Hydrogeological Investigation of a Landfill Area in Cumberland County, Nova Scotia

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Abstract

The County of Cumberland has used a large tract of Crown Land near Springhill Junction as their main municipal waste disposal site since 1978. The site was initially commissioned as a first-generation landfill, known as the Little Forks Landfill, and operated with a minimal leachate treatment system. Increased volumes of waste disposed of at the site forced the County to design and operate a second-generation landfill immediately adjacent to the old site, known as the Cumberland Central Landfill. An elaborate groundwater monitoring program has been established around the perimeter of both sites, and results from this program have been analyzed to determine the presence of leachate in the surrounding area.

Chloride and total dissolved solids were selected as primary indicators for the presence of leachate, and pH was used mainly as a secondary indicator. Seventeen wells at six monitoring sites located downgradient of and adjacent to the landfills were used in this study. The concentration of each indicator parameter in these wells was compared to the background thresholds. Potentially impacted wells in this study occur downgradient and lateral to the first-generation site, and unimpacted wells are downgradient and adjacent to the second-generation site. Where indicator concentrations exceed background levels, only surficial and intermediate wells are affected. Deeper bedrock wells are considered relatively unaffected. Potential impacts are associated with the former Little Forks Landfill. The Cumberland Central Landfill is presently functioning as designed to minimize environmental impact.

Key Words: background threshold, contact time, contaminant plume, first- and second-generation landfill, groundwater, indicator parameters, migration

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ACKNOWLEDGEMENTS

This study has changed form on different occasions throughout the year in response to available monitoring data and previous work on the site. I would like to thank my supervisor, Heather Cross, for her valuable time, patience, and encouragement throughout this project. I would not have completed this thesis in time if it were not for her guidance. Invaluable work experience gained at the Nova Scotia Department of Environment (NSDOE) last summer, under the supervision of Dan Hemsworth, gave me the idea and necessary contacts to accomplish this study. Special thanks to Marcos Zentilli and fellow classmates for their open arms during a brief time of discouragement. Finally, I'd like to thank my family and friends for their support and encouragement throughout the past year.

Chapter 1: Introduction

1.1: General Background

Statistics show that waste production in urban communities is increasing from generation to generation. Many communities exceed their capabilities to handle waste, and as a result several waste management systems have been established. These systems include recycling, reuse, incineration, and landfilling, the last of which is a multi-billion dollar industry in Canada (Eyles & Boyce, 1997). Waste generation and disposal is presently one of the world's largest environmental concerns, and has not been taken seriously until recently. In fact, landfills remained essentially unregulated in Nova Scotia until 1973, and data concerning their contents and operating procedures until this time is almost non-existent.

The study area of this project contains both a first- and a second-generation landfill. Landfills have the potential to impact various components of the surrounding environment. The aim of this thesis is to illustrate the potential impact of the landfills on groundwater, and how landfill designs and operations have evolved over time to decrease this potential impact. Groundwater monitoring data from the site will be used as the basis for analysis.

The annual global production of waste in 1997 was approximately 3 km^3, equivalent to the volume of new rocks produced each year by the processes of continental volcanism (Eyles & Boyce, 1997). The same paper states that Nova Scotia is responsible for the creation of about 400 Kg of waste per capita each year, which ranks fifth amongst Canadian provinces. The use of landfills is widespread throughout the province and this mode of waste disposal is the most common system for municipal purposes.

Approximately 350 landfills have been documented in the province but many of these are now abandoned (NSDOE internal files). Closure procedures for each site range from simple abandonment (restricted mainly to older sites) to hiring environmental consultants to properly cover and monitor the landfill.

According to 1991 statistics, Cumberland County has a population of about 35,000 and produces approximately 15,000 tons of solid waste each year. This number has been forecast to double by the year 2015 (Porter Dillon Ltd., 1989), which means that proper disposal of waste is essential to the protection of the county's environment. The Municipality of the County of Cumberland presently owns or leases ten public dump sites. These sites are now closed, and some have been converted to transfer facilities. The majority are located outside of their respective town boundaries. Management of these sites has been controversial for the Municipality in the past, as smoke, blowing debris, vector control, and site access have all presented problems to nearby residents (D. Hemsworth, NSDOE).

1.2: Site Selection

The site selection process for this thesis study has been based on several factors. Most of the older landfill sites in the province have poor documentation of the different types of waste disposed of and specific operating procedures at the site. The selected landfill sites were therefore limited to those created after 1973, when the Nova Scotia Department of the Environment was formed and began the official regulation and documentation of landfills in the province. Another factor considered was that the landfill had sufficient analytical data to allow a thorough analysis of the site. Since many sites are not well documented and/or monitored, the selection was limited. On the other hand, most of the sites that are documented have had some previous data analysis and interpretation, so new studies should attempt to build on previous knowledge. The selected landfill should also have the potential for an associated environmental problem, such as leachate generation and potential migration toward susceptible receptors, in order to increase interest and importance of the study. Other factors that played a role in the selection process of the landfill will be discussed with specific reference to the selected landfill.

The municipal waste produced in Cumberland County is presently being handled by the Cumberland Central landfill (CCL), located approximately 11 km southeast of Amherst between Highway 2 and the Trans Canada Highway (Fig. 1.1). The CCL was designed and built to handle municipal waste from both Halifax Regional Municipality (HRM) and Cumberland County for the first two years of its operation. The site opened in January 1997, and was operated privately for the first two years. After that period, operation was transferred to the Cumberland Joint Management Services Committee (CJMSC), and HRM waste is now disposed of in Halifax County. The CCL site was selected following intense geotechnical and engineering design programs to ensure proper operations.

The previous disposal site was Little Forks Landfill (LFL), initially commissioned in 1977. The intent of the LFL site was to provide a waste disposal facility for Amherst and Springhill, but increased volumes of waste and closures of other dump sites forced the landfill to become the main site of disposal for the county for a short period. The LFL site operated for almost 20 years, and the working area of the site eventually ran out.

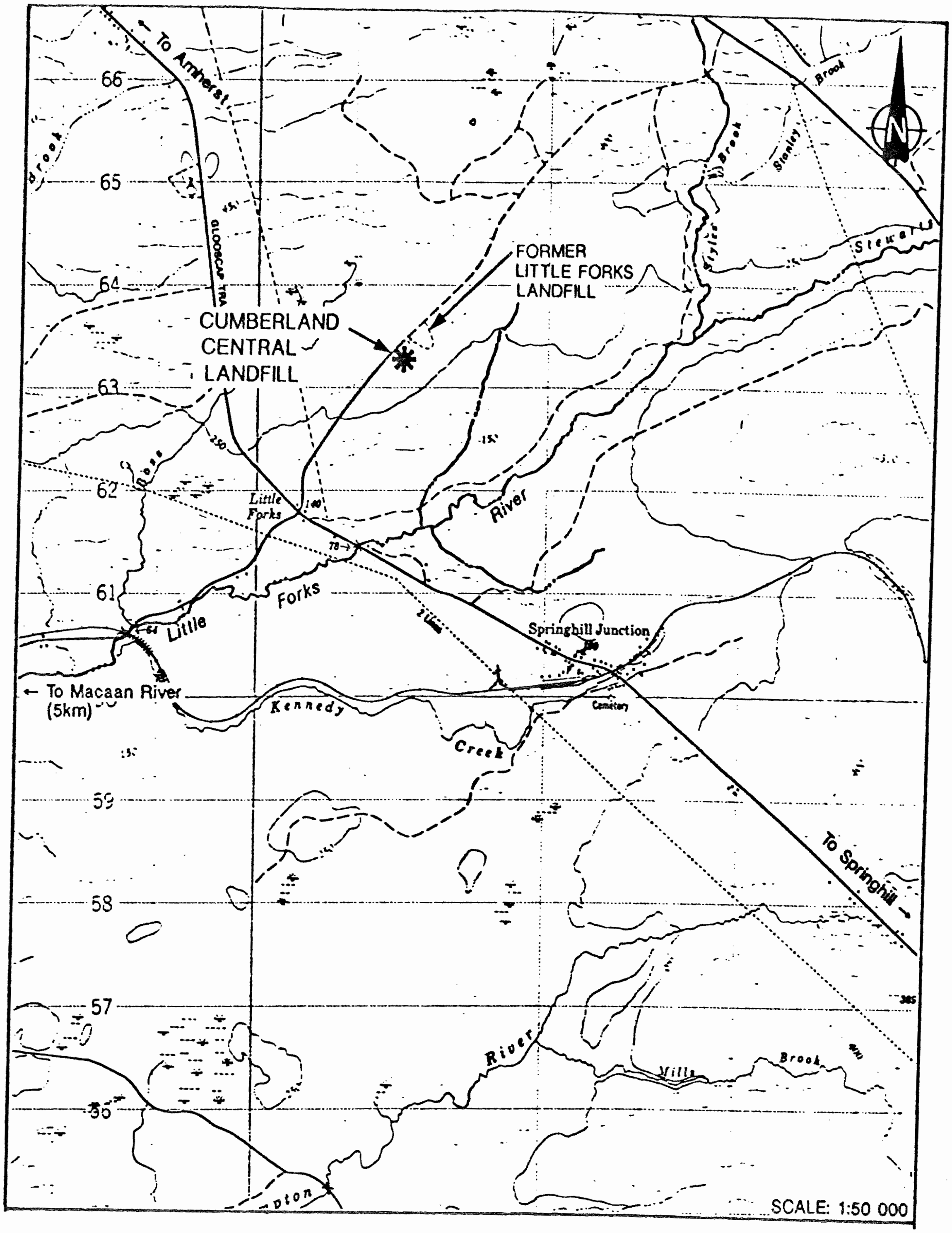

Figure 1.1: Location map of the Little Forks Landfill and Cumberland Central Landfill (PDI, 1997).

The second-generation CCL site was constructed directly adjacent to the LFL site (Fig. 1.1).

Second-generation landfills have evolved in design and technology from past methods of simple dump and cover, as the CCL site possesses an impermeable synthetic liner, a leachate collection and treatment system, and an elaborate monitoring program being performed by Porter Dillon Ltd. (PDL) of Halifax, Nova Scotia. The last factor has been a limitation to this study as PDL analyzes the data from the monitoring wells, however, this thesis attempts to elaborate on past data interpretation.

1.3: Leachate Generation

The degree of contamination of surface water and groundwater due to leachate varies from site to site. Factors such as amount of precipitation, surficial and bedrock geology, depth to groundwater, and the volume and chemistry of the waste are all major influences on leachate generation. As water percolates downward through the waste it reacts with its contents and forms large volumes of fatty acids, which continue to chemically react and create leachate. Chemical evolution of leachate results in organic pollutants, as well as dissolved ions, nutrients, and metals. Leachates from landfills generally have high levels of total organic carbon (TOC), biological oxygen demand (BOD), and chemical oxygen demand (COD) (Sharma & Lewis, 1994). Total Dissolved Solids (TDS) values are also typically high in landfill leachate because the TDS parameter encompasses all the dissolved materials in groundwater. As the leachate continues to be produced, it may form a plume that is able to migrate down-gradient away from the landfill.

Solutes that are dissolved in groundwater are mainly transported by the processes of advection-dispersion and diffusion (Fetter, 1994). The process of advection can be defined as transportation of solutes or contaminants at the same rate as groundwater in response to hydraulic gradient, hydraulic conductivity, and porosity (Sharma & Lewis, 1994). Dispersion can be defined as the spreading out of the solute from the path it would be expected to follow according to the advective transport in the flow system. In practical terms, dispersion results in a larger volume of contaminated aquifer, but with lower concentrations. The process of diffusion involves the solutes or contaminants being transported with respect to the concentration gradient, or from high concentrations to low concentrations. Fetter states that this process can occur without groundwater flow and is probably the main process involved in leachate migration through low permeability materials.

Depending on the landfill's elevation and underlying geology, the leachate is able to come into contact with groundwater, significantly increasing the contamination risk of the surrounding area. For this reason, environmental and human receptors must be given significant consideration during the landfill site selection process, in order to prevent their contamination by migrating leachate. Figure 1.2 illustrates this concept by highlighting the different stages that leachate follows from source to receptor.

SOURCE →	**HAZARD** →	**RELEASE** →	**PATHWAY** →	**RECEPTOR**
(waste storage at site)	(quantity and nature of waste stored at site)	(leaching from storage facility)	(groundwater, surface water, air emissions, and geologic conditions)	(humans, animals, plants, sensitive environments)

Fig. 1.2: The leachate chain, illustrating the cycle that leachate from waste disposal facilities follows from source to receptor (modified from CCME, 1992).

1.4: Effect on Receptors

The LFL and CCL sites are located in the northeast corner of the Maccan River watershed, which is documented as a sensitive environmental area. Several rivers, brooks, and tributaries are present in the surrounding area, and all represent potential environmental receptors for leachate migrating from the area of the landfills. The main potential receptor is the Little Forks River.

The surface waters flow to the Northumberland Strait. Leachate that reaches these surface waters has the potential to be diluted, or to collect in bogs and swamps. In many cases, bogs and swamps work to decrease contaminant concentrations because of the potential for dilution, adsorption and biodegradation in these wetland environments.

The nearest residence to the landfill is approximately 2 km from the site, which means that human receptors have a relatively low potential to be affected by direct contact with the leachate generated on site. No drinking water wells exist in the immediate vicinity of the landfill so contamination of water wells is unlikely to occur.

The site is well hidden from major roads to ensure that the site does not have any negative visual effects. Vector control and blowing debris off site have been documented as presenting problems to nearby residents in the past, but presently seem to be much better managed and not of great concern.

1.5: Organization of Work

This thesis has incorporated data and information from several different resources in an attempt to consolidate all known information pertaining to the LFL/CCL site. Surficial and bedrock geology maps obtained from Nova Scotia Department of Natural

Resources (NSDNR) are used as the basis of geology descriptions, and statistics from NSDOE have been used for climatic conditions. Reports on the CCL/LFL site completed by PDL between 1989 and 1997 were obtained through work contacts at NSDOE, and groundwater monitoring results in these reports was used as the main component of data analysis in this thesis. More recent PDL reports were later found to exist on the site, and some information from these has been incorporated into this study.

Groundwater head data obtained from PDL was used to construct groundwater equipotential lines, and to determine horizontal and vertical hydraulic gradients. Groundwater monitoring data has been used for indicator parameter concentration versus time plots, which is the basis of this thesis. Field values of hydraulic conductivity, determined by in-situ slug tests, were obtained from PDL and used to calculate groundwater velocities using Darcy's Law (Fetter, 1994). These results were then used for data interpretation.

Chapter 2: Geologic and Climatic Factors

2.1: Regional Setting

The LFL and CCL sites are located within a large tract of Crown Land being leased by the province of Nova Scotia (PDL, 1991a). The land is situated in the northeast corner of the Maccan River watershed and, as previously mentioned, is less than 2 km from the nearest residence. Tributaries of the Maccan River, which include the Little Forks River and Styles Brook, are located south and southeast of the landfill site. Due to the relatively low elevations in the region, 100 m and less near the site, there are numerous bogs and swamps in the area. This suggests that the water table is situated very close to the surface, meaning that there could be direct contact between the waste and groundwater in an unlined landfill.

Glacial till covers almost the entire region surrounding the landfill, and ranges in thickness from <1 m to over 20 m (Stea & Finck, 1988). The same map illustrates that the majority of the till in the area is composed of Late Wisconsinan Eatonville-Hants Till, which ranges from a stony to sandy to silty till with clasts predominately derived from Carboniferous sedimentary rocks.

The bedrock in the region surrounding the LFL/CCL site are Early-Mid Carboniferous sedimentary sequences of sandstone, siltstone, mudstone, and conglomerate. There are no major structural disturbances in the area surrounding the landfill, however, a small inferred fault zone exists approximately 1 km south of the site (Ryan et al, 1990). Metamorphism is minimal in the region, and is defined by a sub-greenschist metamorphic facies (Keppie & Muecke, 1979).

2.2: Local Setting

2.2.1: Bedrock Geology

Sanitary landfills are currently designed with an impermeable liner, either natural and/or synthetic, that separates the waste from the underlying bedrock and water table. These systems allow collection and treatment of the leachate generated by the waste efficiently in the short-term (<50 years). The long-term performance is not really known at present, since second-generation landfills are relatively new worldwide.

Haight (1991) suggests that the most desirable natural material underlying any sanitary landfill is a uniform, moderately-textured material with significant sand and/or clay content. This concept applies to both the surficial and bedrock material because sand and clay mixtures are advantageous to natural attenuation. Natural attenuation processes result in breakdown and decreased concentration of contaminants. Materials that have a high clay content are favourable because they allow the highest ion exchange and adsorption (Fetter, 1994). Conversely, materials with low clay contents will allow the passage of fluid at rates too high for attenuation to occur, and the leachate plume may migrate off-site with relatively high contaminant concentrations and velocities.

Sedimentary rocks possess the required intergranular permeability to allow natural attenuation processes as solutions move through the pores and channels between grains. By contrast, igneous and metamorphic bedrock are more heterogeneous in structure and are often characterized by fractures and fissures through which water can flow relatively fast with little or no attenuation (Haight, 1991). In general, groundwater is more easily contaminated in areas in which a landfill is located on or near igneous or metamorphic bedrock. Sedimentary rocks may also have fracture permeability that allows a faster rate of groundwater movement. However, these units are fairly homogenous and are not typically characterized by major variations through the unit.

Most newer sanitary landfills do not rely on natural impermeable liners and natural attenuation of leachate, but rather employ synthetic impermeable or geomembrane liners and leachate collection and treatment systems. Natural attenuation is then not the main process for leachate treatment, but may provide a back up should the impermeable liner fail over the long term.

The bedrock underlying the Little Forks Landfill is known as the Ragged Reef Formation of the Cumberland Group. This sedimentary bedrock was deposited in Upper Carboniferous time and is composed of a grey pebbly sandstone, conglomerate, and fine grained sandstone (Ryan et al., 1990). The bedrock possesses desirable features for natural attenuation , as it is sedimentary and has a moderate to high clay content. Ryan et al. (1990) indicate that occurrences of coal seams, limestone, and subordinate mudrock may predominate locally, however, according to well logs described by PDL (Appendix C), mudrock was the only other unit found to underlie the site. The same well logs show that depth-to-bedrock ranges from approximately 2.0 m to 8.0 m and lithology consists mainly of green to grey sandstone with interbedded siltstone and mudstone. This correlates with expected results based on the Ryan et al. (1990) bedrock geology map of Cumberland County. The sandstone unit is underlain by mudrock of the Springhill Mines Formation. The contact between the two units typically occurs at depths of about 20 m, and only some of the deep monitor wells have been drilled into the mudrock.

The sandstone exists in all of the drilled monitor wells, and the depth to bedrock increases in a southern direction. The sandstone bedrock's bedding dip also increases in a southern direction, which has been interpreted as indicating the edge of a buried bedrock valley that is part of the Little Forks Ravine (PDL, 1997). This can be seen on the Ryan et al. (1990) map as a small fault zone that has been inferred south of the landfill site, with bedding dip increasing near to and south of the zone. A cross section through the site has been constructed to obtain a better understanding of the different lithologies and average depth to the water table underlying the property (Fig. 2.1)

2.2.2: Surficial Geology

Surficial material in the vicinity of a landfill should ideally have a high clay content, since surface soil at the site will be used as cover material for the waste and must be relatively impermeable. This is the case throughout much of Nova Scotia as glacial events in the past are responsible for depositing clay to sand-rich glacial tills of varying depth and clay content. Glacial till thickness in Cumberland County is typically shallow, about 2-5 m, however it may reach depths exceeding 20 m. This is typical for much of the province, as till thickness is usually about 3-8 m most areas, but can locally exceed depths of 50 m (Stea & Fowler, 1981).

The composition of glacial till often reflects the lithology of the underlying bedrock. In other words, siltstone or mudstone bedrock will produce a till with relatively high clay and/or silt content, whereas sandstone bedrock will produce a more granular till with decreased clay content. Glacial till in the immediate vicinity of the landfill is composed of the Eatonville-Hants Till and varies from an upper stony sand unit to a lower silty sand unit (Stea & Finck, 1988). The upper till unit is described by Stea and Finck (1988) as being reddish-brown and loose to moderately compact. Thickness of the

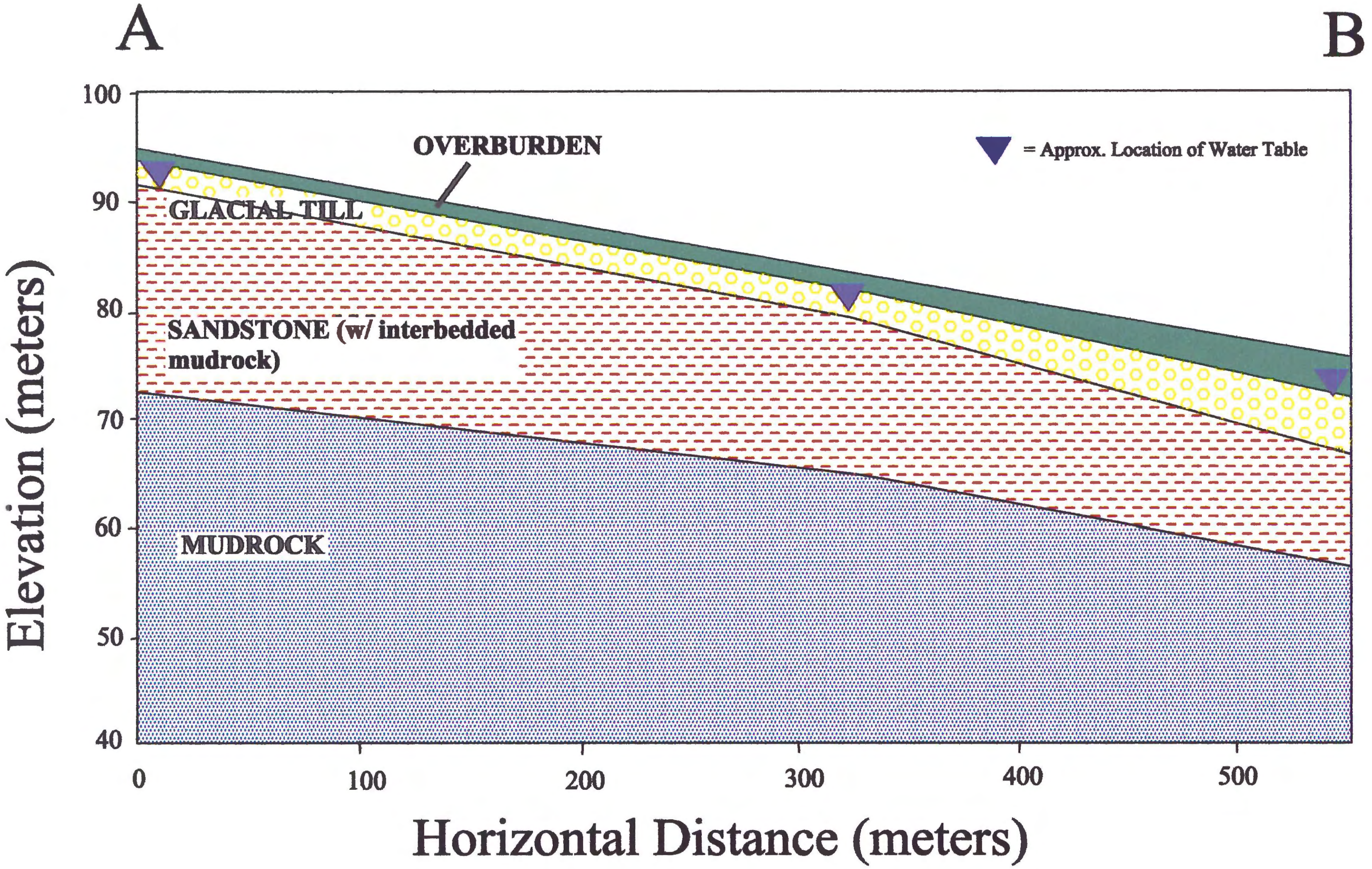

Figure 2.1: Schematic cross section through the site (A to B), approximately perpendicular to strike (section location shown on Figure 4.1). The figure illustrates the thickness of each unit underlying the site, and defines where the average water table exists. Lithologies are based on PDI well logs, and depth to water table is based on average head values for each of the wells used to construct the figure.

unit ranges from about 3 m to 20 m and occurs locally with ice-contact stratified drift, which is the case approximately 1 km east of the site. The lower till unit overlies the sandstone bedrock and is finer grained than the upper unit. Stea and Finck (1988) describe the lower unit as fissile and massive, with a range in thickness from <1-15 m. Both till units underlie the site and possess a total thickness of about 2-10 m, with thickness increasing southerly. The most influential characteristic of the till with respect to the landfill is the fact that it has a hydraulic conductivity of approximately 1×10^{-6} cm/s (PDL, 1993), which means that the till satisfies the criteria of providing a relatively impermeable cover material for the waste.

2.3: Landfill Operations

2.3.1: Site Design and Operational Procedures

The Little Forks Landfill was initially designed to operate as a trench-type landfill where compacted waste is deposited into an excavated trench and covered daily. However, after consulting with the Department of Environment in 1979, the operating procedure for the initial landfill site was changed to an area-type landfill. This was done to compensate for the relatively shallow surficial till, which could not supply sufficient cover material for increasing volumes of waste being disposed of by the trench-type landfill (PDL, 1989).

The area-type landfill requires a longer haul of cover material but allows more flexibility in constructing the height of the landfill. Cover material was excavated from an on-site source, but from an area not used by the landfill operators. The one disadvantage to this system is that the waste was not completely covered daily since the working area is much larger in an area-type landfill. Though the working-cell area was kept to a minimum and newly dumped waste covered daily, a cell was only completed on a weekly basis, which increases the contact time between precipitation and the waste. The newly designed Cumberland Central Landfill site has always operated as an area-type system with daily cover applied to the waste and no excavation of bedrock.

The daily and final cover material for the LFL site was excavated from the eastern part of the disposal area. Cover material was moved from this site to the disposal area by an articulated dump truck, which was loaded by a track-mounted hydraulic excavator. The excavator was, and remains, used for such tasks as site preparation, ditching, and maintenance, as well as a back-up for handling and disposing of waste when the primary dozer is out of service (PDL, 1989).

The LFL site was decommissioned in 1996. The recommended capping system designed for site closure is shown in Fig. 2.2, although the LFL was not completed in this manner. Instead, the working area was covered with a final layer of relatively impermeable soil and graded and seeded.

2.3.2: Landfill Contents

The knowledge of landfill contents is a direct function of the records kept by the landfill operators. Until the establishment of NSDOE in 1973, there were no, or very few, records being kept by landfill operators and the system for accepting waste had no limits. It was essentially an "anything goes" system. The LFL/CCL site was established under the province's Solid Waste Management Study Program. One of the main goals of

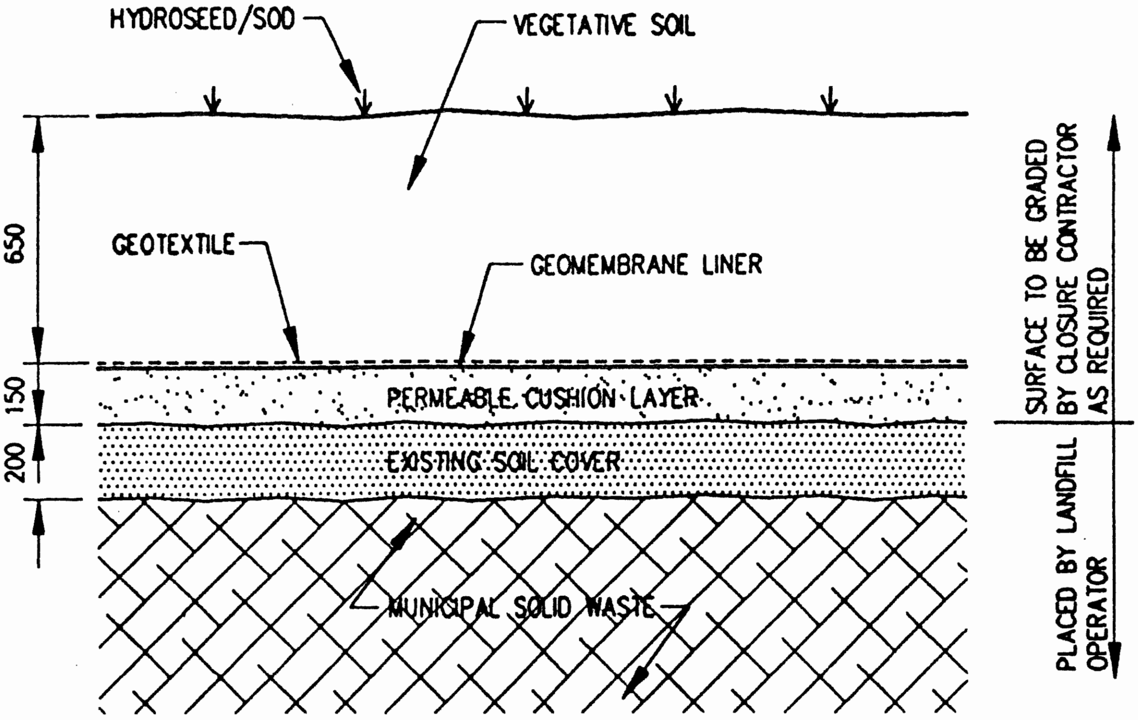

Fig. 2.2: Schematic drawing of the recommended cap system at the LFL site (PDL, 1996)

the program was to determine which types and quantities of waste were accepted in Nova Scotia landfills. For this reason, there have been fairly detailed records kept of the volume and type of wastes disposed of at both the LFL and CCL sites.

The CCL site services the entire population of Cumberland County, either directly or indirectly. As noted earlier, the landfill was built to accept waste from HRM for two years during the construction of the new Otter Lake facility, thus the volume of waste disposed of during that time was greater.

The landfill now accepts waste from the municipal, industrial, and commercial sectors. Cumberland County is very proactive in recycling, and the waste stream is monitored. Some of the waste currently accepted at the landfill site includes paper, glass, plastics, furniture, scrap metal, properly handled asbestos, tree waste, fish residue, and incinerator, fly, and wood ash. Most of these wastes have associated limits to their acceptance and some, such as asbestos and ash, require a secondary handling process before being dumped into the landfill.

Waste that is harmful to the environment, or has the potential to be harmful, must be denied acceptance to any sanitary landfill. Types of non-disposable wastes vary between landfills because some sites are designed to contain and control certain harmful wastes. Materials that are not accepted for disposal at the LFL and CCL include explosives or combustible materials, radioactive material, corrosives, toxic materials, paints, pesticides, and improperly drained gasoline tanks (PDL, 1991). It is important to note that any waste brought to the landfill site that does not fit into any of the regulatory categories is immediately brought to the attention of the NSDOE or CJMSC for approval before proper disposal.

2.4: Hydrogeologic Setting

2.4.1: Climate

The province of Nova Scotia spans a latitude of approximately 45 degrees and is therefore considered a temperate region. The entire province is subject to four seasons and thus has a variable climate. Winter and spring are responsible for the majority of the precipitation accumulation and are considered the wetter seasons, whereas summer and fall represent the drier seasons when precipitation is at a minimum. However, due to its coastal environment, the province is subject to significant precipitation amounts each season compared to inland provinces.

Precipitation levels in Nova Scotia generally average 1300 mm per year and Cumberland County does not deviate far from this trend. Annual rainfall in Cumberland County ranges from approximately 1070 mm on the Cumberland Plain to 1190 mm on the Minas Basin (Vaughan & Somers, 1980). Statistics illustrate a decrease in snowfall accumulation in recent years, but in the past it has reached levels of about 2000 mm per year, which converts to approximately 200 mm of rainfall. Due to its close proximity to the Atlantic Ocean, it is typical for Cumberland County to experience short storms (2-3 days) in which a substantial amount of precipitation occurs. This increases the importance of the cover material to possess a low hydraulic conductivity, as the volume of leachate produced is a function of the meteoric water that is able to migrate through the waste.

Temperatures in Cumberland County typically vary from a mean low of approximately -6°C in January to a mean high of about 18°C in July (NSDOE statistics, 1988). Deviations from these mean temperatures are not uncommon, as there are frequent extended periods of colder temperatures in January and February and warmer temperatures in July and August.

2.4.2: Surface Water

Precipitation that reaches the Earth's surface either runs off as surface water or infiltrates the soil and eventually becomes groundwater. Surface water represents water that moves on the surface through lakes, rivers and streams, and flows naturally in the direction of decreasing elevation in response to drainage patterns (Fetter, 1993).

Cumberland County has few lakes compared to the rest of Nova Scotia, however, the county possesses a total of nine major watersheds. These watersheds are responsible for the collection of surface water draining toward the Bay of Fundy and the Northumberland Strait. The Maccan River watershed is of concern in this study because the LFL and CCL sites exist in its northeast corner. The Little Forks River and Styles Brook are both tributaries of the Maccan River, and are located in close proximity to, and downgradient of, the LFL and CCL sites.

The older LFL site does not have a leachate collection system, which means that surface water and groundwater in the vicinity of the site was susceptible to potentially contaminated runoff and infiltration during landfill operation of uncovered cells. At site closure, some cover was applied, some grading was carried out, and some trees were planted. These measures are expected to reduce infiltration of precipitation, and thus reduce generation of leachate, but there are still some leachate springs at the base of the old landfill area which flow into a wetland area.

One of the main objectives in the design of the new CCL landfill was to reduce and minimize environmental effects on groundwater and surface waters. This is achieved by a combination of sediment control devices and a leachate collection system. Sediment control ponds have been installed around the site to provide treatment of surface runoff from the exposed working areas. Leachate collection and control systems have been installed around the fill areas and work efficiently to collect the leachate. The leachate is collected in a tank, and is disposed of in an off-site location. No leachate springs have been reported on this site. Surface water monitoring by PDL is ongoing to detect any changes in water quality downgradient of both the LFL and CCL sites.

Chapter 3: Methodology

3.1: Introduction and Review of Methodology

The LFL site has been monitored by PDL since 1978, and the CCL site from 1996 to the present. As a result, some of the data analysis completed in this thesis has previously been performed by PDL. Despite this fact, most of the data analysis and interpretation in this thesis has been completed by the author, most without knowledge of previous findings. Regardless, I have gained invaluable experience completing each of the analytical techniques applied to the data.

3.2: Steps in Methodology

3.2.1: Field Methodology

The first step of implementing the monitoring system was to construct a series of monitoring wells that would work efficiently to monitor each site. A total of 7 sites and approximately 20 monitoring wells were strategically placed to monitor the Little Forks Landfill, and 11 sites and about 30 wells were used for the CCL monitoring program (PDL, 1997). Each well site in the CCL monitoring program has a surficial (A Well), an intermediate (B Well), and a deep well (C Well) in place to obtain groundwater characteristics in each zone. A total of six well sites were selected for this study, based on their location and sampling intervals. The depth ranges of these wells are 4.6 to 5.8 m, 9.1 to 15.5 m, and 18.6 to 37.0 m, respectively. The typical monitoring well design for both sites is illustrated in Figure 3.1, and well specifications for the wells analyzed in this study can be found in Appendix C.

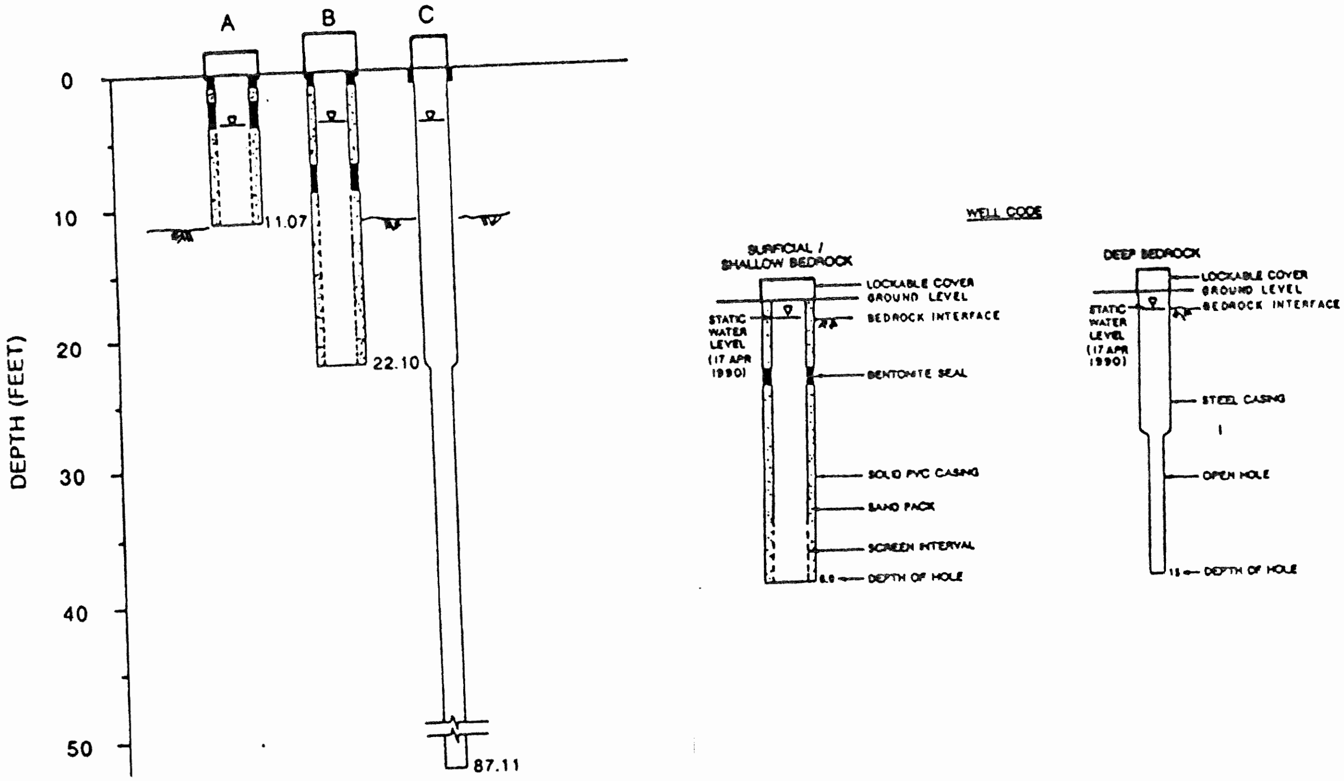

Fig. 3.1: Typical design for monitoring wells on the LFL and CCL sites, including A, B, and C wells. Data included in figure is for MW96-4, however, corresponding wells have similar values (PDL, 1991b).

The CCL monitoring wells are sampled at least annually, but most are sampled either quarterly or biannually, to ensure that the environmental risk associated with the landfill is kept to a minimum. As part of the program, monitoring includes samples of upgradient wells to provide background quality data for comparison to water from the on-site and downgradient monitoring wells. Samples for general chemistry and metals are field filtered, and metals samples are acidified with nitric acid. Selected sampling stations are analyzed for various organic compounds.

Twelve surface water sampling stations have been established at the CCL by PDL. Sampling frequency is at least annually, with some sites being monitored quarterly or biannually. The samples are taken as unfiltered grabs and are tested for general chemistry, metals, and total suspended solids; selected sampling stations are analyzed for various organic compounds. Surface water results are not analyzed in this study.

Other sample sites include several residential wells, leak detection sumps, and leachate. The sumps collect water that drains from the soil layer under the liner system. Results from these sources are not analyzed as this study focuses on selected monitoring wells.

3.2.2: Analytical Methodology

The data analysis for this study is based on monitoring results performed by PDL mainly from 1996 to 1998. Samples taken from the monitoring wells are sent to the Philip Analytical Services Corp. laboratory for analysis. Samples are analyzed for general chemistry and metals on a quarterly basis, and volatile organic compounds

(VOC's) and polyaromatic hydrocarbons (PAH's) have been included on selected wells since 1996.

Analytical techniques performed for this study included construction of groundwater equipotential lines, calculation of horizontal and vertical hydraulic gradients, plotting of contaminant concentration versus time, and calculation of groundwater velocities using Darcy's Law (Fetter, 1994). Field values of hydraulic conductivity, determined by in-situ slug tests, were obtained from PDL. Most of the data used for calculations in this study are from the CCL site, however, due to their immediate adjacency to each other, the parameters are assumed to apply to the LFL site as well.

Chapter 4: Data Analysis and Interpretation

4.1: Introduction

Several different analytical techniques can be utilized when dealing with data obtained from a landfill site and there are no specific regulations with respect to which techniques must be implemented. This was one of the more difficult processes of this project, as either too much or too little could be accomplished, depending on what techniques were used to analyze the monitoring data. It was decided that the parameters mentioned in section 3.2.2, combined with an in-depth interpretation of the contaminant characteristics, would provide a sufficient amount of analysis for this study

4.2: Field Test Results

The first analytical technique performed on the data in this project was the construction of groundwater equipotential lines. The equipotential lines were constructed using the head, or static water level, data from each monitoring well in the vicinity of the landfill (data in Appendix B). Equipotential lines are essential to any groundwater study as they are used to determine and predict groundwater flow direction, and the head data can also be used to establish horizontal and vertical gradients in the groundwater flow system. Equipotential lines and flow directions have been calculated for A Wells, B Wells, and C Wells in order to determine any local variations in head and groundwater flow direction (Figs. 4.1-4.3). The surficial zone, the intermediate zone between the surficial and bedrock material, and the bedrock zone all represent different areas where groundwater may vary in flow direction and velocity. For example, groundwater moves

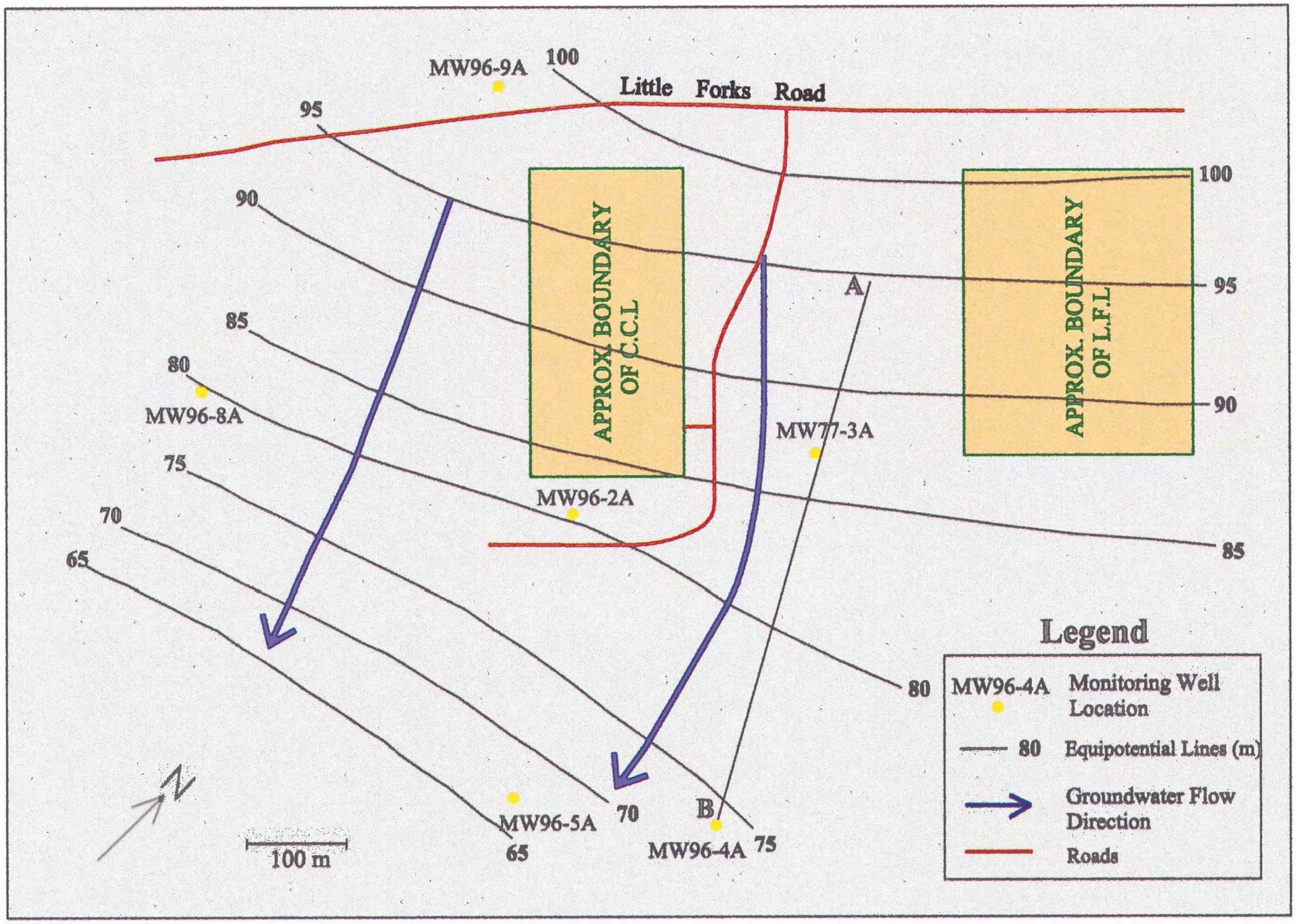

Figure 4.1: Groundwater equipotential lines and corresponding flow directions within surficial wells in the vicinity of the landfill sites. Locations of the surficial wells analyzed in this study are also shown. Head data was used to construct the equipotential and flow lines, and illustrates that groundwater is moving in a south to southeast direction within the surficial zone (modified from PDI, 1997). The figure also shows the location of the line (A-B) used to create the cross section in Fig. 2.1.

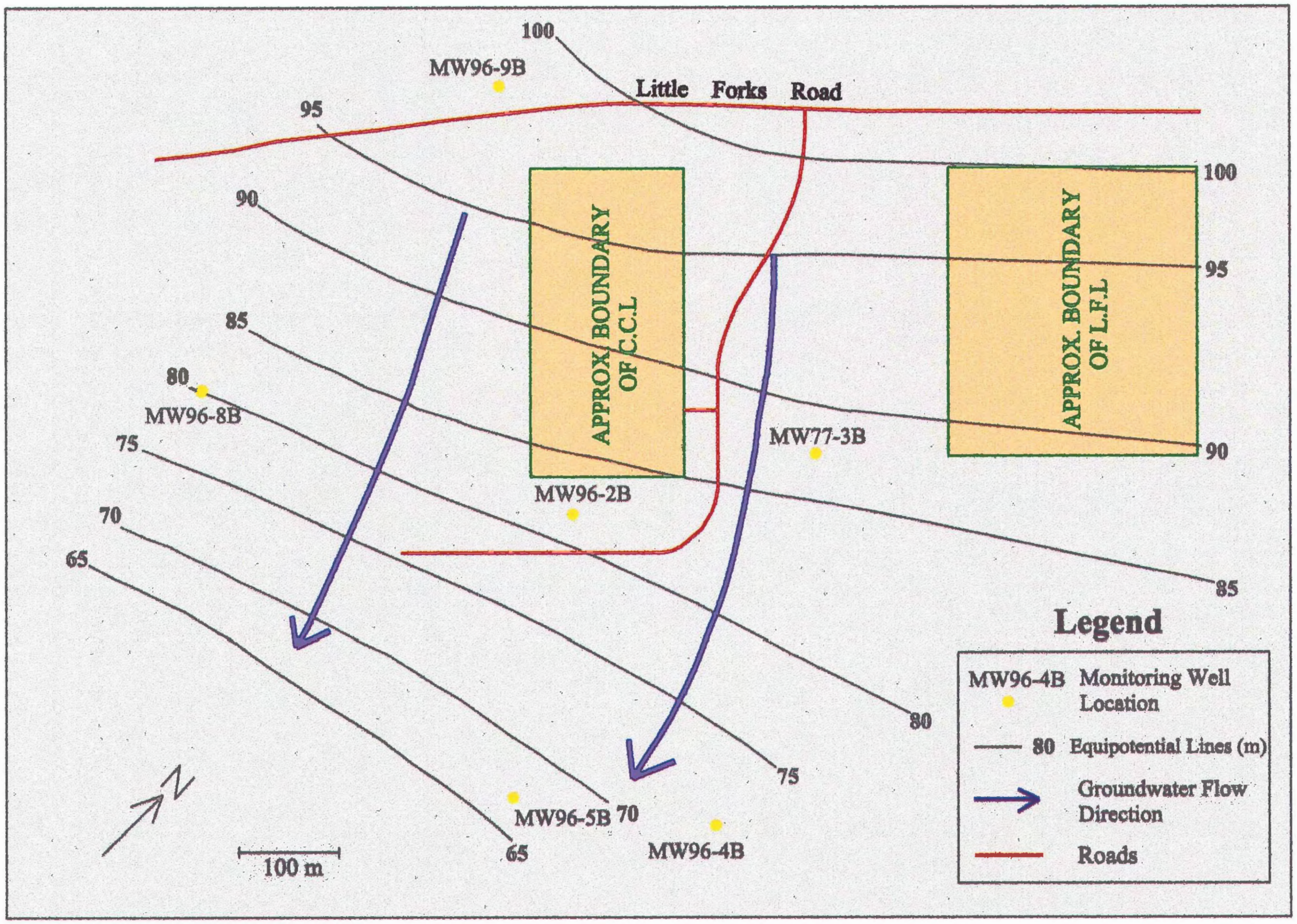

Figure 4.2: Groundwater equipotential lines and corresponding flow directions in intermediate wells surrounding the site. Locations of the intermediate wells analyzed in this study are also shown. The figure illustrates that groundwater flows in a similar pattern within the surficial and intermediate zones, as flow in the intermediate wells occurs in a south to southeast direction (modified from PDI, 1997).

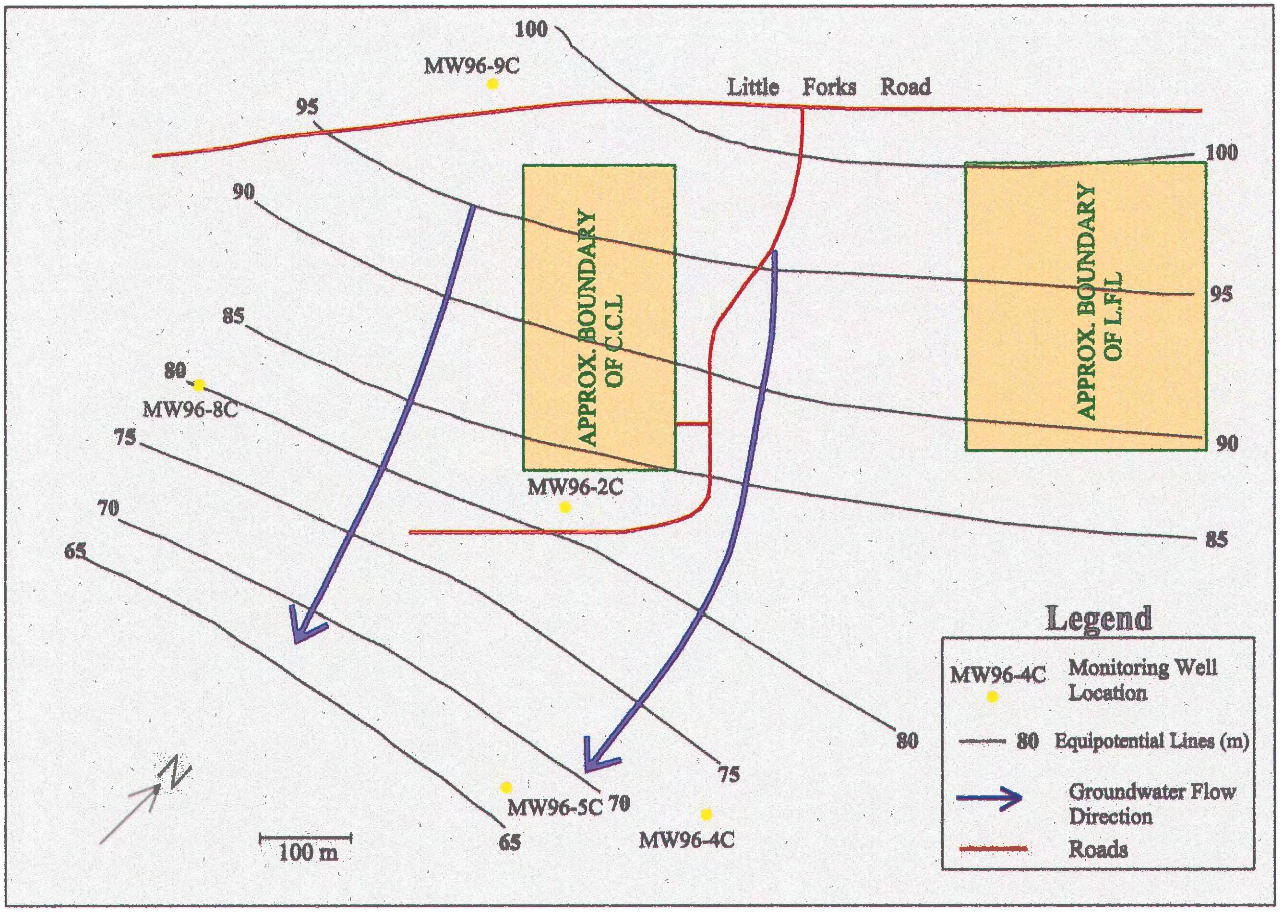

Figure 4.3: Groundwater equipotential lines and corresponding flow directions in deep bedrock wells. Locations of the deep wells used in this study are also shown, and it is noted that a deep well at site 77-3 was not constructed. The figure illustrates that the groundwater flows in a south to southeast direction in the deep wells, and therefore there are very similar flow directions in the surficial, intermediate, and deep wells (modified from PDI, 1997).

relatively fast through sands compared to clays, and any mounding, such as drumlins, may alter the direction of groundwater flow at a specific locality.

The groundwater equipotential lines in the vicinity of the site are nearly parallel to the topography in the area. Since groundwater naturally flows from high to low elevations, its flow direction should follow a similar pattern to surface drainage, which is in a south to southeast direction. Lines constructed perpendicular to the equipotential lines represent groundwater flow direction and suggest a generally southern direction. This statement applies to the surficial, intermediate, and bedrock wells, with minimal variations, as shown by each of the corresponding figures. There appears to be no significant variation in the flow direction between the A, B, and C levels.

As previously mentioned, the head data can also be used to determine the horizontal gradient of the groundwater flow, as well as vertical gradients between the surficial, intermediate, and deep wells at each well location. Horizontal gradients were calculated by constructing three different flow lines, spaced roughly 150 m apart, through the CCL site and determining the change in head along a corresponding length along the flow line:

$$\text{Horizontal Gradient } (i_h) = \frac{\text{head A} - \text{head B}}{\text{distance}}$$

Results of this calculation show that the horizontal gradient of groundwater flow is approximately 5% downgradient, which means that head decreases by about 5 m for every 100 m distance downgradient. The calculated maximum, minimum, and mean horizontal gradients are included in Table 4.1. Since the LFL site lies directly adjacent to the CCL site, it is assumed that the same horizontal gradient exists at the LFL site.

Vertical gradients between the three wells at each site define the vertical movement of groundwater in each zone. This information is valuable because it defines whether groundwater is moving upward or downward at specific locations. Vertical gradients were calculated by dividing the difference in head between each zone by the difference in elevation of the monitoring well midpoints, which is the midpoint of the screen at the bottom of the well:

$$\text{Vertical Gradient } (i_v) = \frac{\text{head A} - \text{head B}}{\text{elev. A} - \text{elev. B}}$$

Results illustrate that the majority of the well sites possess a downward vertical gradient between each zone, which means that groundwater is flowing downward between the zones in most areas surrounding the site (Table 4.2). This correlates with expected results, however, some local variations do exist. For example, an upward vertical gradient exists at MW96-4 between the intermediate and bedrock wells. This means that groundwater is flowing upwards in this zone, which may suggest a more permeable zone or fracture near the intermediate zone. There were no well specifications available for MW77-3, so vertical gradients could not be calculated for this well.

Hydraulic conductivity values for each zone were obtained by PDL during in situ tests during the construction of each monitoring well. Values were obtained by assuming homogeneous aquifer conditions and using the Hvorslev Method:

A WELLS		B WELLS		C WELLS	
FACTORS	Velocity (m/yr)	FACTORS	Velocity (m/yr)	FACTORS	Velocity (m/yr)
Maximum $K = 3.5 \times 10^{-5}$ $i = 0.055$ $n = 0.15$	4.05	**Maximum** $K = 2.2 \times 10^{-3}$ $i = 0.052$ $n = 0.05$	721.54	**Maximum** $K = 9.8 \times 10^{-5}$ $i = 0.053$ $n= 0.05$	32.76
Minimum $K = 2.0 \times 10^{-7}$ $i = 0.042$ $n = 0.3$	0.009	**Minimum** $K = 1.0 \times 10^{-6}$ $i = 0.039$ $n = 0.3$	0.041	**Minimum** $K = 2.0 \times 10^{-5}$ $i = 0.036$ $n = 0.3$	0.757
Mean $K = 1.6 \times 10^{-6}$ $i = 0.049$ $n = 0.2$	0.12	**Mean** $K = 1.6 \times 10^{-4}$ $i = 0.045$ $n = 0.2$	11.28	**Mean** $K = 5.0 \times 10^{-5}$ $i = 0.045$ $n = 0.2$	3.55

Table 4.1: Results of groundwater velocity calculations for A, B, and C wells (modified from PDL, 1997). Velocity was calculated using Darcy's Law (Fetter, 1994) and converted to m/yr. Values for K are shown in cm/sec; values for n estimated from Nielsen (1991).

Monitor Well	A to B Gradient	B to C Gradient
MW96-2	-0.030	-0.012
MW96-4	0.480	-0.149
MW96-5	-0.006	0.044
MW96-8	-0.078	0.074
MW96-9	0.006	0.022
MW77-3	no well specs	no well specs

Table 4.2: Vertical gradients of groundwater flow between each zone. The presence of upward gradients (-ve values) and downward gradients (+ve values) indicates that both recharge and discharge areas occur locally on the site.

$$K_h = \frac{d^2 \ln (2\,mL/D)}{8\,LT}$$

where K_h = horizontal hydraulic conductivity (cm/sec), d = diameter of piezometer (cm), m = transformation ratio, L = length of intake zone (cm), D = diameter of intake zone (cm), and T = basic time lag (sec).

Results of these calculations show that the intermediate zone has the highest hydraulic conductivity, which means that groundwater and any dissolved solutes will travel the fastest in this zone. Hydraulic conductivity values range from 2.0×10^{-7} cm/sec to 3.5×10^{-5} cm/sec in the surficial wells, from 1.0×10^{-6} cm/sec to 2.2×10^{-3} cm/sec in intermediate wells, and from 2.0×10^{-5} cm/sec to 9.8×10^{-5} cm/sec in the bedrock wells (PDL, 1997) (Table 4.1).

Groundwater velocities in the vicinity of the landfill were calculated to determine the theoretical maximum distances that contaminants moving in the groundwater could reach. Velocities were calculated by applying Darcy's Law to the data:

$$\text{Velocity } (v) = \frac{K\,i}{n}$$

where K = horizontal hydraulic conductivity, i = horizontal hydraulic gradient, and n = estimated porosity (porosity values from Nielsen, 1991).

Results illustrate that groundwater velocities are slowest in the surficial wells, intermediate in the bedrock wells, and fastest in the intermediate wells (Table 4.1). These velocities correlate well with the underlying geology of the site, and are interpreted as being a function of the clay content in each zone.

4.3: Laboratory Results

4.3.1: Monitoring Wells and Contaminants Analyzed

A total of six (6) monitoring wells have been chosen for analysis. The location of these wells can be found on Figs. 4.1-4.3. The selected wells include an upgradient well from the CCL site to be used as background data with the baseline water quality study, two lateral monitoring wells, and three downgradient monitoring wells. The lateral monitoring wells have been chosen to detect the extent of any lateral migration of leachate off-site. The downgradient wells have been chosen for the same reason, however, the downgradient wells, in general, should show more impact than the lateral wells since most leachate migrating from the landfill sites travels toward these wells.

The data for the selected wells covers a two year period from June 1996 to June 1998, except for site MW77-3, which has data from November 1983 to June 1998. The 1999 data was not available at the time of writing.

The leachate contaminants analyzed for this study include chloride, conductivity, Total Dissolved Solids (TDS), and pH. Chloride is a conservative tracer element for leachate in groundwater because it is a byproduct of the breakdown of numerous types of wastes and its concentration is not considered to be affected by attenuation processes other than dilution and dispersion. However, the ability for chloride to vary with seasonal effects limits its significance to a certain degree. For example, road salt used on the Little Forks Road during winter months has the ability to increase the concentration detected by the monitoring wells. TDS reflects the amount of solids dissolved in the groundwater. TDS and chloride are used as the primary leachate indicators in this study. The pH parameter is not weighted as heavily as other parameters in this study because it can vary with seasonal trends, however, the overall pH in each well can be used to explain leachate characteristics in impacted wells. Figures 4.4a-4.4c illustrate the trend in TDS concentration over time, and Figures 4.5a-4.5c show how chloride levels vary with time.

Various metals including aluminum, cadmium, iron, and manganese are also elevated in certain areas and may be analyzed briefly. Metals are not as indicative of leachate as the other parameters listed due to either naturally elevated values of some metals in groundwater, or to sampling. Metals are sometimes artificially high due to fine suspended or colloidal solids not completely removed from the water during filtration; when acidified, these solids may dissolve and bias the metals results.

4.3.2: Background Thresholds

Background levels of groundwater quality are essential to this type of study because they represent normal contaminant concentrations for the surrounding area. Background thresholds of contaminant concentrations provide the basis of comparison for impacted areas. Site MW96-9 from the CCL site, along with the baseline water quality study performed by PDL in 1978 for the LFL site, were chosen to represent background groundwater quality for the immediate area around the site. The site is located upgradient of both landfill sites and therefore is not impacted by leachate migrating off-site. The baseline water quality program for LFL was completed in 1978, prior to any landfill operations in the area, and has near-identical contaminant indicator concentrations as those analyzed in MW96-9.

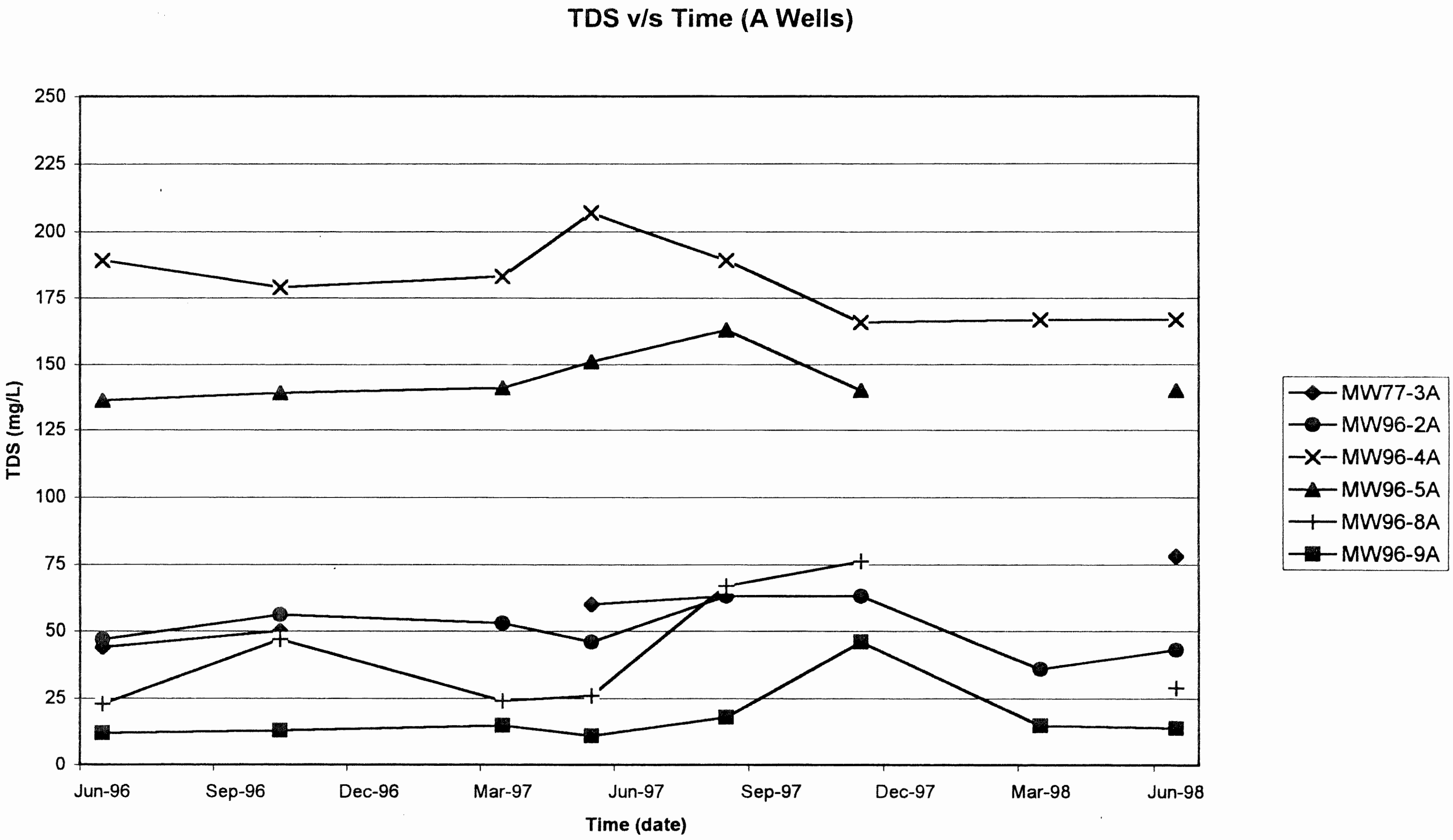

Figure 4.4a: TDS concentration variations with time in A Wells. Results are interpreted in section 4.3.

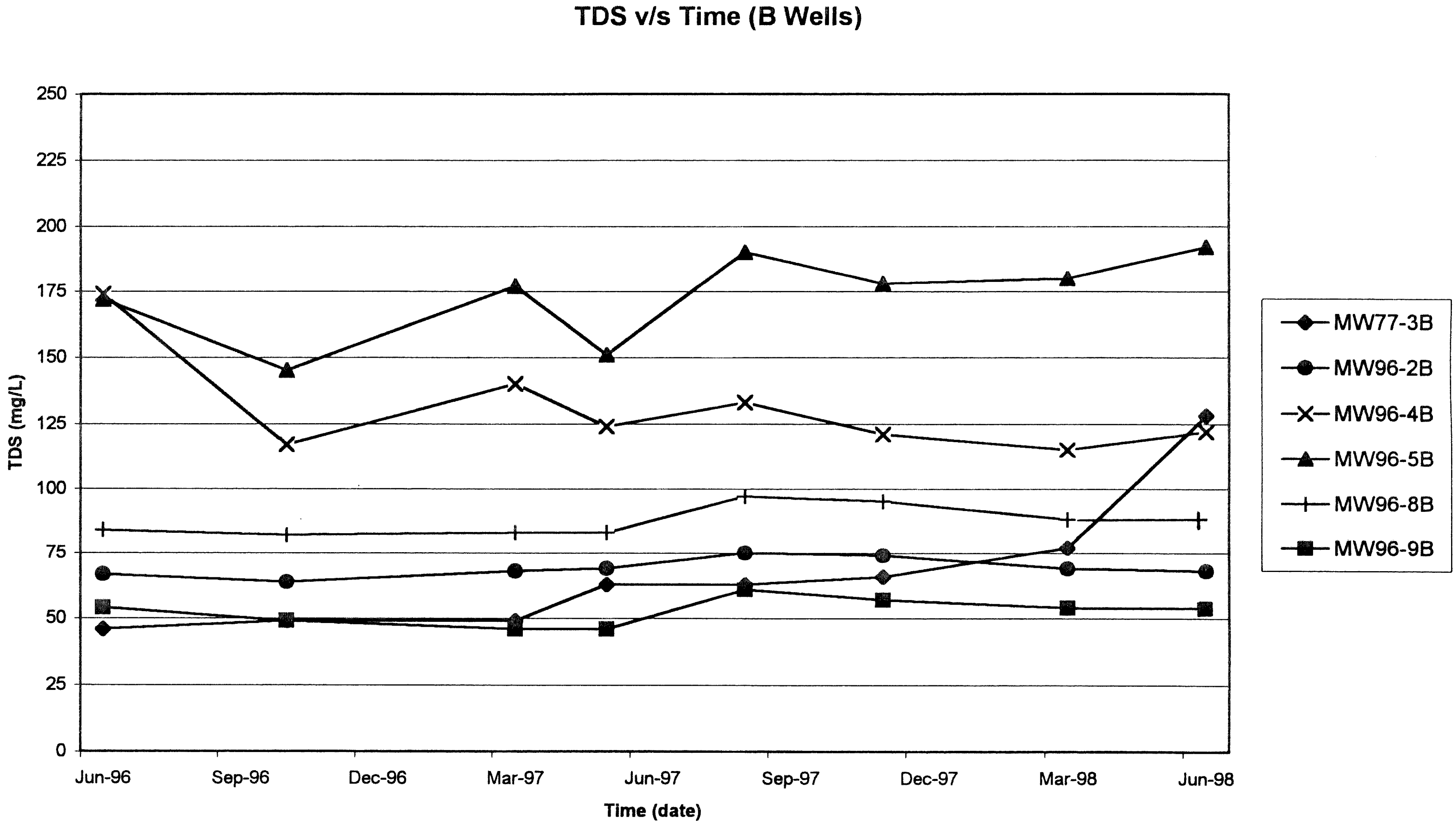

Figure 4.4b: TDS concentration variations with time in B Wells. Results are interpreted in section 4.3.

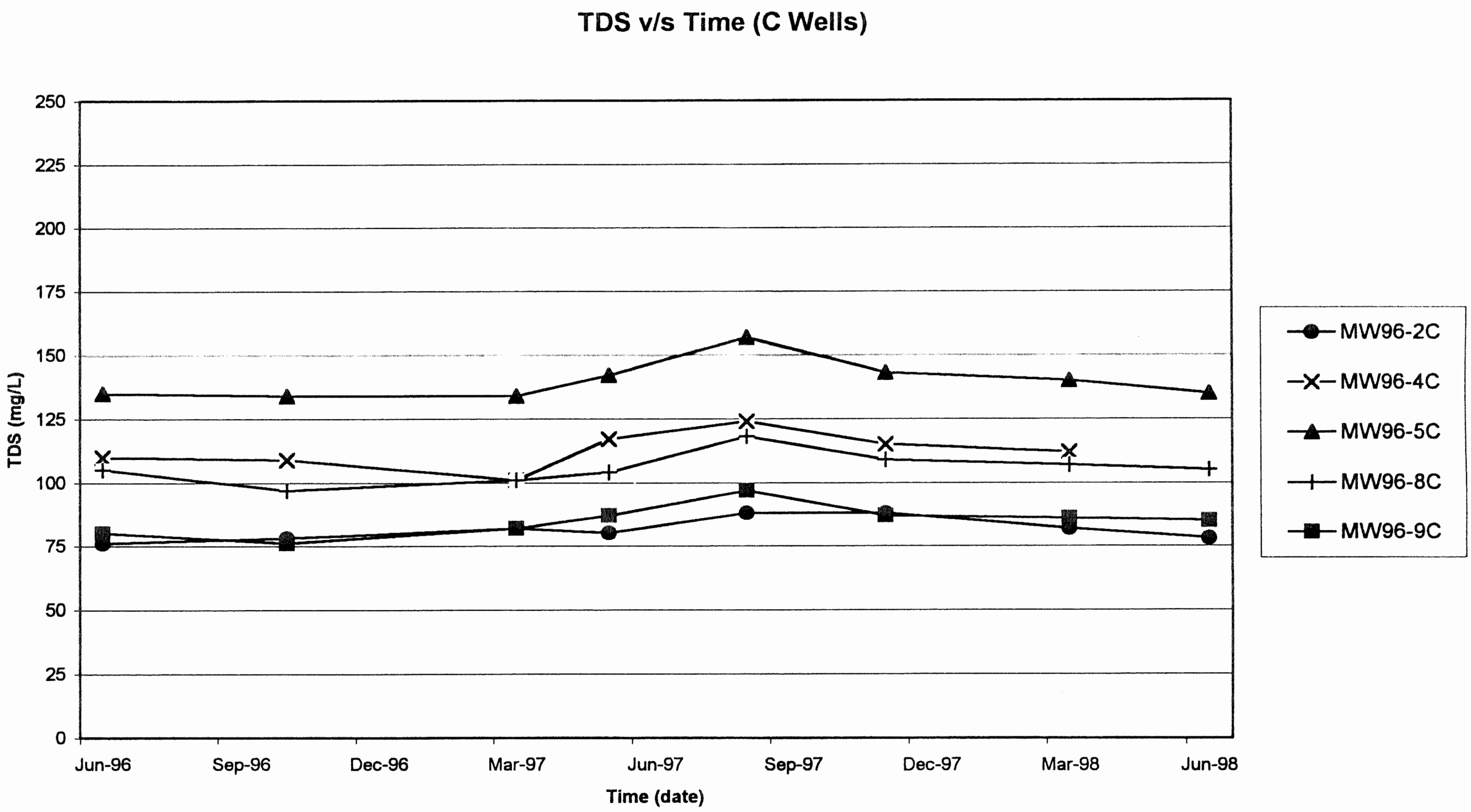

Figure 4.4c: TDS concentration variations with time in C Wells. Results are interpreted in section 4.3.

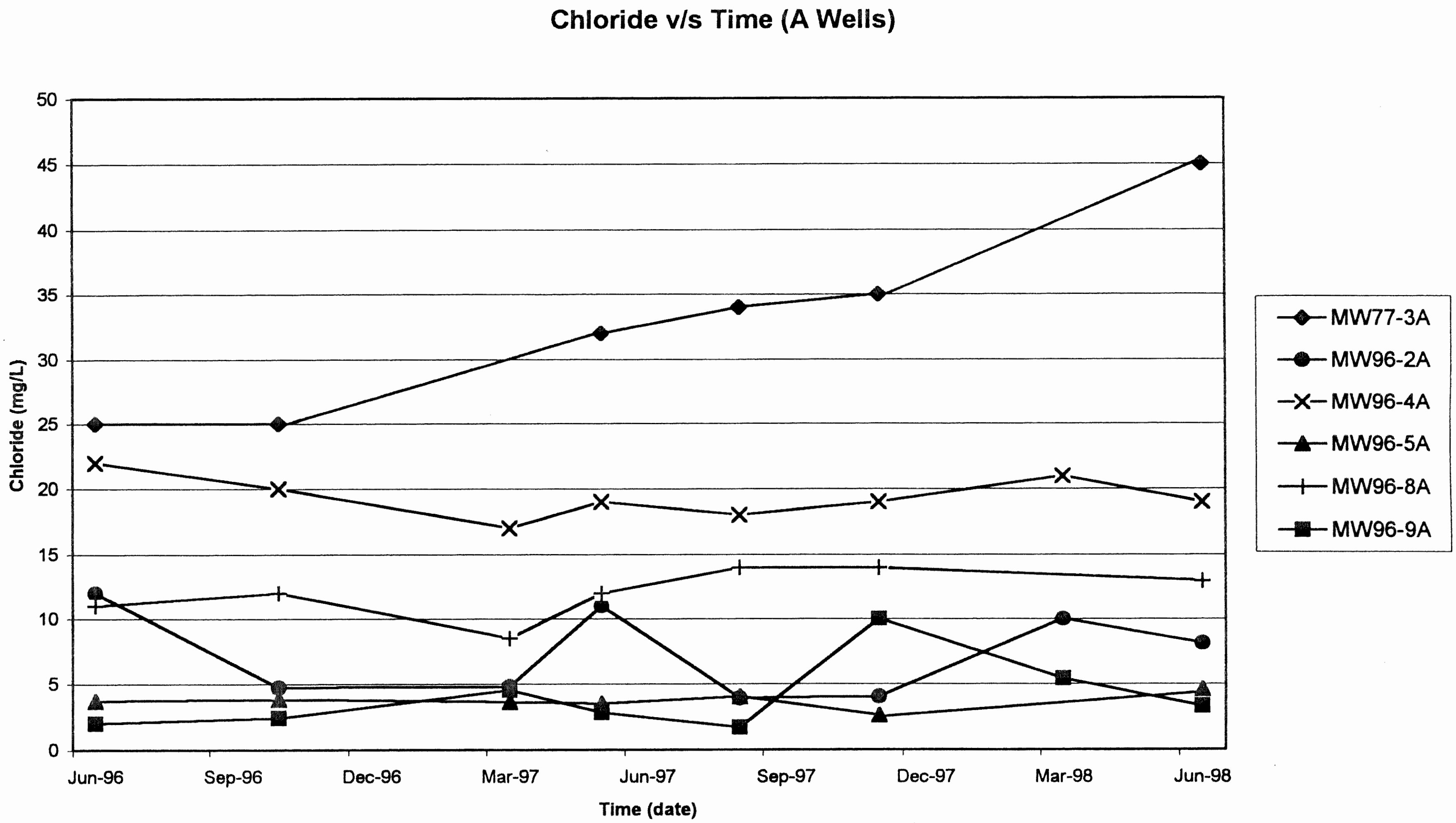

Figure 4.5a: Chloride concentration variations in A Wells. Results are interpreted in section 4.3.

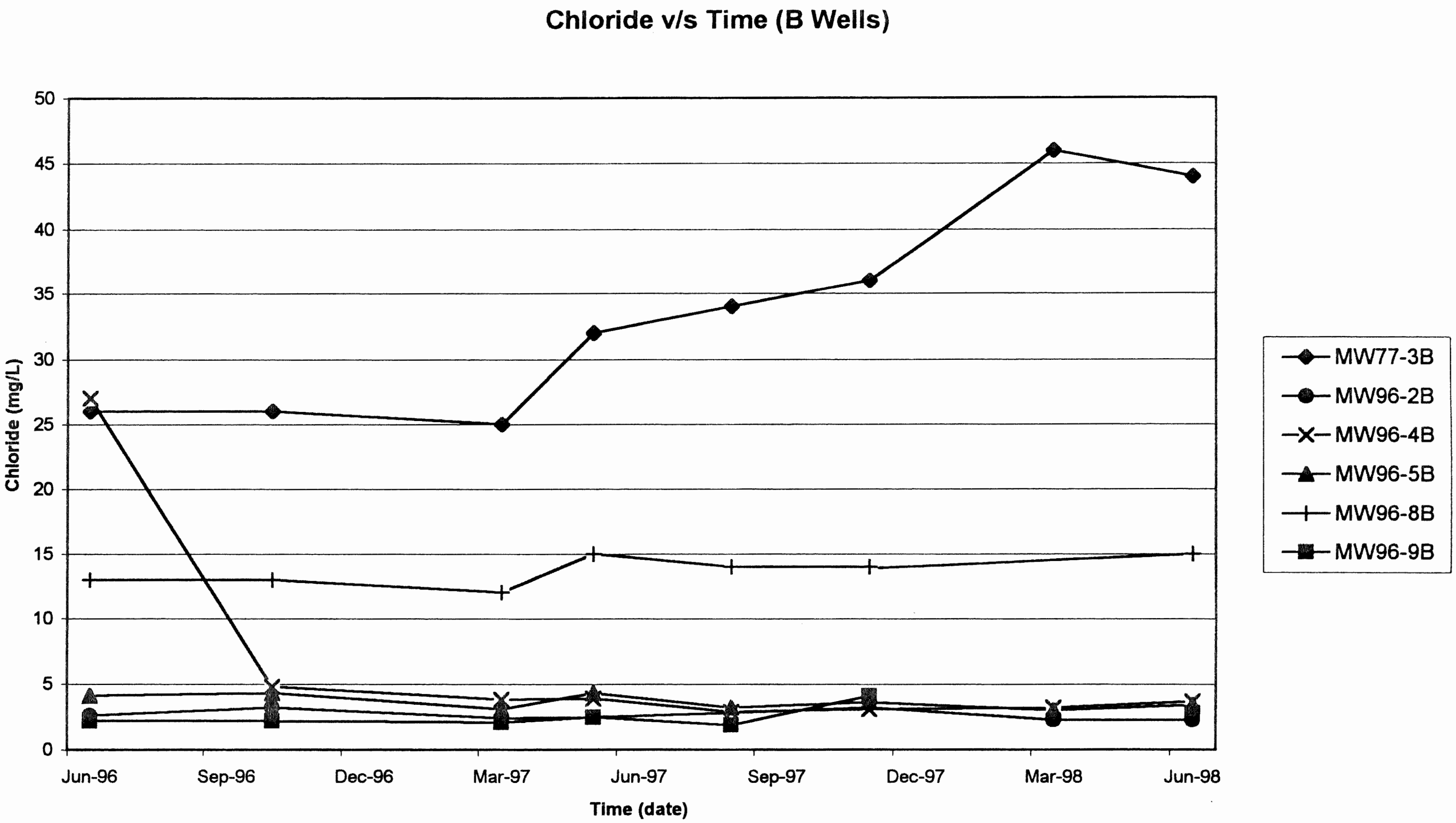

Figure 4.5b: Chloride concentration variations in B Wells. Results are interpreted in section 4.3.

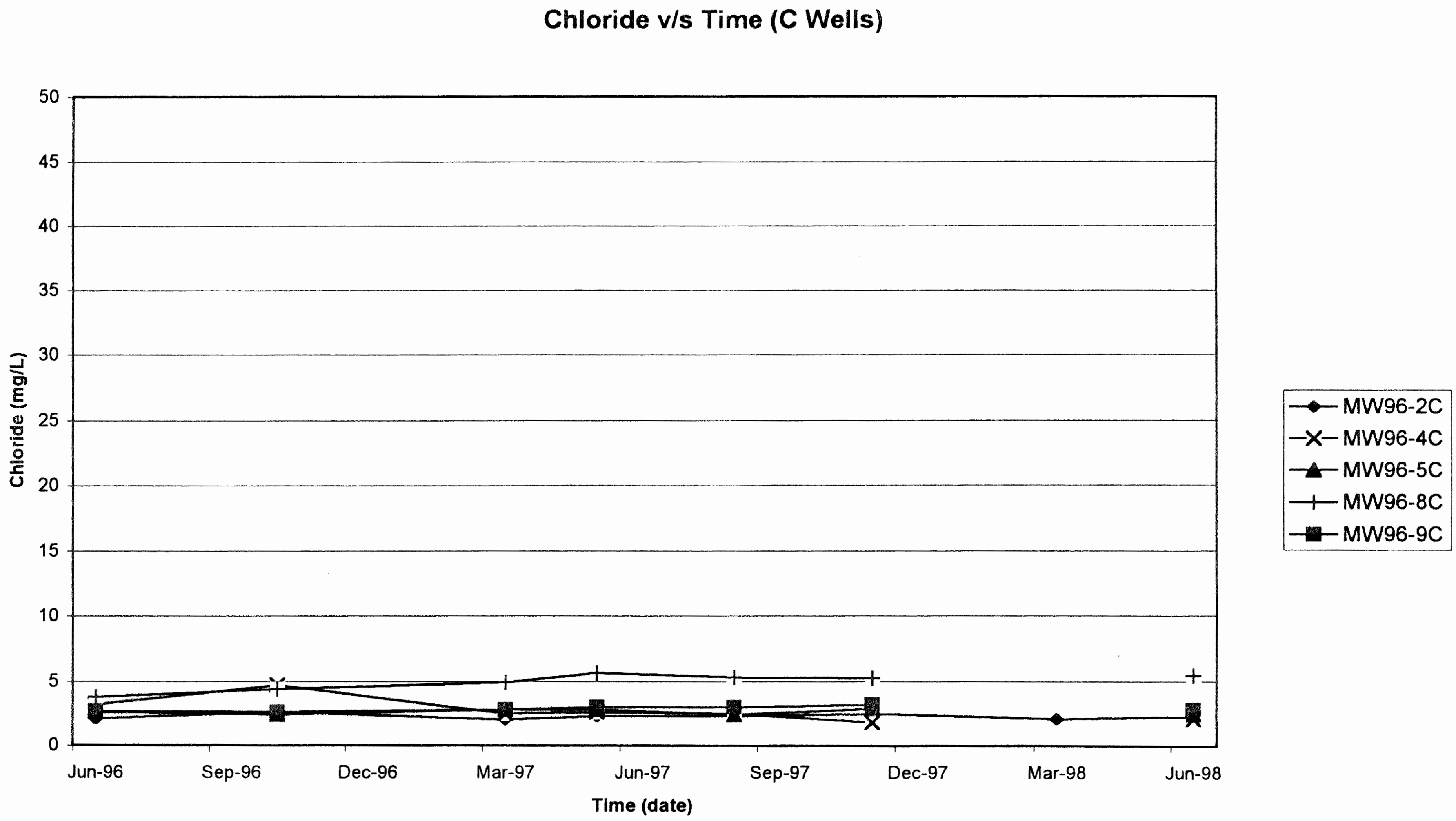

Figure 4.5c: Chloride concentration variations in C Wells. Results are interpreted in section 4.3

Analysis of the monitoring data for site MW96-9 shows that typical concentrations of indicator parameter TDS in the A well range from 12-18 mg/L, in the B well from 46-61 mg/L, and in the C well from 76-97 mg/L. These results indicate that background concentrations of TDS increase with depth. The pH shows a general increase in alkalinity with depth (see Appendix A). This is typical of normal evolution of groundwater quality with increasing depth in a recharge area, due to increased contact time with the geologic material.

Chloride concentrations in the A well range from 1.7-10 mg/L, in the B well from 1.9-4.1 mg/L, and in the C well from 2.6-3.0 mg/L. Chloride concentrations are relatively stable in the B and C wells. The shallow groundwater in the A well is likely affected by road salting activities along the Little Forks Road.

4.3.3: Potentially Impacted Wells

Potentially impacted wells are considered as those wells that have contaminant concentrations significantly higher than background values on a consistent basis where geology is similar, and show a graded increase in leachate indicator parameters with time. In other words, the wells must show an overall impact by contaminants and not just minor seasonal or short-term variations from background levels. A total of four wells at three of the six monitoring sites included in this study show some potential impact with respect to the parameters analyzed. These wells include MW96-4A, MW96-5B, and MW77-3A and 3B, and are discussed further below.

MW96-4A is located downgradient of both landfill sites, approximately 500 m south of the LFL site. Concentration versus time plots show that this well possesses the highest TDS concentrations of all surficial wells (Fig. 4.4a), with typical values in the range of 166-207 mg/L. These values are higher than any of the background values at MW96-9. The TDS concentration has remained relatively constant since the well was constructed, with no overall increasing trend over the study period. Chloride levels are also above background for the area, although they also show a relatively constant concentration (Fig. 4.5a).

Based on comparison to background site MW96-9, it is possible that there is some affect of leachate in well MW96-4A. Since there are no roads in the immediate vicinity of the well, the chloride increase is not considered to be a result of road salting. However, the geology at this site has a thicker glacial till cover than site MW96-9, which could also affect the TDS (refer to Fig. 2.1). If the well is affected by leachate, the plots suggest that either equilibrium has been reached, or that levels are declining slightly. The 1999 monitoring data may help to resolve the interpretation.

Analysis of the intermediate and deep well data for site MW96-4 shows that TDS concentration decreases slightly with increasing depth (Figs. 4.4a-c). This trend is more evident in the intermediate well, where TDS concentration has decreased about 50 mg/L from each of the corresponding surficial values. Chloride level in the B well is essentially background except for a peak of 26 mg/L in June 1996. Chloride level in the C well is also background, although it shows more variability than most other C wells (Figure 4.5c). An upward vertical hydraulic gradient exists between the intermediate (B) and bedrock (C) wells, a downward gradient between the shallow (A) and B wells. Thus downward migration of any dissolved solutes is limited, and dilution by upward moving groundwater is possible.

Site MW96-5 is located approximately 400 m southeast of the CCL site. Due to its location relatively close to site MW96-4, it is expected that similar trends would be detected. The TDS concentration in MW96-5A follows a similar pattern to MW96-4A, but with slightly lower concentrations. Typical values for TDS in MW96-5A range from 136-163 mg/L, which are the second-highest results for surficial wells and above background levels at MW96-9A. Chloride values are little help in explaining this trend as chloride concentration has decreased to background limits in all three wells at this site.

The intermediate well at site MW96-5 shows an overall increase in TDS concentration from the surficial well (Figs. 4.4a-b), with values ranging from 145-192 mg/L. This is verified by the corresponding increase in conductivity from the surficial to the intermediate well. The underlying material is the same in both wells, however the clay content decreases with depth. The TDS values are very similar in the deep wells to those obtained in the surficial wells, ranging from 134-157 mg/L. Chloride values are below background, suggesting that the TDS increase in the B well must be due to other dissolved parameters. The results could suggest possible leachate affect in the B well. However, it is more probable that thicker overburden, especially if it contains calcareous material, may result in increased TDS.

Site MW77-3 is located in the area between the two landfills. The TDS values illustrate an overall increase in concentration over time, especially in the intermediate well. This increase has occurred on a consistent basis since 1996. Chloride concentrations in MW77-3A are the highest of all wells analyzed in this study and show a consistent increase with time (Fig. 4.5a-b), from 25 mg/L in 1996 to 45 mg/L in 1998. The B well shows the same trend. Since the chloride concentrations increase on a consistent basis and lack any obvious seasonal effects, road salt is not considered to be the chloride source. The trend of increasing concentration corresponds to the TDS trend. These results suggest that lateral migration of leachate may be taking place from the LFL site. Future monitoring data will indicate whether this increasing trend continues or not.

4.3.4: Unimpacted Wells

Wells considered as unimpacted in this study are located downgradient of and adjacent to the CCL site. Monitoring wells located downgradient of this site are expected to show background levels of indicator parameters because the site possesses an impermeable liner and an elaborate leachate collection system. Low concentrations of indicator parameters at sites MW96-2 and MW96-8 verifies that the second-generation landfill design at CCL is much more efficient in minimizing leachate migration than the older first-generation design at LFL.

Site MW96-8 is located approximately 350 m southwest of the CCL site and was chosen to monitor the extent of any lateral migration of leachate from the CCL site. Concentrations of TDS and conductivity show an overall increase with depth. Since the values are almost identical to background levels found in MW96-9, this trend is interpreted as natural.

Chloride values are elevated from background levels in the A and B Wells at MW96-8 and consistently range between 12-15 mg/L. Since these high concentrations are only present in the A and B Wells and do not increase over time, it is believed that road salt used on the Little Forks Rd., located about 200 m upgradient, may have a slight affect on the surficial and intermediate zones at this site. The lack of seasonal variations in the chloride concentration does not support this conclusion, however, all other indicator concentrations in the A, B, and C Wells are in the order of background thresholds.

MW96-2 is located less than 10 m downgradient of the CCL site and has been used to detect the extent of contaminants migrating from the site. TDS concentrations in each of the wells are slightly elevated from background levels, however, all TDS values are <90 mg/L and are therefore considered as unaffected by leachate. Chloride concentrations correlate with background levels and support this statement. The elevated conductivity values can be explained by the fact that TDS concentrations are slightly elevated, however, brief analysis of the metals detected in each well determined that there is no indication of leachate affects at this site. This finding suggests that, based on the initial two years of monitoring data from selected sites, indicator parameters show no effect of leachate contamination from the CCL site. Continued monitoring over a number of years will determine whether this trend continues over the long-term.

Chapter 5: Summary and Conclusions

5.1: Overview

Several different conclusions can be drawn after data analysis and interpretation of the groundwater data. The groundwater monitoring program on the CCL site has been conducted by PDL, however, the LFL monitoring program has been contracted to different consultants in the recent past and has made the acquisition of data for the site impossible. Sampling techniques by different consultants may vary, making comparisons difficult. Monitoring at the CCL site began in 1996, and the LFL site has very inconsistent sampling intervals before this time, so that only monitoring data obtained after 1996 has been considered to represent actual values for contaminant indicator parameters.

5.2: Conclusions

In general, the concentration of the TDS indicator parameter increases with depth. Groundwater quality is considered to be a function of contact time between the groundwater and underlying geologic materials, and of any contaminants present. Since most of the vertical gradients between A, B, and C wells at the selected sites are downward, the contact time between groundwater and the geologic materials increases with depth. In addition, the underlying geology possesses a decrease in clay content from the surface to the contact with mudstone bedrock, and therefore groundwater is able to migrate downward to areas of higher hydraulic conductivity, or more permeable areas. Thus the changes with depth at sites MW96-2, MW96-8, and MW96-9 are thought to be natural evolution of water quality.

Some unusual features of TDS and chloride values and/or patterns occur in wells MW96-4A, MW96-5B, MW77-3A, and MW77-3B. The trends at site MW77-3 are most indicative of affects of landfill leachate. Other interpretations are possible at sites MW96-4 and MW96-5. Longer term monitoring data will help refine the interpretation.

The potentially impacted wells at MW77-3 exist lateral to and downgradient of the LFL site. This implies that leachate being generated at the LFL site may be migrating off-site in a southerly direction. Groundwater velocities indicate that a leachate plume travelling in the intermediate zone (fastest velocities) would take between 2.5 and 50,000 years to reach the Little Forks River. Contaminants migrating at the average velocity of the intermediate zone would take approximately 150 years to reach the river. The above calculations assume that groundwater flows at the same rate in the distance between the landfill and river, and that groundwater continues to flow at the same velocity over time. During this travel time and distance, natural attenuation processes will likely mitigate potential impacts on the river. The river itself will also naturally dilute any contaminants that reach it. Current surface water samples from the river do not show any increased contaminant concentrations. However, the potential impact does exist and it is recommended that detection monitoring sampling be continued at the present time.

The apparent lack of impact at site MW96-2 implies that the leachate collection and treatment system at the CCL site is working efficiently to limit the impact of leachate on the surrounding environment. Indicator parameter concentrations are in the ranges of background values in these wells, suggesting that contaminant migration from the site is minimal.

The findings of this study corroborate the general findings in the literature that first-generation landfills were not typically designed to collect and treat leachate being generated by the waste. On the other hand, second-generation landfills possess specifically engineered systems to collect and treat leachate being produced by the waste. This results in contaminant concentrations in the surrounding area that typically represent background thresholds, as the system works to minimize the leachate being released into the groundwater.

Continued monitoring of the LFL and CCL sites will determine the extent of any future contamination to the surrounding area. At the present time, leachate is likely migrating away from the LFL site in a southerly direction towards the Little Forks River. Environmental impacts should be minimized by dilution and other natural attenuation effects, and continued monitoring will detect any impact. Currently, the CCL site's leachate collection and treatment system is working as designed.

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Appendix A

Groundwater monitoring results

APPENDIX A: Groundwater monitoring data

MW96-2A

Date Sampled	TDS (mg/L)	Cond. (uS/cm)	pH (units)	Cl (mg/L)
Jun-96	47	79	6.54	12.0
Oct-96	56	120	6.77	4.7
Mar-97	53	110	6.63	4.8
May-97	46	100	6.43	11.0
Aug-97	63	120	6.48	3.9
Nov-97	63	110	6.69	4.0
Mar-98	36	86	6.27	10.0
Jun-98	43	82	6.54	8.1

MW96-2B

Date Sampled	TDS (mg/L)	Cond. (uS/cm)	pH (units)	Cl (mg/L)
Jun-96	67	140	6.93	2.6
Oct-96	64	130	7.00	3.2
Mar-97	68	140	6.80	2.4
May-97	69	140	7.04	2.5
Aug-97	75	130	6.66	2.8
Nov-97	74	130	6.89	3.2
Mar-98	69	130	6.76	2.3
Jun-98	68	130	7.01	2.3

MW96-2C

Date Sampled	TDS (mg/L)	Cond. (uS/cm)	pH (units)	Cl (mg/L)
Jun-96	76	150	7.22	2.1
Oct-96	78	160	7.35	2.6
Mar-97	82	160	7.48	2.0
May-97	80	160	7.56	2.3
Aug-97	88	150	7.06	2.3
Nov-97	88	150	7.32	2.5
Mar-98	82	150	7.58	2.1
Jun-98	78	140	7.37	2.3

MW96-4A

Date Sampled	TDS (mg/L)	Cond. (uS/cm)	pH (units)	Cl (mg/L)
Jun-96	189	360	7.31	22.0
Oct-96	179	340	7.65	20.0
Mar-97	183	350	8.09	17.0
May-97	207	300	7.60	19.0
Aug-97	189	330	7.23	18.0
Nov-97	166	270	7.32	19.0
Mar-98	167	310	6.87	21.0
Jun-98	167	290	7.74	19.0

MW96-4B

Date Sampled	TDS (mg/L)	Cond. (uS/cm)	pH (units)	Cl (mg/L)
Jun-96	174	340	7.53	27.0
Oct-96	117	230	8.04	4.8
Mar-97	140	240	7.86	3.8
May-97	124	200	7.89	3.9
Aug-97	133	220	7.65	2.9
Nov-97	121	220	7.80	3.1
Mar-98	115	210	7.76	3.2
Jun-98	122	210	8.04	3.7

MW96-4C

Date Sampled	TDS (mg/L)	Cond. (uS/cm)	pH (units)	Cl (mg/L)
Jun-96	110	210	7.81	3.2
Oct-96	109	210	8.01	4.7
Mar-97	101	210	7.71	2.5
May-97	117	150	8.11	2.6
Aug-97	124	210	7.83	2.5
Nov-97	115	200	7.90	1.8
Mar-98				
Jun-98	112	190	8.06	2.1

MW96-5A

Date Sampled	TDS (mg/L)	Cond. (uS/cm)	pH (units)	Cl (mg/L)
Jun-96	136	250	7.47	3.7
Oct-96	139	290	7.75	3.8
Mar-97	141	280	7.98	3.6
May-97	151	290	7.36	3.5
Aug-97	163	290	7.24	4.0
Nov-97	140	260	7.50	2.6
Mar-98				
Jun-98	140	250	7.54	4.6

MW96-5B

Date Sampled	TDS (mg/L)	Cond. (uS/cm)	pH (units)	Cl (mg/L)
Jun-96	172	310	7.75	4.1
Oct-96	145	270	8.07	4.3
Mar-97	177	280	7.94	3.1
May-97	151	280	7.85	4.3
Aug-97	190	310	7.62	3.2
Nov-97	178	310	7.94	3.6
Mar-98	180	300	7.93	3.0
Jun-98	192	310	8.11	3.4

MW96-5C

Date Sampled	TDS (mg/L)	Cond. (uS/cm)	pH (units)	Cl (mg/L)
Jun-96	135	250	7.83	2.6
Oct-96	134	250	8.05	2.4
Mar-97	134	250	7.78	2.8
May-97	142	250	8.12	2.8
Aug-97	157	250	7.95	2.4
Nov-97	143	250	8.04	2.9
Mar-98				
Jun-98	135	230	8.17	2.5

MW96-8A

Date Sampled	TDS (mg/L)	Cond. (uS/cm)	pH (units)	Cl (mg/L)
Jun-96	23	54	5.79	11.0
Oct-96	47	100	6.32	12.0
Mar-97	24	59	5.77	8.5
May-97	26	74	5.95	12.0
Aug-97	67	130	6.42	14.0
Nov-97	76	150	6.59	14.0
Mar-98				
Jun-98	29	58	6.16	13.0

MW96-8B

Date Sampled	TDS (mg/L)	Cond. (uS/cm)	pH (units)	Cl (mg/L)
Jun-96	84	160	7.04	13.0
Oct-96	82	170	6.84	13.0
Mar-97	83	170	6.72	12.0
May-97	83	200	6.98	15.0
Aug-97	97	170	6.70	14.0
Nov-97	95	180	6.86	14.0
Mar-98				
Jun-98	88	170	6.97	15.0

MW96-8C

Date Sampled	TDS (mg/L)	Cond. (uS/cm)	pH (units)	Cl (mg/L)
Jun-96	105	200	7.81	3.8
Oct-96	97	200	7.84	4.4
Mar-97	101	200	7.63	4.9
May-97	104	170	8.02	5.6
Aug-97	118	200	7.73	5.3
Nov-97	109	210	7.72	5.2
Mar-98				
Jun-98	105	190	7.61	5.4

MW96-9A

Date Sampled	TDS (mg/L)	Cond. (uS/cm)	pH (units)	Cl (mg/L)
Jun-96	12	21	5.77	2.0
Oct-96	13	30	5.96	2.4
Mar-97	15	32	5.61	4.5
May-97	11	25	5.89	2.8
Aug-97	18	23	5.89	1.7
Nov-97	46	95	5.43	10.0
Mar-98	15	33	5.55	5.4
Jun-98	14	29	6.01	3.3

MW96-9B

Date Sampled	TDS (mg/L)	Cond. (uS/cm)	pH (units)	Cl (mg/L)
Jun-96	54	110	6.80	2.2
Oct-96	49	110	6.86	2.2
Mar-97	46	97	6.55	2.1
May-97	46	94	6.61	2.5
Aug-97	61	110	6.47	1.9
Nov-97	57	92	6.60	4.1
Mar-98				
Jun-98	54	94	6.54	2.8

MW96-9C

Date Sampled	TDS (mg/L)	Cond. (uS/cm)	pH (units)	Cl (mg/L)
Jun-96	80	160	7.66	2.7
Oct-96	76	160	7.73	2.6
Mar-97	82	97	7.38	2.8
May-97	87	140	7.81	3.0
Aug-97	97	150	7.53	3.0
Nov-97	87	160	7.67	3.2
Mar-98				
Jun-98	85	140	7.53	2.8

MW77-3A

Date Sampled	TDS (mg/L)	Cond. (uS/cm)	pH (units)	Cl (mg/L)
Nov-83	108	34	5.6	8.3
Oct-84	272			8.4
Oct-85	222	24	5.6	10.0
Aug-86	26	24.9	5.1	2.6
Aug-87	23.9	24	5.7	4.5
Sep-88	20			5.7
Jun-96	44	97	5.31	25
Oct-96	50	100	6.11	25
Mar-97				
May-97	60	130	5.24	32
Aug-97	63	140	5	34
Nov-97	63	140	6.06	35
Mar-98				
Jun-98	78	160	5.42	45

MW77-3B

Date Sampled	TDS (mg/L)	Cond. (uS/cm)	pH (units)	Cl (mg/L)
Nov-83	92	120	9.4	4.9
Oct-84	32			3.6
Oct-85	64	48	6.2	3.6
Aug-86	40	38.5	5.6	2.9
Aug-87	42	41.7	6.3	4.9
Sep-88	28			5.2
Jun-96	46	110	5.69	26
Oct-96	49	110	5.57	26
Mar-97	49	120	5.87	25
May-97	63	130	6.87	32
Aug-97	63	140	5.56	34
Nov-97	66	150	5.60	36
Mar-98	77	160	5.62	46
Jun-98	128	170	6.18	44

Appendix B

Groundwater head data

APPENDIX B: Groundwater head data

Monitor Well	Well Depth (m)	Elevation PVC (m)	Average Head (m)	Max. Head (m)	Min. Head (m)
MW96-9A	5.18	101.92	97.52	98.97	95.90
MW77-3A	2.50	88.61	87.42	87.68	86.76
MW96-2A	4.57	83.92	81.14	83.30	80.13
MW96-8A	5.79	83.53	79.66	80.82	77.59
MW96-4A	5.49	75.28	74.09	74.70	73.14
MW96-5A	5.49	68.35	67.25	67.69	66.55

Monitor Well	Well Depth (m)	Elevation PVC (m)	Average Head (m)	Max. Head (m)	Min. Head (m)
MW96-9B	15.54	102.03	97.47	98.93	95.70
MW77-3B	6.70	88.82	87.49	87.82	86.12
MW96-2B	10.67	84.02	81.30	83.54	80.32
MW96-8B	9.14	82.89	80.09	80.82	77.69
MW96-4B	10.36	75.45	71.96	72.57	71.29
MW96-5B	11.58	68.49	67.29	67.64	66.68

Monitor Well	Well Depth (m)	Elevation PVC (m)	Average Head (m)	Max. Head (m)	Min. Head (m)
MW96-9C	37.01	101.63	97.03	98.57	95.46
MW96-2C	21.34	83.70	81.42	83.42	80.78
MW96-8C	18.29	82.38	79.56	80.78	77.69
MW96-4C	18.54	75.45	72.95	74.17	72.11
MW96-5C	19.81	68.73	66.94	67.81	66.71

Appendix C

Monitor well logs

MONITOR WELL RECORD

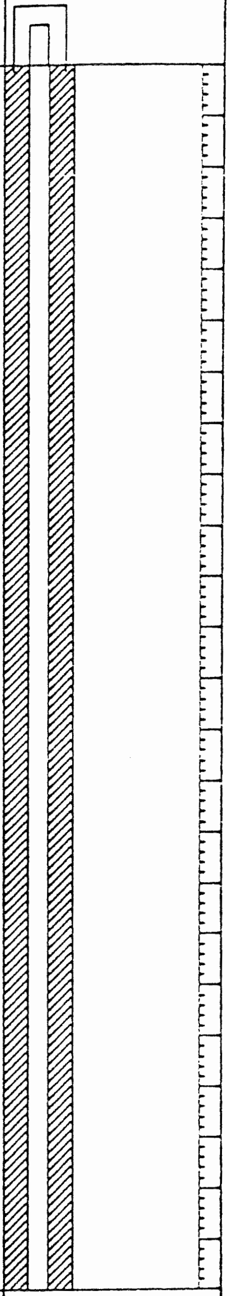
MW 96-2C

CLIENT MIRROR N.S.
LOCATION LITTLE FORKS LANDFILL
DATES: BORING 96/05/31 96/06/01
WATER LEVEL 96/06/11

PROJECT No. 11230
WELL No. MW 96-2C
DATUM GEODETIC

DEPTH(m)	ELEVATION(m)	SOIL DESCRIPTION	STRATA PLOT	SAMPLES TYPE	NUMBER	RECOVERY mm	N-VALUE OR RQD %	FRACTURES /m	ODOUR	VOC ppm, (% LEL)	APPARENT MOISTURE CONTENT	WATER LEVEL	VISIBLE IMPACTS
0	83.17												
		Brown silty coarse-grained SAND											
2	81.04												
		Highly fractured reddish brown MUDSTONE											
	76.77												
		Light grey medium grained carbonaceous SANDSTONE		RC	1	775	RQD 65%	4					
	75.55												
		Highly fractured reddish brown fine-grained MUDSTONE		RC	2	1200	RQD 0%	4					
	74.46												
		Interbedded reddish brown MUDSTONE and light grey fine-grained SANDSTONE											
	73.72												
		Highly fractured reddish brown weak MUDSTONE		RC	3	1500	RQD 20%	5					
	73.11												
		Interbedded reddish brown MUDSTONE with light grey fine-grained SANDSTONE											
	71.69												
		Light grey medium to		RC	4	1500	RQD 27%	6					
12													

WELL CONSTRUCTION DETAILS



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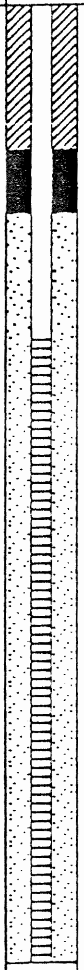
MONITOR WELL RECORD

MW 96-2C

CLIENT	MIRROR N.S.
LOCATION	LITTLE FORKS LANDFILL
DATES: BORING	96/05/31 96/06/01
WATER LEVEL	96/06/11
PROJECT No.	11230
WELL No.	MW 96-2C
DATUM	GEODETIC

DEPTH (m)	ELEVATION (m)	SOIL DESCRIPTION	STRATA PLOT	SAMPLES TYPE	NUMBER	RECOVERY mm	N-VALUE OR RQD %	FRACTURES /m	ODOUR	VOC ppm, (% LEL)	APPARENT MOISTURE CONTENT	WATER LEVEL	VISIBLE IMPACTS	WELL CONSTRUCTION DETAILS
12		coarse grained carbonaceous SANDSTONE												
13				RC	5	850	RQD 47%	2						
14				RC	6	1350	RQD 52%	5						
15–16				RC	7	1500	RQD 47%	3						
17–18				RC	8	1500	RQD 40%	5						
19				RC	9	1500	RQD 33%	5						
20–21				RC	10	1500	RQD 53%	4						
21.6	61.53	End of Hole Artesian conditions												
22														
23														
24														



MONITOR WELL RECORD

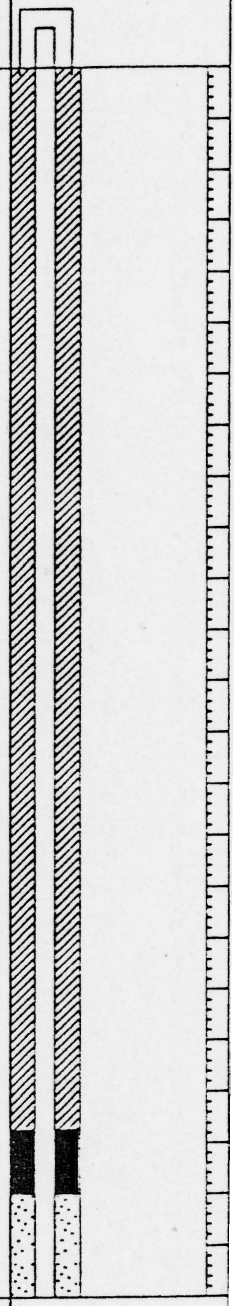
MW 96-4C

CLIENT MIRROR N.S.
LOCATION LITTLE FORKS LANDFILL
DATES: BORING 96/05/25 WATER LEVEL 96/06/03

PROJECT No. 11230
WELL No. MW 96-4C
DATUM GEODETIC

ELEVATION (m)	SOIL DESCRIPTION	TYPE	NUMBER	RECOVERY (mm)	N-VALUE OR RQD %	FRACTURES /m	ODOUR	VOC ppm, (% LEL)	APPARENT MOISTURE CONTENT	WATER LEVEL	VISIBLE IMPACTS
74.92	Overburden									▽	
71.72	Dense reddish brown BASAL TILL with tan coarse grained carbonaceous sandstone cobbles	RC	1	1350	-	-					
70.04	Dense reddish brown sandy SILT, BASAL TILL with tan coarse grained carbonaceous sandstone cobbles	RC	2	1500	-	-					
68.95 68.52	Reddish silty sand TILL with tan coarse grained carbonaceous sandstone cobbles	RC	3	1500	-	-					
67.00	Dense reddish brown sandy silt TILL with grey medium grained carbonaceous sandstone cobbles; sandstone boulder @ 7.0-7.5m	RC	4	1500	RQD 33%	7					
65.47	Mottled grey and reddish brown MUDSTONE										
	Crumbly highly fractured reddish brown weak MUDSTONE	RC	5	1500	RQD 67%	3					

WELL CONSTRUCTION DETAILS



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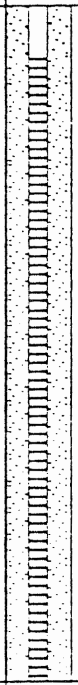
MONITOR WELL RECORD

MW 96-4C

CLIENT MIRROR N.S.
LOCATION LITTLE FORKS LANDFILL
DATES: BORING 96/05/25 WATER LEVEL 96/06/03

PROJECT No. 11230
WELL No. MW 96-4C
DATUM GEODETIC

DEPTH (m)	ELEVATION (m)	SOIL DESCRIPTION	STRATA PLOT	SAMPLES TYPE	SAMPLES NUMBER	SAMPLES RECOVERY mm	SAMPLES N-VALUE OR RQD %	SAMPLES FRACTURES /m	ODOUR	VOC ppm, (% LEL)	APPARENT MOISTURE CONTENT	WATER LEVEL	VISIBLE IMPACTS	WELL CONSTRUCTION DETAILS
12	62.42	Reddish brown weakly cemented MUDSTONE												
13														
14	60.90	Reddish brown fine grained MUDSTONE - grey mottling throughout		RC	6	1500	RQD 60%	18						
15														
16	59.38	Reddish brown sandy MUDSTONE SILT		RC	7	1500	RQD 33%	3						
	58.54	Reddish brown weak MUDSTONE SILT												
17				RC	8	1500	RQD 66%	3						
18	56.33	End of Hole												
19														
20														
21														
22														
23														
24														

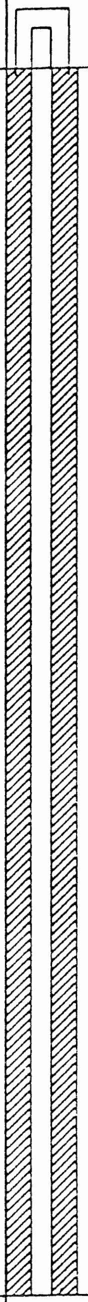


MONITOR WELL RECORD

MW 96-5C

CLIENT MIRROR N.S.
LOCATION LITTLE FORKS LANDFILL
DATES: BORING 96/05/28 WATER LEVEL 96/06/02
PROJECT No. 11230
WELL No. MW 96-5C
DATUM GEODETIC

DEPTH (m)	ELEVATION (m)	SOIL DESCRIPTION	STRATA PLOT		SAMPLES					ODOUR	VOC ppm, (% LEL)	APPARENT MOISTURE CONTENT	WATER LEVEL	VISIBLE IMPACTS	WELL CONSTRUCTION DETAILS
					TYPE	NUMBER	RECOVERY mm	N-VALUE OR RQD %	FRACTURES /m						
0	68.12	Reddish brown CLAY SILT sandy GRAVEL with some sand seams											▽		
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
12															



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MONITOR WELL RECORD

MW 96-5C

CLIENT MIRROR N.S.

LOCATION LITTLE FORKS LANDFILL

DATES: BORING 96/05/28 WATER LEVEL 96/06/02

PROJECT No. 11230

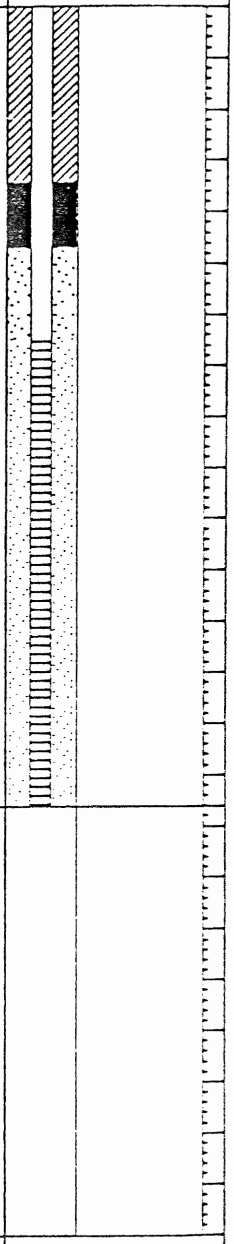
WELL No. MW 96-5C

DATUM GEODETIC

DEPTH (m)	ELEVATION (m)	SOIL DESCRIPTION	SAMPLES TYPE	SAMPLES NUMBER	SAMPLES RECOVERY mm	SAMPLES N-VALUE OR RQD %	SAMPLES FRACTURES /m	ODOUR	VOC ppm, (% LEL)	APPARENT MOISTURE CONTENT	WATER LEVEL	VISIBLE IMPACTS
12												
13												
14												
15	52.42											
16		Interbedded grey coarse grained SANDSTONE with reddish brown fine grained mudstone; progressively more sandstone content	RC	1	1500	RQD 27%	3					
17												
18			RC	2	-	-	9					
19	48.31											
20		End of Hole										
21												
22												
23												
24												

STRATA PLOT

WELL CONSTRUCTION DETAILS



MONITOR WELL RECORD

MW 96-8D

CLIENT MIRROR N.S.
LOCATION LITTLE FORKS LANDFILL
DATES: BORING 96/05/28 WATER LEVEL 96/06/01

PROJECT No. 11230
WELL No. MW 96-8D
DATUM GEODETIC

DEPTH (m)	ELEVATION (m)	SOIL DESCRIPTION	STRATA PLOT	SAMPLES TYPE	NUMBER	RECOVERY mm	N-VALUE OR RQD %	FRACTURES /m	ODOUR	VOC ppm, (% LEL)	APPARENT MOISTURE CONTENT	WATER LEVEL	VISIBLE IMPACTS	WELL CONSTRUCTION DETAILS
0	82.34	Tan silty medium grained SAND -occasional cobble										⊻		
4.4	77.92	Interbedded tan and grey coarse grained SANDSTONE		RC	1	600	RQD 50%	5						
				RC	2	1500	RQD 30%	5						
				RC	3	1575	RQD 63%	5						
8.1	74.19	Light grey medium to coarse grained carbonaceous SANDSTONE		RC	4	775	RQD 26%	3						
				RC	5	575	RQD 0%	1						
				RC	6	1500	RQD 60%	5						

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MONITOR WELL RECORD

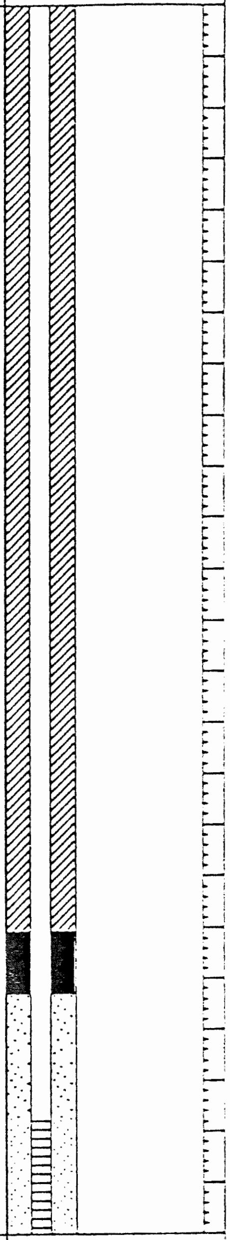
MW 96-8D

CLIENT MIRROR N.S.
LOCATION LITTLE FORKS LANDFILL
DATES: BORING 96/05/28 WATER LEVEL 96/06/01

PROJECT No. 11230
WELL No. MW 96-8D
DATUM GEODETIC

DEPTH (m)	ELEVATION (m)	SOIL DESCRIPTION	TYPE	NUMBER	RECOVERY mm	N-VALUE OR RQD %	FRACTURES /m	ODOUR	VOC ppm, (% LEL)	APPARENT MOISTURE CONTENT	WATER LEVEL	VISIBLE IMPACTS
12			RC	7	1500	RQD 40%	5					
13			RC	8	1500	RQD 60%	4					
15			RC	9	1475	RQD 40%	3					
16	65.73	Reddish brown MUDSTONE; highly fractured from 17-19m	RC	10	1500	RQD 40%	5					
18			RC	11	1500	RQD 6%	4					
19			RC	12	1375	RQD 65%	3					
21			RC	13	1500	RQD 60%	1					
22			RC	14	1375	RQD 36%	5					
24												

WELL CONSTRUCTION DETAILS



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MONITOR WELL RECORD

MW 96-8D

CLIENT MIRROR N.S.
LOCATION LITTLE FORKS LANDFILL
DATES: BORING 96/05/28 WATER LEVEL 96/06/01

PROJECT No. 11230
WELL No. MW 96-8D
DATUM GEODETIC

DEPTH (m)	ELEVATION (m)	SOIL DESCRIPTION	STRATA PLOT	SAMPLES TYPE	NUMBER	RECOVERY mm	N-VALUE OR RQD %	FRACTURES /m	ODOUR	VOC ppm, (% LEL)	APPARENT MOISTURE CONTENT	WATER LEVEL	VISIBLE IMPACTS	WELL CONSTRUCTION DETAILS
24				RC	15	1375	RQD 33%	5						
25	57.35	Interbedded dark grey MUDSTONE with light grey coarse grained SANDSTONE		RC	16	1500	RQD 47%	3						
27				RC	17	1500	RQD 27%	2						
28	54.30	Light grey coarse grained carbonaceous SANDSTONE		RC	18	1500	RQD 47%	4						
30				RC	19	975	RQD 31%	7						
	51.86	End of Hole												

MONITOR WELL RECORD

MW 96-9C

CLIENT MIRROR N.S.
LOCATION LITTLE FORKS LANDFILL
DATES: BORING 96/05/23 96/05/24 WATER LEVEL 96/05/31

PROJECT No. 11230
WELL No. MW 96-9C
DATUM GEODETIC

DEPTH (m)	ELEVATION (m)	SOIL DESCRIPTION	STRATA PLOT	SAMPLES TYPE	SAMPLES NUMBER	SAMPLES RECOVERY mm	SAMPLES N-VALUE OR RQD %	SAMPLES FRACTURES /m	ODOUR	VOC ppm, (% LEL)	APPARENT MOISTURE CONTENT	WATER LEVEL	VISIBLE IMPACTS	WELL CONSTRUCTION DETAILS
0	101.48 100.79	Tan silty SAND		SS	1	425	3							
				SS	2	150	30							
1		Tan coarse grained carbonaceous SANDSTONE		RC	3	675	15							
2				RC	4	675	RQD 15%							
3				RC	5	600	RQD 15%	3						
4	96.47			RC	6	1500	RQD 27%	1				▽		
5 6		Light grey carbonaceous SANDSTONE		RC	7	1500	RQD 27%	7						
7				RC	8	1400	RQD 47%	5						
8 9				RC	9	1300	RQD 31%	2						
10				RC	10	1500	RQD 27%	2						
11 12				RC	11	1500	RQD	7						

Continued Next Page

MONITOR WELL RECORD

MW 96-9C

CLIENT MIRROR N.S.
LOCATION LITTLE FORKS LANDFILL
DATES: BORING 96/05/23 96/05/24
WATER LEVEL 96/05/31
PROJECT No. 11230
WELL No. MW 96-9C
DATUM GEODETIC

DEPTH (m)	ELEVATION (m)	SOIL DESCRIPTION	STRATA PLOT	SAMPLES TYPE	SAMPLES NUMBER	SAMPLES RECOVERY mm	SAMPLES N-VALUE OR RQD %	SAMPLES FRACTURES /m	ODOUR	VOC ppm, (% LEL)	APPARENT MOISTURE CONTENT	WATER LEVEL	VISIBLE IMPACTS	WELL CONSTRUCTION DETAILS
12							27%							
13				RC	12	1500	RQD 33%	7						
14														
15				RC	13	275	-	-						
16				RC	14	1500	-	5						
17														
18				RC	15	1450	RQD 83%	1						
19				RC	16	1500	RQD 27%	2						
20														
21				RC	17	1500	RQD 40%	3						
22				RC	18	1500	RQD 80%							
23														
24														

Continued Next Page

MONITOR WELL RECORD

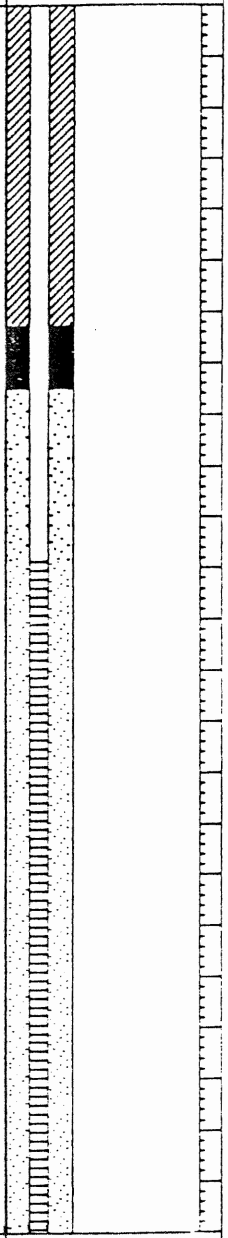
MW 96-9C

CLIENT MIRROR N.S.
LOCATION LITTLE FORKS LANDFILL
DATES: BORING 96/05/23 96/05/24 WATER LEVEL 96/05/31
PROJECT No. 11230
WELL No. MW 96-9C
DATUM GEODETIC

DEPTH (m)	ELEVATION (m)	SOIL DESCRIPTION	SAMPLES TYPE	NUMBER	RECOVERY mm	N-VALUE OR RQD %	FRACTURES /m	ODOUR	VOC ppm, (% LEL)	APPARENT MOISTURE CONTENT	WATER LEVEL	VISIBLE IMPACTS
24			RC	19	1500	RQD 80%	2					
25			RC	20	1500	RQD 60%	5					
26 27			RC	21	1325	RQD 23%	6					
28			RC	22	1500	RQD 60%	4					
29 30			RC	23	1500	RQD 73%	2					
31 32			RC	24	1500	RQD 60%	2					
33	68.48	Dark grey MUDSTONE	RC	25	1275	RQD 39%	3					
34			RC	26	900	RQD 44%	3					
35			RC	27	600	RQD 0%						
36												

STRATA PLOT

WELL CONSTRUCTION DETAILS



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MONITOR WELL RECORD

MW 96-9C

CLIENT MIRROR N.S.
LOCATION LITTLE FORKS LANDFILL
DATES: BORING 96/05/23 96/05/24 WATER LEVEL 96/05/31

PROJECT No. 11230
WELL No. MW 96-9C
DATUM GEODETIC

DEPTH (m)	ELEVATION (m)	SOIL DESCRIPTION	STRATA PLOT		SAMPLES TYPE	NUMBER	RECOVERY	N-VALUE OR RQD %	FRACTURES /m	ODOUR	VOC ppm, (% LEL)	APPARENT MOISTURE CONTENT	WATER LEVEL	VISIBLE IMPACTS	WELL CONSTRUCTION DETAILS
							mm								
36					RC	28	1500	RQD 20%	4						
	64.39														
37		End of Hole													
38															
39															
40															
41															
42															
43															
44															
45															
46															
47															
48															