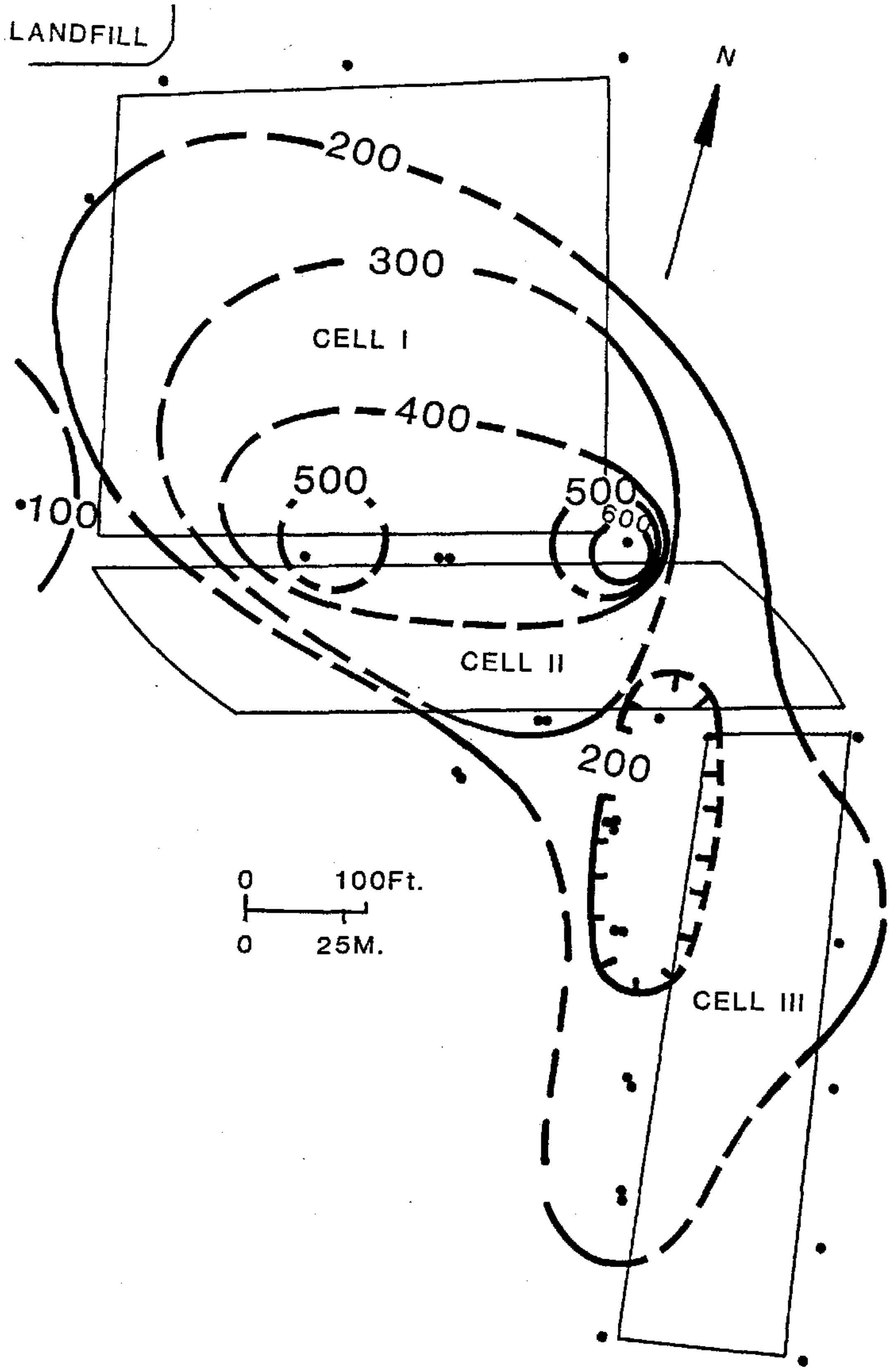
Downgradient of Cell II, the potassium levels are variable perpendicular to the flow path, both with distance and with depth. Some concentrations are greater than those within the lagoon and some are less. At the southern and southeastern border of the site potassium and sodium levels are low, approximately half of the waste-water concentration.

The trace elements arsenic, barium, cadmium and copper were monitored during this study. Arsenic is affected by redox reactions and will be discussed in the section on parameters affected by the redox environment.

Barium in groundwater is commonly attributed to natural sources. The most common barium mineral contributing barium to groundwater is barite ($BaSO_4$), which has a low solubility and can control the barium solute concentration (Robertson, 1984, p.100). Barite is most commonly found in sedimentary rocks.

Background levels of barium are relatively high, but approximately one tenth of the maximum permissible limit for drinking water, which is 1.0 mg/L (US EPA, 1975). The region between the landfill and Cell I contains barium levels in the same range as that of background (Fig. 15). Within the waste-water, barium levels are nearly two times greater than background. Immediately downgradient of Cell I, barium levels reach the maximum values seen at the site, approximately twice the waste-water concentration. Farther

Figure 15. Mean barium concentration (ug/L) in groundwater. Individual plus shallow nested wells. Contour interval is 100 ug/L.

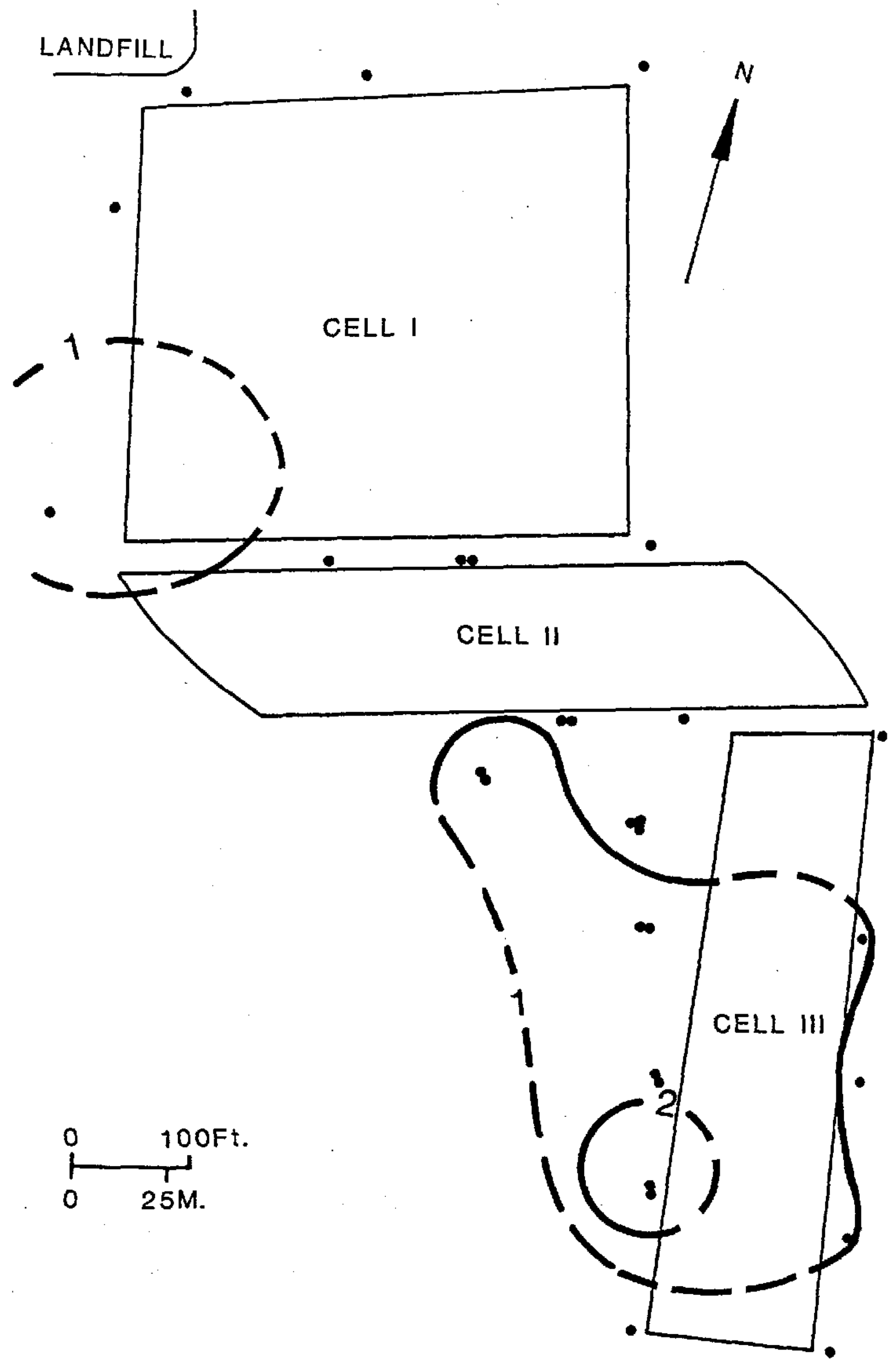

LANDFILL
N
200
300
CELL I
400
500
500
600
100
CELL II
200
0
100Ft.
0
25M.
CELL III

downgradient barium concentrations vary with distance and depth, yet remain at the same level as that in the wastewater at a distance of 150 metres downgradient. Throughout the study period barium levels remained below the maximum permissible limit at every well.

Copper and cadmium in natural waters are typically at low concentrations due to the effects of adsorption by metal oxy-hyroxides and clay minerals, along with minerals of low solubility (Freeze and Cherry, 1979, p. 416). Trace metals are also noted to have a tendency to form complexes with inorganic compounds (HCO_3^-, OH^-, SO_4^{2-}, etc.) (Freeze and Cherry, 1979, p. 416) and organic ligands (Sunda and Hanson, 1979, p. 178). Copper was found to bind predominantly to organic ligands in natural waters (Sunda and Hanson, 1979, p. 178). Complexation is important because the toxicity of copper in natural waters seems to be related to the free ion concentration (Van Der Berg and Kramer, 1979, p. 129). However, adsorption by hydrous iron and manganese oxides has been considered to be the dominant control on dissolved trace metal concentrations.

The areal distribution of cadmium is fairly constant throughout the site. Background, lagoon and landfill leachate levels are in a very narrow range (0.57 to 1.93 ug/L). Downgradient from the lagoon, cadmium levels range from 0.53 to 2.49 ug/L, and display no consistent trends (Fig. 16). All water samples contain cadmium concentrations well below the maximum permissible limit of

Figure 16. Mean cadmium concentration (ug/L) in groundwater. Individual plus deep nested wells. Contour interval is 1 ug/L.


LANDFILL
N
CELL I
1
CELL II
CELL III
1
2
0 100Ft.
0 25M.

10 ug/L (US EPA, 1975).

The lagoon water displays the highest mean copper concentration at the site (greater than 11 ug/L)(Fig. 17). Mean background levels and landfill leachate levels are less than 3.2 ug/L. A narrow, discontinuous plume containing mean copper levels of greater than 6.0 ug/L extends 150 meters downgradient from Cell I. Outside and downgradient of this plume mean copper levels approximate the levels seen upgradient of Cell I.

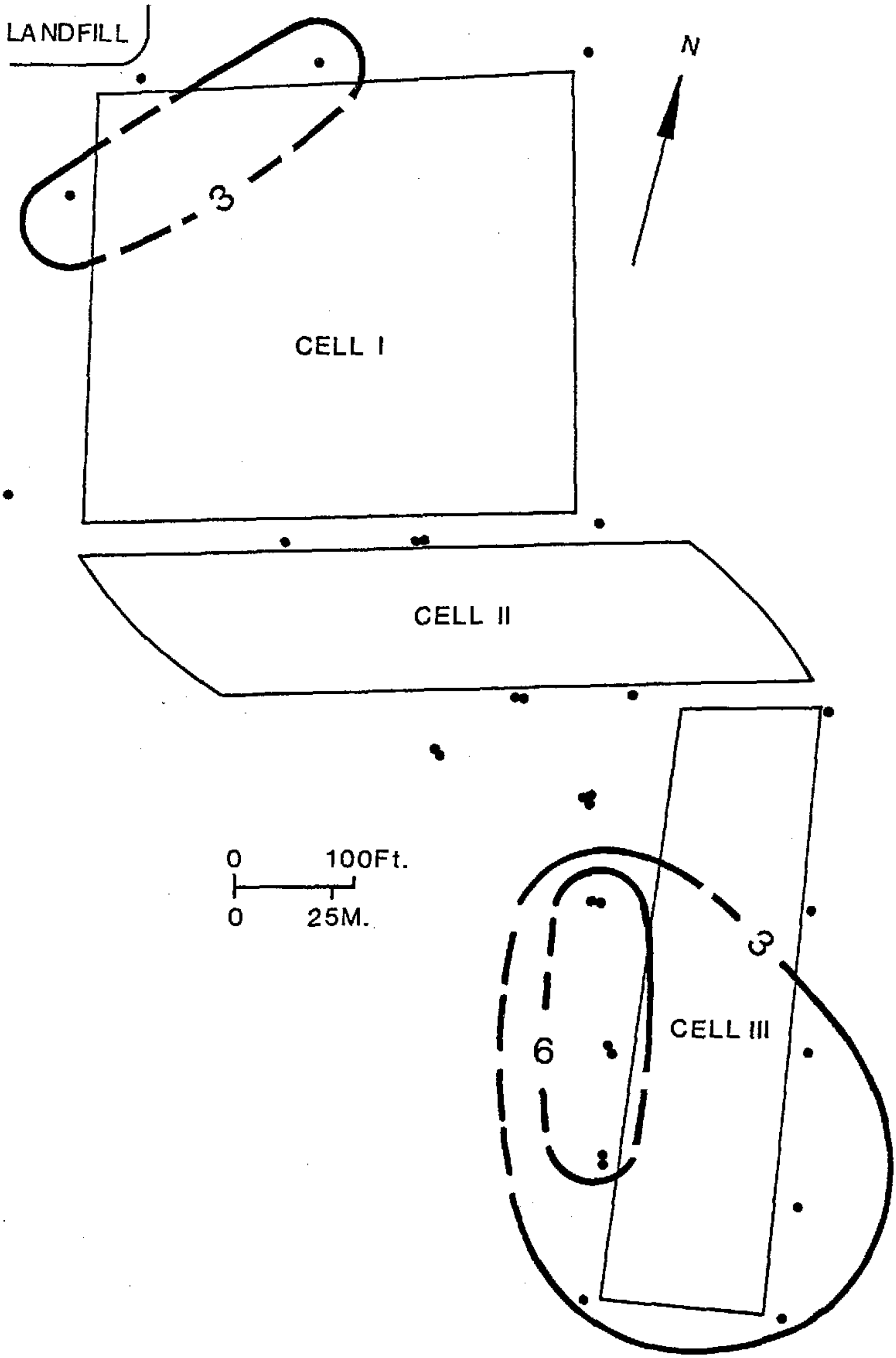
Organics

In 1985, the US EPA conducted a study of organic pollutants in sewage lagoons and nearby groundwaters to establish a reference data base. Nationwide, ten lagoons were monitored, three of which, including McVille, were in North Dakota.

A thorough sampling procedure was followed. Sewage influent was sampled three times spaced approximately one to two hours apart. Lagoon liquid and sludge samples were taken by boat. Groundwater was sampled from one upgradient well and three downgradient wells.

Monitoring wells were sampled using a teflon-coated bailer. An equipment `blank' sample of organic-free water was taken prior to sampling at the first well and the last well to check for contamination due to sampling or analyzing procedures. Wells were purged with a battery operated pump prior to sample collection. The bailer was

Figure 17. Mean copper concentration (ug/L) in groundwater. Individual plus deep nested wells. Contour interval is 3 ug/L.


LANDFILL
N
3
CELL I
CELL II
CELL III
3
6
0
100Ft.
0
25M.

sterilized prior to sampling at each well using soap and brush, then rinsed with organic-free water. Water samples were placed on ice in coolers and shipped by Purolator Courier Service to the EPA lab in Maryland. Samples were analyzed for priority pollutant groups - volatile organics, extractable organics, PCB pesticides, trace metals, and conventional contaminants.

Analysis for volatile and extractable organics detected very few of the priority pollutants and those present were in minor quantities (appendix VI). The majority of the organics were below the detection limit. The highest concentrations were found within the influent samples (mean chloroform concentration of 1.8 ug/L and mean toluene concentration of 10 ug/L). Within the sludge layer minor quantities of organics were detected (ethylbenzene 0.005 ug/L and toluene 0.006 ug/L). The low quantity of these compounds implies a low influent contribution and biochemical stabilization of sewage within the lagoon. Minor amounts of 1,1-dichloroethane (1.4 ug/L) and 1,4-dichlorobenzene (estimated 0.8 ug/L) were detected in well 4. These compounds were not detected within the lagoon, and may have formed in the aquifer. A lack of detection of these organic compounds farther downgradient suggests attenuation, possibly by bacteria. PCB pesticides were not detected in any of the samples taken at the site.

Parameters Affected by Redox Environment

Redox reactions in groundwater involve the transfer of electrons from one compound to another, resulting in changes in the oxidation states of the reactants and products (Freeze and Cherry, 1979, p. 114). The relative electron activity of a system is defined by the dimensionless term pe, defined as:

$$pe = -\log [e],$$

where e is the electron activity. A high pe value indicates an oxidizing tendency, while a low pe value indicates a reducing environment. The pe quanitifes the redox potential of the solution. The variable Eh also quantifies the redox potential, and can be used interchangeably with pe using a numerical conversion.

The mobility of numerous solutes is dependent on the oxidation state of the species. Thus, qualitative knowledge of pe levels greatly aids in interpreting the distribution of redox-sensitive species in contaminant plumes. Approximate levels of redox potential can be interpreted using field-measured redox potentials and concentrations of redox sensitive ionic constituents.

Natural waters having low redox potentials contain dissolved oxygen (DO) at levels below the detection limits. Waters containing low DO levels can develop by a long residence time in aquifers (Champ et al., 1979, p. 12) and by confinement in surface waters under conditions of restricted sunlight such as the bottom of deep lakes and densely vegetated waters. Environments having low redox potential develop when all oxygen is consumed and organic matter becomes a common reducing agent (Drever, 1982, p. 283).

Lowering of the redox potential is a common consequence of anthropogenic activities such as land disposal of organic-rich waste. In an anaerobic environment, oxidation-reduction reactions, which are controlled by microorganisms, occur between organic matter and/or inorganic solids, liquids and gasses. As a system becomes more anaerobic, the change in Gibb's free energy of redox reactions decreases, resulting in a low energy yield per reaction. This decrease in energy yield further lowers the redox potential of a system (Champ et al., 1979, p. 13).

Quantitative determination of redox potentials is limited by several factors, including:

1. Kinetic disequilibrium of redox couples during measurement (Cherry et al., 1984, p.54).
2. Interference between redox couples during detection.
3. Lack of reliable thermodynamic data for the range of materials and conditions found in natural aquatic environments.
4. Limited equipment used for measuring redox potential is; for example, the platinum electrode does not respond to certain redox couples present in groundwater (Drever, 1982, p. 257).
5. Irreversibility of biologically mediated redox reactions

(Cherry et al., 1979, p. 376).

6. The concentration of one member of a redox pair is below the detection limit for some redox couples in natural waters, giving unreliable results (Cherry et al., 1979, p. 376).

The distribution of measured redox potentials is shown in Figure 18. The region beneath and adjacent to Cell II (group 2 wells) contains the lowest redox potentials. Outside of this area, pe levels increase in a subconcentric, elliptical pattern. The highest levels of pe, 8 to 9 pe units, occur in background wells 2 and 9.

Dissolved organic matter commonly occurs in low concentrations throughout natural waters (Freeze and Cherry, 1979, p. 86). A U.S. survey conducted by Leenheer (1974) indicated a median DOC of 0.7 mg/l. Sources most frequently cited for subsurface DOC contamination are landfills and the various disposal methods of sewage and sewage products (Cherry et al., 1984, p.59-60). Sewage contains hundreds of dissolved organic compounds which degrade at varying rates.

McVille wells having DOC values greater than background concentrations provide a direct indication of seepage beneath Cells I and II. A plume of elevated mean DOC concentrations, ranging from 3.1 to 12.0 mg/l, extends the length of the site (Fig. 19). The highest concentration values in this plume are roughly half those found in the waste water and are located just downgradient

Figure 18. Mean field pe levels (pe units) in groundwater. All measured wells. Contour interval 1 pe unit.

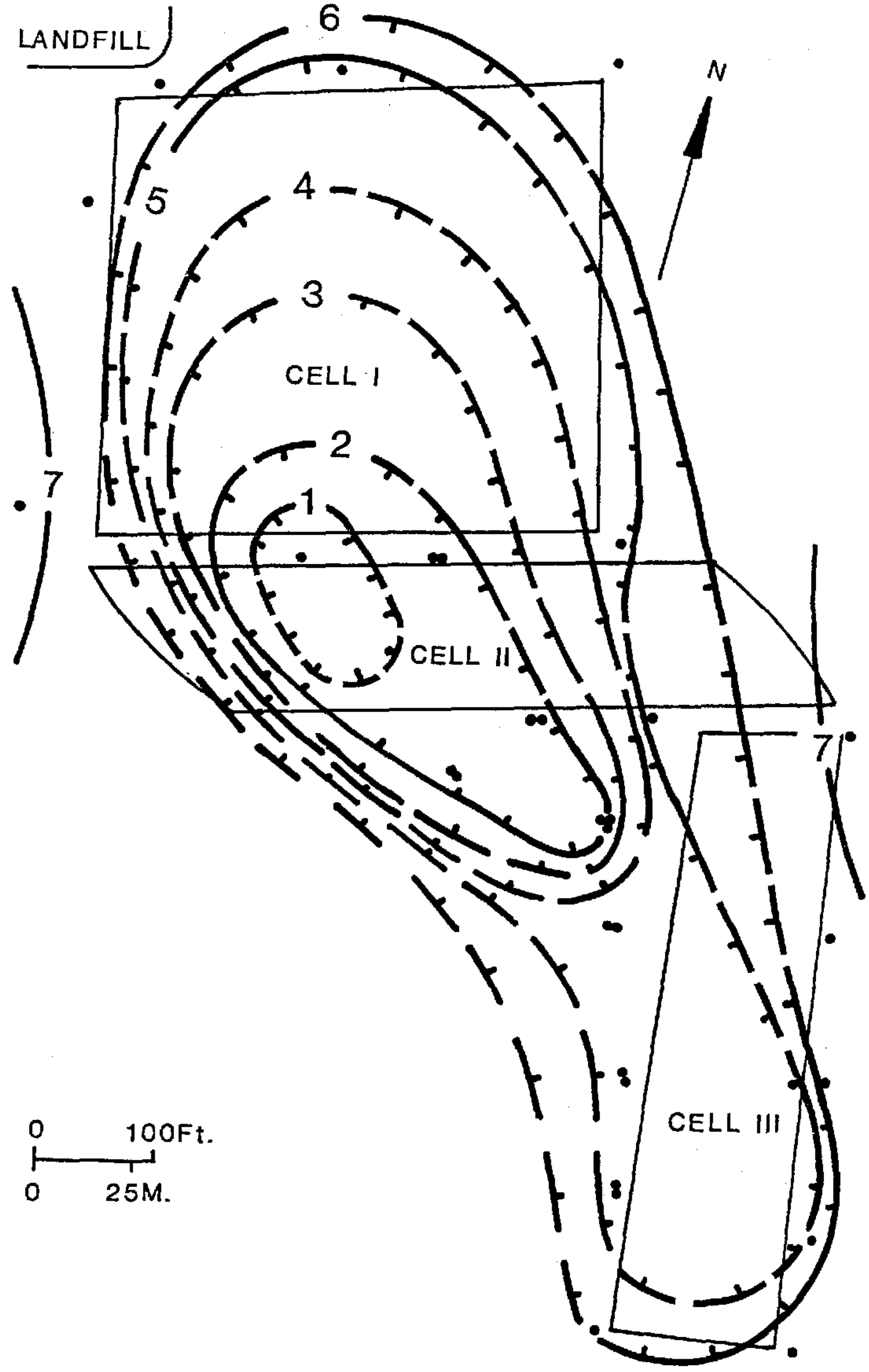
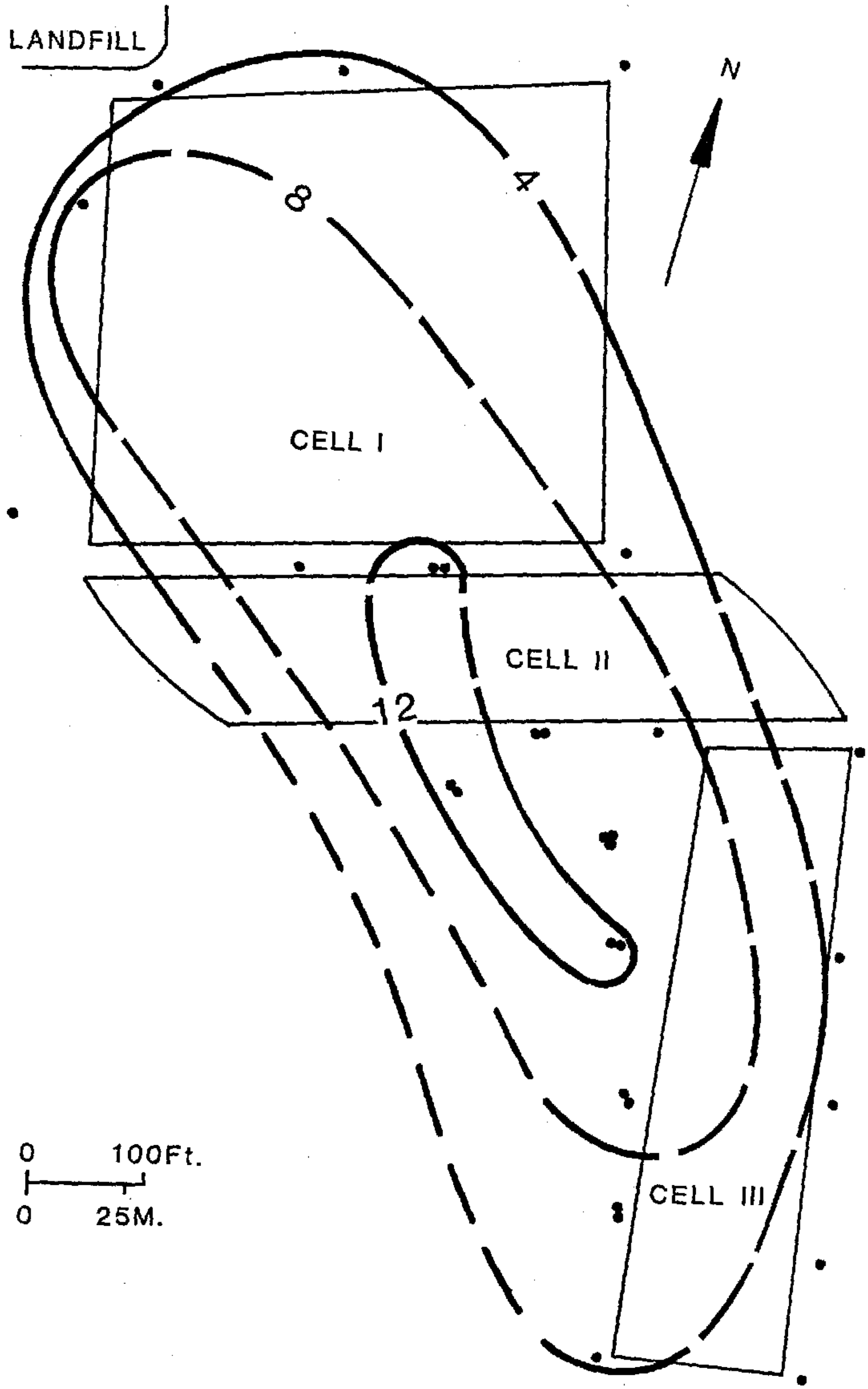

LANDFILL
6
N
5
4
3
CELL I
2
7
1
CELL II
7
CELL III
0
100Ft.
0
25M.

Figure 19. Mean dissolved organic carbon (DOC) concentration (mg/L) in groundwater. Individual plus deep nested wells. Contour interval is 4 mg/L.


LANDFILL
N
4
8
12
CELL I
CELL II
CELL III
0 100Ft.
0 25M.

of Cells I and II. DOC concentrations decrease gradually along the length of the flow path, approaching background levels at the southern edge of the site.

Iron and manganese species behave similarly in an aqueous environment. The reduced forms, having a valence of +2, are more soluble, while the oxidized forms, having charges of +3 and +4 for iron and manganese respectively, are less soluble. Iron and manganese compounds are ubiquitous in sediments but typically occur in minor quantities as cements or detrital grain coatings (Drever, 1982, p. 293). The recommended limits of 0.3 mg/l for iron and 0.05 mg/l for manganese for groundwater consumption are primarily set to avoid water-use problems such as precipitate and stain build-up, rather than for health reasons (Freeze and Cherry, 1979, p. 387).

Municipal sewage generally does not contain high levels of iron and manganese. Furthermore, the McVille Landfill does not contribute iron and manganese to the aquifer, although high iron contents have been noted for leachate produced from some landfills (Cartwright, 1985, p.68). At the McVille site, maximum iron and manganese concentrations reach one to two orders of magnitude higher than waste water and background levels (figures 20 and 21). The maximum concentrations occur in wells of group 2, beneath and just downgradient of Cell II. Iron and manganese concentrations decrease sharply further downgradient, with elevated manganese values occurring

Figure 20. Mean iron concentration (mg/L) in groundwater. Line of cross section displayed in figure 5. Contour interval is 5 mg/L.

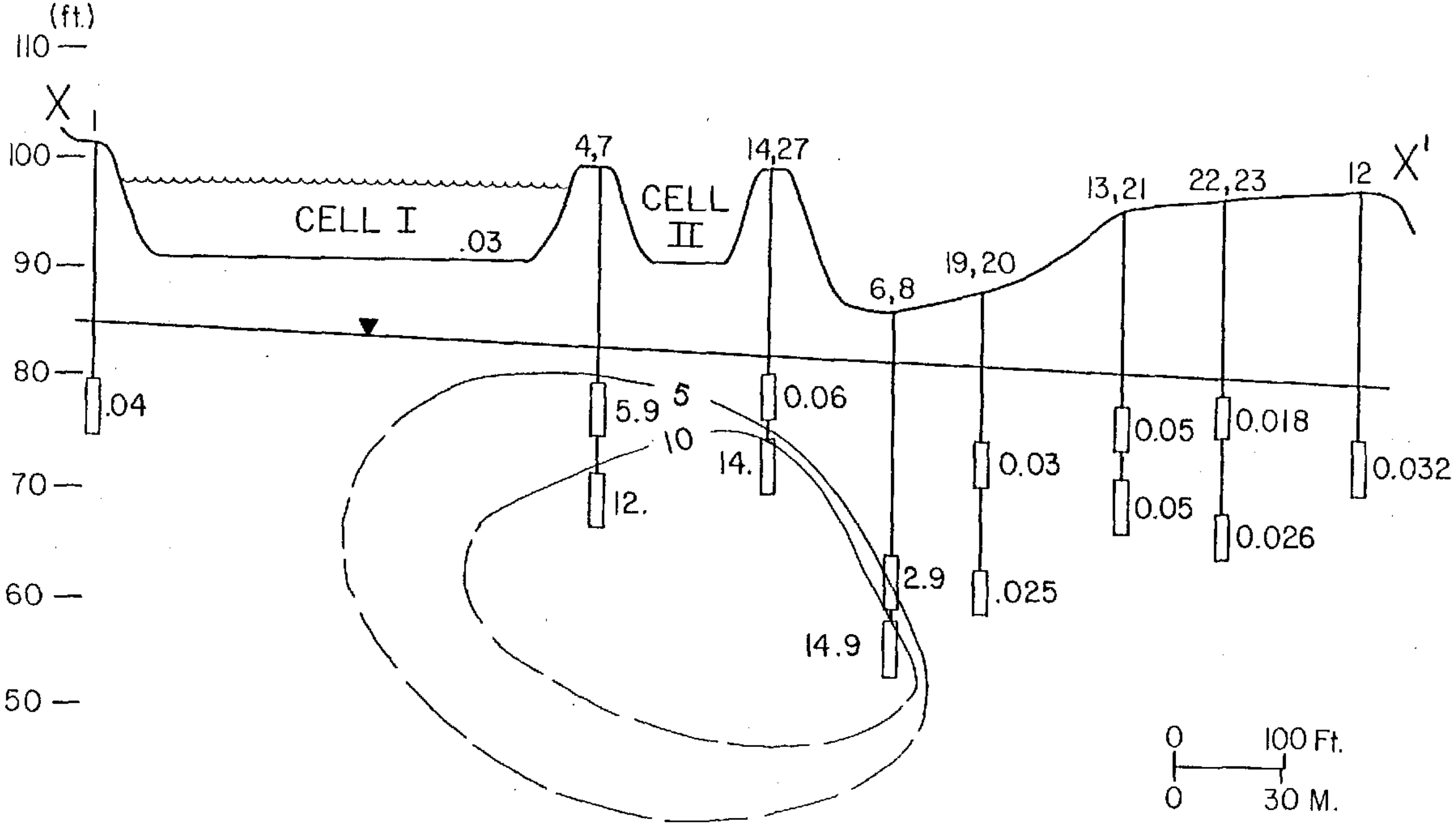
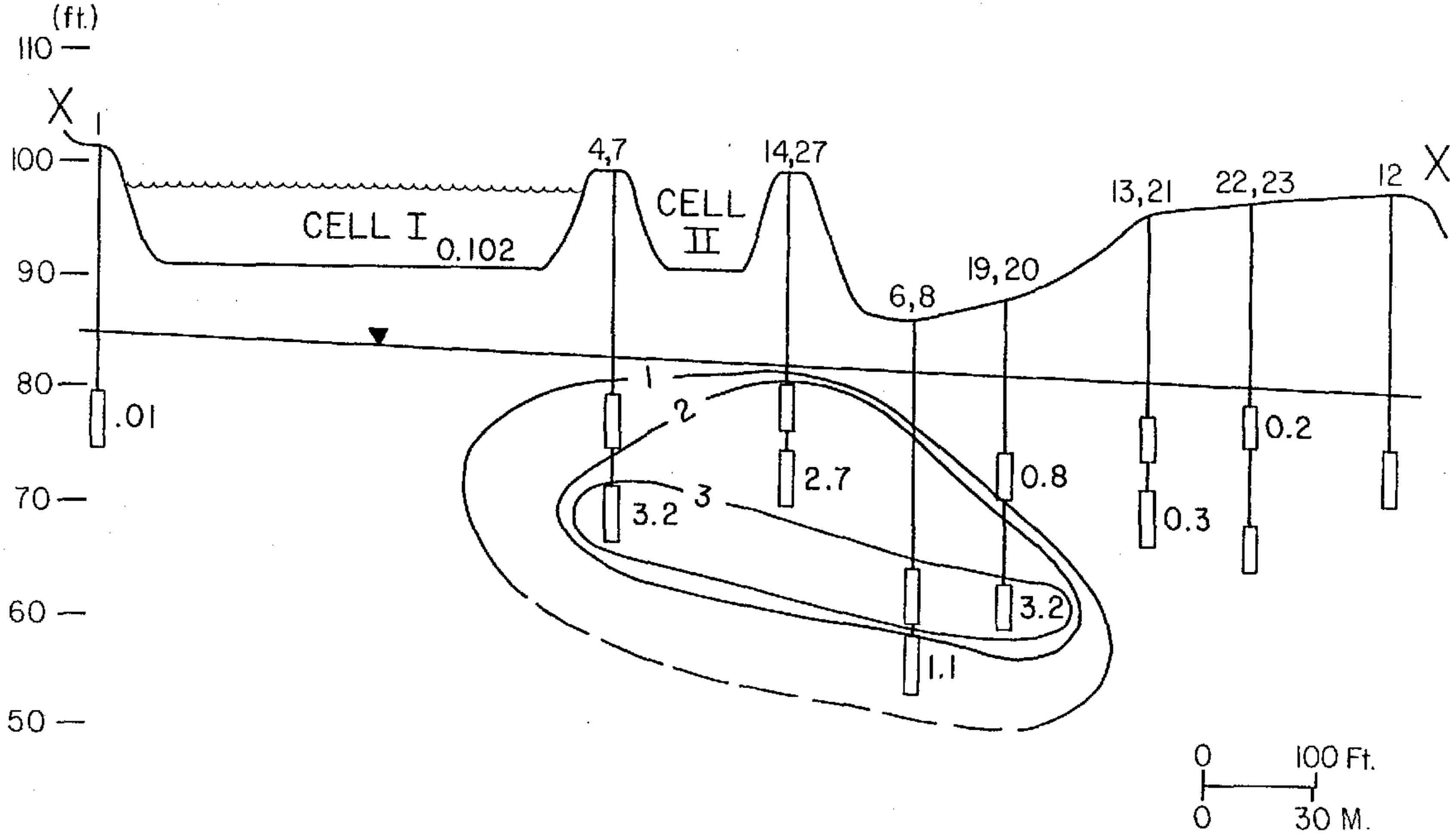

(ft.)
110
100
90
80
70
60
50
X
X'
1
4,7
14,27
6,8
19,20
13,21
22,23
12
CELL I
CELL II
.03
.04
5.9
12.
0.06
14.
2.9
14.9
0.03
.025
0.05
0.05
0.018
0.026
0.032
5
10
0
100 Ft.
0
30 M.

Figure 21. Mean manganese concentration (mg/L) in groundwater. Line of cross section displayed in figure 5. Contour interval is 1 mg/L.



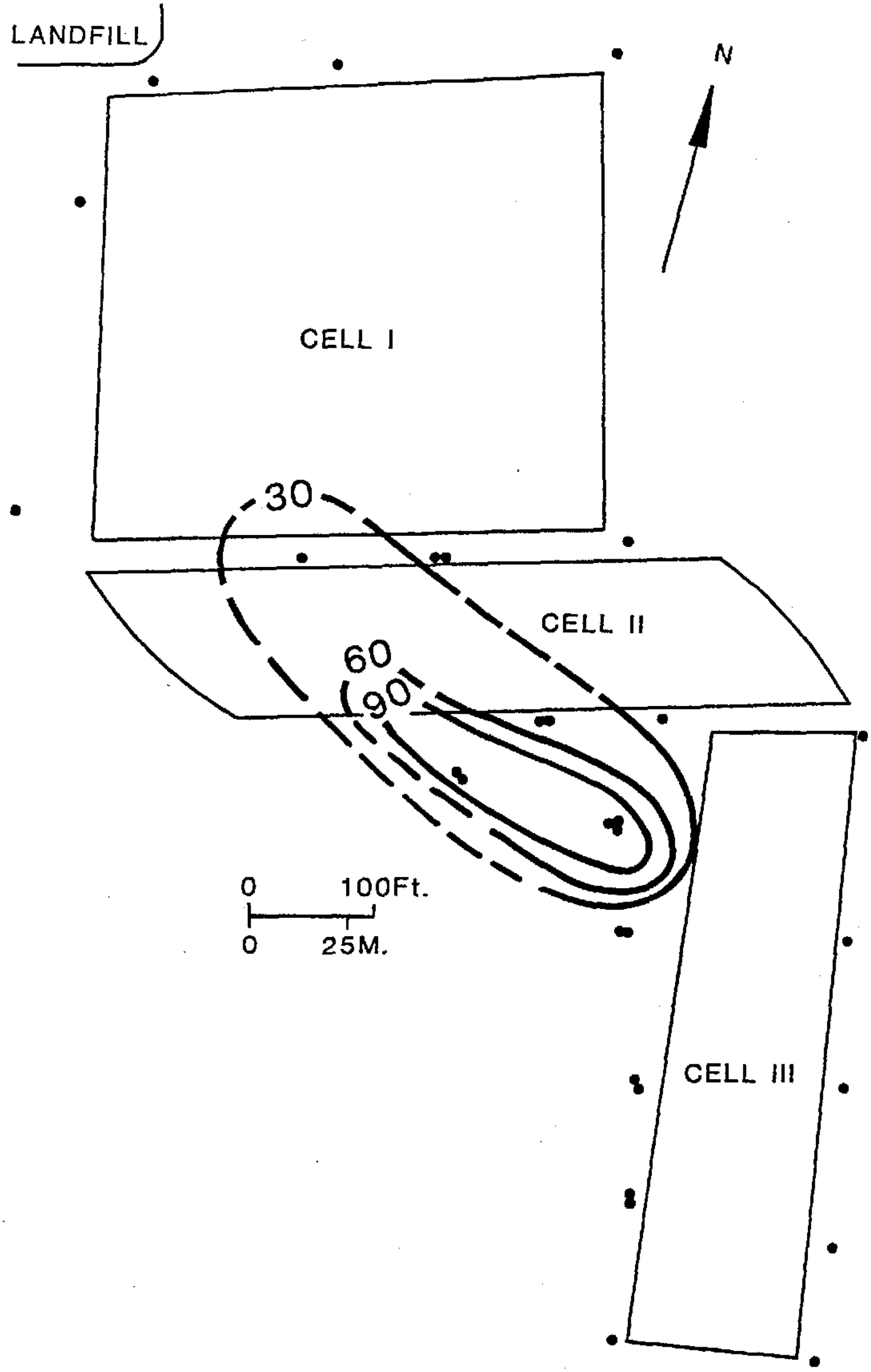
(ft.)
110
100
90
80
70
60
50
X
X'
1
4,7
14,27
6,8
19,20
13,21
22,23
12
CELL I
0.102
CELL II
.01
3.2
2.7
0.8
0.3
0.2
3.2
1.1
1
2
3
0
100 Ft.
0
30 M.

over a larger area. Increasing iron levels to a depth of ten metres below the water table suggests that this plume extends to a considerable depth, although data from greater depths were not obtained due to installation problems.

Mineral occurrences of arsenic primarily include arsenic sulfide compounds. Arsenic is also typically present as a trace element in coal, clay and shale (Roberts et al., 1985, p. 7). Inorganic and organic arsenic solutes occur in a variety of oxidation states, ranging from +5 to -3 (Matisoff et al., 1982, p.446). Modern analytical equipment is capable of determining the fraction of total arsenic occurring in different oxidation states even at very low concentrations (Cherry et al., 1979, p. 379). Measurement of individual species is important for quantifying the redox potential using pe-pH diagrams and because the toxicity of arsenic decreases with increasing oxidation state (Matisoff et al., 1982, p.447). Bacterial activity can also affect the speciation of arsenic (Roberts et al., 1985, p. 8).

Background and waste-water levels of arsenic at the McVille site are fairly low (less than 4.0 ug/l) (Fig. 22). The mean arsenic concentration is also in this range at wells of groups 2 and 4. In the region beneath and immediately downgradient of Cell II (group 3 wells), mean arsenic concentration increases to a maximum of 116 ug/l, twice the permissible limit for drinking water (US EPA, 1975). The concentration drops off abruptly downgradient

Figure 22. Mean arsenic concentration (ug/L) in groundwater. Individual plus deep nested wells. Contour interval is 30 ug/L.


LANDFILL
N
CELL I
30
CELL II
60
90
0
100Ft.
0
25M.
CELL III

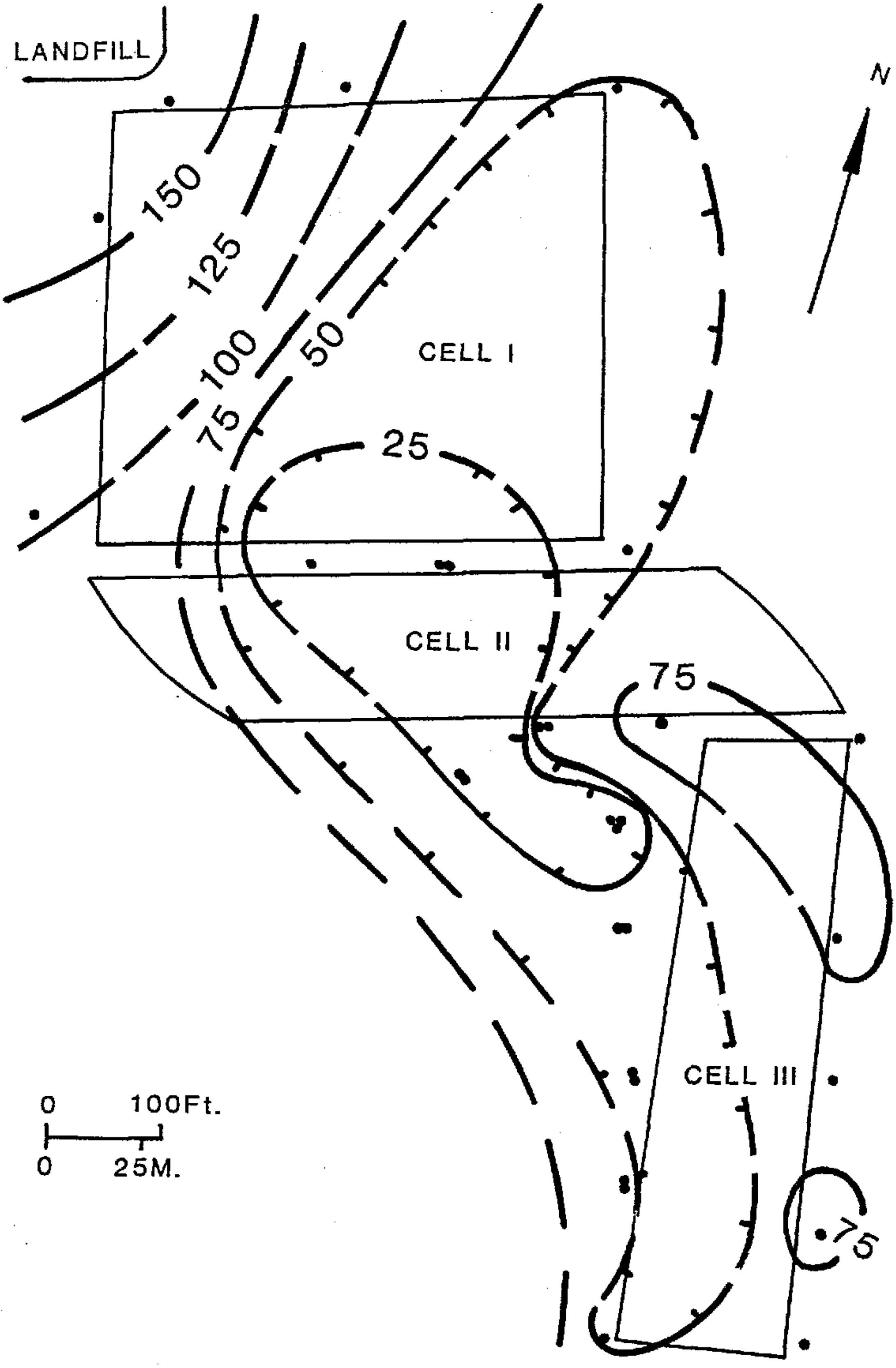
from this region.

The EPA's recommended limit for sulfate is 250 mg/l. The presence of sulfate in groundwater is commonly controlled by the solubility of sulfate minerals such as gypsum (Groenewold et al., 1983, p. 16), barite (Robertson, 1984, p. 100), and the oxidation of sulfide minerals such as pyrite. High concentrations of sulfate in drinking water are known to act as a laxative (Viessman and Hammer, 1985, p. 230).

Substantial mean sulfate concentrations of 42 to 76 mg/l were detected in background wells and in the lagoon waste water (Fig. 23). The highest sulfate levels are associated with the landfill. In the region just downgradient of Cell I, sulfate values decrease to nearly zero mg/l. Sulfate levels increase downgradient of Cell II to background concentrations in the wells at the southern boundary of the site.

Dissolved nitrogen in groundwater has become a major concern due to input from fertilizers, sewage disposal and feedlots (Freeze and Cherry, 1979, p.413; Behnke, 1975, p. 155). In natural waters, where oxidizing conditions predominate, nitrate (NO_3^-) is the principal form of dissolved nitrogen, although other nitrogen oxides, free nitrogen and nitrogen-hydrogen compounds also occur, particularly under less oxidizing conditions (Freeze and Cherry, 1979, p. 413). Nitrogen is an important nutrient to plant life and is transferred between biota, soil, water

Figure 23. Mean sulfate concentration (mg/L) in groundwater. Individual plus deep nested wells. Contour interval is 25 mg/L.


LANDFILL
N
150
125
100
75
50
25
CELL I
CELL II
75
CELL III
75
0 100Ft.
0 25M.

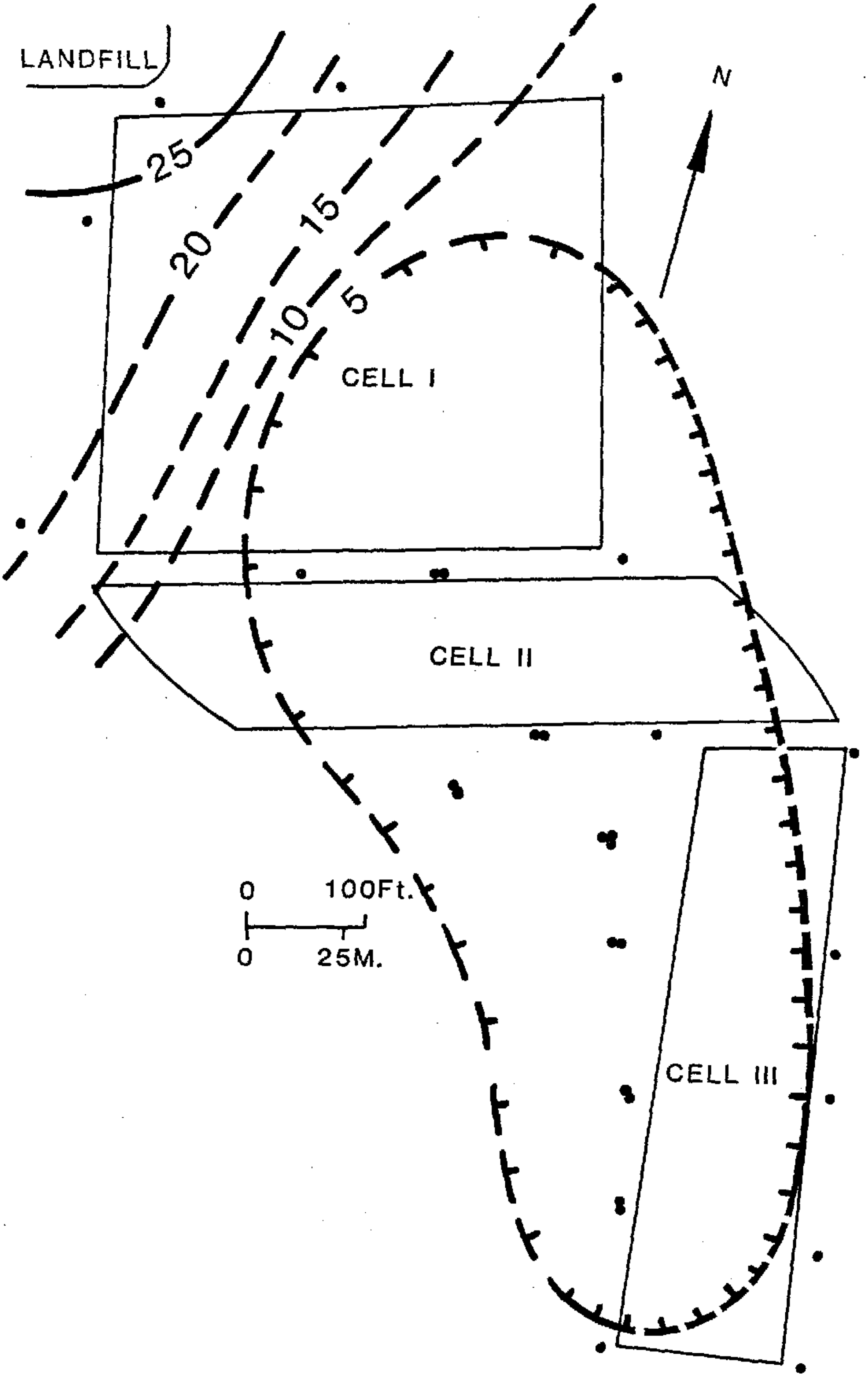
and the atmosphere.

Nitrate commonly undergoes denitrification in the subsurface, being reduced to gaseous nitrogen oxides or nitrogen (N_2) in both aerobic and anaerobic environments (Kaspar et al., 1981, p. 878; Freeze and Cherry, 1979, p.414). Nitrate is stable in groundwater which contains dissolved oxygen, and is highly mobile because it does not interact with the matrix materials. Thus, nitrate is transported at approximately the average groundwater velocity. Nitrate concentrations commonly found in groundwater are not limited by solubility constraints (Freeze and Cherry, 1979, p. 413); thus, high nitrate concentrations in drinking water are a concern. A nitrate concentration of greater than 10 mg/L reported as N is considered dangerous, particularly to infants (US EPA, 1975).

At the McVille site, wells upgradient of the lagoon contain nitrate concentrations (reported as N) two to three times greater than background levels (Fig. 24). The probable source of this nitrate is the landfill. Although it cannot be verified, disposal of agricultural chemicals in the landfill is suspected to be the source of this input, because McVille is an agricultural community. Waste-water nitrate concentrations are very low and the nitrate concentrations downgradient of the lagoon remain low to the southeastern edge of the site.

High ammonium (NH_4^+) concentrations in groundwater are

Figure 24. Mean nitrate concentration (mg/l) in groundwater. Individual plus deep nested wells. Contour interval is 5 mg/L.


LANDFILL
N
25
20
15
10
5
CELL I
CELL II
CELL III
0 100Ft.
0 25M.

associated with sewage disposal (Behnke, 1975, p. 162). Ammonium as a contaminant is of concern because of the ability of this species to oxidize to nitrate (LeBlanc, 1984 p. 18). The ammonium cation may be attenuated by cation exchange. Wells located around the borders of the McVille site display low ammonium concentrations of less than 1 mg/l (Fig. 25). Significant ammonium concentrations are present in the lagoon. An elongate plume of elevated ammonium levels trends northwest-southeast in the center of the site, with concentrations ranging from 2 to 44 mg/l.

The bicarbonate ion (HCO_3^-) in groundwater normally is the result of carbonate mineral dissolution and soil gas input. Carbon dioxide from soil gas input converts to bicarbonate in the pH range of most natural waters by combining with hydroxide.

Background concentrations of bicarbonate are slightly lower than the waste water concentration (Fig. 26). All wells downgradient of Cell I, with the exception of well 9, have concentrations greater than the waste-water. The highest concentrations are located immediately downgradient of Cell I. Bicarbonate levels decrease downgradient to the region of wells 13 and 21, where the levels again increase.

Contaminant Transport

The input parameters used in this analysis are listed in Table 1. Accurate determination of input parameters aids in producing results which closely mimic observed concentrations. The mannner in which input parameters were

Figure 25. Mean ammonium concentration (mg/L) in groundwater. Individual plus deep nested wells. Contour interval is 10 mg/L.

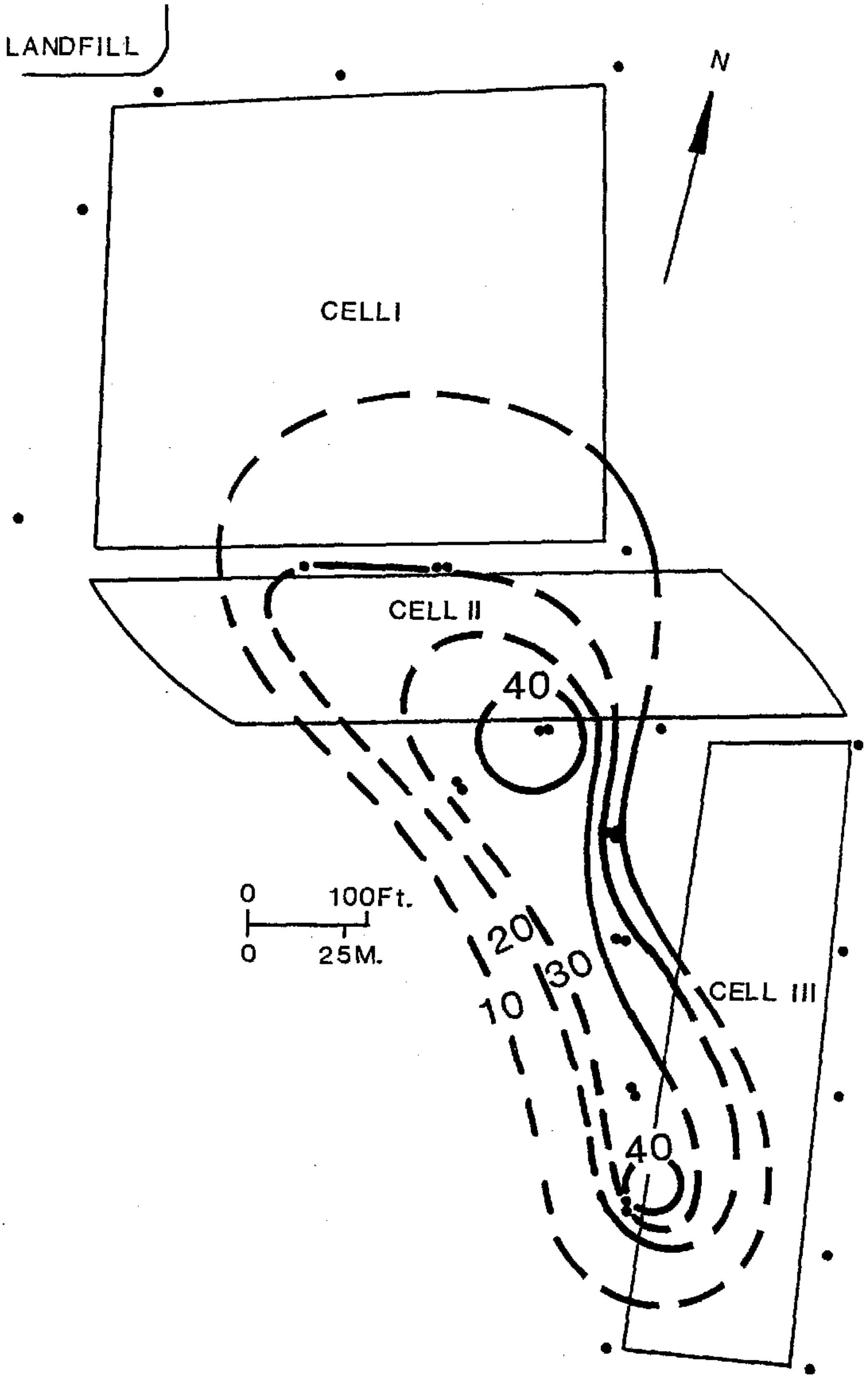

LANDFILL
N
CELL I
CELL II
CELL III
40
40
10
20
30
0 100Ft.
0 25M.

Figure 26. Mean bicarbonate concentration (mg/L) in groundwater. Individual plus deep nested wells. Contour interval is 100 mg/L.

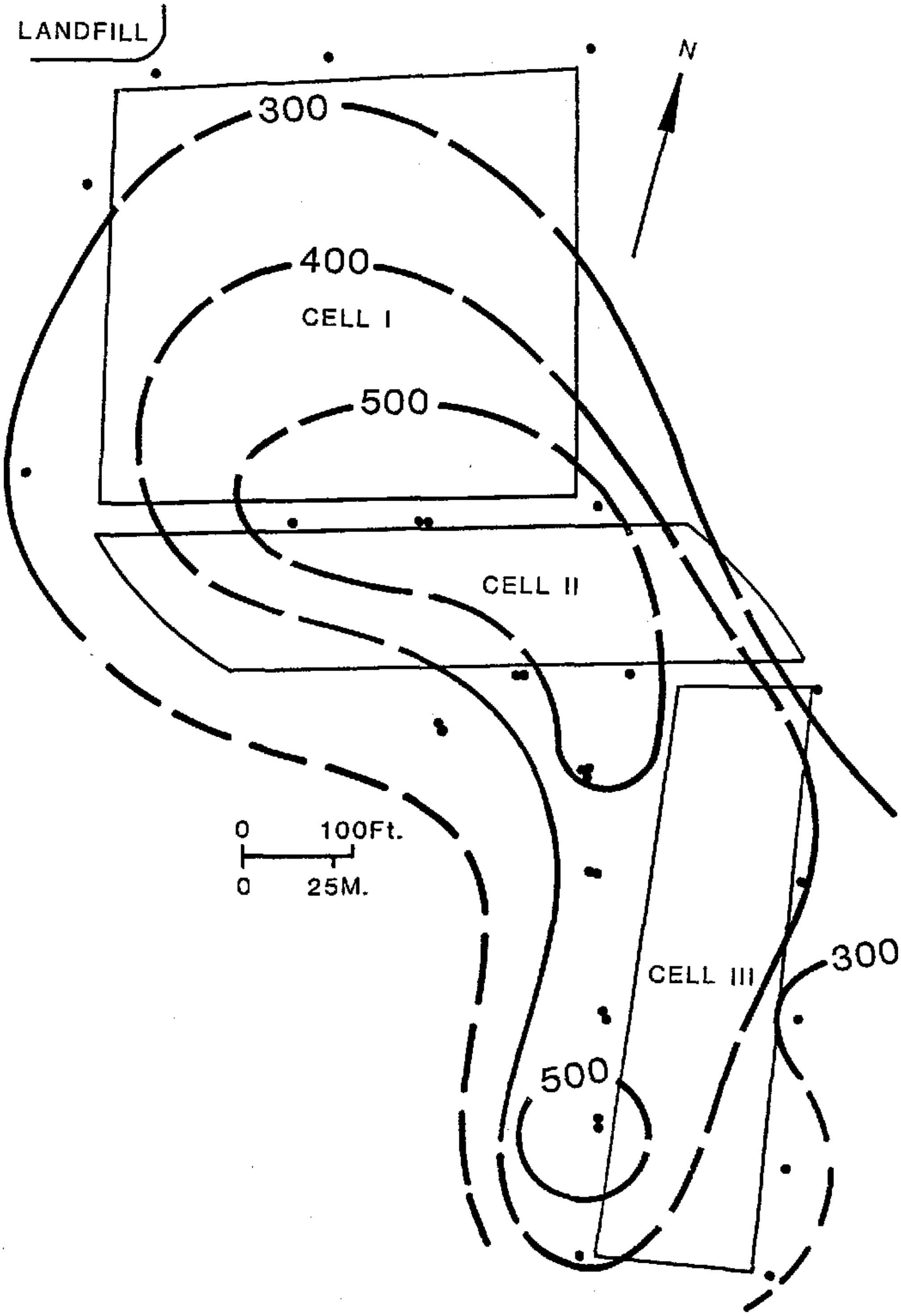

LANDFILL
N
300
400
500
CELL I
CELL II
CELL III
300
500
0 100Ft.
0 25M.

Table 1. Input Data For Contaminant Transport Simulation

Parameter	Best Fit 3D	Best Fit 2D	Range
Darcy velocity (m/day)	0.02	0.13	0.02-0.1
Effective porosity	0.3	0.3	0.3
Aquifer thickness (m)	-	10.0	10.00-25.0
Longitudinal Dispersion (m)	10.0	20.0-25.0	10.00-120.0
Lateral Dispersion (m)	5.0	10.0	5.00-10.0
Vertical Dispersion (m)	5.0-6.0	-	3.50-10.0
Retardation factor	1.0	1.0	1.0
Point sources	10.0	10.0	10.0
Source strength	5.0	5.0	5.0

determined and varied during sensitivity tests is discussed below.

The Darcy velocity was estimated from data obtained during the previous study at the McVille site (Brown, 1983). The velocity was initially estimated to be 0.02 m/d based on hydraulic conductivity values obtained from grain-size distribution and slug tests. The Darcy velocity was then calculated. The estimated velocity was assumed to be a minimum value of the actual average linear velocity for the aquifer, because of the influence of macropore flow. For the 2D case, the velocity was varied between 0.02 and 1.0 m/d, with the best fit obtained using 0.13 m/d. For the 3D case, the velocity was varied between 0.02 and 0.1 m/d, with 0.02 m/d achieving the best match. Velocity values greater than the value of the best match yielded simulated concentrations too low to correspond to field results, while lower velocity values resulted in simulated concentrations greater than measured values.

The effective porosity was input as 0.3, a common estimate for fluvial sand and gravel sediments.

The aquifer thickness parameter is used only in the WMPLUME program and was input at 10 meters, because this is the depth of the deepest well. A run of the program using an aquifer thickness of 25 meters resulted in concentrations much lower than actual. Sensitivity analysis was not pursued further because WMPLUME is written for a fully penetrating injection well, which does not accurately represent the introduction of contaminants at the site.

Contaminant transport models are useful to estimate parameters that are difficult to measure in the field, such as dispersivity. Longitudinal dispersivity was initially input as 20 meters. Selection of this value was based on a table of dispersivity values for different substrates listed in the text accompanying the computer package (Beljin, 1985, p. 163). The longitudinal dispersivity resulting in the best fit was refined by calibration. For the 2D program, dispersivity was input in the range of 15 to 35 meters, with the range of 20 to 25 producing reasonable matches. For the 3D program dispersivity values ranging from 10 to 120 meters were used with 10 meters giving an acceptable match. Dispersivity values greater than those in the acceptable range result in concentrations much lower than those seen in field data, while lower dispersivity values produce higher concentrations than measured.

Lateral dispersivity was initially assumed to be at least half of the longitudinal dispersivity and was input as 10 meters. This parameter was varied from 5 to 10 meters for both models, with 10 meters resulting in the best match for the 2D model and 5 meters for the 3D model.

For the PLUME3D model, vertical dispersivity was initially input at 10 meters, and tested between 3.5 and 10 meters. A value of 5 to 6 meters results in the best fit.

The retardation factor was set equal to one, because chloride is a nonretarded (conservative) species.

To obtain as uniform a distribution of infiltrant in the region of Cells I and II as possible, the maximum number of point sources (10) was used. The location of these point sources was then distributed over the area covered by the two operating cells.

Source strength proved to be the least quantitatively determined input parameter. Source strength was estimated by computing a yearly water budget for the cells. The water budget was not quantitaively determined, but was estimated using several assumptions obtained from similar studies. The first assumption was that in the duration of a year there is no net change in the volume of waste-water in Cell I. Next, waste-water input was estimated at an average of 416 litres/capita/day (Hickok et al., 1978), resulting in 91,187,826 litres/year, for a town of 600 people. Discharge into Cell II was estimated by an assumed loss of 1 meter in the elevation of the waste-water in Cell I per discharge. This volume of water removed from Cell I was computed for three discharges per year. All of the waste-water discharged into Cell II was assumed to be input to the aquifer and distributed over three point sources. The remaining waste-water volume in Cell I was reduced further by arbitrarily estimating a loss of 0.254 cm/d over the area of Cell I, to accommodate for the amount of evaporation minus the amount of precipitation over 90 days during summer. The remaining volume of waste-water, 55,519,082 litres/year, was assumed to be seepage. Based on the mean waste-water concentration (250 mg/l chloride) and a daily seepage rate of 152,107 litres/day, the input to the aquifer is estimated to be 5.0 kg/day/well chloride for 7 injection wells in cell I. The transport was simulated for 25 years, the approximate duration that the lagoon has been used.

The grid was plotted to place a node as close to the well locations as possible and yet use relatively few nodes to decrease the program run time. (Fig. 27). The background wells were placed along the same flow path, and the grid aligned in a northwest-southeast direction to allow for a slight curvature in the flow path. Variations in grid spacing did not seem to affect results.

The results of the simulation yielding the best fit as indicated by the calculated chloride minus the observed concentration are plotted in figure 28.

Mineral Equilibria

Water chemistry data for six wells sampled on 7/10/85 was evaluated using WATEQF. The wells selected are located along cross-section X-X' (Fig. 5). The mineral phases determined to be saturated for each analyses are displayed in Table 2. Only those phases which resulted in a positive log (IAP/KT) are included. The phases are generally listed in descending order of log (IAP/KT).

Water chemistry for wells 4, 8 and 14, was modelled a

Figure 27. Grid used in contaminant transport simulation.

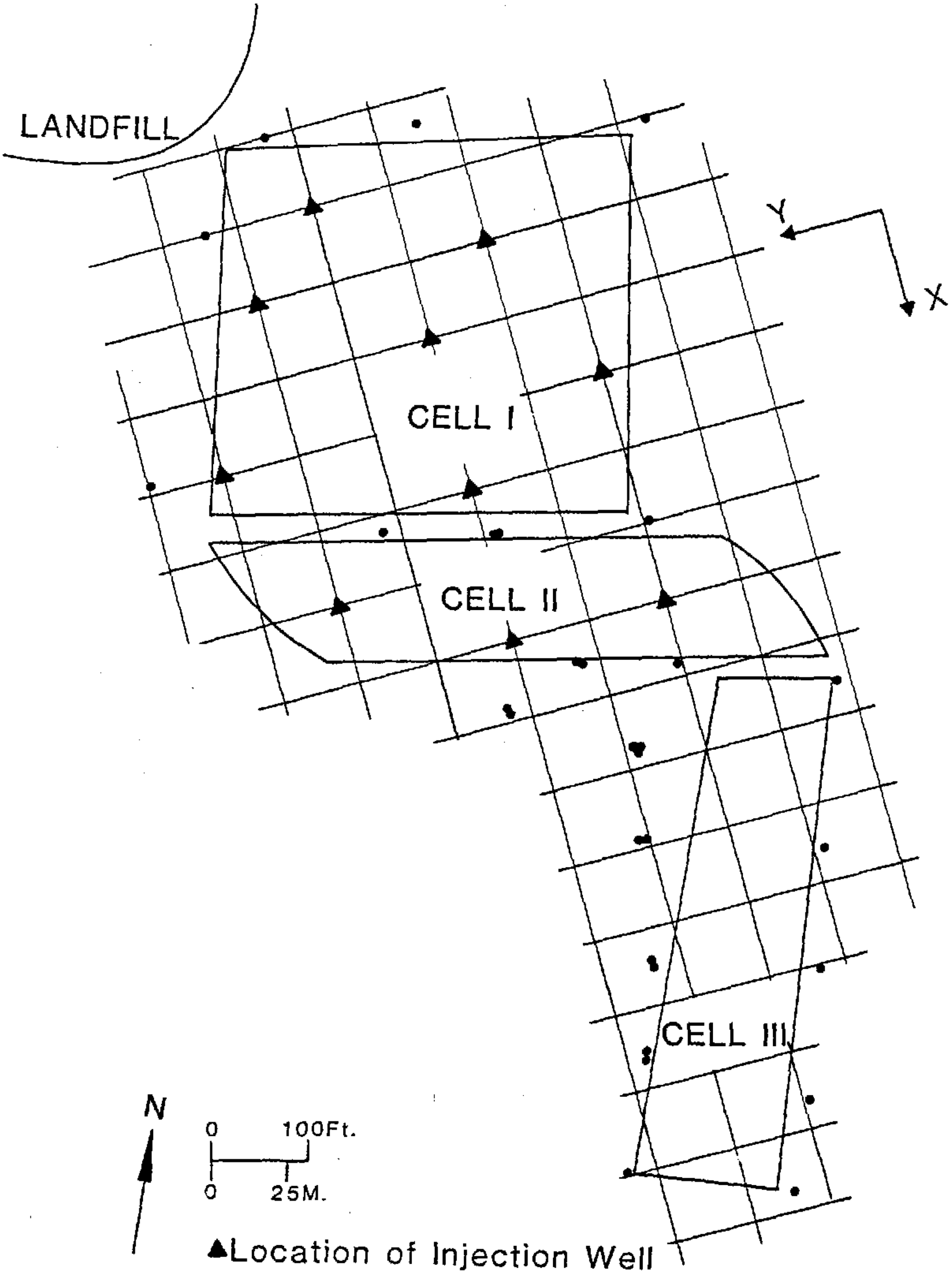

LANDFILL
Y
X
CELL I
CELL II
CELL III
N
0
100Ft.
0
25M.
▲Location of Injection Well

Figure 28. Results of chloride transport simulation. Simulated minus measured mean chloride concentration (mg/L) in groundwater.

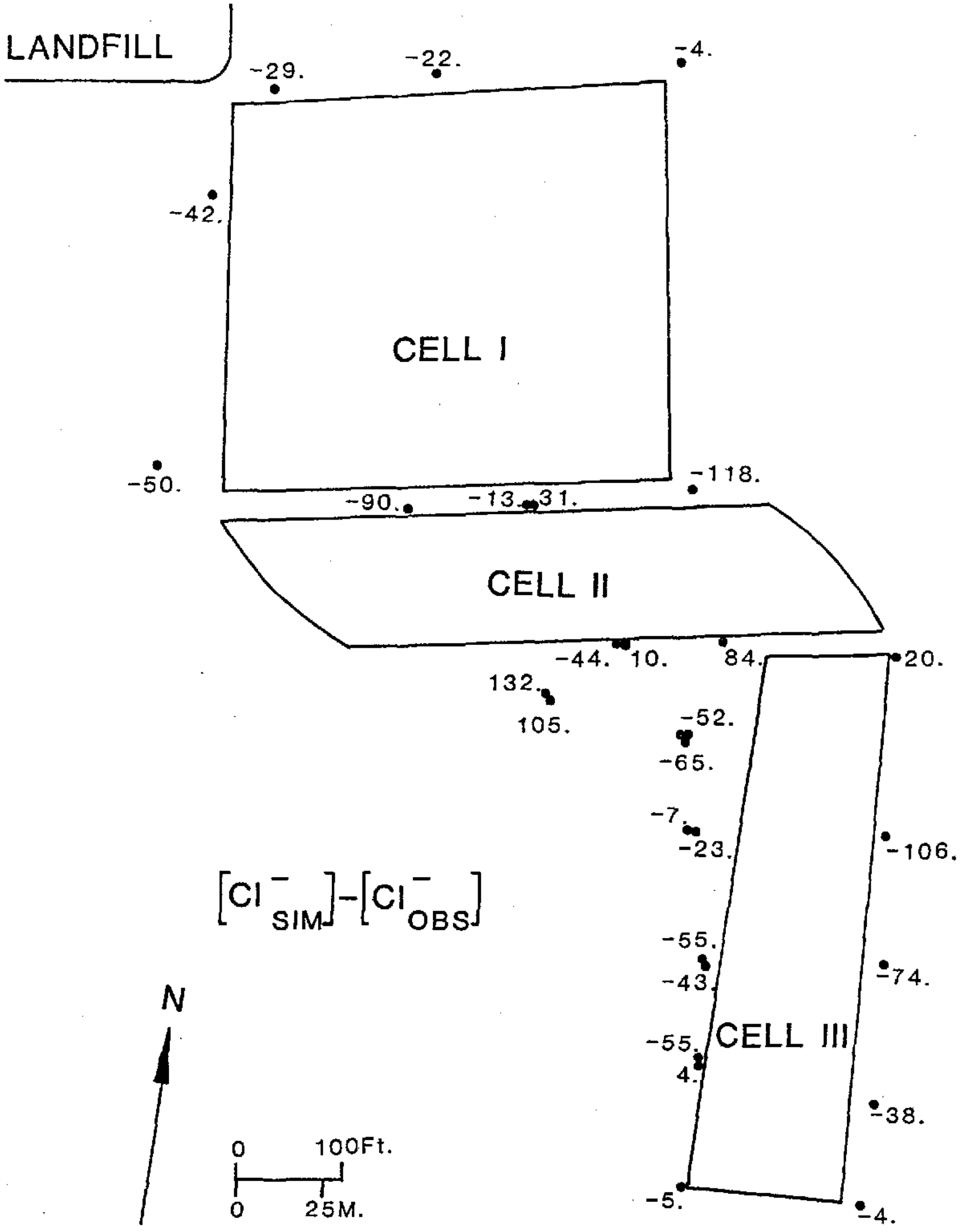

LANDFILL
CELL I
CELL II
CELL III
-29.
-22.
-4.
-42.
-50.
-118.
-90.
-13.
31.
-44.
10.
84.
20.
132.
105.
-52.
-65.
-7.
-23.
-106.
-55.
-43.
-74.
-55.
4.
-38.
-5.
-4.
[Cl$^-_{SIM}$]-[Cl$^-_{OBS}$]
N
0
100Ft.
0
25M.

TABLE 2 - Results of mineral equilibria modeling

Phase	#4	#4a*	#7	#14	#14a*	#27	#8	#8a@	#19	#13
Chalcocite	23.99		19.46	19.98	20.37	20.37	20.99	21.01	14.96	17.14
Hematite	11.90	5.59	10.90	13.44	6.99	2.98	11.36	1.71	13.96	15.15
Magnetite	13.30	7.03	11.99	15.28	9.03	0.67	12.85	3.20	11.36	13.96
$CuFe_2O_4$	6.45		2.86	6.55			4.06		8.61	10.64
$CuFeO_2$	12.42		9.50	11.40	8.26	5.99	10.64	5.82	8.47	10.75
Maghemite	2.81		1.72	4.26			2.18		4.80	5.97
Goethite	3.19	0.03	2.69	3.96	0.73		2.92		4.23	4.81
Jarosite				0.81					2.87	2.81
$Fe(OH)_3$	0.35			1.13			0.09		1.40	1.98
$MnHPO_4$	2.96	2.96	2.73	1.93	1.97	1.34	1.42	1.42	0.72	0.73
Natrojarosite									0.65	0.31
Fluoroapatite	11.31	11.36	8.72	5.92	6.35	2.47	6.15	6.15	0.52	5.70
Witherite	1.88	2.14	1.54	1.39	1.51	0.82	1.73	1.77	0.51	1.69
Barite				0.27	0.27	0.78	0.05	0.09	0.79	0.36
Siderite	0.39	0.42	0.30	0.73	0.85		0.61	0.61		
Vivianite	2.09	2.10	1.07	0.41	0.70		0.08	0.08		
Rhodochrosite				0.17	0.28					
Whitlockite	2.20	2.25	0.44							
$Ba_3(PO_4)_3$	1.35	2.17								
Native Cu	0.19				1.61			3.88		
Hydroxyapatite	0.24	0.12								
Fluorite			0.09							

* Input Eh = - 0.10
@ Input Eh = - 0.20

second time using an estimated redox potential which is lower than the measured value. This was attempted because the true redox potential is thought to be lower than the measured redox value.

A total of 22 phases were considered to be saturated in at least one well. Five phases: hematite (Fe_2O_3), magnetite (Fe_3O_4), MnHPO , fluorapatite ($Ca_5(PO_4)_3F$), and witherite ($BaCO_3$), were determined to be saturated in all 10 water samples.

Statistical Applications

The results obtained from the multiple regression are displayed in Table 2. The correlation coefficient ranges from +1 to -1, with +1 or -1 indicating a perfect positive or negative correlation, respectively. Zero indicates a total lack of correlation.

The pair chloride versus distance downgradient of Cell I produced the highest correlation coefficient and goodness-of-fit. Iron and arsenic and TDS and downgradient distance also correlate well and have a high goodness-of-fit. A moderate correlation coefficient and goodness-of-fit resulted from nitrate versus ammonium, DOC versus distance downgradient, DOC against pe, and iron against distance downgradient. Low statistical values were obtained for the pairs: DOC versus nitrate, DOC versus ammonium, and manganese versus arsenic.

Table 3. Results of statistical tests for selected parameters.

Parameters	Correlation Coefficient	Goodness-of-fit
chloride-distance	-0.847	71.68%
TDS-distance	-0.804	64.56%
Iron-Arsenic	0.712	50.71%
DOC-distance	-0.618	38.24%
DOC-pe	-0.581	33.76%
Iron-distance	-0.519	26.89%
Ammonium-nitrate	-0.506	25.56%
DOC-nitrate	-0.345	11.89%
DOC-ammonium	0.288	8.28%
Manganese-arsenic	0.263	6.89%

DISCUSSION

General Inorganic Parameters, Trace Elements and Organic Constituents

Hydrodynamic dispersion during mixing of contaminated and uncontaminated waters is the dominant attenuation mechanism influencing the concentrations of chloride, TDS and specific conductance. Dispersion has both macroscopic and microscopic components (Anderson, 1984, p. 38). Macroscopic dispersion is mixing due to large scale subsurface heterogeneities. Microscopic dispersion includes both mechanical dispersion and molecular diffusion (Freeze and Cherry, 1979, p. 75). Mechanical dispersion occurs because of velocity variations within pore spaces and from one pore space to another (Anderson, 1984, p. 37). Molecular diffusion results from the thermal-kinetic energy of solute particles which travel in the direction of concentration gradients (Freeze and Cherry, 1979, p.103). If heterogeneities exist in the aquifer matrix, macroscopic dispersion dominates. In contrast, for a homogeneous medium at high velocity, mechanical dispersion dominates, whereas at low velocity molecular diffusion causes mixing.

Groundwater concentrations of chloride, TDS and conductivity in wells of group 2, which are equal to or greater than lagoon concentrations, point to significant seepage and infiltration from Cells I and II, respectively. These parameters decrease steadily downgradient from Cell II, suggesting spreading and mixing (dispersion) of high concentration water with low concentration water. The plume shape for these parameters is contoured in a subelliptical shape; however, limitations on placement of wells lateral to the flow path hinder verification of this pattern. Whereas the elliptical plume shape suggests Fickian behavior in response to dispersion, this shape may actually be due to artistic impression. Field studies have indicated that dispersion is non-Fickian near the contaminant source (less than 10's to 100's of metres) (Anderson, 1984, p. 44). Given the proximity of monitoring wells to the contaminant source at the McVille site, a plume would not be expected to have a Fickian distribution.

All forms of phosphate are consumed by microorganisms and algae as a nutrient within the sewage lagoon. However, phosphate concentrations in the aquifer greater than background levels imply that influent waste-water phosphate concentrations exceed biological demand or else seepage rate exceeds rate of uptake. Phosphate levels decrease rapidly downgradient from Cell I in response to several possible attenuation mechanisms including; bacterial uptake (Ceazan et al., 1984, p.131), adsorption on metal oxides and precipitation as apatite or low solubility iron and aluminum compounds (LeBlanc, 1984, p.16) (Ceazan et al., 1984, p. 131).

Calcium and magnesium levels increase slightly above the waste-water concentration a short distance downgradient of Cells I and II. This is presumably due to displacement of these cations from colloidal surfaces, principally clay minerals, as cations from the waste-water are transported through the subsurface. Magnesium and calcium concentrations decrease in the region of wells 13, 19, 20 and 21, as some adsorption occurs. Farther downgradient, calcium and magnesium levels increase, probably in an ion exchange reaction with ammonium ions, which are more concentrated in this region. Ammonium tends to be adsorbed readily and displace other cations (Behnke, 1975, p.160; Kehew et al., 1983, p. 29). Sodium, which acts essentially as a conservative ion, decreases in concentration steadily downgradient of Cell I.

During this study, the concentrations of calcium were generally lower than concentrations measured in the previous study (with the exception wells 3, 4 and 5). The largest decrease in calcium concentration (ranging from 17 to 48 mg/L) was in the wells of group 4, where calcium is suspected of being displaced by cation exchange. The reason for lower calcium levels in 1985 is not clear; perhaps the aquifer materials are being depleted exchangeable calcium. In contrast to calcium, magnesium concentrations during this study were generally slightly higher (ranging from 2 to 13 mg/L) than those measured in 1982. Again, an explanation of this occurrence is not readily apparent. The largest increase in magnesium is in the region of wells 6 and 8, where calcium decreased. During cation exchange for ammonium, magnesium may be more readily displaced from exchange sites or more abundant, than calcium.

Wells 6, 8, 13, 16, 17, 20 and 21 contain potassium concentrations higher than the waste water concentration during this study. This is most likely due to displacement from colloidal surfaces during cation exchange (Freeze and Cherry, 1979, p. 133). Farther downgradient, the consistent decline in potassium levels in the region of Cell III, along with the weak affinity for adsorption characteristic of most monovalent cations, supports attenuation of sodium and potassium principally due to dispersion (Freeze and Cherry, 1979, p. 133; Kehew et al., 1982, p. 27). Also, the mean potassium concentration displayed by wells of group 4 are up to 27 mg/L lower than concentrations measured on July 27, 1982. The other wells at the site have potassium concentrations which are less than 5 mg/L lower than potassium levels in 1982.

The distribution of barium appears to be influenced by seepage from the sewage lagoon. Barium is concentrated in the aquifer immediately downgradient of Cell I. Elevated barium levels in the same region of the aquifer as low sulfate levels possibly may be caused by release of barium into solution, as sulfate is reduced, due to dissolution of barite. Although it has not been reported in the literature, this mechanism could account for barium levels greater than waste-water levels in the vicinity of group 3 wells. The zone of highest barium concentrations ends beneath Cell II. Barium in groundwater is controlled by mineral solubility equilibria with barite (Robertson, 1984, p. 100).

Barium is preferentially adsorbed relative to calcium and magnesium; this may account for lowering of barium concentrations downgradient of Cell II (Freeze and Cherry, 1979, p.133). However, barium levels are as high as lagoon waste-water levels in the wells adjacent to Cell III. This does not support attenuation of barium due to preferential adsorption, but suggests that dispersion and mineral saturation are the predominant controls on the barium distribution.

The cadmium levels in groundwater downgradient of Cell I are slightly higher than background levels. The difference is slight and the cause of this increase is not apparent. Possibly dissolution of iron and magnesium hydrous oxides could contribute cadmium to the groundwater; however, this has not been observed in similar research and cannot be verified for this study.

The distribution of copper is variable and also difficult to interpret. Copper levels beneath and immediately downgradient of Cell II are lower than upgradient and waste-water concentrations, suggesting that adsorption or precipitation of copper with sulfide is occurring.

Analysis for fourteen trace metals in groundwater contaminated by sewage lagoons was conducted by the EPA, including the four monitored during this study. The EPA obtained results similar to those determined for this study, with the exception of significantly higher copper levels. Most of the fourteen trace elements monitored were detected in the sludge layer, with many of them in high quantities, including Cr, Cu, Pb, Hg and Ag. The high levels of trace metals in the sludge layer suggests the ability and significance of adsorption by this material.

Analysis for organic carbon, chloride, ammonium, and nitrate conducted by the EPA produced results comparable to mean concentrations determined for this study. Total phenolics were determined, with the highest concentrations found in background well #2 and the waste-water. Phenols are a common industrial compound used in pesticides. The high background and waste-water total phenolics levels may be due to use of agricultural pesticides in the McVille area. Cyanide was also monitored, but not detected in any of the samples.

Parameters Affected by Redox Environment

A number of chemical parameters monitored during this study participate in microbiologically controlled oxidation-reduction reactions. Extension of anaerobic conditions from the lagoon bottom into the aquifer, along with abundant nutrients from lagoon seepage, promotes the growth of facultative and anaerobic microbes. The microbes, principally biofilm bacteria, adhere to solid surfaces and interact with groundwater as it flows by

(McCarty et al., 1984, p. 91). These bacteria, which are also present within the sewage lagoon and lagoon sediments, further lower the pe downgradient of Cells I and II through redox reactions. The presence of bacteria control speciation and the distribution of contaminants in wells of groups 3 and 4.

A steady decrease in DOC along the flow path is interpreted to be the result of its use as an electron donor in this anaerobic environment (Drever, 1982, p. 283). In an aerobic environment, O_2 accepts electrons and is reduced as carbon and other compounds are oxidized. Under conditions of depleted O_2 and available organic carbon, oxidized inorganic compounds serve as electron acceptors. During various biochemical redox reactions, O_2, Fe^{3+}, Mn^{4+}, SO_4^{2-}, and NO_3^- serve as electron acceptors, and are reduced in the process. These reactions can be represented by a generalized oxidation-reduction reaction for anaerobic environments (Figure 29). The DOC is used for cell synthesis, whereas inorganic compounds help to supply energy. Carbon dioxide, a product of DOC oxidation, is converted to bicarbonate at a pH of less than nine. Increased bicarbonate in the vicinity of Cell III supports the occurrence of this reaction. The distribution of the afore mentioned species can be explained in relation to qualitative redox levels measured at the site.

The distribution of sulfate at the site is controlled by the redox potential. Sulfate levels downgradient of

Figure 29. Schematic equation representing anaerobic decomposition of organic compounds taking place within the aquifer.

ANAEROBIC DECOMPOSITION

BACTERIA

+

$C_XH_YO_Z$

(electron donor)

+

$NO_3^-, SO_4^=, Fe^{+3}, Mn^{+4}$, etc.

(electron acceptor)

ENZYMES

➡

BACTERIA

(cell growth)

+

$NH_4^+, H_2S, Fe^{+2}, Mn^{+2}$, etc.

(reduced)

+

HCO_3^-

(oxidized)

+

ENERGY

Cell I are low (Fig. 23). In contrast, leachate from the landfill contains high sulfate levels, along with wastewater seepage from the lagoon. In general, the lowest sulfate concentrations are in the area of the lowest redox potentials; higher sulfate concentrations correspond to increasingly higher redox potentials. Thus, reduction of sulfate to sulfide is inferred (Kehew et al., 1983, p.27). The presence of soluble sulfide or odors due to sulfide vapor were not detected in any of the wells at the site. Attenuation of sulfide is most likely occurring through precipitation with soluble reduced metal cations. The slight increase of sulfate levels in wells of group 4 is probably due to landfill leachate flowing around the area of lowest redox potential to the area beneath Cell III.

Trends in the relative concentrations of the soluble species iron, arsenic, and manganese are comparable to one another. The elevated concentrations of these constituents near Cell II are interpreted to be a reflection of reduction and dissolution of solid iron and manganese phases, probably existing as hydrous oxide grain coatings (Drever, 1982, p. 293; Kehew et al., 1983, p.27). Thus, the reduced form of iron and manganese is liberated into solution. Arsenic may be released to solution in the same reaction because arsenic is commonly incorporated in iron oxides in trace quantities (Matisoff et al., 1982, p. 454). Since only total arsenic was analyzed and arsenic is soluble in more than one oxidation state, it is not certain whether arsenic is being reduced. Because the equilibrium redox potentials for the arsenic and iron reduction half reactions are nearly equal (pe = 0.285 and pe = 0.623, respectively; Matisoff et al., 1982, p. 453) and As^{4+} is more mobile than As^{5+}, it is likely that arsenic is being reduced.

The concentration of iron, arsenic, and manganese decreases abruptly in the wells beneath Cell III. Manganese and iron may be oxidized and reprecipitated as hydrous oxides beneath Cell III or with sulfide beneath Cell II. Arsenic is readily adsorbed by hydrous oxides and is thereby attenuated by this mechanism (Gulens et al., 1979, p. 81).

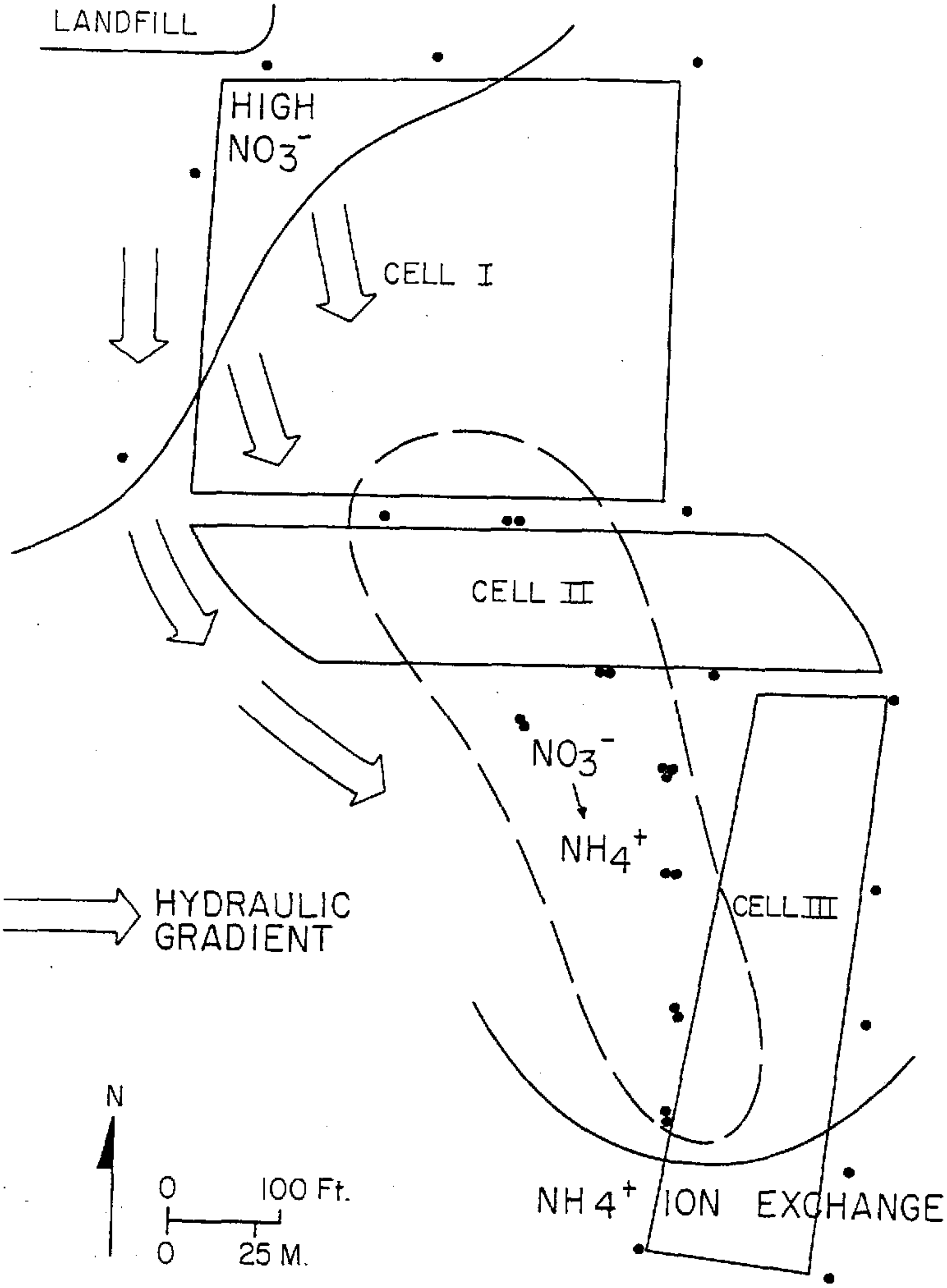
The decrease in nitrate concentration downgradient of the landfill implies reduction of nitrate. Nitrate is commonly reduced to nitrogenous gasses; however, because of sampling problems, these gasses were not monitored during this study. The contrasting distribution of nitrate and ammonium concentrations suggests reduction of nitrate directly to ammonium. The wells located around the entire site display low ammonium levels, whereas in an elongate plume trending northwest-southeast in the area downgradient of Cells I and II, ammonium levels rise above 20 mg/L to a maximum of 44 mg/L (as N). The lagoon contains ammonium well below the concentrations that could produce this plume.

In an anaerobic environment containing organic carbon, reduction of nitrate to ammonium occurs (Knowles, 1982, p. 48-49). Similarly, experimental work conducted by Kaspar et al. (1981) demonstrates the ability of digested sewage sludge to undergo significant dissimilatory nitrate reduction to ammonium. Dissimilatory reduction refers to reduction of a compound for its energy yield, without conversion of the compound to biomass. This process contrasts with assimilatory reduction, where the reduced compound is used for energy and is incorporated into the cell tissue. In Kaspar's study, 30 to 70 percent of the nitrate was reduced to ammonium, with higher ammonium production in fresher sludge samples (Kaspar et al., 1981, p. 882). Based on the results, Kaspar concluded that digested sludge is twice as likely to reduce nitrate to ammonium as it is to cause denitrification (Kaspar et al., 1981, p.884). Denitrification is the dissimilatory reduction of nitrate or nitrite to nitric oxide (NO) or nitrous oxide (N_2O)(Knowles, 1982, p. 43).

Prakash and Sadana (1972, p.21) found that nitrate and nitrite reductase formation was increased in anaerobic conditions, resembling dissimilatory enzymes from other bacteria. Reductase refer to enzymes that catalyze reduction. In the experiments of Prakash and Sadana (1972), nitrate was reduced to nitrite, then to ammonium in "nearly quantitative amounts", with no detection of gaseous nitrogen oxides. Anaerobic soils (sediments) were determined to enhance reduction of nitrate to ammonium in a nonassimilatory pathway (Buresh and Patrick, 1978, p. 913). During this reaction, nitrate was acted as a terminal electron acceptor for bacterial respiration. In related work (Caskey and Tiedje, 1979, p. 935), it was determined that dissimilatory nitrate reduction to ammonium occurs in carbon-rich anoxic soils. Ammonium in soils did not inhibit nitrate reduction to ammonium and the presence of organisms with dissimilatory capacities kinetically dominated nitrate reduction over assimilatory reduction (Caskey and Tiedje, 1979, p. 935). The presence of ammonium inhibits the assimilatory nitrate reduction function in both aerobic and anaerobic states (Van'T Riet et al., 1968, p.1462). When nitrate is the limiting factor, nitrate reduction is thermodynamically favored over denitrification (Caskey and Tiedje, 1979, p. 931).

The presumed manner in which high ammonium concentrations are produced in the region of wells 22 and 23 is illustrated in Figure 30. Some ammonium is input as seepage from Cells I and II, while the majority of ammonium results from nitrate reduction. High nitrate waters from the landfill flow beneath the western edge of Cells I and II. The highland along the southwest border of the site diverts flow to a southeast direction, resulting in mixing of high nitrate water with low pe water in the area just downgradient of Cell II. Nitrate is subsequently reduced to ammonium, producing the high concentration ammonium plume. The quantity of nitrate input, plus the ammonium

Figure 30. Production of high ammonium concentrations. Illustration of nitrate input and flow path resulting in high ammonium concentrations.


LANDFILL
HIGH
NO3⁻
CELL I
CELL II
NO3⁻
NH4⁺
CELL III
HYDRAULIC
GRADIENT
N
0
100 Ft.
0
25 M.
NH4⁺ ION EXCHANGE

input as seepage from Cell I, produces an amount which is nearly quantitatively equal to the ammonium concentrations in wells of group 4.

The 1984 study at Cape Cod indicated similar results. Ammonia concentrations in several wells were higher than the sewage effluent concentration (Smith and Duff, 1984, p. 159). Furthermore, nitrate concentrations decrease to near zero in the area of elevated ammonia. This occurs with the simultaneous depletion of DOC. Experiments on the denitrification potential indicate that the bacterial activity is carbon limited (Smith and Duff, 1984, p. 172). Although experiments to measure dissimilatory reduction of nitrate to ammonia were not conducted, this process was considered to be as important a contribution to the nitrate sink as denitrification (Smith and Duff, 1984, p. 171).

At the downgradient edge of the McVille site, ammonium is apparently being attenuated by ion exchange. It appears that calcium and magnesium are being displaced from colloids by ammonium ions. This is due to the tendency of ammonium to displace other cations (Behnke, 1975, p. 160; Kehew et al., 1983, p. 29). Calcium and magnesium levels increase in this area.

The rate of advancement of the ammonium adsorption front is displayed in table 4. The values tabled were calculated using (Drever, 1983),

$$v = v / (1 + (\rho/n)Kd)$$

where;

v = velocity of the adsorbed parameter

v = average linear groundwater velocity

ρ = bulk density of the sediment

n = porosity

Kd = the distribution coefficient of the solute.

The velocities used were those determined in the contaminant transport modelling. The bulk density and porosity of the materials were obtained from published values for sand and gravel. The distribution cofficient represents the paritioning of an ion between liquids and solids, determined from,

$$Kd = dS/dC$$

where:

S = the mass of the solute adsorbed per unit bulk dry mass of the medium, and

C = the solute concentration.

For ammonium, the distribution coefficient was measured to range from 2 to 10 in sandstone aquifers (Drever, 1983).

The values obtained ranged from 1.3 to 8.1% of the average groundwater velocity. This is equivalent to the range of 0.0013 m/d to 0.0081 m/d. The values cannot be compared to data obtained during the 1983 study because wells 22 and 23 were not installed until 1985. The front appears to be located between wells 22, 23 and well 12.

Field measured pe using a platinum electrode did not detect redox couples involving $NO_3^- - N_2 - NH_4^+$. Thus, plotted pe-pH diagrams are of little use in quantitative

Table 4. Rate of advancement of the ammonium adsorption front. Value expressed as percent of the average linear groundwater velocity.

For v = 0.02 m/d

		Kd	
		2	10
ρ	1.7	8.0	1.5
	2.3	6.0	1.3

For v = 0.10 m/d

		Kd	
		2	10
ρ	1.7	8.1	1.7
	2.3	6.1	1.3

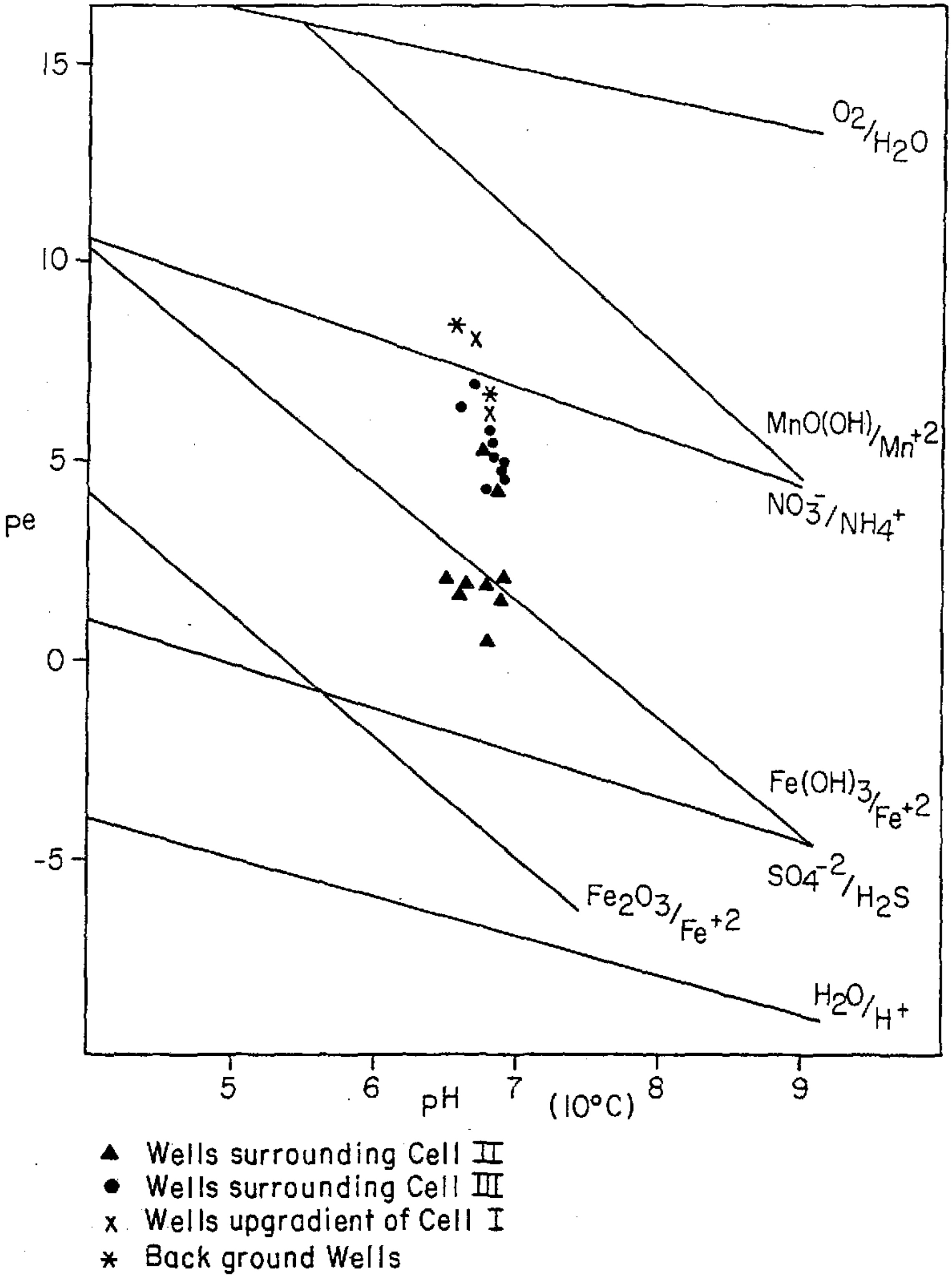
interpretation of the redox environment of these couples.

Comparison of the lateral and vertical distribution of certain species relative to the approximate redox potential provides an indication of the potential for the species to occur in redox reactions. It becomes desirable to know the redox potential of the system because the toxicity and solubility of constituents varies with the valence state. By comparing the relative concentrations of species within a redox couple, one can infer possible redox reactions.

Redox relationships can be interpreted using pe-pH diagrams. A plot of measured pe and pH, with superimposed equilibrium redox reaction lines aids in determining qualitative redox environments (Fig. 31). The reaction lines were plotted based on half reactions for the given species. Half reactions were determined for a system at ten degrees Celsius, assuming activity is equal to molality, and activity for solid phases equals unity. The molality for aqueous species used to determine the location of the equilibrium reduction lines was calculated from measured concentrations.

The equilibrium reaction line for amorphous ferric hydroxide is the only reaction line which separates wells containing the oxidized species from wells containing the reduced species (Fig. 31). The generally poor correspondence of measured pe and suspected reaction lines further illustrates the quantitative limitations of using

Figure 31. pe-pH plot for a 10 degrees Celcius system. Solid lines represent equilibrium reaction lines for specified redox couple.



15
10
5
0
-5
pe
O2/H2O
MnO(OH)/Mn+2
NO3-/NH4+
Fe(OH)3/Fe+2
SO4-2/H2S
Fe2O3/Fe+2
H2O/H+
5
6
7
8
9
pH (10°C)
▲ Wells surrounding Cell II
● Wells surrounding Cell III
x Wells upgradient of Cell I
* Back ground Wells

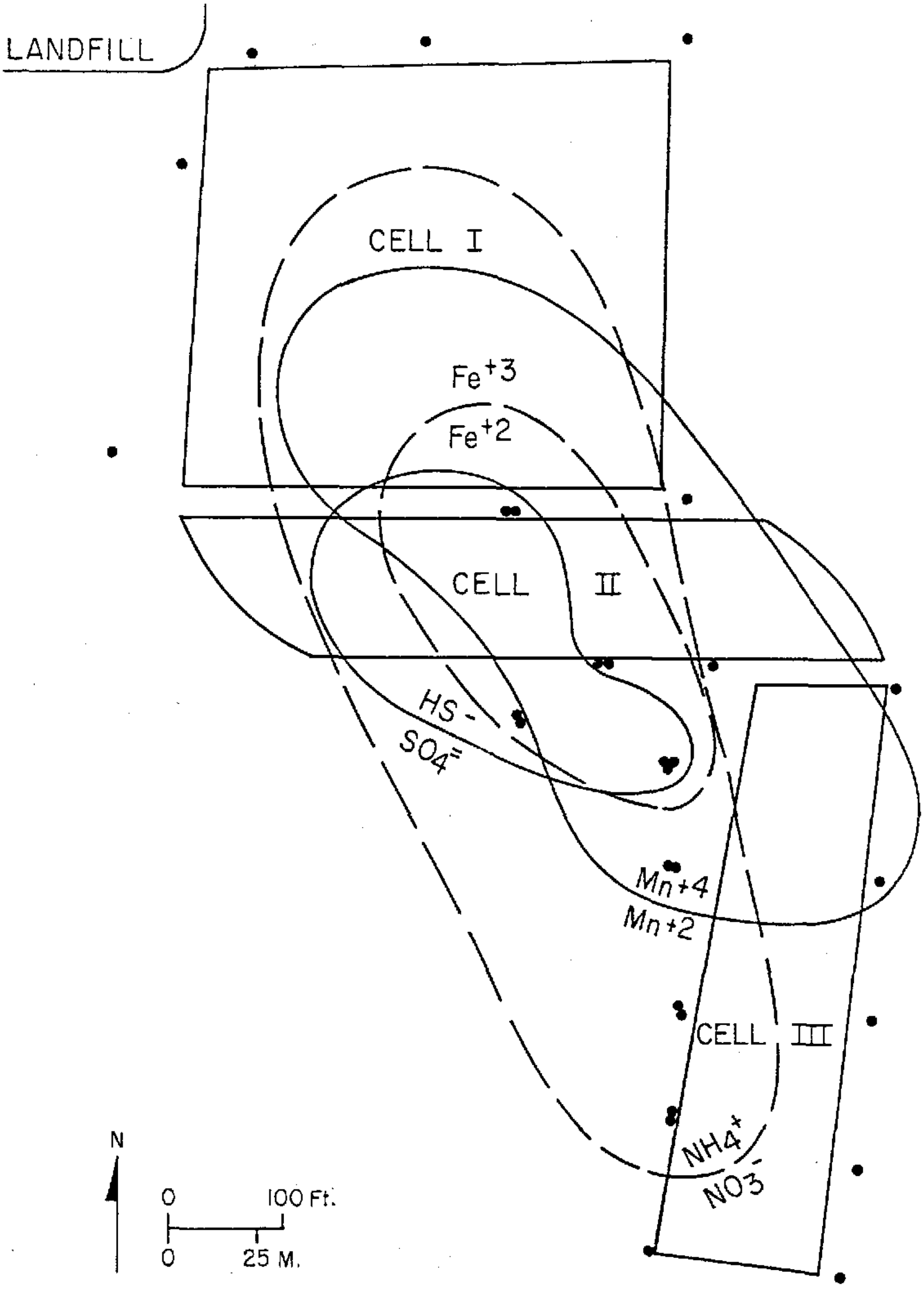
field measured redox potentials. For example, there is evidence for sulfate reduction, yet no measured wells plot near this reduction line. Lindberg and Runnels (1984, p. 925) demonstrate the pervasiveness of disequilibrium within redox couples in groundwater. Also, as in this study, they demonstrated poor agreement between field measured redox potentials and the redox potential calculated from ionic concentrations. Reasons for inaccurate field measurement of redox couples have been cited earlier (p. 72,73). The equilibrium reduction reaction line for arsenic was not included because of a lack of information on relative amounts of arsenic species.

The pe-pH diagram is useful for displaying a redox sequence known to occur in natural waters (Drever, 1982, p. 293; Champ et al. 1979, p. 13). Beginning with oxidizing conditions and proceeding to reducing conditions, the reduction of the inorganic compounds occur in a systematic progression: O_2, NO_3^-, Mn^{4+}, Fe^{3+}, SO_4^{2-}, and HCO_3^-. In natural waters, oxygen is the compund being reduced under aerobic conditions. As the oxygen is depleted, and as conditions become progressively more anaerobic, the compound next in succession is reduced. Reduction of this compound occurs at nearly constant pe until the compound is used up, effectively buffering the pe of the system. This pattern continues as each species in the sequence is reduced. The pe decreases due to depletion of oxidized species and because of a low Gibb's free energy yield from the redox reactions (Drever, 1982, p. 283). Production of hydrogen sulfide, methane and hydrogen gas mark the lowest range of redox potential observed in natural waters.

The sequence can also occur in reverse, where reduced species are oxidized in a systematic progression (Champ et al, 1979, p. 13). It has noted that on some occasions that there is some overlap in the sequence during the transition of reduction or oxidation of specific compounds (Champ et al., 1979, p. 13).

A similar sequence to that proposed by Champ et al. (1979, p. 13) and Drever (1982, p. 283) is seen at the McVille site. Zones where a specific redox reaction occurs are delineated in Figure 32. At the McVille site the sequence of redox zones is best visualized by proceeding from the most reducing conditions beneath Cell II, to more oxidizing conditions moving downgradient. Figure 32 indicates the following sequence of redox zones moving downgradient; SO_4^{2-}-HS^-, Fe^{3+}-Fe^{2+}, Mn^{4+}-Mn^{2+}, and NO_3^--NH_4^+. These reactions occur in approximately the same relative order determined by Drever (1982, p. 283) and Champ et al. (1979, p. 13). Additional support for the reduction of these compounds is indicated by the steady decrease in DOC moving downgradient and the corresponding increase in bicarbonate. Thus, inference of a similar biochemcial mechanism controlling the hydrogeochemistry of these parameters can be made.

Figure 32. Location of reduction zones for various redox couples. Lines represent the transition zone from the reduced species to the oxidized species.


LANDFILL
CELL I
Fe^{+3}
Fe^{+2}
CELL II
HS^-
$SO_4^=$
Mn^{+4}
Mn^{+2}
CELL III
NH_4^+
NO_3^-
N
0
100 Ft.
0
25 M.

Contaminant Transport

The contaminant transport simulation allowed approximation of parameters that were not abtainable using the present monitoring network. Extension of the grid beyond the downgradient edge of the site determined that the chloride plume reached background concentrations of 10 mg/l at a distance of 820 metres away from the grid origin.

The 3D program displays a lower velocity and dispersivity value for the best match than the 2D program. Since the 3D program accounts for vertical flow it is assumed that it is a better representation of field hydraulic parameters than is the 2D program. The 2D program is additionally handicapped in that contaminant is input over the entire thickness of the aquifer, effectively introducing more contaminant than actually occurs. A greater amount of solute would require higher velocity and dispersivity values to result in concentrations similar to field values.

Previous studies of advection-dispersion using field data and simulation models have indicated that at short distances from the contaminant source, flow is governed by macroscopic hydraulic conductivity variations and that dispersivity has not had adequate time and distance to develop Fickian behavior (Anderson, 1984). This could be why field data does not completely match simulation results for the McVille study. The use of injection wells does not give a uniform distribution of contaminant introduction and greatly influences the concentrations at nodes near injection wells. Simulation using injection wells, in contrast to injecting over a horizontal area, affects advection-dispersion, thus hampering accurate simulation of the McVille site. Simulation of lateral dispersivity is probably the parameter most influenced by use of injection wells.

An additional discrepancy in the match of field and simulated concentrations occurs at the downgradient edge of the site (Fig. 7). In this region chloride concentrations decrease 80 mg/l over a distance of 40 metres, which could not be duplicated in the simulation. The lowered concentrations could be due to: a decrease in grain size, curving of flow paths along the western margin resulting mixing of low chloride waters, or a sinking of the chloride plume as suggested by higher concentrations in the deeper well of most nests.

A problem in this simulation is that the results, though valuable, are a non-unique solution. Although the programs were able to match field results reasonably well, one could have conceivably obtained similar accuracy by varying the velocity, dispersivity and source strength. A study could obtain reliable quantitative information concerning source strength by monitoring the quantity of waste water in Cell I influent and effluent.

The velocity and dispersivity values obtained from the simulation fall within the range expected for this type of aquifer matrix. However, they are on the lower end of the expected range and would change with further refinements in data quantifying the source strength. Sensitivity analysis seems to indicate that simulated concentrations respond more to variations in Darcy velocity than to variations in dispersivity.

Mineral Equilibria

Results obtained using WATEQF provide information of mixed reliability. Water samples using an estimated lower Eh are considered to give more accurate results.

The log (IAP/KT) values for mineral phases containing iron, listed in Table 2, are questionable. Hematite and magnetite were modelled to be oversaturated for all wells. However, the concentration of iron in groundwater of wells adjacent to Cell II suggests that iron phases are dissolving in this region, not precipitating. Figure 31 suggested $Fe(OH)$ is the phase being dissolved. Additional support for this hypothesis is indicated by $Fe(OH)_3$ being undersaturated in wells 4a, 8a, and 14a, whereas it is saturated in wells 19 and 13 (outside the zone of the aquifer containing elevated iron levels). This more closely accounts for the distribution of iron. The concentrations of iron are also probably being affected by formation of soluble organic complexes. This could account for iron remaining in solution despite having a high activity product.

The mineral chalcocite (Cu_2S) is considered to be saturated in all samples except well 4a. This could account for the presence of copper in the waste-water, while wells immediately downgradient have essentially no copper. Iron was suspected to be the metal cation coprecipitating with sulfide, not copper, however, WATEQF results do not support this hypothesis. A discrepancy in the results for sulfide minerals, is that wells 19 and 13 are outside the region of the aquifer where sulfide is stable, yet WATEQF indicates that chalcocite should be precipitating near these wells. This suggests some artifact of WATEQF is not eliminated. The increase in copper levels in the region beneath Cell III (Fig. 17) could be due to oxidation of sulfur in chalcocite to sulfate, releasing copper to solution.

Several phosphate minerals are indicated to be oversaturated for the water analysis tested. While phosphate is suspected to be attenuated by adsorption, Stumm and Morgan (1981) state that metastable phosphate phases precipitate out near nuetral pH ranges. Also, calcium phosphates are thermodynamically stable in the pH range of natural waters. Results from WATEQF indicate precipitation of several apatite varieties. Additionally, manganese phosphate is oversaturated in all wells tested. However, the concentrations of manganese are increased in these wells, and manganese may also be forming soluble organic complexes and thus, would not be precipitating in these wells.

Based on the results of WATEQF, barium is thought to be precipitating out of solution. Witherite and barite are both considered saturated in most wells, while $Ba_3(PO_4)$ is saturated in wells 4 and 4a. Based on earlier research, barite is suspected to be controlling the distribution of barium. However, based on the bicarbonate rich waters and the term log (IAP/KT) being higher for witherite, witherite is the more likely to be precipitating out of solution, than barite.

Statistical Applications

The correlation coefficient is close to negative one for the pairs chloride-versus-distance downgradient and TDS-versus-distance downgradient. This indicates attenuation of chloride and TDS with increasing distance by dispersion (dilution). For the pair iron-arsenic, the high positive correlation coefficient suggests their distribution is controlled by similar hydrogeochemical processes. In this case, the processes are believed to be reduction and dissolution of solid iron phases. The results for the iron-arsenic pair indicate a similar source for the dissolved ions.

The moderately negative correlation coefficient for DOC-distance downgradient supports depletion of DOC as the plume moves downgradient from Cell I. Although bacteria were not monitored during this study, it is likely that bacterial population and distance downgradient would produce a similar correlation coefficient. It is also likely that DOC versus bacterial population would produce a high positive correlation.

The relatively negative correlation coefficient for DOC-pe suggests there is a relationship between their levels. The negative relationship implies low pe values in wells where DOC levels are relatively high. This has been interpreted to be a direct result of seepage from the sewage lagoon, indicating the orgainc-rich and low pe nature of the seepage.

The pair nitrate-ammonium produced a negative correlation. This supports dissimilatory reduction of nitrate to ammonium. Nitrification may also be occurring as indicated by an increase in nitrate levels in wells 11 and 12 and the nitrate-ammonium correlation coefficient.

The other statistical tests were not conclusive. Although a correlation may exist between various parameters, the introduction of contaminants from both the sewage lagoon and landfill has affected the correlation coefficient.

CONCLUSIONS

Discharge of waste-water from Cell I to Cell II was thought to aerate instantaneously and influence some of the chemical constituents of the waste-water seeping into the groundwater. Groundwater chemistry, redox potential and water levels were measured before and after the discharge. Water-level measurements detected a distinct rise in the wells near Cell II following discharge. However, analysis of groundwater chemistry and redox potential did not indicate any variation as a result of this discharge.

The dominant attenuation mechanism affecting chloride, TDS and specific conductance appears to be hydrodymanic dispersion. This is based on the distribution of mean concentrations for these parameters. The strong negative correlation coefficient for the pairs chloride-distance downgradient and TDS-distance downgradient, further supports attenuation by dispersion.

The distributions of calcium and magnesium concentrations suggest that these cations take place in cation exchange reactions. Ammonium is being adsorbed in the same region of the aquifer as calcium and magnesium are being released. Calcium levels have decreased since 1982. Dispersion probably accounts for the attenuation of sodium and potassium, although these ions may take place in cation exchange reaction.

Barium increases in wells of group 3, possibly due to dissolution of barite. Further downgradient, the decrease in barium levels is inferred to be a result of dispersion.

Based on measured concentrations of cadmium and copper, there is no distinct hydrogeochemical control indicated to account for their distribution. Analysis of the sludge layer at the bottom of Cell I indicated that trace metals have been concentrated within this blanket by adsorption.

The anaerobic conditions at the base of the lagoon have extended into the aquifer due to excessive seepage. This is verified by the field measured pe distribution. Under anaerobic conditions, organic carbon is oxidized, while inorganic compounds are reduced. The concentrations of several solutes are controlled by redox processes.

Sulfate is being reduced in the region of group 3 wells, indicated by concentrations near zero. Sulfate is reduced to sulfide. The sulfide is probably being attenuated further downgradient by precipitation with metal cations. In wells of group 4, the increase in sulfate levels is interpreted to be a result of landfill leachate which flows around Cell II into this area.

The reduction and dissolution of iron and manganese phases is inferred, based on high concentrations of these parameters in wells near Cells I and II. Arsenic concentrations have a similar distribution and are interpreted to be released to solution from iron and manganese phases. This is supported by a correlation coefficient of 0.712 for the pair iron-arsenic.

Reprecipitation of iron and manganese probably as hydrous oxides or sulfides, occurs in the region of group 4 wells. Arsenic is apparently incorporated into iron phases during reprecipitation.

Anaerobic conditions, along with abundant organic carbon, results in the dissimilatory reduction of nitrate to ammonium. Experimental work on nitrate reduction indicates dissimilatory reduction to ammonium is kinetically and thermodynamically favored under the conditions at the site. Combining the nitrate input from the landfill, which becomes reduced, with ammonium resulting from seepage, is very close to quantitatively accounting for the ammonium levels in the aquifer beneath Cell III. Further downgradient, the ammonium adsorption front is moving at a rate of 0.00026 to 0.0081 m/d.

A pe-pH diagram (Fig. 31) was constructed using pe, pH and ionic concentrations for suspected redox reactions. Measured pe and pH values support the reduction of iron hydroxide. The other suspected reaction lines did not correlate with measured pe and pH, despite evidence that these reactions are occurring. The diagram illustrates a sequence of redox reactions known to occur in natural waters.

Progressing from oxidizing to reducing conditions, the sequence is: O_2/H_2O, $MnO(OH)/Mn^{2+}$, NO_3^-/NH_4^+, $Fe(OH)_3/Fe^{2+}$, SO_4^{2-}/H_2S, H_2O/H_2. A very similar sequence is observed at the site. The 3D models of contaminant transport used a lower velocity and dispersivity values than the 2D model. This is probably due to the manner in which the contaminant is injected for the respective models. Simulation indicated the chloride plume extends 820 m downgradient of Cell I before reaching background levels. The results obtained from the simulation are a non-unique solution, however, the velocity and dispersivity values used fall within the range for unconsolidated sand and gravel.

RECOMMENDATIONS AND SUGGESTED AREAS OF FUTURE RESEARCH

This section is intended to pertain to the construction and operation of waste stabilization lagoons in the northern half of the United States.

Recommendations

1. Low permeability (clay, plastic, etc.) liners are recommended to be installed beneath waste-stabilization lagoons to reduce infiltration. This practice could be foregone at sites where the sediments have a low permeability (approximately 10-9 cm/sec). Also, liners beneath sites installed in arid climates, with a deep water table (greater than 30 meters below the land surface), would not have to be constructed of materials having such a low permeability. Based on presently engineered liners, low permeability liners should not be used for time periods greater than 30 years. Liners should be replaced following this duration.

2. Prior to approval of a potential site, characterization of stratigraphic and hydrologic conditions is advised, using available drilling and geophysical techniques.

3. A minimum number of permanent monitoring wells should be installed. This includes at least one upgradient and downgradient well, located within the leachate flow path. These wells should be sampled quarterly or biannually to detect any adverse effects due to the waste diposal. The sampling schedule should be site specific and altered

depending upon the severity of the contamination.

Suggested Areas of Future Research

1. One area of possible research is that conducted on variables affecting waste stabilization ponds. This research could intend to establish appropriate guidelines for maintaining this treatment process in a manner which minimizes contamination of the environment. Parameters of the aquifers which should be considered include: permeability, hydraulic conductivity, depth to the water table, probable attenuation capacity and mechanisms, and related geochemical processes. Factors pertaining to the treatment of waste-water include: toxicity of the sewage, rate of stabilization of the sewage, temperature, wind, precpitation, sunlight, size of the facility and amount of sewage, and distance to the nearest downgradient water supply well.

2. Detailed cooperative efforts by teams of scientists (geochemists, microbiologists, hydrogeologists, mathematicians and computer scientists) and engineers in order to thoroughly characterize the hydrogeochemical behavior of groundwater contaminants.

3. Extensive microbiological field studies which would characterize subsurface microbiological behavior. Characterization could include, enumeration and identification of varieties of microorganisms, and the

interaction between these organisms and subsurface contamination. This research could also involve experimental use of microorganisms to clean-up subsurface contamination. Microorganisms to be used for clean-up should be selected based on the physical/chemical conditions which they require for food and energy.

4. Another possibility is, continued research in the area of obtaining accurate values for parameters used in transport modeling. Parameters in need of more accurate determination include; dispersivity, hydraulic conductivity, transmissivity, and retardation rates. Also, continued modelling of plumes emanating from sewage disposal sites. These models should use background data obtained prior to construction of the site, whenever possible. Simulations of projected plume development should be analyzed using post-audit data to determine the accuracy of the model and to refine groundwater models.

5. Research on the toxicity of consuming leachate waters generated from sewage disposal.

APPENDICES

APPENDIX I

MONITORING WELL CONSTRUCTION DATA

TABLE 5 - MONITORING WELL CONSTRUCTION DATA

Elevations measured in feet and meters above an arbitrary datum.

WELL NUMBER	SURFACE ELEVATION		ELEVATION OF TOP OF PIPE		ELEVATION OF TOP OF SCREEN		ELEVATION OF BOTTOM OF SCREEN	
	(FT)	(M)	(FT)	(M)	(FT)	(M)	(FT)	(M)
1	101.4	30.9	102.8	31.3	79.8	24.3	74.8	22.8
2	103.0	31.4	104.6	31.9	81.6	24.9	76.6	23.3
3	99.3	30.3	100.8	30.7	77.4	23.6	72.8	22.2
4	99.4	30.3	100.8	30.7	79.2	24.1	74.2	22.6
5	102.5	31.2	104.0	31.7	82.4	25.1	77.4	23.6
6	85.2	26.0	88.8	27.1	63.7	19.4	58.7	17.9
7	99.4	30.3	100.2	30.5	70.8	21.6	65.8	20.1
8	86.9	26.5	88.0	26.8	57.8	17.6	52.8	16.1
9	98.3	30.0	99.6	30.3	72.9	22.2	67.9	20.7
10	93.7	28.5	95.4	29.1	67.9	20.7	62.9	19.2
11	93.2	28.4	94.7	28.9	70.0	21.3	65.0	19.8
12	97.3	29.7	98.3	30.0	73.7	22.5	68.7	20.9
13	95.7	29.2	97.0	29.6	70.6	21.5	65.6	20.0
14	99.0	30.2	100.1	30.5	74.2	22.6	69.2	21.1
15	100.9	30.7	102.0	31.1	82.0	25.0	78.0	23.8
16	90.7	27.6	92.2	28.1	62.2	18.9	58.2	17.7
17	90.3	27.5	91.2	27.8	81.2	24.7	77.2	23.5
18	87.0	26.5	87.8	26.8	77.8	23.7	73.8	22.5
19	88.0	26.8	89.1	27.2	62.5	19.1	58.5	17.8
20	87.5	26.7	88.9	27.1	73.9	22.5	69.9	21.3
21	95.6	29.1	97.0	29.6	77.0	23.5	73.0	22.3
22	96.6	29.4	97.3	29.7	67.3	20.5	63.3	19.3
23	96.3	29.3	97.7	29.8	78.0	23.8	74.0	22.5
24	93.5	28.5	94.9	28.9	65.0	19.8	61.0	18.6
25	94.8	28.9	96.1	29.3	76.1	23.2	72.1	22.0
26	98.8	30.1	100.2	30.5	80.2	24.4	76.2	23.2
27	99.1	30.2	99.9	30.4	79.9	24.3	75.9	23.1
28	99.2	30.2	100.2	30.5	80.2	24.4	76.2	23.2
29	100.0	30.5	101.5	30.9	81.5	24.8	77.5	23.6

APPENDIX II

WATER LEVEL DATA

TABLE 6 - WATER LEVEL DATA

Elevations measured in feet above an arbitrary datum.

WELL NUMBER	SURFACE ELEVATION	6/7/85	6/28/85	7/8/85	7/17/85	8/14/85	9/20/85	AVERAGE
1	101.4	84.6	-	84.7	84.6	84.4	84.4	84.5
2	103.0	84.5	84.8	84.9	84.7	84.6	84.6	84.7
3	99.3	83.1	83.5	83.7	83.4	83.3	83.4	83.4
4	99.4	83.3	83.6	83.9	83.6	83.4	83.4	83.4
5	102.5	83.3	83.6	83.8	83.6	83.4	83.3	83.5
6	85.2	81.6	82.1	82.3	82.1	81.9	81.8	82.0
7	99.4	82.7	83.5	83.7	83.5	83.3	83.3	83.3
8	86.9	82.0	82.1	82.2	82.0	81.9	81.5	82.0
9	98.3	82.4	82.5	82.8	82.4	82.3	82.3	82.5
10	93.7	80.1	80.4	80.5	80.3	80.2	80.2	80.3
11	93.2	78.0	78.6	78.7	78.6	78.5	78.5	78.5
12	97.3	78.2	79.0	79.2	79.1	79.0	78.9	78.9
13	95.7	80.4	81.0	81.0	80.9	80.7	80.7	80.8
14	99.0	82.1	82.2	82.5	82.3	82.1	82.1	82.2
15	100.9	83.9	84.2	84.3	84.2	84.0	84.2	84.1
16	90.7	82.2	82.4	82.8	82.4	82.2	82.1	82.2
17	90.3	81.7	82.4	82.6	82.4	82.2	81.8	82.2
18	87.0	81.6	82.2	82.4	82.1	81.9	81.8	82.2
19	87.9	81.0	81.8	81.8	81.7	81.5	81.5	81.3
20	87.5	81.4	81.7	81.9	81.7	81.5	81.4	81.6
21	95.6	80.8	81.0	81.1	80.9	80.8	80.7	80.9
22	96.5	79.3	79.9	80.0	78.9	78.7	79.6	79.7
23	96.3	79.5	79.8	79.9	79.7	79.6	79.6	79.7
24	93.5	78.7	79.2	79.4	79.3	79.2	79.2	79.2
25	94.8	81.5	81.6	81.7	81.5	81.4	81.3	81.5
26	98.8	81.9	82.6	83.1	82.8	82.6	82.6	82.6
27	99.1	82.1	82.3	82.7	82.3	82.1	82.0	82.3
28	99.2	-	83.6	83.9	83.6	83.4	83.4	83.4
29	100.0	84.7	84.8	84.8	84.6	84.5	84.5	84.6

APPENDIX III

WATER CHEMISTRY DATA

TABLE 7

WELL 1

Parameter	6/19/85	7/11/85	7/25/85
Ammonium (N) (mg/L)	0.058	0.020	0.045
Arsenic (ug/L)	1.0	0.9	0.5
Barium (ug/L)	112.0	111.0	126.
Bicarbonate (mg/L)	289.	295.0	310.
Calcium (mg/L)	91.4	104.0	103.
Cadmium (ug/L)	0.67	0.68	0.67
Carbonate (mg/L)	0.0	0.0	0.
Chloride (mg/L)	27.0	32.1	35.0
Chromium (ug/L)	0.76	-	-
Copper (ug/L)	1.3	1.2	3.8
Diss. Organic Carbon (mg/L)	3.3	3.0	3.5
Diss. Orthophosphate (mg/L)	0.067	0.049	0.068
Diss. Phosphate (mg/L)	0.063	0.080	0.070
Field Conductivity (umhos/cm)	-	1391.	1233.
Field pH	7.0	7.0	-
Fluoride (mg/L)	0.2	0.1	0.1
Iron (mg/L)	0.075	0.033	0.051
Lab Conductivity (umhos/cm)	918.0	1090.	118.0
Lab pH	7.6	7.5	7.7
Lead (ug/L)	0.0	-	-
Magnesium (mg/L)	33.0	36.8	32.8
Manganese (mg/L)	0.020	0.024	0.000
Nitrate (N) (mg/L)	22.8	32.7	31.2
Percent Sodium (%)	28.8	29.4	30.6
Potassium (mg/L)	1.90	1.90	3.80
Selenium (ug/L)	0.10	-	-
Sodium (mg/L)	68.0	79.5	80.1
Sodium Adsorption Ratio	1.55	1.70	1.76
Sulfate (mg/L)	122.	176.	209.
Sulfide (total) (mg/L)	< 0.1	< 0.1	< 0.1
Total Alkalinity (mg/L)	237.	242.	254.
Total Diss. Solids (mg/L)	587.	722.	755.
Total Hardness (mg/L)	364.	413.	393.
Total Phosphate (mg/L)	0.067	0.086	0.066
Turbidity (NTU)	<1.	<1.	3.00
Zinc (ug/L)	20.	-	-

WELL 1 (Continued)

Parameter	9/27/85	Mean
Ammonium (N) (mg/L)	0.070	0.048
Arsenic (ug/L)	0.6	0.8
Barium (ug/L)	115.	116.
Bicarbonate (mg/L)	273.	292.
Cadmium (mg/L)	1.21	0.81
Calcium (ug/L)	67.7	91.5
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	21.7	28.9
Chromium (ug/L)	-	-
Copper (ug/L)	0.5	1.7
Diss. Organic Carbon (mg/L)	2.5	3.1
Diss. Orthophosphate (mg/L)	0.055	0.060
Diss. Phosphate (mg/L)	0.073	0.072
Field Conductivity (umhos/cm)	959.	1194.
Field pH	6.3	6.8
Fluoride (mg/L)	0.1	0.125
Iron (mg/L)	0.009	0.042
Lab Conductivity (umhos/cm)	1018.	786.
Lab pH	7.4	7.6
Lead (ug/L)	-	-
Magnesium (mg/L)	28.3	32.8
Manganese (mg/L)	0.003	0.012
Nitrate (N) (mg/L)	19.0	26.4
Percent Sodium (%)	35.2	31.
Potassium (mg/L)	3.90	2.87
Selenium (ug/L)	-	-
Sodium (mg/L)	71.6	74.8
Sodium Adsorption Ratio	1.84	1.71
Sulfate (mg/L)	169.	169.
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	224.	239.
Total Diss. Solids (mg/L)	582.	661.
Total Hardness (mg/L)	286.	364.
Total Phosphate (mg/L)	0.074	0.073
Turbidity (NTU)	2.00	1.75
Zinc (ug/L)	-	-

TABLE 8

WELL 2

Parameter	6/19/85	7/11/85	7/25/85
Ammonium (N) (mg/L)	0.102	0.008	0.052
Arsenic (ug/L)	1.8	0.9	0.8
Barium (ug/L)	126.	125.	116.
Bicarbonate (mg/L)	250.	247.	237.
Calcium (mg/L)	67.3	63.1	52.5
Cadmium (ug/L)	0.70	1.52	0.19
Carbonate (mg/L)	0.	0.	0.
Chloride (mg/L)	3.3	3.4	4.9
Chromium (ug/L)	1.17	-	-
Copper (ug/L)	0.9	0.8	0.0
Diss. Organic Carbon (mg/L)	3.4	1.4	2.7
Diss. Orthophosphate (mg/L)	0.034	0.020	0.028
Diss. Phosphate (mg/L)	0.025	0.043	0.028
Field Conductivity (umhos/cm)	-	620.	519.
Field pH	7.0	6.7	-
Fluoride (mg/L)	0.2	0.2	0.2
Iron (mg/L)	0.015	0.033	0.072
Lab Conductivity (umhos/cm)	517.	516.	510.
Lab pH	7.6	7.5	7.7
Lead (ug/L)	0.0	-	-
Magnesium (mg/L)	26.1	24.9	18.5
Manganese (mg/L)	0.004	0.003	0.022
Nitrate (N) (mg/L)	8.54	8.69	7.50
Percent Sodium (%)	6.7	7.8	9.5
Potassium (mg/L)	0.500	0.400	1.20
Selenium (ug/L)	0.0	-	-
Sodium (mg/L)	9.10	10.1	10.1
Sodium Adsorption Ratio	0.24	0.27	0.30
Sulfate (mg/L)	44.	42.	40.
Sulfide (total) (mg/L)	< 0.1	< 0.1	< 0.1
Total Alkalinity (mg/L)	205.	202.	194.
Total Diss. Solids (mg/L)	312.	304.	278.
Total Hardness (mg/L)	276.	260.	207.
Total Phosphate (mg/L)	0.032	0.040	0.030
Turbidity (NTU)	< 1.	< 1.	2.00
Zinc (ug/L)	20.	-	-

WELL 2 (Continued)

Parameter	9/27/85	Mean
Ammonium (N) (mg/L)	0.009	0.043
Arsenic (ug/L)	1.4	1.2
Barium (ug/L)	127.	123.
Bicarbonate (mg/L)	256.	247.
Cadmium (mg/L)	1.46	0.97
Calcium (ug/L)	64.4	61.8
Carbonate (mg/L)	0.	0.0
Chloride (mg/L)	4.9	4.13
Chromium (ug/L)	-	-
Copper (ug/L)	0.9	0.6
Diss. Organic Carbon (mg/L)	1.4	2.2
Diss. Orthophosphate (mg/L)	0.012	0.60
Diss. Phosphate (mg/L)	0.036	0.72
Field Conductivity (umhos/cm)	470.	536.
Field pH	6.4	6.7
Fluoride (mg/L)	0.2	0.2
Iron (mg/L)	0.121	0.06
Lab Conductivity (umhos/cm)	513.0	514.
Lab pH	7.6	7.6
Lead (ug/L)	-	-
Magnesium (mg/L)	19.8	22.3
Manganese (mg/L)	0.021	0.013
Nitrate (N) (mg/L)	7.21	7.99
Percent Sodium (%)	8.3	8.07
Potassium (mg/L)	1.40	0.875
Selenium (ug/L)	-	-
Sodium (mg/L)	10.2	9.88
Sodium Adsorption Ratio	0.28	0.273
Sulfate (mg/L)	42.	42.
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	210.	203.
Total Diss. Solids (mg/L)	301.	299.
Total Hardness (mg/L)	242.	246.
Total Phosphate (mg/L)	0.037	0.035
Turbidity (NTU)	7.00	2.75
Zinc (ug/L)	-	-

TABLE 9

WELL 3

Parameter	6/19/85	7/10/85	7/25/85
Ammonium (N) (mg/L)	13.0	13.1	13.2
Arsenic (ug/L)	1.5	0.9	1.0
Barium (ug/L)	670.	739.	659.
Bicarbonate (mg/L)	566.	557.	538.
Cadmium (mg/L)	1.28	1.28	0.52
Calcium (ug/L)	106.	104.	84.
Carbonate (mg/L)	0.	0.	0.
Chloride (mg/L)	262.	253.	226.
Chromium (ug/L)	0.66	-	-
Copper (ug/L)	1.5	1.9	4.0
Diss. Organic Carbon (mg/L)	6.3	4.4	5.9
Diss. Orthophosphate (mg/L)	0.056	0.069	0.066
Diss. Phosphate (mg/L)	0.050	0.096	0.072
Field Conductivity (umhos/cm)	-	1980.	1557.
Field pH	6.8	7.3	-
Fluoride (mg/L)	1.5	1.5	1.5
Iron (mg/L)	0.041	0.046	0.010
Lab Conductivity (umhos/cm)	1685.	1629.	1562.
Lab pH	7.3	7.1	7.2
Lead (ug/L)	0.4	-	-
Magnesium (mg/L)	23.3	26.5	16.3
Manganese (mg/L)	4.74	4.56	2.96
Nitrate (N) (mg/L)	0.606	0.062	0.096
Percent Sodium (%)	55.8	54.4	55.8
Potassium (mg/L)	7.90	8.80	8.80
Selenium (ug/L)	0.16	-	-
Sodium (mg/L)	211.	203.	162.
Sodium Adsorption Ratio	4.82	4.61	4.22
Sulfate (mg/L)	45.	57.	46.
Sulfide (total) (mg/L)	< 0.1	< 0.1	< 0.1
Total Alkalinity (mg/L)	464.	456.	441.
Total Diss. Solids (mg/L)	937.	927.	809.
Total Hardness (mg/L)	361.	368.	227.
Total Phosphate (mg/L)	0.050	0.089	0.071
Turbidity (NTU)	< 1.	< 1.	2.00
Zinc (ug/L)	25.0	-	-

WELL 3 (Continued)

Parameter	9/27/85	Mean
Ammonium (N) (mg/L)	16.4	13.9
Arsenic (ug/L)	0.8	1.1
Barium (ug/L)	528.	629.
Bicarbonate (mg/L)	533.	548.
Cadmium (mg/L)	1.75	1.21
Calcium (ug/L)	75.6	92.4
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	227.	242.
Chromium (ug/L)	-	-
Copper (ug/L)	3.3	2.7
Diss. Organic Carbon (mg/L)	6.2	5.7
Diss. Orthophosphate (mg/L)	0.037	0.057
Diss. Phosphate (mg/L)	0.074	0.073
Field Conductivity (umhos/cm)	959.	1499.
Field pH	6.2	6.77
Fluoride (mg/L)	1.6	1.53
Iron (mg/L)	0.046	0.036
Lab Conductivity (umhos/cm)	1467.	1586.
Lab pH	7.3	7.22
Lead (ug/L)	-	-
Magnesium (mg/L)	17.2	20.8
Manganese (mg/L)	3.59	3.96
Nitrate (N) (mg/L)	0.062	0.206
Percent Sodium (%)	59.8	56.6
Potassium (mg/L)	10.9	9.1
Selenium (ug/L)	-	-
Sodium (mg/L)	179.	189.
Sodium Adsorption Ratio	4.82	4.62
Sulfate (mg/L)	20.	42.
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	437.	450.
Total Diss. Solids (mg/L)	792.	866.
Total Hardness (mg/L)	260.	316.
Total Phosphate (mg/L)	0.079	0.072
Turbidity (NTU)	2.00	1.5
Zinc (ug/L)	-	-

TABLE 10

WELL 4

Parameter	6/19/85	7/ 9/85	7/24/85
Ammonium (N) (mg/L)	16.5	15.9	16.4
Arsenic (ug/L)	12.2	18.7	14.2
Barium (ug/L)	436.	497.	425.
Bicarbonate (mg/L)	608.	596.	566.
Cadmium (mg/L)	0.22	0.20	0.47
Calcium (ug/L)	113.	112.	73.4
Carbonate (mg/L)	0.	0.	0.
Chloride (mg/L)	263.	261.	227.
Chromium (ug/L)	0.88	-	-
Copper (ug/L)	0.0	0.0	0.0
Diss. Organic Carbon (mg/L)	-	12.	-
Diss. Orthophosphate (mg/L)	2.83	3.85	3.34
Diss. Phosphate (mg/L)	2.99	4.09	3.52
Field Conductivity (umhos/cm)	-	-	1572.
Field pH	6.8	-	7.1
Fluoride (mg/L)	2.8	2.8	2.8
Iron (mg/L)	6.60	6.90	4.32
Lab Conductivity (umhos/cm)	1663.	1638.	1478.
Lab pH	7.3	7.2	7.4
Lead (ug/L)	0.5	-	-
Magnesium (mg/L)	27.5	27.1	16.6
Manganese (mg/L)	1.75	1.66	1.05
Nitrate (N) (mg/L)	0.073	0.060	0.000
Percent Sodium (%)	52.5	51.7	58.0
Potassium (mg/L)	7.10	7.5	8.5
Selenium (ug/L)	0.12	-	-
Sodium (mg/L)	201.	193.	160.
Sodium Adsorption Ratio	4.41	4.25	4.40
Sulfate (mg/L)	6.	9.	3.
Sulfide (total) (mg/L)	< 0.1	< 0.1	< 0.1
Total Alkalinity (mg/L)	498.	488.	464.
Total Diss. Solids (mg/L)	917.	903.	767.
Total Hardness (mg/L)	395.	391.	252.
Total Phosphate (mg/L)	3.09	4.72	3.55
Turbidity (NTU)	58.0	68.0	46.0
Zinc (ug/L)	22.	-	-

WELL 4 (Continued)

Parameter	10/3/85	Mean
Ammonium (N) (mg/L)	15.8	16.1
Arsenic (ug/L)	17.2	15.6
Barium (ug/L)	419.	444.
Bicarbonate (mg/L)	552.	581.
Calcium (mg/L)	82.7	95.3
Cadmium (ug/L)	0.42	0.33
Carbonate (mg/L)	0.0	0.
Chloride (mg/L)	248.	250.
Chromium (ug/L)	-	-
Copper (ug/L)	0.8	0.2
Diss. Organic Carbon (mg/L)	13.0	12.5
Diss. Orthophosphate (mg/L)	3.73	3.44
Diss. Phosphate (mg/L)	3.97	3.64
Field Conductivity (umhos/cm)	1417.	1495.
Field pH	6.1	6.67
Fluoride (mg/L)	2.9	2.33
Iron (mg/L)	5.75	5.89
Lab Conductivity (umhos/cm)	1495.	1569.
Lab pH	7.3	7.3
Lead (ug/L)	-	-
Magnesium (mg/L)	17.1	22.1
Manganese (mg/L)	1.21	1.42
Nitrate (N) (mg/L)	0.030	0.041
Percent Sodium (%)	57.4	54.9
Potassium (mg/L)	10.7	8.5
Selenium (ug/L)	-	-
Sodium (mg/L)	172.	181.
Sodium Adsorption Ratio	4.51	4.39
Sulfate (mg/L)	4.	5.5
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	452.	476.
Total Diss. Solids (mg/L)	807.	848.
Total Hardness (mg/L)	277.	329.
Total Phosphate (mg/L)	3.99	3.84
Turbidity (NTU)	34.0	51.5
Zinc (ug/L)	-	-

TABLE 11

WELL 5

Parameter	6/19/85	7/11/85	7/25/85
Ammonium (N) (mg/L)	0.069	0.240	-
Arsenic (ug/L)	1.0	0.9	-
Barium (ug/L)	85.	95.	-
Bicarbonate (mg/L)	408.	295.	-
Cadmium (mg/L)	3.39	0.47	-
Calcium (ug/L)	161.	108.	-
Carbonate (mg/L)	0.	0.	-
Chloride (mg/L)	120.	39.0	-
Chromium (ug/L)	0.73	-	-
Copper (ug/L)	2.9	1.2	-
Diss. Organic Carbon (mg/L)	2.4	2.9	5.5
Diss. Orthophosphate (mg/L)	0.058	0.040	-
Diss. Phosphate (mg/L)	0.052	0.063	-
Field Conductivity (umhos/cm)	-	1099.	-
Field pH	7.0	7.2	-
Fluoride (mg/L)	0.1	0.1	-
Iron (mg/L)	0.022	0.031	-
Lab Conductivity (umhos/cm)	1264.	947.0	-
Lab pH	7.3	7.4	-
Lead (ug/L)	0.0	-	-
Magnesium (mg/L)	49.7	33.3	-
Manganese (mg/L)	0.119	0.099	-
Nitrate (N) (mg/L)	20.2	20.8	-
Percent Sodium (%)	18.0	21.9	-
Potassium (mg/L)	1.90	1.30	-
Selenium (ug/L)	0.00	-	-
Sodium (mg/L)	61.3	52.6	-
Sodium Adsorption Ratio	1.08	1.13	-
Sulfate (mg/L)	109.	129.	-
Sulfide (total) (mg/L)	< 0.1	< 0.1	-
Total Alkalinity (mg/L)	334.	242.	-
Total Diss. Solids (mg/L)	793.	601.	-
Total Hardness (mg/L)	606.	407.	-
Total Phosphate (mg/L)	0.036	0.062	-
Turbidity (NTU)	< 1	< 1	-
Zinc (ug/L)	22.	-	-

WELL 5 (Continued)

Parameter	9/27/85	Mean
Ammonium (N) (mg/L)	-	0.155
Arsenic (ug/L)	-	1.0
Barium (ug/L)	-	90.
Bicarbonate (mg/L)	-	352.
Calcium (mg/L)	-	1.93
Cadmium (ug/L)	-	0.
Carbonate (mg/L)	-	80.
Chloride (mg/L)	-	-
Chromium (ug/L)	-	2.0
Copper (ug/L)	-	3.6
Diss. Organic Carbon (mg/L)	-	3.6
Diss. Orthophosphate (mg/L)	-	0.049
Diss. Phosphate (mg/L)	-	0.057
Field Conductivity (umhos/cm)	-	569.
Field pH	-	6.9
Fluoride (mg/L)	-	0.1
Iron (mg/L)	-	0.027
Lab Conductivity (umhos/cm)	-	1105.
Lab pH	-	7.3
Lead (ug/L)	-	-
Magnesium (mg/L)	-	41.5
Manganese (mg/L)	-	0.109
Nitrate (N) (mg/L)	-	20.5
Percent Sodium (%)	-	20.
Potassium (mg/L)	-	1.6
Selenium (ug/L)	-	-
Sodium (mg/L)	-	57.
Sodium Adsorption Ratio	-	1.11
Sulfate (mg/L)	-	119.
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	-	288.
Total Diss. Solids (mg/L)	-	697.
Total Hardness (mg/L)	-	507.
Total Phosphate (mg/L)	-	0.049
Turbidity (NTU)	-	1.
Zinc (ug/L)	-	-

TABLE 12

WELL 6

Parameter	6/19/85	7/ 9/85	7/24/85
Ammonium (N) (mg/L)	14.6	13.5	13.7
Arsenic (ug/L)	56.0	39.0	54.3
Barium (ug/L)	169.	182.	172.
Bicarbonate (mg/L)	424.	431.	447.
Cadmium (mg/L)	2.30	0.90	0.97
Calcium (ug/L)	114.	115.	91.2
Carbonate (mg/L)	0.	0.	0.
Chloride (mg/L)	255.	277.	255.
Chromium (ug/L)	1.80	-	-
Copper (ug/L)	1.5	1.2	2.7
Diss. Organic Carbon (mg/L)	3.9	5.5	4.6
Diss. Orthophosphate (mg/L)	0.186	0.131	0.189
Diss. Phosphate (mg/L)	0.216	0.179	0.239
Field Conductivity (umhos/cm)	-	-	1699.
Field pH	7.1	-	7.9
Fluoride (mg/L)	1.2	1.2	1.2
Iron (mg/L)	4.52	3.62	3.49
Lab Conductivity (umhos/cm)	1631.	1629.	1653.
Lab pH	7.3	7.3	7.3
Lead (ug/L)	0.0	-	-
Magnesium (mg/L)	41.3	41.9	31.3
Manganese (mg/L)	4.76	5.07	3.06
Nitrate (N) (mg/L)	0.148	0.057	0.000
Percent Sodium (%)	44.0	43.5	47.7
Potassium (mg/L)	5.80	6.20	7.70
Selenium (ug/L)	0.16	-	-
Sodium (mg/L)	166.	164.	151.
Sodium Adsorption Ratio	3.37	3.32	3.47
Sulfate (mg/L)	124.	122.	110.
Sulfide (total) (mg/L)	< 0.1	< 0.1	< 0.1
Total Alkalinity (mg/L)	347.	353.	366.
Total Diss. Solids (mg/L)	916.	939.	866.
Total Hardness (mg/L)	455.	461.	357.
Total Phosphate (mg/L)	0.180	0.211	0.256
Turbidity (NTU)	42.0	42.0	54.0
Zinc (ug/L)	75.	-	-

WELL 6 (Continued)

Parameter	9/29/85	Mean
Ammonium (N) (mg/L)	14.2	14.
Arsenic (ug/L)	23.9	43.3
Barium (ug/L)	180.	176.
Bicarbonate (mg/L)	254.	389.
Cadmium (mg/L)	1.16	1.33
Calcium (ug/L)	46.4	91.7
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	269.	26.4
Chromium (ug/L)	-	-
Copper (ug/L)	1.5	1.7
Diss. Organic Carbon (mg/L)	5.1	4.8
Diss. Orthophosphate (mg/L)	0.029	0.134
Diss. Phosphate (mg/L)	0.053	0.172
Field Conductivity (umhos/cm)	1387.	1543.
Field pH	6.1	7.0
Fluoride (mg/L)	1.2	1.2
Iron (mg/L)	0.281	2.98
Lab Conductivity (umhos/cm)	1336.	1562.
Lab pH	7.4	7.3
Lead (ug/L)	-	-
Magnesium (mg/L)	30.5	36.3
Manganese (mg/L)	0.233	3.28
Nitrate (N) (mg/L)	0.043	0.062
Percent Sodium (%)	59.1	48.6
Potassium (mg/L)	9.70	14.7
Selenium (ug/L)	-	-
Sodium (mg/L)	161.	161.
Sodium Adsorption Ratio	4.51	3.67
Sulfate (mg/L)	90.	111.
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	208.	319.
Total Diss. Solids (mg/L)	733.	864.
Total Hardness (mg/L)	242.	379.
Total Phosphate (mg/L)	0.057	0.176
Turbidity (NTU)	12.0	37.5
Zinc (ug/L)	-	-

TABLE 13

WELL 7

Parameter	6/19/85	7/10/85	7/24/85
Ammonium (N) (mg/L)	19.6	18.5	20.2
Arsenic (ug/L)	19.4	15.8	15.6
Barium (ug/L)	244.	290.	312.
Bicarbonate (mg/L)	656.	636.	659.
Cadmium (mg/L)	0.13	0.39	0.54
Calcium (ug/L)	106.	108.	83.8
Carbonate (mg/L)	0.	0.	0.
Chloride (mg/L)	254.	290.	270.
Chromium (ug/L)	0.63	-	-
Copper (ug/L)	0.5	0.2	1.7
Diss. Organic Carbon (mg/L)	11.	11.	13.
Diss. Orthophosphate (mg/L)	1.64	1.58	1.59
Diss. Phosphate (mg/L)	1.65	1.95	2.00
Field Conductivity (umhos/cm)	-	2130.	1495.
Field pH	7.0	6.6	6.4
Fluoride (mg/L)	3.7	3.4	3.6
Iron (mg/L)	12.0	12.0	11.0
Lab Conductivity (umhos/cm)	1663.	1752.	1618.
Lab pH	7.1	7.1	7.1
Lead (ug/L)	0.7	-	-
Magnesium (mg/L)	34.4	35.7	25.3
Manganese (mg/L)	3.66	3.72	2.78
Nitrate (N) (mg/L)	0.125	0.051	0.000
Percent Sodium (%)	51.2	51.1	55.0
Potassium (mg/L)	6.50	7.60	9.10
Selenium (ug/L)	0.17	-	-
Sodium (mg/L)	197.	201.	177.
Sodium Adsorption Ratio	4.25	4.28	4.36
Sulfate (mg/L)	7.	6.	3.
Sulfide (total) (mg/L)	< 0.1	< 0.1	< 0.1
Total Alkalinity (mg/L)	537.	521.	540.
Total Diss. Solids (mg/L)	930.	963.	893.
Total Hardness (mg/L)	407.	418.	314.
Total Phosphate (mg/L)	1.72	1.99	2.01
Turbidity (NTU)	108.	125.	108.
Zinc (ug/L)	18.	-	-

WELL 7 (Continued)

Parameter	9/27/85	Mean
Ammonium (N) (mg/L)	19.8	19.5
Arsenic (ug/L)	20.1	17.7
Barium (ug/L)	311.	289.
Bicarbonate (mg/L)	442.	598.
Cadmium (mg/L)	0.26	0.33
Calcium (ug/L)	101.	100.
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	304.	280.
Chromium (ug/L)	-	-
Copper (ug/L)	0.0	0.6
Diss. Organic Carbon (mg/L)	12.	12.
Diss. Orthophosphate (mg/L)	1.85	1.66
Diss. Phosphate (mg/L)	1.87	1.87
Field Conductivity (umhos/cm)	1722.	1782.
Field pH	6.1	6.6
Fluoride (mg/L)	3.6	3.6
Iron (mg/L)	13.2	12.
Lab Conductivity (umhos/cm)	1603.	1659.
Lab pH	7.1	7.1
Lead (ug/L)	-	-
Magnesium (mg/L)	28.1	30.9
Manganese (mg/L)	2.80	3.24
Nitrate (N) (mg/L)	0.034	0.053
Percent Sodium (%)	53.1	52.6
Potassium (mg/L)	10.5	8.43
Selenium (ug/L)	-	-
Sodium (mg/L)	193.	192.
Sodium Adsorption Ratio	4.38	4.32
Sulfate (mg/L)	4.	5.
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	362.	490.
Total Diss. Solids (mg/L)	859.	911.
Total Hardness (mg/L)	369.	377.
Total Phosphate (mg/L)	1.88	1.9
Turbidity (NTU)	124.	116.
Zinc (ug/L)	-	-

TABLE 14

WELL 8

Parameter	6/19/85	7/10/85	7/25/85
Ammonium (N) (mg/L)	11.2	11.1	11.6
Arsenic (ug/L)	111.	124.	58.0
Barium (ug/L)	373.	348.	259.
Bicarbonate (mg/L)	575.	602.	560.
Cadmium (mg/L)	0.85	0.56	0.67
Calcium (ug/L)	105.	109.	95.1
Carbonate (mg/L)	0.	0.	0.
Chloride (mg/L)	248.	284.	268.
Chromium (ug/L)	1.17	-	-
Copper (ug/L)	0.8	1.2	0.9
Diss. Organic Carbon (mg/L)	16.	5.2	8.7
Diss. Orthophosphate (mg/L)	0.315	0.185	0.028
Diss. Phosphate (mg/L)	0.405	0.467	0.036
Field Conductivity (umhos/cm)	-	960.	1605.
Field pH	7.1	6.7	-
Fluoride (mg/L)	2.2	2.2	2.1
Iron (mg/L)	20.9	18.9	8.89
Lab Conductivity (umhos/cm)	1588.	1688.	1642.
Lab pH	7.1	7.1	7.3
Lead (ug/L)	0.0	-	-
Magnesium (mg/L)	37.0	37.4	30.1
Manganese (mg/L)	1.44	1.42	1.13
Nitrate (N) (mg/L)	0.110	0.066	0.021
Percent Sodium (%)	48.6	48.2	50.1
Potassium (mg/L)	5.30	4.70	7.00
Selenium (ug/L)	0.20	-	-
Sodium (mg/L)	182.	183.	168.
Sodium Adsorption Ratio	3.87	3.85	3.84
Sulfate (mg/L)	19.	16.	16.
Sulfide (total) (mg/L)	< 0.1	< 0.1	< 0.1
Total Alkalinity (mg/L)	471.	493.	459.
Total Diss. Solids (mg/L)	879.	930.	860.
Total Hardness (mg/L)	415.	425.	362.
Total Phosphate (mg/L)	0.407	0.448	0.039
Turbidity (NTU)	140.	170.	120.
Zinc (ug/L)	30.	-	-

WELL 8 (Continued)

Parameter	9/29/85	Mean
Ammonium (N) (mg/L)	0.031	8.48
Arsenic (ug/L)	97.0	98.
Barium (ug/L)	242.	305.
Bicarbonate (mg/L)	306.	511.
Cadmium (mg/L)	0.50	0.64
Calcium (ug/L)	68.9	94.5
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	294.	273.
Chromium (ug/L)	-	-
Copper (ug/L)	0.0	0.7
Diss. Organic Carbon (mg/L)	3.9	8.5
Diss. Orthophosphate (mg/L)	0.016	0.139
Diss. Phosphate (mg/L)	0.081	0.247
Field Conductivity (umhos/cm)	1350.	1305.
Field pH	6.0	6.6
Fluoride (mg/L)	2.2	2.18
Iron (mg/L)	11.1	14.9
Lab Conductivity (umhos/cm)	1362.	1570.
Lab pH	7.2	7.2
Lead (ug/L)	-	-
Magnesium (mg/L)	25.4	32.5
Manganese (mg/L)	0.533	1.13
Nitrate (N) (mg/L)	0.123	0.08
Percent Sodium (%)	56.0	50.7
Potassium (mg/L)	7.40	6.1
Selenium (ug/L)	-	-
Sodium (mg/L)	163.	174.
Sodium Adsorption Ratio	4.25	3.95
Sulfate (mg/L)	30.	20.2
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	251.	418.
Total Diss. Solids (mg/L)	740.	852.
Total Hardness (mg/L)	277.	370.
Total Phosphate (mg/L)	0.102	0.249
Turbidity (NTU)	128.	140.
Zinc (ug/L)	-	-

TABLE 15

WELL 9

Parameter	6/20/85	7/11/85	7/25/85
Ammonium (N) (mg/L)	0.070	0.020	0.125
Arsenic (ug/L)	0.3	1.0	1.2
Barium (ug/L)	116.	85.	79.
Bicarbonate (mg/L)	294.	261.	258.
Cadmium (mg/L)	1.08	1.90	0.21
Calcium (ug/L)	76.2	72.5	67.5
Carbonate (mg/L)	0.	0.	0.
Chloride (mg/L)	13.1	11.8	10.5
Chromium (ug/L)	0.49	-	-
Copper (ug/L)	1.6	1.6	2.0
Diss. Organic Carbon (mg/L)	1.9	2.2	1.4
Diss. Orthophosphate (mg/L)	0.032	0.023	0.031
Diss. Phosphate (mg/L)	0.047	0.041	0.036
Field Conductivity (umhos/cm)	-	681.	609.
Field pH	-	6.9	-
Fluoride (mg/L)	0.2	0.2	0.2
Iron (mg/L)	0.395	0.043	0.054
Lab Conductivity (umhos/cm)	613.0	671.0	573.0
Lab pH	8.0	7.6	7.6
Lead (ug/L)	0.9	-	-
Magnesium (mg/L)	28.2	28.4	22.7
Manganese (mg/L)	0.410	0.268	0.168
Nitrate (N) (mg/L)	5.80	5.82	4.14
Percent Sodium (%)	13.9	11.7	12.5
Potassium (mg/L)	0.600	0.400	1.20
Selenium (ug/L)	0.03	-	-
Sodium (mg/L)	22.9	18.3	17.3
Sodium Adsorption Ratio	0.57	0.46	0.46
Sulfate (mg/L)	65.	66.	70.
Sulfide (total) (mg/L)	-	< 0.1	< 0.1
Total Alkalinity (mg/L)	241.	214.	211.
Total Diss. Solids (mg/L)	377.	352.	334.
Total Hardness (mg/L)	307.	298.	262.
Total Phosphate (mg/L)	0.057	0.039	0.034
Turbidity (NTU)	5.00	< 1	< 1
Zinc (ug/L)	41.	-	-

WELL 9 (Continued)

Parameter	9/29/85	Mean
Ammonium (N) (mg/L)	0.028	0.061
Arsenic (ug/L)	0.9	0.8
Barium (ug/L)	78.	90.
Bicarbonate (mg/L)	259.	268.
Cadmium (mg/L)	0.73	0.98
Calcium (ug/L)	58.5	68.7
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	4.0	9.85
Chromium (ug/L)	-	-
Copper (ug/L)	1.8	1.7
Diss. Organic Carbon (mg/L)	1.4	1.7
Diss. Orthophosphate (mg/L)	0.022	0.027
Diss. Phosphate (mg/L)	0.028	0.037
Field Conductivity (umhos/cm)	461.	583.
Field pH	6.3	6.6
Fluoride (mg/L)	0.2	0.2
Iron (mg/L)	0.014	0.127
Lab Conductivity (umhos/cm)	534.0	598.0
Lab pH	7.6	7.7
Lead (ug/L)	-	-
Magnesium (mg/L)	19.6	24.7
Manganese (mg/L)	0.008	0.214
Nitrate (N) (mg/L)	4.53	5.07
Percent Sodium (%)	14.0	13.
Potassium (mg/L)	1.30	0.875
Selenium (ug/L)	-	-
Sodium (mg/L)	17.1	18.9
Sodium Adsorption Ratio	0.49	0.50
Sulfate (mg/L)	64.	66.2
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	212.	220.
Total Diss. Solids (mg/L)	312.	344.
Total Hardness (mg/L)	227.	273.
Total Phosphate (mg/L)	0.028	0.040
Turbidity (NTU)	2.00	2.25
Zinc (ug/L)	-	-

TABLE 16

WELL 10

Parameter	6/20/85	7/ 9/85	7/25/85
Ammonium (N) (mg/L)	0.038	0.067	0.042
Arsenic (ug/L)	0.3	1.0	0.9
Barium (ug/L)	156.	100.	107.
Bicarbonate (mg/L)	408.	377.	363.
Cadmium (mg/L)	0.70	0.58	0.81
Calcium (ug/L)	101.	103.	81.8
Carbonate (mg/L)	0.	0.	0.
Chloride (mg/L)	144.	160.	148.
Chromium (ug/L)	0.63	-	-
Copper (ug/L)	3.8	3.3	5.7
Diss. Organic Carbon (mg/L)	3.6	3.8	2.8
Diss. Orthophosphate (mg/L)	0.043	0.039	0.054
Diss. Phosphate (mg/L)	0.062	0.050	0.059
Field Conductivity (umhos/cm)	-	1340.	1077.
Field pH	-	6.9	6.3
Fluoride (mg/L)	0.7	0.8	0.8
Iron (mg/L)	0.029	0.030	0.096
Lab Conductivity (umhos/cm)	1165.	1172.	1131.
Lab pH	7.6	7.6	7.5
Lead (ug/L)	0.7	-	-
Magnesium (mg/L)	32.3	34.5	24.2
Manganese (mg/L)	0.088	0.067	0.055
Nitrate (N) (mg/L)	7.16	5.30	5.82
Percent Sodium (%)	36.6	39.9	44.2
Potassium (mg/L)	2.70	3.50	4.20
Selenium (ug/L)	0.13	-	-
Sodium (mg/L)	103.	123.	111.
Sodium Adsorption Ratio	2.28	2.67	2.77
Sulfate (mg/L)	76.	68.	59.
Sulfide (total) (mg/L)	-	< 0.1	< 0.1
Total Alkalinity (mg/L)	334.	309.	297.
Total Diss. Solids (mg/L)	691.	700.	633.
Total Hardness (mg/L)	385.	399.	304.
Total Phosphate (mg/L)	0.072	0.071	0.056
Turbidity (NTU)	< 1	< 1	< 1
Zinc (ug/L)	23.	-	-

WELL 10 (Continued)

Parameter	9/29/85	Mean
Ammonium (N) (mg/L)	0.023	0.042
Arsenic (ug/L)	1.2	0.9
Barium (ug/L)	120.	121.
Bicarbonate (mg/L)	247.	349.
Cadmium (mg/L)	1.29	0.84
Calcium (ug/L)	58.1	86.
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	156.	152.
Chromium (ug/L)	-	-
Copper (ug/L)	3.2	4.
Diss. Organic Carbon (mg/L)	3.1	3.3
Diss. Orthophosphate (mg/L)	0.049	0.046
Diss. Phosphate (mg/L)	0.051	0.055
Field Conductivity (umhos/cm)	1040.	1152.
Field pH	6.0	6.4
Fluoride (mg/L)	0.8	0.775
Iron (mg/L)	0.013	0.042
Lab Conductivity (umhos/cm)	1009.	1119.
Lab pH	7.6	7.6
Lead (ug/L)	-	-
Magnesium (mg/L)	22.8	28.5
Manganese (mg/L)	0.003	0.053
Nitrate (N) (mg/L)	5.06	5.84
Percent Sodium (%)	50.0	42.7
Potassium (mg/L)	5.10	3.88
Selenium (ug/L)	-	-
Sodium (mg/L)	110.	112.
Sodium Adsorption Ratio	3.10	2.71
Sulfate (mg/L)	62.	66.2
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	202.	285.
Total Diss. Solids (mg/L)	633.*	645.
Total Hardness (mg/L)	239.	332.
Total Phosphate (mg/L)	0.058	0.064
Turbidity (NTU)	2.00	1.25
Zinc (ug/L)	-	-

TABLE 17

WELL 11

Parameter	6/20/85	7/ 9/85	7/24/85
Ammonium (N) (mg/L)	0.043	0.040	0.045
Arsenic (ug/L)	0.3	0.9	0.8
Barium (ug/L)	126.	192.	122.
Bicarbonate (mg/L)	451.	423.	400.
Cadmium (mg/L)	0.55	0.63	0.61
Calcium (ug/L)	129.	131.	120.
Carbonate (mg/L)	0.	0.	0.
Chloride (mg/L)	107.	122.	127.
Chromium (ug/L)	0.89	-	-
Copper (ug/L)	2.6	2.9	4.5
Diss. Organic Carbon (mg/L)	3.0	3.7	3.2
Diss. Orthophosphate (mg/L)	0.029	0.028	0.042
Diss. Phosphate (mg/L)	0.068	0.056	0.044
Field Conductivity (umhos/cm)	-	1149.	1035.
Field pH	-	6.9	6.6
Fluoride (mg/L)	0.8	0.8	0.8
Iron (mg/L)	0.043	0.014	0.000
Lab Conductivity (umhos/cm)	1053.	1052.	1034.
Lab pH	7.7	7.5	7.6
Lead (ug/L)	0.0	-	-
Magnesium (mg/L)	46.4	48.1	38.4
Manganese (mg/L)	0.024	0.067	0.014
Nitrate (N) (mg/L)	0.338	0.297	0.247
Percent Sodium (%)	12.3	11.5	12.4
Potassium (mg/L)	1.40	1.00	2.20
Selenium (ug/L)	0.12	-	-
Sodium (mg/L)	33.3	31.7	30.1
Sodium Adsorption Ratio	0.64	0.60	0.61
Sulfate (mg/L)	71.	56.	54.
Sulfide (total) (mg/L)	-	< 0.1	< 0.1
Total Alkalinity (mg/L)	369.	346.	328.
Total Diss. Solids (mg/L)	612.	599.	571.
Total Hardness (mg/L)	513.	526.	459.
Total Phosphate (mg/L)	0.070	0.052	0.044
Turbidity (NTU)	2.00	< 1	< 1
Zinc (ug/L)	21.	-	-

WELL 11 (Continued)

Parameter	9/29/85	Mean
Ammonium (N) (mg/L)	0.090	0.055
Arsenic (ug/L)	0.0	0.5
Barium (ug/L)	134.	144.
Bicarbonate (mg/L)	382.	414.
Cadmium (mg/L)	1.03	0.71
Calcium (ug/L)	92.1	118.
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	130.	122.
Chromium (ug/L)	-	-
Copper (ug/L)	3.2	3.3
Diss. Organic Carbon (mg/L)	2.7	3.1
Diss. Orthophosphate (mg/L)	0.031	0.033
Diss. Phosphate (mg/L)	0.033	0.050
Field Conductivity (umhos/cm)	885.	1023.
Field pH	6.0	6.5
Fluoride (mg/L)	0.8	0.80
Iron (mg/L)	0.021	0.019
Lab Conductivity (umhos/cm)	1011.	1038.
Lab pH	7.6	7.6
Lead (ug/L)	-	-
Magnesium (mg/L)	36.9	42.5
Manganese (mg/L)	0.000	0.026
Nitrate (N) (mg/L)	1.23	0.528
Percent Sodium (%)	14.9	12.8
Potassium (mg/L)	3.40	2.0
Selenium (ug/L)	-	-
Sodium (mg/L)	31.0	31.5
Sodium Adsorption Ratio	0.69	0.63
Sulfate (mg/L)	49.	57.5
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	313.	339.
Total Diss. Solids (mg/L)	536.	580.
Total Hardness (mg/L)	382.	470.
Total Phosphate (mg/L)	0.034	0.051
Turbidity (NTU)	2.00	1.5
Zinc (ug/L)	-	-

TABLE 18

WELL 12

Parameter	6/19/85	7/ 9/85	7/25/85
Ammonium (N) (mg/L)	0.165	0.077	0.046
Arsenic (ug/L)	2.0	0.8	0.5
Barium (ug/L)	137.	155.	157.
Bicarbonate (mg/L)	488.	516.	474.
Cadmium (mg/L)	0.93	0.95	0.94
Calcium (ug/L)	101.	114.	93.4
Carbonate (mg/L)	0.	0.	0.
Chloride (mg/L)	115.	137.	127.
Chromium (ug/L)	67.0	-	-
Copper (ug/L)	2.4	2.7	4.0
Diss. Organic Carbon (mg/L)	4.4	5.1	5.1
Diss. Orthophosphate (mg/L)	0.071	0.064	0.072
Diss. Phosphate (mg/L)	0.064	0.081	0.072
Field Conductivity (umhos/cm)	-	1285.	1130.
Field pH	7.0	6.6	6.8
Fluoride (mg/L)	0.1	0.1	0.1
Iron (mg/L)	0.017	0.013	0.065
Lab Conductivity (umhos/cm)	1080.	1232.	114.
Lab pH	7.6	7.3	7.4
Lead (ug/L)	0.0	-	-
Magnesium (mg/L)	31.7	35.9	25.1
Manganese (mg/L)	0.739	0.493	0.457
Nitrate (N) (mg/L)	0.047	0.382	4.78
Percent Sodium (%)	38.4	36.8	39.2
Potassium (mg/L)	3.00	3.60	4.00
Selenium (ug/L)	0.14	-	-
Sodium (mg/L)	111.	117.	100.
Sodium Adsorption Ratio	2.46	2.44	2.38
Sulfate (mg/L)	40.	46.	40.
Sulfide (total) (mg/L)	< 0.1	< 0.1	< 0.1
Total Alkalinity (mg/L)	400.	423.	388.
Total Diss. Solids (mg/L)	643.	710.	644.
Total Hardness (mg/L)	384.	433.	337.
Total Phosphate (mg/L)	0.065	0.092	0.069
Turbidity (NTU)	< 1	< 1	2.0
Zinc (ug/L)	18.	-	-

WELL 12 (Continued)

Parameter	9/29/85	Mean
Ammonium (N) (mg/L)	0.019	0.077
Arsenic (ug/L)	-	1.1
Barium (ug/L)	-	150.
Bicarbonate (mg/L)	-	493.
Cadmium (mg/L)	-	0.94
Calcium (ug/L)	-	103.
Carbonate (mg/L)	-	0.
Chloride (mg/L)	-	126.
Chromium (ug/L)	-	-
Copper (ug/L)	-	3.0
Diss. Organic Carbon (mg/L)	4.8	4.9
Diss. Orthophosphate (mg/L)	0.068	0.054
Diss. Phosphate (mg/L)	0.058	0.069
Field Conductivity (umhos/cm)	925.	1113.
Field pH	6.0	6.6
Fluoride (mg/L)	-	0.1
Iron (mg/L)	-	0.032
Lab Conductivity (umhos/cm)	-	809.
Lab pH	-	7.4
Lead (ug/L)	-	-
Magnesium (mg/L)	-	30.9
Manganese (mg/L)	-	0.563
Nitrate (N) (mg/L)	15.8	5.25
Percent Sodium (%)	-	38.1
Potassium (mg/L)	-	3.53
Selenium (ug/L)	-	-
Sodium (mg/L)	-	109.
Sodium Adsorption Ratio	-	2.43
Sulfate (mg/L)	-	42.
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	-	404.
Total Diss. Solids (mg/L)	-	666.
Total Hardness (mg/L)	-	385.
Total Phosphate (mg/L)	0.066	0.073
Turbidity (NTU)	-	1.3
Zinc (ug/L)	-	-

TABLE 19

WELL 13

Parameter	6/19/85	7/ 9/85	7/25/85
Ammonium (N) (mg/L)	33.6	28.7	31.0
Arsenic (ug/L)	1.3	1.1	0.5
Barium (ug/L)	243.	158.	210.
Bicarbonate (mg/L)	448.	478.	461.
Cadmium (mg/L)	1.57	2.66	0.78
Calcium (ug/L)	73.4	84.7	68.2
Carbonate (mg/L)	0.	0.	0.
Chloride (mg/L)	204.	212.	229.
Chromium (ug/L)	0.55	-	-
Copper (ug/L)	7.3	5.1	6.5
Diss. Organic Carbon (mg/L)	11.	11.	6.6
Diss. Orthophosphate (mg/L)	0.062	0.052	0.049
Diss. Phosphate (mg/L)	0.068	0.073	0.051
Field Conductivity (umhos/cm)	-	-	15.05
Field pH	7.1	-	-
Fluoride (mg/L)	2.7	2.2	2.6
Iron (mg/L)	0.117	0.017	0.072
Lab Conductivity (umhos/cm)	1436.	1476.	1505.
Lab pH	7.5	7.3	7.4
Lead (ug/L)	0.6	-	-
Magnesium (mg/L)	20.7	21.3	17.1
Manganese (mg/L)	0.294	0.542	0.164
Nitrate (N) (mg/L)	0.053	0.071	0.196
Percent Sodium (%)	54.7	48.9	56.7
Potassium (mg/L)	12.0	9.30	14.2
Selenium (ug/L)	0.11	-	-
Sodium (mg/L)	150.	132.	146.
Sodium Adsorption Ratio	3.97	3.33	4.09
Sulfate (mg/L)	64.	61.	45.
Sulfide (total) (mg/L)	< 0.1	< 0.1	< 0.1
Total Alkalinity (mg/L)	367.	391.	378.
Total Diss. Solids (mg/L)	744.	756.	748.
Total Hardness (mg/L)	269.	299.	241.
Total Phosphate (mg/L)	0.068	0.098	0.052
Turbidity (NTU)	2.00	2.00	< 1
Zinc (ug/L)	43.	-	-

WELL 13 (Continued)

Parameter	9/29/85	Mean
Ammonium (N) (mg/L)	30.0	30.8
Arsenic (ug/L)	0.6	0.9
Barium (ug/L)	203.	204.
Bicarbonate (mg/L)	491.	470.
Cadmium (mg/L)	1.32	1.58
Calcium (ug/L)	67.5	73.5
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	218.	216.
Chromium (ug/L)	-	-
Copper (ug/L)	6.3	6.3
Diss. Organic Carbon (mg/L)	5.9	8.6
Diss. Orthophosphate (mg/L)	0.063	0.056
Diss. Phosphate (mg/L)	0.046	0.060
Field Conductivity (umhos/cm)	1220.	1363.
Field pH	5.8	6.4
Fluoride (mg/L)	2.6	2.52
Iron (mg/L)	0.002	0.052
Lab Conductivity (umhos/cm)	1447.	1466.
Lab pH	7.4	7.4
Lead (ug/L)	-	-
Magnesium (mg/L)	16.8	18.9
Manganese (mg/L)	0.056	0.264
Nitrate (N) (mg/L)	0.043	0.091
Percent Sodium (%)	59.0	54.8
Potassium (mg/L)	22.5	14.5
Selenium (ug/L)	-	-
Sodium (mg/L)	158.	147.
Sodium Adsorption Ratio	4.46	3.96
Sulfate (mg/L)	27.	49.2
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	402.	385.
Total Diss. Solids (mg/L)	752.	750.
Total Hardness (mg/L)	238.	262.
Total Phosphate (mg/L)	0.047	0.066
Turbidity (NTU)	2.00	1.75
Zinc (ug/L)	-	-

TABLE 20

WELL 14

Parameter	6/20/85	7/ 9/85	7/24/85
Ammonium (N) (mg/L)	43.0	33.9	43.9
Arsenic (ug/L)	37.6	29.8	38.4
Barium (ug/L)	142.	106.	130.
Bicarbonate (mg/L)	495.	483.	495.
Cadmium (mg/L)	1.12	0.46	0.93
Calcium (ug/L)	83.5	84.0	64.4
Carbonate (mg/L)	0.	0.	0.
Chloride (mg/L)	218.	231.	210.
Chromium (ug/L)	0.28	-	-
Copper (ug/L)	0.3	0.4	0.4
Diss. Organic Carbon (mg/L)	16.	6.7	8.2
Diss. Orthophosphate (mg/L)	0.245	0.147	0.262
Diss. Phosphate (mg/L)	0.311	0.197	0.415
Field Conductivity (umhos/cm)	-	-	1650.
Field pH	-	-	6.9
Fluoride (mg/L)	1.2	1.0	1.2
Iron (mg/L)	12.4	17.3	10.8
Lab Conductivity (umhos/cm)	1548.	1575.	1539.
Lab pH	7.3	7.0	7.1
Lead (ug/L)	0.2	-	-
Magnesium (mg/L)	29.9	30.5	22.1
Manganese (mg/L)	3.00	4.18	2.24
Nitrate (N) (mg/L)	2.16	0.061	0.000
Percent Sodium (%)	45.9	47.0	51.2
Potassium (mg/L)	9.90	11.0	15.6
Selenium (ug/L)	0.13	-	-
Sodium (mg/L)	130.	137.	122.
Sodium Adsorption Ratio	3.10	3.26	3.35
Sulfate (mg/L)	66.	80.	65.
Sulfide (total) (mg/L)	-	< 0.1	< 0.1
Total Alkalinity (mg/L)	405.	396.	405.
Total Diss. Solids (mg/L)	791.	813.	743.
Total Hardness (mg/L)	332.	336.	252.
Total Phosphate (mg/L)	0.323	0.452	0.428
Turbidity (NTU)	140.	165.	144.
Zinc (ug/L)	38.	-	-

WELL 14 (Continued)

Parameter	9/27/85	Mean
Ammonium (N) (mg/L)	44.2	41.3
Arsenic (ug/L)	41.3	37.
Barium (ug/L)	113.	123.
Bicarbonate (mg/L)	336.	452.
Cadmium (mg/L)	1.28	0.95
Calcium (ug/L)	79.9	78.
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	225.	221.
Chromium (ug/L)	-	-
Copper (ug/L)	0.0	0.3
Diss. Organic Carbon (mg/L)	7.3	9.5
Diss. Orthophosphate (mg/L)	0.253	0.227
Diss. Phosphate (mg/L)	0.488	0.353
Field Conductivity (umhos/cm)	1493.	1572.
Field pH	6.4	6.6
Fluoride (mg/L)	1.2	1.15
Iron (mg/L)	14.2	13.7
Lab Conductivity (umhos/cm)	1564.	1566.
Lab pH	7.2	7.1
Lead (ug/L)	-	-
Magnesium (mg/L)	23.9	26.6
Manganese (mg/L)	1.24	2.67
Nitrate (N) (mg/L)	0.129	0.587
Percent Sodium (%)	49.6	48.4
Potassium (mg/L)	22.3	14.7
Selenium (ug/L)	-	-
Sodium (mg/L)	136.	131.
Sodium Adsorption Ratio	3.42	3.28
Sulfate (mg/L)	75.	71.5
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	275.	370.
Total Diss. Solids (mg/L)	728.	769.
Total Hardness (mg/L)	298.	305.
Total Phosphate (mg/L)	0.498	0.425
Turbidity (NTU)	108.	139.
Zinc (ug/L)	-	-

TABLE 21

WELL 15

Parameter	6/11/85	7/11/85	7/25/85
Ammonium (N) (mg/L)	-	0.055	0.347
Arsenic (ug/L)	-	0.9	1.1
Barium (ug/L)	-	153.	260.
Bicarbonate (mg/L)	-	320.	351.
Cadmium (mg/L)	-	0.90	0.42
Calcium (ug/L)	-	106.	114.
Carbonate (mg/L)	-	0.	0.
Chloride (mg/L)	-	31.9	53.9
Chromium (ug/L)	-	-	-
Copper (ug/L)	-	1.6	6.1
Diss. Organic Carbon (mg/L)	-	11.0	3.8
Diss. Orthophosphate (mg/L)	-	0.041	0.056
Diss. Phosphate (mg/L)	-	0.069	0.064
Field Conductivity (umhos/cm)	-	1149.	1094.
Field pH	7.2	7.5	-
Fluoride (mg/L)	-	0.2	0.1
Iron (mg/L)	-	0.013	0.009
Lab Conductivity (umhos/cm)	-	982.	1120.
Lab pH	-	7.5	7.5
Lead (ug/L)	-	-	-
Magnesium (mg/L)	-	40.4	38.2
Manganese (mg/L)	-	0.016	0.000
Nitrate (N) (mg/L)	-	21.4	22.4
Percent Sodium (%)	-	23.1	23.0
Potassium (mg/L)	-	1.50	3.20
Selenium (ug/L)	-	-	-
Sodium (mg/L)	-	59.8	60.9
Sodium Adsorption Ratio	-	1.25	1.26
Sulfate (mg/L)	-	136.	146.
Sulfide (total) (mg/L)	-	< 0.1	< 0.1
Total Alkalinity (mg/L)	-	262.	287.
Total Diss. Solids (mg/L)	-	629.	688.
Total Hardness (mg/L)	-	431.	442.
Total Phosphate (mg/L)	-	0.062	0.115
Turbidity (NTU)	-	< 1	2.00
Zinc (ug/L)	-	-	-

WELL 15 (Continued)

Parameter	9/29/85	Mean
Ammonium (N) (mg/L)	0.045	0.149
Arsenic (ug/L)	0.1	0.7
Barium (ug/L)	192.	202.
Bicarbonate (mg/L)	191.	287.
Cadmium (mg/L)	0.89	0.74
Calcium (ug/L)	103.	108.
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	110.	62.3
Chromium (ug/L)	-	-
Copper (ug/L)	2.0	3.2
Diss. Organic Carbon (mg/L)	11.	8.6
Diss. Orthophosphate (mg/L)	0.015	0.037
Diss. Phosphate (mg/L)	0.058	0.064
Field Conductivity (umhos/cm)	932.	1058.
Field pH	5.8	6.8
Fluoride (mg/L)	0.2	0.167
Iron (mg/L)	0.097	0.04
Lab Conductivity (umhos/cm)	924.	1009.
Lab pH	7.6	7.5
Lead (ug/L)	-	-
Magnesium (mg/L)	41.3	40.0
Manganese (mg/L)	0.030	0.015
Nitrate (N) (mg/L)	29.1	24.3
Percent Sodium (%)	22.5	22.9
Potassium (mg/L)	6.10	3.6
Selenium (ug/L)	-	-
Sodium (mg/L)	57.5	59.4
Sodium Adsorption Ratio	1.21	1.24
Sulfate (mg/L)	182.	155.
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	156.	235.
Total Diss. Solids (mg/L)	724.	680.
Total Hardness (mg/L)	428.	434.
Total Phosphate (mg/L)	0.060	0.079
Turbidity (NTU)	4.00	2.33
Zinc (ug/L)	-	-

TABLE 22

WELL 16

Parameter	6/19/85	7/11/85	7/25/85
Ammonium (N) (mg/L)	-	39.7	37.4
Arsenic (ug/L)	-	100.	82.2
Barium (ug/L)	-	196.	180.
Bicarbonate (mg/L)	-	474.	493.
Cadmium (mg/L)	-	1.67	1.10
Calcium (ug/L)	-	53.9	48.8
Carbonate (mg/L)	-	0.	0.
Chloride (mg/L)	-	213.	214.
Chromium (ug/L)	-	-	-
Copper (ug/L)	-	1.9	1.4
Diss. Organic Carbon (mg/L)	-	12.	13.
Diss. Orthophosphate (mg/L)	-	0.022	0.017
Diss. Phosphate (mg/L)	-	0.049	0.021
Field Conductivity (umhos/cm)	-	1735.	1440.
Field pH	-	6.4	-
Fluoride (mg/L)	-	2.8	2.8
Iron (mg/L)	-	8.72	6.34
Lab Conductivity (umhos/cm)	-	1405.	1445.
Lab pH	-	7.2	7.2
Lead (ug/L)	-	-	-
Magnesium (mg/L)	-	22.5	18.4
Manganese (mg/L)	-	1.26	1.00
Nitrate (N) (mg/L)	-	0.121	0.000
Percent Sodium (%)	-	59.4	62.3
Potassium (mg/L)	-	6.30	9.90
Selenium (ug/L)	-	-	-
Sodium (mg/L)	-	154.	151.
Sodium Adsorption Ratio	-	4.43	4.67
Sulfate (mg/L)	-	29.	22.
Sulfide (total) (mg/L)	-	< 0.1	< 0.1
Total Alkalinity (mg/L)	-	388.	404.
Total Diss. Solids (mg/L)	-	712.	707.
Total Hardness (mg/L)	-	227.	198.
Total Phosphate (mg/L)	-	0.042	0.019
Turbidity (NTU)	-	72.0	88.0
Zinc (ug/L)	-	-	-

WELL 16 (Continued)

Parameter	9/29/85	Mean
Ammonium (N) (mg/L)	37.4	38.2
Arsenic (ug/L)	166.	116.
Barium (ug/L)	218.	198.
Bicarbonate (mg/L)	401.	335.
Cadmium (mg/L)	1.44	1.4
Calcium (ug/L)	42.3	48.3
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	220.	217.
Chromium (ug/L)	-	-
Copper (ug/L)	1.4	1.6
Diss. Organic Carbon (mg/L)	12.	12.
Diss. Orthophosphate (mg/L)	0.156	0.065
Diss. Phosphate (mg/L)	0.227	0.099
Field Conductivity (umhos/cm)	1354.	1510.
Field pH	6.2	6.3
Fluoride (mg/L)	2.8	2.80
Iron (mg/L)	11.8	8.95
Lab Conductivity (umhos/cm)	1295.	1382.
Lab pH	7.2	7.2
Lead (ug/L)	-	-
Magnesium (mg/L)	19.5	20.1
Manganese (mg/L)	0.575	0.945
Nitrate (N) (mg/L)	0.066	0.062
Percent Sodium (%)	65.7	62.5
Potassium (mg/L)	15.8	10.7
Selenium (ug/L)	-	-
Sodium (mg/L)	164.	156.
Sodium Adsorption Ratio	5.24	4.78
Sulfate (mg/L)	25.	25.3
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	328.	373.
Total Diss. Solids (mg/L)	685.	701.
Total Hardness (mg/L)	186.	204.
Total Phosphate (mg/L)	0.247	0.103
Turbidity (NTU)	108.	89.3
Zinc (ug/L)	-	-

TABLE 23

WELL 17

Parameter	6/19/85	7/ 9/85	7/24/85
Ammonium (N) (mg/L)	28.2	22.6	27.2
Arsenic (ug/L)	22.0	20.5	21.2
Barium (ug/L)	189.	141.	179.
Bicarbonate (mg/L)	369.	387.	401.
Cadmium (mg/L)	0.79	0.39	1.68
Calcium (ug/L)	76.3	78.7	65.0
Carbonate (mg/L)	0.	0.	0.
Chloride (mg/L)	265.	291.	282.
Chromium (ug/L)	0.70	-	-
Copper (ug/L)	0.3	1.4	0.7
Diss. Organic Carbon (mg/L)	-	2.2	4.0
Diss. Orthophosphate (mg/L)	0.108	0.041	0.135
Diss. Phosphate (mg/L)	0.119	0.193	0.170
Field Conductivity (umhos/cm)	-	-	1790.
Field pH	7.0	6.8	6.4
Fluoride (mg/L)	0.8	0.8	0.7
Iron (mg/L)	15.0	16.1	13.1
Lab Conductivity (umhos/cm)	1544.	1604.	1624.
Lab pH	7.1	7.1	7.0
Lead (ug/L)	0.0	-	-
Magnesium (mg/L)	24.3	27.2	21.4
Manganese (mg/L)	1.44	0.986	0.724
Nitrate (N) (mg/L)	0.522	0.139	0.026
Percent Sodium (%)	54.6	54.3	57.3
Potassium (mg/L)	7.70	9.20	11.6
Selenium (ug/L)	0.08	-	-
Sodium (mg/L)	161.	169.	155.
Sodium Adsorption Ratio	4.11	4.19	4.26
Sulfate (mg/L)	82.	72.	71.
Sulfide (total) (mg/L)	< 0.1	< 0.1	< 0.1
Total Alkalinity (mg/L)	302.	317.	328.
Total Diss. Solids (mg/L)	800.	839.	804.
Total Hardness (mg/L)	291.	309.	251.
Total Phosphate (mg/L)	0.122	0.212	0.190
Turbidity (NTU)	124.	165.	140.
Zinc (ug/L)	41.	-	-

WELL 17 (Continued)

Parameter	9/29/85	Mean
Ammonium (N) (mg/L)	27.7	26.4
Arsenic (ug/L)	19.5	20.8
Barium (ug/L)	139.	162.
Bicarbonate (mg/L)	331.	372.
Cadmium (mg/L)	0.91	0.94
Calcium (ug/L)	60.6	70.2
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	276.	279.
Chromium (ug/L)	-	-
Copper (ug/L)	0.0	0.6
Diss. Organic Carbon (mg/L)	4.9	3.7
Diss. Orthophosphate (mg/L)	0.017	0.075
Diss. Phosphate (mg/L)	0.016	0.125
Field Conductivity (umhos/cm)	1494.	1642.
Field pH	6.0	6.6
Fluoride (mg/L)	0.6	0.725
Iron (mg/L)	12.5	14.2
Lab Conductivity (umhos/cm)	1460.	1558.
Lab pH	7.2	7.1
Lead (ug/L)	-	-
Magnesium (mg/L)	22.7	23.9
Manganese (mg/L)	0.350	0.875
Nitrate (N) (mg/L)	0.078	0.191
Percent Sodium (%)	61.4	57.0
Potassium (mg/L)	17.4	11.5
Selenium (ug/L)	-	-
Sodium (mg/L)	180.	166.
Sodium Adsorption Ratio	5.00	4.39
Sulfate (mg/L)	76.	75.2
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	271.	304.
Total Diss. Solids (mg/L)	796.	810.
Total Hardness (mg/L)	245.	274.
Total Phosphate (mg/L)	0.017	0.135
Turbidity (NTU)	128.	139.
Zinc (ug/L)	-	-

TABLE 24

WELL 19

Parameter	6/20/85	7/11/85	7/25/85
Ammonium (N) (mg/L)	25.8	30.5	25.0
Arsenic (ug/L)	0.6	1.1	0.9
Barium (ug/L)	147.	125.	116.
Bicarbonate (mg/L)	513.	514.	502.
Cadmium (mg/L)	1.74	1.69	1.02
Calcium (ug/L)	79.7	80.7	73.8
Carbonate (mg/L)	0.	0.	0.
Chloride (mg/L)	212.	190.	203.
Chromium (ug/L)	0.76	-	-
Copper (ug/L)	4.8	7.0	7.4
Diss. Organic Carbon (mg/L)	31.	7.6	9.4
Diss. Orthophosphate (mg/L)	0.025	0.023	0.034
Diss. Phosphate (mg/L)	0.034	0.064	0.043
Field Conductivity (umhos/cm)	-	-	1437.
Field pH	-	5.9	-
Fluoride (mg/L)	1.8	1.8	1.8
Iron (mg/L)	0.005	0.019	0.056
Lab Conductivity (umhos/cm)	1452.	1445.	1445.
Lab pH	7.4	7.3	7.2
Lead (ug/L)	0.0	-	-
Magnesium (mg/L)	26.9	26.8	20.7
Manganese (mg/L)	5.53	3.77	2.76
Nitrate (N) (mg/L)	0.152	0.686	0.000
Percent Sodium (%)	51.8	50.8	54.0
Potassium (mg/L)	7.00	5.70	8.60
Selenium (ug/L)	0.21	-	-
Sodium (mg/L)	154.	149.	146.
Sodium Adsorption Ratio	3.80	3.66	3.87
Sulfate (mg/L)	48.	40.	35.
Sulfide (total) (mg/L)	-	< 0.1	< 0.1
Total Alkalinity (mg/L)	420.	421.	411.
Total Diss. Solids (mg/L)	781.	748.	735.
Total Hardness (mg/L)	310.	312.	270.
Total Phosphate (mg/L)	0.040	0.060	0.036
Turbidity (NTU)	2.00	< 1	< 1
Zinc (ug/L)	23.	-	-

WELL 19 (Continued)

Parameter	9/29/85	Mean
Ammonium (N) (mg/L)	23.4	26.2
Arsenic (ug/L)	0.5	0.8
Barium (ug/L)	139.	132.
Bicarbonate (mg/L)	195.	431.
Cadmium (mg/L)	1.13	1.4
Calcium (ug/L)	59.4	73.4
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	248.	213.
Chromium (ug/L)	-	-
Copper (ug/L)	5.6	6.2
Diss. Organic Carbon (mg/L)	5.7	12.
Diss. Orthophosphate (mg/L)	0.024	0.026
Diss. Phosphate (mg/L)	0.028	0.042
Field Conductivity (umhos/cm)	1391.	1414.
Field pH	6.0	6.0
Fluoride (mg/L)	1.6	1.8
Iron (mg/L)	0.021	0.025
Lab Conductivity (umhos/cm)	1304.	1411.
Lab pH	7.5	7.3
Lead (ug/L)	-	-
Magnesium (mg/L)	26.2	25.1
Manganese (mg/L)	0.568	3.16
Nitrate (N) (mg/L)	0.029	0.217
Percent Sodium (%)	58.9	53.9
Potassium (mg/L)	14.7	9.0
Selenium (ug/L)	-	-
Sodium (mg/L)	170.	155.
Sodium Adsorption Ratio	4.60	3.98
Sulfate (mg/L)	47.	42.5
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	160.	353.
Total Diss. Solids (mg/L)	661.	731.
Total Hardness (mg/L)	256.	287.
Total Phosphate (mg/L)	0.031	0.042
Turbidity (NTU)	2.00	1.5
Zinc (ug/L)	-	-

TABLE 25

WELL 20

Parameter	6/19/85	7/11/85	7/25/85
Ammonium (N) (mg/L)	-	38.9	2.28
Arsenic (ug/L)	-	0.8	0.5
Barium (ug/L)	-	171.	157.
Bicarbonate (mg/L)	-	482.	490.
Cadmium (mg/L)	-	2.80	1.11
Calcium (ug/L)	-	99.4	88.5
Carbonate (mg/L)	-	0.	0.
Chloride (mg/L)	-	220.	192.
Chromium (ug/L)	-	-	-
Copper (ug/L)	-	5.6	4.4
Diss. Organic Carbon (mg/L)	-	4.7	5.0
Diss. Orthophosphate (mg/L)	-	0.047	0.056
Diss. Phosphate (mg/L)	-	0.073	0.058
Field Conductivity (umhos/cm)	-	1769.	1482.
Field pH	-	5.9	-
Fluoride (mg/L)	-	0.018	0.056
Iron (mg/L)	-	1.6	1.5
Lab Conductivity (umhos/cm)	-	1462.	1456.
Lab pH	-	7.3	7.3
Lead (ug/L)	-	-	-
Magnesium (mg/L)	-	25.5	18.6
Manganese (mg/L)	-	1.32	0.676
Nitrate (N) (mg/L)	-	0.103	0.000
Percent Sodium (%)	-	43.1	43.8
Potassium (mg/L)	-	8.80	14.6
Selenium (ug/L)	-	-	-
Sodium (mg/L)	-	124.	107.
Sodium Adsorption Ratio	-	2.86	2.70
Sulfate (mg/L)	-	75.	71.
Sulfide (total) (mg/L)	-	< 0.1	< 0.1
Total Alkalinity (mg/L)	-	395.	401.
Total Diss. Solids (mg/L)	-	790.	734.
Total Hardness (mg/L)	-	353.	298.
Total Phosphate (mg/L)	-	0.069	0.057
Turbidity (NTU)	-	< 1	2.00
Zinc (ug/L)	-	-	-

WELL 20 (Continued)

Parameter	9/29/85	Mean
Ammonium (N) (mg/L)	27.5	31.6
Arsenic (ug/L)	0.4	0.6
Barium (ug/L)	170.	166.
Bicarbonate (mg/L)	483.	485.
Cadmium (mg/L)	0.74	1.55
Calcium (ug/L)	90.8	92.9
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	188.	200.
Chromium (ug/L)	-	-
Copper (ug/L)	3.2	4.4
Diss. Organic Carbon (mg/L)	4.1	4.6
Diss. Orthophosphate (mg/L)	0.066	0.056
Diss. Phosphate (mg/L)	0.052	0.061
Field Conductivity (umhos/cm)	1247.	1499.
Field pH	6.0	5.9
Fluoride (mg/L)	1.5	1.5
Iron (mg/L)	0.000	0.025
Lab Conductivity (umhos/cm)	1495.	1471.
Lab pH	7.4	7.3
Lead (ug/L)	-	-
Magnesium (mg/L)	22.9	22.3
Manganese (mg/L)	0.405	0.80
Nitrate (N) (mg/L)	3.60	1.23
Percent Sodium (%)	48.1	45.
Potassium (mg/L)	24.2	15.9
Selenium (ug/L)	-	-
Sodium (mg/L)	137.	123.
Sodium Adsorption Ratio	3.33	2.96
Sulfate (mg/L)	79.	75.
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	396.	397.
Total Diss. Solids (mg/L)	796.	773.
Total Hardness (mg/L)	321.	324.
Total Phosphate (mg/L)	0.058	0.061
Turbidity (NTU)	2.00	1.66
Zinc (ug/L)	-	-

TABLE 26

WELL 21

Parameter	6/20/85	7/10/85	7/25/85
Ammonium (N) (mg/L)	34.1	0.460	36.5
Arsenic (ug/L)	1.0	0.7	0.5
Barium (ug/L)	403.	160.	168.
Bicarbonate (mg/L)	495.	474.	471.
Cadmium (mg/L)	1.43	0.80	0.95
Calcium (ug/L)	101.	91.1	80.0
Carbonate (mg/L)	0.	0.	0.
Chloride (mg/L)	217.	212.	203.
Chromium (ug/L)	0.99	-	-
Copper (ug/L)	4.8	8.1	5.6
Diss. Organic Carbon (mg/L)	-	5.1	7.8
Diss. Orthophosphate (mg/L)	0.050	0.058	0.060
Diss. Phosphate (mg/L)	0.072	0.082	0.064
Field Conductivity (umhos/cm)	-	1710.	1476.
Field pH	-	6.3	-
Fluoride (mg/L)	2.0	2.2	1.9
Iron (mg/L)	0.004	0.192	0.078
Lab Conductivity (umhos/cm)	1505.	1487.	1459.
Lab pH	7.8	7.2	7.3
Lead (ug/L)	0.5	-	-
Magnesium (mg/L)	23.0	21.7	14.5
Manganese (mg/L)	0.694	0.569	0.419
Nitrate (N) (mg/L)	0.000	0.052	0.016
Percent Sodium (%)	46.8	49.2	47.9
Potassium (mg/L)	9.10	7.00	12.9
Selenium (ug/L)	0.00	-	-
Sodium (mg/L)	141.	142.	110.
Sodium Adsorption Ratio	3.29	3.46	2.97
Sulfate (mg/L)	67.	67.	63.
Sulfide (total) (mg/L)	-	< 0.1	< 0.1
Total Alkalinity (mg/L)	405.	388.	386.
Total Diss. Solids (mg/L)	802.	774.	716.
Total Hardness (mg/L)	347.	317.	260.
Total Phosphate (mg/L)	0.080	0.080	0.065
Turbidity (NTU)	2.00	< 1	< 1
Zinc (ug/L)	74.	-	-

WELL 21 (Continued)

Parameter	9/29/85	Mean
Ammonium (N) (mg/L)	33.0	26.0
Arsenic (ug/L)	0.1	0.6
Barium (ug/L)	190.	230.
Bicarbonate (mg/L)	192.	408.
Cadmium (mg/L)	0.72	1.0
Calcium (ug/L)	72.9	82.3
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	186.	205.
Chromium (ug/L)	-	-
Copper (ug/L)	4.4	5.7
Diss. Organic Carbon (mg/L)	6.3	6.4
Diss. Orthophosphate (mg/L)	0.066	0.057
Diss. Phosphate (mg/L)	0.053	0.068
Field Conductivity (umhos/cm)	1185.	1457.
Field pH	5.7	6.0
Fluoride (mg/L)	2.1	2.0
Iron (mg/L)	0.000	0.068
Lab Conductivity (umhos/cm)	1208.	1415.
Lab pH	7.5	7.5
Lead (ug/L)	-	-
Magnesium (mg/L)	17.8	19.3
Manganese (mg/L)	0.022	0.426
Nitrate (N) (mg/L)	0.278	0.086
Percent Sodium (%)	53.4	49.3
Potassium (mg/L)	18.1	11.8
Selenium (ug/L)	-	-
Sodium (mg/L)	135.	132.
Sodium Adsorption Ratio	3.68	3.35
Sulfate (mg/L)	57.	63.5
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	157.	334.
Total Diss. Solids (mg/L)	583.	719.
Total Hardness (mg/L)	255.	295.
Total Phosphate (mg/L)	0.054	0.070
Turbidity (NTU)	2.00	1.5
Zinc (ug/L)	-	-

TABLE 27

WELL 22

Parameter	6/19/85	7/11/85	7/25/85
Ammonium (N) (mg/L)	34.4	54.0	46.5
Arsenic (ug/L)	1.8	0.6	0.4
Barium (ug/L)	381.	193.	176.
Bicarbonate (mg/L)	-	525.	525.
Cadmium (mg/L)	4.43	3.14	1.53
Calcium (ug/L)	-	76.8	68.4
Carbonate (mg/L)	-	0.	0.
Chloride (mg/L)	-	221.	194.
Chromium (ug/L)	1.01	-	-
Copper (ug/L)	9.5	5.7	5.5
Diss. Organic Carbon (mg/L)	-	6.6	6.6
Diss. Orthophosphate (mg/L)	0.048	0.063	0.067
Diss. Phosphate (mg/L)	0.068	0.088	0.072
Field Conductivity (umhos/cm)	-	1818.	1496.
Field pH	6.9	6.1	7.1
Fluoride (mg/L)	-	1.6	1.6
Iron (mg/L)	-	0.017	0.062
Lab Conductivity (umhos/cm)	-	1487.	1493.
Lab pH	-	7.3	7.2
Lead (ug/L)	0.8	-	-
Magnesium (mg/L)	-	30.7	21.8
Manganese (mg/L)	-	0.860	0.696
Nitrate (N) (mg/L)	0.000	0.521	0.029
Percent Sodium (%)	-	42.5	43.6
Potassium (mg/L)	-	12.6	21.3
Selenium (ug/L)	0.00	-	-
Sodium (mg/L)	-	109.	93.2
Sodium Adsorption Ratio	-	2.65	2.51
Sulfate (mg/L)	-	50.	50.
Sulfide (total) (mg/L)	-	< 0.1	< 0.1
Total Alkalinity (mg/L)	-	430.	430.
Total Diss. Solids (mg/L)	-	760.	707.
Total Hardness (mg/L)	-	318.	261.
Total Phosphate (mg/L)	0.066	0.075	0.064
Turbidity (NTU)	-	< 1	< 1
Zinc (ug/L)	166.	-	-

WELL 22 (Continued)

Parameter	9/29/85	Mean
Ammonium (N) (mg/L)	43.0	44.5
Arsenic (ug/L)	0.3	0.8
Barium (ug/L)	191.	235.
Bicarbonate (mg/L)	527.	526.
Cadmium (mg/L)	0.86	2.49
Calcium (ug/L)	80.2	75.1
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	189.	201.
Chromium (ug/L)	-	-
Copper (ug/L)	4.6	6.3
Diss. Organic Carbon (mg/L)	6.1	6.4
Diss. Orthophosphate (mg/L)	0.063	0.060
Diss. Phosphate (mg/L)	0.230	0.114
Field Conductivity (umhos/cm)	1327.	1547.
Field pH	5.8	6.5
Fluoride (mg/L)	1.5	1.6
Iron (mg/L)	0.000	0.026
Lab Conductivity (umhos/cm)	1538.	1506.
Lab pH	7.4	7.3
Lead (ug/L)	-	-
Magnesium (mg/L)	27.4	28.9
Manganese (mg/L)	0.263	0.538
Nitrate (N) (mg/L)	0.019	0.142
Percent Sodium (%)	46.0	44.0
Potassium (mg/L)	34.8	22.9
Selenium (ug/L)	-	-
Sodium (mg/L)	123.	108.
Sodium Adsorption Ratio	3.02	2.73
Sulfate (mg/L)	62.	54.
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	432.	431.
Total Diss. Solids (mg/L)	776.	748.
Total Hardness (mg/L)	313.	297.
Total Phosphate (mg/L)	0.061	0.067
Turbidity (NTU)	3.00	2.0
Zinc (ug/L)	-	-

TABLE 28

WELL 23

Parameter	6/19/85	7/9/85	7/25/85
Ammonium (N) (mg/L)	3.18	3.26	1.64
Arsenic (ug/L)	0.9	0.9	1.1
Barium (ug/L)	272.	227.	229.
Bicarbonate (mg/L)	468.	472.	424.
Cadmium (mg/L)	1.86	0.44	0.60
Calcium (ug/L)	146.	150.	120.
Carbonate (mg/L)	0.	0.	0.
Chloride (mg/L)	166.	181.	143.
Chromium (ug/L)	0.34	-	-
Copper (ug/L)	3.2	2.5	4.2
Diss. Organic Carbon (mg/L)	8.0	4.1	4.2
Diss. Orthophosphate (mg/L)	0.048	0.042	0.043
Diss. Phosphate (mg/L)	0.049	0.063	0.049
Field Conductivity (umhos/cm)	-	1500.	1200.
Field pH	-	6.5	7.1
Fluoride (mg/L)	0.8	0.9	0.8
Iron (mg/L)	0.042	0.000	0.000
Lab Conductivity (umhos/cm)	1318.	1379.	1197.
Lab pH	7.5	7.4	7.5
Lead (ug/L)	0.6	-	-
Magnesium (mg/L)	30.2	31.1	20.2
Manganese (mg/L)	0.328	0.369	0.084
Nitrate (N) (mg/L)	0.252	0.277	1.98
Percent Sodium (%)	31.4	31.9	31.3
Potassium (mg/L)	3.60	5.00	3.70
Selenium (ug/L)	0.18	-	-
Sodium (mg/L)	104.	109.	80.2
Sodium Adsorption Ratio	2.04	2.11	1.78
Sulfate (mg/L)	91.	92.	79.
Sulfide (total) (mg/L)	< 0.1	< 0.1	< 0.1
Total Alkalinity (mg/L)	383.	387.	347.
Total Diss. Solids (mg/L)	772.	802.	663.
Total Hardness (mg/L)	489.	504.	382.
Total Phosphate (mg/L)	0.050	0.066	0.044
Turbidity (NTU)	< 1	< 1	< 1
Zinc (ug/L)	71.	-	-

WELL 23 (Continued)

Parameter	9/29/85	Mean
Ammonium (N) (mg/L)	1.19	2.32
Arsenic (ug/L)	1.0	1.0
Barium (ug/L)	208.	234.
Bicarbonate (mg/L)	317.	420.
Cadmium (mg/L)	0.38	0.82
Calcium (ug/L)	75.5	123.
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	81.2	143.
Chromium (ug/L)	-	-
Copper (ug/L)	2.3	3.1
Diss. Organic Carbon (mg/L)	3.2	4.9
Diss. Orthophosphate (mg/L)	0.040	0.043
Diss. Phosphate (mg/L)	0.050	0.053
Field Conductivity (umhos/cm)	778.	1159.
Field pH	6.0	6.5
Fluoride (mg/L)	1.0	0.9
Iron (mg/L)	0.031	0.018
Lab Conductivity (umhos/cm)	897.0	1198.
Lab pH	7.6	7.5
Lead (ug/L)	-	-
Magnesium (mg/L)	14.6	24.0
Manganese (mg/L)	0.018	0.20
Nitrate (N) (mg/L)	11.6	3.53
Percent Sodium (%)	40.1	33.7
Potassium (mg/L)	5.60	4.47
Selenium (ug/L)	-	-
Sodium (mg/L)	77.1	92.6
Sodium Adsorption Ratio	2.13	2.02
Sulfate (mg/L)	60.	80.5
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	260.	344.
Total Diss. Solids (mg/L)	522.	690.
Total Hardness (mg/L)	249.	406.
Total Phosphate (mg/L)	0.051	0.053
Turbidity (NTU)	3.00	1.5
Zinc (ug/L)	-	-

TABLE 29

WELL 24

Parameter	6/19/85	7/10/85	7/25/85
Ammonium (N) (mg/L)	-	0.058	0.085
Arsenic (ug/L)	-	0.9	0.7
Barium (ug/L)	-	122.	120.
Bicarbonate (mg/L)	-	372.	360.
Cadmium (mg/L)	-	1.16	1.20
Calcium (ug/L)	-	141.	120.
Carbonate (mg/L)	-	0.	0.
Chloride (mg/L)	-	226.	148.
Chromium (ug/L)	-	-	-
Copper (ug/L)	-	3.1	3.4
Diss. Organic Carbon (mg/L)	-	3.3	3.3
Diss. Orthophosphate (mg/L)	-	0.021	0.021
Diss. Phosphate (mg/L)	-	0.037	0.022
Field Conductivity (umhos/cm)	-	1751.	1206.
Field pH	-	7.3	6.4
Fluoride (mg/L)	-	0.6	0.5
Iron (mg/L)	-	0.020	0.038
Lab Conductivity (umhos/cm)	-	1336.	1231.
Lab pH	-	7.4	7.5
Lead (ug/L)	-	-	-
Magnesium (mg/L)	-	49.5	34.6
Manganese (mg/L)	-	0.575	0.040
Nitrate (N) (mg/L)	-	11.6	3.13
Percent Sodium (%)	-	22.3	22.4
Potassium (mg/L)	-	1.80	3.10
Selenium (ug/L)	-	-	-
Sodium (mg/L)	-	73.5	58.9
Sodium Adsorption Ratio	-	1.36	1.22
Sulfate (mg/L)	-	70.	81.
Sulfide (total) (mg/L)	-	< 0.1	< 0.1
Total Alkalinity (mg/L)	-	305.	295.
Total Diss. Solids (mg/L)	-	796.	637.
Total Hardness (mg/L)	-	555.	443.
Total Phosphate (mg/L)	-	0.043	0.194
Turbidity (NTU)	-	< 1	< 1
Zinc (ug/L)	-	-	-

WELL 24 (Continued)

Parameter	9/29/85	Mean
Ammonium (N) (mg/L)	0.022	0.055
Arsenic (ug/L)	0.7	0.8
Barium (ug/L)	105.	116.
Bicarbonate (mg/L)	233.	322.
Cadmium (mg/L)	0.91	1.09
Calcium (ug/L)	45.6	102.
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	49.0	141.
Chromium (ug/L)	-	-
Copper (ug/L)	4.9	3.8
Diss. Organic Carbon (mg/L)	3.9	3.5
Diss. Orthophosphate (mg/L)	0.016	0.019
Diss. Phosphate (mg/L)	0.039	0.033
Field Conductivity (umhos/cm)	831.	1263.
Field pH	5.9	6.5
Fluoride (mg/L)	0.5	0.5
Iron (mg/L)	0.000	0.019
Lab Conductivity (umhos/cm)	686.0	1084.
Lab pH	7.7	7.5
Lead (ug/L)	-	-
Magnesium (mg/L)	28.6	37.6
Manganese (mg/L)	0.000	0.205
Nitrate (N) (mg/L)	6.24	6.99
Percent Sodium (%)	37.2	27.3
Potassium (mg/L)	4.30	3.07
Selenium (ug/L)	-	-
Sodium (mg/L)	63.5	65.3
Sodium Adsorption Ratio	1.81	1.46
Sulfate (mg/L)	90.	80.3
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	191.	264.
Total Diss. Solids (mg/L)	424.	619.
Total Hardness (mg/L)	232.	410.
Total Phosphate (mg/L)	0.040	0.092
Turbidity (NTU)	2.0	1.0
Zinc (ug/L)	-	-

TABLE 30

WELL 25

Parameter	6/19/85	7/10/85	7/25/85
Ammonium (N) (mg/L)	-	0.090	0.043
Arsenic (ug/L)	-	2.1	2.4
Barium (ug/L)	-	266.	273.
Bicarbonate (mg/L)	-	407.	400.
Cadmium (mg/L)	-	1.86	0.61
Calcium (ug/L)	-	112.	104.
Carbonate (mg/L)	-	0.	0.
Chloride (mg/L)	-	207.	190.
Chromium (ug/L)	-	-	-
Copper (ug/L)	-	1.9	2.7
Diss. Organic Carbon (mg/L)	-	4.0	3.7
Diss. Orthophosphate (mg/L)	-	0.186	0.203
Diss. Phosphate (mg/L)	-	0.225	0.197
Field Conductivity (umhos/cm)	-	1587.	1423.
Field pH	-	7.7	-
Fluoride (mg/L)	-	1.0	0.8
Iron (mg/L)	-	0.025	0.035
Lab Conductivity (umhos/cm)	-	1311.	1344.
Lab pH	-	7.8	7.7
Lead (ug/L)	-	-	-
Magnesium (mg/L)	-	25.8	19.2
Manganese (mg/L)	-	4.01	2.92
Nitrate (N) (mg/L)	-	2.24	14.5
Percent Sodium (%)	-	41.6	42.1
Potassium (mg/L)	-	4.10	6.80
Selenium (ug/L)	-	-	-
Sodium (mg/L)	-	127.	114.
Sodium Adsorption Ratio	-	2.80	2.69
Sulfate (mg/L)	-	81.	87.
Sulfide (total) (mg/L)	-	< 0.1	< 0.1
Total Alkalinity (mg/L)	-	333.	328.
Total Diss. Solids (mg/L)	-	766.	783.
Total Hardness (mg/L)	-	385.	340.
Total Phosphate (mg/L)	-	0.230	0.026
Turbidity (NTU)	-	< 1	< 1
Zinc (ug/L)	-	-	-

WELL 25 (Continued)

Parameter	9/29/85	Mean
Ammonium (N) (mg/L)	0.041	0.058
Arsenic (ug/L)	3.1	2.5
Barium (ug/L)	302.	280.
Bicarbonate (mg/L)	428.	412.
Cadmium (mg/L)	0.59	1.02
Calcium (ug/L)	93.7	103.
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	172.	190.
Chromium (ug/L)	-	-
Copper (ug/L)	1.5	2.0
Diss. Organic Carbon (mg/L)	4.0	3.9
Diss. Orthophosphate (mg/L)	0.118	0.169
Diss. Phosphate (mg/L)	0.125	0.182
Field Conductivity (umhos/cm)	1100.	1370.
Field pH	6.1	6.9
Fluoride (mg/L)	0.9	0.9
Iron (mg/L)	0.000	0.02
Lab Conductivity (umhos/cm)	1348.	1334.
Lab pH	7.7	7.7
Lead (ug/L)	-	-
Magnesium (mg/L)	21.0	22.
Manganese (mg/L)	1.73	2.89
Nitrate (N) (mg/L)	4.85	7.19
Percent Sodium (%)	46.9	45.3
Potassium (mg/L)	9.00	6.63
Selenium (ug/L)	-	-
Sodium (mg/L)	131.	124.
Sodium Adsorption Ratio	3.17	2.89
Sulfate (mg/L)	82.	83.3
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	351.	337.
Total Diss. Solids (mg/L)	741.	763.
Total Hardness (mg/L)	321.	349.
Total Phosphate (mg/L)	0.258	0.171
Turbidity (NTU)	2.00	1.0
Zinc (ug/L)	-	-

TABLE 31

WELL 26

Parameter	6/20/85	7/11/85	7/24/85
Ammonium (N) (mg/L)	0.870	0.436	0.672
Arsenic (ug/L)	4.4	4.8	1.0
Barium (ug/L)	153.	119.	146.
Bicarbonate (mg/L)	516.	501.	452.
Cadmium (mg/L)	1.39	0.84	0.35
Calcium (ug/L)	100.	95.4	96.3
Carbonate (mg/L)	0.	0.	0.
Chloride (mg/L)	245.	272.	238.
Chromium (ug/L)	0.50	-	-
Copper (ug/L)	1.8	1.1	2.2
Diss. Organic Carbon (mg/L)	7.1	16.	9.7
Diss. Orthophosphate (mg/L)	0.279	0.298	0.109
Diss. Phosphate (mg/L)	0.325	0.387	0.124
Field Conductivity (umhos/cm)	-	1810.	1879.
Field pH	-	6.3	6.8
Fluoride (mg/L)	1.8	2.1	1.8
Iron (mg/L)	0.497	0.083	0.038
Lab Conductivity (umhos/cm)	1526.	1550.	1792.
Lab pH	7.9	7.4	7.2
Lead (ug/L)	0.6	-	-
Magnesium (mg/L)	26.5	24.2	22.0
Manganese (mg/L)	1.76	1.80	1.43
Nitrate (N) (mg/L)	0.020	0.140	13.8
Percent Sodium (%)	55.8	57.2	58.6
Potassium (mg/L)	5.40	4.70	8.50
Selenium (ug/L)	0.23	-	-
Sodium (mg/L)	210.	209.	216.
Sodium Adsorption Ratio	4.80	4.93	5.17
Sulfate (mg/L)	57.	60.	144.
Sulfide (total) (mg/L)	-	< 0.1	< 0.1
Total Alkalinity (mg/L)	423.	410.	370.
Total Diss. Solids (mg/L)	898.	913.	1010.
Total Hardness (mg/L)	360.	338.	331.
Total Phosphate (mg/L)	0.319	0.356	0.137
Turbidity (NTU)	6.00	< 1	2.00
Zinc (ug/L)	42.	-	-

WELL 26 (Continued)

Parameter	9/29/85	Mean
Ammonium (N) (mg/L)	0.094	0.518
Arsenic (ug/L)	1.2	2.8
Barium (ug/L)	160.	144.
Bicarbonate (mg/L)	536.	501.
Cadmium (mg/L)	0.86	0.86
Calcium (ug/L)	83.0	93.7
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	159.	229.
Chromium (ug/L)	-	-
Copper (ug/L)	2.3	1.9
Diss. Organic Carbon (mg/L)	5.3	9.5
Diss. Orthophosphate (mg/L)	0.138	0.206
Diss. Phosphate (mg/L)	0.164	0.250
Field Conductivity (umhos/cm)	-	1844.
Field pH	-	6.6
Fluoride (mg/L)	1.9	1.9
Iron (mg/L)	0.004	0.156
Lab Conductivity (umhos/cm)	1483.	1238.
Lab pH	7.8	7.6
Lead (ug/L)	-	-
Magnesium (mg/L)	19.1	22.95
Manganese (mg/L)	1.12	1.53
Nitrate (N) (mg/L)	1.68	3.91
Percent Sodium (%)	59.2	57.7
Potassium (mg/L)	8.20	6.70
Selenium (ug/L)	-	-
Sodium (mg/L)	192.	207.
Sodium Adsorption Ratio	4.94	4.96
Sulfate (mg/L)	106.	91.7
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	439.	411.
Total Diss. Solids (mg/L)	839.	915.
Total Hardness (mg/L)	286.	329.
Total Phosphate (mg/L)	0.168	0.245
Turbidity (NTU)	3.00	3.0
Zinc (ug/L)	-	-

TABLE 32

WELL 27

Parameter	6/19/85	7/9/85	7/24/85
Ammonium (N) (mg/L)	-	3.14	2.26
Arsenic (ug/L)	-	0.5	0.7
Barium (ug/L)	-	415.	378.
Bicarbonate (mg/L)	-	487.	508.
Cadmium (mg/L)	-	1.20	0.89
Calcium (ug/L)	-	127.	120.
Carbonate (mg/L)	-	0.	0.
Chloride (mg/L)	-	296.	284.
Chromium (ug/L)	-	-	-
Copper (ug/L)	-	1.7	22.5
Diss. Organic Carbon (mg/L)	-	23.	5.5
Diss. Orthophosphate (mg/L)	-	0.104	0.012
Diss. Phosphate (mg/L)	-	0.044	0.177
Field Conductivity (umhos/cm)	-	2050.	1774.
Field pH	-	6.1	-
Fluoride (mg/L)	-	1.1	1.3
Iron (mg/L)	-	0.048	0.128
Lab Conductivity (umhos/cm)	-	1631.	1781.
Lab pH	-	7.3	7.4
Lead (ug/L)	-	-	-
Magnesium (mg/L)	-	43.3	32.7
Manganese (mg/L)	-	4.61	2.70
Nitrate (N) (mg/L)	-	0.736	4.18
Percent Sodium (%)	-	42.3	44.1
Potassium (mg/L)	-	4.20	6.20
Selenium (ug/L)	-	-	-
Sodium (mg/L)	-	168.	158.
Sodium Adsorption Ratio	-	3.28	3.30
Sulfate (mg/L)	-	72.	86.
Sulfide (total) (mg/L)	-	< 0.1	< 0.1
Total Alkalinity (mg/L)	-	399.	416.
Total Diss. Solids (mg/L)	-	953.	955.
Total Hardness (mg/L)	-	495.	434.
Total Phosphate (mg/L)	-	0.136	0.058
Turbidity (NTU)	-	< 1	5.00
Zinc (ug/L)	-	-	-

WELL 27 (Continued)

Parameter	9/29/85	Mean
Ammonium (N) (mg/L)	1.11	2.17
Arsenic (ug/L)	0.0	0.4
Barium (ug/L)	178.	324.
Bicarbonate (mg/L)	255.	417.
Cadmium (mg/L)	0.82	0.97
Calcium (ug/L)	88.9	112.
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	217.	278.
Chromium (ug/L)	-	-
Copper (ug/L)	1.9	8.7
Diss. Organic Carbon (mg/L)	4.5	11.
Diss. Orthophosphate (mg/L)	0.002	0.039
Diss. Phosphate (mg/L)	0.007	0.076
Field Conductivity (umhos/cm)	1710.	1845.
Field pH	5.9	6.0
Fluoride (mg/L)	1.3	1.2
Iron (mg/L)	0.005	0.060
Lab Conductivity (umhos/cm)	1650.	1687.
Lab pH	7.3	7.3
Lead (ug/L)	-	-
Magnesium (mg/L)	43.9	41.6
Manganese (mg/L)	0.018	2.44
Nitrate (N) (mg/L)	77.1	27.4
Percent Sodium (%)	50.6	45.7
Potassium (mg/L)	6.90	5.77
Selenium (ug/L)	-	-
Sodium (mg/L)	191.	172.
Sodium Adsorption Ratio	4.14	3.57
Sulfate (mg/L)	95.0	84.3
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	209.	341.
Total Diss. Solids (mg/L)	1110.	1006.
Total Hardness (mg/L)	403.	444.
Total Phosphate (mg/L)	0.016	0.07
Turbidity (NTU)	2.00	2.7
Zinc (ug/L)	-	-

TABLE 33

WELL 28

Parameter	6/19/85	7/9/85	7/24/85
Ammonium (N) (mg/L)	23.4	19.1	20.2
Arsenic (ug/L)	45.3	39.4	41.9
Barium (ug/L)	533.	555.	519.
Bicarbonate (mg/L)	603.	565.	577.
Cadmium (mg/L)	0.39	0.70	1.96
Calcium (ug/L)	97.1	88.3	66.9
Carbonate (mg/L)	0.	0.	0.
Chloride (mg/L)	268.	259.	250.
Chromium (ug/L)	1.40	-	-
Copper (ug/L)	0.6	1.3	2.8
Diss. Organic Carbon (mg/L)	10.	9.6	9.4
Diss. Orthophosphate (mg/L)	1.45	0.734	1.56
Diss. Phosphate (mg/L)	1.48	1.62	1.66
Field Conductivity (umhos/cm)	-	-	1640.
Field pH	7.1	-	7.0
Fluoride (mg/L)	2.8	2.6	4.6
Iron (mg/L)	7.55	6.07	5.12
Lab Conductivity (umhos/cm)	1685.	1580.	1601.
Lab pH	7.3	7.3	7.4
Lead (ug/L)	0.0	-	-
Magnesium (mg/L)	27.8	31.7	18.8
Manganese (mg/L)	7.26	6.71	4.94
Nitrate (N) (mg/L)	0.046	0.061	0.041
Percent Sodium (%)	54.2	53.3	60.1
Potassium (mg/L)	5.10	5.60	6.80
Selenium (ug/L)	0.18	-	-
Sodium (mg/L)	196.	185.	170.
Sodium Adsorption Ratio	4.50	4.30	4.73
Sulfate (mg/L)	24.	13.	13.
Sulfide (total) (mg/L)	< 0.1	< 0.1	< 0.1
Total Alkalinity (mg/L)	494.	463.	473.
Total Diss. Solids (mg/L)	915.	862.	810.
Total Hardness (mg/L)	357.	351.	245.
Total Phosphate (mg/L)	1.50	1.52	1.56
Turbidity (NTU)	64.0	70.0	68.0
Zinc (ug/L)	17.	-	-

WELL 28 (Continued)

Parameter	9/27/85	Mean
Ammonium (N) (mg/L)	20.5	20.8
Arsenic (ug/L)	52.8	44.8
Barium (ug/L)	419.	507.
Bicarbonate (mg/L)	581.	582.
Cadmium (mg/L)	0.89	0.98
Calcium (ug/L)	80.1	83.1
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	243.	255.
Chromium (ug/L)	-	-
Copper (ug/L)	1.8	1.6
Diss. Organic Carbon (mg/L)	9.7	9.7
Diss. Orthophosphate (mg/L)	0.760	1.13
Diss. Phosphate (mg/L)	2.24	1.75
Field Conductivity (umhos/cm)	1532.	1586.
Field pH	6.2	6.8
Fluoride (mg/L)	2.6	3.2
Iron (mg/L)	6.38	6.28
Lab Conductivity (umhos/cm)	1620.	1621.
Lab pH	7.3	7.3
Lead (ug/L)	-	-
Magnesium (mg/L)	23.0	25.3
Manganese (mg/L)	5.33	6.06
Nitrate (N) (mg/L)	0.068	0.054
Percent Sodium (%)	58.9	61.1
Potassium (mg/L)	9.00	6.63
Selenium (ug/L)	-	-
Sodium (mg/L)	196.	187.
Sodium Adsorption Ratio	4.95	4.62
Sulfate (mg/L)	23.	18.
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	476.	477.
Total Diss. Solids (mg/L)	861.	862.
Total Hardness (mg/L)	295.	312.
Total Phosphate (mg/L)	2.26	1.71
Turbidity (NTU)	64.0	66.5
Zinc (ug/L)	-	-

TABLE 34

WELL 29

Parameter	6/19/85	7/11/85	7/25/85
Ammonium (N) (mg/L)	0.070	0.183	0.040
Arsenic (ug/L)	3.8	1.6	0.6
Barium (ug/L)	63.	23.	129.
Bicarbonate (mg/L)	261.	263.	236.
Cadmium (mg/L)	1.20	1.45	0.01
Calcium (ug/L)	89.6	81.0	95.4
Carbonate (mg/L)	0.	0.	0.
Chloride (mg/L)	14.9	22.0	29.2
Chromium (ug/L)	1.55	-	-
Copper (ug/L)	3.3	3.8	2.1
Diss. Organic Carbon (mg/L)	2.4	5.4	4.4
Diss. Orthophosphate (mg/L)	0.061	0.033	0.052
Diss. Phosphate (mg/L)	0.029	0.071	0.056
Field Conductivity (umhos/cm)	-	-	896.
Field pH	7.0	6.3	-
Fluoride (mg/L)	0.3	0.3	0.2
Iron (mg/L)	0.034	0.018	0.040
Lab Conductivity (umhos/cm)	724.0	676.0	856.0
Lab pH	7.5	7.6	7.5
Lead (ug/L)	0.0	-	-
Magnesium (mg/L)	26.2	23.9	22.2
Manganese (mg/L)	0.010	0.007	0.003
Nitrate (N) (mg/L)	15.9	13.1	22.6
Percent Sodium (%)	19.9	22.0	18.1
Potassium (mg/L)	1.20	1.20	2.30
Selenium (ug/L)	0.27	-	-
Sodium (mg/L)	38.1	39.2	33.7
Sodium Adsorption Ratio	0.91	0.98	0.81
Sulfate (mg/L)	100.	78.	132.
Sulfide (total) (mg/L)	< 0.1	< 0.1	< 0.1
Total Alkalinity (mg/L)	214.	215.	193.
Total Diss. Solids (mg/L)	469.	433.	532.
Total Hardness (mg/L)	332.	301.	330.
Total Phosphate (mg/L)	0.030	0.084	0.051
Turbidity (NTU)	< 1	< 1	2.00
Zinc (ug/L)	27.	-	-

WELL 29 (Continued)

Parameter	9/27/85	Mean
Ammonium (N) (mg/L)	0.034	0.082
Arsenic (ug/L)	0.0	1.5
Barium (ug/L)	238.	113.
Bicarbonate (mg/L)	284.	261.
Cadmium (mg/L)	1.05	0.93
Calcium (ug/L)	108.	93.5
Carbonate (mg/L)	0.	0.
Chloride (mg/L)	22.9	22.3
Chromium (ug/L)	-	-
Copper (ug/L)	3.2	3.1
Diss. Organic Carbon (mg/L)	5.6	4.4
Diss. Orthophosphate (mg/L)	0.061	0.052
Diss. Phosphate (mg/L)	0.055	0.053
Field Conductivity (umhos/cm)	818.	857.
Field pH	6.3	6.5
Fluoride (mg/L)	0.2	0.2
Iron (mg/L)	0.008	0.025
Lab Conductivity (umhos/cm)	883.0	785.
Lab pH	7.4	7.5
Lead (ug/L)	-	-
Magnesium (mg/L)	26.1	24.6
Manganese (mg/L)	0.014	0.008
Nitrate (N) (mg/L)	23.3	18.7
Percent Sodium (%)	19.9	20.0
Potassium (mg/L)	4.10	2.2
Selenium (ug/L)	-	-
Sodium (mg/L)	43.3	38.6
Sodium Adsorption Ratio	0.97	0.918
Sulfate (mg/L)	141.	113.
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	233.	214.
Total Diss. Solids (mg/L)	588.	471.
Total Hardness (mg/L)	376.	335.
Total Phosphate (mg/L)	0.096	0.065
Turbidity (NTU)	2.00	1.0
Zinc (ug/L)	-	-

TABLE 35

CELL I

Parameter	6/19/85	7/10/85	7/25/85
Ammonium (N) (mg/L)	-	3.46	6.50
Arsenic (ug/L)	-	4.3	4.2
Barium (ug/L)	-	268.	74.
Bicarbonate (mg/L)	-	227.	356.
Cadmium (mg/L)	-	0.70	0.47
Calcium (ug/L)	-	63.3	62.2
Carbonate (mg/L)	-	46.	0.
Chloride (mg/L)	-	255.	260.
Chromium (ug/L)	-	-	-
Copper (ug/L)	-	21.7	6.8
Diss. Organic Carbon (mg/L)	-	30.	21.
Diss. Orthophosphate (mg/L)	-	2.11	2.94
Diss. Phosphate (mg/L)	-	2.43	3.41
Field Conductivity (umhos/cm)	-	1511.	1332.
Field pH	-	8.2	-
Fluoride (mg/L)	-	2.3	2.3
Iron (mg/L)	-	0.044	0.048
Lab Conductivity (umhos/cm)	-	1332.	1434.
Lab pH	-	9.2	8.2
Lead (ug/L)	-	-	-
Magnesium (mg/L)	-	22.5	16.6
Manganese (mg/L)	-	0.090	0.174
Nitrate (N) (mg/L)	-	0.358	0.053
Percent Sodium (%)	-	64.1	63.2
Potassium (mg/L)	-	7.80	8.40
Selenium (ug/L)	-	-	-
Sodium (mg/L)	-	207.	178.
Sodium Adsorption Ratio	-	5.67	5.16
Sulfate (mg/L)	-	78.	76.
Sulfide (total) (mg/L)	-	< 0.1	< 0.1
Total Alkalinity (mg/L)	-	263.	292.
Total Diss. Solids (mg/L)	-	793.	776.
Total Hardness (mg/L)	-	251.	224.
Total Phosphate (mg/L)	-	2.51	3.69
Turbidity (NTU)	-	12.0	4.00
Zinc (ug/L)	-	-	-

CELL I (Continued)

Parameter	9/29/85	Mean
Ammonium (N) (mg/L)	10.2	6.72
Arsenic (ug/L)	2.2	3.6
Barium (ug/L)	338.	227.
Bicarbonate (mg/L)	371.	318.
Cadmium (mg/L)	0.55	0.57
Calcium (ug/L)	63.7	63.1
Carbonate (mg/L)	0.	15.3
Chloride (mg/L)	254.	256.
Chromium (ug/L)	-	-
Copper (ug/L)	11.8	13.4
Diss. Organic Carbon (mg/L)	17.	23.
Diss. Orthophosphate (mg/L)	4.56	3.20
Diss. Phosphate (mg/L)	4.58	3.47
Field Conductivity (umhos/cm)	1284.	1376.
Field pH	6.1	7.1
Fluoride (mg/L)	2.3	2.3
Iron (mg/L)	0.030	0.031
Lab Conductivity (umhos/cm)	1495.	1420.
Lab pH	7.8	8.4
Lead (ug/L)	-	-
Magnesium (mg/L)	17.2	18.8
Manganese (mg/L)	0.043	0.102
Nitrate (N) (mg/L)	0.047	0.153
Percent Sodium (%)	64.5	63.9
Potassium (mg/L)	10.4	8.87
Selenium (ug/L)	-	-
Sodium (mg/L)	193.	193.
Sodium Adsorption Ratio	5.53	5.45
Sulfate (mg/L)	74.	76.
Sulfide (total) (mg/L)	-	-
Total Alkalinity (mg/L)	304.	286.
Total Diss. Solids (mg/L)	795.	788.
Total Hardness (mg/L)	230.	235.
Total Phosphate (mg/L)	4.60	3.6
Turbidity (NTU)	3.00	6.3
Zinc (ug/L)	-	-

TABLE 36

CELL II

Parameter	IIA	IIB	IIC
Ammonium (N) (mg/L)	14.5	13.4	13.2
Arsenic (ug/L)	2.7	3.0	1.2
Barium (ug/L)	58.	68.	51.
Bicarbonate (mg/L)	376.	371.	373.
Cadmium (mg/L)	0.68	0.56	0.36
Calcium (ug/L)	71.9	69.0	70.6
Carbonate (mg/L)	0.	0.	0.
Chloride (mg/L)	263.	248.	243.
Chromium (ug/L)	1.41	1.29	0.85
Copper (ug/L)	11.0	11.7	10.7
Diss. Organic Carbon (mg/L)	-	-	-
Diss. Orthophosphate (mg/L)	4.20	4.22	4.64
Diss. Phosphate (mg/L)	3.98	3.92	3.92
Field Conductivity (umhos/cm)	1483.	1352.	1316.
Field pH	-	-	-
Fluoride (mg/L)	2.5	2.5	2.5
Iron (mg/L)	0.176	0.059	0.060
Lab Conductivity (umhos/cm)	1558.	1470.	1460.
Lab pH	8.2	8.2	8.2
Lead (ug/L)	0.0	2.6	0.0
Magnesium (mg/L)	21.1	18.5	19.0
Manganese (mg/L)	0.173	0.211	0.208
Nitrate (N) (mg/L)	0.390	0.306	0.233
Percent Sodium (%)	64.3	64.7	64.5
Potassium (mg/L)	18.0	18.3	14.5
Selenium (ug/L)	0.02	0.05	0.04
Sodium (mg/L)	222.	210.	214.
Sodium Adsorption Ratio	5.92	5.80	5.82
Sulfate (mg/L)	108.	77.	78.
Sulfide (total) (mg/L)	-	-	-
Total Alkalinity (mg/L)	308.	304.	305.
Total Diss. Solids (mg/L)	891.	825.	824.
Total Hardness (mg/L)	267.	249.	255.
Total Phosphate (mg/L)	4.22	4.30	4.48
Turbidity (NTU)	-	-	-
Zinc (ug/L)	24.	32.	25.

CELL II (Continued)

Parameter	Mean
Ammonium (N) (mg/L)	13.7
Arsenic (ug/L)	2.3
Barium (ug/L)	59.
Bicarbonate (mg/L)	373.
Cadmium (mg/L)	0.53
Calcium (ug/L)	70.5
Carbonate (mg/L)	0.
Chloride (mg/L)	251.
Chromium (ug/L)	1.18
Copper (ug/L)	11.1
Diss. Organic Carbon (mg/L)	-
Diss. Orthophosphate (mg/L)	4.35
Diss. Phosphate (mg/L)	3.94
Field Conductivity (umhos/cm)	1384.
Field pH	-
Fluoride (mg/L)	2.5
Iron (mg/L)	0.10
Lab Conductivity (umhos/cm)	1496.
Lab pH	8.2
Lead (ug/L)	2.6
Magnesium (mg/L)	19.5
Manganese (mg/L)	0.197
Nitrate (N) (mg/L)	0.310
Percent Sodium (%)	64.5
Potassium (mg/L)	16.9
Selenium (ug/L)	0.04
Sodium (mg/L)	215.
Sodium Adsorption Ratio	5.85
Sulfate (mg/L)	87.7
Sulfide (total) (mg/L)	-
Total Alkalinity (mg/L)	306.
Total Diss. Solids (mg/L)	847.
Total Hardness (mg/L)	257.
Total Phosphate (mg/L)	4.33
Turbidity (NTU)	-
Zinc (ug/L)	27.

APPENDIX IV

REDOX POTENTIAL DATA

TABLE 37

Redox measurements expressed in pe units.

WELL NUMBER	7/3/85	7/5/85	7/8/85	7/9/85	7/17/85	7/18/85
1					5.93	
2						4.91
3						4.03
4	1.41		1.44			
5					7.83	
6	1.98		1.98			
7						1.53
8						1.26
9						6.55
10		7.12		5.49		
11						
12		7.14		6.39		
13	3.24		5.54			
14	1.73		1.74			
15						
16						
17	1.28		1.59			
18						
19						
20						
21						
22						
23	7.29		2.30			
24						
25						
26						5.4
27						
28	1.03		1.12			
29						

TABLE 37 - Continued

WELL NUMBER	7/19/85	7/23/85	8/16/85	8/17/85	9/20/85	9/22/85
1				6.02		6.97
2						7.89
3						4.56
4				1.83		2.21
5						
6	1.60		2.30			2.46
7				1.66		2.30
8			1.80			1.66
9				9.40		
10				5.59		
11		7.28		6.14		
12		3.58		4.35		
13	6.73			4.86		
14	1.57		0.76		4.22	
15						
16						
17	1.67		1.91			2.21
18						
19	7.18			4.35		
20	4.65			4.11		
21	5.81			4.11		
22				5.41		
23				4.50		
24		4.92				
25						
26			5.24		5.18	
27						
28				-0.39		
29				0.85		7.57

APPENDIX V

CONTAMINANT TRANSPORT SIMULATION

TABLE 38

Concentrations measured in mg/L for chloride.

A. Results using WMPLUME

Well Number	Location of Nearest Node X,Y	Simulated Concentration	Mean Measured Concentration
1	-	-	-
2	-	-	-
3	-	-	-
4	144, 96	236.	250.
5	96,192	56.3	80.0
6	216, 72	260.	264.
7	144, 96	236.	280.
8	216, 72	260.	273.
9	216, 0	73.0	9.9
10	288, 24	146.	152.
11	360, 72	206.	122.
12	336,120	214.	126.
13	288, 96	241.	216.
14	192, 72	254.	221.
15	24,144	36.0	62.3
16	192, 96	312.	217.
17	192, 96	312.	279.
18	216, 72	260.	-
19	240, 72	252.	213.
20	240, 72	252.	200.
21	288, 96	241.	205.
22	312, 96	232.	201.
23	312, 96	232.	143.
24	336, 48	184.	141.
25	264, 24	147.	190.
26	192, 48	251.	229.
27	192, 72	254.	278.
28	120,120	211.	255.
29	0, 72	0.0	22.3

TABLE 38 - Continued

B. Results using PLUME3D

Well Number	Location of Nearest Node	Simulated Concentration	Mean Measured Concentration
1	-	-	28.9
2	-	-	4.13
3	-	-	242.
4	144, 96, 2	285.	250.
5	96,192, 2	30.5	80.0
6	216, 72, 6	214.	264.
7	144, 96, 6	267.	280.
8	216, 72,10	205.	273.
9	216, 0, 4	29.8	9.85
10	288, 24, 4	78.4	152.
11	360, 72, 4	118.	122.
12	336,120, 8	121.	126.
13	288, 96, 4	162.	216.
14	192, 72, 4	231.	221.
15	24,144, 2	20.3	62.3
16	192, 96, 8	340.	217.
17	192, 96, 2	383.	279.
18	-	-	-
19	240, 72, 6	191.	213.
20	240, 72, 4	193.	200.
21	288, 96, 2	162.	205.
22	312, 96, 4	146.	201.
23	312, 96, 2	147.	143.
24	336, 48, 6	103.	141.
25	264, 24, 2	84.4	190.
26	192, 48, 2	313.	229.
27	192, 72, 2	234.	278.
28	120,120, 2	165.	255.
29	0, 72, 2	0.0	22.3

APPENDIX VI

EPA WASTE STABILIZATION CHARACTERIZATION DATA

TABLE 39 - EPA WASTE STABILZATION LAGOON CHARACTERIZATION DATA

PARAMETER	NDL	MW2	MW4	MW14	MW19	INFC	INF1	INF2	INF3	LL	NDLS	LSC
VOLATILES												
1,1-dichloroetahane	1		1.4	tr							.005	
chloroform	1						1.1	2.7	1.5		.005	
ethylbenzene	1										.005	.005
toluene	1						9.6	11	9.8		.005	.006
trichloroethane	1			tr							.005	
EXTRACTABLE ORGANICS												
phenol	10					10j					33.3	
diethyl phthalate	10					11j					33.3	
1,4-dichlorobenzene	10		.8j			4j					33.3	
METALS												
antimony	5											1.8
arsenic	5		17	28							2.5	5.5
barium	50											
beryllium	5										.5	
cadmium	5			6.6								5.7
chromium	5											36
copper	25			90	26	164						2100
lead	5	16	16	86	14	18				12		223
mercury	.2					3.0						29.6
nickel	50											23
selenium	5										2.5	22
silver	10											95
thallium	2										.5	
zinc	20	30		47	27	131						1340
CONVENTIONAL CONTAMINANTS												
cyanide	.02											
total phenolics	10	10	17		10	137				18.6		
total organic carbon	1	5.5	14	8.7	4.8	110				32.4		
chloride		3.1	229	212	220	776				258		
NH_3-N	.04		18		26	25.4				11.1		
NO_2/NO_3-N	.04	7.3	.09	.08	.14							

tr = trace, j = estimated, below analytical detection limit

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