THE HIGHWAY 101 LANDFILL --

WHAT HAVE WE LEARNED?

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Abstract

The Highway 101 Landfill between Upper Sackville and Mount Uniacke, Nova Scotia, has been in operation since 1977. Hydrochemical tests were routinely collected on 63 monitoring wells located at various depths in and around the landfill site. This project investigated significant chemical changes in the groundwater since the initiation of the landfill. Ammonia, total dissolved solids, and arsenic were selected as primary indicators of contamination with iron, potassium, and sulphate as secondary indicators. Eleven well sites located strategically down-gradient from the landfill were considered. Comparison occurred between the measurements taken from this subset of wells and the previously determined background levels from in and around the landfill site. Impacted wells were defined as those in which measured parameter concentrations were consistently above the threshold of mean background plus two standard deviations. Four of these well sites showed initial impact in the late 1980's to early 1990's. Impact occurred at all depths measured (surficial, shallow bedrock, and deep bedrock), but in general, the first wells impacted were the surficial wells. In most cases the timing of impact for deep bedrock wells was impossible to determine because of late installation dates. The parameters showing first impacts were ammonia and total dissolved solids. Using the initial impact dates and the distance along groundwater flow lines (a few hundred meters) estimates of contaminant flow velocities of 12.8 m/yr to 22.4 m/yr were calculated. These velocities are important as they can give an estimate on when the leachate plume will reach the Sackville River if no remediation methods are installed. The most suitable methods appear to be hydrodynamic control and interceptor wells or a combination of the two.

Key Words: leachate, contaminant plume, monitoring wells, landfill, indicator parameters, hydrogeochemistry, background threshold, impacted wells, remediation

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CHAPTER 1: INTRODUCTION

1.1 The Highway 101 Landfill

The Highway 101 Landfill has been Metro Halifax's solution to its solid waste disposal problem for the past 18 years, and will continue to be so until December 1996. This solution has had a price. The price was not only financial, but involves the environment as well.

The Highway 101 Landfill, located between Upper Sackville and Mount Uniacke, opened in 1977, after a five year debate on a new landfill location (Fig. 1.1). The Highway 101 site was picked after the first two choices, Beaverbank-Windsor Junction and Jack Lake sites, were rejected after strong public opposition (McKechnie et al., 1983).

The first site, in Beaverbank, was suggested by Canplan Consulting in a report to the Metropolitan Authority. Canplan made its suggestion based on: geology, soil, hydrology, accessibility, and land availability (McKechnie et al., 1983). After more studies, the provincial government stopped any further discussion of the site because of strong public opposition (McKechnie et al., 1983).

The Nova Scotia government then set up a five-member committee to find the most suitable site using a revised set of criteria. These included: land availability, the watersheds affected, physical characteristics, cultural implications, and economic factors.

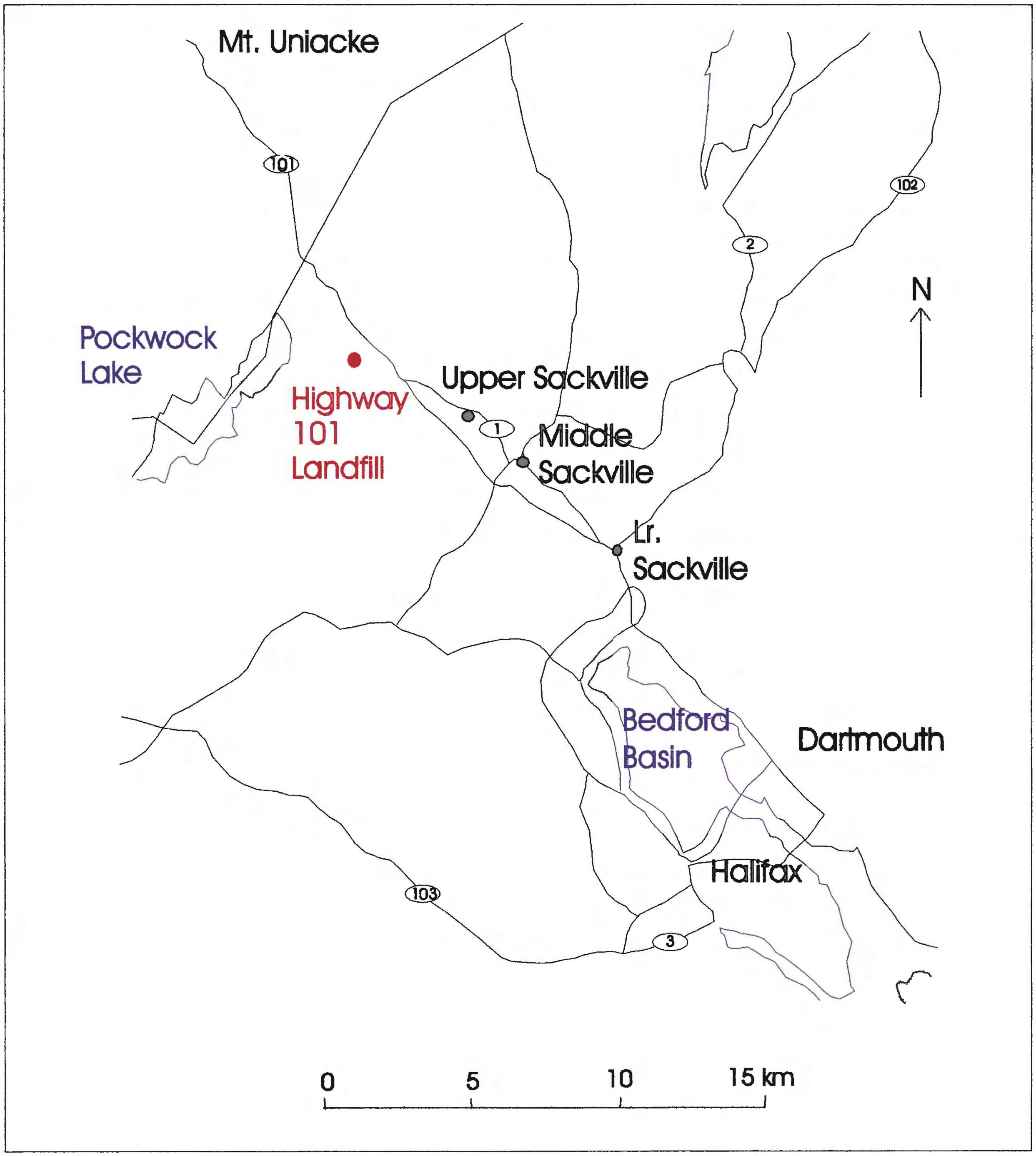


Figure 1.1 Location Map of the Highway 101 Landfill, Halifax County (modified from McKechnie et al., 1983).

Jack Lake, near Bedford, ranked the highest using these criteria. Again, public opposition halted the development of this site (McKechnie et al., 1983).

With the need for a new site growing, the government bought 144 ha of land from a private land owner. By July 1977, preliminary engineering reports were completed, stating that although not as suitable as its predecessors, any problems at this site could be overcome (McKechnie et al., 1983). In November of 1977, the Highway 101 Landfill opened.

The impact of the landfill on the environment has been both long and short term. The short term problems include dust, odour, litter, pests (seagulls, flies, and rodents), and increased traffic and noise (McKechnie et al., 1983). Reduction of these problems occurred through various operational modifications. The long-term problems, that will not go away with the closing of the landfill, are leachate and methane production. These problems will be a continuing concern in the near and distant future.

1.2 Problems with Leachate

Leachate is the liquid created when water percolates through the waste in the landfill. The water picks up many soluble ions, complexes, and organics, changing the chemistry of the water. The exact chemistry of the solution is dependent on what is in the landfill. Typically the leachate is enriched in ammonia, some metals, sulphates etc. (Table 1.1) (World Health Organization, 1993). The best way to reduce the leachate production is to avoid its creation by eliminating the water that come into contact with the waste. This is a nearly impossible feat because of the large area involved and its exposure to weather. For this reason, landfill siting is recommended where there is a low water table and a naturally impervious soil liner.

	Leachate Levels[1] (mg/L)	Background Levels[2] (mg/L)	Impacted Well Mean Levels[1] (mg/L)	U.K. Leachate Levels[3] (mg/L)
Ammonia	9	0.004	11	90 to 1700
Arsenic	0.075	0.036	1.43	not given
Total Dissolved Solids (TDS)	13900	75	834	not given
Iron (filtered)	3	0.565	18.6	0.1 to 2050
Potassium	853	1.35	14	20 to 2050
Sulphate	25.9	8.84	14.1	60 to 460
Chloride	3830	6.36	220	100 to 3000
Manganese	0.07	0.098	20.2	0.3 to 250

Table 1.1 Comparison between leachate composition at Highway 101 Landfill site, with background levels, impacted well levels and U.K. leachate levels.

1. Leachate collected during a pumping test within closed landfill (Jacques Whitford, 1995a)
2. Background levels for all well depths (surficial, intermediate, and deep) (Jacques Whitford, 1995b)
3. U.K. levels for household waste from Dept. of the Environment 1985

The main sources of water that come into contact with the garbage are either the surface water (precipitation) percolating down through garbage or the watertable (if the landfill is below saturation depth). It is practically impossible to eliminate all the water, so the best way to proceed is to minimize it and to treat any leachate produced. The first step in leachate treatment is to collect it via a collection system. This is generally accomplished by the installation of a layer of permeable material that contains perforated pipes leading to the treatment area above an impervious liner. At the Highway 101 site pipes leading to the treatment area above an impervious liner. At the Highway 101 site the "impervious" liner was the natural glacial cover, with at least one meter of compacted cover added material in the peat areas (Beasy Nicoll Engineering and H.J. Porter and Associates, 1977). The collection system consists of perforated PVC pipes leading to the treatment facility. The leachate has a considerably different chemistry than natural groundwater (Table 3.1). It is for this reason that any leachate that escapes the collection system, or any leachate that leaves the treatment area without complete and proper treatment, presents a hazard to the local groundwater.

If the groundwater does become contaminated, it is problematic because it influences both the surface water and anybody using the groundwater. The surface water is vulnerable because the aquifer is semi- to unconfined, allowing for groundwater discharge to the surface. This is of particular concern for the Sackville River and any of the surrounding lakes. If this water becomes too concentrated in contaminants, particularly metals and ammonia, they could have a detrimental effect on aquatic fauna and flora and any wildlife of the surrounding area. Another main concern is for the people who get their drinking water from wells dug in the same aquifer as the landfill. In some of the monitoring wells on the landfill site, concentrations of contaminants exceed Canadian Drinking Water Standards.

1.3 Background to the Highway 101 Leachate Treatment

During construction of the landfill it was realized that leachate would be of concern. For this reason, an on-site leachate treatment plant was constructed with the early construction of the landfill. The initial installation proved inadequate and the system was expanded in 1986 - 1987. The first stage of treatment consists of a pretreatment area. In this area there is precipitation of metals and dissolved solids, and adjustment of pH. This process creates a sludge which is then put back into the landfill. This system currently processes 0.9 L/s of leachate (Jacques Whitford, 1995b).

The next stage is an aerated lagoon system. This is composed of four lagoons where the leachate goes from one lagoon to another. The problem is that the overflow from the pretreatment (3 L/s) is also allowed to enter into lagoons with no precipitation and filtering to get rid of dissolved solids and metals (Jacques Whitford, 1995b). Another problem which has arisen is the fact that some surface drainage is also going into the lagoons contaminating them with leachate.

The final stage of treatment is an engineered wetland where plants take out remaining problematic ions and compounds (Jacques Whitford, 1995b). Figure 1.2 shows a summary of the treatment system. The water from the wetland then drains into the Sackville River. The only provincial regulation, dating from 1990, concerning effluent going into the Sackville River is with respect to ammonia. This regulation requires a sample taken from down-river, surface site S5, must have a value of 2.5 mg/L or less (Jacques Whitford, 1995b). For this regulation to be satisfied, Porter Dillon

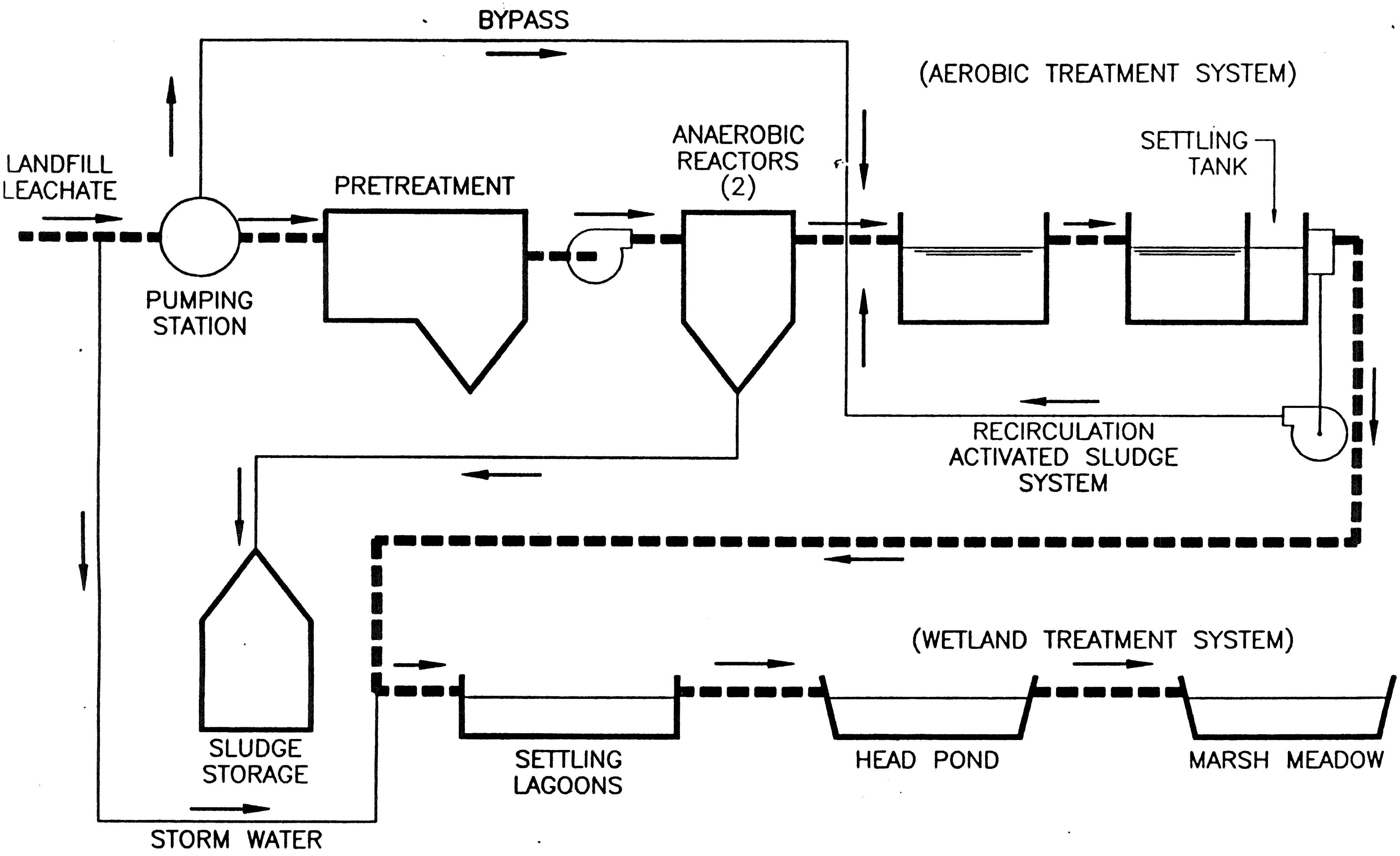


Figure 1.2 Schematic of the Highway 101 Landfill treatment facilities (from Jacques Whitford, 1995b)

(1994) recalculated the limit at end of pipe levels to be 23 mg/L. To date the discharge has been within the limit except for June 1994 (Jacques Whitford, 1995b).

1.4 Scope and Purpose

This project attempts to devise a methodology for determining chemical changes in the groundwater in the vicinity of the Highway 101 Landfill. Particularly, it looks at how the leachate from the Highway 101 Landfill affects certain ion concentrations in groundwater. The aim is to differentiate change caused by leachate from background noise. The background noise arises from a number of variables including: seasonality, the sampling techniques of different contractors, the different laboratories involved, and possible different analytical measuring techniques used by these laboratories. It is important to realize that, because of the large number of wells (63) and parameters (up to 45) tested, only a small subset of wells and parameters were used in this thesis. The first six parameters in Table 1.1 shows the parameters tested. If the impact of leachate on the groundwater can be observed, then the rate and direction of contaminant transport can be predicted. Such information would be particularly important where contaminated groundwater is moving towards the Sackville River. Again, time and effort in the design of any remedial action, which may need to take place upon closure in 1996, would be facilitated by such prior knowledge.

This thesis is divided into three parts. The background material is covered in part one giving insight into the hydrogeological conditions of the locality and the history of development of the landfill. Part two looks at hydrogeochemical changes at particular well-sites, or closely grouped clusters of wells. This should give an indication on dates of impact, level of plume transport, and which parameters show first and most drastic increase with plume arrival. The final part of the thesis discusses the analysis of the results, their limitations, errors in the available data, and provides recommendations both for remediation of the groundwater contamination problem and for an improved monitoring program for the Highway 101 Landfill and the future Metro-area landfill.

CHAPTER 2: SETTING

2.1 Regional Setting

The Highway 101 Landfill is located south of Highway 101 between Upper Sackville and Mount Uniacke. Bedrock in this area is the Goldenville Group of the Meguma Supergroup (Keppie, 1979; Schenk, 1995). The Goldenville Group is of Late Cambrian to Early Ordovician age and consists of greywackes, composed mainly of feldspar and quartz, with interbedded pelitic horizons (Schenk, 1995). These rocks form well defined Bouma sequences, indicating that they were deposited in a deep-water environment (Schenk, 1995). The Acadian Orogeny and the subsequent emplacement of granitoid intrusives of the South Mountain Batholith, metamorphosed the rocks to the greenschist facies (Keppie and Muecke, 1979). Structurally, the landfill is located on the southern flank of a NE-SW trending anticline, with no major faults having been mapped in this area (Corey, 1987; Keppie, 1979).

2.2 Local Setting

2.2.1 Bedrock Geology

The bedrock beneath the landfill is the Goldenville Group (Fig. 2.1). It occurs at a depth of 0.5 to >20 m beneath the overlying surficial cover (Porter Dillon, 1992).

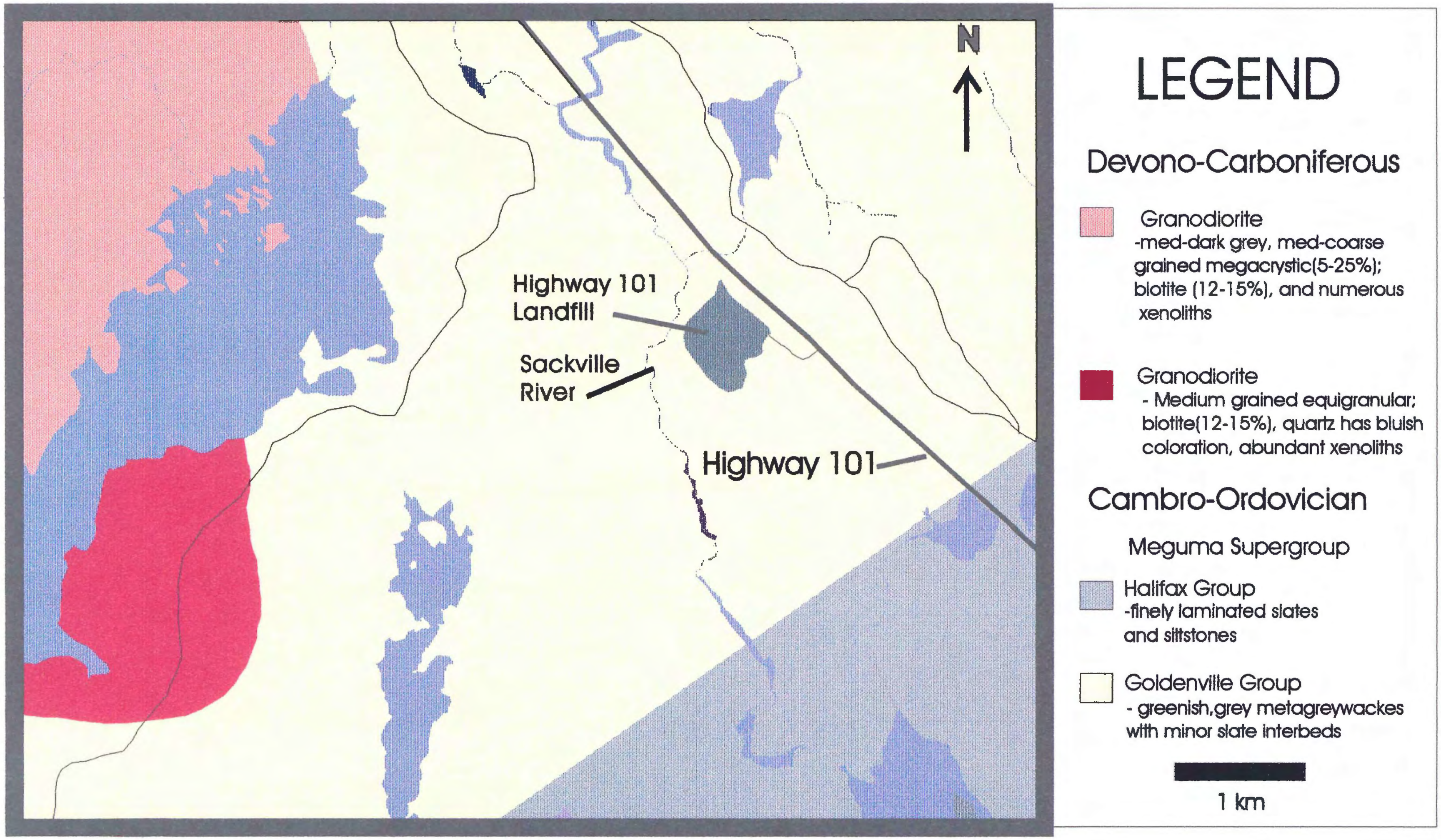


Figure 2.1 Bedrock geology in the vicinity of the landfill (modified from Corey, 1985)

Extensive new outcrops of bedrock, representative of that found beneath the landfill, have recently been created by the widening of Highway 101 between Sackville and Mount Uniacke. I investigated these outcrops in the vicinity of the landfill. The outcrop was found 300 m SE of the landfill entrance and extends for approximately 350 m further south. Greywacke layers are interbedded with slate layers, and the quartzite to slate ratio is approximately 6:1. The greywacke beds are medium-grained grey massive rocks ranging between 30 cm and 4 m thick with the majority of beds being less than 1 m. These thicknesses are relatively low, as most Goldenville beds are usually a few meters thick (O'Brien et al., 1985). Common joints occur perpendicular to bedding (Fig. 2.2).

There is a relatively high concentration of slates in this area. The slate beds range in thickness from 10 cm to 1.5 m, with a near-vertical cleavage. The beds at the outcrop are steeply dipping at 233/88°S. This information indicates that the steeply dipping "fractures" observed in core by the consultants, Jacques Whitford (1995b) were, in fact, steeply dipping bedding and cleavage planes. The outcrop is consistent in compositions, thicknesses, and trends throughout. Projection along strike indicates that similar conditions should exist in the landfill site (Fig. 2.3).

The outcrop in this area indicates a great deal of weathering, as shown by iron oxide staining near the top of the outcrop and deep within the pelitic layers (Fig. 2.4). The iron oxide staining in the pelitic beds is a result of oxidation of sulphides, a common phenomenon in the pelitic Halifax Group. The extensive oxidation in the pelitic rocks and the newness of the outcrop suggest that much of the weathering occurred prior to blasting for the highway widening. This indicates that natural oxidation of the rocks,

Figure 2.2 Photograph of an outcrop approximately 350 m south of the Highway 101 Landfill entrance. It shows: greywacke interbedded with slate, near vertical bedding and joints.

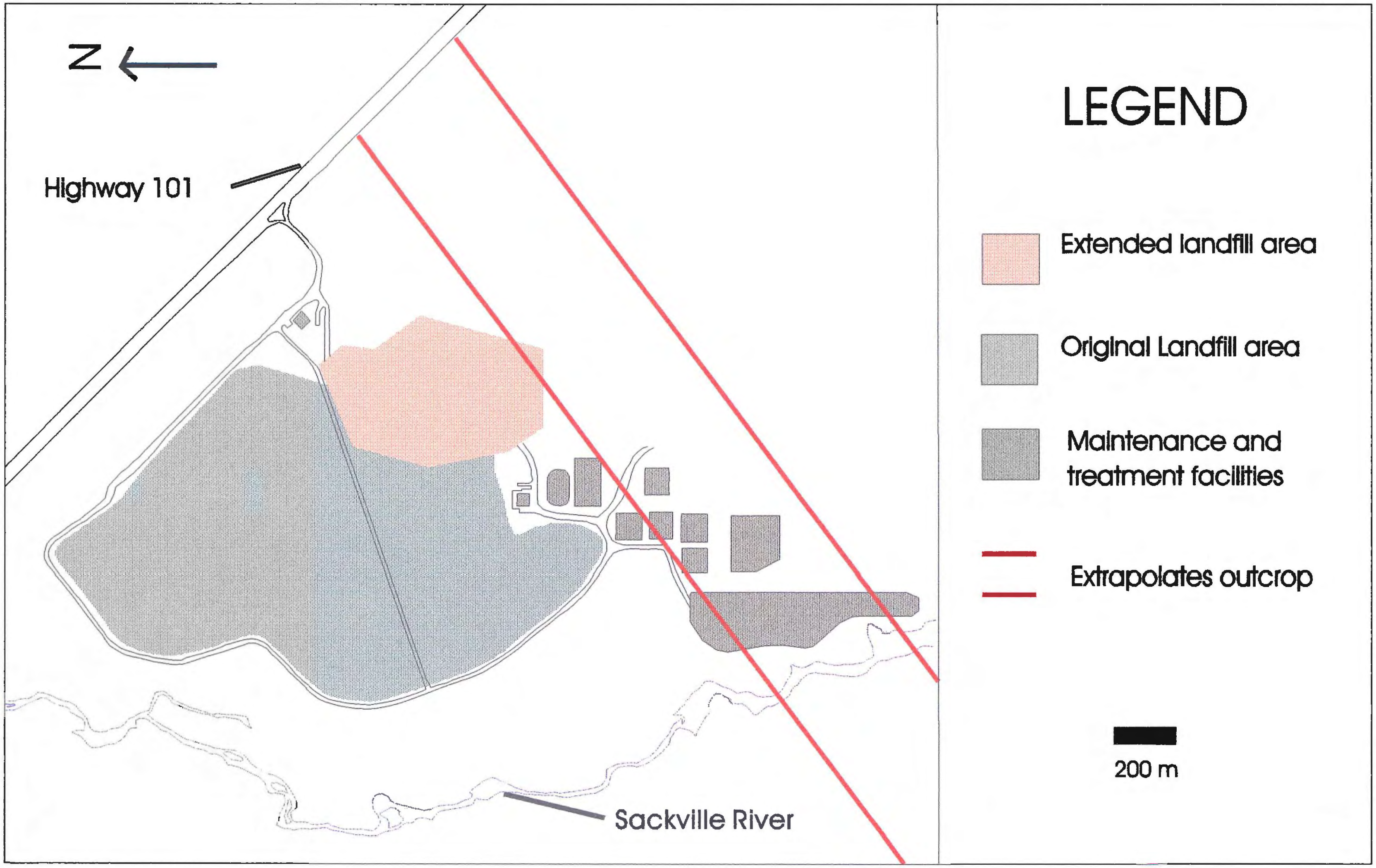


Figure 2.3 Projected strike of bedding at Highway 101 outcrop (modified from Jacques Whitford, 1995b)

Figure 2.4 Photograph of the outcrop area to the south of the landfill entrance showing oxidation and the near-vertical cleavage.

particularly the slate interbeds, must be taken into account when looking at the chemistry of the groundwater.

The outcrops also provide a lot of information concerning the possible flow of groundwater in the bedrock. The lithologies, because they are closely packed and well cemented, indicate that there will be little groundwater transport through the rock matrix. Flow should, therefore, be along the joints, bedding and cleavage planes. The flow in the rocks will be highly anisotropic with most of the flow vertical and along strike direction due to the large number of almost vertically dipping beds and the near-vertical cleavage, and only moderate flow horizontally because of the jointing perpendicular to bedding.

2.2.2 Quaternary Geology

Glacial features, particularly drumlins and tills, dominate the Quaternary geology of the area. The Highway 101 Landfill is located in a 200 km^2 drumlin field (Corey, 1987) (Fig. 2.5). The landfill site originally contained two drumlins composed of compacted quartzite till. These drumlins were used for landfill cover due to their high clay content (low permeability through clay). Quartzite till directly overlies the bedrock as either drumlins or as ground moraine (Jacques Whitford, 1995b). The quartzite till has a matrix of brown sandy silt mixed with grey silty clay . The clasts are quartzite and greywacke that correspond to the underlying bedrock (Jacques Whitford, 1995b).

Overlying most of the ground moraine is a thin (0.2-2 m) ablation till (Porter Dillon, 1992). The ablation till has a sandier composition and is brown in color. The

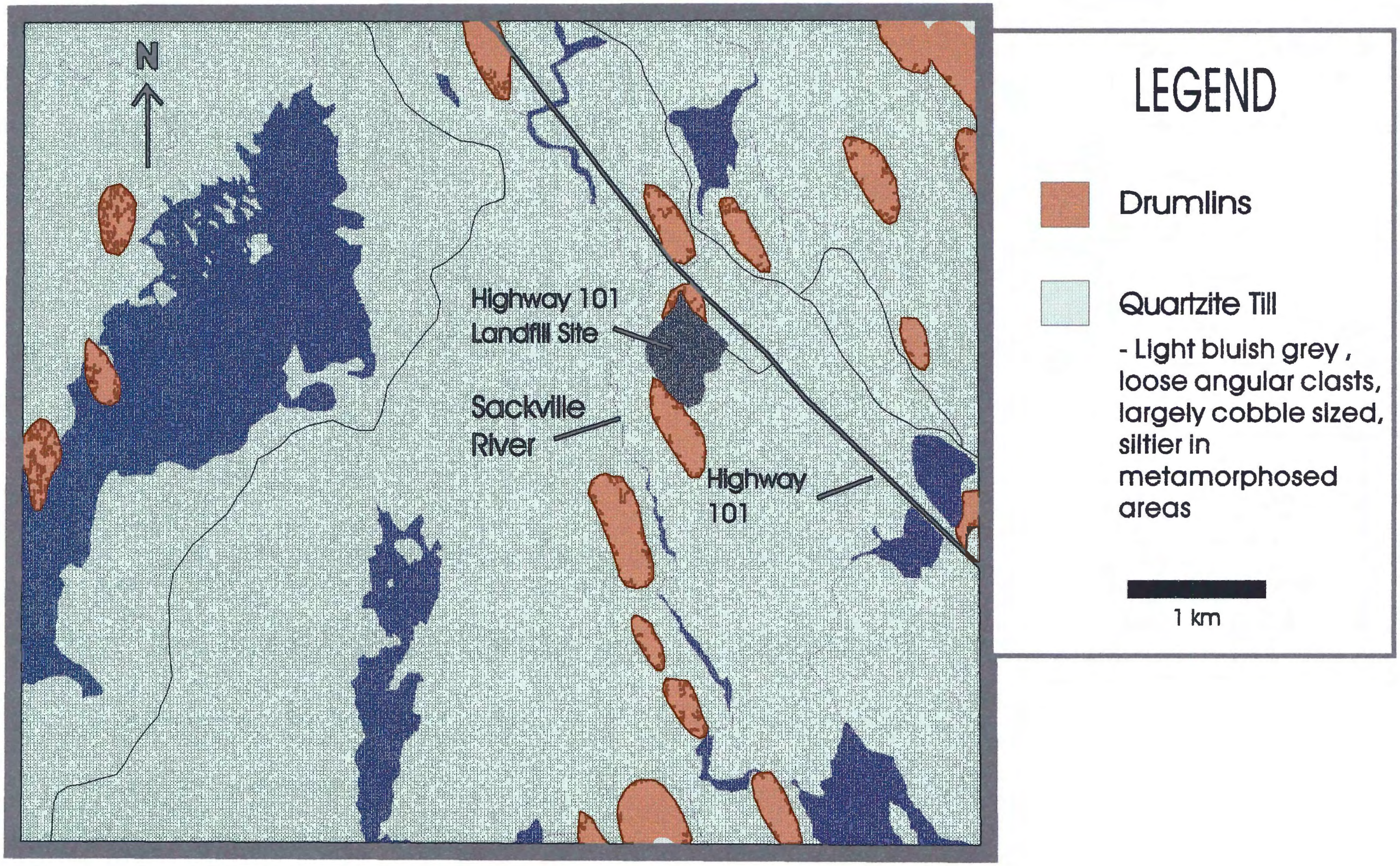


Figure 2.5 Quaternary geology in the in the landfill area (modified from Stea and Fowler, 1980 and

sand in this unit makes it less desirable for cover material because of the higher permeability.

2.3 Hydrogeologic Setting

The hydrogeologic setting encompasses a large number of parameters, including both the chemistry of the water and the physical characteristics of the medium that controls the movement of groundwater. Determination of the hydrogeologic setting of the Highway 101 Landfill has been possible through the use of a number of monitoring wells and piezometers. Currently there are 63 monitoring wells for the landfill. Physical characteristics such as hydraulic conductivity (the rate at which water passes through the rock), the flow direction, and hydraulic gradient remain fairly constant. Hence these characteristics of the rocks have not been calculated on a regular basis. Alternatively, the chemistry of the groundwater may be subject to change if leachate from the landfill affects it. Monitoring the water chemistry of the groundwater was initiated in 1977 and continues to the present. Yearly sampling helps to determine if and to what extent the chemistry is changing.

2.3.1 Monitoring Wells

The monitoring program began in 1977. Since then the program has grown in number of wells and the chemical parameters tested. To date there are 63 monitoring wells located around the Highway 101 Landfill site (Fig. 2.6). The construction of the wells occurred in four main series. The first series of 23 wells were constructed in 1977 and their number was increased to 31 wells by 1991. There are 14 well sites with up to three wells at each location, each sampling at a different depth. The well depths sampled have the following ranges: surficial (above bedrock 0.5 m to ~20 m), intermediate (<7.6 m into bedrock), and deep (>9.6 m into bedrock). The well sites are located around the expected fill area, with a greater concentration of wells along the west and south-west sides of the landfill. The high concentrations of wells in this area is determined by the position of the Sackville River and the predicted groundwater flow direction (in a west to southwest direction). In 1990, the wells were inspected for any problems and in 1991 many wells were abandoned, reestablished, or repaired. The second well series installed were three deep wells. Installation of these wells occurred in 1981 in the vicinity of the leachate treatment facilities in order to see the impact that the facilities were having on the local groundwater. The third well series was established in 1994. This series contained 23 wells at 11 different sites around the extended part of the landfill in the north-east. There were up to four wells at each site, varying in depths from 3.6 to 50.5 m. The final series of six wells was installed in 1995. These wells were installed at three different sites in order to help determine movement of the leachate plume in more detail (Jacques Whitford, 1995b).

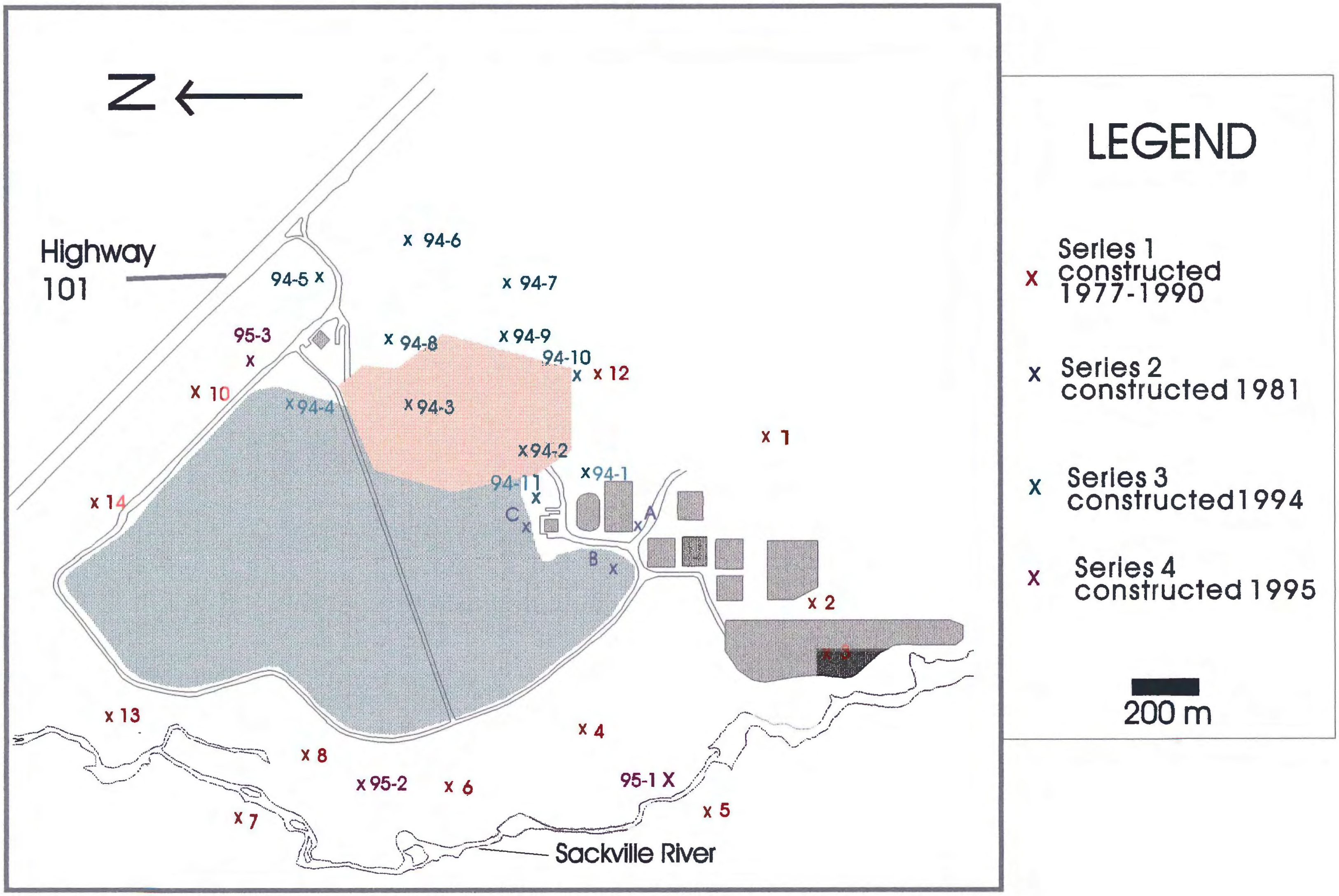
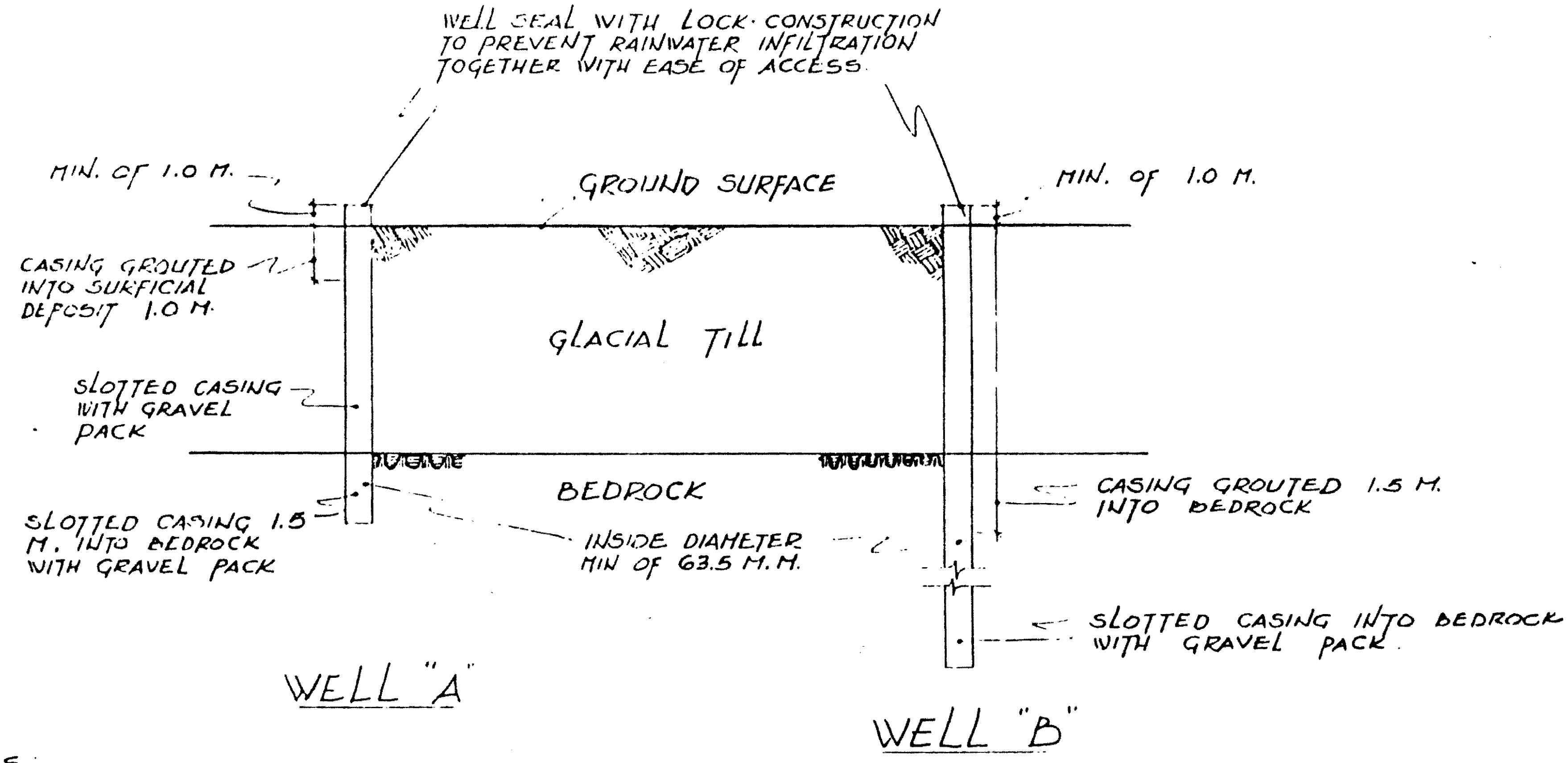


Figure 2.6 Monitoring well location map (modified from Jacques Whitford, 1995)

2.3.1.1 Well Specifications

H. J. Porter Ltd. and Beasy Nicoll Engineering Ltd. set out the original specifications in 1977 for how the wells at the Highway 101 Landfill should be constructed. The specifications for the wells were dependent on the depth of the wells. Originally, there were to be two well types- shallow and deep. All wells were to have a locked seal at the top of the well that is at least 1.0 m above ground level. The shallow wells should have had a casing that is grouted into the surficial material to a 1.0 m depth. The casings were to be slotted through its entire length (1.5 m into bedrock) and packed with gravel (H.J. Porter Ltd. & Beasy Nicoll Engineering Ltd., 1977). Deep wells were grouted 1.5 m into bedrock. The casing was to be slotted at the bottom with a gravel pack. See Figure 2.7 for complete well specifications

In 1990, Porter Dillon, on behalf of the Metropolitan Authority, did a report on the status of the piezometers, then fixed any problems and constructed more deep wells (>9.6 m). In the construction and rehabilitation of these wells, some well specifications were changed. The specifications varied depending on the depth of wells but all wells had a lockable cover installed. The surficial wells all had a 1.5 m screened section that was wrapped in a filter sock, and were finished above ground level with PVC piping. Silica sand was packed between and just above the screen and the hole. A bentonite seal was placed above the sand to act as a water barrier. The remainder of the gap between the hole and piping was backfilled. At the surface, a second bentonite seal was installed to help isolate the groundwater. The intermediate wells were constructed in a similar



NOTES :

1. CASING TO BE P.V.C. (OR EQUAL) RIGID PIPE.
2. SLOT SIZE TO BE NOT GREATER THAN 6.4 M.M.
3. GRAVEL PACK TO BE NOT GREATER THAN 3.2 MM
4. ALL LOCKS ON WELLS TO BE KEYED ALIKE.
5. MAXIMUM DISTANCE BETWEEN TWO WELLS AT ANY ONE STATION TO BE 8.0 M. (MIN. DISTANCE 3.0 M.)
6. WELL DEPTHS (B) INTO BEDROCK AS NOTED IN ATTACHED REPORT.

Figure 2.7 Well Specifications in 1977 (from Beasy Nicoll Engineering and H.J. Porter Associates, 1977).

manner to the surficial wells but the screened section was only 3 m in length.

The deep wells construction was different in that it does not have a screened section. There is a 5 cm casing installed at three meters into the bedrock. Figure 2.8 shows well specifications in 1990.

Provided the seals remain intact, the surficial, intermediate, and deep wells should be sampling groundwater at different depth levels. However, Porter Dillon (1990) noted common problems with the older wells that may have affected the integrity of the seals.

2.3.1.2 Chemical Measurements

Once established, wells were tested approximately once a year for up to 45 different parameters. Samples were tested using a Metal Scan and General Chemistry or a Rapid Chemistry Analysis (RCA) at either Fenwick Laboratory or the Envirochem Laboratory of the Victoria General Hospital in Halifax. In March 1995, the testing parameters were expanded to include organic compounds for those wells suspected to have been impacted (Jacques Whitford, 1995b). These samples were tested by the MDS Laboratories in Halifax and in Mississauga, Ontario.

The duty of sampling for the monitoring program has changed throughout its history. The first samples were collected by the consulting firm H.J. Porter Ltd. Later samples were collected by the Nova Scotia Department of the Environment, then by Porter Dillon, with the final samples being taken by Jacques Whitford and Associate.

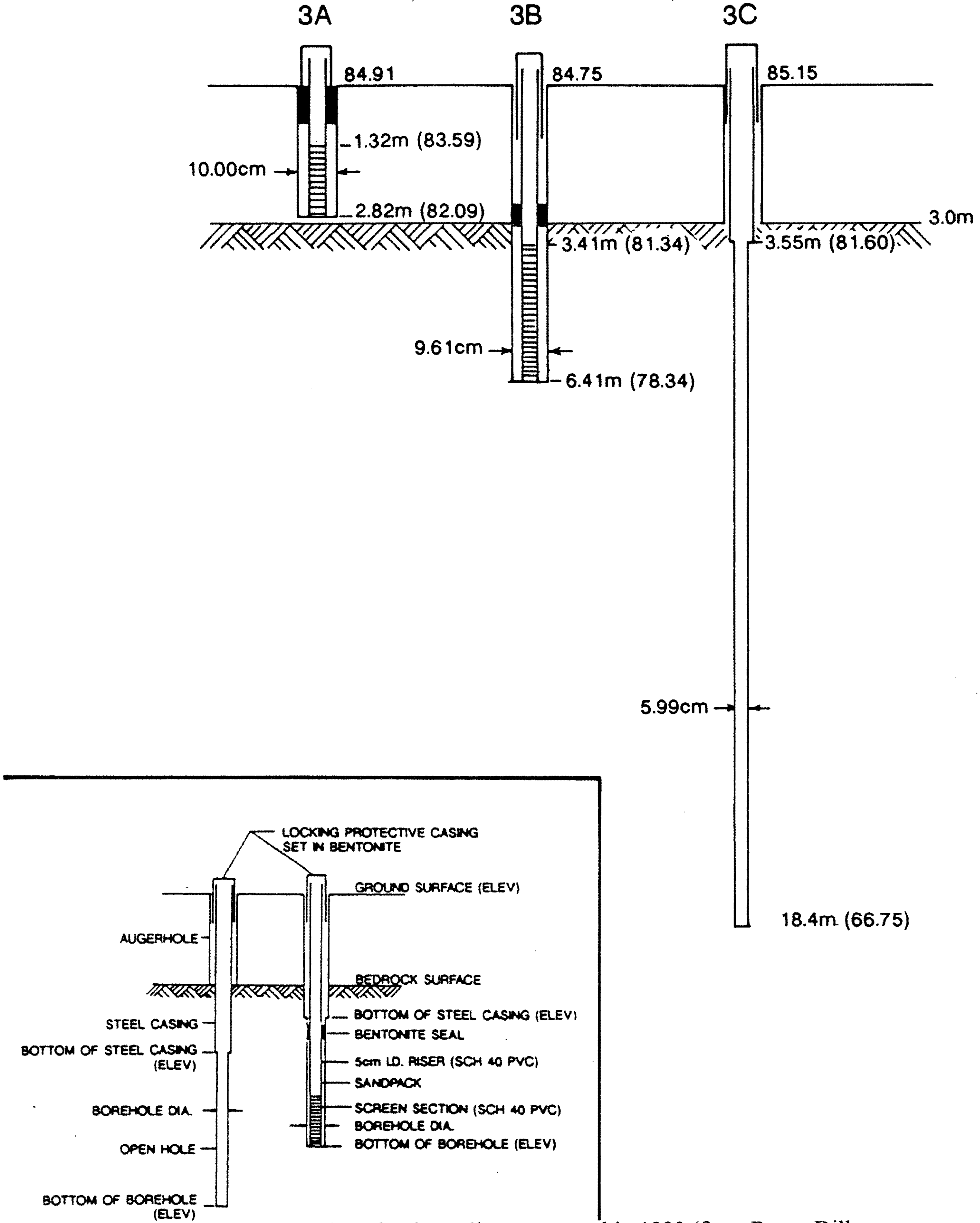


Figure 2.8 Well specifications for the wells constructed in 1990 (from Porter Dillon, 1992).

2.3.2 Physical Measurements

Groundwater is contained in a medium that influences a number of different parameters including hydraulic conductivity, flow direction, hydraulic gradient, and velocity.

The hydraulic conductivity of the wells measures the rate at which the water flows through the rock. Measurement of conductivity was done using the Bail test and the Hvorslev method. In this test water in the water column of the piezometer is withdrawn and measurements are taken to determine how long it takes for the water to reach its original height. The conductivity was measured at 21 different wells at various well depths. The geometric mean for the conductivity for the surficial wells was $6.37*10^{-5}$ cm/s. At the boundary between the surficial layer and the bedrock it was $4.35*10^{-6}$ cm/s (this includes a reading from well 9A which was significantly lower and is questionable). The shallow bedrock geometric mean was $4.33*10^{-5}$ cm/s, and for the deep bedrock was $3.60*10^{-5}$ cm/s (Porter Dillon, 1992). From this information, the hydraulic gradient, and the estimated porosity, an estimate of the velocity of the water was made. The estimates range from $6.88*10^{-6}$ cm/s to $6.88*10^{-5}$ cm/s. Due to the low conductivity of the rock, it was believed that the movement was dominated by the fractures and joints (Jacques Whitford, 1995b). Considering my field observations, the steep vertical fractures described are probably steeply dipping bedding and cleavage planes. It is important to realize that the velocity of the water is faster than the transport velocity of a contaminant. Physical, chemical, and biological mechanisms hinder the contaminant movement.

The flow direction and hydraulic gradient are estimated using hydraulic head in the piezometers. Hydraulic head is the height the water reaches above a datum. In order for measurements to be comparable, they must be within the same unit and measured at approximately the same time. To ensure that the measurements were in the same unit both the stratigraphy and degree of fracturing in cores were used (Porter Dillon, 1992). The height that the water rises is dependent on the pressure, the higher the pressure the higher the water level in the piezometer. From these measurements, equipotential contours are plotted. The hydraulic gradient is the measure of how the gradient changes over a distance. As for air, water flows from high pressure (high potential areas) to low pressure (low potential areas). In the case of the Highway 101 Landfill the flow moves predominately in a SW direction (Porter Dillon, 1992) (Fig. 2.9). Topography influences the groundwater flow, particularly in the surficial material. Although there are no measurements, it is suggested that the drumlin that was on the western side of the landfill could locally have affected the flow directions. The surficial groundwater beneath the drumlin would flow away from the high areas of the drumlin outward in all directions, There is also the possible effect of groundwater mounding beneath the landfill. As waste is put into the landfill, the height of topography increases, and the level of the watertable rises. The groundwater, in this case in a semi- unconfined aquifer, will follow the

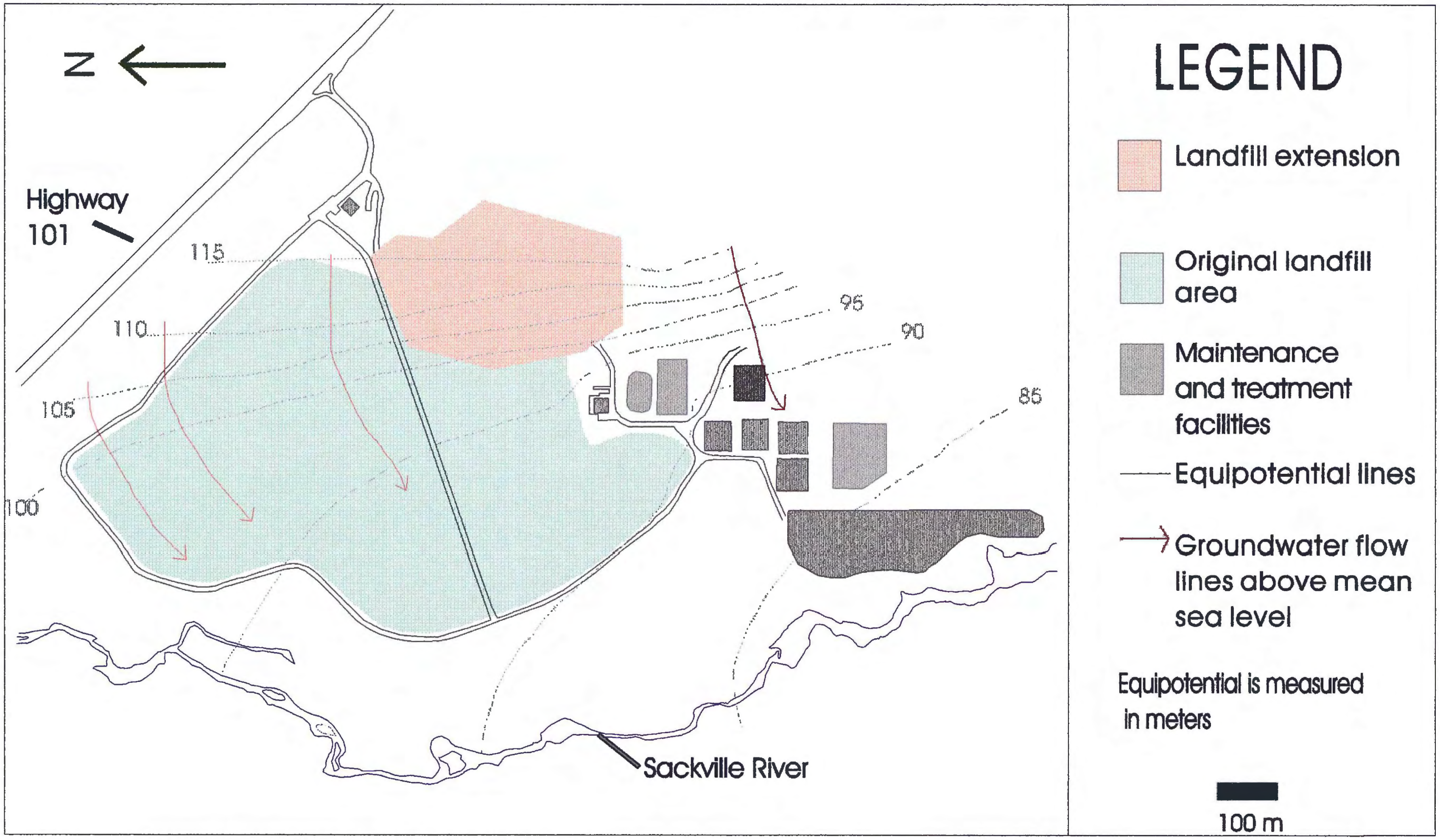


Figure 2.9 Groundwater flow direction at the landfill site (modified from Jacques Whitford 1995b and Porter Dillon, 1992)

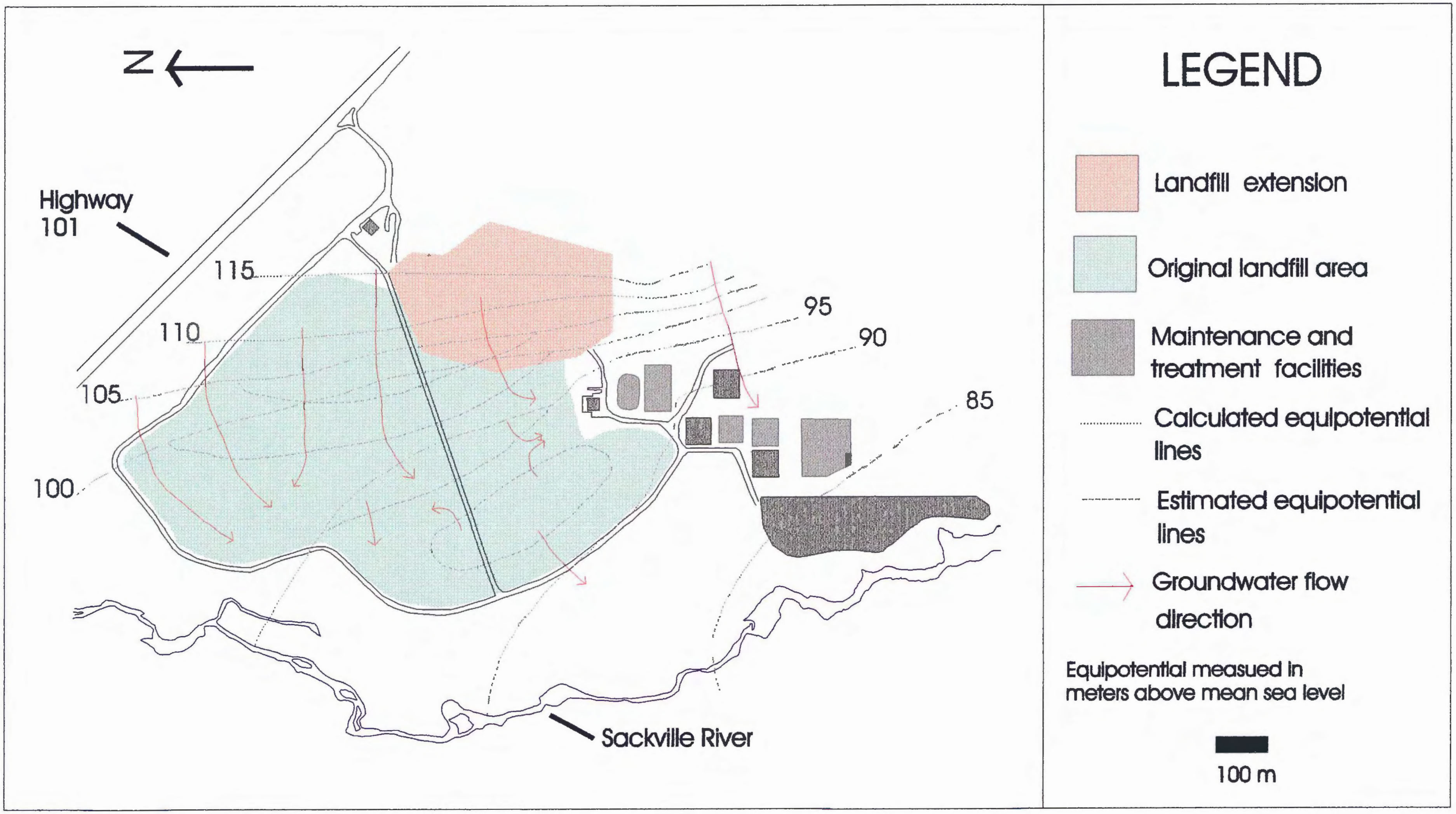


Figure 2.10 Altered groundwater flow direction at the landfill with mounding and drumlin (modified from Jacques Whitford,1995 and Porter Dillon, 1992)

surface topography. This effect was thought to be minimal in the Highway 101 landfill because the leachate collection system which withdraws water from beneath the landfill and lowers the watertable. If mounding were to occur, the flow direction would change to a more westward flow (Porter Dillon, 1992) (Fig. 2.10).

2.3.3 Hydrogeochemical Background

Background water chemistry is needed to determine whether the leachate from the landfill is having any effect on the local groundwater. Establishment of background concentrations occurred twice. The first time in 1978, with the Baseline Water Quality Study (Beasy-Nicoll Engineering Ltd., H.J. Porter and Ass., 1977) and the second time in 1995 (Jacques Whitford, 1995). The Baseline Water Quality Study sampled from residential and monitoring wells and also from surface water. The 1995 study used, as its reference, the chemistry of the monitoring wells that did not appear to be impacted, according to geophysical tests, by either leachate or by road salting.

2.3.4 Leachate Composition

Leachate composition varies from landfill to landfill because of the types of waste in the landfill and its age. Jacques Whitford's (1995b) definition of leachate indicator parameters, parameters that can signal the impact of the leachate on groundwater, were established as being those parameters that had a concentration greater than three standard deviations over the deep well average.

Most of the leachate indicator compounds are within the range of leachate from other municipal landfills (World Health Organization, 1993). There are, however, a few exceptions: chloride is higher than expected, while sulphate and manganese are lower than the reputed average concentrations (World Health Organization, 1993) (Table 1.1).

As leachate ages, it changes its composition (World Health Organization, 1993). With time, most chemical concentrations decrease except for chloride, sodium, and copper which increase in domestic/industrial landfills (World Health Organization, 1993).

2.4 Waste Emplacement

Site preparations, waste emplacement, and other operations may influence contaminant transport. Placement of buildings, roads and waste may alter the velocity and direction of the contaminants. During construction, bedrock surfaces may be exposed, affecting flow of contaminants. Waste placement records may give an indication on distance and time the leachate plume has moved from the landfill (Fig. 2.11).

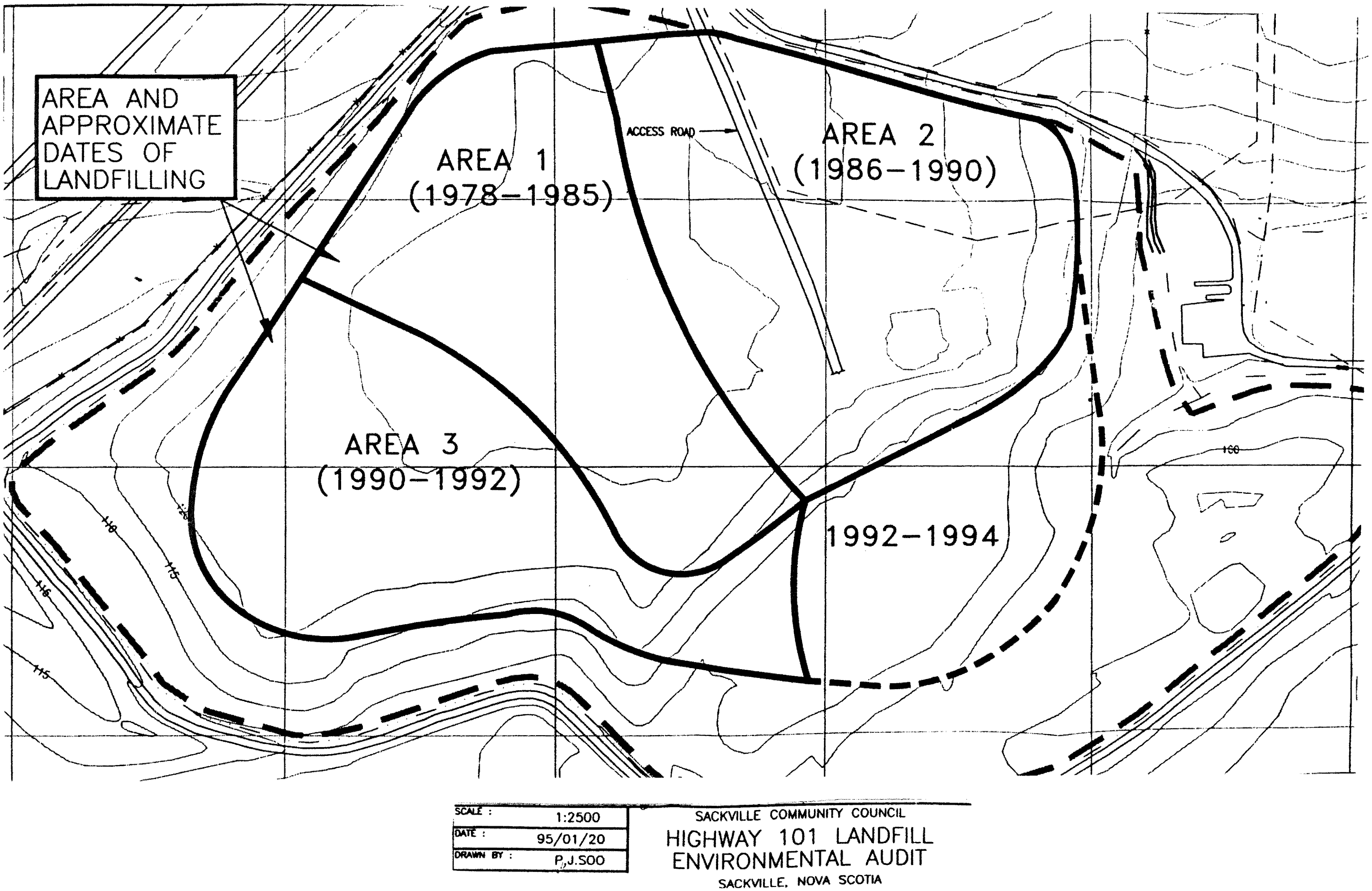


Figure 2.11 Waste emplacement map for the Highway 101 Landfill (from Jacques Whitford, 1995b)

2.4.1 Site Preparation

When the Highway 101 site was chosen as the landfill for the Metropolitan area, work had to be done before any waste could be disposed of. Basic site preparation included the building of access roads, maintenance buildings, as well as installing power and sewer lines. There were also site specific characteristics that were addressed to make the site more secure from leachate transport. In areas where bedrock came to within 1 m of the surface a 1 m thick layer of compacted till was added. Another problem that was of concern was the low-lying peat bog near the center of the landfill. In the peat bog the water table came to the surface, allowing any waste deposited to be in continuous contact with groundwater. To prevent this from occurring, a 1 m layer of compacted fill was added to the boggy area.

2.4.2 Site Operations

The Highway 101 Landfill is a sanitary landfill site. This means that the garbage is compacted and covered on a daily basis. The method used for the landfill site is the area method. In this method waste is placed in strips on top of the existing surface, it is then compacted and covered with material from nearby areas. When the waste reaches 1.5 m in height or the end of the day, it is covered creating cells. These cells are placed on top of one another creating a mound or hill of garbage.

CHAPTER 3: METHODS

3.1 Introduction

The effects of leachate from the Highway 101 Landfill on the groundwater have been a concern since its construction. Precautions to eliminate the contact of leachate with the groundwater have been established (see Chapter 2). The importance of groundwater and the serious effects of its contamination have led to geophysical methods being applied to determine if there has been any leachate escape and, if so, where. This was done in 1995 by the consulting firm of Jacques Whitford and Associates who concentrated their studies on geophysical terrain conductivities. The current project concentrates on water chemistry.

3.2 Present Methods

This project was set up to detect changes in the groundwater chemistry due to the leachate from the Highway 101 Landfill. The method involves tracking changes in water chemistry over time in the monitoring wells and identifying which is “real” change rather then normal background fluctuation and analytical "noise". The data for the project came from the Porter Dillon Groundwater Monitoring Program (1991) and from the Jacques Whitford Environmental Audit Report (1995). The database for the landfill site is very large and consists of 63 wells that have been sampled for up to 18 years for up to 45 different parameters. For this reason, a smaller subset of data was used as a pilot study. Eleven well sites were selected. These wells were picked because of their location (down-gradient from the landfill but up-gradient from the Sackville River) and their long history of sampling. Six parameters were considered for each of these wells: ammonia, total dissolved solids (TDS), arsenic, iron, potassium, and sulphate. These are a subset of the indicator parameters set out by Jacques Whitford (1995).

This pilot test was run to help answer some questions concerning the leachate, its flow, and velocity. In particular, the study aims to provide an idea of background conditions, on flow velocity, at what depth the plume is traveling, whether there are any trends that may indicate the imminent arrival of the contamination plume, and which parameters show first arrival of the plume.

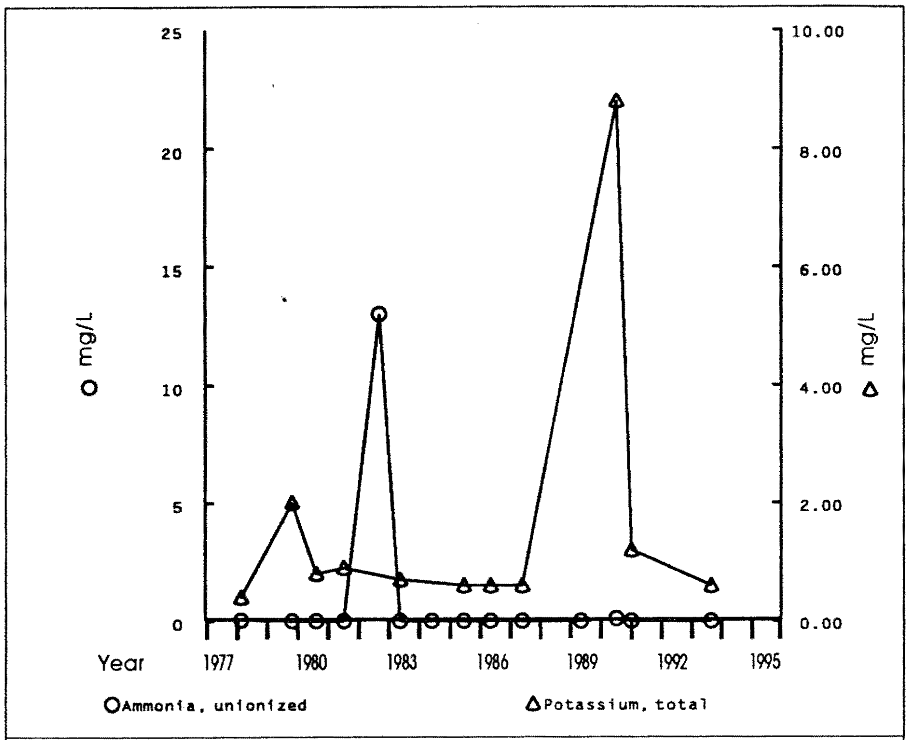
3.2.1 Steps in Methodology

There has been no set method established for how this type of problem should be approached. This thesis tries to establish a logical step-by-step approach for looking at the leachate impact on the groundwater using water chemistry changes through time.

The first step involved the choice of elements and compounds in groundwater that would be good indicators of leachate impact. Elements and compounds were chosen because of their high concentration in the leachate relative to the background (Table 1.1, first six parameters). Another consideration was that a variety of parameter types be included (cations, anions, complexes etc.). Elements avoided were that would increase due to external causes, such as the impact of road salting on Highway 101 on sodium and chloride concentrations. The six parameters chosen were potassium, sulphate, arsenic, iron, ammonia, and total dissolved solids (TDS). The data were then entered into a new database and cross checked with two reports (Porter Dillon Limited, 1991 and Porter Dillon Limited, 1994) for entry errors.

The next step involved eliminating anomalously high values possibly caused by collection or by analytical errors. This process was accomplished with a number of sub-routines. The first part was to eliminate any uncorrelated, isolated, high values or "kicks". The correlation was done with all six parameters at all wells in a particular well site. The rationale is that leachate impact should occur on more than a single parameter and on more than one occasion. An example is shown in Figure 3.1, where potassium is shown to peak but the ammonia remains low. In some cases, isolated, anomalously high values for a particular sample occur for more than one parameter and cannot be eliminated by the above criterion. These samples were left in the database, but lead to questions of validity (Fig. 3.2 shows an isolated high in 1982 in both arsenic and iron)

In testing water quality there was no consistency in whether or not the samples were field filtered, filtered in the lab, or not filtered at all. In many cases no information on filtering was provided. There must be consideration of how filtering affects the samples. This would particularly affect the concentrations of iron, since it commonly occurs in colloidal form, as well as those elements which would be adsorbed on these particles (Fetter, 1993). In view of these uncertainties, little emphasis is placed on trends in the iron concentrations alone. No correlation between filtering and the



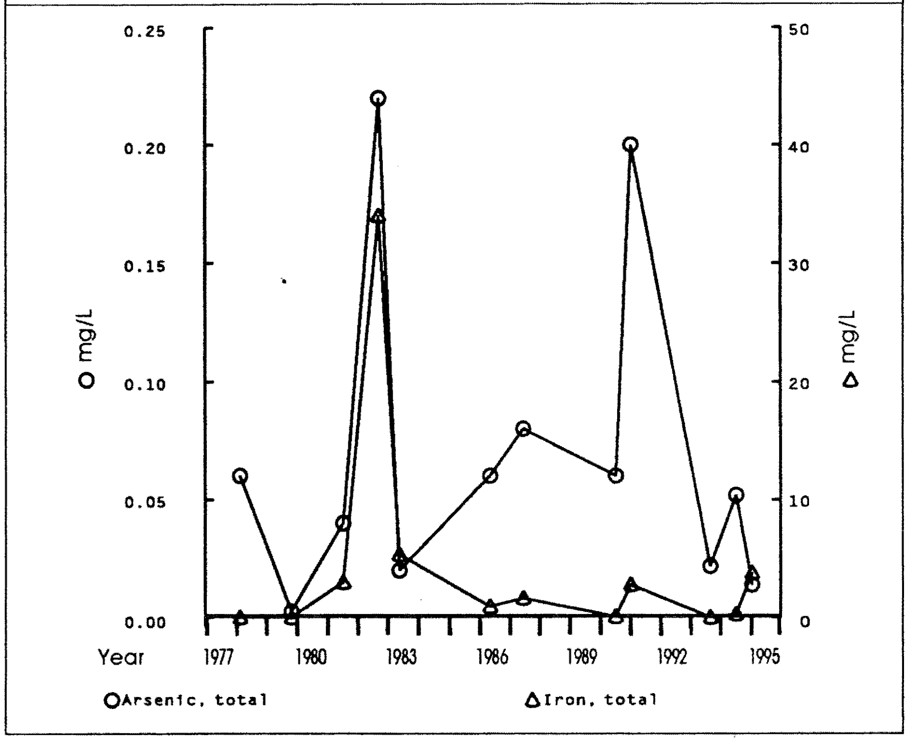


Figure 3.1 Ammonia and potassium concentrations in the intermediate well at well site7.

Figure 3.2 Arsenic and total iron concentrations in the deep well at well site 4.

element/compound concentrations other than iron could be observed.

Another concern was the effect of seasonality on water quality because the water samples were collected at various times of the year. This effect is tested on the unimpacted wells. Seasonality could affect the dissolved component because with abundant precipitation there is dilution of the dissolved components in the groundwater. In contrast, during dry or freezing conditions little or no water may be supplied to the groundwater, thus concentrating the contaminants into the water available. To test for the influence of seasonality, the water monitoring software MANAGES was used (EPRI, 1993; Patel, 1994). Seasonality was determined using the Kruskal-Wallis and Kendall statistical tests. If these tests show seasonality or trends in seasonality, then the effects would have to be extracted from the data when considering long-term trends.

The Kruskal-Wallis test uses a 90% confidence band when considering if seasons have any impact. This test divides the sample population by seasons and then tests to see whether the mean from one season varies from the other seasons (Gilbert, 1987). Once the samples are divided into seasons, they were ranked, the sum of each season is then taken and used to determine the Kruskal-Wallis statistic. If this statistic is greater than the chi-square distribution, then seasonality has an effect. This test can be used because it is non-parametric and data sets do not have to be normal or symmetrical (Gilbert, 1987).

The Kendall test is used with a 95% confidence range. It tests the hypothesis of whether or not the seasonal values are independent of time (Gilbert, 1987). It involves distributing the samples into seasons, then calculating the Mann-Kendall test statistic, variance, and Z value (Gilbert, 1987). The trend in seasonality is accepted if the Z value calculated is greater than the absolute $Z_{0.025}$.

Another feature that was tested in the unimpacted wells was the presence or absence of other than seasonal trends in the data. MANAGES uses Sen estimate of slope to determine trends and the Mann-Kendall statistic to determine the significance of the slope. The Sen slope is used for trend because it is insensitive to a low number of outliers, the data can be non-parametric and for this reason it is robust (Gilbert, 1987). The Sen estimate of slope gives the median slope for all possible pairs of unique data points (EPRI, 1993). The Mann-Kendall statistic defines the significance for the Sen slope estimate. It tests two hypotheses: the null hypothesis that says that there is no trend, and the alternative hypothesis that there is a non-zero trend (EPRI, 1993).

After all conditions were considered, the database was as clear from errors and discrepancies as possible. A series of graphs was constructed, showing each parameter over time for all wells at each well site. Individual parameters and wells were considered over time in order to see trends, as well as selected time-series graphs to show more detail. These resulting graphs help to show where and when the leachate plume impacts the well sites. The graphs enabled the wells to be classified into three groups: unimpacted, impacted, and complex.

The unimpacted wells are those that do not have consistent values above the background threshold. The background threshold is defined as the mean background plus two standard deviations (Table 3.1). There is therefore only a 5 % probability that any value that falls above the threshold belongs to the background population. Using these wells, tests for seasonality and trends were done because of the unimodal nature of the data set.

Impacted wells, on the other hand, are those wells that show a consistent portion of their samples above the background threshold (mean plus two standard deviations). These wells have two distinct populations so trend and seasonality were not considered.

Complex wells are those wells that do not readily fit into either one of these classifications. Some possible explanations for these temporal patterns are given.

Plume velocities were estimated by calculating the distance from the well to the nearest waste location, following back along groundwater flow lines to the nearest edge of waste containment areas. By noting when the well first appears to be impacted, and the dates of the filling areas, a time span can be calculated. These estimates of velocity can then be extrapolated further along the groundwater flow lines for calculation of a date when the contaminants will reach the Sackville River.

DEEP WELLS n = 47

	LEACHATE	BACKGROUND				THRESHOLD
		Minimum	Maximum	Mean	STD	Mean + 2 STD
Potassium	853	0.2	4	1.31	1.02	3.35
Sulfate	25.9	<2.0	112	9.55	7	23.55
Ammonia	9	<0.05	0.15	0.025	0.02	0.065
Iron	3	0.01	1.6	0.283	0.438	1.159
Arsenic	0.075	<0.002	0.079	0.016	0.019	0.054
TDS	13900	14	163	84	43	170

SHALLOW WELLS n = 27

Potassium	853	0.4	5.7	1.4	1.27	3.94
Sulfate	25.9	<2.0	20	7.59	4.82	17.23
Ammonia	9	<0.05	0.06	0.004	0.014	0.032
Iron	3	<0.01	10	1.105	2.769	6.643
Arsenic	0.075	0	0.84	0.072	0.222	0.516
TDS	13900	14	127	59	34	127

ALL WELLS n = 74

Potassium	853	0.2	5.7	1.35	1.12	3.59
Sulfate	25.9	<2.0	33	8.84	6.37	21.58
Ammonia	9	<0.05	0.15	0.004	0.02	0.044
Iron	3	<0.01	10	0.565	1.706	3.977
Arsenic	0.075	<0.002	0.84	0.036	0.136	0.308
TDS	13900	14	163	75	42	159

Table 3.1 Table showing leachate levels compared to background and the impact threshold defined for this study (Modified from Jacques Whitford, 1995).

CHAPTER 4: DATA ANALYSIS AND RESULTS

4.1 Introduction

When considering the impact of leachate on wells, it becomes important to understand which parameters should provide the best indicators of impact and why. By looking at interactions, stabilities etc., it becomes apparent that all parameters are not equal. In decreasing order of importance, the following were considered the best indicators of groundwater contamination by leachate:

a) The first parameter considered was total dissolved ammonia. In general, ammonia is not found naturally in the groundwater of most rocks and soils (Hill, 1982). Ammonia production occurs when nitrate is subjected to reducing conditions (Fetter, 1992; McBride, 1994). The most common sources of nitrate are anthropogenic, particularly from fertilizers and animal excrement (Fetter, 1992). Groundwater generally contains very low concentrations of nitrate as seen in background concentrations around the landfill site (mean value = 0.004 mg/L, Table 3.1). The reducing conditions necessary for nitrate to ammonia conversion are present in all municipal landfills due to the organic component of the waste (Fetter, 1992). In the case of the Highway 101 Landfill site, any increase in nitrate must be from the landfill because there is no farming or agriculture in the immediate area.

b) Total Dissolved Solids (TDS) was the second parameter considered. This was chosen because of its high concentrations in the leachate (13900 mg/L, Table 3.1) and its low levels in the background waters (75 mg/L, Table 3.1). TDS should be a good indicator of leachate impact because it considers all dissolved components of the water; a substantial increase in any one of the major components or combination of components would lead to elevated TDS readings.

c) The third parameter considered to indicate leachate impact was arsenic. Although its concentration is low in leachate (0.075 mg/L, Table 3.1), it is found in the surrounding country rock in the form of arsenopyrite, particularly in the quartz viens and in gold mineralization areas. As leachate begins to impact the wells, a reducing environment would become evident. Under reducing conditions arsenic becomes more mobile and would become incorporated more readily into the groundwater (Fetter, 1992).

d) The remaining three parameters , iron, sulphate, and potassium, were considered less reliable indicators. Iron was looked at with caution because of varying filtering practices (or lack thereof). Filtering is particularly important in the case of iron because it forms colloids and readily precipitates during sampling (Fetter, 1992). Filtering, therefore, can drastically change the amount of iron measured. Sulphate was not used as a main indicator parameter, although its concentrations are high in leachate (mean = 8.84 mg/L, Table 3.1), since under reducing conditions some or all of the sulphate converts to hydrogen sulphide (McBride, 1994). This makes an exact pattern of contaminant influence unclear. Potassium was not used as a prime indicator because its distribution pattern is strongly influenced by adsorption and exchange with clay minerals (McBride, 1994).

By looking at the above parameters, particularly the three primary ones outlined above, a general grouping of the monitoring wells became evident. For the purpose of the discussion that follows, the groupings are: unimpacted well, impacted wells, and complex wells.

4.2 Unimpacted Wells

Unimpacted wells provide valuable information when looking at the influence of leachate. Studying these wells provides background information (mean and standard deviations) that can be compared with other previous background studies. The presence of any seasonal effects that may affect the measured parameters can be determined with the statistical Kruskal-Wallis test (EPRI, 1993). Such an influence would not be readily discerned in the impacted or complex wells. After seasonal effects have been removed, trends can be studied to determine any systematic changes that may precede arrival of the contaminant plume or that may predict the imminent arrival of the contaminant plume. Sen slopes and the Mann-Kendall test of significance were determined to test for any significant trends (EPRI, 1993).

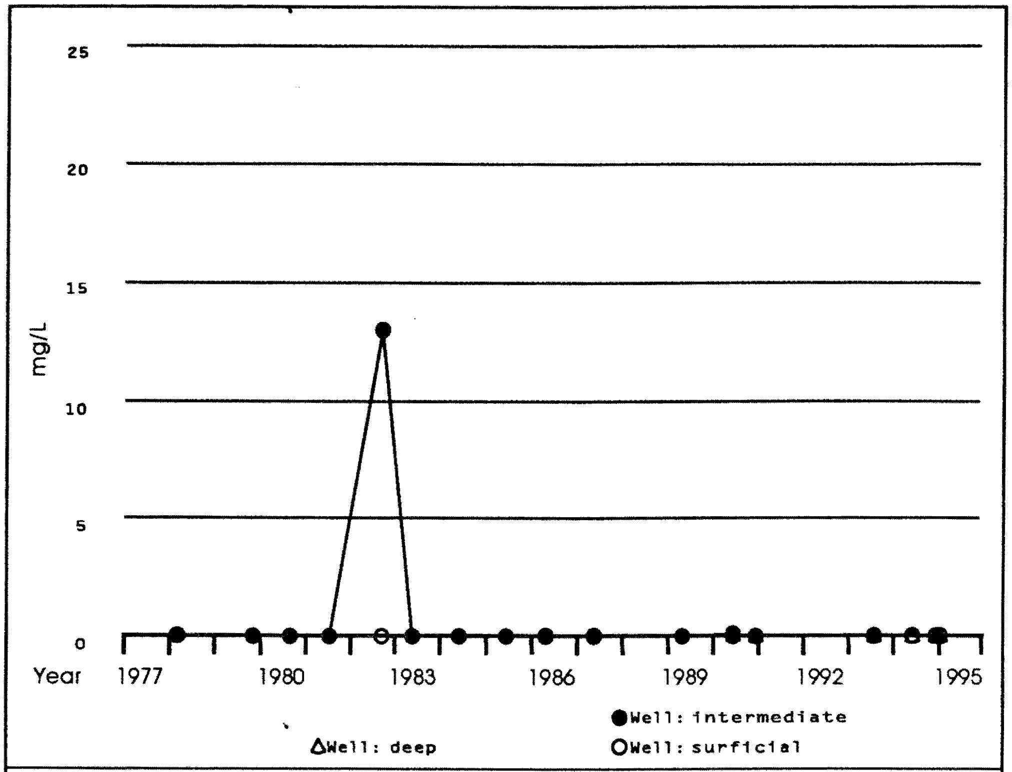
By considering the three parameters, six well sites are deemed as being unimpacted. These include: well site 1, well site 3, well site 4, well site 5, well site 7, and well site B. Of these well sites 1, 3, 5, and 7 can be expected to show little to no impact because of their location. Well site 1 and 3 are to the south of the landfill, and are not in the groundwater flow path determined for the landfill by Porter Dillon (1992)

(Figs. 2.6 and 2.9). Well site 5 and 7 are on the west side of the Sackville River, opposite from the landfill (Fig. 2.6). Therefore the river should act as a divide between separate flow cells and as a barrier to the contaminant transport. Well site 4 is located down-gradient from the landfill but before the Sackville River, because it's location and because it is unimpacted, it stands to reason, that the contaminant plume has not yet reached it (Fig. 2.6). Looking at these wells, the very high variability of some of the parameters becomes obvious (Fig. 4.4). From this data, a lack of consistent levels and anomalously high results that fall above the background threshold can be observed. This greatly affects the means and standard deviations (Table 4.1 through 4.3).

Well site 3 will be discussed in detail and its data are typical of that found in other unimpacted wells. Well site 3 is located to the west of the southern part of the landfill and should not be influenced by the landfill (Fig. 2.6).

Ammonia content is considered first and Figure 4.1 indicates the change in composition over time. The surficial well's ammonia content indicates no change in Sen slope using a 90% confidence level and is within the previously determined background (Table 3.1). With the exception of one anomalously high result, the intermediate well readings fall below background threshold values. This one high result biases the mean which becomes higher than background range. Using a 95% confidence level on the Sen slope indicates there is no trend. The deep well had readings that were consistently below the background range and also showed no trends at a 95% confidence level.

The next consideration is given to the TDS level (Fig. 4.2). The shallow and intermediate wells have the majority of their results within the background range of two



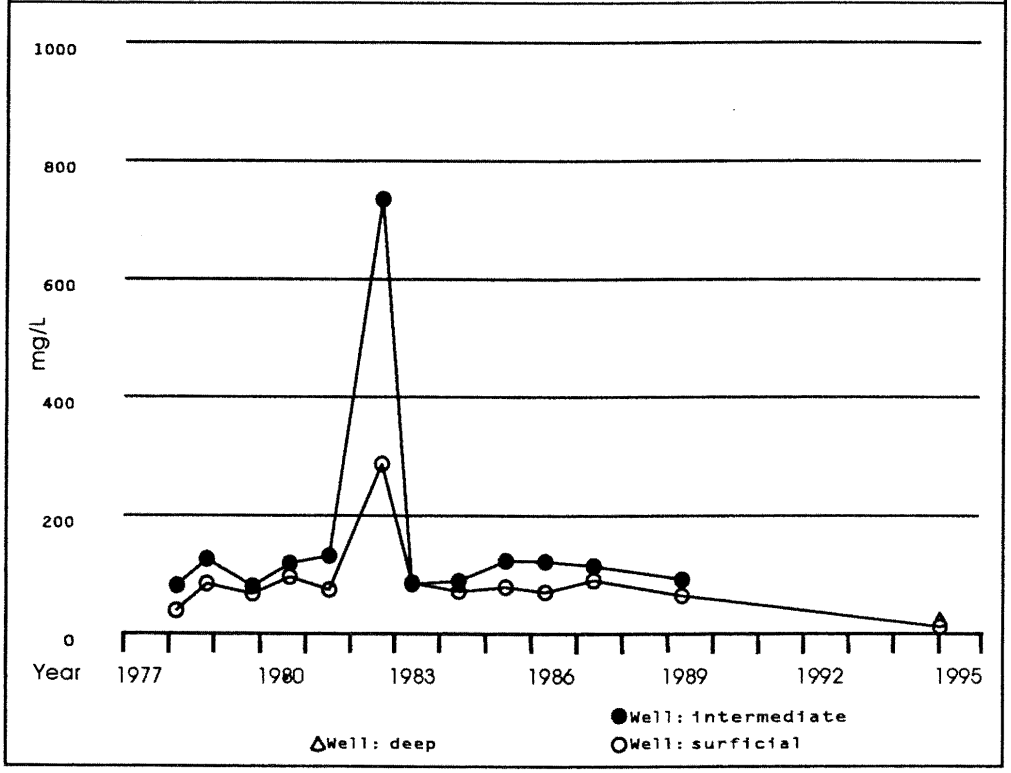


Figure 4.1 Ammonia concentrations at well site 3.

Figure 4.2 Total dissolved solids concentrations at well site 3.

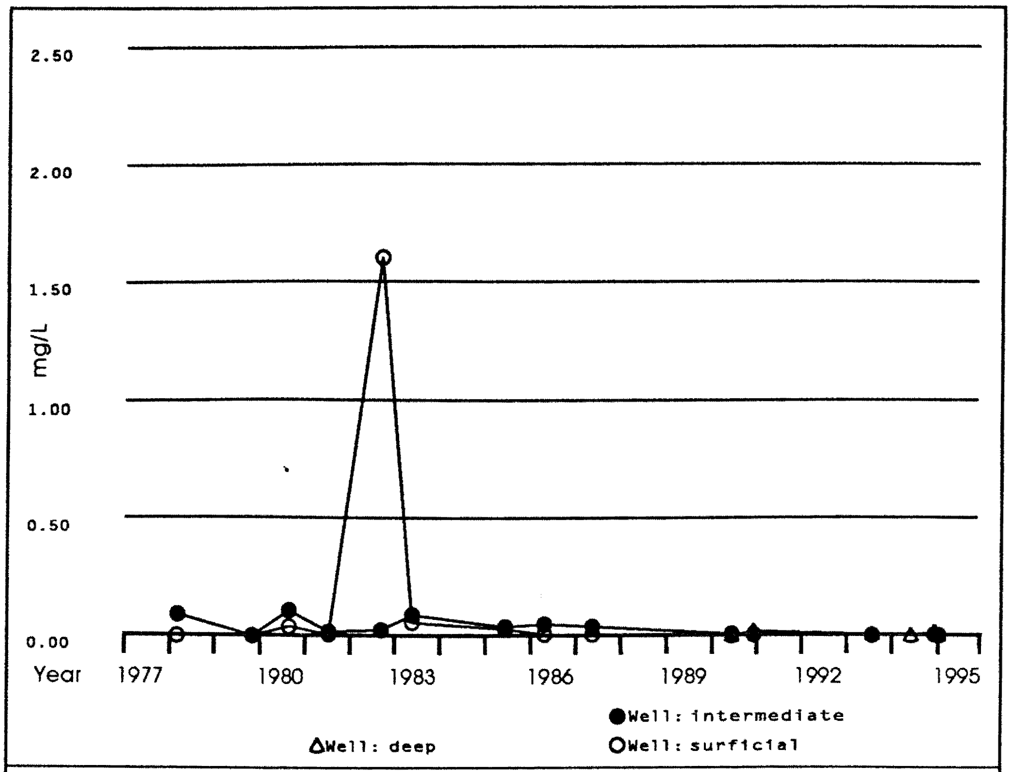
standard deviations above the background mean. Applying tests of seasonality and trend to both of these wells indicate there are no trends detectable at a 95% confidence. Only one sample was taken from the deep well making it impossible to perform statistical procedures, but the value falls within the background range.

Arsenic levels are within the background range for all three wells (Table 3.1). Again, one high result (in the surficial well) affects the concentration of the mean and standard deviation (Fig. 4.3). The seasonality test and trend analysis suggests no change over time.

Iron is another parameter tested. All the wells show highly variable concentrations (Fig. 4.4). Despite this, the arithmetic average in the surficial well is below the background threshold (Table 3.1), and shows no seasonality or trend at a 95% confidence. The mean values in the intermediate and the deep wells are higher than the previously defined background (Table 3.1.). Figure 4.4 shows that although the majority of values are in the background range the high values distort the means and standard deviations.

Most of the potassium levels are within the background threshold (Fig. 4.5). The trend analysis suggests that there is no trend in either the surficial or intermediate wells. The deep well shows a slight negative slope.

All the sulphate measurements were below previously determined background threshold (Fig. 4.6). The trend analysis at a 95% confidence suggests that there are no trends in any of the wells at this site. The other unimpacted well sites show similar patterns to those observed in well site 3. Spuriously high values above background



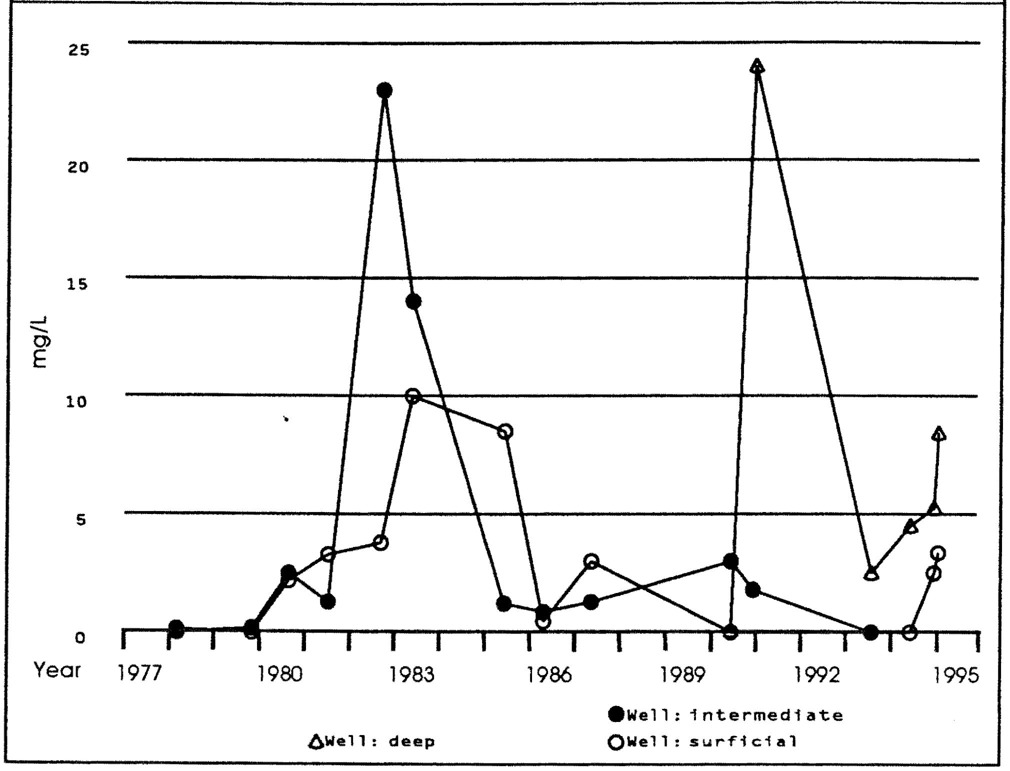
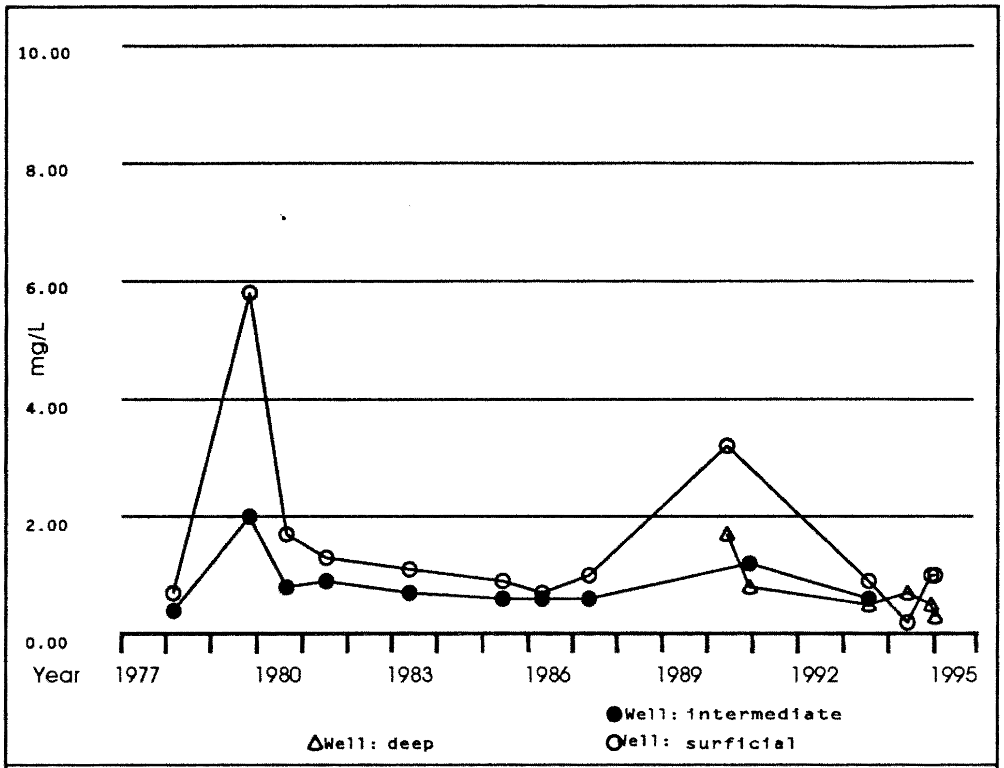


Figure 4.3 Arsenic concentrations at well site 3.

Figure 4.4 Total iron concentrations at well site 3.



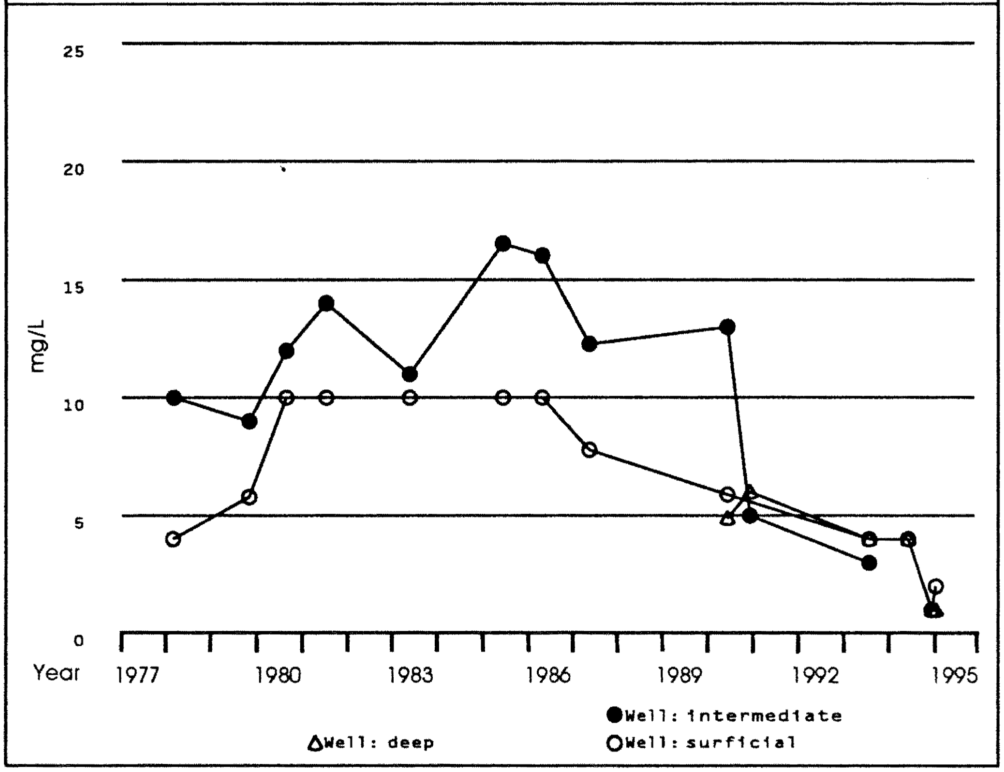


Figure 4.5 Potassium concentrations at well site 3.

Figure 4.6 Sulphate concentrations at well site 3.

threshold are recorded periodically. The transitory and isolated pattern of the values is thought to reflect the sampling and analytical problems, rather than leachate impact. Detection of the initial leachate impact, therefore, has to be based on the appearance of consistently high measurements above the background threshold. The next series of wells conform to such patterns.

Well Number and Site	Mean (mg/L)	Standard Deviation (mg/L)	Sen Slope (mg/L/day) and Mann-Kendall Significance	Seasonality effects	Number of samples
SURFICIAL WELLS					
1-A	0.03	0.01	None	No	13
3-A	0.04	0.02	None	No	16
4-A	0.03	0.02	None	No	10
5-A	0.14	0.10	None	No	14
7-A	0.04	0.03	None	No	10
Average	0.06				
INTERMEDIATE WELLS					
3-B	0.96	3.5	None	No	4
5-B	0.17	0.19	None	No	9
Average	0.56				
DEEP WELLS					
1-C	0.02	0.03	None	No	15
3-C	0.03	0.01	None	No	6
4-C	0.04	0.03	None	No	13
5-C	0.07	0.07	None	No	7
7-C	0.03	0.01	None	No	14
B	0.64	1.3	None	No	12
Average	0.14				

Table 4.1 - Ammonia statistical summary of unimpacted wells

Well number and Site	Mean (mg/L)	Standard Deviation (mg/L)	Sen Slope (mg/L/day) and Mann-Kendall Significance	Seasonality Effects	Number of Samples
SURFICIAL WELLS					
1-A	61	16	None	No	12
3-A	88	64	None	No	13
4-A	94	25	None	No	9
5-A	240	168	None	No	12
7-A	56	18	None	No	8
Average	107				
INTERMEDIATE WELLS					
3-B	160	180	None	No	12
5-B	200	140	None	No	10
Average	180				
DEEP WELLS					
1-C	97	54	None	No	13
4-C	95	14	None	No	11
7-C	58	14	None	No	12
B	156	65	None	No	10
Average	100				

Table 4.2 - TDS statistical summary for unimpacted wells

Well Number and Site	Mean (mg/L)	Standard Deviation (mg/L)	Sen Slope (mg/L/day) and Mann-Kendall Significance	Seasonality Effects	Number of Samples
SURFICIAL WELLS					
1-A	0.239	0.306	None	No	11
3-A	0.136	0.440	None	No	13
4-A	0.033	0.009	None	No	19
5-A	0.043	0.041	None	No	11
7-A	0.011	0.019	None	No	10
Average	0.094				
INTERMEDIATE WELLS					
3-B	0.040	0.034	None	No	12
5-B	0.030	0.021	None	No	6
Average	0.035				
DEEP WELLS					
1-C	0.101	0.054	None	No	13
3-C	0.008	0.008	None	No	6
4-C	0.069	0.070	None	No	12
5-C	0.042	0.014	None	No	7
7-C	0.010	0.020	None	No	12
B	0.015	0.016	None	No	9
Average	0.041				

Table 4.3 - Arsenic statistical summary for unimpacted surficial wells

4.3 Impacted Wells

Studying the impacted wells is important in determining the position and the rate of migration of the leachate contaminant plume. Questions to be addressed are: what particular elements/compounds travel fastest, what element/compound is most drastically affected, and what depth is most affected. This is necessary information for considering what remediation method will be most practical. In determining which wells are impacted, the three parameters: ammonia, TDS, and arsenic are used as primary indicators. The well sites that are clearly impacted are well site 8 and well site C.

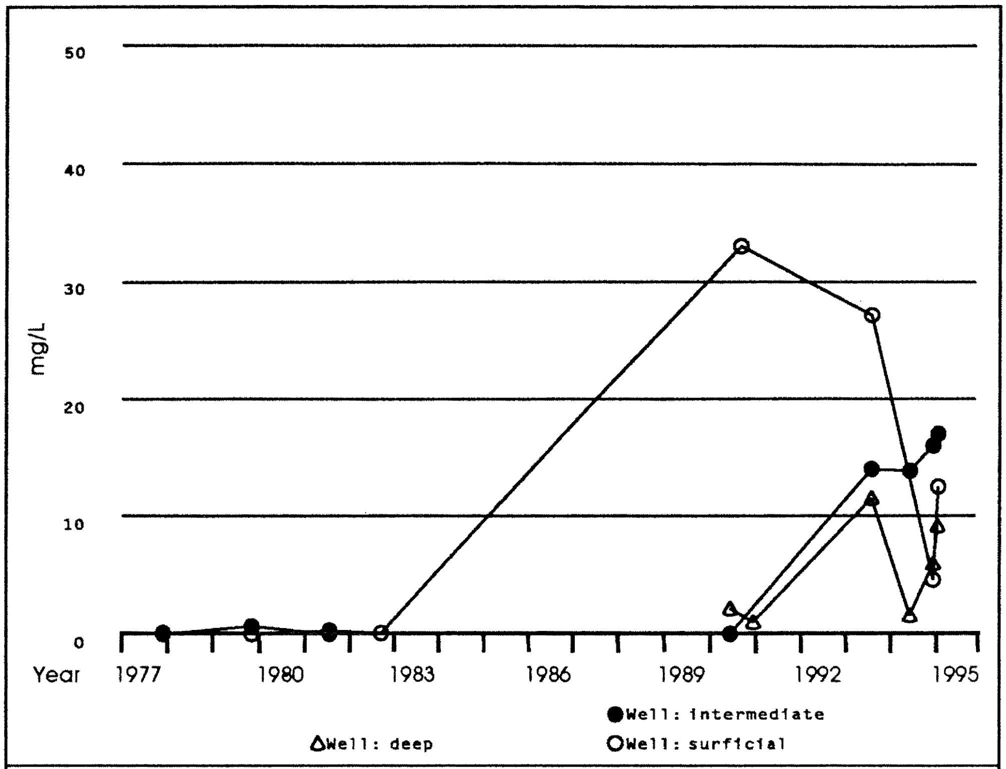
4.3.1 Well Site 8

Ammonia is the first parameter to be considered. From Figure 4.7, the first impact occurs in the surficial well between October 1982 and October 1990. The intermediate well in the nest shows the influence of leachate between October 1990 and September 1993. Determining a date range for impact on the deep well is difficult because of its late installation date (1990), but a value well above background in September 1993 suggests that it was impacted between October 1990 and September 1993. All of these wells showed a drastic increase in ammonia levels (three orders of magnitude above threshold). The surficial well appears to have experienced the most dramatic increase.

The TDS is the next parameter considered. The surficial well shows the first increase in levels between 1981 and 1982 (Fig. 4.8). This is not used as an impact date range because none of the other parameters show such an early date of impact and TDS must be reflected in other major components. It is therefore suggested that the 1982 data point is a feature of the variability of the data set. The earliest impact date for the surficial well is therefore considered to be October 1990. The date of impact for the intermediate well is difficult to determine because of the long period without sampling between August 1981 and February 1995. This date range can be narrowed by calculating the TDS by using the total ion sum. This shows a relatively low concentration of about 180 mg/L in 1990. This indicates that the plume impacted between July 1990 and February 1995. No TDS were measured for the deep well. Calculating the TDS using total ion sum (shown by "c" in Fig. 4.8) shows that impact occurred prior to the installation in 1990. The total ion sums of the deep well indicate that the deep well is the most influenced by the contaminant plume.

When arsenic is used as an indicator parameter, the deep well is the only one that suggests possible impact (Fig. 4.9). However, since there is only one measurement above the background threshold, and since the unimpacted wells displayed a considerable number of isolated peaks (Sect 4.2), little confidence can be placed on this interpretation. Should future data points fall above the threshold, then an initial impact date between January 1991 and September 1993 can be confirmed.

Potassium contamination was also considered. This location shows impact in all three well types (Fig. 4.10). The surficial well contamination occurs between August



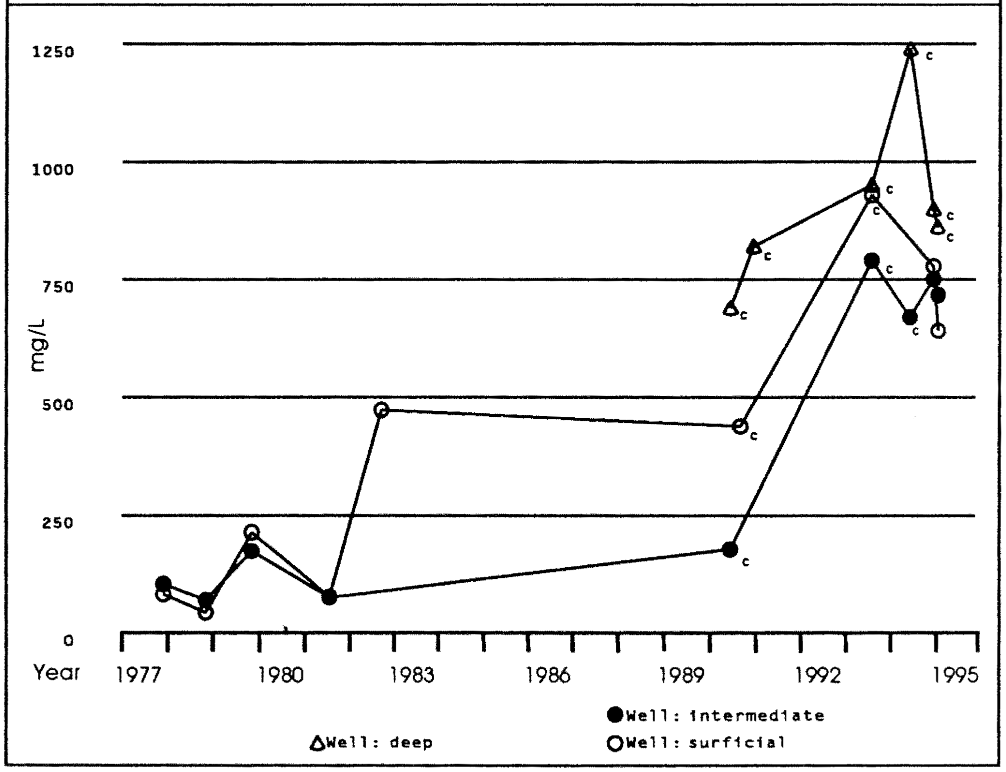


Figure 4.7 Ammonia content at well site 8.

Figure 4.8 Total dissolved solids at well site 8.

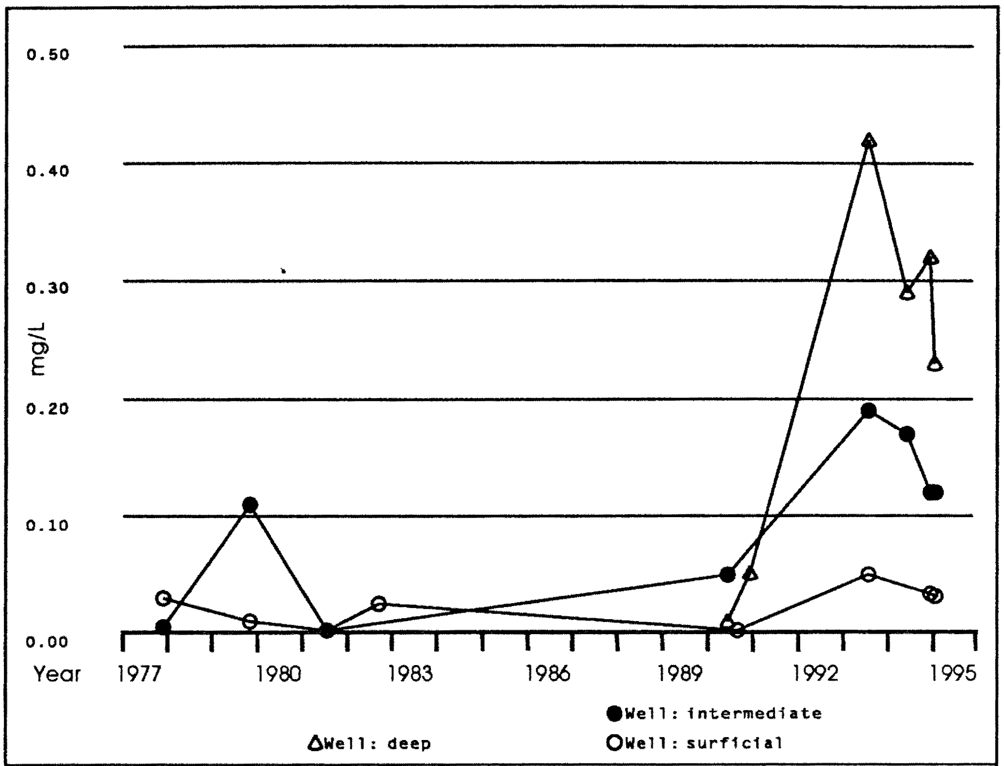
1981 and October 1990. Between October 1990 and September 1993 the intermediate well shows impact. Again, because of the late installation date of the deep well, an initial impact date is impossible to determine since the first measurement in October 1990 already fall above threshold levels.

Iron levels show a great deal of variability and are generally higher than expected background values (Fig. 4.11). This is particularly evident in the surficial well, as it consistently has had readings well above background levels since the installation date in 1977. For this reason, no estimate on an impact date is made. The intermediate well shows the initial samples to be near the threshold of impacted wells. By October 1990, the well was clearly above the background levels. The impact date is therefore calculated between August 1981 and October 1990, but is considered with caution. The deep well only has one data point above background and therefore it is not possible to distinguish confidently between real change or variability in data.

The sulphate concentrations do not appear to show any impact (Fig. 4.12). In all but one case the concentrations are well within the background threshold.

Well Depth	NH_4	TDS	As	K	Fe	SO_4
Surficial	1982-90	1981-90	NI	1981-90	Inc	NI
Intermediate	1990-93	1990-95	NI	1990-93	1981-90	NI
Deep	1990-93 (?)	pre 1990	1990-93 (?)	pre 1990	pre 1993 (?)	NI

Table 4.4 - Summary of Range of Impact Dates for Well Site 8. Inc = inconclusive, NI = no impact detected, and (?) low degree of confidence



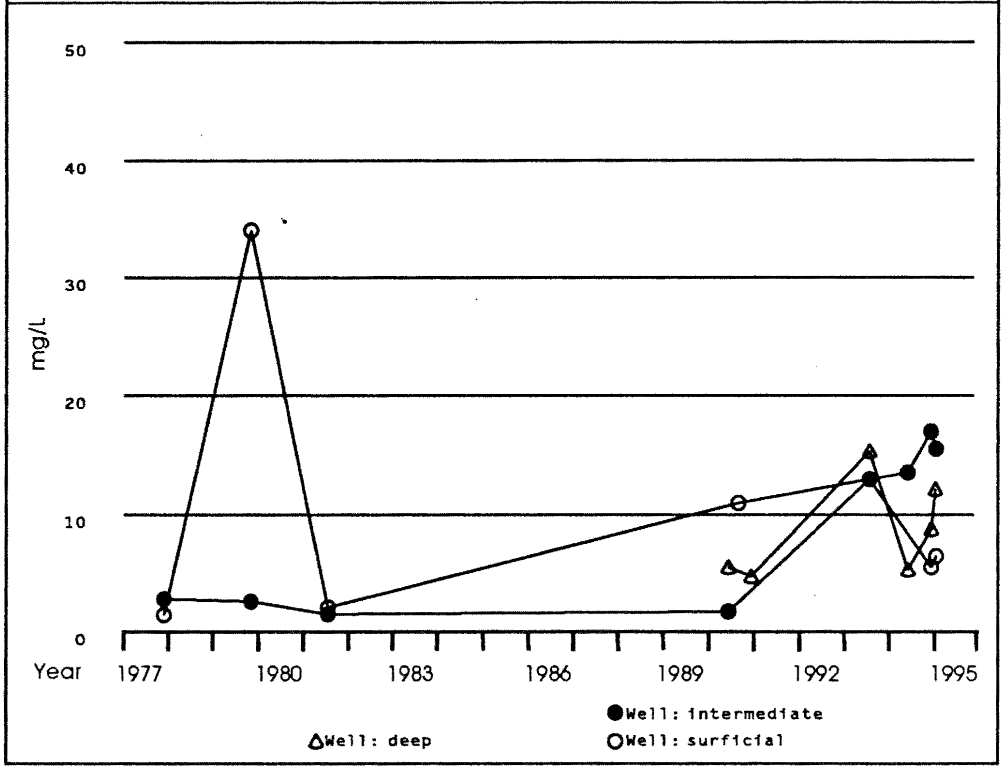
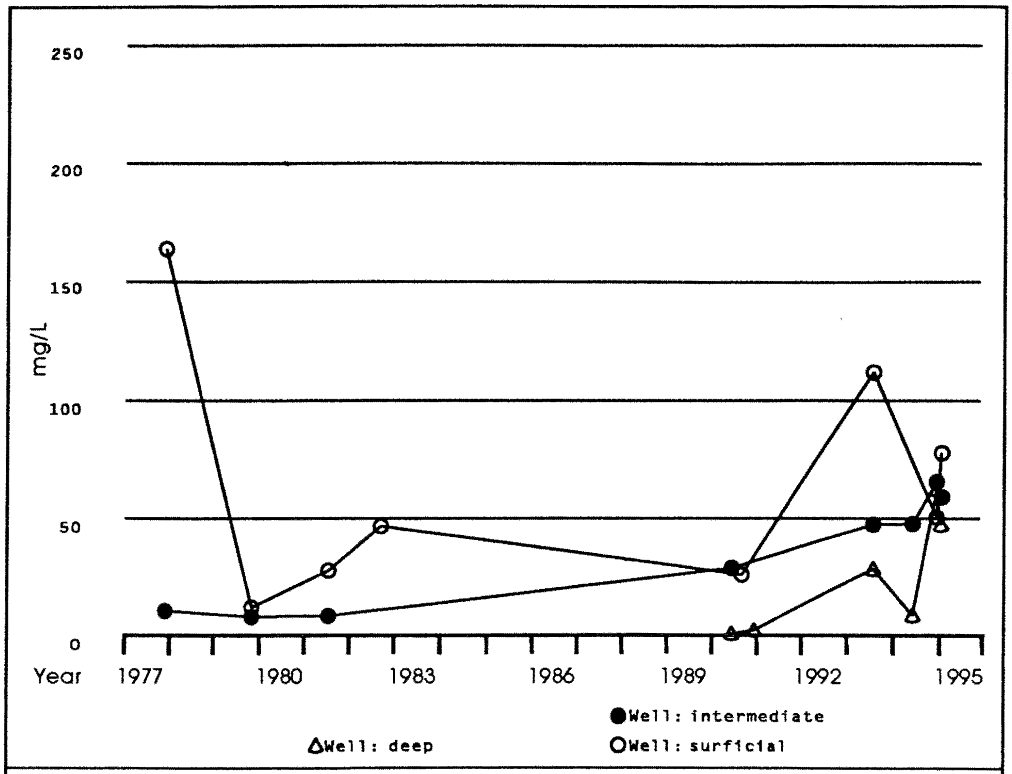


Figure 4.9 Arsenic content at well site 8.

Figure 4.10 Potassium content at well site 8.



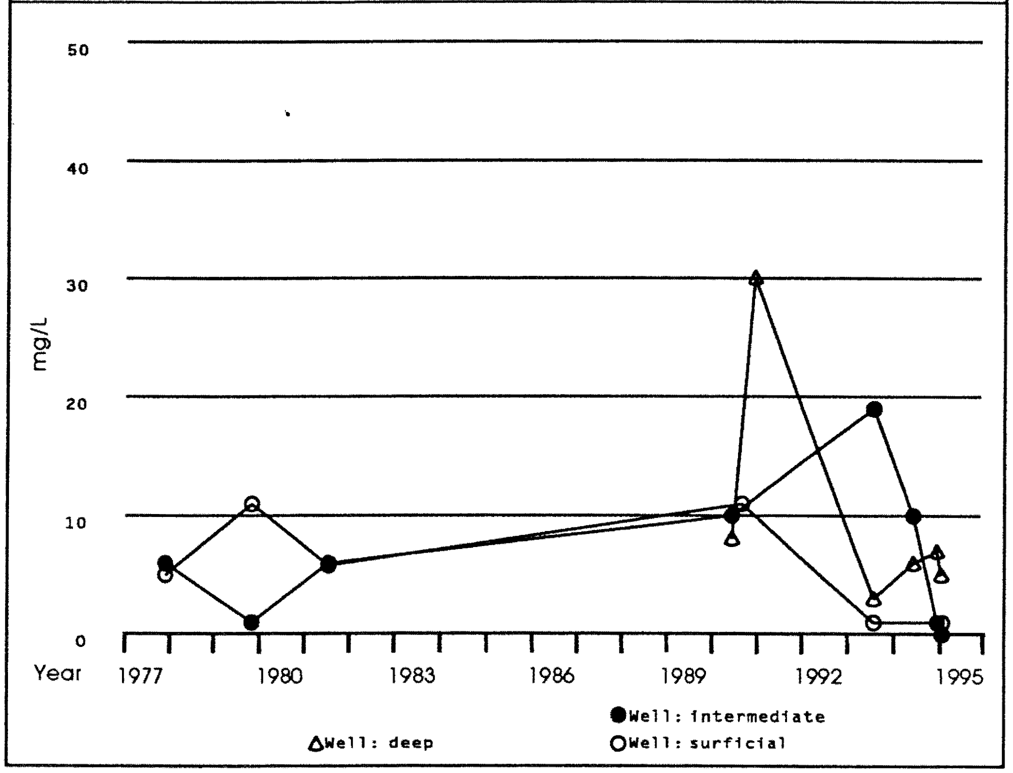


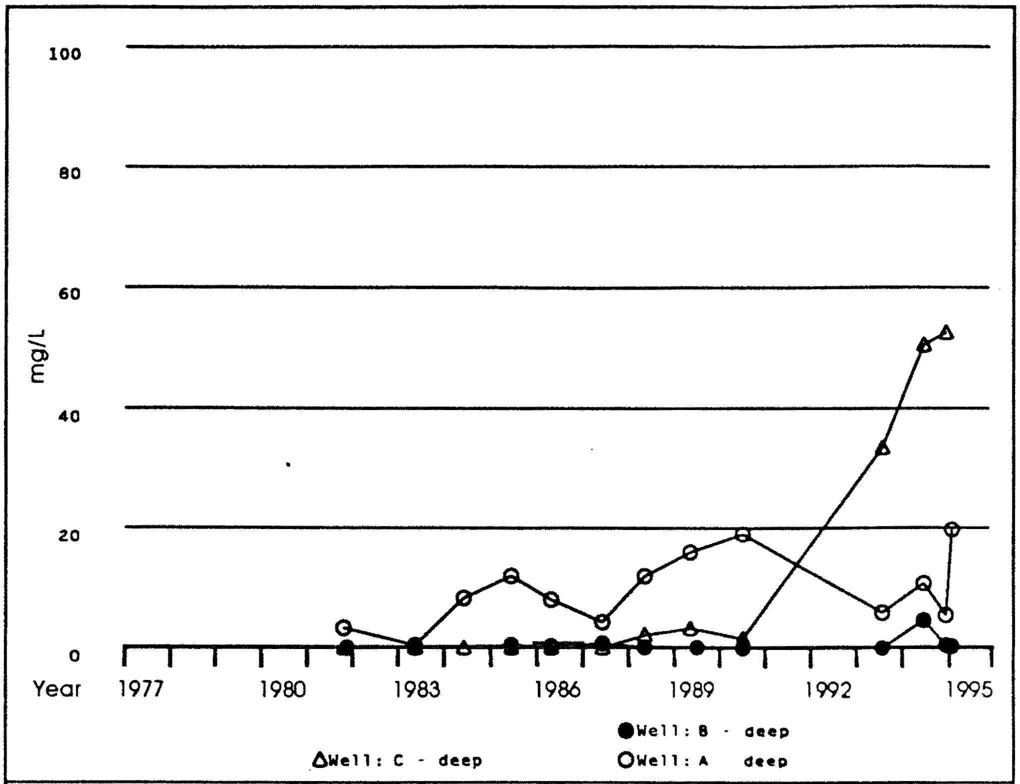
Figure 4.11 Total iron content at well site 8.

Figure 4.12 Sulphate content at well site 8.

4.3.2 Well Site C

Well C is a single deep well site. It is one well in a well series that contains three deep wells. These wells are located at various locations around the leachate treatment facilities (Fig. 2.6). Each one of these wells shows a different pattern in parameter levels through time. From Figures 4.13 through 4.15, well A levels are above the threshold levels since its installation in 1981. Well B, on the other hand, shows that the concentrations of most of the parameters are within or just above threshold, indicating that the well has not yet been impacted. Well C is the only well in this series for which an impact date can be calculated.

The ammonia levels rise above threshold levels, and are therefore impacted, between July 1987 and June 1988, but there is a drastic increase in concentrations placing it orders of magnitude above threshold between August 1990 and September 1993 (Fig. 4.13). The TDS levels from 1981 through 1983 show concentrations is close to threshold levels. The samples between 1984 and 1987 are at threshold values, in 1988 the values are well above threshold. This indicates that impact occurred between July 1987 and June 1988 (Fig. 4.14). Arsenic shows a clear impact between July 1987 and August 1990 (Fig. 4.15). As in the case of the surficial wells in well site 8, iron levels are consistently higher than the background threshold which makes it impossible to determine an initial impact date (Fig. 4.16). Clearly the impact date for potassium is between July 1990 and September 1993, as seen in Figure 4.17. The sulphate levels are consistently below impact levels (Fig. 4.18).



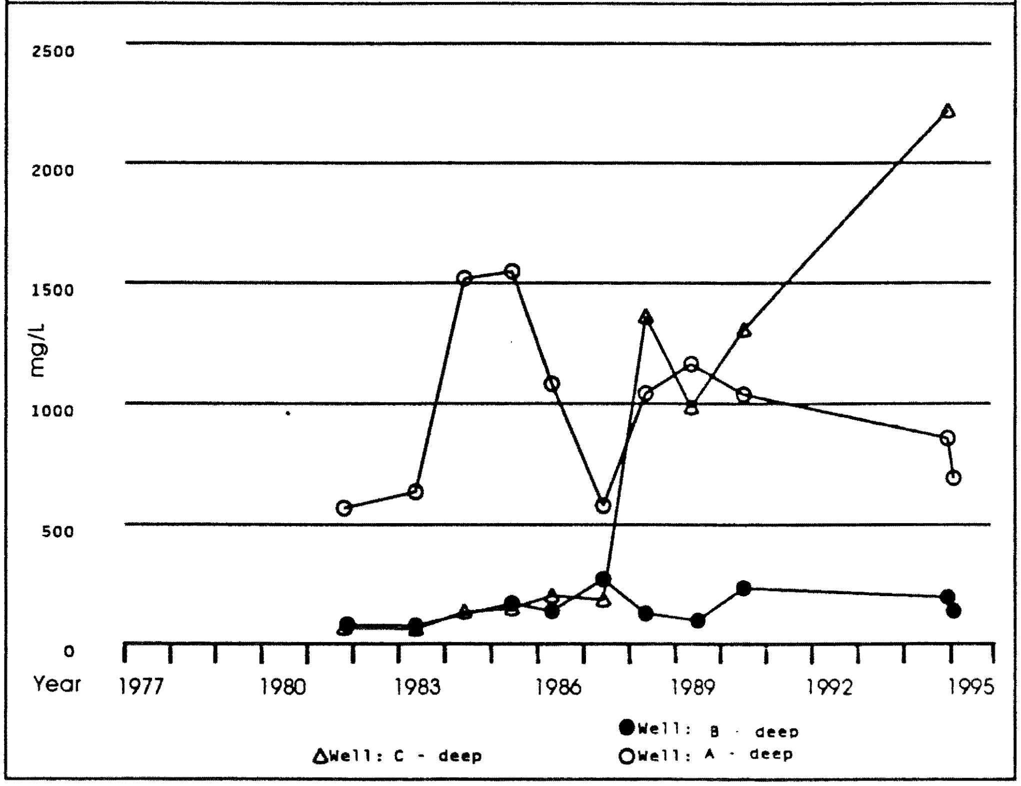
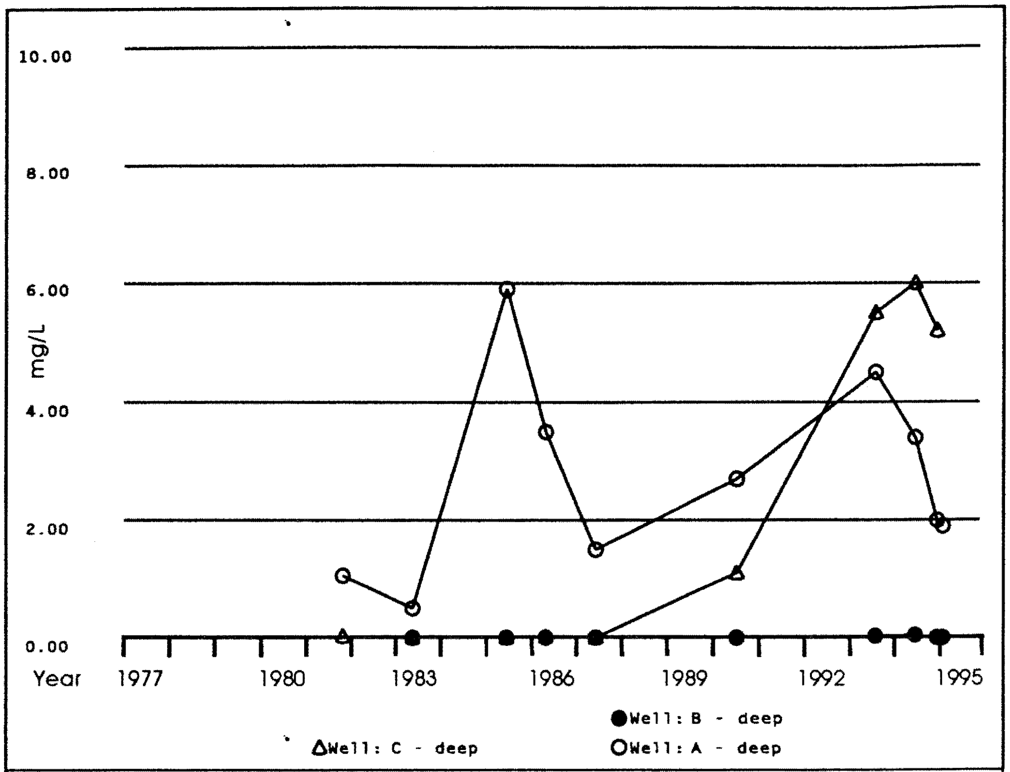


Figure 4.13 Ammonia contents at well site A,B,C.

Figure 4.14 Total Dissolved Solids at well site A,B,C.



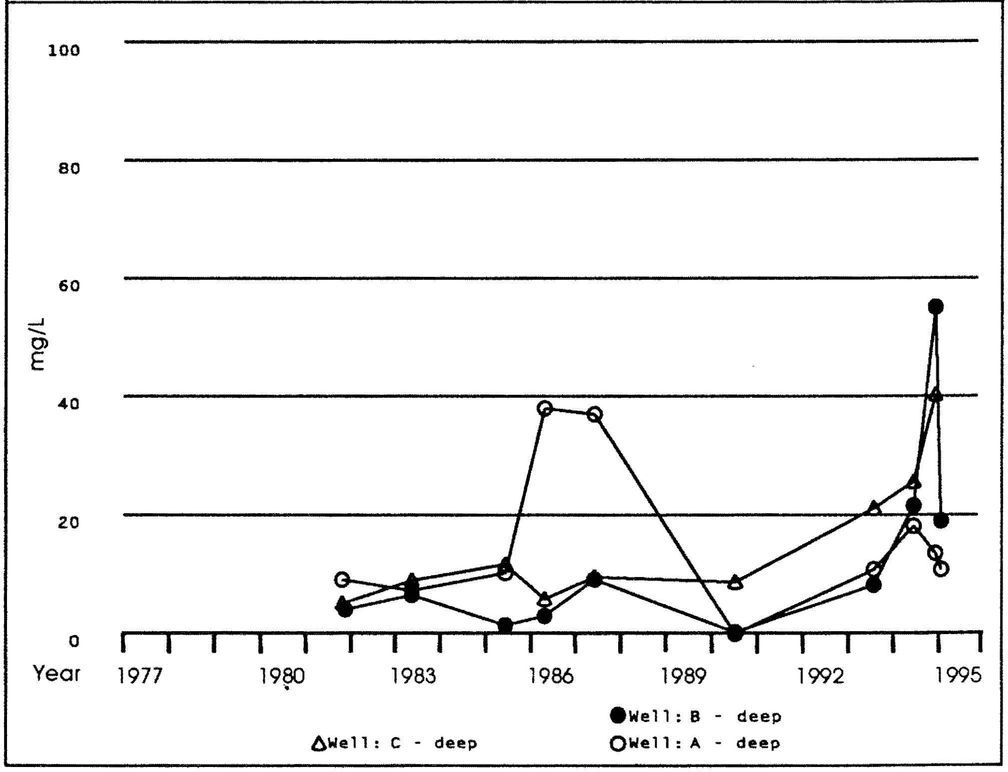
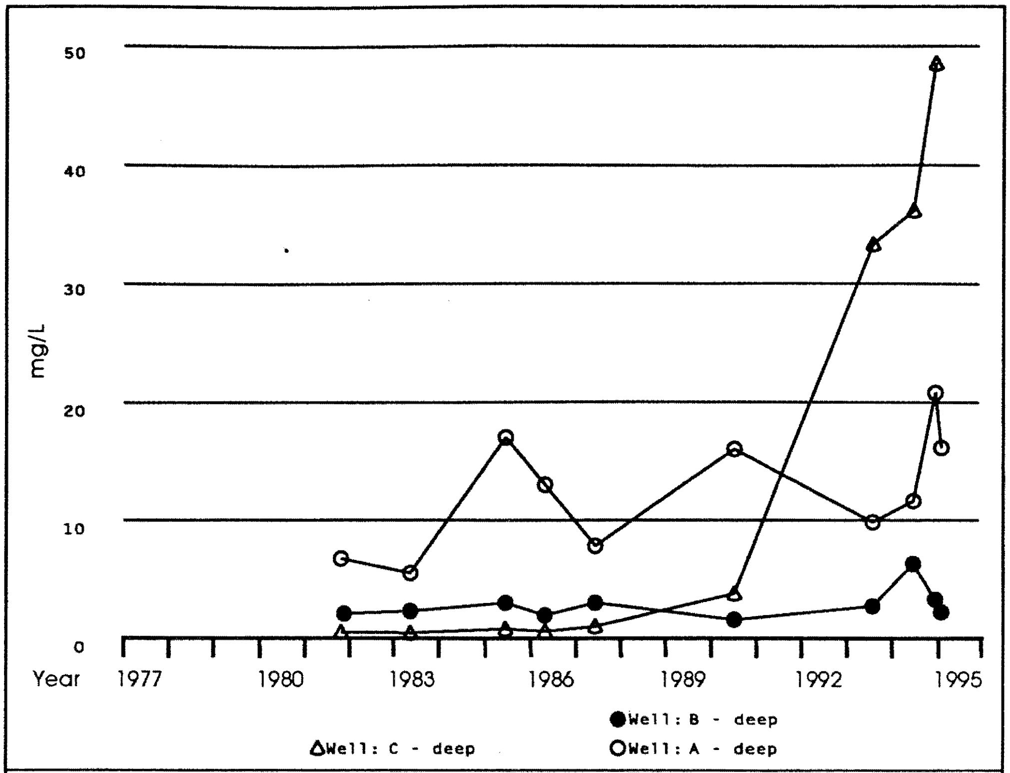


Figure 4.15 Arsenic concentrations in well sites A, B, C.

Figure 4.16 Total iron concentrations in well sites A, B, C.



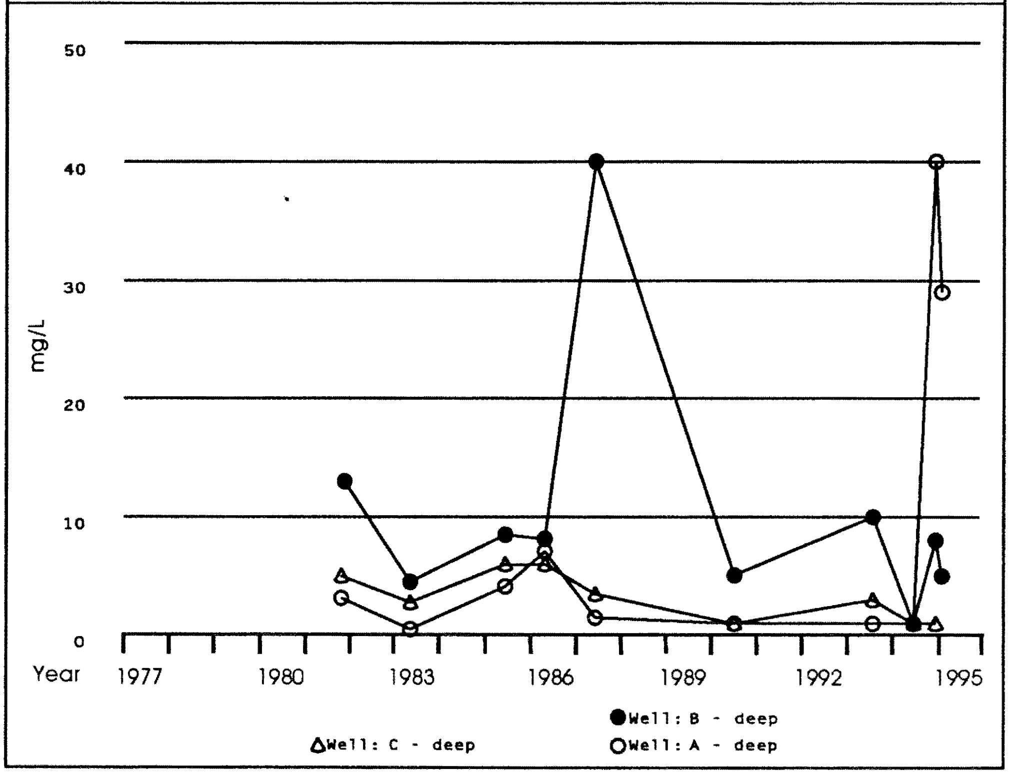


Figure 4.17 Potasium concentrations in wells A, B, C.

Figure 4.18 Sulphate concentrations in wells A, B, C.

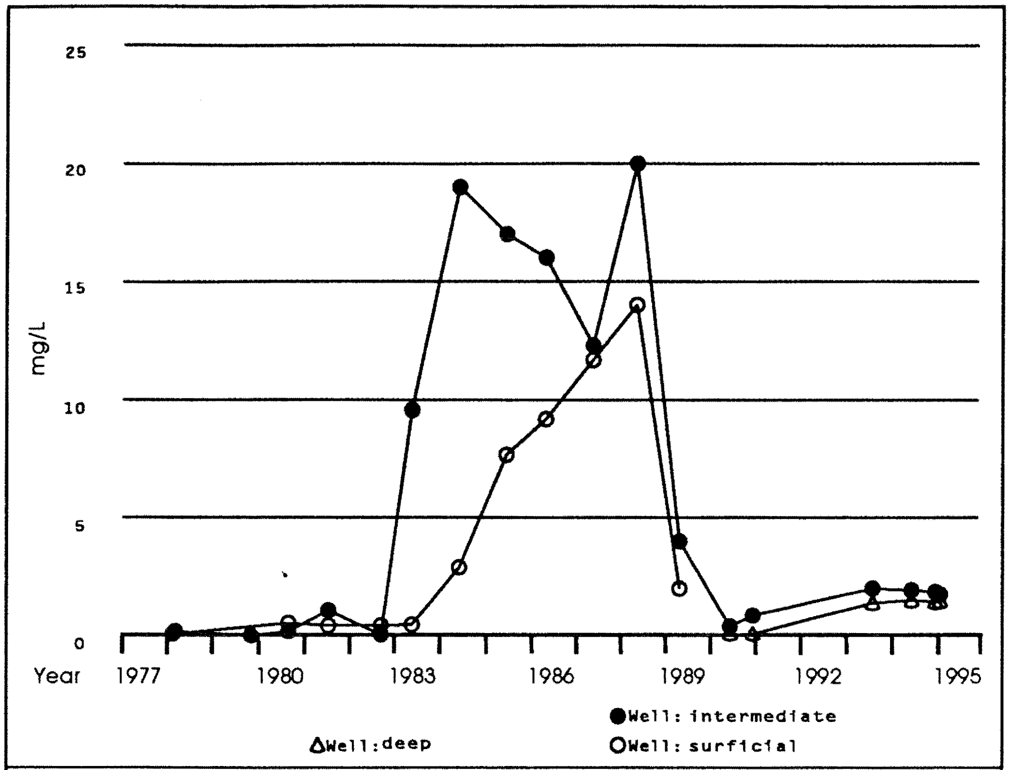
Using these observations the impact sequence is TDS and ammonia between 1987 and 1988, then arsenic between 1987 and 1990, and potassium last between 1990 and 1993.

4.4 Complex Wells

Complex wells are those that do not readily fit into the patterns of either unimpacted and impacted wells just discussed. The objective with this set of wells is to determine initial impact dates and, where possible, to find possible explanations for their complex behavior. Well site 2 and 6 fit into this category.

4.4.1 Well Site 2

Well site 2 is complex because of a peak above threshold found in the middle of the data set (1981 through 1990) for some of the parameters including ammonia, TDS, iron, and potassium (Fig. 4.19 and 4.20). After 1990, concentrations returned to background levels and then began to rise. This pattern is not found in either the sulphate or the arsenic (Fig. 4.21 and 4.22). To explain this pattern well history was considered. In 1989, Porter Dillon conducted a survey of well conditions (Porter Dillon, 1992). Well site 2 had flooded conditions. At the surficial well, the cement seal was destroyed and in the intermediate well the cement seal was destroyed and the well cap and lock were missing. It could be expected that surficial water was able to penetrate these wells for



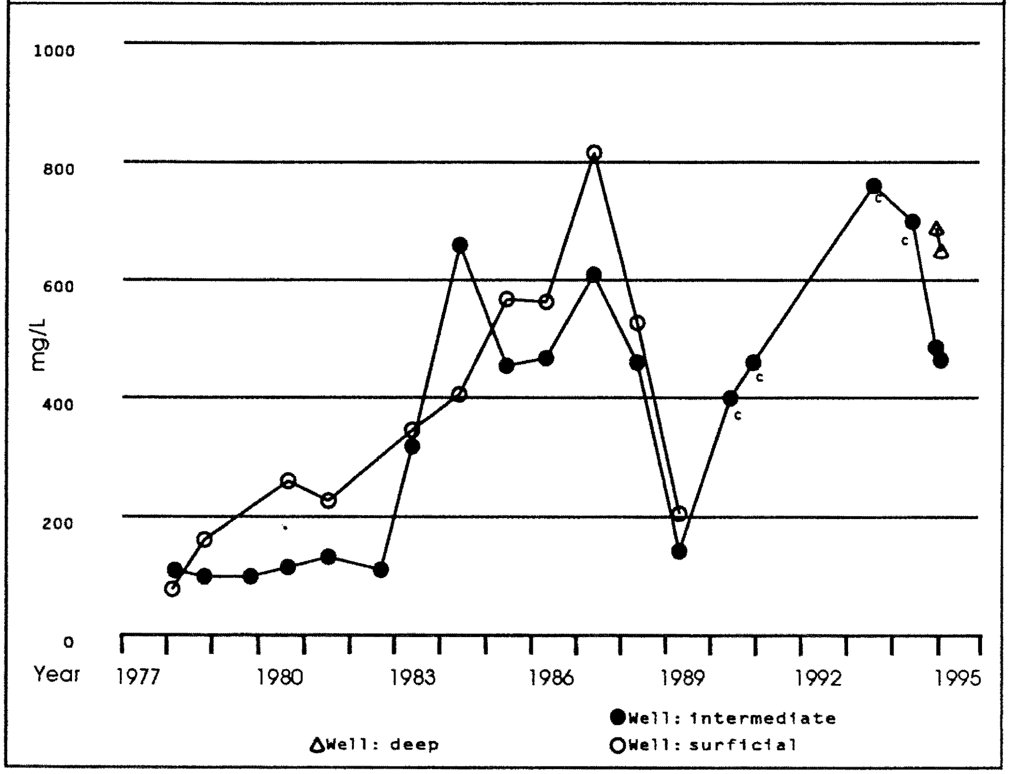
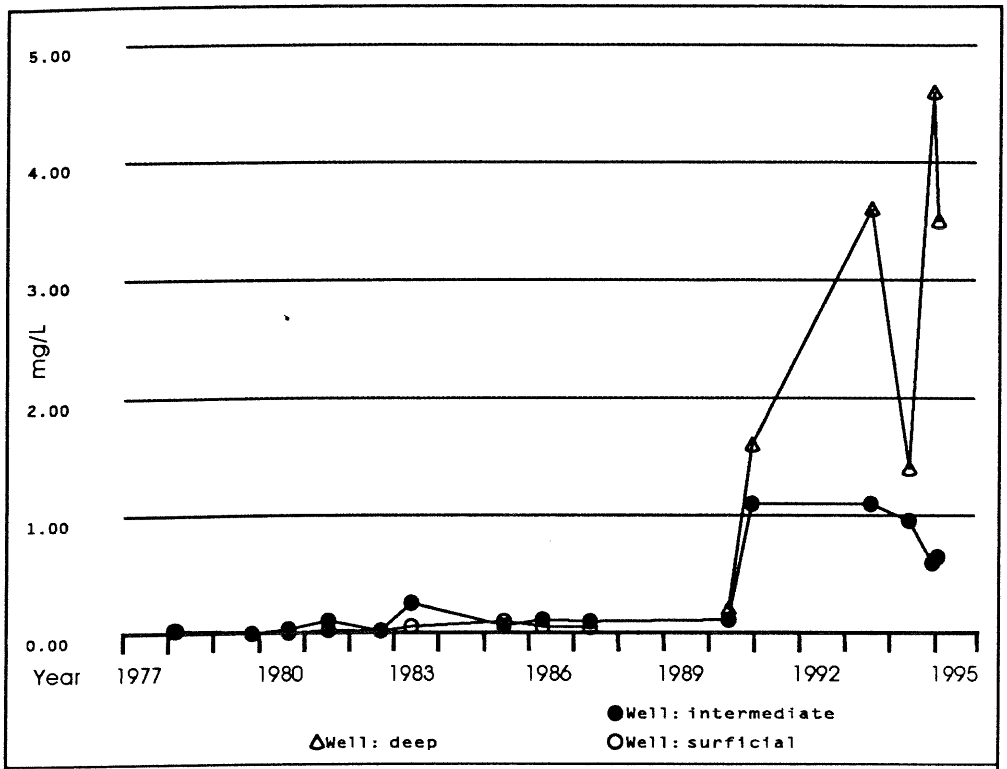


Figure 4.19 Ammonia concentrations at well site 2.

Figure 4.20 Total dissolved solids concentrations at well site 2.



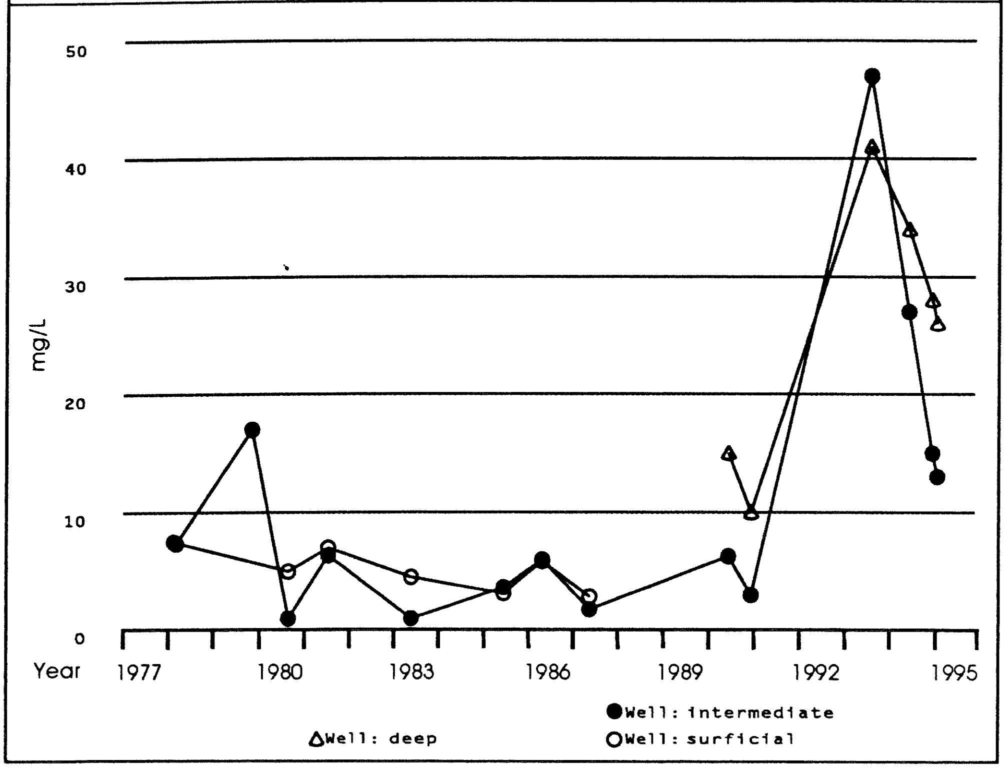


Figure 4.21 Arsenic concentrations at well site 2.

Figure 4.22 Sulphate concentrations at well site 2.

some time (Porter Dillon, 1992). Abandonment of the surficial well and intermediate well occurred in 1990. A new intermediate well replaced the unsuitable old well. The question is still unclear as to why some parameters showed this pattern while others did not. Comparing the leachate and background levels, it becomes apparent that those parameters with peaks are very high in leachate. On the other hand, arsenic and sulphate are both relatively low in the leachate (Table 3.1), but have a common source in the country rock (arsenopyrite and sulphides). I would suggest that the period of impact from October 1982 to October 1990 resulted from the penetration of the contaminated surface water to groundwater levels in these wells and do not reflect arrival of the groundwater contaminant plume. The very high levels of ammonia and TDS suggest the surface water may have originated from a leachate spring (Jacques Whitford, 1995b). The arsenic and sulphate levels remained low because the water coming from the surface did not have enough time to react with the bedrock to mobilize these components. Once the wells were fixed the surface water no longer affected the groundwater and then any change is attributable to the leachate plume. The summary of the initial impact dates is presented in Table 4.5. The placement of the well (Fig. 2.6) is not in the flow groundwater path from the landfill, suggesting that the impact was due to leachate from the treatment facilities.

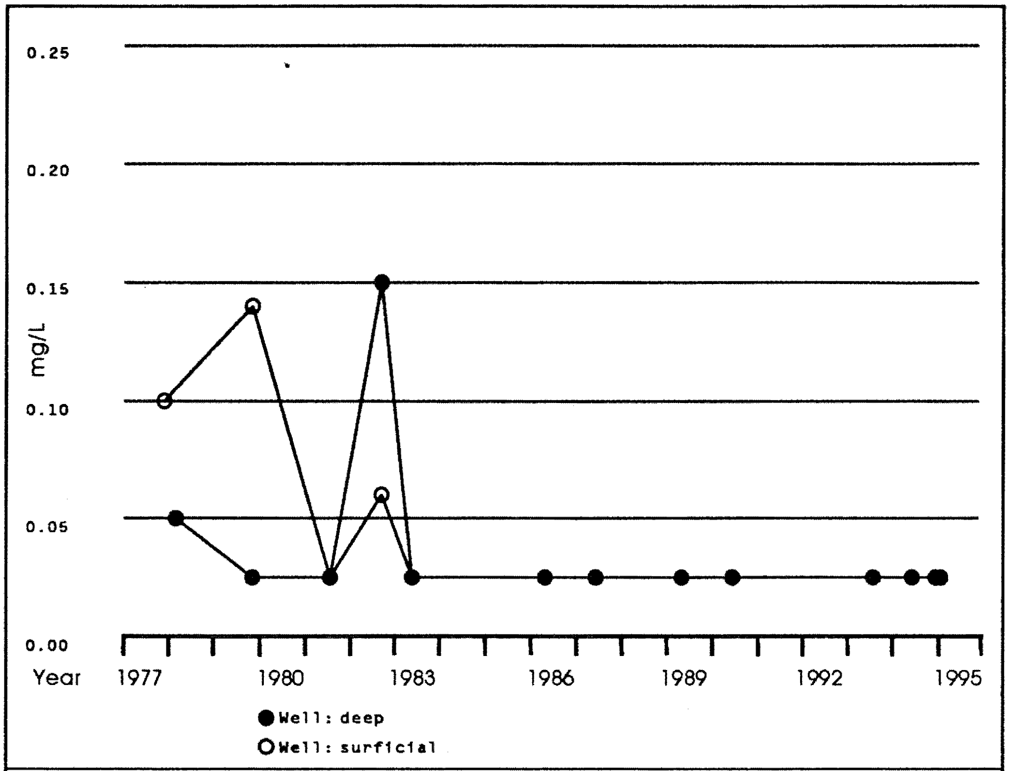
Well Depth	NH_4	TDS	As	Fe	K	SO_4
Surficial	Inc	Inc	NI (abandoned 1990)	Inc	Inc	NI (abanndoned 1990)
Intermediate	Inc	Inc	1990-91	1991-93	Inc	1991-93
Deep	1991-93	Inc	1990-91	1991-93	Inc	1991-93

Table 4.5 - Range in interpreted impact dates for well site 2. Inc = inconclusive and NI = not impacted

4.4.2 Well Site 6

Well site 6 is complex in the sense that only the deep well shows the impact, while the surficial well remained unimpacted. From Sect. 4.3.1, this is not the normal behavior. Another indication that this well does not behave as expected is the lack of ammonia in either of the wells at this site. This is problematic because ammonia generally shows the earliest impact dates. The ammonia level in well site 6 shows some early variations above threshold. From 1983, both the surficial and deep wells are within the background range, indicating that they are unimpacted (Fig. 4.23). Total dissolved solids in the surficial well are consistently below threshold levels, while the deep well is at threshold until 1995, when it reaches impacted levels. The date of impact can be narrowed after calculating the total ion sum. This indicates that the well was impacted between September 1993 and July 1994. Using arsenic as an indicator, the surficial well is consistently below threshold, but the deep well increases above the threshold value between September 1993 and July 1994 (Fig. 4.24).

Looking into well history there does not seem to have been any problems with deep well conditions, although, a cracked cement grout was found in the surficial well (Porter Dillon, 1991). Looking then to the development of the landfill, it shows the presence of a drumlin to the east of the well site in 1991 (Fig. 2.10). The emplacement area of the waste in the landfill changed location in 1992 to this area. The drumlin was removed and used for cover. The area was then filled with waste. It is suggested that



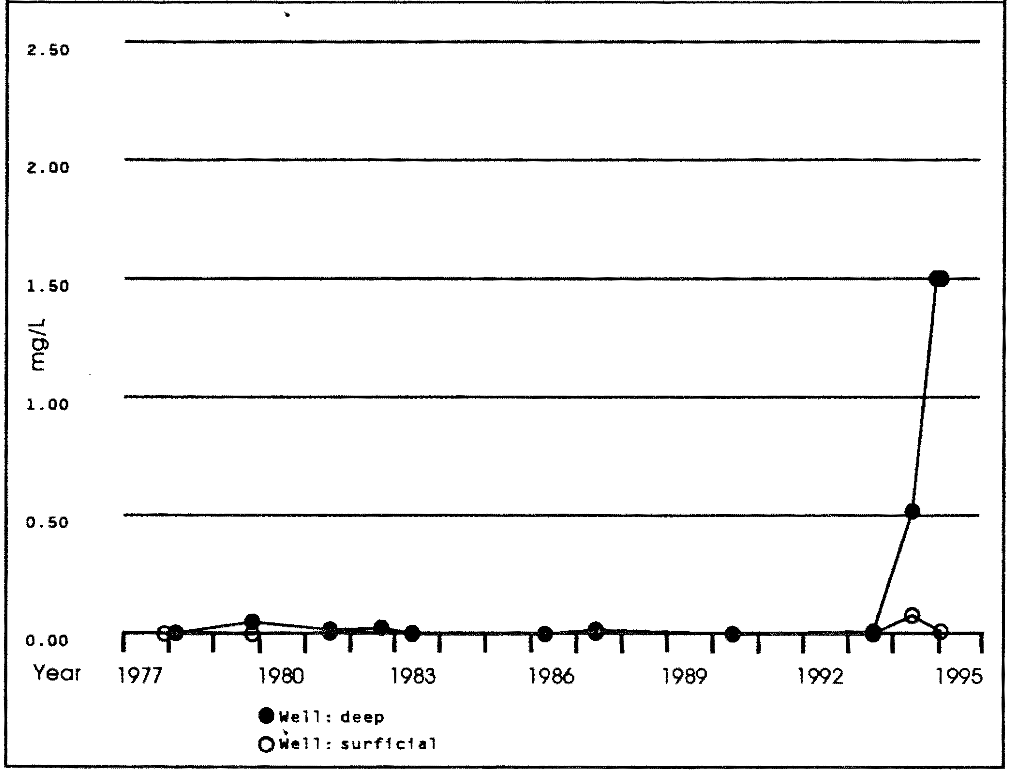


Figure 4.23 Ammonia concentrations at well site 6.

Figure 4.24 Arsenic concentrations at well site 6.

this change in topography may have influenced the flow for the surficial well (water-table in unconfined aquifers follows topography), but that this did not affect the deep bedrock water that would continue to flow toward the Sackville River.

4.5 General Well Summary

From information on the unimpacted wells some generalities can be made about each well type concerning concentrations and trends. The surficial wells generally show similar ammonia and TDS concentrations (with the exception of well site 5), but slightly higher arsenic concentrations compared to the deep wells. The intermediate well should be used with caution because of the low number of well sites. The ammonia concentration is in general an order of magnitude larger than the background (0.004 mg/L, Table 3.1), possibly due to contaminantion by surface run-off. The TDS levels are just above threshold levels (159 mg/L, Table 3.1) as defined by the earlier background concentrations. The arsenic levels are similar to those found in the other background wells (Table 3.1).

No seasonal effects, at 90% confidence, were discovered using the Kruskal-Wallis test. However such trends may be difficult to define because of the large data variability due to other causes. There are no temporal trends evident for any of the major parameters in any of the wells. Again, this could be a result of the large degree of variability masking the trends.

The impacted wells can indicate the impact sequence of both wells and parameters. It can be concluded that the shallow well is the well that shows the first sign of impact. The intermediate wells are also showing impact, but at a later date. The deep well impact date is often inconclusive because of the late date of installation of the wells. The date of impact for the different indicator parameters gives an insight on which chemical species travel fastest. Both ammonia and TDS arrive at similar times with the ammonia arriving later. Iron results do not give any quality data on their own because of the large variation in the concentration levels, however, in conjunction with other parameters it suggests impact dates. Potassium levels commonly show impact,but in general the impact dates were later than the first impacted parameters. The sulphate is consistently below threshold levels. This was interesting because there are two local sources for sulphate: leachate and sulphides in the bedrock. This indicates that low Eh conditions prevail in the groundwater.

4.6 Contaminant Velocities

The contaminant velocities have been calculated to estimate the time of arrival of the contaminant plume at the Sackville River. These estimates are general and only give an approximate time frame. More exact estimates were impossible to determine due to long time periods between sampling (Fig. 4.7), the uncertainty of the placement of the garbage at particular times (Fig. 2.11), and the changing local topography that changes flow directions.

The velocities of contaminant flow can potentially be calculated for all of the impacted wells (well sites C, 2, 6, and 8). Observing the data more closely shows that well site C and well site 2 are impossible to use.

Well site C is located on the southern side of the landfill and begins to show impact in January 1988. Following the flow lines back, the closest filling area is that used from 1986 to 1990 (Figs. 2.9 and 2.11) Because of the overlap in filling and impact it becomes difficult to determine the placement of the waste that contaminated the well and so no velocity was calculated.

Well site 2 is located to on the south side of the landfill (Fig. 2.6). Calculation of the impact from the landfill is impossible. Tracing back on the flow lines from well site 2, there in no intersection with the landfill. As suggested in Sect. 4.4.1, the impact is believed to have originated at the treatment facilities.

Well site 6 provides the first chance to determine initial impact dates for the Sackville River. Following the flow lines back, the two closest filling areas are 1990 - 1992 and 1992 - 1994. Because the filling had either not occurred or had overlapped with the impact date, these sites are not believed to have caused the impact. Therefore, the 1978 - 1985 filling area is believed to have caused the contamination. To determine the time component for the velocity, the earliest filling time of January 1978 and the earliest date of impact (July 1992, TDS) were used. The distance of contaminant travel was measured to be 325 m. From these values an estimated velocity of 22.4 m/yr was calculated. Extrapolating this velocity along the 1991 flow lines, it is estimated that the contaminant plume should begin impacting the Sackville River 10.8 yrs from the initial well impact date. This would give a first impact date on the Sackville River of June 2003. This date should be considered with caution because the local flow directions probably have changed since 1991 because of the changing local topography (due to drumlin removal and changes in garbage emplacement) (Fig. 2.10). Both of these changes would result in a shortened the flow path and would advance the date of impact.

Well site 8 is the other area that can give an estimate on the contaminant flow velocity. It is located on the west side of the landfill (Fig. 2.6). The earliest estimated plume arrival date is July 1990, using the rise in TDS levels in the surficial and deep wells. Going back along flow lines the first filling cell is 1990 to 1992. Because the well shows impact in 1990, it is reasoned that the contaminant plume did not come from this area. Continuing back along the flow line the next filling area encountered is the 1978 to 1985 area. These dates, and the impact date were used to calculate a time, while the distance along flow lines was measured in meters. These values gave an estimated flow velocity of 14.6 m/yr. The first ammonia impact occurred in the deep well in July 1990, this gave an estimated contaminant velocity of 14.6 m/yr. The potassium showed an impact in April 1992 in the intermediate well, this calculated to give an estimated velocity of 12.8 m/yr. Using these velocities to indicate the time of contaminant plume impact on the Sackville River, it was calculated to be between 6.3 to 9.5 yrs from initial impact of the well. This would indicate that the contamination from the plume would reach the river between November 1996 and September 2001.

Parameters and Location	Time Component		Distance Component (m)	Velocity (m/yr)
	First Date of Emplacement	First Date of Impact *		
Site 6C, TDS	01/78	07/92	325	22.4
Site 6C, As	01/78	04/93	325	21.3
Site 8A, TDS	01/78	07/90	182.5	14.6
Site 8A, NH_4	01/78	07/90**	182.5	14.6
Site 8B, K	01/78	07/90	182.5	12.8

Table 4.6 Summary of velocity calculations.

* Linear interpolation between unimpacted date and impacted date

** Because of the long sampling period the first impacted date was used

CHAPTER 5: RECOMMENDATIONS AND CONCLUSIONS

5.1 Critique of Highway 101 Landfill Groundwater Monitoring Program

The size, age, and complexity of the Highway 101 Landfill and its groundwater monitoring program has made this a challenging project. As a result of the shortcomings of the program and the historic database, the geochemical conclusions that could be derived from the data in this project were more limited than had been hoped. For example, lack of statistical evidence for seasonality or trends in the data are probably a function of the data quality. Some ways to improve the situation for this site and for future monitoring projects can be suggested. The main concerns are well maintenance and sampling and analytical techniques.

Well Maintenance

- Assure that all wells are built to the same clearly defined standards. Specifications for materials, depth of wells, and equipment used are a few of the main things that should be included.
- Keep a well log of site conditions whenever wells are sampled. If the conditions are less than suitable ensure that the proper people are notified so well repairs can be made in a timely manner. This record may also provide the answer for anomalous readings in samples.

- Keep track of any construction being done around the landfill site making sure to note the location and duration. This may help to explain anomalous results.

Sampling and Analytical Techniques

- Set up specific clearly defined protocols for collection methods including such things as: filtering procedures, equipment used, sampling jars, purging etc. This should give more consistent results, especially if the responsibility of sample collection changes.
- Test parameters more frequently. The more often this is done the more accurate the results for initial impact dates and velocity determinations will be.
- Set up a list of parameters to be tested and test all of these parameters consistently. This would eliminate some of the gaps in the record and allow for more accurate results.

Specify quality analysis and quality control (QA/QC) procedures. This would give an idea of the precision of the sampling and lab techniques. Specify the methods of testing the parameter by the lab, as not all procedures yield equivalent quality. Periodic duplicates, blind samples and standards should be run to establish accuracy and precision of the data. Such data would allow the incorporation of errors and uncertainties in the data analyzed and subsequent interpretation.

5.2 Possible Remediation Techniques

From the current study and geophysical work (Jacques Whitford, 1995b) there is no question that leachate is escaping from the Highway 101 landfill. The proximity of the landfill to the Sackville River, the groundwater flow directions, and the velocities makes this an immediate concern. From this thesis, the predicted arrival dates of the contaminants at the Sackville River suggest that action will have to be taken soon in order to prevent pollution of the surface water. There are a number of remediation techniques available for eliminating or reducing contamination. The suitability of the methods depends on the: geology, topography, climate, size, and cost. Remediation techniques can be divided into five main areas: source control, containment, hydrodynamic control, pump and treat, and in-situ treatment. These techniques will be reviewed briefly and evaluated with respect to the Highway 101 Landfill site.

5.2.1 Source Control

The main source control methods used are removal and surface run-off controls. Removal would include excavation of the waste and trucking it to a new location. This eliminates any future production of leachate, but does nothing for the leachate already produced. This method is not feasible for the Highway 101 Landfill because of the huge quantity of waste and the lack of a relocation site.

Surface run-off controls are used to eliminate or greatly reduce the surface water /precipitation that comes into contact with the waste. Common methods include capping with an impermeable layer and grading the surface to control the flow away from waste (ditches, berms, terraces, benches, and chutes) (EPA, 1990). Some of these, in particular, capping using natural materials (not completely impermeable) and grading, are already being used. These methods have not proven successful at the landfill and obviously need to be used in conjunction with other methods.

5.2.2 Containment

The purpose of containment is to provide a physical barrier between the unaffected groundwater and the impacted groundwater. Usage of a cover with containment is common for hazardous waste. A number of different barrier materials include: slurry, grout, sheet piling, and geotextiles. Slurry walls are barriers made of soil bentonite, cement bentonite or concrete (EPA, 1990). Placement of the slurry is in a narrow trench. This method is unsuitable for the Highway 101 Landfill because the leachate plume occurs both in surficial material and in bedrock (Sect. 4.3) and trenching into bedrock would be difficult and very expensive.

Grout is a liquid material injected through boreholes into the rock/soil under pressure. Once injected, it solidifies filling the joints, fractures and pore spaces (EPA, 1990). This is usually done in two or three layers of staggered walls (Bedient et al., 1994). The cost and uncertainty of protection limits the use of this technology (Bedient et al., 1994). This method could be used at the Highway 101 Landfill but its effectiveness is in doubt because of the highly anisotropic nature of the hydraulic conductivity of the bedrock which is bedding-plane and fracture controlled.

A sheet piling cutoff is a series of interlocking pieces of material, usually sheet metal (although wood and reinforced concrete have been used in the past), that are driven into unconsolidated material to a layer of low permeability (Bedient et al., 1994; EPA, 1990). This method is unsuitable for the present case because of the consolidated nature of the rock (EPA, 1990).

Geotextile liners are physical barriers made of varying materials such as: polyethylene, PVC, asphalt-based materials, as well as soil bentonite (Bedient et al., 1994). To ensure that the liners do not become punctured they are placed on top of fine-grained soils and are composed of several separate layers (Bedient et al., 1994). This method is best used as a precautionary measure as opposed to a remediation method.

5.2.3 Hydrodynamic Controls

Hydrodynamic control creates a hydraulic barrier between contaminated and uncontaminated water. Creation of a hydraulic barrier is with the use of injection and pumping wells to change the hydraulic gradient around the contamination plume (EPA, 1990). The change in the hydraulic gradient changes the direction that the groundwater flows, thereby isolating the plume.

The main idea in this method is the capture theory that relates the amount of water injected or pumped and the distance that the wells affect. This is mainly a function of thickness and the hydraulic gradient of the units involved (Bedient et al., 1994). The well placement, rate of pumping, and plume flow are all important factors. Usage of computer simulations is common to simulate flow and the alternatives.

This system is most suitable where there is enough permeability to support injection/extraction of water. Suitability drastically decreases if there is low hydraulic conductivity or the geology is complex (due to the heterogeneity) (Bedient et al., 1994).

This method although not ideal, may be an option for the Highway 101 Landfill site. If extraction wells are placed in the landfill and pump vigorously a cone of depression will form. This should isolate the landfill water from the surrounding uncontaminated water. The distance the plume has traveled, the velocity of the leachate plume, and the extent of reach of each well will determine if the flow reversal will reach the plume before it comes into contact with the Sackville River. This method would be expensive because of the number of wells needed to keep the leachate isolated (due to the anisotropic nature of the flow). This method would work best if an impermeable synthetic cover was added above the natural cover to reduce the infiltration into the waste pile. Also, the water produced by the extraction wells would have to be treated before discharge. This would mean that the capacity of the current treatment plant would have to be expanded.

5.2.4 Pump and Treat Systems

The pump and treatment alternative has some similarities to the hydrodynamic control because the pumping creates changes in the hydraulic gradient and the groundwater flow. Pump and treatment is the most commonly used remediation alternative, and involves intercepting the contaminated water (EPA, 1990). For this method, the wells would have to be placed down-gradient between the contaminant plume front and the Sackville River. When the contaminated water is brought to the surface, treatment can occur by physical, chemical, or biological means. Physical treatment includes: reverse osmosis, adsorption, density separation, filtration, or steam stripping (EPA, 1990). Precipitation, oxidation/reduction, ion exchange, and neutralization are the chemical treatments, while activated sludge, aerated surfaces, impoundments, anaerobic digestion, ticking filters and rotating biological discs are the biological alternatives (EPA, 1990).

With removal of the groundwater, there are two things that need consideration. The first is the fact that the water directly down-gradient from the well becomes stagnant and will not be pumped or cleaned. The second is the tailing effect. This is the phenomenon where the rate of contaminant pumped up exponentially decreases (EPA, 1990). The contaminants tend to move into the smaller pores sorbing to the matrix material. A slow release of contaminants from the geologic materials occurs through time (EPA, 1990). Pump and treatment alternatives are most successful when the geologic material is sandy, silty soils.

This method could be used at the landfill site by creating a "wall" of inceptor wells. Placement of the wells would be between the contaminant plume front and the Sackville River. The spacing of these wells is important. If the wells are not spaced closely enough, or there is not enough conductivity between wells, than the leachate will finger between the wells and reach the Sackville River. The treatment of the pumped contaminated water would have to be sufficient to reduce contaminants to acceptable levels for surface discharge

5.2.5 Best Solution for the Highway 101 Landfill

One thing that becomes clear is that none of the remediation methods are very suitable for the Highway 101 Landfill site because the contamination is at all depths, including the deep bedrock (Sect. 4.3), and the anisotropic nature of the groundwater flow. The solutions that show the most potential are the hydrodynamic control and the pump and treat methods. The hydrodynamic control, if used with an impermeable geotexile cover, should keep most of the leachate being produced within the landfill. There is doubt that the extraction wells, in the hydrodynamic method, would have enough extent, to reverse the flow path at the contaminant front. Even if there was enough extent, there is the question that the hydraulic gradient and hence the flow would not be reversed before the contaminant plume reached the Sackville River.

The pump and treat inceptor method could be used to remove the contaminated water before it reached the Sackville River. The anisotropic nature of the groundwater flow limits its effectiveness. For the maximum protection of the surface waters, it is suggested that both of these methods be used simultaneously. It is imperative that a decision on the remediation method be made as soon as possible, as the longer the time before anything is done the closer the leachate plume is to the Sackville River. This will limit the number of effective remediation techniques available. Clearly the prevention of these problems through effective leachate management would have been the easiest and best way to deal with the contamination. Fixing the problem in the future will be both expensive and difficult.

5.3 Conclusions

Several conclusions arise from this study and will be summarized. The depth at which the contaminant plume travels is important, especially in considering remediation techniques. It was found that the contamination plume is evident at all three well depths (surficial, intermediate, and deep). The contamination plume is first evident in the surficial wells, followed by those intermediate depth in shallow bedrock. The timing of the impact on the deep well is unclear because of the late installation dates. From the parameters tested, an impact sequence was determined. The first parameters showing impact were the TDS and ammonia. This is useful in providing an early warning that the main body of the contaminant plume will soon follow. Important information was also found using the unimpacted wells. Statistical tests on these could not detect seasonal or temporal trends; probably because of the high uncertainties of the data values due to sampling and analytical problems. The main indicator parameters, except for ammonia, showed background levels within the threshold of the previously defined background range. The ammonia showed concentrations that were generally at or above the threshold limit.

Estimates on the flow velocity of the contaminant plume are another important concern, especially when considering the timing of future remediation plans. The estimated flow velocities range from 11.4 m/yr to 22.4 m/yr (Porter Dillon, 1992). These estimates are reasonable considering the calculated range in the groundwater flow velocity (2.17 to 21.7 m/yr). The rate of flow of the contaminants cannot be higher than the velocity of the groundwater, because the contaminants are transported by the groundwater and are generally slowed because of physical, chemical, and biological processes. However, the presence of highly fractured zones in the bedrock, which strike semi-parallel to flow lines, may accelerate flow in some directions.

One of the outcomes of this project is that the hydrogeochemical and geophysical methods of determining contamination show different locations of the contaminant front.

In general, the hydrogeochemical method gives a much larger plume extent than the geophysical means. Some of the plumes detected by the geophysical terrain conductivities were not picked up by the hydrogeochemistry, probably because of the lack of wells in the immediate area. One advantage the hydrogeochemical method has over the geophysical method is that contaminant flow velocity estimates can be calculated. Because the geophysical terrain conductivity was only measured once, in 1995, it is impossible to estimate of the rate of plume movement.

Since the contaminant plume occurs in an unconfined to semi-confined aquifer, remediation should occur before the contamination plume reaches the Sackville River. Possible remediation methods have been reviewed, but none of the methods are very suited to the Highway 101 Landfill site. The reason is that the contamination plume travels at all depths, including the deep bedrock (Sect. 4.3). Another problem arises from the anisotropic nature of the hydraulic conductivity in the rocks. The solutions that require a closer look include: hydrodynamic control of the groundwater with an added impermeable cap and inceptor wells. Both of these methods involve pumping contaminated groundwater. This water would require treatment. From the earlier consultant studies, it is obvious that the current leachate treatment plant cannot deal with the present load (Jacques Whitford, 1995). Therefore, construction of a larger treatment facility would be required. The methods for remediation will be expensive and do not guarantee results. Clearly the early prevention of these problems would have been most cost efficient, but that window of opportunity has long since passed.

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Appendix A - Well Summary

A total of 23 wells have been defined.

Well Number	Well* Designation	1st Sample Date	Last Sample Date	Number of Active Samples
1-A	Surficial Well	03/01/78	02/01/95	16
1-C	Deep Well	03/11/78	02/01/95	17
2-A	Surficial Well	02/16/78	06/01/89	12
2-b	Intermediate Well	03/11/78	03/09/95	19
2-C	Deep Well	07/25/90	03/13/95	6
3-A	Surficial Well	03/01/78	03/07/95	19
3-B	Intermediate Well	03/11/78	09/15/93	16
3-C	Deep Well	07/25/90	03/07/95	6
4-A	Surficial Well	03/01/78	09/13/93	13
4-C	Deep Well	03/01/78	02/01/95	16
5-A	Surficial Well	02/16/78	02/01/95	15
5-B	Intermediate Wel 1	04/11/78	06/01/89	10
5-C	Deep Well	07/11/90	02/01/95	7
6-A	Surficial Well	02/16/78	03/15/95	11
6-C	Deep Well	02/01/78	03/15/95	16
7-A	Surficial Well	11/28/77	03/12/95	9
7-C	Intermediate Well	11/28/77	03/13/95	9
8-A	Deep Well	07/25/90	03/03/95	6
8-B	Surficial Well	11/28/77	03/13/95	15
8-C	Deep Well	03/01/78	03/13/95	16
A	Deep Well	11/10/81	03/16/95	13
B	Deep Well	12/08/81	03/16/95	13
C	Deep Well	11/10/81	02/01/95	12