SITE CHARACTERIZATION, DESIGN, CONSTRUCTION, AND MANAGEMENT OF A FIELD EXPERIMENT TO ASSESS GROUNDWATER CONTAMINATION BY AGRICULTURAL WASTE MANAGEMENT PRACTICES

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By

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ABSTRACT

A research study was undertaken to establish a long term groundwater monitoring program to examine the spatial and temporal effects of agricultural waste disposal on cultivated fields and the effectiveness of several containment barriers. The research project attempts to address the effect of agricultural waste storage facilities and common manure fertilization practices on groundwater quality.

The monitoring program included twenty-five sampling wells of which sixteen wells were dedicated to the spreading experiment with the remaining nine for the storage experiment. Initial background site characteristics, namely; instrumentation, determination of soil index properties, and chemical analyses before and after the first manure spreading were determined. The physical and hydrogeological properties of the site were defined using various in situ and laboratory techniques resulting in a geotechnical soil description and hydraulic characterization. The chemical properties of the groundwater were analyzed using samples obtained from the monitoring well network.

Groundwater quality analysis for the period of May 1992 to December 1992 showed no statistical variation in chemical concentrations for the spreading zone experiment. The chemical concentrations, determined thus far, can be considered as

background readings for the site. The statistical analysis of the groundwater chemistry has not shown any statistically significant chemical change in the groundwater signatures after the first manure application on the spreading or background zone. The water quality changes can not be attributed to the experiment. However, it is likely that the local anomalies are caused by extraneous sources.

Continued site surveillance is necessary to estimate long-term trends, be able to define seasonal or other cycles, and forecast chemical concentrations. A detailed study of the storage experiment is necessary to determine its effects on water quality and overall site properties. The sampling scheme should be modified to statistically determine these effects in future.

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LIST OF ABBREVIATIONS

wt. %	Weight Percent
GCL	Geosynthetic Clay Liner
TDS	Total Dissolved Solids
ppm	Parts Per Million
RCRA	Resource Conservation Recovery Act
W	Monitoring Well
P	Piezometer
IW	Infiltration Well
ST	Storage Tank
ASTM	American Society for Testing Materials
PN	Piezometric Nest
GP	Guelph Permeameter
SWL	Static Water Level
MAC	Maximum Allowable Concentration
EC	Electrical Conductivity
k_s	Soil-Saturated Hydraulic Conductivity
k	Hydraulic Conductivity
n^*	Efficient Porosity

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
BGL	Below Ground Level
k_{fs}	Field Saturated Hydraulic Conductivity
N	Number of Nonmissing Values
N*	Number of Missing Values
TRMEAN	Trimmed Mean
STDEV	Standard Deviation
SEMEAN	Standard Error of the Mean
MIN	Minimum Value
MAX	Maximum Value
Q^1	First Quartile
Q^3	Third Quartile

CHAPTER 1

INTRODUCTION

1.1 Background Overview:

In the past, agricultural waste management practices in Newfoundland have focussed insufficient attention towards their potential environmental impact. The low density of farming enterprises in the province, and their relative isolation from major urban developments, required little demand for regulated waste management procedures. Problems encountered were usually localized in extent, and for the most part, ignored. Solutions to these problems, when deemed unacceptable, were resolved on an individual basis. However, the infringement of suburban developments onto previously zoned agricultural lands has emphasized these issues. Such developments demonstrate that many of the common practices presently in use are inadequate to allow future expansion of adjacent agricultural and residential communities. Government agencies reacting to these growing environmental concerns have provided assistance and regulations to benefit both the public and farmers of this province.

The present study originated from a previous case study of an operational farm where the impact of a liquid manure storage lagoon on groundwater quality was examined (Robinson et al., 1991). There was concern for the degradation of the groundwater quality from such a facility so an intensive monitoring program was implemented. The study revealed elevated nitrate + nitrite concentrations exceeding background levels downgrade from the lagoon. However, based upon the groundwater chemistry it was evident that the contamination level was not as high as expected if no sealing at the base of the lagoon occurred. Robinson et al. (1991) concluded that a significant seal existed at the base of the lagoon. The nature and extent of the lagoon seal could not be clearly assessed. One recommendation from the study was to further explore the phenomenon of self-sealing lagoons either by a physical or biological process under more controlled conditions.

1.2 Project Purpose and Thesis Scope:

The main goal of the overall project, on which this thesis is based, was to establish a long term groundwater monitoring program to examine the spatial and temporal effects of agricultural waste disposal on cultivated fields and the effectiveness of several containment barriers. The research project attempts to address the effect of agricultural waste storage facilities and common manure fertilization practices on groundwater quality. To achieve this goal, the following objectives were devised:

- *performance assessment of various liners; bare soil - no preparation, 5 weight percent (wt. %) bentonite - native soil mix, 10 weight percent (wt. %) bentonite - native soil mix, and a GCL (geosynthetic clay liner) used for waste confinement*, and

- *site characterization of the spreading area test site and storage tanks to delineate the movement of pollutants through the aquifer and determine the retardation effects of the soil mass.*

At the completion of the project, (1994 - 1995 depending upon funding) it is hoped that assistance in refining regulations for storage and disposal of agricultural wastes under indigenous Newfoundland climatic and soil conditions can be given.

A major concern was to choose a site that typified the agricultural, climatic, and hydrogeologic conditions of the Avalon Peninsula. Once the location of the study was determined an initial geotechnical, hydrogeological, and groundwater chemical characterization would be conducted. The ensuing groundwater quality monitoring program associated with the experiments was designed to provide information on the effects of agricultural waste management procedures on the surrounding environment.

The present study is part of the overall project and details the initial (background) properties of the selected site and several aspects of the first phase of the project (instrumentation, determination of soil index properties, chemical analyses before and after the first manure spreading, and initial filling of the storage tanks). The physical and hydrogeological properties of the site were defined using various in situ and laboratory techniques resulting in a geotechnical soil description and hydraulic characterization. The chemical properties of the groundwater were determined using samples obtained from the monitoring well network. Analytical work involved the measurement of pH, conductance, TDS (Total Dissolved Solids), and specific water quality chemistry (ie. orthophosphate, nitrate, ammonia nitrogen, chloride, and calcium and magnesium hardness concentrations).

The objective of this thesis is to extract from these data a general representation of the site in terms of overburden and bedrock physical and hydraulic properties. The observation time required to effectively monitor the behaviour of the site, with respect to pollutant transport, either from manure spreading or storage, greatly exceeds the time frame of this work. However, in light of the initial monitoring period, recommendations can be made regarding the further development of that research.

1.3 Thesis Outline:

The organization of the thesis is designed to logically work through the research project as defined in the present chapter. Hypotheses testing, implementation of the monitoring and testing network, collection and interpretation of data are presented, followed by conclusions and recommendations.

Chapter 2 synthesizes the relevant literature pertaining to case studies on spreading and storage of liquid manure. Previous studies are examined to determine the physiochemical effects of spreading and storing liquid manure on soil and groundwater quality. Following this, the provincial regulations for agricultural waste management are reviewed. The methods and instrumentation for detection and monitoring of contaminant plumes in the vadose zone and the various sealing mechanisms in soils follows. A discussion of the construction techniques and applications of soil-bentonite liners and geosynthetic clay liners ends the chapter.

Chapter 3 describes the site in terms of surficial and bedrock geology and overall physiography. A description of the installation of the groundwater sampling instrumentation, the storage tanks, and liners follows. Finally, a summary of the geotechnical index properties performed on the site soils concludes the chapter.

Chapter 4 describes the site hydrogeology in terms of well hydraulics performed on site and in the laboratory. Site surveys provided detailed surface and bedrock topographic maps and water table contour maps. A tracer test experiment, which is currently in progress, will be used to examine the localized groundwater flow system.

Chapter 5 introduces the results of the groundwater quality monitoring program and a statistical analysis of the data follows. The statistics are used to detect significant chemical variations and trends in the data set and to incorporate the necessary changes in the monitoring program for future data interpretation.

Chapter 6 concludes the thesis with a summary of the results and recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Previous Studies and Existing Legislation:

Designing storage facilities for liquid manure disposal from agricultural operations has become a major concern in North America due to the increased size and mechanization of the industry. In the past, manure applications replenished depleted nutrients from agricultural soils. However, manure disposal from commercial feed lots usually involves high application rates which can deteriorate soil and groundwater quality. To rectify this degradation, provincial governments introduced legislation to protect groundwater supplies and to assist the farmer. This has spurred an interest in revising agricultural waste management practices. One inexpensive solution is an unlined earthen storage lagoon as an alternative to expensive concrete, asphalt, steel, or a geosynthetic clay liner (Barrington et al. 1987a). The research emphasis was directed towards these low-cost earthen storage facilities. Any advances in design could prevent further groundwater contamination and encourage favourable associations between the agricultural community and society.

A number of researchers have investigated groundwater contamination and the self-sealing characteristics from the storage of liquid manure, including; Barrington et al. (1987a,b); Barrington and Madramootoo (1989); Ciravolo et al. (1979); Culley and Phillips (1989a,b); DeTar (1979); Ghaly et al. (1988); Miller et al. (1976); Miller et al. (1985); Patni et al. (1981); Robinson et al. (1991); Rowsell et al. (1985); and Sewell (1978). The focus in these studies has been on waste storage lagoons and this will be reflected in the literature review.

Culley and Phillips (1989b) monitored three pairs of small-scale manure storages, 10 m^3 in volume and about 1.5 m deep, constructed in sand, sandy loam, and clay loam. They analyzed for inorganic nitrogen, phosphorous, and mineral content of water in the undisturbed clay underlying each pair of earthen storages. They observed an increase in nutrient concentrations over time beneath all the earthen storages. The greatest increases were observed beneath the storages that were dug in acidic sand. No changes in inorganic nitrogen were reported, however phosphorous showed considerable increases. They concluded that the small-scale storages did not effectively self-seal over the five-year period of the study.

Miller et al. (1985) conducted a case study on a 4500-head beef cattle feeding operation in Wilmot Township, Waterloo County, Ontario. The waste storage pond located on glacial outwash encompassed a surface area of 2 hectares with an approximate volume of 15 000 m^3. The groundwater sampling program consisted of fourteen monitoring wells extending to a maximum depth of 13.7 m below ground level. They concluded that there was an initial flushing of the storage pond into the underlying groundwater for the first eight weeks after filling with liquid manure. This was followed by a significant input reduction after the eighth week. There was conclusive evidence that the pond was effectively sealed within 12 weeks of the first addition of dilute dairy manure into the coarse textured sand bottom of the holding facility (Miller et al. 1985).

Patni et al. (1981) examined groundwater quality beneath cast-in-place reinforced concrete liquid manure storages that were constructed without special consideration for the porosity of the concrete. The study also examined the groundwater quality from heavy land applications of manure in excess of crop requirements. Both the storage and spreading experiments were located on poorly-drained, dark-grey clay loam, underlain by silty marine clay. The groundwater quality in the vicinity of the storages was analyzed from a monitoring well network for a period of seven years and from the manure disposal field for a period of three years. There were two major conclusions from this study: (1.) groundwater pollution potential from below-grade, concrete, liquid manure storages, built without special construction precautions for leakage appeared to be low, and (2.) the practice of manure disposal on land in excessive amounts had potential to excessive load groundwaters in NO_3-N and NH_4-N (Patni et al., 1981).

Robinson et al. (1991) examined a manure lagoon located on a private dairy operation near St. John's, Newfoundland. They inferred the existence of a seal beneath the lagoon through the attenuation of the major chemical constituents emanating from the lagoon into the groundwater aquifer beneath. The soils in the area can be described as sandy to gravelly sandy glacial tills with little or no fines. They assumed that cation exchange was not a dominant process by which ionic concentrations were lowered in the monitoring wells down gradient from the lagoon. Adsorption was also ruled out as a dominant attenuation process because there was little difference between ionic concentrations in the lagoon and the concentrations determined in the monitoring wells. Consequently, advection and mechanical dispersion were favoured to dominate the concentration reductions observed in the monitoring wells, confirming the existence of a seal at the soil-manure interface in the lagoon. However, to what extent, or if the effectiveness could be improved, was not determined by their study.

Legislation throughout the country requires that a minimal storage capacity of liquid manure be maintained to prevent deleterious effects from runoff and seepage into surface and groundwaters. Each of the provinces have implemented regulatory programs covering the management practices of manure. A complete list of these agencies can be found in the Canada Animal Manure Management Guide, Publication 1534. The regulatory emphasis has shifted from enforcing tough detailed regulations to managing farm pollution problems through guidelines and education programs. An increasing number of provinces are adopting a certificate of compliance program wherein written approvals are given to operations that comply with recognized standards.

In Alberta, the objectives of the guidelines for the design of earthen manure storages (Agdex 729-2, 1984) are: (1.) provide a sufficient storage period to allow flexibility for disposal, (2.) watertight characteristics to prevent seepage into surface water and groundwater, (3.) having suitable access for ease of manure removal, and (4.) proper location with respect to neighbours. Alberta Agriculture uses a six month storage volume as a basis for calculating the size of a storage facility.

Ontario and Quebec have legislated design requirements for earthen manure storage facilities based on the field saturated hydraulic conductivity value, k_{fs}. The Agricultural Code of Practice for Ontario requires that a 6-month storage capacity be provided (Miller et al. 1985). No certification will be granted to an operation if this criterion is not achieved. These guidelines are explained in Barrington and Broughton (1988) and are summarized as follows;

In 1982, the Ontario Government established guidelines for earthen manure storage facilities requiring a maximum *k* value of 10^{-6} m/s; a minimum bedrock or aquifer depth of 1.0 m from the bottom of the reservoir; and a soil texture finer than a sandy loam.

The Quebec Ministry of Environment required a soil *k* value equivalent to that of concrete structures (10^{-9} m/s). In 1983, municipal waste water ponds guidelines permitted a maximum nitrogen seepage into the soil of 0.6 $m^{-2}day^{-1}$ for waste waters of 20 - 30 parts per million (ppm) N. Extrapolating for dairy wastes these municipal guidelines suggest a k_{f_s} value of 10^{-7} m/s.

In Nova Scotia, a minimum of 7 months storage in a properly sealed storage structure that is not susceptible to leaking, runoff, or overflowing (Nova Scotia Department of Agriculture and Marketing, 1991) is required prior to operational approval. The proper design of the storage facility can be obtained from agricultural engineers at the department. The aim of these guidelines is to convert the more than 1.6 million tons of manure that is produced annually into fertilizer that can used in good soil management practices.

In Newfoundland, a minimum of 6 months storage in an impervious lagoon system is required for winter accumulation (Newfoundland Department of Rural, Agricultural and Northern Development, and Consumer Affairs and Environmental Branch, 1980). The aim of the Newfoundland document is to provide information to existing and future operators in the areas of good agricultural practice and environmental protection.

2.2 Methods and Instrumentation for Detection and Monitoring of Contaminant Fronts:

2.2.1 Vadose Zone:

Monitoring in the vadose zone can be used as an early detection mechanism for contaminants entering a groundwater aquifer. According to Fetter (1988), the vadose zone can be defined as:

> The zone between the land surface and the water table. It includes the soil (root) zone, intermediate vadose zone, and capillary fringe. The pore spaces contain water at less than atmospheric pressure, as well as air and any other gases. Saturated bodies, such as perched groundwater, may exist in the vadose zone.

In the past, the main emphasis in the majority of monitoring programs at waste management sites has been on groundwater sampling in the free-water (saturated) zone. Recently, the benefit of early contaminant detection in the vadose zone has been realized. In the United States, federal regulators legislate vadose zone monitoring [Subtitle C of the RCRA (Resource Conservation Recovery Act), section 264.278 of 40 CFR, Part 264] for hazardous waste land treatment sites (Wilson, 1990).

The vadose zone has been subdivided into three regions: soil zone, intermediate zone, and the capillary fringe (Davis and de Wiest, 1966). The contact between the soil zone and intermediate vadose zone is generally marked by a gradual transition from weathered to unweathered geologic material (Everett et al., 1984). This zone is generally under negative pressure, therefore water movement in this zone is generally in the unsaturated state. Beneath the intermediate zone, the capillary fringe merges with the underlying saturated material of the principal water bearing formation. In general, the capillary fringe is thicker in finer-grained geologic materials.

Many researchers such as Everett et al. (1984), Greenhouse and Pehme (1991), Reinhard and Parke (1989), Wilson (1982), Wilson (1983), and Wilson (1990) have investigated vadose zone monitoring, its instrumentation, and its usefulness as an early detection mechanism from aquifer contamination. Wilson (1982) defines the motivation behind monitoring in the vadose zone as to characterize the flux and velocity of wastewater during transit to the water table. He defines three stages of liquid transmission in the vadose zone: infiltration, percolation, and recharge. In general, infiltration is the flow of water downward from the land surface and through the upper soil layers. Percolation is a flow process in the vadose zone through conducting channels (pores or fractures). Lastly, recharge occurs in an area with downward components of hydraulic head gradient (ie. liquid moves into the groundwater zone). The reader is referred to Wilson (1982) for a description of the field methods used for determining the rate of liquid transmission in the vadose zone.

Indirect (non-sampling) methods (See **Appendix A** for a summary of the sampling techniques) are used to detect pollutants by measuring parameters that occur above the background concentrations of the regional groundwater. This method does not physically remove material from the test site. Direct sampling techniques for detecting pollutant movement in the vadose zone are grouped into solids and solution sampling methods (Wilson, 1983). These techniques differ from the non-sampling methods in that actual samples are obtained for laboratory analysis.

2.2.2 Free - Water (Saturated) Zone:

Groundwater monitoring wells are used to detect a contaminant once it reaches the groundwater, and to effectively direct remediation efforts. The science of groundwater sampling has advanced greatly in recent years, not only in our understanding of the techniques to be used, but in the development of materials and equipment used in the sampling process (Fetter, 1988). There are many references to sampling in the saturated zone, the methods used to locate contaminant plumes, design and construction of monitoring wells, and the procedures used to clean up contaminated aquifers [Domenico and Schwartz (1990); Driscoll (1986); Environment Canada (1983); Everett et al. (1984); Fetter (1988); Freeze and Cherry (1979)]. The sampling of groundwater from the saturated zone of the subsurface can provide information on the extent of aquifer contamination. Groundwater contamination is more difficult to detect and remediate than surface-water pollution because it moves more slowly and requires specialized monitoring to predict the path and rate of contaminant movement. Therefore, sampling procedures can be moderately complex and variable, depending on the individual hydrogeologic situation. Sampling wells are commonly used to obtain "representative" groundwater samples. Sampling systems that are capable of providing point samples of fluid from the zone of saturation include: (1.) nests of conventional standpipe piezometers, (2.) various multilevel devices installed in a single borehole, and (3.) a packer arrangement that can be moved to various positions in an uncased borehole in rock or cohesive sediments [Cherry, (1983) cited in Domenico and Schwartz, (1990)]. A summary of the techniques used in retrieving groundwater samples is illustrated in **Appendix A**.

2.3 Leakage Control and Liner Construction Techniques:

2.3.1 Sealing Mechanisms in Soils:

The mechanisms of soil sealing by manure can be classified into three distinct groups: physical, biological, and chemical (Barrington and Broughton, 1988). The most predominant sealing mechanism is the physical plugging of the soil pores by organic particles at the soils surface [Barrington et al. (1987a,b); Barrington and Madramootoo (1989); Rowsell et al. (1985)]. Biological and chemical mechanisms are significant at temperatures exceeding 15°C and tend to be secondary in effect compared to physical plugging [Barrington et al. (1987a); Barrington and Madramootoo (1989)]. Moreover, the physical seal occurred in an organic mat accumulating over the soil-manure interface based upon column tests (Barrington et al. 1987b). The degree of sealing is, however, inconclusive. Some installations seal proportionally better than others and the seal formation takes considerable time, during which a significant amount of seepage could impair groundwater quality (DeTar, 1979).

In general, the sealing of soils by manure occurs primarily as a physical process governed by the size of particulate matter clogging the soil voids (Barrington et al. 1987a). One researcher indicated that secondary sealing may be caused by secretions from anaerobic microorganisms, [Hills, (1976) cited in Rowsell et al. (1985)]. However, the physical sealing is enough to attain acceptable infiltration rates. Once a seal is formed it is essential to protect it from any harmful perturbations, such as; drying and cracking, degassing by organic breakdown, freezing and thawing cycles, and fluctuations in the water table (Ciravolo et al. 1979). These disturbances degrade the seal, thus reducing its performance. It has been determined that the soil saturated hydraulic conductivity (k_s) is not the critical soil earthen storage facilities [Barrington and Madramootoo (1989); Culley and Phillips (1989)]. Rather, they define soil texture, water table regime, and chemical transformations within the soil as the major contributing factors.

2.3.2 Soil-Bentonite Liners:

Soil-bentonite liners have frequently been used as hydraulic barriers for waste or waste-water impoundments. The first step to effectively design a soil-bentonite liner is to select a soil and a bentonite and then perform permeability tests to find the optimum bentonite content to achieve the desired degree of imperviousness (Chapuis, 1990a). Chapuis also suggests that once the correct ratio of soil to bentonite is chosen then a slightly higher bentonite content be used because less homogeneous mixing conditions are attainable in the field.

Chapuis (1990a) proposed a method for predicting the hydraulic conductivity of a soil-bentonite mix based on several parameters: bentonite content, degree of saturation, grain-size distribution, porosity, and compaction Proctor curve. From this methodology the performance of in situ soil-bentonite liners can be predicted based on the variabilities of the bentonite and soil properties. See **Appendix A** for further discussion on soil-bentonite liners.

2.3.3 Geosynthetic Clay Liners as Low Permeability Barriers:

To address the problem of leakage from waste-containment facilities in a cost effective manner, one of the first materials ever used as liners or coverings was compacted clay. With the advent of geomembranes and soil-bentonite mixtures new designs were fabricated this way. Furthermore, promising systems can now be designed using a geosynthetic clay liner (GCL) - a geosynthetic/bentonite composite. GCL's can be an integral part of multiple barrier systems and may even replace low, hydraulic conductivity, compacted soil liners (Estornell and Daniel, 1992). See **Appendix A** for a summary of the available geosynthetic clay liners.

GCL's are liners manufactured with bentonite clay sandwiched between two geotextiles or adhered to a geomembrane. The bentonite clay can be bonded to the geotextile with a dissolvable adhesive or it can fixed in place using a needle-punched non-woven geotextile. The limiting factor in a GCL's performance is the bentonite layer. This clay experiences a high degree of swelling when it is exposed to liquids and is very flexible when fully hydrated. Another characteristic of a GCL is its ability to self seal around minor irregularities or punctures. Some manufacturers proclaim that GCL's offer the nearest solution to a zero-leakage liner incorporating the sealing properties of bentonite and the strength of geosynthetics (Jagielski, 1992).

CHAPTER 3

SITE CHARACTERIZATION AND INSTRUMENTATION

3.1 Introduction:

The study site is located close to St. John's on the Avalon Peninsula of Newfoundland at coordinates 47° 31' North latitude and 52° 47' West longitude (see **Figure 3.1**). The larger study area, the Agriculture Canada Research Station, comprises a portion of the Waterford River Basin. The basin can be divided into five major categories: (1.) forested or natural areas, (2.) agricultural areas, (3.) urban or sub-urban areas, (4.) recreational areas, (5.) other areas such as ponds, bogs, barrens, river channels, gravel pits etc. (Robinson and Gibb, 1985). The study site is located in an agricultural zone adjacent to the Waterford River. A complete characterization of the site determined from existing reports, geotechnical investigations, groundwater monitoring, and aquifer hydraulics follows.

The Research Station was selected based upon the following criteria:

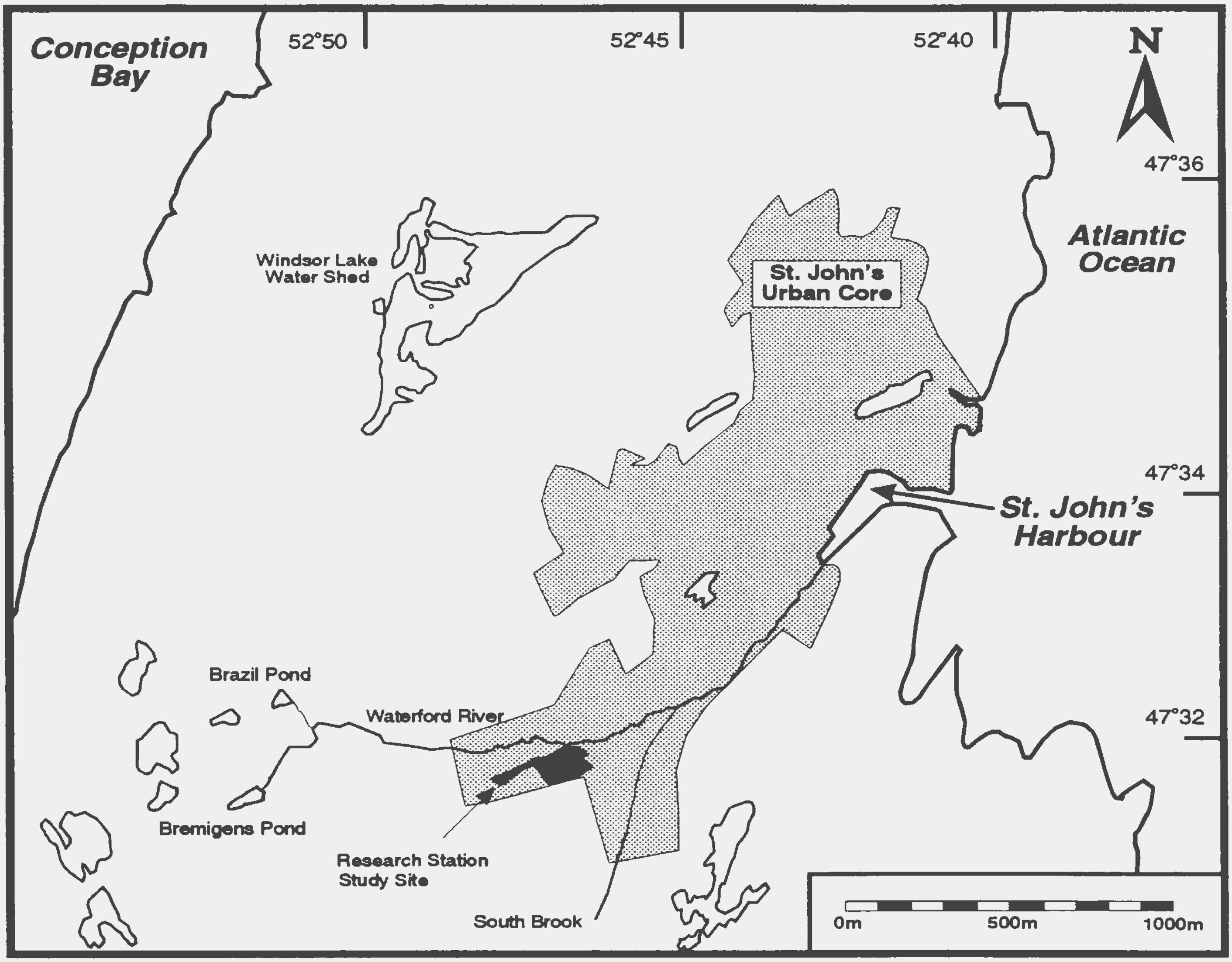


Figure 3.1 Location map of study site.

- *representative of Newfoundland soil and climatic conditions*,

- *three to four metres of overburden with a hydraulic conductivity of* ≈ *10^{-5} cm/s (critical k_{fs} value used in Ontario and Quebec regulations)*,

- *proximity to St. John's, since a major dairy producing sector of Newfoundland is located on the Avalon Peninsula*,

- *serviceability and accessability of the site*, and

- *long term availability and ownership.*

The site met, or exceeded, in certain instances the criteria set forth in the site selection process. The research station, with an area of 825,000 m^2 (≈ 83 hectares) is bounded by the Waterford River to the north and one of its tributaries to the south.

The research station includes both the federal and provincial agriculture branches. This provided rapid response to any technical or logistic problems encountered. A field plot, 7 B, located at the northeast corner of the station, with an area of 16188 m^2 (≈ 1.6 hectares), was dedicated for the two year project duration (see **Figure 3.2**).

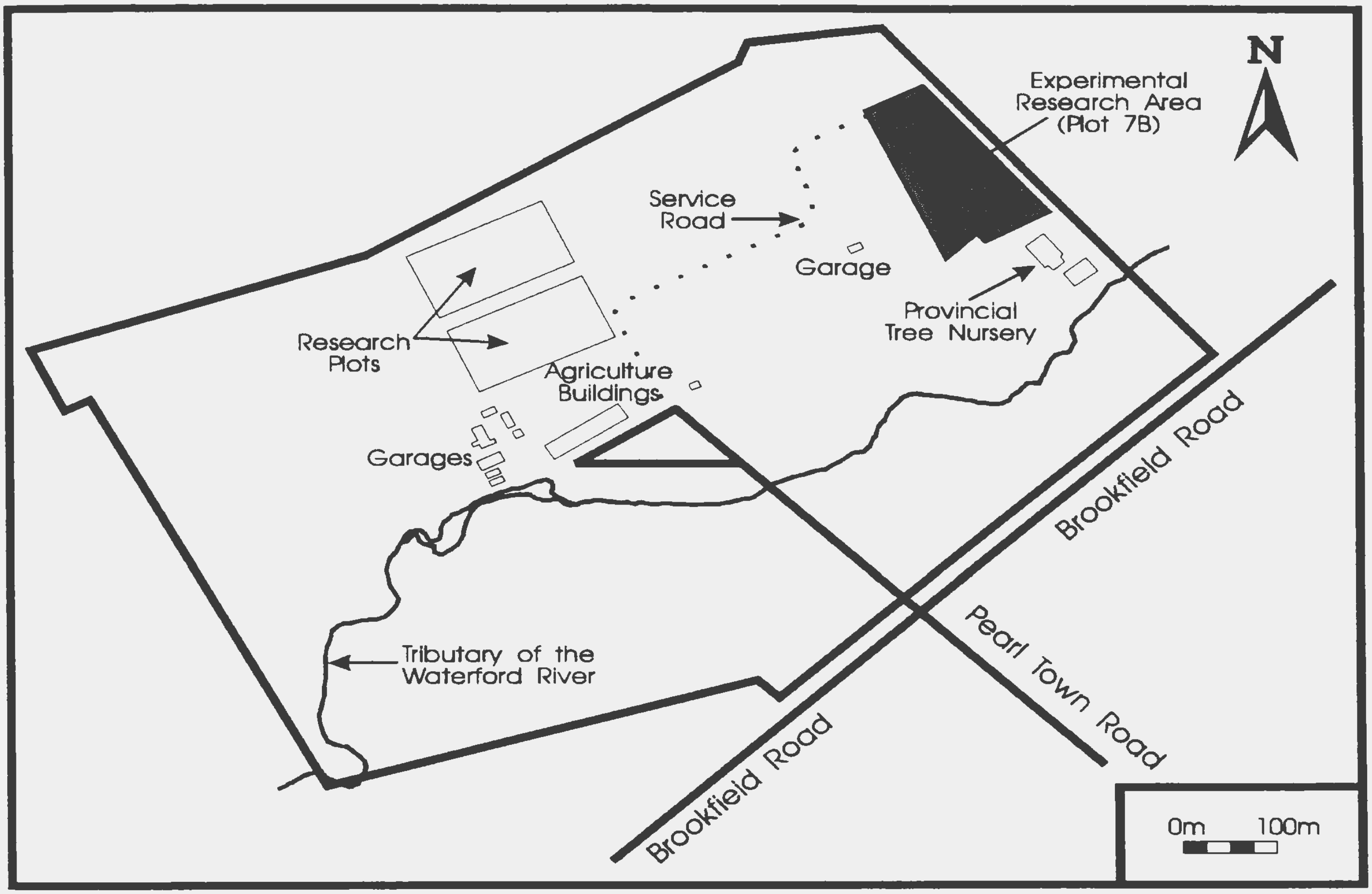


Figure 3.2 Experimental study site location - field plot 7B.

Necessary permits were secured from the former St. John's Metropolitan Board (city of St. John's now) and the Newfoundland Department of Environment and Lands. These approvals for operation depended upon a continuous sampling program of the nearby rivers to identify any possible change in water quality caused by the project.

There are two continuing experiments on the Research Station site, namely, (1.) a spreading experiment which will attempt to isolate the effects of spreading liquid manure over cultivated fields, and (2.) long term storage of liquid dairy manure in four shallow, low capacity, storage tanks. The second experiment commenced in November 1992.

3.2 Local Setting:

3.2.1 Surficial Geology:

The surficial geology and geomorphology of the Avalon Peninsula have been described in detail by Batterson (1984), Henderson (1972), Heringa (1981), and King (1991). The following excerpt will pertain specifically to the experimental site geomorphology and soils contained therein.

The study area is covered by a thin (1-3 m), discontinuous, glacial veneer of till and/or vegetation. The till primarily fills small bedrock valleys or depressions and usually mimics bedrock topography. The glacial deposits in the area are classified as terraced tills which consist of a series of step-like terraces with scarp faces and sub-horizontal surfaces cut in till. Batterson (1984) documents the best exposure along the Waterford River valley although terraced tills constitute a very small portion of the surficial geology of the St.John's area. Thin glacial and glaciofluvial deposits occur along the Waterford River extending from Donovan's to St. John's harbour. Flood plain deposits of fluvial silts, gravel, and sands are localized along river banks and streams in the area.

The study area soils comprise two major orders; podzols and gleysolics. Podzolic soils cover 75% of the greater Waterford River Basin (Batterson, 1984). These soils are well to imperfectly drained soils that develop under coniferous and mixed forest vegetation and heath in cold to temperate climates (Heringa, 1981). They are acidic and characterized by an Ah horizon below the organic surface layers (L-H). These layers are generally leached, light-coloured horizons (Ae) of varying thickness. The soils have Podzolic B horizons consisting of organic matter combined in varying degrees with iron and aluminum. A complete characterization of the soils is given in **Appendix C**. For more information on soil classification and definition of terms the reader is referred to The Canadian System of Soil Classification (1978).

3.2.2 Bedrock Geology:

The bedrock geology of the St. John's area has been reviewed extensively by Bruckner (1979) and King (1984, 1986, 1990). The subsequent description of the bedrock geology summarizes King (1990).

The site is located in the Fermuse Formation of the St. John's Group which is approximately 1400 m thick in the southern Avalon Peninsula and thins to 300 m towards St. John's in the north. The formation is comprised of three main lithofacies consisting mainly of interbedded sandstones and shales with sedimentary depositional features visible. All of the lithofacies conformably overlie one another. Tectonic faulting and folding complicate the structure on a local scale.

3.2.3 Physiography:

The physiography of the Avalon Peninsula has been discussed in detail by Batterson (1984), Bruckner (1979), Henderson (1972), Heringa (1981), Robinson (1986), and Robinson and Gibb (1985). The following is an excerpt of these combined works that pertains to the study site.

The Federal Research Station with an area of 0.83 km^2 is contained in the Waterford River Basin (approximate area 61 km^2) located on the eastern boundary of the city of Mount Pearl. Rising from Bremigens Pond at an elevation of approximately 168 m above sea level, the main channel of the Waterford River flows north-easterly over a distance of about 14.2 km to discharge into salt water in St. John's Harbour (Robinson and Gibb, 1985). The main tributary, South Brook is bordered by farmland and has its source about 2 km south of Bremigens Pond. The principal watershed and land use features are listed in **Table 3.1**.

Surface drainage from the study site flows towards the Waterford River. There is little significant relief over the area (maximum elevation 123.3 m) with gently rolling hills sloping towards the east. Agricultural activity bounds the site on the east, west and south with residential housing towards the north. The general groundwater flow direction for the study area is towards St. John's harbour in the east.

The climate of the Avalon Peninsula is dominated by the arctic waters of the Labrador current and to a lesser extent by continental North America. This current produces cooler summers and milder winters typified by frequent thawing periods. The local topography with its many bays and inlets influences the generation of local weather patterns. Evaporation and general cooling effects are caused by the

Table 3.1
Watershed characteristics and land use of the Waterford River Basin. [Modified after Robinson and Gibb (1985), and Robinson (1986)]

Total Drainage Area	61	km^2
Mean Width	4	km
Axial Length	14	km
Basin Perimeter	40	km
Maximum Relief	259	m
Channel Slope	36	m/km
Length (Waterford River)	14	km
Length (South Brook)	10	km
Length (Tributaries)	34	km
Drainage Density	1.0	km/km^2
Forestry	27.7	km^2
Agriculture	3.88	km^2
Urban and Suburban	12.4	km^2
Recreation	0.81	km^2
Other (Ponds, Bogs, Barren River Channels, Gravel Pits, etc.)	6.53	km^2

prevailing westerly and southwesterly winds in the region. Frequent cloud cover and fog greatly reduces the amount of direct sunshine on the peninsula. The mean annual temperature is 5.0 °c, the average yearly precipitation is 1595 mm, the average yearly number of frost-free days is 130, and the estimated average annual evaporation is 381 mm.

Climatological data was obtained from the Agriculture Canada Federal Research Station in Mount Pearl. A thirty-year precipitation summary for the station is shown in **Table 3.2**. The study site is located within 120 m of the meteorological station. Detailed climatological data is presented in **Appendix B**.

3.3 Installation and Instrumentation of Monitoring Network:

The groundwater instrumentation for the project consisted of 25 monitoring wells with 12 located on the spreading zone, 4 between the spreading zone and storage tanks, and 9 located around the storage tanks (See **Appendix C** for map).

3.3.1 Sampling Well Installation:

There were three distinct drilling phases which fulfilled the mandate of the sampling well program.

Table 3.2
1950-1990 climate normals St. John's West CDA
Federal Research Station (47° 31' N 52° 47' W/O, 114 m)
Courtesy Atmospheric Environment Services, Environment Canada.

	Jan	Feb	Mar	Apr	May	Jun
TEMPERATURE						
DAILY MAXIMUM (°C)	-0.6	-1.0	1.3	5.2	10.7	16.1
DAILY MINIMUM (°C)	-7.5	-8.3	-5.4	-1.6	2.1	6.4
DAILY MEAN (°C)	-4.0	-4.6	-2.0	1.8	6.4	11.3
EXTREME MAXIMUM (°C)	14.4	14.0	16.1	22.0	26.1	28.9
DATE	976/18	984/05	962/31	986/23	972/30	976/17
EXTREME MINIMUM (°C)	-23.3	-25.6	-23.5	-13.0	-7.2	-4.4
DATE	957/17	975/03	986/10	978/05	964/06	970/02
DEGREE-DAYS						
ABOVE 18 °C	0.0	0.0	0.0	0.0	0.0	2.0
BELOW 18 °C	685.3	639.5	620.7	486.1	359.4	202.5
ABOVE 5 °C	0.9	0.9	2.0	10.3	72.2	191.9
BELOW 0 °C	139.7	142.2	87.3	14.6	0.4	0.0
PRECIPITATION						
RAINFALL (mm)	90.9	78.8	88.6	91.7	98.6	92.3
SNOWFALL (cm)	85.3	73.8	53.8	31.8	8.8	1.2
PRECIPITATION (mm)	179.4	154.9	146.3	124.5	107.0	93.5
EXTREME DAILY RAINFALL (mm)	68.6	58.2	56.9	109.6	72.4	71.9
DATE	954/07	970/28	961/22	986/11	985/24	973/17
EXTREME DAILY SNOWFALL (cm)	78.2	50.8	50.8	42.0	27.9	25.4
DATE	966/09	959/15	961/21	978/14	968/14	975/10
EXTREME DAILY PRECIPITATION (mm)	78.2	72.0	73.7	109.6	72.4	71.9
DATE	966/09	986/15	961/21	986/11	985/24	973/17
MONTH-END SNOW COVER (cm)	27	33	17	2	0	0
DAYS WITH						
MAXIMUM TEMPERATURE > 0 °C	13	11	19	27	31	30
MEASURABLE RAINFALL (mm)	8	6	9	11	13	13
MEASURABLE SNOWFALL (cm)	13	12	10	5	1	N/R
MEASURABLE PRECIPITATION	19	16	17	14	14	13
SUNSHINE (Hrs)	74.7	87.9	107.1	117.5	162.1	181.5

Table 3.2 (cont'd)

	Jul	Aug	Sep	Oct	Nov	Dec	Year
TEMPERATURE							
DAILY MAXIMUM (°C)	20.5	19.7	15.7	10.8	6.4	1.7	8.9
DAILY MINIMUM (°C)	11.0	11.3	7.8	3.8	0.2	-4.5	1.3
DAILY MEAN (°C)	15.8	15.6	11.8	7.3	3.3	-1.4	5.1
EXTREME MAXIMUM (°C)	31.1	30.5	27.2	23.3	19.5	17.2	
DATE	975/20	978/13	961/24	976/07	984/06	957/12	
EXTREME MINIMUM (°C)	-1.1	0.6	-1.7	-5.6	-11.1	-20.6	
DATE	952/04	968/21	965/20	974/23	951/26	970/18	
DEGREE-DAYS							
ABOVE 18 °C	16.8	14.7	1.3	0.0	0.0	0.0	35
BELOW 18 °C	86.5	90.0	187.7	331.1	441.1	602.9	4733
ABOVE 5 °C	333.3	327.6	203.7	88.7	26.9	4.0	1262
BELOW 0 °C	0.0	0.0	0.0	0.2	10.0	77.8	472
PRECIPITATION							
RAINFALL (mm)	77.8	113.8	117.0	149.2	133.4	107.5	1239.6
SNOWFALL (cm)	0.0	0.0	0.0	2.3	18.7	53.3	329.0
PRECIPITATION (mm)	77.8	113.8	117.0	149.0	152.8	163.5	1579.5
EXTREME DAILY RAINFALL (mm)	71.4	90.9	77.0	100.3	76.2	78.7	
DATE	958/20	971/05	990/25	953/06	981/26	966/20	
EXTREME DAILY SNOWFALL (cm)	0.0	0.0	0.0	15.2	30.0	45.7	
DATE	990/31	990/31	990/30	965/29	986/19	954/29	
EXTREME DAILY PRECIPITATION (mm)	71.4	90.9	77.0	100.3	76.2	78.7	
DATE	958/20	971/05	990/25	953/06	981/26	966/20	
MONTH-END SNOW COVER (cm)	0	0	0	0	1	12	
DAYS WITH							
MAXIMUM TEMPERATURE > 0 °C	31	31	30	31	28	19	302
MEASURABLE RAINFALL (mm)	13	14	14	18	16	10	145
MEASURABLE SNOWFALL (cm)	0	0	0	N/R	3	10	55
MEASURABLE PRECIPITATION	13	14	14	18	18	18	188
SUNSHINE (Hrs)	224.8	191.8	143.0	104.7	72.3	60.1	1527.4

PHASE I

Phase I commenced on July 8, 1991 and was completed on August 21, 1991. A JKS-15 'Winkie' Drill, owned by Memorial University was used for this first phase. This lightweight, portable, core drill was selected because of its adaptability to either auger or diamond drilling depending upon the overburden conditions.

This drill was used to install four shallow overburden groundwater sampling wells (W1 to W4) situated on the dedicated spreading area of the site. Initially the drill was equipped with 76 mm (3 in) O.D. hardened steel augers with carbide cutting teeth to advance the borehole. However, due to the instability of the overburden soil formations the hole would not remain open and free of debris long enough to install the sampling well. To overcome this problem the drill was fitted with a core barrel and diamond bit that could advance a 57 mm (2.25 in) borehole. The advantage of this configuration was that a 57 mm (2.25 in) temporary casing kept the hole free of debris so the sampling well could be installed. This procedure proved far superior to the auger method but drilling through the boulders was difficult because the core barrel was repeatedly plugged by rock debris. As a result, the borehole became progressively out of vertical alignment each time it was necessary to retrieve the blocked core barrel. It was considered very impractical to continue drilling in this manner since the number of useful sampling wells installed combined with the number of man hours for installation proved far too costly. This, in turn, led to the second phase of drilling.

PHASE II

Phase II of drilling commenced on January 13, 1992 and concluded on January 16, 1992. It was agreed that a commercially air-operated drill rig, a Geo-Drill MK-15, would be used because of its mobility in snow and adverse winter weather conditions and its lightweight footprint. This drill was used to construct sampling wells W5 to W19. A 20 cm (8 in) diameter rotary drill bit advanced the boring to the overburden-bedrock interface. A 20 cm (8 in) temporary casing was simultaneously installed to keep the borehole open, then a 15 cm (6 in) downhole hammer was used to advance the borehole into the bedrock to a depth of approximately 4 m. Each borehole contained two sampling wells completed at two distinct elevations. One sampling well was located at the bottom of the borehole (in the bedrock) while the other was situated at the bedrock-overburden interface.

The sampling well assembly consisted of schedule 80 PVC pipe 25 mm (1 in) in diameter with horizontal perforations over a 30 cm (12 in) length from one end. A geotextile filter, Texel® 7611, that covered the perforated interval was secured with nylon cable ties. The exposed end of the sampling well was capped with a PVC female adaptor and a male coupling assembly. Covering these PVC fittings was a 51 mm (2 in) steel conduit pipe secured by a 6 mm (0.25 in) hardened galvanized steel bolt. This protective conduit served a dual purpose of preventing vandalism or accidental pollution of the groundwater as well as allowing the pressure inside the sampling well to continually equilibrate with the atmosphere. A typical shallow well is shown in **Figure 3.3**.

Once in place, #00 silica sand was emplaced around the perforated end of the PVC pipe to an average height of 45 cm (18 in) for the shallow sampling wells and 160 cm (63 in) in the deeper bedrock wells. The sand was sealed with a 45 cm (18 in) thick bentonite plug (Enviroplug® Medium) forming an annular seal above the perforated interval. The remainder of the annulus was filled with drill cuttings to the surface. The cuttings were mounded around the sampling well. After the sampling wells were installed, each was developed to enhance the flow of the groundwater aquifer and to minimize the turbidity of subsequent samples.

PHASE III

Phase III of the drilling program took place on June 2, 1992. The remainder of the multi-borehole sampling wells W20 to W25 were installed using a Speedstar

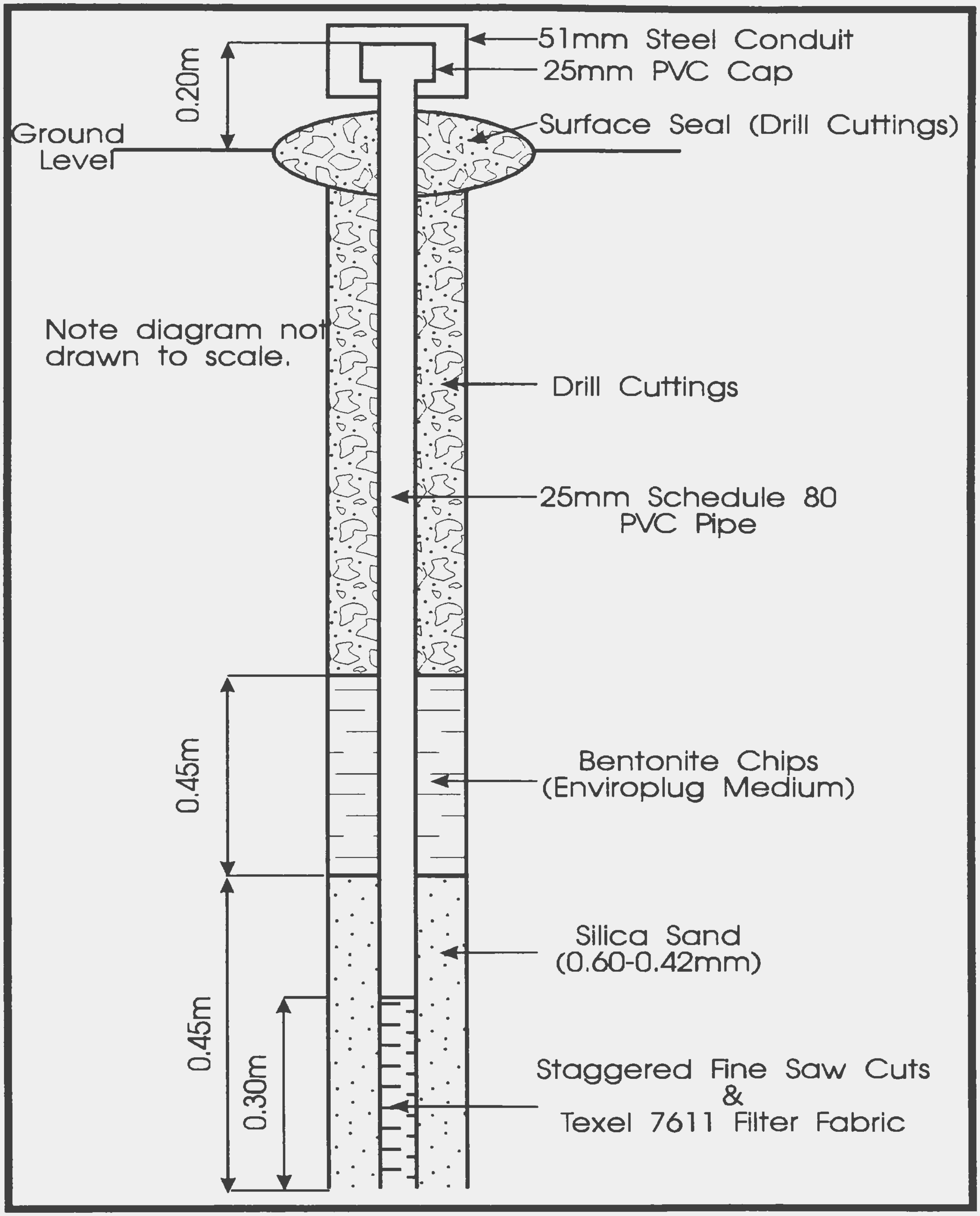


Figure 3.3. Typical shallow well construction details.

SS-15 air hammer drilling rig. These wells were necessary to ensure that the area for the spreading experiment was adequately covered with sampling wells to intercept any agricultural contaminants. Also there was a surficial depression that caused some concern about the direction of the local flow regime that required additional investigation. These wells were installed in a similar manner as those in Phase II.

In total, 25 sampling wells were installed during the three phases of drilling (see **Appendix C** for complete details). Of those, 10 contained two groundwater sampling wells and the other 5 had single groundwater sampling wells. In all, 14 wells were termed "shallow" (average depth 4.0 m) and 11 wells were termed "deep" (average depth 7.0 m). One sampling well, located the furthest from the storage experiment, was extended to a depth of 11.13 m to determine the quality of the groundwater that flowed off the site towards the Waterford River. Piezometer P1, installed on August 24, 1991 during the excavation of a soil profile test pit, was used for water level information only.

3.3.2 Infiltration Well Installation:

On October 20, 1991 four shallow infiltration wells (IW1 to IW4) were constructed on the spreading experiment area to determine the surface infiltration within the upper 1.0 m of overburden. The infiltration wells were situated in a line that spanned the spreading area. No artificial screens were used in the installation of these vadose zone monitoring devices. However, chemical gradients will capture any contaminants. A post hole excavator was used to install the wells to an average depth of 0.80 m.

The infiltration well assembly consisted of a 3.05 m (12 ft) length of schedule 80 PVC solid sewer pipe 100 mm (4 in) in diameter. A geotextile filter, Tyrafix® 270R, covering the open end was secured with nylon cable ties. The exposed end of the infiltration well was capped with a PVC female adaptor and a male coupling assembly.

Once in place, the remainder of the annulus was filled with drill cuttings to the surface. The cuttings were mounded around the sampling well to endure any settling. Since these wells were completed well above the water table in the vadose zone there was no need to develop them. Specialized vadose zone sampling techniques will be used in future to collect samples from these wells.

3.3.3 Interception Trench Installation:

To intercept the lateral movement of contaminants from the spreading zone into the background zone, underground interception trenches were installed on

October 18, 1991. These trenches consisted of three independent sections (Trench #1, Trench #2, and Trench #3) which spanned the entire width of the study site (see **Table 3.3** for installation details). One continuous trench could have been installed but three individual trenches were recommended to reduce the risk of the entire collection system failing. This line of trenches indicated the northernmost limit of manure spreading during successive applications.

The interception trench assembly consisted of a 3.05 m (12 ft) length of schedule 80 PVC slotted sewer pipe 100 mm (4 in) in diameter for the trench catchment. The outlets (intake and clean out) were constructed of a 3.05 m (12 ft) length of schedule 80 PVC solid sewer pipe 100 mm (4 in) in diameter. A geotextile filter, Tyrafix® 270R, covered the entire length of the trench catchment. The clean out extended below trench grade to provide a reservoir for water collection.

The trenches were carefully backfilled by hand to an average height of 0.15 m (6 in) before the backhoe completely filled the trench. This was to ensure that no large boulders punctured the PVC pipe as the backhoe was infilling the trench. The exposed ends of the trench were capped with a PVC female adaptor and a male coupling assembly for easy sampling and maintenance accessibility. A profile of the trenches is shown in **Figure 3.4**.

Table 3.3
Interception trench installation details.

Trench #	Intake Depth (m)	Outlet Depth (m)	Grade (%)†	Average Length (m)	Average Depth BGL (m)
1	0.33	0.85	1.75	30.5	0.61
2	0.85	1.20	1.17	30.5	1.04
3	1.33	1.53	0.77	26.5	2.90

† Minimum acceptable grade for the trenches is 0.1% (Bishop 1991, Pers. Comm.).

NOTE: BGL - Below Ground Level.

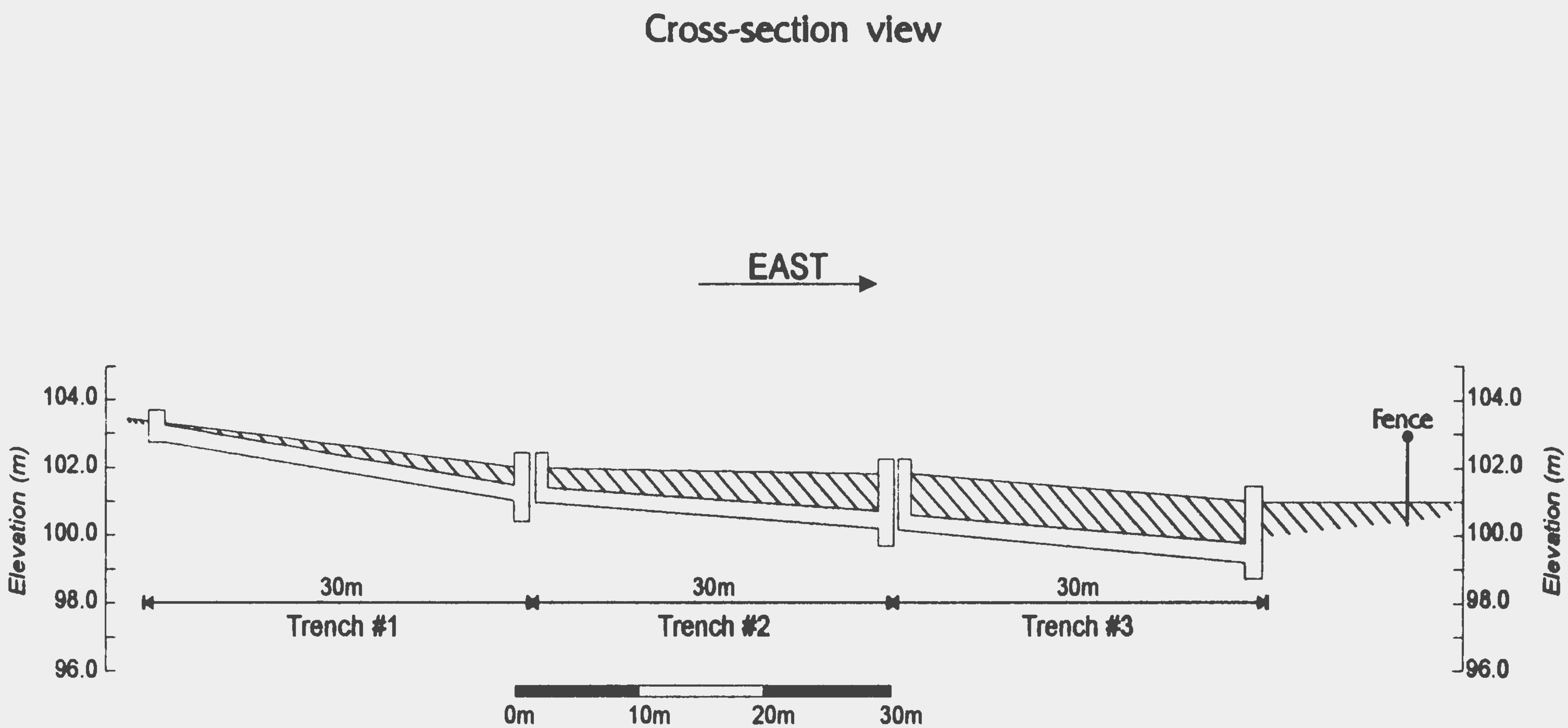


Figure 3.4 Profile of trench location.

3.3.4 Storage Tank Installation and Instrumentation:

Several different construction options were studied before the configuration of the storage tanks was finalized. These options included: (1.) concrete pre-cast circular forms, (2.) pressure treated lumber, (3) galvanized, corrugated steel pipe, (4) solid containers (eg. fibreglass, plastic, metal), and (5) excavations in native soils with no artificial containment structures. The concrete storage tanks and solid containers were cost prohibitive and the pressure treated lumber had adverse permeability characteristics as well as deleterious effects on water quality. The earthen excavations did not conform to the circular walled shape that was more suitable for numerical flow modelling underneath the structures. Finally, the corrugated galvanized steel pipe was chosen to be the best option since a circular design could be prefabricated, transported, and installed with relative ease. This design also had the best endurance characteristics needed for long term storage.

The location for the storage tanks was finalized on October 11, 1991. The tanks were located approximately 85 m down slope from the spreading area experiment to prevent interference between either experiment. The location was also far enough away from any future activity that had been forecasted on the station for the duration of the project. The storage tanks, were equidistantly spaced at 10 m intervals except the first unlined tank which was separated by 20 m from the rest along the same line. The intended excavation depth was 1.0 m. Differences in construction among tanks reflect local variations and available materials.

The storage tanks were made of galvanized corrugated steel pipe with the following dimensions, 3000 mm diameter x 2.5 m long x 2.8 mm thick. One continuous, helically-corrugated, galvanized steel pipe 10 m in length was manufactured and then cut into the required lengths. A continuous, lock-seam join, seals the pipe to form a watertight closure. Four lifting lugs were installed on one end of each of the sections to aid in positioning the tanks upon delivery.

The site for storage tank #1 was excavated on October 16, 1991 to a depth of 0.94 m below ground surface. It was observed that water flowed freely into the excavation prior to placement of the corrugated section. The corrugated steel culvert was lowered into place using a front end loader and backfilled using a backhoe. The culvert rested on a grey hard-pan layer at an approximate depth of 1.0 m.

There was no special consideration given for the preparation of the bottom of the first storage tank since this simulated a common agricultural scenario of an excavated bare soil bottom. The soil at the bottom of the tank was levelled for the purpose of determining measurement dimensions only. A rim of bentonite (Enviroplug® Medium) was placed around the base of the storage tank to ensure no piping effects along the exterior walls of the tank occurred during filling or storage.

The site for storage tank #2 was excavated on October 16, 1991 to a depth of 1.14 m below ground surface. There was water flowing into the excavation but significantly less than that for storage tank #1. It was considered that the excavation for storage tank #1 may have lowered the water table. However, the influx of surface water was attributed to earlier heavy precipitation events. The bottom of the excavation was levelled prior to culvert placement. The corrugated steel culvert was lowered into place and positioned approximately 0.45 m into the weathered hard-pan layer.

The site for storage tank #3 was excavated on October 16, 1991 to a depth of 1.22 m below ground surface. The water flowing into this excavation was comparable to storage tank #2. The corrugated steel culvert was lowered into place and positioned approximately 0.45 m into the weathered hard-pan layer.

The site for storage tank #4 was excavated on October 16, 1991 to a depth of 1.07 m below ground surface. There was still minor seepage of water into the excavation but this was considered minimal compared to the other excavations. The corrugated steel culvert was lowered into place and it was set approximately 0.60 m into the grey hard pan layer. A rim of coarse bentonite (Enviroplug® Medium) was placed around the base of the storage tank to ensure no piping effects along the exterior of the tank wall occurred.

On October 20, 1991 a protective wooden fence was installed around each one of the storage tanks. The nominal dimensions are 4.6 m (15 ft) x 4.6 m (15 ft) x 1.83 m (6 ft). An access door was installed in each secured with a padlock. During the installation of the fences wooden safety decking for each of the storage tanks was built. Each decking was equipped with sliding planks to ensure easy access to the inside of the tank as well as added protection from possible accidents while working on the tanks. Steel warning signs were erected on each of the security fences as a final protection measure.

Instrumentation was necessary beneath the four storage tanks because there was no other way to directly analyze the leachate. The liners installed will eventually leak but at what rate and its impact on the groundwater quality surrounding the tanks is unknown.

On November 8, 1991 the instrumentation in storage tanks #1 and #2 (ST1-1, ST1-2; ST2-1, ST2-2) was installed to determine if any leakage may occur and its subsequent chemistry. The first storage tank had no special liner installed and there was no pretreatment of the bottom before the commencement of permeability testing or storage. The second storage tank contained the 5 wt. % bentonite-soil liner. A hydraulic powered jack hammer was used to install the sampling wells to an average depth of 0.45 m into the natural soil. The wells were positioned equidistant in the centre of each tank.

The sampling well assembly for storage tank #1 consisted of a length of schedule 80 PVC solid sewer pipe 100 mm (4 in) in diameter. A geotextile filter, Tyrafix® 270R, covering the open end was secured with nylon cable ties. The exposed end of the sampling well was capped with a PVC female adaptor and a male coupling assembly.

Once in place, #00 silica sand was emplaced around the perforated end of the PVC pipe to an average height of 51 mm (2 in). The sampling well was then sealed with a 0.25 m (10 in) thick bentonite plug (Enviroplug® Medium) forming an annular seal. The remainder of the annulus was filled with cuttings and compacted to prevent any leakage through the liner around the sampling well.

The sampling well assembly for storage tank #2 consisted of a length of schedule 80 PVC pipe 25 mm (1 in) in diameter. A geotextile filter, Tyrafix® 270R, covering the open end was secured with nylon cable ties. The exposed end of the sampling well was capped with a PVC female adaptor and a male coupling assembly.

Once in place, #00 silica sand was emplaced around the perforated end of the PVC pipe to an average height of 51 mm (2 in). The sampling well was then sealed with a 0.25 m (10 in) thick bentonite plug (Enviroplug® Medium) forming an annular seal. The remainder of the annulus was filled with cuttings and compacted to prevent any leakage through the liner around the sampling well.

On July 24, 1992 the remaining instrumentation for storage tanks #2, #3 and #4 was installed. A collection pan with a peaked cap was designed to be installed in each of the liners to intercept any leakage. The collection pans were 500 mm (20 in) x 500 mm (20 in) x 75 mm (3 in) and made from 16 gage stock galvanized sheet metal at Memorial University Technical Services. Each collection pan had a storage volume of 0.012 m^3. A total of 10 were made with 2 installed in storage tank #2, 4 installed in storage tank #3, and 3 installed in storage tank #4. One was reserved for laboratory testing. Crush stone was used to level the bottoms of the storage tanks and to accommodate the collection pans.

Storage tank #2 had a 125 mm (5 in) thick layer of crush stone with 2 collection pans contained therein. Both collection pans were installed at the soil surface beneath the crush stone. Two additional sampling wells each made of a length of schedule 80 PVC pipe 25 mm (1 in) in diameter were installed 0.70 m (28 in) from the edge of the tank and equidistant from the previously installed sampling wells. The collection pans were installed in the crush stone directly beneath the open end of the PVC pipe. The pans were then filled with crush stone and the bottom of the tank levelled. The exposed ends of the sampling wells were capped with a PVC female adaptor and a male coupling assembly.

Storage tank #3 had a 100 mm (4 in) thick layer of crush stone at the base of the tank. Four collection pans were installed at the soil surface beneath the crush stone equidistant from the sides of the tank. Four sampling wells consisting of a length of schedule 80 PVC pipe 25 mm (1 in) in diameter were installed directly above the collection pans. The pans were then filled with crush stone and the bottom of the tank levelled. The exposed ends of the sampling wells were capped with a PVC female adaptor and a male coupling assembly.

Storage tank #4 had a 200 mm (8 in) thick layer of crush stone which served as a level base to install the Bentomat® GCL. Three collection pans were installed at the base of the crush stone beneath three sampling wells located equidistant from the sides of the storage tank. The sampling wells consisted of a length of schedule 80 PVC pipe 25 mm (1 in) in diameter. Once the sampling wells were in place the pans were then filled with crush stone and the bottom of the tank levelled. The exposed ends of the sampling wells were capped with a PVC female adaptor and a male coupling assembly.

3.4 Liner Installation Details:

On July 17, 1992, 5 and 10 wt % bentonite-soil mixtures were prepared at Memorial University. The soil had been obtained previously from the site during the excavation of the interception trench system. A rough screening of the soil through a 50 mm (2 in) mesh eliminated any larger boulders. Visible root systems were removed by hand prior to soil mixing. The calculated soil volumes to obtain a 200 mm thick 5 wt% bentonite-soil liner and a 100 mm thick 10 wt % bentonite-soil liner were mixed with an appropriate weight of bentonite (Enviroplug® #16). To facilitate the mixing process a portable concrete mixer was used to thoroughly mix the soil and bentonite in batches. The soil was wetted to the optimum moisture content prior to mixing. This value was obtained from a series proctor tests. Care was taken to ensure homogeneous mixing of the soil-bentonite mixtures while preventing changes in moisture content.

The bentonite-soil liners and the Bentomat® GCL were installed on July 21, 1992. The 10 wt % liner, with a nominal thickness of 240 mm, was installed in storage tank #2 over the previously prepared soil bottom. The 5 wt % liner, with a nominal thickness of 120 mm, was installed in storage tank #3 over the previously prepared soil bottom. Minimal compaction was achieved by foot and raking of the mixtures. No special care was taken to prevent downward flow around the instrumentation. The Bentomat® GCL was installed in storage tank #4. It was custom fitted around the instrumentation and additional bentonite pellets were added to prevent any vertical flow through the liner. A rim of bentonite pellets was placed at the contact of the liner and the storage tank wall. A 10 cm (4 in) layer of crush stone on top of the liner provided the necessary confining pressure. On July 23, 1992 storage tanks #2, #3, and #4 were filled with water pumped from a nearby river to fully hydrate the liners.

3.5 Geotechnical Index Properties:

On September 24, 1991, a test pit was excavated adjacent to the storage tanks to obtain a complete soil profile. Soil samples were obtained from each of the seven soil horizons. Water contents, relative densities, and bulk densities estimated from field samples were determined for each soil horizon. A geotechnical interim report was submitted to the Newfoundland Department of Forestry and Agriculture on October 15, 1991 (see **Appendix C** for details). Additional soil samples were obtained from the excavations for the storage tanks. This soil was stored at Memorial University and was used for the bentonite - soil liners and laboratory permeability testing.

A summary of the index properties used to describe the various soil horizons is given in **Table 3.4**. The total soil profile extends to a depth of 2.1 m (7 ft) below ground level. Seven distinct soil horizons were identified each with varying thickness. The water contents differ among horizons, however the relative densities are similar with an average of 2.63. An average bulk density estimate of 1.69 g/cm^3 was made from field samples taken from the Bf horizon. Each soil horizon was described using a Munsel chart for classification.

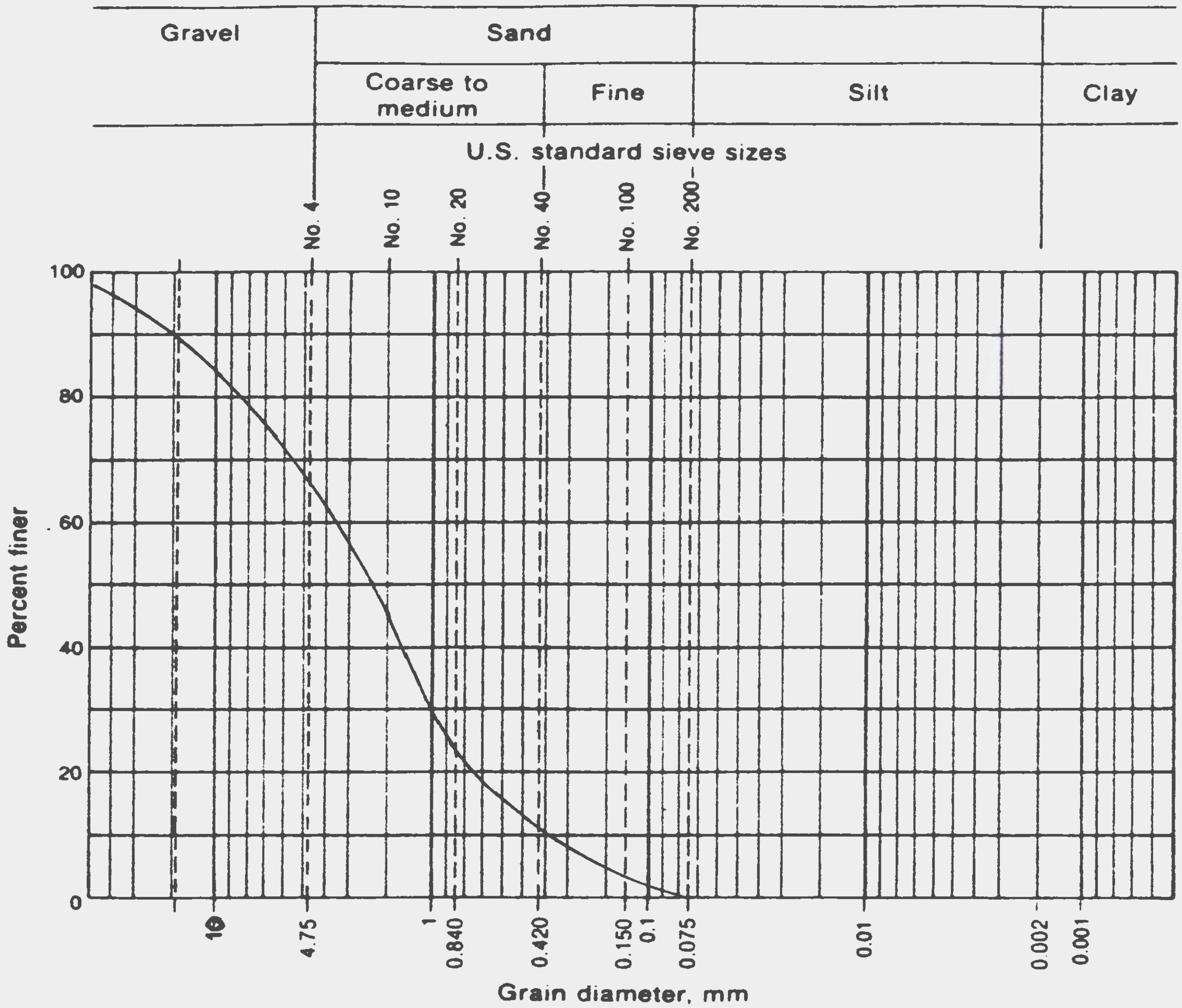
Grain size analysis is commonly used in the engineering classification of soils and provides information on the sorting and the gradation of grain sizes (Bowles, 1986). Grain size analysis were performed at Memorial University according to American Society for Testing Materials (ASTM) standards D 421 and D 422. A representative distribution curve is presented in **Figure 3.5**.

The grain size distribution curves are similar for soil horizons Ah, Bf, and Bg. Subtle differences occur in horizons Bg2, Bfg, Bg^2, and Bc. However, the overall pattern is consistent for typical glacial tills found in Newfoundland. The following classes are representative of these tills: 20 % gravel, 70 % sand, $<$ 10 % silt and clay.

The coefficient of uniformity C_u and the coefficient of concavity C_c were determined for applicable soil horizons. C_u indicates the range of grain sizes and is

Table 3.4
Summary of soil index properties.

SOIL HORIZON	DEPTH (cm)	USC SOIL CLASSIFICATION	MUNSEL #	WATER CONTENT (%)	RELATIVE DENSITY	BULK DENSITY (g/cm^3)
Ah	0 - 25	SP - SM	10 YR/3/6	34.41	2.46	
Bf	25 - 45	SM	10 YR/5/8	25.97	2.61	0.989
Bg	45 - 70	SW	10 YR/3/3 10 YR/4/6	5.86	2.67	
Bg2	70 - 110	GW - GP	10 YR/3/2	4.14	2.72	
Bfg	110 - 130	GW - GP	7.5 YR/3/4	4.24	2.63	
Bg (Bg^2)	130 - 135	SM - SC	7.5 YR/6/2	13.28		
Bc	135 - 210	GW - GP	5 Y/4/2	6.89	2.71	



SIEVE ANALYSIS:

Diameter of Mesh (mm)	11	10	2	0.85	0.15	0.106	0.075
% Finer	93	90	47	23	2.7	1.8	1.4

Figure 3.5 Representative grain size distribution curve and corresponding sieve analysis.

defined as:

$$C_u = \frac{D_{60}}{D_{10}}$$

C_c indicates the shape of the curve between D_{60} and D_{10} grain sizes and is defined as:

$$C_c = \frac{D^2_{30}}{D_{10}D_{60}}$$

where D refers to the grain size of the soil particles and the numerical subscript following it refers to the percent that is smaller than this size (Bowles, 1986). Soils with values of $C_u > 6$ are considered to be poorly sorted (Fetter, 1988).

A summary of these distribution parameters is found in **Table 3.5**. The Ah and Bf soil horizons have C_u values < 6 and C_c values > 1. The Bg soil horizon has a C_u value > 6 and a C_c value < 1. All these horizons have more than 50 % of the coarse fraction smaller than No. 4 sieve and little or no fines. A soil classification, based upon the Unified Soil Classification Scheme, would be as follows: a poorly graded, gravelly sand, with little or no fine fraction.

Table 3.5
Numerical grain size distribution parameters.

Soil Horizon	D_{10}	D_{30}	D_{60}	C_u	C_c
Ah	0.42	1.00	1.13	2.69	2.11
Bf	0.20	0.73	1.15	5.75	2.32
Bg	0.21	0.95	5.80	27.62	0.74

CHAPTER 4

SITE HYDROGEOLOGY

4.1 Introduction:

As previously discussed, the bedrock in the study area is comprised of the St. John's Group, a shallowing upward marine sequence of shales and interbedded sandstones. This 300 - 700 m thick unit constitutes a continuous, conformable sequence of grey to black cleaved shales and grey to buff sandstones with gradational contacts (King, 1990). The bedrock is overlain by terraced tills which consist of a series of step-like terraces with scarp faces and sub-horizontal surfaces cut in till. In general, the primary permeability of these two formations is low (Gale et al. 1984). The bedrock is well cemented and the glacial till typically overconsolidated, thus the porosity of each is reduced (Robinson and Gibb, 1985). Due to low matrix permeability, approaching those of metamorphic and granitic rocks, fractures are the primary conduits for groundwater movement, at least in the near surface (Gale et al. 1984).

A hydrostratigraphic unit, as used here, is a formation or a group of formations in which there are similar hydrogeologic characteristics from which groundwater potential approximations can be made. Gale et al., (1984) define eight different bedrock hydrostratigraphic units, with the study area contained in Unit D. This unit includes rocks of the St. John's Group and is defined by wells with moderate yield (20 - 40 L/min). Gale et al., (1984) also define two surficial hydrostratigraphic units; (1.) S1 - consisting primarily of ground moraines with a yield of 0.0001 - 0.1 L/min, and (2.) S2 - consisting of outwash plain deposits with a yield of 5.7 - 182 L/min. In all cases unit S1 is underlain by unit S2 and the latter is reported overlying the bedrock for the entire study area (Robinson and Gibb, 1985).

4.2 Water Table and Bedrock Topography:

On October 10, 1991, a ground elevation survey was completed on the study site with a grid spacing of 25 m. A detailed topographic map was prepared from this survey (**see Figure 4.1**). This map was used as a guide to predict the shape of the water table since it was assumed that the water table was closely related to topography. This detailed map enabled closer inspection of water table fluctuations over the controlled experimental site. A bedrock topographic map was constructed

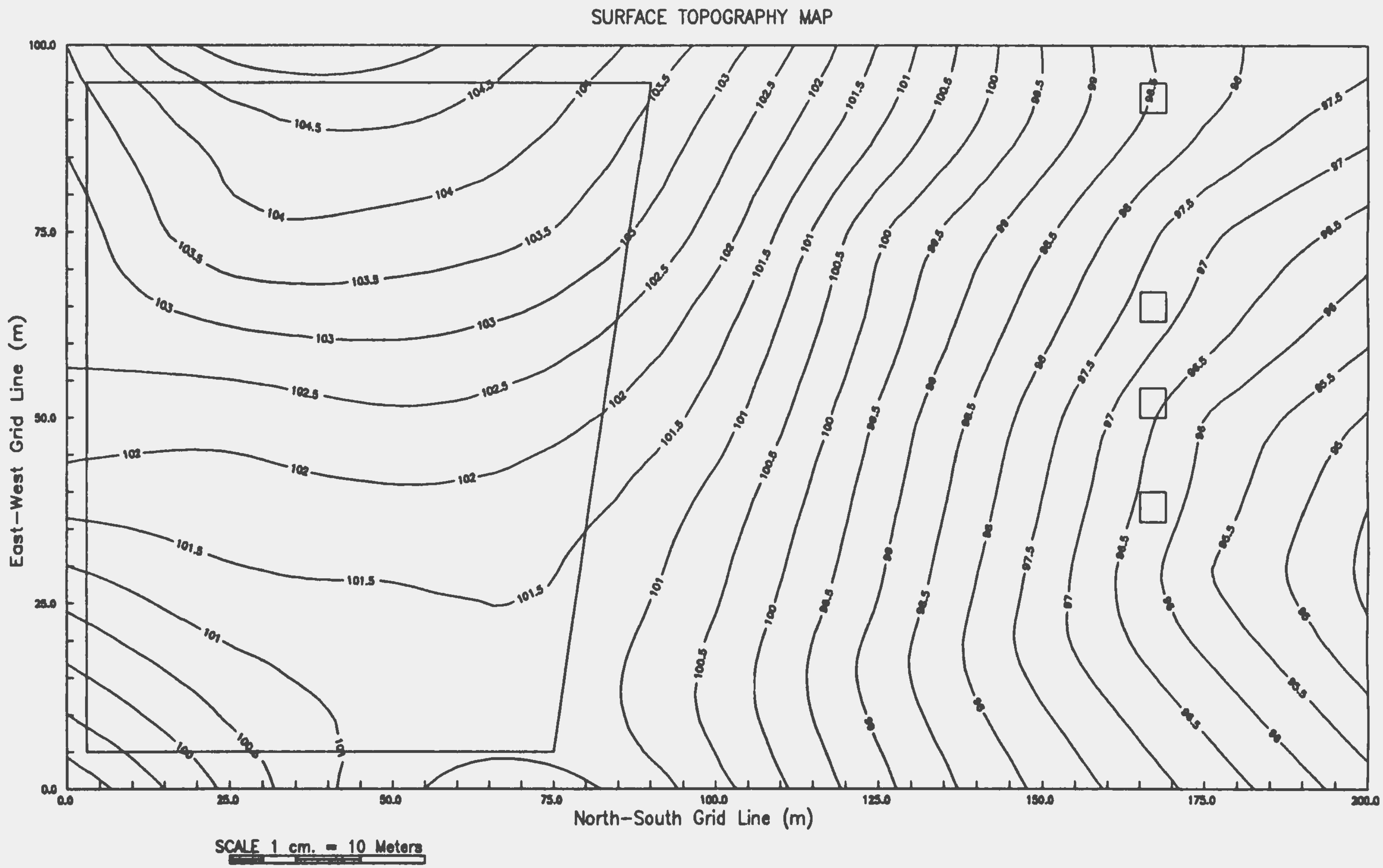


Figure 4.1 Surface topography map. (Contours in meters)

from bedrock elevations obtained from the borehole logs for the sampling wells (**see Figure 4.2**).

Once the sampling wells were installed and allowed to stabilize, the water table elevations were obtained and water table contour maps constructed. These maps were possible because of constant monitoring of the static water levels from the sampling wells (Complete water level data is presented in **Appendix D**). Water table contour maps for various dates in 1992 are shown in **Figure 4.3 - Figure 4.6**.

The predominant direction of groundwater flow is in a north to northeasterly direction. This conforms with the local topography and in turn the bedrock topography. The previous assumption that the water table was closely related to topography seems to be valid. The general flow pattern is similar for periods of winter recharge and summer recession.

There is also an easterly flow component originating from a topographic high located on the spreading area site. Figure 4.2 shows a topographic high located in that area. Figure 4.3 shows a similar pattern. The water table configuration obtained on July 7, 1992, is suppressed due to the deeper water table as a result of low precipitation during the month. Figure 4.4, taken on October 10, 1992, shows a similar water table contour configuration.

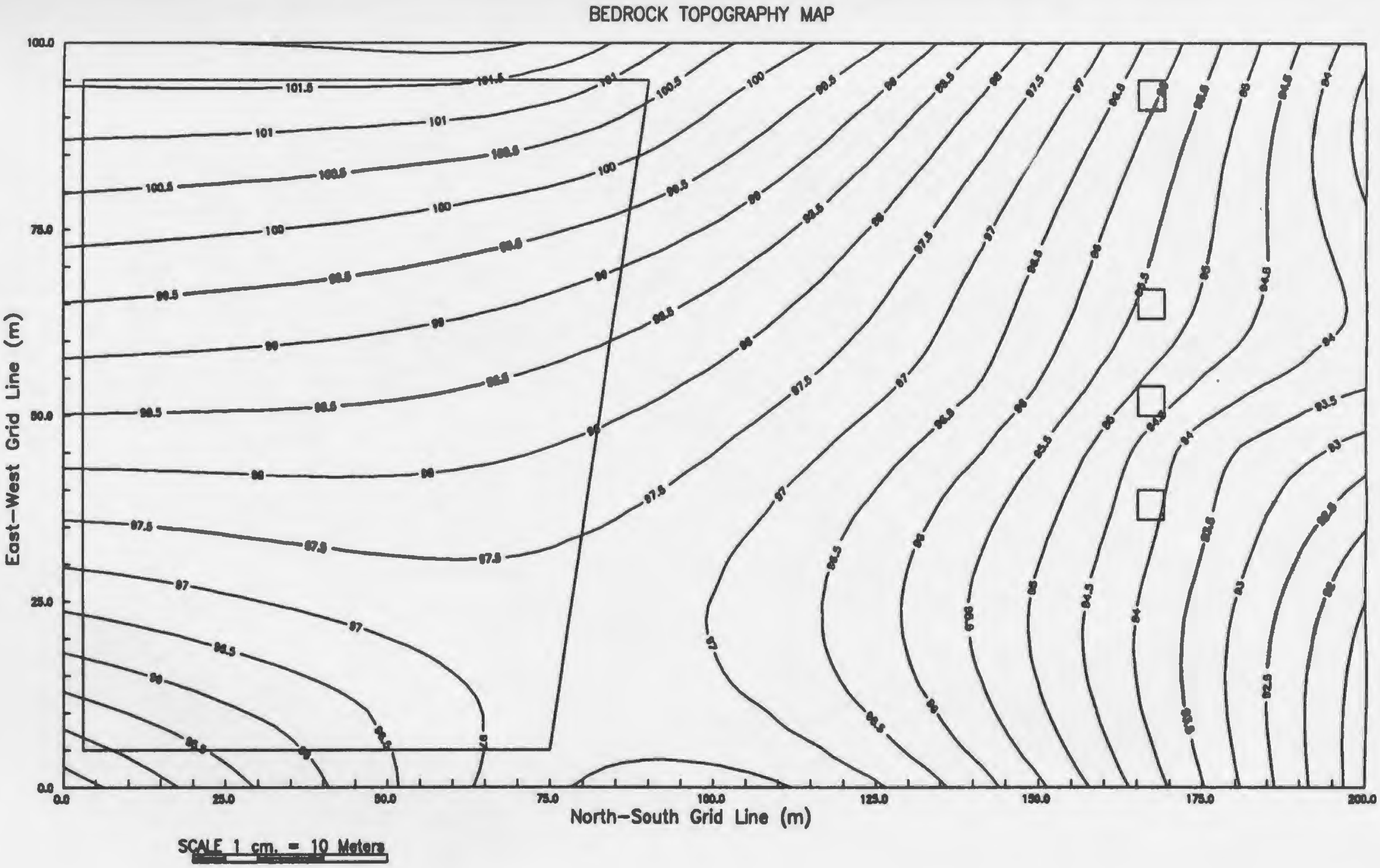


Figure 4.2 Bedrock topography map. (Contours in meters)

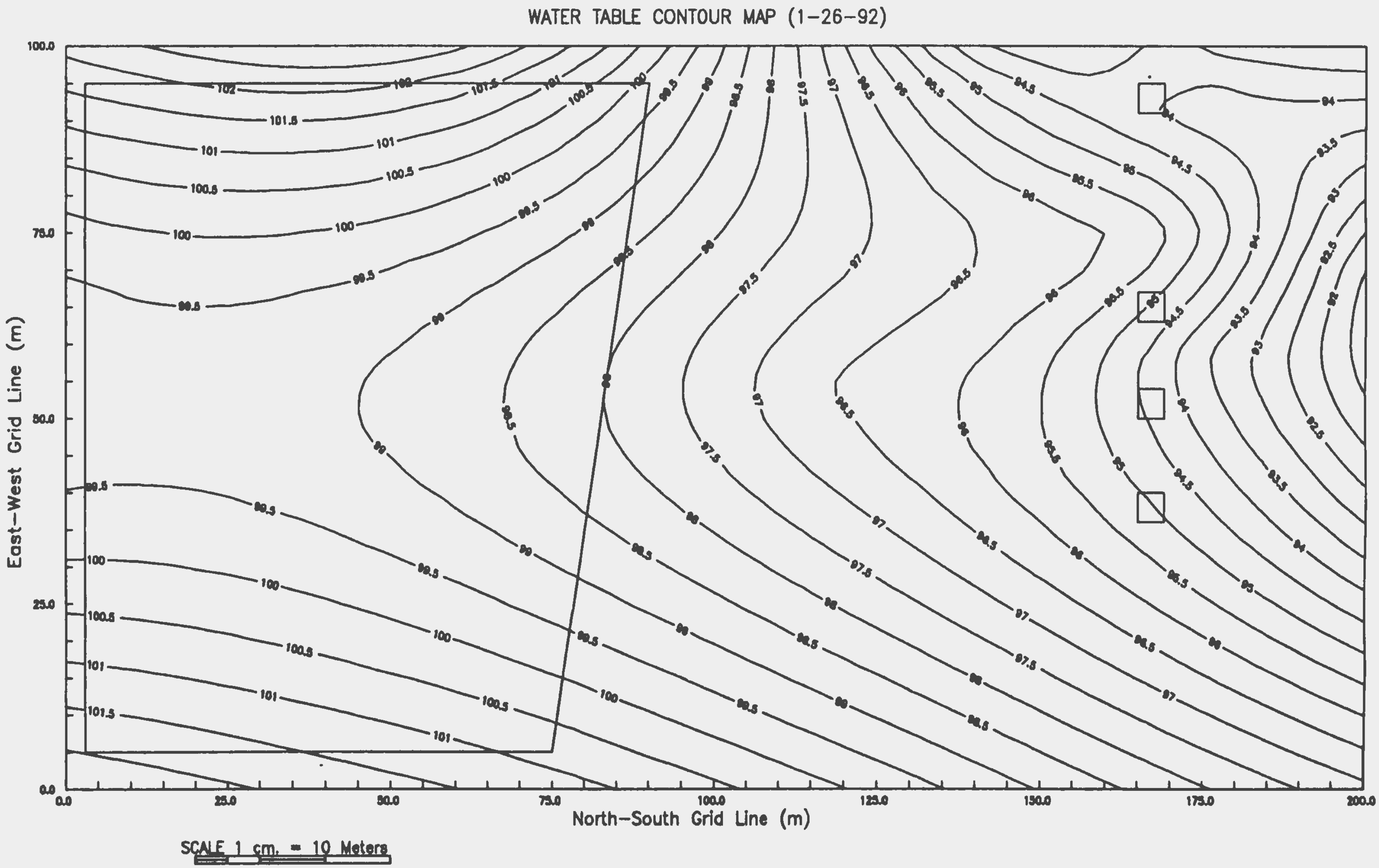


Figure 4.3 January 26, 1992 water table contour map. (Contours in meters)

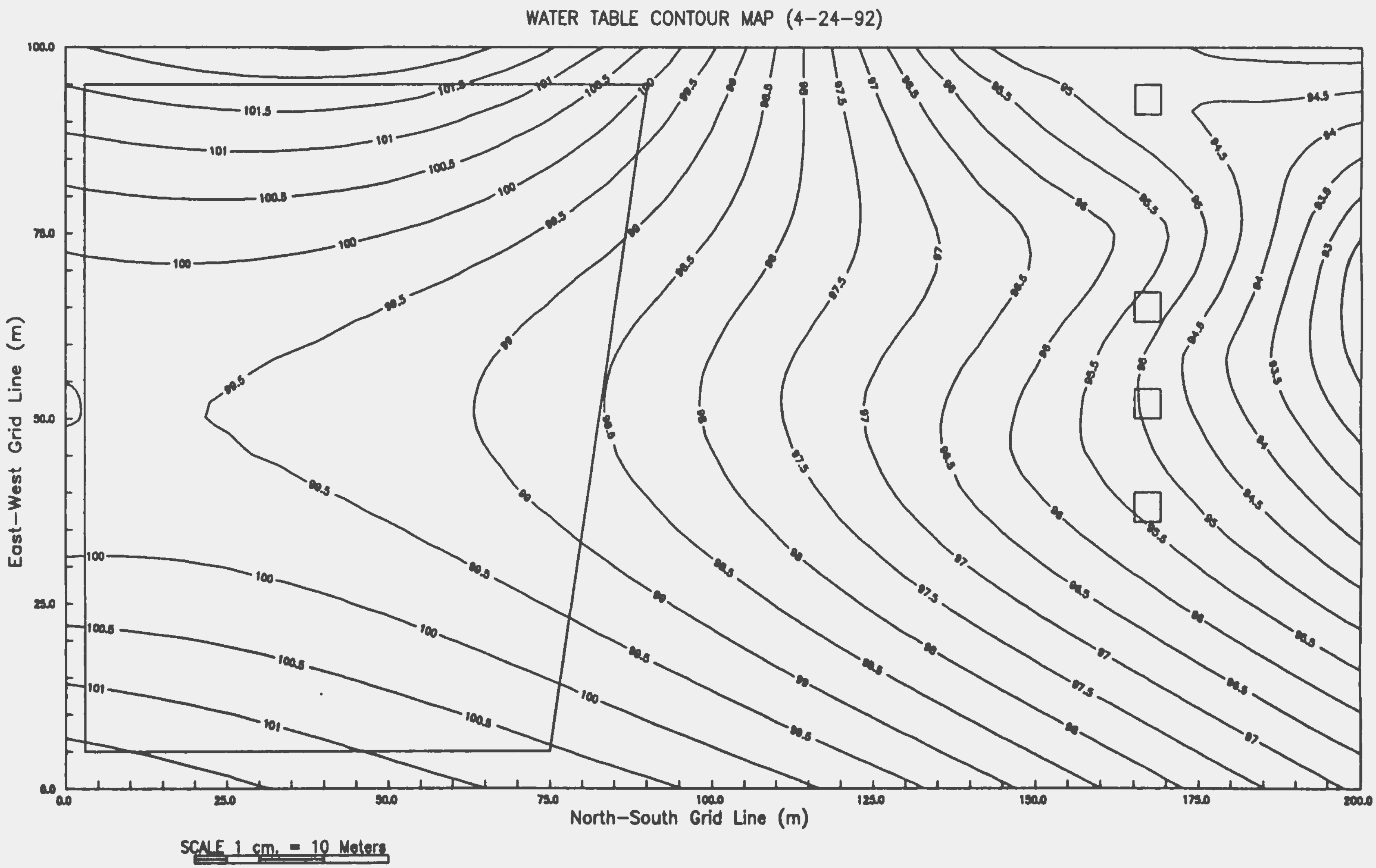


Figure 4.4 April 24, 1992 water table contour map. (Contours in meters)

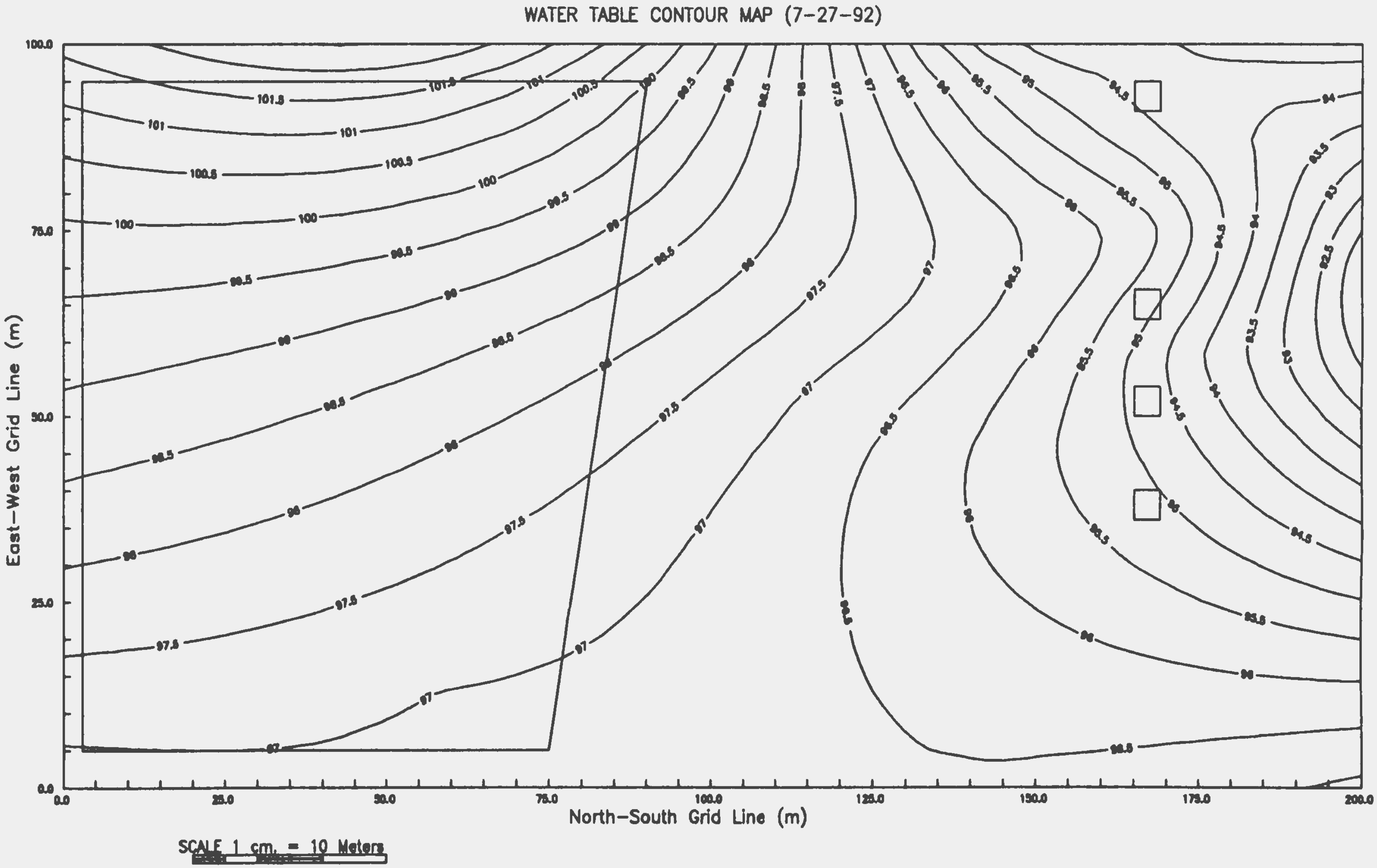


Figure 4.5 July 27, 1992 water table contour map. (Contours in meters)

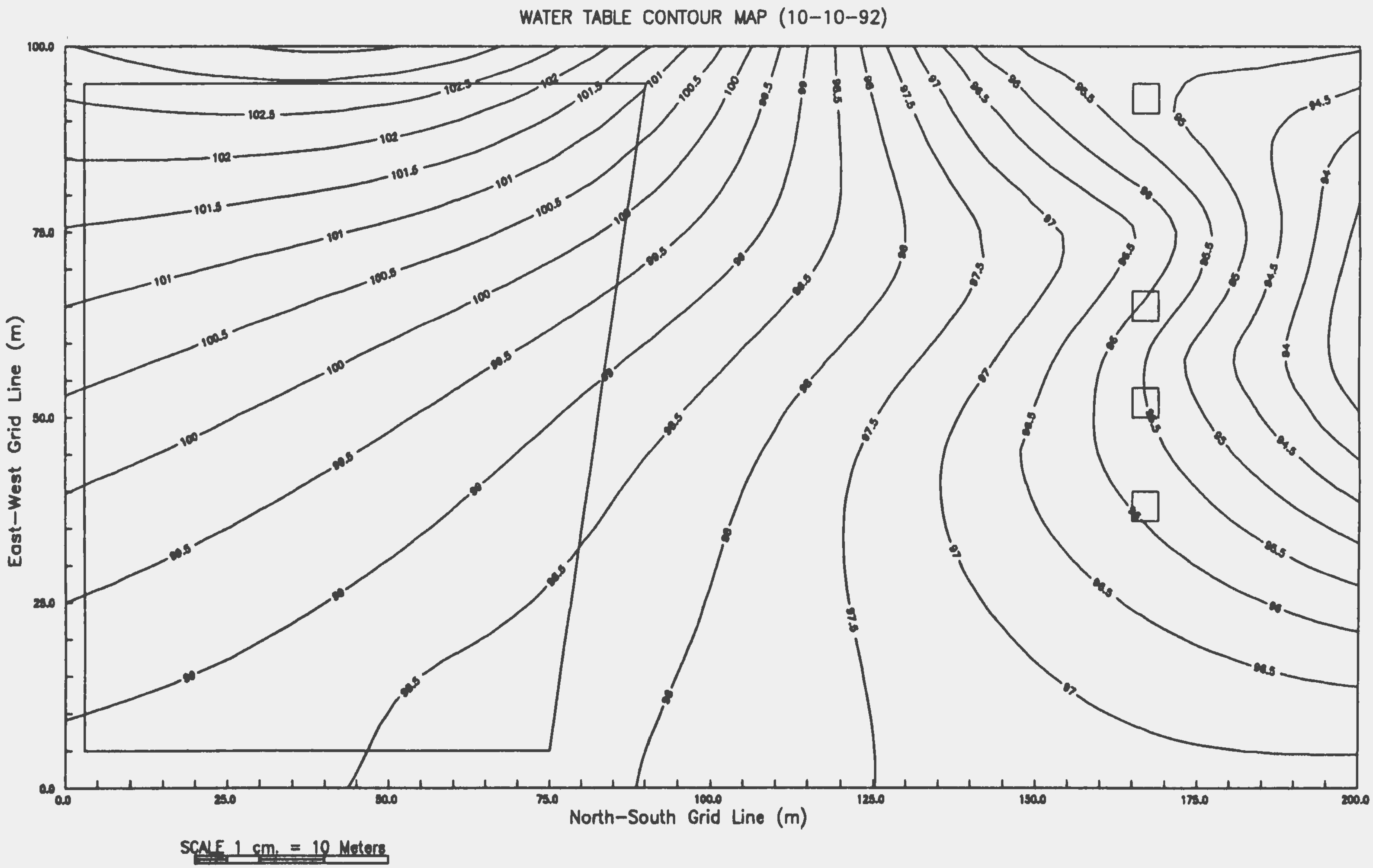


Figure 4.6 October 10, 1992 water table contour map. (Contours in meters)

Vertical hydraulic gradients influence the equipotential lines of groundwater flow maps. In an unconfined aquifer, recharge areas are usually located by topographic highs where the water table is relatively deep. Discharge areas are located in topographic lows where the water table is often at the surface or is represented by surface water. In a recharge area the vertical gradient is downwards while in discharge areas the gradient is upwards. This information can be obtained by taking water level readings at various depths below a specific point.

Table 4.1 summarizes the gradients obtained from nested sampling wells during July, 1992 and December, 1992. These two periods were chosen to represent "dry" and "wet" seasons respectively. The sampling well nests, piezometric nest A - piezometric nest I (PN-A, PN-I) cover the entire study site. During a dry season, PN-A, PN-B, PN-G, and PN-I show a decreasing hydraulic potential with depth, thus a downward gradient. Conversely, PN-C, PN-D, PN-E, PN-F, and PN-H show an increasing hydraulic potential with depth, consequently an upward gradient. During a typical wet "season" PN-A, PN-B, PN-G, and PN-I show a decreasing hydraulic potential with depth while PN-C, PN-D, and PN-E show an increasing hydraulic potential with depth. PN-F and PN-H show no gradient for that time period. From the established flow patterns PN-A, PN-B, PN-G, and PN-I are located in a recharge area with the corresponding discharge area near PN-C, PN-D, PN-E, and PN-F. This conforms to the topography of the site with the recharge area towards the hill

Table 4.1
Vertical hydraulic gradients in nested sampling wells.

** Dry "Season"*

WELL#	DATE	DEPTH TO INTAKE (m)	SWL ELEVATION (m)	GRADIENT
# 5 **(A)**	7/27/92	5.49	100.94	-0.0759
# 6		3.91	101.06	
# 7 **(B)**	7/27/92	5.49	96.78	-0.2953
# 8		3.56	97.35	
# 9 **(C)**	7/27/92	5.74	95.51	0.0224
# 10		3.51	95.46	
# 11 **(D)**	7/27/92	3.30	93.75	0.0119
# 12		2.46	93.74	
# 14 **(E)**	7/27/92	3.81	94.04	0.0164
# 15		5.03	94.06	
# 16 **(F)**	7/27/92	5.36	94.13	0.0038
# 17		2.72	94.12	
# 20 **(G)**	7/27/92	3.50	99.11	-0.4706
# 21		6.05	97.91	
# 22 **(H)**	7/27/92	3.66	97.07	0.0235
# 23		5.79	97.12	
# 24 **(I)**	7/27/92	4.11	96.98	-0.0155
# 25		6.05	96.95	

NOTE: (-) downward flow, (+) upward flow.

Table 4.1 (cont'd)

** Wet "Season"*

WELL#	DATE	DEPTH TO INTAKE (m)	SWL ELEVATION (m)	GRADIENT
# 5 **(A)**	12/11/92	5.49	100.33	-0.6709
# 6		3.91	101.39	
# 7 **(B)**	12/11/92	5.49	97.00	-0.2539
# 8		3.56	97.49	
# 9 **(C)**	12/11/92	5.74	95.59	0.0359
# 10		3.51	95.51	
# 11 **(D)**	12/11/92	3.30	93.83	0.0238
# 12		2.46	93.81	
# 14 **(E)**	12/11/92	3.81	94.10	0.0164
# 15		5.03	94.12	
# 16 **(F)**	12/11/92	5.36	94.17	0.0000
# 17		2.72	94.17	
# 20 **(G)**	12/11/92	3.50	99.36	-0.4078
# 21		6.05	98.32	
# 22 **(H)**	12/11/92	3.66	97.35	0.00000
# 23		5.79	97.35	
# 24 **(I)**	12/11/92	4.11	97.53	-0.1804
# 25		6.05	97.18	

NOTE: (-) downward flow, (+) upward flow.

south of the site and the discharge located at the base of the hill to the north.

The anomalous gradient obtained for PN-H suggests a groundwater discharge in that area. This does not conform to local topography. A similar pattern is seen in Figure 4.6 where a groundwater mound is present directly beneath Nest H. Nest I is in a topographic low and it is reasonable to conclude that this would be a discharge area. However, this is not the case since there are downward flow gradients beneath the sampling well nest and there is no supportive evidence to suggest a groundwater mound in that area from Figures 4.3 - 4.6. This could possibly be due to a hydraulic short-circuit between the two piezometers.

The location of five geologic cross-sections is given in **Figure 4.7**. These sections provide detailed subsurface information on bedrock and water table elevations. The water table elevations for two dates, January 26, 1992 and July 27, 1992, are included for comparison. **Figure 4.8** details the five geologic cross-sections. In cross-section A-A, the bedrock slopes away from the first storage tank towards the north which is confirmed by the bedrock topographic map in Figure 4.2. Cross-section B-B shows no relative slope beneath the four storage tanks. The water table is located in the bedrock along this cross section. Cross-section C-C, depicts the sloping bedrock beneath the background zone between the spreading area and the storage tanks. Cross-section E-E, shows minor topographic changes in the bedrock

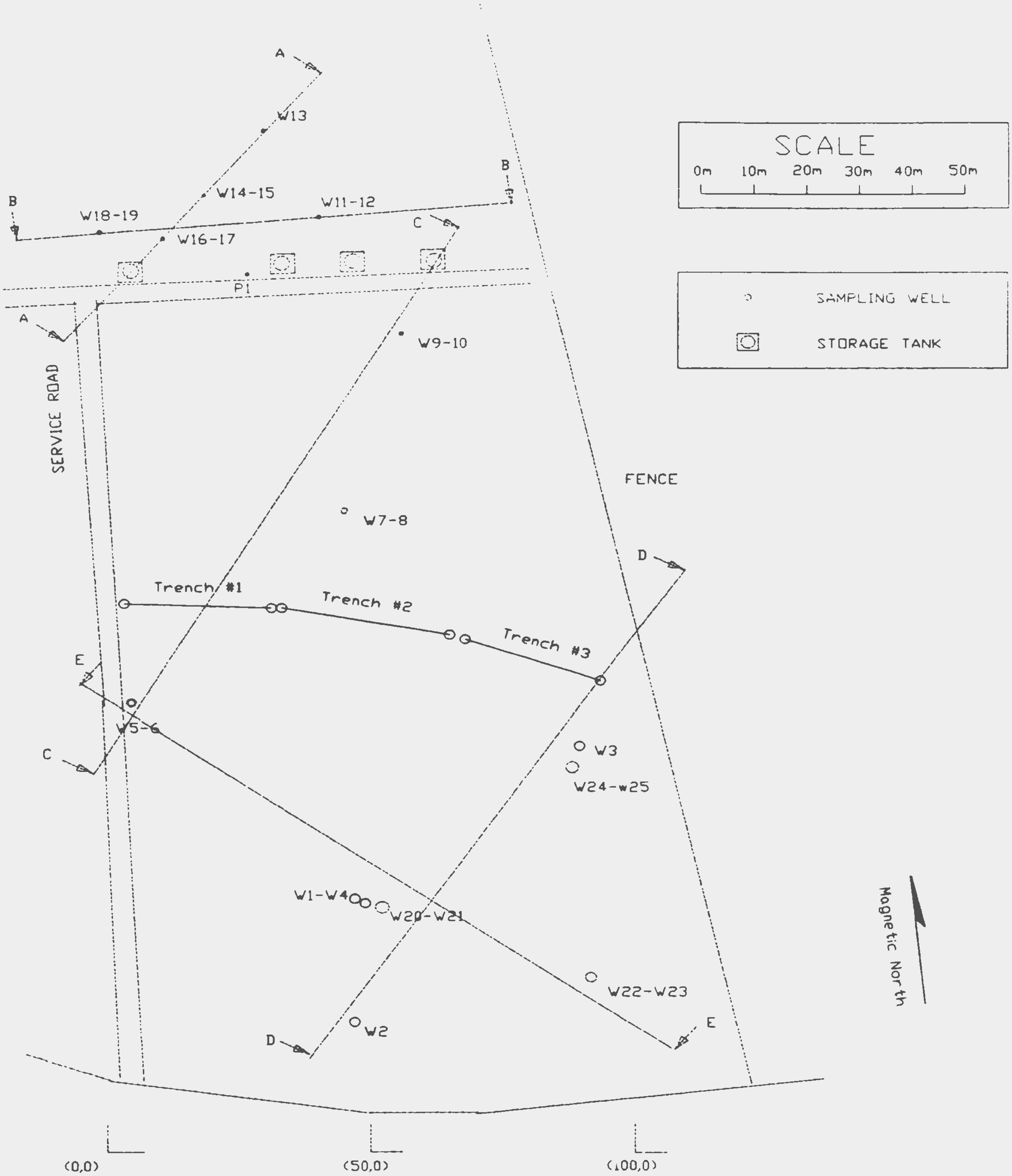


Figure 4.7 Location map of five geologic cross-sections.

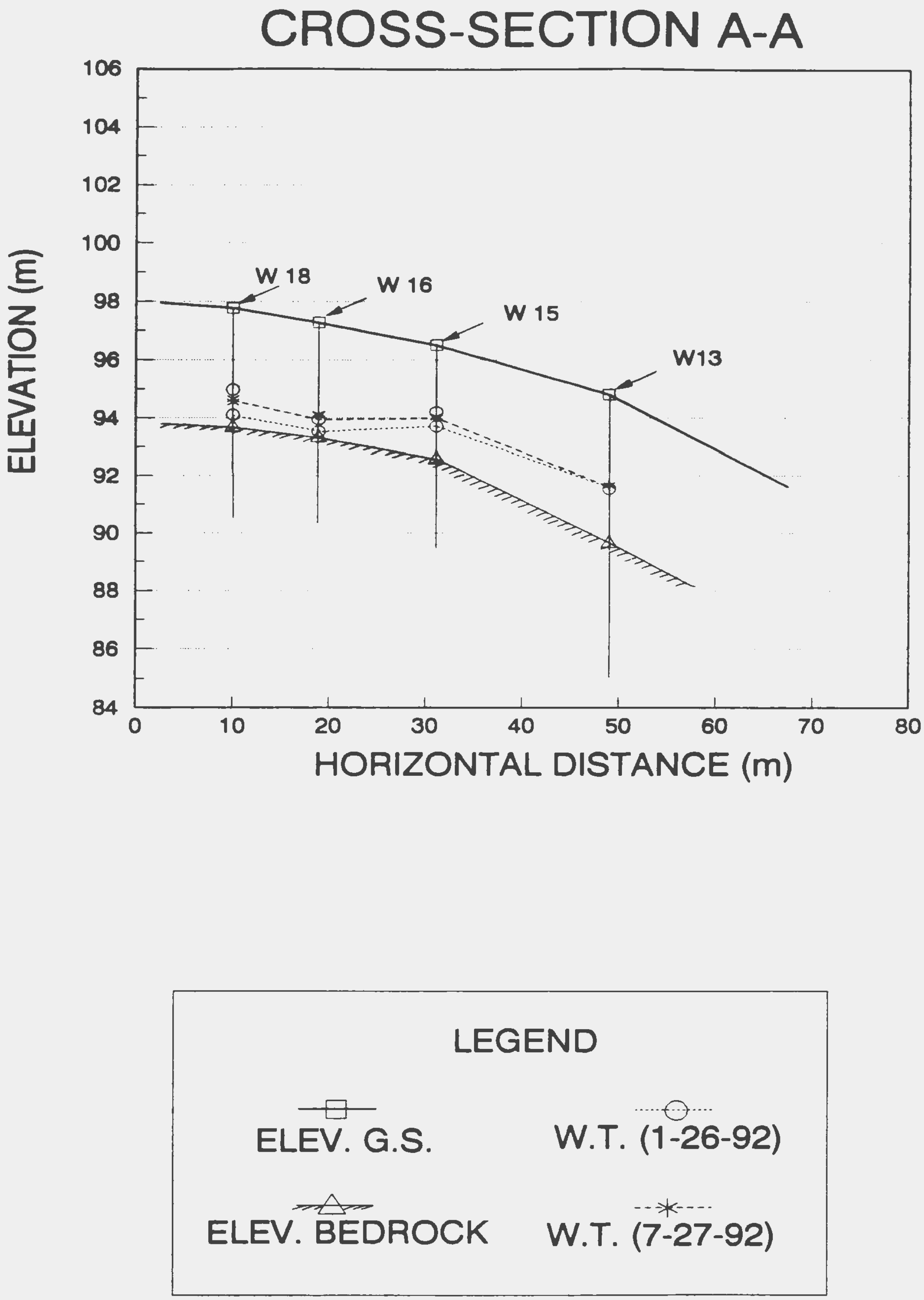
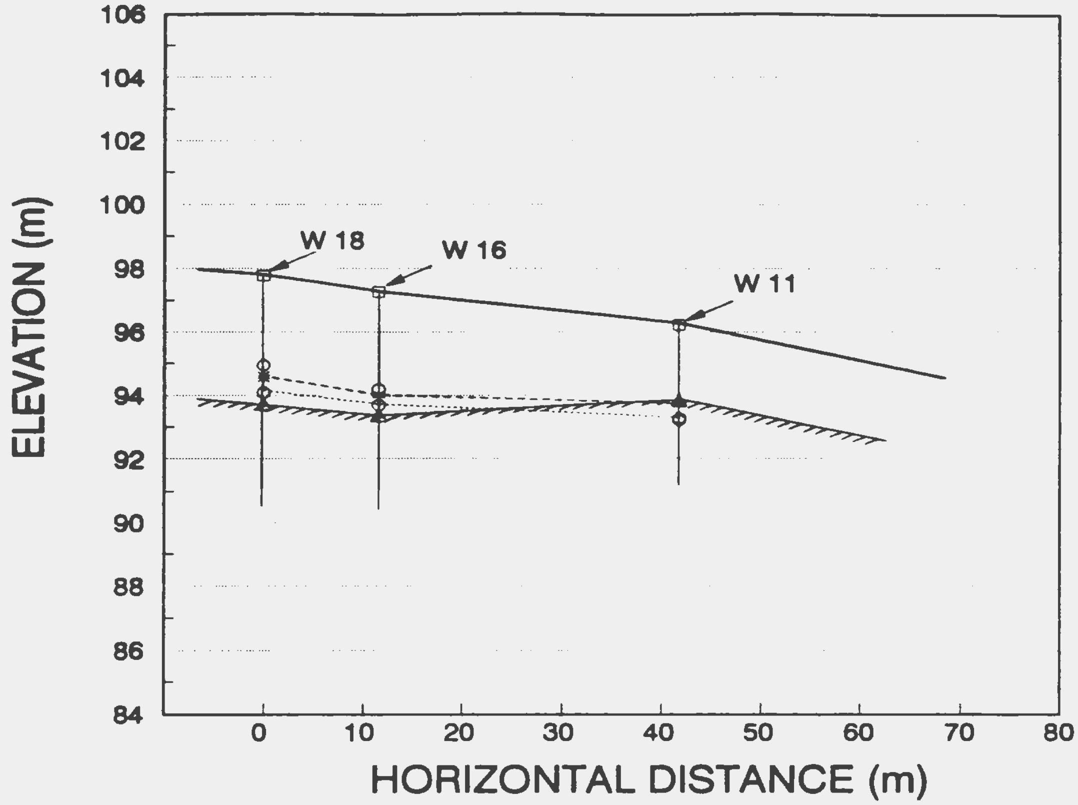
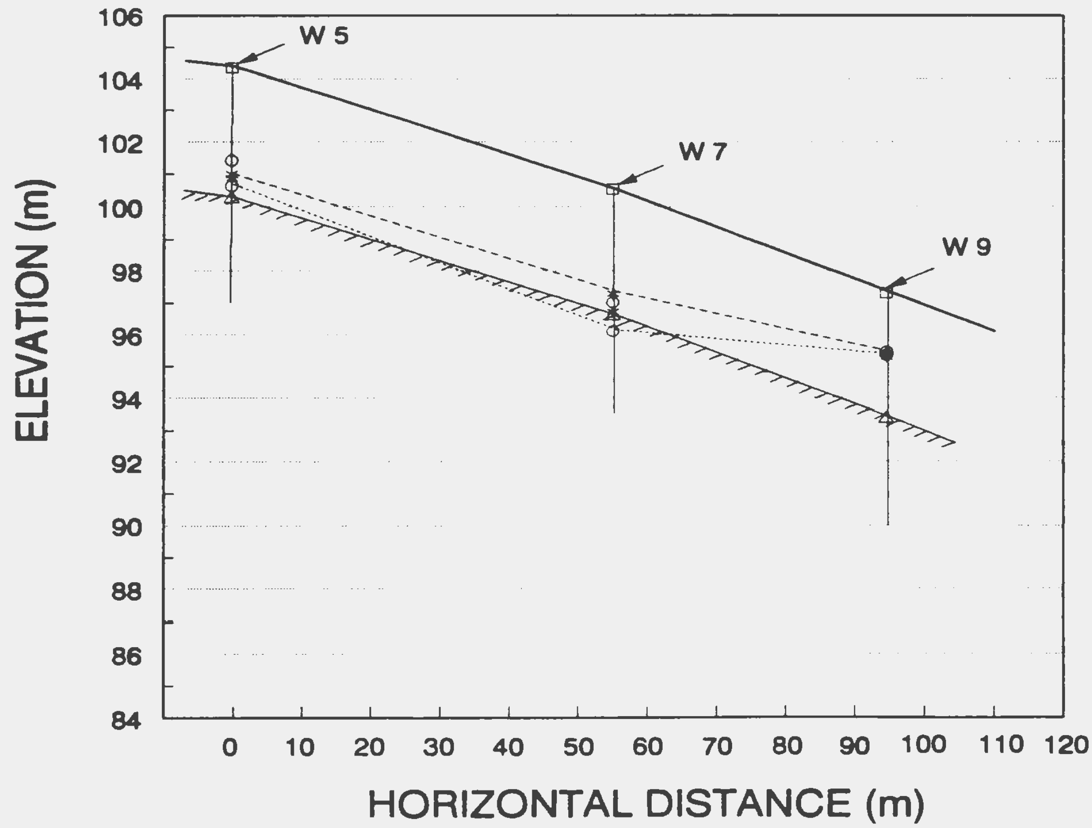


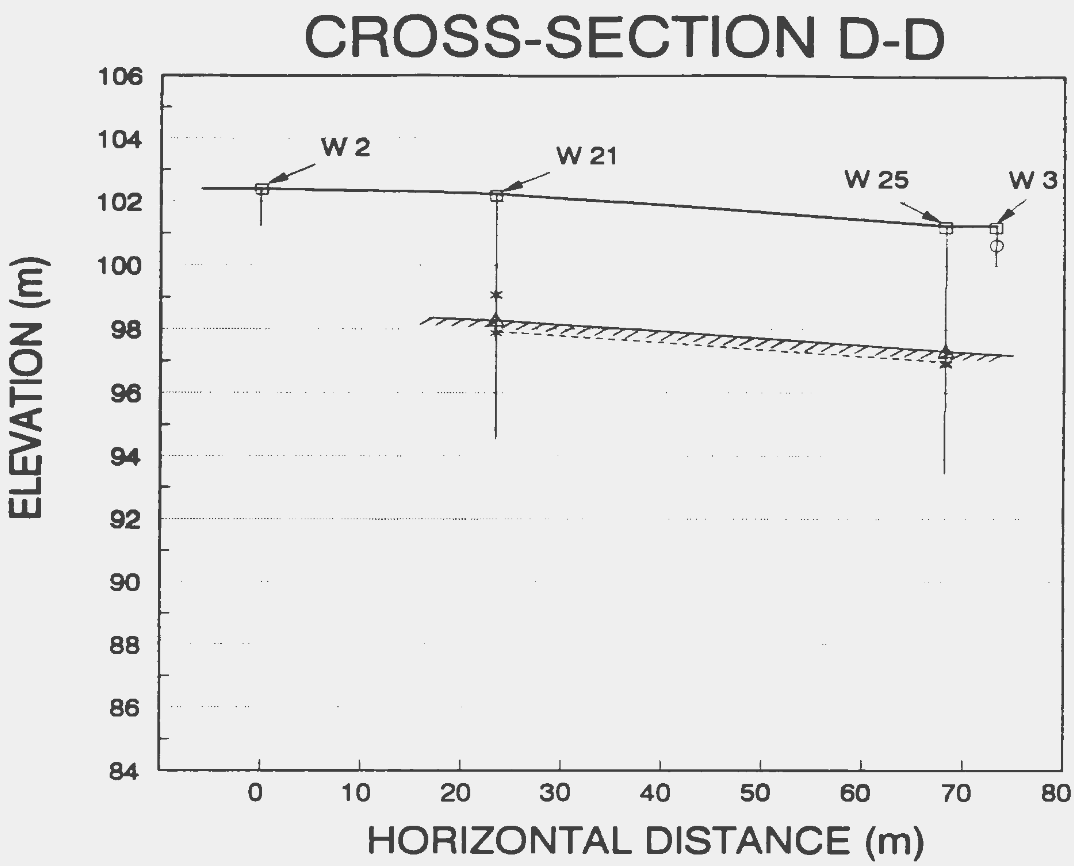
Figure 4.8 Geologic cross-sections A-A, B-B, C-C, D-D, and E-E.

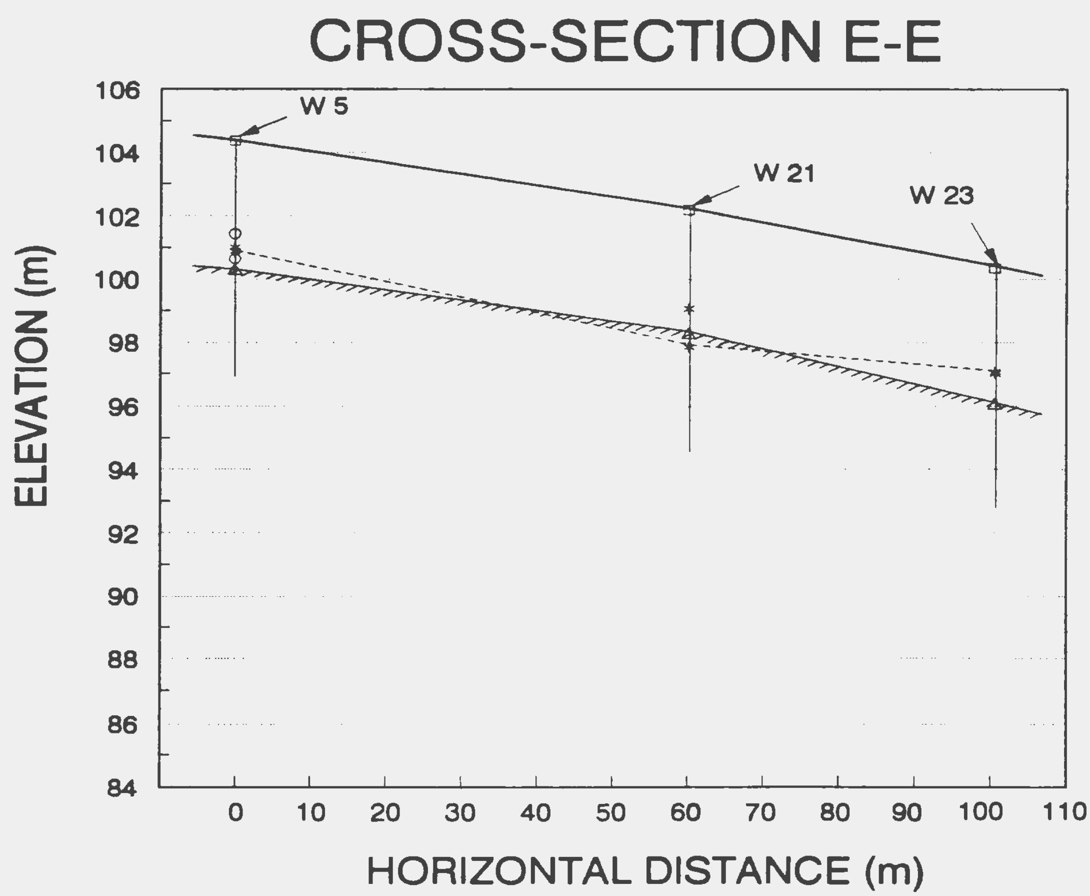
CROSS-SECTION B-B



CROSS-SECTION C-C




CROSS-SECTION D-D
ELEVATION (m)
HORIZONTAL DISTANCE (m)
W 2
W 21
W 25
W 3
106
104
102
100
98
96
94
92
90
88
86
84
0
10
20
30
40
50
60
70
80


CROSS-SECTION E-E
ELEVATION (m)
HORIZONTAL DISTANCE (m)
W 5
W 21
W 23
106
104
102
100
98
96
94
92
90
88
86
84
0
10
20
30
40
50
60
70
80
90
100
110

beneath the spreading area experiment.

4.3 Well Hydraulics:

4.3.1 Introduction:

As noted previously, there was insufficient depth of water above the bedrock to install effective sampling wells in the overburden. Therefore, the only in situ method of determining the overburden permeability was by the Guelph Permeameter method. Laboratory permeability testing on disturbed soil samples was also used for permeability estimates. To determine the permeability of the bedrock aquifer, falling head permeability tests were performed on the sampling well network. Pumping tests were not a practical alternative because of the physical limitations of conventional pumps and anticipated flows. A natural gradient tracer test, which is currently in progress down gradient of storage tank #1, will be used to determine the permeability of the material beneath this storage tank.

The purpose of hydraulic testing was to determine the degree of difficulty with which a contaminant could be transported in the groundwater system. This information was necessary for the physical interpretation of the groundwater quality data. To evaluate the effects of agricultural waste management practices, an understanding of the transport capabilities was essential. The limited sampling program offered here can not completely accomplish this objective. However, it is an important step to furthering our knowledge on agrochemical contaminant transport.

4.3.2 In-Situ Permeability Testing:

4.3.2.1 Introduction:

Grain size analysis can be used to estimate soil permeability in sandy soils, but direct permeability measurements are generally more accurate (Bowles, 1986). Aquifer pump tests could not be performed on the sampling wells due to low well yield and pump restrictions. To obtain permeability information, falling head permeability tests were performed. The method of Hvorslev (1951) was utilized (see Freeze and Cherry (1979) for a summary of this method). The method induces a water column in the borehole and logs the water level recovery to its initial level.

The test consisted of adding an extension to the desired well to be tested prior to the test start. The initial static water level was recorded. This well was then filled to a preset level with water (the slug). The initial time $t=0$ was recorded. The time intervals at which readings were recorded depended upon the rate of descent of the water column into the aquifer. After the level returned to pre-test conditions, or no change between successive readings was recorded, the test concluded. Mass conservation and Darcy's Law for hydraulic conductivity states that the ratio of the rate of change in water level to the water level itself should be constant. A graphical representation of the rate of change in water level versus the water level readings should yield a straight line slope.

4.3.2.2 Discussion of Results:

The Hvorslev slug test method was used to determine the hydraulic conductivity of the shallow bedrock in which the wells were constructed. For a well point-filter at an impervious boundary, with the length of the sampling well more than 4 times the radius of the well screen (2mL/D > 4) then the following equation applies:

$$k = \frac{d^2 \cdot \ln\left[\frac{2mL}{D} + \sqrt{1+\left(\frac{2mL}{D}\right)^2}\right]}{8 \cdot L \cdot (t_2 - t_1)} \ln\frac{h_1}{h_2}$$

where

k = the hydraulic conductivity ($k_h = k_v$, assumed),

d = the radius of the sampling well,

m = transformation ratio, m = 1,

L = the length of the well screen including sand pack,

D = the radius of the well screen, usually taken as the borehole radius,

h_1 = piezometric head for time $t = t_1$,

h_2 = piezometric head for time $t = t_2$,

t_1 = time interval for h_1, and

t_2 = time interval for h_2.

Several assumptions made are as follows:

(1.) infinite depth and directional anisotropy ($k_h = k_v$),

(2.) hydraulic losses in pipe and well point are negligible,

(3.) no air or gas in pipe or well point,

(4.) no sedimentation or leakage may occur, and

(5.) no disturbance, swelling, segregation or consolidation of test material may develop.

To determine the basic time lag, a plot of the velocity [change in hydraulic head for a corresponding change in time,($\partial h/\partial t$)] versus the hydraulic head was constructed. The slope of this line is equal to the basic time lag. The graphs of the velocity ($\partial h/\partial t$) versus the hydraulic head and the recovery data are listed in **Appendix E**. The hydraulic conductivity values for the sampling wells tested are given in **Table 4.2**.

Table 4.2
Hydraulic conductivity values of shallow bedrock as determined by slug tests.

Well #	Date	Hydraulic Conductivity (cm/s)
W2	May, 20, 1992	4.26×10^{-4}
W3	May 20, 1992	9.53×10^{-5}
W5	May 20, 1992	1.31×10^{-5}
W6 (Ave.)	May 29, 1992	4.54×10^{-4}
W13	May 14, 1992	1.02×10^{-5}
W14	May 14, 1992	9.87×10^{-5}

These values, although of comparable magnitude may be slightly high due to the use of an air hammer rotary drilling rig. This method of drilling disturbs a larger diameter than the nominal drill bit size. Drilling fluids create high hydraulic gradients that cause internal borehole erosion inducing natural soils to wash out (Chapuis, 1989).

The hydraulic conductivities calculated for the overburden and the upper six metres of bedrock are of the same order of magnitude, 10^{-5} cm/s. The first falling head permeability test performed on W6 produced a hydraulic conductivity of 1.88 x 10^{-3} cm/s. This value is unusually high compared to the other two test values for the same borehole. This conductivity is suspect because it is believed that equilibrium conditions in the borehole were not achieved during the test. Thus, the velocity data obtained is not characteristic of the overburden materials and is not included in the average for W6.

4.3.3 Guelph Permeameter Tests:

4.3.3.1 Introduction:

The field saturated hydraulic conductivity (k_{fs}) of soils is an important parameter governing soil infiltration rates and is often used in hydrologic modelling.

One method frequently used is the Guelph permeameter (GP) method. This constant-head well technique was developed to measure in situ saturated hydraulic conductivity, sorptivity, and the conductivity-pressure head relationship. The subsequent technique used follows that of Reynolds and Elrick (1986).

The GP method is used to determine the hydraulic conductivity of soils in the upper 10 m of overburden - this being limited by the practical operation of the Mariotte Bottle. The GP Method is well suited for soils with an average k value between 10^{-4} and 10^{-6} cm/s. Reynolds and Elrick (1986) cited the following advantages using the GP method: (1.) inexpensive, simple and easy to use by one person, (2.) the method requires less time per measurement (between 10 minutes to 2 hours depending on soil type) and small volumes of water (0.25 to 1.0 L depending upon soil type), and (3.) no specialized training is required for the operator.

The objective for using the GP method was to determine the field saturated hydraulic conductivity (k_{fs}) in the upper 0.45 m of the overburden.

4.3.3.2 Discussion of Results:

The GP method was used to determine three important parameters that govern liquid transmission in the vadose zone, namely, field-saturated hydraulic conductivity

(k_{fs}), matrix flux potential (ϕ_m), sorptivity (S), and the porous medium constant (α). The permeameter Model #2 was used for low-conductivity porous media with the following dimensions given in **Table 4.3**.

The least squares approach is a more labour intensive but accurate method for determining the above relationships. The following equations are used in this approach:

LEAST SQUARES APPROACH:

$$k_{fs} = \frac{\sum_{i=1}^{n} H_i^2 \sum_{i=1}^{n} C_i Q_i \left(\frac{C a_i^2}{2} + H_i^2\right) - \sum_{i=1}^{n} H_i C_i Q_i \sum_{i=1}^{n} H_i \left(\frac{C a_i^2}{2} + H_i^2\right)}{2\Pi \left\{ \sum_{i=1}^{n} H_i^2 \sum_{i=1}^{n} \left(\frac{C a_i^2}{2} + H_i^2\right)^2 - \left[\sum_{i=1}^{n} H_i \left(\frac{C a_i^2}{2} + H_i^2\right) \right]^2 \right\}}$$

where

k_{fs} = field-saturated hydraulic conductivity,

H = the constant head level in the borehole,

n = the number of H-levels per test,

C = proportionality constant for the H/a relationship,

Q = steady flow rate,

a = radius of the borehole.

Table 4.3
Approximate dimensions of the Guelph Permeameter Model #2. (Modified after Reynolds and Elrick, 1986)

	Inside Diameter (cm)	Wall Thickness (cm)	GP Length (cm)
Air-inlet tube	0.32	0.32	185
Reservoir tube	N/A	N/A	N/A
Outlet tube	1.91	0.32	175
Side tube	0.32	0.16	175
Permeameter Tip:			
Perforations	0.32 cm diameter		
Length	2.0 - 6.0 cm		
Syringe volume	200 cm^3		

N/A - Not applicable.

$$\phi_m = \frac{\sum_{i=1}^{n} C_i Q_i \left(\frac{C\rho_i^2}{2} + H_i^2\right) \sum_{i=1}^{n} H_i \left(\frac{C\rho_i^2}{2} + H_i^2\right) - \sum_{i=1}^{n} H_i C_i Q_i \sum_{i=1}^{n} H_i \left(\frac{C\rho_i^2}{2} + H_i^2\right)^2}{2\Pi \left\{ \left[\sum_{i=1}^{n} H_i \left(\frac{C\rho_i^2}{2} + H_i^2\right) \right]^2 - \sum_{i=1}^{n} H_i^2 \sum_{i=1}^{n} \left(\frac{C\rho_i^2}{2} + H_i^2\right)^2 \right\}}$$

where

ϕ_m = matrix flux potential.

$$S = \sqrt{2(\Delta\Theta)\Phi_m}$$

where

S = sorptivity,

$\Delta\Theta$ = the change in liquid content in the soil adjacent to the well from the initial value (Θ_i) to the field-saturated value (Θ_{fs}).

$$\alpha = \frac{k_{fs}}{\Phi_m}$$

where

α = constant dependent on porous medium properties that describes the slope of ln k vs Ψ.

The values of the field-saturated hydraulic conductivity (k_{fs}), the matrix flux potential (ϕ_m), sorptivity (S), and the porous medium constant (α) are given in **Table 4.4.** Field data for the Guelph permeameter method can be found in **Appendix E.**

Table 4.4
Field-saturated hydraulic conductivity (k_{fs}), matrix flux potential (ϕ_m), sorptivity (S), and the porous medium constant (α) for the overburden as determined by the Guelph Permeameter method.

Well #	k_{fs} (ms^{-1})	ϕ_m (m^2s^{-1})	S ($ms^{-1/2}$)	α (m^{-1})
GP-1	1.19×10^{-6}	1.23×10^{-7}	N/A	N/A
GP-2	3.5×10^{-6}	$- 4.1 \times 10^{-8}$	N/A	N/A
GP-3	5.2×10^{-7}	6.9×10^{-8}	1.4×10^{-4}	7.6
GP-4	1.5×10^{-5}	$- 5.3 \times 10^{-7}$	N/A	N/A

Heterogeneities in porous media can give unrealistic calculations of k_{fs}, ϕ_m, S, and α. When a significant heterogeneity, such as a large macropore or a layer boundary, is encountered between two H-levels, the calculations based on those H-levels may yield a negative k_{fs} or ϕ_m value - both values should be discarded (Reynolds and Elrick, 1986). The H-levels must be altered to ensure that they do not fall between the H-levels that produce the negative results. As seen in Table 4.4 both GP-2 and GP-4 produce negative ϕ_m values, therefore these, along with the k_{fs} values must be discarded. Based upon the remaining values for GP-1 and GP-3 the k_{fs} and ϕ_m values are within one order of magnitude. However, without additional data no estimates for S and α can be given.

4.3.4 Small Cell Permeameter Test:

4.3.4.1 Introduction:

Laboratory permeability tests can measure point values for hydraulic conductivity. The device used is called a permeameter. If samples are repacked into the permeameter chamber then the values for hydraulic conductivity will only be approximate for the undisturbed parent material. Recompacted hydraulic conductivities depend upon the density to which the sample is compacted.

The laboratory testing program used both constant-head and falling-head permeameters to determine the saturated hydraulic conductivity of the site soil (see **Figure 4.9** for schematic diagrams). In a constant-head test, a soil sample is enclosed between two porous plates in a cylindrical tube, and a constant-head differential is established across the cross section of the sample. In a falling-head permeability test, the head, as measured in a tube of given cross sectional area is allowed to fall a given height within a given time. To accurately record the constant-head and falling-head measurements, a strip chart recorder with a digital readout was implemented. The procedures used for the tests followed ASTM (American Society for Testing Materials) Guidelines D2434-68.

4.3.4.2 Discussion of Results:

The equation used to interpret the constant-head permeability is:

$$k = \frac{QL}{AH}$$

where

k = constant head hydraulic conductivity in (cm/s),

Q = volume of water discharging in time t (cm^3/s),

L = length of the soil sample (cm),

A = cross-sectional area of the sample (cm^2), and

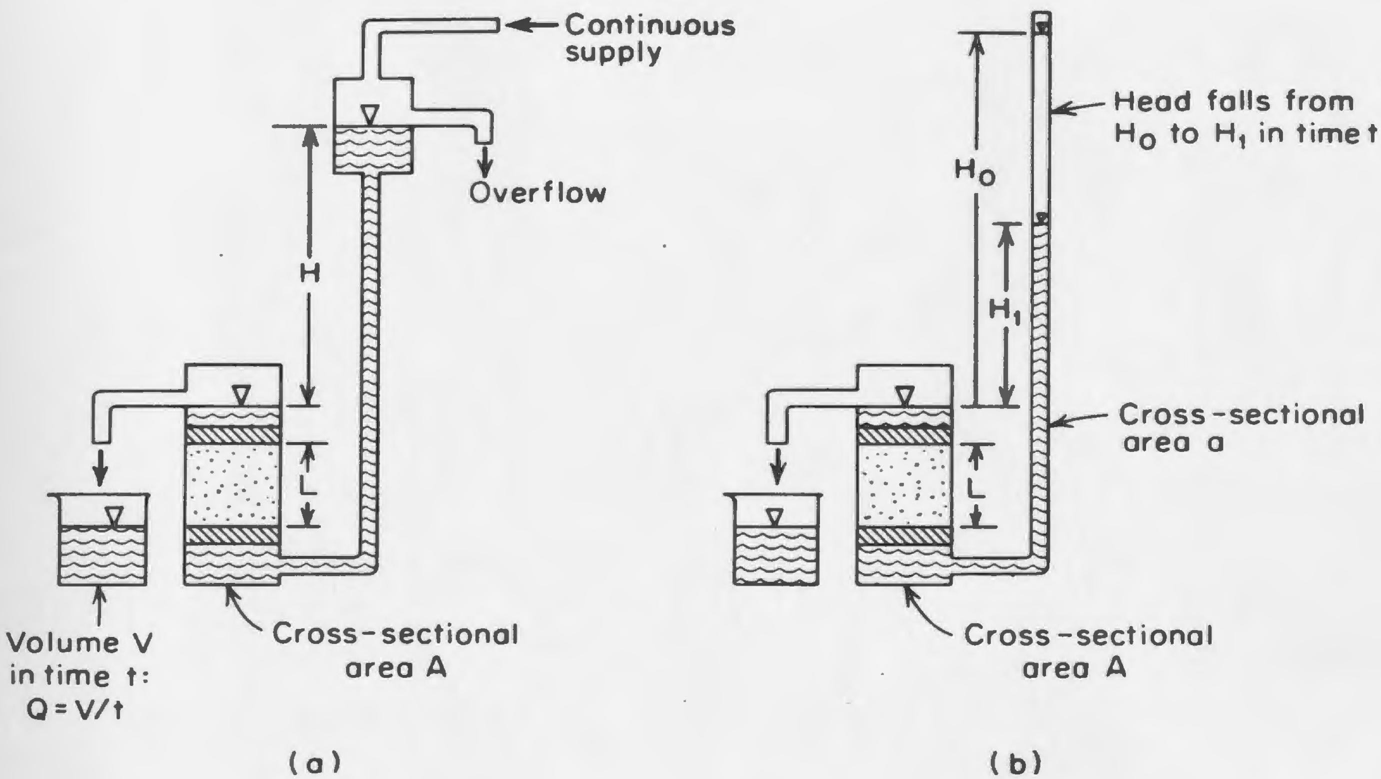


Figure 4.9 (a) Constant-head permeameter; (b) falling-head permeameter [(After Todd, (1959) cited in Freeze and Cherry (1979)]

H = hydraulic head (cm).

Similarly, the equation for the falling-head permeability measurements is:

$$k = \frac{aL}{At} \ln \left(\frac{h_o}{h_1}\right)$$

where

k = constant head hydraulic conductivity in (cm/s),

a = cross-sectional area of the burette (cm^2),

L = length of the soil sample (cm),

A = cross sectional area of the soil sample (cm^2),

t = time duration of the test (s),

h_0 = hydraulic head at start of test (cm), and

h_1 = hydraulic head at end of test (cm).

The hydraulic conductivity values obtained from both the constant-head and falling-head permeability test are summarized in **Table 4.5** along with the accompanying grain size distributions. The value for each coefficient of permeability is an average based on three trials. As shown in the table, the coefficient of permeability generally decreases with increasing sample density. The tests confirmed this conclusion with the finer grained samples being significantly less permeable. Specimen #6 demonstrated the highest density and the lowest permeability.

Table 4.5
Hydraulic conductivity values of disturbed soil samples as determined by small cell permeameter tests.

SPECIMEN #	1	2	3	4	5	6
DESCRIPTION	COMPACT	LOOSE	MEDIUM	COMPACT	#10 SIEVE	#4 SIEVE
DRY DENSITY (g/cm^3)	1.70	1.52	1.62	1.75	1.60	2.01
FALLING-HEAD PERMEABILITY (10^{-6} cm/s)	10.7	16.4	16.2	3.41	0.793	0.098
CONSTANT-HEAD PERMEABILITY (10^{-6} cm/s)	N/M	22.7	14.0	5.74	1.43	0.176
VOID RATIO	0.559	0.743	0.636	0.514	0.656	0.318

SIEVE ANALYSIS:

	DIAMETER OF SIEVE MESH (mm)					
10			0.08			
20	0.11	0.08		0.09		0.11
30						0.10
50	1.04	0.70	1.05	0.65	0.30	0.70
100	12.5	12.5	12.5	12.5	2.00	4.75

A representative plot of velocity versus head and the accompanying data sets for all the tests are given in **Appendix E**.

There are numerous reasons why neither of these small cell permeameter methods yield very reliable values for a soil's coefficient of permeability. First, a soil sample is never in the same field state during testing and the exact density can never be reproduced in the lab. Thus, its internal structure is destroyed by sampling and laboratory preparation. The boundary conditions can only be approximated and under such circumstances the permeability measured may differ from field measurements. The degree of saturation was not measured (specimens were left overnight to saturate under atmospheric pressure). Consequently, trapped air within the permeameter may reduce the cross-sectional area of flow, resulting in lowered measurements of conductivity (Fetter, 1988).

The hydraulic conductivity values obtained from the small cell permeameter were used to estimate the rate of pollutant movement through the overburden at the study site. These estimates were incorporated into the designs of the liners for the storage tanks.

4.3.5 Experimental Permeability Drum Tests:

4.3.5.1 Introduction:

As seen in previous sections, on site permeability tests and small cell permeameter tests determined hydraulic conductivity values for the site soils. Another method of permeability testing was the construction of a scale model to simulate overburden site conditions. **Figure 4.10** shows a schematic of this experimental drum. This aluminum drum was mounted on a steel frame and twenty piezometers were installed at 5 cm spacings from the base of the tank. These piezometers extended into the tank approximately 20 cm so the hydraulic head at that depth could be measured. The base of the drum was connected to a constant head tank. To facilitate testing, two pressure transducers were attached to the sides of the drum. In turn each was attached to a digital readout and a strip chart recorder to measure water level fluctuations.

Two 25 mm (1 in) schedule 80 PVC wells in the drum simulated the monitoring well network in the field. Well (W1) had an overall length of 0.72 m and well (W2) 0.48 m. Both wells had a screened interval of 100 mm (4 in) which was covered with a low permeability fabric, Tyrafix® 270. The base of the drum had a 50 mm (2 in) filter layer of sand and the soil surface had a 25 mm (1 in) sand covering

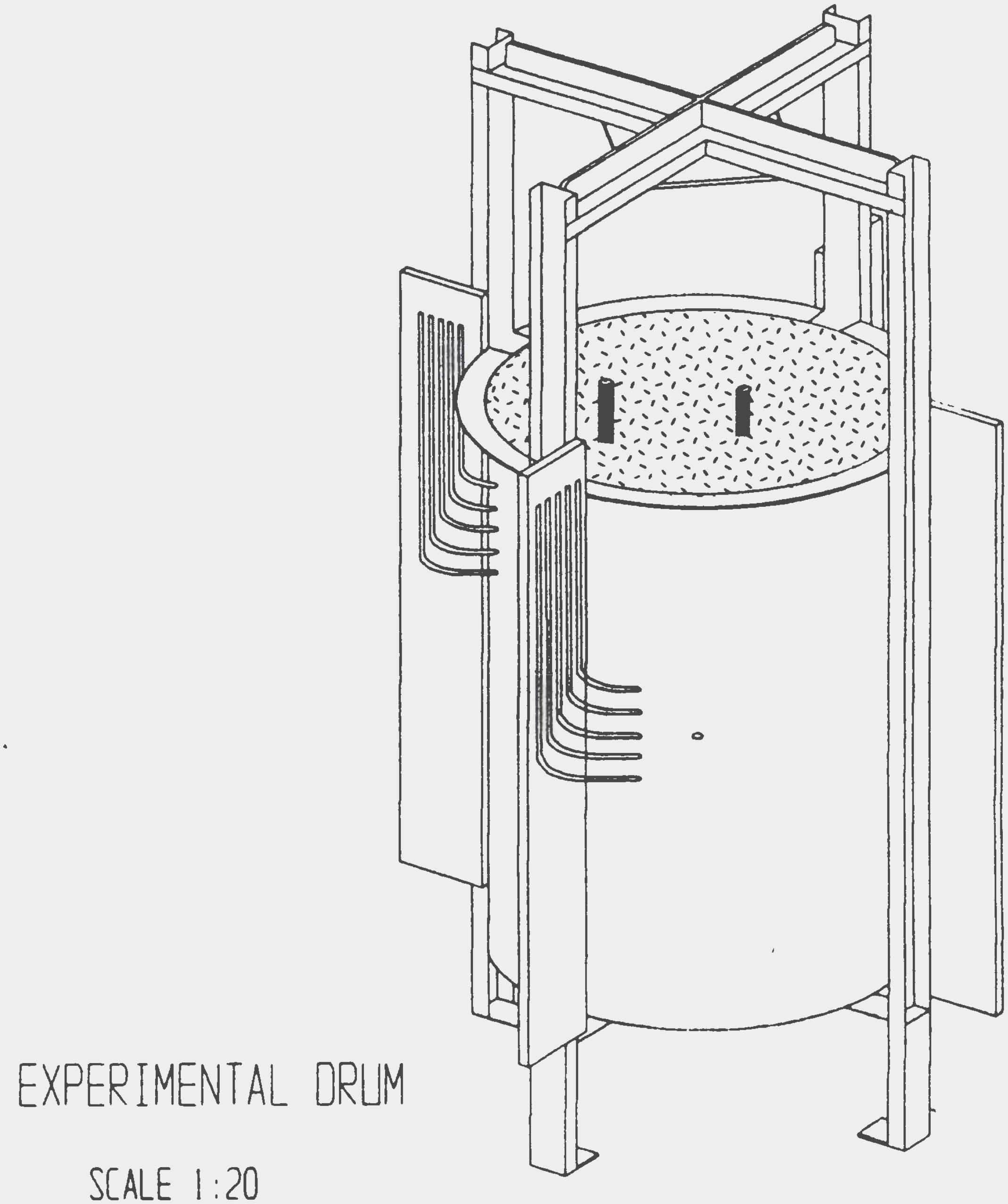


Figure 4.10 Schematic diagram of the experimental permeability tank.

to prevent moisture loss from the underlying soil .

On May 26, 1992 the soil mass in the experimental drum was constructed. The soil was obtained from the study site previously that fall and stored for the winter. The soil was initially screened to 38 mm (1.5 in) in size and wetted to optimum compaction prior to filling the drum. The soil mass was constructed in 100 mm (4 in) layers with each layer weighed to determine its density. Each layer was compacted using a 10 kg hammer to achieve optimum compaction for the entire drum. Each of the piezometer extensions were installed within successive layers. The wells W1 and W2 were installed and attached to the exterior of the drum via quick disconnect couplings. The density of each soil layer was calculated during construction of the soil mass. However, compaction of successive layers resulted in overcompaction of the lower layers resulting in uneven compaction throughout the drum. Therefore, only an approximate density based on the overall drum height of 105 cm (41 in) and a total mass of 905 kg yielded a value of 1.95 g/cm^3.

The drum was saturated for two weeks prior to any testing. During that time the piezometers were monitored and developed if necessary to remove any trapped air inside the soil mass. After water levels in the drum stabilized, falling and rising head permeability tests were conducted at various states of saturation. The corresponding piezometric response was recorded and later used for permeability calculations.

On July 17, 1992 the soil was removed from the drum and allowed to partially dry prior to refilling. The homogeneous mix of soil was placed back in the drum but not compacted. Wells W1 and W2 were reinstalled and hooked up to the pressure transducers. The drum was allowed to saturate for two weeks prior to any testing. A similar series of permeability tests were performed as before. The in situ density of the soil mass was calculated by the sand cone density method (ASTM D1556-62). An average of three successive values resulted in a dry density of 1.90 g/cm^3.

4.3.5.2 Discussion of Results:

Since the experimental drum was a scale model of the overburden monitoring well network the Hvorslev slug test method was used to determine hydraulic conductivities. For a well point-filter at an impervious boundary, the following equation applies:

$$k = \frac{d^2 \cdot \ln\left[\frac{2mL}{D} + \sqrt{1+\left(\frac{2mL}{D}\right)^2}\right]}{8 \cdot L \cdot (t_2 - t_1)} \quad \ln\frac{h_1}{h_2}$$

where

k = the hydraulic conductivity ($k_h = k_v$, assumed),

d = the radius of the sampling well,

m = transformation ratio, $m = 1$,

L = the length of the well screen including sand pack,

D = the radius of the well screen, usually taken as the borehole radius,

h_1 = piezometric head for time $t = t_1$,

h_2 = piezometric head for time $t = t_2$,

t_1 = time interval for h_1, and

t_2 = time interval for h_2.

Same assumptions made as for Section 4.3.2.

To determine the basic time lag, a plot of the velocity [change in hydraulic head for a corresponding change in time,($\partial h/\partial t$)] versus the hydraulic head was constructed. The slope of this line is equal to the basic time lag. Polynomial fit statistics were used to determine the equation that best fit this line. The data were then transformed using this equation and the straight line plotted. A representative graph of the velocity ($\partial h/\partial l$) versus the hydraulic head and the recovery data are listed in **Appendix E**. The hydraulic conductivity values for the wells in the experimental drum are summarized in **Table 4.6**.

The hydraulic conductivity values obtained are within 10^{-4} - 10^{-6} cm/s. As previously mentioned the specimens may not have been fully saturated prior to testing. Specimen preparation (remolding) may explain this relative scattering of values. Longer saturation times may be necessary to eliminate this problem.

Table 4.6
Summary of the experimental drum hydraulic conductivity tests.

WELL #	COMPACTION STATE	TEST #	TEST DATE	SWL (mm arp)	TYPE	k (cm/s)	COMMENTS
1	COMPACTED	1	6-5-92	876	FH	2.77E-05	MAY 25-MAY 29 DRUM PREPARATION
1	COMPACTED	2	6-7-92	876	FH	2.77E-05	COMPACTED STATE- SWL 876 mm
2	COMPACTED	1	6-8-92	900	FH		
2	COMPACTED	2	6-10-92	900	FH		
2	COMPACTED	3	6-10-92	900	FH		
1	COMPACTED	1	6-15-92	958	FH	2.77E-05	
2	COMPACTED	1	6-16-92	974	FH		
2	COMPACTED	2	6-16-92	1017	FH		
1	COMPACTED	1	6-16-92	1017	RH	6.40E-04	
1	COMPACTED	2	6-17-92	1017	RH	2.56E-04	
2	UNCOMPACTED	1	6-24-92	900	RH		JULY 17 REASSEMBLE TANK IN
2	UNCOMPACTED	2	6-24-92	907	RH		SATURATED , UNCOMPACTED STATE
1	UNCOMPACTED	1	8-18-92	1155	FH	1.11E-04	
1	UNCOMPACTED	2	8-18-92	1155	FH	9.24E-06	
1	UNCOMPACTED	3	8-19-92	1157	FH	2.16E-06	
1	UNCOMPACTED	1	9-9-92	825	FH	5.20E-05	
1	UNCOMPACTED	2	9-10-92	840	FH	6.93E-05	
2	UNCOMPACTED	1	9-11-92	840	FH		
2	UNCOMPACTED	2	9-11-92	840	FH		
1	UNCOMPACTED	1	9-21-92	450	FH	5.23E-05	AUGUST 21 LOWERED CONSTANT HEAD
1	UNCOMPACTED	2	9-29-92	480	FH	4.71E-05	TANK TO 840 mm
1	UNCOMPACTED	3	9-30-92	480	FH	4.85E-05	
2	UNCOMPACTED	1	10-6-92	500	FH		
2	UNCOMPACTED	2	10-6-92	500	FH		
2	UNCOMPACTED	3	10-8-92	500	FH		

KEY:
RH - RISING HEAD
FH - FALLING HEAD
arp - ABOVE REFERENCE POINT

CHAPTER 5

GROUNDWATER QUALITY MONITORING

5.1 Introduction:

The purpose of the groundwater quality monitoring program was to determine the impact of spreading liquid dairy manure on land and the long term effects of seasonal storage. It was evident that the water quality of the area had been affected for some time by the close proximity of neighbouring farms and the urbanization of the area. The background water quality would therefore be a combination of these anthropogenic factors. These factors established a baseline by which any changes in water quality from the spreading experiment could be compared.

In the deeper wells, the upper three to four metres of the bedrock aquifer was isolated with a screened interval and a bentonite seal to ensure only the groundwater at that level was collected. All the monitoring wells used for groundwater quality analysis were developed to minimize sediment effects and two to three borehole volumes of water were removed prior to sampling. These measures ensured the retrieval of acceptable representative samples of groundwater, as indicated in the next section.

5.2 Sampling Procedures:

The procedure for sampling the monitoring wells was adapted from the Environment Canada Guidelines, Sampling for Water Quality, (1983). These guidelines refer to surface water sampling but have been adapted by the Newfoundland Department of Environment and Lands for groundwater sampling. The sampling procedure is as follows:

1. The static water level (SWL) was measured.

2. The temperature of the water in the sampling well was measured after probe stabilization.

3. The sampling well was bailed of 2-3 borehole volumes or until the well was bailed dry.

4. The sample bottle was rinsed with the well water prior to sample collection.

5. A 500 ml sample was obtained for chemical analysis.

6. The samples were stored in a cooler and transported to the laboratory for immediate analysis within 24 hours.

The diameter of the sampling wells prohibited the use of conventional, commercially available samplers, such as pumps or bailers. Therefore, samplers were designed to meet these requirements. The first sampler design consisted of a length of low density polyethylene tubing [12.7 mm (0.5 in) ID] with a laboratory grade rubber stopper connected to one end. An appropriate length of nylon draw cord was attached to the rubber stopper. This provided a watertight seal at one end of the sampler. The other sampler, a PVC bailer, consisted of a length of machined schedule 80 PVC pipe with a 25.4 mm (1 in) diameter Delrin® foot valve with a stainless steel ball. The other end had a steel pin to secure the nylon bailer cord. Two bailers were constructed, one with a length of 44 cm (volume = 223 cm^3) and the other a length of 75 cm (volume = 380 cm^3).

The PVC bailers proved to be more successful in sample retrieval than the polyethylene tubing which had a tendency for sample contamination. The compact bailers were more manageable when obtaining samples while reducing the risk of external contamination. The sampling was problematic because cross-contamination between sampling wells was to be kept to a minimum. To achieve this, the wells assumed to be the least contaminated were sampled first in progression to those considered the most contaminated. The bailers were rinsed periodically during sampling and cleaned and stored when sampling was complete. This proved to be the most effective field method for groundwater quality sampling analysis for the present study.

The yield of most of the sampling wells could not withstand prolonged bailing, consequently, these wells were bailed dry and allowed to recover before sample retrieval. It was not possible to remove all of the stagnant water in the borehole prior to sampling. However, removing as much of the water as feasible initially, proved more advantageous than simply removing 2 - 3 borehole volumes of water from the well. The advantage was the reduced mixing of fresh aquifer water with the stagnant well water. The disadvantage for water quality sampling was the increased turbulence in the well during collection, hence, increasing the amount of suspended sediment in each sample. However, the bailer continually removed sediment that filtered through the sand pack and settled at the bottom of the well. The removal of this material reduced the effects of organic or inorganic chemical alteration of the sampling well water.

5.3 Chemical Analysis:

It is well known that persistent agricultural activity causes nutrient enrichment and elevated concentrations of certain inorganic constituents, such as nitrate and ammonia, in the underlying groundwater [Miller, (1980) cited in Robinson et al. (1991)]. In view of this information, and other previous studies, a list of chemical test parameters was chosen to define the groundwater quality of the study site. These parameters are listed in **Table 5.1**.

Sampling commenced on May 14, 1992 and continued on May 20, May 29, and June 3, 1992 to determine the background groundwater quality of the study area prior to beginning any experiments. The first application of manure was spread on June 25, 1992 at a rate of 64 tons/acre (143 tonnes/hectare). This is approximately two times what is needed for the clover-timothy crop cover (Bishop, 1992 Pers. Comm.). Water quality sampling concentrated on the shallow wells in the spreading zone because it was assumed that any increase in the detection parameters would be noticed first in the shallower wells. It was also believed that if any increase was detected then its downward migration would be confirmed by increased concentrations in the deeper sampling wells. The sampling scheduled following the first spreading of manure was every three days for three consecutive readings, every week for three consecutive readings, every two weeks for three consecutive readings, and finally

Table 5.1
Physical and chemical parameters analyzed.

PARAMETER	RANGE - UNITS
Orthophosphate, $(PO_4)^{3-}$	0 - 2.50 mg/L
Nitrate, $N\text{-}NO_3^-$	0 - 30.0 mg/L
Ammonia Nitrogen, $N\text{-}NH_3^-$	0 - 0.50 mg/L
Chloride, Cl^-	10 - 8000 mg/L
pH	0.00 - 14.00 Units
Temperature	0.0 - 100.0 °C
Conductance	0.0 - 20.0 ms/cm
Total Dissolved Solids (TDS)	0.0 - 20.0 g/L
Total Hardness	10 - 4000 mg/L
Calcium Hardness, $Ca\text{-}CaCO_3$	10 - 4000 mg/L
Magnesium Hardness, $Mg\text{-}CaCO_3$	10 - 4000 mg/L

once a month until December 11, 1992. The second manure application (same rate as June 25, 1992) was applied on December 11, 1992. Although the sampling program continued in 1993, none of these analyses are included in the current study.

5.4 GROUNDWATER CHEMISTRY:

Groundwater acquires characteristics particular to the rock type or types through which it passes. Thus, the geochemical signatures are determined by: (1.) the order in which water encounters particular rock types, (2.) the residence time in a particular rock type, and (3.) the solubility of the rock mineral constituents (Gale et al., 1984). One aim of the water quality testing program was to determine the degree of interaction of the agricultural waste disposal experiments and the surrounding geologic materials.

The chemical analyses were performed at Memorial University using the HACH DREL/2000 (Direct Reading Environmental Laboratory) portable laboratory. The kit consisted of a DR/2000 (Direct Reading) spectrophotometer, digital titrator, conductivity/TDS meter (accuracy, ± 1 % of reading), supplies, apparatus, and reagents. The spectrophotometer is a microprocessor-controlled instrument with an optical system that uses a high-dispersion prism and a tungsten light source for wavelength measurements in the 400 - 900 nm (nanometer) range. The wavelength accuracy of the instrument is $\pm$ 2 nm from 400 - 700 nm and $\pm$ 3 nm from 700 - 900 nm with a resolution of 1 nm. The spectrophotometer stores preprogrammed calibrations that eliminate the manual conversion of absorbance data to concentration values. The reagents are premeasured and shipped in single-dose powder pillows. The pH measurements were obtained using a Fisher Model 910 Accumet laboratory pH meter. The pH meter has a relative accuracy of $\pm$ 0.02 pH units and was calibrated using a two point standardization and manual slope control method prior to sample measurements.

The results of the water quality analyses are presented in **Appendix F**. For the purpose of comparison, the Maximum Allowable Concentration (MAC) set in the Canadian Water Quality Guidelines (1992) will be referenced.

A general indicator of agricultural pollution is elevated concentrations of orthophosphate, nitrate, and ammonia. **Figure 5.1** plots these concentrations with respect to time. Additional chemical plots of the other parameters analyzed can be found in **Appendix F**.

Phosphorus can occur in numerous organic and inorganic forms, and is present in groundwaters as a particulate or dissolved species. The inorganic form of

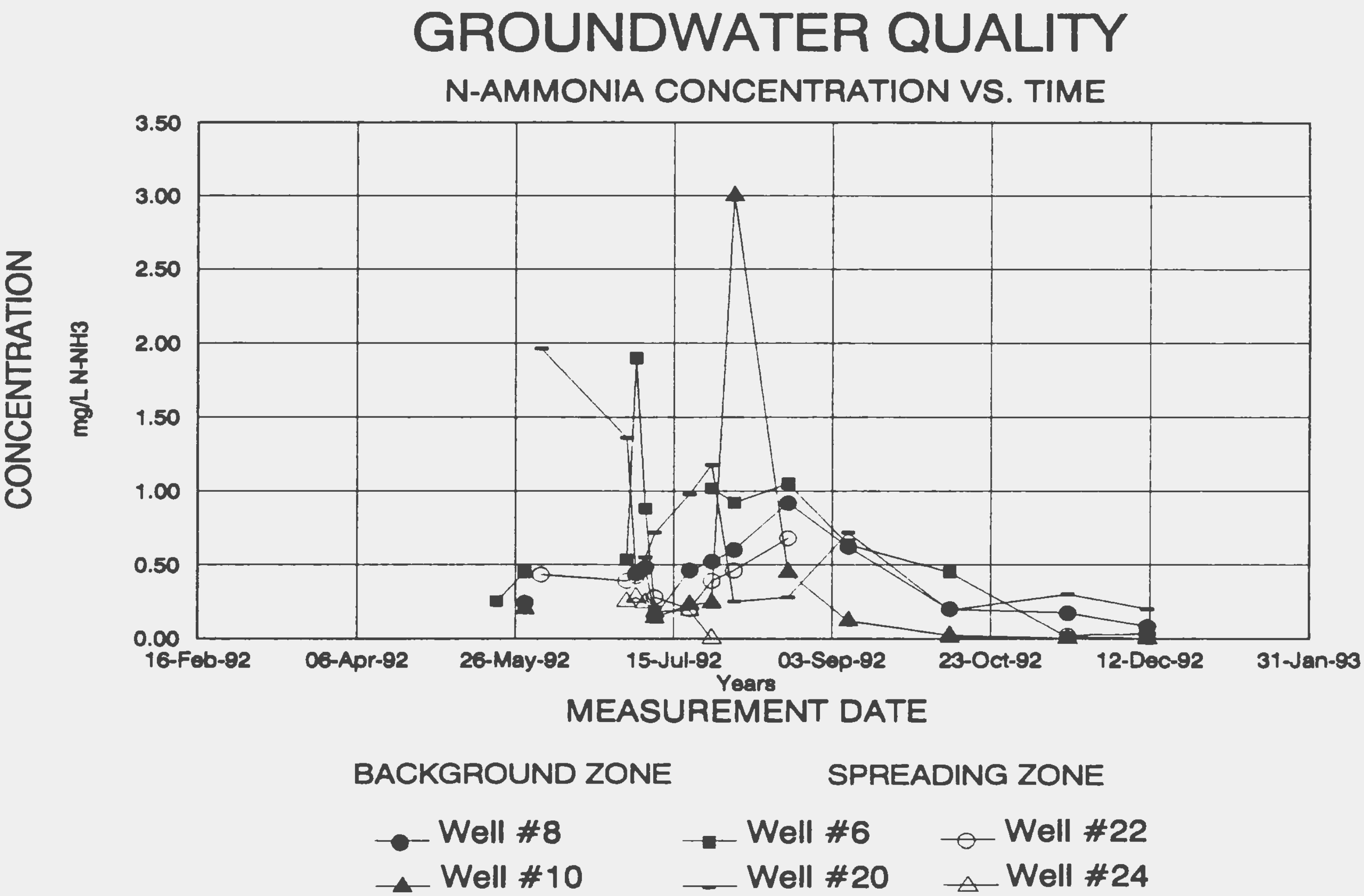
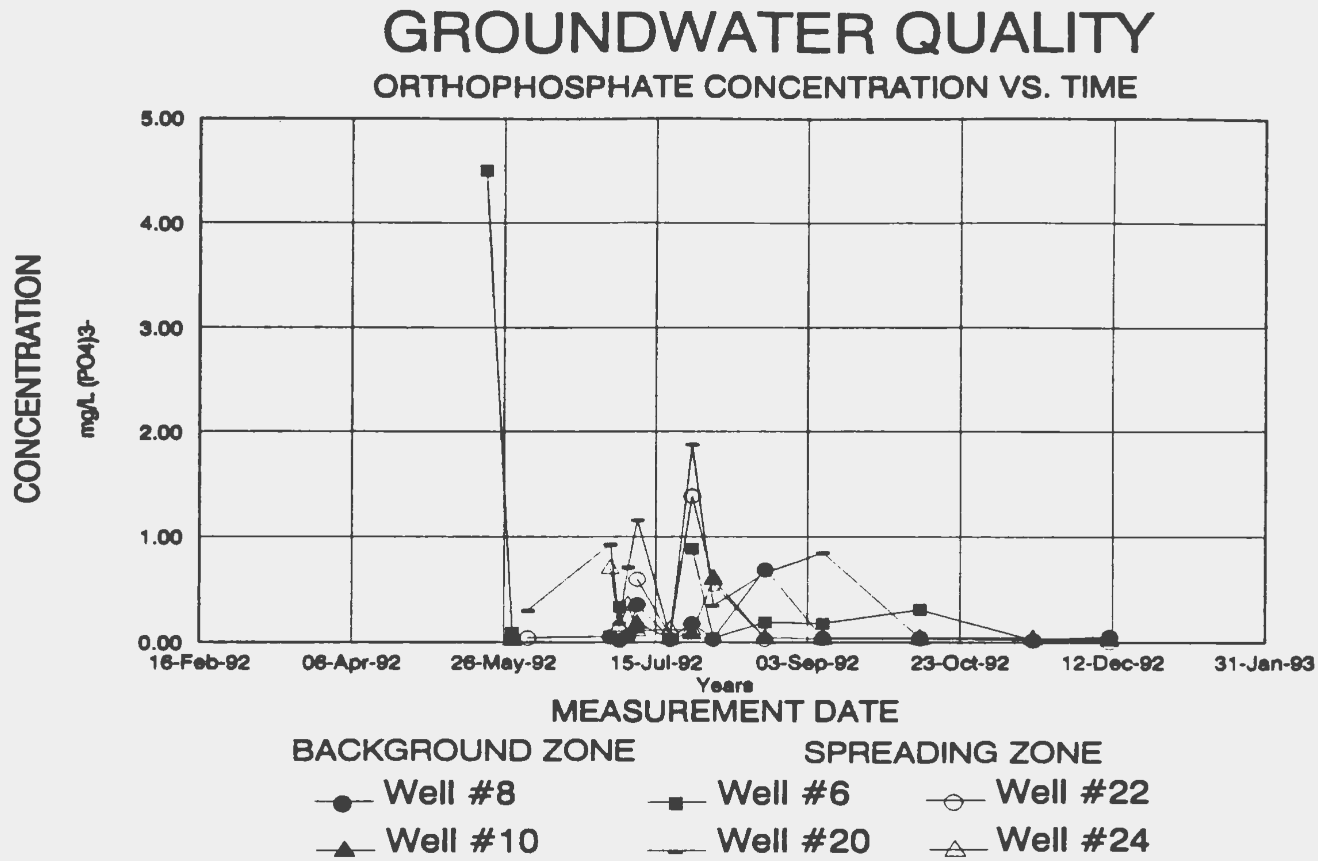
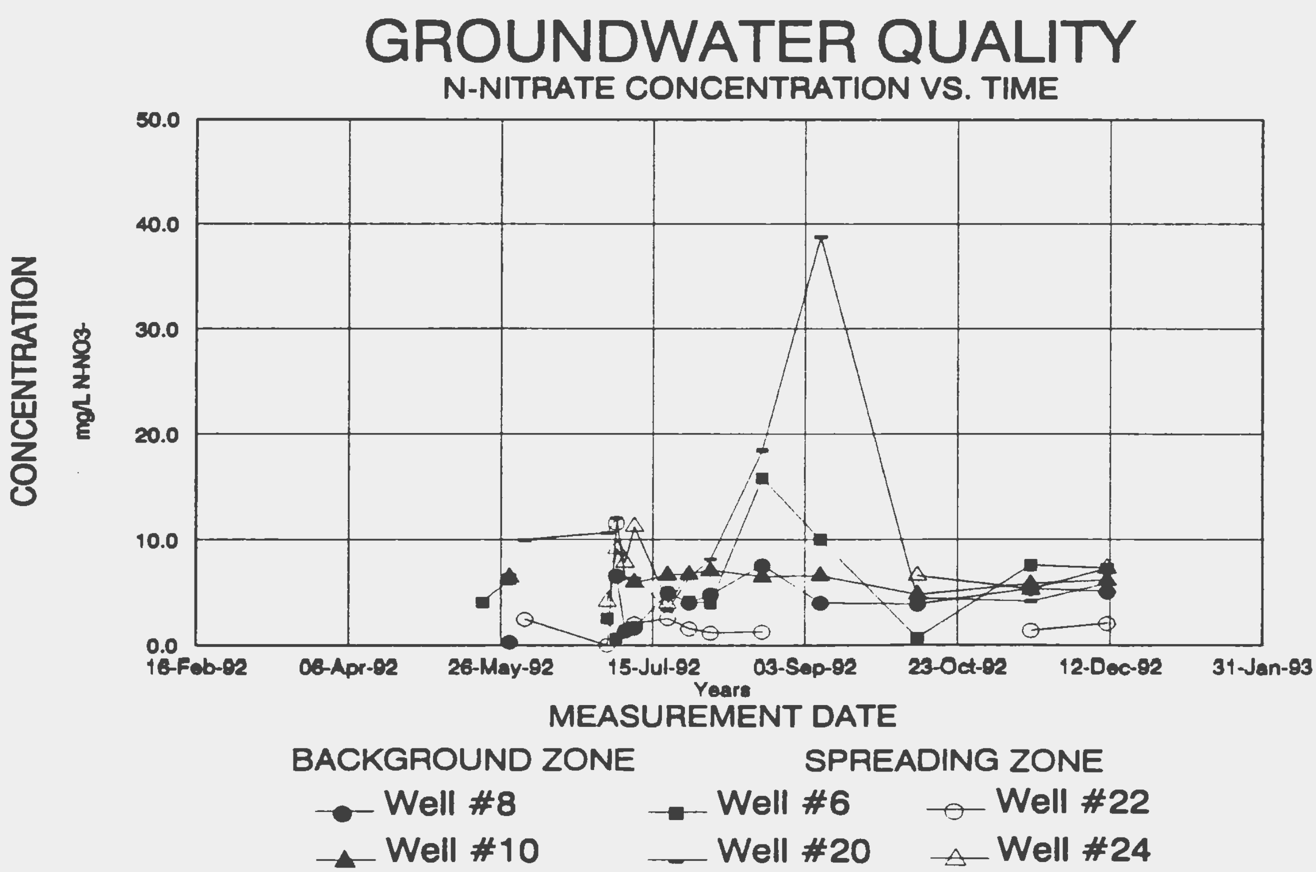


Figure 5.1 Ammonia, orthophosphate, and nitrate concentrations versus time.



GROUNDWATER QUALITY
ORTHOPHOSPHATE CONCENTRATION VS. TIME
CONCENTRATION
mg/L (PO4)3-
5.00
4.00
3.00
2.00
1.00
0.00
16-Feb-92
06-Apr-92
26-May-92
15-Jul-92
03-Sep-92
23-Oct-92
12-Dec-92
31-Jan-93
Years
MEASUREMENT DATE
BACKGROUND ZONE
SPREADING ZONE
Well #8
Well #10
Well #6
Well #20
Well #22
Well #24



GROUNDWATER QUALITY
N-NITRATE CONCENTRATION VS. TIME
CONCENTRATION
mg/L N-NO3-
50.0
40.0
30.0
20.0
10.0
0.0
16-Feb-92
06-Apr-92
26-May-92
15-Jul-92
03-Sep-92
23-Oct-92
12-Dec-92
31-Jan-93
Years
MEASUREMENT DATE
BACKGROUND ZONE
SPREADING ZONE
Well #8
Well #10
Well #6
Well #20
Well #22
Well #24

phosphorus, orthophosphate (PO_4^{3-}), was analyzed in this study. Phosphorus is essential to plant growth, therefore, it is particularly important from an agricultural viewpoint. There is no MAC for orthophosphate set in the Canadian Water Quality Guidelines. The low solubility of phosphorus compounds in groundwater, the limited mobility of phosphorus due to its tendency to sorb on solids, and the lack of proven health problems diminish its potential as a source of groundwater contamination (Domenico and Schwartz, 1990).

The orthophosphate concentrations are typically below 1.0 mg/L with the exception of one reading of 4.5 mg/L recorded in W6 (see Figure 5.1). This reading was measured early in the sampling program and could be a result of manure spreading activities on nearby farms or by crop fertilization from Agriculture Canada activities. No increasing trends in orthophosphate concentrations were detected. This is contrary to what was anticipated following manure application on the study site. The small peaks visible in the chemical signatures are conceivably caused by extraneous sources.

Nitrate (NO_3^-) is the principal form of combined nitrogen in natural waters. The nitrate ion is highly soluble and is the most stable form of combined nitrogen resulting from the oxidation of nitrogen compounds. The nitrification process converts ammonium (NH_4^+) to nitrate. The MAC for nitrate is 45.0 mg/L. Contamination by agricultural activities and the disposal of sewage on or beneath the land surface can elevate nitrate concentrations well above the maximum level. The main health effects related to contamination by nitrogen compounds are (1.) methaemoglobinaemia, a blood disorder in which oxygen transport in young babies or unborn fetuses is impaired, or (2.) the possibility of forming cancer-causing compounds after drinking contaminated water (Domenico and Schwartz, 1990).

The concentrations of nitrate, as seen in Figure 5.1, are usually below 10.0 mg/L with the exception of one reading of 38.8 mg/L in W20. This anomalously high value is supported by other previous readings that indicate an increasing trend, whereas, this elevated concentration is not supported by similar increases in the other wells. The validity of this trend is questionable with no supportive evidence from the other wells. It is more plausible to assume that given the nitrate variation in W20, the concentrations of the other wells indicate chemical variations caused by other sources.

Ammonia (NH_3) is a secondary form by which dissolved nitrogen occurs in groundwater. Ammonia can enter an aquifer through precipitation, sewage disposal, and mineral fertilizers. The conversion of ammonia to nitrate is one of the principal processes of the nitrogen cycle and can contribute to excess nitrate in an aquifer. The same health hazards and groundwater contamination problems pertaining to nitrates can occur for ammonia.

The ammonia concentrations are usually below 1.00 mg/L except for one value of 3.00 mg/L in W10. This high reading was obtained after the first application of manure. Therefore, it would be safe to assume that the high value is a direct result of manure spreading. However, the lack of supportive evidence from the other sampling wells questions this assumption. It would appear that another source is responsible for this elevated ammonia value. There is no direct evidence that relates the manure spreading to the increased ammonia values. However, as previously discussed, the elevated concentrations are presumably from extraneous sources.

5.5 STATISTICAL DATA ANALYSIS:

5.5.1 Introduction:

The increasing expense involved in the collection of groundwater samples requires statistically effective sampling programs. The variability of groundwater quality trends has prompted the use of appropriate statistical methods. The conclusions derived from groundwater quality analyses are often used as early warning systems for contamination or to direct remediation efforts. The design of the monitoring program and the statistical treatment of the data require an understanding of the interaction of the random variables of concern. Without this the entire sampling program may be suspect.

It is safe to consider that many groundwater quality variables are not normally, or even symmetrically, distributed based upon various studies conducted in the United States (Montgomery et al., 1987). They conclude that some distributions are fairly symmetric about a central value. Some "exceedingly high" values however, tend to skew the distribution. Two possible reasons for these large values are: (1.) measurement errors and (2.) groundwater contamination, in which case the high values may belong to a "population" different from that of the remaining sample values. In this case, nonparametric (distribution free) statistical procedures are often recommended. These procedures do not require the statistical distribution to be Gaussian.

Other problems that can affect environmental data sets are: (1.) accurately defining the environmental "population" of interest, (2.) large measurement errors (both random and systematic), (3.) data near or below measurement detection limits, (4.) missing and/or suspect data values, and (5.) complex trends and patterns in mean concentration levels over time and/or space, complicated cause and effect relationships, and the frequent need to measure more than one variable at a time (Gilbert, 1987).

5.5.2 Field Sampling Design:

Data are easily collected but difficult to interpret unless they are drawn from a well-defined population of environmental units, termed the target population and sample population (Gilbert, 1987). The target population, as defined by Gilbert (1987), is the set of N population units about which inferences are made and the sample population as the set of population units directly available for measurements. In order to define the environmental population of interest, a space-time sampling framework should be the first priority before any sampling occurs.

Four sampling plan criteria are as follows (Gilbert, 1987):

* *objectives of the study*,
* *cost-effectiveness of alternate sampling designs*,
* *environmental contamination and variability patterns*, and
* *non-statistical practical considerations*.

The non-statistical practical considerations could be site accessibility, security of sampling devices and equipment, convenience of sampling, etc. These variables can greatly influence the final design of the sampling program but are non-statistical variables.

changes that occur as a result of a manure disposal experiment (spreading) or a long term storage experiment. The sampling program consisted of fixed sampling points (monitoring wells) to determine groundwater quality changes over time. To detect trends it is necessary to have continuous monitoring at fixed intervals over an extended time period.

According to the National Academy of Sciences (1977), cited in Gilbert (1987), a given sampling design should either achieve a specified level of effectiveness at minimum cost or an acceptable level of effectiveness at specified cost. The magnitude of the sampling errors should be assessed for different sampling designs. Specific to the sampling program the water quality analysis were performed either by digital titration, UV spectrophotometry, a pH meter, or a conductivity/TDS meter depending upon the parameter to be tested. These methods of analysis proved to be very cost effective for multiple analyses. The analytical procedures used are standard in most commercial and university laboratories. It was agreed that the magnitude of the results and the associated errors were acceptable for the cost of analysis.

Prior knowledge of possible temporal or spatial patterns of contamination could assist the development of an effective sampling plan. These patterns are often complex where topography, meteorology, and external influences combine and where baseline transitions in time are common (Gilbert, 1987). Based upon previous knowledge of the study area's persistent agricultural activity that has occurred for some time, the close proximity of neighbouring farms, and the farming operations on the station that coincide with the time table of the study experiments, all affect the interpretation of any data collected. These external influences are taken into consideration when interpreting variability within the data set.

The method chosen for selecting sampling locations and the time schedule implemented for the groundwater chemical analysis was judgement sampling. This means of subjective sampling selects the population units for analysis. The sampling scheme tested the shallower wells located in the spreading zone and the slope down from it. It was presumed that any contamination entering the aquifer would be detected first in the shallow wells before the deeper bedrock wells. It was also important to detect any lateral contaminant migration so the shallow wells down slope from the spreading zone were sampled. One problem in judgment sampling may be systematically choosing samples that are too large or small thus introducing an analysis bias (Gilbert, 1987). **Table 5.2** summarizes common sampling designs and the conditions when they are useful.

Table 5.2
Sampling design summary and their usage. (Modified after Gilbert, 1987)

Type of sampling design:	Conditions when sampling should be used:
Haphazard sampling	Homogeneous population over time and space is essential if unbiased estimates of population parameters are needed. Not recommended.
Judgment sampling	Target population should be clearly defined, homogeneous, and completely assessable so that sample selection bias is not a problem.
Probability sampling	
* *simple random sampling*	Simplest probability sampling technique.
* *stratified random sampling*	Useful when the population can be broken down into internally homogeneous parts.
* *multistage sampling*	Effective when measurements are made on subsamples or aliquots of the field sample.
* *cluster sampling*	Useful when population units cluster together and every unit in each randomly selected cluster can be measured.
* *systematic sampling*	Frequently the method of choice when estimating trends or patterns over space. Also useful for estimating the mean when trends and patterns in concentrations are not present.
* *double sampling*	Effective when there is a strong linear relationship between the variable of interest and a more easily measured variable.
Search sampling	Useful when historical information or prior samples indicate the location of the object.

5.5.3 Population Comparisons:

One of the objectives of the groundwater sampling program was to make comparisons between the spreading zone and the background zone over time before and after manure spreading. Since the chemical data do not follow a normal distribution, nonparametric methods are used to make comparisons. These methods can accommodate missing data and values that are below detection limits.

The data set is assumed to be independent because there is no natural way of pairing the data between populations. There is no reasonable way to compare the water quality among the sampling wells over the site. The only wells that were grouped are those positioned in identical boreholes since no spatial variation occurs. The Mann-Whitney test for comparisons of two populations and the Kruskal-Wallis test for comparison of more than two populations are the nonparametric methods used. The Mann-Whitney and Kruskal-Wallis test statistics are defined as follows (McClave and Benson, 1991):

> **Mann-Whitney Test Statistic**: A comparison of two populations based on individual random samples in a Mann-Whitney u-statistic. The u-statistic is a simple function of rank sum.
>
> H_o (Null Hypothesis): The two sample populations have identical probability distributions.

H_a (Alternate Hypothesis): The probability distribution for Population A is shifted to the right/left of that for Population B.

Assumptions: (1.) The two samples are random and independent.

(2.) The two probability distributions from which the samples are drawn are continuous.

The test statistic as defined by Conover (1980);

$$T = \sum_{i=1}^{n} R(X_i)$$

where

T = the test statistic,
n = number of samples, and
$R(X_i)$ = rank assigned to X_i for all i.

If there are many ties in the sample set, subtract the mean from T and divide by the standard deviation to get the following;

$$T_1 = \frac{T - n\frac{N+1}{2}}{\sqrt{\frac{nm}{N(N-1)} \sum_{i=1}^{N} R_i^2 - \frac{nm(N+1)^2}{4(N-1)}}}$$

where

n = random sample size from population 1,
m = random sample size from population 2,
N = n + m, and
ΣR_i^2 = sum of the squares of all N of the ranks or average ranks actually used in both samples.

Kruskal-Wallis Test Statistic: A nonparametric technique that requires no assumption concerning the population probability distribution to compare populations.

H_o: The probability distributions are identical.

H_a: At least one of the P-probability distributions differ in location.

Assumptions: (1.) The P samples are random and independent.

(2.) There is five or more measurements in each sample.

(3.) The probability distributions from which the samples are drawn are continuous.

The test statistic as defined by Conover (1980);

$$T = \frac{1}{S^2} \left(\sum_{i=1}^{k} \frac{R_i^2}{n_i} - \frac{N(N+1)^2}{4} \right)$$

where

T = the test statistic,
k = number of samples,
N = n + m,
ΣR_i^2 = sum of the squares of all N of the ranks or average ranks actually used in both samples,

and

$$S^2 = \frac{1}{N-1} \left(\sum_{all\ ranks} R(X_{ij})^2 - N\frac{(N+1)^2}{4} \right)$$

If there are no ties S^2 simplifies to $N(N+1)/12$, and the test statistic reduces to;

$$T = \frac{12}{N(N+1)} \sum_{i=1}^{k} \frac{R_i^2}{n_i} - 3(N+1)$$

Minitab Release 8.0 was used to perform all the statistical calculations.

Statistical analyses were performed on the data obtained from the spreading experiment. This area was divided into a spreading zone and a background zone. The spreading zone contained 6 wells (W3, W4, W6, W20, W22, W24) and the background zone contained 2 wells (W8, W10). **Figure 5.2** shows a schematic of the spreading zone experiment. The following comparison criteria were tested to detect statistical changes within the chemical data set:

* *Within the background zone, are there any statistically significant chemical differences between wells ?*

* *Within the background zone, are there any statistically significant chemical differences between wells before or after the first application of manure ?*

* *Within the spreading zone, are there any statistically significant chemical differences among wells ?*

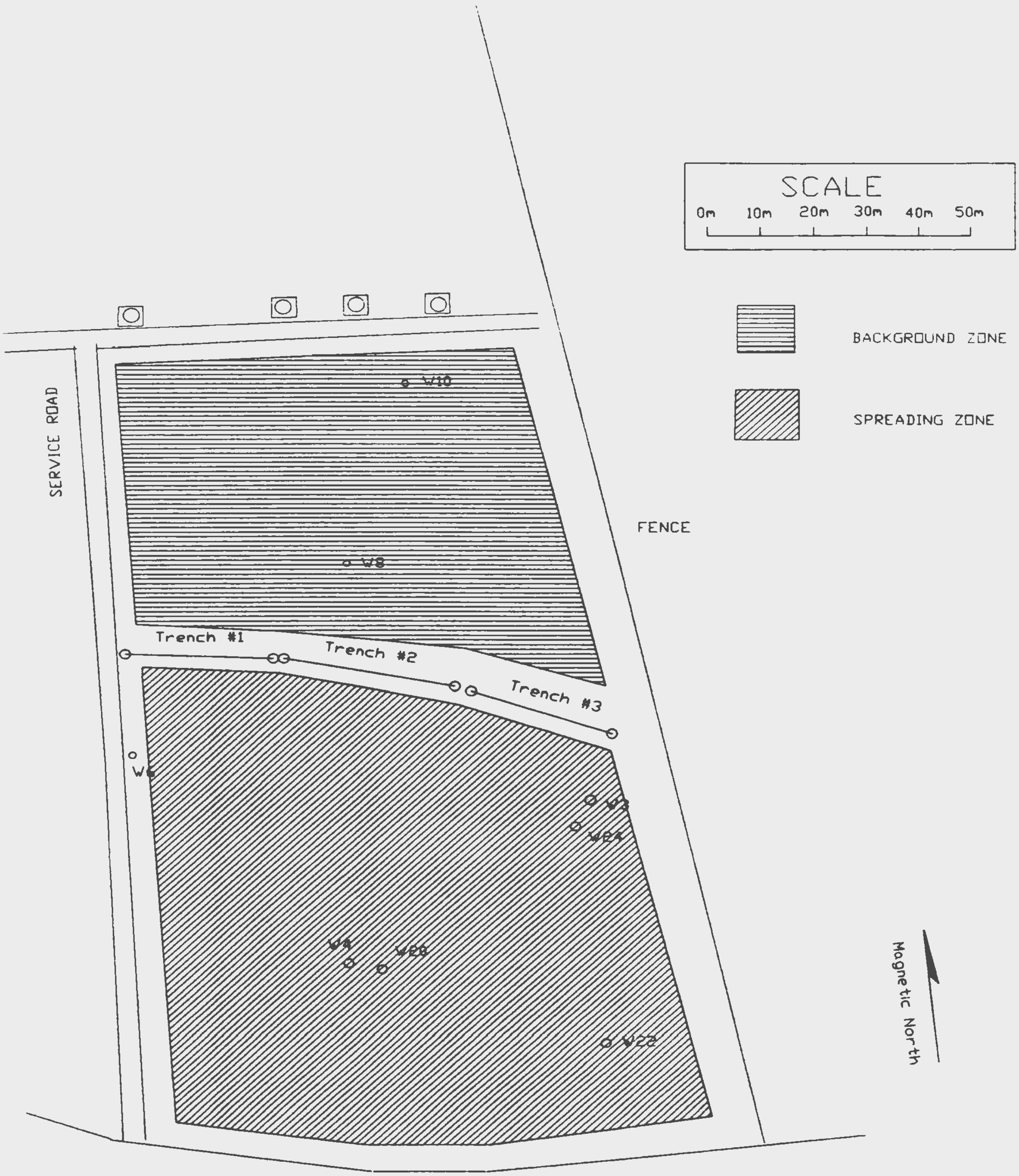


Figure 5.2 Location map of spreading and background zones.

* *Within the spreading zone, are there any statistically significant chemical differences among wells before or after the first application of manure ?*

* *Is there any statistically significant chemical difference among all the wells for the entire data set ?*

* *Is there any statistically significant chemical difference among all the wells for the entire data set before or after the first application of manure ?*

The data was divided into three different groups namely: (1.) background zone data, (2.) spreading zone data, and (3.) complete data set. A summary of the descriptive statistics by sampling well for the complete data set are given in **Appendix F**. The pertinent summary statistics for the entire data set are presented in **Table 5.3**. This table describes the data in terms of chemical parameter.

The background zone data set was tested for the above mentioned criteria. First the data were graphically represented using boxplots to determine if there was any statistically significant difference between sampling wells within the background zone.

Table 5.3
Summary descriptive statistics of the chemical analyses for the complete data set.

PARAMETER	N	N*	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN	MIN	MAX	Q^1	Q^3
PO_4^{3-}	100	0	0.327	0.085	0.248	0.565	0.057	0.000	4.500	0.033	0.418
NO_3^-	100	0	5.311	4.450	4.788	5.152	0.515	0.000	38.800	1.525	7.250
NH_3	100	0	0.393	0.250	0.332	0.443	0.044	0.000	3.000	0.170	0.460
Cl^-	100	0	16.670	14.350	15.060	11.890	1.190	3.000	86.000	11.020	19.350
pH	100	0	7.054	7.230	7.090	0.661	0.066	4.360	8.000	6.613	7.530
Cond	100	0	0.327	0.298	0.314	0.176	0.018	0.068	0.940	0.181	0.412
TDS	100	0	0.163	0.149	0.157	0.088	0.009	0.034	0.460	0.090	0.206
T Hard	97	3	86.230	77.000	80.200	54.500	5.530	14.500	318.000	46.300	112.200
Ca Hard	97	3	66.260	54.400	60.810	44.960	4.570	11.800	246.000	33.800	87.200
Mg Hard	97	3	19.970	16.000	18.570	14.360	1.460	1.700	72.000	10.000	25.400

Abbreviations used:

N	- number of nonmissing values.
N*	- number of missing values.
TRMEAN	- trimmed mean.
STDEV	- standard deviation.
SEMEAN	- standard error of the mean.
MIN	- minimum value.
MAX	- maximum value.
Q^1	- first quartile.
Q^3	- third quartile.

Boxplots are concise graphical displays that summarize the main features of a data set for a single variable. The middle half of each variable is represented by a box and the median is marked with a "+". Upper and lower hinges used, in the context of a boxplot, are essentially quartiles.

(H-spread) = (upper hinge - lower hinge)

Inner fences are at:

(lower hinge) - 1.5 x (H-spread)
(upper hinge) + 1.5 x (H-spread)

Outer fences are at:

(lower hinge) - 3 x (H-spread)
(upper hinge) + 3 x (H-spread)

In a boxplot, "whiskers" run from the hinges to the adjacent values on each side. Values between the inner and outer fences are possible outliers, and are plotted with an "*". Values beyond the outer fences are probable outliers, and are plotted with an "o".

Minitab prioritizes what symbols will be displayed in the Boxplot output. If the median and a notch fall on the same space, the notch will not be displayed. Similarly, if the median and a quartile fall on the same space, the quartile is not displayed. (Schaefer and Farber, 1991).

The corresponding boxplots are presented in **Appendix F**. To verify the conclusions drawn from the boxplots, Mann-Whitney test statistics were also calculated for the data set. The results from this nonparametric statistical test are illustrated in **Table 5.4**.

The Mann-Whitney test and the boxplots comparing chemical parameter by sampling well conclude that there is a statistical difference between W8 and W10 for

Table 5.4
Mann-Whitney test statistic for background zone chemical analyses (95.0 % confidence interval).

Comparison of chemical parameter by sampling well.

PARAMETER	MANN-WHITNEY STATISTIC	STATISTICALLY SIGNIFICANT
Orthophosphate	0.4026	
Nitrate	0.0171	*
Ammonia Nitrogen	0.0161	*
Chloride	0.8342	
pH	0.0000	*
Conductance	0.0002	*
Total Dissolved Solids	0.0002	*
Total Hardness	0.0001	*
Calcium Hardness	0.0001	*
Magnesium Hardness	0.0004	*

Table 5.4 (cont'd)

Comparison of chemical parameter by application date.

PARAMETER	MANN-WHITNEY STATISTIC	STATISTICALLY SIGNIFICANT
Orthophosphate	0.0442	*
Nitrate	0.0992	
Ammonia Nitrogen	0.1792	
Chloride	0.0352	*
pH	0.5216	
Conductance	0.5621	
Total Dissolved Solids	0.6916	
Total Hardness	0.3763	
Calcium Hardness	0.4102	
Magnesium Hardness	0.1514	

nitrate, ammonia, pH, conductance, TDS, total hardness, calcium hardness, and magnesium hardness. These statistical differences between W8 and W10 prohibit any groupings within the data set. Therefore, these wells remain as independent populations for each of the chemical parameters. The Mann-Whitney test and the boxplots comparing chemical parameter by application date conclude that there is a statistical difference between W8 and W10 for orthophosphate and chloride. Consequently, no groupings between these wells can be made before or after manure spreading, the wells remain as independent populations.

The spreading zone data set was also tested for the previous criteria. Again the data were graphically represented using boxplots to determine if there were any statistically significant differences among sampling wells within the spreading zone. The corresponding boxplots are presented in **Appendix F**. To verify the conclusions drawn from the boxplots, Kruskal-Wallis and Mann-Whitney tests were also calculated for the data set, depending upon the number of samples. The results from these nonparametric tests are presented in **Table 5.5**. The Kruskal-Wallis test and the boxplots comparing chemical parameter by sampling well conclude that there is a statistical difference among all the wells. These statistical differences prohibit any groupings within the data set by well. Therefore, these wells remain as independent populations for each of the chemical parameters. The Mann-Whitney test and the boxplots comparing chemical parameter by application date conclude that there is no

Table 5.5
Kruskal-Wallis and Mann-Whitney test statistics for spreading zone chemical analyses (95.0 % confidence interval).

Comparison of chemical parameter by sampling well.

PARAMETER	KRUSKAL-WALLIS STATISTIC	STATISTICALLY SIGNIFICANT
Orthophosphate	0.041	*
Nitrate	0.000	*
Ammonia Nitrogen	0.008	*
Chloride	0.000	*
pH	0.000	*
Conductance	0.000	*
Total Dissolved Solids	0.000	*
Total Hardness	0.002	*
Calcium Hardness	0.001	*
Magnesium Hardness	0.016	*

Table 5.5 (cont'd)

Comparison of chemical parameter by application date.

PARAMETER	MANN-WHITNEY STATISTIC	STATISTICALLY SIGNIFICANT
Orthophosphate	0.7519	
Nitrate	0.9510	
Ammonia Nitrogen	0.4245	
Chloride	0.2002	
pH	0.3478	
Conductance	0.8607	
Total Dissolved Solids	0.7991	
Total Hardness	0.7008	
Calcium Hardness	0.7753	
Magnesium Hardness	0.4552	

statistical difference among the wells before or after the application of manure. Therefore, the manure application had no statistically significant effect on the chemical concentrations of the groundwater.

The complete data set was also tested in a similar manner. The data was graphically represented using boxplots to determine if there were any statistically significant differences among all the sampling wells. The corresponding boxplots are presented in **Appendix F**. To verify the conclusions drawn from the boxplots, Kruskal-Wallis and Mann-Whitney tests were also calculated for the data set, depending upon the number of samples. The results from this nonparametric test are presented in **Table 5.6**.

The Kruskal-Wallis test and the boxplots comparing chemical parameter by sampling well conclude that there is a statistical difference among all the wells. These statistical differences prohibit any groupings within the data set. Therefore, these wells remain as independent populations for each of the chemical parameters. The Mann-Whitney test and the boxplots comparing chemical parameter by application date conclude that there is no statistical difference among the wells, with the exception of chloride. Chloride is the only parameter that shows a statistical difference before or after the application of the manure. This anomaly will be considered further in the discussion section.

Table 5.6
Kruskal-Wallis and Mann-Whitney test statistics for the complete data set chemical analyses (95.0 % confidence interval).

Comparison of chemical parameter by sampling well.

PARAMETER	KRUSKAL-WALLIS STATISTIC	STATISTICALLY SIGNIFICANT
Orthophosphate	0.008	*
Nitrate	0.000	*
Ammonia Nitrogen	0.003	*
Chloride	0.000	*
pH	0.000	*
Conductance	0.000	*
Total Dissolved Solids	0.000	*
Total Hardness	0.000	*
Calcium Hardness	0.000	*
Magnesium Hardness	0.000	*

Table 5.6 (cont'd)

Comparison of chemical parameter by application date.

PARAMETER	MANN-WHITNEY STATISTIC	STATISTICALLY SIGNIFICANT
Orthophosphate	0.2119	
Nitrate	0.3482	
Ammonia Nitrogen	0.9550	
Chloride	0.0440	*
pH	0.2773	
Conductance	0.9836	
Total Dissolved Solids	0.8818	
Total Hardness	0.3076	
Calcium Hardness	0.3736	
Magnesium Hardness	0.1215	

5.5.4 Data Association Analysis:

The relationships between two or more variables can be termed statistical association. This association, thereby, implies lack of independence on the part of the individual variable. If the variables are independent, there is no relationship between them and the value of one has no effect on the values of the others. However, if they are not independent, then some kind of association exists.

Spearman's rank correlation test statistic measures the degree of association among variables. The measure is based upon the relative magnitudes of the variables within each of the data sets and it is assumed that the bivariate population is continuous, or that the probability of a tie within the data sets is equal to zero (Gibbons, 1976). Spearman's Rho (rank correlation) can be defined as follows (Gibbons, 1976):

> **Spearman's Rho**: A rank correlation between two variables can be calculated by ranking the variables and correlating the columns of ranks. If some data are missing, the correlations between each pair of columns are calculated using "pairwise deletion" of missing values.
>
> H_o: The population variables are independent - no association exists.
>
> H_a: There is an association among the population variables.
>
> The measure of correlation is given by (Conover, 1980);

$$\rho = \frac{\sum_{i=1}^{n} [R(X_i) - \frac{n+1}{2}] [R(Y_i) - \frac{n+1}{2}]}{n(n^2-1)/12}$$

where

ρ = Spearman's Rho,
$R(X_i)$ = rank assigned to X_i for all i,
$R(Y_i)$ = rank assigned to Y_i for all i, and
n = random sample size

If there are many ties then the following equation is used:

$$\rho = \frac{\sum_{i=1}^{n} R(X_i)R(Y_i) - n(\frac{n+1}{2})^2}{(\sum_{i=1}^{n} R(X_i)^2 - n(\frac{n+1}{2})^2)^{\frac{1}{2}} (\sum_{i=1}^{n} R(Y_i)^2 - n(\frac{n+1}{2})^2)^{\frac{1}{2}}}$$

The Spearman's rank correlation coefficient for each of the three groupings of the data set are summarized in **Table 5.7**. When the coefficient is not significantly different from zero there is no linear correlation. Higher absolute values of the coefficient reflect higher degrees of correlation, up to one, the highest degree of correlation.

Table 5.7 suggests the existence of a linear association among the population variables (chemical parameters) for each of the data sets. Of all the chemical parameters analyzed, a higher degree of association exists among pH, conductance, TDS, total hardness, calcium hardness, and magnesium hardness for all three data

Table 5.7
Spearman's rank correlation test statistic.

Background zone data set.

	PO_4^{3-}	NO_3^-	NH_3	Cl^-	pH	Cond.	TDS	T.Hard	CaHard
NO_3^-	-0.066								
NH_3	0.307	0.078							
Cl^-	-0.082	-0.410	0.082						
pH	0.234	-0.697	0.435	0.416					
Cond.	0.221	-0.630	0.339	0.421	0.849				
TDS	0.233	-0.633	0.336	0.415	0.850	0.998			
T. Hard	0.135	-0.630	0.337	0.428	0.888	0.868	0.865		
Ca Hard	0.138	-0.638	0.195	0.328	0.833	0.905	0.901	0.947	
Mg Hard	0.093	-0.497	0.406	0.469	0.805	0.674	0.665	0.866	0.714

Spreading zone data set.

	PO_4^{3-}	NO_3^-	NH_3	Cl^-	pH	Cond.	TDS	T.Hard	CaHard
NO_3^-	0.125								
NH_3	0.356	-0.069							
Cl^-	-0.081	-0.043	0.191						
pH	0.496	0.054	0.567	0.275					
Cond.	0.346	0.231	0.410	0.564	0.745				
TDS	0.347	0.223	0.400	0.562	0.744	0.999			
T. Hard	0.307	0.196	-0.051	0.463	0.378	0.577	0.574		
Ca Hard	0.268	0.118	-0.031	0.491	0.393	0.570	0.567	0.962	
Mg Hard	0.281	0.264	0.093	0.391	0.295	0.492	0.483	0.715	0.537

Complete data set.

	PO_4^{3-}	NO_3^-	NH_3	Cl^-	pH	Cond.	TDS	T.Hard	CaHard
NO_3^-	0.097								
NH_3	0.362	-0.039							
Cl^-	-0.127	-0.147	0.141						
pH	0.415	-0.143	0.527	0.254					
Cond.	0.296	-0.005	0.357	0.489	0.788				
TDS	0.299	-0.008	0.350	0.487	0.787	0.999			
T. Hard	0.176	-0.034	0.035	0.453	0.493	0.659	0.658		
Ca Hard	0.174	-0.083	0.009	0.443	0.494	0.669	0.668	0.960	
Mg Hard	0.120	0.067	0.108	0.439	0.359	0.504	0.501	0.772	0.597

sets. Conversely, a lower degree of association exists among orthophosphate, nitrate, ammonia, and chloride. The calculated correlation coefficient between conductance and TDS is 0.999. This reflects a high degree of linear association between these two parameters. Whereas, the correlation coefficient for nitrate and conductance for the entire data set is -0.005. This reflects the lowest degree of linear association therefore, the null hypothesis is valid; the nitrate measurements are independent of the conductance measurements.

5.6 Discussion:

The groundwater quality plots, as discussed previously, show little variation over time for any of the chemical parameters tested. Infrequently high values in some of the chemical plots do not justify a trend in the data set. Other variables or factors that could not be controlled are potential causes of these values. The chemical signatures shown in the plots are conceivably due to external influences. Alternatively, the study site could effectively buffer the influx of chemical constituents in the manure during the spreading process. In other words, the soil-crop system effectively buffers or uses the nutrients and chemicals in the liquid manure thus, no groundwater contamination occurs. The lower than expected concentrations of nitrogen bearing compounds could result from volatilization of nitrogen into the atmosphere during spreading. Presumably a combination of previously mentioned factors are responsible for the lower chemical concentrations obtained.

With no apparent visible trend in the data, statistical procedures were employed to determine if any significant differences between the spreading and background zone data were present before or after manure application. If no groupings among the wells could be made to simplify analysis, then each well must be considered as an independent population. If no statistical differences occur, then the entire data set can be classified as background concentrations for the study site. With these baseline concentrations subsequent data analysis comparing the background values to the new analyses can be performed.

The background zone data showed significant statistical differences between W8 and W10 for nitrate, ammonia, pH, conductance, TDS, total hardness, calcium hardness, and magnesium hardness. This variability among chemical parameters prohibited any groupings. The Mann-Whitney statistic showed variability in concentration for orthophosphate and chloride after application of manure. Initially this would tend to suggest that there is some significant effect due to the manure spreading. However, this is not the case since there is no statistical difference before or after manure application in the spreading zone for those parameters. This conclusion is based on the assumption that a change in the spreading zone data with respect to application date would occur before any changes in the background zone occurred. A deviation in the overall groundwater flow patterns at those particular well sites could account for no difference detected in the spreading zone wells. Therefore, it is possible that a chemical change could occur in the background zone wells with no change detected in the spreading zone wells. However, the well hydraulics do not suggest any groundwater flow deviation that could be responsible. The reported differences could be due to other external variables affecting the experiment that could not be controlled nor accounted for. The lack of statistical significance before or after manure application suggests that the data can be classified as background water quality.

The spreading zone data demonstrated significant difference among many of the parameters analyzed for comparison by sampling well. No groupings among the wells can be made therefore, the wells remain as independent populations. The Mann-Whitney statistic for comparison of parameter by application date produced no statistically significant difference. Therefore, no chemical difference was detected before or after the application of manure in the spreading zone. The chemical analyses can be grouped as background values since no differences were detected.

The entire data set was subjected to similar statistical treatment. As with the spreading zone data, there was a statistically significant differences among all the wells. This eliminated any well groupings that could be made. The comparison of chemical parameter by application date produced no statistical differences in the parameters, except chloride. The change in chloride concentration would suggest that the manure application did have a significant effect. It is presumed that chloride would be the first ion to show a considerable increase after application because of its conservative nature. The lack of supportive evidence from the other chemical parameters renders this conclusion suspect and it is more plausible to assume that the data exhibits normal background variations. It is possibly a combination of other extraneous agricultural sources not related to the present experiments.

A measure of association is simply a description of the relationship between two variables; the existence of a significant association provides no evidence of about any kind of a casual relationship between the variables (Gibbons, 1976). The association between two variables may be caused by other factors or variables that may or may not be identifiable.

The calculations for the Spearman's rank correlation coefficient for the background data set indicate a lower correlation between nitrate and chloride, pH, conductance, TDS, total hardness, calcium hardness, and magnesium hardness. This is contrary to the other chemical parameters which indicate a higher degree of association. Essentially, there is perfect correlation between conductance and TDS (0.998) since both these parameters are closely related and depend upon ionic concentrations and temperature. The pH, conductance, TDS, total hardness, calcium hardness, and magnesium hardness values exhibit a higher degree of association. This positive correlation reinforces the data groupings for the background zone data subset.

The correlation coefficients for the spreading zone data set indicate an overall positive association among the chemical parameters. A similar negative correlation, as seen in the background zone data set is not present. Although the correlation between conductance and TDS (0.999) is shown. In general, the degree of association is not as strong as in the background data set. This is confirmed by the lower relative magnitude of the correlation coefficients.

The association among the parameters for the entire data set shows a positive tendency as well. There is moderately negative correlation between nitrate, chloride, pH, conductance, TDS, total hardness, calcium hardness, and magnesium hardness, as shown in the background data set. The perfect agreement between conductance and TDS (0.999) is shown also. It is clear that the correlation coefficient for the entire data set is some combination of the background and spreading zone data sets. This conclusion is valid since individual data set correlations are echoed in the individual data sets. The correlations are likely due to a combination of factors.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS:

6.1 CONCLUSIONS:

The potential for groundwater contamination by current agricultural waste management practices is a serious problem for many Newfoundlanders. A project was initiated to establish a long term groundwater monitoring program to examine the spatial and temporal effects of agricultural waste disposal on cultivated fields and in winter storage facilities.

For that purpose, 25 groundwater monitoring wells were installed with 12 located on the spreading zone, 4 in between the spreading zone and storage tanks, and 9 located around the storage tanks. Using these wells the quality of the groundwater and the aquifer hydraulics of the study site were determined.

The grain size distributions for the site soils are similar for all samples. In general, the soil contains the following classes: 20 % gravel, 70 % sand, < 10 % silt and clay. This is typical Newfoundland glacial till. A common soil description would be: a poorly graded, gravelly sand, with little or no fines.

The permeability tests performed in the laboratory and the slug tests conducted in the bedrock gave hydraulic conductivity values on the order of 10^{-4} to 10^{-5} cm/s. Given the errors inherent in slug tests and in using disturbed soil samples, the k values for the upper bedrock and the overburden are essentially the same. Thus, it would seem, that the water table variations are not governed by the overburden-bedrock interface. However, local variations in fracture connectivity can cause bedrock controlled flow.

The statistical analysis of the groundwater chemistry has not shown any statistically significant chemical change in the groundwater signatures up to five months after the first manure application on the spreading or background zones. Mann-Whitney, Kruskal-Wallis test statistics, and boxplots were used to verify any trends or possible groupings in the data. There are no significant groupings in either the spreading or background zone wells. Local anomalies in the data set can not be attributed to statistical variations, however, they are possibly due to extraneous influences.

6.2 RECOMMENDATIONS:

This thesis established a site where the long term effects of agricultural disposal practices on both soils and groundwaters can be examined. Continued surveillance of the site is needed to detect any seasonal variations in groundwater quality or to determine if the soil mass can buffer excessive disposal of manure. The natural gradient tracer test is incomplete at present, so further testing is required to determine the flow patterns beneath the storage tanks.

The sampling scheme should reflect a more statistically sound approach since this may be the only reliable tool to determine chemical variations over time. The monitoring program should be able to estimate long-term trends, be able to define seasonal or other cycles, and forecast chemical concentrations. Therefore, a systematic probability sampling scheme is advised. This scheme is well suited for estimating trends or patterns over space and for estimating the mean when trends are not present.

To accurately determine the effectiveness of the waste containment liners carefully controlled laboratory testing is essential. In conjunction with this, a series of sorption and diffusion experiments should be performed to determine the soil's ability to retard pollutants.

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APPENDIX A

*	Table A.1	Methods for Monitoring Pollutant Movement in the Vadose Zone
*	Table A.2	Water Quality Sampling Devices for Monitoring Wells
*	Supplementary Information on Soil-Bentonite Liners	
*	Figure A.1	A Typical Cross-Section of a Soil-Bentonite Liner
*	Geosynthetic Clay Liners as Low Permeability Barriers	
*	Table A.3	Summary of Available Geosynthetic Clay liners
*	Mass Transport of Solutes	

Advection
Molecular Diffusion
Hydrodynamic Dispersion
Mechanical Dispersion
Retardation

Table A.1

Methods for monitoring pollutant movement in the vadose zone. (Modified after Wilson, 1983)

INDIRECT METHODS:

Method: Four probe electrical method.

Principle: Used for measuring in situ soil salinity using the Wenner four probe array. The apparent bulk soil conductivity is related to the conductivity of the saturated extract using calibration relationships.

Advantages: In situ method by which readings are quickly and easily obtained. Can be used to detect saline shallow groundwaters and lateral and vertical transects in salinity. Salinities of large soil volumes can be obtained.

Disadvantages: Accuracy decreases in layered soils and calibration relationships are tedious. Chronological in situ changes can not be measured except through sequential traverses. Useful only for shallow depths and does not provide data on specific pollutants.

Method: Electrical Conductivity (EC) Probe.

Principle: The electrical conductivity probe consists of a cylindrical probe containing electrodes at fixed spacings. The probe is positioned in a cavity and the resistivity is measured at successive depths. Calibration is required. Can be permanently installed.

Advantages: Changes in salinity are measured at discrete depths in soil strata. In-place units permit determining salinity changes with time.

Disadvantages: Calibration required for individual soil strata. Variations in water content may effect results. Useful only for shallow depths and does not provide data on specific pollutants.

Method: Salinity sensors.

Principle: Sensors consist of electrodes embedded in porous ceramic which hydraulically equilibrates with the surrounding soil water. Electrodes measure the specific conductance of the soil solution. Calibration curves are required.

Table A.1 (cont'd)

Advantages: Simple, easily read, and sufficiently accurate for salinity monitoring. Readings are taken at same depths each time. Chronological salinity profiles can be determined and output can be interfaced to data acquisition systems.

Disadvantages: More expensive, less durable, and subject to calibration changes than four electrode method. Time lag in response to changing salinity. Can not be used at soil water pressures < -2 atmospheres. Soil disturbance may affect results. Not pollutant specific.

DIRECT METHODS:

Method: Solids sampling - laboratory extraction of pore waters.

Principle: Solids samples are obtained by augering and transported to a laboratory. Normally samples are taken in depth - wise increments. Samples are used to prepare saturated extracts that are then analyzed to determine the concentrations of specific constituents.

Advantages: Depth-wise profiles of specific pollutants can be prepared. Variations in ionic concentrations with changes in layering are possible. Solids samples can be used for additional analyses such as grain size, cation exchange capacity, etc.

Disadvantages: Due to the spatial variability of soil properties inordinate numbers of samples are required which can increase expense. Changes in soil water composition occur therefore samples should be extracted at prevailing water contents. A destructive method.

Method: Solids sampling - organic and microbial constituents (dry tube coring procedure).

Principle: A hole is augered to above the desired sampling depth. A dry-tube core sampler of special design is forced into the sampling region. Separate subsamples are obtained for analyses of organics and microorganisms. Extreme care is necessary to avoid contamination.

Advantages: Contamination of samples is minimized. Subsamples for chemical analysis can be taken.

Disadvantages: Expensive and time consuming. Difficult to obtain samples at depth. Samples can not be obtained directly below impoundments. A destructive method. Results are affected by spatial variabilities in properties of the vadose zone.

Table A.1 (cont'd)

Method: Ceramic vacuum lysimeters.

Principle: A ceramic cup is mounted on the end of a small diameter PVC tube. A one - hole rubber stopper with a small diameter tube is inserted into the PVC tube. Unit is placed in shallow soil depth. A vacuum is applied to the small tube and soil water moves through the ceramic cup into a collection flask. Samples are analyzed in the laboratory. Acid pretreatment of cups necessary.

Advantages: A direct method for determining the chemical characteristics of soil water. Samples can be obtained repeatedly at the same depth. Inexpensive and simple. Can be installed below shallow impoundments and landfills prior to construction, for later monitoring.

Disadvantages: Generally limited to soil depths < 6 feet and soil water pressures < -1 atmospheres. Point samplers - small volumes retrieved, representativeness of results questionable. Samples may not be representative of pore waters. Pore water in the soil blocks sampled. Suction may affect soil - water flow patterns.

Method: Ceramic vacuum pressure suction lysimeters.

Principle: A ceramic body tube contains a two hole rubber stopper. A small diameter tube is pushed into the opening, terminating at the base of the cup. Another tube is pushed into the other opening terminating below the rubber stopper. A sample line is connected to a bottle. A short line is connected to a pressure - vacuum source. A vacuum is applied to draw the sample and pressure fills the bottle.

Advantages: Can be used at depths below the suction lift of water. Several units can be installed in the same borehole. Same advantages as the ceramic vacuum lysimeters.

Disadvantages: Air pressure causes some of the solution to be forced through the walls of the cup. Same disadvantages as the ceramic vacuum lysimeters with the exception of the 6 feet operating depth.

Method: Ceramic high pressure-vacuum suction lysimeters.

Principle: The two chamber sampler incorporates a porous ceramic lower cup and an upper chamber connected via tubing and a one-way valve. The upper chamber has a plug with two openings. One opening is connected to a pressure-vacuum source and the other connects to

Table A.1 (cont'd)

the upper chamber. A vacuum draws solution into the upper chamber and then pressure forces the sample into a collection flask. The one-way valve prevents solution from being forced out of the cup.

Advantages: Prevents air pressure from blowing sample out of cup. Can be used at great depths. Several units can be installed in a common borehole. Several units can be installed in the same borehole. Same advantages as the ceramic vacuum lysimeters.

Disadvantages: Same disadvantages as the ceramic vacuum pressure lysimeter with the exception of air pressure application forcing sample through the walls of the cup.

Method: Sampling perched groundwater.

Principle: For shallow perched groundwater samples can be obtained by installing wells, piezometer nests or multilevel samplers. For deeper perched groundwater there are two possibilities: (1.) sampling cascading water in existing wells, or (2.) special well construction.

Advantages: Large sample volumes are obtainable. More representative than point samples. Cheaper than installing deep wells with suction samplers. Can be located near ponds or landfills without concern about causing leaks. Multilevel samplers can be used to delineate vertical and lateral extent of plumes and hydraulic gradients.

Disadvantages: Perched zones are not always present in source area. Detection may be expensive. Some zones are ephemeral and may dry up. Method most suitable for diffuse sources. Multilevel sampling is restricted to regions with shallow water tables permitting vacuum pumping.

Table A.2
Water quality sampling devices for monitoring wells. (Modified after Driscoll, 1986)

TYPE	ADVANTAGES	DISADVANTAGES
Bailer	• Can be constructed in a variety of diameters. • Can be constructed from a wide variety of materials. • No external power source required. • Low surface-area-to-volume ratio, resulting in a very small amount of outgassing of volatile organics while sample is contained in bailer. • Readily available, easy to clean, and inexpensive.	• Sampling procedure is time consuming; sometimes impractical to properly evacuate casing before taking samples. • Aeration may result when transferring water to the sample bottle.
Suction-lift Pump	• Relatively portable. • Readily available. • Inexpensive.	• Sampling is limited to situations where water levels are within about 20 ft. of the ground surface. • Vacuum effect can cause the water to lose some dissolved gas.
Air-lift Samplers	• Relatively portable. • Readily available. • Inexpensive.	• Causes changes in carbon dioxide concentrations; therefore this method is unsuitable for sampling pH-sensitive parameters. • In general, this method is not an appropriate method for acquisition of water samples for detailed chemical analyses because of degassing effect on sample. • Oxygenation is unavoidable unless precautions are taken.

Table A.2 (cont'd)

TYPE	ADVANTAGES	DISADVANTAGES
Gas-operated Pump	• Can be constructed in diameters as small as 25 mm. • Can be constructed from a wide variety of materials. • Relatively portable. • Reasonable range of pump rates. • Driving gas does not contact water sample, eliminating possible contamination or gas stripping.	• Gas source required. • Large gas volumes and long cycles are necessary when pumping from deep wells. • Pumping rates are lower than those of suction or jet pumps. • Commercial units are relatively expensive.
Submersible Pump	• Wide range of diameters. • Constructed from various materials. • 12-volt pump is highly portable. • Depending on size of pump and pumping depths, relatively large pumping rates are possible for wells larger than 51 mm diameter. • Readily available. • 44.5 mm helical screw pump has rotor and stator construction that permits pumping of fine-grained materials without damage to the pump.	• With one exception, submersible pumps are too large for 51 mm diameter wells. • Conventional units are unable to pump sediment-laden water without incurring damage to the pump. • 44.5 mm pump delivers low pumping rates at high heads. • Smallest diameter pump is relatively expensive.

SOIL-BENTONITE LINERS

A typical cross section of a soil-bentonite liner is shown in **Figure A.1** which includes an initial filter layer (A), if required, laid over the prepared natural soil (A), the impervious soil-bentonite mix (C), an upper filter (D), and a circulation layer (cleaning and maintenance of ponds) or a coarse layer (protection against wind, wave, and ice action) (E), (Chapuis, 1990 a).

Usually the bentonite is a fine powder that will eventually be mixed with native soil. Mixing is usually done on site with a rotary tiller or other agricultural mixing equipment. Problematic areas where mixing can not be done in this fashion require a cement mixer and hand application of the mixture. Cement mixers have shown to provide the most homogeneous mixes. In Quebec the usual mix thickness is 15 - 30 cm after compaction, for differences in hydraulic heads under 5 m (Chapuis, 1990a).

Laboratory permeability tests are essential to determine the degree of imperviousness of the soil-bentonite mix provided by the bentonite content. Chapuis (1990a) found that the following recommendations must be met to adequately simulate field conditions: (1.) use of a confining vertical stress no higher than that in the field in order to allow the mix to swell, (2.) testing a layer of the mix with its two filter layers, the natural soil foundation, and the protective layer, and (3.) allowing sufficient time for

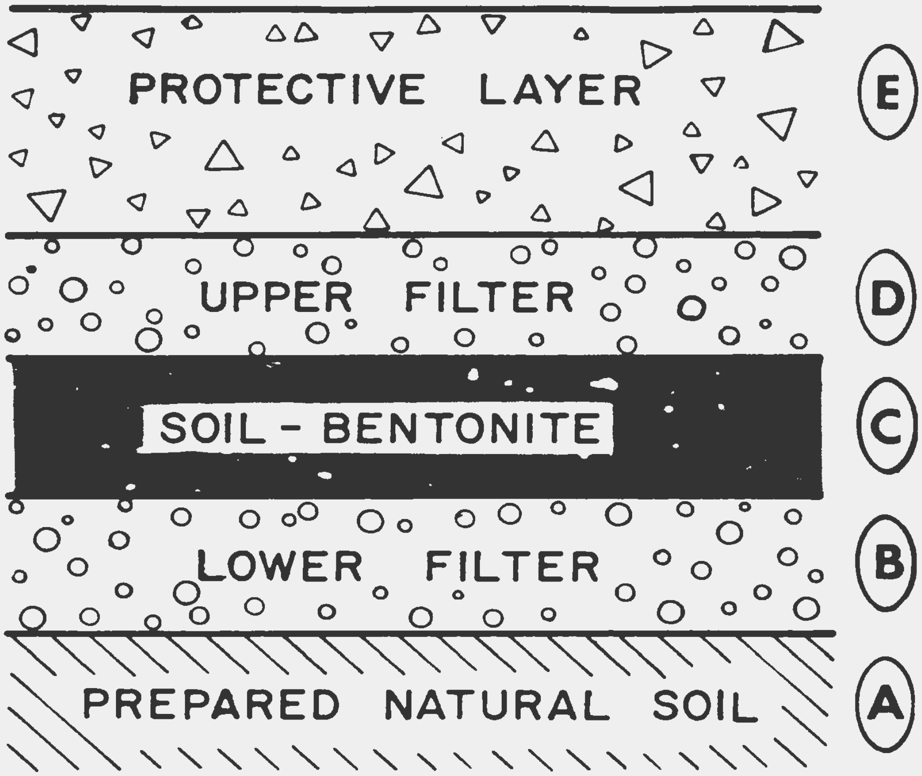

Figure A.1 A typical cross section of a soil-bentonite liner (After Chapuis, 1990a).

hydration, consolidation, and steady-state seepage conditions.

Chapuis (1990a) details a method for predicting the in situ performance of soil-bentonite liners. The data has shown that the hydraulic conductivity is poorly correlated to porosity, bentonite content, or total fines content alone. This, in part, may be due to different laboratories employing different testing methods resulting in difficult parameter constraint. The hydraulic conductivity, k, was shown to correlate with an "efficient" porosity, n^*, which corresponds to the pore space available for seepage of the fast-moving water. A negative value indicates that all water seeps through the hydrated bentonite. Field values of n^* and k may be predicted using the results of a modified Proctor test and a permeameter test performed on the soil alone, and the bentonite content (Chapuis, 1990a).

Once a soil-bentonite liner is installed in the field, performance must be controlled in situ to ensure optimum efficiency. Chapuis (1990b) describes direct (local field permeability tests and total leakage measurement) and indirect (compaction control and bentonite content) field control methods. These methods can be used to analyze the total leakage of a soil-bentonite liner and to locate hydraulic defects.

GEOSYNTHETIC CLAY LINERS

Estornell and Daniel (1992) tested three conventionally available GCL's (Bentomat®, Claymax®, and Paraseal/Gundseal®) first to determine the hydraulic properties of the GCL's and the self-sealing of overlap seams, and secondly to evaluate the sealing performance of a punctured geomembrane-GCL composite liner. They performed three types of tests: (1.) control test - no overlap of the GCL liner material, (2.) seam test - overlap of the GCL sheets, and (3.) punctured geomembrane/GCL composite test. The latter test involved a composite with the GCL overlain by a 60 mil high density polyethylene geomembrane with various punctures in the composite. Simultaneously, small-scale hydraulic conductivity tests were conducted on 100 mm diameter GCL specimens. Their results demonstrated that there was little difference in hydraulic conductivities between overlap seams and the parent material except in cases of low vertical effective stress (< 7 kPa). It was observed that bentonite migrated out of the geotextile-bentonite composite liner and into the drainage layer beneath.

The United States Environmental Protection Agency sponsored a technical conference on the Design and Construction of Resource Conservation and Recovery Act (RCRA) and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Final Covers in 1990 discussed extensively the advantages and disadvantages of geomembranes and soil-bentonite membranes. The following conclusions were reached:

1. For fully intact membranes with no punctures, an "average" plastic membrane will have a "permeability" in the range of 1×10^{-12} cm/s while a soil/bentonite (clay) membrane will typically be in the range of 1×10^{-6} to 1×10^{-9} cm/s. If a leakage rate is incorporated the flow rates between these membranes will be significantly different.

2. A recent study of 28 sites with commercially installed geomembrane liners showed there were from 0 to 79 penetrations per site with an average of 26 penetrations which 70% were at the seams and 15% were in the parent material. These penetrations ranged from pin holes to large tears. It is good engineering design to assume that a leak free liner can not be installed.

3. It had been shown that a composite liner (consisting of a geomembrane liner immediately overlying the soil liner) provides better leakage values than either the soil liner or the plastic liner with any holes. This also correlates to performance of liners with the composite liner giving the best performance and the geomembrane with any leaks the worst.

4. In order to provide extra assurance against any leakage through a liner the use of a composite liner system is advised. For storage of non-hazardous materials using only a single liner system, a soil/bentonite membrane is preferred over a plastic membrane.

Wong and Haug (1991) examined the effects of closed-system freeze-thaw cycles on the permeability of clay, till, and sand-bentonite mixtures in a laboratory test program. They concluded that in a freeze-thaw environment with no free water available, the permeabilities of both the clay and till specimens increased. In contrast, the sand-bentonite mixtures showed no signs of increasing permeability or deterioration due to freeze-thaw cycles. Linell and Kaplar (1959), cited in Wong and Haug (1991), concluded that the addition of bentonite to a soil mixture inhibits the movement of moisture to the freezing front and also reduces the permeability of the soil.

Barrington et al., (1990) examined the usage of geotextiles as sealing liners for earthen manure reservoirs. Earthen manure storages are deemed environmentally safe if built of soils meeting specified requirements for grain size distribution and porosity. Coarser materials that do not meet these specifications must be artificially lined. The premise that physical mechanisms are primarily responsible for the manure sealing of porous media was the basis for their research. They concluded that the finest porosity fabric (20 μm) yielded significantly higher infiltration rates subjected to a 5 percent total solids swine slurry. This may be attributed to the fact that the finest geotextile also had the lowest hydraulic conductivity. Excluding these differences, minimum infiltration rates (volume of seepage collected over time per area of non-woven geotextile exposed to swine slurry during the time which the volume was collected) for all experimental combinations ranged between 1.3 x 10^{-8} to 1.8 x 10^{-8} m/s.

Table A.3
Summary of available geosynthetic clay liners. (Modified after Geotechnical Fabrics Report 1992)

PRODUCT NAME	MANUFACTURER	GCL COMPOSITION	STANDARD ROLL WIDTH-LENGTH (m)
Bentofix	Albarrie Naue Ltd.	Sodium bentonite soil sandwiched between two protective filter stable geotextiles and bonded by needle-punching.	4.63 x 30.5
Bentomat	Colloid Environmental Technologies (CETCO)	Volclay sodium bentonite sandwiched between woven and nonwoven needle-punched geotextiles.	4.57 x 38.1
Claymax	James Clem Corp	Sodium bentonite held together in a water soluble glue sandwiched between two non-woven geotextiles.	4.12 x 30.5
Gundseal	Gundle Lining Systems Inc.	Sodium bentonite mixture attached to a high-density polyethelene (HDPE) geomembrane of varying thickness from 20 - 80 mils (0.05 - 0.20 mm).	5.33 (W) 45.7 - 70.0 (L)

Table A.3 (cont'd)

PRODUCT NAME	BENTONITE MASS/UNIT AREA (Kg/m^3)	PERMEABILITY (cm/s) ASTM D 5084 (Deaired Water)	GCL TENSILE STRENGTH ASTM D 4632 (Kg)	GCL % ELONGATION ASTM D 463
Bentofix	3.42 - 4.88	1.0×10^{-9} [1]	54 - 95	N/A
Bentomat	4.88	2.0×10^{-10} [2]	40	20
Claymax	4.64	5.0×10^{-10}	45	20
Gundseal	5.03 (minimum)	$< 4.0 \times 10^{-12}$	821 - 3393 Kg/m^3 (width)	13

Mass Transport of Solutes

Many authors have discussed the theory behind the movement of pollutants through groundwater, including: Dagan (1989); Domenico and Schwartz (1990); Fetter (1988); Freeze and Cheery (1979); Greenkorn (1983); Luckner and Schestakow (1991); and Todd (1980). The following compilation follows the work of these authors.

Advection

Advection is the process by which solutes are transported by the motion of flowing groundwater (Fetter, 1988). Nonreactive solutes are carried at an average rate equal to the average linear velocity of the groundwater (Freeze and Cherry, 1979). The basic equation governing the advective process is:

$$v_x = \frac{k}{n_e} \frac{\partial h}{\partial l}$$

where

v_x = average linear velocity,

k = hydraulic conductivity,

n_e = effective porosity, and

$\partial h/\partial l$ = hydraulic gradient.

The linear groundwater velocity and therefore the velocity of advective transport increases with decreasing effective porosity. Such is the case for fractured rocks where the effective porosity can be much less than the total porosity, often as low as 1 x 10^{-4} or 1 x 10^{-5} (Domenico and Schwartz, 1990).

There are cases when the average linear groundwater velocity is different from the advective velocity of the mass. Krupp (1972), cited in Domenico and Schwartz (1990), has shown that negatively charged ions can move faster than the water in which they are dissolved. Also the presence of clay minerals can force the anions to remain at the centre of pores, the location of the maximum microscopic velocity. Thus the water may flow through the lower-velocity regime within a pore. Domenico and Schwartz (1990) document another alternative reduction in advective velocity through geologic materials that possess properties of semipermeable membranes. Solutes will not enter the membrane because of electrokinetic effects or size restrictions.

Molecular Diffusion

Diffusion is the process by which both ionic and molecular species dissolved in water move from areas of higher concentration to areas of lower concentration (Fetter, 1988). Ionic electrical neutrality must be maintained during diffusion. For mass transport by diffusion for a simple aqueous nonporous system Fick's laws govern. Fick's first law for one-dimensional analysis under steady-state conditions is:

$$F_x = -D \frac{\partial C}{\partial x}$$

where

F_x = mass flux of solute per unit area per unit time,

D = diffusion coefficient,

C = solute concentration, and

$\partial C/\partial x$ = concentration gradient.

The negative sign indicates that the solute movement is from greater to lesser concentrations. Values of D are well known for electrolytes in water and range from 1×10^{-9} to 2×10^{-9} m^2/s for the major cations and anions (Fetter, 1988).

In porous media diffusion is slower than in water because the ions must follow longer pathways around mineral grains and adsorption onto those particles may occur. The apparent diffusion coefficient for a nonadsorbed species in porous media, D^*, is represented by:

$$D^* = \omega D$$

where

D^* = apparent diffusion coefficient, and

ω = empirical coefficient that takes into account the effect of the solid phase of the porous medium on the diffusion ($0.01 < \omega < 0.5$).

For systems where the concentrations may be changing with time, Fick's second law for one-dimensional analysis applies:

$$\frac{\partial C}{\partial t} = D^* \frac{\partial^2 C}{\partial x^2}$$

where

$\partial C/\partial t$ = change in concentration with time,

D^* = apparent diffusion coefficient, and

$\partial^2 C/\partial x^2$ = first spatial derivative of the concentration gradient.

It is possible for solutes to move through a porous medium by diffusion, eventhough the groundwater is not flowing (Fetter, 1988). In rocks and soils of very low permeability, the groundwater may be flowing very slowly. Under these conditions, diffusion may cause a solute to travel faster than the groundwater is flowing. Under such conditions, diffusion is more important than advection.

Hydrodynamic Dispersion

Hydrodynamic dispersion is a process by which groundwater containing a solute is diluted with uncontaminated groundwater as it moves through an aquifer. It is impossible to separate molecular diffusion and mechanical dispersion in flowing groundwater. The coefficient of hydrodynamic dispersion takes into account both of these phenomena. The coefficient can be expressed in terms of the following:

$$D_l = \alpha_l v_x + D^*$$

where

D_l = coefficient of hydrodynamic dispersion,

α_l = dispersivity,

v_x = average linear groundwater velocity, and

D^* = coefficient of molecular diffusion.

The one-dimensional form of the hydrodynamic dispersion equation for nonreactive dissolved constituents in saturated, homogeneous, isotropic, materials under steady-state, uniform flow is:

$$D_l \frac{\partial^2 C}{\partial x^2} - v_x \frac{\partial C}{\partial x} = \frac{\partial C}{\partial t}$$

where

D_l = longitudinal hydrodynamic dispersion coefficient,

C = solute concentration,

v_x = average groundwater velocity, and

t = time since start of solute transport.

Domenico and Schwartz (1990), Fetter (1988), and Freeze and Cherry (1979) detail the classical sand column tracer experiment to illustrate the physical meaning of the one-dimensional form of the hydrodynamic dispersion equation.

The concentration of solutes will decrease with distance from the source because of hydrodynamic dispersion. The solute will spread in the direction of groundwater movement more than it will in the direction perpendicular to the flow because longitudinal dispersivity is greater than lateral dispersivity (Fetter, 1988). Heterogeneities in the aquifer can distort the dispersion of a solute. Those pathways with the most contaminant will be those that are the most permeable.

Mechanical Dispersion

Mechanical dispersion is an advective process by which mixing occurs as a consequence of local variations in velocity around some mean velocity of flow (Domenico and Schwartz, 1990). The mixing of contaminated fluid with non-contaminated water will result in a dilution effect. Mechanical dispersion in the transverse direction is a much weaker process than dispersion in the longitudinal direction, but at low velocities where molecular diffusion is the dominant dispersive mechanism, the coefficients of longitudinal and transverse dispersion are nearly equal (Freeze and Cherry, 1979).

The three basic causes of longitudinal dispersion are (after Fetter, 1988): (1.) as fluid moves through pores it will move faster through the centre of the pore than along the edges, (2.) some of the fluid will travel in longer pathways than other fluid, and (3.) fluid that travels through larger pores will travel faster than fluid moving in smaller pores.

Lateral dispersion is caused by contaminated fluid flowing though a porous medium that can split and branch out to one side (Fetter, 1988). This can occur even under laminar flow conditions.

Mechanical dispersion can be mathematically defined as follows:

$$D_m = \alpha_l v_x$$

where

D_m = coefficient of mechanical dispersion,

α_l = dispersivity, and

v_x = the average linear groundwater velocity.

Retardation

Retardation is a combination of processes that act to remove the solutes in groundwater; for many solutes the solute front will travel more slowly than the rate of the advecting groundwater (Fetter, 1988). The retardation of the contaminant front relative to the bulk mass of the contaminated groundwater is described by the retardation equation:

$$\frac{v_x}{v_c} = 1 + \frac{\rho_b}{n} \cdot K_d$$

where

v_x = average linear groundwater velocity,

v_c = velocity of the solute front where the solute concentration is one-half of the original value,

ρ_b = bulk density,

n = porosity, and

K_d = distribution coefficient for the solute with the soil.

The overall effect of retardation causes the solute front to move more slowly than an unretarded solute.

There are two broad classes of solutes: reactive and conservative. Reactive solutes are those which undergo chemical, biological, or radioactive change that will reduce the concentration of the solute. If a solute is reactive, it will travel at a slower rate than the groundwater due to adsorption. Conservative solutes do not react with the soil or groundwater and will not undergo biological or radioactive decay. A good example of a conservative solute is the chloride ion.

If the contaminant source contains multiple solutes with distinctive K_d's there will be a number of solute fronts. The retardation effects will be different for each solute. In combination with the processes of advection, dispersion, and diffusion very complex contaminant plumes can result.

APPENDIX B

CLIMATOLOGICAL DATA

PRECIPITATION DATA
N0. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
91	1	1	33239	01/01/91	0.0
91	1	2	33240	01/02/91	0.4
91	1	3	33241	01/03/91	3.4
91	1	4	33242	01/04/91	2.4
91	1	5	33243	01/05/91	0.2
91	1	6	33244	01/06/91	2.4
91	1	7	33245	01/07/91	0.0
91	1	8	33246	01/08/91	0.0
91	1	9	33247	01/09/91	0.0
91	1	10	33248	01/10/91	6.8
91	1	11	33249	01/11/91	41.0
91	1	12	33250	01/12/91	2.8
91	1	13	33251	01/13/91	8.8
91	1	14	33252	01/14/91	0.0
91	1	15	33253	01/15/91	0.0
91	1	16	33254	01/16/91	0.0
91	1	17	33255	01/17/91	13.2
91	1	18	33256	01/18/91	0.0
91	1	19	33257	01/19/91	0.0
91	1	20	33258	01/20/91	1.4
91	1	21	33259	01/21/91	27.8
91	1	22	33260	01/22/91	0.2
91	1	23	33261	01/23/91	0.6
91	1	24	33262	01/24/91	8.0
91	1	25	33263	01/25/91	3.4
91	1	26	33264	01/26/91	2.2
91	1	27	33265	01/27/91	0.6
91	1	28	33266	01/28/91	5.2
91	1	29	33267	01/29/91	0.0
91	1	30	33268	01/30/91	17.0
91	1	31	33269	01/31/91	7.8
				TOTALS:	155.6

PRECIPITATION DATA
N0. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
91	2	1	33270	02/01/91	0.0
91	2	2	33271	02/02/91	2.2
91	2	3	33272	02/03/91	4.2
91	2	4	33273	02/04/91	0.0
91	2	5	33274	02/05/91	4.2
91	2	6	33275	02/06/91	0.0
91	2	7	33276	02/07/91	0.0
91	2	8	33277	02/08/91	1.4
91	2	9	33278	02/09/91	0.0
91	2	10	33279	02/10/91	0.0
91	2	11	33280	02/11/91	1.0
91	2	12	33281	02/12/91	15.8
91	2	13	33282	02/13/91	4.8
91	2	14	33283	02/14/91	5.6
91	2	15	33284	02/15/91	43.0
91	2	16	33285	02/16/91	16.2
91	2	17	33286	02/17/91	1.2
91	2	18	33287	02/18/91	0.0
91	2	19	33288	02/19/91	2.0
91	2	20	33289	02/20/91	6.4
91	2	21	33290	02/21/91	0.4
91	2	22	33291	02/22/91	14.4
91	2	23	33292	02/23/91	5.0
91	2	24	33293	02/24/91	0.0
91	2	25	33294	02/25/91	0.0
91	2	26	33295	02/26/91	1.0
91	2	27	33296	02/27/91	16.8
91	2	28	33297	02/28/91	0.0
				TOTALS:	145.6

PRECIPITATION DATA
N0. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
91	3	1	33298	03/01/91	0.0
91	3	2	33299	03/02/91	10.0
91	3	3	33300	03/03/91	0.0
91	3	4	33301	03/04/91	15.2
91	3	5	33302	03/05/91	10.0
91	3	6	33303	03/06/91	0.0
91	3	7	33304	03/07/91	0.0
91	3	8	33305	03/08/91	1.0
91	3	9	33306	03/09/91	3.4
91	3	10	33307	03/10/91	1.2
91	3	11	33308	03/11/91	10.6
91	3	12	33309	03/12/91	4.0
91	3	13	33310	03/13/91	3.6
91	3	14	33311	03/14/91	0.0
91	3	15	33312	03/15/91	2.6
91	3	16	33313	03/16/91	3.0
91	3	17	33314	03/17/91	3.2
91	3	18	33315	03/18/91	0.0
91	3	19	33316	03/19/91	8.0
91	3	20	33317	03/20/91	30.0
91	3	21	33318	03/21/91	1.0
91	3	22	33319	03/22/91	0.0
91	3	23	33320	03/23/91	0.0
91	3	24	33321	03/24/91	0.0
91	3	25	33322	03/25/91	4.0
91	3	26	33323	03/26/91	37.8
91	3	27	33324	03/27/91	7.4
91	3	28	33325	03/28/91	0.0
91	3	29	33326	03/29/91	0.0
91	3	30	33327	03/30/91	7.8
91	3	31	33328	03/31/91	0.0
				TOTALS:	163.8

PRECIPITATION DATA
N0. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
91	4	1	33329	04/01/91	12.6
91	4	2	33330	04/02/91	0.0
91	4	3	33331	04/03/91	0.0
91	4	4	33332	04/04/91	0.0
91	4	5	33333	04/05/91	0.2
91	4	6	33334	04/06/91	0.0
91	4	7	33335	04/07/91	1.8
91	4	8	33336	04/08/91	1.8
91	4	9	33337	04/09/91	0.0
91	4	10	33338	04/10/91	3.0
91	4	11	33339	04/11/91	5.0
91	4	12	33340	04/12/91	0.0
91	4	13	33341	04/13/91	0.0
91	4	14	33342	04/14/91	14.6
91	4	15	33343	04/15/91	0.0
91	4	16	33344	04/16/91	0.0
91	4	17	33345	04/17/91	0.0
91	4	18	33346	04/18/91	6.0
91	4	19	33347	04/19/91	1.4
91	4	20	33348	04/20/91	0.0
91	4	21	33349	04/21/91	0.6
91	4	22	33350	04/22/91	6.6
91	4	23	33351	04/23/91	17.6
91	4	24	33352	04/24/91	8.2
91	4	25	33353	04/25/91	4.2
91	4	26	33354	04/26/91	0.0
91	4	27	33355	04/27/91	0.0
91	4	28	33356	04/28/91	0.0
91	4	29	33357	04/29/91	0.4
91	4	30	33358	04/30/91	2.2
				TOTALS:	86.4

PRECIPITATION DATA
N0. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
91	5	1	33359	05/01/91	0.4
91	5	2	33360	05/02/91	0.3
91	5	3	33361	05/03/91	14.4
91	5	4	33362	05/04/91	2.4
91	5	5	33363	05/05/91	3.4
91	5	6	33364	05/06/91	0.0
91	5	7	33365	05/07/91	15.0
91	5	8	33366	05/08/91	0.0
91	5	9	33367	05/09/91	0.0
91	5	10	33368	05/10/91	0.0
91	5	11	33369	05/11/91	0.0
91	5	12	33370	05/12/91	0.0
91	5	13	33371	05/13/91	1.8
91	5	14	33372	05/14/91	4.0
91	5	15	33373	05/15/91	0.0
91	5	16	33374	05/16/91	0.0
91	5	17	33375	05/17/91	0.0
91	5	18	33376	05/18/91	10.5
91	5	19	33377	05/19/91	0.8
91	5	20	33378	05/20/91	0.0
91	5	21	33379	05/21/91	0.0
91	5	22	33380	05/22/91	5.2
91	5	23	33381	05/23/91	14.4
91	5	24	33382	05/24/91	1.6
91	5	25	33383	05/25/91	13.0
91	5	26	33384	05/26/91	0.0
91	5	27	33385	05/27/91	0.0
91	5	28	33386	05/28/91	2.4
91	5	29	33387	05/29/91	11.4
91	5	30	33388	05/30/91	31.8
91	5	31	33389	05/31/91	10.0
			TOTALS:		142.8

PRECIPITATION DATA
N0. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
91	6	1	33390	06/01/91	0.8
91	6	2	33391	06/02/91	0.6
91	6	3	33392	06/03/91	1.2
91	6	4	33393	06/04/91	0.0
91	6	5	33394	06/05/91	3.0
91	6	6	33395	06/06/91	7.6
91	6	7	33396	06/07/91	0.0
91	6	8	33397	06/08/91	2.0
91	6	9	33398	06/09/91	0.4
91	6	10	33399	06/10/91	0.0
91	6	11	33400	06/11/91	0.0
91	6	12	33401	06/12/91	5.6
91	6	13	33402	06/13/91	7.4
91	6	14	33403	06/14/91	0.0
91	6	15	33404	06/15/91	0.0
91	6	16	33405	06/16/91	0.0
91	6	17	33406	06/17/91	0.0
91	6	18	33407	06/18/91	0.0
91	6	19	33408	06/19/91	5.6
91	6	20	33409	06/20/91	0.0
91	6	21	33410	06/21/91	0.0
91	6	22	33411	06/22/91	0.2
91	6	23	33412	06/23/91	0.0
91	6	24	33413	06/24/91	0.0
91	6	25	33414	06/25/91	0.0
91	6	26	33415	06/26/91	0.0
91	6	27	33416	06/27/91	0.0
91	6	28	33417	06/28/91	0.4
91	6	29	33418	06/29/91	14.2
91	6	30	33419	06/30/91	5.0
			TOTALS:		54.0

PRECIPITATION DATA
N0. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
91	7	1	33420	07/01/91	0.4
91	7	2	33421	07/02/91	0.0
91	7	3	33422	07/03/91	0.0
91	7	4	33423	07/04/91	0.4
91	7	5	33424	07/05/91	0.0
91	7	6	33425	07/06/91	0.0
91	7	7	33426	07/07/91	0.4
91	7	8	33427	07/08/91	0.0
91	7	9	33428	07/09/91	7.4
91	7	10	33429	07/10/91	2.2
91	7	11	33430	07/11/91	0.0
91	7	12	33431	07/12/91	1.2
91	7	13	33432	07/13/91	0.0
91	7	14	33433	07/14/91	1.0
91	7	15	33434	07/15/91	12.0
91	7	16	33435	07/16/91	0.0
91	7	17	33436	07/17/91	0.0
91	7	18	33437	07/18/91	0.0
91	7	19	33438	07/19/91	1.4
91	7	20	33439	07/20/91	0.0
91	7	21	33440	07/21/91	0.0
91	7	22	33441	07/22/91	25.0
91	7	23	33442	07/23/91	0.0
91	7	24	33443	07/24/91	0.0
91	7	25	33444	07/25/91	0.0
91	7	26	33445	07/26/91	0.0
91	7	27	33446	07/27/91	2.4
91	7	28	33447	07/28/91	6.0
91	7	29	33448	07/29/91	0.0
91	7	30	33449	07/30/91	0.0
91	7	31	33450	07/31/91	0.0
			TOTALS:		59.8

PRECIPITATION DATA
N0. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
91	8	1	33451	08/01/91	0.0
91	8	2	33452	08/02/91	11.4
91	8	3	33453	08/03/91	3.8
91	8	4	33454	08/04/91	8.0
91	8	5	33455	08/05/91	0.2
91	8	6	33456	08/06/91	0.4
91	8	7	33457	08/07/91	3.2
91	8	8	33458	08/08/91	0.8
91	8	9	33459	08/09/91	0.0
91	8	10	33460	08/10/91	0.0
91	8	11	33461	08/11/91	0.0
91	8	12	33462	08/12/91	7.6
91	8	13	33463	08/13/91	0.0
91	8	14	33464	08/14/91	0.0
91	8	15	33465	08/15/91	0.0
91	8	16	33466	08/16/91	1.0
91	8	17	33467	08/17/91	0.0
91	8	18	33468	08/18/91	0.0
91	8	19	33469	08/19/91	5.0
91	8	20	33470	08/20/91	24.8
91	8	21	33471	08/21/91	0.6
91	8	22	33472	08/22/91	0.0
91	8	23	33473	08/23/91	3.8
91	8	24	33474	08/24/91	0.0
91	8	25	33475	08/25/91	0.0
91	8	26	33476	08/26/91	0.0
91	8	27	33477	08/27/91	0.2
91	8	28	33478	08/28/91	0.0
91	8	29	33479	08/29/91	0.0
91	8	30	33480	08/30/91	0.0
91	8	31	33481	08/31/91	0.0
			TOTALS:		70.6

PRECIPITATION DATA
N0. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
91	9	1	33482	09/01/91	1.2
91	9	2	33483	09/02/91	6.4
91	9	3	33484	09/03/91	0.0
91	9	4	33485	09/04/91	0.0
91	9	5	33486	09/05/91	0.0
91	9	6	33487	09/06/91	0.0
91	9	7	33488	09/07/91	0.6
91	9	8	33489	09/08/91	27.6
91	9	9	33490	09/09/91	0.0
91	9	10	33491	09/10/91	3.4
91	9	11	33492	09/11/91	0.0
91	9	12	33493	09/12/91	1.0
91	9	13	33494	09/13/91	7.4
91	9	14	33495	09/14/91	0.4
91	9	15	33496	09/15/91	0.0
91	9	16	33497	09/16/91	1.6
91	9	17	33498	09/17/91	2.2
91	9	18	33499	09/18/91	0.0
91	9	19	33500	09/19/91	0.0
91	9	20	33501	09/20/91	0.0
91	9	21	33502	09/21/91	35.8
91	9	22	33503	09/22/91	2.7
91	9	23	33504	09/23/91	0.0
91	9	24	33505	09/24/91	0.0
91	9	25	33506	09/25/91	0.0
91	9	26	33507	09/26/91	0.2
91	9	27	33508	09/27/91	0.0
91	9	28	33509	09/28/91	0.6
91	9	29	33510	09/29/91	2.4
91	9	30	33511	09/30/91	0.0
				TOTALS:	93.5

PRECIPITATION DATA
N0. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
91	10	1	33512	10/01/91	18.2
91	10	2	33513	10/02/91	7.4
91	10	3	33514	10/03/91	3.0
91	10	4	33515	10/04/91	43.4
91	10	5	33516	10/05/91	7.4
91	10	6	33517	10/06/91	0.0
91	10	7	33518	10/07/91	2.2
91	10	8	33519	10/08/91	23.4
91	10	9	33520	10/09/91	0.0
91	10	10	33521	10/10/91	0.0
91	10	11	33522	10/11/91	0.0
91	10	12	33523	10/12/91	25.0
91	10	13	33524	10/13/91	4.2
91	10	14	33525	10/14/91	3.8
91	10	15	33526	10/15/91	2.8
91	10	16	33527	10/16/91	2.4
91	10	17	33528	10/17/91	0.0
91	10	18	33529	10/18/91	0.0
91	10	19	33530	10/19/91	0.0
91	10	20	33531	10/20/91	0.0
91	10	21	33532	10/21/91	0.6
91	10	22	33533	10/22/91	0.0
91	10	23	33534	10/23/91	0.0
91	10	24	33535	10/24/91	0.0
91	10	25	33536	10/25/91	0.0
91	10	26	33537	10/26/91	0.0
91	10	27	33538	10/27/91	0.0
91	10	28	33539	10/28/91	9.0
91	10	29	33540	10/29/91	14.6
91	10	30	33541	10/30/91	0.0
91	10	31	33542	10/31/91	0.0
				TOTALS:	167.4

PRECIPITATION DATA
N0. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
91	11	1	33543	11/01/91	6.2
91	11	2	33544	11/02/91	31.4
91	11	3	33545	11/03/91	0.2
91	11	4	33546	11/04/91	0.0
91	11	5	33547	11/05/91	0.0
91	11	6	33548	11/06/91	11.9
91	11	7	33549	11/07/91	0.0
91	11	8	33550	11/08/91	0.0
91	11	9	33551	11/09/91	0.0
91	11	10	33552	11/10/91	0.0
91	11	11	33553	11/11/91	12.0
91	11	12	33554	11/12/91	39.4
91	11	13	33555	11/13/91	3.1
91	11	14	33556	11/14/91	15.2
91	11	15	33557	11/15/91	3.6
91	11	16	33558	11/16/91	1.4
91	11	17	33559	11/17/91	7.2
91	11	18	33560	11/18/91	11.0
91	11	19	33561	11/19/91	0.6
91	11	20	33562	11/20/91	0.0
91	11	21	33563	11/21/91	5.6
91	11	22	33564	11/22/91	0.0
91	11	23	33565	11/23/91	0.0
91	11	24	33566	11/24/91	0.0
91	11	25	33567	11/25/91	11.6
91	11	26	33568	11/26/91	0.6
91	11	27	33569	11/27/91	0.0
91	11	28	33570	11/28/91	0.0
91	11	29	33571	11/29/91	5.2
91	11	30	33572	11/30/91	1.0
				TOTALS:	167.6

PRECIPITATION DATA
N0. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
91	12	1	33573	12/01/91	1.2
91	12	2	33574	12/02/91	0.2
91	12	3	33575	12/03/91	0.0
91	12	4	33576	12/04/91	3.6
91	12	5	33577	12/05/91	3.4
91	12	6	33578	12/06/91	5.2
91	12	7	33579	12/07/91	13.8
91	12	8	33580	12/08/91	0.0
91	12	9	33581	12/09/91	0.0
91	12	10	33582	12/10/91	4.0
91	12	11	33583	12/11/91	9.6
91	12	12	33584	12/12/91	0.0
91	12	13	33585	12/13/91	0.0
91	12	14	33586	12/14/91	4.6
91	12	15	33587	12/15/91	5.8
91	12	16	33588	12/16/91	1.2
91	12	17	33589	12/17/91	7.4
91	12	18	33590	12/18/91	2.6
91	12	19	33591	12/19/91	17.2
91	12	20	33592	12/20/91	1.3
91	12	21	33593	12/21/91	2.0
91	12	22	33594	12/22/91	0.0
91	12	23	33595	12/23/91	0.6
91	12	24	33596	12/24/91	2.2
91	12	25	33597	12/25/91	36.1
91	12	26	33598	12/26/91	0.0
91	12	27	33599	12/27/91	0.0
91	12	28	33600	12/28/91	34.4
91	12	29	33601	12/29/91	0.0
91	12	30	33602	12/30/91	14.1
91	12	31	33603	12/31/91	0.0
				TOTALS:	170.5

CLASS 'A' EVAPORATION PAN DATA

NO. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	WATER ADDED (mm)	IN REMOVED (mm)	RAIN GAUGE (mm)	PAN NET WATER LOSS (mm)	MEAN WATER TEMP (C)	MEAN AIR TEMP (C)
91	6	1	33390	06/01/91	0.0	0.0	0.8	0.8	7.3	6.0
91	6	2	33391	06/02/91	1.6	0.0	0.6	2.2	7.3	7.0
91	6	3	33392	06/03/91	2.4	0.0	1.2	3.6	11.8	10.5
91	6	4	33393	06/04/91	2.0	0.0	0.0	2.0	8.0	6.0
91	6	5	33394	06/05/91	0.0	0.4	3.0	2.6	7.0	3.5
91	6	6	33395	06/06/91	0.0	7.0	7.6	0.6	7.8	5.3
91	6	7	33396	06/07/91	4.8	0.0	0.0	4.8	11.8	13.5
91	6	8	33397	06/08/91	2.4	0.0	2.0	4.4	12.3	10.0
91	6	9	33398	06/09/91	11.6	0.0	0.4	12.0	11.5	7.5
91	6	10	33399	06/10/91	3.4	0.0	0.0	3.4	10.8	12.0
91	6	11	33400	06/11/91	7.2	0.0	0.0	7.2	16.0	16.3
91	6	12	33401	06/12/91	0.0	0.6	5.6	5.0	15.8	13.5
91	6	13	33402	06/13/91	0.0	6.4	7.4	1.0	11.0	8.5
91	6	14	33403	06/14/91	3.4	0.0	0.0	3.4	13.5	10.5
91	6	15	33404	06/15/91	3.8	0.0	0.0	3.8	12.8	9.3
91	6	16	33405	06/16/91	2.4	0.0	0.0	2.4	12.8	8.8
91	6	17	33406	06/17/91	6.0	0.0	0.0	6.0	14.0	10.3
91	6	18	33407	06/18/91	7.6	0.0	0.0	7.6	14.8	12.5
91	6	19	33408	06/19/91	0.0	4.8	5.6	0.8	14.0	13.3
91	6	20	33409	06/20/91	7.2	0.0	0.0	7.2	16.3	17.3
91	6	21	33410	06/21/91	3.6	0.0	0.0	3.6	14.3	12.5
91	6	22	33411	06/22/91	2.4	0.0	0.2	2.6	7.8	5.3
91	6	23	33412	06/23/91	6.6	0.0	0.0	6.6	13.0	13.3
91	6	24	33413	06/24/91	6.0	0.0	0.0	6.0	15.0	12.8
91	6	25	33414	06/25/91	4.8	0.0	0.0	4.8	9.0	6.8
91	6	26	33415	06/26/91	1.8	0.0	0.0	1.8	9.5	4.8
91	6	27	33416	06/27/91	5.0	0.0	0.0	5.0	15.5	10.8
91	6	28	33417	06/28/91	4.2	0.0	0.4	4.6	13.0	9.5
91	6	29	33418	06/29/91	0.0	13.6	14.2	0.6	10.5	9.8
91	6	30	33419	06/30/91	0.0	1.6	5.0	3.4	9.3	7.3
				TOTALS:	100.2	34.4	54.0	119.8		
				MEANS:					11.9	9.8

NOTE:
Pan evaporation rates are higher than actual lake evaporation and must be adjusted for radiation and heat exchange effects.

CLASS 'A' EVAPORATION PAN DATA

NO. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	WATER ADDED (mm)	IN REMOVED (mm)	RAIN GAUGE (mm)	PAN NET WATER LOSS (mm)	MEAN WATER TEMP (C)	MEAN AIR TEMP (C)
91	7	1	33420	07/01/91	5.6	0.0	0.4	6.0	12.8	9.8
91	7	2	33421	07/02/91	4.8	0.0	0.0	4.8	13.0	11.0
91	7	3	33422	07/03/91	3.2	0.0	0.0	3.2	12.0	10.3
91	7	4	33423	07/04/91	4.4	0.0	0.4	4.8	14.3	10.5
91	7	5	33424	07/05/91	3.4	0.0	0.0	3.4	16.5	11.8
91	7	6	33425	07/06/91	3.2	0.0	0.0	3.2	18.5	16.5
91	7	7	33426	07/07/91	2.4	0.0	0.4	2.8	10.8	12.0
91	7	8	33427	07/08/91	2.4	0.0	0.0	2.4	13.8	10.3
91	7	9	33428	07/09/91	0.0	8.5	9.6	1.1	11.3	10.3
91	7	10	33429	07/10/91	6.9	0.0	0.0	6.9	16.5	15.3
91	7	11	33430	07/11/91	7.4	0.0	0.0	7.4	18.5	16.0
91	7	12	33431	07/12/91	7.2	0.0	1.2	8.4	14.5	15.5
91	7	13	33432	07/13/91	4.8	0.0	0.0	4.8	16.0	13.0
91	7	14	33433	07/14/91	0.0	0.8	1.0	0.2	14.8	12.0
91	7	15	33434	07/15/91	0.0	10.2	12.0	1.8	12.8	9.5
91	7	16	33435	07/16/91	7.0	0.0	0.0	7.0	19.0	15.0
91	7	17	33436	07/17/91	7.6	0.0	0.0	7.6	19.3	20.5
91	7	18	33437	07/18/91	1.8	0.0	0.4	2.2	16.0	19.3
91	7	19	33438	07/19/91	3.4	0.0	1.0	4.4	16.3	14.5
91	7	20	33439	07/20/91	5.0	0.0	0.0	5.0	18.8	17.0
91	7	21	33440	07/21/91	0.0	12.0	18.6	6.6	22.8	20.6
91	7	22	33441	07/22/91	0.0	2.4	6.8	4.4	13.5	21.8
91	7	23	33442	07/23/91	6.4	0.0	0.0	6.4	15.8	13.0
91	7	24	33443	07/24/91	2.4	0.0	0.0	2.4	15.8	15.5
91	7	25	33444	07/25/91	2.6	0.0	0.0	2.6	16.8	14.3
91	7	26	33445	07/26/91	5.4	0.0	0.0	5.4	18.3	16.3
91	7	27	33446	07/27/91	0.0	6.8	7.4	0.6	14.0	17.3
91	7	28	33447	07/28/91	4.8	0.0	1.0	5.8	18.0	13.8
91	7	29	33448	07/29/91	5.8	0.0	0.0	5.8	18.0	17.0
91	7	30	33449	07/30/91	6.2	0.0	0.0	6.2	18.0	14.5
91	7	31	33450	07/31/91	8.2	0.0	0.4	8.6	20.0	19.0
				TOTALS:	122.3	40.7	60.6	142.2		
				MEANS:					16.0	14.6

NOTE:
Pan evaporation rates are higher than actual lake evaporation and must be adjusted for radiation and heat exchange effects.

CLASS 'A' EVAPORATION PAN DATA

NO. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	WATER ADDED (mm)	IN REMOVED (mm)	RAIN GAUGE (mm)	PAN NET WATER LOSS (mm)	MEAN WATER TEMP (C)	MEAN AIR TEMP (C)
91	8	1	33451	08/01/91	0.0	15.8	15.8	0.0	12.5	11.8
91	8	2	33452	08/02/91	0.0	0.8	3.2	2.4	11.8	10.0
91	8	3	33453	08/03/91	0.0	8.6	8.6	0.0	10.0	9.3
91	8	4	33454	08/04/91	4.2	0.0	0.6	4.8	10.8	9.5
91	8	5	33455	08/05/91	0.0	11.0	11.4	0.4	11.5	10.0
91	8	6	33456	08/06/91	0.0	2.4	2.6	0.2	13.3	13.0
91	8	7	33457	08/07/91	3.6	0.0	1.8	5.4	13.5	11.5
91	8	8	33458	08/08/91	2.4	0.0	0.0	2.4	12.8	10.0
91	8	9	33459	08/09/91	7.2	0.0	0.0	7.2	15.5	14.0
91	8	10	33460	08/10/91	7.0	0.0	0.0	7.0	18.0	17.0
91	8	11	33461	08/11/91	2.4	0.0	0.0	2.4	15.3	15.8
91	8	12	33462	08/12/91	0.0	6.0	7.6	1.6	17.8	16.5
91	8	13	33463	08/13/91	7.2	0.0	0.0	7.2	20.3	20.3
91	8	14	33464	08/14/91	5.2	0.0	0.0	5.2	21.5	20.8
91	8	15	33465	08/15/91	1.0	0.0	0.0	1.0	19.5	19.5
91	8	16	33466	08/16/91	1.2	0.0	1.0	2.2	18.0	17.3
91	8	17	33467	08/17/91	3.2	0.0	0.0	3.2	19.8	17.0
91	8	18	33468	08/18/91	1.2	0.0	5.0	6.2	20.8	20.8
91	8	19	33469	08/19/91	0.0	5.2	9.8	4.6	17.0	15.3
91	8	20	33470	08/20/91	0.0	14.4	15.4	1.0	12.3	13.0
91	8	21	33471	08/21/91	5.8	0.0	0.0	5.8	16.3	14.3
91	8	22	33472	08/22/91	0.0	1.6	3.8	2.2	15.3	16.0
91	8	23	33473	08/23/91	5.8	0.0	0.0	5.8	18.5	15.8
91	8	24	33474	08/24/91	3.0	0.0	0.0	3.0	10.8	7.5
91	8	25	33475	08/25/91	3.8	0.0	0.0	3.8	13.5	11.5
91	8	26	33476	08/26/91	5.6	0.0	0.0	5.6	15.3	16.8
91	8	27	33477	08/27/91	3.4	0.0	0.2	3.6	15.8	16.3
91	8	28	33478	08/28/91	4.4	0.0	0.0	4.4	15.5	12.0
91	8	29	33479	08/29/91	5.8	0.0	0.0	5.8	15.5	16.5
91	8	30	33480	08/30/91	1.6	0.0	0.0	1.6	16.5	17.8
91	8	31	33481	08/31/91	1.4	0.0	1.6	3.0	17.8	17.8
				TOTALS:	86.4	65.8	88.4	109.0		
				MEANS:					15.6	14.7

NOTE:
Pan evaporation rates are higher than actual lake evaporation and must be adjusted for radiation and heat exchange effects.

CLASS 'A' EVAPORATION PAN DATA

NO. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	WATER ADDED (mm)	IN REMOVED (mm)	RAIN GAUGE (mm)	PAN NET WATER LOSS (mm)	MEAN WATER TEMP (C)	MEAN AIR TEMP (C)
91	9	1	33482	09/01/91	0.0	3.6	5.4	1.8	11.0	10.8
91	9	2	33483	09/02/91	0.0	1.2	2.2	1.0	7.3	6.0
91	9	3	33484	09/03/91	1.8	0.0	0.5	2.3	9.5	8.0
91	9	4	33485	09/04/91	2.4	0.0	0.0	2.4	16.8	15.8
91	9	5	33486	09/05/91	4.0	0.0	0.0	4.0	18.3	15.0
91	9	6	33487	09/06/91	1.2	0.0	0.6	1.8	18.8	17.0
91	9	7	33488	09/07/91	0.0	1.2	2.6	1.4	18.8	16.3
91	9	8	33489	09/08/91	0.0	24.8	26.4	1.6	14.3	14.3
91	9	9	33490	09/09/91	0.8	0.0	3.8	4.6	10.5	10.5
91	9	10	33491	09/10/91	3.6	0.0	0.4	4.0	11.5	10.5
91	9	11	33492	09/11/91	3.2	0.0	0.0	3.2	12.3	8.0
91	9	12	33493	09/12/91	0.0	7.2	7.2	0.0	8.3	7.0
91	9	13	33494	09/13/91	0.0	0.2	1.4	1.2	9.0	7.3
91	9	14	33495	09/14/91	1.2	0.0	0.2	1.4	8.8	7.5
91	9	15	33496	09/15/91	0.0	1.2	1.6	0.4	9.5	9.0
91	9	16	33497	09/16/91	2.2	0.0	0.0	2.2	14.5	11.3
91	9	17	33498	09/17/91	2.2	0.0	2.2	4.4	14.0	15.0
91	9	18	33499	09/18/91	3.4	0.0	0.0	3.4	16.3	14.0
91	9	19	33500	09/19/91	4.4	0.0	0.0	4.4	18.8	15.3
91	9	20	33501	09/20/91	0.0	19.0	21.6	2.6	16.5	14.8
91	9	21	33502	09/21/91	0.0	8.8	15.8	7.0	14.8	12.8
91	9	22	33503	09/22/91	1.4	0.0	1.1	2.5	12.8	8.3
91	9	23	33504	09/23/91	3.2	0.0	0.0	3.2	14.0	12.3
91	9	24	33505	09/24/91	3.0	0.0	0.0	3.0	16.0	14.0
91	9	25	33506	09/25/91	3.8	0.0	0.2	4.0	16.8	15.3
91	9	26	33507	09/26/91	1.4	0.0	0.0	1.4	18.8	18.3
91	9	27	33508	09/27/91	2.4	0.0	0.0	2.4	20.3	19.3
91	9	28	33509	09/28/91	0.0	1.2	3.0	1.8	19.5	15.3
91	9	29	33510	09/29/91	2.4	0.0	0.0	2.4	8.0	7.3
91	9	30	33511	08/30/91	0.0	14.6	16.8	2.2	9.5	6.0
				TOTALS:	48.0	83.0	113.0	78.0		
				MEANS:					13.8	12.1

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CLASS 'A' EVAPORATION PAN DATA

NO. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	WATER ADDED (mm)	IN REMOVED (mm)	RAIN GAUGE (mm)	PAN NET WATER LOSS (mm)	MEAN WATER TEMP (C)	MEAN AIR TEMP (C)
91	10	1	33512	10/01/91	0.0	1.2	3.2	2.0	7.3	6.3
91	10	2	33513	10/02/91	0.0	6.8	6.6	1.8	9.3	11.3
91	10	3	33514	10/03/91	2.4	0.0	0.0	2.4	15.3	16.3
91	10	4	33515	10/04/91	0.0	46.2	50.8	4.6	11.8	11
91	10	5	33516	10/05/91	3.0	0.0	0.0	3.0	10.5	8.0
91	10	6	33517	10/06/91	1.2	0.0	0.8	2.0	9.3	7.3
91	10	7	33518	10/07/91	0.0	10.8	12.0	1.2	11.5	12.8
91	10	8	33519	10/08/91	0.0	10.4	12.8	2.4	10.5	10.8
91	10	9	33520	10/09/91	2.4	0.0	0.0	2.4	8.5	6.0
91	10	10	33521	10/10/91	2.4	0.0	0.0	2.4	8.3	7.8
91	10	11	33522	10/11/91	0.0	2.0	3.4	1.4	9.8	9.3
91	10	12	33523	10/12/91	0.0	21.6	21.6	0.0	11.5	11.5
91	10	13	33524	10/13/91	0.0	5.0	8.0	3.0	12.0	12.3
91	10	14	33525	10/14/91	0.0	0.0	0.0	0.0	10.3	9.0
91	10	15	33526	10/15/91	0.0	3.8	5.2	1.4	5.3	4.8
91	10	16	33527	10/16/91	0.8	0.0	0.0	0.8	5.0	3.0
91	10	17	33528	10/17/91	1.0	0.0	0.0	1.0	7.0	5.8
91	10	18	33529	10/18/91	2.4	0.0	0.0	2.4	9.8	7.5
91	10	19	33530	10/19/91	0.0	0.0	0.0	0.0	9.8	7.0
91	10	20	33531	10/20/91	0.0	0.0	0.6	0.6	9.8	7.8
91	10	21	33532	10/21/91	3.0	0.0	0.0	3.0	5.5	6.0
91	10	22	33533	10/22/91	0.0	0.0	0.0	0.5	4.3	1.8
91	10	23	33534	10/23/91	0.0	0.0	0.0	0.5	4.3	4.3
91	10	24	33535	10/24/91	1.6	0.0	0.0	0.5	4.3	5.0
91	10	25	33536	10/25/91	4.2	0.0	0.0	4.2	11.0	12.5
91	10	26	33537	10/26/91	2.0	0.0	0.0	2.0	10.5	12.8
91	10	27	33538	10/27/91	0.0	0.0	0.0	0.7	6.3	4.0
91	10	28	33539	10/28/91	0.0	0.0	0.0	0.7	1.0	0.8
91	10	29	33540	10/29/91	2.2	0.0	0.0	0.7	1.8	1.3
91	10	30	33541	10/30/91	0.8	0.0	0.0	0.8	2.3	2.8
91	10	31	33542	10/31/91	1.0	0.0	0.0	0.0	4.5	4.0
				TOTALS:	30.4	107.8	127.0	48.4		
				MEANS:					8.0	7.4

NOTE:
Pan evaporation rates are higher than actual lake evaporation and must be adjusted for radiation and heat exchange effects.

PRECIPITATION DATA

NO. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
92	1	1	33604	01/01/92	0.0
92	1	2	33605	01/02/92	0.0
92	1	3	33606	01/03/92	0.0
92	1	4	33607	01/04/92	0.0
92	1	5	33608	01/05/92	0.0
92	1	6	33609	01/06/92	0.0
92	1	7	33610	01/07/92	17.4
92	1	8	33611	01/08/92	8.4
92	1	9	33612	01/09/92	0.6
92	1	10	33613	01/10/92	1.0
92	1	11	33614	01/11/92	14.8
92	1	12	33615	01/12/92	5.0
92	1	13	33616	01/13/92	2.2
92	1	14	33617	01/14/92	0.0
92	1	15	33618	01/15/92	3.6
92	1	16	33619	01/16/92	2.8
92	1	17	33620	01/17/92	5.8
92	1	18	33621	01/18/92	1.0
92	1	19	33622	01/19/92	1.0
92	1	20	33623	01/20/92	4.6
92	1	21	33624	01/21/92	0.8
92	1	22	33625	01/22/92	0.0
92	1	23	33626	01/23/92	0.0
92	1	24	33627	01/24/92	2.4
92	1	25	33628	01/25/92	24.2
92	1	26	33629	01/26/92	0.2
92	1	27	33630	01/27/92	10.6
92	1	28	33631	01/28/92	0.0
92	1	29	33632	01/29/92	0.0
92	1	30	33633	01/30/92	3.0
92	1	31	33634	01/31/92	1.0
				TOTALS:	110.4

PRECIPITATION DATA

NO. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
92	2	1	33635	02/01/92	1.6
92	2	2	33636	02/02/92	19.8
92	2	3	33637	02/03/92	4.8
92	2	4	33638	02/04/92	11.8
92	2	5	33639	02/05/92	15.2
92	2	6	33640	02/06/92	12.6
92	2	7	33641	02/07/92	13.8
92	2	8	33642	02/08/92	0.0
92	2	9	33643	02/09/92	13.8
92	2	10	33644	02/10/92	6.6
92	2	11	33645	02/11/92	0.0
92	2	12	33646	02/12/92	16.1
92	2	13	33647	02/13/92	0.0
92	2	14	33648	02/14/92	0.0
92	2	15	33649	02/15/92	14.0
92	2	16	33650	02/16/92	0.0
92	2	17	33651	02/17/92	26.0
92	2	18	33652	02/18/92	0.0
92	2	19	33653	02/19/92	0.0
92	2	20	33654	02/20/92	24.2
92	2	21	33655	02/21/92	0.0
92	2	22	33656	02/22/92	0.6
92	2	23	33657	02/23/92	2.0
92	2	24	33658	02/24/92	0.6
92	2	25	33659	02/25/92	0.0
92	2	26	33660	02/26/92	0.8
92	2	27	33661	02/27/92	26.0
92	2	28	33662	02/28/92	0.4
92	2	29	33663	02/29/92	2.8
				TOTALS:	213.7

PRECIPITATION DATA

NO. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
92	3	1	33664	03/01/92	13.7
92	3	2	33665	03/02/92	6.4
92	3	3	33666	03/03/92	0.0
92	3	4	33667	03/04/92	0.0
92	3	5	33668	03/05/92	0.0
92	3	6	33669	03/06/92	0.4
92	3	7	33670	03/07/92	0.0
92	3	8	33671	03/08/92	12.6
92	3	9	33672	03/09/92	25.0
92	3	10	33673	03/10/92	1.2
92	3	11	33674	03/11/92	0.0
92	3	12	33675	03/12/92	8.2
92	3	13	33676	03/13/92	0.0
92	3	14	33677	03/14/92	0.0
92	3	15	33678	03/15/92	1.0
92	3	16	33679	03/16/92	0.6
92	3	17	33680	03/17/92	0.0
92	3	18	33681	03/18/92	1.2
92	3	19	33682	03/19/92	6.0
92	3	20	33683	03/20/92	4.6
92	3	21	33684	03/21/92	0.0
92	3	22	33685	03/22/92	29.2
92	3	23	33686	03/23/92	0.0
92	3	24	33687	03/24/92	7.0
92	3	25	33688	03/25/92	38.2
92	3	26	33689	03/26/92	6.0
92	3	27	33690	03/27/92	0.0
92	3	28	33691	03/28/92	8.0
92	3	29	33692	03/29/92	9.5
92	3	30	33693	03/30/92	1.2
92	3	31	33694	03/31/92	0.0
				TOTALS:	178.0

PRECIPITATION DATA

NO. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
92	4	1	33695	04/01/92	0.6
92	4	2	33696	04/02/92	12.8
92	4	3	33697	04/03/92	0.0
92	4	4	33698	04/04/92	4.6
92	4	5	33699	04/05/92	0.0
92	4	6	33700	04/06/92	0.0
92	4	7	33701	04/07/92	41.0
92	4	8	33702	04/08/92	2.6
92	4	9	33703	04/09/92	6.4
92	4	10	33704	04/10/92	0.0
92	4	11	33705	04/11/92	9.6
92	4	12	33706	04/12/92	1.8
92	4	13	33707	04/13/92	4.8
92	4	14	33708	04/14/92	0.0
92	4	15	33709	04/15/92	0.0
92	4	16	33710	04/16/92	0.0
92	4	17	33711	04/17/92	0.0
92	4	18	33712	04/18/92	0.0
92	4	19	33713	04/19/92	0.0
92	4	20	33714	04/20/92	0.0
92	4	21	33715	04/21/92	1.8
92	4	22	33716	04/22/92	5.0
92	4	23	33717	04/23/92	4.6
92	4	24	33718	04/24/92	1.8
92	4	25	33719	04/25/92	0.0
92	4	26	33720	04/26/92	0.0
92	4	27	33721	04/27/92	21.0
92	4	28	33722	04/28/92	0.0
92	4	29	33723	04/29/92	0.0
92	4	30	33724	04/30/92	0.0
				TOTALS:	118.8

PRECIPITATION DATA

N0. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
92	5	1	33725	05/01/92	32.4
92	5	2	33726	05/02/92	1.6
92	5	3	33727	05/03/92	1.8
92	5	4	33728	05/04/92	0.0
92	5	5	33729	05/05/92	1.6
92	5	6	33730	05/06/92	1.6
92	5	7	33731	05/07/92	0.0
92	5	8	33732	05/08/92	0.0
92	5	9	33733	05/09/92	24.2
92	5	10	33734	05/10/92	0.0
92	5	11	33735	05/11/92	0.0
92	5	12	33736	05/12/92	0.0
92	5	13	33737	05/13/92	0.0
92	5	14	33738	05/14/92	1.6
92	5	15	33739	05/15/92	0.0
92	5	16	33740	05/16/92	0.0
92	5	17	33741	05/17/92	0.0
92	5	18	33742	05/18/92	0.0
92	5	19	33743	05/19/92	0.0
92	5	20	33744	05/20/92	0.0
92	5	21	33745	05/21/92	0.0
92	5	22	33746	05/22/92	1.6
92	5	23	33747	05/23/92	0.0
92	5	24	33748	05/24/92	0.0
92	5	25	33749	05/25/92	1.6
92	5	26	33750	05/26/92	0.4
92	5	27	33751	05/27/92	0.0
92	5	28	33752	05/28/92	3.2
92	5	29	33753	05/29/92	7.4
92	5	30	33754	05/30/92	0.0
92	5	31	33755	05/31/92	0.0
			TOTALS:		79.0

PRECIPITATION DATA

N0. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
92	6	1	33756	06/01/92	0.0
92	6	2	33757	06/02/92	0.4
92	6	3	33758	06/03/92	1.0
92	6	4	33759	06/04/92	0.0
92	6	5	33760	06/05/92	0.0
92	6	6	33761	06/06/92	0.0
92	6	7	33762	06/07/92	0.4
92	6	8	33763	06/08/92	1.4
92	6	9	33764	06/09/92	0.0
92	6	10	33765	06/10/92	20.8
92	6	11	33766	06/11/92	0.0
92	6	12	33767	06/12/92	0.0
92	6	13	33768	06/13/92	1.4
92	6	14	33769	06/14/92	0.0
92	6	15	33770	06/15/92	0.0
92	6	16	33771	06/16/92	57.4
92	6	17	33772	06/17/92	0.0
92	6	18	33773	06/18/92	24.6
92	6	19	33774	06/19/92	0.4
92	6	20	33775	06/20/92	9.8
92	6	21	33776	06/21/92	0.0
92	6	22	33777	06/22/92	1.0
92	6	23	33778	06/23/92	0.4
92	6	24	33779	06/24/92	0.0
92	6	25	33780	06/25/92	0.0
92	6	26	33781	06/26/92	3.1
92	6	27	33782	06/27/92	0.4
92	6	28	33783	06/28/92	1.4
92	6	29	33784	06/29/92	1.6
92	6	30	33785	06/30/92	9.7
			TOTALS:		135.2

PRECIPITATION DATA

N0. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
92	7	1	33786	07/01/92	3.1
92	7	2	33787	07/02/92	24.0
92	7	3	33788	07/03/92	1.6
92	7	4	33789	07/04/92	0.0
92	7	5	33790	07/05/92	0.0
92	7	6	33791	07/06/92	17.2
92	7	7	33792	07/07/92	24.8
92	7	8	33793	07/08/92	0.6
92	7	9	33794	07/09/92	0.0
92	7	10	33795	07/10/92	23.8
92	7	11	33796	07/11/92	0.6
92	7	12	33797	07/12/92	0.8
92	7	13	33798	07/13/92	0.0
92	7	14	33799	07/14/92	0.0
92	7	15	33800	07/15/92	0.0
92	7	16	33801	07/16/92	1.0
92	7	17	33802	07/17/92	0.0
92	7	18	33803	07/18/92	1.4
92	7	19	33804	07/19/92	6.6
92	7	20	33805	07/20/92	0.0
92	7	21	33806	07/21/92	0.8
92	7	22	33807	07/22/92	0.0
92	7	23	33808	07/23/92	0.0
92	7	24	33809	07/24/92	0.0
92	7	25	33810	07/25/92	0.0
92	7	26	33811	07/26/92	0.0
92	7	27	33812	07/27/92	0.0
92	7	28	33813	07/28/92	30.2
92	7	29	33814	07/29/92	0.0
92	7	30	33815	07/30/92	0.0
92	7	31	33816	07/31/92	0.0
			TOTALS:		136.5

PRECIPITATION DATA

N0. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
92	8	1	33817	08/01/92	6.4
92	8	2	33818	08/02/92	1.4
92	8	3	33819	08/03/92	0.0
92	8	4	33820	08/04/92	0.0
92	8	5	33821	08/05/92	11.2
92	8	6	33822	08/06/92	0.0
92	8	7	33823	08/07/92	0.0
92	8	8	33824	08/08/92	0.0
92	8	9	33825	08/09/92	0.0
92	8	10	33826	08/10/92	0.0
92	8	11	33827	08/11/92	0.4
92	8	12	33828	08/12/92	1.2
92	8	13	33829	08/13/92	0.0
92	8	14	33830	08/14/92	0.0
92	8	15	33831	08/15/92	0.0
92	8	16	33832	08/16/92	0.0
92	8	17	33833	08/17/92	0.0
92	8	18	33834	08/18/92	4.2
92	8	19	33835	08/19/92	3.5
92	8	20	33836	08/20/92	0.0
92	8	21	33837	08/21/92	4.6
92	8	22	33838	08/22/92	3.1
92	8	23	33839	08/23/92	0.0
92	8	24	33840	08/24/92	0.0
92	8	25	33841	08/25/92	6.2
92	8	26	33842	08/26/92	0.0
92	8	27	33843	08/27/92	0.8
92	8	28	33844	08/28/92	26.4
92	8	29	33845	08/29/92	2.4
92	8	30	33846	08/30/92	7.0
92	8	31	33847	08/31/92	2.6
			TOTALS:		81.4

PRECIPITATION DATA
N0. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
92	9	1	33848	09/01/92	2.6
92	9	2	33849	09/02/92	1.0
92	9	3	33850	09/03/92	3.2
92	9	4	33851	09/04/92	0.8
92	9	5	33852	09/05/92	0.0
92	9	6	33853	09/06/92	0.0
92	9	7	33854	09/07/92	0.0
92	9	8	33855	09/08/92	2.0
92	9	9	33856	09/09/92	2.2
92	9	10	33857	09/10/92	0.0
92	9	11	33858	09/11/92	0.0
92	9	12	33859	09/12/92	71.8
92	9	13	33860	09/13/92	0.0
92	9	14	33861	09/14/92	0.0
92	9	15	33862	09/15/92	0.0
92	9	16	33863	09/16/92	1.8
92	9	17	33864	09/17/92	1.4
92	9	18	33865	09/18/92	2.0
92	9	19	33866	09/19/92	0.0
92	9	20	33867	09/20/92	20.4
92	9	21	33868	09/21/92	3.2
92	9	22	33869	09/22/92	0.0
92	9	23	33870	09/23/92	11.6
92	9	24	33871	09/24/92	11.2
92	9	25	33872	09/25/92	0.0
92	9	26	33873	09/26/92	0.0
92	9	27	33874	09/27/92	0.0
92	9	28	33875	09/28/92	2.4
92	9	29	33876	09/29/92	9.6
92	9	30	33877	09/30/92	0.0
				TOTALS:	147.2

PRECIPITATION DATA
N0. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
92	10	1	33878	10/01/92	9.0
92	10	2	33879	10/02/92	0.0
92	10	3	33880	10/03/92	0.6
92	10	4	33881	10/04/92	1.2
92	10	5	33882	10/05/92	0.6
92	10	6	33883	10/06/92	58.8
92	10	7	33884	10/07/92	34.0
92	10	8	33885	10/08/92	23.6
92	10	9	33886	10/09/92	8.0
92	10	10	33887	10/10/92	0.0
92	10	11	33888	10/11/92	0.0
92	10	12	33889	10/12/92	0.0
92	10	13	33890	10/13/92	3.8
92	10	14	33891	10/14/92	8.6
92	10	15	33892	10/15/92	0.0
92	10	16	33893	10/16/92	0.0
92	10	17	33894	10/17/92	8.3
92	10	18	33895	10/18/92	1.0
92	10	19	33896	10/19/92	2.6
92	10	20	33897	10/20/92	3.8
92	10	21	33898	10/21/92	0.0
92	10	22	33899	10/22/92	8.4
92	10	23	33900	10/23/92	1.2
92	10	24	33901	10/24/92	0.0
92	10	25	33902	10/25/92	1.0
92	10	26	33903	10/26/92	36.4
92	10	27	33904	10/27/92	1.8
92	10	28	33905	10/28/92	0.0
92	10	29	33906	10/29/92	0.0
92	10	30	33907	10/30/92	2.7
92	10	31	33908	10/31/92	0.0
				TOTALS:	215.4

PRECIPITATION DATA
N0. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
92	11	1	33909	11/01/92	2.6
92	11	2	33910	11/02/92	1.6
92	11	3	33911	11/03/92	2.0
92	11	4	33912	11/04/92	0.0
92	11	5	33913	11/05/92	3.6
92	11	6	33914	11/06/92	3.2
92	11	7	33915	11/07/92	0.0
92	11	8	33916	11/08/92	0.0
92	11	9	33917	11/09/92	0.4
92	11	10	33918	11/10/92	0.0
92	11	11	33919	11/11/92	2.6
92	11	12	33920	11/12/92	0.4
92	11	13	33921	11/13/92	13.8
92	11	14	33922	11/14/92	0.8
92	11	15	33923	11/15/92	1.8
92	11	16	33924	11/16/92	4.2
92	11	17	33925	11/17/92	2.2
92	11	18	33926	11/18/92	0.4
92	11	19	33927	11/19/92	1.2
92	11	20	33928	11/20/92	0.0
92	11	21	33929	11/21/92	0.0
92	11	22	33930	11/22/92	2.5
92	11	23	33931	11/23/92	0.3
92	11	24	33932	11/24/92	0.0
92	11	25	33933	11/25/92	0.0
92	11	26	33934	11/26/92	2.6
92	11	27	33935	11/27/92	9.4
92	11	28	33936	11/28/92	0.0
92	11	29	33937	11/29/92	0.0
92	11	30	33938	11/30/92	1.0
				TOTALS:	56.4

PRECIPITATION DATA
N0. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	PRECIPITATION (mm)
92	12	1	33939	12/01/92	1.0
92	12	2	33940	12/02/92	7.8
92	12	3	33941	12/03/92	24.8
92	12	4	33942	12/04/92	0.0
92	12	5	33943	12/05/92	25.2
92	12	6	33944	12/06/92	2.0
92	12	7	33945	12/07/92	0.0
92	12	8	33946	12/08/92	2.8
92	12	9	33947	12/09/92	0.0
92	12	10	33948	12/10/92	0.0
92	12	11	33949	12/11/92	0.0
92	12	12	33950	12/12/92	0.0
92	12	13	33951	12/13/92	0.0
92	12	14	33952	12/14/92	0.0
92	12	15	33953	12/15/92	0.0
92	12	16	33954	12/16/92	1.0
92	12	17	33955	12/17/92	2.0
92	12	18	33956	12/18/92	1.7
92	12	19	33957	12/19/92	0.0
92	12	20	33958	12/20/92	33.6
92	12	21	33959	12/21/92	0.0
92	12	22	33960	12/22/92	0.0
92	12	23	33961	12/23/92	10.4
92	12	24	33962	12/24/92	11.0
92	12	25	33963	12/25/92	21.0
92	12	26	33964	12/26/92	13.4
92	12	27	33965	12/27/92	0.0
92	12	28	33966	12/28/92	2.4
92	12	29	33967	12/29/92	0.0
92	12	30	33968	12/30/92	0.0
92	12	31	33969	12/31/92	0.0
				TOTALS:	160.1

CLASS 'A' EVAPORATION PAN DATA

NO. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	WATER ADDED (mm)	IN REMOVED (mm)	RAIN GAUGE (mm)	PAN NET WATER LOSS (mm)	MEAN WATER TEMP (C)	MEAN AIR TEMP (C)
92	6	1	33756	06/01/92	2.4	0.0	0.4	2.8	18.0	14.3
92	6	2	33757	06/02/92	4.0	0.0	1.0	5.0	19.0	15.8
92	6		33758	06/03/92	6.2	0.0	0.0	6.2	15.3	13.3
92	6	4	33759	06/04/92	7.6	0.0	0.0	7.6	14.5	14.0
92	6	5	33760	06/05/92	2.4	0.0	0.4	2.8	11.3	5.5
92	6	6	33761	06/06/92	7.2	0.0	0.0	7.2	12.0	8.0
92	6	7	33762	06/07/92	3.0	0.0	1.4	4.4	13.5	11.5
92	6	8	33763	06/08/92	4.8	0.0	0.0	4.9	19.5	17.0
92	6	9	33764	06/09/92	0.0	16.0	20.8	4.8	18.3	18.5
92	6	10	33765	06/10/92	1.6	0.0	0.0	1.6	9.8	8.5
92	6	11	33766	06/11/92	3.2	0.0	0.0	3.2	13.5	8.0
92	6	12	33767	06/12/92	2.0	0.0	1.4	3.4	14.0	7.0
92	6	13	33768	06/13/92	2.2	0.0	0.0	2.2	13.0	9.8
92	6	14	33769	06/14/92	7.2	0.0	0.0	7.2	16.5	14.5
92	6	15	33770	06/15/92	0.0	52.0	56.0	4.0	18.5	16.6
92	6	16	33771	06/16/92	0.0	1.4	3.2	1.8	16.0	13.0
92	6	17	33772	06/17/92	3.6	0.0	0.0	3.6	9.0	8.8
92	6	18	33773	06/18/92	0.0	22.2	24.6	2.4	6.0	5.3
92	6	19	33774	06/19/92	0.8	0.0	0.4	1.2	10.0	7.0
92	6	20	33775	06/20/92	0.0	8.6	9.8	1.2	9.3	8.5
92	6	21	33776	06/21/92	0.8	0.0	0.0	0.8	11.3	9.5
92	6	22	33777	06/22/92	0.0	0.6	1.0	0.4	11.0	8.3
92	6	23	33778	06/23/92	0.4	0.0	0.4	0.8	12.3	9.8
92	6	24	33779	06/24/92	2.2	0.0	0.0	2.2	15.8	12.0
92	6	25	33780	06/25/92	2.8	0.0	0.0	2.8	16.8	13.8
92	6	26	33781	06/26/92	0.0	2.7	3.1	0.4	10.8	8.5
92	6	27	33782	06/27/92	0.9	0.0	0.4	1.3	12.8	11.0
92	6	28	33783	06/28/92	0.8	0.0	1.4	2.2	15.0	12.8
92	6	29	33784	06/29/92	0.4	0.0	1.6	2.0	10.5	9.8
92	6	30	33785	06/30/92	0.0	6.2	9.7	3.5	13.5	9.5
				TOTALS:	66.5	109.7	137.0	93.8		
				MEANS:					13.6	11.0

NOTE:
Pan evaporation rates are higher than actual lake evaporation and must be adjusted for radiation and heat exchange effects.

CLASS 'A' EVAPORATION PAN DATA

NO. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	WATER ADDED (mm)	IN REMOVED (mm)	RAIN GAUGE (mm)	PAN NET WATER LOSS (mm)	MEAN WATER TEMP (C)	MEAN AIR TEMP (C)
92	7	1	33786	07/01/92	0.6	0.0	3.1	3.7	13.0	11.5
92	7	2	33787	07/02/92	0.0	22.8	24.0	1.2	7.0	5.5
92	7	3	33788	07/03/92	0.0	0.1	1.6	1.5	7.3	6.3
92	7	4	33789	07/04/92	1.2	0.0	0.0	1.2	6.8	5.0
92	7	5	33790	07/05/92	5.0	0.0	0.0	5.0	14.5	9.8
92	7	6	33791	07/06/92	0.0	17.2	17.2	0.0	10.0	10.8
92	7	7	33792	07/07/92	0.0	24.2	24.8	0.6	18.2	13.0
92	7	8	33793	07/08/92	3.2	0.0	0.6	3.8	17.0	16.5
92	7	9	33794	07/09/92	4.8	0.0	0.0	4.8	17.3	14.8
92	7	10	33795	07/10/92	0.0	23.2	23.8	0.6	17.4	11.8
92	7	11	33796	07/11/92	0.6	0.0	0.8	1.4	15.8	12.8
92	7	12	33787	07/12/92	1.4	0.0	0.6	2.0	10.5	10.3
92	7	13	33798	07/13/92	2.4	0.0	0.0	2.4	13.5	10.0
92	7	14	33799	07/14/92	5.4	0.0	0.0	5.4	14.5	10.5
92	7	15	33800	07/15/92	4.8	0.0	0.0	4.8	16.8	13.0
92	7	16	33801	07/16/92	4.8	0.0	1.0	5.8	14.5	13.0
92	7	17	33802	07/17/92	2.6	0.0	0.0	2.6	12.8	10.3
92	7	18	33803	07/18/92	2.4	0.0	1.4	3.8	16.5	11.5
92	7	19	33804	07/19/92	0.0	3.4	6.6	3.2	14.5	13.8
92	7	20	33805	07/20/92	5.8	0.0	0.0	5.8	18.5	17.0
92	7	21	33806	07/21/92	3.2	0.0	0.8	4.0	18.9	12.8
92	7	22	33807	07/22/92	3.0	0.0	0.0	3.0	17.0	16.8
92	7	23	33808	07/23/92	8.4	0.0	0.0	8.4	17.5	13.5
92	7	24	33809	07/24/92	3.2	0.0	0.0	3.2	16.8	16.5
92	7	25	33810	07/25/92	6.8	0.0	0.0	6.8	19.0	17.5
92	7	26	33811	07/26/92	9.6	0.0	0.0	9.6	17.5	18.3
92	7	27	33812	07/27/92	3.0	0.0	0.0	3.0	18.8	17.0
92	7	28	33813	07/28/92	0.0	26.4	30.2	3.8	14.5	11.5
92	7	29	33814	07/29/92	3.2	0.0	0.0	3.2	18.8	15.3
92	7	30	33815	07/30/92	6.2	0.0	0.0	6.2	20.5	17.8
92	7	31	33816	07/31/92	8.0	0.0	0.0	8.0	21.5	17.0
				TOTALS:	99.6	117.3	136.5	118.8		
				MEANS:					15.4	12.9

NOTE:
Pan evaporation rates are higher than actual lake evaporation and must be adjusted for radiation and heat exchange effects.

CLASS 'A' EVAPORATION PAN DATA

NO. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	WATER ADDED (mm)	IN REMOVED (mm)	RAIN GAUGE (mm)	PAN NET WATER LOSS (mm)	MEAN WATER TEMP (C)	MEAN AIR TEMP (C)
92	8	1	33817	08/01/92	0.0	4.8	6.4	1.6	15.3	12.0
92	8	2	33818	08/02/92	2.5	0.0	1.4	3.9	12.5	13.5
92	8	3	33819	08/03/92	4.8	0.0	0.0	4.8	15.0	14.0
92	8	4	33820	08/04/92	6.2	0.0	0.0	6.2	17.5	15.8
92	8	5	33821	08/05/92	0.0	9.2	11.2	2.0	18.3	16.5
92	8	6	33822	08/06/92	6.1	0.0	0.0	6.1	17.3	17.8
92	8	7	33823	08/07/92	7.2	0.0	0.0	7.2	13.3	18.0
92	8	8	33824	08/08/92	5.7	0.0	0.0	5.7	19.5	19.0
92	8	9	33825	08/09/92	7.8	0.0	0.0	7.8	19.8	20.0
92	8	10	33826	08/10/92	6.2	0.0	0.0	6.2	18.5	18.3
92	8	11	33827	08/11/92	1.0	0.0	0.4	1.4	18.3	18.3
92	8	12	33828	08/12/92	4.0	0.0	1.2	5.2	18.8	19.3
92	8	13	33829	08/13/92	5.4	0.0	0.0	5.4	15.5	14.3
92	8	14	33830	08/14/92	2.8	0.0	0.0	2.8	14.0	14.3
92	8	15	33831	08/15/92	7.0	0.0	0.0	7.0	16.8	14.5
92	8	16	33832	08/16/92	8.2	0.0	0.0	8.2	17.3	16.5
92	8	17	33833	08/17/92	2.4	0.0	0.0	2.4	15.8	16.8
92	8	18	33834	08/18/92	0.0	0.6	4.2	3.6	18.8	19.5
92	8	19	33835	08/19/92	0.0	1.0	3.5	2.5	17.8	19.5
92	8	20	33836	08/20/92	2.4	0.0	0.0	2.4	18.0	14.3
92	8	21	33837	08/21/92	0.0	2.4	4.6	2.2	18.0	16.8
92	8	22	33838	08/22/92	0.0	2.4	3.1	0.7	12.5	13.5
92	8	23	33839	08/23/92	2.0	0.0	0.0	2.0	9.0	10.0
92	8	24	33840	08/24/92	1.2	0.0	0.0	1.2	12.3	11.5
92	8	25	33841	08/25/92	0.0	5.0	6.2	1.2	11.3	8.3
92	8	26	33842	08/26/92	3.6	0.0	0.0	3.6	12.3	8.5
92	8	27	33843	08/27/92	0.0	0.8	0.8	0.0	12.5	11.5
92	8	28	33844	08/28/92	0.0	21.4	26.4	5.0	17.3	18.5
92	8	29	33845	08/29/92	0.0	2.2	3.4	1.2	15.3	10.5
92	8	30	33846	08/30/92	0.0	4.6	4.6	0.0	12.3	16.0
92	8	31	33847	08/31/92	2.6	0.0	2.6	5.2	17.3	19.0
				TOTALS:	88.9	54.4	80.0	114.5		
				MEANS:					15.7	15.4

NOTE:
Pan evaporation rates are higher than actual lake evaporation and must be adjusted for radiation and heat exchange effects.

CLASS 'A' EVAPORATION PAN DATA

NO. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	WATER ADDED (mm)	IN REMOVED (mm)	RAIN GAUGE (mm)	PAN NET WATER LOSS (mm)	MEAN WATER TEMP (C)	MEAN AIR TEMP (C)
92	9	1	33848	09/01/92	4.8	0.0	2.6	7.4	16.8	19.0
92	9	2	33849	09/02/92	0.7	0.0	1.0	1.7	13.0	12.8
92	9	3	33850	09/03/92	0.0	2.8	3.2	0.4	10.8	9.5
92	9	4	33851	09/04/92	1.0	0.0	0.8	1.8	8.8	9.0
92	9	5	33852	09/05/92	1.4	0.0	0.0	1.4	8.5	8.3
92	9	6	33853	09/06/92	4.4	0.0	0.0	4.4	12.8	7.5
92	9	7	33854	09/07/92	1.9	0.0	0.0	1.9	14.0	12.0
92	9	8	33855	09/08/92	0.0	0.8	2.0	1.2	13.8	13.3
92	9	9	33856	09/09/92	0.0	1.4	2.2	0.8	13.3	13.5
92	9	10	33857	09/10/92	3.1	0.0	0.0	3.1	20.3	19.3
92	9	11	33858	09/11/92	4.8	0.0	0.0	4.8	20.8	20.3
92	9	12	33859	09/12/92	0.0	43.2	71.8	28.6	17.8	20.8
92	9	13	33860	09/13/92	5.3	0.0	0.0	5.3	8.8	10.8
92	9	14	33861	09/14/92	3.5	0.0	0.0	3.5	13.3	11.8
92	9	15	33862	09/15/92	4.8	0.0	0.0	4.8	16.5	15.3
92	9	16	33863	09/16/92	1.0	0.0	1.8	2.8	14.0	16.3
92	9	17	33864	09/17/92	0.5	0.0	1.4	1.9	14.0	11.8
92	9	18	33865	09/18/92	0.0	1.6	2.0	0.4	15.0	13.5
92	9	19	33866	09/19/92	4.6	0.0	0.0	4.6	18.5	18.3
92	9	20	33867	09/20/92	0.0	22.0	20.4	-1.6	13.5	14.5
92	9	21	33868	09/21/92	0.0	1.8	3.2	1.4	10.0	9.0
92	9	22	33869	09/22/92	1.0	0.0	0.0	1.0	12.5	10.5
92	9	23	33870	09/23/92	0.0	11.4	11.6	0.2	14.3	13.5
92	9	24	33871	09/24/92	0.0	7.5	11.2	3.7	8.8	9.3
92	9	25	33872	09/25/92	2.4	0.0	0.0	2.4	9.8	8.3
92	9	26	33873	09/26/92	4.2	0.0	0.0	4.2	12.0	11.8
92	9	27	33874	09/27/92	2.0	0.0	0.0	2.0	15.0	14.8
92	9	28	33875	09/28/92	0.0	0.6	2.4	1.8	15.5	14.3
92	9	29	33876	09/29/92	0.0	5.6	9.6	4.0	16.3	15.3
92	9	30	33877	09/30/92	4.0	0.0	0.0	4.0	12.5	14.0
				TOTALS:	55.4	98.7	147.2	103.9		
				MEANS:					13.7	13.2

NOTE:
Pan evaporation rates are higher than actual lake evaporation and must be adjusted for radiation and heat exchange effects.

CLASS 'A' EVAPORATION PAN DATA

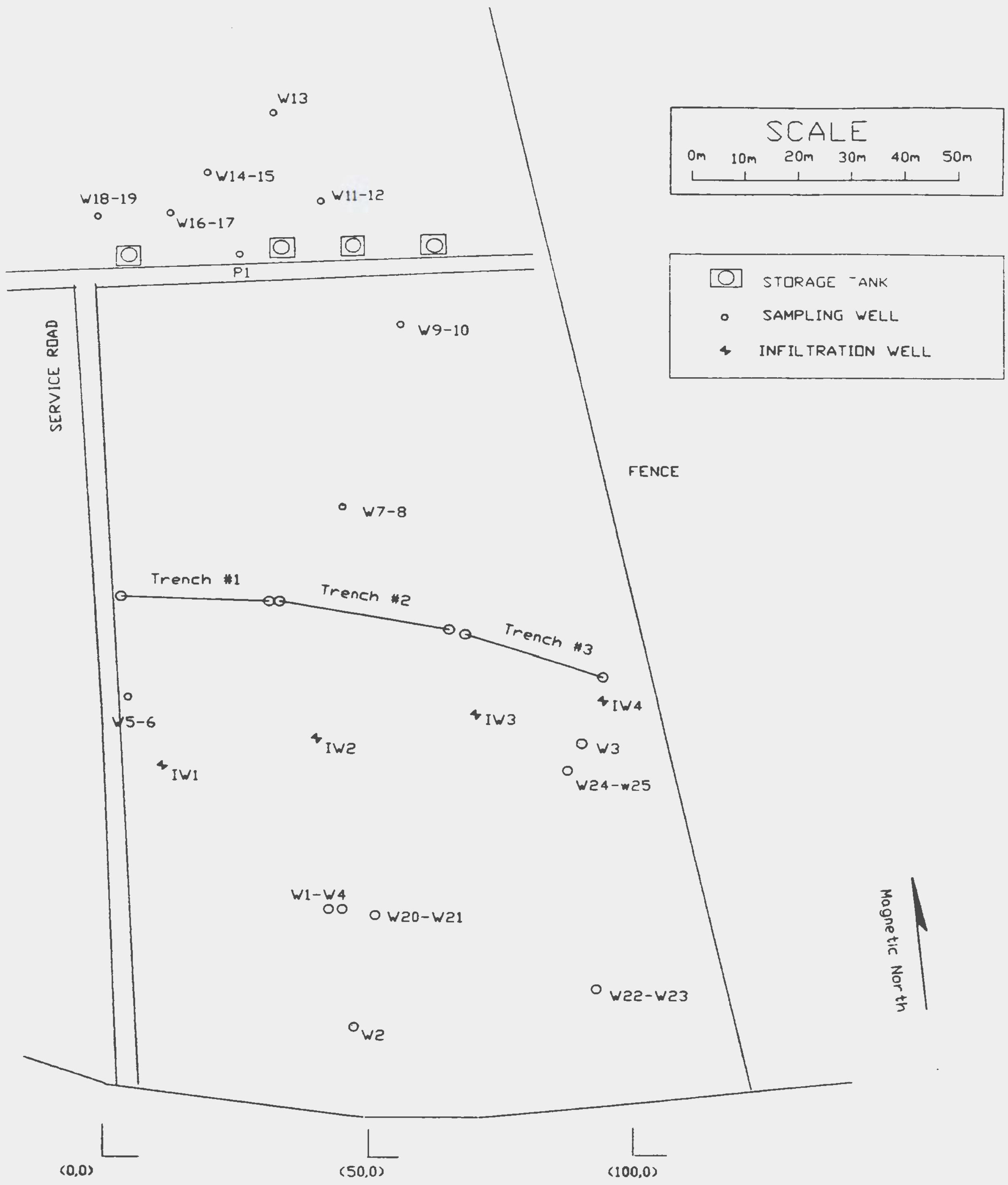
NO. 8403600 ST. JOHN'S WEST CDA

YEAR	MONTH	DAY	SERIAL #	DATE	WATER IN ADDED (mm)	REMOVED (mm)	RAIN GAUGE (mm)	PAN NET WATER LOSS (mm)	MEAN WATER TEMP (C)	MEAN AIR TEMP (C)
92	10	1	33878	10/01/92	0.0	7.4	9.0	1.6	9.0	10.3
92	10	2	33879	10/02/92	0.0	0.0	0.0	0.0	9.0	8.3
92	10	3	33880	10/03/92	0.8	0.0	0.6	1.4	9.5	9.0
92	10	4	33881	10/04/92	0.0	0.0	1.2	1.2	10.0	14.5
92	10	5	33882	10/05/92	1.4	0.0	0.6	2.0	8.5	6.3
92	10	6	33883	10/06/92	0.0	27.4	58.8	31.4	3.0	4.5
92	10	7	33884	10/07/92	0.0	30.2	34.0	3.8	5.5	3.8
92	10	8	33885	10/08/92	0.0	21.6	23.6	2.0	4.8	5.5
92	10	9	33886	10/09/92	1.4	0.0	8.0	9.4	5.0	4.5
92	10	10	33887	10/10/92	1.8	0.0	0.0	1.8	7.3	5.5
92	10	11	33888	10/11/92	1.0	0.0	0.0	1.0	8.0	6.3
92	10	12	33889	10/12/92	0.8	0.0	0.0	0.8	6.8	6.8
92	10	13	33890	10/13/92	0.0	0.0	3.8	3.8	6.5	6.0
92	10	14	33891	10/14/92	0.0	7.2	8.6	1.4	8.0	8.3
92	10	15	33892	10/15/92	2.0	0.0	0.0	2.0	7.5	7.8
92	10	16	33893	10/16/92	1.8	0.0	0.0	1.8	7.8	7.3
92	10	17	33894	10/17/92	0.0	3.8	8.3	4.5	7.8	8.0
92	10	18	33895	10/18/92	0.0	0.4	1.0	0.6	8.5	10.3
92	10	19	33896	10/19/92	0.0	0.0	2.6	2.6	8.0	7.5
92	10	20	33897	10/20/92	0.0	2.4	3.8	1.4	7.3	10.0
92	10	21	33898	10/21/92	1.8	0.0	0.0	1.8	5.0	2.8
92	10	22	33899	10/22/92	0.0	0.0	8.4	8.4	3.8	2.3
92	10	23	33900	10/23/92	0.0	0.0	1.2	1.2	3.5	4.0
92	10	24	33901	10/24/92	1.1	0.0	0.0	1.1	4.8	4.3
92	10	25	33902	10/25/92	0.6	0.0	1.0	1.6	9.8	9.8
92	10	26	33903	10/26/92	0.0	32.2	36.4	4.2	5.3	6.5
92	10	27	33904	10/27/92	0.0	1.0	1.8	0.8	8.8	9.0
92	10	28	33905	10/28/92	0.8	0.0	0.0	0.8	5.8	6.5
92	10	29	33906	10/29/92	1.6	0.0	0.0	1.6	4.8	6.0
92	10	30	33907	10/30/92	0.0	2.4	2.7	0.3	6.5	6.8
92	10	31	33908	10/31/92	0.0	0.0	0.0	0.0	4.8	5.3
				TOTALS:	16.7	136.0	215.4	96.1		
				MEANS:					6.8	6.9

NOTE:
Pan evaporation rates are higher than actual lake evaporation and must be adjusted for radiation and heat exchange effects.

APPENDIX C

SURVEY, WELL CONSTRUCTION, AND GEOTECHNICAL DETAILS



Instrumentation location map.

SUMMARY OF WELL INSTALLATION DETAILS

WELL #	ELEV. GS (m)	ELEV. TOP TUBE (m)	ELEV. BOT. TUBE (m)	ELEV. BEDROCK (m)	LENGTH SAND (m)	LENGTH BENTONITE (m)
1	102.37	102.46	100.74	101.37	0.61	0.31
2	102.43	102.52	101.31	101.49	0.46	0.35
3	101.24	101.37	100.00	100.27	0.40	0.46
4	102.37	102.49	98.97	100.46	1.22	0.30
5	104.41	104.73	96.94	100.30	1.98	0.46
6	104.41	104.73	100.14	100.30	0.36	0.46
7	100.60	100.80	93.59	96.64	1.52	0.32
8	100.60	100.90	96.54	96.64	0.50	0.46
9	97.36	97.89	90.05	93.40	1.57	0.31
10	97.36	97.79	93.40	93.40	0.45	0.33
11	96.26	96.61	91.23	93.81	1.73	0.28
12	96.26	96.66	93.47	93.81	0.33	0.35
13	94.83	95.33	83.70	89.65	1.78	0.46
14	96.52	97.15	92.25	92.56	0.46	0.36
15	96.52	97.02	89.66	92.56	1.83	0.46
16	97.29	97.67	90.36	93.33	1.57	0.41
17	97.29	97.53	94.14	93.33	0.43	0.33
18	97.79	98.19	90.47	93.68	1.58	0.56
19	97.79	98.17	93.37	93.68	0.76	0.46
20	102.24	102.51	98.13	98.28	0.61	0.60
21	102.24	102.70	94.54	98.28	1.65	0.61
22	100.04	100.39	95.93	96.08	0.45	0.56
23	100.04	100.44	92.88	96.08	1.37	0.61
24	101.25	101.59	96.55	97.29	0.59	0.60
25	101.25	101.74	93.63	97.29	1.57	0.56
P1	97.11	97.61	94.77	94.77	0.00	0.00

NOTE 1: SCREENED INTERVAL = 0.31 m.

NOTE 2: SWL'S IN W#9 AND W#10 WILL BE COMPENSATED FOR THE ELEV. OF TOP OF TUBE FROM JUNE 26, 1992 ONWARD.

BOREHOLE W1 **GRID LOC.** 48 m E 55 m N **GROUND ELEV.** 102.4 m **TOTAL DEPTH** 1.63 m **BOREHOLE DIAM.** 57 mm	**DRILLER** Memorial University, Faculty of Engineering, St. John's **RIG** JKS Winkie **BIT** Diamond Bit (60 mm) **FLUID** Water	**START DATE** 7-11-91 **FINISH DATE** 7-11-91 **GEOPHYS. LOG** No **USAGE** SAMPLING WELL **LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	
				End of hole @ 1.6 m
5 m				
10 m				
15 m				
20 m				

BOREHOLE W2 **GRID LOC.** 47 m E 28 m N **GROUND ELEV.** 102.4 m **TOTAL DEPTH** 1.12 m **BOREHOLE DIAM.** 57 mm	**DRILLER** Memorial University, Faculty of Engineering, St. John's **RIG** JKS Winkie **BIT** Diamond Bit (60 mm) **FLUID** Water	**START DATE** 7-11-91 **FINISH DATE** 7-11-91 **GEOPHYS. LOG** No **USAGE** SAMPLING WELL **LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	End of hole @ 1.1 m
5 m				
10 m				
15 m				
20 m				

BOREHOLE W3	**DRILLER** Memorial University, Faculty of Engineering, St. John's	**START DATE** 7-11-91
GRID LOC. 90 m E 88 m N		**FINISH DATE** 7-11-91
GROUND ELEV. 101.2 m	**RIG** JKS Winkie	**GEOPHYS. LOG** No
TOTAL DEPTH 1.24 m	**BIT** Diamond Bit (60 mm)	**USAGE** SAMPLING WELL
BOREHOLE DIAM. 57 mm	**FLUID** Water	**LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	End of hole @ 1.2 m
5 m				
10 m				
15 m				
20 m				

BOREHOLE W4	**DRILLER** Memorial University, Faculty of Engineering, St. John's	**START DATE** 7-11-91
GRID LOC. 48 m E 55 m N		**FINISH DATE** 7-11-91
GROUND ELEV. 102.4 m	**RIG** JKS Winkie	**GEOPHYS. LOG** No
TOTAL DEPTH 3.40 m	**BIT** Diamond Bit (60 mm)	**USAGE** SAMPLING WELL
BOREHOLE DIAM. 57 mm	**FLUID** Water	**LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	
				End of hole @ 3.4 m
5 m				
10 m				
15 m				
20 m				

BOREHOLE W5 **GRID LOC.** 5 m E 97 m N **GROUND ELEV.** 104.4 m **TOTAL DEPTH** 7.50 m **BOREHOLE DIAM.** 150 mm	**DRILLER** P.Sullivan & Sons Ltd., Paradise, Newfoundland **RIG** Geo-Drill MK-15 **BIT** Air Hammer (20 cm) **FLUID** Air	**START DATE** 1-14-92 **FINISH DATE** 1-14-92 **GEOPHYS. LOG** No **USAGE** SAMPLING WELL **LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	
		▼		Bedrock @ 4.1 m
5 m			Black shale	Highly fractured
				End of hole @ 7.5 m
10 m				
15 m				
20 m				

BOREHOLE W6 **GRID LOC.** 5 m E 97 m N **GROUND ELEV.** 104.4 m **TOTAL DEPTH** 4.30 m **BOREHOLE DIAM.** 150 mm	**DRILLER** P.Sullivan & Sons Ltd., Paradise, Newfoundland **RIG** Geo-Drill MK-15 **BIT** Air Hammer (20 cm) **FLUID** Air	**START DATE** 1-14-92 **FINISH DATE** 1-14-92 **GEOPHYS. LOG** No **USAGE** SAMPLING WELL **LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			**Topsoil**	
			Glacial till	
		▾		End of hole @ 4.3 m
5 m				
10 m				
15 m				
20 m				

BOREHOLE W7 **GRID LOC.** 45 m E 139 m N **GROUND ELEV.** 100.6m **TOTAL DEPTH** 7.00 m **BOREHOLE DIAM.** 150 mm	**DRILLER** P.Sullivan & Sons Ltd., Paradise, Newfoundland **RIG** Geo-Drill MK-15 **BIT** Air Hammer (20 cm) **FLUID** Air	**START DATE** 1-14-92 **FINISH DATE** 1-14-92 **GEOPHYS. LOG** No **USAGE** SAMPLING WELL **LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	
				Loose, Bouldery
		▼		Bedrock @ 3.9 m
5 m			Black shale	
				End of hole @ 7.0 m
10 m				
15 m				
20 m				

BOREHOLE W8 **GRID LOC.** 45 m E 139 m N **GROUND ELEV.** 100.6 m **TOTAL DEPTH** 4.06 m **BOREHOLE DIAM.** 150 mm	**DRILLER** P.Sullivan & Sons Ltd., Paradise, Newfoundland **RIG** Geo-Drill MK-15 **BIT** Air Hammer (20 cm) **FLUID** Air	**START DATE** 1-14-92 **FINISH DATE** 1-14-92 **GEOPHYS. LOG** No **USAGE SAMPLING WELL** **LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	
		▼		End of hole @ 4.0 m
5 m				
10 m				
15 m				
20 m				

BOREHOLE W9 **GRID LOC.** 56 m E 178 m N **GROUND ELEV.** 97.4 m **TOTAL DEPTH** 7.31 m **BOREHOLE DIAM.** 150 mm	**DRILLER** P.Sullivan & Sons Ltd., Paradise, Newfoundland **RIG** Geo-Drill MK-15 **BIT** Air Hammer (20 cm) **FLUID** Air	**START DATE** 1-15-92 **FINISH DATE** 1-15-92 **GEOPHYS. LOG** No **USAGE** SAMPLING WELL **LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	
		▼		Bedrock @ 4.0 m
5 m			Black - grey shale	Douldery @ base
				End of hole @ 7.3 m
10 m				
15 m				
20 m				

BOREHOLE W10 **GRID LOC.** 56 m E 178 m N **GROUND ELEV.** 97.4 m **TOTAL DEPTH** 3.96 m **BOREHOLE DIAM.** 150 mm	**DRILLER** P.Sullivan & Sons Ltd., Paradise, Newfoundland **RIG** Geo-Drill MK-15 **BIT** Air Hammer (20 cm) **FLUID** Air	**START DATE** 1-15-92 **FINISH DATE** 1-15-92 **GEOPHYS. LOG** No **USAGE** SAMPLING WELL **LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	
		▼		End of hole @ 4.0 m
5 m				
10 m				
15 m				
20 m				

BOREHOLE W11 **GRID LOC.** 40 m E 203 m N **GROUND ELEV.** 96.3 m **TOTAL DEPTH** 5.03 m **BOREHOLE DIAM.** 150 mm	**DRILLER** P.Sullivan & Sons Ltd., Paradise, Newfoundland **RIG** Geo-Drill MK-15 **BIT** Air Hammer (20 cm) **FLUID** Air	**START DATE** 1-15-92 **FINISH DATE** 1-15-92 **GEOPHYS. LOG** No **USAGE** SAMPLING WELL **LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	Bedrock @ 2.5 m
		▼		
5 m			Grey - black shale	End of hole @ 5.0 m
10 m				
15 m				
20 m				

BOREHOLE W12 **GRID LOC.** 40 m E 203 m N **GROUND ELEV.** 96.3 m **TOTAL DEPTH** 2.79 m **BOREHOLE DIAM.** 150 mm	**DRILLER** P.Sullivan & Sons Ltd., Paradise, Newfoundland **RIG** Geo-Drill MK-15 **BIT** Air Hammer (20 cm) **FLUID** Air	**START DATE** 1-15-92 **FINISH DATE** 1-15-92 **GEOPHYS. LOG** No **USAGE** **SAMPLING WELL** **LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	
				End of hole @ 2.8 m
5 m				
				End of hole @ 7.5 m
10 m				
15 m				
20 m				

BOREHOLE W13 **GRID LOC.** 29 m E 222 m N **GROUND ELEV.** 94.8 m **TOTAL DEPTH** 11.13 m **BOREHOLE DIAM.** 150 mm	**DRILLER** P.Sullivan & Sons Ltd., Paradise, Newfoundland **RIG** Geo-Drill MK-15 **BIT** Air Hammer (20 cm) **FLUID** Air	**START DATE** 1-15-92 **FINISH DATE** 1-15-92 **GEOPHYS. LOG** No **USAGE** SAMPLING WELL **LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	
5 m		▼		Bedrock @ 5.2 m
				Competent rock
			Black shale	
10 m				
				End of hole @ 11.1 m
15 m				
20 m				

BOREHOLE W14	**DRILLER** P.Sullivan & Sons Ltd., Paradise, Newfoundland	**START DATE** 1-15-92
GRID LOC. 18 m E 208 m N	**RIG** Geo-Drill MK-15	**FINISH DATE** 1-15-92
GROUND ELEV. 96.5 m	**BIT** Air Hammer (20 cm)	**GEOPHYS. LOG** No
TOTAL DEPTH 4.27 m	**FLUID** Air	**USAGE** **SAMPLING WELL**
BOREHOLE DIAM. 150 mm		**LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	
		▼		End of hole @ 4.3 m
5 m				
10 m				
15 m				
20 m				

BOREHOLE W15 **GRID LOC.** 18 m E 208 m N **GROUND ELEV.** 96.5 m **TOTAL DEPTH** 6.86 m **BOREHOLE DIAM.** 150 mm	**DRILLER** P.Sullivan & Sons Ltd., Paradise, Newfoundland **RIG** Geo-Drill MK-15 **BIT** Air Hammer (20 cm) **FLUID** Air	**START DATE** 1-15-92 **FINISH DATE** 1-15-92 **GEOPHYS. LOG** No **USAGE** SAMPLING WELL **LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	
		▼		Bedrock @ 4.0 m
5 m				Highly fractured
				End of hole @ 6.9 m
10 m				
15 m				
20 m				

BOREHOLE W16 **GRID LOC.** 10 m E 199 m N **GROUND ELEV.** 97.3 m **TOTAL DEPTH** 6.93 m **BOREHOLE DIAM.** 150 mm	**DRILLER** P.Sullivan & Sons Ltd., Paradise, Newfoundland **RIG** Geo-Drill MK-15 **BIT** Air Hammer (20 cm) **FLUID** Air	**START DATE** 1-16-92 **FINISH DATE** 1-16-92 **GEOPHYS. LOG** No **USAGE** SAMPLING WELL **LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	
		▼		Bedrock @ 4.0 m
5 m				
			Black shale	
				End of hole @ 6.9 m
10 m				
15 m				
20 m				

BOREHOLE W17	**DRILLER** P.Sullivan & Sons Ltd., Paradise, Newfoundland	**START DATE** 1-16-92
GRID LOC. 10 m E 199 m N	**RIG** Geo-Drill MK-15	**FINISH DATE** 1-16-92
GROUND ELEV. 97.3 m	**BIT** Air Hammer (20 cm)	**GEOPHYS. LOG** No
TOTAL DEPTH 3.15 m	**FLUID** Air	**USAGE** SAMPLING WELL
BOREHOLE DIAM. 150 mm		**LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	
				End of hole @ 3.2 m
5 m				
10 m				
15 m				
20 m				

BOREHOLE W18	**DRILLER** P.Sullivan & Sons Ltd., Paradise, Newfoundland	**START DATE** 1-16-92
GRID LOC. -1.8m E 200 m N	**RIG** Geo-Drill MK-15	**FINISH DATE** 1-16-92
GROUND ELEV. 97.8 m	**BIT** Air Hammer (20 cm)	**GEOPHYS. LOG** No
TOTAL DEPTH 7.32 m	**FLUID** Air	**USAGE** SAMPLING WELL
BOREHOLE DIAM. 150 mm		**LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	
				Bouldery
		▼		Bedrock @ 4.1 m
5 m				
			Grey shale	
				End of hole @ 7.3 m
10 m				
15 m				
20 m				

BOREHOLE W19 **GRID LOC.** -1.8m E 200 m N **GROUND ELEV.** 97.8 m **TOTAL DEPTH** 4.42 m **BOREHOLE DIAM.** 150 mm	**DRILLER** P.Sullivan & Sons Ltd., Paradise, Newfoundland **RIG** Geo-Drill MK-15 **BIT** Air Hammer (20 cm) **FLUID** Air	**START DATE** 1-16-92 **FINISH DATE** 1-16-92 **GEOPHYS. LOG** No **USAGE** SAMPLING WELL **LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	
				Broken well screen
		▼		End of hole @ 4.4 m
5 m				
10 m				
15 m				
20 m				

BOREHOLE W20 **GRID LOC.** 52 m E 53 m N **GROUND ELEV.** 102.2 m **TOTAL DEPTH** 4.11 m **BOREHOLE DIAM.** 150 mm	**DRILLER** P.Sullivan & Sons Ltd., Paradise, Newfoundland **RIG** Speedstar SS-15 **BIT** Air Hammer (20 cm) **FLUID** Air	**START DATE** 6-2-92 **FINISH DATE** 6-2-92 **GEOPHYS. LOG** No **USAGE** SAMPLING WELL **LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	
				Highly fractured bedrock
		▼		End of hole @ 4.1 m
5 m				
10 m				
15 m				
20 m				

BOREHOLE W21	**DRILLER** P.Sullivan & Sons Ltd., Paradise, Newfoundland	**START DATE** 6-2-92
GRID LOC. 52 m E 53 m N	**RIG** Speedstar SS-15	**FINISH DATE** 6-2-92
GROUND ELEV. 102.2 m	**BIT** Air Hammer (20 cm)	**GEOPHYS. LOG** No
TOTAL DEPTH 7.70 m	**FLUID** Air	**USAGE** SAMPLING WELL
BOREHOLE DIAM. 150 mm		**LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			**Topsoil**	
			Glacial till	
		▼		
5 m				Highly fractured bedrock
			Black shale	
				End of hole @ 7.7 m
10 m				
15 m				
20 m				

BOREHOLE W22	**DRILLER** P.Sullivan & Sons Ltd., Paradise, Newfoundland	**START DATE** 6-2-92
GRID LOC. 92 m E 38 m N	**RIG** Speedstar SS-15	**FINISH DATE** 6-2-92
GROUND ELEV. 100.0 m	**BIT** Air Hammer (20 cm)	**GEOPHYS. LOG** No
TOTAL DEPTH 4.11 m	**FLUID** Air	**USAGE** SAMPLING WELL
BOREHOLE DIAM. 150 mm		**LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	
		▼		End of hole @ 4.1 m
5 m				
10 m				
15 m				
20 m				

BOREHOLE W23 **GRID LOC.** 92 m E 38 m N **GROUND ELEV.** 100.0 m **TOTAL DEPTH** 7.16 m **BOREHOLE DIAM.** 150 mm	**DRILLER** P.Sullivan & Sons Ltd., Paradise, Newfoundland **RIG** Speedstar SS-15 **BIT** Air Hammer (20 cm) **FLUID** Air	**START DATE** 6-2-92 **FINISH DATE** 6-2-92 **GEOPHYS. LOG** No **USAGE** SAMPLING WELL **LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			**Topsoil**	
			Glacial till	
		▼		Bedrock @ 4.0 m
5 m				
			Black shale	
				End of hole @ 7.2 m
10 m				
15 m				
20 m				

BOREHOLE W24 GRID LOC. 89 m E 83 m N GROUND ELEV. 101.2 m TOTAL DEPTH 4.70 m BOREHOLE DIAM. 150 mm	DRILLER P.Sullivan & Sons Ltd., Paradise, Newfoundland RIG Speedstar SS-15 BIT Air Hammer (20 cm) FLUID Air	START DATE 6-2-92 FINISH DATE 6-2-92 GEOPHYS. LOG No USAGE SAMPLING WELL LOGGED BY PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	
		▼		Bedrock @ 4.0 m
5 m				End of hole @ 4.7 m
10 m				
15 m				
20 m				

BOREHOLE W25 **GRID LOC.** 89 m E 83 m N **GROUND ELEV.** 101.2 m **TOTAL DEPTH** 7.62 m **BOREHOLE DIAM.** 150 mm	**DRILLER** P.Sullivan & Sons Ltd., Paradise, Newfoundland **RIG** Speedstar SS-15 **BIT** Air Hammer (20 cm) **FLUID** Air	**START DATE** 6-2-92 **FINISH DATE** 6-2-92 **GEOPHYS. LOG** No **USAGE** SAMPLING WELL **LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	
		▼		
5 m			Grey - black shale	
				Highly fractured
				End of hole @ 7.6 m
10 m				
15 m				
20 m				

BOREHOLE P1	**DRILLER** N/A	**START DATE** 9-24-91
GRID LOC. 27 m E 191 m N		**FINISH DATE** 9-24-91
GROUND ELEV. 97.1 m	**RIG** N/A	**GEOPHYS. LOG** No
TOTAL DEPTH 2.37 m	**BIT** N/A	**USAGE** Piezometer
BOREHOLE DIAM. N/A	**FLUID** N/A	**LOGGED BY** PI

DEPTH	SAMP.	SYM.	MATERIAL	COMMENTS
0 m			Topsoil	
			Glacial till	
				End of hole @ 2.4 m
5 m				
10 m				
15 m				
20 m				

SOIL PROFILE – SUMMARY

PROJECT: SOIL PROFILE #1
TOTAL DEPTH: 2.13 m
PROJECT LOCATION: FED. RES. STN. – AG. CAN.
SOIL DESCRIPTION: GLACIAL TILL
TESTED BY: PAI
DATES OF TESTING: 10–01–91 TO 10–02–91

SOIL HORIZON	DEPTH (cm)	USC SOIL CLASSIFICATION ASTM REFERENCE: D 2487	MUNSEL #	LAB. TESTS
Ah	0 – 25	SP – SM with gravel, Cu=2.7, Cc=2.1	10 YR/3/6	WC = 34.41 % , DR = 2.46
Bf	25 – 45	SM, Cu=5.75, Cc=2.29	10 YR/5/8	WC = 25.97 % , DR = 2.61 , BD (AVE.) = 0.989
Bg	45 – 70	SW, Cu=27.62, Cc=0.74	10 YR/3/3, 10 YR/4/6	WC = 5.86 % , DR = 2.67
Bg2	70 – 110	GW – GP	10 YR/3/2	WC = 4.14 % , DR = 2.72
Bfg	110 – 130	GW – GP	7.5 YR/3/4	WC = 4.24 % , DR = 2.63
Bg (Bg^2)	130 – 135	SM – SC	7.5 YR/6/2	WC = 13.28 %
BC	135 – 210	GW – GP	5 Y/4/2	WC = 6.89 % , DR = 2.71

KEY:

WC – WATER CONTENT (%)
DR – RELATIVE DENSITY
BD – BULK DENSITY (g/cm^3)
ESTIMATED FROM FIELD SAMPLES

WATER CONTENT DETERMINATION – BULK DENSITY

ASTM REFERENCE: D2216
PROJECT: SOIL PROFILE #1
PROJECT LOCATION: FED. RES. STN. – AG. CAN.
SOIL DESCRIPTION: GLACIAL TILL
SAMPLE DEPTH: Bf HORIZON
MUNSEL NO: 10 YR/5/8
TESTED BY: PAI
DATE OF TESTING: 9–25–91
DATE OF WEIGHING: 9–26–91

BORING NO.	Bf#1	Bf#2
WT. OF CUP + WET SOIL (gm)	316.3	313.09
WT. OF CUP + DRY SOIL (gm)	243.96	245.59
WT. OF CUP (gm)	13.49	12.94
WT. OF DRY SOIL (gm)	230.47	232.65
WT. OF WATER (gm)	72.34	67.5
WATER CONTENT (w %)	31.39	29.01
SOIL VOL. (cm ^ 3)	137.413	137.413
ESTIMATED FIELD SOIL DENSITY (g/cm ^ 3)	1.677	1.693

LET SAMPLES STAND FOR THREE DAYS – THEN WEIGH THEM

BORING NO.	Bf#1	Bf#2
WT. OF CUP + WET SOIL (gm)	316.3	313.09
WT. OF CUP + DRY SOIL (gm)	248.12	249.40
WT. OF CUP (gm)	13.49	12.94
WT. OF DRY SOIL (gm)	234.63	236.46
WT. OF WATER (gm)	68.18	63.69
WATER CONTENT (w %)	29.06	26.93
SOIL VOL. (cm ^ 3)	137.413	137.413
ESTIMATED FIELD SOIL DENSITY (g/cm ^ 3)	1.707	1.721

WATER CONTENT DETERMINATION

ASTM REFERENCE: D2216
PROJECT: SOIL PROFILE #1
PROJECT LOCATION: FED. RES. STN. – AG. CAN.
SOIL DESCRIPTION: GLACIAL TILL
TESTED BY: PAI
DATE OF TESTING: 10–01–91
DATE OF WEIGHING: 9–30–91

SOIL SAMPLE HORIZON	Ah	Bf	Bg	Bg2	Bfg	Bg^2	Bc
WT. OF CUP + WET SOIL (gm)	162.3	633.8	414.32	654.1	658.1	154.28	302.8
WT. OF CUP + DRY SOIL (gm)	124.11	505.82	392.11	628.6	631.9	137.74	284.14
WT. OF CUP (gm)	13.14	13.1	13.12	13.16	13.29	13.21	13.28
WT. OF DRY SOIL (gm)	110.97	492.72	378.99	615.44	618.61	124.53	270.86
WT. OF WATER (gm)	38.19	127.98	22.21	25.5	26.2	16.54	18.66
WATER CONTENT (w %)	34.41	25.97	5.86	4.14	4.24	13.28	6.89

GRAIN SIZE ANALYSIS – MECHANICAL

ASTM REFERENCE:	D421, D422
PROJECT:	SOIL PROFILE #1
PROJECT LOCATION:	FED. RES. STN. – AG. CAN.
SOIL DESCRIPTION:	GLACIAL TILL
SAMPLE DEPTH:	Ah HORIZON
MUNSEL NO:	10 YR/3/6
TESTED BY:	PAI
DATE OF TESTING:	10–1–91

Wt. of dry soil + container	508.01
Wt. of container	13.26
Wt. of dry sample, Ws	494.75

SIEVE ANALYSIS AND GRAIN SHAPE

SIEVE NO.	DIAM (mm)	WT. OF BAG (gm)	WT. OF BAG + SAMPLE (gm)	WT. RTN. (gm)	% RTN.	% PASS.
----	11.2	3.58	37.69	34.11	6.89	93.11
----	9.5	3.54	17.42	13.88	2.81	90.30
10	2	3.56	217.19	213.63	43.18	47.12
20	0.85	3.52	124.58	121.06	24.47	22.65
100	0.15	3.52	102.1	98.58	19.93	2.73
140	0.106	3.55	8.12	4.57	0.92	1.80
200	0.075	3.51	5.72	2.21	0.45	1.36
PAN	----	3.63	10.2	6.57	1.33	0.03

SUM = 494.61 g
% SOIL LOSS = 0.028 %

GRAIN SIZE ANALYSIS – MECHANICAL

ASTM REFERENCE:	D421, D422
PROJECT:	SOIL PROFILE #1
PROJECT LOCATION:	FED. RES. STN. – AG. CAN.
SOIL DESCRIPTION:	GLACIAL TILL
SAMPLE DEPTH:	Bf HORIZON
MUNSEL NO:	10 YR/5/8
TESTED BY:	PAI
DATE OF TESTING:	10–1–91

Wt. of dry soil + container	747.6
Wt. of container	13.29
Wt. of dry sample, Ws	734.31

SIEVE ANALYSIS AND GRAIN SHAPE

SIEVE NO.	DIAM (mm)	WT. OF BAG (gm)	WT. OF BAG + SAMPLE (gm)	WT. RTN. (gm)	% RTN.	% PASS.
----	11.2	3.59	72.93	69.34	9.44	90.56
----	9.5	3.53	27.92	24.39	3.32	87.24
10	2	3.54	235.24	231.7	31.55	55.68
20	0.85	3.58	148.69	145.11	19.76	35.92
100	0.15	3.62	208.26	204.64	27.87	8.05
140	0.106	3.56	22.91	19.35	2.64	5.42
200	0.075	3.61	8.35	4.74	0.65	4.77
PAN	----	3.54	38.44	34.9	4.75	0.02

SUM = 734.17 g
% SOIL LOSS = 0.019 %

GRAIN SIZE ANALYSIS – MECHANICAL

ASTM REFERENCE:	D421, D422
PROJECT:	SOIL PROFILE #1
PROJECT LOCATION:	FED. RES. STN. – AG. CAN.
SOIL DESCRIPTION:	GLACIAL TILL
SAMPLE DEPTH:	Bg HORIZON
MUNSEL NO:	10 YR/3/3 – 0 YR/4/6
TESTED BY:	PAI
DATE OF TESTING:	10–1–91

Wt. of dry soil + container	879.3
Wt. of container	13.01
Wt. of dry sample, Ws	866.29

SIEVE ANALYSIS AND GRAIN SHAPE

SIEVE NO.	DIAM (mm)	WT. OF BAG (gm)	WT. OF BAG + SAMPLE (gm)	WT. RTN. (gm)	% RTN.	% PASS.
––––	11.2	3.25	254.42	251.17	28.99	71.01
––––	9.5	3.25	50.18	46.93	5.42	65.59
10	2	3.25	216.23	212.98	24.59	41.00
20	0.85	3.28	114.52	111.24	12.84	28.16
100	0.15	3.23	166.34	163.11	18.83	9.33
140	0.106	3.18	24.55	21.37	2.47	6.87
200	0.075	3.22	3.49	0.27	0.03	6.84
PAN	––––	3.31	61.68	58.37	6.74	0.10

SUM = 865.44 g

% SOIL LOSS = 0.098 %

GRAIN SIZE ANALYSIS – MECHANICAL

ASTM REFERENCE: D421, D422
PROJECT: SOIL PROFILE #1
PROJECT LOCATION: FED. RES. STN. – AG. CAN.
SOIL DESCRIPTION: GLACIAL TILL
SAMPLE DEPTH: Bg2 HORIZON
MUNSEL NO: 10 YR/3/2
TESTED BY: PAI
DATE OF TESTING: 10–1–91

Wt. of dry soil + container	1346.7
Wt. of container	13.4
Wt. of dry sample, Ws	1333.3

SIEVE ANALYSIS AND GRAIN SHAPE

SIEVE NO.	DIAM (mm)	WT. OF BAG (gm)	WT. OF BAG + SAMPLE (gm)	WT. RTN. (gm)	% RTN.	% PASS.
----	11.2	3.24	635.2	631.96	47.40	52.60
----	9.5	3.29	33.2	29.91	2.24	50.36
10	2	3.31	281.26	277.95	20.85	29.51
20	0.85	3.22	125.04	121.82	9.14	20.38
100	0.15	3.25	178.98	175.73	13.18	7.19
140	0.106	3.31	23.29	19.98	1.50	5.70
200	0.075	3.23	15.01	11.78	0.88	4.81
PAN	----	3.27	66.28	63.01	4.73	0.09

SUM = 1332.14 g
% SOIL LOSS = 0.087 %

GRAIN SIZE ANALYSIS – MECHANICAL

ASTM REFERENCE:	D421, D422
PROJECT:	SOIL PROFILE #1
PROJECT LOCATION:	FED. RES. STN. – AG. CAN.
SOIL DESCRIPTION:	GLACIAL TILL
SAMPLE DEPTH:	Bfg HORIZON
MUNSEL NO:	7.5 YR/3/4
TESTED BY:	PAI
DATE OF TESTING:	10–1–91

Wt. of dry soil + container	1029.4
Wt. of container	13.17
Wt. of dry sample, Ws	1016.23

SIEVE ANALYSIS AND GRAIN SHAPE

SIEVE NO.	DIAM (mm)	WT. OF BAG (gm)	WT. OF BAG + SAMPLE (gm)	WT. RTN. (gm)	% RTN.	% PASS.
----	11.2	3.54	764.6	761.06	74.89	25.11
----	9.5	3.54	46.99	43.45	4.28	20.83
10	2	3.55	155.25	151.7	14.93	5.91
20	0.85	3.55	20.62	17.07	1.68	4.23
100	0.15	3.56	25.62	22.06	2.17	2.06
140	0.106	3.57	7.32	3.75	0.37	1.69
200	0.075	3.56	4.04	0.48	0.05	1.64
PAN	----	3.61	19.97	16.36	1.61	0.03

SUM = 1015.93 g

% SOIL LOSS = 0.030 %

GRAIN SIZE ANALYSIS – MECHANICAL

ASTM REFERENCE: D421, D422
PROJECT: SOIL PROFILE #1
PROJECT LOCATION: FED. RES. STN. – AG. CAN.
SOIL DESCRIPTION: GLACIAL TILL
SAMPLE DEPTH: Bg^2 HORIZON
MUNSEL NO: 7.5 YR/6/2
TESTED BY: PAI
DATE OF TESTING: 10–1–91

Wt. of dry soil + container	280.37
Wt. of container	13.29
Wt. of dry sample, Ws	267.08

SIEVE ANALYSIS AND GRAIN SHAPE

SIEVE NO.	DIAM (mm)	WT. OF BAG (gm)	WT. OF BAG + SAMPLE (gm)	WT. RTN. (gm)	% RTN.	% PASS.
----	11.2	3.23	32.37	29.14	10.91	89.09
----	9.5	3.24	8.63	5.39	2.02	87.07
10	2	3.26	29.51	26.25	9.83	77.24
20	0.85	3.18	25.56	22.38	8.38	68.86
100	0.15	3.23	62.36	59.13	22.14	46.72
140	0.106	3.32	19.64	16.32	6.11	40.61
200	0.075	3.25	14.91	11.66	4.37	36.25
PAN	----	3.21	98.64	95.43	35.73	0.52

SUM = 265.7 g
% SOIL LOSS = 0.517 %

GRAIN SIZE ANALYSIS – MECHANICAL

ASTM REFERENCE: D421, D422
PROJECT: SOIL PROFILE #1
PROJECT LOCATION: FED. RES. STN. – AG. CAN.
SOIL DESCRIPTION: GLACIAL TILL
SAMPLE DEPTH: Bc HORIZON
MUNSEL NO: 5 YR/4/2
TESTED BY: PAI
DATE OF TESTING: 10–1–91

Wt. of dry soil + container	810.7
Wt. of container	13.1
Wt. of dry sample, Ws	797.6

SIEVE ANALYSIS AND GRAIN SHAPE

SIEVE NO.	DIAM (mm)	WT. OF BAG (gm)	WT. OF BAG + SAMPLE (gm)	WT. RTN. (gm)	% RTN.	% PASS.
----	11.2	3.21	357.66	354.45	44.44	55.56
----	9.5	3.25	34.46	31.21	3.91	51.65
10	2	3.16	186.02	182.86	22.93	28.72
20	0.85	3.07	51.28	48.21	6.04	22.68
100	0.15	3.23	53.99	50.76	6.36	16.31
140	0.106	3.24	15.19	11.95	1.50	14.81
200	0.075	3.27	12.95	9.68	1.21	13.60
PAN	----	3.19	108.9	105.71	13.25	0.35

SUM = 794.83 g
% SOIL LOSS = 0.347 %

RELATIVE DENSITY OF SOIL SOLIDS (DR)

ASTM REFERENCE: D854
PROJECT: SOIL PROFILE #1
PROJECT LOCATION: FED. RES. STN. – AG. CAN.
SOIL DESCRIPTION: GLACIAL TILL
TESTED BY: PAI
DATE OF TESTING: 10–02–91

SOIL SAMPLE HORIZON	Ah	Bf	Bg	Bg2	Bfg	Bc
VOL OF FLASK @ 20 c (ml)	500	500	500	500	500	500
METHOD OF AIR REMOVAL	VACUUM	VACUUM	VACUUM	VACUUM	VACUUM	VACUUM
WT. FLASK + WATER + SOIL = Wbws	732.6	739.9	800.7	833.8	709.3	752.8
TEMPERATURE (c)	23	23	23	23	23	23
WT. FLASK + WATER = Wbw	681.9	675.8	688.7	679.1	673.6	664
WT. OF CUP + SOIL	98.99	116.73	212.84	312.03	98.45	185.95
WT. OF CUP	13.67	13.08	34.08	67.64	40.91	45.43
WT. OF DRY SOIL = Ws	85.32	103.65	178.76	244.39	57.54	140.52
Ww = Ws + Wbw – Wbws	34.62	39.55	66.76	89.69	21.84	51.72
DR = @ Ws/Ww	2.46	2.61	2.67	2.72	2.63	2.71

WHERE @ IS THE TEMPERATURE CORRECTION COEFFICIENT AT 23 c = 0.99756.

APPENDIX D

WATER LEVEL DATA

WELL ID #				1		2		3		4	
ELEVATION OF GROUND SURFACE (m)				102.37		102.43		101.24		102.37	
ELEVATION OF MEASURING POINT (m)				102.46		102.52		101.37		102.49	
ELEVATION OF BOTTOM OF HOLE (m)				100.74		101.31		100.00		96.97	
ELEVATION OF BEDROCK (m)				101.37		101.49		100.27		100.46	

YEAR	MONTH	DAY	DATE CODE	SWL B.M.P. (m)	WT ELEV. (m)	SWL B.M.P. (m)	WT ELEV. (m)	SWL B.M.P. (m)	WT ELEV. (m)	SWL B.M.P. (m)	WT ELEV. (m)
91	9	27	33508	DRY	DRY	DRY	DRY	1.25	100.12	DRY	DRY
91	10	10	33521	1.23	101.23	DRY	DRY	0.89	100.48	3.13	99.37
91	10	16	33527	1.22	101.24	DRY	DRY	0.91	100.46	2.75	99.74
91	10	27	33538	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
91	11	3	33545	1.14	101.33	1.16	101.36	0.58	100.79	3.08	99.41
91	11	6	33550	1.22	101.24	DRY	DRY	0.87	100.50	2.88	99.61
91	11	15	33557	1.15	101.32	1.07	101.45	0.50	100.87	2.38	100.11
91	11	20	33562	1.03	101.43	2.30	100.22	1.21	100.16	2.29	100.20
91	11	24	33566	DRY	DRY	DRY	DRY	1.03	100.35	2.74	99.76
91	12	1	33573	DRY	DRY	DRY	DRY	1.22	100.15	3.20	99.29
92	1	7	33610	DRY	DRY	0.57	101.95	0.28	101.09	DRY	DRY
92	1	12	33615	DRY	DRY	DRY	DRY	N/M	N/M	3.19	99.31
92	1	16	33621	DRY	DRY	DRY	DRY	1.02	100.35	3.34	99.15
92	1	26	33629	DRY	DRY	N/M	N/M	0.68	100.69	3.30	99.19
92	2	2	33636	DRY	DRY	DRY	DRY	1.35	100.02	DRY	DRY
92	2	8	33642	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
92	2	15	33649	N/M	N/M	N/M	N/M	N/M	N/M	N/M	N/M
92	2	23	33657	N/M	N/M	N/M	N/M	N/M	N/M	N/M	N/M
92	3	8	33671	N/M	N/M	N/M	N/M	N/M	N/M	N/M	N/M
92	3	16	33679	N/M	N/M	N/M	N/M	N/M	N/M	N/M	N/M
92	3	21	33684	N/M	N/M	N/M	N/M	N/M	N/M	N/M	N/M
92	3	29	33692	DRY	DRY	0.50	102.02	FLOODED	FLOODED	2.87	99.62
92	4	12	33706	DRY	DRY	DRY	DRY	N/M	N/M	2.61	99.88
92	4	18	33712	DRY	DRY	DRY	DRY	N/M	N/M	2.96	99.53
92	4	24	33718	DRY	DRY	DRY	DRY	0.90	100.47	3.05	99.44
92	5	5	33729	1.01	101.45	1.13	101.39	0.62	100.75	2.10	100.39
92	5	12	33736	DRY	DRY	DRY	DRY	0.91	100.46	2.47	100.02
92	5	20	33744	DRY	DRY	0.78	101.74	1.38	99.99	3.18	99.31
92	5	29	33753	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
92	6	3	33758	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
92	6	12	33767	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
92	6	25	33780	DRY	DRY	DRY	DRY	0.24	101.13	2.93	99.56
92	7	3	33788	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
92	7	9	33794	DRY	DRY	1.16	101.34	1.78	99.59	2.83	99.66
92	7	20	33805	DRY	DRY	DRY	DRY	DRY	DRY	3.10	99.39
92	7	27	33812	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
92	8	3	33819	DRY	DRY	DRY	DRY	1.35	100.02	DRY	DRY
92	8	11	33827	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
92	8	20	33836	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
92	9	8	33855	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
92	10	10	33887	1.06	101.40	1.20	101.32	0.72	100.65	1.95	100.54
92	11	10	33918	N/M	N/M	DRY	DRY	DRY	DRY	3.30	99.19
92	12	11	33949	N/M	N/M	DRY	DRY	1.10	100.27	3.12	99.37

WT ELEV. = Water Table Elevation
SWL B.M.P. = Static Water Level Below Measuring Point
N/M = No Measurement

WELL ID #				5		6		7		8	
ELEVATION OF GROUND SURFACE (m)				104.41		104.41		100.60		100.60	
ELEVATION OF MEASURING POINT (m)				104.73		104.73		100.80		100.90	
ELEVATION OF BOTTOM OF HOLE (m)				96.94		100.14		93.59		96.54	
ELEVATION OF BEDROCK (m)				100.30		100.30		96.64		96.64	
YEAR	MONTH	DAY	DATE CODE	SWL B.M.P. (m)	WT ELEV. (m)	SWL B.M.P. (m)	WT ELEV. (m)	SWL B.M.P. (m)	WT ELEV. (m)	SWL B.M.P. (m)	WT ELEV. (m)
91	9	27	33508								
91	10	10	33521								
91	10	16	33527								
91	10	27	33538								
91	11	3	33545								
91	11	8	33550								
91	11	15	33557								
91	11	20	33562								
91	11	24	33566								
91	12	1	33573								
92	1	7	33610								
92	1	12	33615								
92	1	18	33621	3.86	100.87	3.43	101.30	4.55	96.25	3.81	97.09
92	1	26	33629	4.03	100.70	3.23	101.50	4.64	96.16	3.83	97.07
92	2	2	33636	4.05	100.68	3.35	101.38	4.50	96.30	3.89	97.01
92	2	8	33642	4.16	100.57	3.40	101.33	4.06	96.74	3.60	97.30
92	2	15	33649	4.28	100.45	3.52	101.22	4.21	96.59	3.65	97.25
92	2	23	33657	4.23	100.50	3.39	101.34	4.17	96.63	3.66	97.24
92	3	8	33671	4.35	100.38	3.55	101.19	4.25	96.55	3.72	97.18
92	3	16	33679	4.28	100.45	3.51	101.22	4.14	96.66	3.72	97.18
92	3	21	33684	3.55	101.18	4.28	100.45	4.17	96.63	3.73	97.17
92	3	29	33692	4.12	100.61	3.63	100.90	3.81	96.99	3.57	97.33
92	4	12	33706	3.77	100.96	3.11	101.62	3.48	97.32	3.23	97.67
92	4	18	33712	3.88	100.85	3.27	101.46	3.52	97.28	3.22	97.68
92	4	24	33718	4.01	100.72	3.40	101.33	3.63	97.17	3.35	97.55
92	5	5	33729	3.68	101.05	2.85	101.88	3.15	97.65	2.62	98.28
92	5	12	33736	3.57	101.16	3.00	101.73	3.15	97.65	2.76	98.14
92	5	20	33744	3.50	101.23	3.41	101.32	3.63	97.17	3.22	97.68
92	5	29	33753	3.58	101.15	3.56	101.17	4.03	96.77	3.51	97.39
92	6	3	33758	3.61	101.12	3.59	101.14	4.11	96.69	3.59	97.31
92	6	12	33767	3.77	100.96	3.74	100.99	4.31	96.49	3.66	97.24
92	6	25	33780	3.35	101.38	3.32	101.41	3.62	97.18	3.29	97.61
92	7	3	33768	3.48	101.25	3.46	101.27	3.96	96.64	3.51	97.39
92	7	9	33794	3.18	101.55	3.11	101.62	3.71	97.09	3.30	97.60
92	7	20	33805	3.69	101.04	3.41	101.32	3.67	97.13	3.33	97.57
92	7	27	33812	3.79	100.94	3.67	101.06	4.02	96.78	3.55	97.35
92	8	3	33819	3.64	101.09	3.61	101.12	4.19	96.61	3.62	97.28
92	8	11	33827	3.74	100.99	3.62	101.11	4.23	96.57	3.65	97.25
92	8	20	33836	3.84	100.89	3.69	101.04	4.32	96.48	3.70	97.20
92	9	8	33855	3.88	100.85	3.76	100.95	4.42	96.38	3.75	97.15
92	10	10	33887	2.70	102.03	2.65	102.08	3.04	97.76	2.58	98.32
92	11	10	33916	3.52	101.21	3.48	101.25	3.84	96.96	3.44	97.46
92	12	11	33949	3.40	101.33	3.34	101.39	3.80	97.00	3.41	97.49

WT ELEV. = Water Table Elevation
SWL B.M.P. = Static Water Level Below Measuring Point
N/M = No Measurement

WELL ID #	9	10	11	12
ELEVATION OF GROUND SURFACE (m)	97.36	97.36	96.26	96.26
ELEVATION OF MEASURING POINT (m)	97.89	97.79	96.61	96.66
ELEVATION OF BOTTOM OF HOLE (m)	90.05	93.40	91.23	93.47
ELEVATION OF BEDROCK (m)	93.40	93.40	93.81	93.81

YEAR	MONTH	DAY	DATE CODE	SWL B.M.P. (m)	WT ELEV. (m)	SWL B.M.P. (m)	WT ELEV. (m)	SWL B.M.P. (m)	WT ELEV. (m)	SWL B.M.P. (m)	WT ELEV. (m)
91	9	27	33508								
91	10	10	33521								
91	10	16	33527								
91	10	27	33538								
91	11	3	33545								
91	11	8	33550								
91	11	15	33557								
91	11	20	33562								
91	11	24	33566								
91	12	1	33573								
92	1	7	33610								
92	1	12	33615								
92	1	18	33621	2.33	95.56	2.31	95.48	3.32	93.29	3.37	93.29
92	1	26	33629	2.39	95.50	2.39	95.40	3.30	93.31	3.42	93.24
92	2	2	33636	2.38	95.51	2.38	95.41	3.46	93.15	3.50	93.16
92	2	8	33642	2.43	95.46	2.44	95.35	2.72	93.89	2.80	93.86
92	2	15	33649	2.54	95.35	2.54	95.25	2.83	93.78	2.91	93.75
92	2	23	33657	2.60	95.29	2.58	95.21	2.82	93.79	2.88	93.78
92	3	8	33671	N/M	N/M	N/M	N/M	2.90	93.71	3.01	93.86
92	3	16	33679	N/M	N/M	N/M	N/M	2.83	93.78	2.90	93.76
92	3	21	33684	N/M	N/M	N/M	N/M	2.87	93.74	2.96	93.70
92	3	29	33692	2.54	95.35	2.56	95.23	2.65	93.96	2.72	93.94
92	4	12	33706	1.95	95.94	1.93	95 86	2.26	94.35	2.33	94.33
92	4	18	33712	2.09	95.80	2.12	95.67	2.49	94.12	2.56	94.10
92	4	24	33718	2.15	95.74	2.20	95.59	2.59	94.02	2.65	94.01
92	5	5	33729	1.66	96.23	1.66	96.13	2.15	94.46	2.22	94.44
92	5	12	33736	1.78	96.11	1.81	95.98	2.31	94.30	2.39	94.27
92	5	20	33744	2.24	95.65	2.20	95.59	2.68	93.93	2.75	93.91
92	5	29	33753	2.45	95.44	2.41	95.38	2.86	93.75	2.92	93.74
92	6	3	33758	2.54	95.35	2.49	95.30	2.90	93.71	2.97	93.69
92	6	12	33767	2.68	95.21	2.62	95.17	2.97	93.64	3.04	93 62
92	6	25	33780	2.22	95.67	2.24	95.55	2.73	93.88	2.79	93.87
92	7	3	33788	2.27	95.56	2.34	95.33	N/M	N/M	N/M	N/M
92	7	9	33794	2.17	95.66	2.12	95.55	2.66	93.95	2.73	93.93
92	7	20	33805	2.18	95.65	2.15	95.52	2.72	93.89	2.79	93.87
92	7	27	33812	2.38	95.45	2.33	95.34	2.66	93.75	2.92	93.74
92	8	3	33819	2.48	95.35	2.44	95.23	2.93	93.68	3.00	93.66
92	8	11	33827	2.58	95.25	2.54	95.13	2.99	93.62	3.06	93.60
92	8	20	33836	2.67	95.16	2.62	95.05	3.04	93.57	3.11	93.55
92	9	8	33855	2.82	95.01	2.75	94.92	3.13	93.48	3.20	93.46
92	10	10	33887	1.58	96.25	1.59	96.08	2.04	94.57	2.10	94.56
92	11	10	33918	2.20	95.63	2.21	95.46	2.76	93.85	2.83	93.83
92	12	11	33949	2.30	95.53	2.28	95.39	2.78	93.83	2.85	93.81

WT ELEV. = Water Table Elevation
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N/M = No Measurement

WELL ID #				13		14		15		16	
ELEVATION OF GROUND SURFACE (m)				94.83		96.52		96.52		97.29	
ELEVATION OF MEASURING POINT (m)				95.33		97.15		97.02		97.67	
ELEVATION OF BOTTOM OF HOLE (m)				83.70		92.25		89.66		90.36	
ELEVATION OF BEDROCK (m)				89.65		92.56		92.56		93.33	
YEAR	MONTH	DAY	DATE CODE	SWL B.M.P. (m)	WT ELEV. (m)	SWL B.M.P. (m)	WT ELEV. (m)	SWL B.M.P. (m)	WT ELEV. (m)	SWL B.M.P. (m)	WT ELEV. (m)
91	9	27	33508								
91	10	10	33521								
91	10	16	33527								
91	10	27	33538								
91	11	3	33545								
91	11	8	33550								
91	11	15	33557								
91	11	20	33562								
91	11	24	33566								
91	12	1	33573								
92	1	7	33610								
92	1	12	33615								
92	1	18	33621	3.50	91.83	3.35	93.80	2.77	94.25	3.90	93.77
92	1	26	33629	3.78	91.55	3.43	93.72	2.81	94.21	3.71	93.96
92	2	2	33636	3.66	91.67	3.47	93.68	3.84	93.18	4.00	93.67
92	2	8	33642	3.70	91.63	3.06	94.10	2.91	94.12	3.46	94.21
92	2	15	33649	N/M	N/M	3.13	94.02	2.99	94.03	3.57	94.10
92	2	23	33657	3.95	91.38	3.01	94.14	3.16	93.86	N/M	N/M
92	3	8	33671	N/M	N/M	3.20	93.95	N/M	N/M	N/M	N/M
92	3	16	33679	3.03	92.30	3.16	93.99	N/M	N/M	N/M	N/M
92	3	21	33684	3.56	91.77	N/M	N/M	3.15	93.87	N/M	N/M
92	3	29	33692	2.60	92.73	3.04	94.11	2.92	94.10	3.34	94.33
92	4	12	33706	2.43	92.90	2.66	94.49	2.53	94.49	3.02	94.65
92	4	18	33712	2.80	92.53	2.80	94.35	2.66	94.36	3.16	94.51
92	4	24	33718	3.08	92.25	2.75	94.40	2.74	94.28	3.23	94.44
92	5	5	33729	2.13	93.20	2.58	94.57	2.45	94.57	2.92	94.75
92	5	12	33736	2.47	92.86	2.66	94.49	2.53	94.49	2.99	94.68
92	5	20	33744	3.17	92.16	2.93	94.22	2.79	94.23	3.33	94.34
92	5	29	33753	3.87	91.46	3.10	94.05	2.97	94.05	3.54	94.13
92	6	3	33758	4.02	91.31	3.17	93.96	3.02	94.00	3.62	94.05
92	6	12	33767	4.18	91.15	3.25	93.90	3.09	93.93	3.71	93.96
92	6	25	33780	3.66	91.67	2.97	94.18	2.85	94.17	3.41	94.26
92	7	3	33788	N/M	N/M	N/M	N/M	N/M	N/M	N/M	N/M
92	7	9	33794	3.39	91.94	2.95	94.20	2.82	94.20	3.38	94.29
92	7	20	33805	2.91	92.42	2.94	94.21	2.82	94.20	3.36	94.31
92	7	27	33812	3.66	91.67	3.11	94.04	2.96	94.06	3.54	94.13
92	8	3	33819	4.09	91.24	3.20	93.95	3.05	93.97	3.65	94.02
92	8	11	33827	4.32	91.01	3.26	93.89	3.10	93.92	3.74	93.93
92	8	20	33836	4.43	90.90	3.31	93.64	3.16	93.86	3.78	93.89
92	9	8	33855	4.54	90.79	3.40	93.75	3.24	93.78	2.89	94.78
92	10	10	33887	2.09	93.24	2.42	94.73	2.29	94.73	2.81	94.86
92	11	10	33916	3.08	92.25	2.94	94.21	2.80	94.22	3.34	94.33
92	12	11	33949	3.71	91.62	3.05	94.10	2.90	94.12	3.50	94.17

WT ELEV. = Water Table Elevation
SWL B.M.P. = Static Water Level Below Measuring Point
N/M = No Measurement

WELL ID #				17		18		19		20	
ELEVATION OF GROUND SURFACE (m)				97.29		97.79		97.79		102.24	
ELEVATION OF MEASURING POINT (m)				97.53		98.19		98.17		102.51	
ELEVATION OF BOTTOM OF HOLE (m)				94.14		90.47		93.37		98.13	
ELEVATION OF BEDROCK (m)				93.33		93.68		93.68		98.28	
YEAR	MONTH	DAY	DATE CODE	SWL B.M.P. (m)	WT ELEV. (m)	SWL B.M.P. (m)	WT ELEV. (m)	SWL B.M.P. (m)	WT ELEV. (m)	SWL B.M.P. (m)	WT ELEV. (m)
91	9	27	33508								
91	10	10	33521								
91	10	18	33527								
91	10	27	33536								
91	11	3	33545								
91	11	8	33550								
91	11	15	33557								
91	11	20	33562								
91	11	24	33566								
91	12	1	33573								
92	1	7	33610								
92	1	12	33615								
92	1	18	33621	4.04	93.49	3.06	95.13	4.03	94.14		
92	1	26	33629	3.98	93.55	3.21	94.98	4.05	94.12		
92	2	2	33636	3.47	94.06	3.18	95.01	4.09	94.08		
92	2	8	33642	3.38	94.15	3.22	94.97	3.57	94.60		
92	2	15	33649	3.50	94.03	3.29	94.90	3.62	94.55		
92	2	23	33657	N/M	N/M	3.37	94.82	3.65	94.52		
92	3	8	33671	N/M	N/M	3.40	94.80	3.70	94.47		
92	3	16	33679	N/M	N/M	N/M	N/M	N/M	N/M		
92	3	21	33684	N/M	N/M	N/M	N/M	N/M	N/M		
92	3	29	33692	3.37	94.16	2.62	95.57	3.15	95.02		
92	4	12	33706	2.92	94.61	3.22	94.97	2.76	95.41		
92	4	18	33712	3.06	94.47	3.26	94.93	2.88	95.29		
92	4	24	33718	3.12	94.41	3.32	94.87	2.91	95.26		
92	5	5	33729	2.80	94.73	3.15	95.04	2.67	95.50		
92	5	12	33736	2.89	94.64	3.22	94.97	2.68	95.49		
92	5	20	33744	3.21	94.32	3.39	94.80	3.33	94.84		
92	5	29	33753	3.43	94.10	3.39	94.80	3.52	94.65		
92	6	3	33758	3.50	94.03	3.45	94.74	3.65	94.52		
92	6	12	33767	3.59	93.94	3.51	94.68	3.74	94.43	3.60	98.91
92	6	25	33780	3.28	94.25	3.57	94.62	3.50	94.67	2.96	99.55
92	7	3	33788	N/M	N/M	N/M	N/M	N/M	N/M	3.30	99.21
92	7	9	33794	3.25	94.28	3.53	94.66	3.43	94.74	2.83	99.68
92	7	20	33805	3.24	94.29	3.47	94.72	3.33	94.84	3.13	99.38
92	7	27	33812	3.41	94.12	3.63	94.56	3.50	94.67	3.40	99.11
92	8	3	33819	3.52	94.01	3.75	94.44	3.62	94.55	3.53	98.98
92	8	11	33827	3.60	93.93	3.80	94.39	3.69	94.48	3.57	98.94
92	8	20	33836	3.64	93.89	3.84	94.35	3.72	94.45	3.67	98.64
92	9	8	33855	3.74	93.79	N/M	N/M	3.79	94.38	3.86	98.65
92	10	10	33887	2.66	94.87	3.08	95.11	2.81	95.36	2.03	100.48
92	11	10	33918	3.24	94.30	3.53	94.66	3.25	94.92	3.32	99.19
92	12	11	33949	3.36	94.17	3.61	94.58	3.40	94.77	3.15	99.36

WT ELEV. = Water Table Elevation
SWL B.M.P. = Static Water Level Below Measuring Point
N/M = No Measurement

WELL ID #	21	22	23	24
ELEVATION OF GROUND SURFACE (m)	102.24	100.04	100.04	101.25
ELEVATION OF MEASURING POINT (m)	102.70	100.39	100.44	101.59
ELEVATION OF BOTTOM OF HOLE (m)	94.54	95.93	92.88	98.55
ELEVATION OF BEDROCK (m)	98.28	98.08	98.08	97.29

YEAR	MONTH	DAY	DATE CODE	SWL B.M.P. (m)	WT ELEV. (m)	SWL B.M.P. (m)	WT ELEV. (m)	SWL B.M.P. (m)	WT ELEV. (m)	SWL B.M.P. (m)	WT ELEV. (m)
91	9	27	33508								
91	10	10	33521								
91	10	18	33527								
91	10	27	33538								
91	11	3	33545								
91	11	8	33550								
91	11	15	33557								
91	11	20	33562								
91	11	24	33566								
91	12	1	33573								
92	1	7	33610								
92	1	12	33615								
92	1	18	33621								
92	1	26	33629								
92	2	2	33636								
92	2	8	33642								
92	2	15	33649								
92	2	23	33657								
92	3	8	33671								
92	3	18	33679								
92	3	21	33684								
92	3	29	33692								
92	4	12	33706								
92	4	18	33712								
92	4	24	33718								
92	5	5	33729								
92	5	12	33736								
92	5	20	33744								
92	5	29	33753								
92	8	3	33758								
92	6	12	33767	4.88	97.82	3.47	96.92	3.45	96.99	4.97	96.62
92	6	25	33780	4.17	98.53	2.80	97.59	2.84	97.80	3.77	97.82
92	7	3	33788	4.28	98.42	2.13	98.26	2.96	97.48	4.41	97.18
92	7	9	33794	4.23	98.47	2.58	97.81	2.75	97.69	3.88	97.71
92	7	20	33805	4.18	98.52	2.99	97.40	2.68	97.76	3.99	97.60
92	7	27	33612	4.79	97.91	3.32	97.07	3.32	97.12	4.81	96.98
92	8	3	33619	4.78	97.92	3.46	96.93	3.44	97.00	4.80	96.79
92	8	11	33827	4.92	97.78	3.53	96.86	3.54	96.90	4.88	96.71
92	8	20	33836	5.02	97.68	3.61	96.78	3.62	96.82	4.99	96.60
92	9	8	33855	5.08	97.62	3.78	96.63	3.69	96.75	DRY	DRY
92	10	10	33887	3.40	99.30	1.53	98.86	1.59	98.85	3.09	98.50
92	11	10	33918	4.40	98.30	3.16	97.23	3.19	97.25	4.33	97.26
92	12	11	33949	4.38	98.32	3.04	97.35	3.09	97.35	4.06	97.53

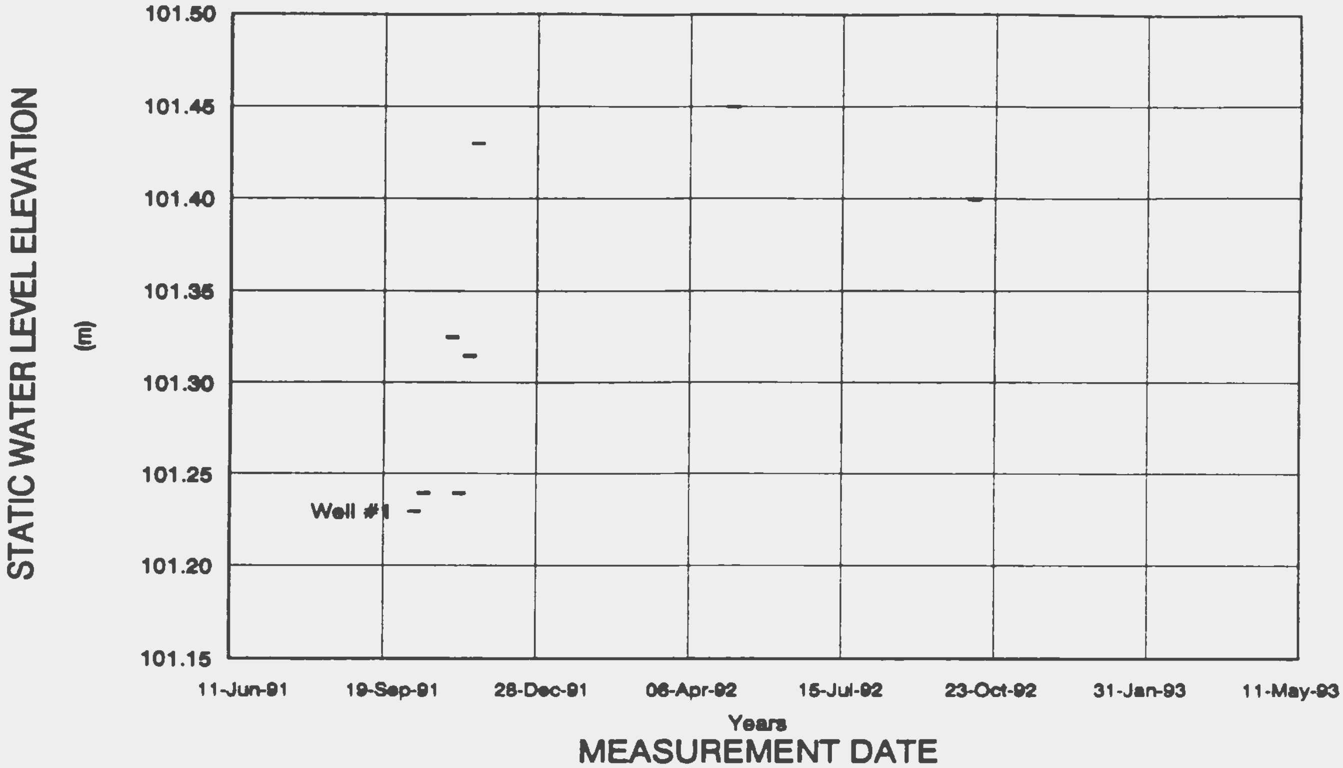
WT ELEV. = Water Table Elevation
SWL B.M.P. = Static Water Level Below Measuring Point
N/M = No Measurement

WELL ID #	25	P1
ELEVATION OF GROUND SURFACE (m)	101.25	97.11
ELEVATION OF MEASURING POINT (m)	101.74	97.61
ELEVATION OF BOTTOM OF HOLE (m)	93.63	94.77
ELEVATION OF BEDROCK (m)	97.29	94.77

YEAR	MONTH	DAY	DATE CODE	SWL B.M.P. (m)	WT ELEV. (m)	SWL B.M.P. (m)	WT ELEV. (m)
91	9	27	33508			2.37	95.25
91	10	10	33521			2.06	95.55
91	10	16	33527			1.87	95.74
91	10	27	33538			1.72	95.89
91	11	3	33545			1.37	96.24
91	11	8	33550			1.40	96.21
91	11	15	33557			1.10	96.51
91	11	20	33562			N/M	N/M
91	11	24	33566			1.50	96.11
91	12	1	33573			1.56	96.05
92	1	7	33610			1.50	96.11
92	1	12	33615			N/M	N/M
92	1	18	33621			1.74	95.87
92	1	26	33629			1.74	95.87
92	2	2	33636			1.80	95.81
92	2	8	33642			1.84	95.78
92	2	15	33649			N/M	N/M
92	2	23	33657			N/M	N/M
92	3	8	33671			N/M	N/M
92	3	16	33679			N/M	N/M
92	3	21	33684			N/M	N/M
92	3	29	33692			1.72	95.89
92	4	12	33706			0.49	97.12
92	4	18	33712			0.64	96.97
92	4	24	33718			1.71	95.90
92	5	5	33729			1.23	96.38
92	5	12	33736			1.50	96.11
92	5	20	33744			1.76	95.85
92	5	29	33753			1.84	95.77
92	6	3	33758			1.88	95.73
92	6	12	33767	5.08	96.66	1.93	95.68
92	6	25	33780	4.36	97.38	0.76	96.85
92	7	3	33788	4.68	97.06	N/M	N/M
92	7	9	33794	4.41	97.33	1.73	95.88
92	7	20	33805	4.46	97.28	1.75	95.86
92	7	27	33812	4.79	96.95	1.83	95.78
92	8	3	33819	4.94	96.80	1.89	95.72
92	8	11	33827	5.01	96.73	1.93	95.68
92	8	20	33836	5.10	96.64	2.04	95.57
92	9	8	33855	5.20	96.54	2.17	95.44
92	10	10	33887	3.51	98.23	1.04	96.57
92	11	10	33918	4.64	97.10	1.77	95.84
92	12	11	33949	4.56	97.18	0.77	96.84

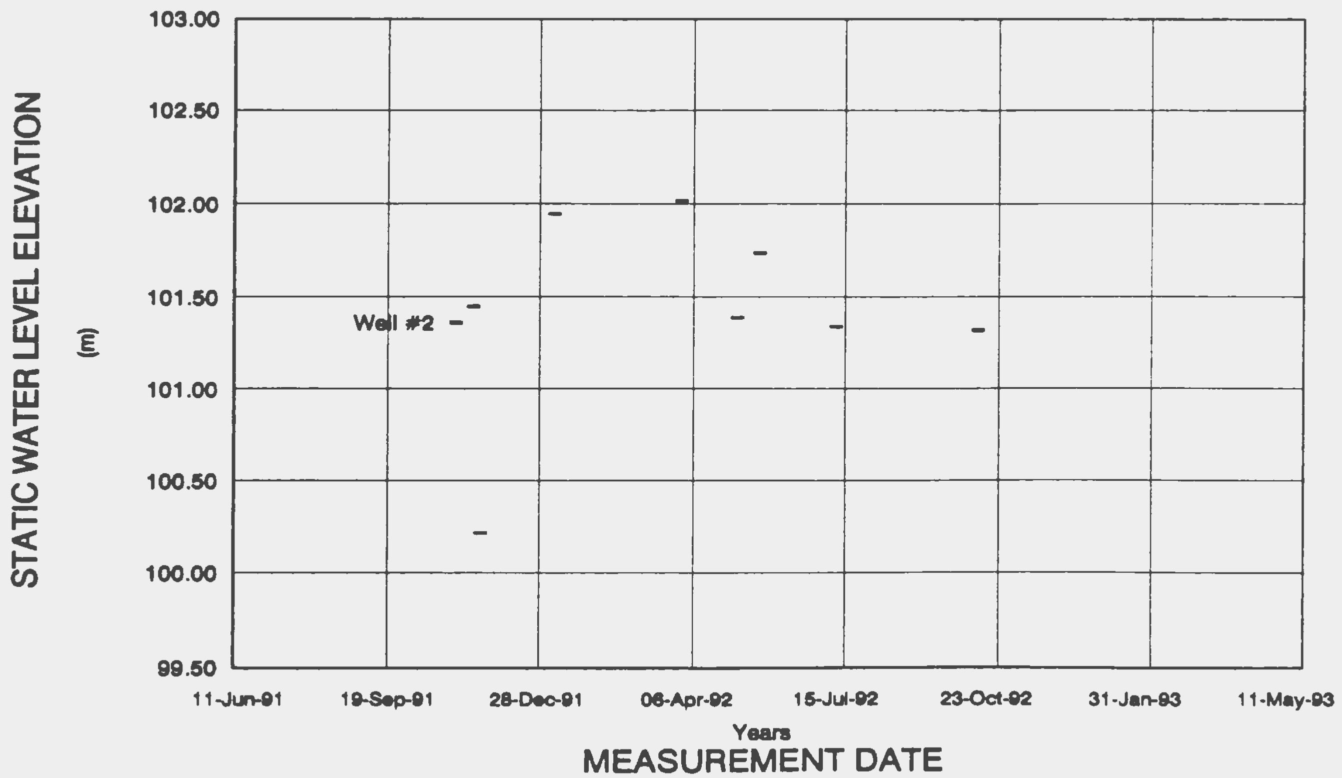
WT ELEV - Water Table Elevation
SWL B.M.P. - Static Water Level Below Measuring Point
N/M = No Measurement

SAMPLING WELL HYDROGRAPH



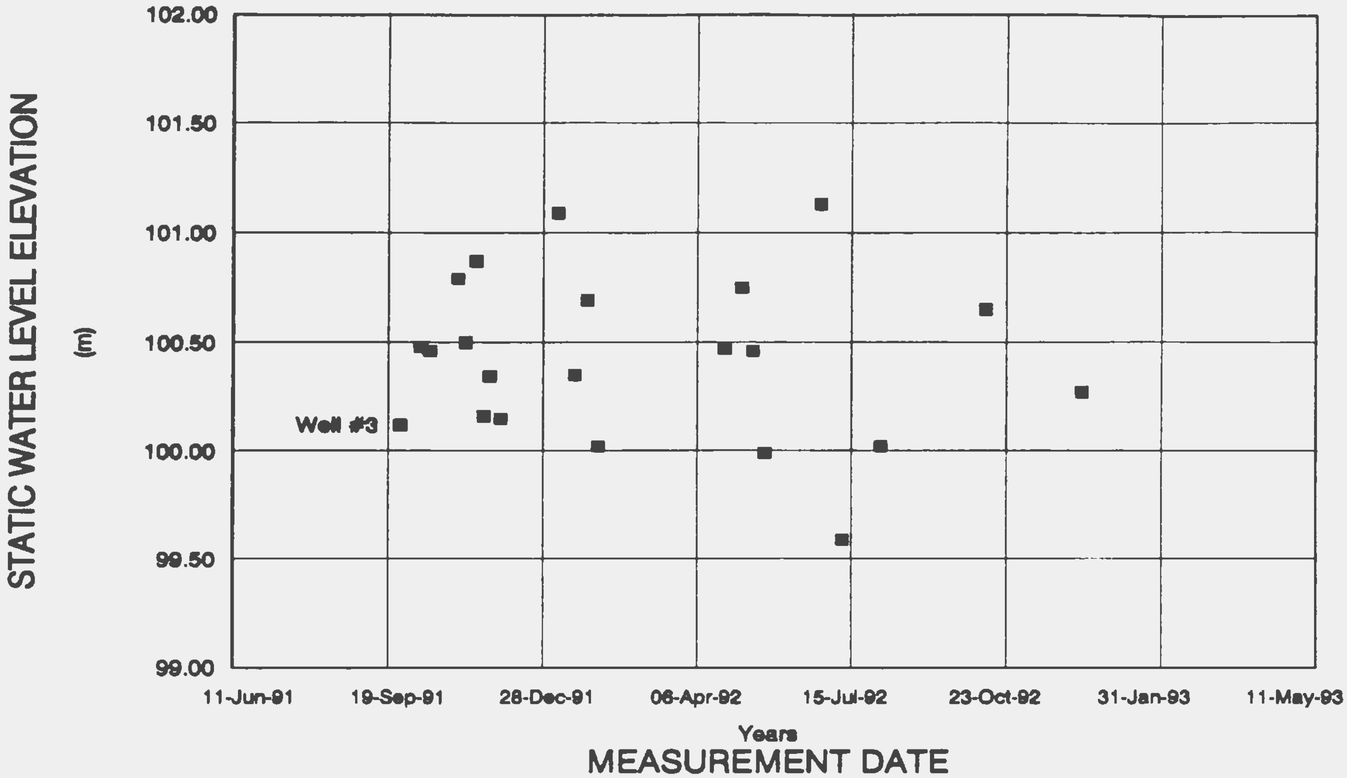
Well #1 -Shallow Well

SAMPLING WELL HYDROGRAPH



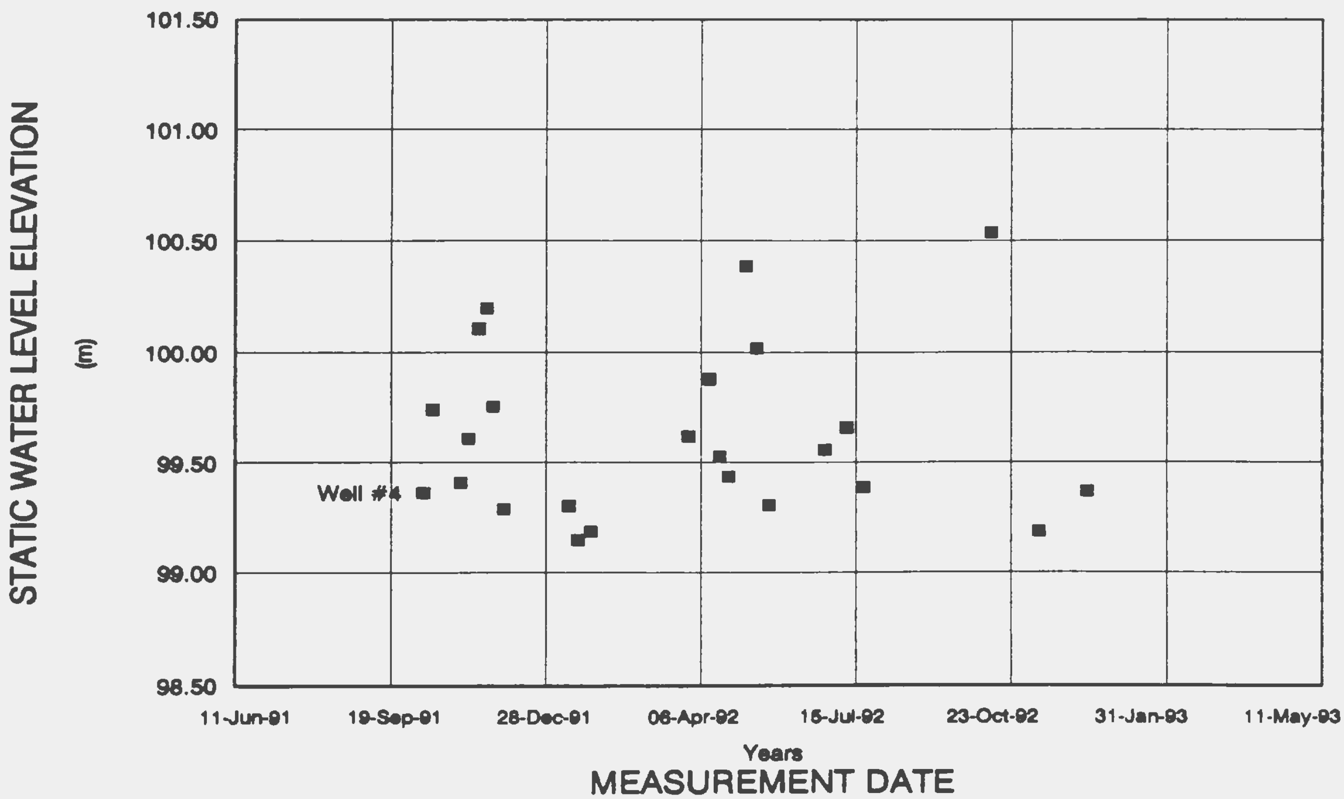
Well #2 - Shallow Well

SAMPLING WELL HYDROGRAPH



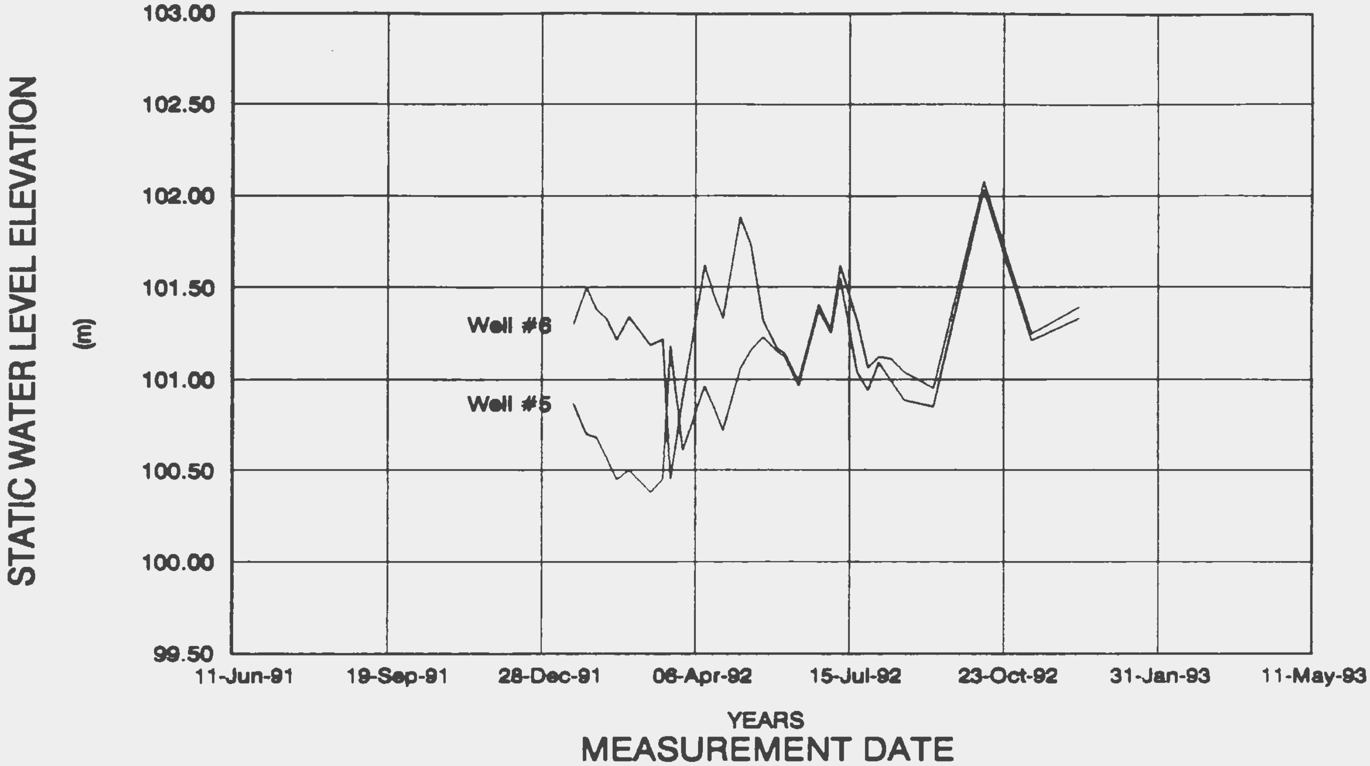
Well #3 - Shallow Well

SAMPLING WELL HYDROGRAPH



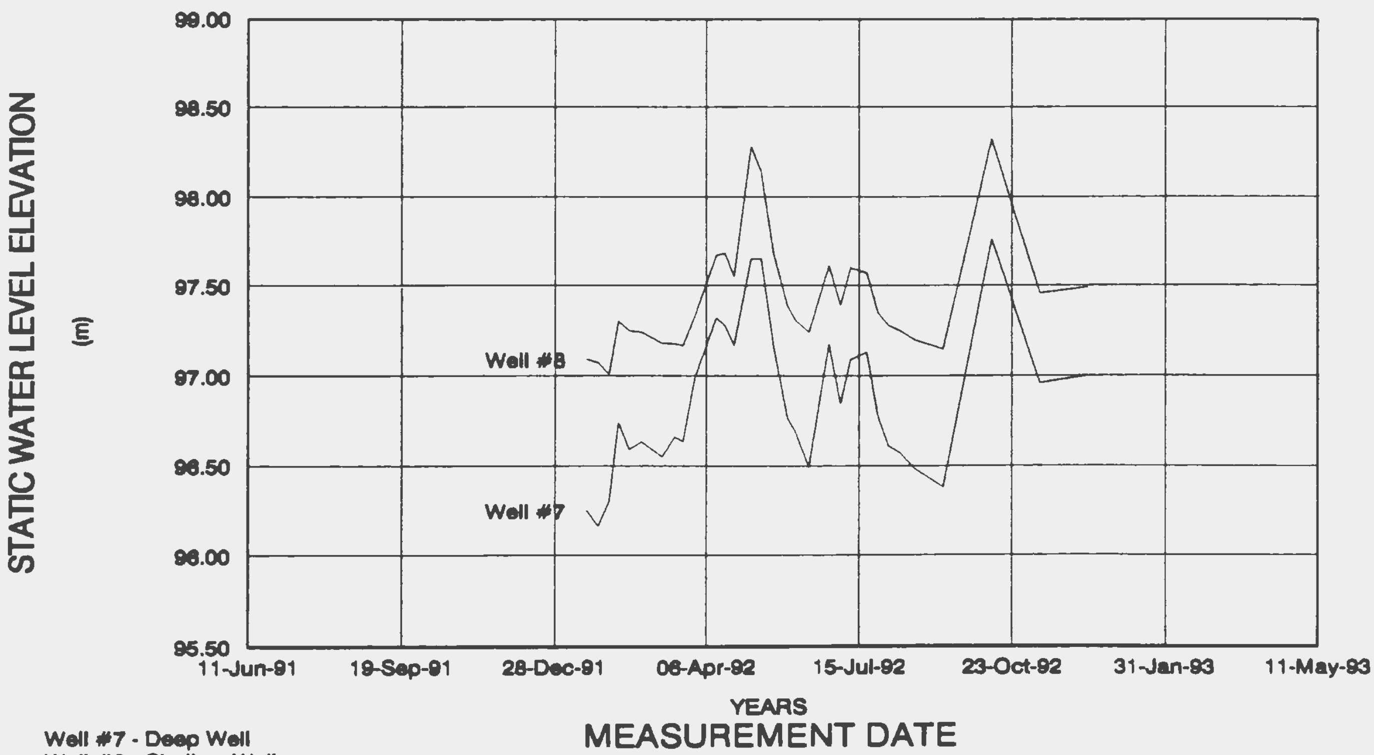
Well #4 - Shallow Well

SAMPLING WELL HYDROGRAPH

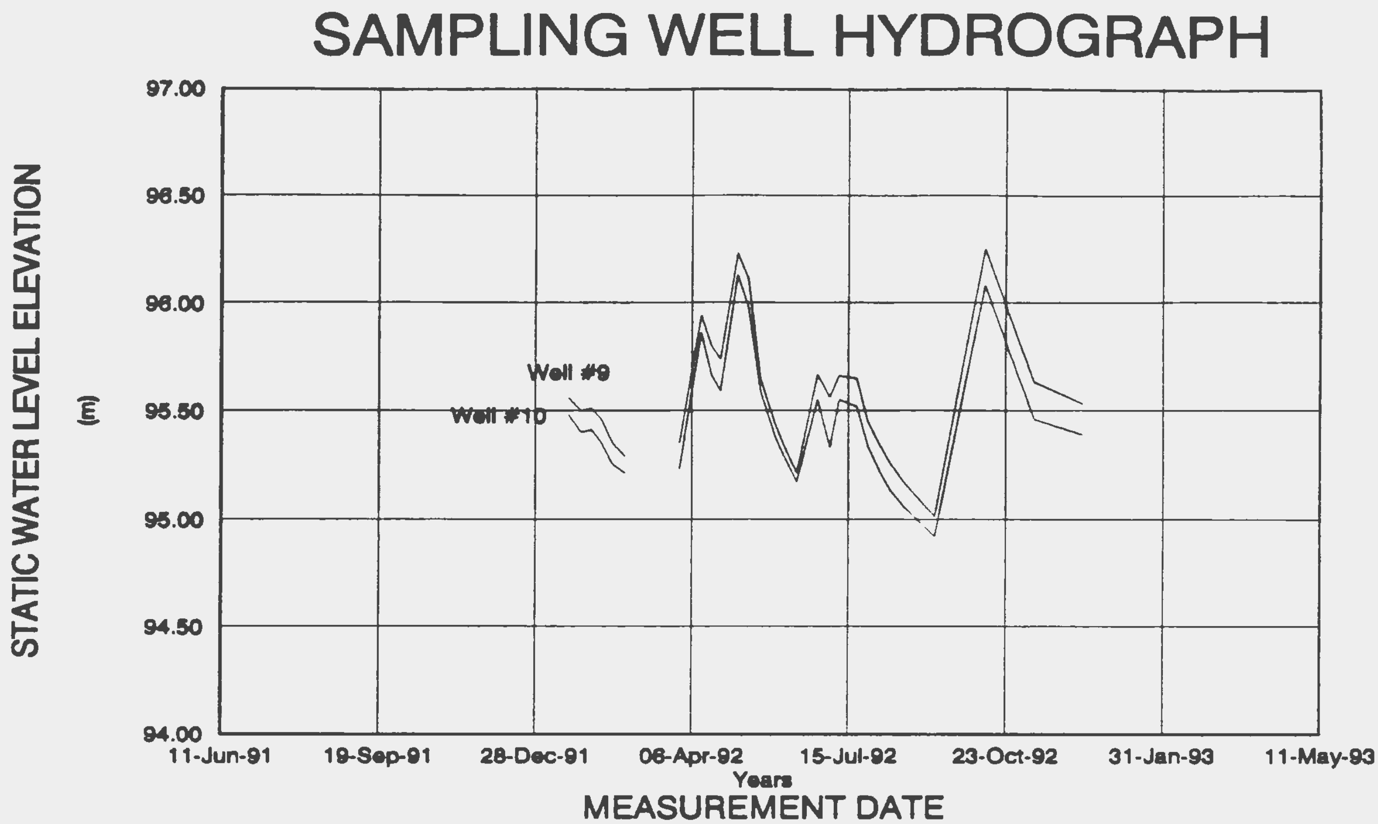


Well #5 - Deep Well
Well #6 - Shallow Well

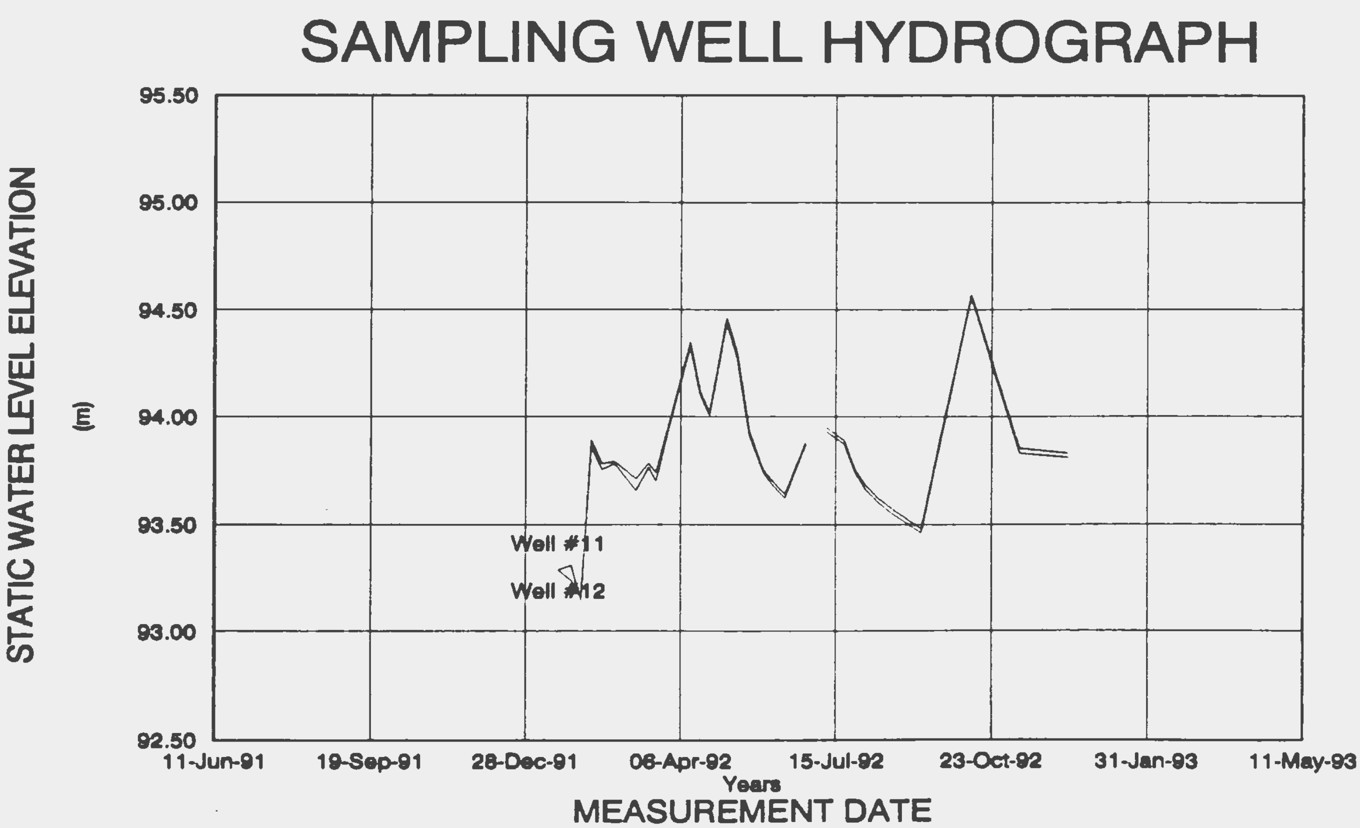
SAMPLING WELL HYDROGRAPH



Well #7 - Deep Well
Well #8 - Shallow Well

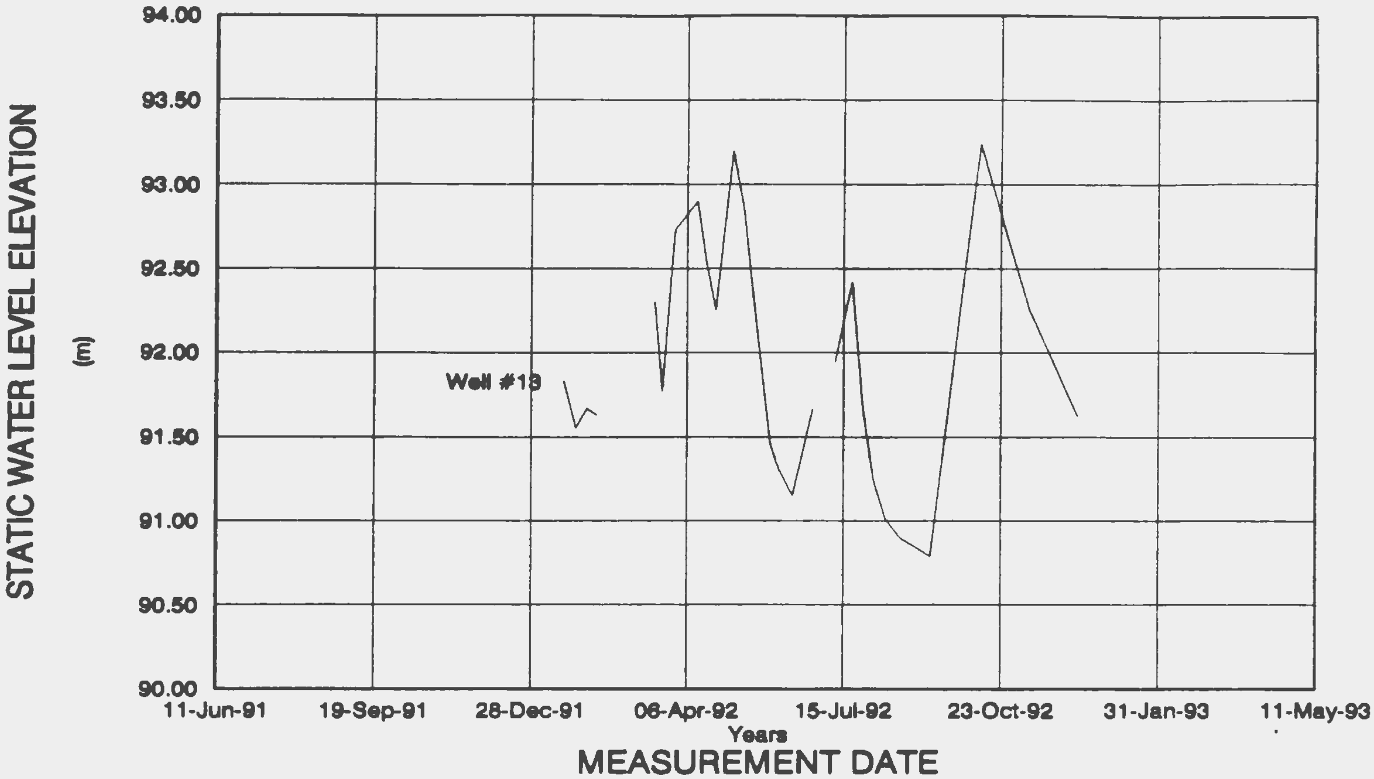


Well #9 - Deep Well
Well #10 - Shallow Well



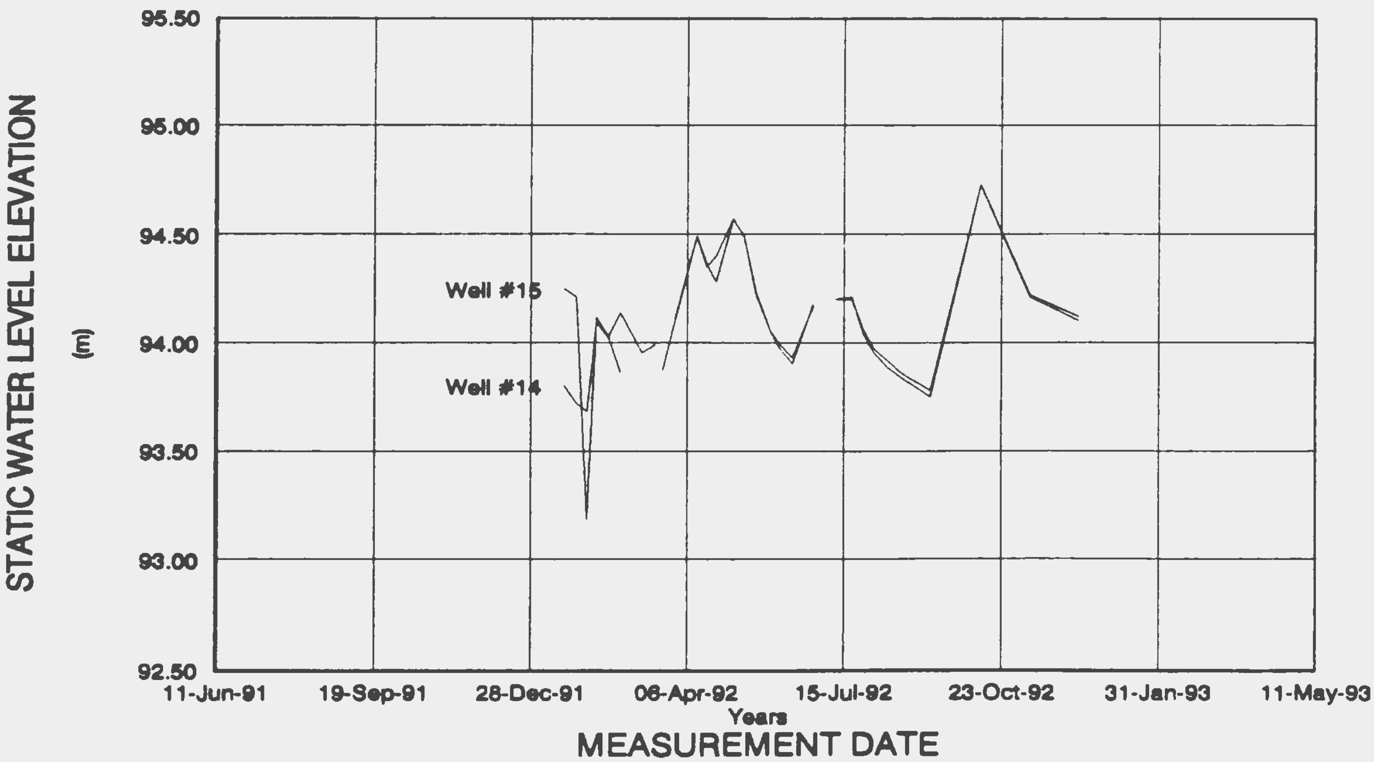
Well #11 - Deep Well
Well #12 - Shallow Well

SAMPLING WELL HYDROGRAPH

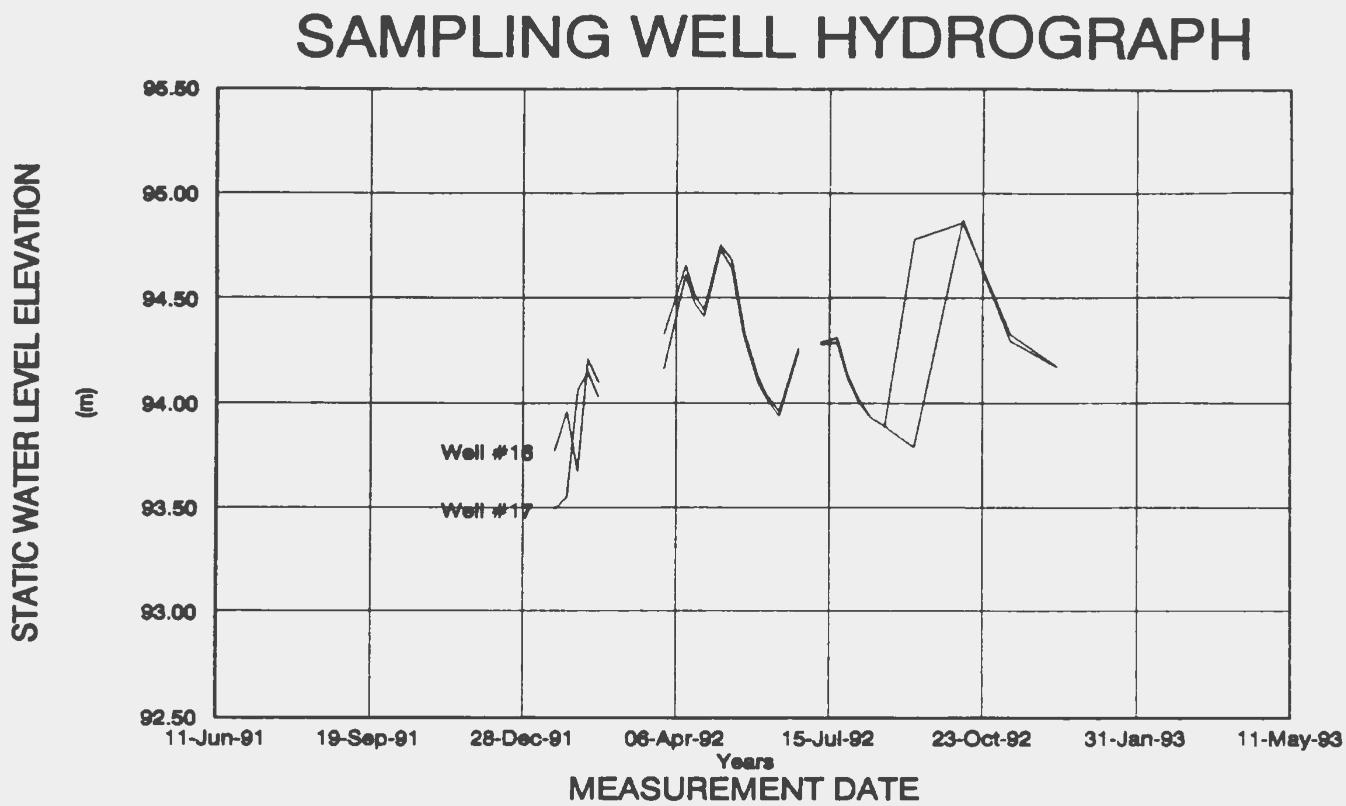


Well #13 - Deep Well

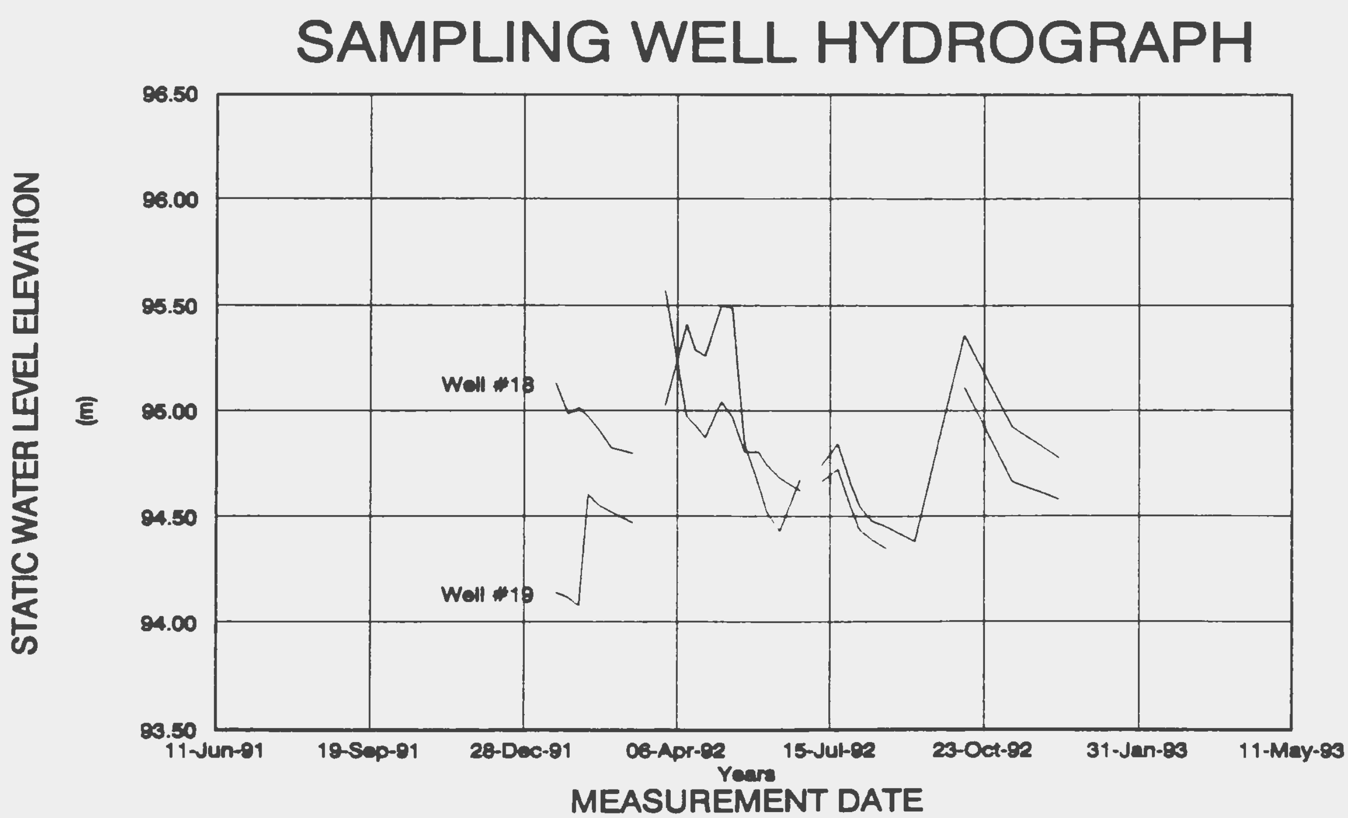
SAMPLING WELL HYDROGRAPH



Well #14 - Shallow Well
Well #15 - Deep Well

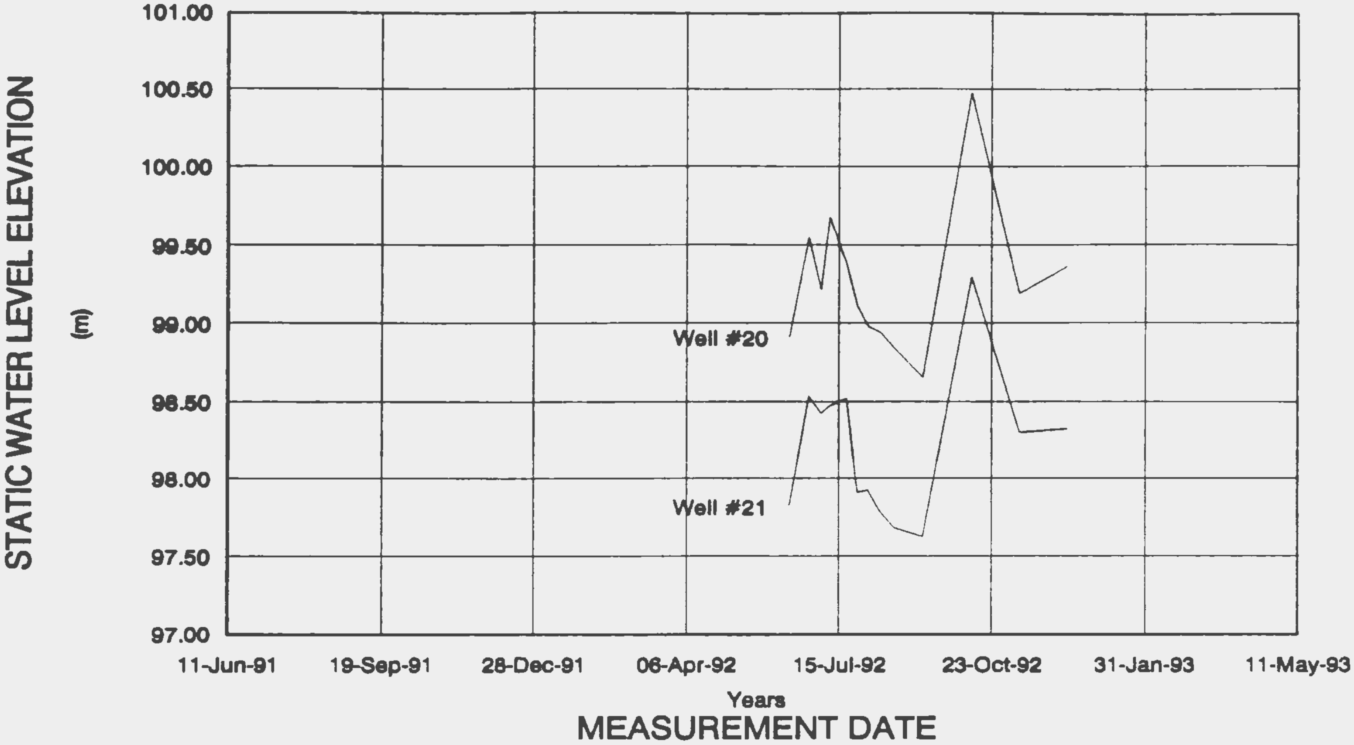


Well #16 - Deep Well
Well #17 - Shallow Well



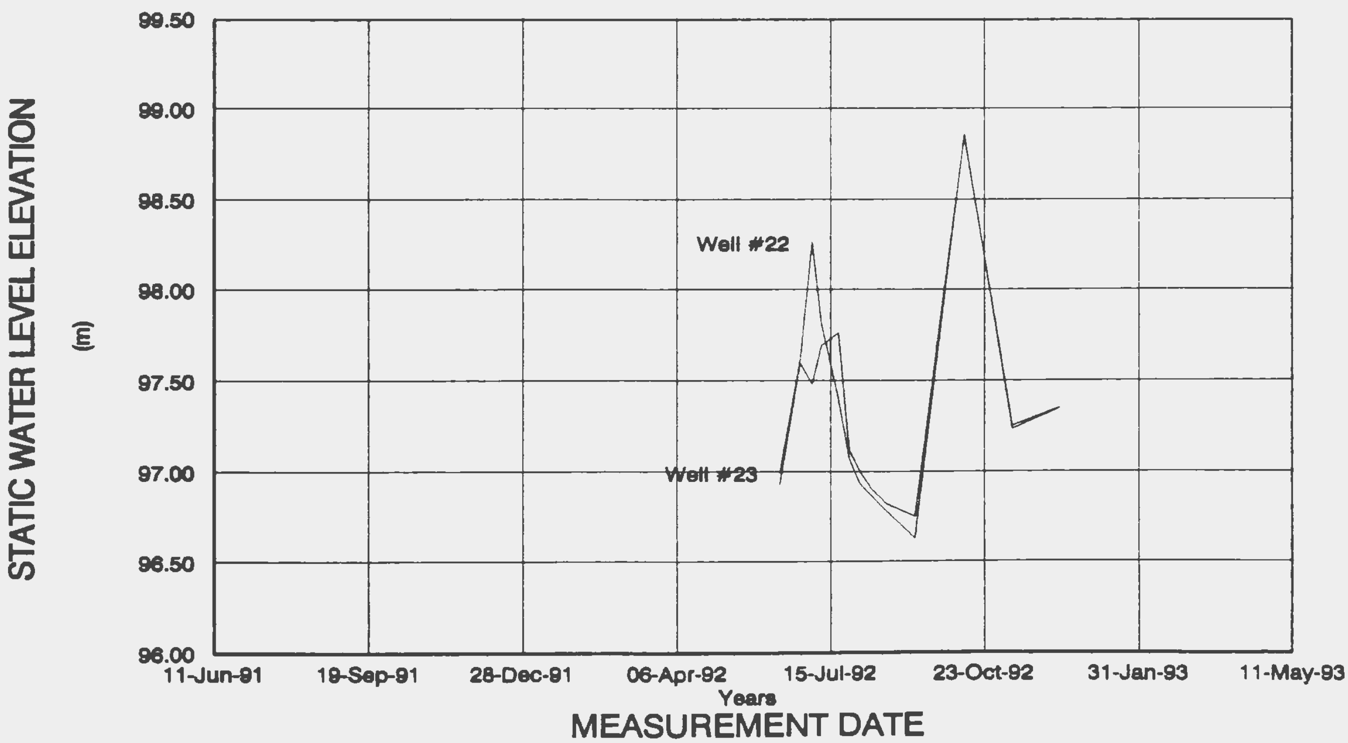
Well # 18 - Deep Well
Well #19 - Shallow Well

SAMPLING WELL HYDROGRAPH



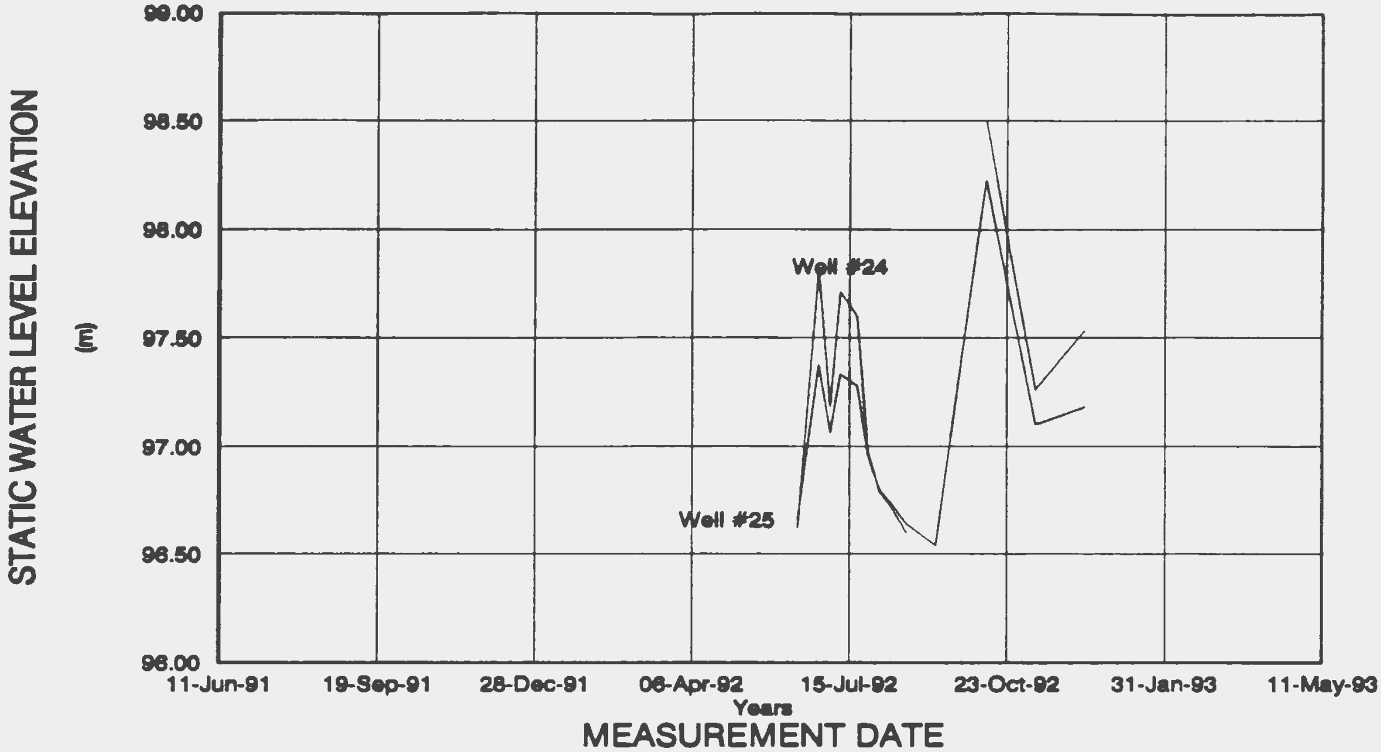
Well #20 - Shallow Well
Well #21 - Deep Well

SAMPLING WELL HYDROGRAPH



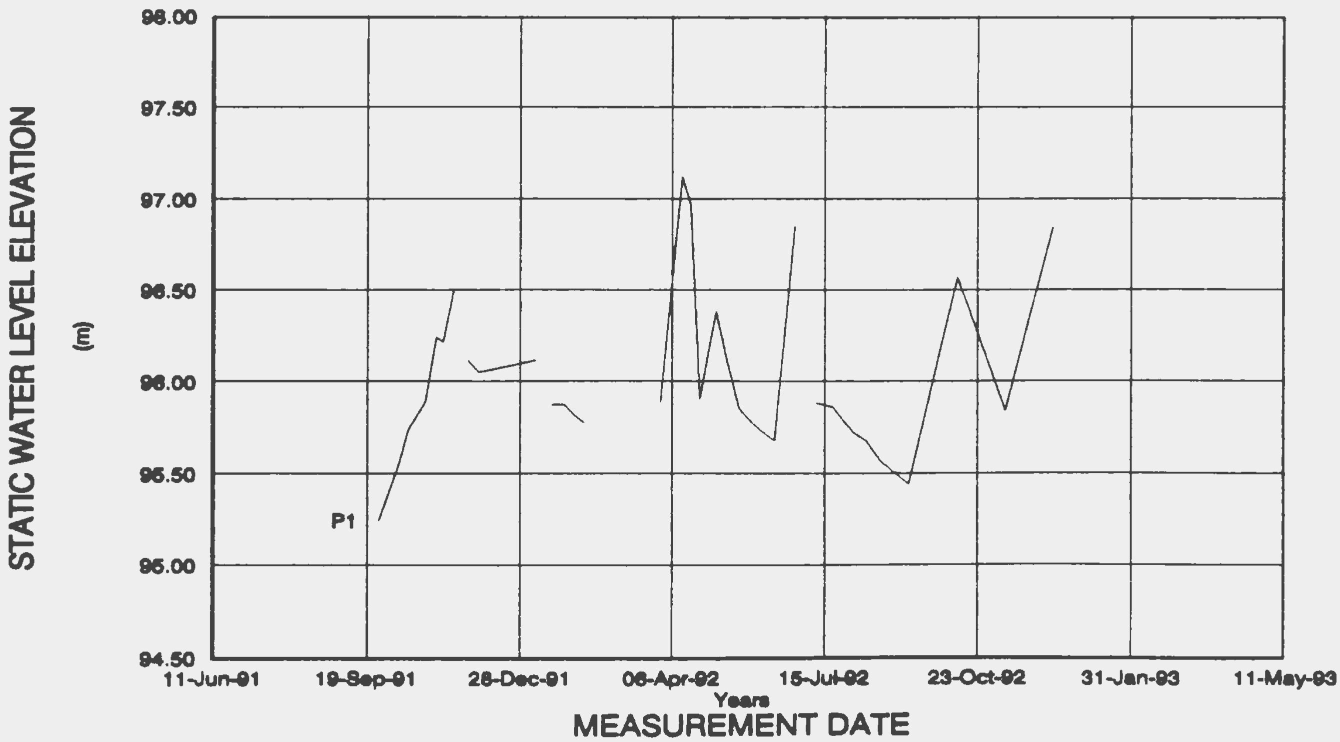
Well #22 - Shallow Well
Well #23 - Deep Well

SAMPLING WELL HYDROGRAPH



Well #24 - Shallow Well
Well #25 - Deep Well

PIEZOMETRIC WELL HYDROGRAPH



APPENDIX E

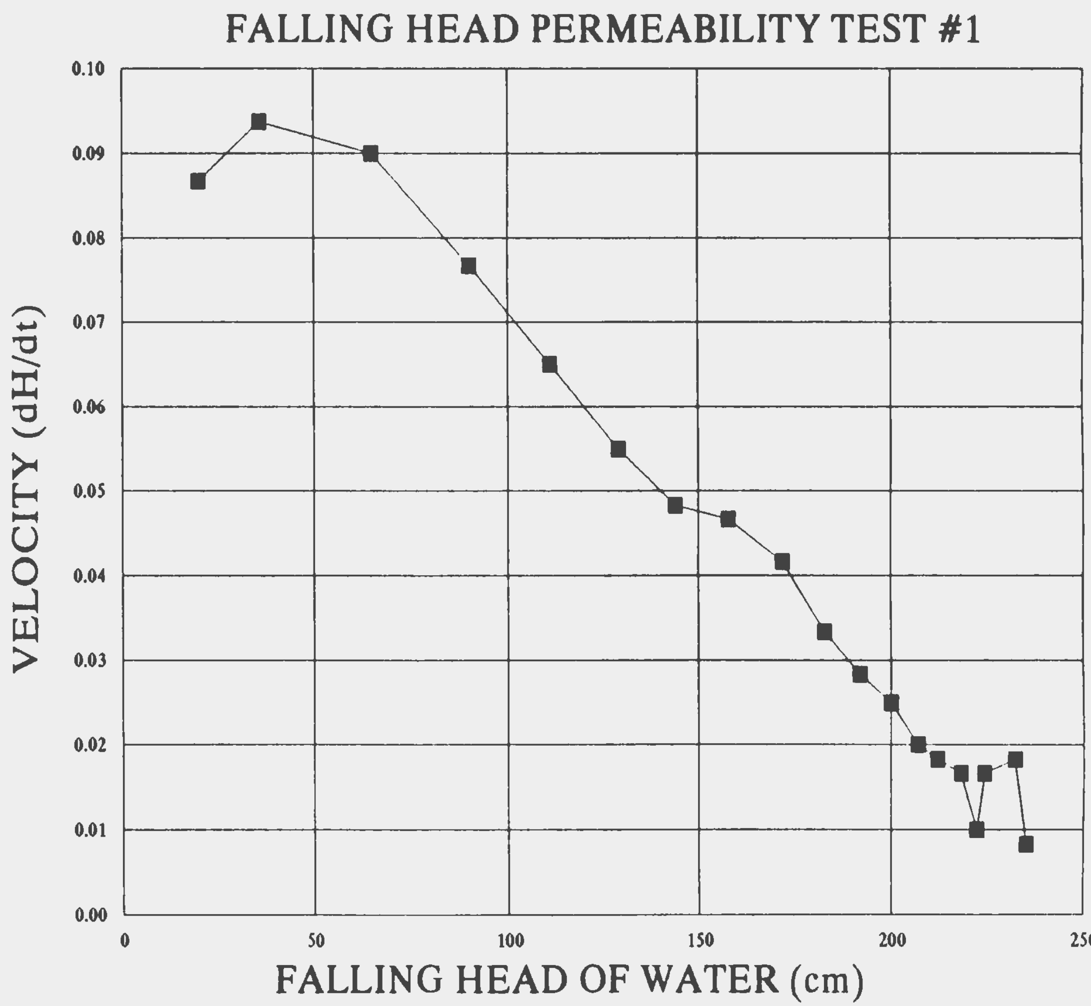
HYDRAULIC CONDUCTIVITY DATA

IN SITU FALLING HEAD PERMEABILITY TESTS:

WELL # W13
DATE 5/14/92
TEST # 1-1

TIME (s)	HEAD (cm)	VELOCITY (dH/dt)
0	10	
120	20	0.0867
300	36	0.0938
600	65	0.0900
900	90	0.0767
1200	111	0.0650
1500	129	0.0550
1800	144	0.0483
2100	158	0.0467
2400	172	0.0417
2700	183	0.0333
3000	192	0.0283
3300	200	0.0250
3600	207	0.0200
3900	212	0.0183
4200	218	0.0167
4500	222	0.0100
4800	224	0.0167
5100	232	0.0183
5400	235	0.0083
5700	237	

WELL #13

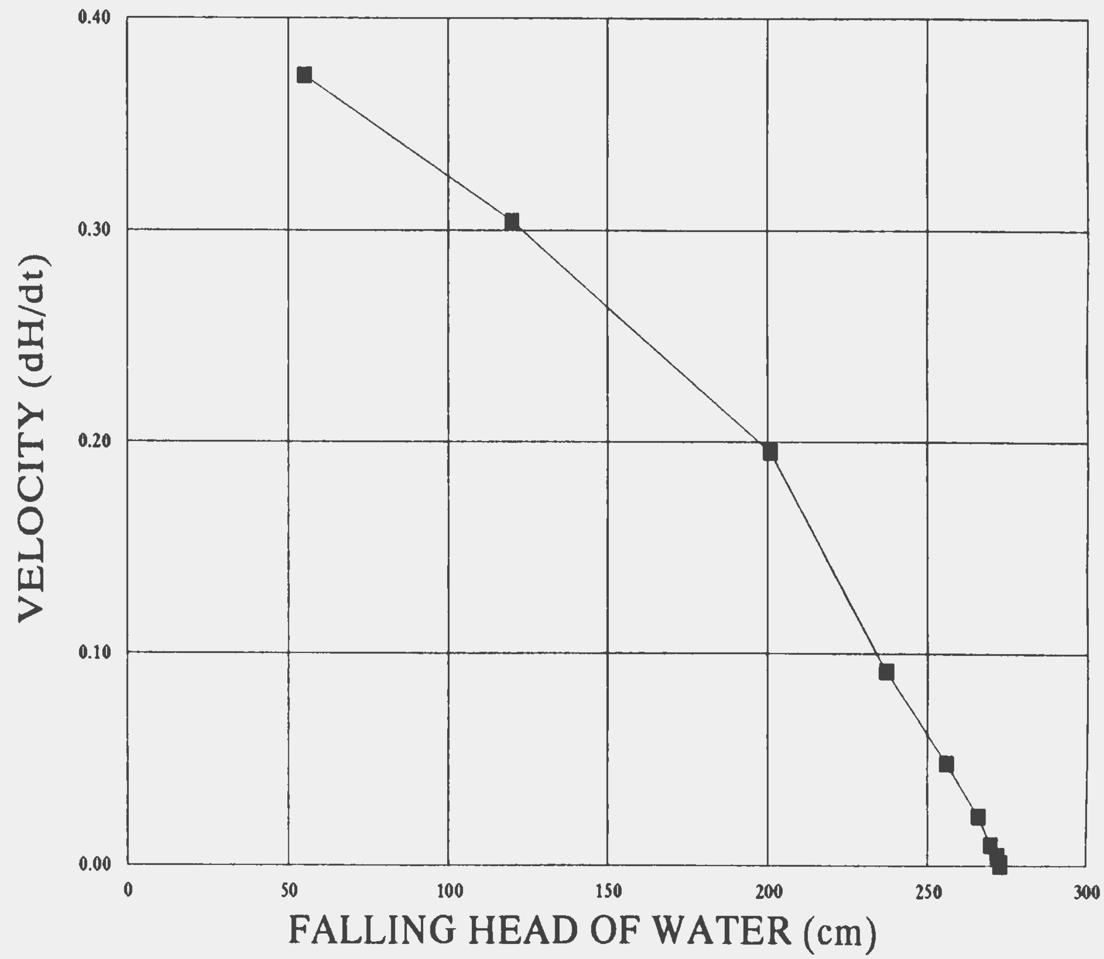


WELL #	W14
DATE	5/14/92
TEST #	1–1

TIME (s)	HEAD (cm)	VELOCITY (dH/dt)
0	8	
120	55	0.3733
300	120	0.3042
600	201	0.1950
900	237	0.0917
1200	256	0.0483
1500	266	0.0233
1800	270	0.0100
2100	272	0.0050
2400	273	0.0017
2700	273	0.0000
3000	273	

WELL #14

FALLING HEAD PERMEABILITY TEST #1

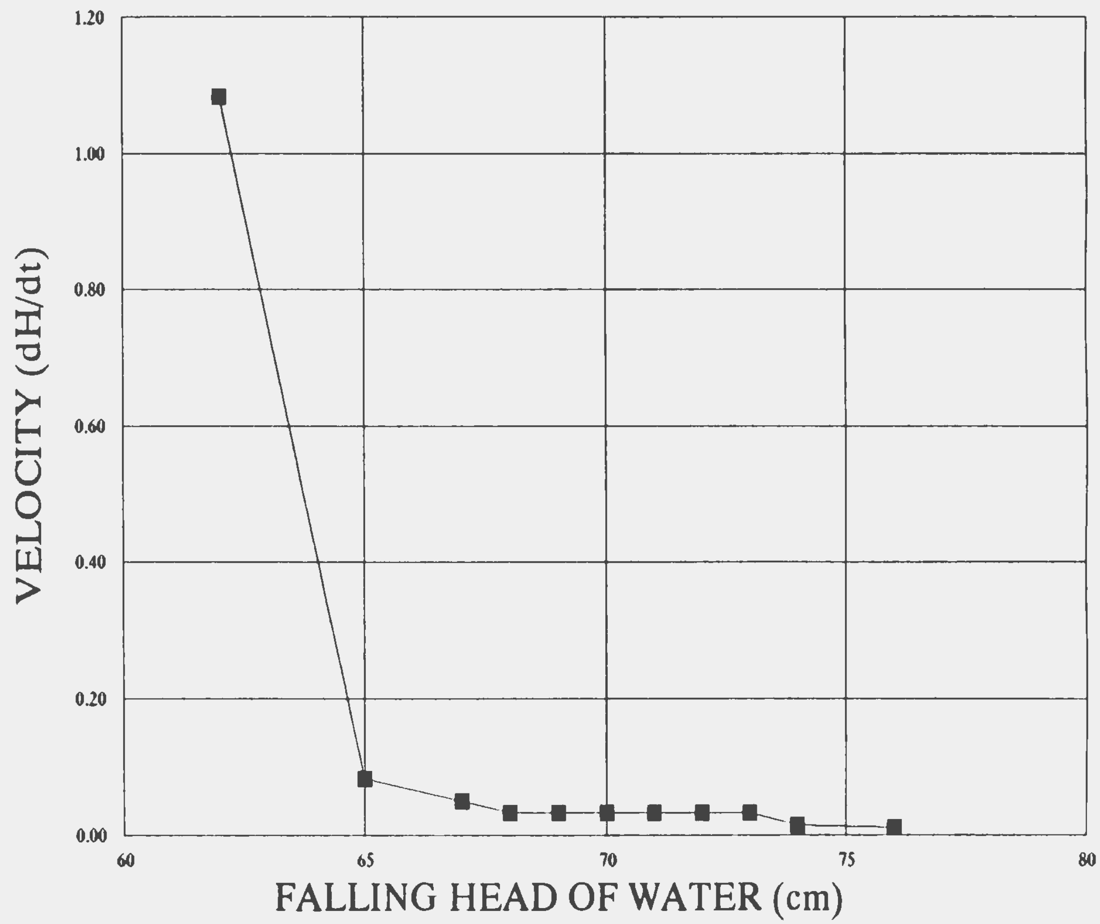


WELL # W2
DATE 5/20/92
TEST # 1–1

TIME (s)	HEAD (cm)	VELOCITY (dH/dt)
0	0	
30	62	1.0833
60	65	0.0833
90	67	0.0500
120	68	0.0333
150	69	0.0333
180	70	0.0333
210	71	0.0333
240	72	0.0333
270	73	0.0333
300	74	0.0143
480	76	0.0111
660	78	

WELL #2

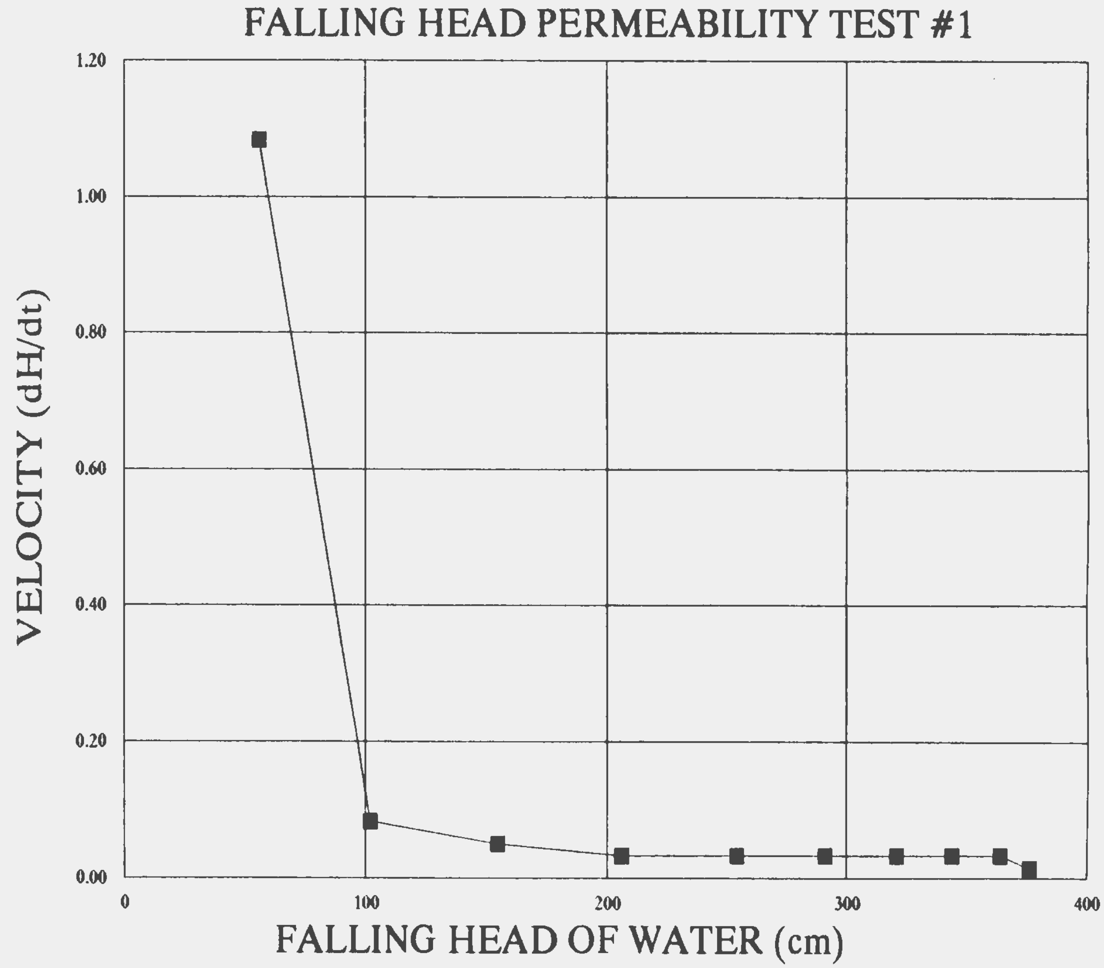
FALLING HEAD PERMEABILITY TEST #1



WELL # W3
DATE 5/20/92
TEST # 1-1

TIME (s)	HEAD (cm)	VELOCITY (dH/dt)
12	0	
24	56	0.9444
120	102	0.4583
240	155	0.3467
420	206	0.3300
540	254	0.2833
720	291	0.1861
900	321	0.1104
1200	344	0.0512
1740	364	0.0381
2040	376	

WELL #3

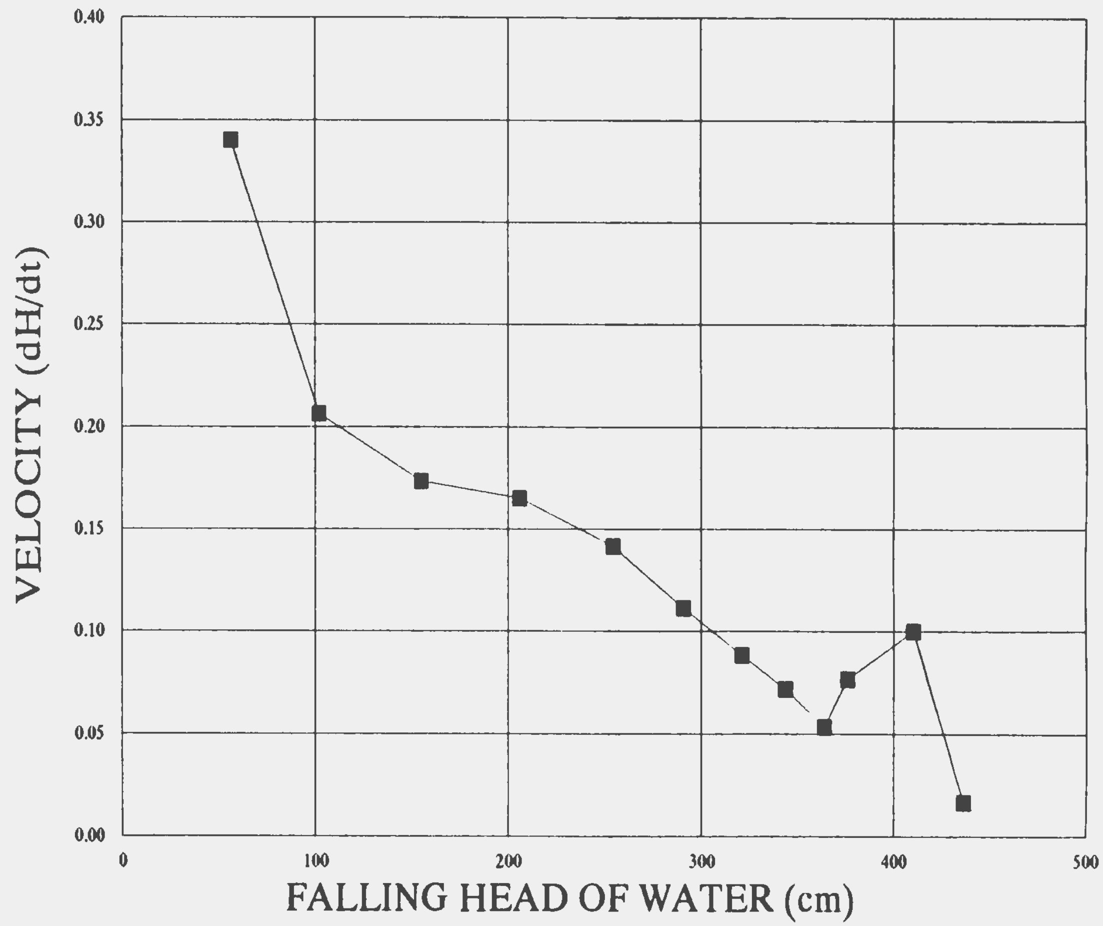


WELL #	W5
DATE	5/20/92
TEST #	1 – 1

TIME (s)	HEAD (cm)	VELOCITY (dH/dt)
0	0	
120	56	0.3400
300	102	0.2063
600	155	0.1733
900	206	0.1650
1200	254	0.1417
1500	291	0.1117
1800	321	0.0883
2100	344	0.0717
2400	364	0.0533
2700	376	0.0767
3000	410	0.1000
3300	436	0.0167
3900	425	

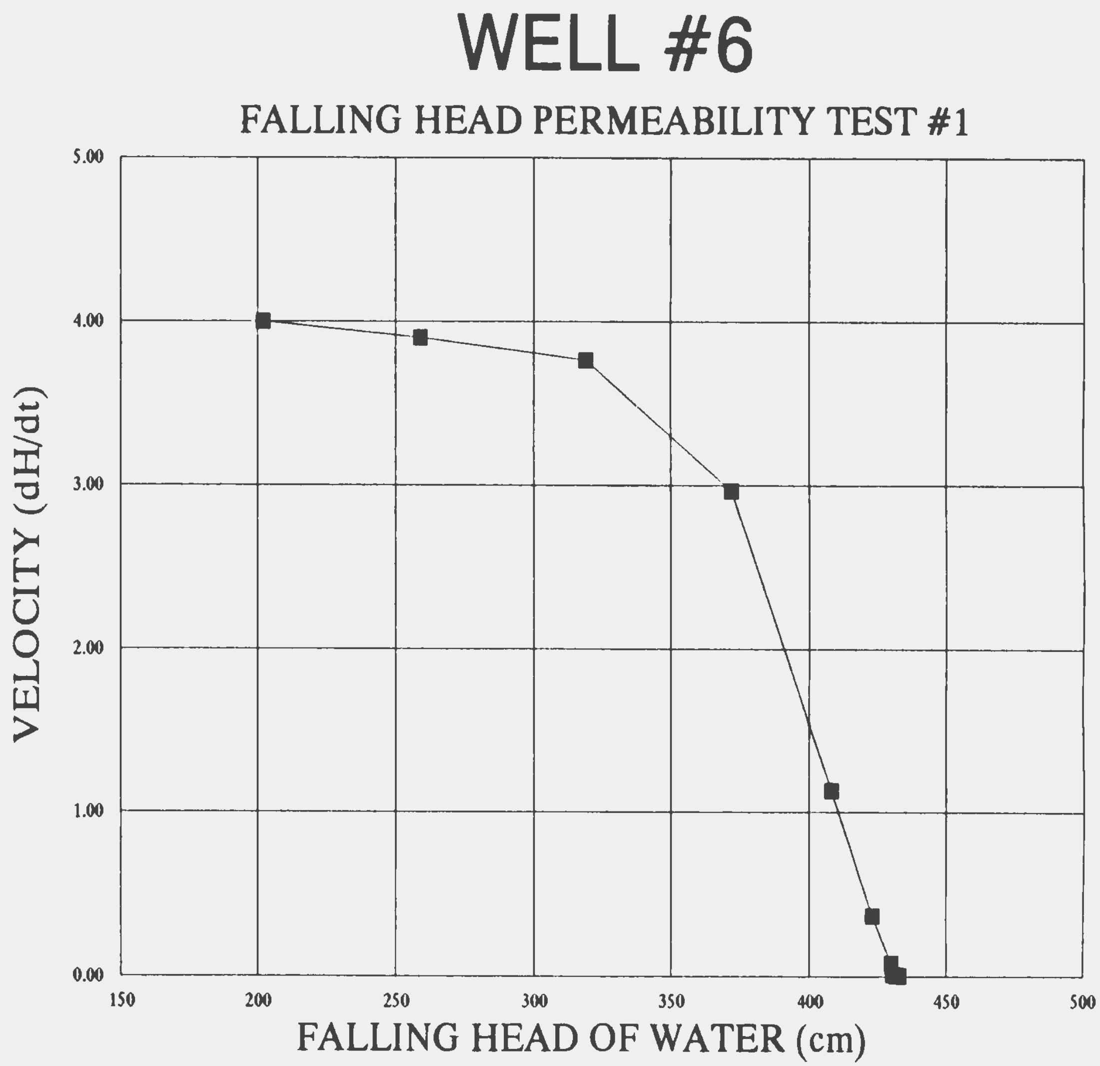
WELL #5

FALLING HEAD PERMEABILITY TEST #1



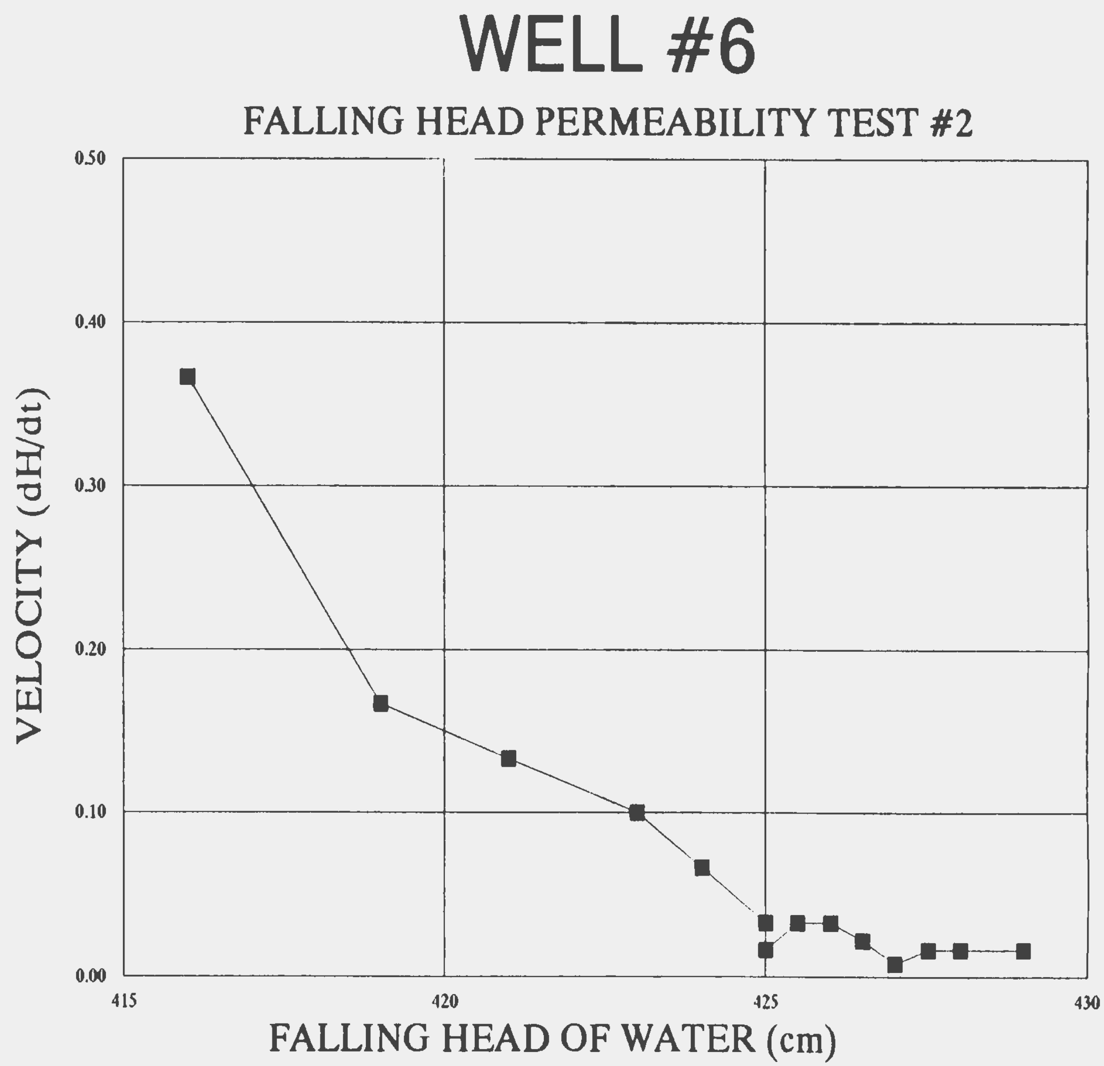
WELL # W6
DATE 5/29/92
TEST # 1–3

TIME (s)	HEAD (cm)	VELOCITY (dH/dt)
0	0	
15	50	3.2333
30	97	2.9667
45	139	3.5000
60	202	4.0000
75	259	3.9000
90	319	3.7667
105	372	2.9667
120	408	1.1333
150	423	0.3667
180	430	0.0833
240	430.5	0.0125
300	431.5	0.0083
420	432	0.0063
540	433	0.0042
660	433	



WELL # W6
DATE 5/29/92
TEST # 2–3

TIME (s)	HEAD (cm)	VELOCITY (dH/dt)
0	0	
15	334	13.6000
30	408	2.7333
45	416	0.3667
60	419	0.1667
75	421	0.1333
90	423	0.1000
105	424	0.0667
120	425	0.0333
135	425	0.0167
150	425.5	0.0333
165	426	0.0333
180	426.5	0.0222
210	427	0.0083
240	427	0.0083
270	427.5	0.0167
300	428	0.0167
360	429	0.0167
420	430	

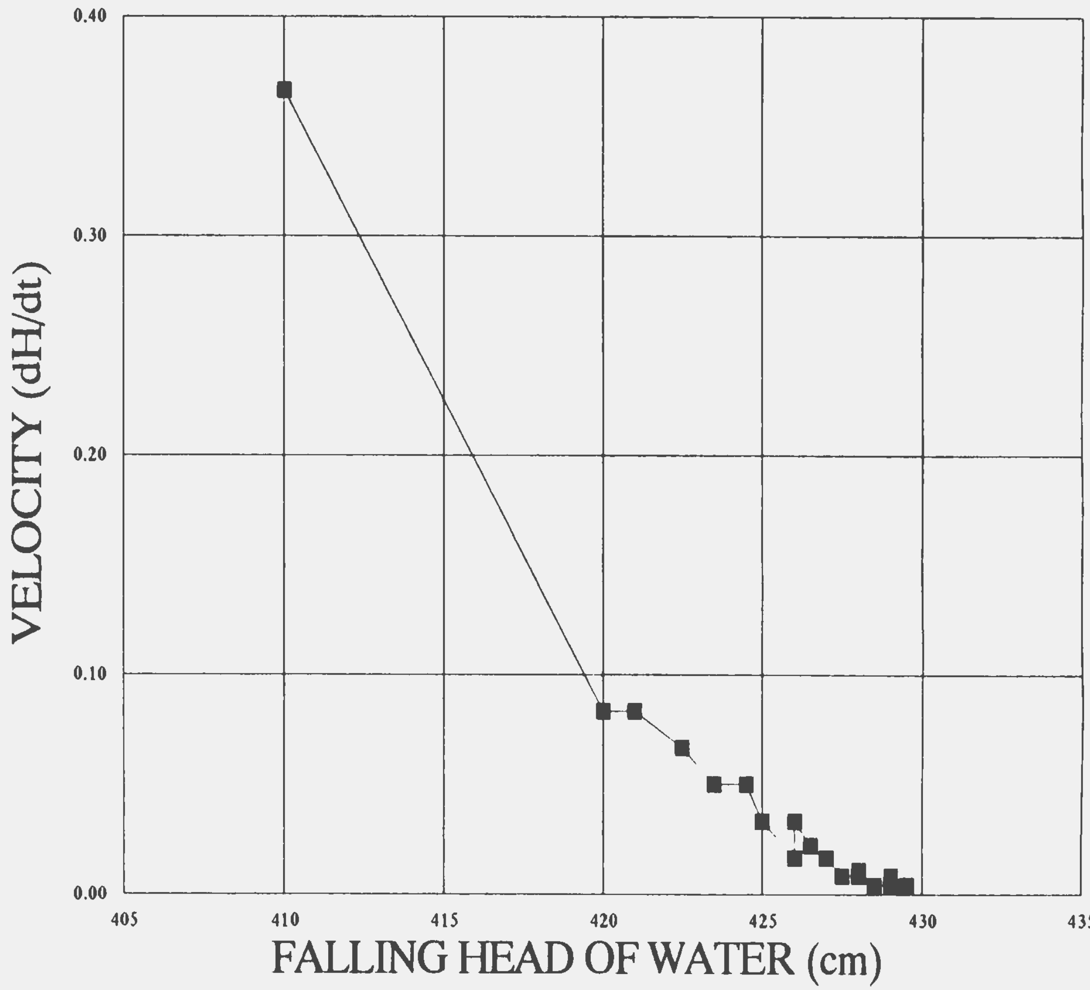


WELL # W6
DATE 5/29/92
TEST # 3-3

TIME (s)	HEAD (cm)	VELOCITY (dH/dt)
0	0	
15	346	13.6667
30	410	2.4667
45	420	0.3667
60	421	0.0833
75	422.5	0.0833
90	423.5	0.0667
105	424.5	0.0500
120	425	0.0500
135	426	0.0333
150	426	0.0167
165	426.5	0.0333
180	427	0.0222
210	427.5	0.0167
240	428	0.0083
270	428	0.0083
300	428.5	0.0111
360	429	0.0042
420	429	0.0042
480	429.5	0.0083
540	430	0.0042
600	430	

WELL #6

FALLING HEAD PERMEABILITY TEST #3



GUELPH PERMEAMETER FIELD DATA SHEET

SITE: SPREADING AREA
WELL #: GP-1
PERMEAMETER MODEL #2

DATE: 9-17-92
DEPTH OF WELL: 0.13 m

H1 = 0.06 m a = 0.02 m

CUMULATIVE TIME (t) (MIN)	READING L (cm)	RATE R dL/dt
0	113.5	3.8
2	109.7	3.5
4	106.2	3.3
6	102.9	3.4
8	99.5	3.3
10	96.2	3.3
12	92.9	3.2
14	89.7	3.2
16	86.5	3.2
	83.3	

H2 = 0.10 m a = 0.02 m

CUMULATIVE TIME (t) (MIN)	READING L (cm)	RATE R dL/dt
0	70.5	5.0
1	65.5	4.0
2	61.5	4.0
3	57.5	3.5
4	54.0	3.5
5	50.5	3.5
6	47.0	3.5
7	43.5	3.5
8	40.0	3.5
9	36.5	3.5
10	33.0	

NOTE: MINIMUM OPERATING DEPTH OF 0.15 m FOR THE SECOND H2 LEVEL.

GUELPH PERMEAMETER FIELD DATA SHEET

SITE: SPREADING AREA
WELL #: GP−2
PERMEAMETER MODEL #2

DATE: 9−17−92
DEPTH OF WELL: 0.46 m

H1 = 0.10 m   a = 0.02 m

H2 = 0.10 m   a = 0.02 m

CUMULATIVE TIME (t) (MIN)	READING L (cm)	RATE R dL/dt	CUMULATIVE TIME (t) (MIN)	READING L (cm)	RATE R dL/dt
0	114.9	3.4			
2	111.5	3.3			
4	108.2	2.6			
6	105.6	2.9			
8	102.7	2.9			
10	99.8	3.0			
12	96.8	2.7			
14	94.1	3.0			
16	91.1	2.8			
18	88.3	2.5			
20	85.8	2.6			
22	83.2	2.8			
24	80.4	2.9			
26	77.5	2.6			
28	74.9	2.8			
30	72.1				

NOTE: WELL TOO SHALLOW TO RAISE INNER RESERVOIR TO SECOND H2 READING.

GUELPH PERMEAMETER FIELD DATA SHEET

SITE: SPREADING AREA
WELL #: GP−3
PERMEAMETER MODEL #2

DATE: 9−17−92
DEPTH OF WELL: 0.46 m

H1 = 0.10 m a = 0.02 m

CUMULATIVE TIME (t) (MIN)	READING L (cm)	RATE R dL/dt
0	108.0	2.4
2	105.6	2.0
4	103.6	1.9
6	101.7	1.9
8	99.8	1.8
10	98.0	1.7
12	96.3	1.8
14	94.5	1.7
16	92.8	1.8
18	91.0	1.8
20	89.2	

H2 = 0.10 m a = 0.02 m

CUMULATIVE TIME (t) (MIN)	READING L (cm)	RATE R dL/dt
0	76	3.0
2	73	3.0
4	70	2.9
6	67.1	2.5
8	64.6	2.7
10	61.9	2.7
12	59.2	2.7
14	56.5	2.7
16	53.8	2.7
18	51.1	2.7
20	48.4	

GUELPH PERMEAMETER FIELD DATA SHEET

SITE: SPREADING AREA
WELL #: GP–4
PERMEAMETER MODEL #2

DATE: 9–17–92
DEPTH OF WELL: 0.26 m

H1 = 0.10 m   a = 0.02 m

CUMULATIVE TIME (t) (MIN)	READING L (cm)	RATE R dL/dt
0	116.0	11.0
1	105.0	8.1
2	96.9	8.0
3	88.9	8.4
4	80.5	8.1
5	72.4	7.9
6	64.5	7.8
7	56.7	

H2 = 0.10 m   a = 0.02 m

CUMULATIVE TIME (t) (MIN)	READING L (cm)	RATE R dL/dt
0	43.5	12.3
1	31.2	12.0
2	19.2	11.4
3	7.8	

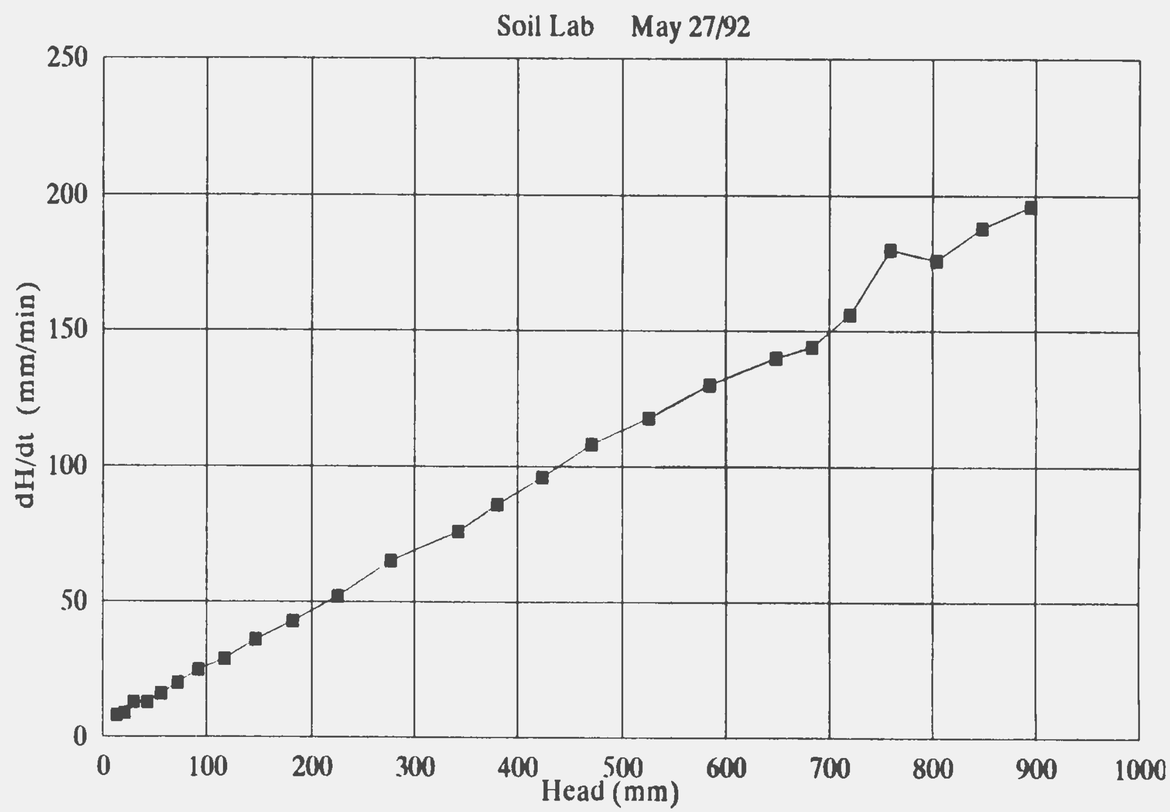
NOTE: WATER RESERVOIR WENT DRY FOR THE H2 READING – THEREFORE DISCARD.

SMALL CELL FALLING HEAD PERMEABILITY TEST

Specimen #1
SAMPLE FROM BROOKFIELD RD SITE
Heavily compacted

TIME (min)	HEIGHT (mm)	dH/dt (mm/min)
0	978.0	
0	944.0	136.0
1	895.0	196.0
1	848.0	188.0
1	804.0	176.0
1	759.0	180.0
2	720.0	156.0
2	684.0	144.0
2	649.0	140.0
3	584.0	130.0
3	525.0	118.0
4	471.0	106.0
4	423.0	96.0
5	380.0	86.0
5	342.0	76.0
8	277.0	65.0
7	225.0	52.0
8	182.0	43.0
9	146.0	36.0
10	117.0	29.0
11	92.0	25.0
12	72.0	20.0
13	56.0	16.0
14	43.0	13.0
15	30.0	13.0
16	21.0	9.0
17	13.0	8.0
16	7.0	

Falling Head Permeability Test



SMALL CELL FALLING HEAD PERMEABILITY TEST (SOIL LAB)

Specimen #1 Heavily compacted

MAY 27/92 SAMPLE FROM BROOKFIELD RD SITE

TEST 1

TIME (min)	HEIGHT (mm)	dH/dt (mm/min)
0	974.0	
0	908.0	264.0
1	860.0	192.0
1	817.0	172.0
1	773.0	176.0
1	734.0	156.0
2	695.0	156.0
2	662.0	132.0
2	628.0	136.0
2	596.0	128.0
3	565.0	124.0
3	536.0	116.0
3	510.0	104.0
3	483.0	108.0
4	459.0	96.0
4	435.0	96.0
4	413.0	88.0
4	392.0	84.0
5	372.0	80.0
5	354.0	72.0
5	335.0	76.0
5	318.0	68.0
6	302.0	64.0
6	287.0	60.0
6	274.0	52.0
6	259.0	60.0
7	246.0	52.0
7	233.0	52.0
7	223.0	40.0
7	211.0	48.0
8	200.0	44.0
8	189.0	44.0
8	180.0	36.0
8	171.0	36.0
9	162.0	36.0
9	154.0	32.0
9	145.0	36.0
9	138.0	28.0
10	131.0	28.0
10	124.0	28.0
10	118.0	24.0
11	105.0	26.0
11	94.0	22.0
12	83.0	22.0
12	75.0	16.0
13	65.0	20.0
13	58.0	14.0
14	50.0	16.0
14	45.0	10.0
15	39.0	12.0
15	34.0	10.0
16	29.0	10.0
16	24.5	9.0
17	20.0	9.0
17	16.0	8.0
18	13.0	

TEST 2

TIME (min)	HEIGHT (mm)	dH/dt (mm/min)
0	971.5	
0	910.0	246.0
1	851.0	236.0
1	794.0	228.0
1	740.0	216.0
1	691.0	196.0
2	645.0	184.0
2	604.0	164.0
2	560.0	176.0
2	524.0	144.0
3	492.0	128.0
3	458.0	136.0
3	429.0	116.0
3	398.0	124.0
4	374.0	96.0
4	347.0	108.0
4	325.0	88.0
4	303.0	88.0
5	283.0	80.0
5	264.0	76.0
5	245.0	76.0
5	231.0	56.0
6	215.0	64.0
6	201.0	56.0
6	188.0	52.0
6	175.0	52.0
7	164.0	44.0
7	152.0	48.0
7	142.0	40.0
7	131.0	44.0
8	122.0	36.0
8	113.0	36.0
8	105.0	32.0
8	97.0	32.0
9	89.0	32.0
9	82.0	28.0
9	75.0	28.0
9	69.0	24.0
10	63.0	24.0
10	58.0	20.0
10	53.0	20.0
10	48.0	20.0
11	44.0	16.0
11	39.0	20.0
11	35.0	16.0
11	31.0	16.0
12	27.0	16.0
12	23.0	16.0
12	20.0	12.0
12	17.0	12.0
13	14.0	12.0
13	12.0	8.0
13	9.0	12.0
13	6.0	12.0
14	4.0	8.0
14	1.0	

SMALL CELL FALLING HEAD PERMEABILITY TEST (SOIL LAB)

Specimen #2 Loosely compacted Small Cell

June 4, 1992 SAMPLE FROM BROOKFILED RD SITE

TEST #1

TIME (s)	HEIGHT (cm)	dH/dt (cm/s)
0	93.0	
30	67.0	0.9
60	50.0	0.6
90	36.0	0.5
120	23.0	0.4
150	13.0	0.3
180	4.0	

TEST #2

TIME (s)	HEIGHT (cm)	dH/dt (cm/s)
0	94	
30	68	0.87
60	49	0.63
90	32	0.57
120	20	0.40
150	8	

TEST #3

TIME (s)	HEIGHT (cm)	dH/dt (cm/s)
0	102	
30	79	0.77
60	58	0.70
90	41	0.57
120	27	0.47
150	15	0.40
180	6	

SMALL CELL FALLING HEAD PERMEBILTY TEST

Medium Compaction

Specimen #3

Small Cell

MAY 8,1992

SAMPLE FROM BROOKFIELD RD SITE

Test #1

TIME (min)	Height (cm)	Head (cm)	dh/dt (cm/min)
0	98.1	113.9	
2	86.7	102.5	5.7
4	77.6	93.4	4.5
6	69.8	85.6	3.9
8	63.2	79.0	3.3
10	57.4	73.2	2.9
12	52.3	68.1	2.5
14	47.8	63.6	2.3
16	43.7	59.5	2.0
18	40.4	56.2	1.6
20	37.2	53.0	1.6
22	34.5	50.3	1.4
24	32.4	48.2	1.0
26	30.5	46.3	1.0
28	28.7	44.5	0.9
30	27.9	43.7	0.4
32	27.1	42.9	0.4
34	26.3	42.1	0.4
36	25.4	41.2	0.4
41	22.8	38.6	0.5
46	20.5	36.3	0.5
51	18.3	34.1	0.4
56	16.8	32.6	0.3
61	14.8	30.6	0.4
68	12.6	28.4	0.3
76	10.3	26.1	

SMALL CELL FALLING HEAD PERMEABILITY TEST (SOIL LAB)

Specimen #4

June 11/92 SAMPLE FROM BROOKFIELD RD SITE Highly Compact Soil Small Cell

TEST #1

TIME (s)	HEIGHT (cm)	dH/dt (cm/s)
0	100.0	
36	94.0	0.2
60	90.0	0.2
90	85.0	0.2
120	81.0	0.1
150	77.0	0.1
180	73.0	0.1
210	68.0	0.2
240	65.0	0.1
300	58.0	0.1
400	48.0	

TEST #2

TIME (s)	HEIGHT (cm)	dH/dt (cm/s)
0	95.0	
30	78.0	0.6
60	66.0	0.4
90	54.0	0.4
120	43.0	0.4
150	35.0	0.3
180	26.0	0.3
210	19.0	0.2
240	12.0	0.2
270	7.0	0.2
300	2.0	

TEST #3

TIME (s)	HEIGHT (cm)	dH/dt (cm/s)
0	96.0	
30	87.0	0.3
60	78.0	0.3
90	69.0	0.3
120	61.0	0.3
150	54.0	0.2
180	48.0	0.2
210	43.0	0.2
240	37.0	0.2
270	31.0	0.2
300	26.0	0.2
360	17.0	0.2
390	14.0	

SMALL CELL FALLING HEAD PERMEABILITY TEST (SOIL LAB)

Specimen #5

June 17/92 SAMPLE FROM BROOKFIELD RD SITE No. 10 sieve

TEST #1

TIME (s)	HEIGHT (cm)	dH/dt (cm/s)
0	97.0	
50	79.0	0.4
100	69.0	0.2
150	60.0	0.2
200	51.0	0.2
250	44.0	0.1
300	37.0	0.1
350	31.0	0.1
400	24.0	0.1
450	18.0	0.1
500	13.0	0.1
550	8.0	

TEST #2

TIME (s)	HEIGHT (cm)	dH/dt (cm/s)
0	97.0	
50	84.0	0.3
100	75.0	0.2
150	65.0	0.2
200	58.0	0.1
250	49.0	0.2
300	42.0	0.1
350	36.0	0.1
400	30.0	0.1
450	22.0	0.2
500	17.0	0.1
550	12.0	

FALLING HEAD PERMEABILITY TEST

WELL # 1
TEST # 1 (c)

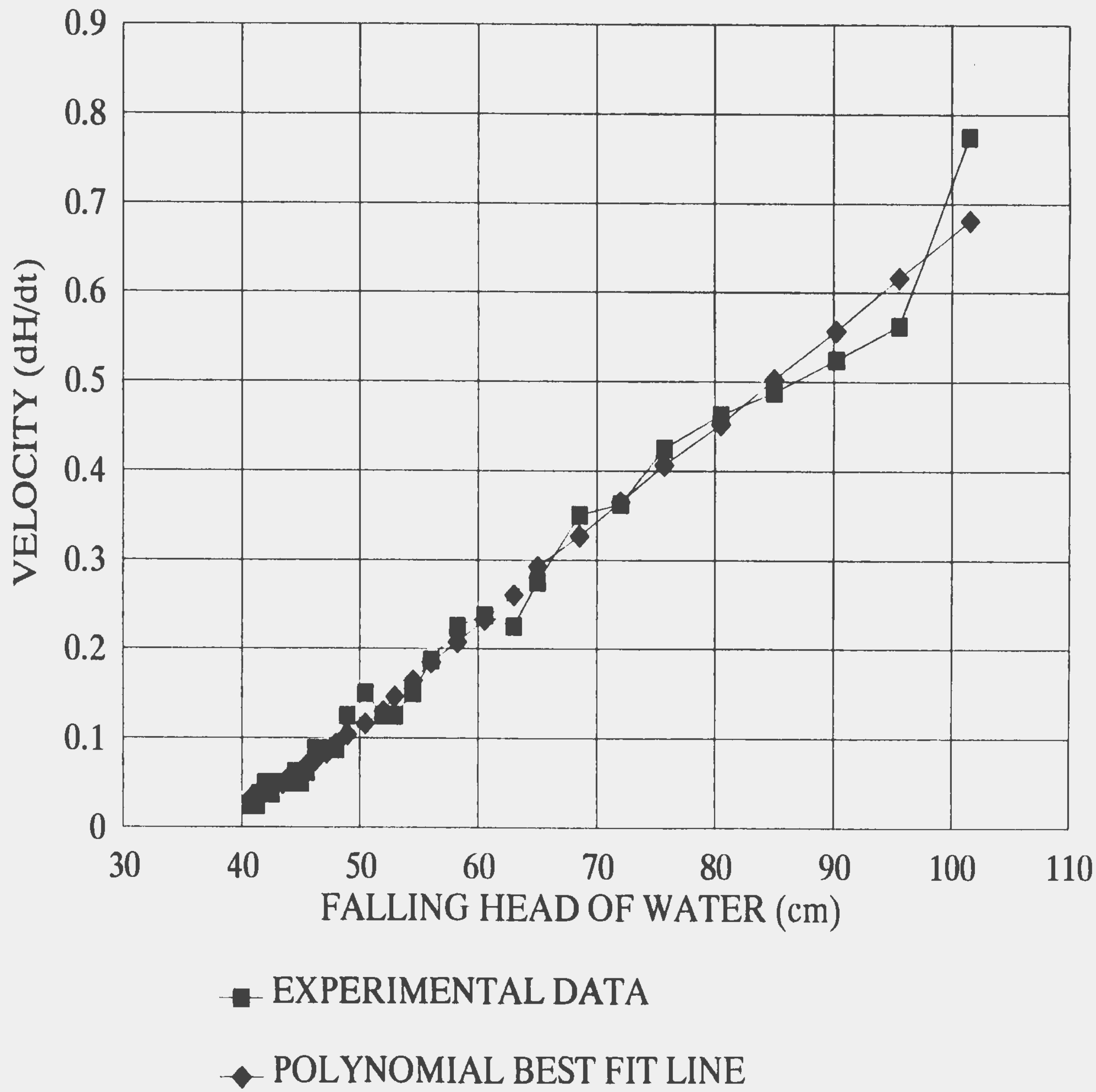
TEST START DATE: JUNE 05, 1992

SWL (arp) = 876 mm

TIME (min)	HEAD (cm)	dH/dt (cm/min)	POLY EQ
0	111.0		
10	101.5	0.8	0.6806
20	95.5	0.6	0.6162
30	90.3	0.5	0.5569
40	85.0	0.5	0.5023
50	80.5	0.5	0.4523
60	75.8	0.4	0.4064
70	72.0	0.4	0.3646
80	68.5	0.4	0.3266
90	65.0	0.3	0.2920
100	63.0	0.2	0.2608
110	60.5	0.2	0.2326
120	58.3	0.2	0.2072
130	56.0	0.2	0.1845
140	54.5	0.2	0.1642
150	53.0	0.1	0.1462
160	52.0	0.1	0.1302
170	50.5	0.2	0.1161
180	49.0	0.1	0.1038
190	48.0	0.1	0.0930
200	47.3	0.1	0.0836
210	46.3	0.1	0.0754
220	45.5	0.1	0.0684
230	45.0	0.1	0.0623
240	44.5	0.1	0.0571
250	43.8	0.1	0.0527
260	43.5	0.1	0.0488
270	42.8	0.1	0.0455
280	42.5	0.0	0.0427
290	42.0	0.1	0.0402
300	41.5	0.0	0.0380
310	41.3	0.0	0.0360
320	41.0	0.0	0.0341
330	40.8	0.0	0.0323
340	40.5		

WELL # 1

FALLING HEAD PERMEABILITY TEST



FALLING HEAD PERMEABILITY TEST

WELL # 1
TEST # 2 (c)

TEST START DATE: JUNE 07, 1992

SWL (arp) = 876 mm

TIME (min)	HEAD (cm)	dH/dt (cm/min)	POLY EQ
0	115.0		
10	108.0	0.7	0.6549
20	101.5	0.6	0.5957
30	96.0	0.5	0.5410
40	91.5	0.5	0.4906
50	86.5	0.5	0.4441
60	82.0	0.4	0.4014
70	78.0	0.4	0.3622
80	74.5	0.3	0.3263
90	71.5	0.3	0.2934
100	68.5	0.3	0.2634
110	66.5	0.2	0.2361
120	64.0	0.2	0.2113
130	62.0	0.2	0.1888
140	60.5	0.2	0.1685
150	59.0	0.2	0.1501
160	57.5	0.1	0.1336
170	56.5	0.1	0.1188
180	55.0	0.1	0.1055
190	54.0	0.1	0.0936
200	53.5	0.1	0.0831
210	52.5	0.1	0.0737
220	51.8	0.1	0.0654
230	51.0	0.1	0.0581
240	50.5	0.1	0.0517
250	50.0	0.1	0.0460
260	49.5	0.1	0.0411
270	49.0		

WELL # 2
TEST # 1 (c)

TEST START DATE: JUNE 08, 1992

SWL (arp) = 900 mm

TIME (sec)	TIME (min)	HEAD (cm)	dH/dt (cm/min)
0	0.0	85.0	
30	0.5	76.0	16.0
60	1.0	69.0	12.5
90	1.5	63.5	9.5
120	2.0	59.5	7.5
150	2.5	56.0	7.0
180	3.0	52.5	6.0
210	3.5	50.0	4.5
240	4.0	48.0	3.8
270	4.5	46.3	3.5
300	5.0	44.5	3.3
330	5.5	43.0	2.5
360	6.0	42.0	2.0
390	6.5	41.0	2.0
420	7.0	40.0	2.0
450	7.5	39.0	2.0
480	8.0	38.0	1.5
510	8.5	37.5	1.0
540	9.0	37.0	1.5
570	9.5	36.0	1.5
600	10.0	35.5	1.0
630	10.5	35.0	1.0
660	11.0	34.5	1.0
690	11.5	34.0	1.0
720	12.0	33.5	0.5
750	12.5	33.5	0.5
780	13.0	33.0	0.5
810	13.5	33.0	0.5
840	14.0	32.5	0.5
870	14.5	32.5	0.5
900	15.0	32.0	0.5
930	15.5	32.0	0.5
960	16.0	31.5	0.5
990	16.5	31.5	0.5
1020	17.0	31.0	31.5
1050	17.5		

WELL # 2
TEST # 2 (c)

TEST START DATE: JUNE 08, 1992

SWL (arp) = 900 mm

TIME (min)	HEAD (cm)	dH/dt (cm/min)
0	84.0	
1	60.5	13.0
2	47.5	8.0
3	39.5	4.0
4	35.5	2.5
5	33.0	2.0
6	31.0	1.5
7	29.5	1.0
8	28.5	0.5
9	28.0	1.0
10	27.0	0.5
11	26.5	0.5
12	26.0	0.5
13	25.5	0.0
14	25.5	0.5
15	25.0	0.3
20	23.5	0.2
25	22.5	0.2
30	21.5	0.1
35	21.0	

WELL # 2
TEST # 3 (c)

TEST START DATE: JUNE 8, 1992

SWL (arp) = 900 mm

TIME (min)	HEAD (cm)	dH/dt (cm/min)
0	85.0	
1	60.0	12.5
2	47.5	6.5
3	41.0	4.0
4	37.0	2.5
5	34.5	2.0
6	32.5	1.0
7	31.5	1.0
8	30.5	1.0
9	29.5	0.5
10	29.0	1.0
11	28.0	0.5
12	27.5	0.5
13	27.0	0.5
14	26.5	0.5
15	26.0	0.2
20	25.0	

FALLING HEAD PERMEABILITY TEST

WELL # 1
TEST # 1 (c)

TEST START DATE: JUNE 15, 1992

SWL (arp) = 958 mm

TIME (min)	HEAD (cm)	dH/dt (cm/min)	POLY EQ
0	131.0		
10	124.0	0.7	0.5218
20	117.0	0.4	0.4827
30	113.0	0.4	0.4456
40	109.0	0.3	0.4106
50	106.0	0.4	0.3776
60	102.5	0.4	0.3465
70	98.5	0.3	0.3173
80	95.5	0.3	0.2899
90	92.5	0.2	0.2642
100	90.5	0.2	0.2403
110	88.5	0.3	0.2179
120	86.0	0.2	0.1972
130	84.0	0.2	0.1779
140	82.5	0.2	0.1602
150	81.0	0.1	0.1438
160	80.0	0.1	0.1288
170	79.0	0.1	0.1150
180	78.0	0.1	0.1025
190	77.0	0.1	0.0912
200	76.0	0.1	0.0810
210	75.0	0.1	0.0718
220	74.5	0.1	0.0636
230	73.5	0.1	0.0564
240	72.5		

WELL # 2
TEST # 1 (c)

TEST START DATE: JUNE 16, 1992

SWL (arp) = 974 mm

TIME (min)	HEAD (cm)	dH/dt (cm/min)
0	89.0	
1	73.0	10.5
2	62.5	6.5
3	56.0	4.5
4	51.5	2.5
5	49.0	2.0
6	47.0	2.0
7	45.0	1.0
8	44.0	1.0
9	43.0	0.5
10	42.5	1.0
11	41.5	0.5
12	41.0	0.5
13	40.5	0.0
14	40.5	0.5
15	40.0	0.0
16	40.0	0.2
17	39.8	0.3
18	39.5	0.2
21	39.0	0.0
24	39.0	0.0
27	39.0	

WELL # 2
TEST # 2 (c)

TEST START DATE: JUNE 16, 1992

SWL (arp) = 1017 mm

TIME (min)	HEAD (cm)	dH/dt (cm/min)
0	91.0	
1	76.0	10.5
2	65.5	5.5
3	60.0	4.0
4	56.0	2.7
5	53.3	1.8
6	51.5	1.0
7	50.5	1.5
8	49.0	1.0
9	48.0	0.5
10	47.5	1.0
11	46.5	0.5
12	46.0	0.5
13	45.5	0.5
14	45.0	0.5
15	44.5	0.0
16	44.5	0.5
17	44.0	

RISING HEAD PERMEABILITY TEST

WELL # 1
TEST # 1 (c)

TEST START DATE: JUNE 16, 1992

SWL (arp) = 1017 mm

TIME (min)	HEAD (cm)	dH/dt (cm/min)
0	7.0	
1	19.0	5.0
2	24.0	7.0
3	31.0	5.0
4	36.0	4.0
5	40.0	3.0
6	43.0	3.5
7	46.5	2.5
8	49.0	2.0
9	51.0	2.0
10	53.0	2.0
11	55.0	1.0
12	56.0	1.5
13	57.5	1.0
14	58.5	1.0
15	59.5	1.0
16	60.5	0.5
17	61.0	0.5
18	61.5	0.5
19	62.0	0.5
20	62.5	0.5
21	63.0	0.0
22	63.0	0.5
23	63.5	0.0
24	63.5	0.0
25	63.5	0.5
26	64.0	0.0
27	64.0	

WELL # 1
TEST # 2 (c)

TEST START DATE: JUNE 17, 1992

SWL (arp) = 1017 mm

TIME (min)	HEAD (cm)	dH/dt (cm/min)
0	10.0	
1	15.0	5.0
2	20.0	4.0
3	24.0	2.5
4	26.5	3.0
5	29.5	3.0
6	32.5	2.5
7	35.0	3.0
8	38.0	2.0
9	40.0	1.5
10	41.5	1.5
11	43.0	1.5
12	44.5	1.5
13	46.0	1.5
14	47.5	1.0
15	48.5	1.0
16	49.5	0.5
17	50.0	0.0
18	50.0	1.0
19	51.0	0.5
20	51.5	0.0
21	51.5	0.5
22	52.0	0.0
23	52.0	0.5
24	52.5	0.0
25	52.5	0.0
30	52.5	0.0
35	52.5	

WELL # 2
TEST # 1 (u)

TEST START DATE: June 24, 1992

SWL (arp) = 900 mm

TIME (min)	HEAD (cm)	dH/dt (cm/min)
0	3.0	
3	9.0	1.0
6	12.0	0.7
9	14.0	0.2
12	14.5	0.2
15	15.0	0.2
18	15.5	0.2
21	16.0	0.0
24	16.0	0.0
27	16.0	0.2
30	16.5	0.0
35	16.5	0.0
40	16.5	0.0
45	16.5	0.1
50	17.0	0.2
55	18.0	

WELL # 2
TEST # 2 (u)

TEST START DATE: June 24, 1992

SWL (arp) = 907 mm

TIME (min)	HEAD (cm)	dH/dt (cm/min)
0	27.0	
3	37.5	1.0
6	40.5	0.7
9	42.5	0.3
12	43.5	0.3
15	44.5	0.2
18	45.0	0.0
21	45.0	0.2
24	45.5	0.0
27	45.5	0.2
30	46.0	0.0
33	46.0	

FALLING HEAD PERMEABILITY TEST

NO TESTS WERE PERFORMED ON WELL #2 BECAUSE OF THE HIGH SWL IN THE TANK THEREFORE LITTLE HEAD DIFFERENCE.

WELL # 1
TEST # 1 (u)

TEST START DATE: AUGUST 18, 1992

SWL (arp) = 1155 mm

TIME (min)	HEAD (cm)	dH/dt (cm/min)	POLY EQ.
0	121.0		
3	119.5	0.6	0.5988
8	117.0	0.5	0.4973
12	115.0	0.5	0.4149
16	113.0	0.2	0.3451
20	112.0	0.3	0.2838
24	111.0	0.2	0.2343
28	110.0	0.1	0.1899
33	109.5	0.1	0.1545
37	109.0	0.1	0.1269
41	108.5	0.1	0.1049
45	108.0	0.1	0.0885
49	107.5	0.1	0.0771
58	107.0	0.1	0.0649
66	106.5	0.1	0.0624
91	105.0	0.0	0.0504
116	105.0		

WELL # 1
TEST # 2 (u)

TEST START DATE: AUGUST 18, 1992

SWL (arp) = 1155 mm

TIME (min)	HEAD (cm)	dH/dt (cm/min)	POLY EQ.
0	115.0		
33	113.0	0.1	0.0768
67	110.5	0.1	0.0672
100	108.0	0.1	0.0586
133	106.0	0.0	0.0510
167	104.5	0.0	0.0443
200	103.0	0.0	0.0385
233	102.0	0.0	0.0336
267	101.0	0.0	0.0293
300	100.5	0.0	0.0258
333	99.5	0.0	0.0229
367	98.5	0.0	0.0205
400	98.0	0.0	0.0187
433	97.5	0.0	0.0173
467	97.0	0.0	0.0163
500	96.0	0.0	0.0156
533	96.0	0.0	0.0151
567	95.5	0.0	0.0149
600	94.5	0.0	0.0147
633	94.0	0.0	0.0147
667	93.5	0.0	0.0146
700	93.0	0.0	0.0146
733	93.0	0.0	0.0143
767	92.5	0.0	0.0140
800	92.0	0.0	0.0133
833	91.5	0.0	0.0124
867	91.0	0.0	0.0111
900	91.0	0.0	0.0094
933	90.5	0.0	0.0073
967	90.0		

WELL # 1
TEST # 3 (u)

TEST START DATE: AUGUST 19, 1992

SWL (arp) = 1157 mm

TIME (min)	HEAD (cm)	dH/dt (cm/min)	POLY EQ.
0	115.5		
33	114.0	0.0	0.0339
67	113.0	0.0	0.0322
100	112.0	0.0	0.0306
133	111.0	0.0	0.0292
167	110.5	0.0	0.0279
200	110.0	0.0	0.0267
233	109.0	0.0	0.0256
267	107.5	0.0	0.0246
310	106.5	0.0	0.0235
377	104.5	0.0	0.0221
443	102.5	0.0	0.0210
510	101.5	0.0	0.0202
577	101.5	0.0	0.0196
643	100.0	0.0	0.0192
710	98.5	0.0	0.0189
777	97.5	0.0	0.0187
843	96.0	0.0	0.0185
910	94.5	0.0	0.0182
977	93.0	0.0	0.0179
1043	92.0	0.0	0.0175
1110	91.0	0.0	0.0169
1177	90.0	0.0	0.0161
1243	89.0	0.0	0.0150
1310	88.0		

FALLING HEAD PERMEABILITY TEST

WELL # 1
TEST # 1 (u)

TEST START DATE: SEPTEMBER 9, 1992

SWL (arp) = 825 mm

TIME (min)	HEAD (cm)	dH/dt (cm/min)	POLY EQ
0	112.0		
7	104.0	1.0	1.1278
13	97.5	0.9	1.0200
20	91.5	1.0	0.9097
27	85.0	0.5	0.8131
31	83.0	1.0	0.7554
34	80.0	0.8	0.7170
42	74.0	0.6	0.6218
51	69.0	0.5	0 5307
59	64.5	0.4	0 4517
67	61.5	0.3	0.3849
76	58.5	0.3	0.3208
84	56.0	0.3	0.2672
92	54.0	0.1	0.2219
101	53.0	0.2	0.1769
109	51.5	0.1	0.1436
117	50.5	0.1	0.1142
142	48.5	0.0	0.0470
159	49.0		

WELL # 1
TEST # 2 (u)

TEST START DATE: SEPTEMBER 10, 1992

SWL (arp) = 840 mm

TIME (min)	HEAD (cm)	dH/dt (cm/min)	POLY EQ
0	110.0		
5	103.5	1.4	1.1425
10	96.5	1.4	1.0596
13	92.0	1.4	1.0073
17	87.5	0.9	0.9568
20	84.5	0.5	0.9068
40	74.5	0.4	0.6489
60	67.0	0.3	0.4472
80	62.0	0.2	0.2935
100	58.0	0.2	0.1799
120	55.0	0.1	0.0994
140	52.5	0.1	0.0456
160	50.5	0.1	0.0126
180	49.0		

WELL # 2
TEST # 1 (u)

TEST START DATE: SEPTEMBER 11, 1992

SWL (arp) = 840 mm

TIME (sec)	TIME (min)	HEAD (cm)	dH/dt (cm/min)
0	0.00	100.0	
2	0.03	92.0	210.0
4	0.07	85.0	165.0
6	0.10	79.5	150.0
8	0.13	74.5	120.0
10	0.17	70.5	90.0
12	0.20	67.5	90.0
14	0.23	64.5	75.0
16	0.27	62.0	60.0
18	0.30	60.0	45.0
20	0.33	58.5	45.0
24	0.40	55.5	30.0
28	0.47	53.5	22.5
32	0.53	52.0	22.5
36	0.60	50.5	7.5
40	0.67	50.0	15.0
44	0 73	49.0	15.0
48	0.80	48.0	10.0
57	0.95	46.5	5.0
75	1 25	45.0	2.4
100	1.67	44.0	1.0
160	2.67	43.0	0.5
217	3.62	42.5	

WELL # 2
TEST # 2 (u)

TEST START DATE: SEPTEMBER 11, 1992

SWL (arp) = 840 mm

TIME (sec)	TIME (min)	HEAD (cm)	dH/dt (cm/min)
0	0.000	100	210.0
2	0.033	93	225.0
4	0.067	85.5	120.0
6	0.100	81.5	150.0
8	0.133	76.5	75.0
10	0.167	74	90.0
12	0.200	71	90.0
14	0.233	68	60.0
16	0 267	66	60.0
18	0.300	64	60.0
20	0.333	62	30.0
22	0.367	61	45.0
24	0.400	59.5	30.0
26	0.433	58.5	45.0
28	0.467	57	15.0
30	0.500	56.5	30 0
32	0.533	55.5	15.0
34	0.567	55	15.0
36	0.600	54.5	15.0
38	0.633	54	15.0
40	0.667	53.5	15.0
42	0.700	53	15.0
44	0.733	52.5	15.0
46	0.767	52	0.0
48	0.800	52	15.0
50	0.833	51.5	15.0
52	0.867	51	0.0
54	0.900	51	

APPENDIX F

GROUNDWATER QUALITY DATA

GROUNDWATER QUALITY DATA

WELL #	YEAR	MONTH	DAY	DATE CODE	DATE	ORTHOPHOS. mg/l (PO4)3-	N-NITRATE mg/l (N-NO3-)	N-AMMONIA mg/l (N-NH3)	CHLORIDE mg/l (Cl-)	pH Units	TEMP. Degree C	CONDUC. mS/cm	T D S g/L	Tot. HARD. mg/l CaCO3	Ca. HARD. mg/l CaCO3	Mg. HARD. mg/l CaCO3
3	92	5	14	33738	14-May-92	1.25	11.0	0.35	3.0	7.35	19.4	0.128	0.063	N/A	N/A	N/A
3	92	5	20	33744	20-May-92											
3	92	5	20	33753	29-May-92											
3	92	6	3	33758	03-Jun-92											
3	92	6	30	33785	30-Jun-92											
3	92	7	3	33788	03-Jul-92											
3	92	7	6	33791	06-Jul-92											
3	92	7	9	33794	09-Jul-92	0.55	14.6	0.18	6.9	4.36	22.1	0.191	0.096	93.0	40.0	53.0
3	92	7	20	33805	20-Jul-92											
3	92	7	27	33812	27-Jul-92											
3	92	8	3	33819	03-Aug-92											
3	92	8	20	33836	20-Aug-92											
3	92	9	8	33855	08-Sep-92											
3	92	10	10	33887	10-Oct-92	0.25	0.0	0.30	5.2	6.60	21.5	0.068	0.034	15.7	14.0	1.7
3	92	11	16	33924	16-Nov-92											
3	92	12	11	33949	11-Dec-92											
4	92	5	14	33738	14-May-92	0.01	5.2	0.16	9.0	5.93	19.5	0.091	0.044	N/A	N/A	N/A
4	92	5	20	33744	20-May-92	0.18	4.3	0.46	10.0	6.23	19.5	0.090	0.040	34.0	20.0	14.0
4	92	5	29	33753	29-May-92											
4	92	6	3	33758	03-Jun-92											
4	92	6	30	33785	30-Jun-92											
4	92	7	3	33788	03-Jul-92											
4	92	7	6	33791	06-Jul-92											
4	92	7	9	33794	09-Jul-92	0.47	7.9	0.19	11.5	6.01	21.2	0.142	0.071	56.0	32.0	24.0
4	92	7	20	33805	20-Jul-92											
4	92	7	27	33812	27-Jul-92											
4	92	8	3	33819	03-Aug-92											
4	92	8	20	33836	20-Aug-92											
4	92	9	8	33855	08-Sep-92											
4	92	10	10	33887	10-Oct-92	0.00	10.3	0.09	8.7	5.98	23.2	0.112	0.056	30.5	22.0	8.5
4	92	11	16	33924	16-Nov-92											
4	92	12	11	33949	11-Dec-92											
5	92	5	14	33738	14-May-92	0.07	1.3	0.23	23.0	7.49	19.6	0.370	0.200			
5	92	5	20	33744	20-May-92											
5	92	5	29	33753	29-May-92	0.02	1.8	0.24	86.0	6.83	25.9	0.180	0.080	47.0	40.0	7.0
5	92	6	3	33758	03-Jun-92											
5	92	6	30	33785	30-Jun-92											
5	92	7	3	33788	03-Jul-92	0.02	0.2	0.51	19.6	6.95	23.6	0.318	0.160	80.8	65.2	15.6
5	92	7	6	33791	06-Jul-92	0.77	0.0	0.44	22.2	7.58	23.0	0.399	0.195	106.8	86.8	20.0
5	92	7	9	33794	09-Jul-92	0.23	2.4	0.42	22.5	7.33	22.0	0.391	0.200	122.0	101.0	21.0
5	92	7	20	33805	20-Jul-92	0.67	1.4	0.58	27.2	7.43	19.9	0.599	0.283	136.4	111.2	25.2
5	92	7	27	33812	27-Jul-92											
5	92	8	3	33819	03-Aug-92											
5	92	8	20	33836	20-Aug-92											
5	92	9	8	33855	08-Sep-92											
5	92	10	10	33887	10-Oct-92											
5	92	11	16	33924	16-Nov-92											
5	92	12	11	33949	11-Dec-92											
6	92	5	14	33738	14-May-92											
6	92	5	20	33744	20-May-92	4.50	4.1	0.25	26.0	7.91	19.3	0.940	0.460	149.0	114.0	35.0
6	92	5	29	33753	29-May-92	0.09	6.3	0.45	71.0	7.85	23.6	0.830	0.420	117.0	106.0	11.0
6	92	6	3	33758	03-Jun-92											
6	92	6	30	33785	30-Jun-92	0.06	2.6	0.53	69.0	7.23	20.3	0.705	0.352	43.6	33.6	10.0
6	92	7	3	33788	03-Jul-92	0.34	0.7	1.90	24.3	7.89	22.7	0.534	0.266	60.8	42.8	18.0
6	92	7	6	33791	06-Jul-92	0.04	1.4	0.88	20.8	7.59	22.8	0.405	0.202	63.2	39.6	23.6
6	92	7	9	33794	09-Jul-92	0.14	1.8	0.18	14.8	6.85	19.3	0.265	0.133	67.0	53.0	14.0
6	92	7	20	33805	20-Jul-92											
6	92	7	27	33812	27-Jul-92	0.89	4.2	1.02	18.8	7.75	23.3	0.415	0.207	66.8	37.6	29.2
6	92	8	3	33819	03-Aug-92	0.04	4.0	0.92	21.5	7.13	20.0	0.293	0.147	66.0	49.6	16.4
6	92	8	20	33836	20-Aug-92	0.19	15.9	1.06	23.4	7.27	20.8	0.341	0.170	96.8	72.0	24.8
6	92	9	8	33855	08-Sep-92	0.18	10.1	0.64	22.3	7.36	22.4	0.336	0.167	56.0	42.8	13.2
6	92	10	10	33887	10-Oct-92	0.31	0.7	0.45	10.1	7.64	22.5	0.252	0.126	52.2	43.2	9.0
6	92	11	16	33924	16-Nov-92	0.02	7.6	0.01	24.4	6.73	19.5	0.335	0.167	73.5	47.9	25.6
6	92	12	11	33949	11-Dec-92	0.05	7.3	-0.00	20.1	7.07	19.4	0.291	0.146	72.0	40.4	31.8

GROUNDWATER QUALITY DATA

WELL #	YEAR	MONTH	DAY	DATE CODE	DATE	ORTHOPHOS. mg/l (PO4)3-	N-NITRATE mg/l (N-NO3-)	N-AMMONIA mg/l (N-NH3)	CHLORIDE mg/l (Cl-)	pH Units	TEMP. Degree C	CONDUC. mS/cm	T D S g/L	Tot. HARD. mg/l CaCO3	Ca. HARD. mg/l CaCO3	Mg. HARD. mg/l CaCO3
7	92	5	14	33738	14-May-92	0.02	0.2	0.05	24.0	7.58	19.1	0.810	0.400	318.0	246.0	72.0
7	92	5	20	33744	20-May-92											
7	92	5	29	33753	29-May-92											
7	92	6	3	33758	03-Jun-92											
7	92	6	30	33785	30-Jun-92											
7	92	7	3	33788	03-Jul-92	0.23	3.0	0.31	18.4	7.74	21.9	0.719	0.359	265.2	221.6	43.6
7	92	7	6	33791	06-Jul-92	1.13	1.8	0.30	14.9	7.81	21.9	0.712	0.355	258.4	214.0	44.4
7	92	7	9	33794	09-Jul-92	0.41	0.1	0.34	22.4	7.74	20.1	0.645	0.322	244.0	201.0	43.0
7	92	7	20	33805	20-Jul-92	0.04	0.2	0.34	31.2	7.72	19.7	0.616	0.307	205.6	177.6	28.0
7	92	7	27	33812	27-Jul-92											
7	92	8	3	33819	03-Aug-92											
7	92	8	20	33836	20-Aug-92											
7	92	9	8	33855	08-Sep-92											
7	92	10	10	33887	10-Oct-92											
7	92	11	16	33924	16-Nov-92											
7	92	12	11	33949	11-Dec-92											
8	92	5	14	33738	14-May-92											
8	92	5	20	33744	20-May-92											
8	92	5	29	33753	29-May-92	0.04	0.3	0.24	20.0	7.76	21.8	0.430	0.210	140.0	103.0	37.0
8	92	6	3	33758	03-Jun-92											
8	92	6	30	33785	30-Jun-92											
8	92	7	3	33788	03-Jul-92	0.02	6.6	0.44	16.3	7.16	21.1	0.412	0.206	117.6	80.4	37.2
8	92	7	6	33791	06-Jul-92	0.06	1.4	0.48	17.6	7.73	21.5	0.411	0.205	118.4	73.6	44.8
8	92	7	9	33794	09-Jul-92	0.36	1.7	0.15	17.7	7.52	19.6	0.422	0.211	103.0	78.0	25.0
8	92	7	20	33805	20-Jul-92	0.03	5.0	0.46	16.1	7.38	20.1	0.366	0.195	71.2	53.2	18.0
8	92	7	27	33812	27-Jul-92	0.18	4.0	0.52	16.1	7.47	22.4	0.406	0.202	90.0	67.6	22.4
8	92	8	3	33819	03-Aug-92	0.03	4.8	0.60	14.4	7.53	20.0	0.366	0.194	103.2	72.4	30.8
8	92	8	20	33836	20-Aug-92	0.60	7.6	0.92	13.8	7.51	20.8	0.375	0.187	117.6	85.2	32.4
8	92	9	8	33855	08-Sep-92	0.04	4.0	0.62	16.6	7.51	20.8	0.166	0.083	115.2	50.0	65.2
8	92	10	10	33887	10-Oct-92	0.04	3.9	0.20	10.4	7.38	23.2	0.339	0.170	108.6	90.8	17.8
8	92	11	16	33924	16-Nov-92	0.02	5.4	0.17	13.3	7 12	20.2	0.345	0.172	112.8	89.2	23.6
8	92	12	11	33949	11-Dec-92	0.05	5.1	0.08	11.2	7.01	19.4	0.315	0.158	112.4	90.0	22.4
9	92	5	14	33738	14-May-92	0.03	0.2	0.04	17.0	6.96	19.3	0.210	0.100	83.0	62.0	21.0
9	92	5	20	33744	20-May-92											
9	92	5	29	33753	29-May-92											
9	92	6	3	33758	03-Jun-92											
9	92	6	30	33785	30-Jun-92											
9	92	7	3	33788	03-Jul-92											
9	92	7	6	33791	06-Jul-92											
9	92	7	9	33794	09-Jul-92	0.35	4.4	0.03	19.5	6.51	20.0	0.252	0.127	99.0	69.0	30.0
9	92	7	20	33805	20-Jul-92	0.03	1.5	0.24	21.4	7.40	20.2	0.496	0.248	167.6	144.0	23.6
9	92	7	27	33812	27-Jul-92											
9	92	8	3	33819	03-Aug-92											
9	92	8	20	33836	20-Aug-92											
9	92	9	8	33855	08-Sep-92											
9	92	10	10	33887	10-Oct-92											
9	92	11	16	33924	16-Nov-92											
9	92	12	11	33949	11-Dec-92											
10	92	5	14	33738	14-May-92											
10	92	5	20	33744	20-May-92											
10	92	5	29	33753	29-May-92	0.02	6.5	0.20	23.0	6.34	22.9	0 170	0.080	79.0	43.0	36.0
10	92	6	3	33758	03-Jun-92											
10	92	6	30	33785	30-Jun-92											
10	92	7	3	33788	03-Jul-92											
10	92	7	6	33791	06-Jul-92											
10	92	7	9	33794	09-Jul-92	0.18	6.0	0.14	11.1	5.66	21.6	0.179	0.090	49.0	38.0	11.0
10	92	7	20	33805	20-Jul-92	0.03	6.7	0.23	16.1	6.06	20.1	0.176	0.088	67.2	50.4	16.8
10	92	7	27	33812	27-Jul-92	0.08	6.8	0.24	17.4	6.09	22.2	0.188	0.094	45.6	36.0	9.6
10	92	8	3	33819	03-Aug-92	0.60	7.1	3.00	15.2	6.05	20.1	0.180	0.090	50.4	34.0	16.4
10	92	8	20	33836	20-Aug-92	0.04	6.5	0.45	14.6	6.44	20.4	0.182	0.091	64.0	41.6	22.4
10	92	9	8	33855	08-Sep-92	0.03	6.6	0.12	26.2	6.65	20.8	0.166	0.083	51.6	37.6	14.0
10	92	10	10	33887	10-Oct-92	0.03	4.8	0.02	12.5	6.33	23.1	0.143	0.071	37.2	31.3	5.9
10	92	11	16	33924	16-Nov-92	0.03	5.8	-0.00	12.9	5.71	18.9	0.142	0.071	33.2	21.4	11.8
10	92	12	11	33949	11-Dec-92	0.04	6.2	-0.00	14.3	5.91	19.6	0.148	0.074	41.0	29.1	11.9

GROUNDWATER QUALITY DATA

WELL #	YEAR	MONTH	DAY	DATE CODE	DATE	ORTHOPHOS. mg/l (PO4)3-	N-NITRATE mg/l (N-NO3-)	N-AMMONIA mg/l (N-NH3)	CHLORIDE mg/l (Cl-)	pH Units	TEMP. Degree C	CONDUC. mS/cm	T D S g/L	Tot. HARD. mg/l CaCO3	Ca. HARD. mg/l CaCO3	Mg. HARD. mg/l CaCO3
11	92	5	14	33738	14-May-92	0.05	4.5	0.32	14.0	7.93	19.3	0.310	0.150	138.0	92.0	46.0
11	92	5	20	33744	20-May-92											
11	92	5	29	33753	29-May-92											
11	92	6	3	33758	03-Jun-92											
11	92	6	30	33785	30-Jun-92											
11	92	7	3	33788	03-Jul-92											
11	92	7	6	33791	06-Jul-92											
11	92	7	9	33794	09-Jul-92											
11	92	7	20	33805	20-Jul-92											
11	92	7	27	33812	27-Jul-92											
11	92	8	3	33819	03-Aug-92											
11	92	8	20	33836	20-Aug-92											
11	92	9	8	33855	08-Sep-92											
11	92	10	10	33887	10-Oct-92											
11	92	11	16	33924	16-Nov-92											
11	92	12	11	33949	11-Dec-92											
12	92	5	14	33738	14-May-92											
12	92	5	20	33744	20-May-92											
12	92	5	29	33753	29-May-92	0.03	3.3	0.16	25.0	7.09	22.6	0.270	0.130	102.0	89.0	13.0
12	92	6	3	33758	03-Jun-92											
12	92	6	30	33785	30-Jun-92											
12	92	7	3	33788	03-Jul-92											
12	92	7	6	33791	06-Jul-92											
12	92	7	9	33794	09-Jul-92											
12	92	7	20	33805	20-Jul-92											
12	92	7	27	33812	27-Jul-92											
12	92	8	3	33819	03-Aug-92											
12	92	8	20	33836	20-Aug-92											
12	92	9	8	33855	08-Sep-92											
12	92	10	10	33887	10 Oct-92											
12	92	11	16	33924	16-Nov-92											
12	92	12	11	33949	11-Dec-92											
13	92	5	14	33738	14-May-92	0.31	0.1	0.42	27.0	7.55	19.1	0.630	0.310	152.0	124.0	28.0
13	92	5	20	33744	20-May-92											
13	92	5	29	33753	29-May-92											
13	92	6	3	33758	03-Jun-92											
13	92	6	30	33785	30-Jun-92											
13	92	7	3	33788	03-Jul-92											
13	92	7	6	33791	06-Jul-92											
13	92	7	9	33794	09-Jul-92											
13	92	7	20	33805	20-Jul-92											
13	92	7	27	33812	27-Jul-92											
13	92	8	3	33819	03-Aug-92											
13	92	8	20	33836	20 Aug-92											
13	92	9	8	33855	08-Sep-92											
13	92	10	10	33887	10-Oct-92											
13	92	11	16	33924	16-Nov-92											
13	92	12	11	33949	11-Dec-92											
14	92	5	14	33738	14-May-92	0.05	3.8	0.18	21.0	7.03	19.3	0.200	0.100	93.0	56.0	37.0
14	92	5	20	33744	20-May-92											
14	92	5	29	33753	29-May-92											
14	92	6	3	33758	03-Jun-92											
14	92	6	30	33785	30-Jun-92											
14	92	7	3	33788	03-Jul-92											
14	92	7	6	33791	06-Jul-92											
14	92	7	9	33794	09-Jul-92											
14	92	7	20	33805	20-Jul-92											
14	92	7	27	33812	27-Jul-92											
14	92	8	3	33819	03-Aug-92											
14	92	8	20	33836	20-Aug-92											
14	92	9	8	33855	08-Sep-92											
14	92	10	10	33887	10-Oct-92											
14	92	11	16	33924	16-Nov-92											
14	92	12	11	33949	11-Dec-92											

GROUNDWATER QUALITY DATA

WELL #	YEAR	MONTH	DAY	DATE CODE	DATE	ORTHOPHOS. mg/l (PO4)3-	N-NITRATE mg/l (N-NO3-)	N-AMMONIA mg/l (N-NH3)	CHLORIDE mg/l (Cl-)	pH Units	TEMP. Degree C	CONDUC. mS/cm	T D S g/L	Tot. HARD. mg/l CaCO3	Ca. HARD. mg/l CaCO3	Mg. HARD. mg/l CaCO3
15	92	5	14	33738	14-May-92											
15	92	5	20	33744	20-May-92											
15	92	5	29	33753	29-May-92	0.06	4.8	0.31	26.0	5.95	23.9	0.140	0.060	44.0	31.0	13.0
15	92	6	3	33758	03-Jun-92											
15	92	6	30	33785	30-Jun-92											
15	92	7	3	33788	03-Jul-92											
15	92	7	6	33791	06-Jul-92											
15	92	7	9	33794	09-Jul-92											
15	92	7	20	33805	20-Jul-92											
15	92	7	27	33812	27-Jul-92											
15	92	8	3	33819	03-Aug-92											
15	92	8	20	33836	20-Aug-92											
15	92	9	8	33855	08-Sep-92											
15	92	10	10	33887	10-Oct-92											
15	92	11	16	33924	16-Nov-92											
15	92	12	11	33949	11-Dec-92											
16	92	5	14	33738	14-May-92	0.21	1.5	0.04	16.0	7.31	19.1	0.220	0.100	113.0	79.0	34.0
16	92	5	20	33744	20-May-92											
16	92	5	29	33753	29-May-92											
16	92	6	3	33758	03-Jun-92											
16	92	6	30	33785	30-Jun-92											
16	92	7	3	33788	03-Jul-92											
16	92	7	6	33791	06-Jul-92											
16	92	7	9	33794	09-Jul-92											
16	92	7	20	33805	20-Jul-92											
16	92	7	27	33812	27-Jul-92											
16	92	8	3	33819	03-Aug-92											
16	92	8	20	33836	20-Aug-92											
16	92	9	8	33855	08-Sep-92											
16	92	10	10	33887	10-Oct-92											
16	92	11	16	33924	16-Nov-92											
16	92	12	11	33949	11-Dec-92											
17	92	5	14	33738	14-May-92											
17	92	5	20	33744	20-May-92											
17	92	5	29	33753	29-May-92	0.08	4.6	0.20	16.0	6.85	24.3	0.160	0.070	53.0	43.0	10.0
17	92	6	3	33758	03-Jun-92											
17	92	6	30	33785	30-Jun-92											
17	92	7	3	33788	03-Jul-92											
17	92	7	6	33791	06-Jul-92											
17	92	7	9	33794	09-Jul-92											
17	92	7	20	33805	20-Jul-92											
17	92	7	27	33812	27-Jul-92											
17	92	8	3	33819	03-Aug-92											
17	92	8	20	33836	20-Aug-92											
17	92	9	8	33855	08-Sep-92											
17	92	10	10	33887	10-Oct-92											
17	92	11	16	33924	16-Nov-92											
17	92	12	11	33949	11-Dec-92											
18	92	5	14	33738	14-May-92	0.78	1.9	0.14	20.0	8.07	19.3	0.340	0.160	142.0	126.0	16.0
18	92	5	20	33744	20-May-92											
18	92	5	29	33753	29-May-92											
18	92	6	3	33758	03-Jun-92											
18	92	6	30	33785	30-Jun-92											
18	92	7	3	33788	03-Jul-92											
18	92	7	6	33791	06-Jul-92											
18	92	7	9	33794	09-Jul-92											
18	92	7	20	33805	20-Jul-92											
18	92	7	27	33812	27-Jul-92											
18	92	8	3	33819	03-Aug-92											
18	92	8	20	33836	20-Aug 92											
18	92	9	8	33855	08-Sep-92											
18	92	10	10	33887	10-Oct-92											
18	92	11	16	33924	16-Nov-92											
18	92	12	11	33949	11-Dec-92											

GROUNDWATER QUALITY DATA

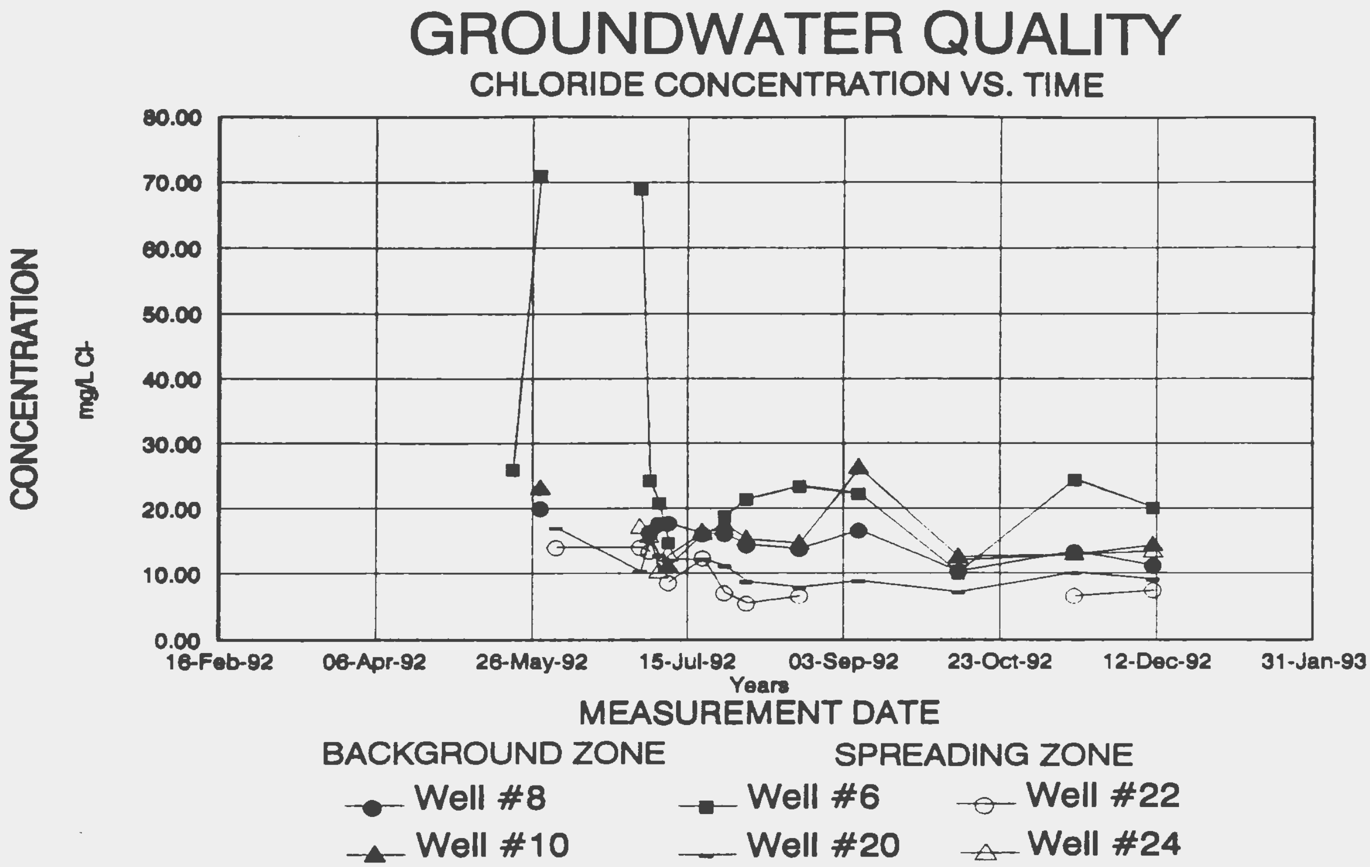
WELL #	YEAR	MONTH	DAY	DATE CODE	DATE	ORTHOPHOS. mg/l (PO4)3-	N-NITRATE mg/l (N-NO3-)	N-AMMONIA mg/l (N-NH3)	CHLORIDE mg/l (Cl-)	pH Units	TEMP. Degree C	CONDUC. mS/cm	T D S g/L	Tot. HARD. mg/l CaCO3	Ca. HARD. mg/l CaCO3	Mg. HARD. mg/l CaCO3
20	92	5	14	33738	14-May-92											
20	92	5	20	33744	20-May-92											
20	92	5	29	33753	29-May-92											
20	92	6	3	33758	03-Jun-92	0.30	10.0	1.98	17.0	7.56	19.4	0.290	0.140	41.0	26.0	15.0
20	92	6	30	33785	30-Jun-92	0.93	10.7	1.36	10.4	7.70	19.3	0.600	0.300	60.0	48.4	11.6
20	92	7	3	33788	03-Jul-92	0.18	12.1	0.45	15.6	7.73	20.8	0.541	0.270	35.6	27.2	8.4
20	92	7	6	33791	06-Jul-92	0.71	6.4	0.55	12.8	7.98	19.9	0.508	0.254	58.0	39.0	19.0
20	92	7	9	33794	09-Jul-92	1.16	6.4	0.72	12.0	7.56	21.0	0.382	0.192	77.0	64.0	13.0
20	92	7	20	33805	20-Jul-92	0.05	3.4	0.98	12.2	7.84	20.2	0.460	0.230	71.2	59.6	11.6
20	92	7	27	33812	27-Jul-92	1.98	6.4	1.18	11.2	7.98	23.2	0.429	0.214	81.6	78.4	3.2
20	92	8	3	33819	03-Aug-92	0.35	8.2	0.25	8.8	7.92	20.0	0.416	0.207	109.2	61.2	48.0
20	92	8	20	33836	20-Aug-92	0.65	18.5	0.28	7.9	8.00	21.0	0.462	0.230	112.0	85.2	26.8
20	92	9	8	33855	08-Sep-92	0.85	38.8	0.72	8.9	7.53	21.8	0.302	0.150	50.4	36.8	13.6
20	92	10	10	33887	10-Oct-92	0.04	4.5	0.19	7.2	7.42	21.9	0.334	0.167	39.8	31.7	8.1
20	92	11	16	33924	16-Nov-92	0.04	4.2	0.30	10.1	7.08	19.3	0.255	0.127	35.6	26.4	9.2
20	92	12	11	33949	11-Dec-92	1.31	5.9	0.20	9.1	7.53	19.6	0.312	0.155	35.3	28.9	6.4
21	92	5	14	33738	14-May-92											
21	92	5	20	33744	20-May-92											
21	92	5	29	33753	29-May-92											
21	92	6	3	33758	03-Jun-92											
21	92	6	30	33785	30-Jun-92											
21	92	7	3	33788	03-Jul-92	0.07	11.1	0.17	13.7	7.38	21.0	0.340	0.171	112.8	100.4	12.4
21	92	7	6	33791	06-Jul-92	0.07	12.0	0.16	11.4	6.91	19.9	0.341	0.170	117.6	94.0	23.6
21	92	7	9	33794	09-Jul-92	0.75	2.5	0.20	12.4	7.41	21.3	0.279	0.140	87.0	77.0	10.0
21	92	7	20	33805	20-Jul-92	0.67	10.0	0.20	11.3	7.24	20.2	0.250	0.126	82.0	70.4	11.6
21	92	7	27	33812	27-Jul-92											
21	92	8	3	33819	03-Aug-92											
21	92	8	20	33836	20-Aug-92											
21	92	9	8	33855	08-Sep-92											
21	92	10	10	33887	10-Oct-92											
21	92	11	16	33924	16-Nov-92											
21	92	12	11	33949	11-Dec-92											
22	92	5	14	33738	14-May-92											
22	92	5	20	33744	20-May-92											
22	92	5	29	33753	29-May-92											
22	92	6	3	33758	03-Jun-92	0.04	2.5	0.43	14.0	7.79	19.7	0.390	0.190	102.0	76.0	26.0
22	92	6	30	33785	30-Jun-92	0.05	0.0	0.39	14.0	7.02	19.3	0.187	0.094	51.6	46.0	5.6
22	92	7	3	33788	03-Jul-92	0.02	11.6	0.42	13.4	6.51	20.0	0.246	0.122	38.0	33.2	4.8
22	92	7	6	33791	06-Jul-92											
22	92	7	9	33794	09-Jul-92	0.60	2.1	0.28	6.6	6.72	20.9	0.173	0.086	42.0	33.0	9.0
22	92	7	20	33805	20-Jul-92	0.08	2.6	0.20	12.4	6.42	20.1	0.140	0.070	32.0	26.4	5.6
22	92	7	27	33812	27-Jul-92	1.39	1.6	0.39	7.1	6.68	23.0	0.173	0.087	24.0	20.6	3.2
22	92	8	3	33819	03-Aug-92	0.55	1.2	0.46	5.5	6.49	19.8	0.144	0.072	38.0	27.2	10.8
22	92	8	20	33836	20-Aug-92	0.03	1.3	0.66	6.7	7.00	20.6	0.139	0.069	45.6	32.8	12.8
22	92	9	8	33855	08-Sep-92											
22	92	10	10	33887	10-Oct-92											
22	92	11	16	33924	16-Nov-92	0.02	1.4	0.02	6.7	6.21	18.8	0.083	0.041	14.5	11.8	2.7
22	92	12	11	33949	11-Dec-92	0.00	2.1	0.03	7.5	6.06	19.5	0.084	0.041	18.3	14.1	4.2
23	92	5	14	33738	14-May-92											
23	92	5	20	33744	20-May-92											
23	92	5	29	33753	29-May-92											
23	92	6	3	33758	03-Jun-92											
23	92	6	30	33785	30-Jun-92											
23	92	7	3	33788	03-Jul-92											
23	92	7	6	33791	06-Jul-92											
23	92	7	9	33794	09-Jul-92	0.42	0.3	0.16	11.0	7.27	19.9	0.251	0.126	107.0	91.0	16.0
23	92	7	20	33805	20-Jul-92	0.07	1.4	0.17	11.2	7.26	19.7	0.269	0.135	108.8	95.2	13.6
23	92	7	27	33812	27-Jul-92											
23	92	8	3	33819	03-Aug-92											
23	92	8	20	33836	20-Aug-92											
23	92	9	8	33855	08-Sep-92	0.08	1.3	0.36	7.0	7.23	20.6	0.137	0.068	30.8	24.8	6.0
23	92	10	10	33887	10-Oct-92	0.03	0.5	0.04	6.9	5.85	22.8	0.081	0.040	23.0	17.6	5.4
23	92	11	16	33924	16-Nov-92											
23	92	12	11	33949	11-Dec-92											

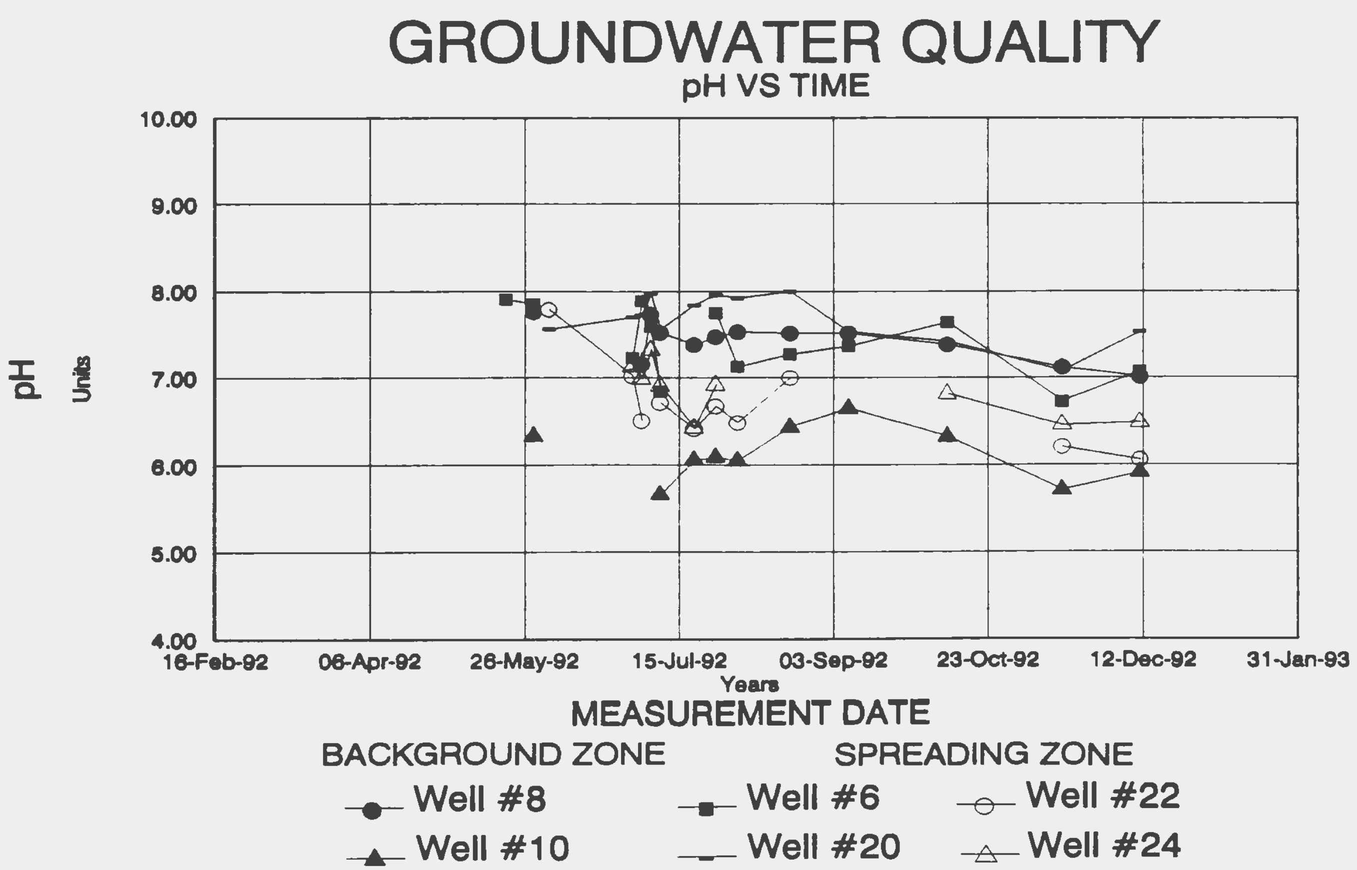
GROUNDWATER QUALITY DATA

WELL #	YEAR	MONTH	DAY	DATE CODE	DATE	ORTHOPHOS. mg/l (PO4)3-	N-NITRATE mg/l (N-NO3-)	N-AMMONIA mg/l (N-NH3)	CHLORIDE mg/l (Cl-)	pH Units	TEMP. Degree C	CONDUC. mS/cm	T D S g/L	Tot. HARD. mg/l CaCO3	Ca. HARD. mg/l CaCO3	Mg. HARD. mg/l CaCO3
24	92	5	14	33738	14-May-92											
24	92	5	20	33744	20-May-92											
24	92	5	29	33753	29-May-92											
24	92	6	3	33758	03-Jun-92											
24	92	6	30	33785	30-Jun-92	0.70	4.2	0.25	17.0	7.13	20.6	0.277	0.139	124.0	86.4	37.6
24	92	7	3	33788	03-Jul-92	0.15	9.2	0.28	15.6	6.99	20.1	0.372	0.186	125.6	106.4	19.2
24	92	7	6	33791	06-Jul-92	0.35	7.9	0.24	10.2	7.32	19.7	0.432	0.216	149.6	114.4	35.2
24	92	7	9	33794	09-Jul-92	0.11	11.3	0.18	12.8	6.91	19.4	0.338	0.167	109.0	99.0	10.0
24	92	7	20	33805	20-Jul-92	0.12	4.0	0.19	16.3	6.43	19.1	0.466	0.233	67.2	54.4	12.8
24	92	7	27	33812	27-Jul-92	0.12	6.6	N/A	16.7	6.92	19.8	0.268	0.135	88.0	78.4	10.0
24	92	8	3	33819	03-Aug-92											
24	92	8	20	33836	20-Aug-92											
24	92	9	8	33855	08-Sep-92											
24	92	10	10	33887	10-Oct-92	0.04	6.6	0.01	12.1	6.82	22.6	0.265	0.132	26.5	19.2	7.3
24	92	11	16	33924	16-Nov-92	0.03	5.3	-0.00	12.9	6.46	19.5	0.210	0.104	62.5	55.2	7.3
24	92	12	11	33949	11-Dec-92	0.02	7.3	0.00	13.3	6.49	19.3	0.241	0.120	83.8	63.2	20.6
25	92	5	14	33738	14-May-92											
25	92	5	20	33744	20-May-92											
25	92	5	29	33753	29-May-92											
25	92	6	3	33758	03-Jun-92											
25	92	6	30	33785	30-Jun-92											
25	92	7	3	33788	03-Jul-92	0.02	7.8	0.28	25.2	6.70	23.8	0.277	0.139	92.8	78.0	14.8
25	92	7	6	33791	06-Jul-92	0.97	7.9	0.19	17.5	7.22	19.6	0.432	0.217	166.0	97.0	69.0
25	92	7	9	33794	09-Jul-92	0.34	0.3	0.21	18.9	7.24	20.5	0.271	0.137	115.0	98.0	17.0
25	92	7	20	33805	20-Jul-92	0.16	0.2	0.21	17.7	7.37	19.2	0.289	0.145	97.6	87.6	10.0
25	92	7	27	33812	27-Jul-92											
25	92	8	3	33819	03-Aug-92											
25	92	8	20	33836	20-Aug-92											
25	92	9	8	33855	08-Sep-92											
25	92	10	10	33887	10-Oct-92											
25	92	11	16	33924	16-Nov-92											
25	92	12	11	33949	11-Dec-92											
MS #1 (92-08-21)	92	7	14	33799	14-Jul-92	10000 (TP)	20.0			6.20	20.0	5.800	3.700		17000 (TCa)	5000 (TMg)
MAC						NDL	45.0	NDL	250.0	6.5 - 8.5	NDL	NDL	500	NDL	NDL	NDL

NOTES:

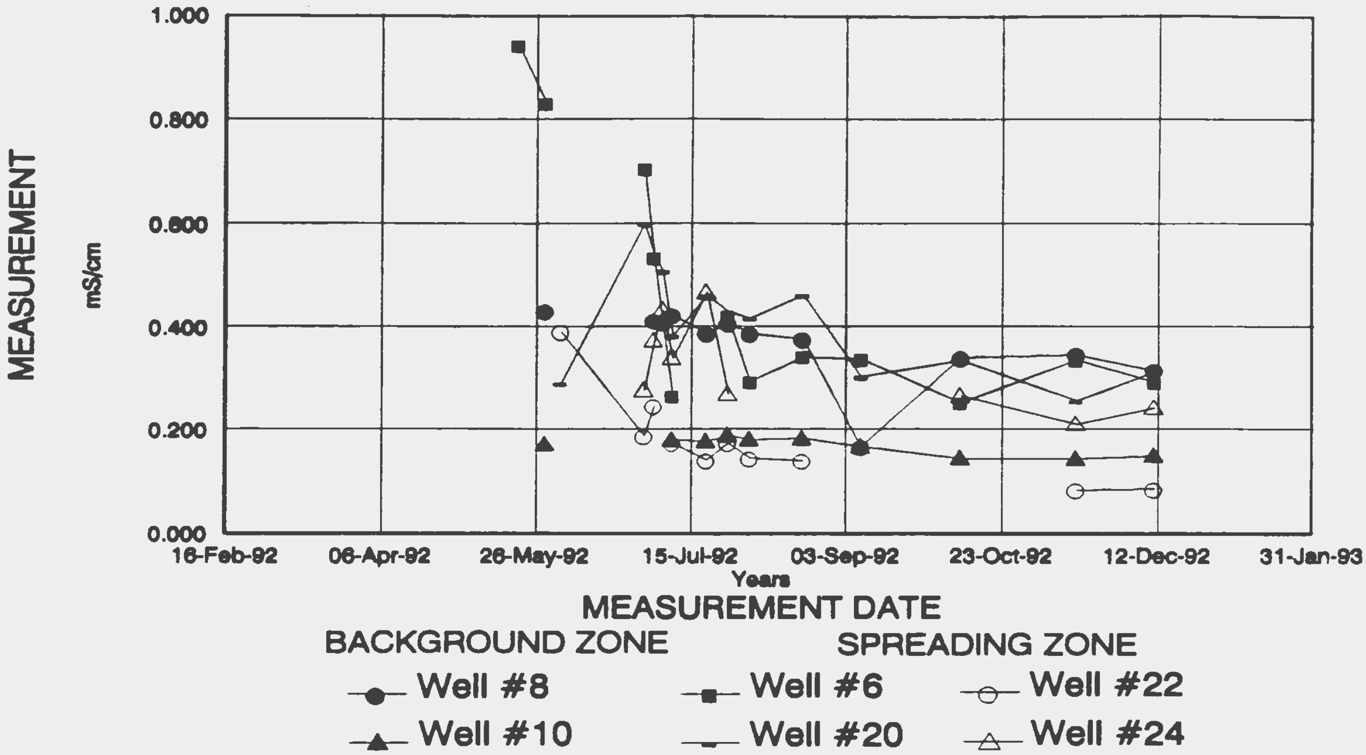
N/A - Not Analyzed
MS - Manure Sample
TP - Total Phosphorous
MAC - Maximum Allowable Concentration
NDL - No Detection Limit


GROUNDWATER QUALITY
CHLORIDE CONCENTRATION VS. TIME
CONCENTRATION
mg/L Cl-
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
16-Feb-92
06-Apr-92
26-May-92
15-Jul-92
03-Sep-92
23-Oct-92
12-Dec-92
31-Jan-93
Years
MEASUREMENT DATE
BACKGROUND ZONE
SPREADING ZONE
Well #8
Well #6
Well #22
Well #10
Well #20
Well #24


GROUNDWATER QUALITY
pH VS TIME
pH
Units
10.00
9.00
8.00
7.00
6.00
5.00
4.00
16-Feb-92
06-Apr-92
26-May-92
15-Jul-92
03-Sep-92
23-Oct-92
12-Dec-92
31-Jan-93
Years
MEASUREMENT DATE
BACKGROUND ZONE
SPREADING ZONE
Well #8
Well #6
Well #22
Well #10
Well #20
Well #24

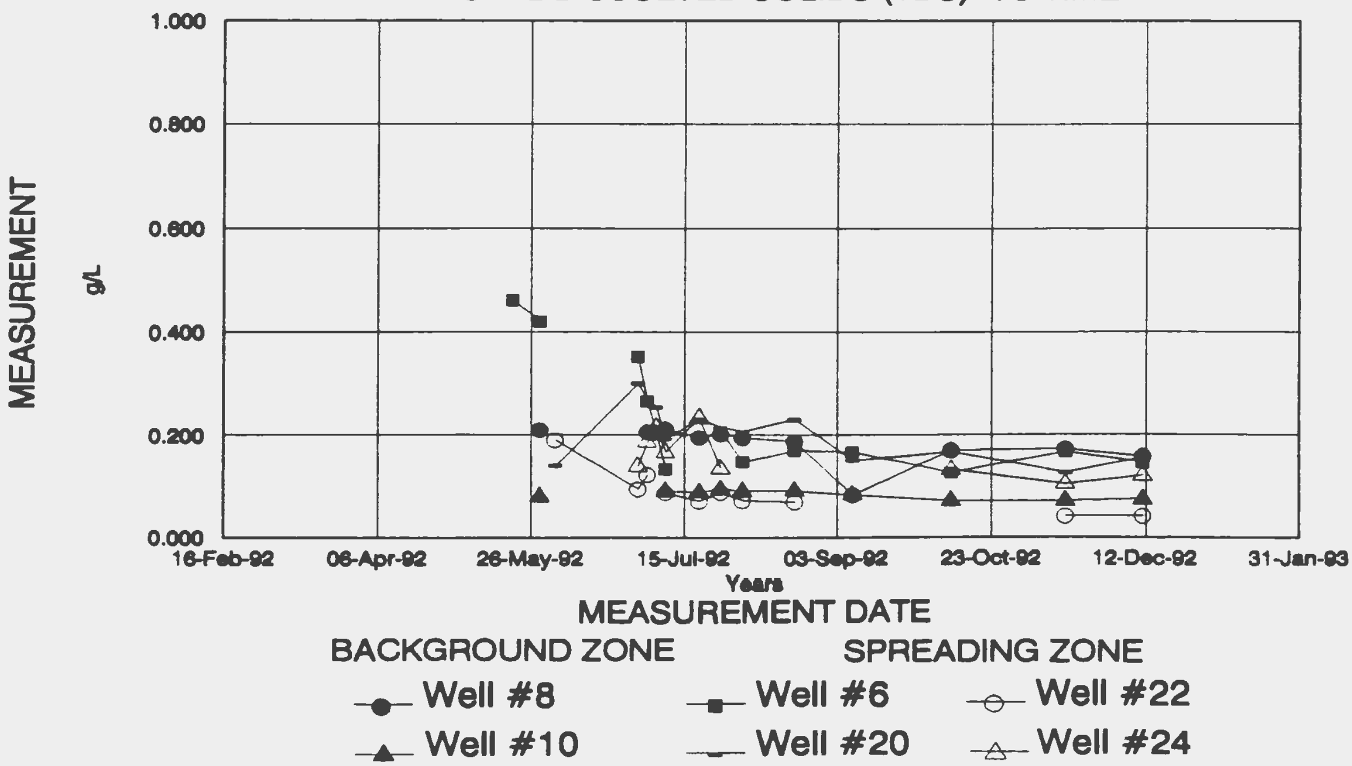
GROUNDWATER QUALITY

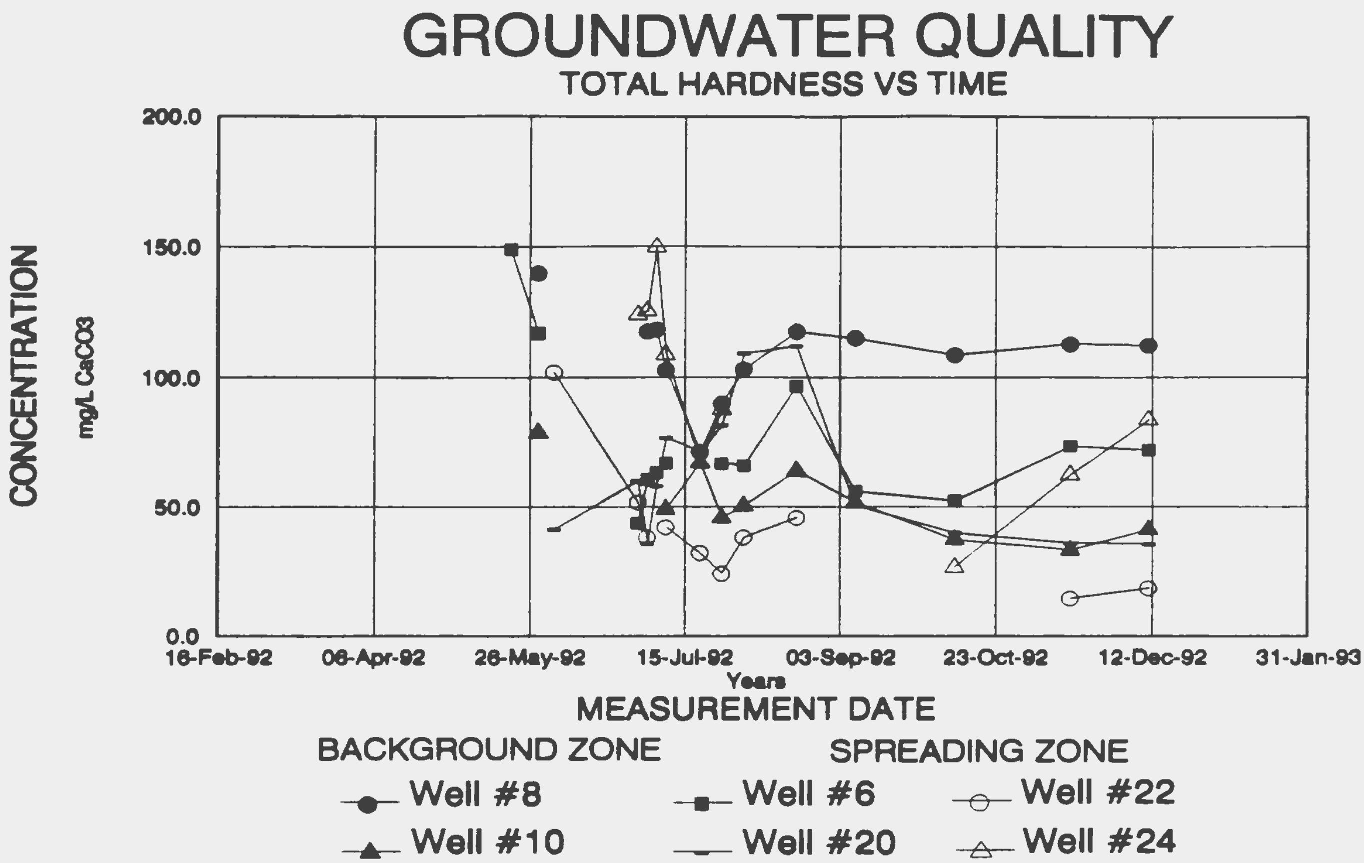
CONDUCTANCE VS TIME

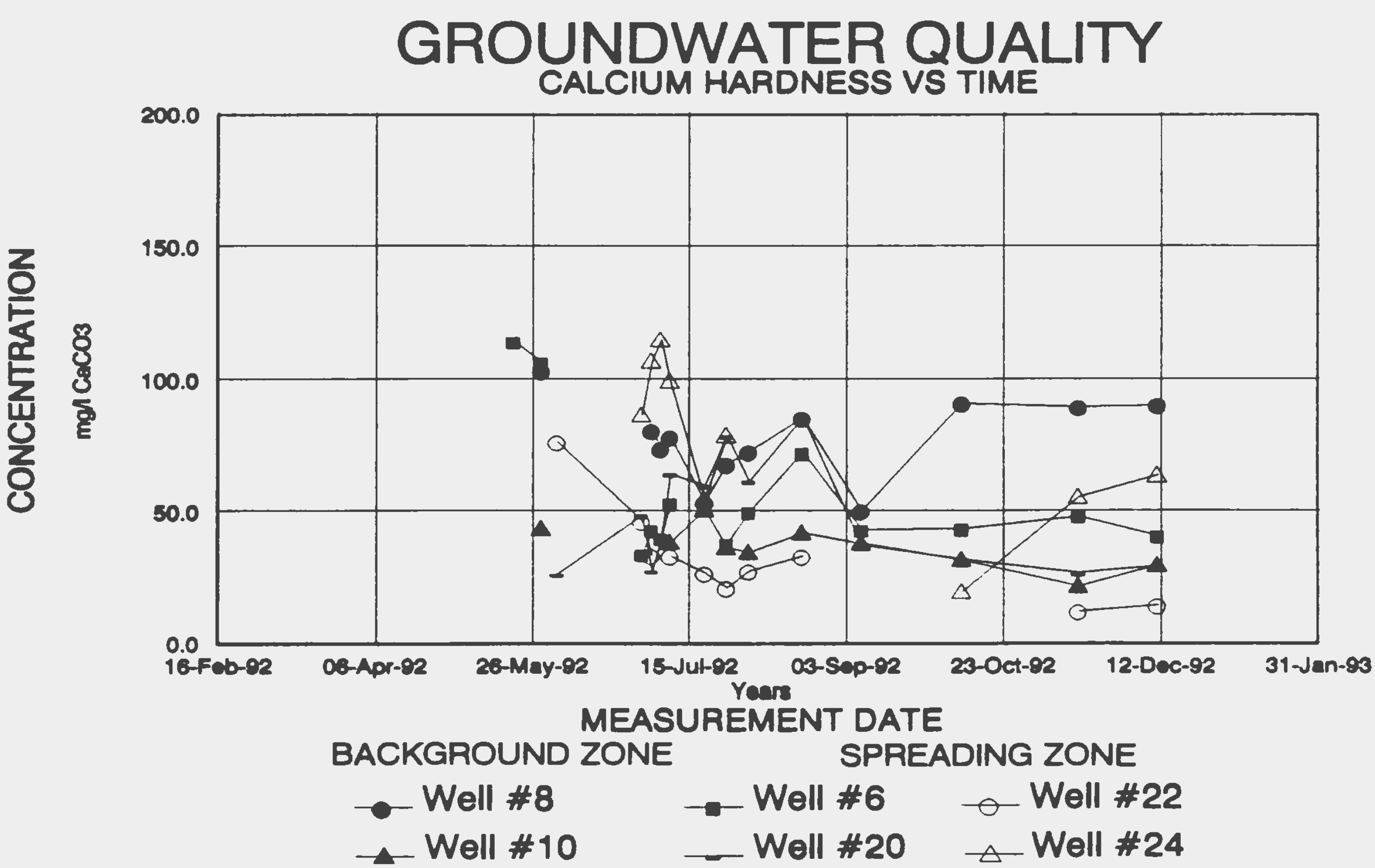


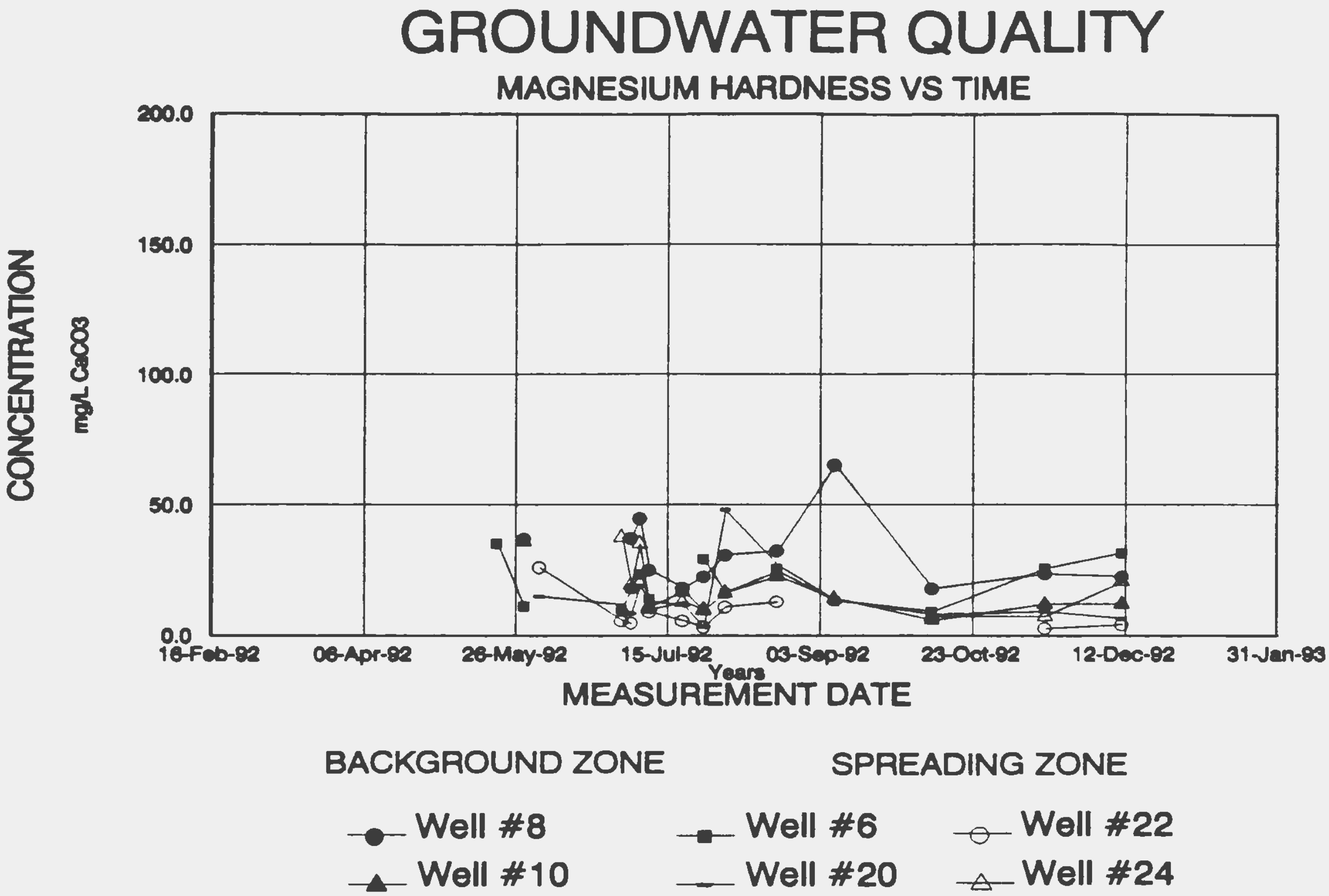
GROUNDWATER QUALITY

TOTAL DISSOLVED SOLIDS (TDS) VS TIME




GROUNDWATER QUALITY
TOTAL HARDNESS VS TIME
CONCENTRATION
mg/L CaCO3
200.0
150.0
100.0
50.0
0.0
16-Feb-92
06-Apr-92
26-May-92
15-Jul-92
03-Sep-92
23-Oct-92
12-Dec-92
31-Jan-93
Years
MEASUREMENT DATE
BACKGROUND ZONE
SPREADING ZONE
Well #8
Well #6
Well #22
Well #10
Well #20
Well #24


GROUNDWATER QUALITY
CALCIUM HARDNESS VS TIME
CONCENTRATION
mg/l CaCO3
200.0
150.0
100.0
50.0
0.0
16-Feb-92
06-Apr-92
26-May-92
15-Jul-92
03-Sep-92
23-Oct-92
12-Dec-92
31-Jan-93
Years
MEASUREMENT DATE
BACKGROUND ZONE
SPREADING ZONE
Well #8
Well #6
Well #22
Well #10
Well #20
Well #24

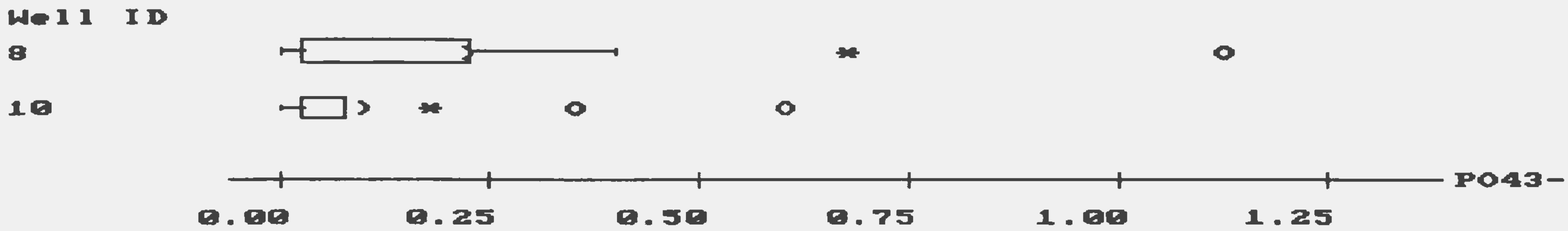

GROUNDWATER QUALITY
MAGNESIUM HARDNESS VS TIME
CONCENTRATION
mg/L CaCO3
200.0
150.0
100.0
50.0
0.0
16-Feb-92
06-Apr-92
26-May-92
15-Jul-92
03-Sep-92
23-Oct-92
12-Dec-92
31-Jan-93
Years
MEASUREMENT DATE
BACKGROUND ZONE
SPREADING ZONE
Well #8
Well #10
Well #6
Well #20
Well #22
Well #24

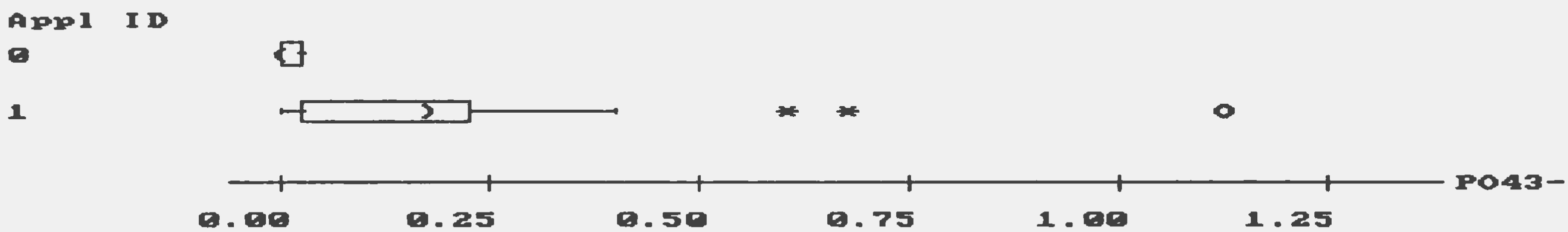
Parameter	Well ID	N	N*	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN	MIN	MAX	Q1	Q3
PO43–	3	3	0	0.683	0.550	0.683	0.513	0.296	0.25	1.25	0.25	1.25
	4	4	0	0.165	0.095	0.165	0.219	0.110	0.00	0.47	0.00	0.40
	6	19	0	0.454	0.140	0.242	1.015	0.233	0.02	4.50	0.04	0.34
	8	17	0	0.199	0.040	0.149	0.304	0.074	0.02	1.13	0.03	0.30
	10	13	0	0.115	0.030	0.079	0.173	0.048	0.02	0.60	0.03	0.13
	20	17	0	0.589	0.650	0.539	0.530	0.128	0.04	1.88	0.07	0.89
	22	14	0	0.239	0.055	0.163	0.392	0.105	0.00	1.39	0.03	0.45
	24	13	0	0.241	0.120	0.195	0.290	0.080	0.02	0.97	0.04	0.35
NO3–	3	3	0	8.530	11.000	8.530	7.610	4.390	0.00	14.60	0.00	14.60
	4	4	0	6.930	6.550	6.930	2.720	1.360	4.30	10.30	4.53	9.70
	6	19	0	3.884	2.400	3.406	4.048	0.929	0.00	15.90	1.30	6.30
	8	17	0	3.241	3.900	3.160	2.377	0.577	0.10	7.60	0.85	5.05
	10	13	0	5.315	6.200	5.618	2.142	0.594	0.20	7.10	4.60	6.65
	20	17	0	10.060	8.200	8.650	8.420	2.040	2.50	38.80	5.20	11.55
	22	14	0	2.136	1.400	1.525	2.831	0.757	0.00	11.60	1.03	2.20
	24	13	0	6.062	6.800	6.118	3.231	0.896	0.20	11.30	4.10	7.90
NH3	3	3	0	0.277	0.300	0.277	0.087	0.050	0.18	0.35	0.18	0.35
	4	4	0	0.230	0.175	0.230	0.172	0.086	0.09	0.48	0.11	0.41
	6	19	0	0.563	0.450	0.518	0.448	0.103	0.00	1.90	0.24	0.88
	8	17	0	0.366	0.340	0.350	0.223	0.054	0.05	0.92	0.19	0.50
	10	13	0	0.362	0.140	0.156	0.803	0.223	0.00	3.00	0.03	0.24
	20	17	0	0.581	0.300	0.517	0.518	0.126	0.16	1.96	0.20	0.85
	22	14	0	0.288	0.320	0.278	0.193	0.052	0.02	0.68	0.13	0.42
	24	13	0	0.156	0.190	0.158	0.110	0.030	0.00	0.28	0.01	0.25
CL–	3	3	0	5.030	5.200	5.030	1.960	1.130	3.00	6.90	3.00	6.90
	4	4	0	9.800	9.500	9.800	1.262	0.631	8.70	11.50	8.78	11.13
	6	19	0	29.840	22.500	27.700	20.830	4.780	10.10	86.00	20.10	26.00
	8	17	0	17.320	16.300	16.850	5.030	1.220	10.40	31.20	14.10	19.20
	10	13	0	17.020	16.100	16.720	4.430	1.230	11.10	26.20	13.60	20.45
	20	17	0	11.294	11.300	11.187	2.610	0.633	7.20	17.00	9.00	12.60
	22	14	0	9.429	8.050	9.375	3.094	0.827	5.50	14.00	6.85	12.65
	24	13	0	15.860	16.300	15.530	3.830	1.060	10.20	25.20	12.85	17.60
pH	3	3	0	6.103	6.600	6.103	1.556	0.898	4.36	7.35	4.36	7.35
	4	4	0	6.038	5.995	6.038	0.133	0.066	5.93	6.23	5.94	6.18
	6	19	0	7.362	7.360	7.367	0.369	0.085	6.73	7.91	7.07	7.64
	8	17	0	7.510	7.520	7.523	0.239	0.058	7.01	7.81	7.38	7.74
	10	13	0	6.316	6.330	6.277	0.492	0.136	5.66	7.40	5.98	6.58
	20	17	0	7.574	7.560	7.589	0.318	0.077	6.91	8.00	7.40	7.88
	22	14	0	6.751	6.700	6.739	0.540	0.144	5.85	7.79	6.37	7.24
	24	13	0	6.923	6.920	6.927	0.329	0.091	6.43	7.37	6.60	7.23

Notes: Refer to List of Abbreviations for heading definitions.

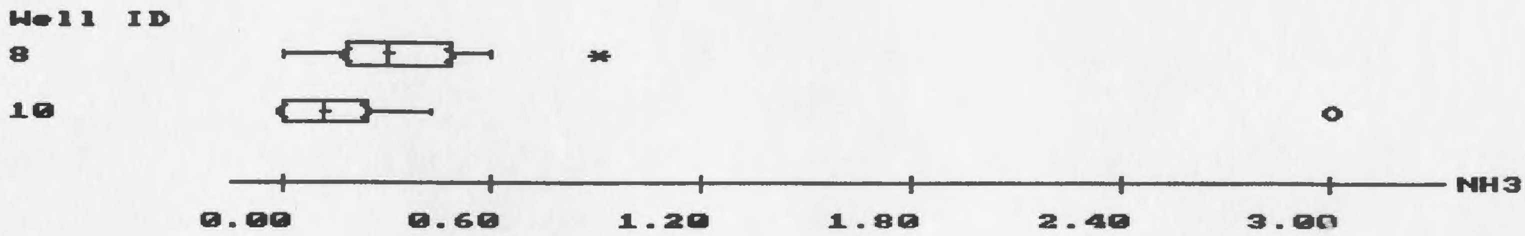
Parameter	Well ID	N	N*	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN	MIN	MAX	Q1	Q3
Cond	3	3	0	0.129	0.128	0.129	0.062	0.036	0.07	0.19	0.07	0.19
	4	4	0	0.109	0.102	0.109	0.024	0.012	0.09	0.14	0.09	0.13
	6	19	0	0.431	0.370	0.416	0.203	0.047	0.18	0.94	0.29	0.53
	8	17	0	0.464	0.411	0.461	0.172	0.042	0.17	0.81	0.36	0.63
	10	13	0	0.203	0.179	0.181	0.093	0.026	0.14	0.50	0.16	0.20
	20	17	0	0.382	0.341	0.377	0.104	0.025	0.25	0.60	0.30	0.46
	22	14	0	0.178	0.159	0.169	0.086	0.023	0.08	0.39	0.12	0.25
	24	13	0	0.318	0.277	0.315	0.082	0.023	0.21	0.47	0.27	0.40
TDS	3	3	0	0.064	0.063	0.064	0.031	0.018	0.03	0.10	0.03	0.10
	4	4	0	0.053	0.050	0.053	0.014	0.007	0.04	0.07	0.04	0.07
	6	19	0	0.215	0.195	0.208	0.100	0.023	0.08	0.46	0.15	0.27
	8	17	0	0.232	0.205	0.230	0.085	0.021	0.08	0.40	0.18	0.31
	10	13	0	0.101	0.090	0.090	0.047	0.013	0.07	0.25	0.08	0.10
	20	17	0	0.191	0.171	0.188	0.052	0.013	0.13	0.30	0.15	0.23
	22	14	0	0.089	0.079	0.084	0.042	0.011	0.04	0.19	0.06	0.12
	24	13	0	0.159	0.139	0.158	0.041	0.011	0.10	0.23	0.13	0.20
T.Hard	3	2	1	54.300	54.300	54.300	54.700	38.700	15.70	93.00	*	*
	4	3	1	40.170	34.000	40.170	13.820	7.980	30.50	56.00	30.50	56.00
	6	18	1	82.050	69.500	80.270	31.680	7.470	43.60	149.00	59.60	109.35
	8	17	0	153.000	117.600	147.500	74.200	18.000	71.20	318.00	105.90	224.80
	10	13	0	66.750	51.600	60.640	36.000	9.990	33.20	167.60	43.30	81.00
	20	17	0	70.950	71.200	70.210	29.530	7.160	35.30	117.60	40.40	98.10
	22	14	0	48.260	38.000	46.020	32.940	8.800	14.50	108.80	23.75	64.20
	24	13	0	100.600	97.600	101.400	37.300	10.300	26.50	166.00	75.50	124.80
Ca Hard	3	2	1	27.000	27.000	27.000	18.400	13.000	14.00	40.00	*	*
	4	3	1	24.670	22.000	24.670	6.430	3.710	20.00	32.00	20.00	32.00
	6	18	1	62.590	48.750	61.190	28.370	6.690	33.60	114.00	40.30	90.35
	8	17	0	117.300	89.200	113.200	65.600	15.900	50.00	246.00	73.00	189.30
	10	13	0	49.030	38.000	42.910	31.360	8.700	21.40	144.00	32.65	56.20
	20	17	0	56.150	59.600	55.210	25.210	6.110	26.00	100.40	30.30	77.70
	22	14	0	39.280	30.000	36.910	27.790	7.430	11.80	95.20	20.00	53.50
	24	13	0	79.780	86.400	82.150	26.150	7.250	19.20	114.40	59.20	98.50
Mg Hard	3	2	1	27.400	27.400	27.400	36.300	25.600	1.70	53.00	*	*
	4	3	1	15.500	14.000	15.500	7.860	4.540	8.50	24.00	8.50	24.00
	6	18	1	19.460	19.000	19.260	8.130	1.920	7.00	35.00	12.65	25.30
	8	17	0	35.740	32.400	34.520	15.430	3.740	17.80	72.00	23.00	44.00
	10	13	0	17.720	16.400	17.140	8.600	2.390	5.90	36.00	11.40	23.00
	20	17	0	14.790	11.600	13.350	10.390	2.520	3.20	48.00	8.80	17.00
	22	14	0	8.980	5.800	8.080	6.420	1.720	2.70	26.00	4.65	13.00
	24	13	0	20.830	14.800	17.680	17.430	4.830	7.30	69.00	10.00	27.90

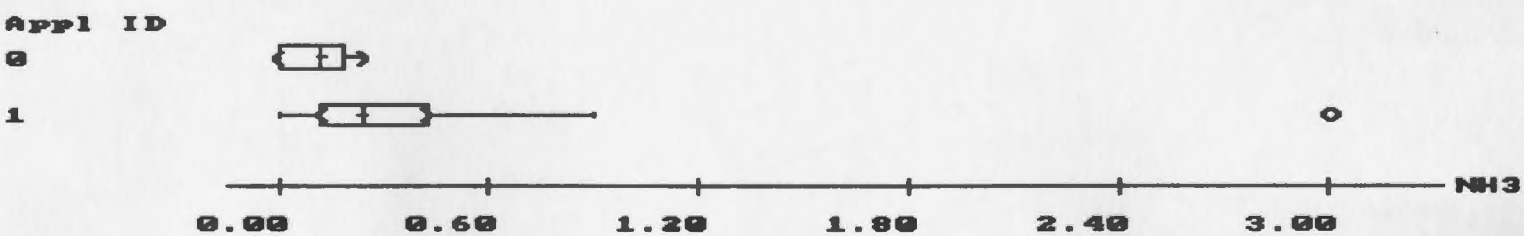
NOTES: Refer to List of Abbreviations for heading definitions.

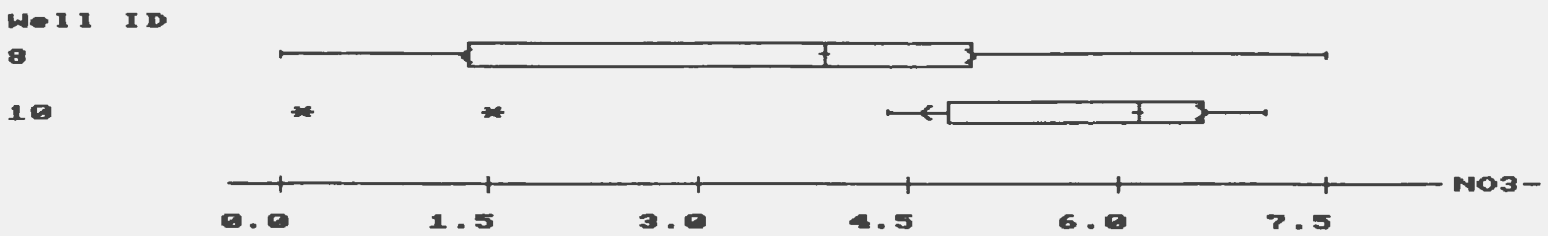


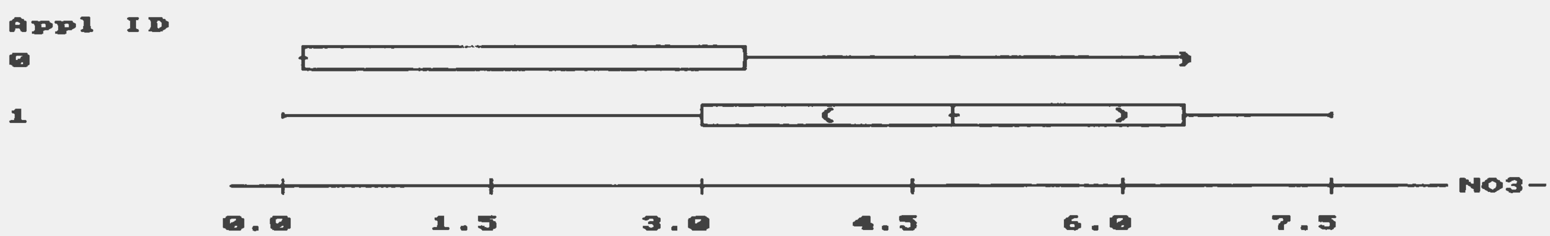


Boxplots comparing chemical parameter by Well ID and Application ID for the background zone data set.


Well ID
8
10
NH3
0.00
0.60
1.20
1.80
2.40
3.00


Appl ID
0
1
NH3
0.00
0.60
1.20
1.80
2.40
3.00


Well ID
8
10
NO3-
0.0
1.5
3.0
4.5
6.0
7.5


Appl ID
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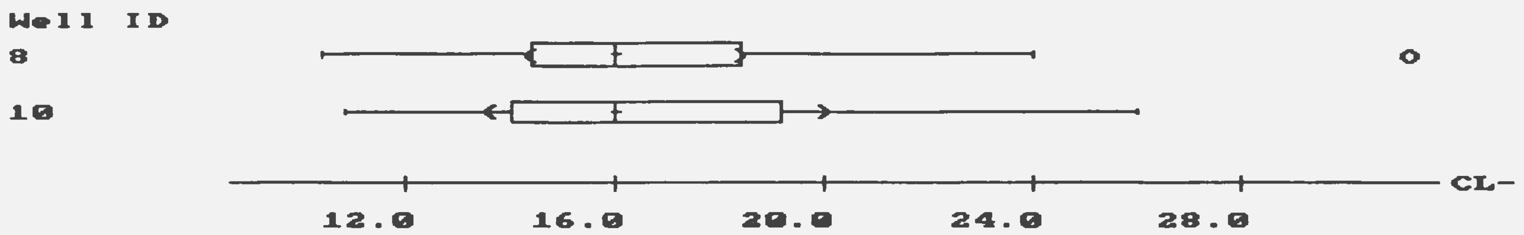
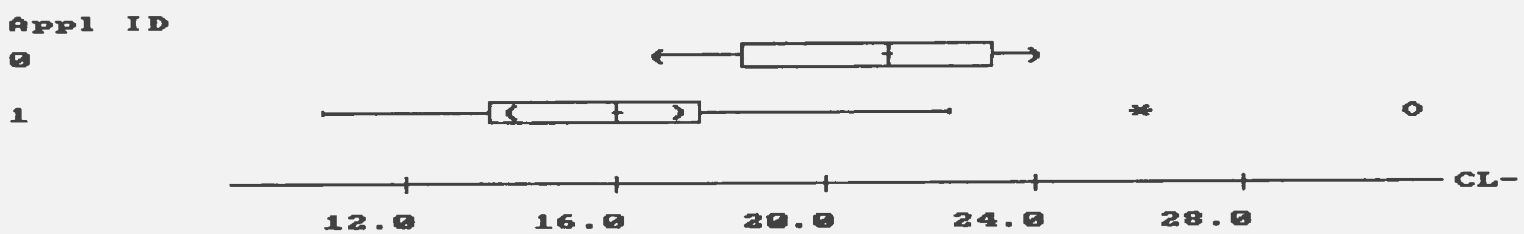
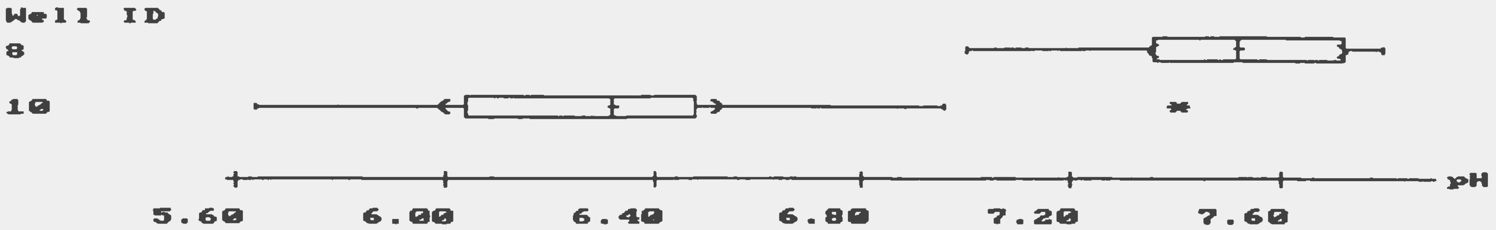
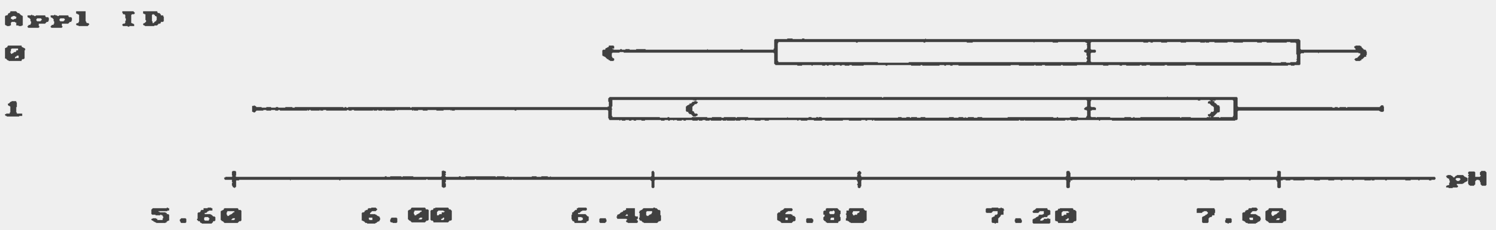
NO3-
0.0
1.5
3.0
4.5
6.0
7.5


Well ID
8
10
CL-
12.0
16.0
20.0
24.0
28.0

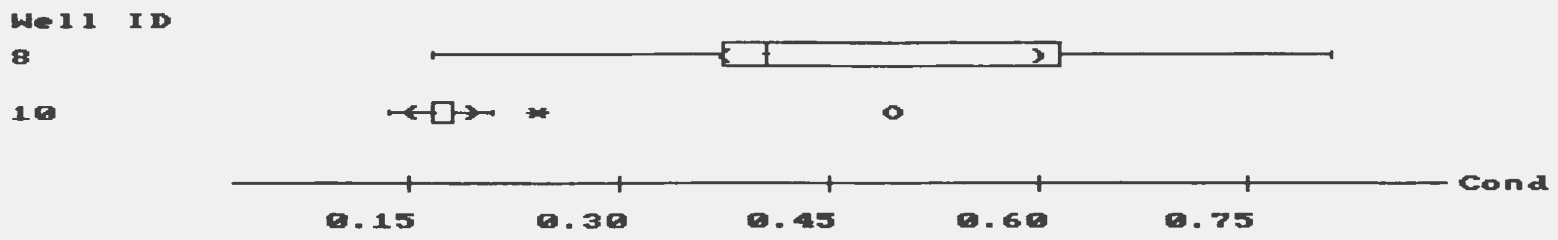

Appl ID
0
1
CL-
12.0
16.0
20.0
24.0
28.0

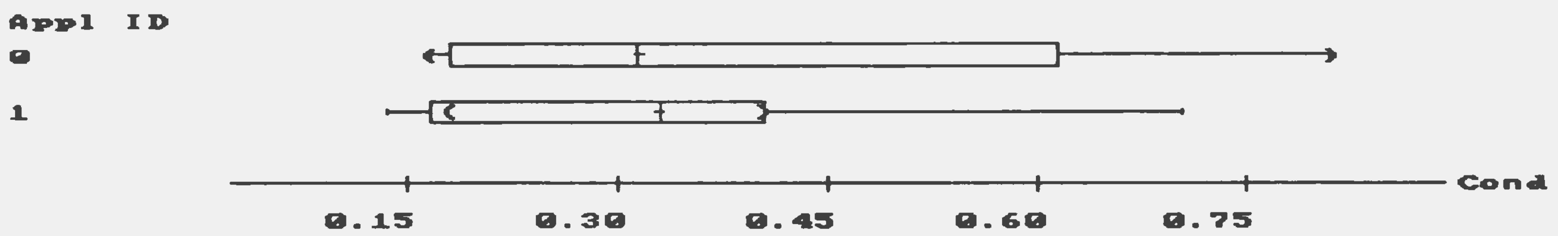


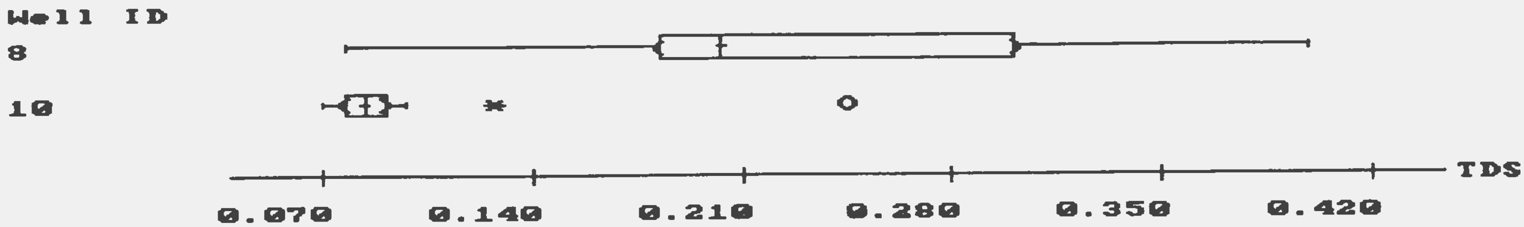
Well ID
8
10
pH
5.60
6.00
6.40
6.80
7.20
7.60

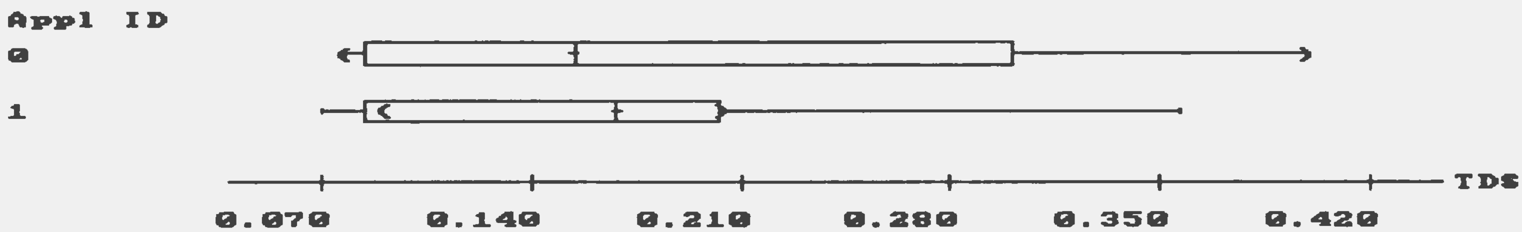


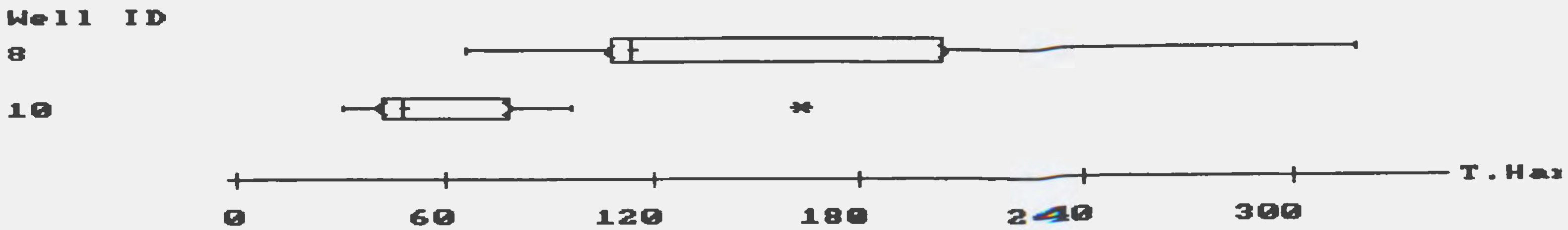
Appl ID
0
1
pH
5.60
6.00
6.40
6.80
7.20
7.60


Well ID
8
10
Cond
0.15
0.30
0.45
0.60
0.75


Appl ID
0
1
Cond
0.15
0.30
0.45
0.60
0.75

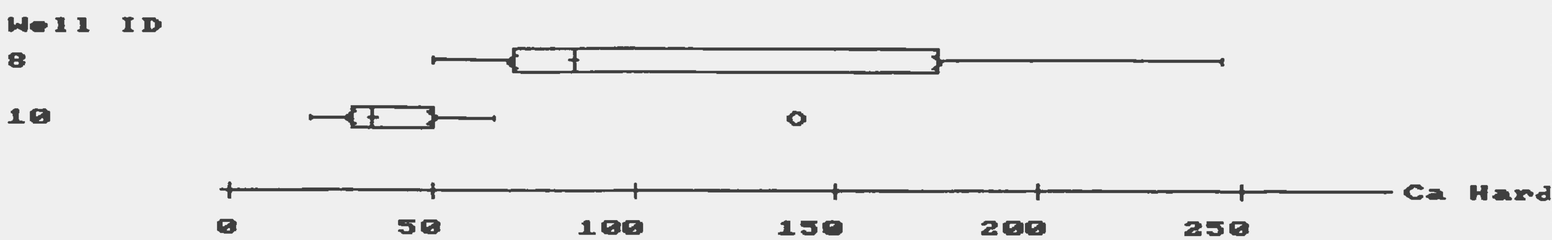

Well ID
8
10
TDS
0.070
0.140
0.210
0.280
0.350
0.420

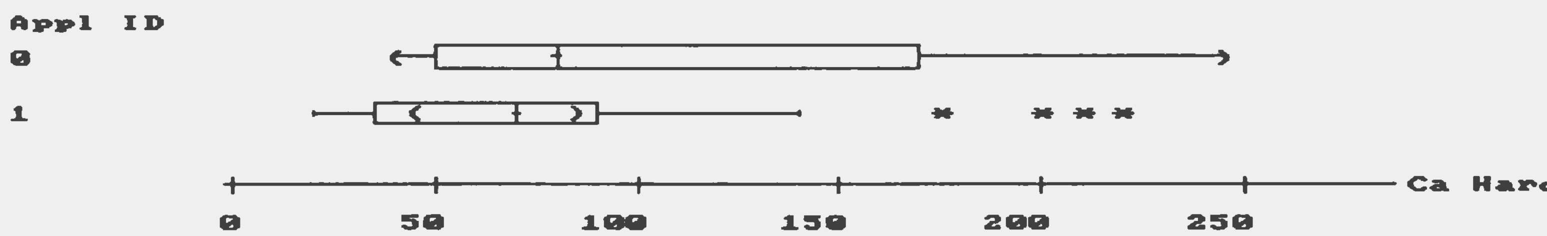

Appl ID
0
1
TDS
0.070
0.140
0.210
0.280
0.350
0.420

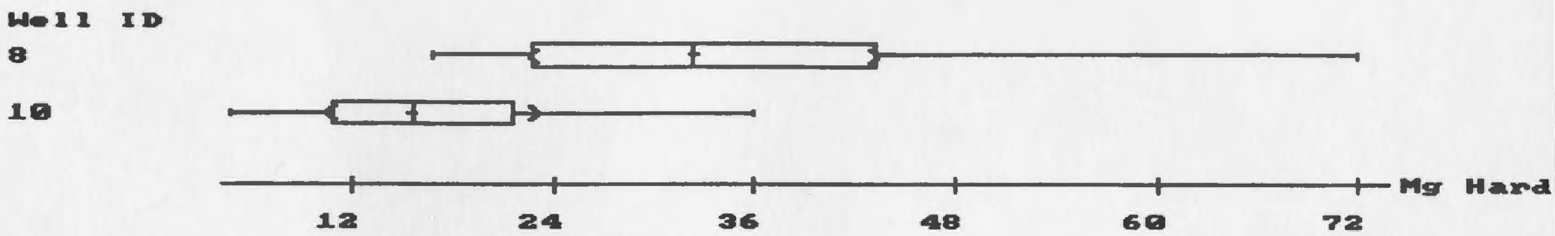


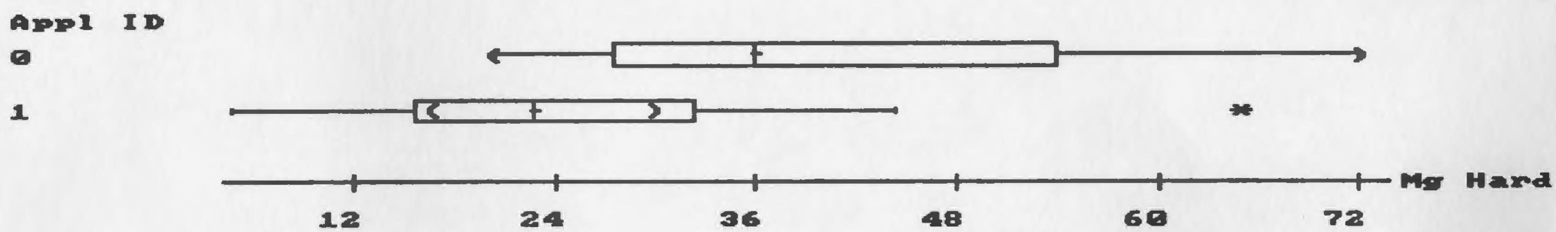
Well ID
8
10
T.Ha
0
60
120
180
240
300

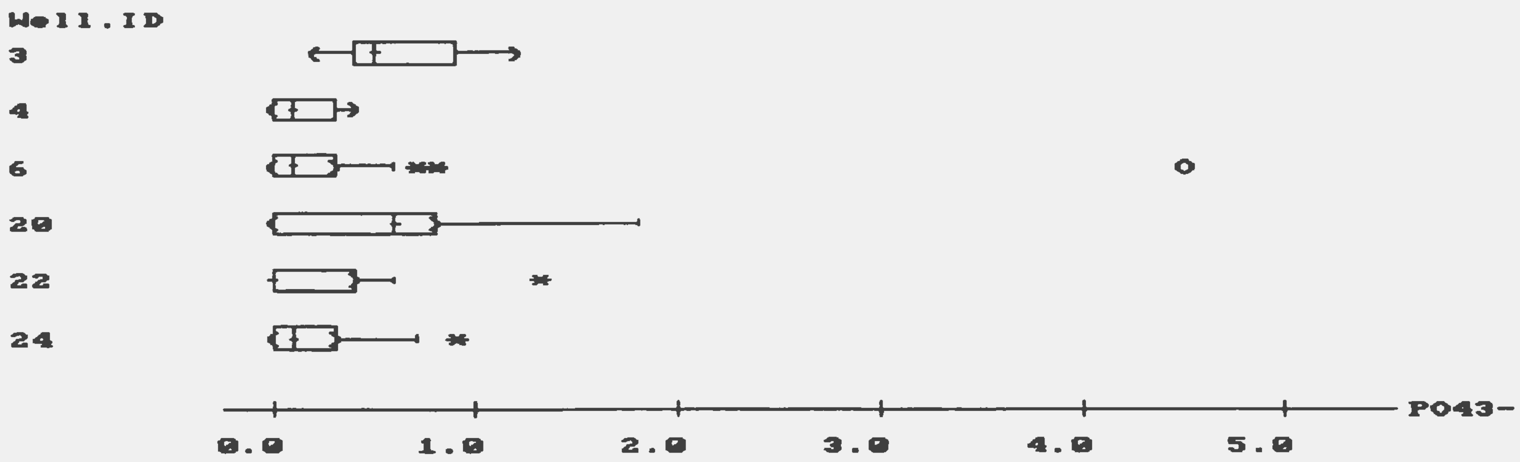
Appl ID
0
1
T.Ha
0
60
120
180
240
300

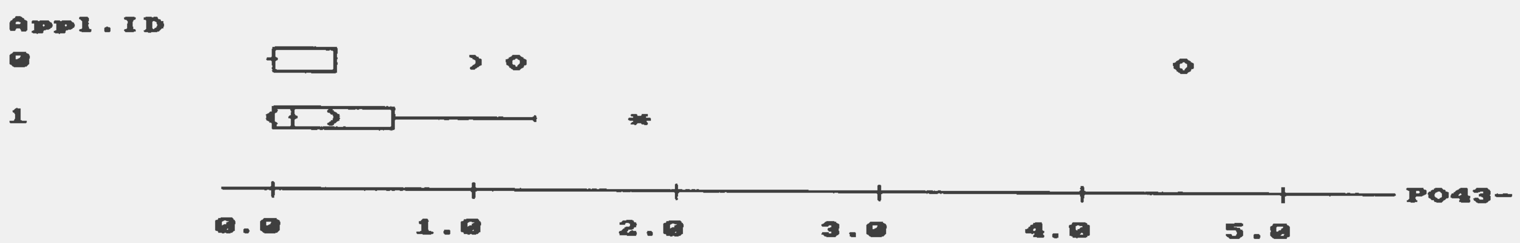

Well ID
8
10
Ca Hard
0
50
100
150
200
250


Appl ID
0
1
Ca Hard
0
50
100
150
200
250

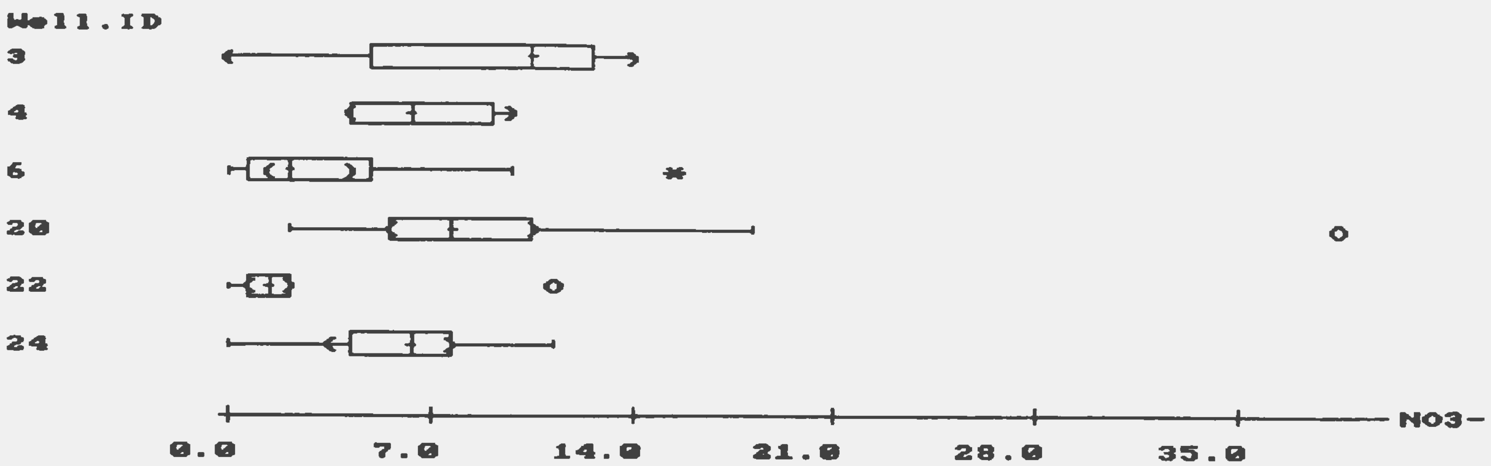

Well ID
8
10
Mg Hard
12
24
36
48
60
72

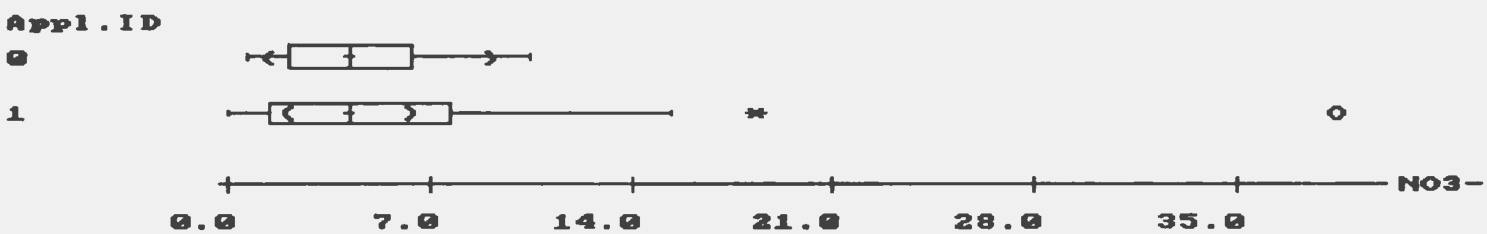

Appl ID
0
1
Mg Hard
12
24
36
48
60
72

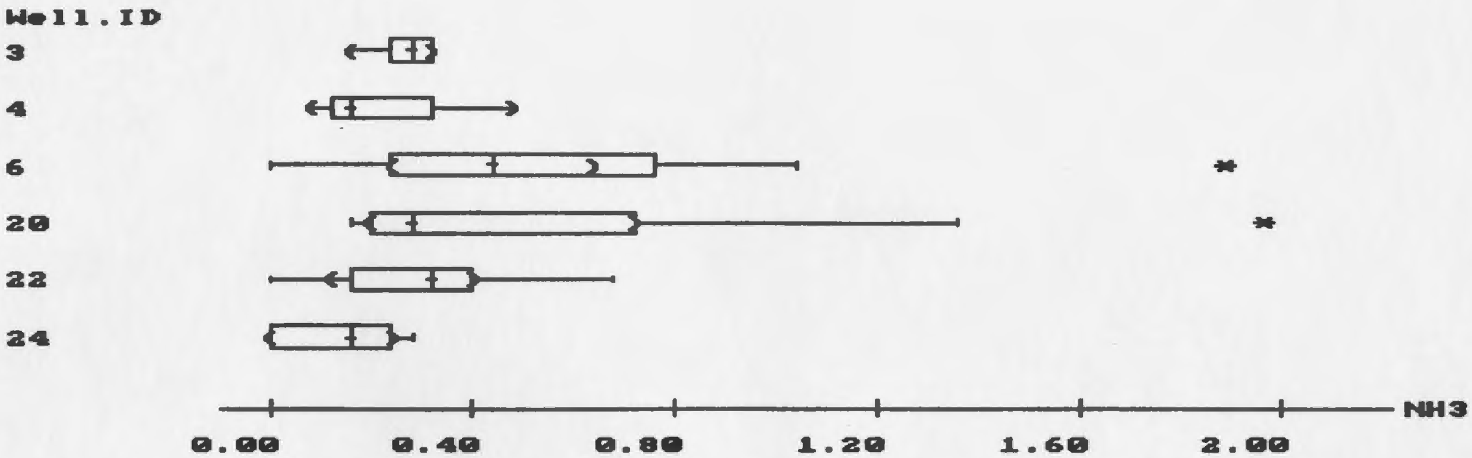




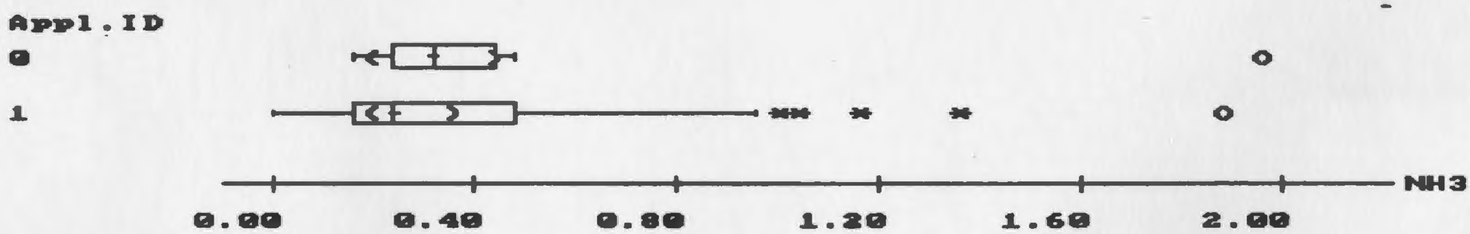
Boxplots comparing chemical parameter by Well ID and Application ID for the spreading zone data set.


Well.ID
3
4
6
20
22
24
NO3-
0.0
7.0
14.0
21.0
28.0
35.0

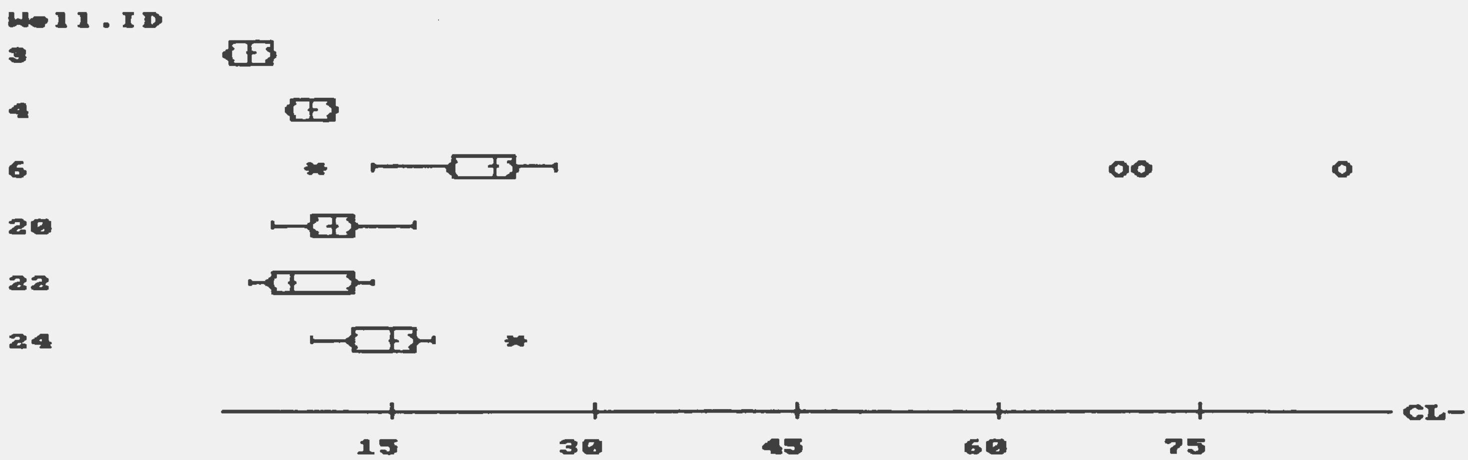

Appl.ID
0
1
NO3-
0.0
7.0
14.0
21.0
28.0
35.0



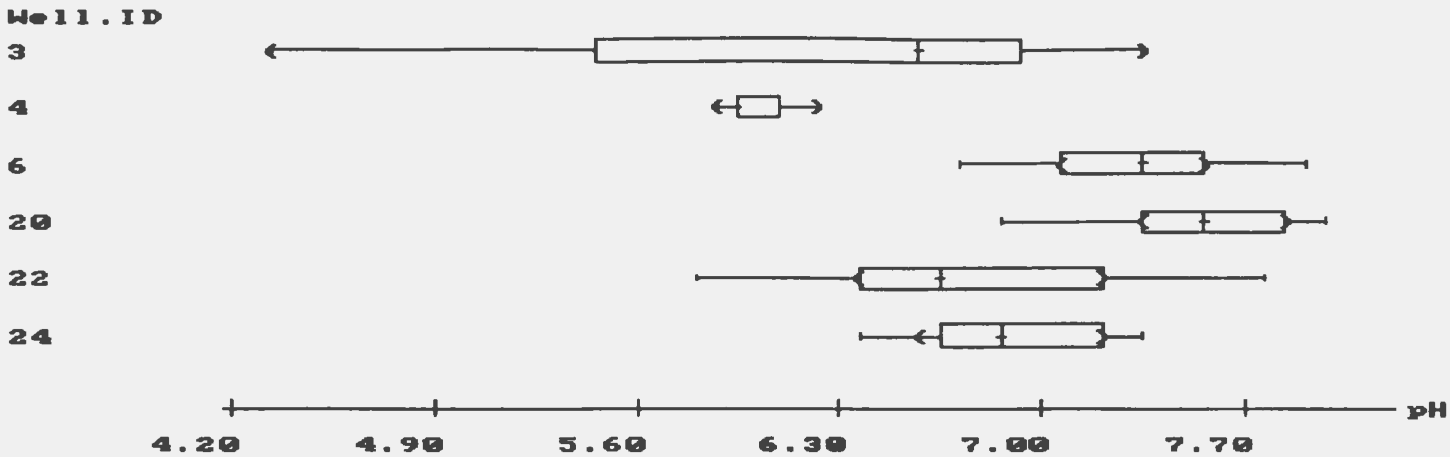
Well.ID
3
4
6
20
22
24
NH3
0.00
0.40
0.80
1.20
1.60
2.00

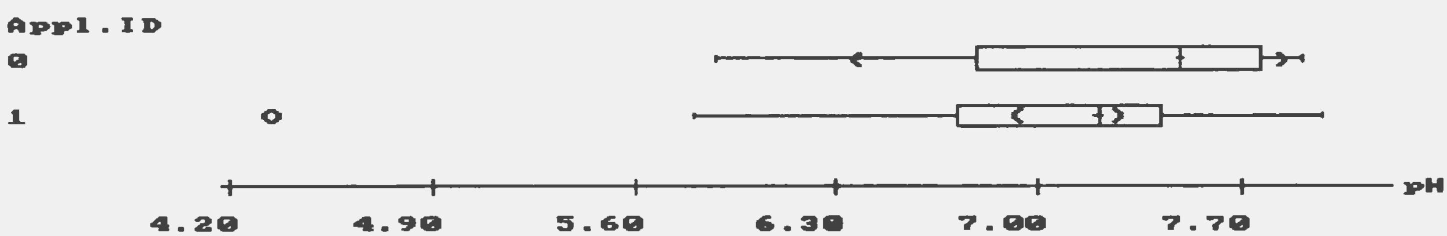


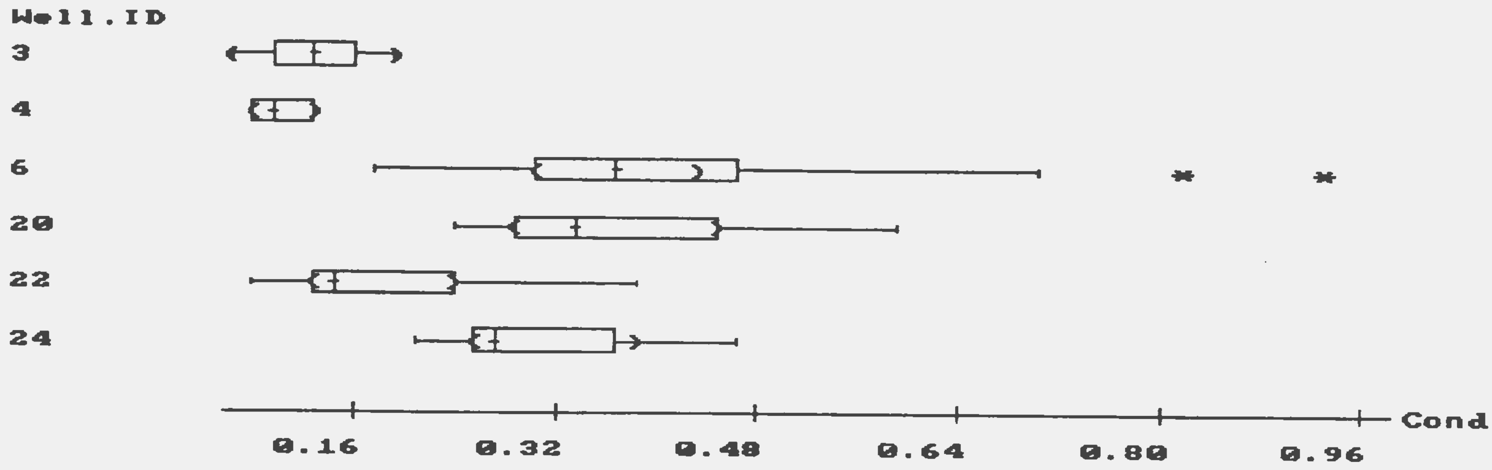
Appl.ID
0
1
NH3
0.00
0.40
0.80
1.20
1.60
2.00


Well.ID
3
4
6
20
22
24
15
30
45
60
75
CL-

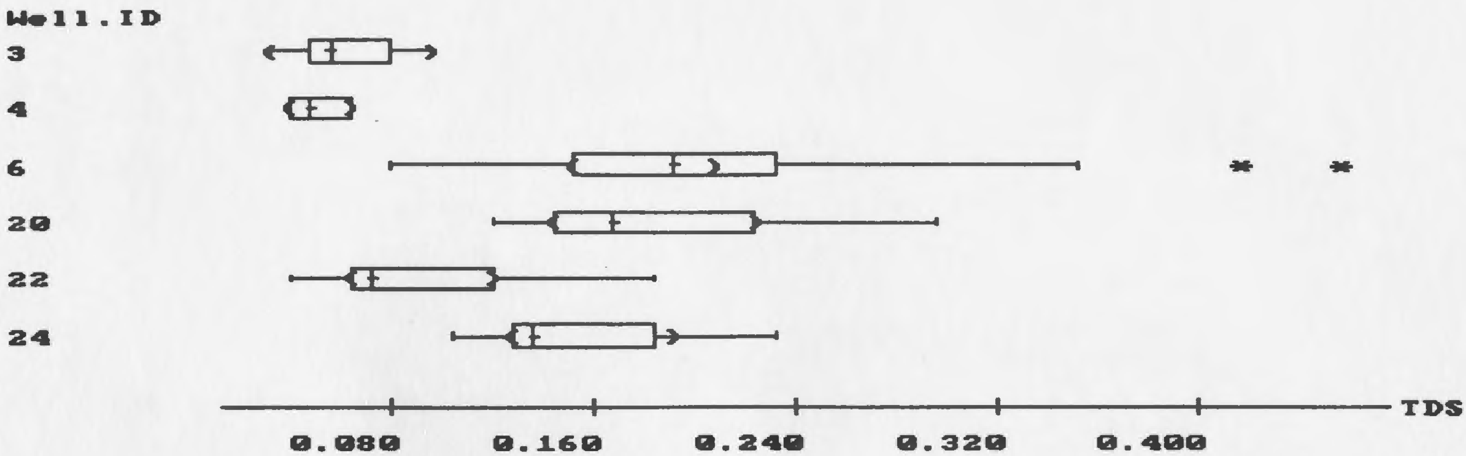

Appl.ID
0
1
15
30
45
60
75
CL-


Well.ID
3
4
6
20
22
24
pH
4.20
4.90
5.60
6.30
7.00
7.70

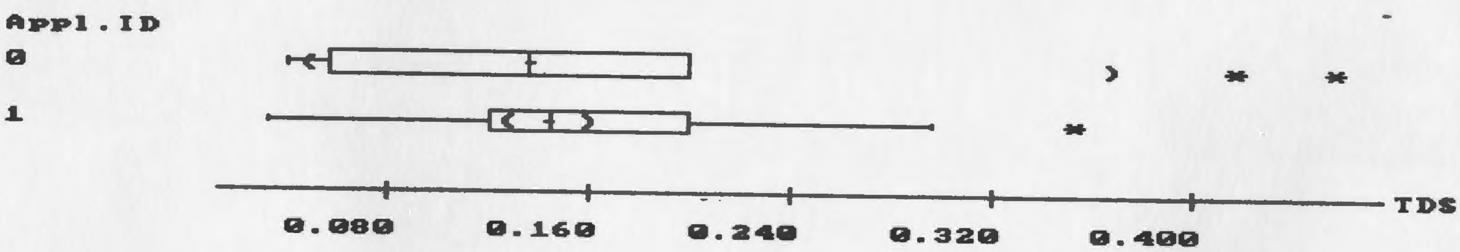

Appl.ID
0
1
pH
4.20
4.90
5.60
6.30
7.00
7.70


Well.ID
3
4
6
20
22
24
Cond
0.16
0.32
0.48
0.64
0.80
0.96

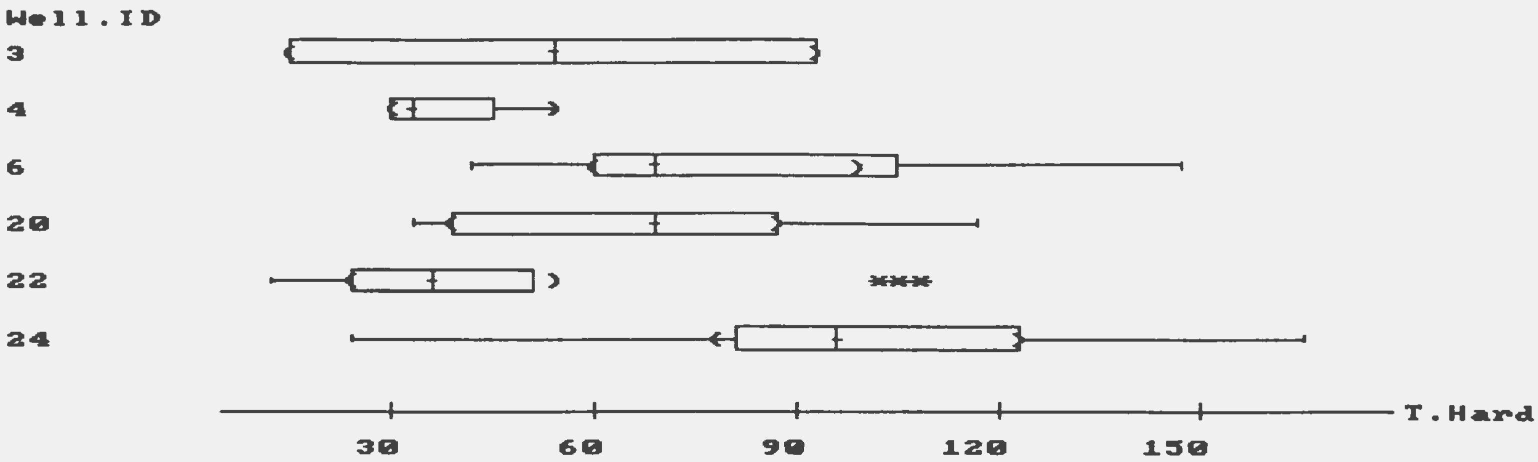

Appl.ID
0
1
Cond
0.16
0.32
0.48
0.64
0.80
0.96

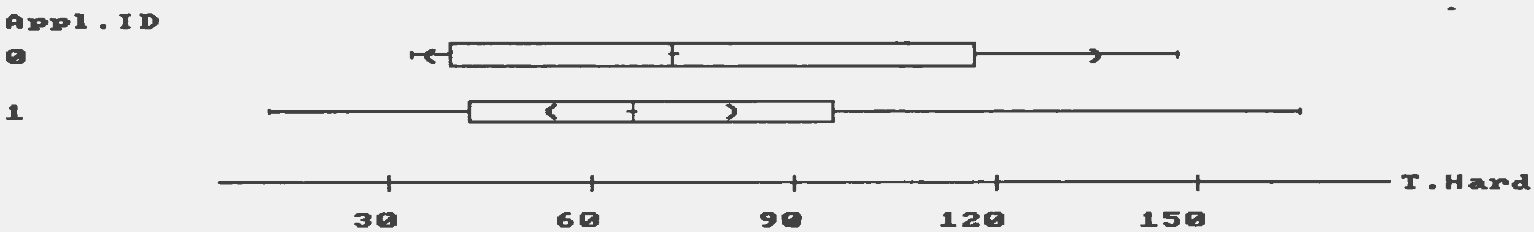


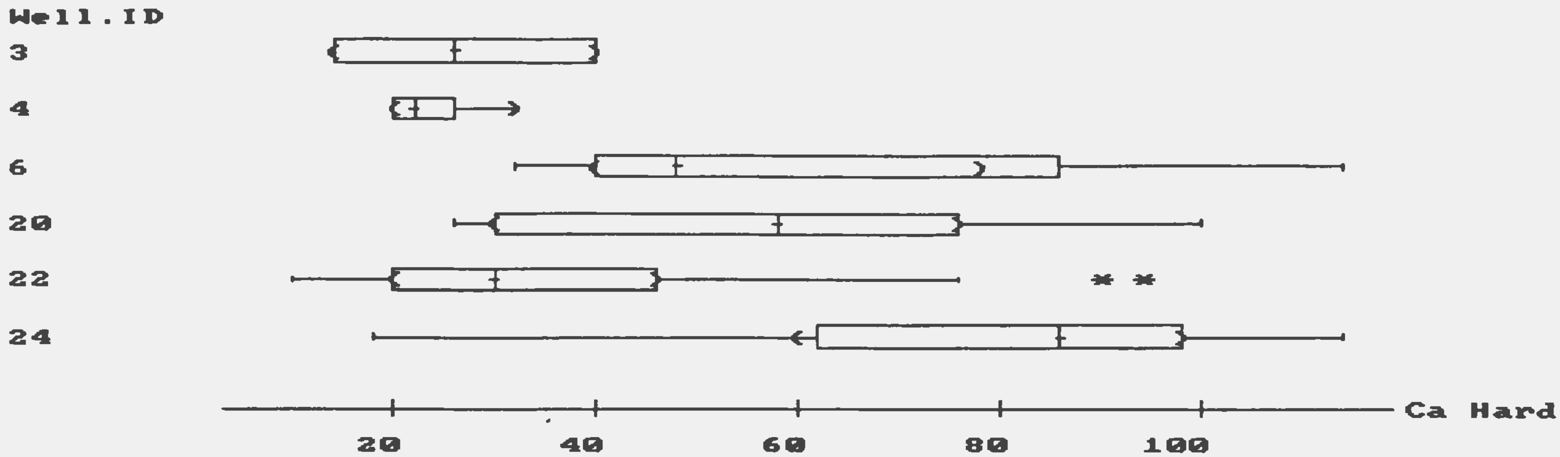
Well.ID
3
4
6
20
22
24
TDS
0.080
0.160
0.240
0.320
0.400

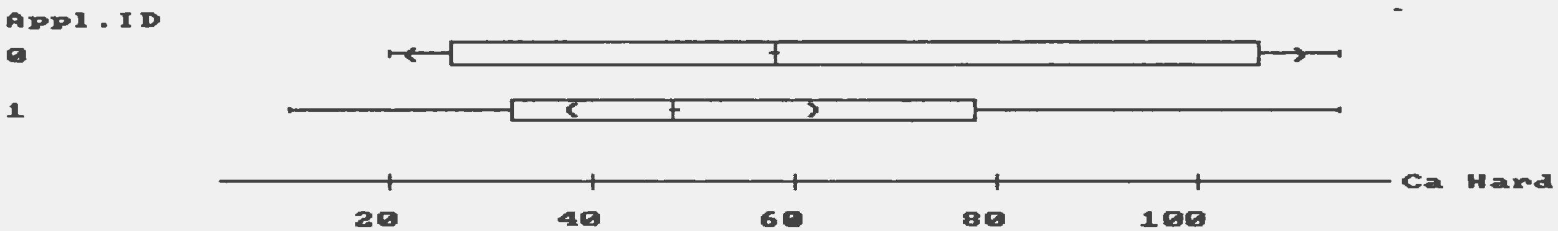


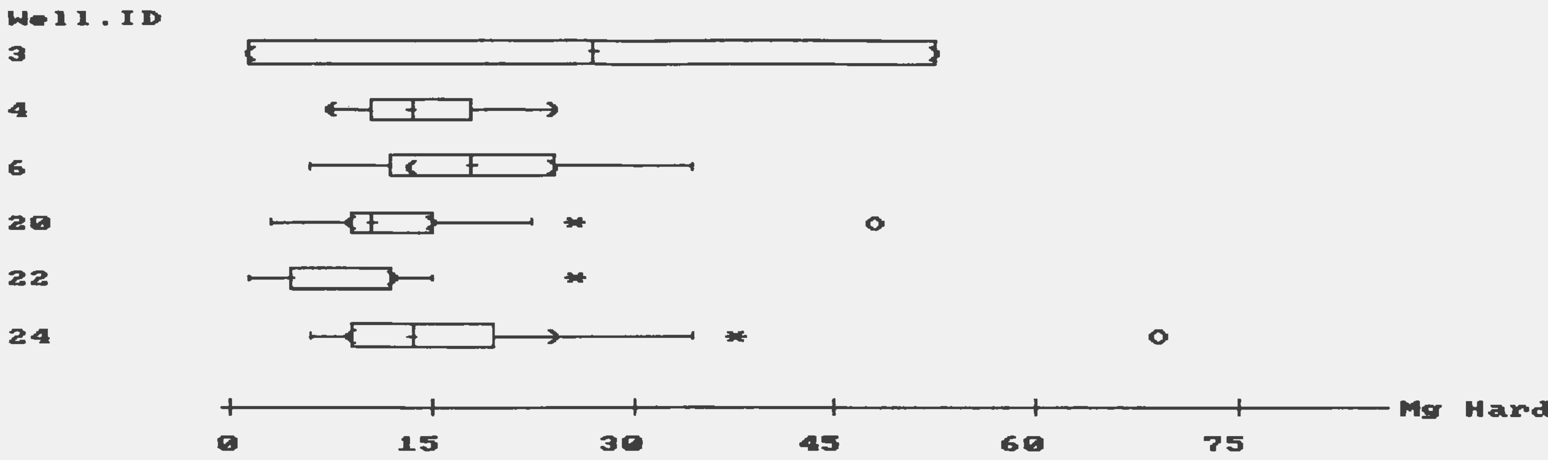
Appl.ID
0
1
TDS
0.080
0.160
0.240
0.320
0.400

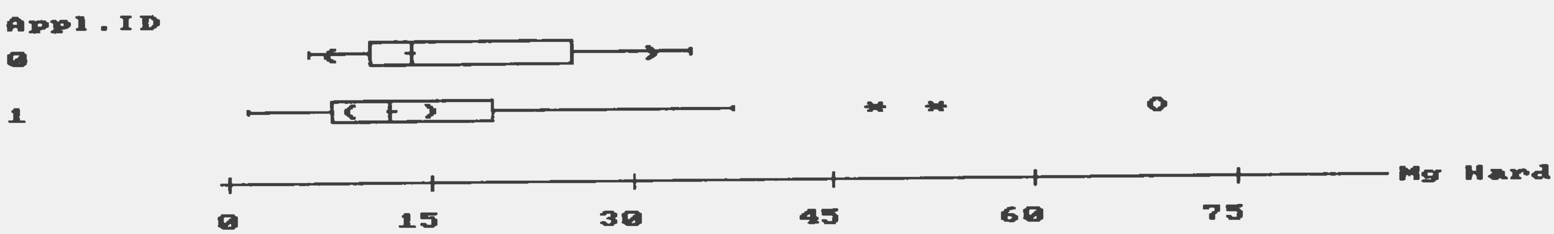

Well.ID
3
4
6
20
22
24
30
60
90
120
150
T.Hard

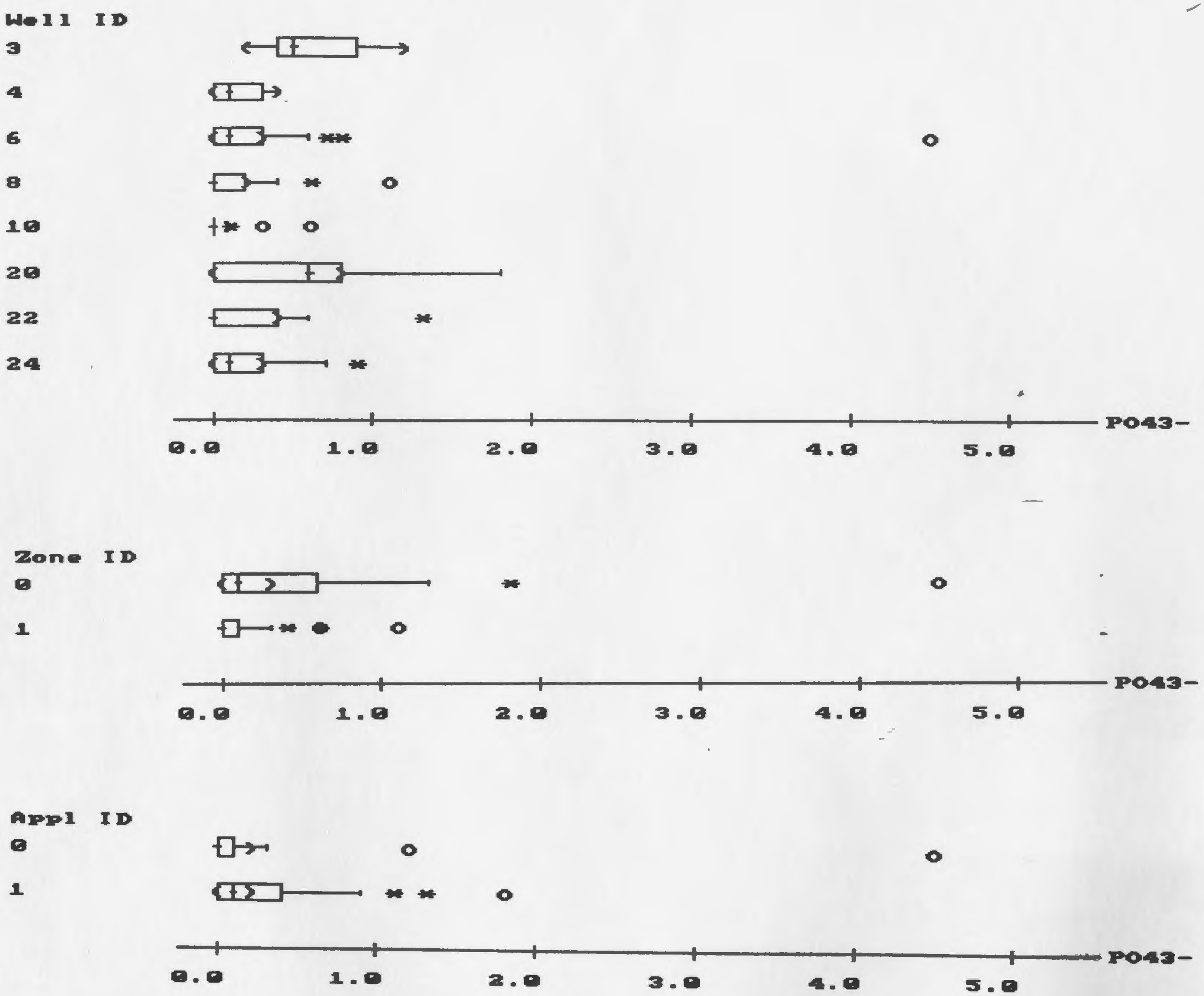

Appl.ID
0
1
30
60
90
120
150
T.Hard


Well.ID
3
4
6
20
22
24
Ca Hard
20
40
60
80
100

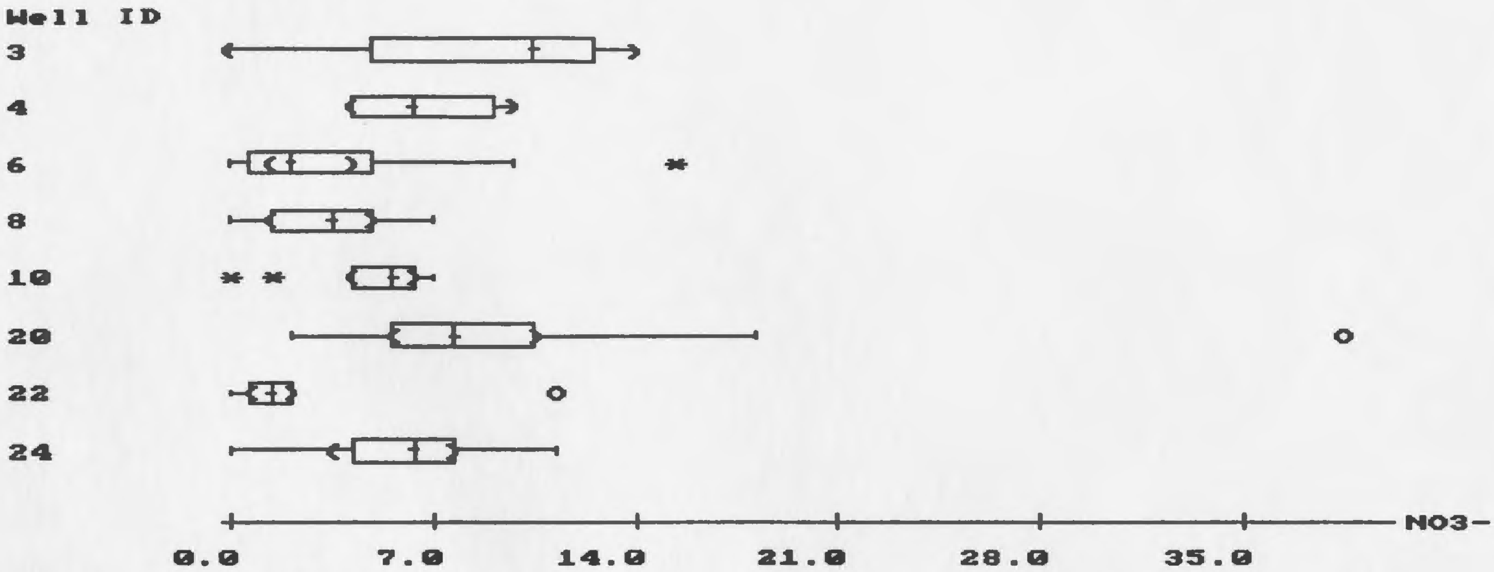

Appl.ID
0
1
Ca Hard
20
40
60
80
100

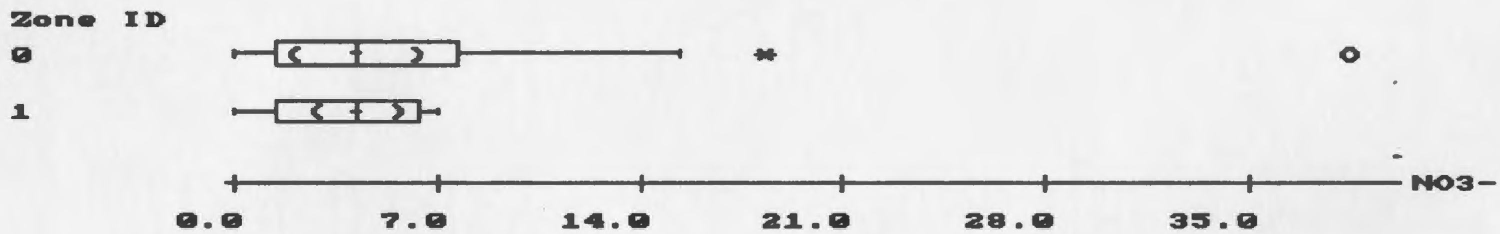

Well.ID
3
4
6
20
22
24
Mg Hard
0
15
30
45
60
75

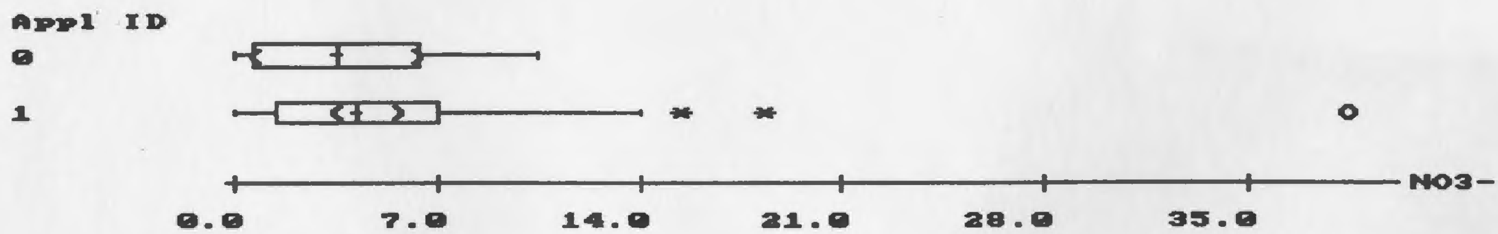

Appl.ID
0
1
Mg Hard
0
15
30
45
60
75

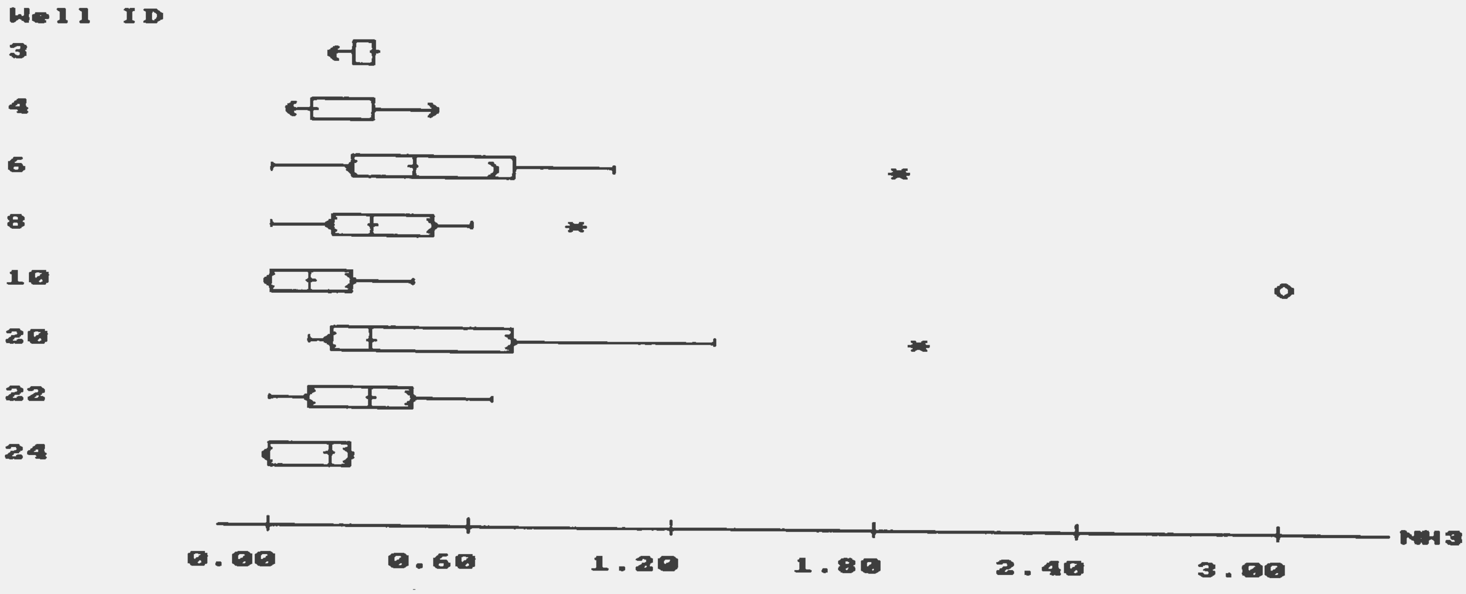


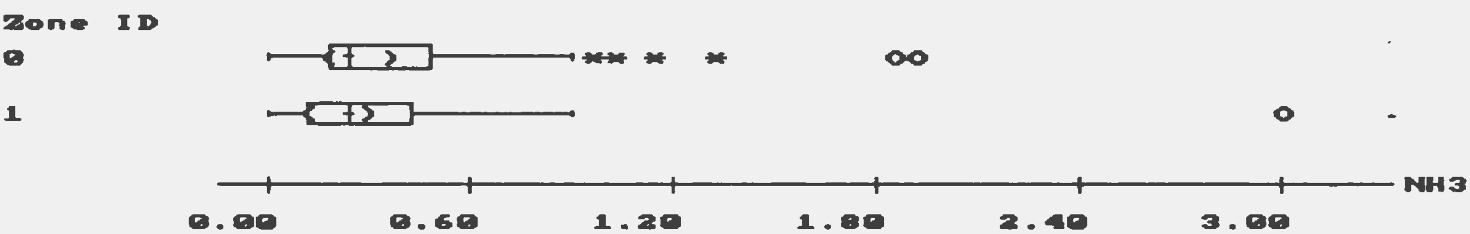
Boxplots comparing chemical parameter by Well ID, Zone ID, and Application ID for the entire data set.

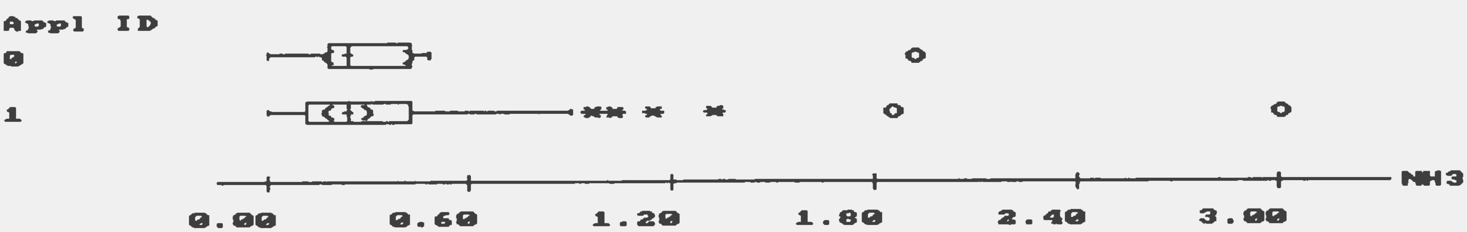

Well ID
3
4
6
8
10
20
22
24
NO3-
0.0
7.0
14.0
21.0
28.0
35.0

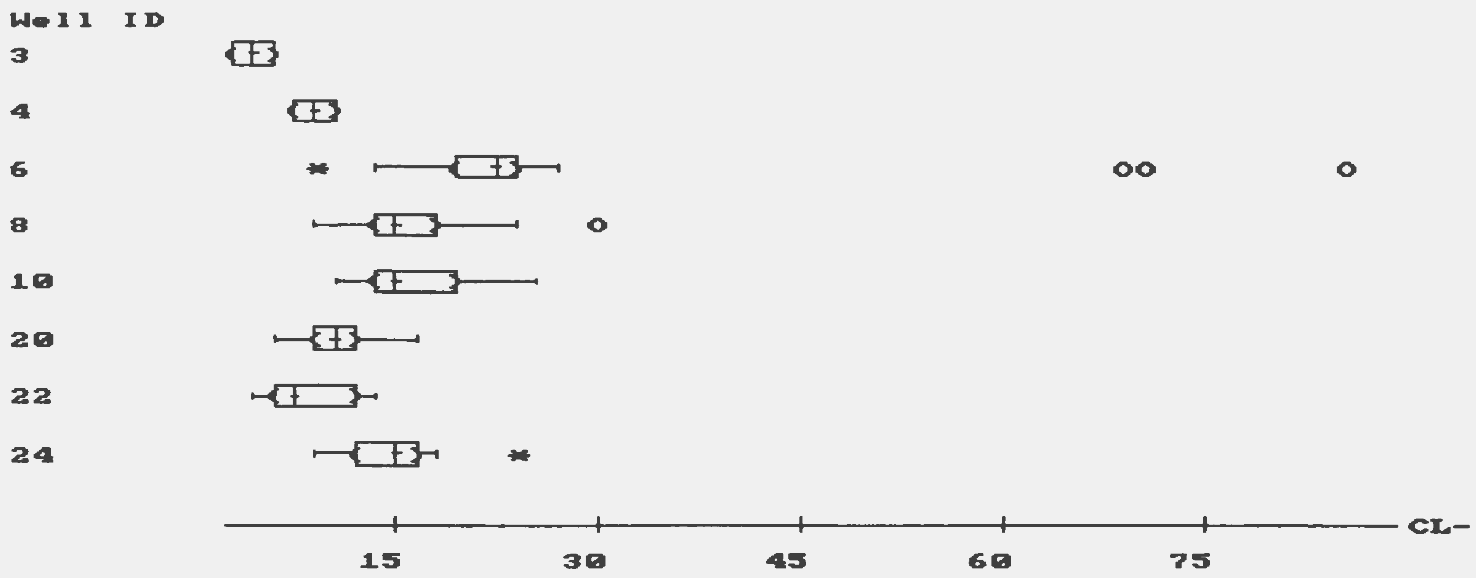

Zone ID
0
1
NO3-
0.0
7.0
14.0
21.0
28.0
35.0

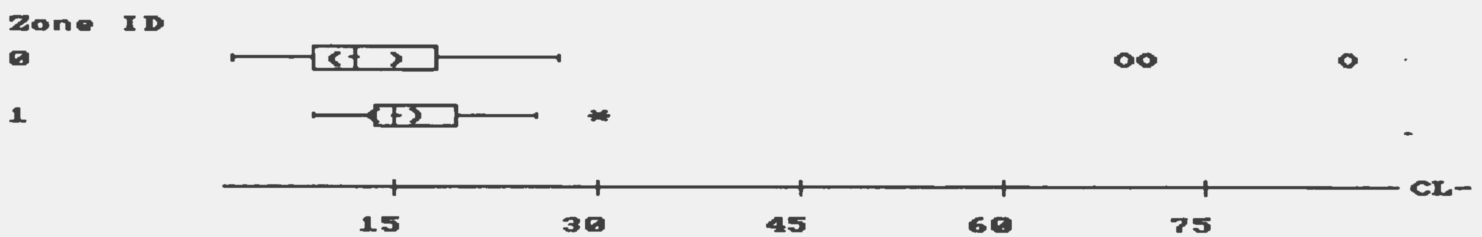

Appl ID
0
1
NO3-
0.0
7.0
14.0
21.0
28.0
35.0

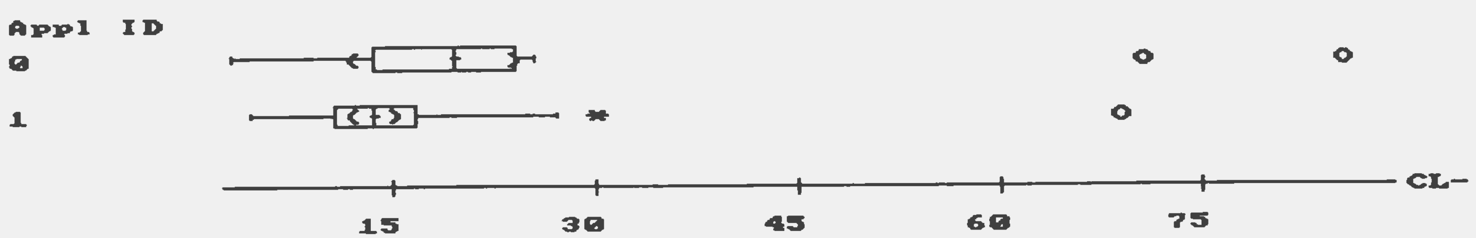

Well ID
3
4
6
8
10
20
22
24
0.00
0.60
1.20
1.80
2.40
3.00
NH3

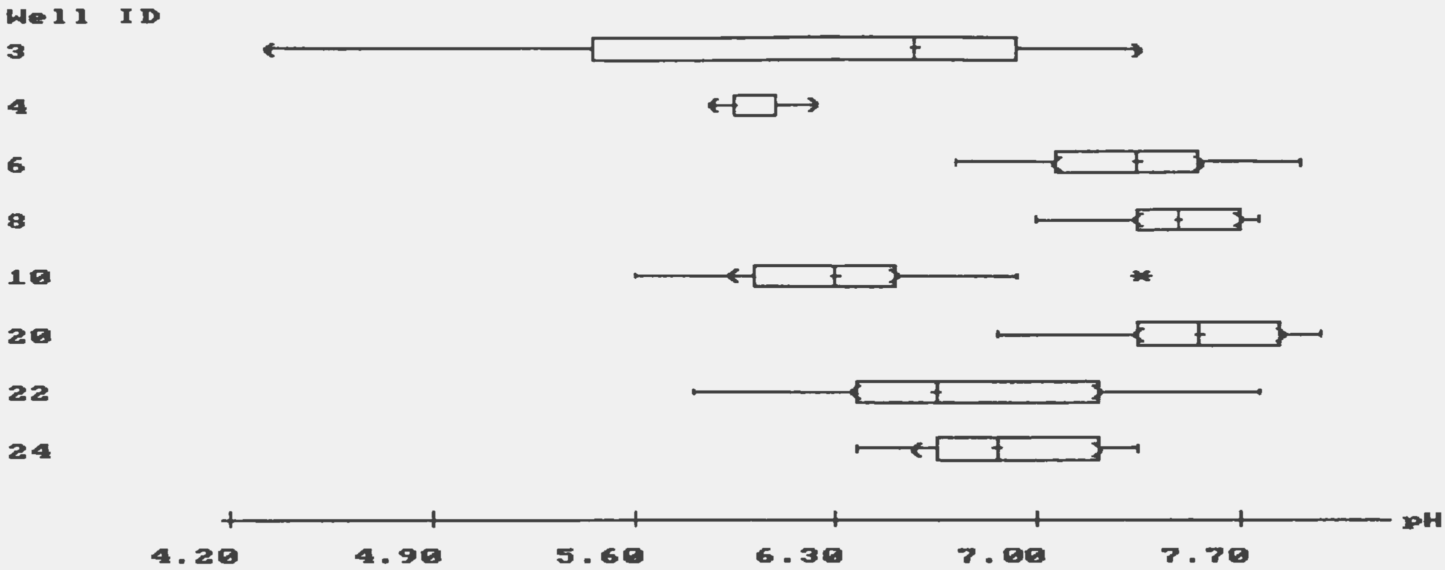

Zone ID
0
1
0.00
0.60
1.20
1.80
2.40
3.00
NH3

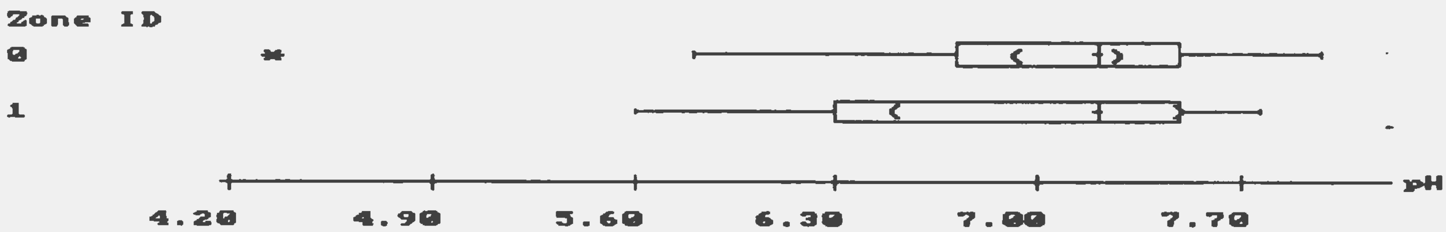

Appl ID
0
1
0.00
0.60
1.20
1.80
2.40
3.00
NH3

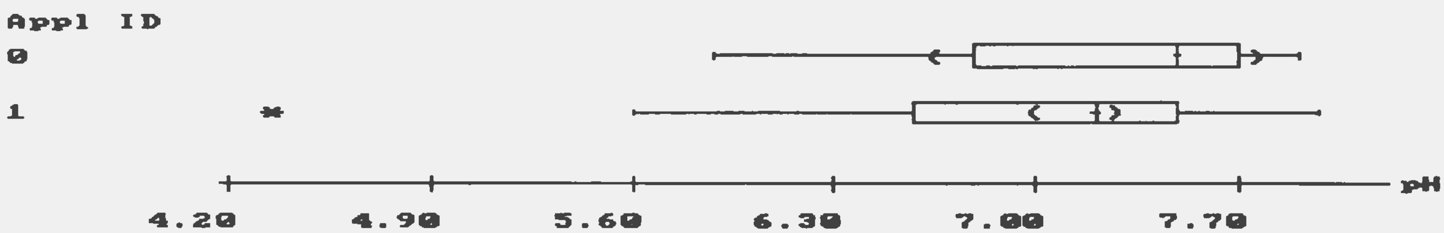

Well ID
3
4
6
8
10
20
22
24
15
30
45
60
75
CL-

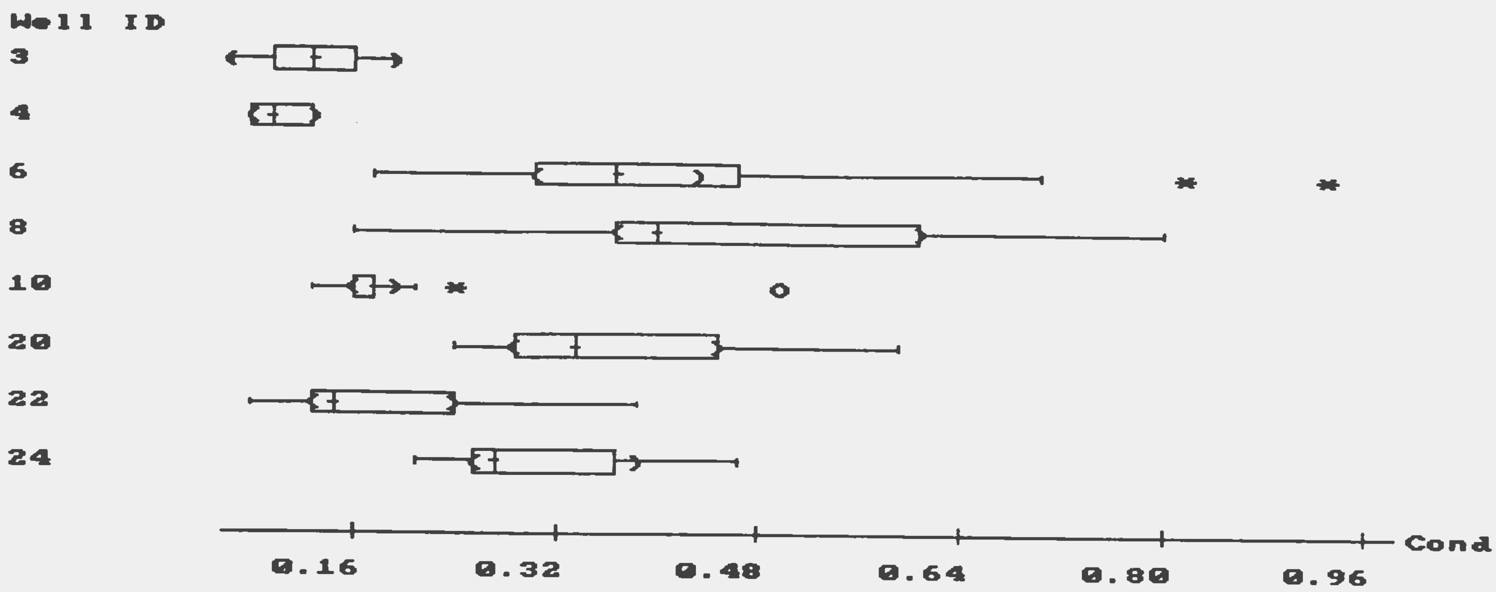

Zone ID
0
1
15
30
45
60
75
CL-

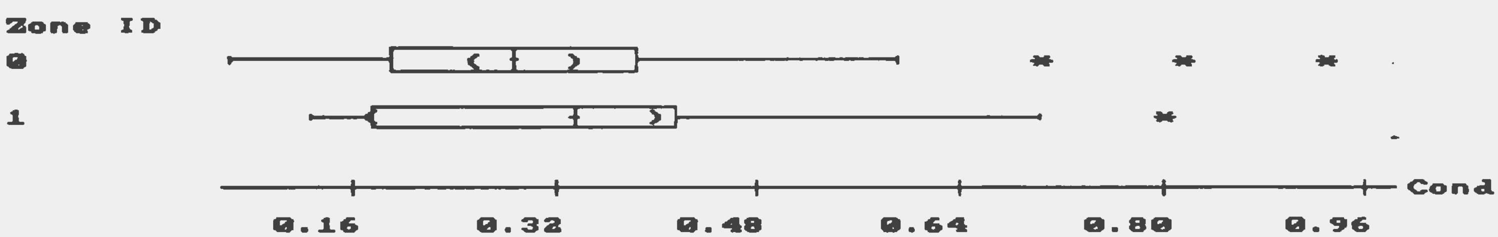

Appl ID
0
1
15
30
45
60
75
CL-

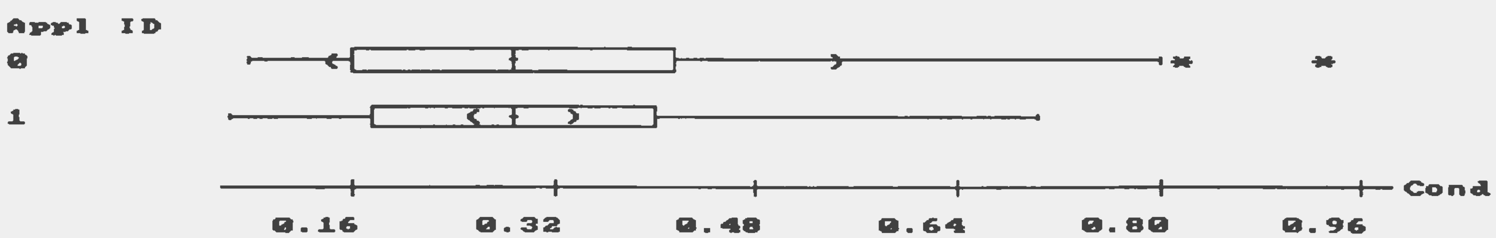

Well ID
3
4
6
8
10
20
22
24
pH
4.20
4.90
5.60
6.30
7.00
7.70

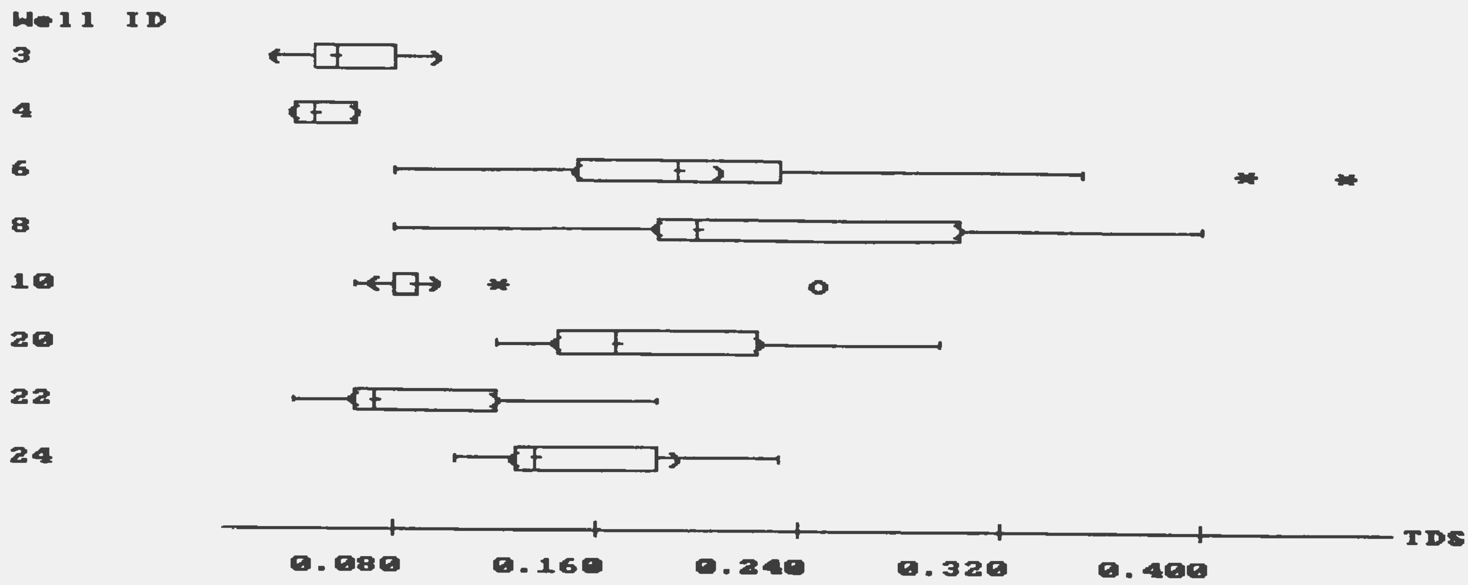

Zone ID
0
1
pH
4.20
4.90
5.60
6.30
7.00
7.70

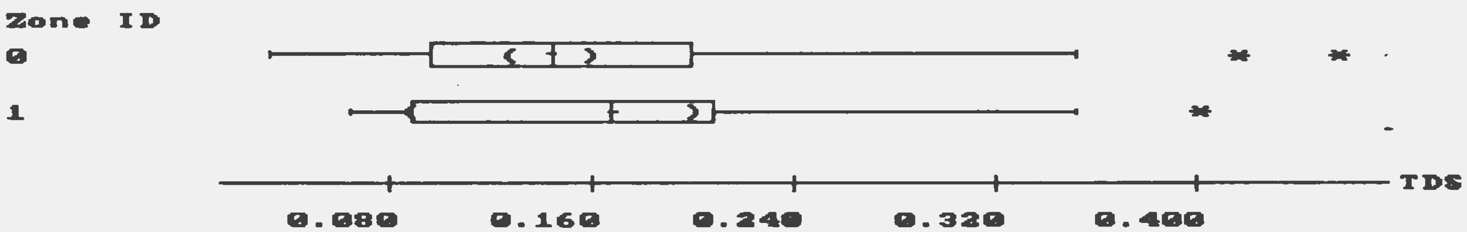

Appl ID
0
1
pH
4.20
4.90
5.60
6.30
7.00
7.70

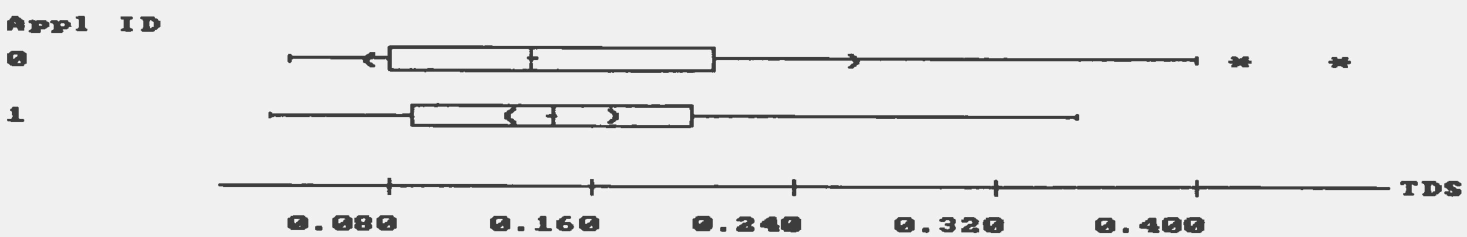

Well ID
3
4
6
8
10
20
22
24
Cond
0.16
0.32
0.48
0.64
0.80
0.96

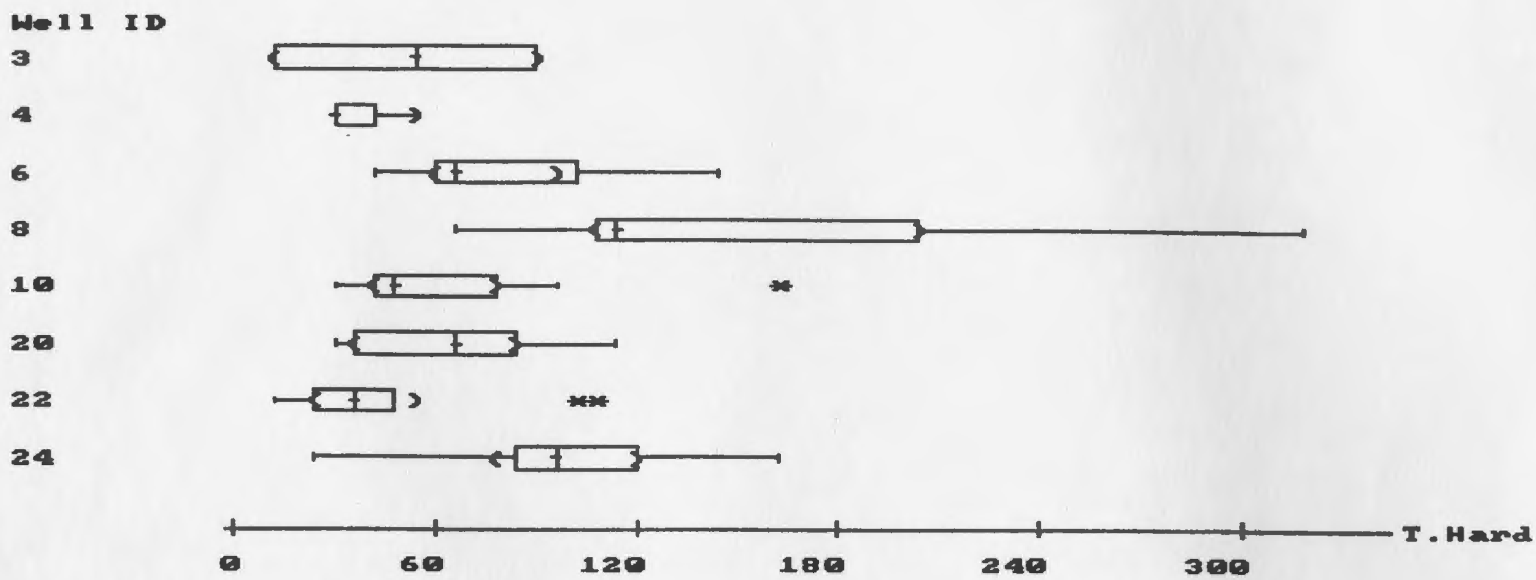

Zone ID
0
1
Cond
0.16
0.32
0.48
0.64
0.80
0.96

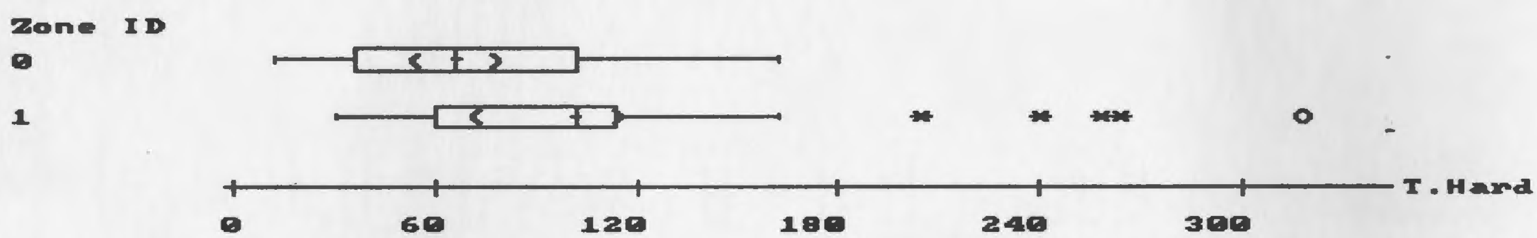

Appl ID
0
1
Cond
0.16
0.32
0.48
0.64
0.80
0.96

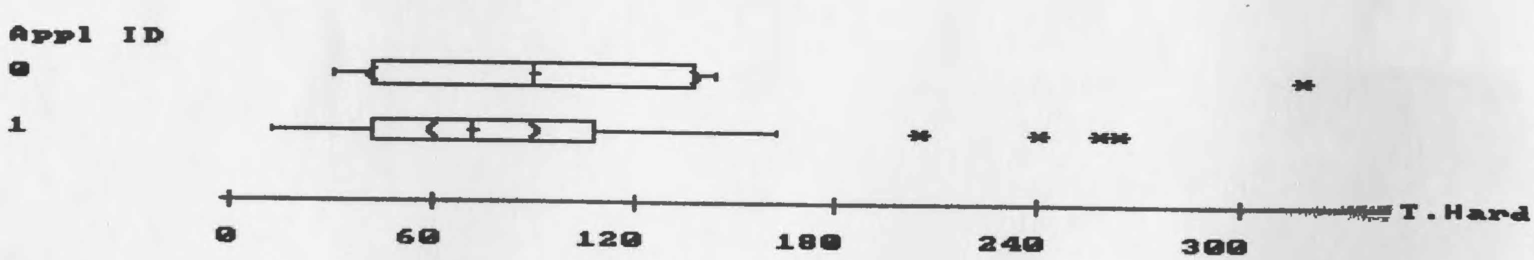

Well ID
3
4
6
8
10
20
22
24
TDS
0.080
0.160
0.240
0.320
0.400


Zone ID
0
1
TDS
0.080
0.160
0.240
0.320
0.400


Appl ID
0
1
TDS
0.080
0.160
0.240
0.320
0.400


Well ID
3
4
6
8
10
20
22
24
0
60
120
180
240
300
T.Hard


Zone ID
0
1
0
60
120
180
240
300
T.Hard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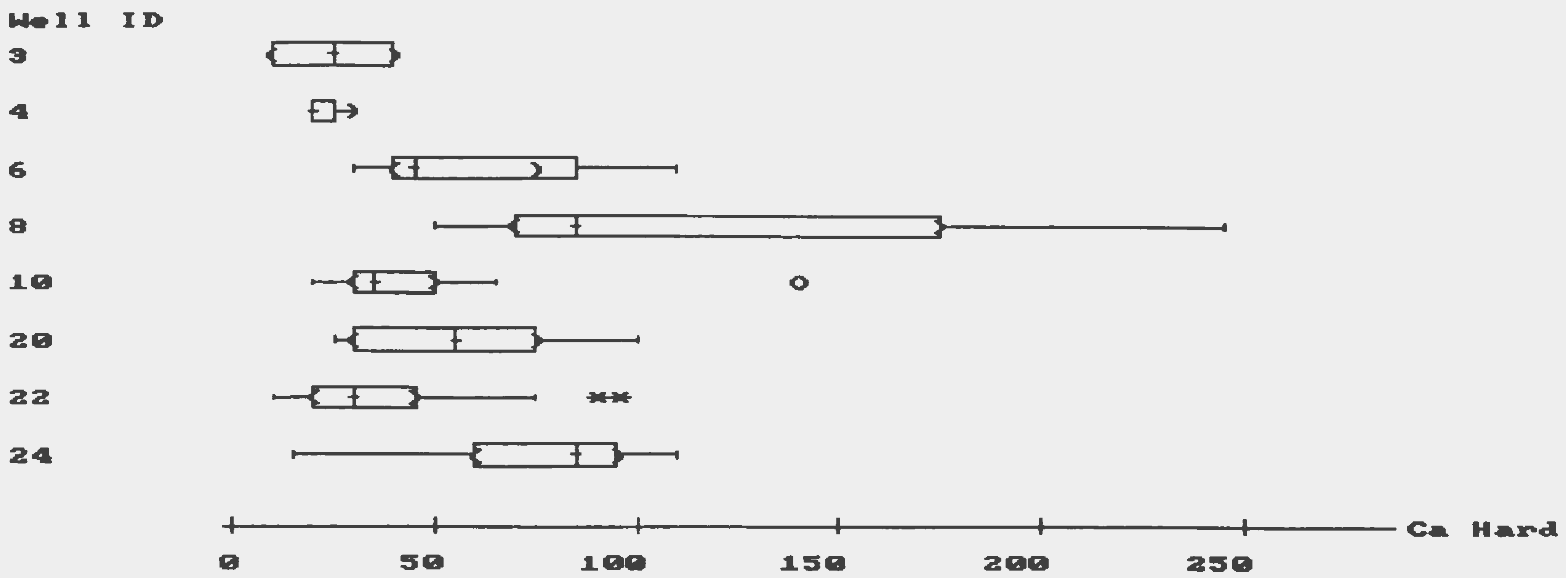
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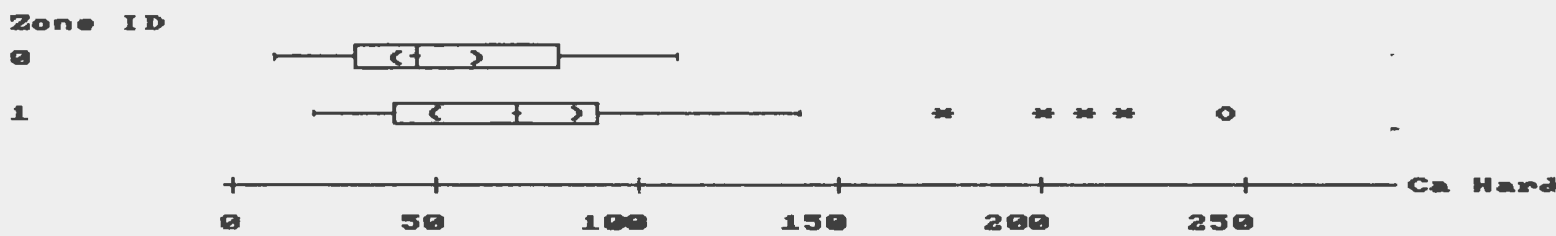
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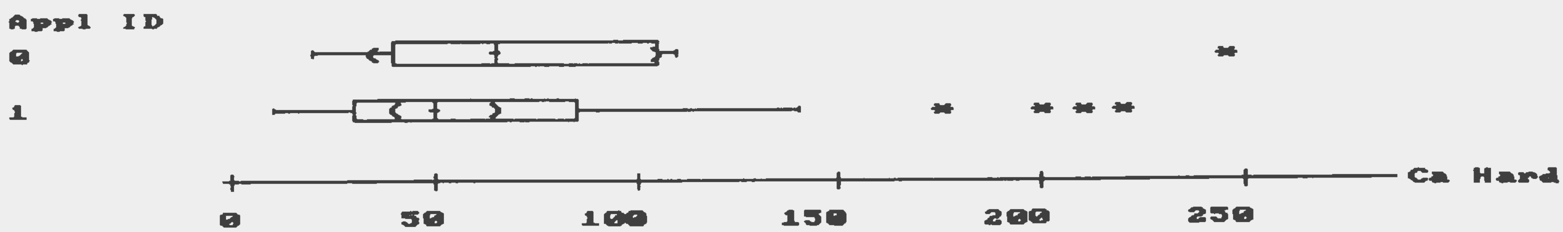
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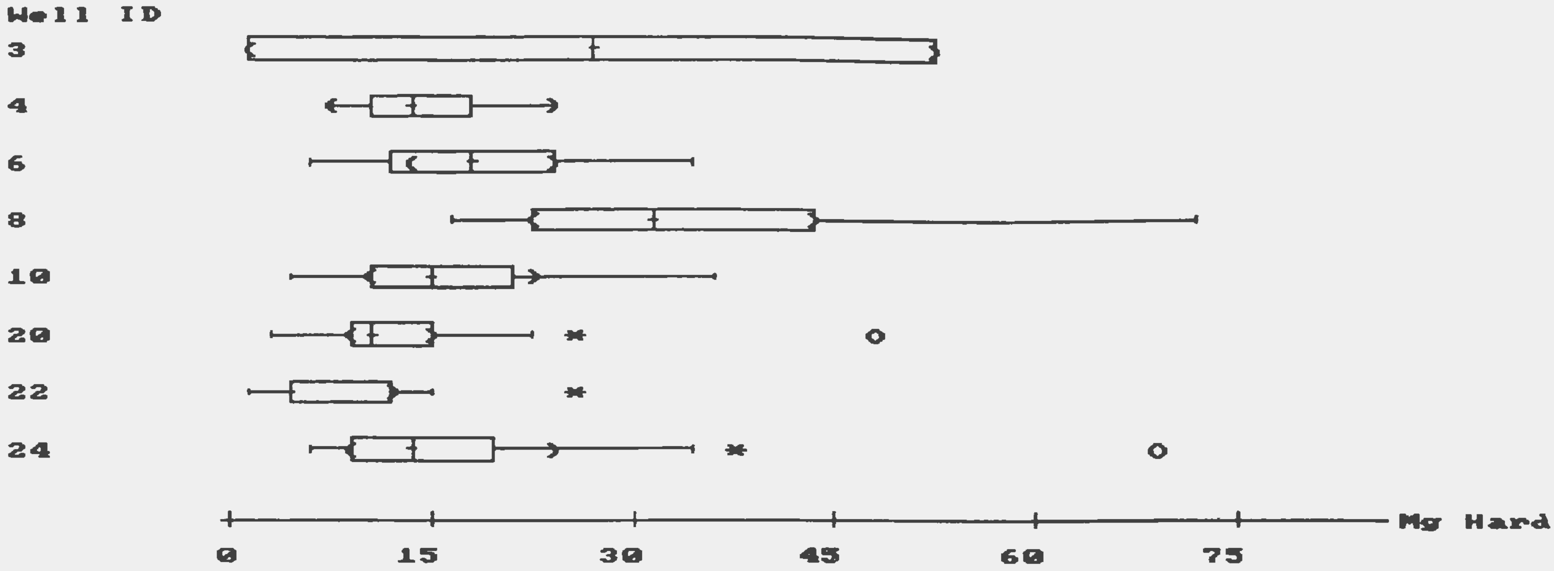
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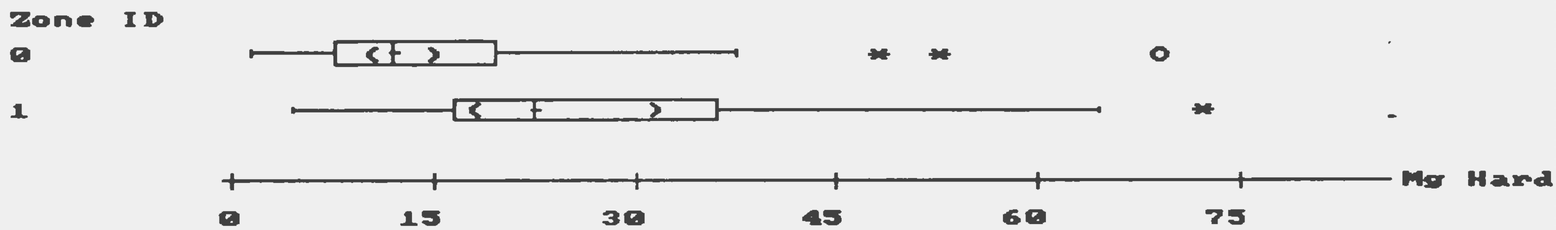
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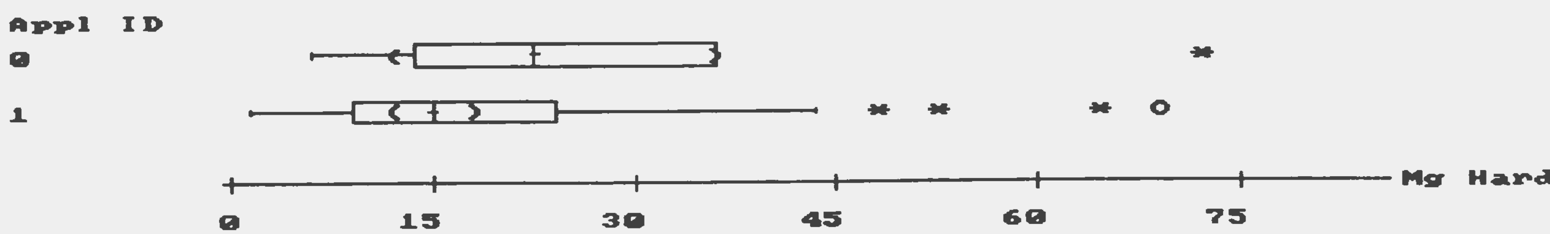
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