Management, Environmental and Energy Considerations for Woodwaste

by

Jason Garatti

A Thesis
Submitted to the Faculty of Graduate Studies
In Partial Fulfillment of the Requirements
for the Degree of

Master of Science in Environmental Engineering

Faculty of Engineering
Lakehead University
Thunder Bay, Ontario
August 2009

Abstract

Manufacturing operations that process raw wood, such as sawmills and pulp and paper mills, generate wood residue, such as woodwaste, sawdust, shavings, wood chips and off-cuts, also known as woodwaste. The decomposition of woodwaste at these landfill sites is a slow process that results in the generation of leachate. Woodwaste leachate can impact receiving groundwater and surface water resources, as such, the monitoring of water quality downgradient of these waste landfill sites is important. Although woodwaste is generally considered a waste, there is the potential for the recovery and utilization of woodwaste as an alternative energy resource. This research is a study of the generation, management, environmental effects and monitoring, and energy capabilities of woodwaste with a focus on a particular woodwaste site in northwestern Ontario.

The study site consists of a woodwaste pile of approximately 156,000 m^3 and is bordered by a roadway, forested area, and a Lake, located 260 m west and downgradient of the woodwaste pile. The subsurface geology at the study site consists of an upper fine to medium grained sand, underlain by a silt to silty sand, followed by fine to medium grained sand with trace silt to the depth investigated. The water levels measured in monitoring wells at the study site suggest a southwest slope of the potentiometric surface toward the Lake with a gradient of approximately 0.02 m/m. Estimated flow rates range from 50 to 630 m/year.

The woodwaste site design and operations generally meet with standard Ontario Ministry of the Environment (MOE) guidelines with no major deficiencies. In the event the woodwaste pile is not removed for energy purposes, consideration could be made for covering the woodwaste pile with a multilayer sealing system consisting of a geosynthetic clay liner with a geomembrane to minimize water infiltration and the generation of leachate.

Samples of soil and woodwaste upgradient and downgradient from the pile were collected for analysis. The woodwaste is characterized by elevated concentrations of total carbon, inorganic carbon and organic carbon, aluminum, barium, calcium, iron, magnesium, manganese, molybdenum, nickel, phosphorus, uranium and vanadium relative to the soil samples. Groundwater and surface water sampling and laboratory analyses have also been completed twice annually since 2003. Groundwater quality is assessed using the Reasonable Use Guideline. Exceedances for total dissolved solids, colour, dissolved organic carbon, aluminum, arsenic, barium, chromium, iron and manganese have been observed. To enhance the environmental monitoring program and provide a second level of protection, a proposed trigger program was developed for monitoring water quality downgradient of the site.

Visual MODFLOW and MT3D were used to simulate groundwater flow and the fate and transport of iron, manganese, barium and arsenic (indicator parameters) at the site. Simulated concentrations at source monitoring well and downgradient well locations compare well with average observed concentrations measured from 2003 to 2008. Simulated model results for capped woodwaste conditions indicate an estimated 73% decrease in the indicator parameters modeled. Following woodwaste removal for energy purposes, concentrations of all indicator parameters at source and downgradient wells were calculated to be below the applicable MOE criteria in eight years.

Test pits were excavated across the woodwaste pile to assess material composition. Woodwaste samples from the test pits were submitted for laboratory analysis of moisture and energy content. The material in the woodwaste pile appears to be relatively consistent and is potentially suitable for use in energy recovery initiatives at the mill site. Moisture and energy content were consistent with vendor supplied material. The relative energy content of this usable woodwaste would be approximately 7.6 billion BTUs, which is equal to $2.2 \times 10^{+6}$ kilowatt-hour. A pilot study could be designed to determine the operational requirements, costs and limitations to mine, transport, handle, process and combust the material.

Acknowledgements

This work would not have been possible without the support and encouragement of my advisor, Dr. Bruce Kjartanson. Under difficult time constraints, Dr. Kjartanson went above and beyond the call of duty to provide technical support and guidance. I would also like to thank Dr. Eltayeb Mohamedelhassan and Dr. Charles Xu for providing technical reviews of my thesis prior to final submission.

I would like to thank the staff at True Grit Consulting for their support and patience. Most importantly, I would like to thank Jen, Tyler, Lucas and soon to come Zoe for your support and patience during the preparation of this thesis.

Table of Contents

List of Appendices

List of Tables

List of Figures

1.0 Introduction

1.1 Background

Manufacturing operations that process raw wood, such as sawmills and pulp and paper mills, generate wood residue, such as woodwaste, sawdust, shavings, wood chips and off-cuts, also known as woodwaste (MOE, 1991). In Ontario, woodwaste is regulated under the Environmental Protection Act (EPA), and is designated as a waste by Ontario Regulation 347. Woodwaste is disposed of at private and municipal landfill sites. The design and operations of these landfill sites are governed by the EPA and licensed by the Ontario Ministry of the Environment (MOE).

The decomposition of woodwaste at these landfill sites is a slow process that results in the generation of leachate. When the woodwaste is saturated, natural compounds of the wood, such as resin acids, lignins, terpenes, fatty acids and tannins, dissolve into the water at concentrations above background concentrations. Woodwaste leachate can impact receiving groundwater and surface water resources, as such, the monitoring of water quality downgradient of these waste landfill sites is important. The proper closure of these sites (i.e. low permeability capping) is also important to reduce the generation of leachate from the woodwaste during and following landfill operations (i.e. progressive landfill capping). Although woodwaste is generally considered a waste, there is the potential for the recovery and utilization of woodwaste as an alternative energy resource (hog fuel) for use in industrial combustion systems (i.e. boilers, cogeneration facilities, etc).

In northwestern Ontario and other provinces in Canada, large volumes of woodwaste are produced in the forest products industry which can have an adverse impact on the environment; therefore, the management and monitoring of these sites are considered important issues for the industry.

This research is on the generation, management, environmental effects and monitoring, and energy capabilities of woodwaste with a focus on a particular woodwaste site in northwestern Ontario. Based on a review of available literature, there appears to be a lack of detailed site studies reported on this subject.

1.2 Research Objectives

The objectives of this research are to:

1. Assess current conditions (environmental monitoring and design) of the northwestern Ontario woodwaste study site relative to Ontario Ministry of the Environment Guidelines. Recommend improvements/changes to the current groundwater and surface water quality monitoring program (well network design, trigger and contingency program) and to the design of the woodwaste site (pile configuration, final cover materials) to improve environmental conditions at the site.

2. Develop and apply groundwater models to assess the fate and transport of contaminants released from the northwestern Ontario woodwaste study site, including downgradient water quality under capped and uncapped conditions, downgradient water quality following woodwaste removal for energy purposes. Assess the relationship between the characteristics of the woodwaste and groundwater quality and assess the sensitivity of the model to potential variation in flow and transport parameters, such as dispersivity and sorption.

3. Assess the feasibility of using woodwaste for bio-energy and compare energy content results to other sources of bio-energy historically used at the study site.

1.3 Organization of Thesis

This thesis is organized as follows. Chapter 2 provides a literature review pertaining to the study. The characterization of the study site is provided in Chapter 3. Groundwater modeling of the woodwaste study site is provided in Chapter 4. Chapter 5 provides the bio-energy feasibility study completed at the site. Chapters 6, 7 and 8 provides an overall discussion of the research, conclusions and recommendations. The appendices contain all the data and details of the site and modeling studies.

2.0 Literature Review

The following sections provide a literature review of topics related to the generation, management, environmental effects and monitoring, and energy potential of woodwaste.

2.1 Management of Woodwaste

2.1.1 Generation of Woodwaste

In northwestern Ontario, large volumes of woodwaste are produced in the forest products industry. Survey data from the Forest Products Association of Canada indicate that woodwaste is the largest overall waste generated at forest products facilities (Maltby, 2006).

In the prime of the forest products industry in Ontario, the MOE estimated that approximately 3 million bone dry (BD) tonnes of woodwaste were generated in Ontario in 1988 (MOE, 1991). Current production levels in Canada have decreased as the result of market conditions; therefore, the waste generated on an annual basis would likely be lower than 1991 MOE projections.

The primary sources of the woodwaste are as follows (MOE, 1991):

- 30% generated by the wood container industry,
- 60% generated by the forest products industry, secondary manufacturers and demolition/construction industry, and
- 10% generated by municipalities, conservation areas, provincial parks and commercial landscaping.

The MOE also estimated that approximately 50% of wood residual is disposed of as waste and that the remaining 50% is utilized for mainly agricultural/landscaping or bio-energy purposes in Ontario (MOE, 1991).

In northwestern Ontario, woodwaste is typically disposed of at licensed private and municipal waste disposal sites; however, there are also several smaller scale woodwaste piles associated with historical portable sawmills that are not licensed or regulated (MOE, 1991).

2.1.2 Regulatory Guidelines for Woodwaste Sites

Woodwaste is designated as a waste by Ontario Regulation 347 (General-Waste Management), under the *Environmental Protection Act* (EPA). Under the EPA, woodwaste sites that have total volumes of <40,000 m^3 are regulated under Ontario Regulation 347 and sites that have total volumes >40,000 m^3 are regulated under Ontario Regulation 232 (Landfill Sites).

Ontario Regulation 347 defines "woodwaste" as a waste:

(a) that is wood or a wood product, including tree trunks, tree branches, leaves and brush;

(b) that is not contaminated with chromated copper arsenate, ammoniacal copper arsenate, pentachlorophenol or creosote; and,

(c) from which easily removable hardware, fittings and attachments, unless they are predominantly wood or cellulose, have been removed.

The MOE regulates hundreds of woodwaste landfilll sites in Ontario. In addition, the MOE estimates that there are hundreds of abandoned woodwaste sites, mainly associated with the historical portable sawmills.

Landfill sites in Ontario are regulated by a site specific Certificate of Approval (CofA) which, at a minimum, outlines the location and size of the site, as well as the approved wastes to be landfilled. The MOE CofA for a site may also include information such as the monitoring and reporting requirements for the site, as well as general maintenance and operation requirements.

Woodwaste leachate generated from larger volume disposal sites can have an adverse impact on downgradient groundwater and surface water resources, as such, the management and environmental monitoring of these sites are important. In northwestern Ontario, woodwaste sites typically do not have engineered containment systems such as low permeability liners or leachate collection systems typically due to their isolated locations and historical landfilling practises. Natural attenuation processes are relied on for environmental protection in Ontario with final cover material consisting of a low permeability material (i.e. clay).

Where applicable, the MOE also regulates the quality of both groundwater and surface waters downgradient of these landfill sites, as outlined below.

- Groundwater Quality Criteria:
    - Reasonable Use Guidelines (RUG) are used to regulate groundwater quality downgradient of woodwaste sites in Ontario, allowing off-site impacts within established guidelines based on the reasonable use of groundwater, which is typically assumed to be drinking water and are calculated based on the Ontario Drinking Water Standards (ODWS) made under Ontario Regulation 169 (Safe Drinking Water Act). ODWS are established guidelines for drinking water in Ontario. When based on the ODWS, the guideline allows for increases of up to 25 or 50 percent of the difference between background concentrations and the ODWS for health-related and non-health-related parameters, respectively.
- Surface Water Quality Criteria:
    - Provincial Water Quality Objectives (PWQO), established by the MOE, are criteria established for the protection of aquatic life and recreational uses of surface water. PWQO criteria have also been applied to

groundwater quality where impacted groundwater from a landfill site is likely to discharge to a surface water body.

2.1.3 Woodwaste Landfill Design and Operations

New woodwaste disposal sites in Ontario are required to meet typical MOE design criteria which are provided in Ontario Regulation 232 (Landfill Sites); however, many of the historical sites do not meet these criteria.

When applying for a new or expanded landfill site, Ontario Regulation 232 requires that a design, operations and maintenance plan be completed for the site which includes the following information prior to approval and licensing:

- Site Conditions (geology, hydrogeology, separation distances (100 m buffer zone in all directions)).

- Design Concept (i.e. waste type, landfill waste limits, side (4H:1V) and crown (5%) slopes, buffer zones (100m), signage, fencing, general maintenance and operations, service life, end use).

- Existing and Proposed Site Infrastructure (i.e. signage, roadways, buildings, etc).

- Waste Processing, Placement and Sequencing (i.e. working areas, compaction, interim and final cover, equipment, final waste elevation, etc).

- Safety, Security and Health (i.e. training, rules/site regulations, security, inspection, fire control, traffic, operation schedule, emergency response plan).

- Environmental Controls (i.e. contamination attenuation zone, groundwater monitoring wells, methane gas monitoring locations, control of dust, litter, odour, aesthetics and noise).

- Site Closure Plans such as final site geometry and capacity, final cover materials (layer with permeability less than or equal to 1×10^{-9} m/s), and post-closure monitoring (minimum of 25 years following closure).

- Record Keeping and Reporting (public complaints, annual operation and environmental monitoring reports).

2.2 Environmental Considerations Related to Woodwaste Landfills

2.2.1 Woodwaste Leachate Generation and Characteristics

The major component of woodwaste is usually bark (McCubbin, 1983). Leachate is generated when precipitation percolates through a pile of decomposing woodwaste (Tao et al., 2005). Woodwaste leachate is created by the dissolution of the following major natural compounds of wood (MOE, 1991): resin and fatty acids, tannins and lignins, lignans, terpenes, and phenolics. It is estimated that over 95% of woodwaste leachate is composed mainly of water (Wiegand, 1992),

There are many important factors that affect leachate characteristics at each specific site, including: age of waste, volume and density, wood species (hardwoods/softwoods), hydrogeology and geochemistry. The amount of leachate generated is relative to the amount of leachable wood extractives in a given volume of wood.

According to the MOE (1991), the major components contributing to woodwaste leachate are:

- **Resin extracts** of woodwaste consist of a mixture of compounds that make up the oily constituents of wood and woodwaste that provide living trees with a defense against wood boring insects. These compounds include resin and fatty acids, lignans, terpenes and phenolics. Bark, which is the main component of woodwaste, contains a higher proportion of these extractives. These resinous extracts give the leachate its oily (sheen) appearance.

- **Resin acids** are hydrophobic, non-volatile compounds that are natural protectants and wood preservatives. Resin acids have a relatively high affinity for solids and tend to accumulate and persist in the bottom sediments of receiving waters. Although most hardwood species typically contain only trace concentrations of resin acids, they make up 25-50% of the total resins in coniferous species (Taylor et al., 1988).

- **Lignans** are aromatic compounds that can be found in the woodwaste, root, heartwood, foliage, fruits and are resin extracts of living trees.

- **Terpenes** are volatile oils that are found in foliage in association with the resin ducts of softwood. The presence of terpenes in woodwaste leachates can result in iridescent slicks on the surface of waters receiving leachate discharges.

- **Phenolic** extracts of wood include tannins and lignins. The strong odour of woodwaste leachates is primarily due to the presence of these compounds (McNeeley et al. 1979).

- **Tannins** are highly soluble and are found mainly in the woodwaste. The reaction of tannins with naturally occurring dissolved iron causes the blue-black colour associated with woodwaste leachate (Thomas 1977).

- **Lignins** are high molecular weight polymers that give wood its structural rigidness. Since very few microorganisms are capable of breaking down lignin, it decomposes very slowly. Lignins are not readily soluble or extracted. Woodwaste typically contains more water extractable lignins than either heartwood or sapwood. Tannin-lignin concentrations in leachate impacted groundwater can range as high as 7.5 mg/L (Sweet and Fetrow, 1975). Concentrations of 2-4 mg/L gives a woody taste and odour to water, with odours and colours observed as low as 0.4 mg/L (Sweet and Fetrow, 1975).

- **The pH** of woodwaste leachate may be acidic due to the production of carbonic acid during the decomposition process and from the presence of organic acids (Haygreen and Bowyer, 1989). Thomas (1977) found pH ranging from 4.6 to 7.4 for woodwaste leachate and from 4.7 to 7.2 for spruce/pine sawdust leachate. In Ontario, leachate is often neutral to slightly basic, based on the types of wood harvested (Thomas, 1977).

- **Inorganics and Heavy Metals**, typically iron and manganese, are dissolved from the woodwaste and surrounding soils and can be notably elevated relative to natural background concentrations. This is due to the presence of a reducing environment and/or non-acidic conditions downgradient of woodwaste sites. According to Thomas (1977), elevated heavy metal concentrations are among the most persistent adverse characteristics of woodwaste leachate. Metal levels which may be elevated are aluminum, chromium, copper, iron and manganese (Thomas, 1977). Re-precipitation of these metals may also create streaks of coloured sediments in the bottom of more alkali, oxygenated receiving surface water bodies (Sweet and Fetrow 1975). Typical metal concentrations were not provided for comparison to this study site results.

- **Major Ions** may be elevated in woodwaste leachate, and include alkalinity, calcium, magnesium and sodium (Thomas 1977).

- **The oxygen demand** of woodwaste leachate is usually high due to decomposition of organics. Thomas (1977) found dissolved organic carbon (DOC) values of 65 to 1050 mg/L in woodwaste leachate and 45 to 8500 mg/L for spruce/pine sawdust leachate. These organics reduce concentrations of dissolved oxygen in leachate and receiving waters. Thomas (1977) reported Biological Oxygen Demand (BOD) values as high as 1140 mg/L in woodwaste leachate and 6638 mg/L in spruce/pine sawdust leachate.

According to Tao et al. (2005), the "young" woodwaste leachate produced in the piles placement period was amber; acidic (pH 3.4 to 3.7), nutrient poor (inorganic nitrogen 1.4 to 32.0 mg/L; contained orthophosphate concentrations of 3.3 to 4.3 mg/L, of very high oxygen demand (chemical oxygen demand 12,559 to 14,254 mg/L); contained tannin and lignin concentrations of 3,066 to 5,150 mg/L as tannic acid; contained volatile fatty acid concentrations of 1,564 to 2,132 mg/L; and was very toxic to aquatic life (96-h median lethal concentration of 0.74% leachate). The leachate at 1.5 years old in the closure period had lower oxygen demand and higher ammonia and became darker and less acidic. The leachate had a 5-day biochemical oxygen demand to chemical oxygen demand ratio of 0.33 in the placement period and 0.14 in the late closure period. Volatile fatty acids accounted for 6 to 34% chemical oxygen demand, varying as the pile developed and with woodwaste age. Tannins and lignins accounted for 33 to 45% of the chemical oxygen demand. More than 98% of the contaminants were in dissolved form. The monthly variation of leachate quality was likely a result of both temperature and precipitation variations. pH was significantly correlated to chemical oxygen demand, tannin and lignin content, and volatile fatty acids. There were no metal concentrations ranges provided to compare to the study site results.

2.2.2 Environmental Monitoring of Woodwaste Sites

Environmental monitoring plans for a woodwaste landfill site are developed with the objective of assessing the site for compliance with regulatory requirements and demonstrating the environmental integrity of the site. Water quality monitoring is typically required by the MOE to assess environmental impacts on downgradient groundwater and surface water receptors associated with the landfilling of woodwaste at a site. At larger woodwaste sites, the monitoring and management of methane gas may also be required.

As typically required by the MOE, the following factors are considered when developing an environmental monitoring program for a landfill site:

- Site Conditions:
    - Site location
    - Geological and hydrogeological conditions (i.e. groundwater flow direction, flow velocities, primary flow pathways.)
    - On and off-site surface water courses
    - Adjacent land and water uses
- Groundwater Quality Monitoring Program:
    - Location and number of monitoring wells (background, source and compliance downgradient wells)
    - Drilling techniques and well design
    - Protection and labeling of wells
- Surface Water Quality Monitoring Program:
    - Location of surface water sampling points (i.e. upstream and downstream)
- Methane Gas Monitoring Program
    - Location of gas monitors (i.e. situated between landfill and nearby residences or on-site buildings with below grade spaces)
- Monitoring Frequency:
    - Water quality at landfill sites is typically monitored three times annually, with sampling reductions accepted when historical trends suggest that the leachate concentrations in downgradient wells/surface water bodies are stable or decreasing (i.e. trend analysis).

- Field and Analytical Programs:
    - Monitoring Protocols:
        - Water level measurements, well purging (at least three well volumes of water), filtering groundwater samples for metals.
    - Field Measurements:
        - pH, conductivity, temperature, dissolved oxygen, redox potential and colour.
    - Laboratory Measurements:
        - Reporting limits to accommodate assessment against Ontario Drinking Water Standards and calculated Reasonable Use Guidelines.
        - pH, conductivity, colour, hardness, phenols, tannins/lignins, resin/fatty acids, total/dissolved organic carbon, ammonia, total/dissolved solids, biological oxygen demand, organic nitrogen, major anions/cations, aluminum, antimony, arsenic, barium, beryllium, bismuth, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, phosphorus, selenium, silicon, silver, tin titanium, vanadium and zinc.

2.2.3 Retention of Inorganics in the Subsurface

Sources of inorganics (metals) contamination of soil and groundwater include land application activities such as industrial and residential waste disposal sites (woodwaste sites), industrial activities (e.g. plating), mine tailings and waste rock disposal/storage sites, and natural weathering of bedrock with metal bearing minerals. A focus of the groundwater and contaminant transport modeling portion of this thesis is the attenuation of inorganics downgradient of a woodwaste landfill site. The following sections provide a literature review on the mechanisms responsible for the natural attenuation (retention) of metals in the subsurface.

Several natural attenuation processes in the subsurface can aid in reducing high metal concentrations in downgradient soil and groundwater. Natural attenuation is defined as the process where there is a reduction in mass or concentration of metals over time and distance from the source due to naturally occurring physical, chemical and/or biological processes (Sara, 2003). Natural attenuation processes are important at sites where engineered remedial options are not in place and/or feasible due to site-specific conditions.

The following discussion is based on Sara (2003). Natural attenuation under certain conditions, such as sorption reactions, effectively reduces the dissolved concentrations and/or toxic forms of metal contaminants in groundwater and soil. Metals can be attenuated by sorption reactions such as precipitation, adsorption on the surfaces of soil minerals, absorption into the matrix of soil minerals or partitioning onto organic matter.

The following are important geochemical processes affecting the natural attenuation of metals:

- Adsorption
- Precipitation of metals as:
    - Carbonates
    - Sulfides
    - Hydroxides
    - Organic complexation and ligand exchange

These reactions are the dominant mechanisms responsible for the reduction of mobility, toxicity or bioavailability of metals. A summary of the processes involved in the attenuation of heavy metals in leachate plumes is provided in Table 2.1.

The specific mechanism responsible for the retention of metals is important because some mechanisms are more desirable than others. For example, precipitation reactions and adsorption into a soil solid structure are generally stable, whereas surface adsorption and organic partitioning (complexation reactions) are more reversible. Complexation of metals with carrier (chelating) agents (i.e. EDTA) may increase metal concentrations in water and enhance their mobility. Changes in a metals concentration, pH and chemical speciation may reduce the stability of a metal at a site and release it into the environment.

Assessing the existence and demonstrating the irreversibility of these mechanisms are key components in proving that natural attenuation processes at a given site are capable of achieving clean-up criteria and objectives in a reasonable time frame.

2.2.3.1 Inorganic Species in Natural Waters

The geochemical species present in the subsurface governs the metal attenuation capacity of a soil. Metals in soil solution exist as free uncomplexed metal ions (e.g. Cd^{2+}, Zn^{2+}, Cr^{3+}), soluble complexes with inorganic or organic ligands and complexes with inorganic and organic colloidal material (Evans, 1989).

Common inorganic and organic ligands include:

- Inorganic Ligands: SO^{42-}, CO^{32-}, HCO^{3-} and OH^{-}
- Organic Ligands: Aromatic and amino acids and fulvic acids

Since various metal species, whether bound to small colloidal particles or by dissolved organic or inorganic complexes, seem so prevalent in leachate impacted groundwater, the free metal ion is expected to make up only a small fraction of the measured metal concentrations in leachate plumes (Christensen, 2001). Colloids are present in leachate impacted groundwater in terms of organic and inorganic particles in the size range of 0.001 micrometer to the particle cut off of the filters used in separating the sample into suspended matter and a dissolved fraction (Christensen, 2001).

Evans (1989) describes the following two types of dissolved complexes formed between metals and complexant ligands:

- Outer sphere complexes consisting of weak electrostatic associations formed between a hydrated cation and a complexant ligand, in which one or both of the charged species retains a hydration shell, and

- Inner sphere complexes forming strong associations between metal and complexant ligands in which a covalent bond is formed between a metal ion and a ligand.

Metal ions generally behave as Lewis acids that have vacant orbitals into which electrons can be introduced. Ligands behave as Lewis bases that have at least one pair of electrons not shared in a covalent bond. Therefore, Lewis acids can be considered as ions that accept electrons, and Lewis bases as ions that donate electrons (Evans, 1989).

Metals in soil solution can be transported as (Gunn et al., 1998; Gallacher and Pulford, 1989):

- Dissolved metals.

- Dissolved complexes with inorganic/organic species or in association with organic or inorganic particulate matter.

Attenuation of metals in soil solution can occur due to the following:

- Metals or complexes bind chemically to soil substrate.
- Insoluble metal phase precipitates.
- Filtration removes particulate matter from solution

Based on Sparks (2003), the ability to assess metal impacted soil and groundwater is critical in developing viable and cost effective remediation strategies and in predicting mobility and bioavailability of the metals. Although total ion concentrations (sum of free and complexed ions) of a soil solution can be measured by analytical techniques such as spectrometry, chromatography and colorimetry, it is not possible to determine all the individual ion species that can occur in soil solutions. To speciate the soil solution, one must apply ion association or speciation models (i.e. VMINTEQ) using the total concentration data for each metal and ligand in the soil solution.

2.2.3.2 Soil Processes

A soil's capacity to adsorb metals from soil solution depends on the number and type of cation exchange and adsorption sites available. A soil capable of removing a maximum mass of metal from solution would contain significant organic and/or clay material while containing coarse material to allow dissolved metals to move freely through the soil (Benner et al., 1997).

Major soil factors controlling the adsorption of metals include: pH, clay content/mineralogy, soil organic matter, Fe and Mn oxides and calcium carbonate content. The interactions between adsorption processes and various soil factors may increase or decrease the mobility of metals in soil solution.

Based on Sparks (2003) soils consist of primary and secondary minerals and organic matter. Primary minerals such as clays and organic matter, which have net negative surface charges and large surface area, have the highest capacity for metal attenuation. Each clay mineral will have a different attenuation capacity, which will depend on the mass of contaminant which can be bound to a mass of clay. Organic matter that is most resistant to degradation (refractory organic matter) has the highest capacity for binding with dissolved metals. Soils dominated by sand and gravel have low specific surface area and as a result have low attenuation capabilities.

Secondary minerals such as metal oxides and hydroxides in soils also increase the attenuation of dissolved metals by forming complexes/precipitation with metal oxides and hydroxides. These secondary minerals typically have high specific surface areas and form from dissolved metal species under oxidizing surface conditions at pH levels greater than 3 (Yariv and Cross, 1979). Important metal oxides in soil include aluminum oxides, iron oxides and manganese oxides. Examples of oxides, oxyhydroxides and hydroxides found in soil are provided in Table 2.2.

2.2.3.3 Natural Attenuation Processes

The following natural processes are responsible for the attenuation of dissolved and particulate metals from soil solution.

- Precipitation and Co-precipitation
- Adsorption
- Organic Complexation and Ligand Exchange

The following sections discuss the above processes.

Precipitation

Removal of metals by precipitation occurs when the concentration of component species in the remaining solution exceeds the solubility of the mineral

(Anisimova, 1988). Precipitation is an effective mechanism of natural attenuation when precipitates are stable under the environmental condition of the site.

The two types of precipitates are:

- Pure solids: formed when metal is compatible with the element of the host mineral and can uniformly replace it through the mineral, and
- Mixed solids: formed when various elements co-precipitate.

Evans (1989) notes that concentrations of many heavy metals in industrial and municipal wastes leached to the subsurface are generally several orders of magnitude higher than their natural concentrations. In these environments, the elevated concentrations can result in the precipitation of the metals as secondary minerals. The most important of these precipitates are oxides, oxyhydroxides, hydroxides, and carbonates. A diagram showing metal-hydroxide solubility curves for heavy metals is provided in Figure 2.1.

Under anoxic conditions, precipitation of sulphide minerals can also be an effective mechanism for metal attenuation, provided that reducing conditions prevail (Krauskopf and Bird, 1995).

Evans (1989) describes the following precipitation conditions:

- Metal-hydroxide minerals: can limit the solubility of Fe^{3+} and Al^{3+} under aerobic conditions.
- Metal-carbonate minerals: can limit the solubility of Ca^{2+}, Sr^{2+} and Ba^{2+} under neutral or basic conditions.
- Metal-sulfide minerals: can limit the solubility of Ag^{+}, Zn^{2+}, Cd^{2+} and Hg^{2+} under anoxic and reducing conditions.

Co-precipitation is also an important mechanism of natural attenuation. The mechanism involves the incorporation of metal species into the crystal structure of a forming mineral by substitution or by diffusion (Krauskopf and Bird, 1995). Metal attenuation by co-precipitation is mainly concerned with oxides, hydroxides and oxyhydroxides of iron and manganese. These generally have high specific surface areas which facilitate diffusive attenuation of dissolved metals and form surface coatings on soil particles, minerals and rocks (Bertsch and Seaman, 1999). Iron and manganese precipitates often form from water influenced by sulphide oxidation and are thus able to remove other metals of concern from the same water (Webster et al., 1994).

Adsorption of Inorganics

Adsorption consists of interactions at a solid/liquid interface between a charged mineral or colloid surface and an oppositely charged species in the liquid (Yariv and Cross, 1979). Adsorption of solutes from solution include both physical and chemical forces (Sparks, 2003), including:

- Physical forces: van der Waals forces and electrostatic outer sphere complexes.

- Chemical forces: inner sphere complexation involving ligand exchange, covalent bonding and hydrogen bonding.

Adsorption of heavy metal cations in soils generally occurs on negatively charged clay mineral surfaces and organic matter, amorphous inorganic materials and metal oxide precipitates (Sparks, 1995).

Adsorption complexes between metal and soil surfaces that control the mobility of metals are illustrated in Figure 2.2 and include:

- Outer sphere complexes:
    - Surrounded by water

- Not directly bonded to surface
- Response of electrostatic forces (exchange sites)
- Reactions are rapid and reversible
- More mobile depending on environment

- Inner sphere complexes:
  - Metal bonded directly to surface
  - Ionic, covalent bonds or hydrogen bonds (high bonding energy)
  - Other cations do not effectively compete for surface site
  - Adsorbed metal cations are relatively immobile

Factors Affecting Adsorption

Factors affecting adsorption include soil properties, competing cations, complex formation, pH, and redox. A discussion of these factors by McLean and Bledsoe (1992) is provided in the following sections.

Soil Properties Affecting Adsorption

The adsorption capacity of a soil is determined by the number and type of sites available. Factors controlling the adsorption of metal cations include soil properties such as pH, redox potential, clay, soil organic matter, iron and manganese oxides, and calcium carbonate content. Adsorption processes are affected by these various soil factors, by the form of the metal added to the soil, and by the solvent introduced along with the metal. These interactions may increase or decrease the movement of metals in the soil solution.

Effects of Competing Cations

For specific adsorption sites, trace cationic metals are preferentially adsorbed over the major cations. However, when the specific adsorption sites become saturated, exchange reactions dominate and competition for these sites with the soil major ions becomes important. The presence of other cations, whether major or trace metals, can significantly effect the mobility of the metal of interest.

Exchangeable cations are those cations, which are readily displaced, by mass ion effect, from negatively charged colloids on which they are adsorbed. Cation exchange capacity (CEC) refers to the number of exchangeable cations that soil solids can adsorb.

Effect of Complex Formation

Metal cations form complexes with inorganic and organic ligands. The resulting association has a lower positive charge than the free metal ion, and may be uncharged or carry a net negative charge. The interaction between metal ions and complexing ligands may result in either a complex that is weakly adsorbed to the soil surface or in a complex that is more strongly adsorbed relative to the free metal ion. The decrease in positive charge on the complexed metal reduces adsorption to a negatively charged surface. The presence of complexing ligands may increase metal retention or greatly increase metal mobility.

Effect of pH

The pH affects several mechanisms of metal retention by soils either directly or indirectly. Adsorption of metal cations increase with pH. The effects of soil pH on maximum metal retention are illustrated in Figure 2.3.

The pH dependence of adsorption reactions of metals is due to the preferential adsorption of the hydrolyzed metal species in comparison to the free metal ion. The pH dependent charged surfaces are associated with edges of clay minerals, surfaces of oxides, hydroxides and carbonates and organic matter (acid functional groups). The charge on these surfaces is caused by the association and dissociation of protons from surface functional groups. As the pH decreases, the number of negative sites for metal adsorption decreases. When the pH becomes more acidic, metals also face competition for available permanent charged sites by Al^{3+} and H^{+}. The pH of a soil system is very important parameter directly influencing adsorption of metals. Figure 2.1 also gives an indication of this effect.

Effect of Oxidation-Reduction

Redox reactions can greatly affect metal transport, in slightly acidic to alkaline environments, Fe^{3+} precipitates as a highly adsorptive solid phase (ferric hydroxide), while Fe^{2+} is very soluble and does not retain other metals. In general, oxidixing conditions favour retention of metals in soils, while reducing conditions contribute to accelerated migration.

Adsorption of Barium and Arsenic (Study Site Leachate Indicator Parameters)

Review of literature indicates that there is very little batch sorption results for the woodwaste study site indicator parameters iron, manganese, barium and arsenic on granular sandy soils. As indicated by McLean and Bledsoe (1992), sandy soils with low pH (which is representative of the study site conditions) do not retain the cations or metals effectively.

Sorption values for arsenic (2.5×10^{-5} L/mg) and barium (1.1×10^{-5} L/mg) were obtained from U.S. EPA *Soil Screening Guidance Technical Background Document* (1996). These values represent metal adsorption to FeOx and solid organic matter. It is recognized that numerous other natural sorbents exist (e.g. clay and carbonate minerals); therefore, these values are considered conservative and will under predict sorption for soils with significant amounts of such sorption sites. Since soils at the study site do not contain clay, these sorption values were considered to be reasonable. The Guidance Technical Background Document provided sorption values at high, medium and low subsurface pH conditions (i.e. pH of 4.9, 6.8 and 8). Sorption values for barium and arsenic at the lower pH of 4.9 were selected for modeling purposes. This low pH was considered representative of the pH of soil at the study site (pH of 4.9 and 5).

Organic Complexation and Ligand Exchange

Metal and organic matter interactions take the form of electrostatic bonding, complexation (involving one or more bonds between a metal ion and a functional group on the organic surface), or ligand exchange (in which a metal ion or complex displaces a functional group with similar characteristics from the organic surface) (Sparks, 1995).

Complex formations between metals and organic ligands affect metal adsorption and hence mobility (McLean and Bledose, 1992). Metals that readily form stable complexes with soluble organic matter are likely to be more mobile in soils (McLean and Bledose, 1992). In systems where the organic ligand adsorbs to the soil surface, metal adsorption may be enhanced (reducing mobility) by the complexation of the metal to the surface-adsorbed ligand (McLean and Bledose, 1992).

The efficiency of metal retention by organic matter depends on pH, metal complexation and the amount of organic matter available with efficiency being highest for low metal concentrations, neutral pH and high proportions of organic matter (Schnitzer, 1984).

Inner sphere complexes between metals and soil organic matter can be formed by associations between cations and coordinating functional groups found in humic substances, in which the functional groups behave like complexant organic ligands (Evans, 1989).

The biochemicals (amino acids, proteins, carbohydrates, organic acids, polysaccharides, lignin, etc.) and humic substances provide sites (acid functional groups, such as carboxylic, phenolics, alcoholic, enolic-OH and amino groups) for metal sorption (McLean and Bledsoe, 1992).

Stevenson (1991) and Stevenson and Fitch (1986) give the following discussion on the nature of soil organic matter and its role in the retention of metals in soil. The biochemicals form water soluble complexes with metals, increasing metal mobility. The humic substances consist of insoluble polymers of aliphatic and aromatic substances produced through microbial action. Humic substances contain a highly complex mixture of functional groups. Binding of metals to organic matter involves a continuum of reactive sites, ranging from weak forces of attraction to the formation of strong chemical bonds. Soil organic matter can be a main source of soil cation exchange capacity. However, organic matter content decreases with depth, so that the mineral constituents of soil will become a more important surface for sorption as the organic matter content of the soil diminishes.

2.2.4 Groundwater Modeling

As discussed by Thompson (2007), groundwater modeling is a tool that can be used to assess groundwater flow regimes and the fate and transport of contaminants at a landfill site. Models can range from simple mathematical equations and analytical solutions to complex computer generated models such as Visual MODFLOW. The two main components of groundwater modeling is flow and contaminant fate and transport. Groundwater models are generally used to support remedial decisions or predict contaminant levels over time and at distance from the source (landfill site). Modeling results can be used as a tool for decision making; however, sufficient field and analytical data are required to delineate the contaminant plume and confirm model predictions in order to develop an initial site conceptual model.

Models only provide a scenario based on specific assumptions and specific input values. Varying these input values can have a dramatic effect on the results of a model. Selecting proper boundary conditions and other site specific parameters can be difficult. Models should be calibrated to existing site conditions (geological conditions, groundwater levels, hydraulic conductivities, recharge values, contaminant concentrations, etc.) Once calibrated the model can be used to predict flow or transport results for a range of sensitive parameters.

Visual MODFLOW v.4.3. (MODFLOW 2005 and MT3D v5.2) was used for modeling groundwater flow and contaminant transport scenarios for the woodwaste study site. A description of the model used is provided in the below sections and is based on discussions provided by Downs and Webster (2007) and the Visual MODFLOW v.4.3 User's Manual.

Flow Engine

MODFLOW 2005 is the numeric groundwater flow engine used by Visual MODFLOW v.4.3 and uses three dimensional finite difference grid formulation to solve the general 3D flow equation and simulates groundwater flow through a saturated porous medium.

The 3D steady state groundwater flow equation (2.1) is as follows:

$$(\partial/\partial x(k_{xx}*\partial h/\partial x)+ \partial/\partial y(k_{yy}*\partial h/\partial y)+ \partial/\partial z(k_{zz}*\partial h/\partial z)-W=0 \quad (2.1)$$

where:

k_{xx}, k_{yy}, k_{zz} are the hydraulic conductivities in the x,y, and z directions

$\partial/\partial y$ = hydraulic gradient; where h = total head and y = length of grid

W = volumetric flux per unit volume

The grid system for the model allows the user to define and discretize the modeling domain. Hydraulic head is calculated across the grid system using groundwater flow equation (2.1) (Visual MODFLOW v.4.3 User's Manual). MODFLOW uses an iterative numerical solver (WHS) to undertake iterations to solve to the partial differential flow equations.

Flow Properties

Flow properties such as hydraulic conductivity, porosity, storage and initial head values are assigned to each grid cell in the model to run the flow simulation. These properties are typically adjusted during the calibration of the model to provide a representative flow model. The use of parameter estimation (PEST) software can facilitate the calibration of a groundwater flow model.

Flow property values can be obtained from site specific tests or literature values for studies completed at sites with similar conditions.

Flow Boundary Conditions

MODFLOW requires a minimum of one active grid cell in the model to contain a head dependent boundary condition type such as a constant head, river or stream in order for the model to converge to a solution for steady state conditions.

A constant head that simulates a constant infinite water source to the model can be assigned along the boundary for a confined or an unconfined aquifer. A typical model could be designed to have a constant head boundary at each end of the grid with no flow boundaries on each side of the grid. The constant head values are typically obtained from on-site head values measured from groundwater monitoring wells. Recharge is assigned to the grid (i.e. upgradient and downgradient edges) to simulate the infiltration of precipitation at the site. These data can be obtained from site specific tests or data obtained from Environment Canada.

Observation Wells

Observation wells are used to provide groundwater and contaminant levels over time periods and can be used to calibrate the flow or transport model across the site. Observation well head levels are used to calibrate the model to simulate actual site conditions. Simulated head values can be adjusted to observed head values by adjusting hydraulic conductivity, recharge or flow boundaries through trial and error and by using PEST to refine the flow model.

Running Model and Calibration

The MODFLOW 2005 flow engine is run to initiate the groundwater flow simulation. The steady state simulation time is the time over which the simulation runs to coincide with the period of analysis.

The use of the optimization module PEST is important to expedite the efficient calibration of a groundwater flow model. The user determines the data to be refined such as hydraulic conductivity, recharge and storage for each zone of the model. A weight is applied to each prior condition; the higher the weight, the greater the impact on the objective function. The observed head values from observation well data form the range within which the objective function operates to estimate a superior set of hydraulic conductivity values.

Transport Engine

MT3D v.5.2 is a 3D modular Multi-Species Transport engine for simulating advection, dispersion and reactions (sorption and biodegradation) of contaminants in groundwater systems. The standard iterative solver GCG uses weighted finite difference approximations to resolve the terms in the advection/dispersion equation after receiving flow information from MODFLOW 2005.

MT3D solves equation (2.2) from the Visual MODFLOW v.4.3. User's Manual is used to define contaminant transport through the model.

(2.2) $$\partial(\theta C^k)/\partial t = \partial/\partial x_i[\theta D_{ij}{*}\partial C^k/\partial x_j] - \partial/\partial x_i{*}(\theta v_i C^k)+q_s C^{ks}+\sum R_n$$

where:

C^k = *dissolved concentration of species k*

θ = *porosity of the subsurface medium*

t = *time*

x_i = *distance along the respective Cartesian coordinate axis*

D_{ij} = *hydrodynamic dispersion coefficient tensor*

V_i = *seepage or linear pore water velocity.*

q_s = *volumetric flow rate per unit volume of aquifer representing fluid source and sinks*

C^{ks} = *concentration of the source or sink flux for species k*

$\sum R_n$ = *chemical reaction term*

Other options such as the RT3D reactive multi-species transport engine can be selected for simulating reaction based models such as the aerobic decay and multi-path degradation of petroleum hydrocarbon constituents, rate-limited sorption reactions, degradation and sequential decay reactions.

Transport Properties Used in MT3D Analyses

For modeling sorption with MT3D, a retardation factor (Rd) approach is used. The Rd is calculated using the equation (2.3)

(2.3) $$Rd = 1 + (p_b \cdot K_d)/n_e$$

In equation (2.3), the bulk density (p_b) is the porous medium dry density in units of lb/ft^3 or kg/m^3 (from site soil analysis), effective porosity (n_e) is the porosity representing the fluid conducting porosity in the porous medium, and the distribution coefficient (K_d) is the slope of the linear sorption isotherm for the particular chemical soil/water system.

For species parameters, K_d values in units of L/mg and decay rates (λ) in units of d^{-1} for each contaminant are entered into the model as determined from calculations and correlation with literature sources. Longitudinal (∂_L), transverse (∂_T) and horizontal (∂_H) dispersivities, and molecular diffusion coefficient (D*) values are entered into the model to simulate the contaminant plume based on site specific or literature values.

Transport Boundaries

The contaminant source concentration (in either mg/L or µg/L) can be represented in the model as either a recharge, point or constant concentration, where the contaminant has been observed over a period of time.

The concentration is assigned to the model grid boundaries on a cell by cell basis for each layer where the contaminant has been observed from existing groundwater or soil data.

Fate and Transport

The MT3D numeric transport engine can be initiated by selecting the implicit GCG solver as the solution method, which uses standard finite difference methods such as Upstream Finite Difference (UFD) or Central Finite Difference (CFD) to solve the advection term and implicitly solve for dispersion and sorption. This solver is suitable for most contaminant transport applications where advection, dispersion, linear sorption and first order biodegradation are considered simultaneously. After entering the numeric engine parameters, the solver runs through the transport steps over the simulation time selected by the user. Selective runs can be made for differing advection, dispersion, sorption, and biodegradation values to assess the impact on the plume evolution and natural attenuation.

Sensitivity Analysis

A sensitivity analysis involves individually adjusting one of the input parameters by, for example, an order of magnitude while keeping the others constant, to determine its influence on the contaminant plumes. A high sensitivity indicates that small changes to a particular parameter will have a significant impact on the contaminant plume. An advisable approach is to set up a table of runs that indicates the logic behind each run, the numerical changes made to each parameter and the outcome of each run. This allows the user to chart their progress for further analysis and to avoid unproductive testing. A reference chart is provided as Figure 2.4 (Downs and Webster, 2007).

2.3 Use of Woodwaste for Bio-Energy Production

While wood residuals may have at one time been considered by the industry to be woodwaste destined for landfill disposal, the forest products industry in Canada currently utilizes the majority of these materials for energy recovery (Maltby, 2006). Many pulp and paper facilities are assessing the potential for the recovery and utilization of woodwaste as an alternative energy resource for use in their combustion systems (i.e. boilers, cogeneration facilities, etc). With increasing concern about energy security and greenhouse gas emissions, growing attention has been drawn to bio-energy in recent years (Jianbang Gan et al., 2005). Woody biomass energy is renewable and carbon neutral, namely its net carbon emissions are close to zero (Jianbang Gan et al., 2005). The Canadian pulp and paper industry has been reported as the leader of biomass use, operating 45 co-generation plants nationwide, which combined produce 1,500 megawatts of electric power and process steam from woodwaste (GreenBaum, 2005). As the use of biomass and co-generation increases, so does the demand for woodwaste. Mills that have sawmills or woodwaste resource piles in proximity to their operations are in a much better position than those who have to rely on outside resources.

An assessment of the feasibility of using woodwaste from existing disposal sites is site specific and dependent on the following factors:

- Type of woodwaste present (woodwaste, chips, round wood, etc.)
- Moisture content (saturated, moist, dry)
- Degree of decomposition (age of woodwaste)
- Presence of other materials (soil, rocks, other process wastes)
- Laboratory values associated with combustion potential including: British Thermal Units (BTU) per pound (lb), moisture content, heat content
- Potential volume of usable woodwaste

Process	Cadmium Cd	Chromium Cr	Copper Cu	Lead Pb	Nickel Ni	Zinc Zn
Dilution	+	+	+	+	+	+
Complexation[a]	+	+	+ +	+ +	+	+
Redox processes	–	–[b]	–	–	–	–
Sorption	+	+	+	+	+	+
Precipitation						
Sulphides	+	–	+	+	+	+
Carbonates	(+)	–	–	+	–	(+)
Other	+	+ +	+	+	–	–

[a] Complexation is not an attenuation process, since complexation results in increased solubility and mobility.
[b] Cr as Cr (III). Cr (VI) may appear in chemical waste, but presumably is rapidly reduced to Cr (III) under the anaerobic conditions in the landfill (Richard and Bourg, 1991).

Table 2.1: Summary of processes involved in attenuation of heavy metals in leachate plumes (+ +: very important, +: important, (+): usually of minor importance, -: not important) (T.H. Christensen et al. Applied Geochemistry 16 (2001))

Aluminum oxides	
	Bayerite α-$Al(OH)_3$
	Boehmite γ-AlOOH
	Corundum Al_2O_3
	Diaspore α-AlOOH
	Gibbsite γ-$Al(OH)_3$
Iron oxides	
	Akaganeite β-FeOOH
	Ferrihydrite $Fe_5HO_8 \cdot 4H_2O$
	Feroxyhyte δ-FeOOH
	Goethite α-FeOOH
	Hematite α-Fe_2O_3
	Lepidocrocite γ-FeOOH
	Maghemite γ-Fe_2O_3
	Magnetite Fe_3O_4
Manganese oxides	
	Birnessite δ-MnO_2
	Manganite γ-MnOOH
	Pyrolusite β-MnO_2
Titanium oxides	
	Anatase TiO_2
	Ilmenite $FeTiO_3$
	Rutile TiO_2

Table 2.2: Oxides, Oxyhydroxides and Hydroxides Found in Soils (Adapted from Taylor (1987), Hsu (1989), McKenzie (1989) and Schwertmann and Cornell (1991)

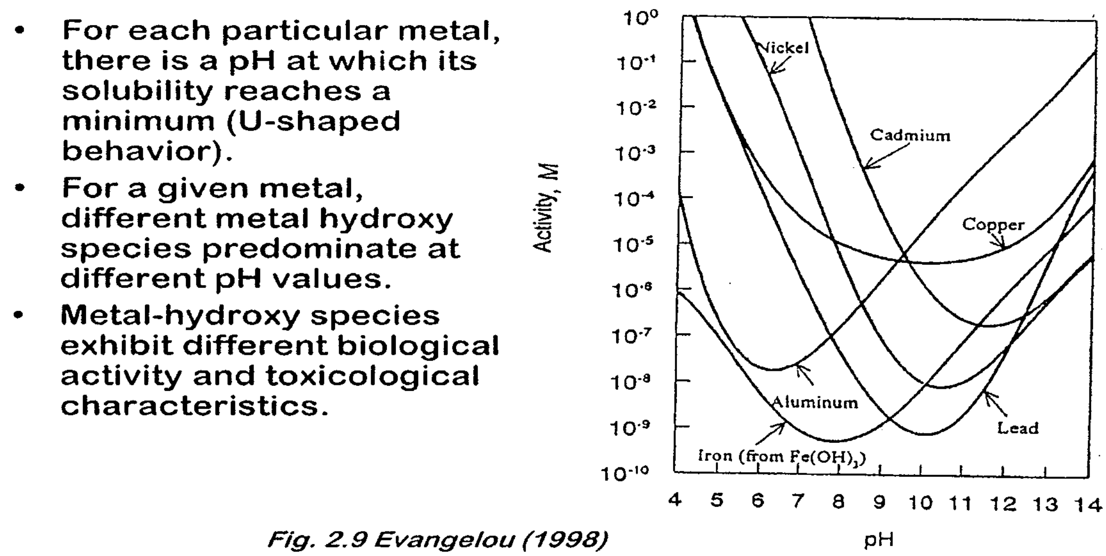


Figure 2.1: Metal-Hydroxides Solubility Diagrams (Figure 2.9 Evangelou 1998)

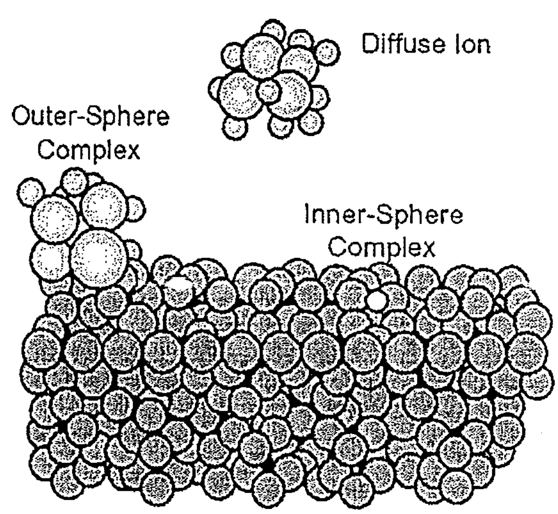


Figure 2.2: The Three Mechanisms of Cation Adsorption on a Siloxane Surface (e.g. montmorillonite). (Sposito, 1989)

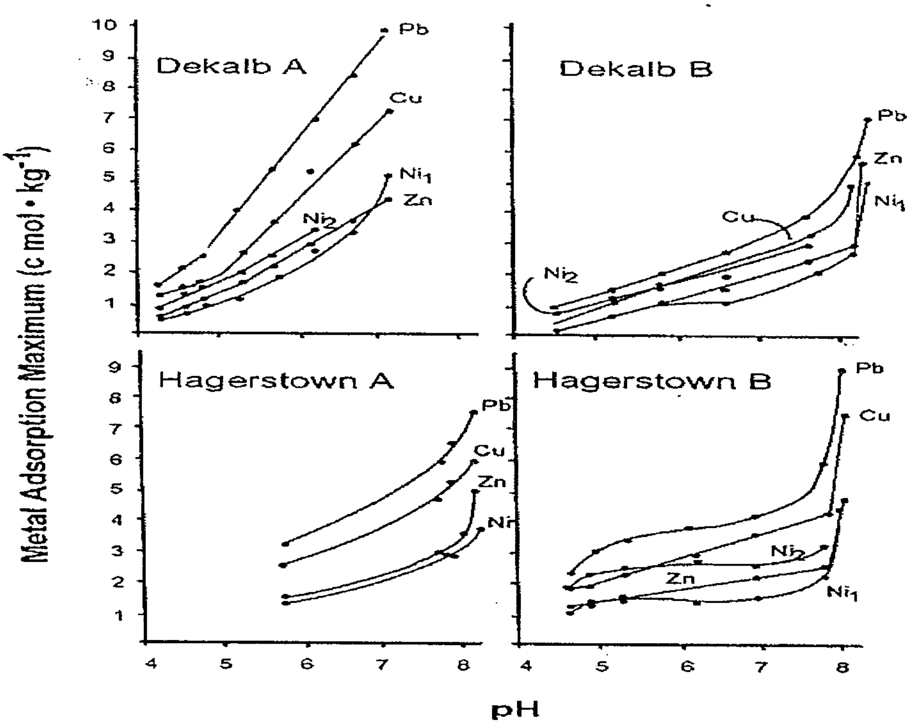


Figure 2.3: Effect of Soil pH on Maximum Pb, Cu, Zn and Ni retential by Dekalb and Hagerstown A and B horizons. Ni1 and Ni2 refer to Two Apparent Sorption Maxima (Harter, 1983).

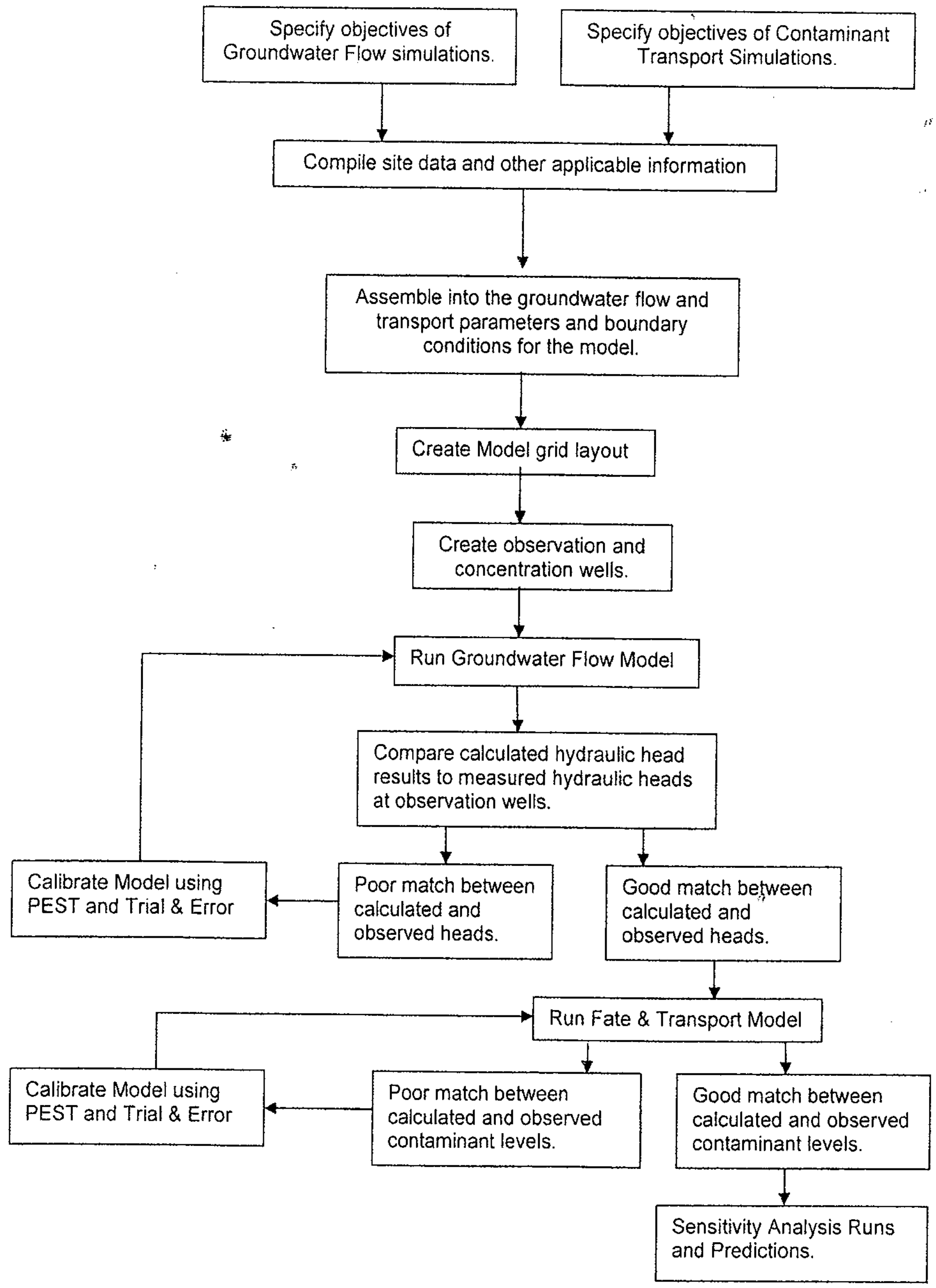


Figure 2.4: Flowchart of the groundwater flow and contaminant transport Modeling process (Downs and Webster, 2007)

3.0 Woodwaste Landfill Study Site Characteristics

3.1 Site Description

The woodwaste landfill site studied in this research is located in northwestern Ontario and consists of a woodwaste pile estimated to be approximately 156,000 m^3 in volume, based on a total station survey completed at the site.

The woodwaste landfill site is bordered by a roadway on the northeast, forested area on the east, a log storage/wood debris area further to the south, and a site access road on the west. A lake (dammed portion of a former river) is located 260 m west and downgradient of the woodwaste pile. A plan showing key site features is provided as Figure 3.1 (Site Layout).

3.2 Management of Woodwaste at the Study Site

3.2.1 Physical and Chemical Properties of Woodwaste at Study Site

Overall the woodwaste material in the pile was confirmed to mainly be comprised of woodwaste with < 10% by mass of wood chips and small diameter round wood. Very little to no granular material (i.e. gravel, cobbles) and no foreign substances such as steel or unrelated waste materials such as process wastes (i.e. sludges, lime mud, etc) were observed in the pile. The majority of the material examined in the field appeared only slightly decomposed, particularly at depths below 3 m. These observations were made from the test pit program conducted for the bio-energy feasibility study, described in Chapter 5, which consisted of the advancement of 13 test pits across the woodwaste pile to maximum depths of 6 m below the top of the woodwaste.

Upgradient and downgradient soil and woodwaste samples at the site were collected for laboratory analysis of a suite of chemical parameters to characterize the material at the site. Soil samples were collected approximately 100 m east and west of the pile and a woodwaste sample, representing degraded woodwaste, was collected near the bottom of the pile adjacent to source well MW1. Sample locations are shown Figure 3.1.

Soil samples were collected both upgradient and downgradient of the woodwaste pile at a depth of approximately 6 m below ground surface (below the groundwater table) using a hand auger on May 22, 2009. Woodwaste samples were collected by advancing a shovel to a depth of approximately 1 m below the top of the woodwaste pile along the west toe of the pile on April 29, 2009.

Both soil and woodwaste samples were submitted to a certified laboratory for analysis of pH, total organic/inorganic carbon, anions and metals in order to characterize the material. The analytical methods followed are provided in Section 3.5.3

Table 3.1 provides a summary of the results for both soil and woodwaste samples. Based on the results in Table 3.1, the chemistry of the leachable and acid extractable compounds of the upgradient and downgradient soil is somewhat similar and characterized by elevated concentrations of total carbon/organic carbon, aluminum, calcium, iron, magnesium, manganese, phosphorus and potassium as well as other detectable metals. The woodwaste sample was characterized by elevated concentrations of total carbon, inorganic carbon and organic carbon, and acid extractable compounds of aluminum, barium, calcium, iron, magnesium, manganese, molybdenum, nickel, phosphorus, uranium and vanadium relative to the soil samples.

The elevated chloride concentration in the downgradient soil may be due to road salting activities on the access road, which is located on the west side of the woodwaste pile. Concentrations of both leachable and acid extractable metals and pH for both upgradient and downgradient soil samples were similar with no apparent trends. Total carbon and total organic carbon concentrations were elevated in downgradient soils relative to upgradient soil, which is likely due to the organic nature of the upgradient woodwaste pile.

Leachable metal concentrations were generally below the laboratory's detection limit; however, detectable leachable concentrations were measured for boron in both soil and woodwaste and barium in the woodwaste sample.

3.2.2 Study Site Landfill Design and Operations

The total existing volume of material at the site is estimated to be 156,000 m^3 over an area of 2.56 ha. The only material stored at the site is "woodwaste" as defined in Ontario Regulation 347. No material has been added to the site since 2003; however, the pile was regraded in 2003 to promote surface water runoff and minimize leachate production. The current pile is approximately 225 m long (north-south) and 155 m wide (east-west). The overall maximum height of the existing pile is approximately 10 m above the surrounding ground surface and is not situated below grade at any point. Side slopes are estimated to be approximately 4H:1V with a 5% slope on the crown, which is consistent with standard MOE design criteria for site closure configurations. The existing site has been utilized to stockpile wood residue for approximately 20 years, with the intention of removing the woodwaste over time for use as supplemental fuel in the mill boiler system.

The existing site has no major surface water drainage features. The overall site topography is a gentle slope from east to west towards the Lake, with a steep embankment along the shoreline of the lake. The surface soils in the immediate vicinity of the woodwaste site are sandy and the majority of precipitation is expected to infiltrate into the ground.

Groundwater and surface water downgradient of the woodwaste site is monitored twice annually with a water quality report submitted to the MOE on an annual basis. Although typically the MOE requires sampling three times annually, the groundwater quality results since 2003 for downgradient groundwater suggest that water quality at the site has stabilized with no apparent increasing trends for leachate indicator parameters; therefore, the MOE recommended that only two monitoring events are required annually at the site.

Prior to 2009, the woodwaste site was not licensed by the MOE. The current MOE CofA for the site (issued January 2009) has a condition that all woodwaste be removed from the site within 5 years of issuance of the CofA (i.e. by January 2013) with the woodwaste being used as bio-fuel for the on-site boiler system or landfilled at their other licensed on-site landfill site.

3.3 Site Geology

Ontario Geological Survey (OGS) Map No. 2554 (*Quaternary Geology of Ontario, West-Central Sheet*, Scale 1:1,000,000) indicates surficial geology consisting of glaciolacustrine deposits of sand, gravelly sand and gravel (i.e. nearshore and beach deposits). OGS Map 2542 (*Bedrock Geology of Ontario, West-Central Sheet*, Scale 1:1,000,000) indicates bedrock geology consisting of massive granodiorite to granite rock.

A total of 10 boreholes (MW1 to MW10) were drilled on the site at the locations shown on Figure 3.1. Boreholes MW1 to MW6 were drilled in 2003, MW7 and MW8 were drilled in 2004 and MW9 and MW10 were drilled in 2007. Monitoring wells, with screen intervals as shown on the borehole logs, were completed in all of the boreholes. Based on the borehole logs (Appendix A), the subsurface geology at the site (Site Geological Assessment, 2003) consists of an upper fine to medium grained sand to an average depth of 6 m below ground surface, underlain by a silt-silty sand to a depth of approximately 8 m below ground surface, followed by fine to medium grained sand with trace silt to the maximum depth investigated of 10 m below ground surface. A layer of silt ranging in thickness from about 0.5 to 1.2 metres was encountered at depths of 4 to 5 metres in boreholes MW3, MW4 and MW7. This silt layer is not continuous across the site. A geological cross section of the site is shown on Figure 3.2, with the section line shown on Figure 3.1.

A grain size analysis (Appendix B) was completed on a soil sample collected from a depth of approximately 6 m below ground surface approximately 100 m west (downgradient) of the woodwaste pile. According to the Unified Soil Classification System (USCS), the soil sample is classified as poorly-graded sand (SP).

3.4 Site Hydrogeology and Recharge

Based on groundwater levels measured from 2003 to 2008, groundwater recharge is flowing to the southwest toward the lake through the underlying sandy soil. A summary of groundwater levels measured at each well location during this time period are provided in Table 3.2. These values are plotted versus time in Appendix C.

Based on comparison with previously reported groundwater levels as shown in Table 3.2, the 2008 levels are consistent with previous levels. Site potentiometric contours using the most current groundwater levels (October 2008) are shown on Figure 3.3 (Groundwater Contour Plan). In 2008, groundwater levels ranged from 4.6 m below ground surface in MW2 (October) to 9.39 m below ground surface in MW6 (October).

When plotted on a plan and contoured, the water level elevations indicate the general shape of the potentiometric surface. Figure 3.3 shows the October 2008 water levels and potentiometric surface contours for the site based on information collected from the existing monitoring wells.

The groundwater water levels suggest a southwest slope toward the Lake with a gradient of approximately 0.02 m/m. Using the average hydraulic gradient, mean conductivities (from the rising head test results) and an effective porosity of 0.3 (Fetter, 1994), the groundwater flow rates are estimated to be 50 to 630 m/year. This flow rate is consistent with the rates calculated historically for the site.

Based on rising head tests completed at the site (Site Geological Assessment, 2003), a summary of the hydraulic conductivity values measured at the site is provided in Table 3.3 and shown on Figure 3.4 (Site Hydraulic Conductivities). Rising head test analysis and results are provided in Appendix D. As shown in Table 3.3, the hydraulic conductivities at the site range from 2.99×10^{-4} m/s at MW2 to 2.42×10^{-5} m/s at MW1.

The hydraulic conductivity was also estimated from the grain-size distribution curve using the Hazen Method (Fetter, 1994). This method is applicable to sands where the effective grain size (d_{10}) is between approximately 0.1 and 3.0 mm. The Hazen approximation is defined in equation (3.1):

(3.1)
$$K = C(d_{10})^2$$

where:

K = hydraulic conductivity (cm/s)

d_{10} = effective grain size (cm)

C = coefficient based on soil type

For the representative soil sample collected at the study site, d_{10} was equal to 0.014 cm (grain size distribution curve obtained from a standard seize analysis) and the coefficient was estimated to be 60 (based on poorly sorted fine sand, Fetter 1994). Based on equation (3.1), the hydraulic conductivity for the soil sample using the Hazen Method was estimated to be 1.18×10^{-4} m/sec, which is comparable to the hydraulic conductivity estimated from the rising head tests completed on individual wells at the site.

Annual groundwater recharge rates for the site were estimated using a simple linear runoff/infiltration model as is commonly used in stormwater runoff estimates. The total annual groundwater recharge at the site was calculated based on an annual average precipitation surplus (i.e. total annual precipitation –

evapotranspiration) and an allowance for infiltration based on soil type (sandy soils) and slope. Equation (3.2) was used to model the annual groundwater recharge:

(3.2) $$R = iS$$

where:

R = Annual Recharge Rate (m/year)

i = Infiltration Factor (unitless) from Viessman and Lewis, 2003 for sandy soils

S = Annual Surplus (m/year) from Chapmen and Thomas, 1968

Runoff coefficients were then inverted to represent infiltration of the annual precipitation surplus as opposed to runoff. Recharge to the sandy soils and the woodwaste pile were assumed to be the same for the purposes of this research.

Based on equation (3.2), the annual recharge volume for the site was estimated to be 0.24 m/year based on an infiltration factor for sandy soil of 0.8 and an annual surplus for the Terrace Bay area of 0.3 m, which was obtained from *The Climate in Northern Ontario* by Chapman & Thomas (1968).

3.5 Water Monitoring Program

The annual monitoring program for the woodwaste study site consists of two field monitoring and sampling of groundwater and surface water per year (spring and fall).

3.5.1 Groundwater and Surface Water Sampling Program

Groundwater samples were collected from existing monitoring wells located at the site and from surface water locations in the downgradient Lake from 2003 to 2008 to assess water quality at the site.

The monitoring locations are summarized below and shown on Figure 3.1. Distances to each well location were measured from the toe of the woodwaste pile.

Groundwater:

- MW1: West toe of woodwaste pile (source well).
- MW2: 10 m east and upgradient of the woodwaste pile (background well).
- MW3: 13 m west and downgradient of woodwaste pile.
- MW4: 38 m east and upgradient of the woodwaste pile (background well).
- MW5: 98 m west and downgradient of woodwaste pile.
- MW6: 142 m west and downgradient of woodwaste pile.
- MW7: 158 m west and downgradient of woodwaste pile.
- MW8: 130 m west and downgradient of woodwaste pile.

Surface Water:

- SW1: 6 km upstream of woodwaste pile.
- SW2: Directly downgradient of woodwaste pile.

3.5.2 Monitoring and Sampling Protocols

The following monitoring and sampling protocols for groundwater and surface water were followed at the site from 2003 to 2008.

The conditions of the monitoring wells were assessed and documented during each sampling event to ensure representative groundwater samples are obtained from each sample location. Static groundwater levels in the monitoring wells were measured relative to the top of the riser pipes using an electronic water level meter and recorded. Following water level measurements, standing water was purged from the wells to obtain fresh formation water for collection and analysis. Dedicated Waterra foot valves and polyethylene tubing were used to purge approximately three well casing volumes of groundwater from each well prior to sample collection. The tubing inlet was placed at approximately the mid height of the well screen in order to collected representative water from the aquifer.

Prior to sample collection, an aliquot of water from each well was field tested for pH, temperature and conductivity for comparison to laboratory results. Following purging, groundwater samples were collected directly from the pumping system into laboratory-supplied cleaned bottles for chemical analysis. Groundwater samples for major cations and metals were field-filtered using 0.45 micro inline filters prior to placing the samples in the laboratory-supplied bottles to remove solids from the samples. The cations and metals samples were also acidified in the field with nitric acid. The samples were stored in insulated containers with ice packs and shipped to a certified and accredited laboratory for chemical analysis.

Prior to collecting surface water samples at the upstream and downstream locations, pH, temperature and conductivity were measured. Surface water samples were collected from the lake while taking care to minimize disturbance of sediment in the water.

3.5.3 Laboratory Analysis

Laboratory analysis of water samples was completed by a Canadian Association for Laboratory Accreditation (CALA) accredited laboratory.

The analytical program comprised the suite of chemical parameters based on typical woodwaste leachate indicator parameters, as summarized in Table 3.4.

The analytical methods followed by the laboratory for the analysis of woodwaste, soil and water are provided below:

- Toxicity Characterization Leaching Procedure (TCLP):
    - pH for woodwaste and soil: MOE Regulation 461/106
    - Mercury for woodwaste and soil: MOE SW846 7470A

  - Metals for woodwaste and soil: EPA 200.8

- Soil for major cations: EPA 6010 B
- Water for major anions: American Public Health Association (APHA) 4110 B
- Water for cations: APHA 3120 B
- Water for alkalinity: APHA 2320 B
- Water for conductivity: APHA 2510 B
- Water for pH: APHA 4500 H
- Water for colour: COL-TRU
- Water for turbidity: APHA 2130 B

3.5.4 Quality Assurance/Quality Control (QA/QC)

Field QA/QC was established by following procedures outlined in the MOE Standards Development Branch *Guidance on Sampling and Analytical Methods for use at Contaminated Sites in Ontario* (December, 1996).

Existing dedicated Waterra foot valves and tubing were used to sample each well. Clean disposable nitrile gloves were worn during purging and sampling, and then discarded and replaced after purging each well or collecting each sample to prevent sample contamination and to maintain sample integrity. None of the maximum hold times were exceeded. Internal QC analyses including replicates, method blanks, standard reference materials and matrix spikes were also completed by the laboratory.

Ion balances were calculated and compared to the acceptable difference outlined in Standard Methods (American Public Health Association, APHA, 17th Edition, 1991) as a check on the results. Based on the Standard Methods, the acceptable percent difference for ion balances with the anion concentrations present in these samples is 2 to 5%, dependent on the anion concentration. Since the standards are difficult, in practice, to meet due to the highly variable nature and matrices of field samples, 10% is generally considered acceptable. However, the chemistry of groundwater affected by leachate can be complex and should not necessarily be expected to meet this electrochemical balance since other charged ions not considered may have a significant impact on the balance. Therefore, only the anion-cation balances of background monitoring wells are considered in detail, or where the sources of error were identifiable.

3.5.5 Water Quality Assessment Criteria

The following assessment criteria were applied to the groundwater and surface water analytical results and are considered to be applicable to woodwaste landfill sites in Ontario.

The groundwater data at the study site have been referenced to criteria calculated based on methods outlined in MOE Guideline B-7 (1994), commonly known as the Reasonable Use Guideline (RUG). RUG allows off-site impact from disposal sites within established guidelines based on the reasonable use of the downgradient groundwater now or in the future in order to allow for attenuation of impacts while protecting existing and potential downgradient groundwater users. Typically, the reasonable use of the groundwater is considered to be drinking water and the criteria are calculated based on the Ontario Drinking Water Standards (ODWS). When based on the ODWS, the guideline allows for increases of up to 25 or 50 percent of the difference between background concentrations and the ODWS for health-related and non-health-related parameters, respectively.

For compliance purposes, the RUG criteria apply only in groundwater at the designated boundary (typically the property or attenuation zone boundary). Since the Lake forms the potential downgradient boundary to the west and the mill controls all of the downgradient land in which groundwater could be used in this direction, the assumption of drinking water as the reasonable use for the groundwater west of the site is considered to be conservative. RUG criteria at the study site have been calculated based on background concentrations considered to be represented by the mean results (2003 to 2008) from MW2 and MW4, located east and upgradient of the pile.

The quality of water discharging to the downgradient Lake has also been referenced to the Provincial Water Quality Objectives (PWQO) for comparison purposes, although these criteria are generally only applied to surface water. Groundwater quality from wells located closest to the lake (MW6, MW7, MW8, MW9 and MW10) are compared to the PWQO criteria only for comparison purposes to assess the potential water quality discharging to the lake. Surface water results for samples collected from the Lake upstream (SW1) and downstream (SW2) are compared to PWQO criteria.

3.5.6 Water Characterization Trends

Time series graphs (provided in Appendix E) were generated for selected woodwaste indicator parameters (alkalinity, TDS, hardness, DOC, chloride, arsenic, barium, iron and manganese) to facilitate identification of trends and progressive water quality variations over time.

In addition, water quality characterization plots using the Durov method were prepared. Where concentrations were below the laboratory's limit of quantification, a concentration equal to the detection limit was used for statistical and graphical purposes. Durov plots are provided in Appendix E.

3.6 Water Quality Results

The following sections summarize the water quality results from 2003 to 2008.

3.6.1 Field Testing Results

Field testing results for pH, temperature and conductivity from 2003 to 2008 are summarized in Appendix F.

Conductivity, temperature and pH levels at each sample location have been relatively stable with no significant trends since sampling began in 2003. The pH in source, downgradient and background water quality appears to be similar with no apparent trends. However, conductivity levels were notably elevated in source and downgradient water samples relative to background water samples.

3.6.2 Groundwater Quality and Leachate Plumes

Historical analytical results are summarized in Appendix F. The applicable MOE RUG criteria and exceedances are also highlighted in Appendix F and summarized in the following sections. Time series graphs of selected indicator parameters to illustrate water quality over time and Durov plots are provided in Appendix E.

3.6.2.1 Upgradient (Background) Groundwater Quality

Based on the apparent direction of groundwater flow since 2003, monitoring wells MW2 and MW4 appear to be upgradient of the woodwaste pile and are considered to represent background water quality for the purposes of assessing the water quality at the site. Both monitoring wells are located east of the woodwaste pile.

Since 2003 there have been very few exceedances of the applicable RUG criteria in groundwater at both background locations MW2 and MW4. The chemistry of water in MW2 and MW4 are generally similar, with the exception of slightly elevated conductivity, TDS, DOC, hardness, alkalinity, chloride and sodium concentrations in MW2 relative to MW4. The most current results (2008) for MW2 and MW4 are generally consistent. No trends in the historical analytical results are apparent for groundwater at these locations. The Durov plots for both

MW2 and MW4 contained in Appendix E indicate bicarbonate and calcium dominated water.

3.6.2.2 Source Groundwater Quality

Monitoring wells MW1 and MW3 are located on the western toe of the woodwaste pile and are considered to represent source water quality.

Parameters with elevated concentrations relative to background and exceedances of the RUG criteria since 2003 are summarized and compared with background conditions in Table 3.5.

Since 2003, barium concentrations at MW1 and MW3, and the chromium concentration at MW3 only slightly exceeded the RUG criteria. Concentrations of general chemistry, major anions and cations, and metals measured at MW1 and MW3 were notably elevated relative to background concentrations at MW2 and MW4. The time series graphs (see Appendix E) indicate increasing trends for alkalinity, hardness, barium, iron and manganese at MW1 and MW3, as well as for arsenic at MW1.

The Durov plot for MW1 (Appendix E) indicates bicarbonate and calcium dominated water, with no apparent trends. The plot for MW3 indicates bicarbonate dominated water with no dominant cation.

3.6.2.3 Downgradient Groundwater Quality

Based on the apparent direction of groundwater flow, monitoring wells MW5, MW6, MW7, MW8, MW9 and MW10 appear to be in the potential downgradient direction of the woodwaste pile and are considered to represent downgradient water quality. However, the analytical results for MW6, MW7 and MW10 suggest that these wells may be located cross-gradient of the leachate plume. Since 2003 no exceedances of the RUG criteria have been measured at monitoring wells MW6 or MW7. TDS has been slightly exceeded at MW10; however, no metal criteria have been exceeded at this location. Parameters with elevated concentrations relative to background and exceedances of the RUG criteria since 2003 are summarized in Table 3.6.

Concentrations of general chemistry, major anions and cations, and metals measured at MW5, MW8, MW9 and MW10 were elevated relative to background concentrations. However, concentrations at these wells generally had lower concentrations than source wells MW1 and MW3 (see Table 3.6). Water quality in MW6 and MW7 is generally similar to background water quality. The average concentrations and the estimated extent of the leachate plume area are shown on Figure 3.5.

The time series graphs indicate a slight increasing trend for DOC at MW5 and MW8; however, no other trends were apparent at these downgradient wells. The Durov plots (Appendix E) indicate bicarbonate and calcium dominated water.

3.6.2.4 Groundwater Quality Discharging to the Lake

Monitoring wells within the leachate plume MW8 and MW9, located closest to the downgradient Lake, were also compared to PWQO criteria (MOE surface water criteria) to assess the quality of water discharging to the Lake. Results were compared to PWQO criteria for comparison purposes only since these criteria generally only apply to surface water. A summary of the results compared to PWQO criteria are provided in Appendix F.

Parameters with concentrations exceeding PWQO criteria since sampling began are summarized in Table 3.7.

3.6.2.5 Surface Water (Lake) Quality

Surface water samples were collected directly from the Lake downgradient (SW2) and approximately 6 km upstream (SW1) of the woodwaste pile site to assess lake water quality. Surface water sample locations are shown on Figure 3.1.

A summary of the surface water sample results are provided in Appendix F. Surface water samples collected directly downgradient of the woodwaste pile site (SW2) were similar to upstream lake samples (SW1), with no exceedances of the PWQO criteria. Analytical results for downstream samples do not indicate any measurable leachate impacts from the woodwaste pile.

3.7 Summary of Groundwater Monitoring Results

3.7.1 Water Quality

Several parameters measured in the groundwater adjacent to and downgradient of the woodwaste pile exceeded the RUG criteria, most consistently TDS, colour, DOC, aluminum, arsenic, barium, chromium, iron and manganese. Of these parameters, elevated concentrations of barium and chromium were only measured in the source wells and were below the ODWS criteria.

Concentrations of metals in the woodwaste were elevated relative to both upgradient and downgradient soil samples collected at the site. The elevated metals in the woodwaste appear to be the source of the elevated dissolved metals in the groundwater downgradient of the woodwaste pile. In the woodwaste, elevated concentrations of aluminum, barium, calcium, iron, magnesium, manganese, molybdenum, nickel, phosphorus, uranium and vanadium were present, which is generally consistent with the elevated metals measured in the groundwater.

TDS, colour, DOC, aluminum, iron and manganese are considered aesthetic parameters and are not considered health-related according to the ODWS. However, arsenic is considered a health-related parameter sometimes found at higher levels in groundwater in hard rock areas and in association with mine waste through the dissolution of arsenic containing minerals. The elevated arsenic concentration in source and downgradient groundwater is not expected to be associated with the disposal of this woodwaste and there is no site specific information regarding a potential source of arsenic at the site. No arsenic, however, was detected in the upgradient wells MW2 and MW4. Further investigation would be required in order to determine the source of arsenic at the site.

Increasing trends were apparent for alkalinity, hardness, barium and iron at source wells MW1 and MW3 and for arsenic at MW1. No definitive increasing trends were apparent for indicator parameters in downgradient wells located near the Lake (i.e. MW5, MW6, MW7 and MW8) indicating that the leachate plume may have stabilized over the 20 years of leaching.

Based on historical and current water quality results, groundwater impacts appear to extend at least 200 m west-southwest of the woodwaste pile in the area of MW8 and MW9. The water quality at MW10, which had slightly elevated leachate indicator parameters relative to background water quality at MW2, indicates that this well is located near the southern limit of the leachate plume. The northern limit of the leachate plume does not appear to extend as far north as MW6 and MW7, based on the analytical results for these wells, which are similar to background water quality. An illustration of the average concentrations (2003 to 2008) for the predominant woodwaste leachate parameters TDS, DOC, arsenic, barium, iron and manganese is provided on Figure 3.5, which is a good indicator of the extent of the leachate plume.

Groundwater quality and off-site impacts, although important, are not considered to be the primary concerns at this site because the groundwater is unlikely to be used for drinking water or other purposes since downgradient attenuation areas are within the mill property. The primary concern at this site is the potential for surface water impact since the site is bounded by the Lake to which local groundwater discharges.

Groundwater monitoring results for wells located near the Lake were also compared to surface water criteria (i.e. PWQO) to identify the issues of greatest potential concern for surface water impact. This assessment indicates that the compounds of concern in the groundwater, which exceeded the PWQO criteria, are consistently arsenic, cobalt, iron and vanadium; however, these elevated concentrations were not apparent in surface water collected in the Lake directly downgradient of the woodwaste pile in SW2, which had water quality similar to upstream water quality in SW1.

Impacts to the Lake in association with the woodwaste pile do not appear to be significant based on groundwater quality near the lake as well as surface water quality directly downgradient of the woodwaste pile site. Furthermore, no definitive increasing trends were apparent in wells located within the assumed leachate pathway (i.e. MW5, MW8 and MW9) suggesting that the leachate plume may have stabilized; however, continued monitoring is required to assess water quality and trends over time downgradient of the site.

Based on the current results and interpreted groundwater flow regime, the monitoring well network appears to be reasonably monitoring the lateral extent of the leachate plume downgradient of the woodwaste pile site.

3.7.2 Contaminant Life Span Calculation

The contaminating lifespan is the length of time required for the concentration of a contaminant to meet or reduce below applicable Reasonable Use Guidelines (RUG). The contaminating lifespan of each of the contaminants found to exceed the established RUG Criteria at the woodwaste pile (TDS, DOC, iron, manganese, barium and arsenic) were calculated based on the R.K. Rowe method (Rowe, 1991), as shown in equation (3.3). This method considers only dilution and is considered conservative in the estimation of the contaminating lifespan of the site.

(3.3) $t = (-mtc / q_0 \times C_0 \times A_0) * \ln(C_t / C_0) * (1 \times 10^{+6}\ mg/kg * 1\ m^3 / 1{,}000\ L)$

where:

t = *the contaminating lifespan (in years)*

mtc = *the total mass of the contaminant in the waste (kg)*

C_o = *the average concentration of the contaminant at MW1 and MW3 (mg/L)*

C_t = *the target (RUG Criteria) concentration of the contaminant (mg/L)*

A_o = *the total landfill area (m^2)*

q_o = *the infiltration rate through the landfill (m/year)*

Values of the mtc were calculated using equation (3.4).

(3.4) *mtc (kg) = Mass to Waste Proportion (mg/kg) * Landfill Capacity (m^3)*Waste Density (kg/m^3) * (1 kg / 1 x 10^{+6} mg)*

The woodwaste volume and area were obtained from the Site Geological Assessment (2003). The estimated woodwaste density of 500 kg/m^3 was based on specific gravities provided in the paper, *The Moisture Content and Specific Gravity of the Woodwaste and Wood of Northern Pulpwood Species*, United States Department of Agriculture Forest Service, 1972 (USDA, 1972).

The mass to waste proportion was calculated using equation (3.5).

(3.5) *Mass to Waste Proportion (mg/kg) = C_0 (mg/L) * Moisture Content (kg/kg) * (1 m^3 / 1,000 kg * 1,000 L / 1 m^3)*

An average mass based moisture content of in-situ woodwaste of 69% (see Table 5.1, Section 5) was used, which is based on laboratory analysis completed by the laboratory. Values for C_o consisted of the average concentrations from source wells MW1 and MW3 from 2003 to 2008. Values for C_t were based on RUG criteria calculations using analytical data from background wells MW2 and MW4 from 2003 to 2008.

The value of q_0 was determined using equation (3.2) based on an assumed annual surplus of 0.3 m (Chapman & Thomas, 1968) and an infiltration rate of 0.8 for sandy soils (Viessman and Lewis, 2003) which gives a recharge rate of 0.240 m/year.

The results of the contaminating lifespan calculations are summarized in Table 3.8.

Based on the calculations shown in Table 3.8, DOC (33.3 years), iron (48.3 years) and manganese (32.4 years) have the longest contaminating life span at the study site, which is consistent with the results of the annual monitoring program at the site. The shortest contaminating life span is for barium (3.7 years).

3.7.3 Leachate Production Calculation

Leachate is generated as surface water and the excess liquid within the waste filters through the waste mass. The volume (V) of leachate generated annually was estimated by multiplying equation (3.2) by the area (A) of the woodwaste pile, as shown in equation (3.6).

$$V = iSA \qquad (3.6)$$

Since the current MOE CofA for the site has a condition that all woodwaste must be removed from the site in five years (2009 to 2013), leachate production rates were calculated considering this condition.

Using the data and equation (3.6), theoretical annual leachate volumes were calculated. The results are summarized in Table 3.9.

Based on the calculation results, leachate production would be reduced from 6,144 m^3 in 2009 to 1,229 m^3 in 2013 (proposed site closure date).

3.7.4 Proposed Trigger Program

As part of this research, a proposed trigger program for the woodwaste landfill site has been developed. The purpose of the trigger program would be to assess water quality at the site, provide sufficiently conservative advance warnings for potential off-site impacts and establish appropriate site specific contingency plans in the event the established trigger criteria are exceeded.

3.7.4.1 Groundwater

Trigger Criteria

Trigger criteria were established using historical water quality monitoring data for the site. Based on the water quality at the site, trigger criteria have been developed considering surface water criteria, PWQO, and groundwater criteria, *Ontario Drinking Water Standards* (ODWS) and RUG.

RUG criteria were calculated using the 95th percentile of background concentrations at MW4. The 95th percentile is slightly less than two standard deviations above the mean. Where concentrations were below the laboratory's limit of quantification, a concentration equal to the detection limit was used for statistical purposes.

For groundwater, trigger criteria were developed using the conditions below:

1. If no RUG criteria exists or if PWQO criteria are less than RUG criteria, then PWQO criteria becomes the trigger.

2. If PWQO criteria are greater than RUG criteria, then the average of PWQO and RUG criteria becomes the trigger.
3. If PWQO criteria do not exist, then RUG criteria become the trigger.

The proposed trigger parameters and criteria are summarized in Table 3.10.

Trigger Location

Since there are no groundwater monitoring wells directly along the shoreline of the Lake and the mill's property boundary, it is recommended that a new well (MW11) be installed directly downgradient of existing monitoring wells MW8, MW9 and MW10 along the shoreline of the Lake, as shown on Figure 3.6 (Proposed Trigger Program). This new well will be the trigger location for assessing groundwater quality discharging from the site to the Lake and instrumental to the implementation of the trigger program.

3.7.4.2 Surface Water

Trigger Criteria

Similar to groundwater, the 95^{th} percentile of the background surface water results (SW1) was used to represent background concentrations in the Lake. The trigger criteria were calculated using the same formula used to develop the RUG criteria (i.e. half the difference between the PWQO and background added to the background concentration). Where concentrations were below the laboratory's limit of quantification, a concentration equal to the detection limit was used for statistical purposes; however, laboratory detection limits above the PWQO were not considered in the calculation since they would bias the criteria high.

The proposed trigger parameters and criteria are summarized in Table 3.11.

Trigger Location

The proposed surface water trigger location is SW2, located in the Lake directly downgradient of MW8, MW9, MW10 and proposed well MW11.

3.7.4.3 Trigger Responses

A trigger response is proposed if the concentrations of two or more parameters exceed the trigger criteria at one location on one date. The initial response will be to collect replicate sample sets (filtered samples for surface water) on the next regular monitoring event for laboratory analysis of the exceedance parameters. If the reported results for both the prime and replicate samples are below the trigger criteria, no further response will be required and the next regular sampling event will be considered the first sample for trigger consideration. For surface water, if the filtered results are less than the trigger criteria, factors affecting suspended solids in the samples will be assessed with the objective to minimize the introduction of sediment in the samples on the next sampling event. If the results of the prime and replicate samples confirm the elevated concentrations, the contingency process, as outlined below, will be implemented.

3.7.4.4 Contingency Plans

In the event the trigger program results indicate that contingency plans should be implemented, the first step will involve a detailed review of long term trends for the complete monitoring program at the trigger location(s) as well as a comprehensive assessment of site activities and conditions that could be contributing to the apparent impacts. This process would involve the preparation of a detailed written report prepared in consultation with the MOE that identifies, to the extent possible, the causes of the impacts and potential mitigation strategies, including potential environmental responses that could be expected from the mitigation efforts (i.e. estimated time line for measureable improvement). Recommendations for further assessment and mitigative responses will also be included in the report.

Assessment and mitigative responses may include the following:

1. Install additional monitoring wells and establish surface water sample locations to assess the extent and source of impacts.

2. Complete a site specific risk assessment and, if appropriate, develop site specific criteria.

3. Develop and implement a remedial action plan to address identified impacts (i.e. engineered barriers, pump and treat system, installation of a perimeter leachate collection system, etc).

In addition, water quality at the site is expected to improve over time and potentially return to background conditions as the woodwaste is progressively removed from the site for use as an alternative energy use (hog fuel).

Parameter	Units	Upgradient Soil May 22, 2009	Downgradient Soil May 22, 2009	Woodwaste April 29, 2009
General Chemistry				
pH	pH	4.89	4.89	5.00
Total Carbon (C)	mg/kg	940	3,000	269,000
Total Inorganic Carbon (C)	mg/kg	<500	<500	190,000
Total Organic Carbon	mg/kg	930	2900	79,000
Anions				
Orthophosphate (P)	µg/g	0.2	<0.2	7 (2)
Chloride (Cl)	µg/g	<20	83	<100 (1)
Sulphate (SO4)	µg/g	<20	<20	<100 (3)
Nitrite (N)	µg/g	<0.5	<0.5	<0.5
Nitrate (N)	µg/g	<2	<2	<2
Nitrate + Nitrite	µg/g	<3	<3	<3
Leachable Metals				
Arsenic (As)	mg/L	<0.2	<0.2	<0.2
Barium (Ba)	mg/L	<0.2	<0.2	0.3
Boron (B)	mg/L	0.2	0.2	0.2
Cadmium (Cd)	mg/L	<0.05	<0.05	<0.05
Chromium (Cr)	mg/L	<0.1	<0.1	<0.1
Lead (Pb)	mg/L	<0.1	<0.1	<0.1
Mercury (Hg)	mg/L	<0.001	<0.001	<0.001
Selenium (Se)	mg/L	<0.1	<0.1	<0.1
Silver (Ag)	mg/L	<0.01	<0.01	<0.01
Uranium (U)	mg/L	<0.01	<0.01	<0.01

Table 3.1: Chemical Properties of Woodwaste and Soil

Parameter	Units	Upgradient Soil	Downgradient Soil	Woodwaste
		May 22, 2009	May 22, 2009	April 29, 2009
Acid Extractable Metals				
Aluminum (Al)	µg/g	6,200	9,300	3,600
Antimony (Sb)	µg/g	<0.2	<0.2	<0.2
Arsenic (As)	µg/g	1	2	<1
Barium (Ba)	µg/g	14	15	83
Beryllium (Be)	µg/g	0.3	0.4	<0.2
Cadmium (Cd)	µg/g	<0.1	<0.1	0.5
Calcium (Ca)	µg/g	1,400	1,200	14,000
Chromium (Cr)	µg/g	21	24	26
Cobalt (Co)	µg/g	4.5	5.2	3.8
Copper (Cu)	µg/g	6.2	6.7	13
Iron (Fe)	µg/g	9,700	10,000	8,300
Lead (Pb)	µg/g	2	3	3
Magnesium (Mg)	µg/g	2,800	2,900	2,900
Manganese (Mn)	µg/g	260	160	210
Mercury (Hg)	µg/g	<0.05	<0.05	<0.5
Molybdenum (Mo)	µg/g	<0.5	<0.5	10
Nickel (Ni)	µg/g	11	13	380
Phosphorus (P)	µg/g	360	350	480
Potassium (K)	µg/g	210	390	<0.5
Selenium (Se)	µg/g	<0.5	<0.5	<0.2
Silver (Ag)	µg/g	<0.2	<0.2	<100
Sodium (Na)	µg/g	<100	<100	21
Strontium (Sr)	µg/g	4	3	<0.05
Thallium (Tl)	µg/g	<0.05	0.06	0.25
Uranium (U)	µg/g	0.30	0.33	20
Vanadium (V)	µg/g	18	18	76
Zinc (Zn)	µg/g	13	15	

Table 3.1 (Continued): Chemical Properties of Woodwaste and Soil

Well ID		MW1	MW2	MW3	MW4	MW5
Ground Elevation (m)		90.42	91.09	90.63	92.08	89.13
Top of Pipe Elevation (m)		91.45	92.11	91.69	93.06	90.28
Bottom of Screen (m)		9.10	7.30	6.70	7.00	9.40
Screen Length (m)		1.50	1.50	1.50	1.50	1.50
10-Apr-03	SWL	7.21	5.69	6.41	6.64	8.47
	GWE	84.23	86.42	85.27	86.42	81.80
8-Jul-04	SWL	6.69	5.16	5.90	6.06	7.93
	GWE	84.76	86.95	85.79	87.00	82.35
26-Oct-04	SWL	6.68	5.12	5.94	6.12	8.02
	GWE	84.77	86.99	85.75	86.94	82.26
14-Jul-05	SWL	6.51	4.98	5.73	5.91	7.82
	GWE	84.94	87.13	85.95	87.15	82.46
25-Oct-05	SWL	6.47	5.00	5.77	5.89	7.80
	GWE	84.98	87.11	85.92	87.17	82.47
27-Jun-06	SWL	6.39	3.82	5.60	5.77	7.72
	GWE	85.06	88.29	86.09	87.29	82.56
26-Sep-06	SWL	6.45	5.16	5.93	6.14	8.05
	GWE	84.99	86.95	85.76	86.92	82.23
29-May-07	SWL	7.25	5.67	6.45	6.57	8.43
	GWE	84.19	86.44	85.23	86.48	81.84
19-Sep-07	SWL	6.96	5.47	6.20	6.38	8.17
	GWE	84.49	86.64	85.49	86.68	82.11
6-Jun-08	SWL	6.39	4.81	5.59	5.69	7.87
	GWE	85.06	87.30	86.10	87.37	82.41
8-Oct-08	SWL	6.15	4.60	5.37	5.65	7.71
	GWE	85.29	87.51	86.31	87.41	82.57
SWL = Static water level (m)						
GWE = Groundwater elevation (m)						

Table 3.2: Summary of Historical Groundwater Levels

Well ID		MW6	MW7	MW8	MW9	MW10
Ground Elevation (m)		88.33	88.63	88.32	88.45	88.70
Top of Pipe Elevation (m)		89.36	89.51	89.14	89.40	89.79
Bottom of Screen (m)		10.06	9.00	9.80	10.67	10.67
Screen Length (m)		1.50	1.50	1.50	3.05	3.05
10-Apr-03	SWL	9.95	-	-	-	-
	GWE	79.41	-	-	-	-
8-Jul-04	SWL	9.33	7.51	8.58	-	-
	GWE	80.03	81.99	80.57	-	-
26-Oct-04	SWL	9.46	7.66	8.59	-	-
	GWE	79.90	81.84	80.56	-	-
14-Jul-05	SWL	9.31	7.43	8.52	-	-
	GWE	80.05	82.07	80.62	-	-
25-Oct-05	SWL	9.34	7.53	8.49	-	-
	GWE	80.02	81.97	80.66	-	-
27-Jun-06	SWL	8.25	7.37	8.44	-	-
	GWE	81.11	82.14	80.70	-	-
26-Sep-06	SWL	9.50	7.66	8.72	-	-
	GWE	79.86	81.84	80.42	-	-
29-May-07	SWL	9.63	7.97	8.94	-	-
	GWE	79.73	81.54	80.21	-	-
19-Sep-07	SWL	9.46	7.73	8.72	8.70	8.58
	GWE	79.90	81.78	80.43	80.71	81.21
6-Jun-08	SWL	9.29	7.34	8.46	8.40	8.20
	GWE	80.07	82.17	80.69	81.01	81.60
8-Oct-08	SWL	9.39	7.39	8.49	8.35	8.05
	GWE	79.97	82.11	80.66	81.06	81.74
SWL = Static water level (m) GWE = Groundwater elevation (m)						

Table 3.2 (Continued): Summary of Historical Groundwater Levels

Well ID	Hydraulic Conductivity (m/sec)
MW1	2.42×10^{-5}
MW2	2.99×10^{-4}
MW3	5.53×10^{-5}
MW4	9.87×10^{-5}
MW5	4.45×10^{-5}
MW6	2.71×10^{-5}
Min	$2.42 \times 10\text{-}^{5}$
Max	2.99×10^{-4}
Average	9.15×10^{-5}

Table 3.3: Summary of Hydraulic Conductivities at Study Site

Sample Type	Parameters
Groundwater and Surface Water	pH, conductivity, colour, turbidity, alkalinity, total dissolved solids (TDS), total suspended solids (TSS), biological oxygen demand (BOD), dissolved organic carbon (DOC), chemical oxygen demand (COD), hardness, ammonia, tannins and lignins, total Kjeldahl nitrogen (TKN), major anions and cations, and metals.

Table 3.4: Summary of Analytical Program for Woodwaste Study Site

Parameters (mg/L)	RUG Criteria	MW2	MW4	MW1	MW3
		(average of results from 2003 to 2008)			
TDS	376.34	304.82	193.18	1218.64	1215.08
Colour	4.11	3.74	4.22	145.80	212.08
DOC	3.38	1.84	1.08	151.64	150.68
Aluminum	0.054	0.008	0.007	0.067	0.19
Arsenic	0.007	0.001	0.001	0.063	0.031
Barium	0.27	0.034	0.02	0.483	0.33
Chromium	0.015	0.004	0.004	0.011	0.019
Iron	0.18	0.054	0.055	43.59	45.53
Manganese	0.027	0.007	0.003	1.07	1.12

Table 3.5: Summary of Background Water Quality and Source Groundwater Impacts at the Study Site

Parameters (mg/L)	RUG Criteria	MW5	MW8	MW9	MW10
		(average results from 2003 to 2008)			
TDS	376.34	468.08	667.09	993.67	388.33
Colour	4.11	41.16	39.9	48.0	3.33
DOC	3.38	29.95	41.54	45.07	3.17
Aluminum	0.054	0.024	0.031	0.048	0.0078
Arsenic	0.007	0.025	0.057	0.032	0.001
Barium	0.27	0.08	0.146	0.30	0.046
Chromium	0.015	0.0001	0.0002	0.005	0.005
Iron	0.18	9.24	17.22	36.0	0.1
Manganese	0.027	0.714	0.53	0.65	0.0047

Table 3.6: Summary of Downgradient Groundwater Impacts at the Study Site

Parameters (mg/L)	PWQO Criteria	MW8	MW9
		(average results from 2003 to 2008)	
Arsenic	0.005	0.057	0.032
Cobalt	0.0009	0.0099	0.0129
Iron	0.3	17.22	36.0
Vanadium	0.006	0.53	0.65

Table 3.7: Summary of Groundwater Quality Discharging to Lake at the Study Site

Parameters	TDS	DOC	Iron	Manganese	Arsenic	Barium
Ave Leachate Conc (mg/L) C_o	1216.86	151.16	44.56	1.095	0.047	0.41
Mass Proportion to Waste (mg/kg)	832.45	100.94	31.27	0.72	0.03	0.28
Total Capacity (m^3)	156,000	156,000	156,000	156,000	156,000	156,000
Waste Density (kg/m^3)	500	500	500	500	500	500
Total Mass (kg)	64930.87	7873.06	2439.39	55.97	2.64	21.69
Infiltration Rate (m/year), q_o	0.240	0.240	0.240	0.240	0.240	0.240
Footprint Area (m^2)	25,600	25,600	25,600	25,600	25,600	25,600
Target Concentration (mg/L), C_t	376.34	3.38	0.18	0.027	0.007	0.27
Contaminating Lifespan (years)	**10.28**	**33.29**	**48.28**	**32.43**	**16.68**	**3.66**

Table 3.8: Contaminating Life Span Calculation

Year	Landfill Footprint Area (m^2)	Leachate Volume (m^3/yr)
January 2009	25,600	6,144
January 2010	20,480	4,915
January 2011	15,360	3,686
January 2012	10,240	2,457
January 2013	5,120	1,228
	Total	**18,432**

Table 3.9: Leachate Production Calculation

Parameter	Concentration (mg/L)	Condition
TDS	359	3
DOC	3.75	3
Manganese	0.03	3
Barium	0.271	3
Iron	0.25	2
Arsenic	0.005	1
Cobalt	0.0009	1
Vanadium	0.006	1

Table 3.10: Proposed Groundwater Triggers for the Study Site

Parameter	Concentration (mg/L)
Iron	0.25
Cobalt	0.0007
Vanadium	0.0055

Table 3.11: Proposed Surface Water Triggers for the Study Site

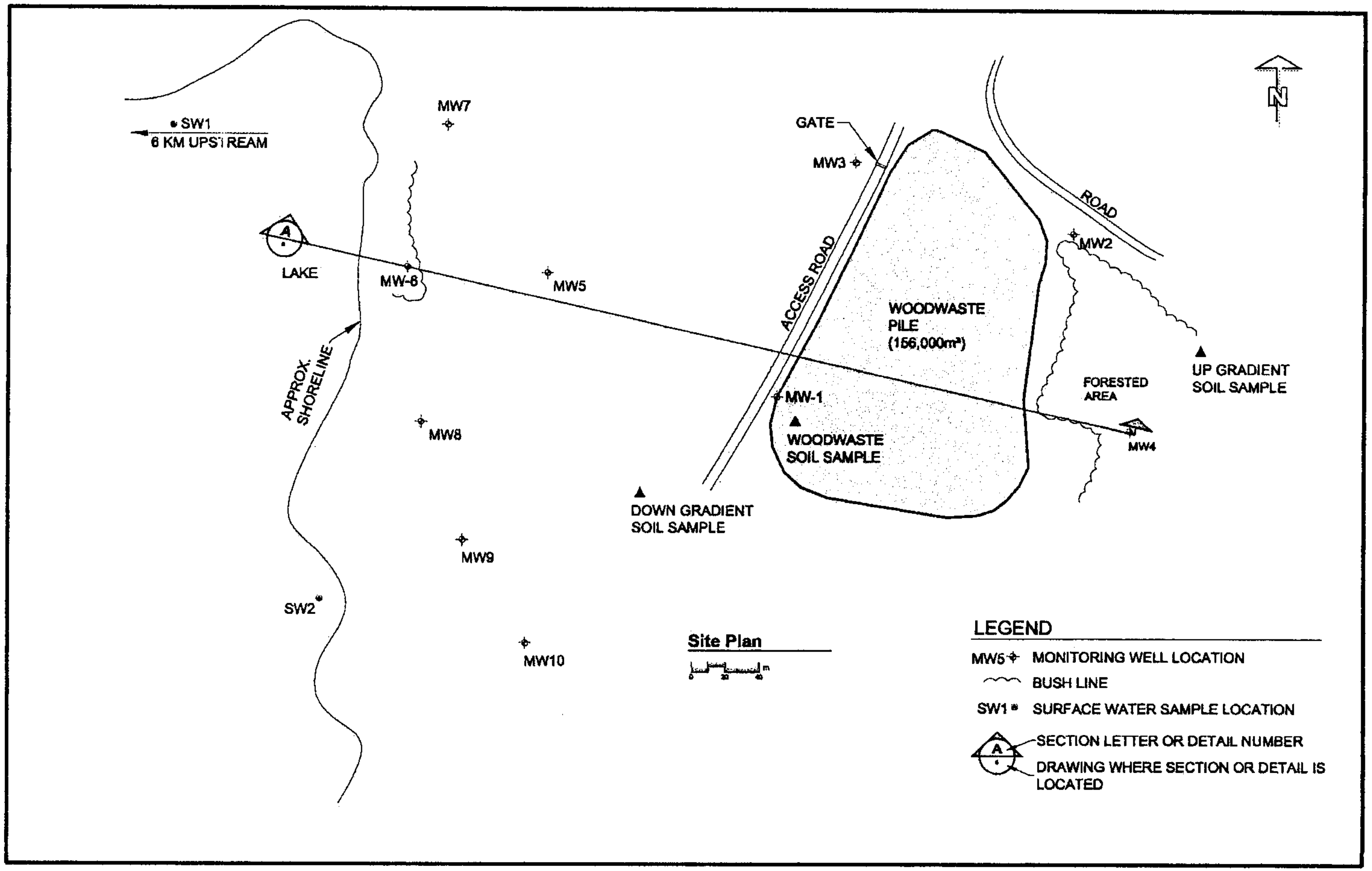


Figure 3.1: Site Layout

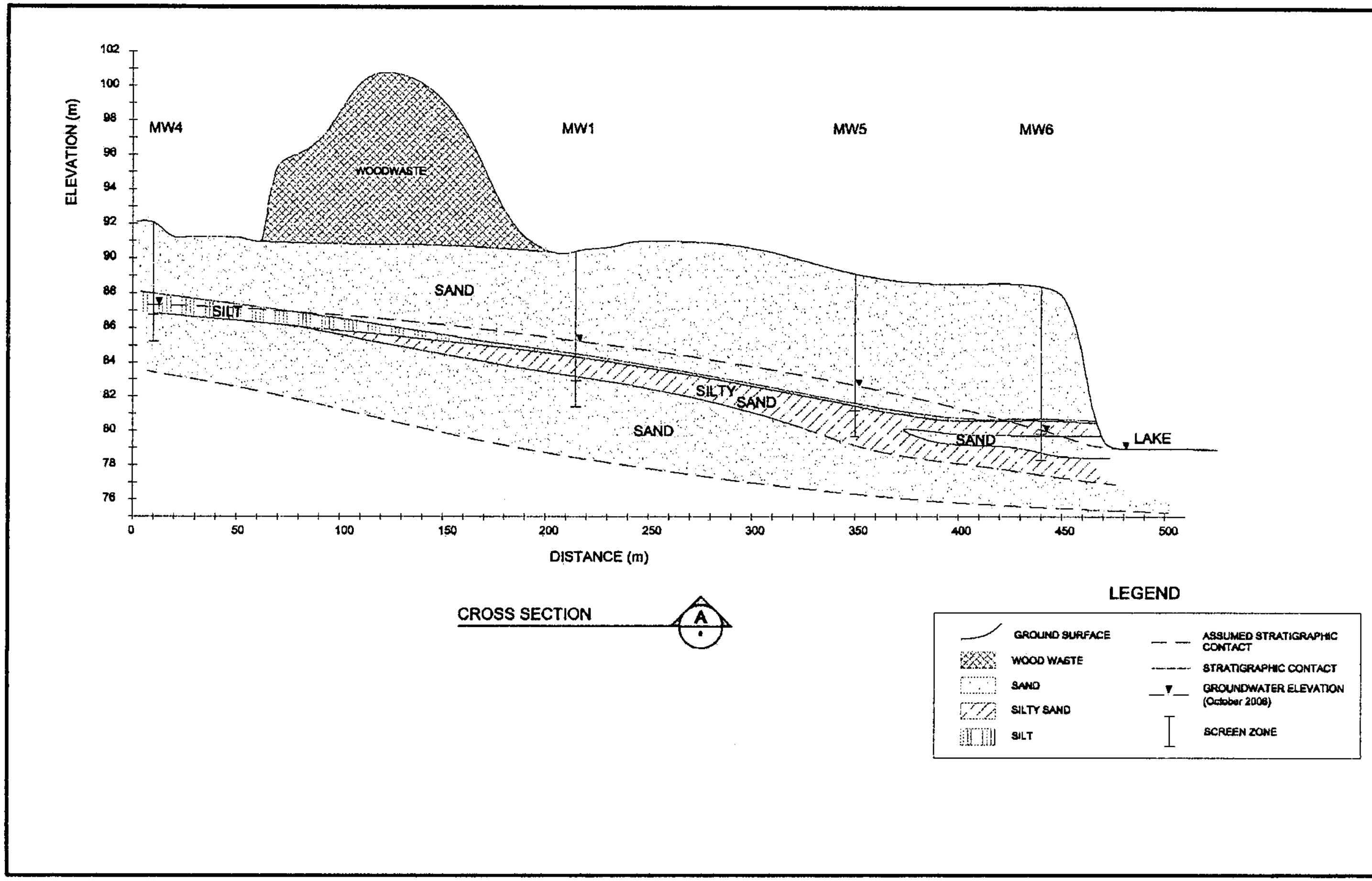


Figure 3.2: Geological Cross Section

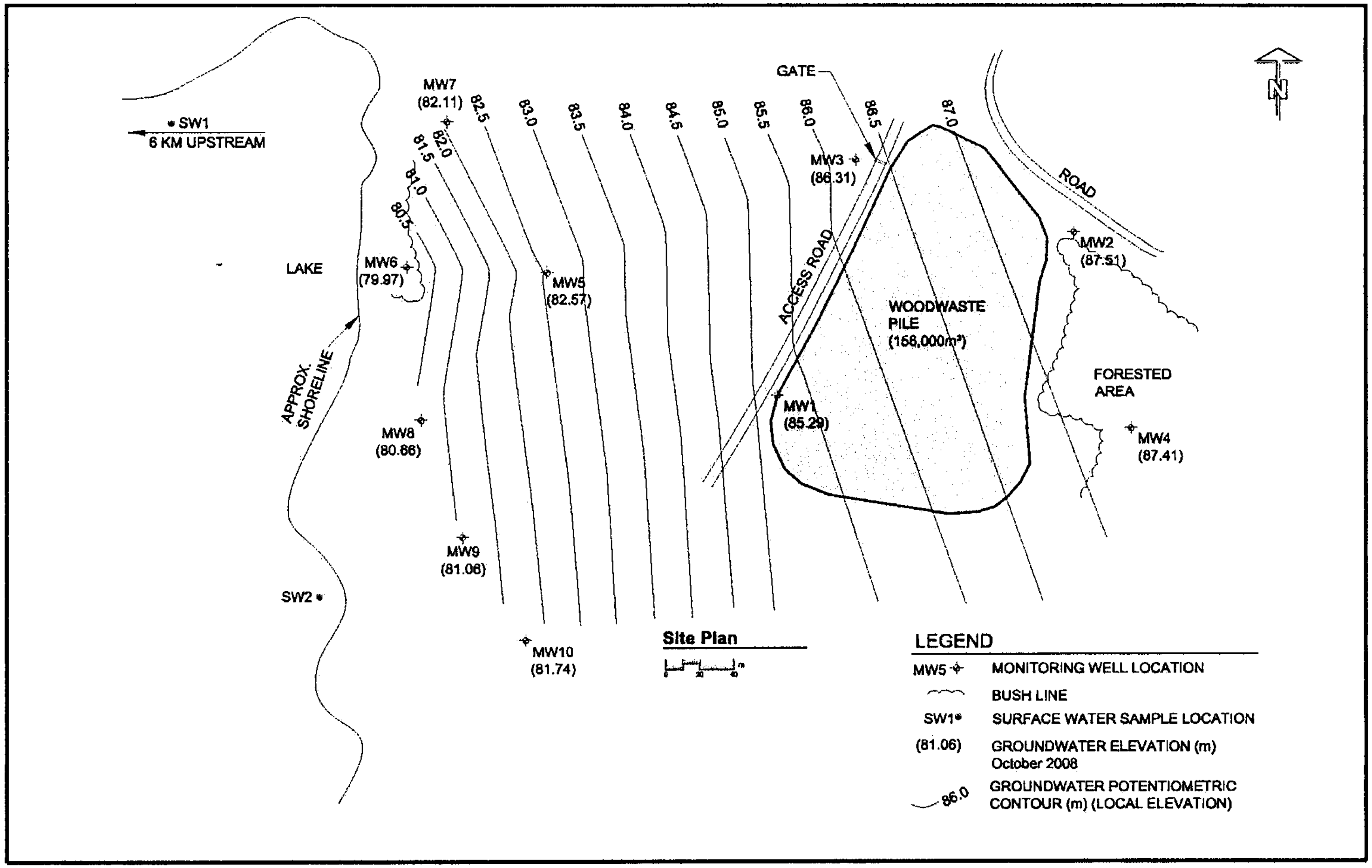


Figure 3.3: Groundwater Potentiometric Contour Plan

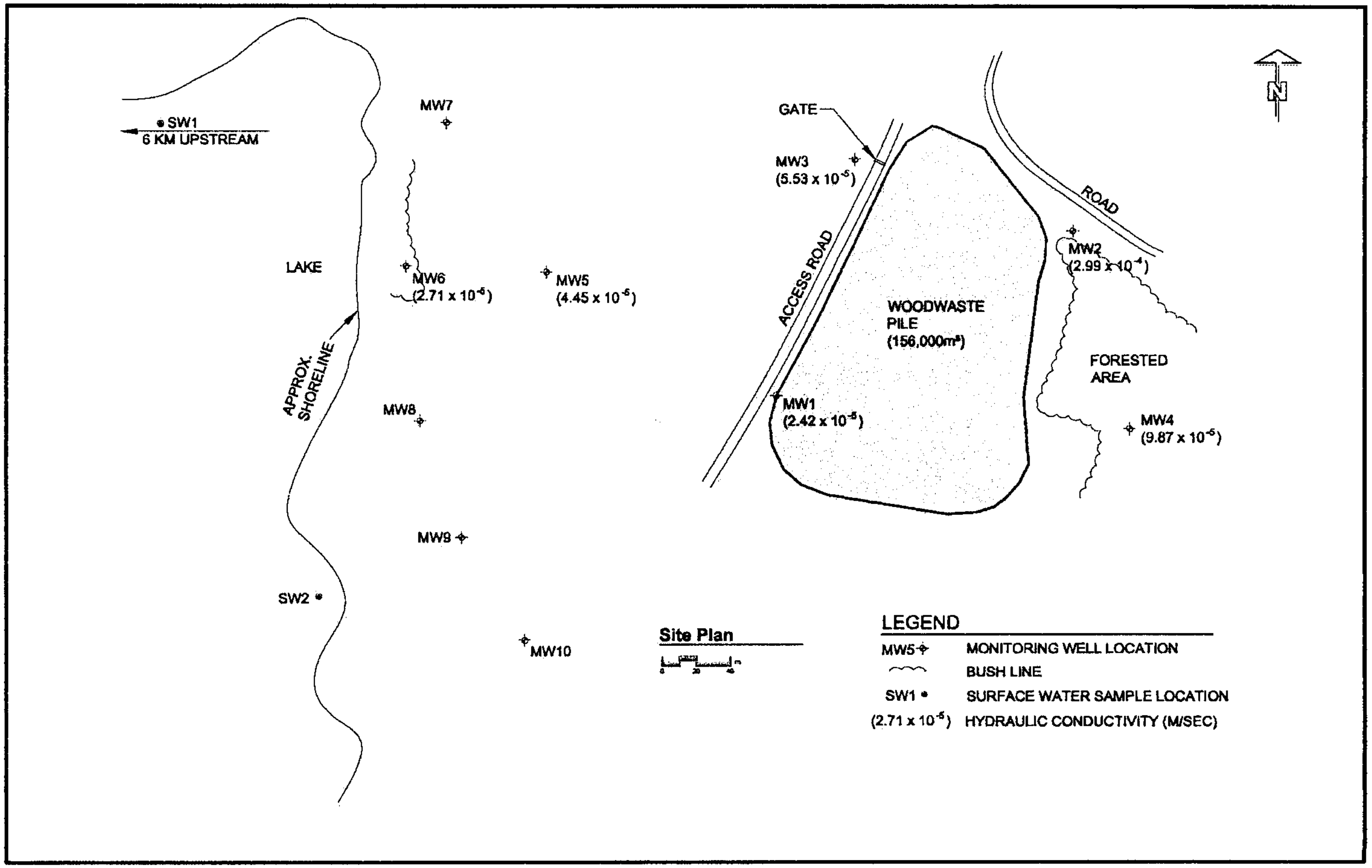


Figure 3.4: Site Hydraulic Conductivities

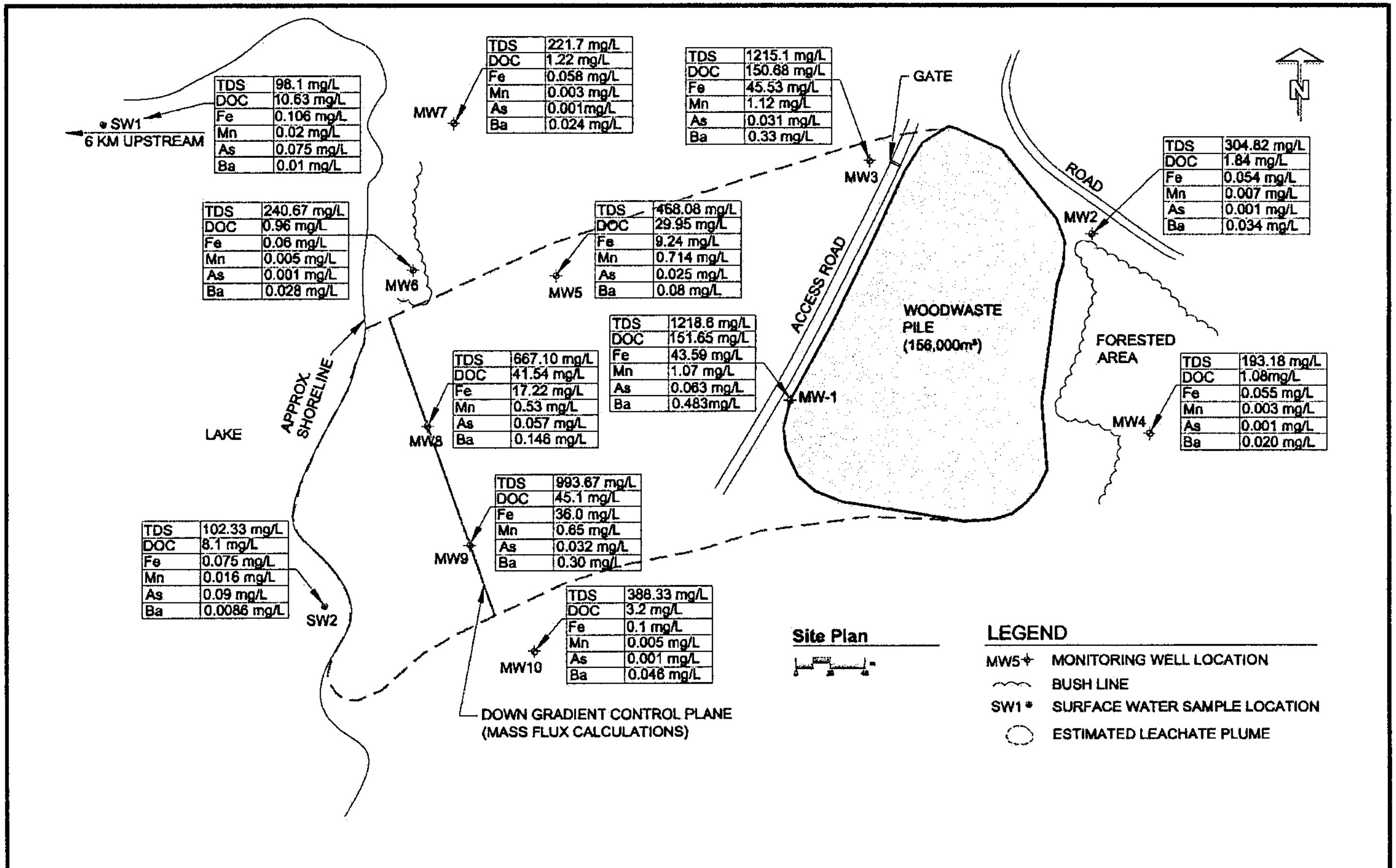


Figure 3.5: Woodwaste Leachate Indicator Parameters - Average Concentrations (2003 to 2008)

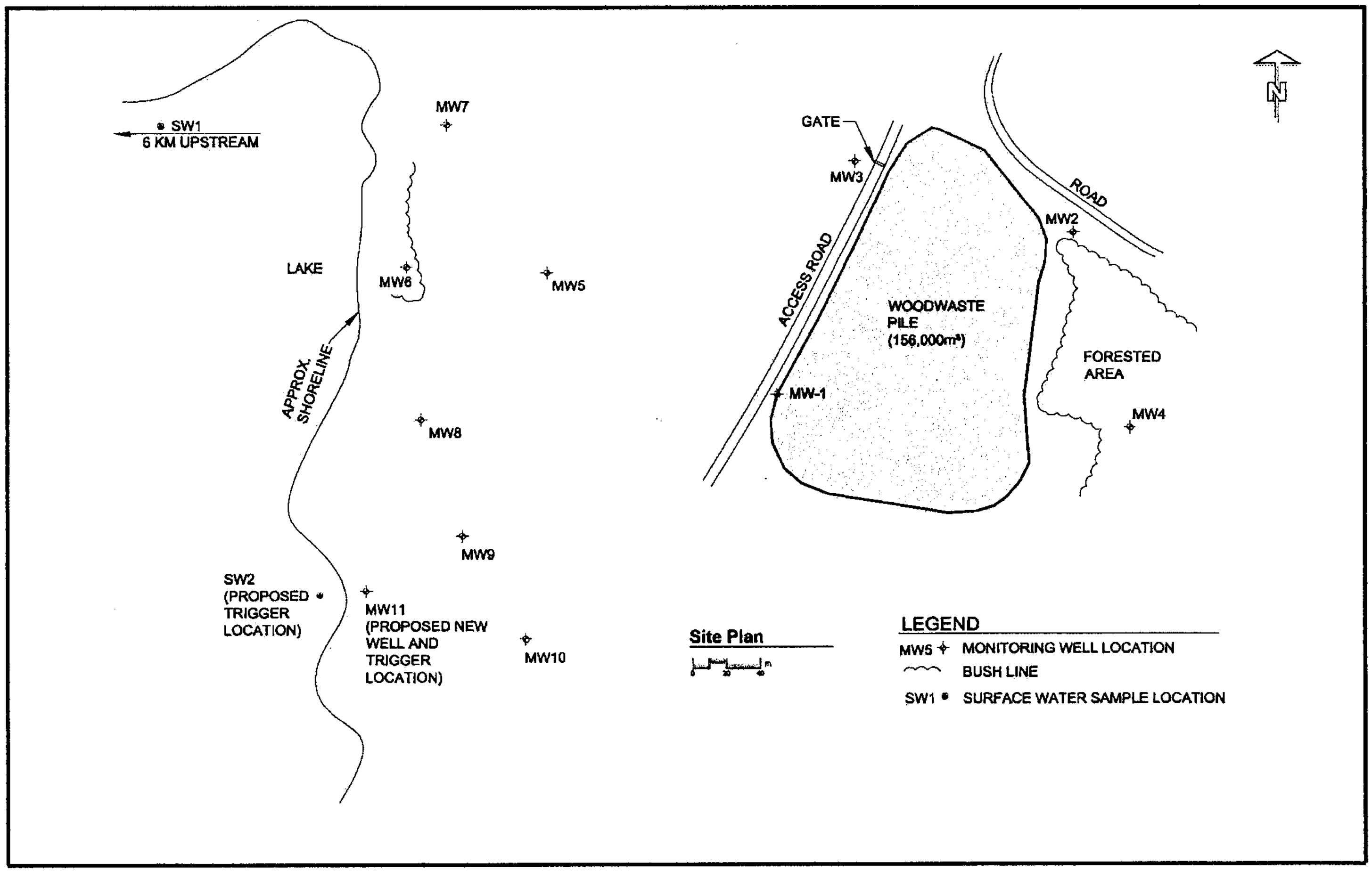


Figure 3.6: Proposed Trigger Program

4.0 Groundwater Modeling

4.1 Model Construction

The groundwater flow model was developed to simulate groundwater flow and contaminant fate and transport scenarios at the woodwaste disposal study site. The contaminants used for the transport model were the inorganic parameters that consistently exceeded the applicable MOE criteria for the site at source and some downgradient monitoring well locations (i.e. iron, manganese, barium and arsenic).

Visual MODFLOW finite difference grid was selected to encompass the woodwaste pile and potential leachate plume extents. The grid is 720 m long (68 columns) and 470 m wide (62 rows), as shown on Figure 4.1.

The model is divided into three layers for vertical refinement purposes; however, each vertical layer was assigned the same flow and transport parameters (i.e. hydraulic conductivity, storage, porosity, etc). The model considers homogenous conditions and the results should be viewed with this in mind.

4.2 Groundwater Flow Properties and Boundary Conditions

The groundwater flow properties selected for the study site, based on site specific information or literature values, are summarized in Table 4.1.

The site model was developed by establishing a constant head boundary along the east model boundary of the site (Figure 4.2) with a head value of 88 m which is consistent with the head values measured in nearby upgradient wells MW2 and MW4. A river boundary was established at the west model boundary to simulate the downgradient lake. The river stage (water level) was established at 79 m, which is consistent with levels measured in groundwater wells located near the lake (Figure 4.2), and the river bottom was established at 77.8 m, which is consistent with the bottom of the groundwater model. The bottom of the model was established as the depth of the deepest borehole drilled at the site (MW9). The north and south boundaries were established as no flow boundaries since groundwater flow at the site is generally from east to west toward the lake (Figure 4.2).

Groundwater levels from the 10 on-site monitoring wells (MW1 to MW10) were initially used to calibrate the groundwater flow model; however, due to large head differences between observed and simulated values at monitoring well MW7, this observation point was not considered in the model calibration. Since this observation well is located cross gradient of the plume, the data from this well are not considered to be significantly important to this model.

Calibration of the flow model was established by changing the model layers from initially one to three for vertical refinement and running PEST which adjusted the recharge and hydraulic conductivity to better match the observed and simulated heads at the monitoring well locations. Groundwater flow calibration runs are summarized on Table 4.2 (Flow Model Runs #1 to #3) and simulated versus observed head values at monitoring well locations are presented on Figures 4.3 to 4.5.

Note that for Run #3, the PEST run, the recharge to the site and the hydraulic conductivities were varied by the software to minimize the difference in hydraulic head between the simulated and observed results at the on-site monitoring well locations. As indicated in Figure 4.6, the maximum difference is approximately 0.5 m at MW3, the root mean squared in 0.344 m and the correlation coefficient of the fit is 0.997, which is very high.

4.3 Transport Properties and Boundary Conditions

The transport properties selected and the boundary conditions used for the study site are summarized in Table 4.3.

The recharge rate for the capped woodwaste pile was esitimated to be 0.0315 m/year using equation (3.2) with an infiltration rate of 0.105 (for clay, Viessman and Lewis, 2003) and an annual surplus of 0.3 m (Chapman & Thomas, 1968).

The diffusion coefficient (D) was determined from a literature value provided by Fetter (1994) which is an average D value for cations and anions in water, which is considered representative for the purposes of this model. Parameter specific diffusion coefficients were not applied since diffusion is not considered to be a significant transport mechanism at the study site since the groundwater flow rate is fast (i.e. 50 to 630 m/yr); therefore, the major transport mechanisms are likely advection and dispersion.

Longitudinal dispersivity (∂_L) was calculated using equation (4.1) as provided by Fetter (1994) for flow paths less than 3,500 m long.

(4.1) $$\partial_L = 0.0175L^{1.46}$$

where:

∂_L = Longitudinal Dispersivity (m)

L = length of flow path (m)

Values provided by Fetter (1994) for transverse (∂_T) (0.1 m) and vertical dispersivities (∂_V) (0.01 m) were used in the model.

Varying recharge concentrations were assigned to the woodwaste pile until the concentrations at source well MW1 generally matched average observed concentrations measured in MW1. The baseline recharge concentrations used for the transport model are provided in Table 4.3.

As discussed in Section 2.2.3.3 (Chapter 2), sorption values for arsenic (2.5×10^{-5} L/mg) and barium (1.1×10^{-5} L/mg) were obtained from U.S. EPA *Soil Screening Guidance Technical Background Document* (1996). These values represent metal adsorption to FeOx and solid organic matter. It is recognized that numerous other natural sorbents exist (e.g. clay and carbonate minerals); therefore, these values are considered conservative and will underpredict sorption for soils with significant amounts of such sorption sites. Since soil conditions at the study site do not contain clay, these sorption values were considered to be reasonable. The document provided sorption values at high, medium and low subsurface pH conditions (i.e. pH of 4.9, 6.8 and 8). Sorption values for barium and arsenic at the lower pH of 4.9 were selected for modeling purposes. This low pH was considered representative of the pH of soil at the study site (pH of 4.9 and 5).

4.4 Modeling Results

4.4.1 Groundwater Flow Transport Results

As described in Section 4.2, PEST was run to optimize the groundwater flow properties that would minimize the differences between the observed and simulated hydraulic heads at monitoring well locations. The results of the groundwater flow transport calibration results are presented in Table 4.2.

Based on the calibration results, Flow Model Run #3 using PEST resulted in similar simulated head and gradient values compared to observed conditions at the site. Figure 4.6 shows the site groundwater potentiometric contours for the calibrated flow model. Therefore, Flow Model Run #3 was considered to generally represent flow conditions at the site and was used for simulating the transport of leachate downgradient of the woodwaste pile.

4.4.2 Transport Model Results

The transport model was run with the baseline parameters for a simulation time of 9,125 days (25 years). Based on the results for Transport Model Runs #1 to #5 (Table 4.4), concentrations of iron, manganese, barium and arsenic stabilized at 3,285 days (9 years), which is considered to represent steady state conditions at the site (Figures 4.7 to 4.10).

The simulated transport model results were compared to observed source concentrations at well MW1 and average concentrations at downgradient wells MW8 and MW9 to assess the leachate plume. Model results were compared to average concentrations at MW8 and MW9 because the orientation of the plume simulated by the model was slightly more concentrated to the north (centred on MW8) relative to the observed plume (centred on MW9).

Initial transport runs were conducted with dispersion but no sorption. Good matching between simulated and observed results at MW1 and an average of MW8 and MW9 at steady state indicates that significant sorption was likely not occurring.

Figures 4.7 to 4.10 show that the plumes extend farther to the north than indicated by the observed results (see Figure 3.5). This could be due to more of a southwest trend to the groundwater flow than indicated by the modeling or the well screen at MW6 is not at the elevation of the plume. In any case, there is currently not enough information available to resolve this issue.

The sensitivity of the leachate plume to the dispersivity values was assessed by systematically varying these values above and below the literature baseline values listed in Table 4.3. The effect on the leachate plume from these analyses is provided in Table 4.4 (Transport Model Runs #6 to #10) and summarized in Table 4.5.

The results of Transport Model Runs #6 to #8 in Table 4.4 and 4.5 indicate that raising the transverse and horizontal dispersivities causes more spreading of the plume and lowers simulated concentrations at downgradient wells MW8 and MW9. Lowering these dispersivity values does the opposite. Both results are what would be expected. The results of Runs #9 and #10 indicate that reducing the longitudinal dispersivity reduces longitudinal spreading of the plume, giving higher concentrations at MW8 and MW9, while increasing the longitudinal dispersivity has the opposite effect. Again both results are as expected. Overall, concentration changes are well within an order of magnitude as compared with the baseline values. This sensitivity analysis indicates that the transport is not that sensitive to dispersivity values.

Based on the dispersivity sensitivity results, the literature values are considered acceptable and were used to simulate the transport of leachate from the woodwaste site.

4.4.3 Effects of Sorption on Leachate Plume

The sorption values for arsenic and barium provided by U.S. EPA (1996) were input into the model to assess the effects of sorption on the leachate plume relative to non-sorption conditions.

Transport Model Run #11 (Table 4.4) was conducted to assess the effects of sorption of arsenic and barium on the evolution of their plumes. All other transport parameters were held at their baseline values.

Concentrations of arsenic and barium at steady state conditions at the source and downgradient of the source under sorption and non-sorption conditions are shown in Table 4.4 (Transport Model Runs #6 and #11) and summarized in Table 4.6. Figures showing the leachate plume under sorption conditions for barium and arsenic are shown on Figures 4.11 and 4.12, respectively.

Sorption has a significant effect on concentration of arsenic and barium downgradient of the woodwaste pile. This is evident by comparing Figure 4.11 with Figure 4.9 (for barium) and Figure 4.12 with Figure 4.10 (for arsenic). Based on the simulated and observed concentrations for arsenic and barium, sorption does not appear to be a significant attenuation process at the site. This is likely due to the sandy soil conditions. In addition, since only inorganics were modeled, biodegradation was also not considered to be a significant attenuation process and not simulated in this model. The remainder of the modeling simulations were conducted with baseline transport parameters with no sorption.

4.4.4 Mass Flux of Contaminants

The mass flux of the selected contaminants was calculated at a control plane downgradient of the woodwaste pile near the lake using observed indicator concentrations at MW8 and MW9 and estimated plume limits (see Figure 3.5 for plume limits). This calculation was completed to estimate the potential mass loading of the selected leachate parameters to the receiving lake.

The mass flux of a contaminant at any given control plane was calculated using the equation (4.2) (Wood, 2008).

(4.2) $$M_d = \sum q_i * A_i * C_i$$

where:

M_d = mass flux of contaminants (g/day)

A_i = x*y (cross sectional area of control plane – m^2), where x is the lateral distance represented by a monitoring point (well) and y is the vertical thickness through which mass flux is occurring

q_i = -k*i (Darcy flux – m/day), where k is hydraulic conductivity and i hydraulic gradient

C_i = contaminant concentration (g/m^3)

Since the contaminated thickness of the aquifer is not accurately known along the selected downgradient control plane, assumed aquifer thicknesses of 2 m, 2.5 m and 3 m were used for the calculation to provide a range of potential mass flux of contaminants to the lake for varying aquifer thicknesses. The potential mass flux of iron, manganese, barium and arsenic to the receiving lake is shown on Table 4.7. The location and length of the control plane relative to the source, the monitoring wells and plume is shown on Figure 3.5.

Based on the calculations, the mass flux of iron to the lake would be 1455.3 g/day for an assumed aquifer thickness of 2 m, 1819.1 g/day for an assumed aquifer thickness of 2.5 m, and 2182.9 g/day for an assumed aquifer thickness of 3 m. As per expectations, the mass flux to the lake increases as the aquifer thickness increases.

4.4.5 Downgradient Water Quality under Uncapped and Capped Woodwaste Conditions

The downgradient groundwater quality under uncapped and capped woodwaste conditions at steady state (3,285 days or 9 years) is provided in Table 4.4 (Transport Model Runs #6 and #12) and summarized in Table 4.8. Figures showing the leachate plume under capped conditions are shown on Figures 4.13 to 4.16.

Based on the results, concentrations of the selected leachate indicator parameters are reduced by approximately 73% at steady state conditions by adding a low permeability cap on the woodwaste pile.

4.4.6 Downgradient Water Quality Following Woodwaste Removed for Bio-Energy

The downgradient groundwater quality following the removal of woodwaste for bio-energy purposes was simulated from steady state conditions at 3,285 days (9 years) to a time in which each leachate indicator parameter was below their applicable MOE criterion. The time period and concentration simulated for each parameter is provided in Table 4.4 (Transport Model Run #13) and summarized in Table 4.9. Figures showing the decreasing indicator parameter concentrations over time for source and downgradient wells are shown on Figures 4.17 to 4.33. Graphs showing decreasing concentrations of iron, manganese, barium and arsenic at the MW1 and MW8 and MW9 locations over time are shown on Figures 4.34 to 4.37.

Concentrations of indicator parameters at source and downgradient wells were calculated to be below the applicable MOE criteria at a time of:

- 2,920 days (8 years) for iron,
- 2,190 days (6 years) for manganese,
- 730 days (2 years) for barium, and
- 365 days (1 year) for arsenic.

4.4.7 Assumptions and Limitations of the Modeling

The groundwater modeling effort incorporates several basic simplifying assumptions, which could cause variations in plume configuration and fate and transport simulations. Some of the more significant assumptions are described below.

- Homogenous geological and hydrogeological conditions were applied to the study site.
- Vertical extent of the leachate plume was estimated since available information does not define a vertical depth.
- Uniform recharge was estimated across the entire site, including the woodwaste pile, and a constant leachate concentrations were applied to the source (woodwaste pile) over time.

The applicability and accuracy of the model results are subject to limitations. Models only approximate natural phenomenon and are inherently inexact because the mathematical description is imperfect and/or our understanding of phenomena is incomplete. The mathematical parameters used in models to represent real processes are often uncertain because these parameters are empirically determined or represent multiple processes. Additionally, the initial or starting conditions and/or the boundary conditions in a model may not be well known. Consideration of the above is recommended when assessing the modeling results.

4.4.8 Summary of Modeling Results

The groundwater model was developed to simulate groundwater flow and contaminant fate and transport scenarios at the woodwaste disposal site, with a focus on modeling the transport of leachate indicators iron, manganese, barium and arsenic downgradient of the site.

The groundwater model was developed using Visual MODFLOW software with model input values obtained from site specific testing results or from relevant literature. The objectives of the modeling were to simulate groundwater flow conditions as well as model downgradient groundwater quality under three different scenarios: uncapped and capped woodwaste pile conditions and the removal of woodwaste from the site. Although sorption was not considered to be a significant attenuation process at the site due to the sandy aquifer conditions, values reported by the literature for the sorption of barium and arsenic were modeled to assess the effects on the leachate plume downgradient of the site.

The groundwater flow model was calibrated using PEST software and generally compared well with the observed head measured at the site.

The transport model was calibrated by completing sensitivity analysis for recharge concentrations at the woodwaste pile and varying dispersivity values to match the observed plume extents. The simulated leachate concentrations at source well MW1 compared well to average observed concentrations measured from 2003 to 2008. Concentrations of the indicator parameters in downgradient wells MW8 and MW9 also generally compared well when both simulated and observed concentrations were averaged. This approach was considered acceptable for assessing the overall leachate plume downgradient of the site.

Based on the results for the calibrated transport model, concentrations of iron, manganese, barium and arsenic stabilized at times of: 3,285 days or 9 years, which was considered to represent steady state conditions for the transport model.

Based on the model simulation for sorption of barium and arsenic, sorption has a significant effect on the leachate plume downgradient of the woodwaste pile. This supports the observation that simulated results agree well with observed results when only dispersion and not sorption is used in the transport analysis. Therefore, sorption does not appear to be a significant attenuation process at the site and was not included in the main modeling scenarios.

The mass flux of the selected contaminants was calculated at a control plane downgradient of the woodwaste pile near the lake using observed indicator concentrations at MW8 and MW9 and estimated plume limits. This calculation was completed to estimate the potential mass loading of the selected leachate parameters to the receiving lake. Based on the calculations, the mass flux of iron to the lake would be 1455.3 g/day for an assumed aquifer thickness of 2 m, 1819.1 g/day for an assumed aquifer thickness of 2.5 m, and 2182.9 g/day for an assumed aquifer thickness of 3 m. Mass flux calculations for manganese, barium and arsenic were also completed (results shown on Table 4.7). As expected, the mass flux to the lake increases as the aquifer thickness increases.

Under capped (low permeability cover) woodwaste pile conditions at steady state, the model estimated that the indicator parameters would be reduced by approximately 73%.

The downgradient groundwater quality following the removal of woodwaste for bio-energy purposes was also simulated to a time in which each leachate indicator parameter was below their applicable MOE criterion. Concentrations of indicator parameters at source and downgradient wells were calculated to be below the applicable MOE criteria at 2,920 days (8 years) for iron; 2,190 days (6 years) for manganese; 730 days (2 years) for barium; and 365 days (1 year) for arsenic.

Overall, the flow and transport model results generally compared well with observed conditions at the site. Additional hydrogeological information through borehole drilling, monitoring well installations and water analysis and field testing for site specific information (i.e. hydraulic conductivity, dispersivity, etc.) would help better define the model results. In particular, the three dimensional configuration of the plume needs to be better defined.

Parameter	Unit	Result	Reference
Hydraulic Conductivity (kx,kv,ky)	m/s	9.15×10^{-5}	2003 Site Geological Assessment (average of rising head test results)
Specific Storage (Ss)	1/m	0.00032	Domenico and Schwartz (1990)
Specific Yield (Sy)		0.21	Fetter (1994)
Effective Porosity (ne)		0.3	Fetter (1994)
Total Porosity (n)		0.3	Fetter (1994)
Recharge	mm/y	240	Viessman and Lewis (2003) for infiltration factor and Chapman and Thomas (1968) for surplus

Table 4.1: Groundwater Flow Properties

Flow Model Run		1	2	3 (Pest)
Groundwater Model Input				
Boundary Condition	Constant Head (m)	88	88	88
	River (m)	79	79	79
Layers		1	3	3
Recharge (mm/yr)		240	240	122.3
Hydraulic Conductivity (m/sec)	kx	9.15E-05	9.15E-05	7.35E-05
	ky	9.15E-05	9.15E-05	3.81E-05
	kz	9.15E-05	9.15E-05	5.97E-05
Storage	Ss	0.00032	0.00032	0.00032
	Sy	0.21	0.21	0.21
	ne	0.3	0.3	0.3
	n	0.3	0.3	0.3
Groundwater Model Output				
Root Mean Square (m)		0.624	0.376	0.344
Correlation Coefficient		0.997	0.997	0.997
Calibration Plots		Figure 4.3	Figure 4.4	Figure 4.5

Table 4.2: Groundwater Flow Model Calibration

Parameter	Unit	Result	Reference
Diffusion Coefficient (D)	m^2/d	1.30×10^{-4}	Fetter (1994), typical value for anions and cations
Longitudinal Dispersivity (∂_L)	m	26	Fetter (1994)
Transverse Dispersivity (∂_T)	m	0.1	
Vertical Dispersivity (∂_V)	m	0.01	
Uncapped Woodwaste Pile Recharge	mm/yr	122.3	Visual MODFLOW (PEST Result)
Capped Woodwaste Pile Recharge	mm/yr	31.5	Viessman and Lewis (2003) for infiltration factor and Chapman and Thomas (1968) for surplus
Recharge Concentration at Woodwaste Pile			
Iron	mg/L	465	
Manganese	mg/L	11.1	
Arsenic	mg/L	0.67	
Barium	mg/L	5.2	
Sorption (Kd)			
Arsenic	L/mg	2.5×10^{-5}	U.S. EPA (1996)
Barium	L/mg	1.1×10^{-5}	

Table 4.3: Transport Properties

Transport Model Run	Transport Model Inputs											Transport Model Outputs							
	Dispersivity			Diffusion	Woodwaste Pile Condition	Woodwaste Pile Recharge (mm/yr)	Recharge Concentrations at Woodwaste Pile (mg/L)				Sorption L/mg (Kd)	Observation Well	Simulation Time (days)	Observed / Simulated	Concentrations at MW1 and MW8/MW9 (mg/L)				Figure Output
	∂_L (m)	∂_T (m)	∂_V (m)	D* (m^2/day)			Iron	Manganese	Barium	Arsenic					Iron	Manganese	Barium	Arsenic	
	26	0.1	0.01	1.32E-04	Uncapped	122.3	465	11.1	5.2	0.67	0	MW1		Observed	43.59	1.07	0.483	0.063	
												Average MW8/MW9		Observed	26.61	0.59	0.223	0.0445	
1												MW1	365	Simulated	22.49	0.53	0.248	0.0346	
2													1,825	Simulated	42.96	1.025	0.480	0.0619	
3													3,285	Simulated	43.48	1.04	0.482	0.0627	Figures 4.7 to 4.10
4													5,840	Simulated	43.48	1.04	0.482	0.0627	
5													9,125	Simulated	43.48	1.04	0.482	0.0627	
1												Average MW8/MW9	365	Simulated	1.48	0.0329	0.0154	0.0198	
2													1,825	Simulated	24.39	0.582	0.273	0.035	
3													3,285	Simulated	25.86	0.618	0.289	0.037	Figures 4.7 to 4.10
4													5,840	Simulated	25.86	0.618	0.289	0.037	
5													9,125	Simulated	25.86	0.618	0.289	0.037	
6	26	0.1	0.01	1.32E-04	Uncapped	122.3	465	11.1	5.2	0.67	0	MW1	3,285	Simulated	43.48	1.04	0.482	0.0627	
												MW8	3,285	Simulated	34.26	0.818	0.383	0.049	
												MW9	3,285	Simulated	17.46	0.417	0.195	0.025	
												Average MW8/MW9	3,285	Simulated	25.86	0.618	0.289	0.037	Figures 4.7 to 4.10
7	26	0.2	0.02	1.32E-04	Uncapped	122.3	465	11.1	5.2	0.67	0	MW1	3,285	Simulated	41.28				
												MW8	3,285	Simulated	30.51				
												MW9	3,285	Simulated	17.78				
												Average MW8/MW9	3,285	Simulated	24.145				
8	26	0.01	0.001	1.32E-04	Uncapped	122.3	465	11.1	5.2	0.67	0	MW1	3,285	Simulated	51.96				
												MW8	3,285	Simulated	38.92				
												MW9	3,285	Simulated	15.98				
												Average MW8/MW9	3,285	Simulated	27.45				
9	2.6	0.1	0.01	1.32E-04	Uncapped	122.3	465	11.1	5.2	0.67	0	MW1	3,285	Simulated	54.22	1.29	0.606	0.078	
												MW8	3,285	Simulated	39.73	0.948	0.44	0.057	
												MW9	3,285	Simulated	15.95	0.777	0.178	0.023	
												Average MW8/MW9	3,285	Simulated	27.84	0.8625	0.309	0.04	
10	100	0.1	0.01	1.32E-04	Uncapped	122.3	465	11.1	5.2	0.67	0	MW1	3,285	Simulated	32.85	0.784	0.367	0.047	
												MW8	3,285	Simulated	24.24	0.578	0.271	0.0349	
												MW9	3,285	Simulated	15.89	0.379	0.178	0.0228	
												Average MW8/MW9	3,285	Simulated	20.07	0.681	0.319	0.041	
11	26	0.1	0.01	1.32E-04	Uncapped	122.3	465	11.1	5.2	0.67	2.5E-5 L/mg for As 1.1E-5 L/mg for Ba	MW1	3,285	Simulated			0.037	0.00019	Figures 4.11 and 4.12
												MW8	3,285	Simulated			8.50E-09	1.07E-15	
												MW9	3,285	Simulated			1.80E-10	3.19E-18	
												Average MW8/MW9	3,285	Simulated			4.34E-09	5.37E-16	
12	26	0.1	0.01	1.32E-04	Capped	31.5	465	11.1	5.2	0.67	0	MW1	3,285	Simulated	11.8	0.282	0.131	0.017	Figures 4.13 to 4.16
												Average MW8/MW9	3,285	Simulated	6.79	0.251	0.116	0.0151	
13	26	0.1	0.01	1.32E-04	Removed	122.3	0	0	0	0	0	MW1	3,650	Simulated	21.76	0.519	0.230	0.0031	Figures 4.17 to 4.20
													4,015	Simulated	8.68	0.207	0.097		Figures 4.21 to 4.23
													4,380	Simulated	3.31	0.079			Figures 4.24 to 4.25
													4,745	Simulated	1.26	0.03			Figures 4.26 to 4.27
													5,110	Simulated	0.48	0.012			Figures 4.28 to 4.29
													5,475	Simulated	0.189	0.0045			Figures 4.30 to 4.31
													5,840	Simulated	0.076				Figure 4.32
													6,205	Simulated	0.032				Figure 4.33
												Average MW8/MW9	3,650	Simulated	24.78	0.592	0.277	0.0036	Figures 4.17 to 4.20
													4,015	Simulated	16.73	0.399	0.188		Figures 4.21 to 4.23
													4,380	Simulated	8.36	0.203			Figures 4.24 to 4.25
													4,745	Simulated	3.71	0.09			Figures 4.26 to 4.27
													5,110	Simulated	1.59	0.038			Figures 4.28 to 4.29
													5,475	Simulated	0.671	0.0161			Figures 4.30 to 4.31
													5,840	Simulated	0.288				Figure 4.32
													6,205	Simulated	0.129				Figure 4.33

Table 4.4: Transport Model Results

Transport Model Run	Dispersivity (m)			Effect on Leachate Concentrations
	∂_L	∂_T	∂_V	
6	26	0.1	0.01	Provides good match to observed leachate concentrations in source and downgradient wells (MW8/MW9)
7	26	0.2	0.02	Slightly lower concentrations at source and downgradient wells relative to observed concentrations
8	26	0.01	0.001	Slightly higher concentrations at source and downgradient wells relative to observed concentrations
9	2.6	0.1	0.01	Higher concentration at source and downgradient wells relative to observed concentrations
10	100	0.1	0.01	Lower concentrations at source and downgradient wells relative to observed concentrations

Table 4.5: Dispersivity Sensitivity Analysis

Parameters	Sorption Conditions	Non-Sorption Conditions
Source Well MW1 (mg/L)		
Barium	0.037	0.482
Arsenic	0.00019	0.0627
Downgradient Wells MW8/MW9 (average mg/L)		
Barium	4.34×10^{-9}	0.289
Arsenic	5.37×10^{-16}	0.037

Table 4.6: Effects of Sorption on Leachate Plume

Parameters (mg/L)	Mass Flux (g/day) at Downgradient Control Plane
Aquifer Thickness of 2 m	
Iron	1455.3
Manganese	33.2
Barium	12.2
Arsenic	2.6
Aquifer Thickness of 2.5 m	
Iron	1819.1
Manganese	41.5
Barium	15.3
Arsenic	3.3
Aquifer Thickness of 3 m	
Iron	2182.9
Manganese	49.8
Barium	18.3
Arsenic	3.9

Table 4.7: Mass Flux of Contaminants

Parameters	Uncapped Condition	Capped Condition
Recharge Rate at Woodwaste Pile (mm/year)	122.3	31.5
Source Well MW1 (mg/L)		
Iron	43.48	11.8
Manganese	1.04	0.282
Barium	0.482	0.131
Arsenic	0.0627	0.017
Downgradient Wells MW8/MW9 (average mg/L)		
Iron	25.86	6.79
Manganese	0.618	0.251
Barium	0.289	0.116
Arsenic	0.037	0.0151

Table 4.8: Water Quality Under Uncapped and Capped Conditions at 3,285 Days

Parameters	MOE Criteria (mg/L)	Concentration (mg/L)	Simulation Time Following Waste Removal (Days)
Source Well MW1			
Iron	0.18	0.032	2,920
Manganese	0.027	0.0045	2,190
Barium	0.27	0.097	730
Arsenic	0.007	0.0031	365
Downgradient Wells MW8/MW9 (average)			
Iron	0.18	0.129	2,920
Manganese	0.027	0.0161	2,190
Barium	0.27	0.188	730
Arsenic	0.007	0.0036	365

Table 4.9: Water Quality Following Woodwaste Removal

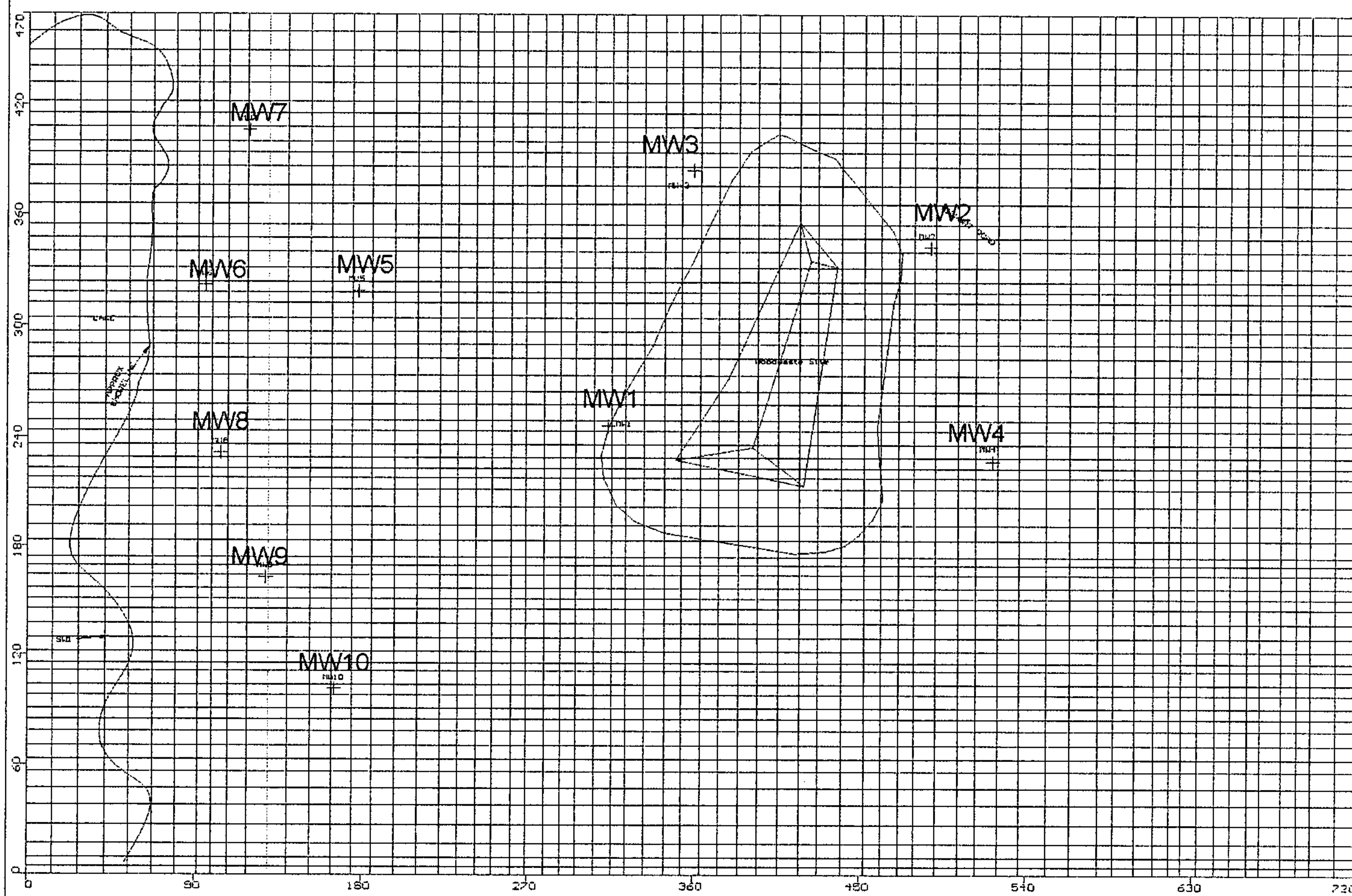


Figure 4.1: Woodwaste Disposal Site Grid Layout (grid deminsions in metres)

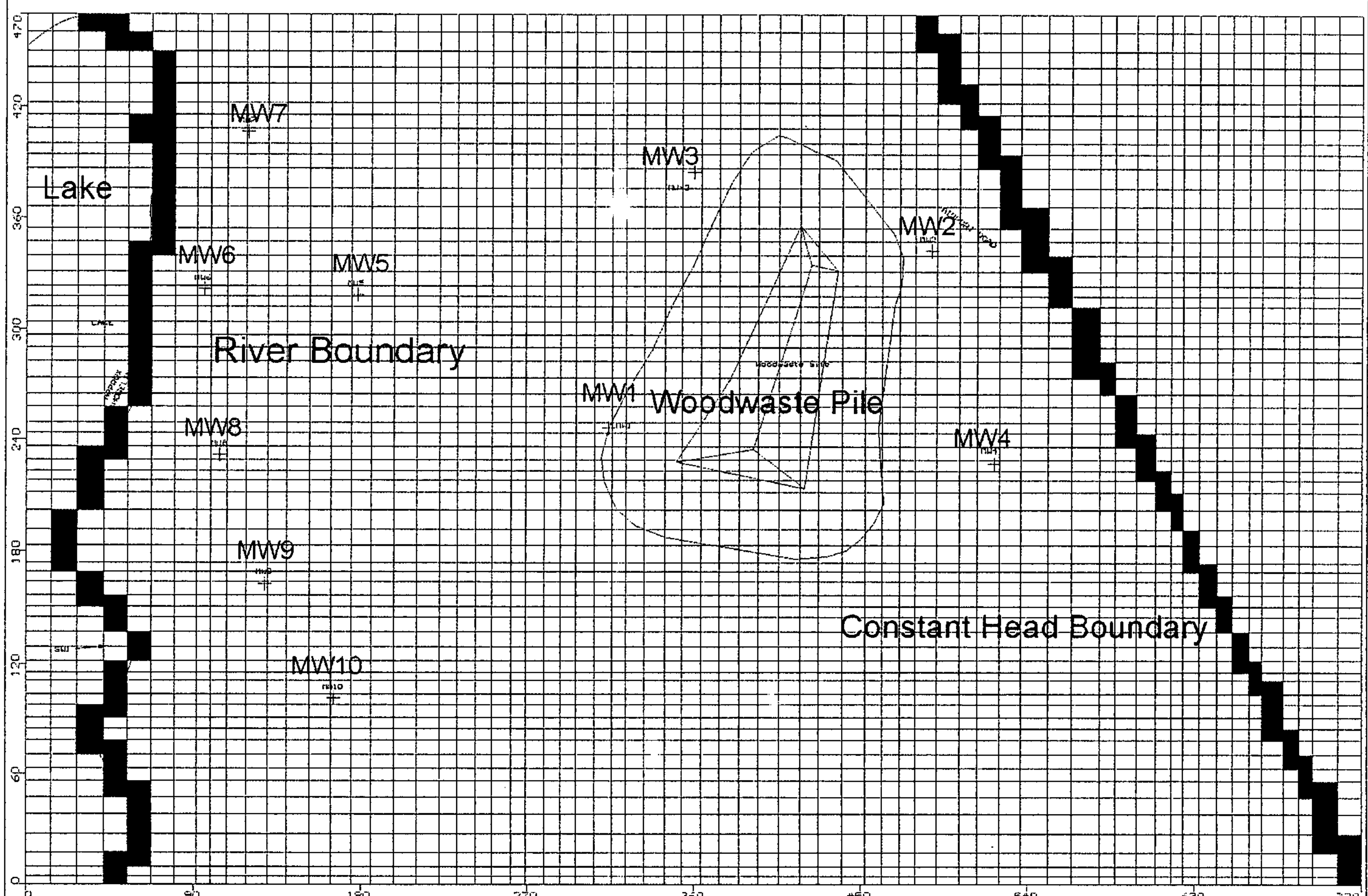


Figure 4.2: Woodwaste Site Model Boundary Conditions (grid dimensions in metres)

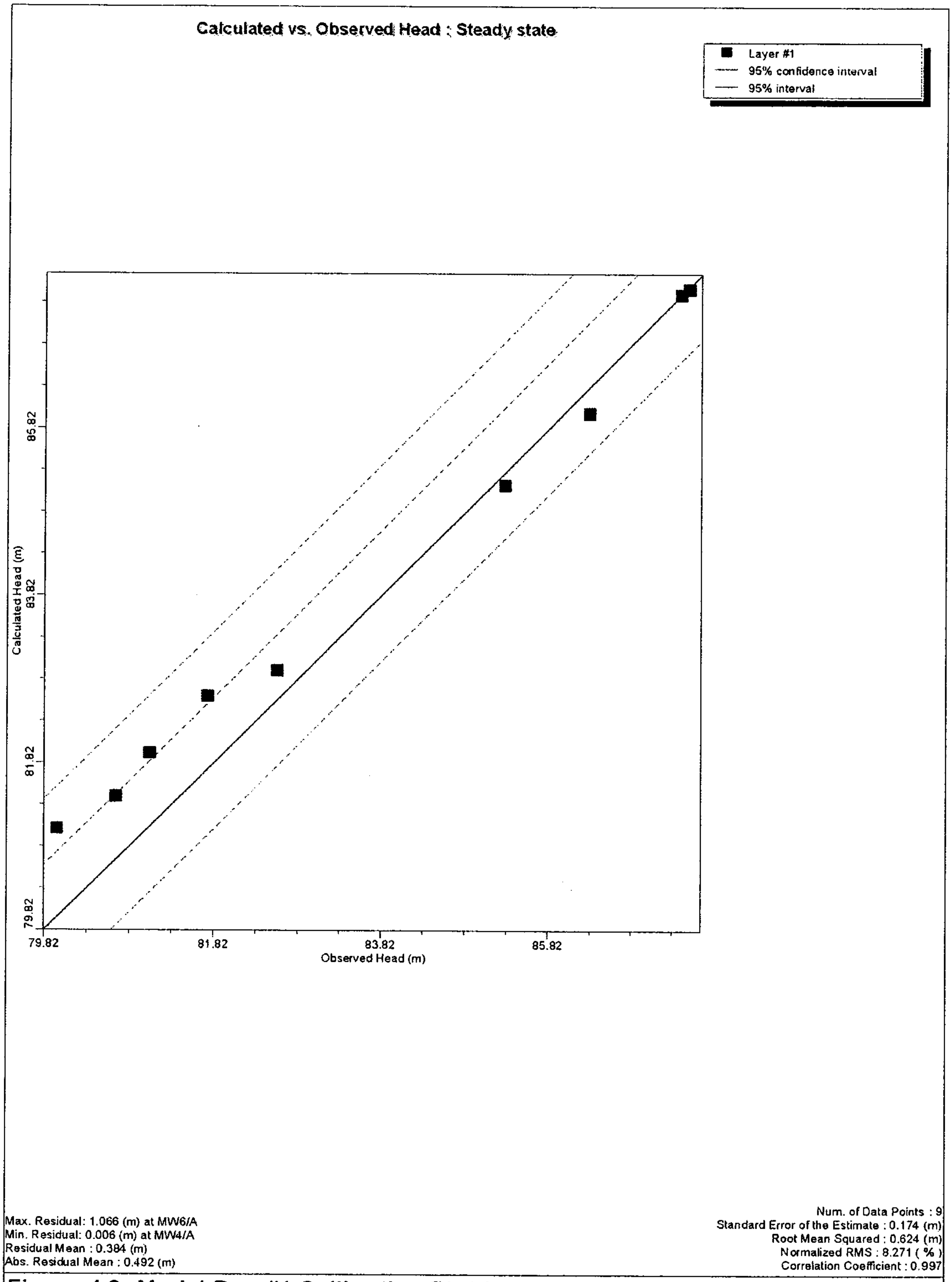


Figure 4.3: Model Run #1 Calibration Plot (metres)

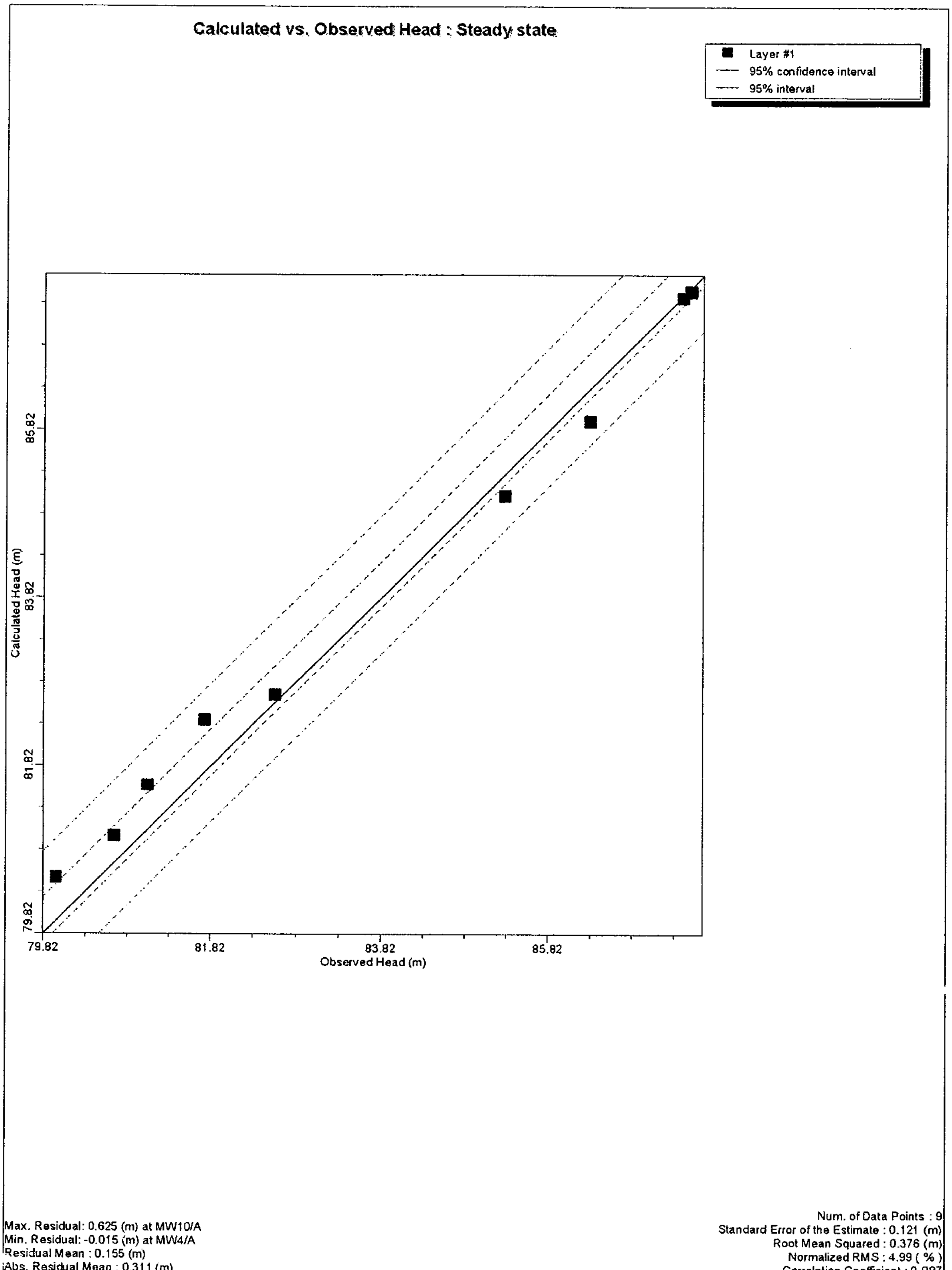


Figure 4.4. Model Run #2 Calibration Plot (metres)

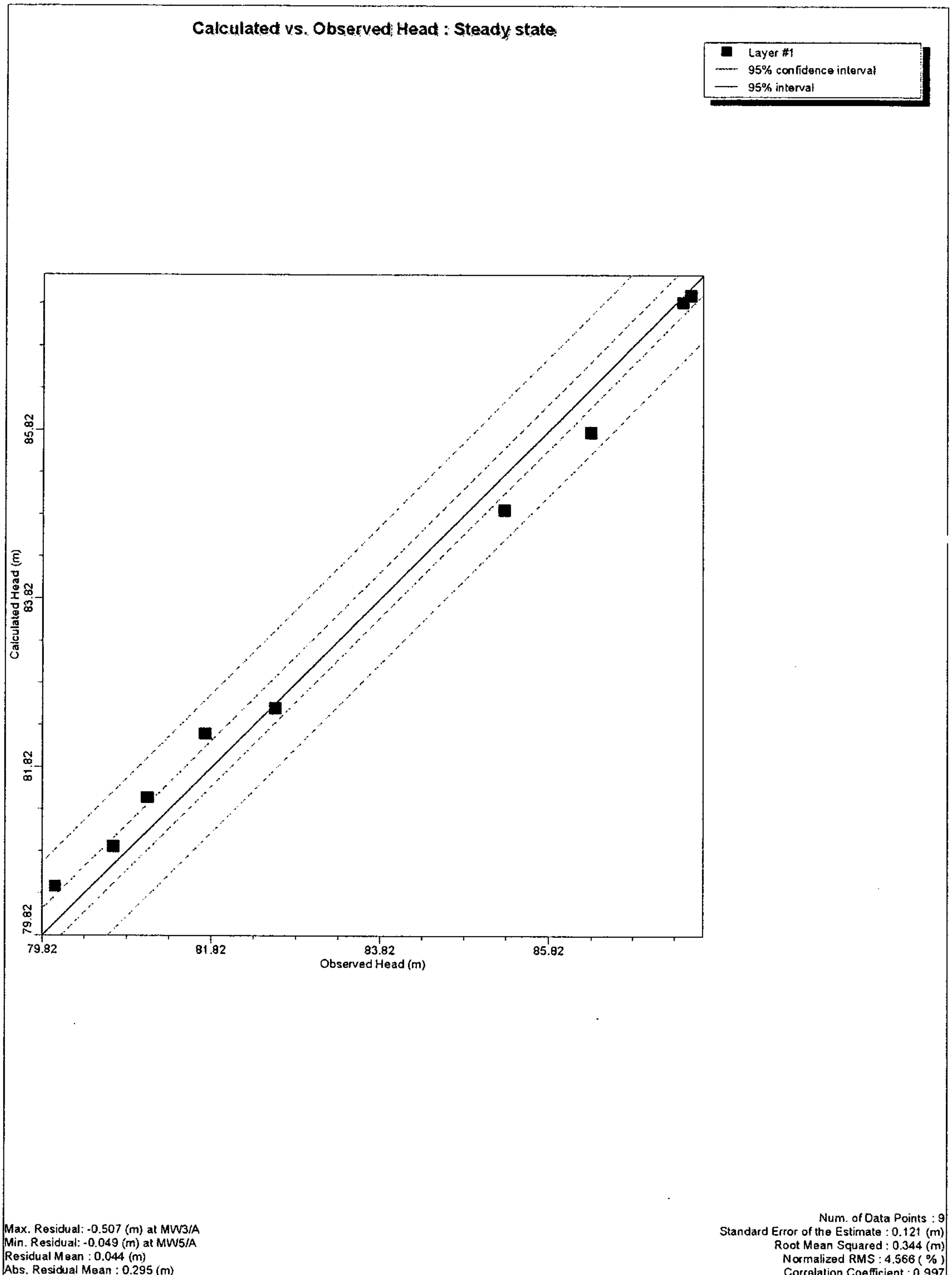


Figure 4.5: Model Run #3 (Pest) Calibration Plot (metres)

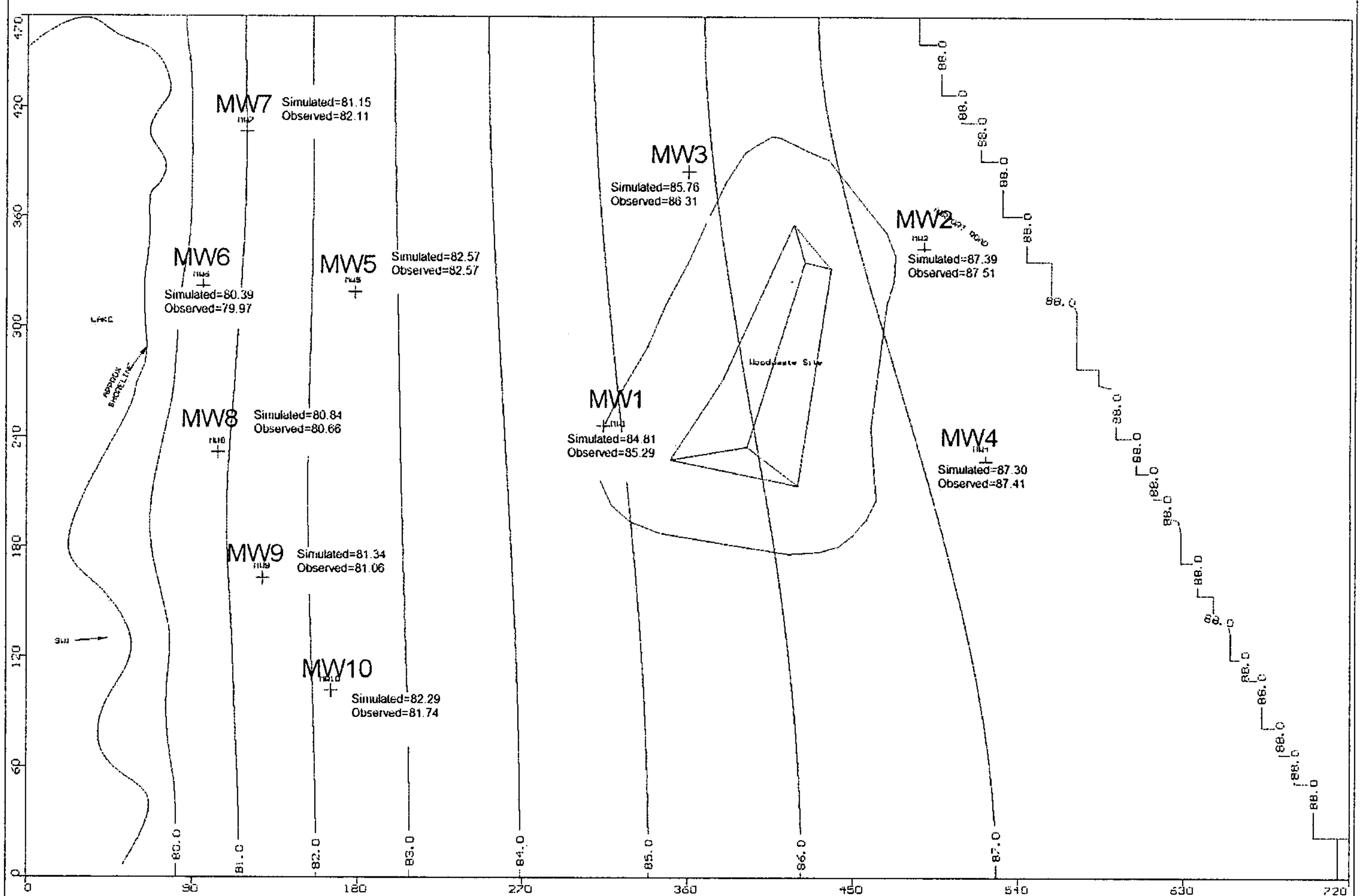


Figure 4.6: Simulated Groundwater Potentiometric Contours (metres)

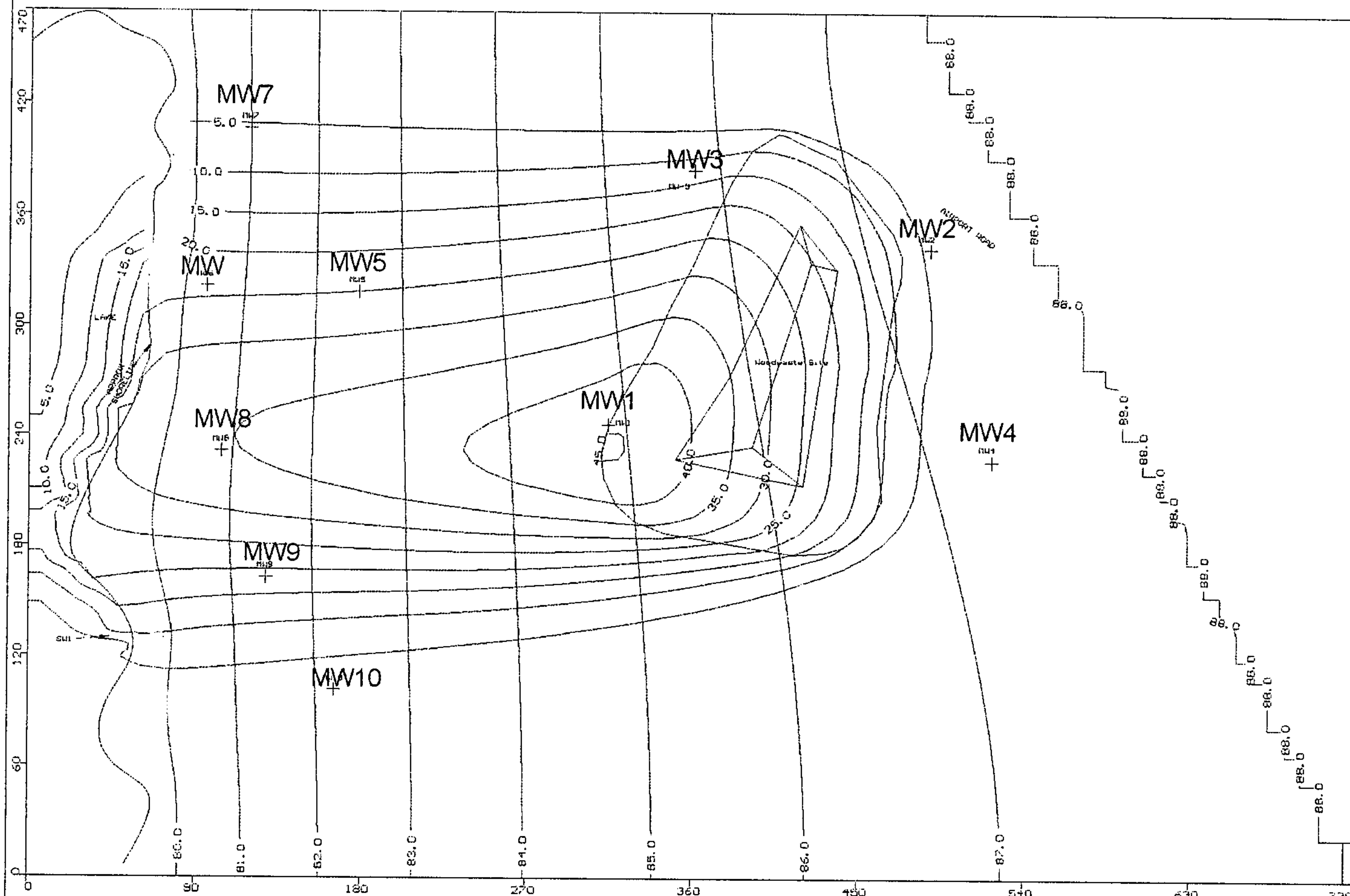


Figure 4.7: Simulated Iron Plume at 3,285 Days Under Uncapped Waste Conditions (mg/L)

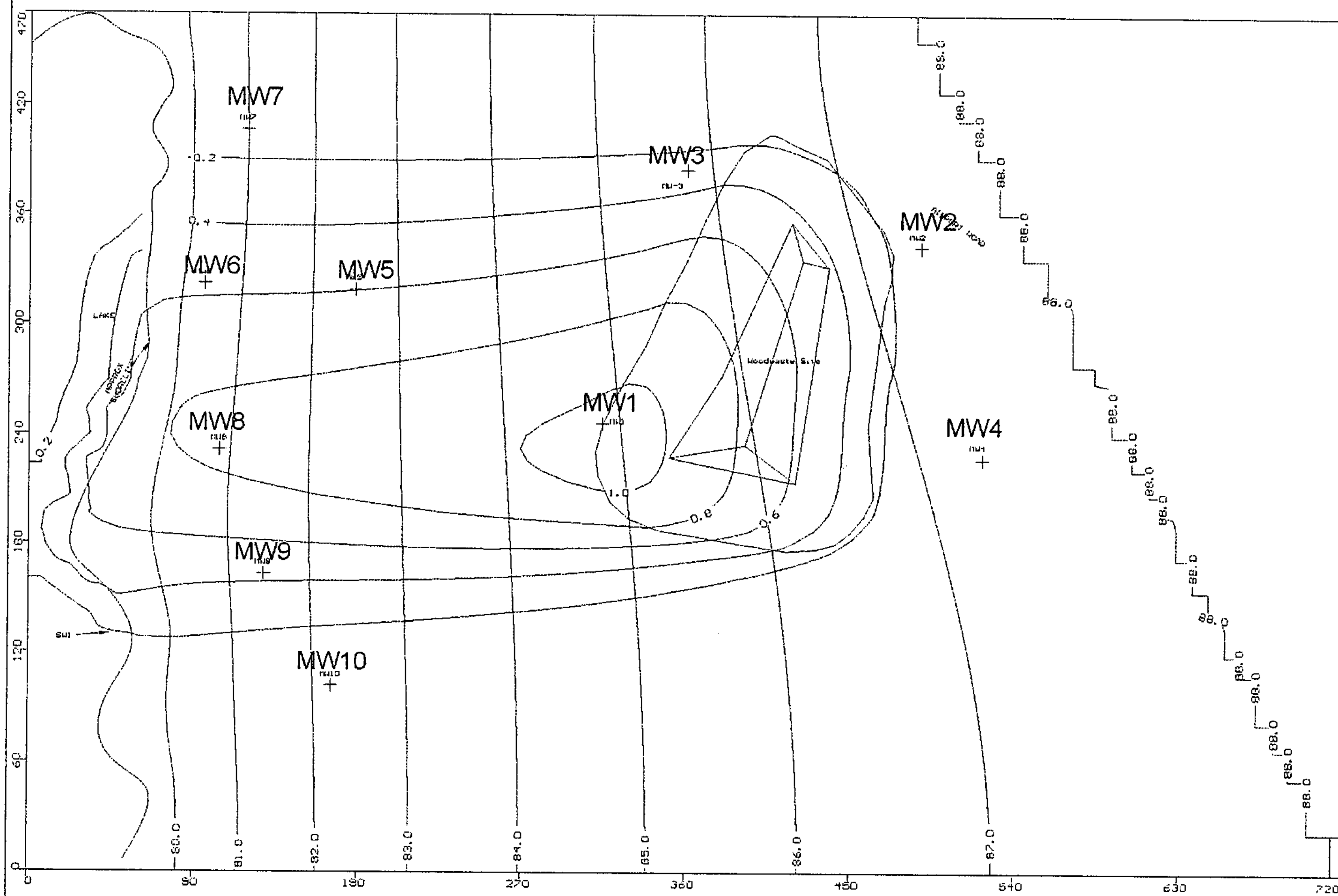


Figure 4.8: Simulated Manganese Plume at 3,285 Days Under Uncapped Waste Conditions (mg/L)

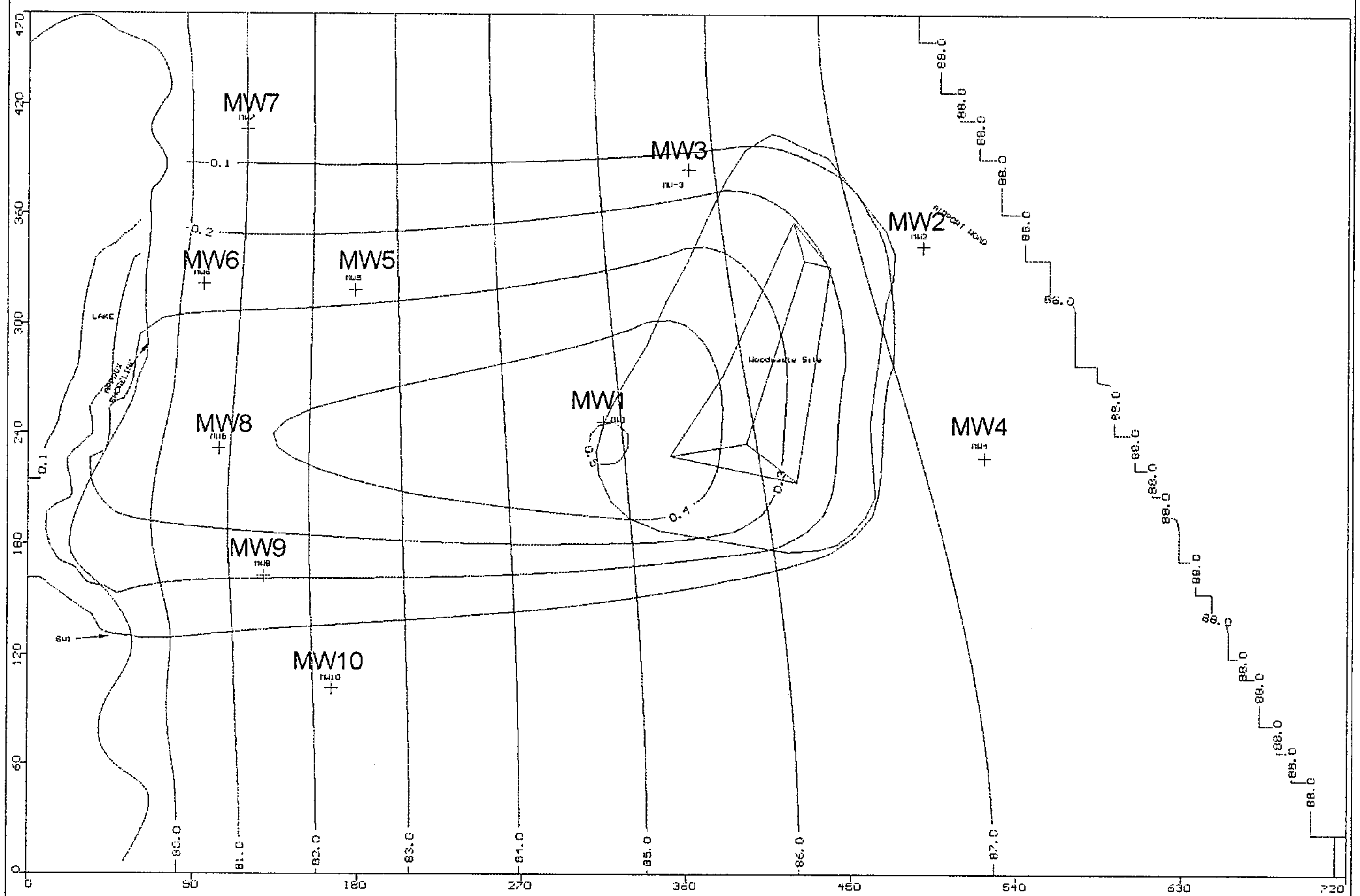


Figure 4.9: Simulated Barium Plume at 3,285 Days Under Uncapped Waste Conditions (mg/L)

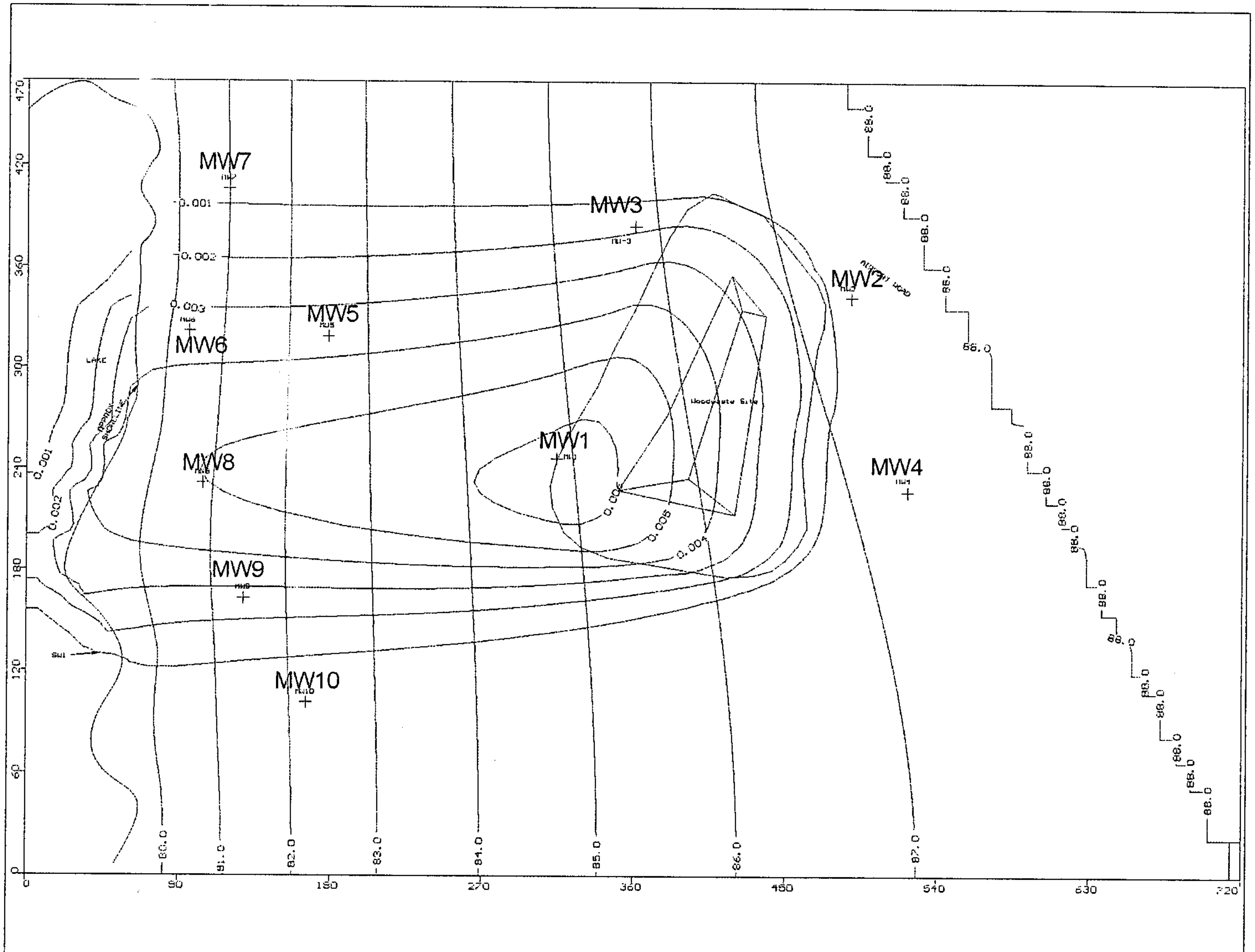


Figure 4.10: Simulated Arsenic Plume at 3,285 Days Under Uncapped Waste Conditions (mg/L)

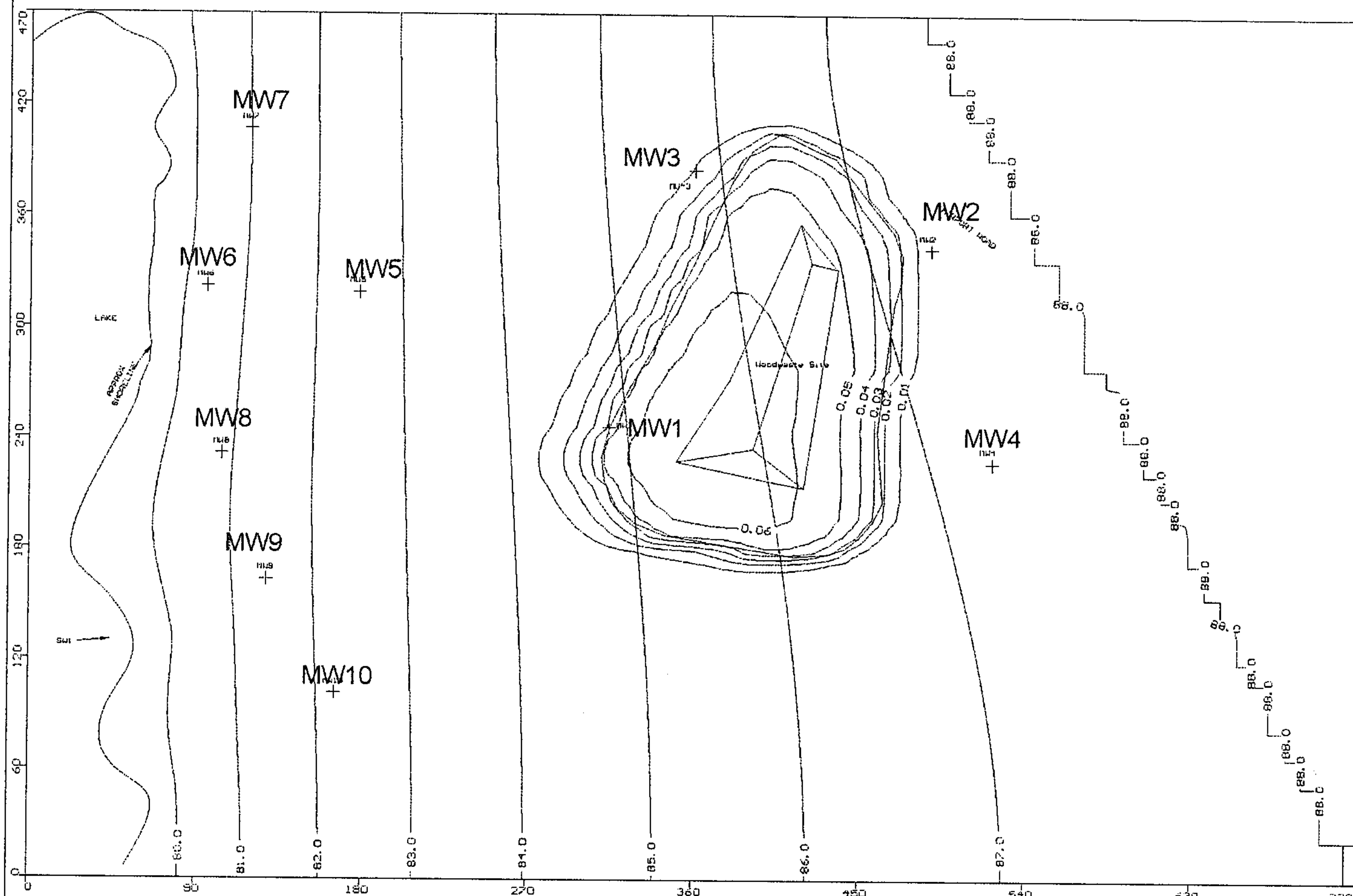


Figure 4.11: Transport Model Run with Sorption for Barium at 3,285 Days (mg/L)

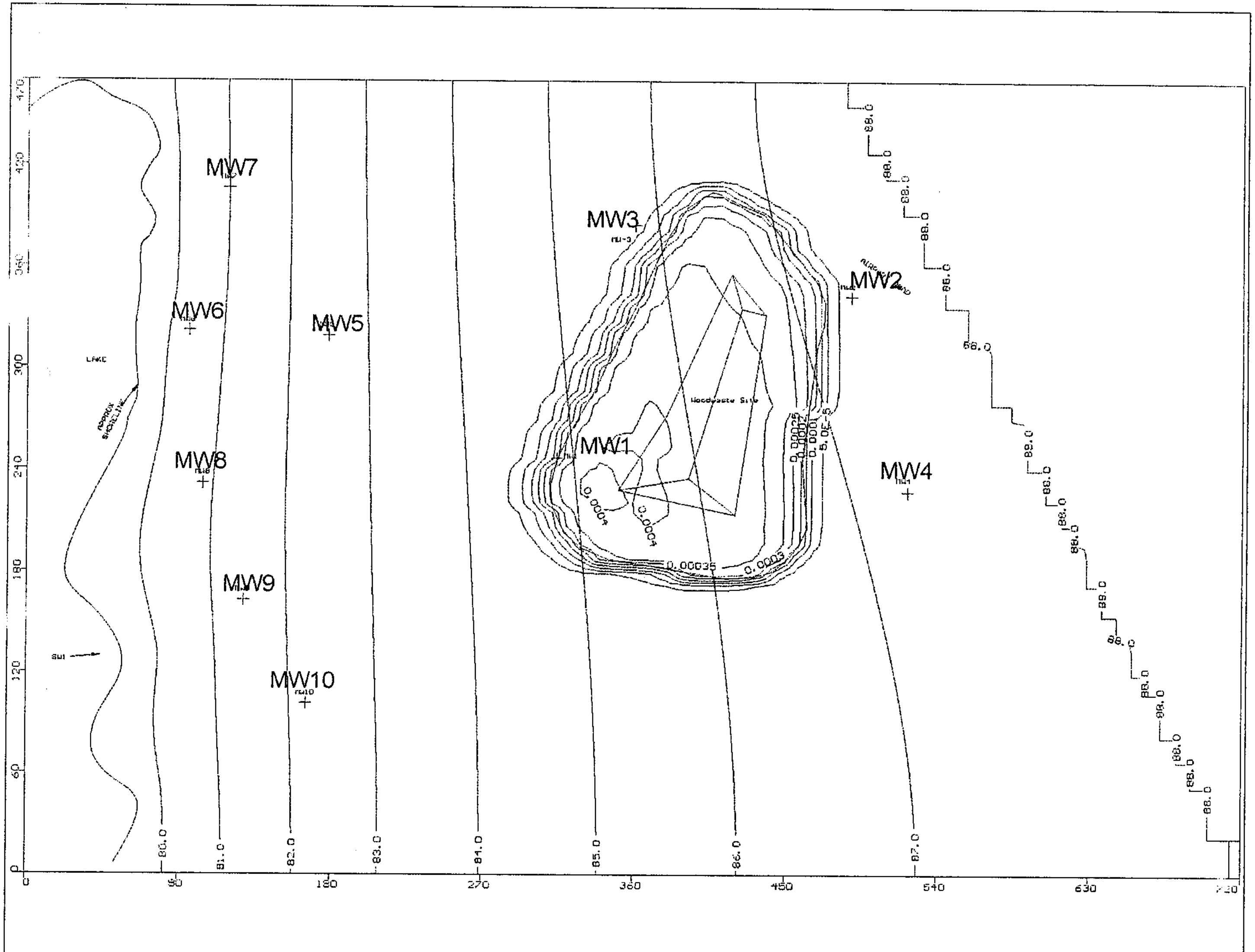


Figure 4.12: Transport Model Run with Sorption for Arsenic at 3,285 Days (mg/L)

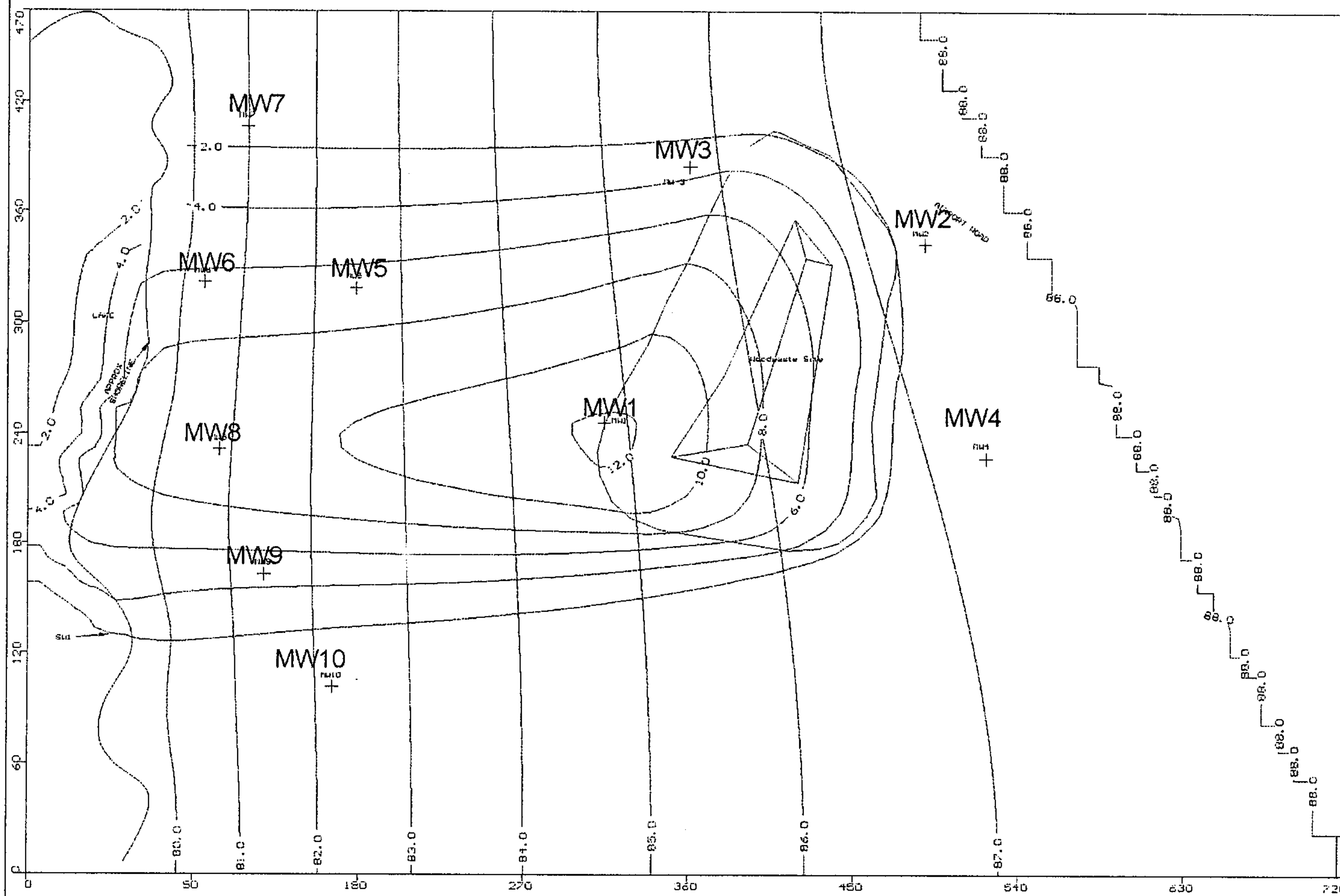


Figure 4.13: Simulated Iron Plume at 3,285 Days Under Capped Waste Conditions (mg/L)

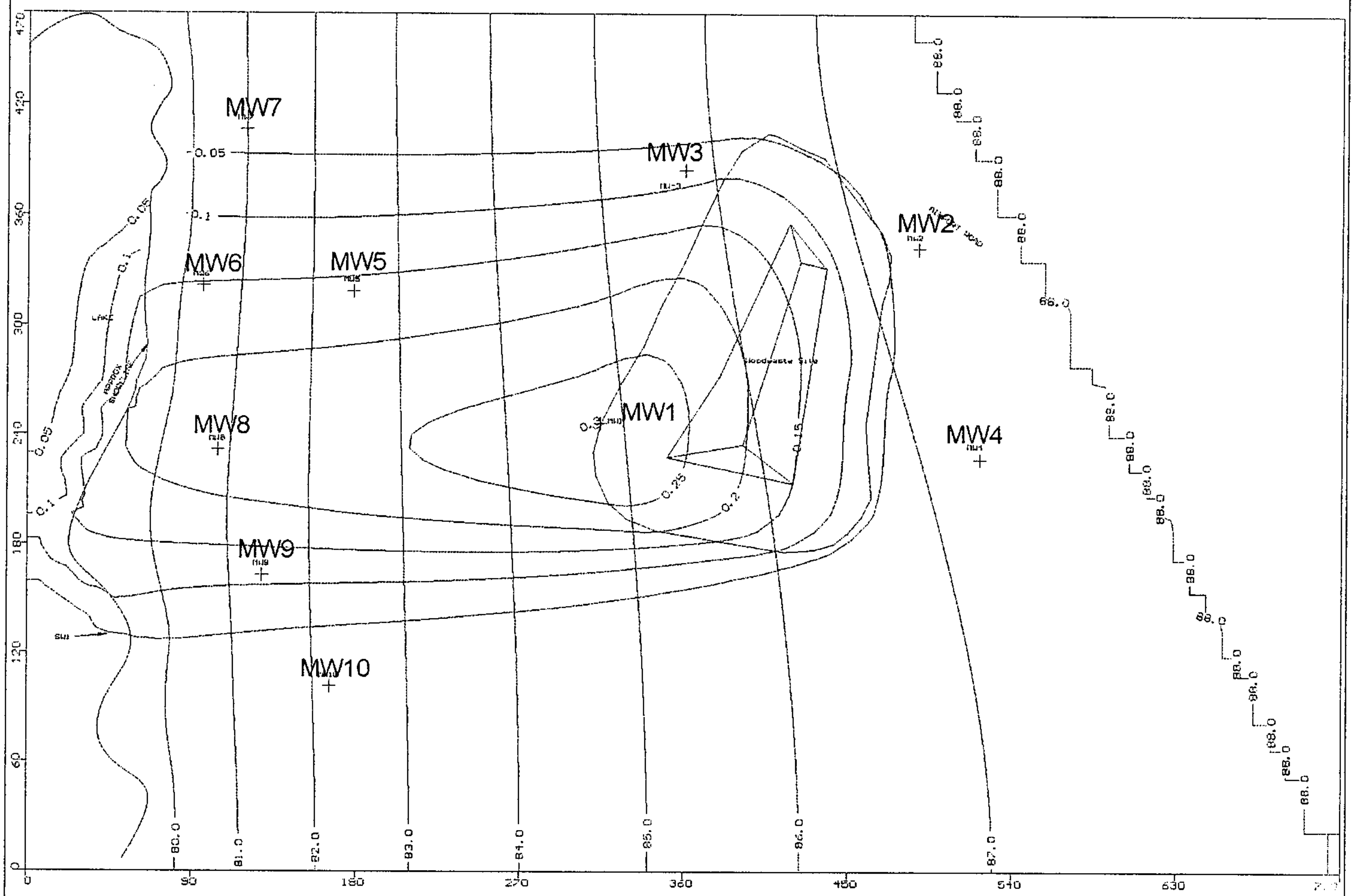


Figure 4.14: Simulated Manganese Plume at 3,285 Days Under Capped Waste Conditions (mg/L)

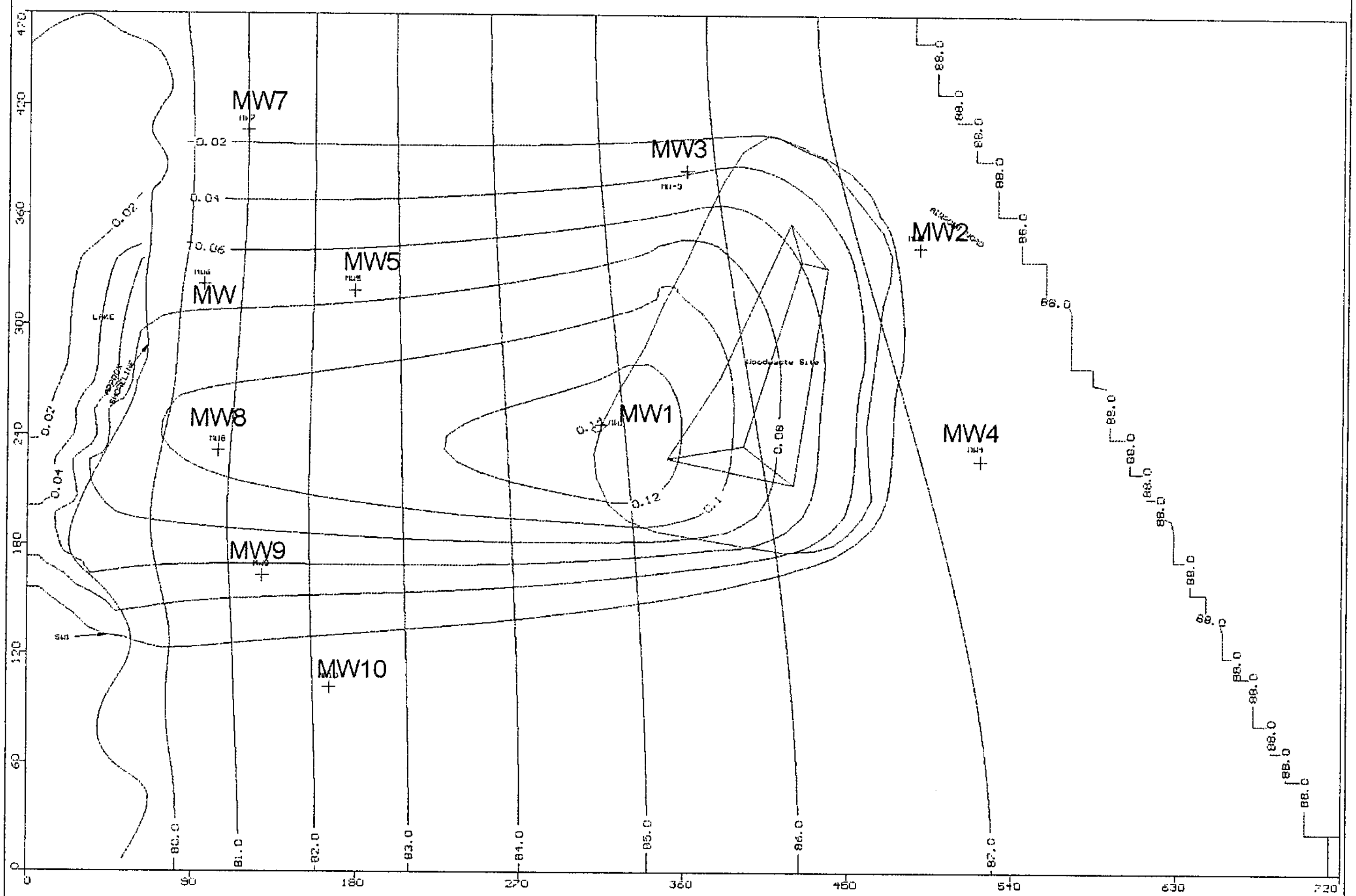


Figure 4.15: Simulated Barium Plume at 3,285 Days Under Capped Waste Conditions (mg/L)

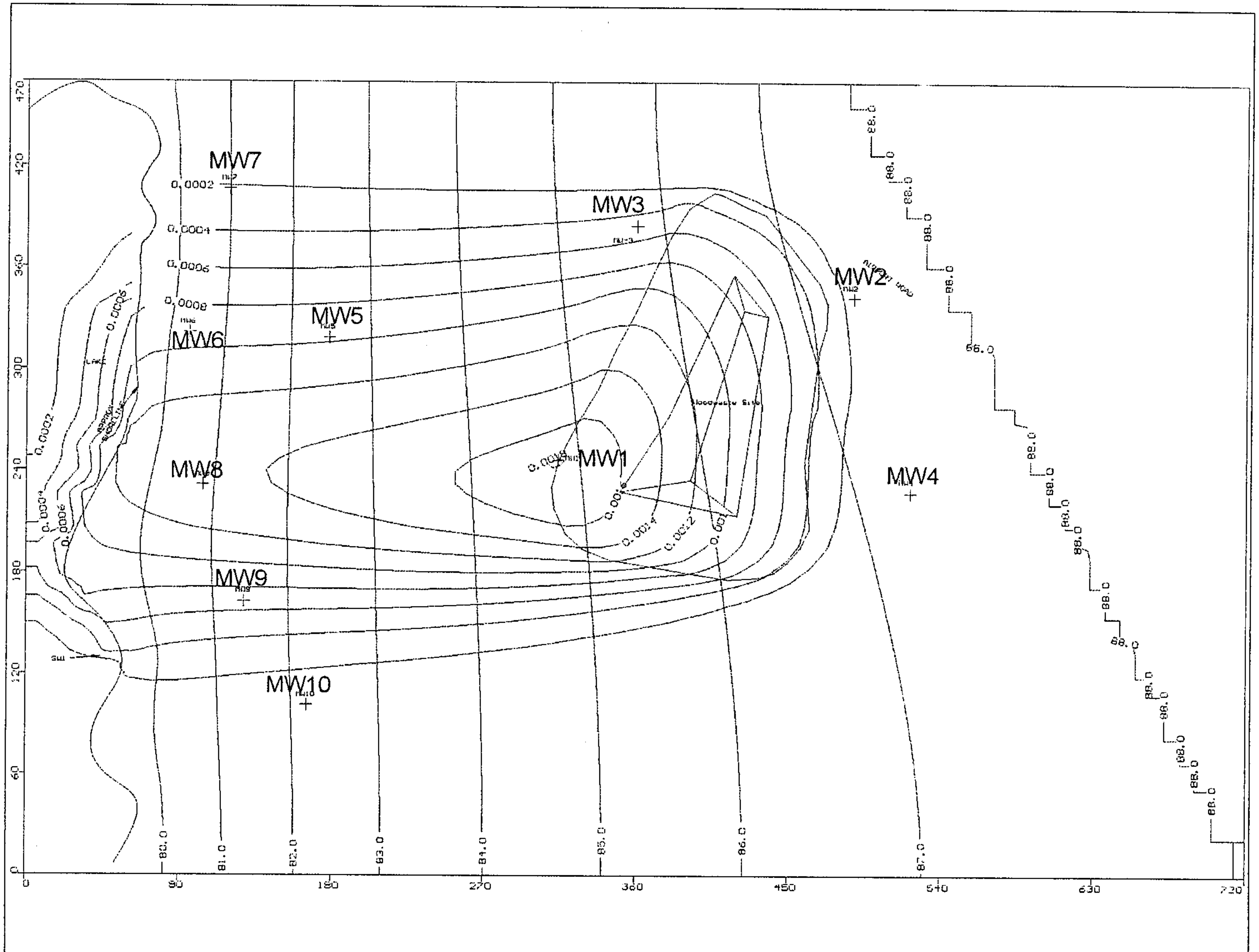


Figure 4.16: Simulated Arsenic Plume at 3,285 Days Under Capped Waste Conditions (mg/L)

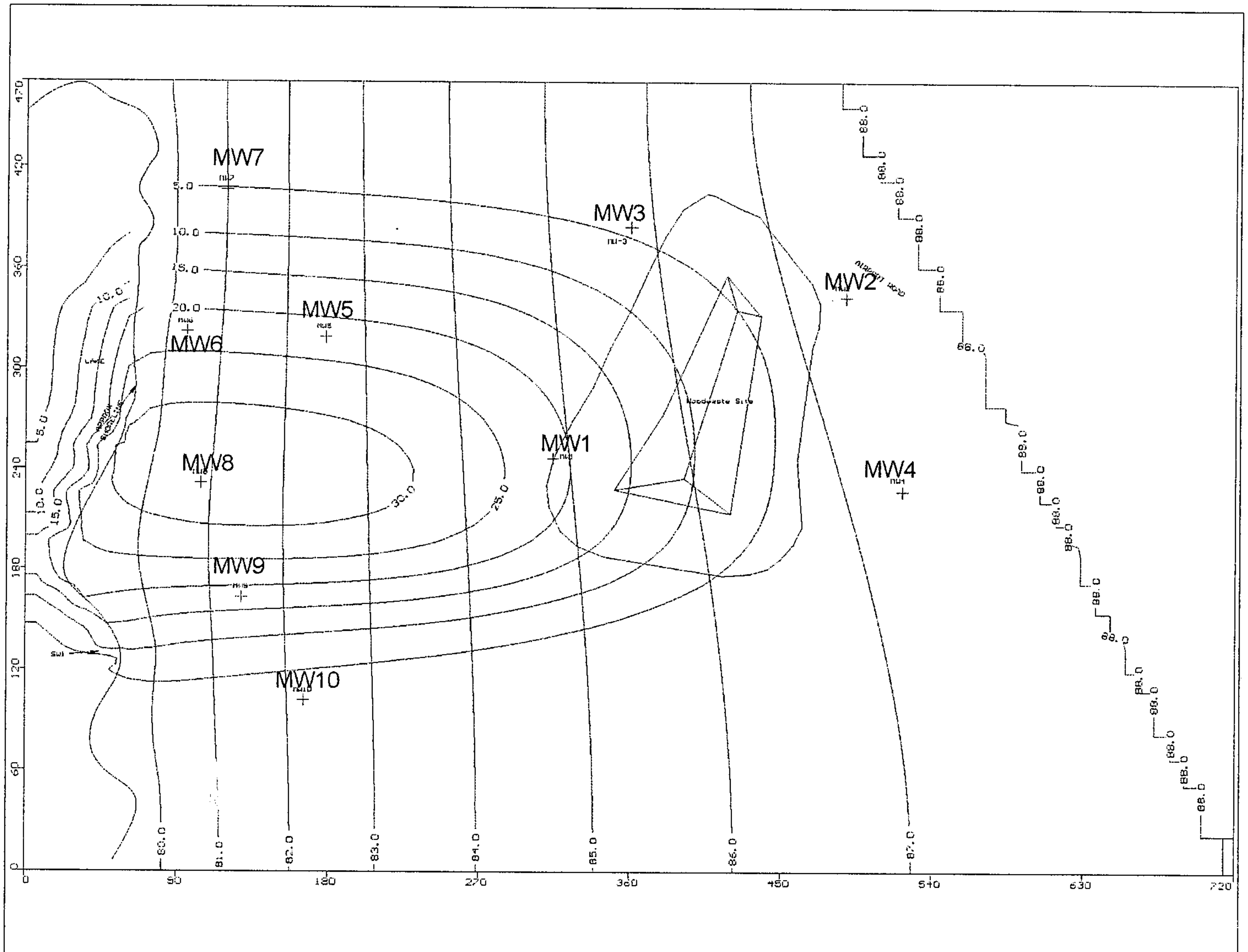


Figure 4.17: Simulated Iron Plume at 3,650 Days Under Waste Removal Conditions (mg/L)

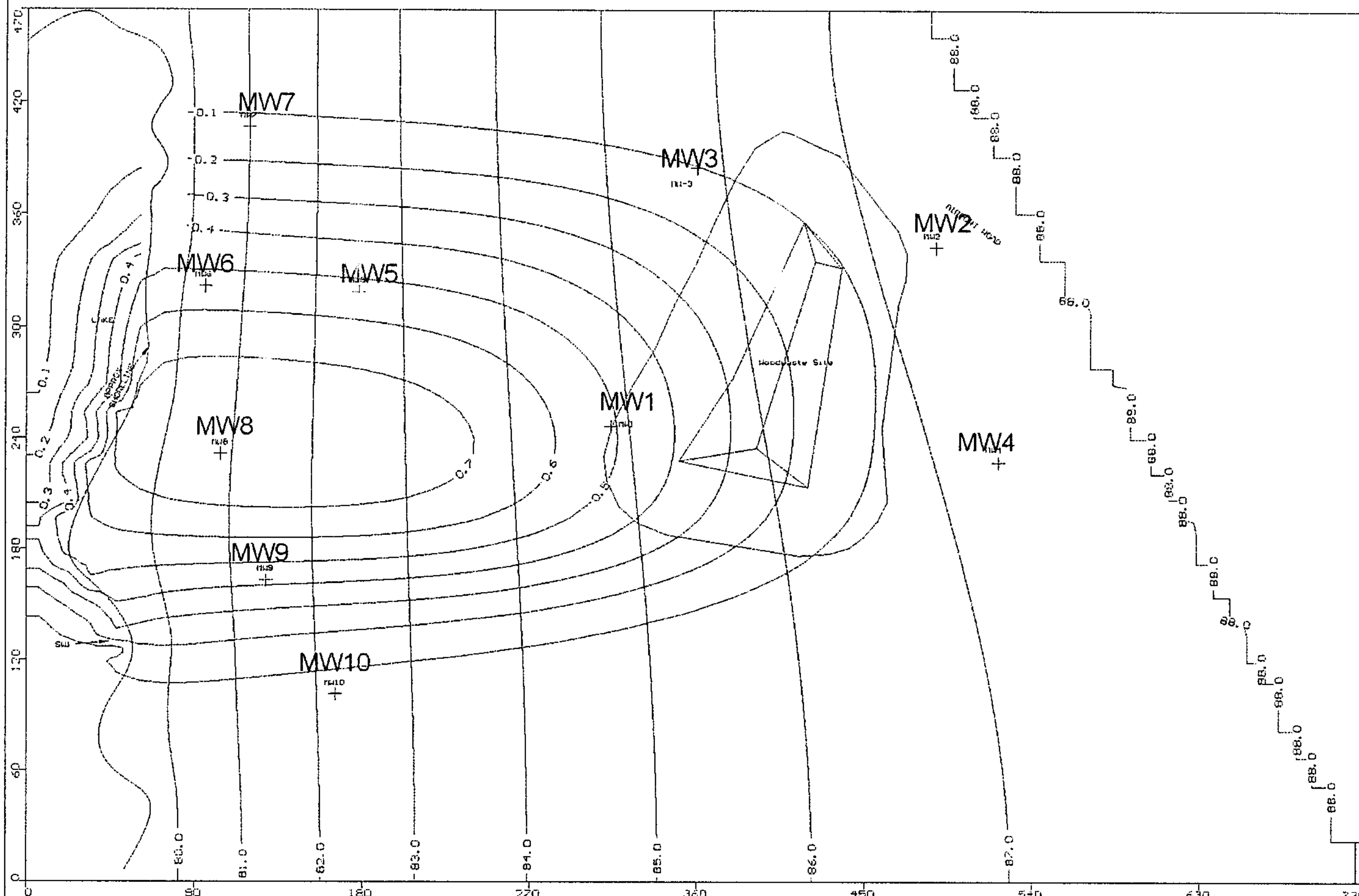


Figure 4.18: Simulated Manganese Plume at 3,650 Days Under Waste Removal Conditions (mg/L)

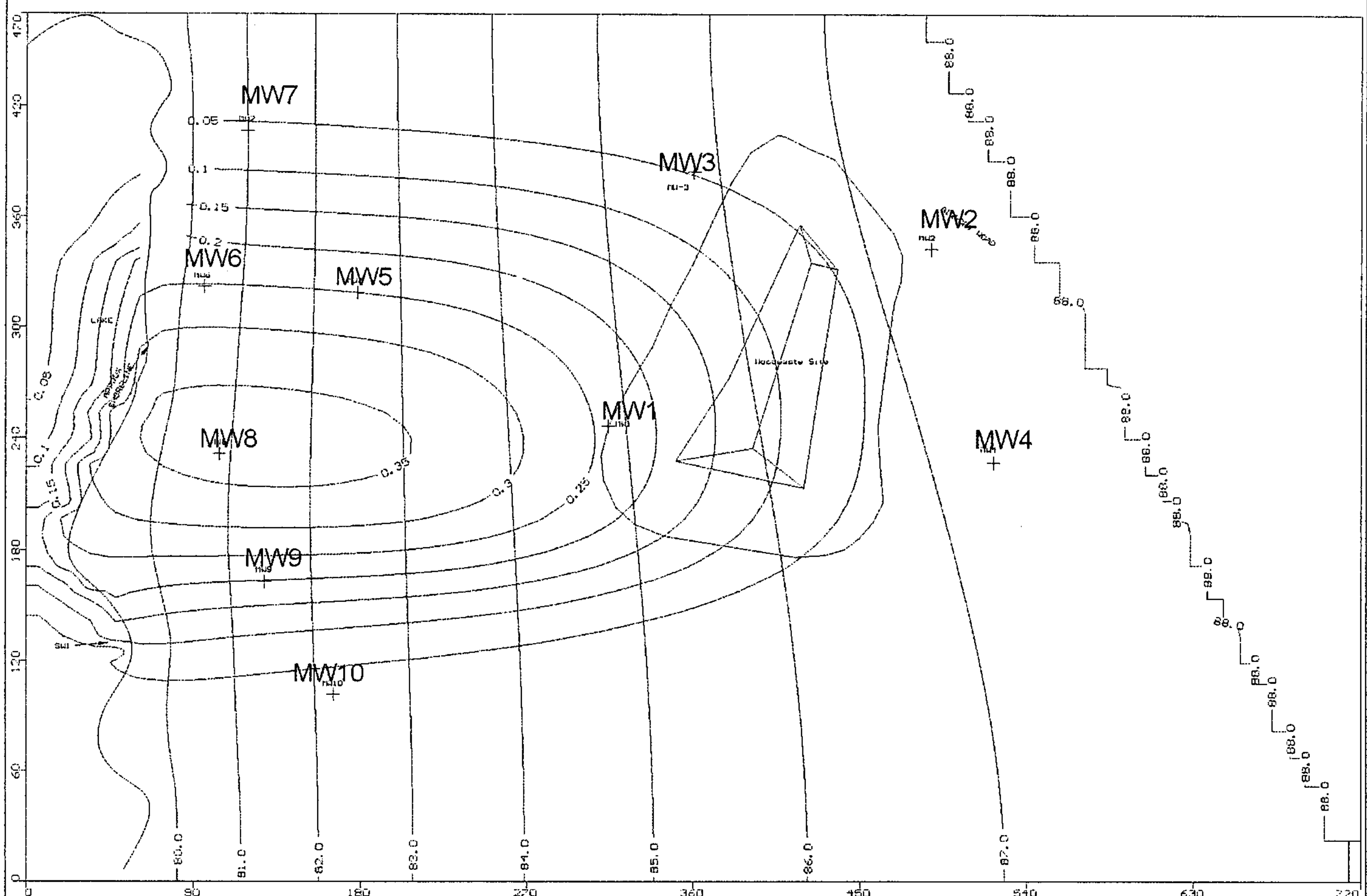


Figure 4.19: Simulated Barium Plume at 3,650 Days Under Waste Removal Conditions (mg/L)

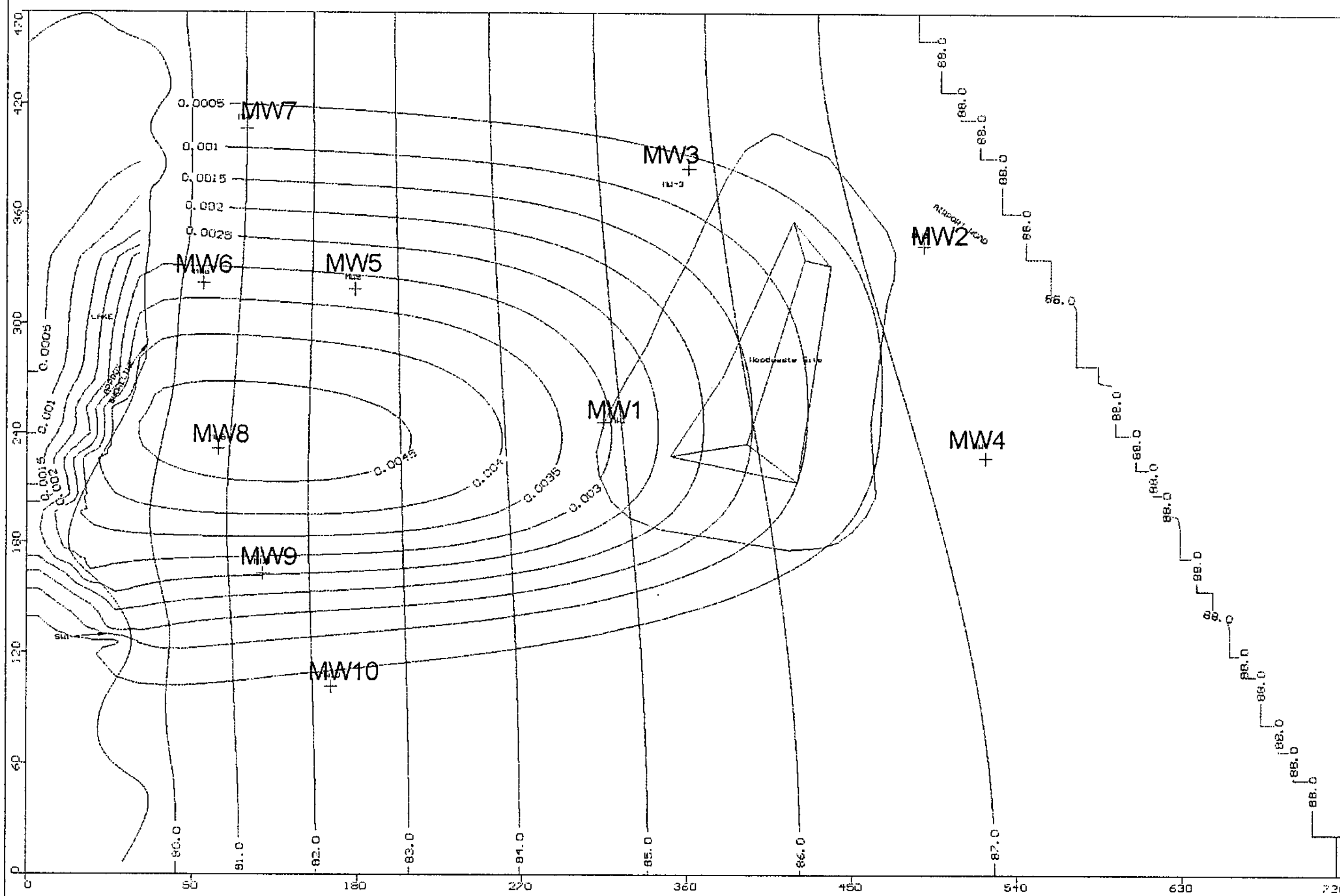


Figure 4.20: Simulated Arsenic Plume at 3,650 Days Under Waste Removal Conditions (mg/L)

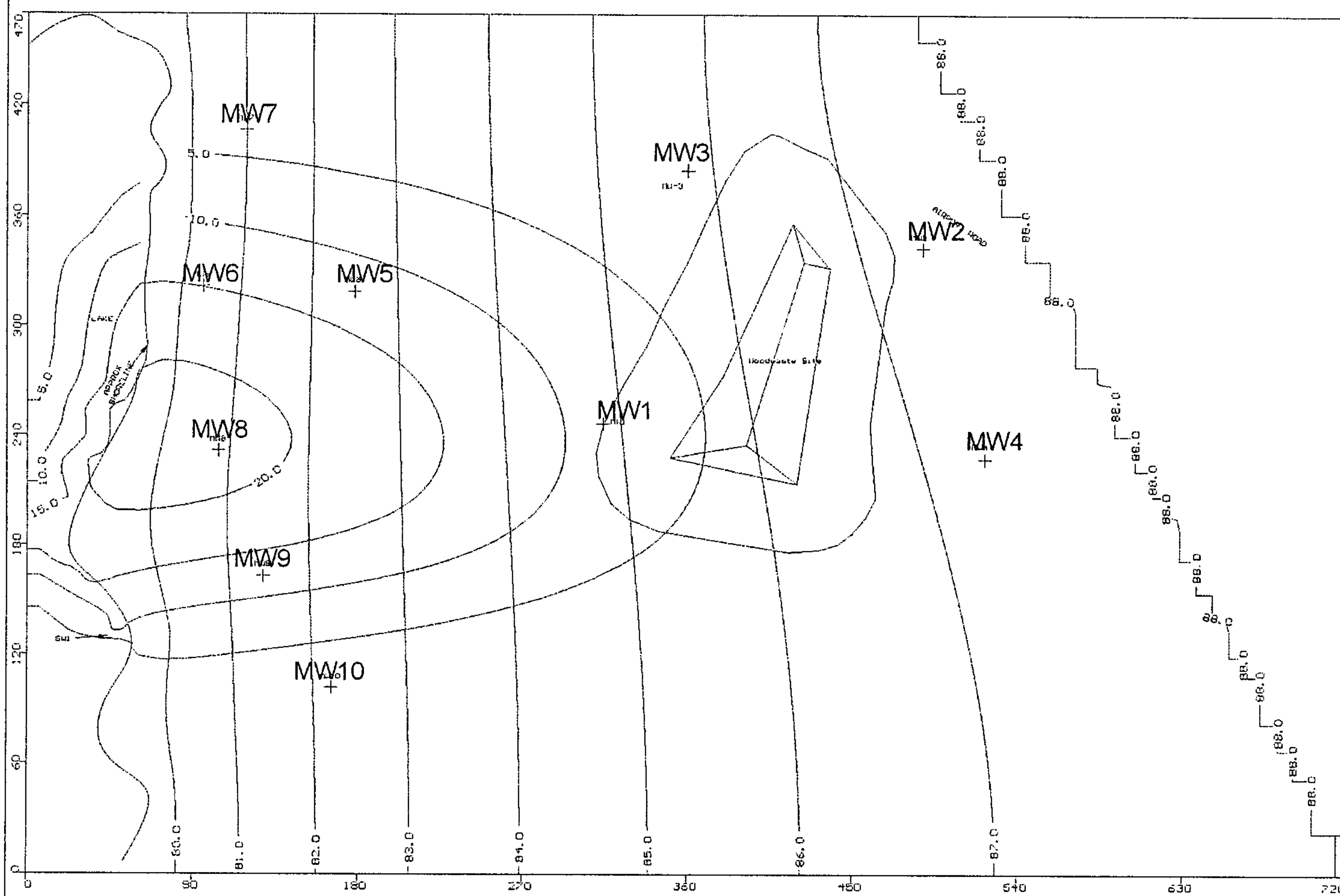


Figure 4.21: Simulated Iron Plume at 4,015 Days Under Waste Removal Conditions (mg/L)

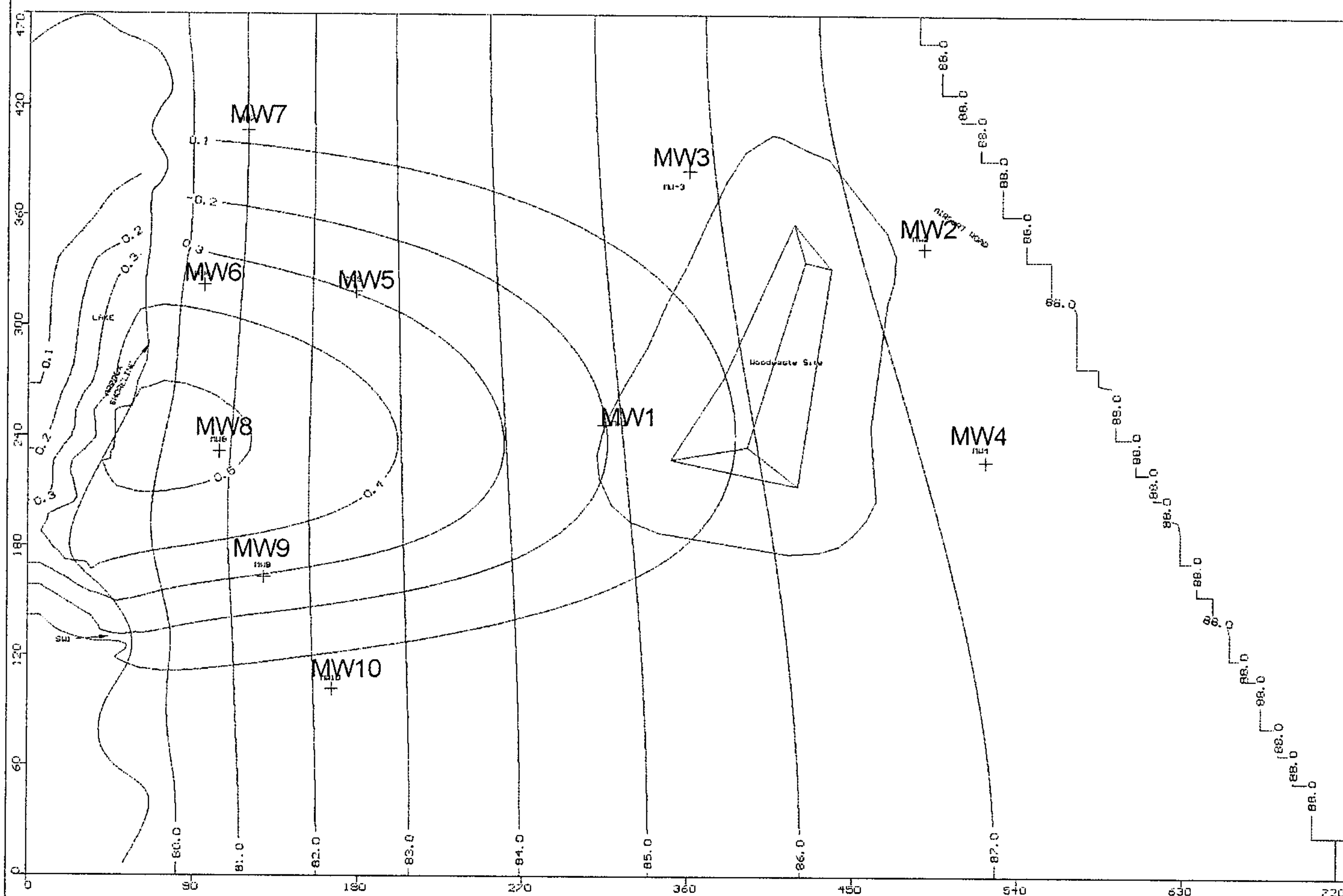


Figure 4.22: Simulated Manganese Plume at 4,015 Days Under Waste Removal Conditions (mg/L)

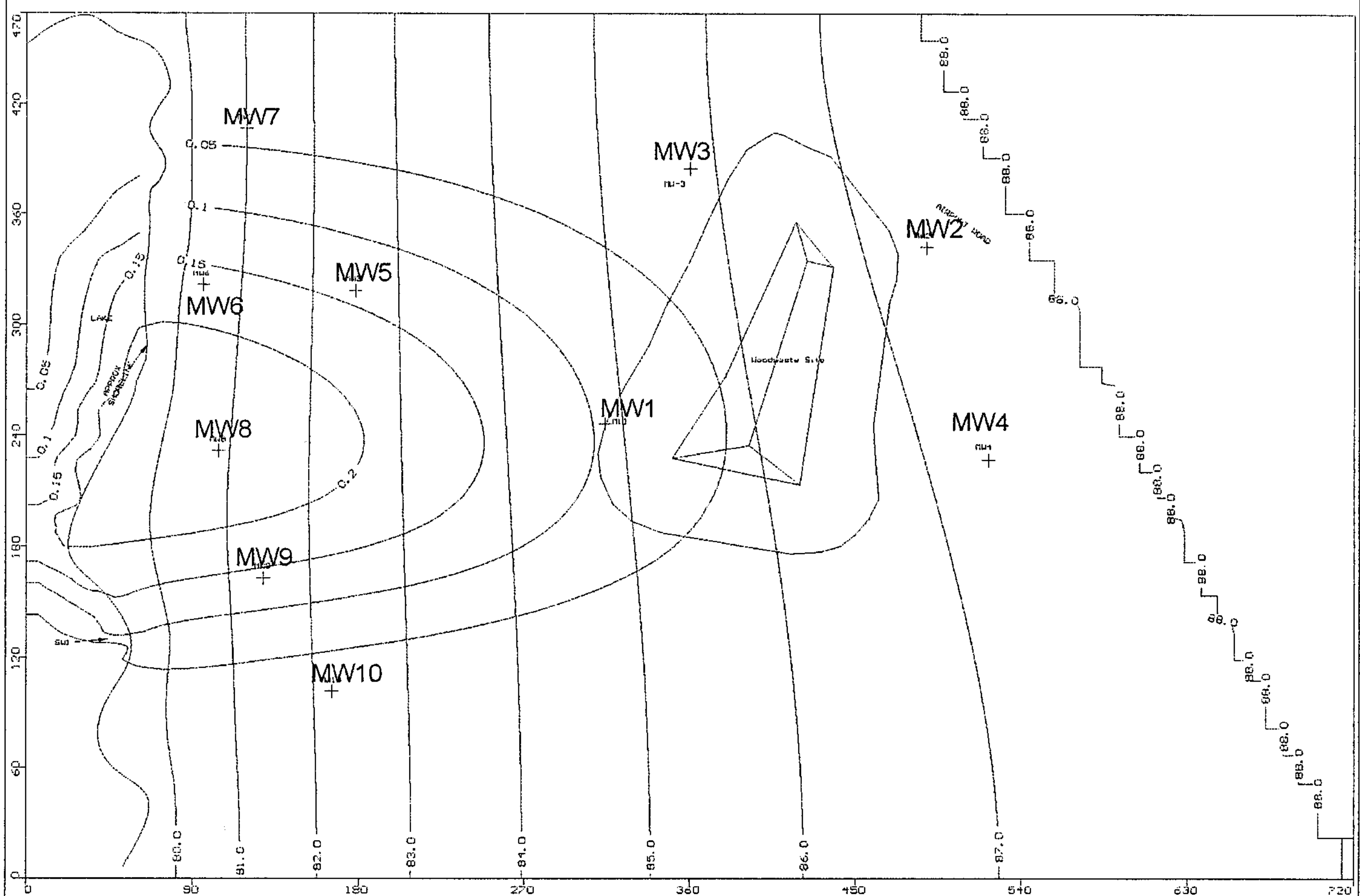


Figure 4.23: Simulated Barium Plume at 4,015 Days Under Waste Removal Conditions (mg/L)

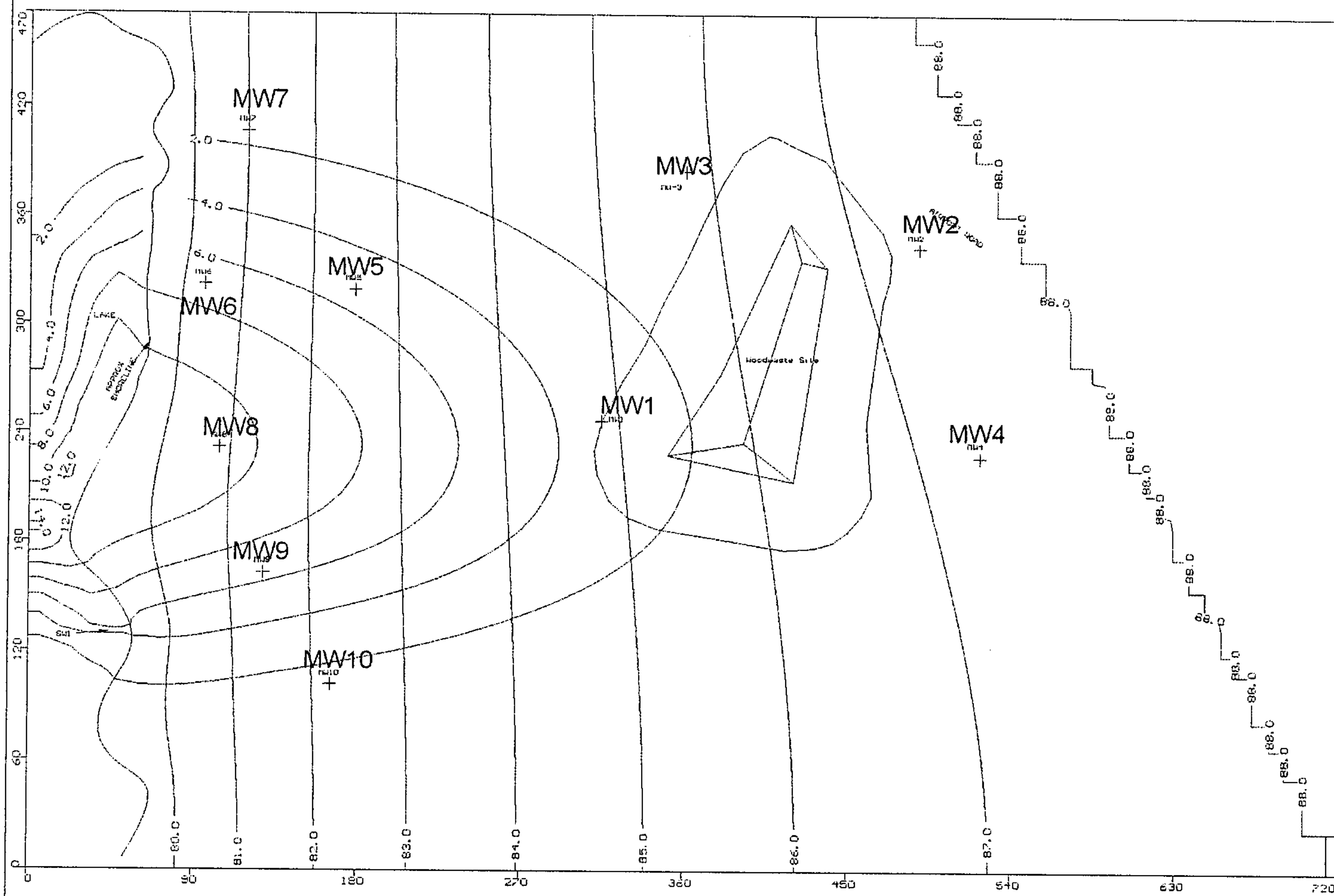


Figure 4.24: Simulated Iron Plume at 4,380 Days Under Waste Removal Conditions (mg/L)

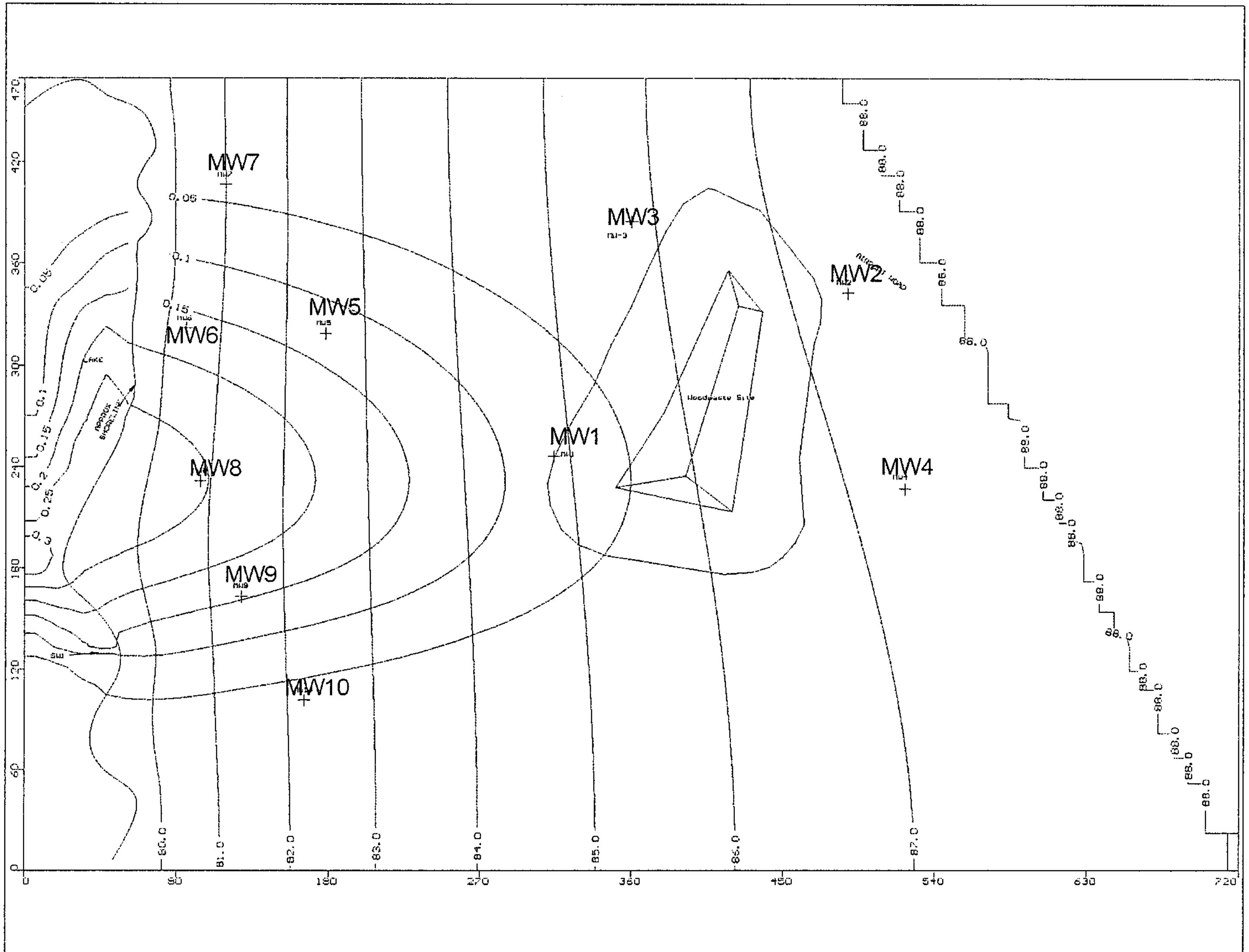


Figure 4.25: Simulated Manganese Plume at 4,380 Days Under Waste Removal Conditions (mg/L)

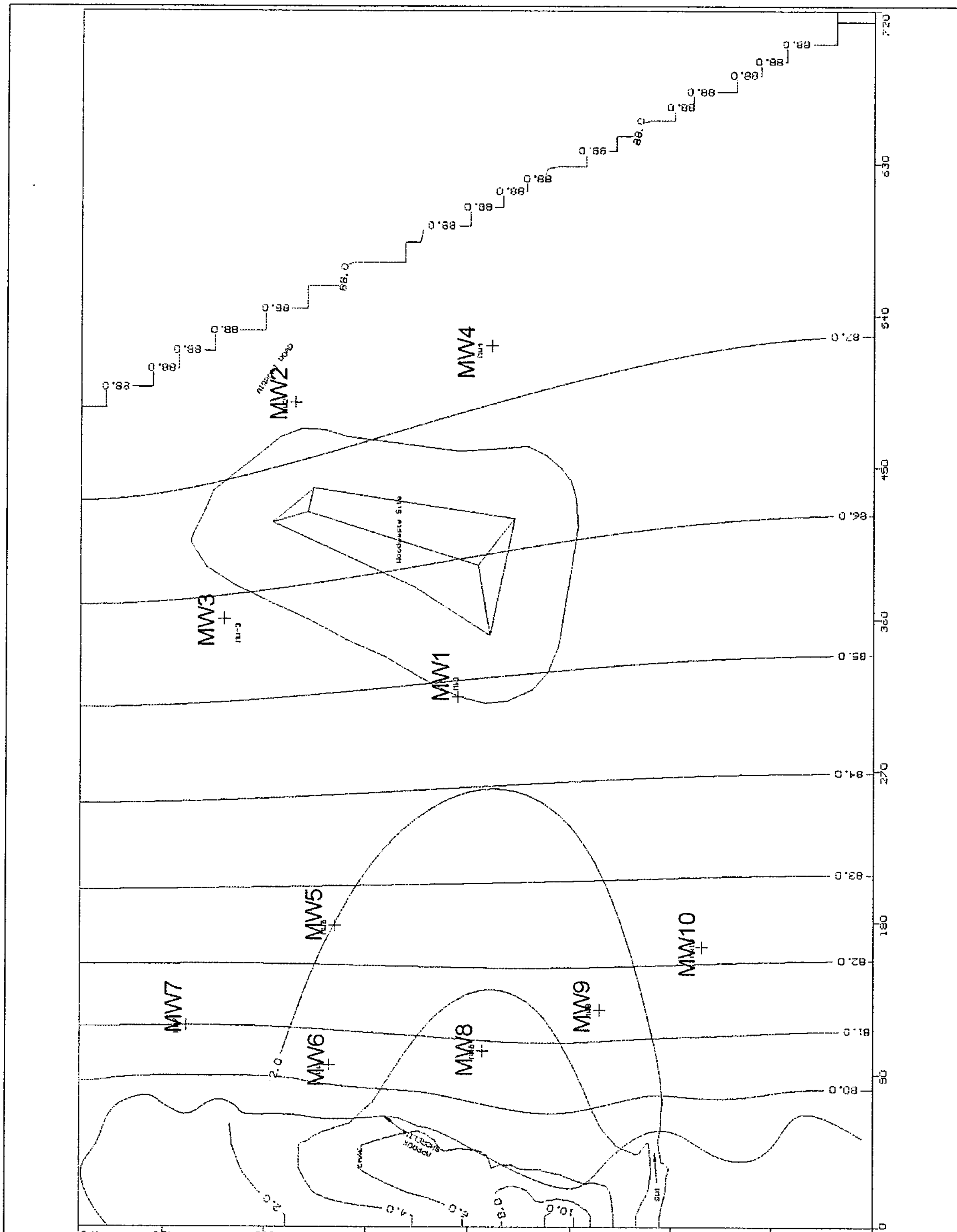


Figure 4.26: Simulated Iron Plume at 4,745 Days Under Waste Removal Conditions (mg/L)

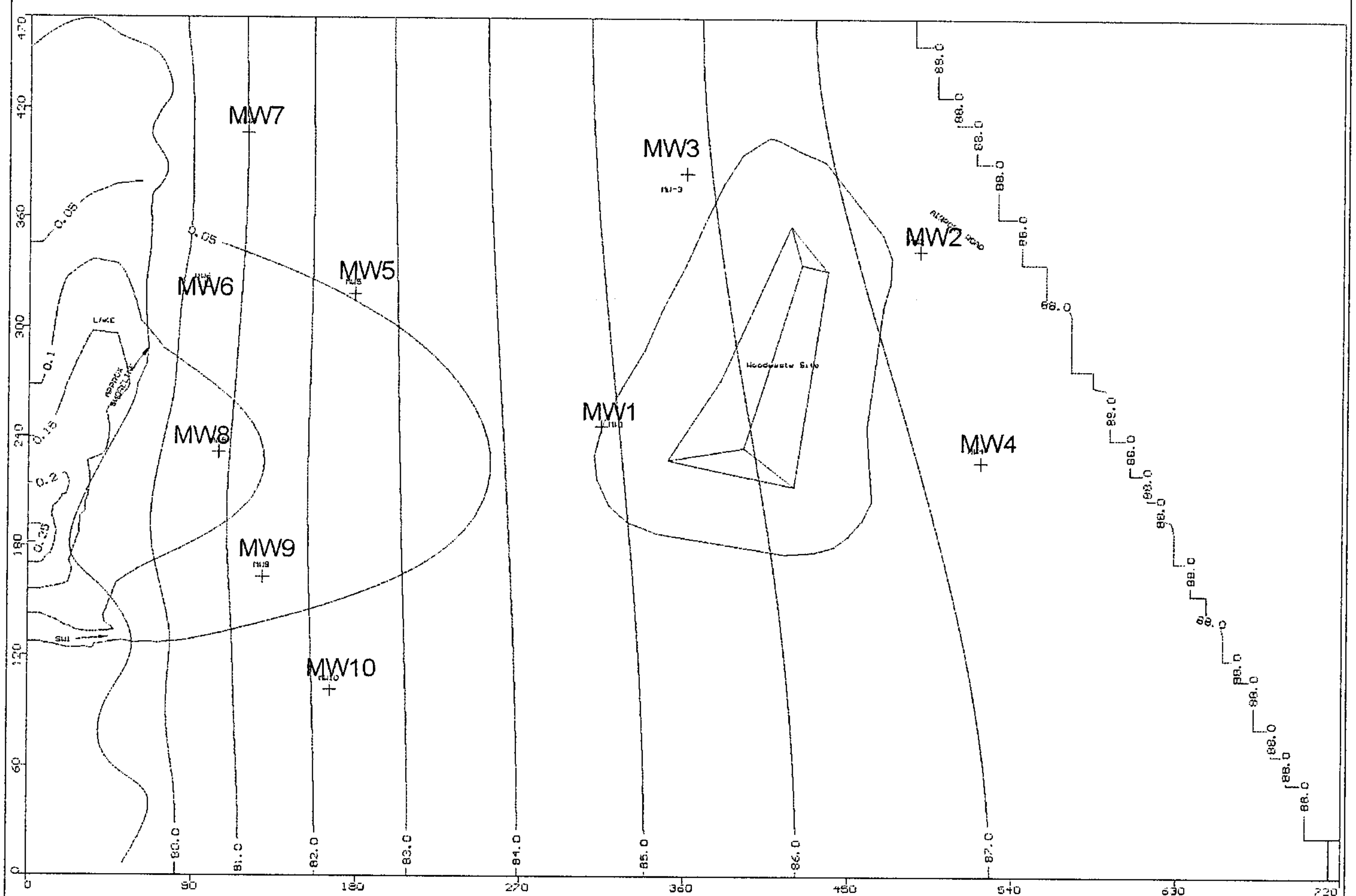


Figure 4.27: Simulate Manganese Plume at 4,745 Days Under Waste Removal Conditions (mg/L)

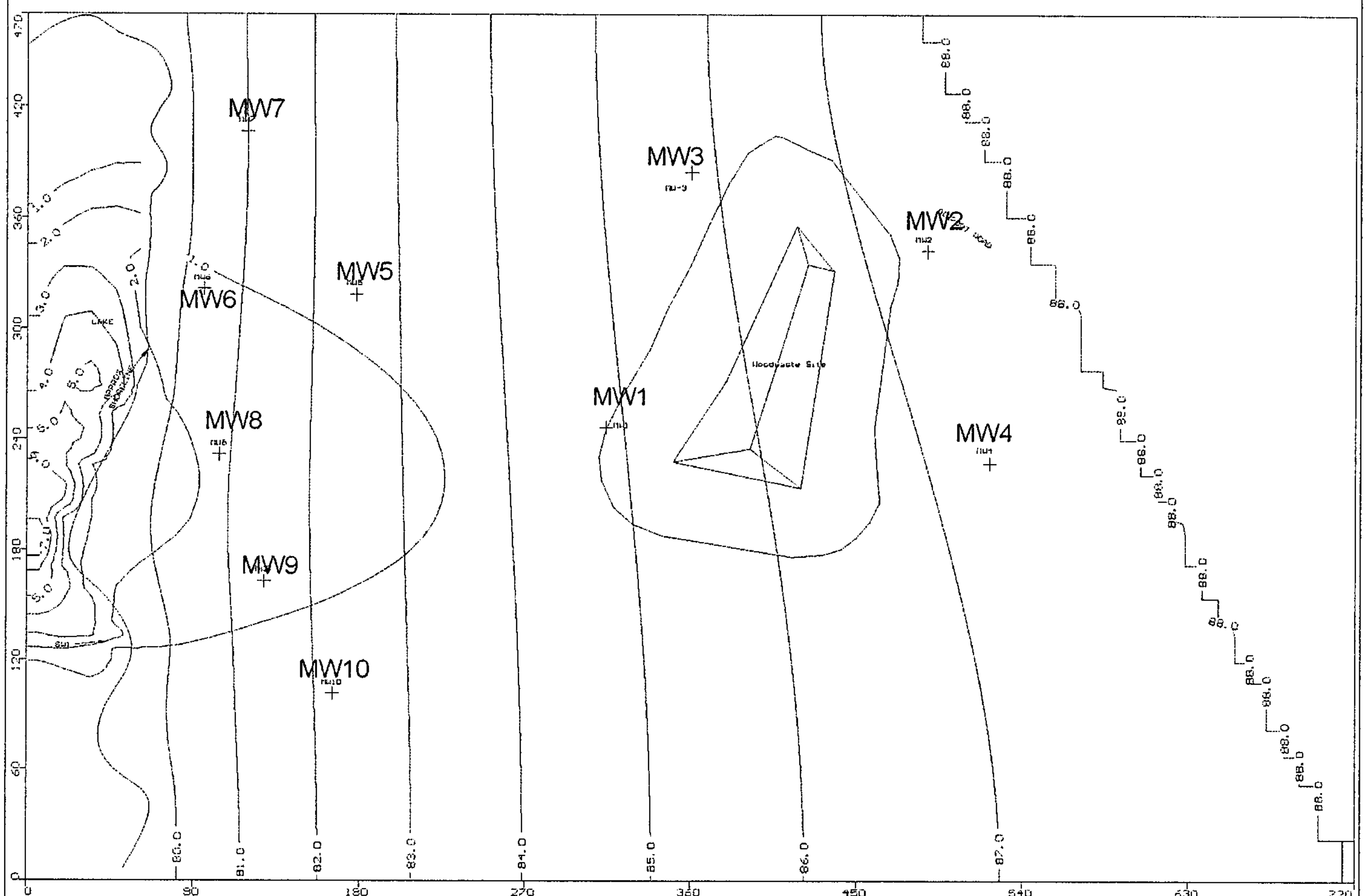


Figure 4.28: Simulated Iron Flume at 5,110 Days Under Waste Removal Conditions (mg/L)

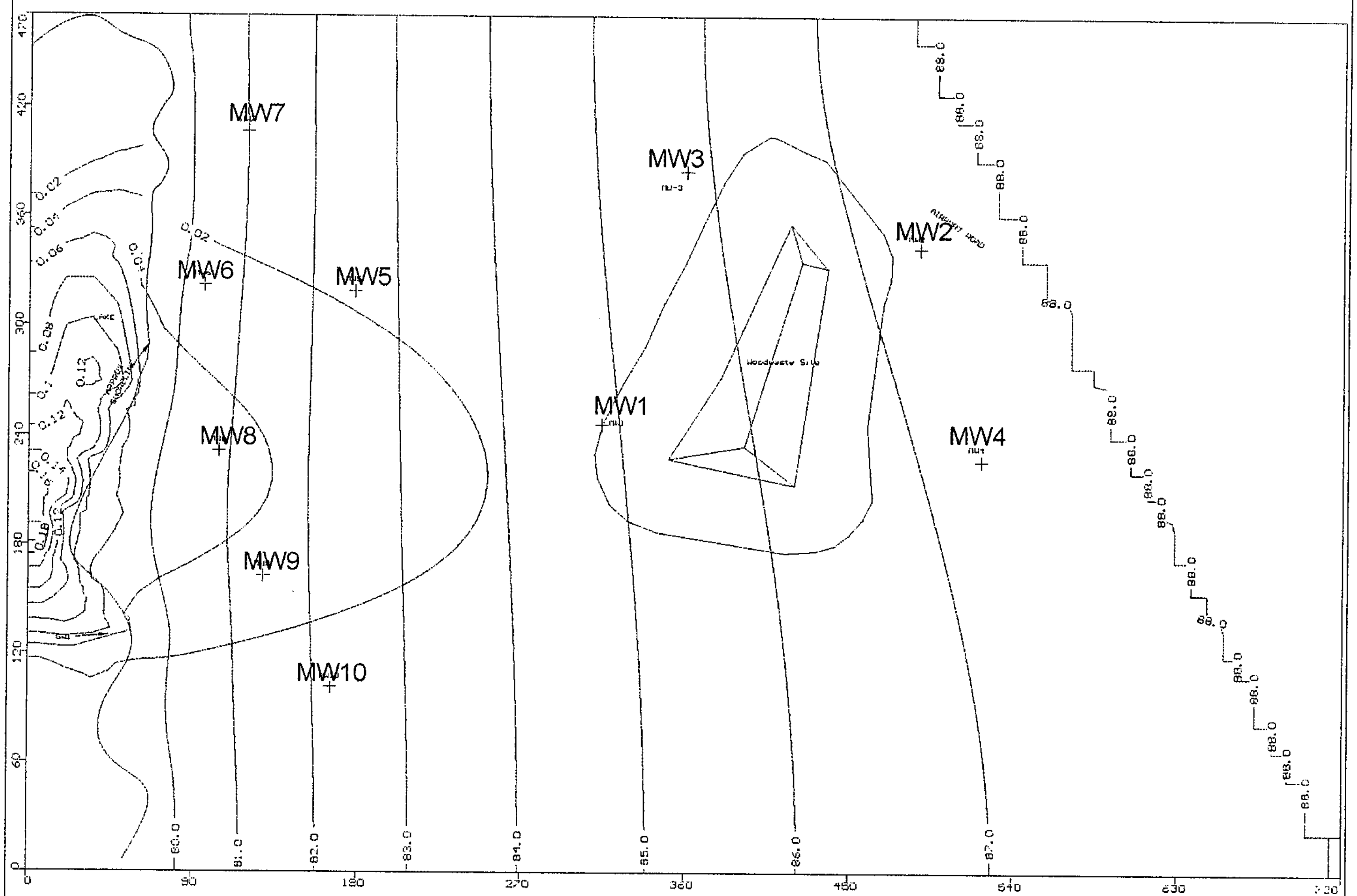


Figure 4.29: Simulated Manganese Plume at 5,110 Days Under Waste Removal Conditions (mg/L)

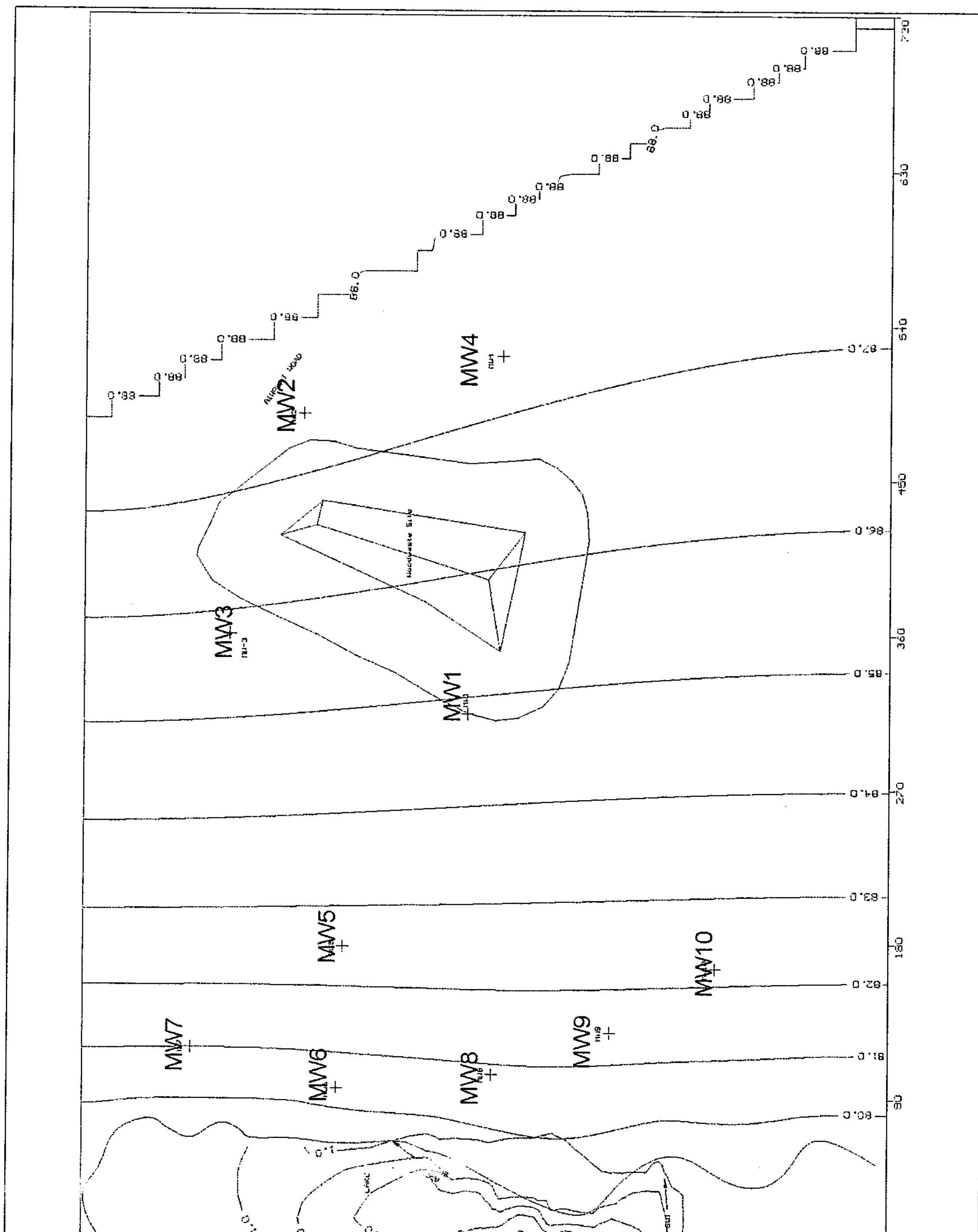


Figure 4.30: Simulated Iron Plume at 5,475 Days Under Waste Removal Conditions (mg/L)

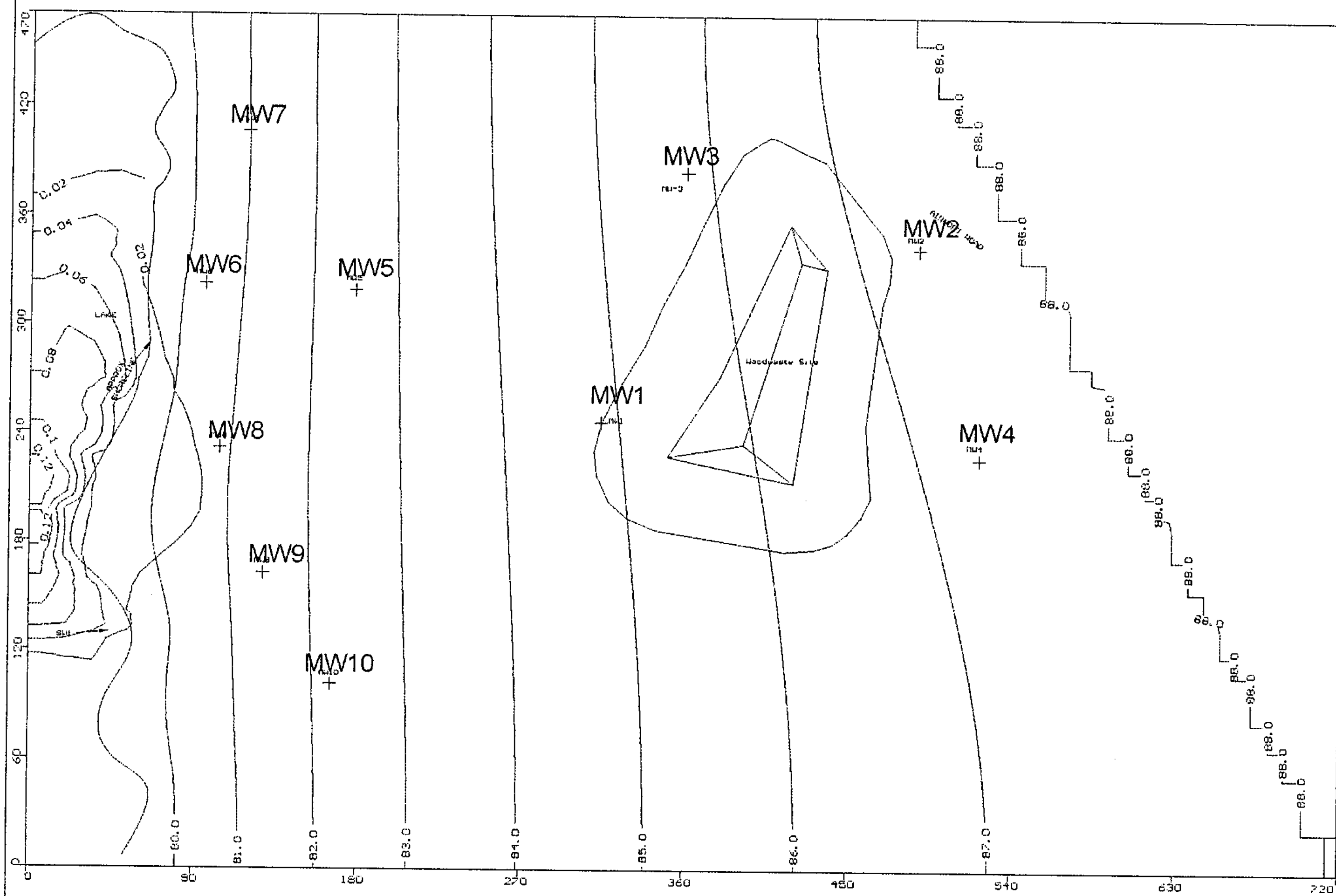


Figure 4.31: Simulated Manganese Plume at 5,475 Days Under Waste Removal Conditions (mg/L)

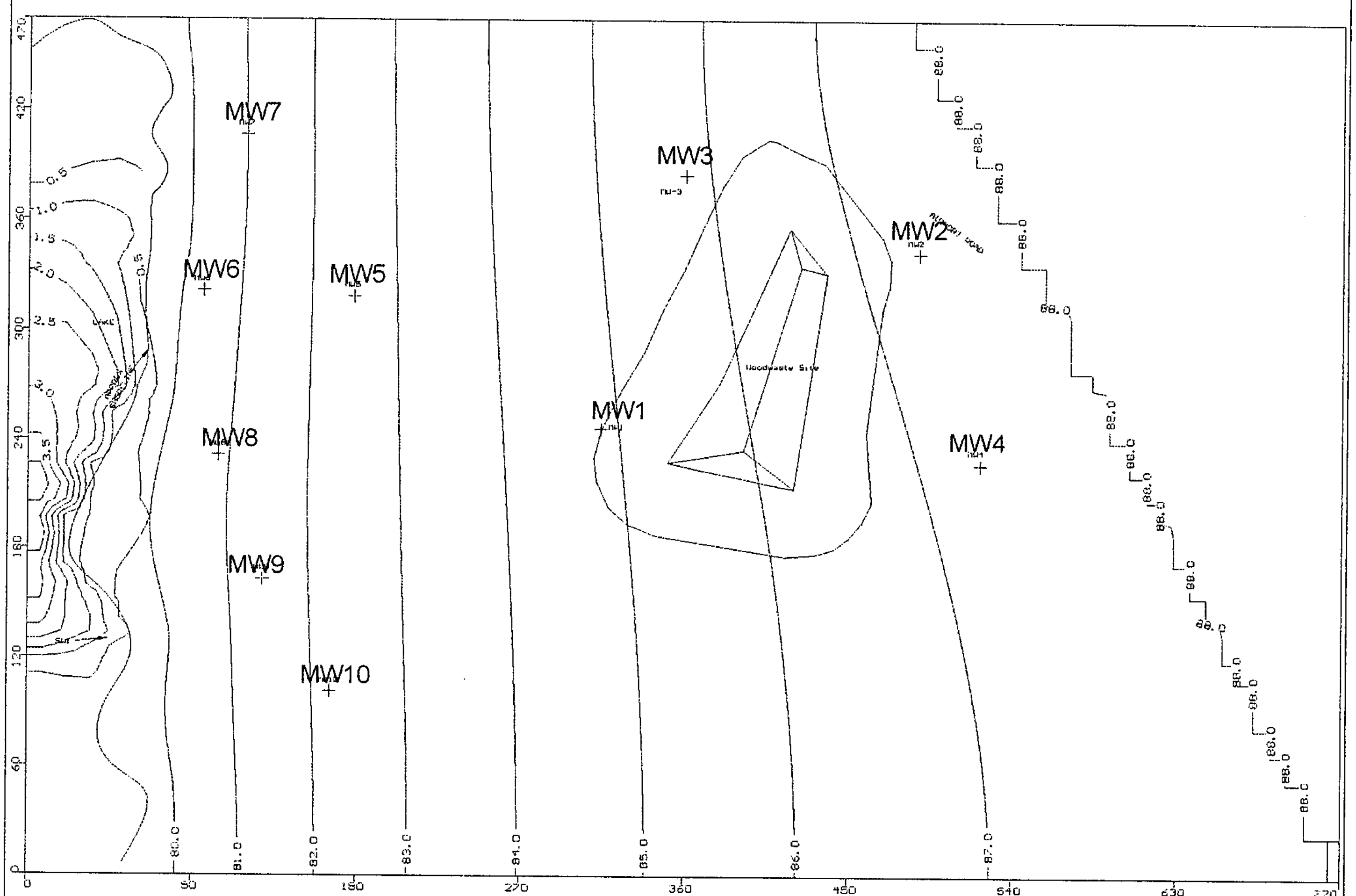


Figure 4.32: Simulated Iron Plume at 5,840 Days Under Waste Removal Conditions (mg/L)

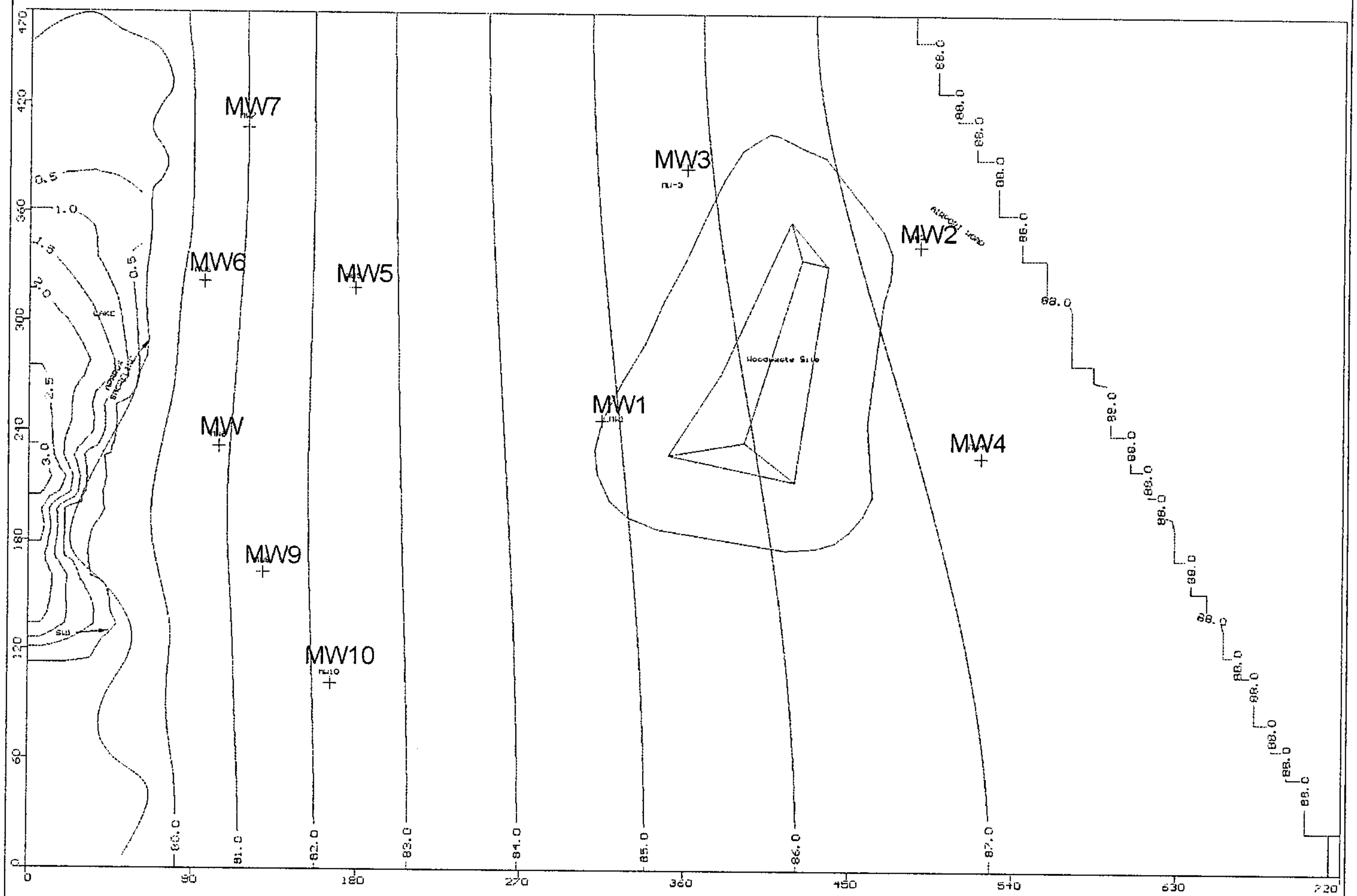


Figure 4.33: Simulated Iron Plume at 6,205 Days Under Waste Removal Conditions (mg/L)

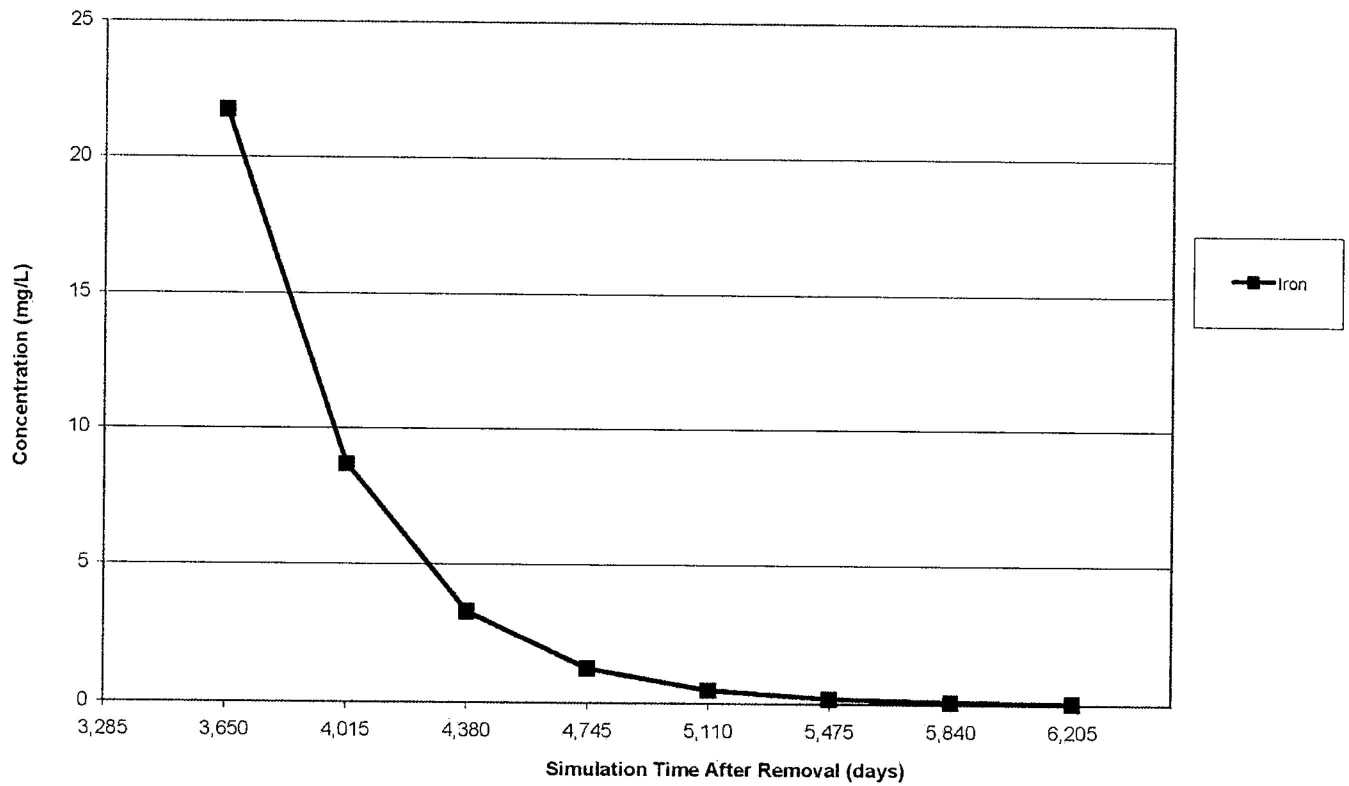


Figure 4.34: Graph of Iron Concentrations at MW1 Following Waste Removal

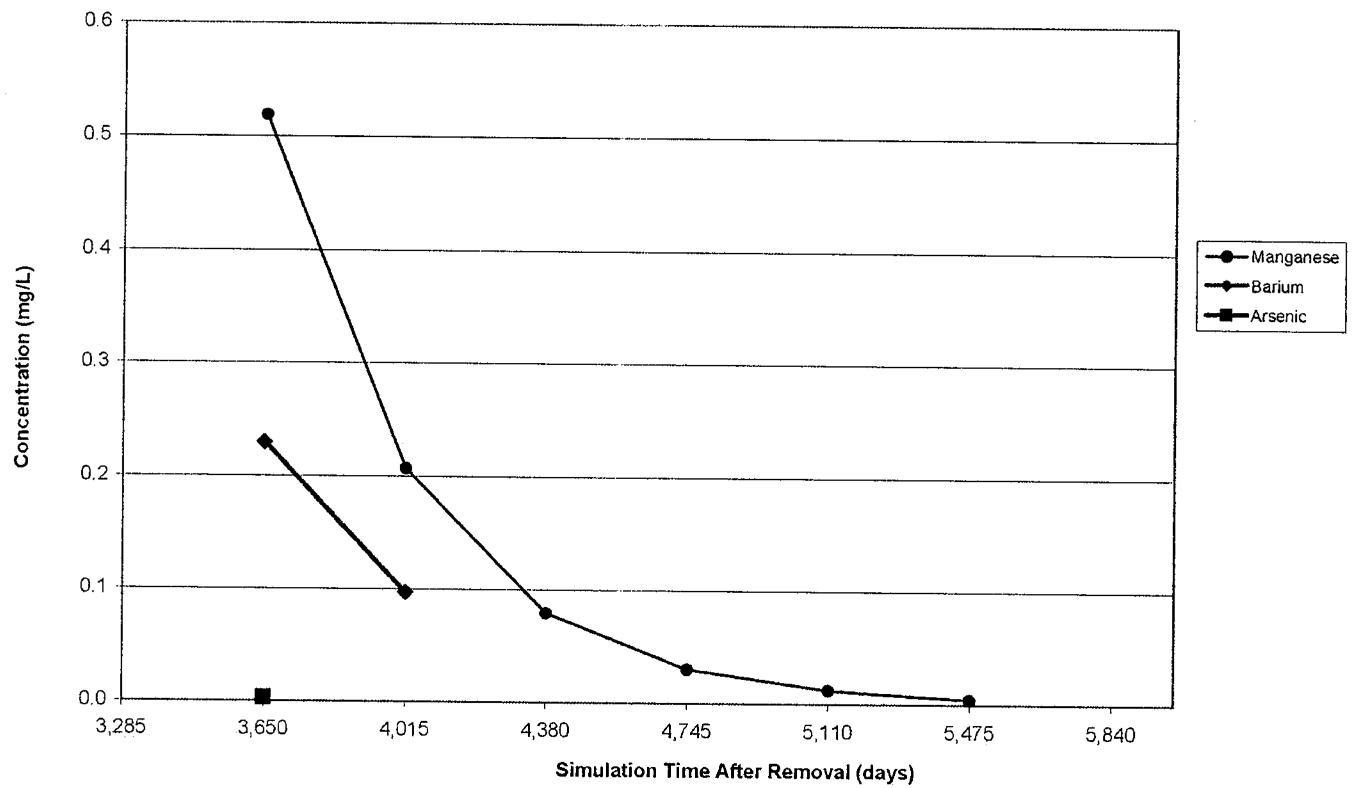


Figure 4.35: Graph of Mn, Ba and As Concentrations at MW1 Following Waste Removal

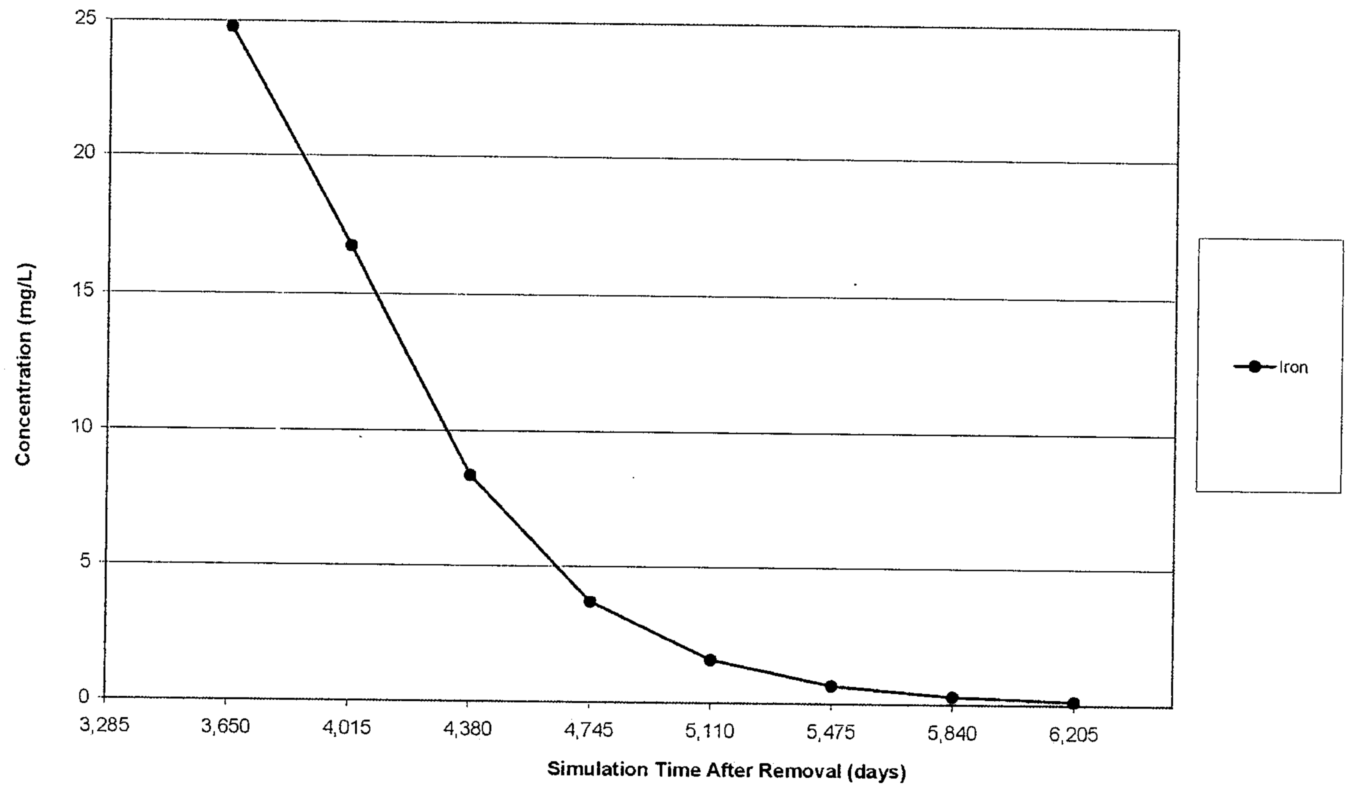


Figure 4.36: Graph of Iron Concentrations at MW8/MW9 Following Waste Removal

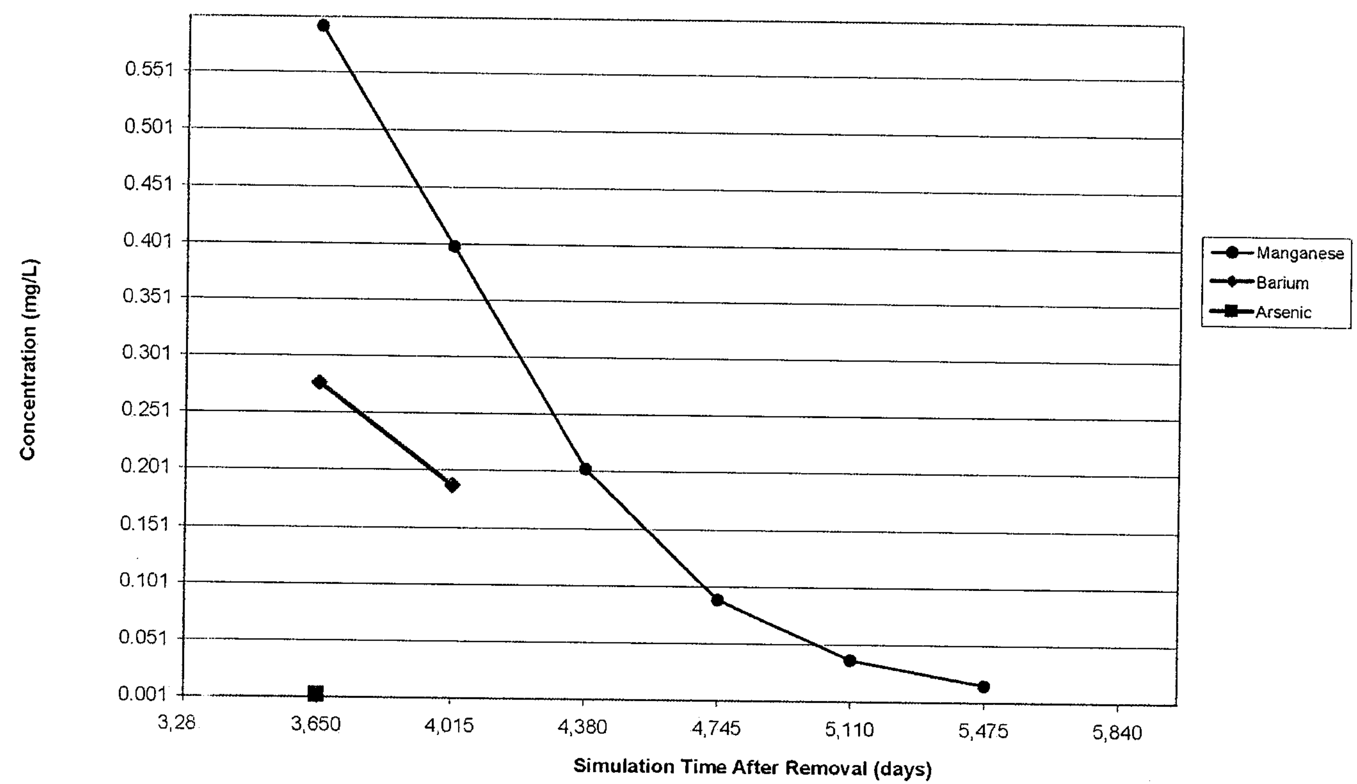


Figure 4.37: Graph of Mn, Ba and As at MW8/MW9 Following Waste Removal

5.0 Woodwaste Bio-Energy Feasibility Study

5.1 Background

With the dramatic increase in regional demand of renewable energy alternatives, an investigation was completed to assess the potential for recovery and utilization of the woodwaste resource. This option was considered warranted prior to simply capping the pile and eliminating any opportunity for resource recovery and waste diversion.

This research includes a field and analytical program to evaluate the feasibility of utilizing the woodwaste pile material for energy recovery. This study was initiated as the first stage of an overall strategic plan for the management of the woodwaste resource pile.

5.2 Test Pitting and Material Sampling Program

A total of 13 test pits were excavated across the woodwaste resource pile on December 19, 2006 using a track-mounted excavator provided by the mill. The test pits ranged in depth from 5.2 to 6.0 metres below the top of the woodwaste pile. Each test pit was logged in the field for material composition including type of material (i.e. woodwaste, round wood, rock, etc), moisture content and relative degree of decomposition.

A total of 53 depth discrete samples were collected from the test pits, generally at 1 to 1.5 m intervals or based on observed changes in the material composition or consistency. Each sample was collected directly from the excavator bucket and placed into heavy gauge, sterile polyethylene bags for potential laboratory analysis.

A total of eight composite samples were also prepared from discrete samples collected from six test pit locations. Each composite sample was prepared by measuring out equal volumes of material from two or more depth discrete samples to represent a larger vertical sample profile. Generally, the composite samples were prepared to represent specific layers of consistent material such as the top 0 – 3 m and/or the bottom 3 – 6 m of select test pits.

Figure 5.1 shows the test pit locations. Figures 5.2 through 5.7 document the test pitting and material sampling activities.

5.3 Laboratory Analysis and Results

A total of 19 samples (eight composites and 11 discrete) were submitted for analysis of moisture and energy content to the mill's internal laboratory. The energy content was analyzed by ASTM D5865-07a (determination of the gross calorific value of coal and coke by an isoperibol bomb calorimeter). The specific unit used for the test procedure was the Parr Instrument Company 1341 Oxygen Bomb Calorimeter.

5.4 Woodwaste Pile Characterization

The test pitting program revealed that the woodwaste resource pile material is generally consistent, both horizontally across the pile geometry and vertically to the physical limits of investigation (6 m below ground surface). The majority of the material encountered across the pile consisted of woodwaste comprised of small pieces (i.e. < 50 mm) up to elongated strands (i.e. "stringy" up to 2 m in length). Well sorted and preserved wood chips were found at several locations along the west face of the pile including test pits TP1, TP2, TP3 and TP5 (Figures 5.3, 5.4, 5.6 and 5.7). Test pits TP6 through TP13 along the center and east half of the pile were found to generally have woodwaste material with some round wood and chips present.

Granular material (i.e. gravel or cobbles) was only observed at two test pit locations. A minor amount of sand was observed at test pit TP5 at depths below 5 m below ground surface and larger rocks (cobbles) were found at test pit TP12 near the surface of the woodwaste pile, likely a result of recent pile grading activities.

Moisture content was observed to be relatively consistent across the pile with the upper 3 m being somewhat less wet than the bottom 3 m of each test pit (i.e. 3 to 6 m below the surface of the pile). At approximately 75% of the test pit locations, the decomposition of the material was observed to be relatively low as there was no visible degradation present.

5.5 Laboratory Results

Table 5.1 summarizes the laboratory results for moisture and energy content analysis for the samples collected from the test pitting investigation.

As shown in Table 5.1, the minimum energy content was 13,093 BTU/kg while the maximum was 19,901 BTU/kg with an average of 18,050 BTU/kg. Woodwaste moisture ranged from 57% to 86% with an average of 69%.

5.6 Comparative Values

Table 5.2 summarizes comparative values, as provided by the mill for vendor-supplied hog fuel used in mill's boiler system in late 2005 and 2006.

As shown in Table 5.2, the minimum energy content was 12,881 BTU/kg while the maximum was 20,983 BTU/kg.

5.7 Summary of Results

Based on the field observations and laboratory analytical results, the material in the woodwaste pile appears to be relatively consistent and is potentially suitable for use in energy recovery initiatives at the mill site. Overall the material in the pile was confirmed to mainly be comprised of woodwaste with lesser percentages (i.e. < 10% by mass) of wood chips and small diameter round wood (Figure 5.4). Very little to no granular material (i.e. gravel, cobbles, etc) and no foreign substances such as steel or unrelated waste materials such as process wastes (i.e. sludges, lime mud, etc) were observed in the pile. The majority of the material examined in the field appeared only slightly decomposed, particularly at depths below 3 m. The underlying geologic conditions consisting of sand with a somewhat deeper water table (4 to 8 m below ground surface) combined with the radially sloped topography of the pile have likely aided drainage conditions and reduced degradation processes.

As indicated in the above tables, the energy content results were relatively consistent among all the samples submitted for analysis. The average energy content for the 19 samples analyzed was approximately 18,000 BTU/kg. In comparison, the average energy content for wood residue or "hog fuel" supplied to the mill site for combustion in the MOE approved boiler system was approximately 17,500 BTU/kg.

The moisture analysis confirmed that the material in the woodwaste resource pile is generally moist to damp with the average moisture content of 69%. The vendor-supplied material had an average moisture content of approximately 50%, thus demonstrating that the material in the pile has accumulated and retained some additional water in comparison to material that is staged for a short period of time (i.e. one season). Available information from the State of Oregon Department of Energy indicates that the moisture content of typical hogged fuel is about 50 percent and its energy content is 9,921 BTU/kg with a typical dry bulk density of 16 to 22 pounds per cubic foot (256 to 352 kg/m^3). The laboratory results indicate that the material in the woodwaste pile may be consistently better than these documented typical values.

Assuming that approximately 90% of the woodwaste resource pile is suitable for extraction, processing and combustion, then about 140,000 m^3 of material may be available. Assuming an average energy content of 18,000 BTU/kg, the relative energy content of this usable mass would be approximately 7.6 billion BTUs (18,050 BTU/kg x 300 kg/m^3 (dry) x 140,000 m^3), which is equal to 2.2 x 10^{+6} kilowatt-hour (7.6 x 10^{+9} BTU x 2.9 x 10^{-4} kilowatt-hour).

In terms of utilization of the material at the woodwaste resource pile, a pilot study would be useful. The pilot study could be designed to determine the operational requirements, costs and limitations to mine, transport, handle, process and combust the material. Based on the confirmed moisture content of the material, at a minimum, some staged approach to drying the material (i.e. windrows, etc) would likely be required to reach boiler system tolerances.

In order to further assess the suitability of the woodwaste pile material for energy purposes, a pilot project is recommended to test the performance of the material in the existing mill power boiler systems. The purpose of the pilot project is to provide real performance data on the associated mill systems that would be involved in the material handling and combustion processes. A secondary objective of the pilot project would be to provide the mill with actual cost information for use in projections related to the handling and use of the material on a full scale basis.

The mill could begin the mining of woodwaste at the north limits of the existing pile. This will ensure positive site drainage throughout the duration of mining operations as this is the low end of the pile.

Material should be excavated on a daily or as required basis, depending on fuel requirements, and trucked to the mill's existing woodwaste processing area for grinding (hogging), storage (drying) and supply to the mill's boilers. The material should be trucked over the existing haul roads within the secured mill site. Material handling and staging should be completed alongside the north-south access road located immediately adjacent to the west side of the pile.

Grinding should be accomplished via the use of third party contractors with existing mobile Ministry of Environment Certificates of Approval for both air and noise for their respective systems (as required). The mill historically has used third party contractors for this purpose (for their existing woodwaste reclamation operations) and should integrate the use of the woodwaste from the site into this arrangement.

The woodwaste should be temporarily stockpiled in cone shaped arrangements for drying. Once suitable moisture levels are achieved, the material would then be mixed with the existing newer woodwaste feedstock and supplied to the boilers.

Sample ID	Depth (m)	Sample Description	Moisture (%)	BTU/kg
TP1-S2	1.8 – 2.1	Woodwaste, some small logs.	70.5	18,543
TP1-S5	5.5 – 5.8	Woodwaste, wood chips, low decomp.	73.5	16,799
TP2-COMP1	3.7 - 4, 4.9 - 5.2	90% wood chips, 10% woodwaste, low decomp.	66	18,638
TP3-COMP1	0.6 – 1.2, 2.1 – 2.4	90% woodwaste, 10% round wood, low decomp.	67	18,726
TP3-S4	5.2 – 5.5	90% fine wood chips, woodwaste, no decomp.	66	18,042
TP4-S3	3.7 - 4	Woodwaste (coarse), trace round wood.	NA	19,473
TP5-COMP1	0 - 0.9, 2.1- 2.9	Woodwaste, trace round wood, low decomp.	69	16,847
TP5-COMP2	3.7 – 4, 5.8 – 6.1	Wood chips, trace round wood, trace sand.	57	13,093
TP6-S3	4.3 – 4.9	Woodwaste, some wood chips, trace round wood.	68.5	16,680
TP7-S1	0.3 – 1.2	Woodwaste, trace wood chips, decomposed.	65.5	19,883
TP8-COMP1	4 – 4.3, 5.5 – 6.1	Woodwaste.	67.5	18,611
TP9-COMP1	0.9 – 1.5, 2.1 – 2.7	Woodwaste, trace wood chips and round wood.	66	18,228
TP10-S3	4.3 – 4.9	Woodwaste, trace wood, decomposed.	70.5	19,901
TP11-S2	1.3 – 1.8	Woodwaste, low decomposition.	67.5	18,975
TP11-S4	5.5 – 6.1	Woodwaste, larger diameter, low decomposition.	66	18,975
TP12-S1	0.6 – 0.9	Woodwaste, trace round wood and cobbles.	68	17,015
TP12-S4	4.6 – 4.9	Woodwaste, trace wood chips, decomposed.	80	18,135
TP13-COMP1	0.3 – 0.9, 1.8 – 2.1	Woodwaste.	66.5	18,186
TP13-COMP2	3.7 – 4.3, 5.5 – 6.1	Woodwaste, round wood.	86	18,201
		Average	**69**	**18,050**

Table 5.1: Summary of Moist and Energy Content Results for Woodwaste

Sample Date	Vendor	Moisture (%)	BTU/kg
12-05-2006	Vendor # 1	44.5	16,920
12-05-2006	Vendor # 2	42.0	17,484
12-05-2006	Vendor # 3	46.5	16,120
12-06-2005	Vendor # 4	51.5	20,983
12-06-2005	Vendor # 5	50	17,888
12-06-2005	Vendor # 6	43.5	18,884
12-06-2005	Vendor # 7	44.5	17,105
12-06-2005	Vendor # 8	51	17,458
12-12-2006	Vendor # 3	52.0	19,356
12-12-2006	Vendor # 9	54.0	14,063
12-12-2006	Vendor # 3	54.0	18,964
12-13-2005	Vendor # 1	55	16,433
12-13-2005	Vendor # 4	59	16,422
12-19-2006	Vendor # 3	49.0	12,881
12-19-2006	Vendor # 10	60.0	15,985
12-19-2006	Vendor # 1	52.0	18,737
12-20-2005	Vendor # 8	49.5	18,069
12-20-2005	Vender # 4	45.5	19,826
12-05-2006	Vendor # 1	44.5	16,920
12-05-2006	Vendor # 2	42.0	17,484
12-05-2006	Vendor # 3	46.5	16,120
	Average	**50.2**	**17,421**

Table 5.2: Summary of Vendor-Supplied Hog Fuel Results

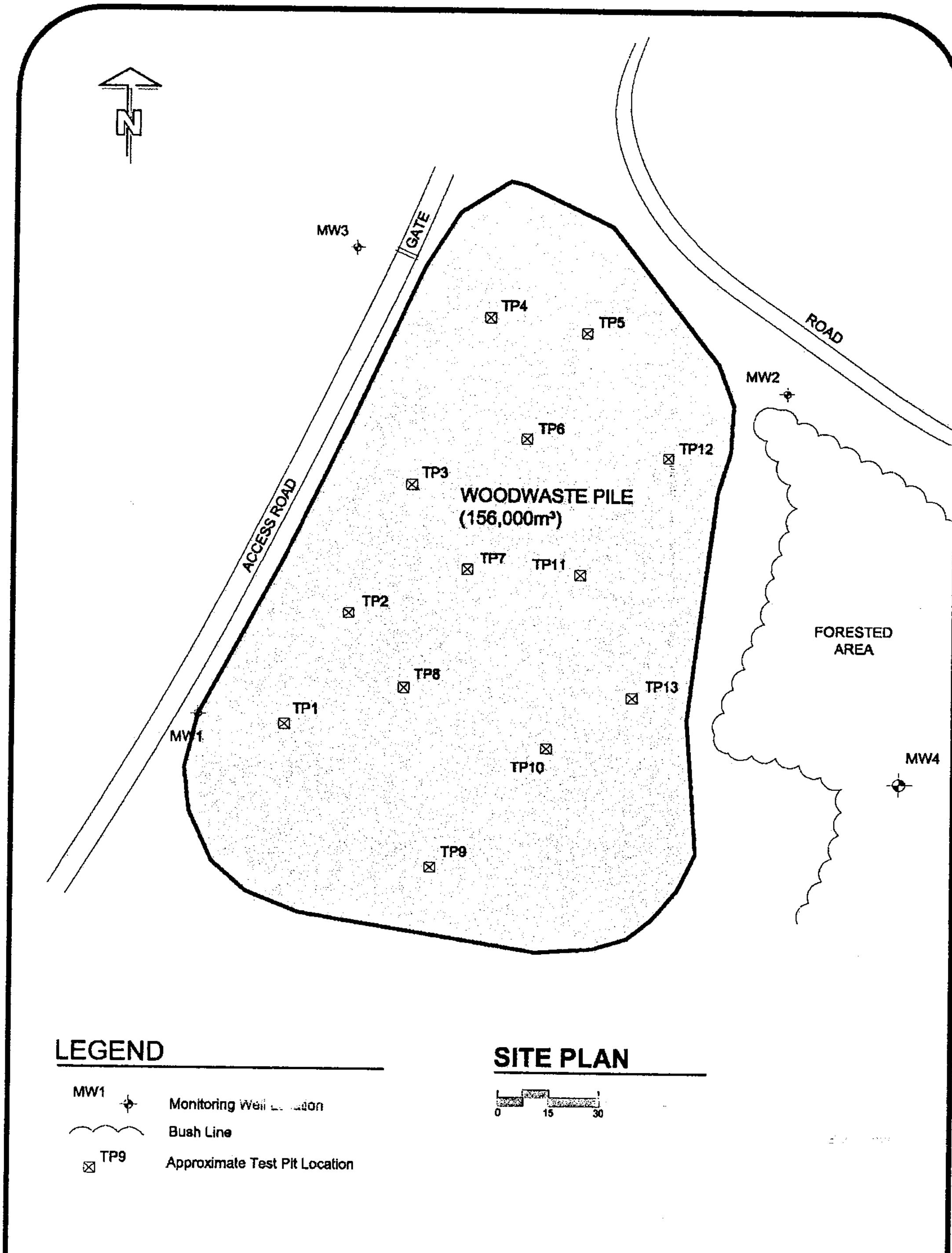


Figure 5.1: Test Pit Locations for Bio-Energy Feasibility Study

Figure 5.2: View facing northeast at test pit TP11 material from 3 m below ground surface.

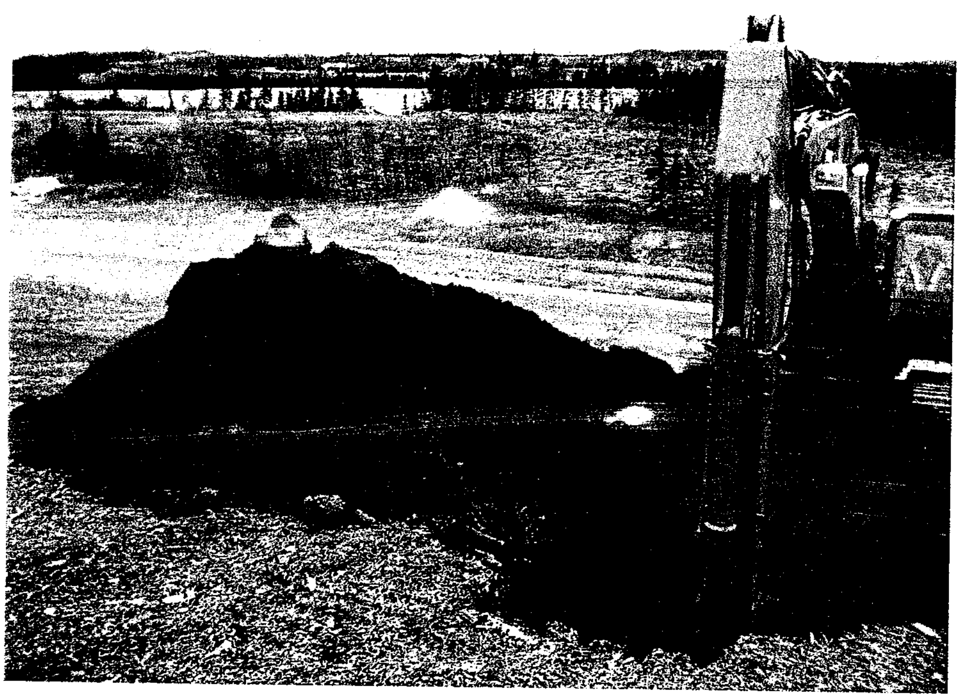


Figure 5.3: View facing southwest at test pit TP2 excavation.

Figure 5.4: View of test pit TP3 material from 5 m below ground surface.

Figure 5.5: View facing north at test pit TP6 material from 4 m below ground surface.

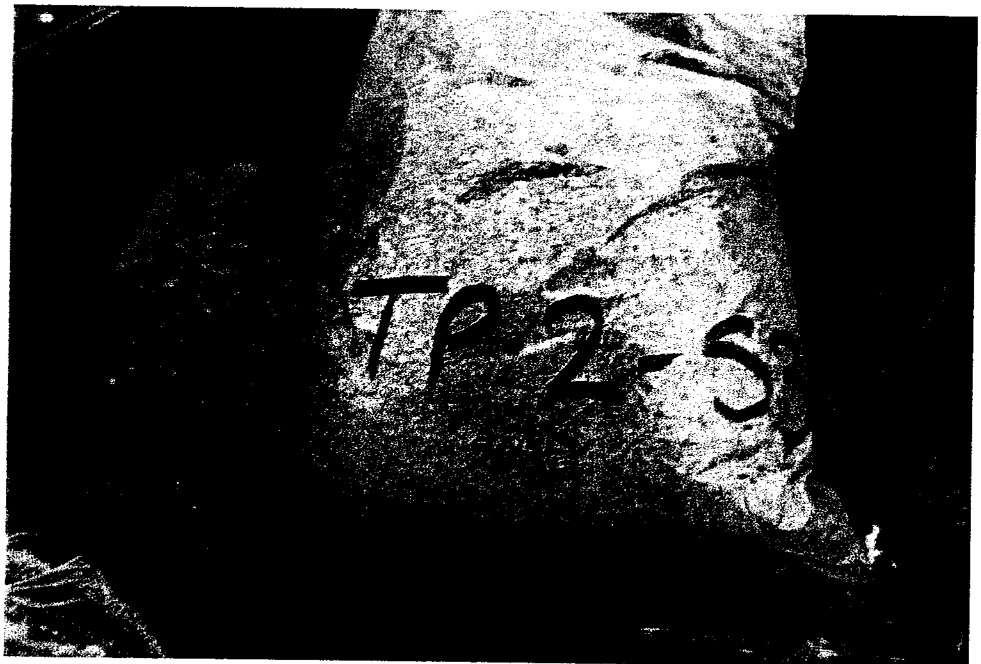


Figure 5.6: View of material from test pit TP2 at 5 m below ground surface.

Figure 5.7: View of material from test pit TP3 at 2.8 m below ground surface.

6.0 Discussion and Conclusions

6.1 Management of Woodwaste

The existing site has been utilized to stockpile wood residue for approximately 20 years, with the intention of removing the woodwaste over time for use as supplemental fuel in the mill boiler system.

The woodwaste study site is estimated to be 156,000 m^3 over an area of 2.56 ha and consists of woodwaste. The current pile is approximately 10 m in height with no waste disposed of below grade. Side slopes are estimated to be approximately 4H:1V with a 5% slope on the crown. The woodwaste site is bordered by a roadway on the northeast, forested area on the east, a log storage/wood debris area father to the south, and a site access road on the west. A lake is located 260 m west and downgradient of the woodwaste pile. The site has a minimum buffer zone of 100 m in all directions.

The existing site has no major surface water drainage features. The overall site topography is a gentle slope from east to west towards the Lake, with a steep embankment along the shoreline of the lake. The surface soils in the immediate vicinity of the woodwaste site are sandy and the majority of precipitation is expected to infiltrate into the ground.

Groundwater and surface water downgradient of the woodwaste site has been monitored twice annually (spring and fall) with an annual water quality report submitted to the MOE for compliance purpose. Monitoring has been completed at the site since 2003. Twice annually sampling has been accepted by the MOE since the water quality downgradient of the site has been stable with no indication of increasing leachate parameter trends generally since sampling began in 2003.

Based on the above, the site design and operations generally meet with standard MOE guidelines with no major deficiencies.

To enhance the environmental monitoring program and provide a second level of protection, a proposed trigger program was developed for monitoring water quality downgradient of the site. The purpose of the trigger program is to provide sufficiently conservative advance warnings for potential off-site impacts (i.e. to the receiving lake) and establish appropriate site specific contingency plans in the event the established trigger criteria are exceeded. The proposed program includes both downgradient groundwater and surface water trigger locations and trigger parameters (based on leachate indicators) to provide advance warnings for off-site impacts.

In the event the woodwaste is not extracted for bio-energy purposes, the pile should be covered to reduce the infiltration of water and generation of leachate. The installation of a low permeability cap (i.e. clay) on the woodwaste pile will likely reduce leachate generation at the site; however, the clay cap would likely degrade rapidly over time from physical weathering processes, causing increased leachate production. Consideration could be made for covering the woodwaste pile with a multilayer sealing system consisting of a geosynthetic clay liner with a geomembrane for stability and longevity.

6.2 Environmental Considerations Related to Woodwaste Landfills

The characteristics of the woodwaste at the study site are similar to the characteristics of woodwaste provided in the literature review (Chapter 2).

Based on analytical results, upgradient and downgradient soils collected below the water table at the study site were similar and characterized by elevated concentrations of total carbon/organic carbon, aluminum, calcium, iron, magnesium, manganese, phosphorus and potassium. Total carbon and total organic carbon concentrations were elevated in downgradient soils relative to upgradient soil, which may be due to the organic nature of the upgradient woodwaste pile.

The woodwaste at the study site is characterized by elevated concentrations of total carbon, inorganic carbon and organic carbon and acid extractable concentrations of aluminum, barium, calcium, iron, magnesium, manganese, molybdenum, nickel, phosphorus, uranium and vanadium relative to the soil samples. Leachable metal concentrations were generally below the laboratory's detection limit for both soil and woodwaste; however, detectable leachable concentrations were measured for boron in both soil and woodwaste and barium in the woodwaste sample.

Several parameters measured in the groundwater adjacent to and downgradient of the woodwaste pile exceeded the applicable Reasonable Use Guidelines, most consistently TDS, DOC, arsenic, barium, iron and manganese. The elevated arsenic concentration in source and downgradient groundwater is not expected to be associated with the disposal of this woodwaste and there is no site specific information regarding a potential source of arsenic at the site. No arsenic, however, was detected in the upgradient wells MW2 and MW4. Further investigation would be required in order to determine the source of arsenic at the site. The elevated TDS, DOC, barium, iron and manganese concentrations are consistent with information provided in available literature for this subject.

The current and historical data indicates that the leachate plume has likely stabilized over the 20 years of leaching. The observed concentrations indicate that the leachate plume extends at least 200 m west-southwest of the woodwaste pile in the area of MW8 and MW9. The water quality at MW10, which had slightly elevated leachate indicator parameters relative to background water quality at MW2, indicates that this well is located near the southern limit of the leachate plume. The northern limit of the leachate plume does not appear to extend as far north as MW6 and MW7, based on the analytical results for these wells, which are similar to background water quality. The observed plume has a northeast-southwest trend with the highest leachate parameter concentrations centering on MW9, which is consistent with the general groundwater flow direction. Based on the current volume and waste area, the current leachate production from the pile is estimated to be approximately 6,144 m^3 per year.

Based on contaminant life span calculations completed for the site, the estimated contaminating life span is 10 years for TDS, 33 years for DOC, 48 years for iron, 32 years for manganese, 17 years for arsenic and 4 years for barium.

Groundwater quality and off-site impacts, although important, are not considered to be the primary concerns at this site because the groundwater is unlikely to be used for drinking water or other purposes since downgradient attenuation areas are within the mill property. The primary concern at this site is the potential for surface water impact since the site is bounded by the Lake to which local groundwater discharges.

Based on the analytical results, impacts to the Lake in association with the woodwaste pile do not appear to be significant based on groundwater quality near the lake as well as surface water quality directly downgradient of the woodwaste pile site. Furthermore, no definitive increasing trends were apparent in wells located within the assumed leachate pathway (i.e. MW5, MW8 and MW9) suggesting that the leachate plume may have stabilized. Based on the current results and interpreted groundwater flow regime, the monitoring well network appears to be reasonably monitoring the lateral extent of the leachate plume downgradient of the woodwaste pile site. The three-dimensional configuration of the plume, particularly in the vertical direction, needs to be better defined. This could be effectively done with a program of direct push technology depth discrete groundwater samples. Once the three dimensional limits of the plume have been better defined, additional monitoring wells could be installed at strategic locations.

The groundwater model was developed to simulate groundwater flow and contaminant fate and transport scenarios at the woodwaste disposal site, with a focus on modeling the transport of leachate indicators iron, manganese, barium and arsenic downgradient of the site.

The objectives of the modeling were to simulate groundwater flow conditions as well as model downgradient groundwater quality under three different scenarios: uncapped and capped woodwaste pile conditions and the removal of woodwaste from the site.

The groundwater flow model was calibrated using PEST software and generally compared well with the observed head measured at the site with a head difference root mean square of 0.344 m and a correlation coefficient of 0.997, which is considered acceptable for the purposes of this study.

The transport model was calibrated by completing sensitivity analysis for recharge concentrations at the woodwaste pile and varying dispersivity values to match the observed plume extents. The simulated leachate concentrations at source well MW1 compare well with average observed concentrations measured from 2003 to 2008. Concentrations of the indicator parameters in downgradient wells MW8 and MW9 also generally compare well when both simulated and observed concentrations were averaged. This approach was considered acceptable for assessing the overall leachate plume downgradient of the site.

Based on the results for the calibrated transport model, concentrations of iron, manganese, barium and arsenic stabilized at 3,285 days or 9 years, which was considered to represent steady state conditions for the transport model.

Based on the model simulation for sorption of barium and arsenic, sorption has a significant effect on the leachate plume downgradient of the woodwaste pile, This supports the observation that simulated results agree well with observed results when only dispersion and not sorption is used in the transport analysis.

Therefore, sorption does not appear to be a significant attenuation process at the site and was not included in the main modeling scenarios.

The mass flux of the selected contaminants was calculated at a control plane downgradient of the woodwaste pile near the lake using observed indicator concentrations at MW8 and MW9 and estimated plume limits. This calculation was completed to estimate the potential mass loading of the selected leachate parameters to the receiving lake. Based on the calculations, the mass flux of iron to the lake would be 1455.3 g/day for an assumed aquifer thickness of 2 m, 1819.1 g/day for an assumed aquifer thickness of 2.5 m, and 2182.9 g/day for an assumed aquifer thickness of 3 m. Mass flux calculations for manganese, barium and arsenic were also completed. As expected, the mass flux to the lake increases as the aquifer thickness increases.

Under capped (low permeability cover) woodwaste pile conditions at steady state, the model estimated that the indicator parameters would be reduced by approximately 73%. As discussed earlier, however, a clay cap will likely rapidly degrade over time due to physical weathering processes and a multilayer sealing system consisting of a geosynthetic clay liner with a geomembrane should be considered.

The downgradient groundwater quality following the removal of woodwaste for bio-energy purposes was also simulated to a time in which each leachate indicator parameter was below their applicable MOE criterion. Concentrations of indicator parameters at source and downgradient wells were calculated to be below the applicable MOE criteria at times of: 2,920 days (8 years) for iron; 2,190 days (6 years) for manganese; 730 days (2 years) for barium; and 365 days (1 year) for arsenic.

Overall, the flow and transport model results generally compared well with observed conditions at the site.

6.3 Woodwaste Bio-Energy Feasibility

Based on the field observations and laboratory analytical results, the material in the woodwaste pile appears to be relatively consistent and is potentially suitable for use in energy recovery initiatives at the mill site.

The energy content results were relatively consistent among all the samples submitted for analysis and were similar to average energy content for wood residue or "hog fuel" supplied to the mill site for combustion by outside vendors.

The moisture analysis confirmed that the material in the woodwaste resource pile is generally moist to damp with the average moisture content of 69%, which is slightly higher than the average vendor supplied material moisture content of 50%. The laboratory energy results indicate that the material in the woodwaste pile may be consistently better than these documented typical values.

Assuming that approximately 90% of the woodwaste resource pile is suitable for extraction, processing and combustion, then about 140,000 m^3 of material may be available. Assuming an average energy content of 18,000 BTU/kg, the relative energy content of this usable mass would be approximately 7.6 billion BTUs (18,050 BTU/kg x 300 kg/m^3 (dry) x 140,000 m^3), which is equal to $2.2 \times 10^{+6}$ kilowatt-hour ($7.6 \times 10^{+9}$ BTU x 2.9×10^{-4} kilowatt-hour).

In terms of utilization of the material at the woodwaste resource pile, a pilot study would be useful. The pilot study could be designed to determine the operational requirements, costs and limitations to mine, transport, handle, process and combust the material. Based on the confirmed moisture content of the material, at a minimum, some staged approach to drying the material (i.e. windrows, etc) would likely be required to reach boiler system tolerances.

7.0 Recommendations

Based on the results of this research, the following recommendations can be made:

- Monitoring of the groundwater and surface water at the study site should continue on a semi-annual basis to assess water quality relative to applicable MOE Guidelines at and downgradient of the woodwaste pile.

- In the event the woodwaste is not extracted for bio-energy purposes, the pile should be covered to reduce the infiltration of water and generation of leachate. The installation of a low permeability cap (i.e. clay) on the woodwaste pile will likely reduce leachate generation at the site; however, the clay cap would likely degrade rapidly over time due to physical weathering processes, causing increased leachate production. Consideration could be made for covering the woodwaste pile with a multilayer sealing system consisting of a geosynthetic clay liner with a geomembrane for stability and longevity.

- Further investigation is required in order to determine the source of arsenic at the site. Further investigation could include a review of all historical data (disposal records, reports, aerial photos, etc.) and the drilling and installation of wells in the area of the pile to determine the source.

- The proposed trigger program should be implemented at the site to assess water quality at the site, provide sufficiently conservative advance warnings for potential off-site impacts and establish appropriate site specific contingency plans in the event the established trigger criteria are exceeded.

- Carry out a groundwater direct push sampling program to better define the three dimensional configuration of the leachate plume. Once the three dimensional limits of the plume have been defined, additional monitoring wells could be installed at strategic locations.

- Site specific sorption and dispersivity values could be investigated further through field and laboratory tests.

- In order to further assess the suitability of the woodwaste resource pile material for energy recovery, a pilot project is recommended to test the performance of the material in the existing mill power boiler systems. The purpose of the pilot project is to provide real performance data on the associated mill systems that would be involved in the material handling and combustion processes. Mill energy systems management and various other mill departments that may be involved in the excavation, handling, preparation and combustion of material during a "test burn" could be consulted to identify the parameters for a suitable pilot project. At a minimum, the following details would have to be examined and the requirements defined:

    - Yard system requirements (material handling/transportation requirements and staging areas).

    - Material preparation and staging requirements (hogging/grinding and drying).

    - Boiler system material tolerances (moisture, foreign material/debris, size, consistency, BTU/kg, and feed rates).

A secondary objective of the pilot project would be to provide the mill with actual cost information for use in projections related to the handling and use of the material on a full scale basis.

8.0 References

Anisimova, N.P. (1988). On the method of cryohydrogeochemical investigations. In Proceedings of the Fifth International Conference on Permafrost, Trondheim, Norway, August 2-5, 1988, Volume I, 1988, p.290-293.

American Public Health Association (APHA), Analytical Methods.

American Society for Testing and Materials, Designation: D 5865 – 07a, Standard Test Method for Gross Calorific Value of Coal and Coke.

Barden, M.J. (2001). Natural Attenuation for Remediation of Contaminated Sites, Course Notes.

Benner S.G., Blowes, D.W. and Ptacek, C.J. 1997. A full-scale porous reactive wall for prevention of acid mine drainage. Ground Water Monitoring and Remediation; 17: (4), pp.99-107.

Bertsch, P.M. and Seaman, J.C. (1999). Characterisation of complex mineral assemblages: implications for contaminant transport and environmental remediation. Proceedings of the National Academy of Sciences, U.S.A.; 96, pp. 3350-3357.

B.C. Ministry of Environment (1991) "Waste Management Guidelines for Classification of Wood waste discharges - DRAFT".

Chapman & Thomas (1968) "*The Climate in Northern Ontario, Climatological Studies)*".

Christensen, T.H., et al. (2001). Biogeochemistry of Landfill Leachate Plumes. Applied Geochemistry, vol. 16, p.659-718.

Domenico, P.A., and F.W. Schwartz (1990). Physical and Chemical Hydrogeology, John Wiley and Sons, New York.

Downs and Webster (2007). Modelling Groundwater Flow and Transport of Contaminants at the Former Manufactured Gas Plant in Vinton, Iowa. Department of Civil Engineering, Fourth Year Degree Project Report, Lakehead University.

Evangelou, V.P. (1998) Environmental Soil and Water Quality. pp.429-433.

Evans, L.J. (1989). Chemistry of Metal Retention by Soils. Environmental Science and Technology. vol. 23, No. 9, p. 1046-1056.

Fetter, C.W. (1994). Applied Hydrogeology, Third Addition. Prentice-Hall Inc., New Jersey.

Gallacher, S. and Pulford, I.D. Adsorption of copper and cadmium by soil from solutions of low metal concentration. /n International Conference on Heavy Metals in the Environment, Geneva, September 1989: Volume 2. CEP Consultants, Edinburgh, UK. pp. 189-192.

Greenbaum, P.J. (2005) "The Future of Energy in the Post-Kyoto World". Pulp and Paper Canada, pg. 21-22.

Gunn, A.M., Winnard, D.A. and Hunt, D.T.E. (1988). Chapter 12: Trace metal speciation in soils and sediments. /n Metal Speciation: Theory, analysis and application. Edited fry J.R. Kramer and H.E. Allen. Lewis Publishers, Inc., Chelsea, Michigan. pp. 261-294.

Harter, R.D., (1983), "effect of soil pH and adsorption of lead, copper, zinc and nickel", *Soil Sci. Soc. Amer. J.*, 47:47-51.

Haygreen, J. and J. Bowyer (1989), Forest products and wood science, 2nd ed., Iowa State University Press, Ames, Iowa.

Hsu, P.H. (1989). Aluminum Oxides and Oxyhydroxides. "Minerals in Soil Environments". Soil Sci. Soc. Am., Madison, WI.

Jianbang Gan and C.T. Smith (2005) "Availability of Logging Residues and potential for electricity production and carbon displacement in the USA.

Krauskopf, K.B. and Bird, D.K. (1995). Chapter 6: Surface chemistry: the solution-mineral interface. /n Introduction to Geochemistry, 3rd edition. McGraw-Hill, 1995. Toronto, ON. pp. 135164.

Maltby, V., (2006) "A Review of Canadian Forest Products Industry Landfill Design, Construction, Operations and Closure". ISSN 0886-0882.

McCubbin, H (1983) "The Basic Technology of the Pulp and Paper Industry and Its Environmental Protection Practices". EPA 6-EP-83-1. Environmental Protection Service. Environment Canada, Ottawa.

McKenzie, R.M. (1989). Manganese Oxides and Hydroxides. "Mineral Soil Environments". Soil Sci. Soc. Am., Madison, WI.

McLean, J.E., Bledsoe, B.E. (1992). Behavior of Metals in Soils. EPA Groundwater Issue.

McNeeley, R., V. Neimanis and L. Dwyer (1979) "Water quality sourcebook: A guide to water quality parameters", Inland Waters Directorate, Environment Canada, Ottawa, Ontario.

Ministry of Energy and Ministry of Environment (1991) "Woodwaste Generation and Management in Ontario", ISBN 0-7729-7708-9.

Ministry of Environment (1989) "Woodwaste Disposal and Provisions of the Environmental Assessment Act", Woodwaste Committee Report.

Ministry of Environment and Energy Standards Development Branch (1996) "Guidance on Sampling and Analytical Methods for use at Contaminated Sites in Ontario", ISBN-0-7778-4056-1.

Ministry of Environment and Energy (1994) "Guideline B-7 (formerly 15-08), Incorporation of the Reasonable Use Concept into MOEE Groundwater Management Activities".

Rowe, R.K. (1991). Contaminant impact assessment and the contaminating lifespan of landfills, Canadian Journal of Civil Engineering, vol 18, pp. 244-253.

Sara, M.N. (2003). Site Assessment and Remediation Handbook, Second Edition. Lewis Publishers. P. 901-923

Schnitzer, m. (1984). Chapter 10: Soil organic matter: its role in the environment. In Mineralogical Association of Canada: Short course in environmental geochemistry. Ed: Fleet, M.E. Mineralogical Association of Canada, Toronto, ON. p. 237-268.

Schwertmann and Cornell (1991). "Iron Oxides in the Laboratory". VCH, Weinheim.

Sparks, D.L. (2003). Environmental soil chemistry. Academic Press, Inc. San Diego, California.

Sparks, D.L. (1995). Environmental soil chemistry. Academic Press, Inc. Toronto, Canada.

Sposito, G. (1989), The chemistry of soils, Oxford University Press
ytfn

Stevenson, F.J and Fitch. (1986). Chemistry of complexation of metal ions with soil solution organics. In P.M. Huang and M. Schnitzer (eds). Interactions of soil minerals with natural organics and microbes. Soil Sci. Soc. Special Publication. No. 17, Soil Sci. Soc. Amer., Madison, WI.

Sweet, H. and R. Fetrow (1975) "Ground-Water Pollution by Woodwaste Disposal", Groundwater 13(2): 227-231.

Tao, W.; Hall, K.J.; Masbough, A.; Frankowski, K.; Duff, S.J.B (2005) "Characterization of Leachate from a Woodwaste Pile". Water Quality Research Journal of Canada. Canadian Association of Water Quality.

Taylor, B., K. Yeager, S. Abernathy and G. Westlake (1988) "Scientific criteria document for development of Provincial water quality objectives and guidelines - Resin acids", Ontario Ministry of the Environment.

Taylor, R.M. (1987). Nonsilicate oxides and hydroxides. "The Chemistry of Clays and Clay Minerals". Longman Group Ltd., Harlow, Essex, England

Thomas, P. (1977) "Consequences of Leaching From Pulp and Paper Mill Landfill Operations", Co-operative Pollution Abatement Research Program 363, Canadian Forestry Service, Environment Canada, Prepared by Econotech Services Ltd.

Thompson, S (2007) “Groundwater Modeling and Contaminant Transport”, Oklahoma Department of Environment Quality, Oklahoma Department of Libraries.

Site Geological Assessment (2003).

United States Department of Agriculture Forest Service (1972). The Moisture Content and Specific Gravity of the Woodwaste and Wood of Northern Pulpwood Species.

U.S. EPA (1996). Soil Screening Guidance: Technical Background Document. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC, EPA/540/R-95/128, July 1996.

Viessman and Lewis (2003). Introduction to Hydrology, fifth adition, Pearson Education Inc.

Visual MODFLOW v.4.3 User's Manual. For Professional Applications in Three-Dimensional Groundwater Flow and Contaminant Transport Modeling. Schlumberger Water Services.

Webster, J.G., Nordstrom, D.K. and Smith, K.S. (1994). Transport and natural attenuation of Cu, Zn, As and Fe in the Acid Mine Drainage of Leviathan and Bryant Creek. American Chemical Society, Washington, DC. pp. 244-260.

Wiegand, P. (1992). Chemical Composition of Pulp and Paper Industry Landfill Leachates. National Council of the Paper Industry for Air and Stream Improvement Technical Bulletin No. 643.

Wood, L. (2008). Flux-Based Site Management. Triad Conference. June 10, 2008.

Yariv,, S. and Cross, t-i. (1979). Geochemistry of colloid systems for earth scientists. Springer Verlag, New York, USA. 450 p.

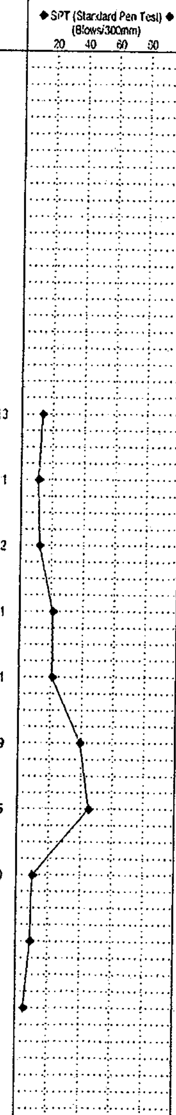
Appendix A: Borehole Logs

PROJECT: Bark Pile Hydrogeologic Assessment	CLIENT:	TESTHOLE NO: MW-1
LOCATION: Southwest Corner of Bark Pile		PROJECT NO.:
CONTRACTOR: Paddock Drilling Ltd.	METHOD: 6 1/4 Hollow Stem Auger	ELEVATION (m): 90.424

SAMPLE TYPE: GRAB, SHELBY TUBE, SPLIT SPOON, BULK, NO RECOVERY, CORE

BACKFILL TYPE: BENTONITE, GRAVEL, SLOUGH, GROUT, CUTTINGS, SAND

DEPTH (m)	USC	SOIL DESCRIPTION	SAMPLE #	SPT (N)	COMMENTS
0	SA	SAND -greyish brown, moist, fairly loose, mainly fine - med., trace coarse - frost to 0.6 m	S1		
		-turns grey, dry and well graded and coarser at 1.7m	S2		
		-slightly finer below 3m	S3	13	
			S4	11	
		-changes to fine sand, poorly graded, slightly denser below 4.8m	S5	12	
		-wet below 5.3m	S6	21	
		-silt lense, wet, medium dilatency between 5.85 and 6m	S7	21	
	SM	SAND and SILT -very moist, grey, dense, very fine grained -frost at 0.6m	S8	39	
			S9	45	S9 Grain Size = 47.9% Sand 52.1% Silt
	SA	SAND -trace silt, grey, wet, loose, fine grained	S10	10	S10 Grain Size = 83.6% Sand 16.4% Silt
		-increased silt content below 8.4m	S11	9	
			S12	5	
		END OF TEST HOLE IN SAND AT 9.1m TOP OF PIPE ELEVATION = 91.445m			



LOGGED BY: Cliff Long	COMPLETION DEPTH: 9.14 m
REVIEWED BY: Doug Steele	COMPLETION DATE: 7/4/03
PROJECT ENGINEER: Steve Wiecek	Page 1 of 1

LOG OF TESTHOLE E902-002-00 DRILL LOGS.GPJ UMA.GDT 6/5/03

PROJECT: Bark Pile Hydrogeologic Assessment	CLIENT:	TESTHOLE NO: MW-2
LOCATION: 20m south of Airport Rd. and approximately 30m from edge of pile		PROJECT NO.: ...
'ONTRACTOR: Paddock Drilling Ltd.	METHOD: 6 1/4 Hollow Stem Auger	ELEVATION (m): 91.091

,AMPLE TYPE	GRAB	SHELBY TUBE	SPLIT SPOON	BULK	NO RECOVERY	CORE
BACKFILL TYPE	BENTONITE	GRAVEL	SLOUGH	GROUT	CUTTINGS	SAND

DEPTH (m)	USC	SOIL DESCRIPTION	SAMPLE #	SPT (N)	ELEVATION (m)
0	OR	WOODWASTE -brown, frozen			91
1	SM	SAND -with silt, brownish grey, dry, loose, very fine - fine -moist at 1m	S1		90
2	SA	SAND -trace silt, brown, dry, fine grained - very uniform -sand and silt lense, grey, wet, fairly dense, slow dilatency from 2.3 to 2.7m -grey and dry below 2.7m	S2, S3		89
3			S4	13	88
4		-wet below 4.6m	S5	11	87
5		-silt content increases slightly below 5.3m -increasing brown below 5.5m	S6	14	86
6			S7	9	85
			S8	7	
7			S9	8	84
		END OF TEST HOLE IN SAND AT 7.3m TOP OF PIPE ELEVATION = 92.109m			
8					83
9					82

◆ SPT (Standard Pen Test) ◆ (Blows/300mm) 20 40 60 80

COMMENTS

LOGGED BY: Cliff Long	COMPLETION DEPTH: 7.32 m
REVIEWED BY: Doug Steele	COMPLETION DATE: 4/8/03
PROJECT ENGINEER: Steve Wiecek	Page 1 of 1

LOG OF 'OLE E902-002-00 DRILL LOGS.GPJ UMA.GDT 6/5/03

PROJECT: Bark Pile Hydrogeologic Assessment	CLIENT:	TESTHOLE NO: MW-3
LOCATION: 25m west of access rd., on hill west of ditch and 6m south of fence		PROJECT NO.:
CONTRACTOR: Paddock Drilling Ltd.	METHOD: 6 1/4 Hollow Stem Auger	ELEVATION (m): 90.631

SAMPLE TYPE: GRAB, SHELBY TUBE, SPLIT SPOON, BULK, NO RECOVERY, CORE

BACKFILL TYPE: BENTONITE, GRAVEL, SLOUGH, GROUT, CUTTINGS, SAND

DEPTH (m)	USC	SOIL DESCRIPTION	SAMPLE #	SPT (N)
0	PEAT	PEAT -dark brown, loose, moist, no frost		
1	SA	SAND -orangish brown, dry, loose, fine grained (loam)	S1	
		-changes to lighter brown, moist, and slightly coarser below 1.8m	S2	
4	MI	SILT -trace sand, greyish brown, wet, rapid dilatency	S3	8
	SA	SAND -some silt, greyish brown, fine grained, fairly dense, very moist -trace silt, grey, wet below 4.8m	S4	21
			S5	18
			S6	25
		-very fine sand with silt below 6.4m	S7	11
6.7		END OF TEST HOLE IN SAND AT 6.7m TOP OF PIPE ELEVATION = 91.686m		

◆ SPT (Standard Pen Test) ◆ (Blows/300mm) 20 40 60 80

COMMENTS

ELEVATION (m): 90, 89, 88, 87, 86, 85, 84, 83, 82, 81

DEPTH (m): 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10

LOGGED BY: Cliff Long	COMPLETION DEPTH: 6.71 m
REVIEWED BY: Doug Steele	COMPLETION DATE: 4/8/03
PROJECT ENGINEER: Steve Wiecek	Page 1 of 1

LOG OF TESTHOLE E902-C02-30 DRILL LOGS.GPJ UMA.GDT 6/5/03

PROJECT: Bark Pile Hydrogeologic Assessment	CLIENT:	TESTHOLE NO: MW-4
LOCATION: West side of landfill and approximately 20m in bushline behind ashpiles		PROJECT NO.:
CONTRACTOR: Paddock Drilling Ltd.	METHOD: 6 1/4 Hollow Stem Auger	ELEVATION (m): 92.081

SAMPLE TYPE: GRAB, SHELBY TUBE, SPLIT SPOON, BULK, NO RECOVERY, CORE

BACKFILL TYPE: BENTONITE, GRAVEL, SLOUGH, GROUT, CUTTINGS, SAND

DEPTH (m) | USC | SOIL SYMBOL | SOIL DESCRIPTION | SAMPLE TYPE | SAMPLE # | SPT (N) | ◆ SPT (Standard Pen Test) ◆ (Blows/300mm) 20 40 60 80 | COMMENTS | ELEVATION (m)

Depth (m)	USC	Soil Description
0	PEAT	PEAT/ORGANICS -black, frozen to 0.3m
0.3	SA	SAND -orangish brown, dry, loose, fine to medium grained -changes to light brown and fine grained at 1.5m
4.1	ML	SILT -greyish brown, wet, dense, medium dilatency -fine grained, moist, brown sand lense from 4.4 to 4.7m
5.3	SA	SAND -greyish brown, wet, fine to medium grained, fairly dense -becomes slightly coarser with depth
7.0		END OF TEST HOLE IN SAND AT 7.0m TOP OF PIPE ELEVATION = 93.058m

Sample #	SPT (N)
S1	
S2	
S3	24
S4	30
S5	21
S6	30
S7	7

Depth scale (m): 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Elevation scale (m): 92, 91, 90, 89, 88, 87, 86, 85, 84, 83

LOGGED BY: Cliff Long	COMPLETION DEPTH: 7.01 m
REVIEWED BY: Doug Steele	COMPLETION DATE: 8/4/03
PROJECT ENGINEER: Steve Wiecek	Page 1 of 1

LOG OF TESTHOLE E902-002-00 DRILL LOGS.GPJ UMA.GDT 6/5/03

PROJECT: Bark Pile Hydrogeologic Assessment	CLIENT:	TESTHOLE NO: MW-5
LOCATION: In between and west of MW-1 and MW-3, approx. 100m from lake		PROJECT NO.:
CONTRACTOR: Paddock Drilling Ltd.	METHOD: 6 1/4 Hollow Stem Auger	ELEVATION (m): 89.13

SAMPLE TYPE: GRAB, SHELBY TUBE, SPLIT SPOON, BULK, NO RECOVERY, CORE

BACKFILL TYPE: BENTONITE, GRAVEL, SLOUGH, GROUT, CUTTINGS, SAND

DEPTH (m)	USC	SOIL DESCRIPTION	SAMPLE TYPE	SAMPLE #	SPT (N)	COMMENTS	ELEVATION (m)
0	PEAT	PEAT -dark brown, frozen					89
		SAND -orangish brown, dry, loose, well graded, trace pea sized gravel to 2.4m					
1			GRAB	S1			88
2							87
		-sand becomes brown, moist and slightly coarser from 2.4 to 4m	GRAB	S2			
3							86
4	SA	-fine to medium grained between 4 and 5m	SPLIT SPOON	S3	11		85
5		-coarser sand lense from 5 to 5.3m	SPLIT SPOON	S4	12		84
		- turns fine grained and denser at 5.3 m, trace silt					
6			SPLIT SPOON	S5	30		83
		-grey below 6.4m	SPLIT SPOON	S6	16		
7		-wet below 7m (perched)	SPLIT SPOON	S7	9		82
	SM	-silt some sand lense at 7.47 - 7.62 m					
		SAND -with silt, grey, wet, very fine - fine grained -silt content decreases below 7.9m	SPLIT SPOON	S8	10		
8	SM		SPLIT SPOON	S9	7	S9 Grain Size = 82.7% Sand 17.3 % Silt	81
9			SPLIT SPOON	S10	8		80
		END OF TEST HOLE IN SAND AT 9.4m TOP OF PIPE ELEVATION = 90.277m					
10							

◆ SPT (Standard Pen Test) ◆ (Blows/300mm): 20 40 60 80

LOG OF TESTHOLE E902-002-00 DRILL LOGS.GPJ UMA.GDT 6/5/03

LOGGED BY: Cliff Long	COMPLETION DEPTH: 9.45 m
REVIEWED BY: Doug Steele	COMPLETI[illegible] DATE: 4/8/03
PROJECT ENGINEER: Steve Wiecek	Page 1 of 1

PROJECT: Bark Pile Hydrogeologic Assessment	CLIENT:	TESTHOLE NO: MW-6
LOCATION: Approx. 30m from lake, downgradient of MW-5		PROJECT NO.:
CONTRACTOR: Paddock Drilling Ltd.	METHOD: 6 1/4 Hollow Stem Auger	ELEVATION (m): 88.329

SAMPLE TYPE: GRAB, SHELBY TUBE, SPLIT SPOON, BULK, NO RECOVERY, CORE

BACKFILL TYPE: BENTONITE, GRAVEL, SLOUGH, GROUT, CUTTINGS, SAND

DEPTH (m)	USC	SOIL DESCRIPTION	SAMPLE #	SPT (N)	COMMENTS
0	PEAT	PEAT/ORGANICS -dark brown, frozen			
	SA	SAND -orangish brown, dry, loose, well graded, trace pea sized gravel			
1			S1		
2		-changes to light brown and fine grained at 2.2m	S2		
4		-turns to fine - medium sand at 4m	S3	9	
5			S4	10	
6		-changes to greyish brown, finer with some silt at 5.6m	S5	15	
7	SM	SAND AND SILT -greyish brown, dry, fairly loose, very fine grained	S6	16	
		-silt content decreases to some below 7.62m -10cm very moist silt lense from 7.6 to 7.7m	S7	14	
8		-changes to very moist below 8.4m	S8	11	
9	SA	SAND -trace silt, greyish brown, wet at 8.5 m, fine grained -slightly coarser at 9.1m	S9	12	S9 Grain Size = 93.7% Sand 6.3 % Silt
	SM	-silt and sand, very fine grained at 9.4m	S10	22	
10		END OF TEST HOLE IN SILT AND SAND AT 10.06m TOP OF PIPE ELEVATION = 89.359m	S11	24	

SPT (Standard Pen Test) (Blows/300mm): 20, 40, 60, 80

ELEVATION (m): 88, 87, 86, 85, 84, 83, 82, 81, 80, 79, 78, 77

LOGGED BY: Cliff Long	COMPLETION DEPTH: 10.06 m
REVIEWED BY: Doug Steele	COMPLETION DATE: 4/9/03
PROJECT ENGINEER: Steve Wiecek	Page 1 of 1

LOG OF TESTHOLE E902-002-00 DRILL LOGS.GPJ UMA.GDT 6/5/03

PROJECT: Bark Pile Follow Up Investigation	CLIENT:	TESTHOLE NO: MW-7
LOCATION: 90m north of MW-6		PROJECT NO.:
CONTRACTOR: Paddock Drilling Ltd.	METHOD: 6 1/4 Hollow Stem Auger	ELEVATION (m): 88.627

SAMPLE TYPE: GRAB, SHELBY TUBE, SPLIT SPOON, BULK, NO RECOVERY, CORE

BACKFILL TYPE: BENTONITE, GRAVEL, SLOUGH, GROUT, CUTTINGS, SAND

DEPTH (m)	USC	SOIL DESCRIPTION	SAMPLE TYPE	SPT (N)	ELEVATION (m)
0	OR	ORGANICS -black, moist			
	SA	SAND -brown, some pea sized gravel, moist, looser -becoming denser at 1.0 m -becoming coarser, grey at 1.5 m			88
2			Split spoon	4	87
			Split spoon	15	86
		-changing to medium/fine grained sand without gravel at 3.4 m	Split spoon	22	85
4			Split spoon	14	84
5	ML	SILT -some fine sand, grey, fairly loose, increased moisture	Split spoon	23	
	SA	SAND -fine grained, some silt, grey, loose, moist -silt lense 0.05 m thick at 5.6 m	Split spoon	19	83
		-increased moisture below 6.4 m	Split spoon	15	82
7		-oxidation between 6.7 and 6.9 m -wet below 6.9 m	Split spoon	16	81
8			Split spoon	17	
			Split spoon	12	80
9		END OF TEST HOLE IN SAND AT 9.0m TOP OF PIPE ELEVATION = 89.506m			79
10					78
11					

◆SPT (Standard Pen Test)◆ (Blows/300mm) 20 40 60 80

COMMENTS

LOG OF TESTHOLE E902-002-00 DRILL LOGS.GPJ UMA.GDT 17/9/04

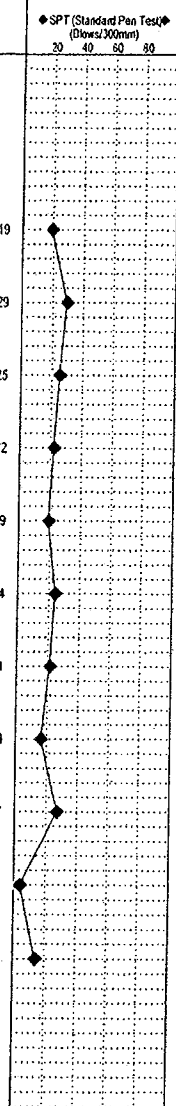
LOGGED BY: Kris Tuultila	COMPLETION DEPTH: 8.99 m
REVIEWED BY: Doug Steele	COMPLETION DATE: 7/8/04
PROJECT ENGINEER: Steve Wiecek	Page 1 of 1

PROJECT: Bark Pile Follow Up Investigation	CLIENT:	TESTHOLE NO: MW-8
LOCATION: 85 m south of MW-6, in log storage area		PROJECT NO.:
CONTRACTOR: Paddock Drilling Ltd.	METHOD: 6 1/4 Hollow Stem Auger	ELEVATION (m): 88.316

SAMPLE TYPE: GRAB, SHELBY TUBE, SPLIT SPOON, BULK, NO RECOVERY, CORE

BACKFILL TYPE: BENTONITE, GRAVEL, SLOUGH, GROUT, CUTTINGS, SAND

DEPTH (m)	USC	SOIL DESCRIPTION	SAMPLE TYPE	SAMPLE #	SPT (N)	COMMENTS	ELEVATION (m)
0	FILL	WOODWASTE -brown, dry					88
	SA	SAND -medium grained, brown, slightly moist, loose -becoming light brown with trace silt below 1.0 m					87
2	SA	-becoming coarse grained with some pea gravel between 1.8 and 2.0 m -changing to medium/coarse sand with some fine grained material below 2.0 m	Split spoon		19		86
			Split spoon		29		
3		-changing to fine sand, grey, dense below 3.2 m	Split spoon		25		85
4			Split spoon		22		84
5	SM	SILT AND FINE SAND -grey, moist, dense	Split spoon		19		83
6		-15 cm thick silt lense, very dense, wet (perched layer) at 5.5 m	Split spoon		24		
	SASI	SILT -some fine sand, dark grey, dense, wet (perched layer)	Split spoon		21		82
7	SA	SAND -fine to medium grained, grey, moist, loose -oxidized layer between 7.2 and 7.5 m -wet below 7.5 m	Split spoon		18		81
8			Split spoon		27		80
9			Split spoon		4		79
			Split spoon		14		
10		END OF TEST HOLE IN SAND AT 9.8m TOP OF PIPE ELEVATION = 89.142m					78
11							



LOGGED BY: Kris Tuuttila	COMPLETION DEPTH: 9.75 m
REVIEWED BY: Doug Steele	COMPLETION DATE: 7/8/04
PROJECT ENGINEER: Steve Wiecek	Page 1 of 1

LOG OF TESTHOLE E902-002-00 DRILL LOGS.GPJ UMA.GDT 17/9/04

WELL NUMBER BH-9

PAGE 1 OF 1

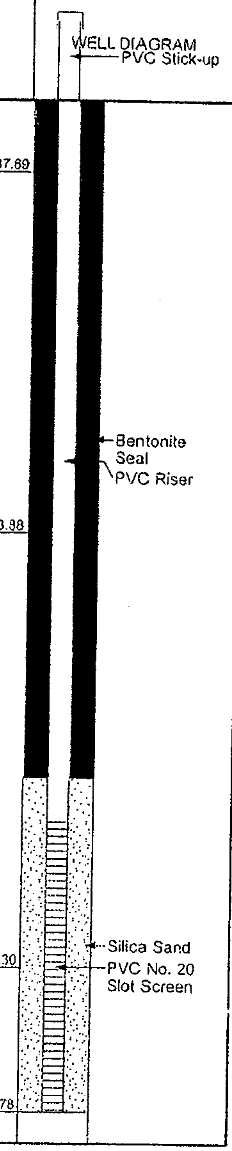
CLIENT ____
PROJECT NUMBER ____
PROJECT NAME Bark Pile Drilling Program
PROJECT LOCATION ____

DATE STARTED 06/25/07 COMPLETED 06/25/07
DRILLING CONTRACTOR Landcore Ltd.
DRILLING METHOD 4.25 Hollow Stem Augers
LOGGED BY Mike Stachejczuk CHECKED BY Jason Garatti
NOTES ____

GROUND ELEVATION 88.45 m HOLE SIZE 0.11m
GROUND WATER LEVELS:
AT TIME OF DRILLING ---
AT END OF DRILLING ---
AFTER DRILLING 7.75 m / Elev 80.70 m

DEPTH (m)	SAMPLE TYPE NUMBER	RECOVERY % (RQD)	BLOW COUNTS (N VALUE)	MATERIAL DESCRIPTION
	AU S1			Fine to Medium Sand, Some Fine Gravel, reddish-brown, moist, loose
0.76				(Elev. 87.69) Medium to Coarse Sand, Trace Fine Gravel, brown, moist, loose
	SS S2	84 (100)	8-8-9-9 (17)	
2	SS S3	54 (100)	5-6-8-7 (14)	
	SS S4	59 (100)	3-3-4-4 (7)	
	SS S5	48 (100)	3-5-7-6 (12)	
4				
4.57				(Elev. 83.88) Fine Sand, light brown, moist, loose - wet at 7.47m
	SS S6	67 (100)	6-8-10-12 (18)	
6				
	SS S7	75 (100)	6-9-8-12 (17)	
	SS S8	72 (100)	6-8-7-9 (15)	
8	SS S9	59 (100)	4-4-4-5 (8)	
9.15				(Elev. 79.30) Medium to Fine Sand, grey, wet, loose
	SS S10	67 (100)	1-2-3-3 (5)	
10	SS S11	87 (100)	2-3-4-7 (7)	
10.67				(Elev. 77.78) End of test hole at 10.67m

WELL DIAGRAM

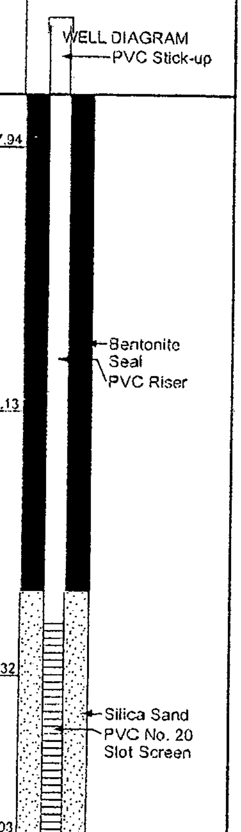


WELL NUMBER BH-10

CLIENT ____
PROJECT NUMBER ____
PROJECT NAME Bark Pile Drilling Program
PROJECT LOCATION ____

DATE STARTED 06/25/07 COMPLETED 06/25/07
GROUND ELEVATION 88.7 m HOLE SIZE 0.11m
DRILLING CONTRACTOR Landcore Ltd.
GROUND WATER LEVELS:
DRILLING METHOD 4.25 Hollow Stem Augers
AT TIME OF DRILLING ---
LOGGED BY Mike Stachejczuk CHECKED BY Jason Garatti
AT END OF DRILLING ---
NOTES ____
AFTER DRILLING 7.49 m / Elev 81.21 m

DEPTH (m)	SAMPLE TYPE NUMBER	RECOVERY % (RQD)	BLOW COUNTS (N VALUE)	GRAPHIC LOG	MATERIAL DESCRIPTION	Elev.
	AU S1			0.76	Medium to Coarse Sand, Trace Fine Gravel, reddish-brown, moist, loose	87.94
	SS S2	54 (100)	6-8-9-7 (17)		Medium to Coarse Sand, brown, moist, loose -some fine gravel appeared at 3.05m	
2	SS S3	56 (100)	5-5-7-6 (12)			
	SS S4	62 (100)	4-6-6-6 (12)			
4	SS S5	67 (100)	4-6-8-10 (14)	4.57		84.13
	SS S6	49 (100)	4-7-9-11 (16)		Fine Sand, light brown, moist, loose - wet at 7.16m	
6	SS S7	62 (100)	4-6-8-8 (14)			
	SS S8	61 (100)	7-10-10-10 (20)			
	SS S9	62 (100)	4-8-10-12 (18)			
8	SS S10	75 (100)	6-10-12-15 (22)	8.38		80.32
	SS S11	87 (100)	7-13-13-9 (26)		Medium to Fine Sand, light brown, wet, loose	
10	SS S12	75 (100)	2-4-8-18 (12)	10.67		78.03
					End of test hole at 10.67m	



Appendix B: Grain Size Analysis

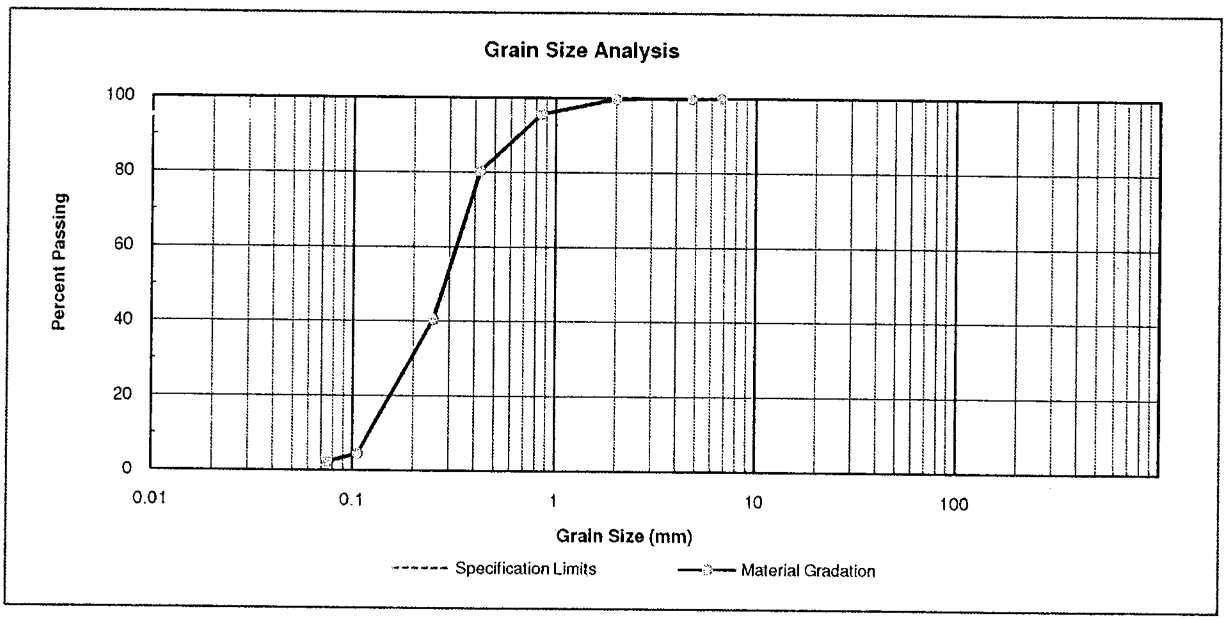
Grain Size Analysis Test Report

Client: Jason Garatti
Project Description:
True Grit Project No.:
Client Project No.:

Material Type:
Source:
Sample Location: Upgradient Soil
Sampled By:
Date Sampled:

Lab No.:
Specification:
Date Received:
Tested By: D.K.
Date Tested: July 2 / 09

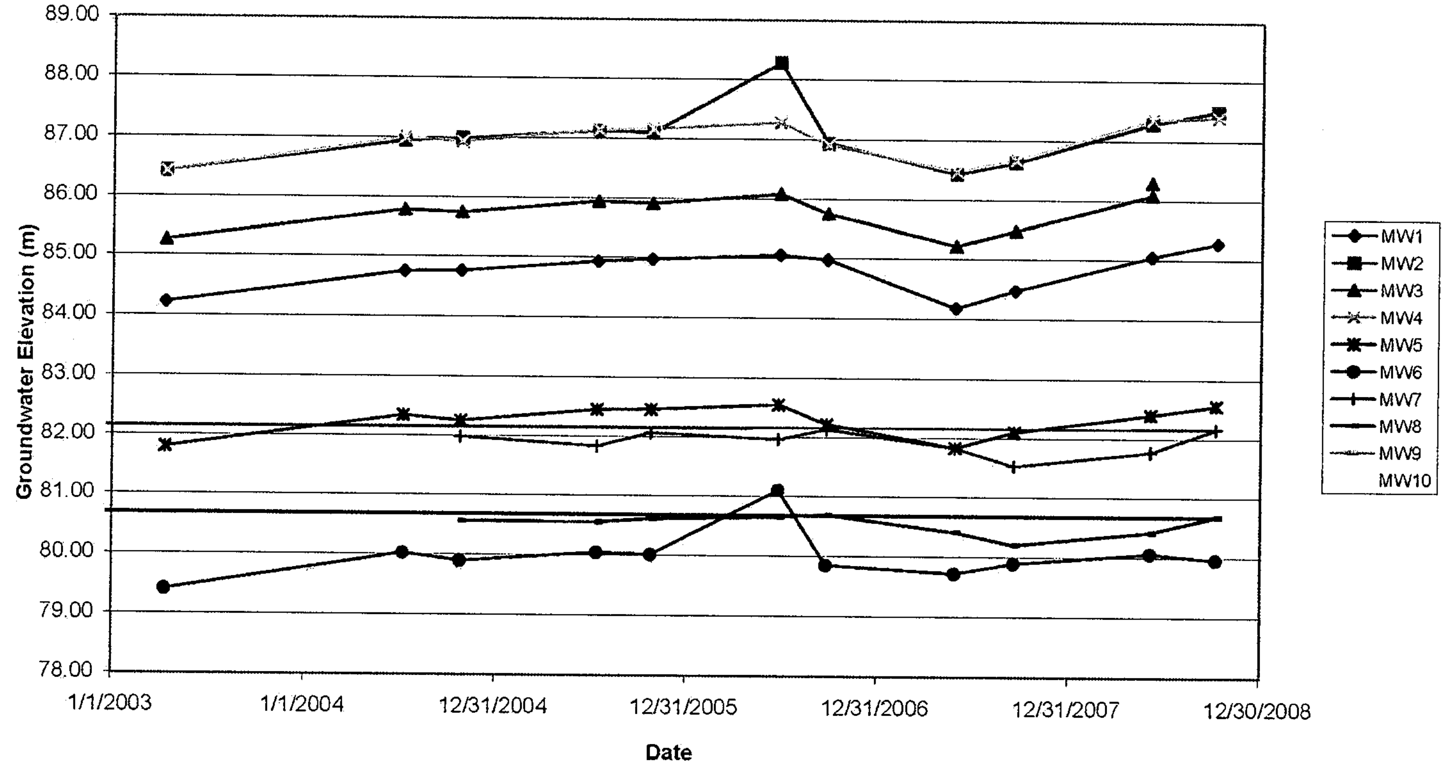
Grain Size Analysis		
Sieve	Percent Passing	
Sizes,mm	Sample	Specification
26.5		
19		
16		
13.2		
9.5		
6.7	100	
4.75	99.8	
2	99.7	
0.85	95.6	
0.425	80.4	
0.25	40.5	
0.106	4.5	
0.075	2.3	



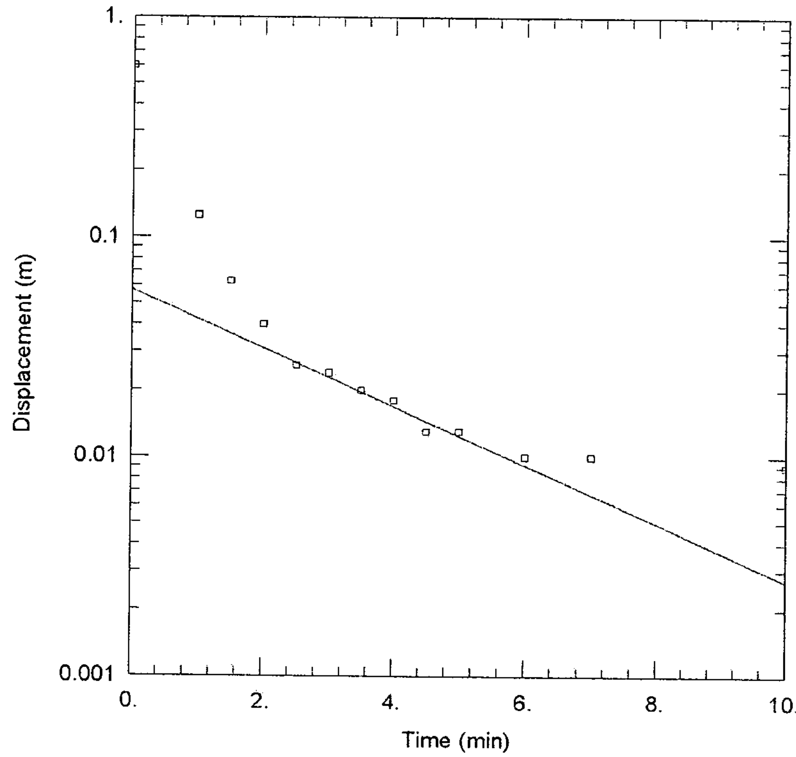
Remarks: -Tested in accordance with LS-601/602

Appendix C: Water Level vs Time

Groundwater Elevations 2003 - 2008



Appendix D: Rising Head Test Results



WELL TEST ANALYSIS

Data Set: E:\ENVIRO~2\PROJECTS\2003PR~1\E902KI~1\E902-0~2\PH01-H~1\HYD~1.CON\MW-1.AQT
Date: 05/30/03 Time: 10:45:38

PROJECT INFORMATION

Company:
Client:
Project:
Test Location: Bark Pile
Test Well: MW-1
Test Date: 09/04/03

AQUIFER DATA

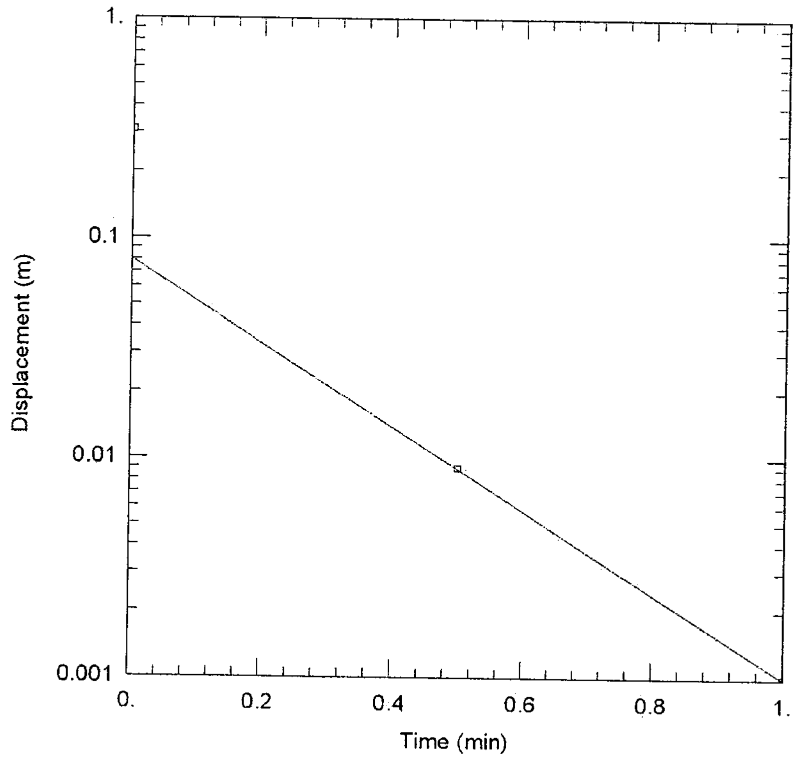
Saturated Thickness: 2.813 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Initial Displacement: 0.6 m
Casing Radius: 0.025 m
Screen Length: 1.5 m
Water Column Height: 2.813 m
Wellbore Radius: 0.15 m
Gravel Pack Porosity: 0.3

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 2.423E-05 m/sec
y0 = 0.0573 m



WELL TEST ANALYSIS

Data Set: E:\ENVIRO~2\PROJECTS\2003PR~1\E902KI~1\E902-0~2\PH01-H~1\HYD~1.CON\MW-2.AQ
Date: 05/30/03 Time: 10:45:56

PROJECT INFORMATION

Company:
Client:
Project:
Test Location: Bark Pile
Test Well: MW-2
Test Date: 09/04/03

AQUIFER DATA

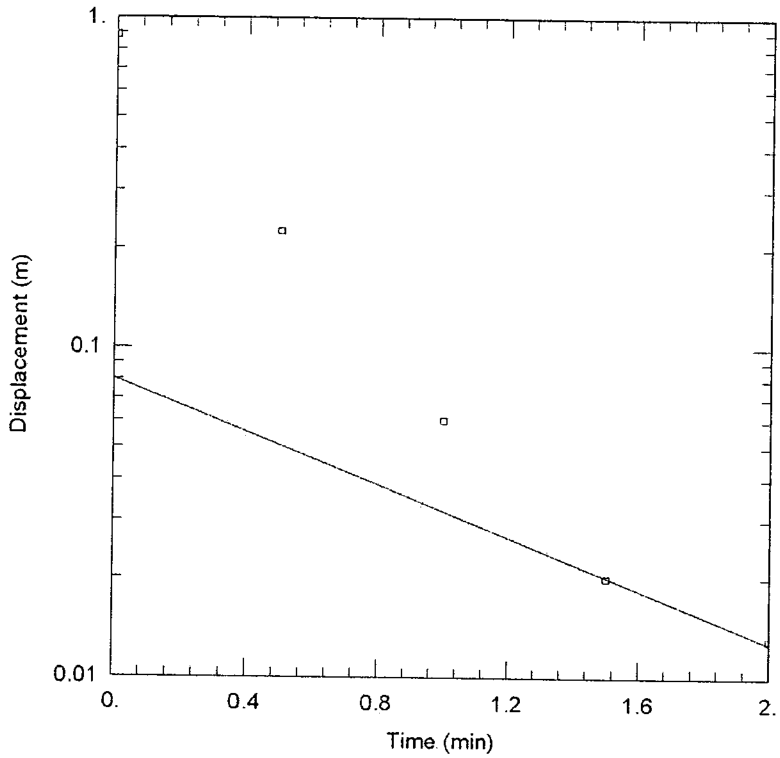
Saturated Thickness: 1.675 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Initial Displacement: 0.309 m
Casing Radius: 0.025 m
Screen Length: 1.5 m
Water Column Height: 1.675 m
Wellbore Radius: 0.15 m
Gravel Pack Porosity: 0.3

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.0002992 m/sec
y0 = 0.07931 m



WELL TEST ANALYSIS

Data Set: E:\ENVIRO~2\PROJECTS\2003PR~1\E902KI~1\E902-0~2\PH01-H~1\HYD~1.CON\MW-3.AQ
Date: 05/30/03 Time: 10:46:09

PROJECT INFORMATION

Company:
Client:
Project:
Test Location: Bark Pile
Test Well: MW-3
Test Date: 09/04/03

AQUIFER DATA

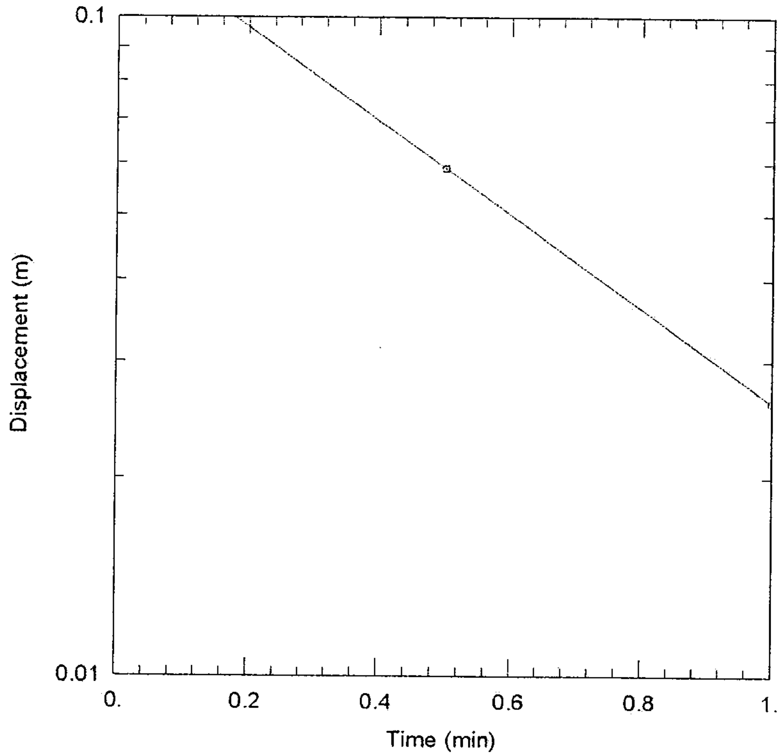
Saturated Thickness: 1.164 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Initial Displacement: 0.885 m
Casing Radius: 0.025 m
Screen Length: 1.5 m
Water Column Height: 1.164 m
Wellbore Radius: 0.15 m
Gravel Pack Porosity: 0.3

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 5.531E-05 m/sec
y0 = 0.08036 m



WELL TEST ANALYSIS

Data Set: E:\ENVIRO~2\PROJECTS\2003PR~1\E902KI~1\E902-0~2\PH01-H~1\HYD~1.CON\MW-4.AQ
Date: 05/30/03 Time: 10:46:23

PROJECT INFORMATION

Company: UMA Engineering
Client:
Project:
Test Location: Bark Pile
Test Well: MW-4
Test Date: 09/04/03

AQUIFER DATA

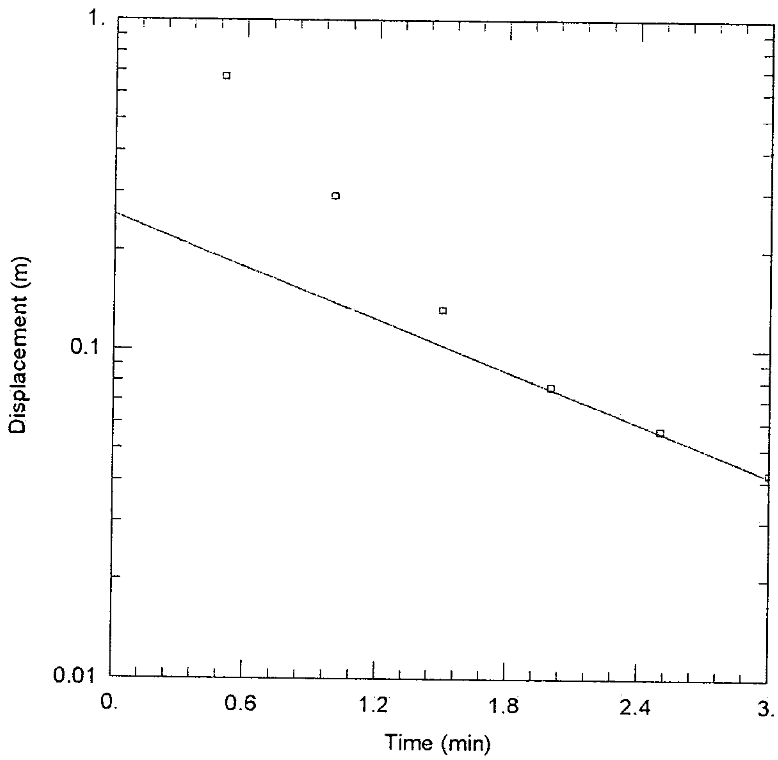
Saturated Thickness: 1.173 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Initial Displacement: 0.83 m
Casing Radius: 0.025 m
Screen Length: 1.5 m
Water Column Height: 1.173 m
Wellbore Radius: 0.15 m
Gravel Pack Porosity: 0.3

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 9.869E-05 m/sec
y0 = 0.1339 m



WELL TEST ANALYSIS

Data Set: E:\ENVIRO~2\PROJECTS\2003PR~1\E902KI~1\E902-0~2\PH01-H~1\HYD~1.CON\MW-5.AQ
Date: 05/30/03 Time: 10:46:37

PROJECT INFORMATION

Company: ______
Client: ______
Project: ______
Test Location: Bark Pile
Test Well: MW-5
Test Date: 09/04/03

AQUIFER DATA

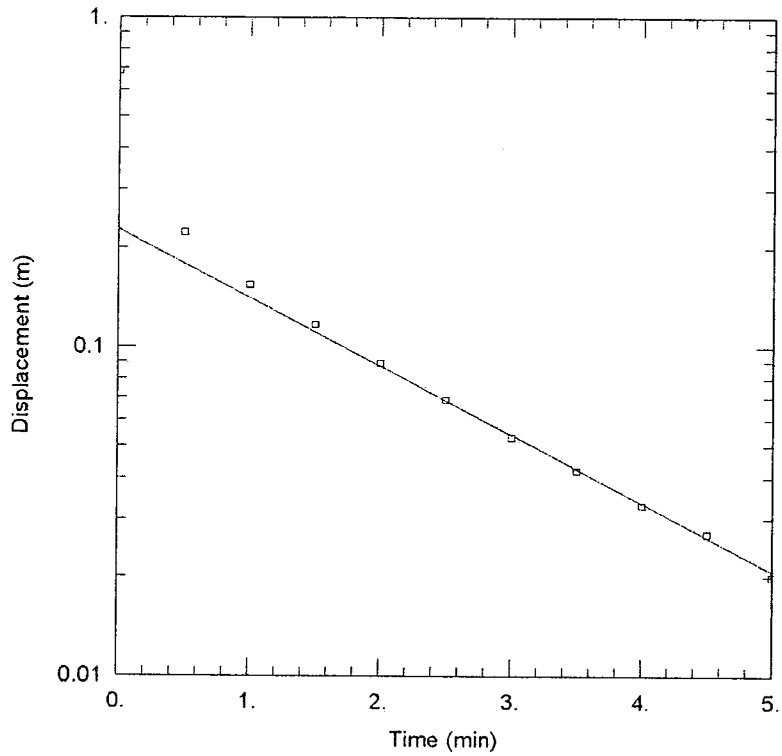
Saturated Thickness: 2.104 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Initial Displacement: 1.387 m
Casing Radius: 0.025 m
Screen Length: 1.5 m
Water Column Height: 2.104 m
Wellbore Radius: 0.15 m
Gravel Pack Porosity: 0.3

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 4.446E-05 m/sec
y0 = 0.2554 m



WELL TEST ANALYSIS

Data Set: E:\ENVIRO~2\PROJECTS\2003PR~1\E902KI~1\E902-0~2\PH01-H~1\HYD~1.CON\MW-6.AQ
Date: 05/30/03 Time: 10:46:51

PROJECT INFORMATION

Company: ______
Client: ______
Project: ______
Test Location: Bark Pile
Test Well: MW-6
Test Date: 10/04/03

AQUIFER DATA

Saturated Thickness: 1.006 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Initial Displacement: 0.687 m
Casing Radius: 0.025 m
Screen Length: 1.5 m

Water Column Height: 1.006 m
Wellbore Radius: 0.15 m
Gravel Pack Porosity: 0.3

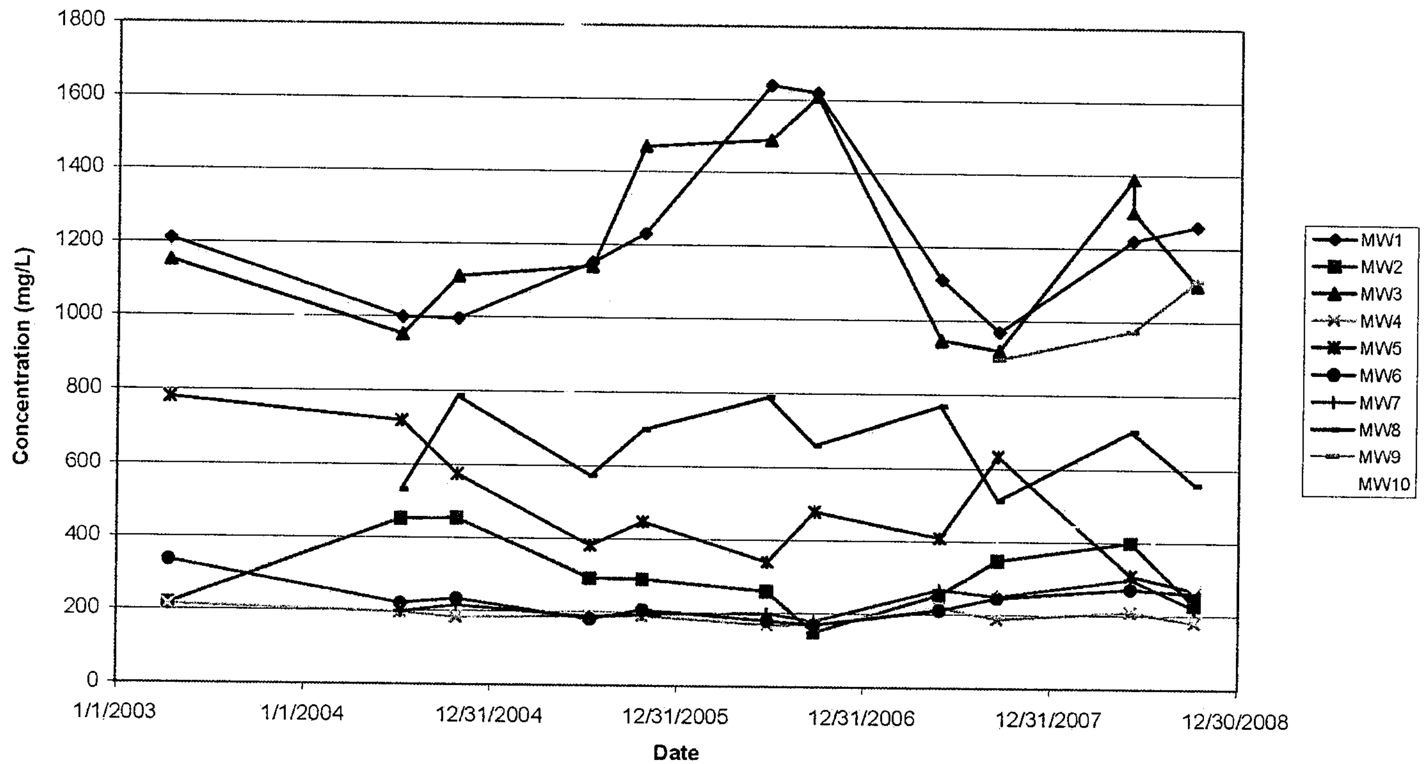
SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

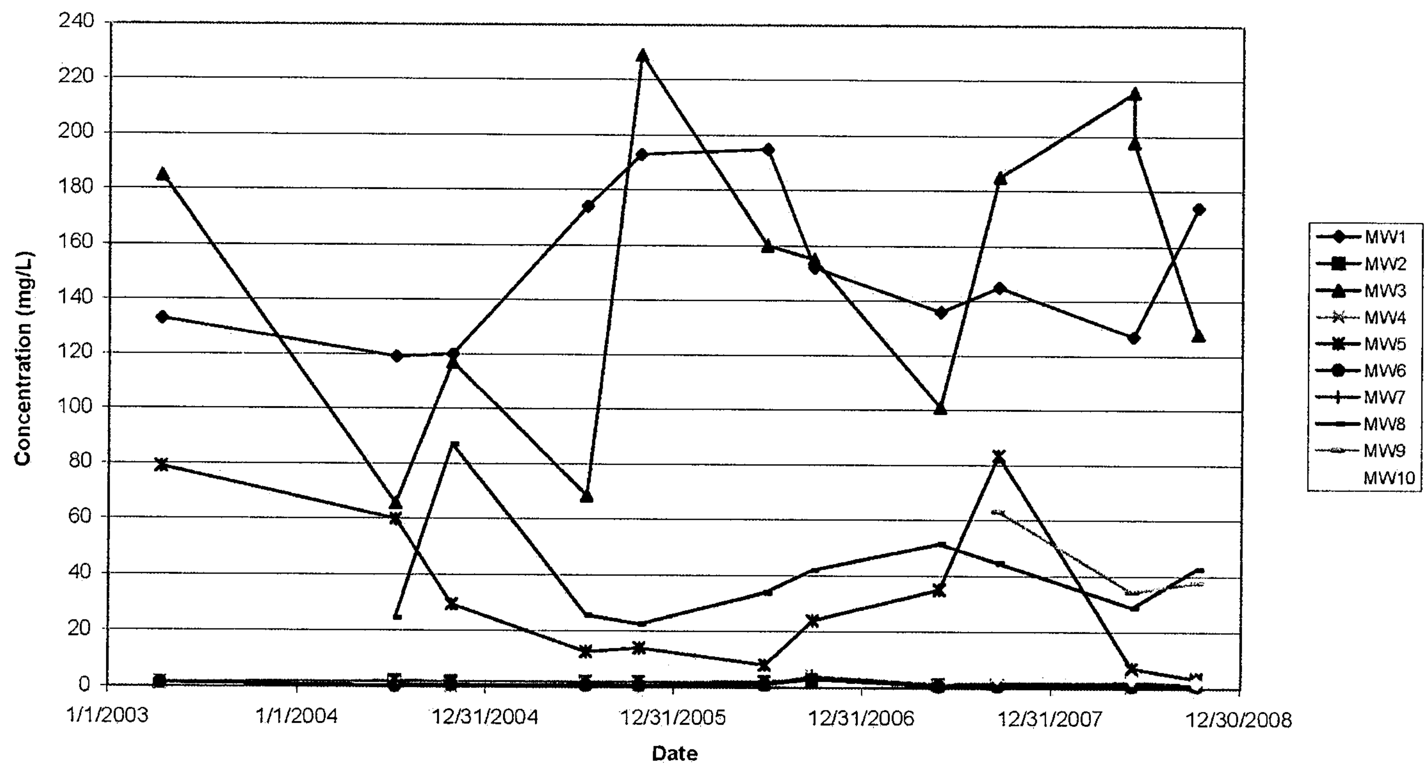
K = 2.705E-05 m/sec
y0 = 0.2274 m

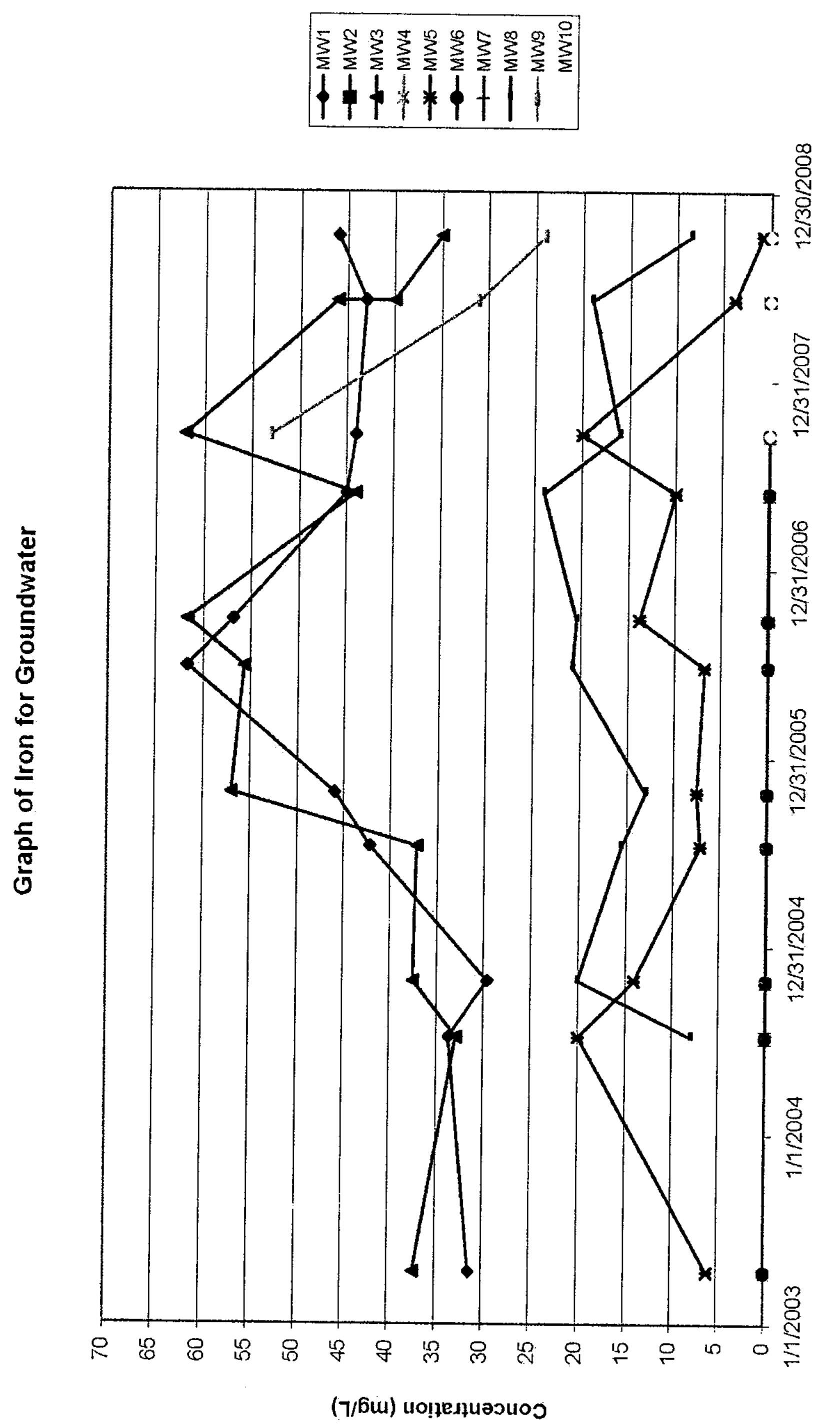
Appendix E: Time Series and Durov Plots

Graph of TDS for Groundwater

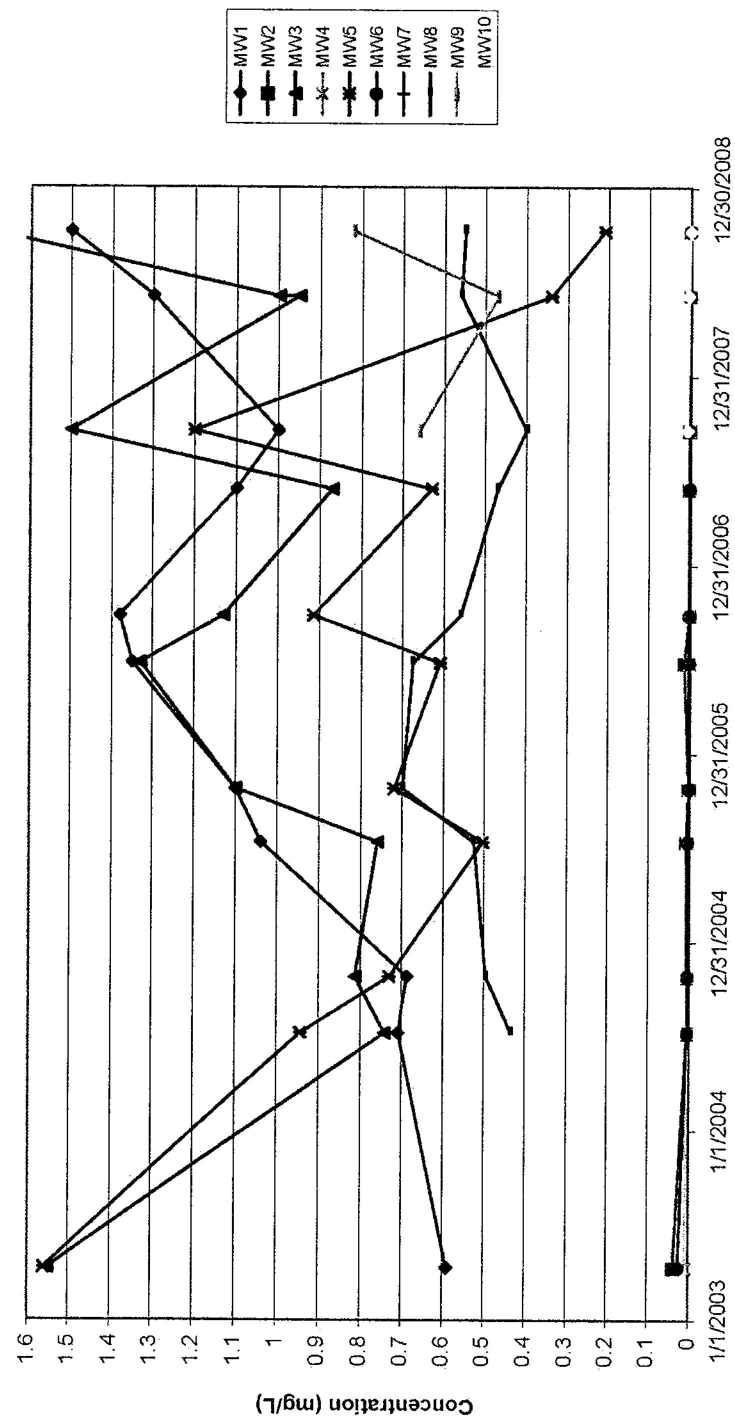


Graph of DOC for Groundwater

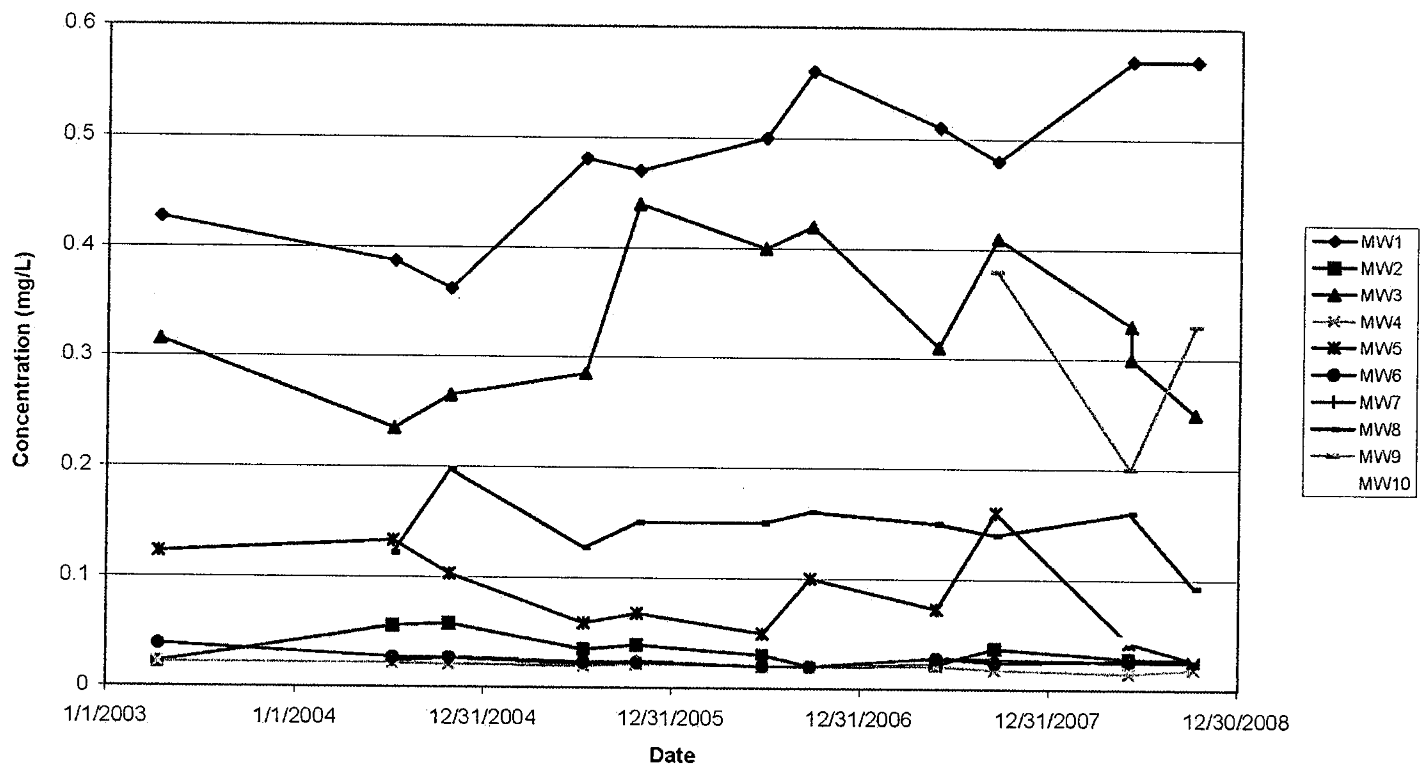


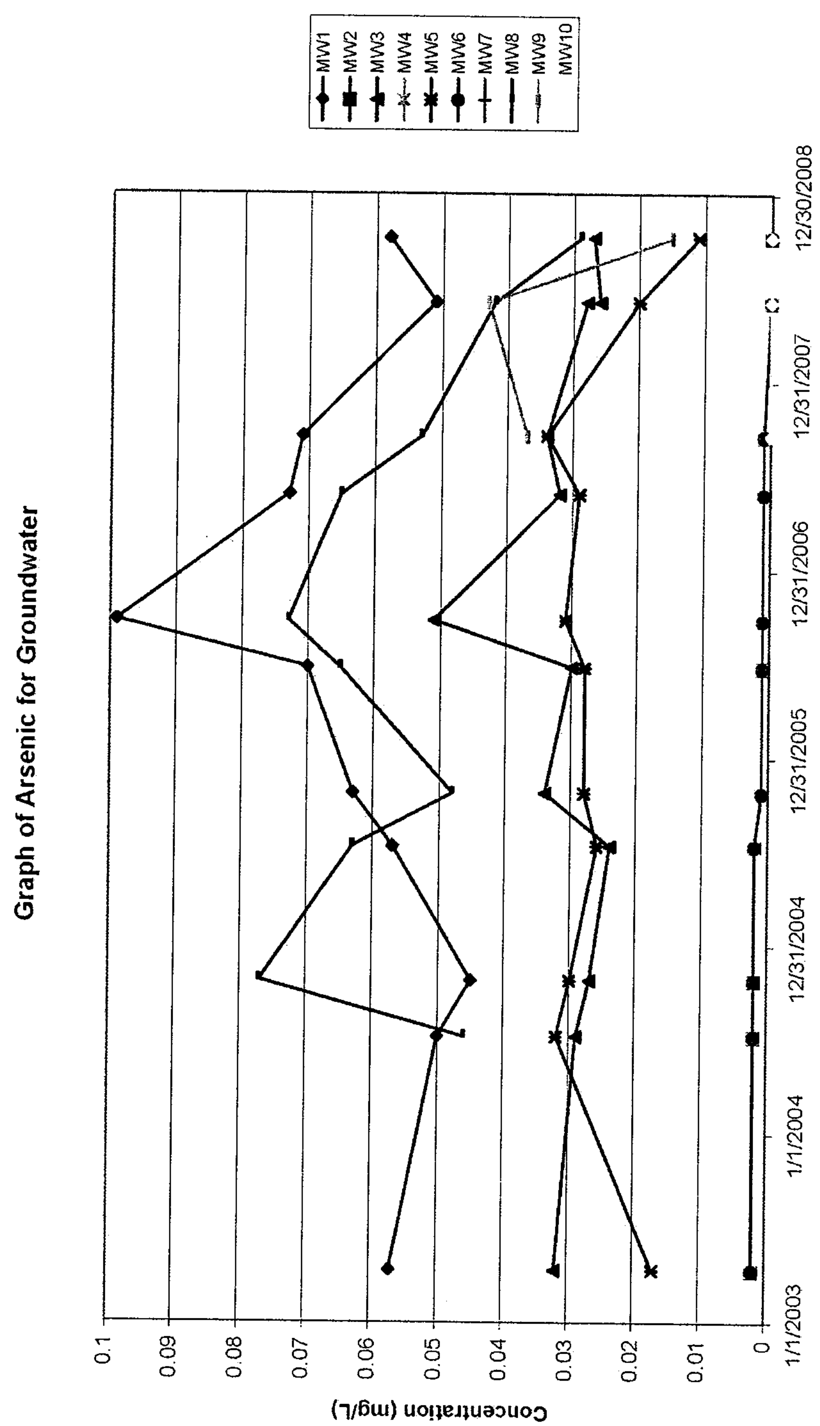

Graph of Iron for Groundwater
Concentration (mg/L)
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
1/1/2003
1/1/2004
12/31/2004
12/31/2005
12/31/2006
12/31/2007
12/30/2008
Date
MW1
MW2
MW3
MW4
MW5
MW6
MW7
MW8
MW9
MW10

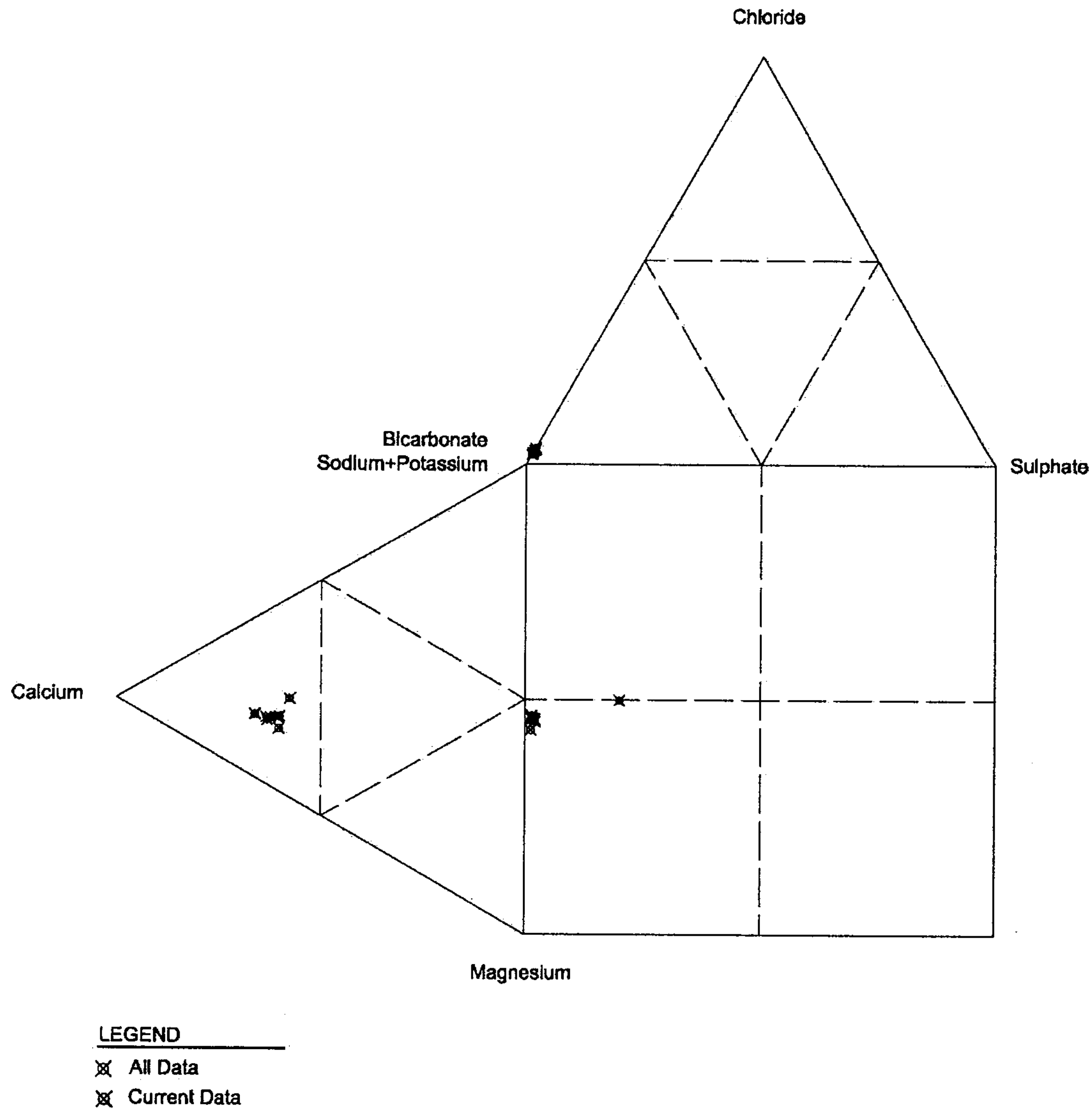
Graph of Manganese for Groundwater



Graph of Barium for Groundwater

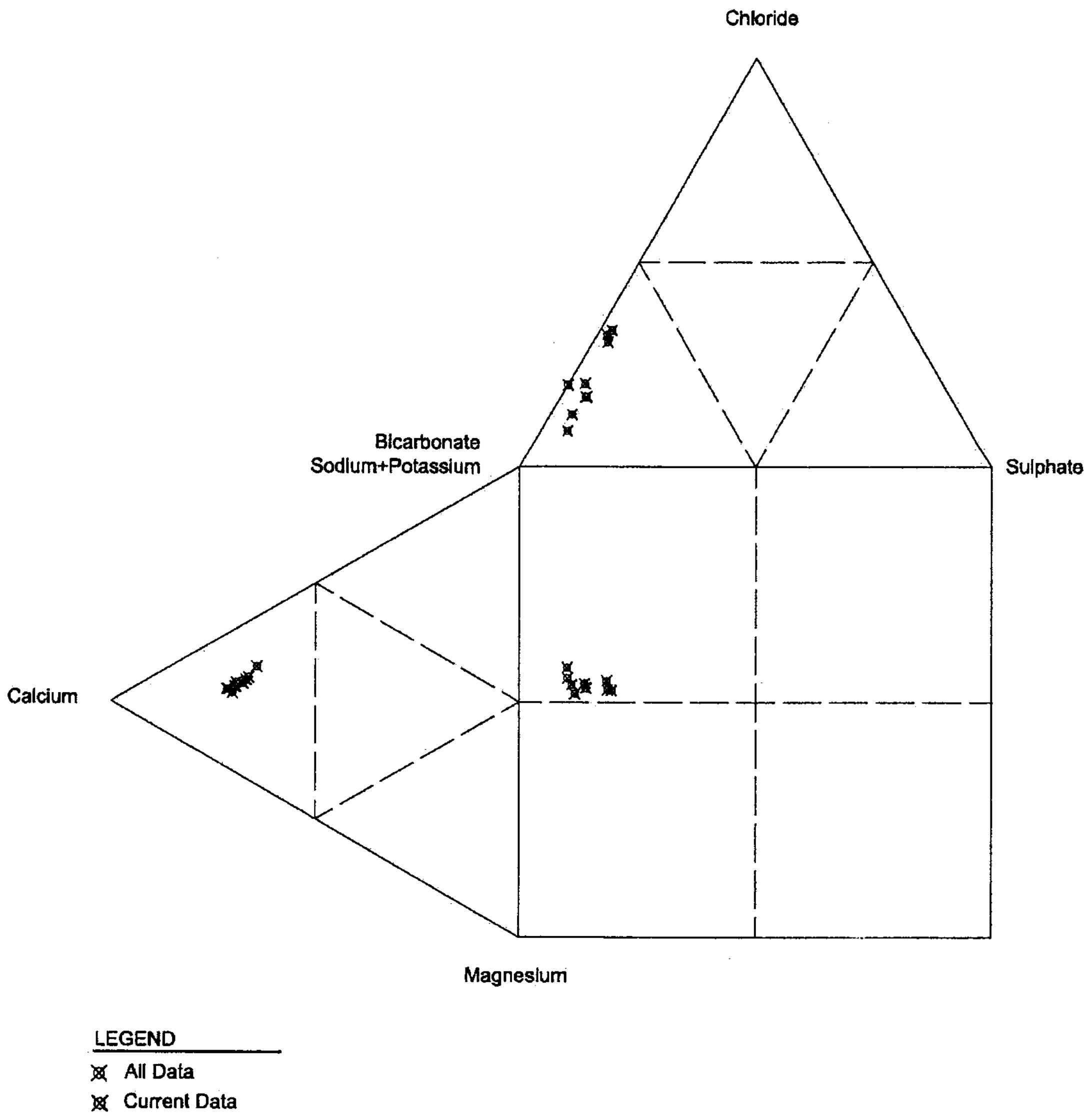



Graph of Arsenic for Groundwater
Concentration (mg/L)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1/1/2003
1/1/2004
12/31/2004
12/31/2005
12/31/2006
12/31/2007
12/30/2008
Date
MW1
MW2
MW3
MW4
MW5
MW6
MW7
MW8
MW9
MW10



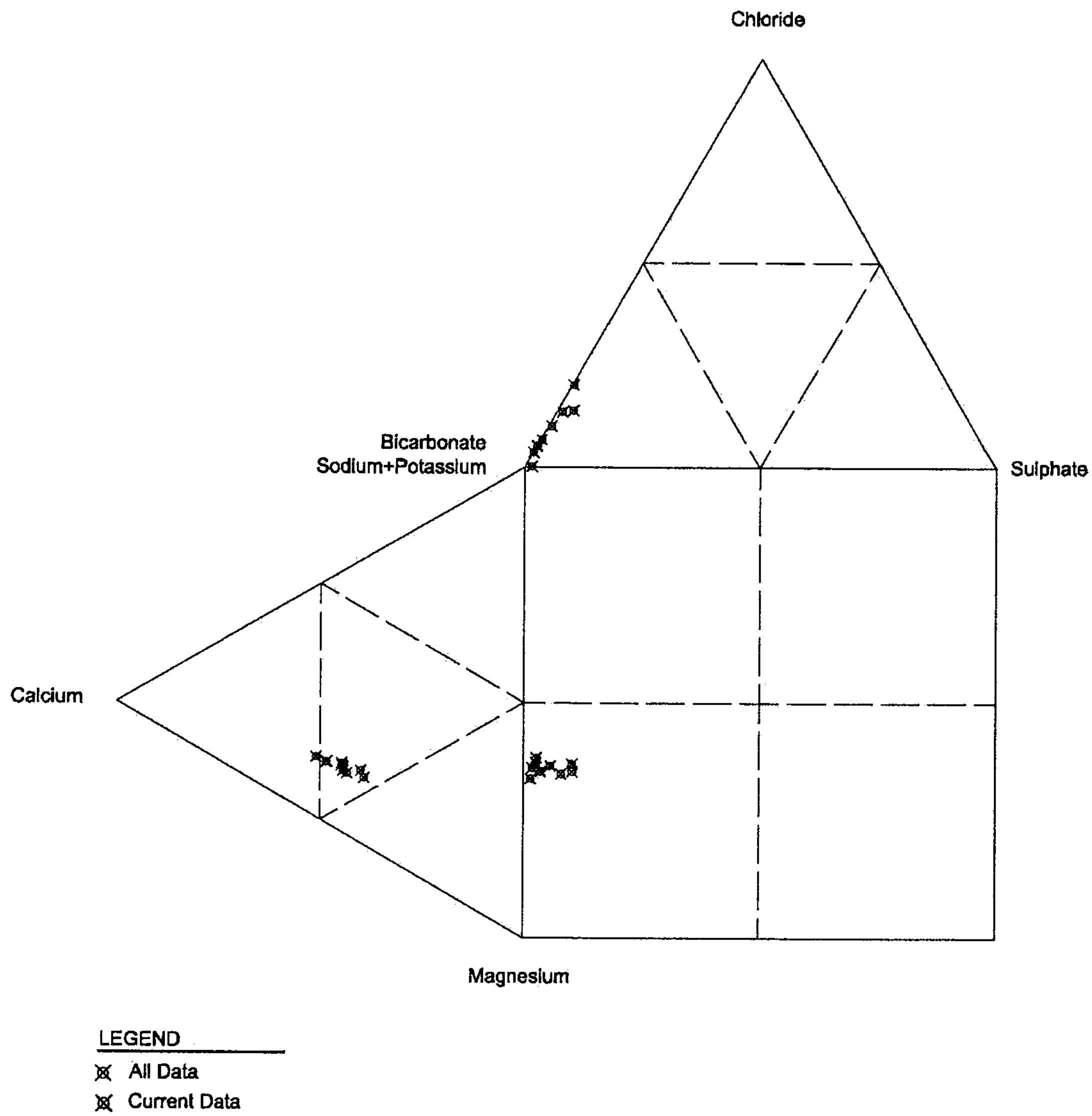
Woodwaste Study Site
Northwestern Ontario

Durov Plot MW1



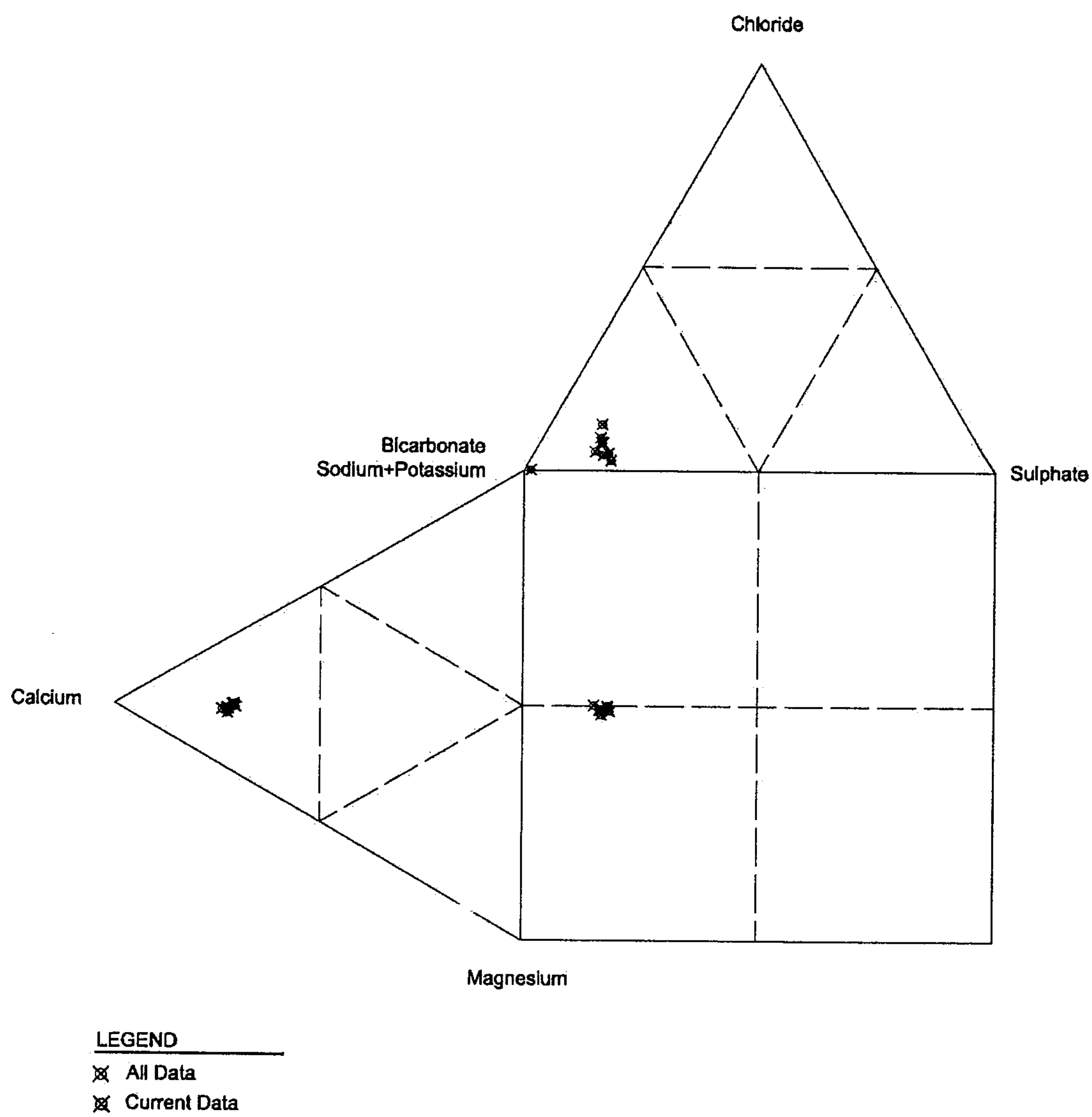
Woodwaste Study Site
Northwestern Ontario

Durov Plot MW2



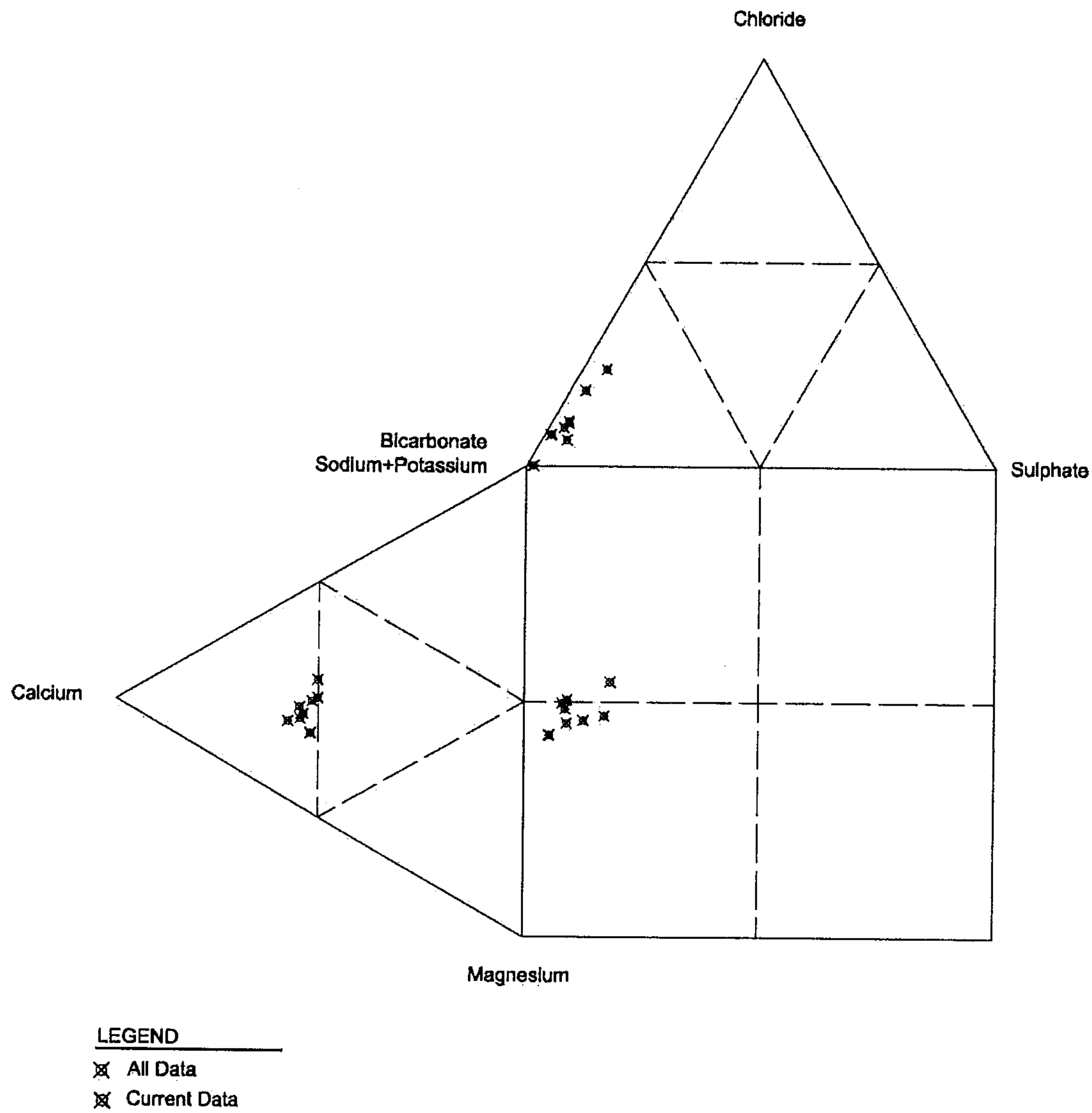
Woodwaste Study Site
Northwestern Ontario

Durov Plot MW3



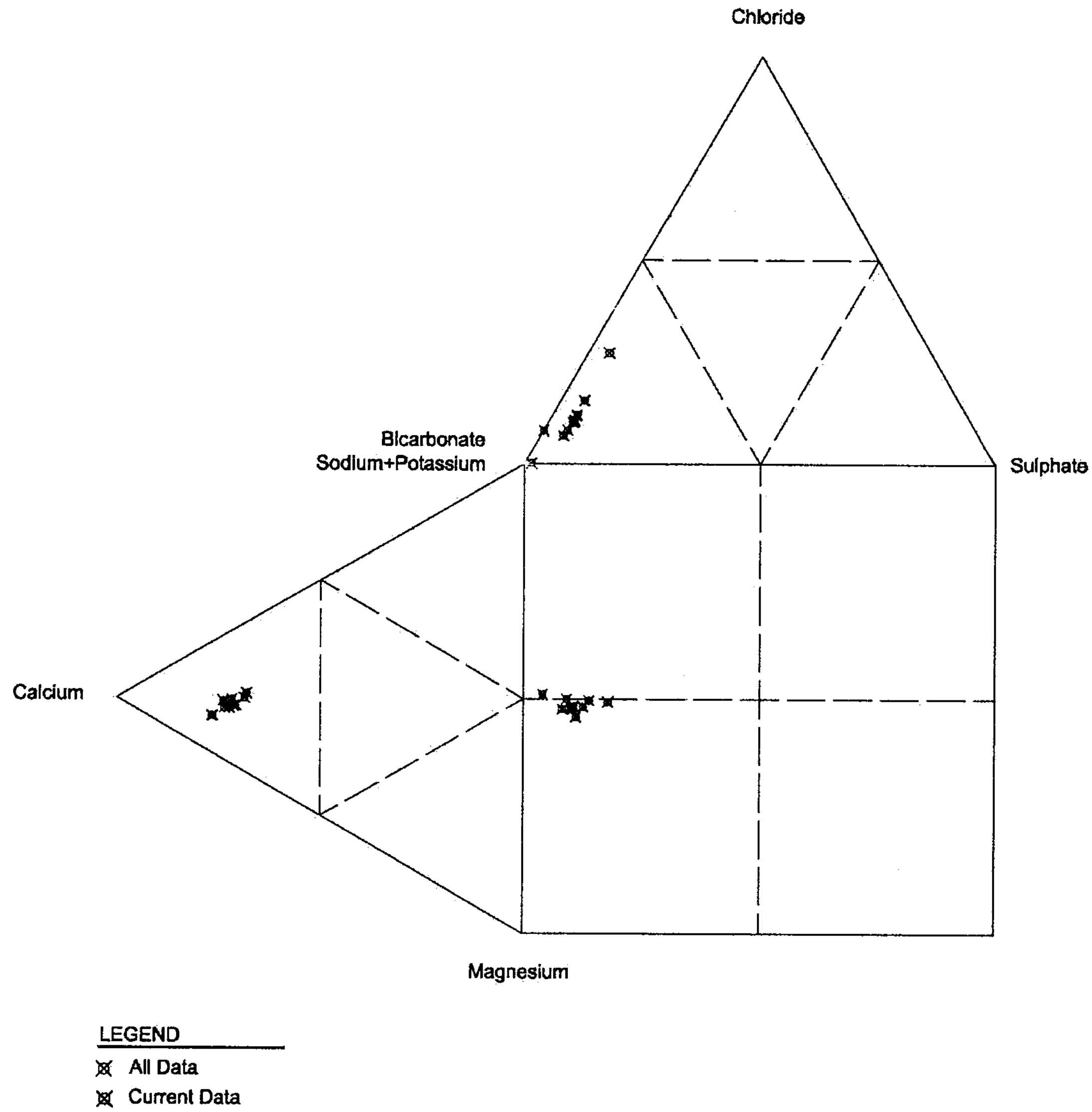
Woodwaste Study Site
Northwestern Ontario

Durov Plot MW4



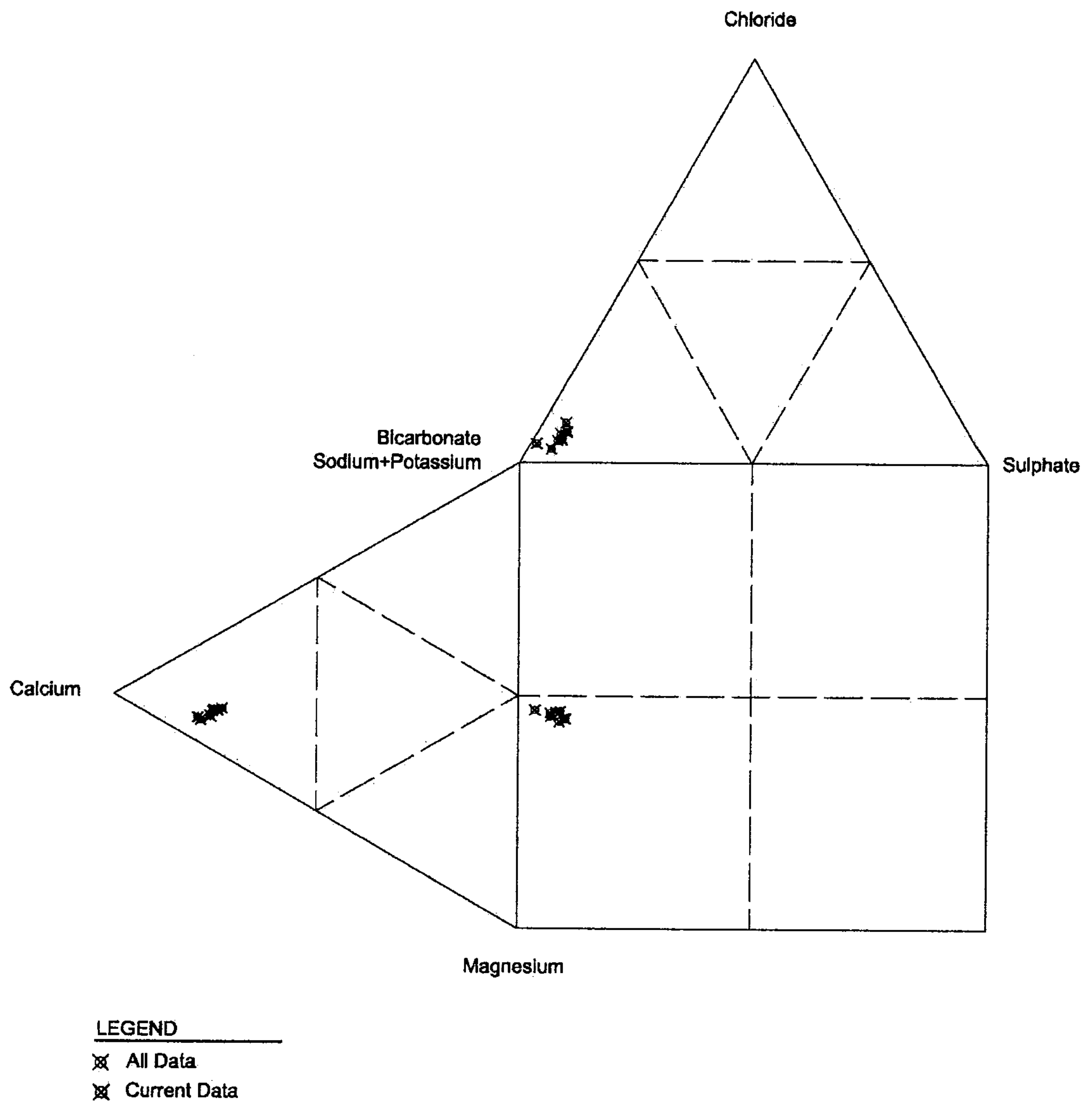
Woodwaste Study Site
Northwestern Ontario

Durov Plot MW5



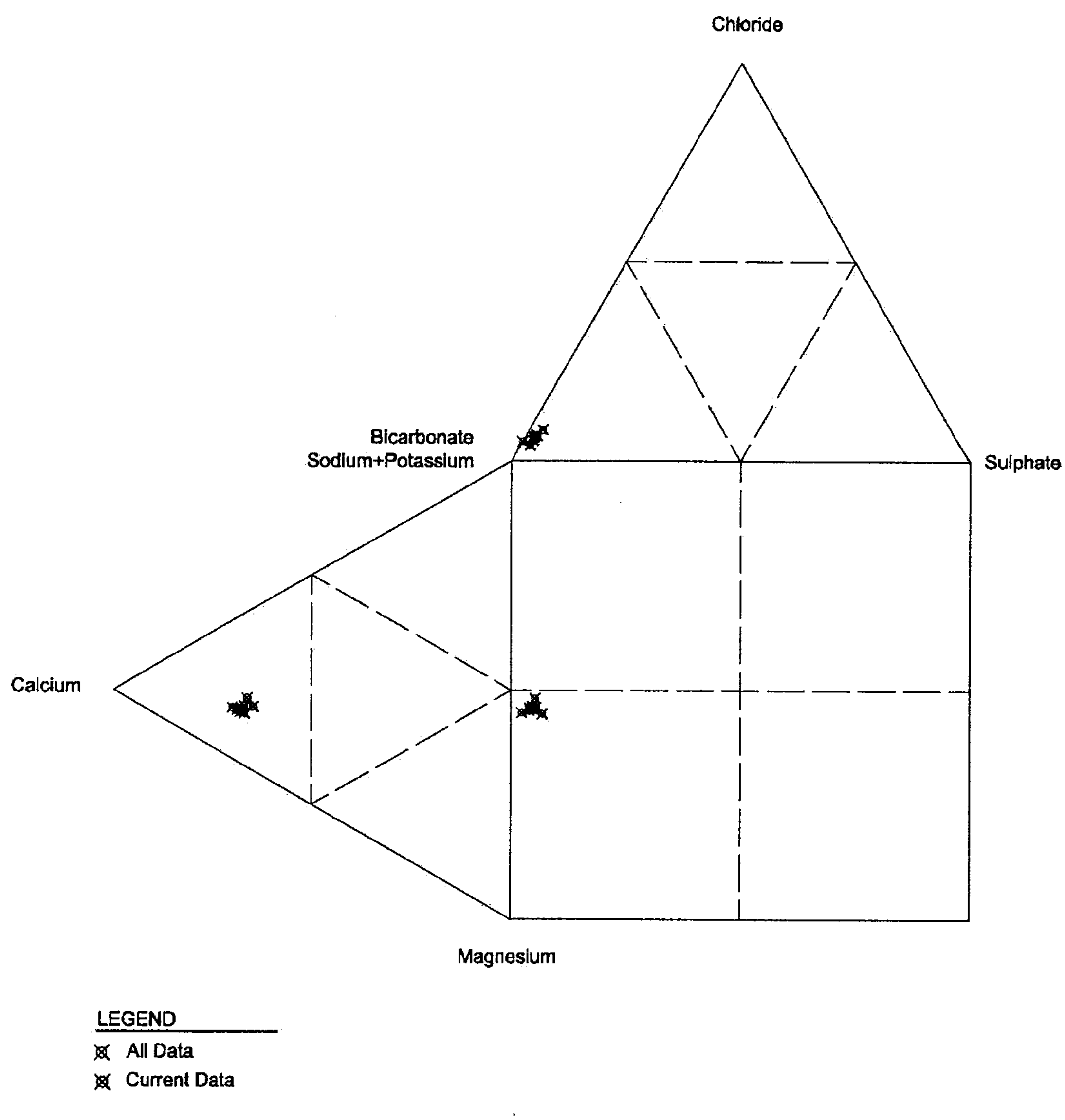
Woodwaste Study Site
Northwestern Ontario

Durov Plot MW6



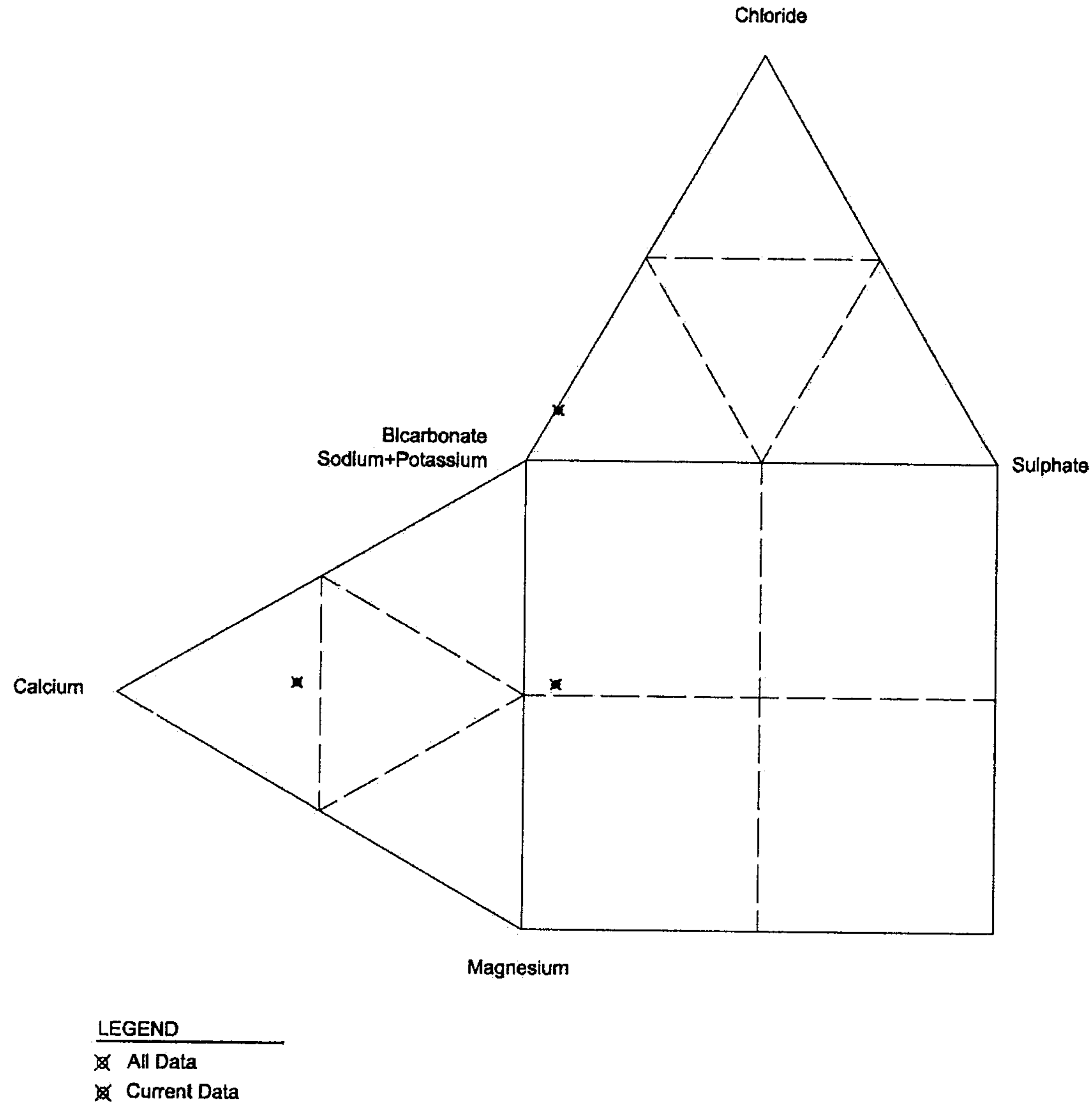
Woodwaste Study Site
Northwestern Ontario

Durov Plot MW7



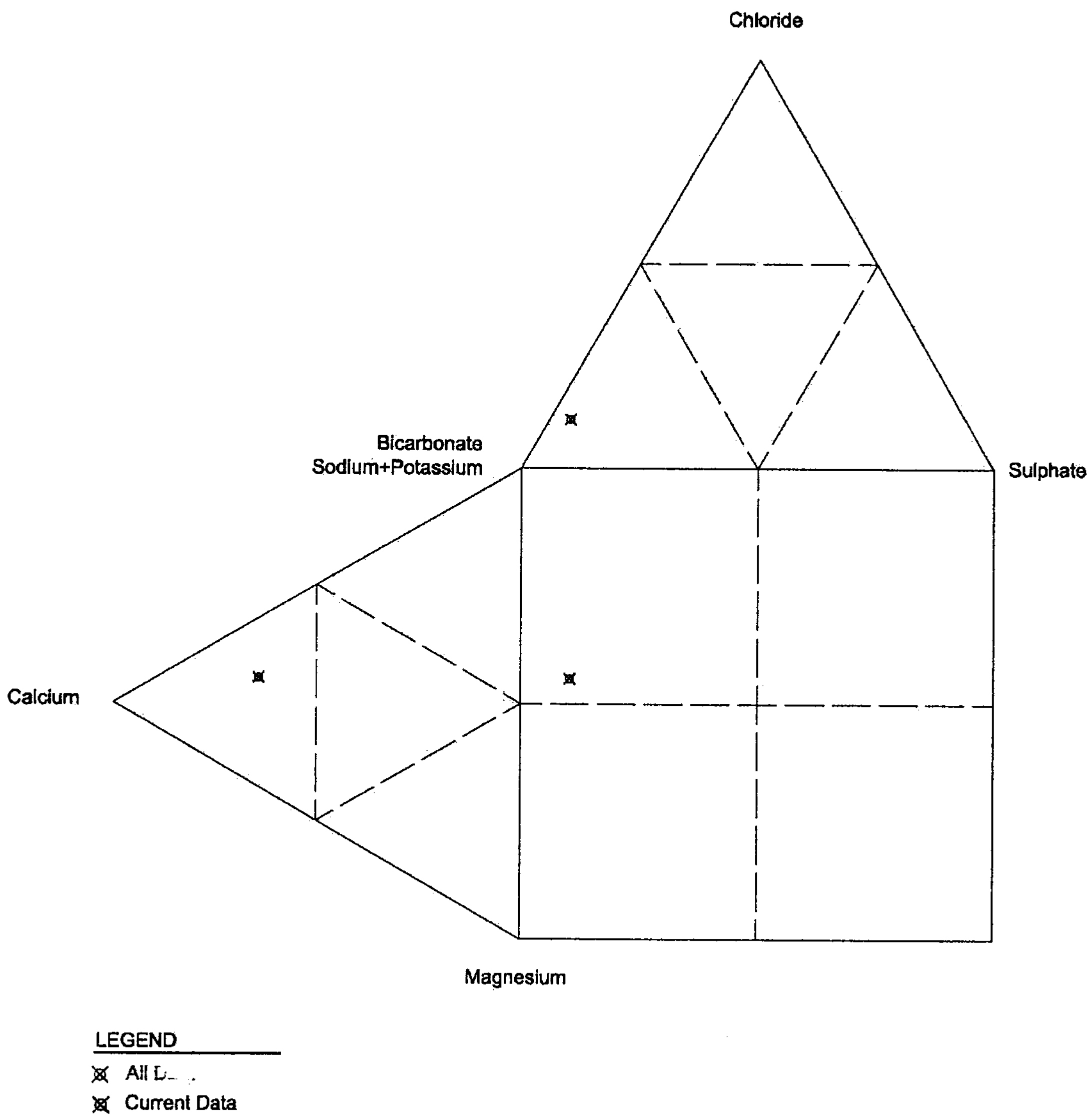
Woodwaste Study Site
Northwestern Ontario

Durov Plot MW8



Woodwaste Study Site
Northwestern Ontario

Durov Plot MW9



Woodwaste Study Site
Northwestern Ontario

Durov Plot MW10

Appendix F: Water Quality Results

Parameter	Units	ODWS	RUG Criteria	MW1										
				4/12/2003	7/9/2004	10/26/2004	7/14/2005	10/25/2005	6/27/2006	9/26/2006	5/29/2007	9/19/2007	6/5/2008	10/8/2008
Field Testing Results														
pH	units			6.5	6.9	6.4	7.2	7.2	7	7	6.85	6.96	7.13	6.71
Temperature	C			14.0	12.1	11.0	12.2	10.9	12.5	11.2	11	11.8	13	11.3
Specific Conductance 25°C	mg/L				1672	1573	1507	1402	2250	1283	2016	2076	1965	1870
General Chemistry														
pH		6.5-8.5		7.19	7	7.06	7.73	7.88	7	7.1	7.9	7.8	7.8	7.4
Specific Conductance 25°C	µS/cm			1691	1710	1610	1840	1710	1550	1960	1900	1940	1890	1900
Total Dissolved Solids	mg/L	500	376.34	**1210**	**999**	**996**	**1150**	**1230**	**1640**	**1620**	**1110**	**970**	**1220**	**1260**
Total Suspended Solids	mg/L			159	615	232			201	353	310	210	140	260
Colour	TCU	5	4.11	**128**	**120**	**132**		**166**	**129**	**123**	**170**	**170**	**180**	**140**
Turbidity	NTU	1		17.6	23	6.8		484	1040	920	484	578	460	480
Dissolved Organic Carbon	mg/L	5	3.38	**133**	**119**	**120**	**174**	**193**	**195**	**152**	**136**	**145**	**127**	**174**
Hardness (as CaCO3)	mg/L	80-100		861.2	810	768	950	1000	1090	1110	1100	1000	1000	1100
Biological Oxygen Demand	mg/L			8	17.7	18.4	20	34	23	21	13	16	9	10
Chemical Oxygen Demand	mg/L			368	380	396	470	100	548	507	400	210	350	390
Ammonia (as N)	mg/L			0.72	0.81	0.6	0.77	0.54	0.68	0.58	0.68	0.64	0.68	0.61
Tannins and Lignins	mg/L			18.4	36	14.6	16.5	16	36	16.5	16	16	11.8	12.8
Anions														
Alkalinity (as CaCO3)	mg/L	30-500		916	954	986	1080	1150	1260	1250	1140	1160	1090	1090
Bicarbonate	mg/L			1110	953	985	1070	1140	1540	1520	1140	1150	1090	1090
Carbonate	mg/L			1	<1	1	5	8	<5	<5	8	7	7	3
Chloride	mg/L	250	134.55	25.3	25.6	28.9	22.8	22	21.9	24.4	29	23	21	24
Sulphate	mg/L	500	257.36	208	2	0.6	<1	<1	<0.3	1.7	<10	<10	<5	<5
Nitrate (as N)	mg/L	10	2.63	**6.2**	<0.2	<0.2	<0.2	<0.2	<0.03	<0.03	<0.1	<0.1	<0.1	<0.1
Nitrite (as N)	mg/L	1	0.297	<0.2	<0.2	<0.2	<0.2	<0.3	<0.02	<0.02	<0.01	<0.01	<0.01	<0.01
Bromide	mg/L			<0.5			<0.5		<0.2	<0.2				
Orthophosphate (as P)	mg/L			<1	<0.3	<0.3	<0.3	<1	<0.04	<0.04	<0.01	<0.01	<0.01	<0.05
Cations														
Calcium	mg/L			251	237	225	275	290	302	317	340	310	290	300
Magnesium	mg/L			56.4	53.2	50.1	64.6	70	80.4	76.5	73	58	73	77
Potassium	mg/L			32.5	38.7	35.7	49.3	49	44.3	60.2	52	47	61	71
Sodium	mg/L	200	108.63	86.1	41	35.4	51.6	60	50.9	60.9	57	45	52	56
Dissolved Metals														
Aluminum	mg/L	0.1	0.054	0.043	0.041	0.048	**0.066**	**0.073**	<0.1	0.05	**0.12**	0.037	**0.078**	**0.076**
Antimony	mg/L			<0.0005	<0.0005	<0.0005	<0.0005	<0.001	<0.05	<0.005	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic	mg/L	0.025	0.007	**0.057**	**0.05**	**0.045**	**0.057**	**0.063**	**0.07**	**0.099**	**0.073**	**0.071**	**0.051**	**0.058**
Barium	mg/L	1	0.271	**0.427**	**0.387**	**0.362**	**0.481**	**0.47**	**0.5**	**0.56**	**0.51**	**0.48**	**0.57**	**0.57**
Beryllium	mg/L			<0.001	<0.001	<0.0005	<0.001	<0.0005	<0.01	<0.001	<0.0005	<0.0005	<0.0005	<0.0005
Bismuth	mg/L			<0.001	<0.001	<0.001	<0.001	<0.001	0.04	0.004	<0.001	<0.001	<0.001	<0.001
Boron	mg/L	5	1.266	0.092	0.106	0.095	0.13	0.13	<0.5	0.13	0.16	0.13	0.19	0.17
Cadmium	mg/L	0.005	0.0013	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium	mg/L	0.05	0.015	0.005	0.006	0.007	[illegible]	0.014	**0.02**	**0.035**	<0.005	0.005	0.007	0.01
Cobalt	mg/L			0.0183	0.0187	0.0153	[illegible]	0.025	0.032	0.0315	0.024	0.023	0.023	0.029
Copper	mg/L	1	0.50	<0.0005	<0.0005	0.0006	[illegible]	0.002	<0.01	0.007	<0.001	0.003	<0.001	0.001
Iron	mg/L	0.3	0.18	**31.4**	**33.7**	**29.6**	[illegible]	**46**	**61.7**	**56.9**	**45**	**44**	**43**	**46**
Lead	mg/L	0.01	0.003	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.01	0.002	<0.0005	<0.0005	<0.0005	<0.0005
Manganese	mg/L	0.05	0.027	**0.59**	**0.709**	**0.688**	**1.04**	**1.1**	**1.35**	**1.38**	**1.1**	**1**	**1.3**	**1.5**
Molybdenum	mg/L			0.003	<0.001	<0.001	<0.001	<0.001	<0.01	0.079	<0.001	<0.001	<0.001	<0.001
Nickel	mg/L			0.008	0.006	0.006	0.011	0.009	<0.02	0.013	<0.005	0.007	0.008	0.008
Phosphorus	mg/L			<0.05	0.09	0.08	0.12	0.17	0.142	0.124			<0.1	
Selenium	mg/L	0.01	0.0045	**0.011**	<0.002	<0.002	<0.002	<0.002	<0.05	<0.005	<0.002	<0.002	<0.002	<0.002
Silicon	mg/L			13.8			15.6	16	14	14.8	16	14	14	15
Silver	mg/L			<0.0001	<0.0001	<0.0001	<0.0001	<0.0005	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Strontium	mg/L			0.437	0.512	0.45	0.548	0.58	0.81	0.685	0.59	0.57	0.59	0.64
Tin	mg/L			<0.001	<0.001	<0.001	<0.001		<0.01	<0.001	<0.001			
Titanium	mg/L			0.01	0.014	0.012	0.02	0.022	<0.003	0.035	0.019	0.016	0.029	0.035
Vanadium	mg/L			0.0253	0.0241	0.0183	0.024	0.028	0.03	0.026	0.025	0.024	0.028	0.037
Zinc	mg/L	5	2.50	0.024	<0.005	<0.005	0.016	0.005	<0.03	0.004	0.017	0.051	0.015	<0.005
Ion Balance														
Total Anions	meq/L			23.8	19.8	20.5	22.2	23.6	25.8	25.7	23.6	23.8	22.4	27.3
Total Cations	meq/L			22.9	20.3	18.9	24.2	25.8	27.4	28.5	28.5	25.1	26	22.5
Percent Difference	%			-1.8	1.1	-4.0	4.2	4.5	2.9	5.1	9.4	2.5	7.36	9.62

Notes:
ODWS - Ontario Drinking Water Standards.
RUG - Reasonable Use Guidelines.
RUG exceedances shown highlighted and in bold text.

Summary of Groundwater Results

Parameter	Units	ODWS	RUG Criteria	MW2 4/12/2003	7/9/2004	10/26/2004	7/14/2005	10/25/2005	6/26/2006	9/26/2006	5/29/2007	9/19/2007	6/5/2008	10/8/2008
Field Testing Results														
pH	units			7.3	7.6	6.9	7.8	8.0	7.9	7.7	7.9	7.74	7.76	8.02
Temperature	C			9.0	6.7	7.3	6.4	6.2	6.8	7	7.9	8.2	7.3	8.5
Specific Conductance 25°C	mg/L				809	790	519	493	500	315	401	529	646	422
General Chemistry														
pH		6.5-8.5		7.89	7.56	7.65	8.17	8.09	7.9	8	8.2	8.2	8.2	8.1
Specific Conductance 25°C	uS/cm			378	836	804	516	513	453	332	397	516	466	403
Total Dissolved Solids	mg/L	500	0.00	218	**453**	**455**	293	291	260	150	254	348	**400**	231
Total Suspended Solids	mg/L			346	919	462			8	188	190	110	65	240
Colour	TCU	5	0.00	**12**	<2	<2		<5	1	<0.4	<5	<5	2	3
Turbidity	NTU	1		9.2	1.8	0.7		104	8.41	81.9	39.8	24.9	16.6	21
Dissolved Organic Carbon	mg/L	5	0.00	1.4	1.9	1.8	1.8	1.7	2	3	1.2	1.6	1.9	1.9
Hardness (as CaCO3)	mg/L	80-100		174.2	319	332	230	250	207	138	180	240	200	180
Biological Oxygen Demand	mg/L			<0.5	<0.5	<0.5	<0.5	<2.0	<2	<2	<2	<2	<2	<2
Chemical Oxygen Demand	mg/L			<5	6	7	6	9	<3	<3	6	6	5	7
Ammonia (as N)	mg/L			<0.03	0.05	<0.03	0.06	<0.05	<0.02	<0.02	<0.05	<0.05	<0.05	<0.05
Tannins and Lignins	mg/L			<0.05	0.08	0.31	<0.05	0.3	<0.1	<0.1	<0.2	<0.2	<0.2	<0.2
Anions														
Alkalinity (as CaCO3)	mg/L	30-500		175	289	284	227	178	187	149	173	217	202	187
Bicarbonate	mg/L			211	288	283	224	176	226	181	170	214	199	185
Carbonate	mg/L			1	<1	1	3	2	<5	<5	2	3	3	2
Chloride	mg/L	250	0.00	21.7	101	105	40.3	58	35.4	10.8	19	34	23	13
Sulphate	mg/L	500	0.00	9.1	8.7	11	<1	8	8	9.2	9	14	8	7
Nitrate (as N)	mg/L	10	0.00	0.2	0.7	1	<0.2	<0.2	0.22	0.06	0.2	0.3	0.3	0.4
Nitrite (as N)	mg/L	1	0.000	<0.2	<0.2	<0.2	<0.2	<0.3	<0.02	<0.02	<0.01	<0.01	<0.01	<0.01
Bromide	mg/L			<0.5					<0.2	<0.2				
Orthophosphate (as P)	mg/L			<1	<0.3	<0.3	<0.3	<1.0	<0.04	<0.04	<0.01	<0.01	<0.01	<0.01
Cations														
Calcium	mg/L			58.9	108	114	78.1	86	71.2	47.6	62	81	67	63
Magnesium	mg/L			6.6	11.8	11.5	8.4	8.4	7.04	4.73	6.9	8.6	7.6	6.7
Potassium	mg/L			1.5	2.1	1.9	2	1.8	1.55	1.34	1.4	2.2	2.1	2.3
Sodium	mg/L	200	0.00	15	37.6	29.8	28.3	22	21.7	20.5	20	23	23	19
Dissolved Metals														
Aluminum	mg/L	0.1	0.000	<0.005	0.005	<0.005	<0.005	<0.005	<0.01	<0.01	0.023	0.007	<0.005	<0.005
Antimony	mg/L			<0.0005	<0.0005	<0.0005	<0.005	<0.001	<0.005	<0.005	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic	mg/L	0.025	0.000	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Barium	mg/L	1	0.000	0.022	0.056	0.058	0.035	0.039	0.03	0.02	0.022	0.037	0.028	0.027
Beryllium	mg/L			<0.001	<0.001	<0.0005	<0.0005	<0.0005	<0.001	<0.001	<0.0005	<0.0005	<0.0005	<0.0005
Bismuth	mg/L			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Boron	mg/L	5	0.000	0.008	0.009	0.009	<0.005	<0.01	<0.05	<0.05	0.01	<0.01	<0.01	<0.01
Cadmium	mg/L	0.005	0.0000	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium	mg/L	0.05	0.000	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005
Cobalt	mg/L			0.0005	<0.0001	<0.0001	<0.0001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Copper	mg/L	1	0.00	0.0005	0.0009	0.0006	0.006	0.002	<0.001	<0.001	0.002	0.001	0.002	0.003
Iron	mg/L	0.3	0.00	<0.03	<0.03	<0.03	<0.03	<0.05	0.06	0.06	<0.05	<0.05	<0.1	<0.1
Lead	mg/L	0.01	0.000	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.001	0.001	<0.0005	<0.0005	<0.0005	<0.0005
Manganese	mg/L	0.05	0.000	**0.037**	<0.005	<0.005	0.007	<0.002	0.013	<0.001	0.003	<0.002	<0.002	<0.002
Molybdenum	mg/L			0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.068	<0.001	<0.001	<0.001	<0.001
Nickel	mg/L			<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001
Phosphorus	mg/L			<0.05	<0.05	<0.05	<0.05	<0.05	<0.003	0.176			<0.1	<0.1
Selenium	mg/L	0.01	0.0000	<0.002	<0.002	<0.002	<0.002	<0.002	<0.005	<0.005	<0.002	<0.002	<0.002	<0.002
Silicon	mg/L			2.77			3.39	3	2.4	2.6	2.7	2.7	3.1	3.1
Silver	mg/L			<0.0001	<0.0001	<0.0001	<0.0001	<0.0005	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Strontium	mg/L			0.065	0.119	0.122	0.09	0.1	0.103	0.056	0.065	0.1	0.077	0.077
Tin	mg/L			<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001			
Titanium	mg/L			<0.005	<0.005	<0.005	<0.005	<0.005	<0.0003	0.002	<0.005	<0.005	<0.005	<0.005
Vanadium	mg/L			<0.0005	0.0016	0.0011	0.001	0.001	0.002	<0.001	0.001	0.001	0.001	0.002
Zinc	mg/L	5	0.00	<0.005	<0.005	<0.005	0.015	0.006	<0.003	<0.003	0.009	0.012	<0.005	<0.005
Ion Balance														
Total Anions	meq/L			4.3	8.9	8.9	5.7	5.4	4.9	3.5	4.2	5.6	4.89	4.56
Total Cations	meq/L			4.2	8.1	8.0	5.9	6.0	5.1	3.7	4.6	5.8	5.04	4.28
Percent Difference	%			-1.6	-4.7	-5.6	1.8	5.5	2.0	3.0	4.3	1.8	1.48	3.12

Notes:
ODWS - Ontario Drinking Water Standards.
RUG - Reasonable Use Guidelines.
RUG exceedances shown highlighted and in bold text.

Summary of Groundwater Results

Parameter	Units	ODWS	RUG Criteria	MW3											
				4/12/2003	7/9/2004	10/26/2004	7/14/2005	10/25/2005	6/27/2006	9/26/2006	5/29/2007	9/19/2007	6/5/2008	6/5/2008	10/8/2008
Field Testing Results															
pH	units			6.6	7.2	6.5	7.4	7.3	7	7.4	6.92	6.82	7.31	-	6.88
Temperature	C			10.0	7.2	7.9	7.7	7.0	9.8	8.9	9.3	10.3	10.1	-	9.7
Specific Conductance 25°C	mg/L				1475	1688	1554	1758	2210	1280	1905	2234	1404	-	1585
General Chemistry															
pH		6.5-8.5		7.08	7.2	7.24	7.83	7.97	7	7.3	7.9	7.8	7.8	7.8	7.7
Specific Conductance 25°C	uS/cm			1645	1660	1800	1920	2190	1550	1970	1730	2130	2070	2270	1810
Total Dissolved Solids	mg/L	500	0.00	**1151**	**953**	**1110**	**1140**	**1470**	**1490**	**1610**	**947**	**920**	**1390**	**1300**	**1100**
Total Suspended Solids	mg/L			191	1460	362			208	365	740	780	1500	1000	740
Colour	TCU	5	0.00	**350**	**160**	**162**		**328**	**124**	**178**	**240**	**280**	**180**	**230**	**110**
Turbidity	NTU	1		24	76	7.4		615	780	908	800	456	600	630	350
Dissolved Organic Carbon	mg/L	5	0.00	**185**	**65.6**	**117**	**68.5**	**229**	**160**	**155**	**101**	**185**	**216**	**198**	**128**
Hardness (as CaCO3)	mg/L	80-100		1006	781	939	980	1400	1010	1140	1000	1200	1000	970	920
Biological Oxygen Demand	mg/L			5	9.1	8.1	12	36	12	15	4	11	10	12	9
Chemical Oxygen Demand	mg/L			483	246	327	200	640	286	548	280	520	540	520	280
Ammonia (as N)	mg/L			0.6	0.6	0.59	0.15	0.12	0.16	0.27	0.4	0.37	0.6	0.61	0.42
Tannins and Lignins	mg/L			17	25.8	1.9	5.99	23	29.8	15.4	7.7	18	12	14.7	9.2
Anions															
Alkalinity (as CaCO3)	mg/L	30-500		1150	795	974	887	1380	1050	1200	1040	1270	1190	1340	1010
Bicarbonate	mg/L			1400	794	972	881	1370	1280	1460	1030	1270	1180	1330	1000
Carbonate	mg/L			1	1	2	6	12	<5	<5	8	7	7	8	5
Chloride	mg/L	250	0.00	43.6	94.8	110	**159**	2	83.9	61.7	28	50	35	33	47
Sulphate	mg/L	500	0.00	2.1	30.5	13	3	19	7.3	3.2	<20	<10	<5	<10	7
Nitrate (as N)	mg/L	10	0.00	<0.2	<0.2	0.2	<0.2	<0.2	<0.03	<0.03	<0.1	<0.1	<0.1	<0.1	<0.1
Nitrite (as N)	mg/L	1	0.000	<0.2	<0.2	<0.2	<0.2	<0.3	<0.02	<0.1	<0.01	<0.01	<0.01	<0.01	<0.01
Bromide	mg/L			<0.5					0.5	0.2					
Orthophosphate (as P)	mg/L			<1	<0.3	<0.3	<0.3	<1.0	<0.04	<0.04	<0.2	<0.01	<0.01	<0.1	<0.01
Cations															
Calcium	mg/L			235	164	188	185	250	210	233	210	270	230	210	220
Magnesium	mg/L			101	90.5	114	125	180	117	135	120	130	110	110	88
Potassium	mg/L			27.6	30.9	34.3	42.2	53	37	43.9	46	50	45	42	36
Sodium	mg/L	200	0.00	51	43.3	45.1	56.5	73	54.9	53.6	49	54	43	41	33
Dissolved Metals															
Aluminum	mg/L	0.1	0.000	**0.223**	**0.154**	**0.169**	**0.163**	**0.26**	**0.2**	**0.2**	**0.31**	**0.22**	**0.15**	**0.14**	**0.092**
Antimony	mg/L			<0.0005	<0.0005	<0.0005	<0.0005	<0.001	<0.05	<0.005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic	mg/L	0.025	0.000	**0.032**	**0.029**	**0.027**	**0.024**	**0.034**	**0.03**	**0.051**	**0.032**	**0.034**	**0.028**	**0.026**	**0.027**
Barium	mg/L	1	0.000	**0.315**	0.235	0.265	**0.285**	**0.44**	**0.4**	**0.42**	**0.31**	**0.41**	**0.33**	**0.3**	0.25
Beryllium	mg/L			<0.001	<0.001	<0.0005	<0.0005	<0.0005	<0.01	<0.001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Bismuth	mg/L			<0.001	<0.001	<0.001	<0.001	<0.001	0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Boron	mg/L	5	0.000	0.41	0.366	0.302	0.33	0.57	<0.5	0.36	0.22	0.37	0.37	0.33	0.18
Cadmium	mg/L	0.005	0.0000	<0.0001	<0.0001	<0.0001	<0.001	<0.0001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001
Chromium	mg/L	0.05	0.000	**0.021**	0.013	**0.017**	0.011	**0.022**	**0.03**	**0.051**	0.012	**0.02**	0.013	0.012	0.01
Cobalt	mg/L			0.019	0.0142	0.0145	0.0152	0.028	0.024	0.0277	0.017	0.023	0.02	0.018	0.013
Copper	mg/L	1	0.00	<0.0005	0.0007	0.0006	0.005	0.002	<0.01	0.003	<0.001	0.002	<0.001	<0.001	0.001
Iron	mg/L	0.3	0.00	**37.3**	**32.9**	**37.5**	**37.2**	**57**	**55.7**	**61.7**	**44**	**62**	**46**	**40**	**35**
Lead	mg/L	0.01	0.000	0.0015	<0.0005	<0.0005	<0.0005	<0.0005	<0.01	<0.001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Manganese	mg/L	0.05	0.000	**1.55**	**0.742**	**0.813**	**0.76**	**1.1**	**1.33**	**1.13**	**0.87**	**1.5**	**0.95**	**1**	**1.7**
Molybdenum	mg/L			0.004	<0.001	<0.001	<0.001	<0.001	<0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nickel	mg/L			0.013	0.004	0.004	0.005	0.012	<0.02	0.012	0.004	0.011	0.007	0.007	0.003
Phosphorus	mg/L			<0.05	0.11	0.11	0.15	0.16	0.135	0.348			<0.1	0.1	<0.1
Selenium	mg/L	0.01	0.0000	<0.002	<0.002	<0.002	<0.002	<0.002	<0.05	<0.005	<0.002	<0.002	<0.002	<0.002	<0.002
Silicon	mg/L			11.5			12.2	14	10	11.2	14	12	11	12	10
Silver	mg/L			<0.0001	<0.0001	<0.0001	<0.0001	<0.0005	<0.001	<0.0001	0.0001	0.0001	<0.0001	<0.0001	<0.0001
Strontium	mg/L			0.444	0.367	0.408	0.455	0.66	0.6	0.643	0.45	0.58	0.49	0.49	0.42
Tin	mg/L			<0.001	<0.001	<0.001	<0.001		<0.01	<0.001	<0.001				
Titanium	mg/L			0.072	0.049	0.047	0.045	0.097	<0.003	0.108	0.054	0.081	0.057	0.049	0.03
Vanadium	mg/L			0.0646	0.0439	0.0424	0.036	0.069	0.06	0.065	0.045	0.063	0.043	0.04	0.026
Zinc	mg/L	5	0.00	0.024	0.006	<0.005	0.012	0.007	<0.03	0.012	0.008	0.11	<0.005	<0.005	<0.005
Ion Balance															
Total Anions	meq/L			24.3	19.2	22.9	22.3	28.0	23.5	25.8	21.6	26.8	24.7	27.72	22
Total Cations	meq/L			24.4	19.6	23.0	24.5	34.0	25.5	28.5	25.3	30.1	25.5	23.92	21.6
Percent Difference	%			0.3	1.0	0.4	4.7	9.5	4.1	5.0	8.0	5.9	1.48	-7.35	0.98

Notes:
ODWS - Ontario Drinking Water Standards.
RUG - Reasonable Use Guidelines.
RUG exceedances shown highlighted and in bold text.

Summary of Groundwater Results

Parameter	Units	ODWS	RUG Criteria	MW4 4/12/2003	7/9/2004	10/26/2004	7/14/2005	10/25/2005	6/26/2006	9/26/2006	5/29/2007	9/19/2007	6/5/2008	10/8/2008
Field Testing Results														
pH	units			7.5	8.0	7.1	7.9	7.9	8.2	8	8.02	8.34	8.27	8.1
Temperature	C			6.0	5.4	5.1	5.1	4.4	6.8	5.8	7.9	8.4	11.2	7.6
Specific Conductance 25°C	mg/L				343	333	339	331	323	321	350	286	302	300
General Chemistry														
pH		6.5-8.5		8.21	8.13	8.09	8.21	7.93	8.2	8.2	8.2	8.3	8.2	8
Specific Conductance 25°C	uS/cm			373	362	322	342	324	285	341	354	302	298	312
Total Dissolved Solids	mg/L	500	0.00	216	198	185	190	191	170	170	221	190	211	183
Total Suspended Solids	mg/L			242	733	186			11	231	65	130	570	260
Colour	TCU	5	0.00	**8**	**10**	4		<5	0.8	<0.4	<5	<5	<2	<2
Turbidity	NTU	1		4.9	2	1.3		174	3.68	113	19.9	40	185	46
Dissolved Organic Carbon	mg/L	5	0.00	0.9	0.9	0.4	0.9	0.9	1	**4**	0.7	0.7	0.6	0.9
Hardness (as CaCO3)	mg/L	80-100		169.8	153	149	160	160	155	163	170	140	140	150
Biological Oxygen Demand	mg/L			<0.5	<0.5	<0.5	<0.5	<2.0	<2	<2	<2	<2	<2	<2
Chemical Oxygen Demand	mg/L			<5	6	<5	5	<4.0	<3	<3	<4	5	<4	<4
Ammonia (as N)	mg/L			<0.03	<0.03	<0.03	<0.03	<0.05	<0.02	<0.02	<0.05	<0.05	<0.05	<0.05
Tannins and Lignins	mg/L			0.06	0.08	0.08	<0.05	<0.2	<0.1	<0.1	<0.2	0.4	<0.2	<0.2
Anions														
Alkalinity (as CaCO3)	mg/L	30-500		154	149	136	144	148	137	142	150	131	129	139
Bicarbonate	mg/L			186	147	134	142	147	165	171	148	129	127	137
Carbonate	mg/L			0	2	2	2	1	<5	<5	2	2	2	1
Chloride	mg/L	250	0.00	28.9	15.5	9.8	9	6	4.6	5.5	9	3	3	3
Sulphate	mg/L	500	0.00	17.4	20.1	20.1	22.4	22	24.3	27.1	24	27	23	21
Nitrate (as N)	mg/L	10	0.00	<0.2	<0.2	0.2	<0.2	<0.2	<0.03	0.03	<0.1	<0.1	0.4	0.7
Nitrite (as N)	mg/L	1	0.000	<0.2	<0.2	<0.2	<0.2	<0.3	<0.02	<0.02	<0.01	<0.01	<0.01	<0.01
Bromide	mg/L			<0.5					<0.2	<0.2				
Orthophosphate (as P)	mg/L			<1	<0.3	<0.3	<0.03	<1.0	<0.04	<0.04	<0.01	<0.01	<0.01	<0.01
Cations														
Calcium	mg/L			56.1	50.9	49.8	52.2	54	51.5	54.1	56	47	46	50
Magnesium	mg/L			7.2	6.34	6.07	6.95	6.7	6.34	6.66	7.4	5.5	6.1	6.3
Potassium	mg/L			1.3	1.2	1	1.2	1.3	0.88	0.95	1	0.94	1	0.9
Sodium	mg/L	200	0.00	12.2	9.7	9.5	11.3	12	10.2	11.9	9.9	8.2	9.3	9.3
Dissolved Metals														
Aluminum	mg/L	0.1	0.000	0.005	0.005	0.006	0.01	<0.005	<0.01	0.01	0.006	0.006	0.005	<0.005
Antimony	mg/L			<0.0005	<0.0005	<0.0005	<0.0005	<0.001	<0.005	<0.005	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic	mg/L	0.025	0.000	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Barium	mg/L	1	0.000	0.022	0.022	0.021	0.02	0.022	0.02	0.02	0.021	0.018	0.015	0.019
Beryllium	mg/L			<0.001	<0.001	<0.0005	<0.005	<0.0005	<0.001	<0.001	<0.0005	<0.0005	<0.0005	<0.0005
Bismuth	mg/L			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Boron	mg/L	5	0.000	0.008	0.005	0.008	<0.005	<0.01	<0.05	<0.05	<0.01	<0.01	<0.01	<0.01
Cadmium	mg/L	0.005	0.0000	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001
Chromium	mg/L	0.05	0.000	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005
Cobalt	mg/L			<0.0001	<0.0001	<0.0001	<0.0001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Copper	mg/L	1	0.00	<0.0005	0.001	<0.0005	<0.0005	0.002	<0.001	<0.001	<0.001	0.002	<0.001	0.002
Iron	mg/L	0.3	0.00	<0.03	<0.03	<0.03	<0.03	<0.05	<0.05	0.09	<0.05	<0.05	<0.1	<0.1
Lead	mg/L	0.01	0.000	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.001	0.001	<0.0005	<0.0005	<0.0005	<0.0005
Manganese	mg/L	0.05	0.000	0.009	<0.005	<0.005	<0.005	<0.002	<0.001	0.001	<0.002	<0.002	<0.002	<0.002
Molybdenum	mg/L			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.062	<0.001	<0.001	<0.001	<0.001
Nickel	mg/L			<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001
Phosphorus	mg/L			<0.05	<0.05	<0.05	<0.05	<0.05	0.003	0.11			<0.1	<0.1
Selenium	mg/L	0.01	0.0000	<0.002	<0.002	<0.002	<0.002	<0.002	<0.005	<0.005	<0.002	<0.002	<0.002	<0.002
Silicon	mg/L			2.82			3.09	3	2.5	3	3.2	2.8	3	3.1
Silver	mg/L			<0.0001	<0.0001	<0.0001	<0.0001	<0.0005	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Strontium	mg/L			0.052	0.045	0.041	0.042	0.046	0.05	0.044	0.043	0.04	0.041	0.045
Tin	mg/L			<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001			
Titanium	mg/L			<0.005	<0.005	<0.005	<0.005	<0.005	<0.0003	0.003	<0.005	<0.005	<0.005	<0.005
Vanadium	mg/L			0.0007	0.0013	0.0011	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001
Zinc	mg/L	5	0.00	<0.005	<0.005	<0.005	<0.005	<0.005	<0.003	0.004	0.013	<0.005	<0.005	<0.005
Ion Balance														
Total Anions	meq/L			4.3	3.8	3.4	3.6	3.6	3.4	3.6	3.8	3.3	3.19	3.42
Total Cations	meq/L			4.0	3.5	3.4	3.7	3.8	3.6	3.8	3.9	3.2	3.24	3.35
Percent Difference	%			-3.6	-4.3	0.0	1.4	2.9	2.7	3.2	1.4	-1.3	0.82	0.98

Notes:
ODWS - Ontario Drinking Water Standards.
RUG - Reasonable Use Guidelines.
RUG exceedances shown highlighted and in bold text.

Summary of Groundwater Results

Parameter	Units	ODWS	RUG Criteria	MW5											
				4/12/2003	7/9/2004	10/26/2004	7/14/2005	10/25/2005	6/26/2006	9/26/2006	5/29/2007	9/19/2007	6/5/2008	10/8/2008	10/8/2008
Field Testing Results															
pH	units			6.9	7.2	6.8	7.3	7.6	7.7	7.3	7.31	7.32	8.08	7.87	-
Temperature	C			7.0	6.4	5.8	6.8	5.1	7	6.8	9.2	8.4	10.7	8.9	-
Specific Conductance 25°C	mg/L				1122	1010	643	687	524	658	650	751	450	402	-
General Chemistry															
pH		6.5-8.5		7.57	7.22	7.43	8.14	8.23	7.7	7.6	8.2	8	8.2	7.9	8
Specific Conductance 25°C	uS/cm			1175	1220	921	696	726	546	811	705	1050	455	501	485
Total Dissolved Solids	mg/L	500	0.00	**781**	**720**	**576**	**382**	**449**	340	**480**	**410**	**634**	310	269	266
Total Suspended Solids	mg/L			911	1560	1190			404	810	270	350	490	570	620
Colour	TCU	5	0.00	**100**	**100**	**44**		**24**	**10.5**	**11.3**	**55**	**73**	**19**	**8**	**8**
Turbidity	NTU	1		4.3	2.2	1.4		163	193	222	106	118	105	64	98
Dissolved Organic Carbon	mg/L	5	0.00	**79**	**59.9**	**29.5**	**12.7**	**14.1**	**8**	**24**	**35.1**	**83.4**	**7**	3.3	**3.4**
Hardness (as CaCO3)	mg/L	80-100		509	542	427	160	340	261	387	370	730	220	200	200
Biological Oxygen Demand	mg/L			6.5	3.1	1.8	<0.5	3	<2	2	<2	<2	<2	<2	<2
Chemical Oxygen Demand	mg/L			189	246	87	38	41	28	72	96	220	20	12	14
Ammonia (as N)	mg/L			0.37	0.5	0.39	0.37	0.13	0.19	0.31	0.42	0.38	0.08	<0.05	<0.05
Tannins and Lignins	mg/L			6.96	9.56	3	1.1	1.3	0.6	1.3	2.6	4.4	0.7	0.6	0.5
Anions															
Alkalinity (as CaCO3)	mg/L	30-500		593	548	383	314	374	288	393	359	541	225	242	236
Bicarbonate	mg/L			721	547	382	310	368	349	477	354	535	221	240	234
Carbonate	mg/L			1	<1	<1	4	6	<5	<5	5	5	3	2	2
Chloride	mg/L	250	0.00	40.2	92.5	90.7	27.6	29	15	36	22	32	5	7	7
Sulphate	mg/L	500	0.00	106	21.5	26.6	13.3	13	16.9	15.2	5	16	18	19	18
Nitrate (as N)	mg/L	10	0.00	**3**	<0.2	0.2	<0.2	<0.2	<0.03	<0.03	<0.1	<0.1	<0.1	<0.1	<0.1
Nitrite (as N)	mg/L	1	0.000	<0.2	<0.2	<0.2	<0.2	<0.3	<0.02	<0.02	<0.01	<0.01	<0.01	<0.01	<0.01
Bromide	mg/L			<0.5					<0.2	<0.2					
Orthophosphate (as P)	mg/L			<1	<0.3	<0.3	<0.3	<1	<0.04	<0.04	<0.01	<0.01	<0.01	<0.01	<0.01
Cations															
Calcium	mg/L			144	3	115	75.5	94	72.6	107	94	190	61	61	62
Magnesium	mg/L			35.9	2	33.7	22.3	27	19.4	29	34	6.	16	12	12
Potassium	mg/L			7.1	.4	9.7	9.1	9.9	7.66	9.31	10	14	7.7	5.6	5.6
Sodium	mg/L	200	0.00	91.4	1.4	43.4	38.2	44	27.6	30	29	37	18	10	10
Dissolved Metals															
Aluminum	mg/L	0.1	0.000	0.036	0.047	0.034	0.018	0.016	0.03	0.02	0.029	0.03	0.017	<0.005	<0.005
Antimony	mg/L			<0.0005	<0.0005	<0.0005	<0.0005	<0.001	<0.005	<0.005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic	mg/L	0.025	0.000	**0.017**	**0.032**	**0.03**	**0.026**	**0.028**	**0.028**	**0.031**	**0.029**	**0.034**	**0.02**	**0.011**	**0.011**
Barium	mg/L	1	0.000	0.123	0.133	0.103	0.059	0.068	0.05	0.1	0.073	0.16	0.043	0.026	0.026
Beryllium	mg/L			<0.001	<0.001	<0.0005	<0.0005	<0.0005	<0.001	<0.001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Bismuth	mg/L			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Boron	mg/L	5	0.000	0.187	0.278	0.135	.07	0.048	<0.05	<0.05	0.14	0.18	0.07	<0.01	<0.01
Cadmium	mg/L	0.005	0.0000	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium	mg/L	0.05	0.000	<0.005	0.009	0.007	<0.005	<0.005	0.003	0.008	<0.005	0.005	<0.005	<0.005	<0.005
Cobalt	mg/L			0.0267	0.013	0.0084	0.0035	0.0038	0.0033	0.0066	0.0061	0.011	0.0022	<0.0005	<0.0005
Copper	mg/L	1	0.00	0.0082	0.0022	0.0017	0.006	0.006	<0.001	0. 01	0.001	0.001	<0.001	<0.001	<0.001
Iron	mg/L	0.3	0.00	**6.09**	**20**	**14.1**	**7.1**	**7.5**	**6.77**	**1..8**	**10**	**20**	**3.8**	**0.9**	**0.8**
Lead	mg/L	0.01	0.000	<0.0005	<0.0005	.0005	<0.0005	<0.0005	<0.001	0.002	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Manganese	mg/L	0.05	0.000	**1.56**	**0.944**	**.731**	**0.504**	**0.72**	**0.609**	**0.915**	**0.63**	**1.2**	**0.34**	**0.21**	**0.21**
Molybdenum	mg/L			0.004	0.001	.001	0.002	0.002	0.001	0.059	0.002	0.002	0.001	0.001	0.001
Nickel	mg/L			0.011	0.003	0.002	<0.001	<0.001	<0.002	0.003	<0.001	0.003	<0.001	<0.001	<0.001
Phosphorus	mg/L			<0.05	0.05	.05	0.07	<0.05	0.225	0.641			<0.1	<0.1	<0.1
Selenium	mg/L	0.01	0.0000	**0.011**	<0.002	02	0.002	<0.002	<0.005	<0.005	<0.002	<0.002	<0.002	<0.002	<0.002
Silicon	mg/L			9.78			12.1	12	8.9	11	13	12	8.7	4	4.1
Silver	mg/L			<0.0001	<0.0001	<0.0001	0.0005	<0.0005	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Strontium	mg/L			0.241	0.317	0.236	0.136	0.16	0.15	0.227	0.18	0.4	0.11	0.079	0.079
Tin	mg/L			<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001				
Titanium	mg/L			0.008	0.018	0.009	<0.005	<0.005	<0.0003	0.009	0.007	0.011	<0.005	<0.005	<0.005
Vanadium	mg/L			0.0166	0.0378	0.0191	0.009	0.007	0.006	0.006	0.016	0.022	0.009	<0.001	<0.001
Zinc	mg/L	5	0.00	0.008	<0.005	<0.005	0.024	0.007	<0.003	0.006	0.009	0.025	<0.005	<0.005	<0.005
Ion Balance															
Total Anions	meq/L			15.4	14.0	10.8	7.3	8.6	6.5	9.2	7.9	12.1	5.01	4.61	4.69
Total Cations	meq/L			14.6	14.1	11.2	7.8	9.4	6.9	9.8	9.4	17.4	5.44	5.44	5.29
Percent Difference	%			-2.7	0.4	1.9	3.1	4.6	2.7	3.3	8.8	18.2	4.17	8.34	6.01

Notes:
ODWS - Ontario Drinking Water Standards.
RUG - Reasonable Use Guidelines.
RUG exceedances shown highlighted and in bold text.

Summary of Groundwater Results

Parameter	Units	ODWS	RUG Criteria	MW6											
				4/12/2003	7/9/2004	10/26/2004	7/14/2005	10/25/2005	6/26/2006	9/26/2006	5/29/2007	9/19/2007	9/19/2007	6/5/2008	10/8/2008
Field Testing Results															
pH	units			7.1	7.7	7.4	7.8	7.8	8.1	7.5	7.87	8.11	8.11	8.05	8.31
Temperature	C			7.0	5.8	4.8	6.4	4.2	6	5.7	8	9.4	9.4	12.2	8.1
Specific Conductance 25°C	mg/L				373	431	339	360	381	331	353	345	345	403	370
General Chemistry															
pH		6.5-8.5		7.89	7.97	8.04	8.23	8.22	8.1	8.1	7.9	8.2	8.2	8.2	8
Specific Conductance 25°C	uS/cm			571	409	417	348	343	308	345	538	367	368	387	403
Total Dissolved Solids	mg/L	500	0.00	336	221	234	181	207	180	170	369	212	246	272	260
Total Suspended Solids	mg/L			921	561	230			24	483	2600	640	1200	1400	1400
Colour	TCU	5	0.00	<3	<2	<2		<5	0.7	<0.4	<5	<5	<5	23	<2
Turbidity	NTU	1		13.9	1.9	0.6		179	19.4	289	752	232	281	450	120
Dissolved Organic Carbon	mg/L	5	0.00	1.3	0.3	0.7	0.6	0.6	1	3	1.1	0.6	0.7	0.8	0.8
Hardness (as CaCO3)	mg/L	80-100		285.5	177	185	160	170	169	176	290	190	190	200	210
Biological Oxygen Demand	mg/L			1	<0.5	<0.5	<0.5	<2.0	<2	<2	<2	<2	<2	<2	<2
Chemical Oxygen Demand	mg/L			<5	8	<5	<5	<4	<3	<3	<4	<4	<4	<4	<4
Ammonia (as N)	mg/L			<0.03	<0.03	<0.03	0.06	<0.05	<0.02	<0.02	<0.05	0.07	<0.05	<0.05	<0.05
Tannins and Lignins	mg/L			<0.05	0.05	0.08	<0.05	<0.2	<0.1	<0.1	<0.2	0.5	0.6	<0.2	<0.2
Anions															
Alkalinity (as CaCO3)	mg/L	30-500		252	183	1. 3	162	177	159	163	191	164	165	177	204
Bicarbonate	mg/L			305	181	176	159	174	192	196	190	161	162	174	202
Carbonate	mg/L			1	2	[illegible]	3	3	<5	<5	2	2	2	2	2
Chloride	mg/L	250	0.00	39	15.9	24.7	10.3	12	14.4	9.1	54	14	17	15	5
Sulphate	mg/L	500	0.00	17.4	10.5	10.8	0	10	9.7	8.6	12	10	10	9	8
Nitrate (as N)	mg/L	10	0.00	0.4	0.3	0.8	<0.2	<0.2	0.16	0.13	0.4	0.3	0.3	0.2	0.1
Nitrite (as N)	mg/L	1	0.000	<0.2	<0.2	<0.2	<0.2	<0.3	<0.02	<0.02	<0.01	<0.01	<0.01	<0.01	<0.01
Bromide	mg/L			<0.5			<0.5		<0.2	<0.2					
Orthophosphate (as P)	mg/L			<1	<0.3	<0.3	<0.3	<1.0	<0.04	<0.04	<0.01	<0.01	<0.01	<0.01	<0.01
Cations															
Calcium	mg/L			95	57.8	60.2	51.8	56	56	58.2	97	64	63	64	68
Magnesium	mg/L			11.7	7.92	8.38	6.93	7.8	7.07	7.41	11	8.6	7.8	8.6	9.2
Potassium	mg/L			2	1.2	1.1	1.3	1.2	0.98	0.95	1.4	1.5	1.1	1.1	1.2
Sodium	mg/L	200	0.00	19.9	11.1	12	14	14	10	9.53	18	11	6.9	7.2	7.9
Dissolved Metals															
Aluminum	mg/L	0.1	0.000	0.006	<0.005	<0.005	<0.005	<0.005	<0.01	0.01	<0.005	<0.005	<0.005	<0.005	<0.005
Antimony	mg/L			<0.0005	<0.0005	<0.0005	<0.0005	<0.001	<0.005	<0.005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic	mg/L	0.025	0.000	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Barium	mg/L	1	0.000	0.039	0.027	0.027	0.023	0.023	0.02	0.02	0.043	0.028	0.024	0.026	0.027
Beryllium	mg/L			<0.001	<0.001	<0.0005	<0.0005	<0.0005	<0.001	<0.001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Bismuth	mg/L			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Boron	mg/L	5	0.000	0.011	0.007	0.011	<0.01	<0.01	<0.05	<0.05	0.01	<0.01	<0.01	<0.01	<0.01
Cadmium	mg/L	0.005	0.0000	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	0.0003	<0.0001
Chromium	mg/L	0.05	0.000	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005	<0.005
Cobalt	mg/L			<0.0001	<0.0001	<0.0001	<0.0001	<0.0005	0.001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Copper	mg/L	1	0.00	0.0008	<0.0005	0.0074	0.006	0.002	<0.001	0.001	<0.001	0.002	0.001	<0.001	0.001
Iron	mg/L	0.3	0.00	<0.03	0.05	<0.03	<0.03	<0.05	0.06	0.1	0.07	<0.05	<0.05	<0.1	<0.1
Lead	mg/L	0.01	0.000	0.0007	<0.0005	0.0013	<0.0005	<0.0005	<0.001	0.001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Manganese	mg/L	0.05	0.000	0.025	<0.005	<0.005	<0.005	<0.002	0.002	0.003	<0.002	<0.002	<0.002	<0.002	<0.002
Molybdenum	mg/L			0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.058	<0.001	<0.001	<0.001	<0.001	<0.001
Nickel	mg/L			0.002	<0.001	<0.001	<0.001	<0.001	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001
Phosphorus	mg/L			<0.05	<0.05	<0.05	<0.05	<0.05	0.015	0.265				<0.1	<0.1
Selenium	mg/L	0.01	0.0000	<0.002	<0.002	<0.002	<0.002	<0.002	<0.005	<0.005	<0.002	<0.002	<0.002	<0.002	<0.002
Silicon	mg/L			3.69			2.93	3.1	2.7	3	3.9	3.2	2.9	3.2	3.4
Silver	mg/L			<0.0001	<0.0001	<0.0001	<0.0001	<0.0005	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001
Strontium	mg/L			0.089	0.052	0.05	0.046	0.048	0.053	0.048	0.079	0.059	0.051	0.054	0.056
Tin	mg/L			<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001				
Titanium	mg/L			<0.005	<0.005	<0.005	<0.005	<0.005	<0.0003	0.003	<0.005	<0.005	<0.005	<0.005	<0.005
Vanadium	mg/L			0.0006	0.001	0.0007	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001
Zinc	mg/L	5	0.00	<0.005	<0.005	0.01	0.012	0.005	<0.003	0.004	0.012	0.035	0.009	<0.005	<0.005
Ion Balance															
Total Anions	meq/L			6.5	4.3	4.5	3.5	4.1	3.8	3.7	5.6	3.9	4.0	4.16	4.54
Total Cations	meq/L			6.6	4.1	4.2	3.8	4.1	3.8	4.0	6.6	4.4	4.1	4.25	4.41
Percent Difference	%			0.7	-3.5	-3.3	3.7	-0.1	0.5	3.3	7.8	6.3	1.3	1.14	1.39

Notes:
ODWS - Ontario Drinking Water Standards.
RUG - Reasonable Use Guidelines.
RUG exceedances shown highlighted and in bold text.

Summary of Groundwater Results

Parameter	Units	ODWS	RUG Criteria	MW7 7/9/2004	10/26/2004	7/14/2005	10/25/2005	6/26/2006	9/26/2006	5/29/2007	9/19/2007	6/5/2008	10/8/2008
Field Testing Results													
pH	units			7.8	7.2	8.3	8.1	8.1	7.6	7.8	7.85	8.03	7.99
Temperature	C			7.1	4.8	7.1	4.5	7.8	6	8.3	9.8	11	7.3
Specific Conductance 25°C	mg/L			366	391	349	347	382	347	401	398	428	403
General Chemistry													
pH		6.5-8.5		7.95	7.96	8.24	8.11	8.1	8.1	8	8.1	8.1	8
Specific Conductance 25°C	uS/cm			359	369	355	306	314	373	408	412	412	388
Total Dissolved Solids	mg/L	500	0.00	199	216	188	195	200	180	268	250	300	221
Total Suspended Solids	mg/L			185	65			38	409	1200	320	630	330
Colour	TCU	5	0.00	4	4		<5	0.9	<0.4	<5	<5	<2	<2
Turbidity	NTU	1		1.8	0.4		86.7	35	319	624	183	405	200
Dissolved Organic Carbon	mg/L	5	0.00	0.8	0.4	0.8	0.7	1	**4**	1.3	1.1	1.2	0.9
Hardness (as CaCO3)	mg/L	80-100		178	197	180	200	186	192	230	220	230	210
Biological Oxygen Demand	mg/L			<0.5	<0.5	<0.5	<2.0	<2	<2	<2	<2	<2	<2
Chemical Oxygen Demand	mg/L			5	<5	5	<4.0	<3	5	<4	5	<4	5
Ammonia (as N)	mg/L			<0.03	<0.03	0.07	<0.05	<0.02	<0.02	<0.05	<0.05	<0.05	<0.05
Tannins and Lignins	mg/L			0.06	0.07	<0.05	<0.2	<0.1	<0.1	0.2	<0.2	<0.2	0.3
Anions													
Alkalinity (as CaCO3)	mg/L	30-500		175	180	169	161	175	182	183	190	180	178
Bicarbonate	mg/L			174	178	167	159	210	219	181	187	178	176
Carbonate	mg/L			1	2	3	2	<5	<5	2	2	2	2
Chloride	mg/L	250	0.00	5.6	10.4	6	7	8	4.7	15	12	19	12
Sulphate	mg/L	500	0.00	8.8	10.1	2	9	11.6	9.5	10	13	12	11
Nitrate (as N)	mg/L	10	0.00	<0.2	0.4	<0.2	<0.2	0.7	0.32	0.3	0.3	0.2	0.2
Nitrite (as N)	mg/L	1	0.000	<0.2	<0.2	<0.2	<0.3	<0.02	<0.02	<0.01	<0.01	<0.01	<0.01
Bromide	mg/L					<0.5		<0.2	<0.2				
Orthophosphate (as P)	mg/L			<0.3	<0.3	<0.3	<1.0	<0.04	<0.04	<0.01	<0.01	<0.01	<0.01
Cations													
Calcium	mg/L			59	65.6	60	64	61.6	63.6	74	75	76	69
Magnesium	mg/L			7.55	8.15	8.08	8.5	7.71	8	9.8	8.7	10	8.7
Potassium	mg/L			1.3	1.2	1.8	1.7	1.1	1.08	1.3	1.2	1.4	1.2
Sodium	mg/L	200	0.00	5.6	4.1	8.4	8.1	7.71	7.44	7	5	6.1	5.4
Dissolved Metals													
Aluminum	mg/L	0.1	0.000	<0.005	<0.005	<0.005	<0.005	<0.01	<0.01	0.006	<0.005	<0.005	<0.005
Antimony	mg/L			<0.0005	<0.0005	0.001	<0.001	<0.005	<0.005	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic	mg/L	0.025	0.000	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Barium	mg/L	1	0.000	0.024	0.026	0.022	0.024	0.02	0.02	0.028	0.027	0.025	0.025
Beryllium	mg/L			<0.001	<0.0005	<0.0005	<0.0005	<0.001	<0.001	<0.0005	<0.0005	<0.0005	<0.0005
Bismuth	mg/L			0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Boron	mg/L	5	0.000	0.007	0.008	<0.01	<0.01	<0.05	<0.05	0.01	<0.01	<0.01	<0.01
Cadmium	mg/L	0.005	0.0000	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	0.0001	<0.0001	0.001	<0.0001
Chromium	mg/L	0.05	0.000	<0.005	<0.005	<0.005	<0.005	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005
Cobalt	mg/L			<0.0001	<0.0001	<0.0001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Copper	mg/L	1	0.00	<0.0005	<0.0005	0.006	0.005	<0.001	<0.001	0.002	0.001	0.001	0.002
Iron	mg/L	0.3	0.00	<0.03	<0.03	<0.03	<0.05	0.06	0.08	<0.05	<0.05	<0.1	<0.1
Lead	mg/L	0.01	0.000	<0.0005	<0.0005	<0.0005	<0.0005	<0.001	0.001	<0.0005	<0.0005	<0.0005	<0.0005
Manganese	mg/L	0.05	0.000	<0.005	<0.005	<0.005	<0.002	<0.001	<0.001	<0.002	<0.002	<0.002	<0.002
Molybdenum	mg/L			<0.001	<0.001	<0.001	<0.001	<0.001	0.06	<0.001	<0.001	<0.001	<0.001
Nickel	mg/L			<0.001	<0.001	<0.001	<0.001	<0.002	0.002	<0.001	<0.001	<0.001	<0.001
Phosphorus	mg/L			<0.05	<0.05	0.06	<0.05	0.022	0.275			<0.1	<0.1
Selenium	mg/L	0.01	0.0000	0.002	<0.002	<0.002	<0.002	<0.005	<0.005	<0.002	<0.002	<0.002	<0.002
Silicon	mg/L					3.32	3.4	2.9	3.3	3.7	3.2	3.6	3.3
Silver	mg/L			<0.0001	<0.0001	<0.0001	<0.0005	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Strontium	mg/L			0.054	0.054	0.051	0.054	0.06	0.054	0.057	0.061	0.066	0.058
Tin	mg/L			<0.001	<0.001	<0.001		<0.001	<0.001	<0.001			
Titanium	mg/L			<0.005	<0.005	<0.005	<0.005	<0.0003	0.003	<0.005	<0.005	<0.005	<0.005
Vanadium	mg/L			0.0012	0.0008	<0.001	<0.001	0.001	<0.001	<0.001	0.001	<0.001	<0.001
Zinc	mg/L	5	0.00	<0.005	<0.005	0.006	0.007	<0.003	<0.003	0.043	0.045	<0.005	<0.005
Ion Balance													
Total Anions	meq/L			3.8	4.1	3.6	3.6	4.0	4.0	4.3	4.4	4.41	4.43
Total Cations	meq/L			3.8	4.2	4.1	4.3	4.1	4.2	4.8	4.7	4.93	4.12
Percent Difference	%			0.1	0.3	6.3	8.7	0.7	2.4	5.8	3.1	5.52	3.63

Notes:
ODWS - Ontario [illegible]nking Water Standards.
RUG - Reasonal [illegible] Use Guidelines.
RUG exceedances shown highlighted and in bold text.

Summary of Groundwater Results

Parameter	Units	ODWS	RUG Criteria	MW8										
				7/9/2004	10/26/2004	7/14/2005	10/25/2005	6/26/2006	9/26/2006	5/29/2007	5/29/2007	9/19/2007	6/5/2008	10/8/2008
Field Testing Results														
pH	units			7.5	7.5	7.3	7.5	7.5	7.4	7.02	7.02	7.18	7.44	7.26
Temperature	C			10.4	8.6	10.3	8.2	10.2	9.6	10	10	11.6	13.1	10.4
Specific Conductance 25°C	mg/L			909	1172	891	966	1135	845	1286	1286	1022	797	698
General Chemistry														
pH		6.5-8.5		7.24	7.31	7.96	7.9	7.5	7.5	8	7.9	8	8.1	7.8
Specific Conductance 25°C	uS/cm			912	1180	997	1140	951	1050	1290	1260	953	906	1070
Total Dissolved Solids	mg/L	500	0.00	**533**	**786**	**574**	**700**	**790**	**660**	**770**	**745**	**515**	**704**	**561**
Total Suspended Solids	mg/L			369	134			58	131	110	120	130	230	94
Colour	TCU	5	0.00	**44**	**42**		**38**	**28.3**	**25.7**	**70**	**66**	**36**	**17**	**32**
Turbidity	TU	1		2.3	1.5		237	290	255	200	282	140	230	200
Dissolved Organic Carbon	mg/L	5	0.00	**24.7**	**87.1**	**25.**	**22.6**	**34**	**42**	**51.4**	**53.2**	**44.6**	**28.9**	**42.6**
Hardness (as CaCO3)	mg/L	80-100		423	692	510	570	578	542	630	640	510	550	360
Biological Oxygen Demand	mg/L	.		17.7	4.9	11	14	8	7	5	4	<2	3	9
Chemical Oxygen Demand	mg/L			109	209	75	73	115	122	140	150	120	76	110
Ammonia (as N)	mg/L			0.36	0.88	0.62	0.22	0.48	0.61	0.54	0.57	0.67	0.25	0.64
Tannins and Lignins	mg/L			4.66	4.8	2.7	2.3	4.1	3.6	5.7	5	3.1	2.2	4.4
Anions														
Alkalinity (as CaCO3)	mg/L	30-500		467	658	533	676	624	577	707	671	492	475	556
Bicarbonate	mg/L			466	657	528	671	759	701	700	666	488	470	552
Carbonate	mg/L			<1	1	5	5	<5	<5	6	5	4	6	4
Chloride	mg/L	250	0.00	25.6	40.9	19.3	21	18.8	22.7	33	32	25	12	20
Sulphate	mg/L	500	0.00	8.7	21.1	<1	14	13.4	12.9	13	14	12	21	23
Nitrate (as N)	mg/L	10	0.00	<0.2	0.3	<0.2	<0.2	0.18	0.11	<0.1	<0.1	<0.1	0.3	<0.1
Nitrite (as N)	mg/L	1	0.000	<0.2	<0.2	<0.3	<0.3	<0.02	<0.02	<0.01	<0.01	<0.01	<0.01	0.01
Bromide	mg/L					<1		<0.2	<0.2					
Orthophosphate (as P)	mg/L			<0.3	<0.3	<0.3	<1.0	<0.04	<0.04	<0.01	<0.01	<0.01	<0.01	<0.01
Cations														
Calcium	mg/L			132	209	155	180	182	167	200	200	150	170	110
Magnesium	mg/L			22.6	41.2	2[illegible]	32	29.9	30.4	35	37	30	30	19
Potassium	mg/L			7.5	12.6	11	10	10.5	12.4	12	12	14	11	9.6
Sodium	mg/L	200	0.00	30.2	33.4	22.	28	27.3	30.2	32	34	29	32	14
Dissolved Metals														
Aluminum	mg/L	0.1	0.000	0.026	0.053	0.039	0.017	0.02	0.03	0.036	**0.056**	0.021	0.032	0.008
Antimony	mg/L			<0.0005	<0.0005	<0.0005	<0.001	<0.005	<0.005	<0.0005	<0.0005	<0.0005	<0.0005	0.0005
Arsenic	mg/L	0.025	0.000	**0.046**	**0.077**	**0.063**	**0.048**	**0.065**	**0.073**	**0.065**	**0.065**	**0.053**	**0.042**	**0.029**
Barium	mg/L	1	0.000	0.122	0.197	0.127	0.15	0.15	0.16	0.15	0.16	0.14	0.16	0.093
Beryllium	mg/L			<0.001	<0.0005	<0.0005	<0.0005	<0.001	<0.001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Bismuth	mg/L			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Boron	mg/L	5	0.000	0.07	0.118	0.06	0.049	0.06	0.08	0.1	0.1	0.06	0.08	0.03
Cadmium	mg/L	0.005	0.0000	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	**0.0018**	<0.0001
Chromium	mg/L	0.05	0.000	<0.005	0.006	<0.005	<0.005	0.008	0.012	<0.005	<0.005	<0.005	<0.005	<0.005
Cobalt	mg/L			0.0065	0.012	0.0081	0.0066	0.0108	0.0122	0.014	0.014	0.0087	0.011	0.0051
Copper	mg/L	1	0.00	0.0008	0.0006	0.021	0.002	0.001	<0.001	<0.001	<0.001	0.002	0.003	0.002
Iron	mg/L	0.3	0.00	**7.94**	**20.1**	**15.5**	**13**	**20.9**	**20.5**	**24**	**24**	**16**	**19**	**8.5**
Lead	mg/L	0.01	0.000	<0.0005	<0.0005	<0.0005	<0.0005	<0.001	0.001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Manganese	mg/L	0.05	0.000	**0.434**	**0.496**	**0.526**	**0.7**	**0.675**	**0.559**	**0.47**	**0.46**	**0.4**	**0.56**	**0.55**
Molybdenum	mg/L			0.003	0.003	0.002	0.002	0.002	0.056	0.002	0.002	0.002	0.002	0.003
Nickel	mg/L			0.006	0.007	0.004	0.002	0.005	0.007	0.005	0.004	0.004	0.005	<0.001
Phosphorus	mg/L			0.05	0.06	0.08	0.072	0.032	0.112				<0.1	<0.1
Selenium	mg/L	0.01	0.0000	<0.002	<0.002	<0.002	<0.002	<0.005	<0.005	<0.002	<0.002	<0.002	<0.002	<0.002
Silicon	mg/L					15	13	11.5	13.8	14	14	15	11	9.9
Silver	mg/L			<0.0001	<0.0001	0.0018	<0.0005	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Strontium	mg/L			0.248	0.431	0.256	0.096	0.347	0.311	0.27	0.27	0.27	0.25	0.15
Tin	mg/L			<0.001	<0.001	<0.001		0.012	<0.001	<0.001	<0.001			
Titanium	mg/L			<0.005	0.008	<0.005	<0.005	<0.0003	0.014	0.007	0.008	<0.005	<0.005	<0.005
Vanadium	mg/L			0.0109	0.0162	0.008	0.006	0.012	0.011	0.012	0.012	0.007	0.008	0.002
Zinc	mg/L	5	0.00	0.006	<0.005	0.012	0.007	<0.003	0.006	0.005	0.006	0.094	0.018	<0.005
Ion Balance														
Total Anions	meq/L			10.2	14.8	11.2	14.4	13.3	12.5	15.3	14.6	10.8	10.3	12.16
Total Cations	meq/L			10.3	16.4	12.0	13.6	13.8	13.3	15.5	15.7	12.2	13.3	8.27
Percent Difference	%			0.2	5.2	3.5	-2.9	1.9	3.2	0.5	3.7	6.2	12.5	-19.02

Notes:
ODWS - Ontario Drinking Water Standards.
RUG - Reasonable Use Guidelines.
RUG exceedances shown highlighted and in bold text.

Summary of Groundwater Results

Parameter	Units	ODWS	RUG Criteria	MW9			MW10		
				9/19/2007	6/5/2008	10/8/2008	9/19/2007	6/5/2008	10/8/2008
Field Testing Results									
pH	units			6.94	7.18	6.72	7.5	7.72	7.66
Temperature	C			9.4	12.3	8.7	7.8	9.4	7.2
Specific Conductance 25°C	mg/L			1925	1517	1713	730	674	466
General Chemistry									
pH		6.5-8.5		7.8	8	7.6	7.9	8.1	8
Specific Conductance 25°C	uS/cm			1860	1510	1760	671	698	490
Total Dissolved Solids	mg/L	500	0.00	**897**	**974**	**1110**	**417**	**466**	282
Total Suspended Solids	mg/L			19000	20000	99000	78000	280000	100000
Colour	TCU	5	0.00	**62**	**45**	**37**	<5	<2	3
Turbidity	NTU	1		1600	988	200	1500	840	220
Dissolved Organic Carbon	mg/L	5	0.00	**63.2**	**34.3**	**37.7**	**4**	**3.5**	2
Hardness (as CaCO3)	mg/L	80-100		940	680	860	340	270	210
Biological Oxygen Demand	mg/L			4	<2	5	<2	<2	<2
Chemical Oxygen Demand	mg/L			180	210	87	33	29	11
Ammonia (as N)	mg/L			0.63	0.63	0.48	<0.05	0.05	<0.05
Tannins and Lignins	mg/L			4.5	2.8	4.1	0.2	<0.2	<0.2
Anions									
Alkalinity (as CaCO3)	mg/L	30-500		976	754	864	304	328	229
Bicarbonate	mg/L			970	747	861	302	324	227
Carbonate	mg/L			6	7	3	2	4	2
Chloride	mg/L	250	0.00	99	59	83	31	23	14
Sulphate	mg/L	500	0.00	5	22	17	15	15	11
Nitrate (as N)	mg/L	10	0.00	<0.1	<0.1	<0.1	0.7	0.8	0.7
Nitrite (as N)	mg/L	1	0.000	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Bromide	mg/L								
Orthophosphate (as P)	mg/L			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cations									
Calcium	mg/L			280	200	250	110	93	69
Magnesium	mg/L			60	42	55	13	10	8.3
Potassium	mg/L			34	15	30	2.5	2	1.6
Sodium	mg/L	200	0.00	**120**	65	95	44	37	30
Dissolved Metals									
Aluminum	mg/L	0.1	0.000	0.024	**0.099**	0.02	0.007	0.016	<0.0005
Antimony	mg/L			<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic	mg/L	0.025	0.000	**0.037**	**0.043**	**0.015**	<0.001	<0.001	<0.001
Barium	mg/L	1	0.000	**0.38**	0.2	**0.33**	0.058	0.048	0.033
Beryllium	mg/L			<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Bismuth	mg/L			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Boron	mg/L	5	0.000	0.11	0.07	0.06	0.02	0.02	<0.01
Cadmium	mg/L	0.005	0.0000	<0.0001	0.012	<0.0001	<0.0001	0.0028	<0.0001
Chromium	mg/L	0.05	0.000	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cobalt	mg/L			0.013	0.0047	0.021	<0.0005	<0.0005	<0.0005
Copper	mg/L	1	0.00	0.002	0.003	0.001	0.004	0.003	<0.001
Iron	mg/L	0.3	0.00	**53**	**31**	**24**	<0.1	<0.1	<0.1
Lead	mg/L	0.01	0.000	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Manganese	mg/L	0.05	0.000	**0.66**	**0.47**	**0.82**	0.007	0.005	<0.002
Molybdenum	mg/L			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nickel	mg/L			0.004	0.002	0.014	<0.001	<0.001	<0.001
Phosphorus	mg/L				0.1	<0.1		<0.1	<0.1
Selenium	mg/L	0.01	0.0000	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Silicon	mg/L			14	13	13	4.1	3.6	3.5
Silver	mg/L			<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Strontium	mg/L			0.56	0.39	0.53	0.11	0.08	0.063
Tin	mg/L								
Titanium	mg/L			0.009	0.015	<0.005	<0.005	<0.005	<0.005
Vanadium	mg/L			0.015	0.017	0.011	<0.001	0.001	<0.001
Zinc	mg/L	5	0.00	0.005	0.01	<0.005	0.019	0.007	<0.005
Ion Balance									
Total Anions	meq/L			22.4	17.2	22.9	7.3	7.57	5.45
Total Cations	meq/L			27.0	18	20	8.5	7.15	5.26
Percent Difference	%			9.3	2.18	6.73	7.7	2.89	1.8

Notes:
ODWS - Ontario Drinking Water Standards.
RUG - Reasonable Use Guidelines.
RUG exceedances shown highlighted and in bold text.

Summary of Groundwater Results

Parameter	Units	PWQO Criteria	MW8 7/9/2004	MW8 10/26/2004	MW8 7/14/2005	MW8 10/25/2005	MW8 6/26/2006	MW8 9/26/2006	MW8 5/29/2007	MW8 5/29/2007	MW8 9/19/2007	MW8 6/5/2008	MW8 10/8/2008	MW9 9/19/2007	MW9 6/5/2008	MW9 10/8/2008
Field Testing Results																
pH	units		7.5	7.5	7.3	7.5		7.4	7.02	7.02	7.18	7.44	7.26	6.94	7.18	6.72
Temperature	C		10.4	8.6	10.3	8.2		9.6	10	10	11.6	13.1	10.4	9.4	12.3	8.7
Specific Conductance 25°C	mg/L		909	1172	891	966		845	1286	1286	1022	797	698	1925	1517	1713
General Chemistry																
pH		6.5-8.5	7.24	7.31	7.96	7.9	7.5	7.5	8	7.9	8	8.1	7.8	7.8	8	7.6
Specific Conductance 25°C	uS/cm		912	1180	997	1140	951	1050	1290	1260	953	906	1070	1860	1510	1760
Total Dissolved Solids	mg/L		533	786	574	700	790	660	770	745	515	704	561	897	974	1110
Total Suspended Solids	mg/L		369	134			58	131	110	120	130	230	94	19000	20000	99000
Colour	TCU		44	42		38	28.3	25.7	70	66	36	17	32	62	45	37
Turbidity	NTU		2.3	1.5		237	290	255	200	282	140	230	200	1600	988	200
Dissolved Organic Carbon	mg/L		24.7	87.1	25.8	22.6	34	42	51.4	53.2	44.6	28.9	42.6	63.2	34.3	37.7
Hardness (as CaCO3)	mg/L		423	692	510	570	578	542	630	640	510	550	360	940	680	860
Biological Oxygen Demand	mg/L		17.7	4.9	11	14	8	7	5	4	<2	3	9	4	<2	5
Chemical Oxygen Demand	mg/L		109	209	75	73	115	122	140	150	120	76	110	180	210	87
Ammonia (as N)	mg/L		0.36	0.88	0.62	0.22	0.48	0.61	0.54	0.57	0.67	0.25	0.64	0.63	0.63	0.48
Tannins and Lignins	mg/L		4.66	4.8	2.7	2.3	4.1	3.6	5.7	5	3.1	2.2	4.4	4.5	2.8	4.1
Anions																
Alkalinity (as CaCO3)	mg/L		467	658	533	676	624	577	707	671	492	475	556	976	754	864
Bicarbonate	mg/L		466	657	528	671	759	701	700	666	488	470	552	970	747	861
Carbonate	mg/L		<1	1	5	5	<5	<5	6	5	4	6	4	6	7	3
Chloride	mg/L		25.6	40.9	19.3	21	18.8	22.7	33	32	25	12	20	99	59	83
Sulphate	mg/L		8.7	21.1	<1	14	13.4	12.9	13	14	12	21	23	5	22	17
Nitrate (as N)	mg/L		<0.2	0.3	<0.2	<0.2	0.18	0.11	<0.1	<0.1	<0.1	0.3	<0.1	<0.1	<0.1	<0.1
Nitrite (as N)	mg/L		<0.2	<0.2	<0.3	<0.3	<0.02	<0.02	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01
Bromide	mg/L				<1		<0.2	<0.2								
Orthophosphate (as P)	mg/L		<0.3	<0.3	<0.3	<1.0	<0.04	<0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cations																
Calcium	mg/L		132	209	155	180	182	167	200	200	150	170	110	280	200	250
Magnesium	mg/L		22.6	41.2	29	32	29.9	30.4	35	37	30	30	19	60	42	55
Potassium	mg/L		7.5	12.6	11.3	10	10.5	12.4	12	12	14	11	9.6	34	15	30
Sodium	mg/L		30.2	33.4	22.4	28	27.3	30.2	32	34	29	32	14	120	65	95
Dissolved Metals																
Aluminum	mg/L	0.075	0.026	0.053	0.039	0.017	0.02	0.03	0.036	0.056	0.021	0.032	0.008	0.024	**0.099**	0.02
Antimony	mg/L	0.02	<0.0005	<0.0005	<0.0005	<0.001	<0.005	<0.005	<0.0005	<0.0005	<0.0005	<0.0005	0.0005	<0.0005	<0.0005	<0.0005
Arsenic	mg/L	0.005	**0.046**	**0.077**	**0.063**	**0.048**	**0.065**	**0.073**	**0.065**	**0.065**	**0.053**	**0.042**	**0.029**	**0.037**	**0.043**	**0.015**
Barium	mg/L		0.122	0.197	0.127	0.15	0.15	0.16	0.15	0.16	0.14	0.16	0.093	0.38	0.2	0.33
Beryllium	mg/L	1.1	<0.001	<0.0005	<0.0005	<0.0005	<0.001	<0.001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Bismuth	mg/L		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Boron	mg/L	0.2	0.072	0.118	0.06	0.049	0.06	0.08	0.1	0.1	0.06	0.08	0.03	0.11	0.07	0.06
Cadmium	mg/L	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	**0.0018**	<0.0001	<0.0001	**0.012**	<0.0001
Chromium	mg/L	0.1	<0.005	0.006	<0.005	<0.005	0.008	0.012	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cobalt	mg/L	0.0009	**0.0065**	**0.012**	**0.0081**	**0.0066**	**0.0108**	**0.0122**	**0.014**	**0.014**	**0.0087**	**0.011**	**0.0051**	**0.013**	**0.0047**	**0.021**
Copper	mg/L	0.005	0.0008	0.0006	**0.021**	0.002	0.001	<0.001	<0.001	<0.001	0.002	0.003	0.002	0.002	0.003	0.001
Iron	mg/L	0.3	**7.94**	**20.1**	**15.5**	**13**	**20.9**	**20.5**	**24**	**24**	**16**	**19**	**8.5**	**53**	**31**	**24**
Lead	mg/L	0.025	<0.0005	<0.0005	<0.0005	<0.0005	<0.001	0.001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Manganese	mg/L		0.434	0.496	0.526	0.7	0.675	0.559	0.47	0.46	0.4	0.56	0.55	0.66	0.47	0.82
Molybdenum	mg/L	0.04	0.003	0.003	0.002	0.002	0.002	**0.056**	0.002	0.002	0.002	0.002	0.003	<0.001	<0.001	<0.001
Nickel	mg/L	0.025	0.006	0.007	0.004	0.002	0.005	0.007	0.005	0.004	0.004	0.005	<0.001	0.004	0.002	0.014
Phosphorus	mg/L	0.03	**0.05**	**0.06**	**0.08**	**0.072**	**0.032**	**0.112**				<0.1	<0.1		**0.1**	<0.1
Selenium	mg/L	0.1	<0.002	<0.002	<0.002	<0.002	<0.005	<0.005	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Silicon	mg/L				15	13	11.5	13.8	14	14	15	11	9.9	14	13	13
Silver	mg/L	0.0001	<0.0001	<0.0001	**0.0018**	<0.0005	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Strontium	mg/L		0.248	0.431	0.256	0.096	0.347	0.311	0.27	0.27	0.27	0.25	0.15	0.56	0.39	0.53
Tin	mg/L		<0.001	<0.001	<0.001		0.012	<0.001	<0.001	<0.001						
Titanium	mg/L		<0.005	0.008	<0.005	<0.005	<0.0003	0.014	0.007	0.008	<0.005	<0.005	<0.005	0.009	0.015	<0.005
Vanadium	mg/L	0.006	**0.0109**	**0.0162**	**0.008**	0.006	**0.012**	**0.011**	**0.012**	**0.012**	**0.007**	**0.008**	0.002	**0.015**	**0.017**	**0.011**
Zinc	mg/L	0.02	0.006	<0.005	0.012	0.007	<0.003	0.006	0.005	0.006	**0.094**	0.018	<0.005	0.005	0.01	<0.005
Ion Balance																
Total Anions	meq/L		10.2	14.8	11.2	14.4	13.3	12.5	15.3	14.6	10.8	10.3	8.34	22.4	17.2	22.9
Total Cations	meq/L		10.3	16.4	12.0	13.6	13.8	13.3	15.5	15.7	12.2	13.3	12.2	27.0	18	20
Percent Difference	%		0.2	5.2	3.5	-2.9	1.9	3.2	0.5	3.7	6.2	12.5	18.6	9.3	2.18	6.73

Notes:
PWQO - Provincial Water Quality Objectives.
PWQO exceedances shown highlighted and in bold text.

Summary of Groundwater Results Compared to PWQO

Parameters	Units	PWQO	SW1 (Upstream)																					
Field Testing Results			5/24/2001	8/28/2001	10/17/2001	6/12/2002	8/22/2002	10/21/2002	5/27/2003	8/1/2003	10/1/2003	5/28/2004	8/1/2004	10/21/2004	5/26/2005	8/29/2005	10/24/2005	5/29/2006	8/22/2006	9/26/2006	5/28/2007	9/19/2007	6/4/2008	10/9/2008
pH	units																				7.9	8.2	8.01	7.97
Temperature	C					5.6	18.1	6.7	11			8.1	18	7.8	9.4	19.4	7.7				12.7	17.2	10.9	12.2
Specific Conductance 25°C	uS/cm			144	151	162	147	119.7	123			125	147	136.3	133	148	93				80	148	130	140
Dissolved Oxygen	mg/L				10.3	0	9.2	11.9	10.3			12.8	7.8	12	9.89	6.80	6.3							
General Chemistry																								
pH	units	6.5-8.5		7.1	7.83	7.42	8.02					**6.42**	6.83	8.1		7		7.9	7.7	7.8	6.9	8.1	8.1	8.3
Specific Conductance 25°C	uS/cm																	135	151	160.6	81	149	129	1530
Colour	TCU		70	50	38	46	49	63	66	51	51	53	34	42	52	23.8	54.4	36.9	25.1	21.3	63	37	39	90
Total Dissolved Solids	mg/L			92	112	120	98	86	86	84	66	100	90	102	95	100	90	130	100	100	47	154	90	
Total Kjeldahl Nitrogen (TKN)	mg/L		0.4	0.43	0.35	0.36	0.31														0.6			
Hardness (as CaCO3)	mg/L			87	81	81.3	78.0														36	71	68	79
Chemical Oxygen Demand	mg/L			757	24	23	22														26			
Dissolved Organic Carbon	mg/L		7.5	58.8	7.9	8.1	8.6	9.0	9.6	7.8	8.5	8.8	7.6	10.2	9.4	6.0	9.0	8	6	6	8.9	8.2		9.5
Biological Oxygen Demand	mg/L			<0.5	0.6	0.8	1.1														<2			
Phenols	mg/L	0.001			<0.001	<0.001	<0.001																	
Tannins and Lignins	mg/L			0.94	0.6	0.85	0.70														1.3			
Ammonia (as N)	mg/L		<0.05	<0.03	<0.03	<0.03	<0.03	<0.03		<0.03	<0.03	<0.03	<0.03	<0.03	0.07	<0.02	0.02	0.04	0.03	<0.02	<0.05	<0.05	<0.05	<0.05
Anions																								
Alkalinity (as CaCO3)	mg/L		57	70	76	76		56	58	7.2	63	64	70	67	61.9	76	41	64	75	78	33	71	62	267
Bicarbonate	mg/L																	77	91		33	70	61	263
Chloride	mg/L				2.2	1.2	1.4	1.0	1.1	1.7	1.9	2.2	1.8	1.8	17.1	2.1	1.5	1.7	2	1.9	<1	3	2	190
Sulphate	mg/L		12.5	2.8	2.4	2.6	2.5								2.8	4.2	4.9	3.7	3.7	3.73	7	5	1	246
Nitrate	mg/L		<0.1	<0.3	0.3	<0.2	<0.2	<0.2	<0.2	<0.2	2	<0.2	<0.2	<0.2	< 0.1	<0.03	0.15	0.14	0.04	0.05	0.3	0.1	<0.1	<0.1
Nitrite	mg/L		<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	< 0.1	<0.02	<0.02	<0.02	<0.02	<0.02	<0.01	<0.01	<0.01	<0.01
Orthophosphate (as P)	mg/L																				<0.01	<0.01	<0.01	<0.05
Cations																								
Calcium	mg/L			27.2	24.5	24.6	26.8	18.4	20.2	24.1	22.2	19.1	26.4	21.5	22	23.2	14.1	23.1	24.6	25.9	13	23	19	25
Magnesium	mg/L			4.58	4.77	5.1	4.67	3.70	3.88	4.71	4.04	3.52	4.79	4.51	4.5	4.83	2.3	4.1	5.2	4.7	2.5	4.8	3.9	5
Potassium	mg/L		2	1.3	<1	1	<1		<1	1.00	1.00	0.60	0.70	0.70	0.60	1.22	11.90	<1	<1	1	0.7	0.56	0.6	0.7
Sodium	mg/L		1.33	1.5	1.3	1.2	1.3	1.1	1.2	1.3	1.1	1.1	1.3	1.3	1.2	1.37	1.07	1.33	1.42	1.4	1	1.4	1.2	1.6
Metals																								
Aluminum	mg/L	0.075		<0.03	0.06	0.03	0.06	0.05	**0.08**	<0.05	<0.05	0.061	0.028	0.038	**0.13**	0.02	**0.08**	**0.09**	0.04	0.01	**0.1**	0.025	0.047	**0.17**
Antimony	mg/L	0.02	<0.001	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.0005	<0.0005	<0.0005	<0.001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic	mg/L	0.1	0.003	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.003	0.003	0.003	0.003	0.003	0.002	0.002	0.004	0.003	<0.001	0.003	0.003	0.003
Barium	mg/L		0.008	0.015	0.01	0.011	0.009	0.009	0.009	0.009	0.009	0.008	0.009	0.009	0.009	<0.01	<0.01	<0.01	0.01	0.01	0.009	0.008	0.008	0.01
Beryllium	mg/L	1.1	<0.0001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.001	<0.001	<0.001	<0.0005	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0005	<0.0005	<0.0005	<0.0005
Bismuth	mg/L			<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001
Boron	mg/L	0.2	<0.005	<0.01	<0.01	<0.01	0.01	<0.01	0.01	<0.01	<0.01	<0.005	<0.005	<0.005	<0.01	<0.05	<0.05	<0.05	<0.05	<0.05	<0.01	<0.01	0.01	<0.01
Cadmium	mg/L	0.0002	**0.0005**	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.0001	<0.0001	<0.0001	<0.0001	<0.00009	<0.00009	**0.00043**	<0.00009	<0.00009	<0.0001	<0.0001	<0.0001	<0.0001
Chromium	mg/L	0.0089	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005
Cobalt	mg/L	0.0009	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.0001	<0.0001	<0.0001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Copper	mg/L	0.005	<0.0002	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.001	0.0011	0.0009	<0.005	0.002	<0.001	0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.001
Iron	mg/L	0.3		0.11	0.06	0.21	0.06	0.1	0.08	0.04	0.07	0.05	0.18	0.04	0.20	0.07	0.20	0.1	0.12	0.09	0.11	0.053	<0.1	0.2
Lead	mg/L	0.005	<0.002	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.0005	<0.0005	<0.0005	<0.0005	<0.001	0.004	0.001	<0.001	<0.001	<0.0005	<0.0005	<0.0005	<0.0005
Lithium	mg/L														< 0.005	<0.1	<0.1	<0.1	<0.1					
Manganese	mg/L			0.114	0.02	0.034	0.012	0.010	0.007	0.011	0.010	<0.005	0.008	0.008	0.010	0.011	0.020	0.006	0.054	0.019	0.01	0.009	0.004	0.014
Molybdenum	mg/L	0.04	<0.006	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.005	<0.001	<0.001	<0.001	<0.001	<0.001
Mercury	mg/L	0.0002	<0.0001													<0.0001	<0.0001	<0.0001	<0.0001	<0.0001			<0.0001	<0.0001
Nickel	mg/L	0.025	<0.1	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.001	<0.001	<0.001	<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001
Phosphorous	mg/L	0.02	**0.04**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	**0.05**	**0.1**	**0.07**								0.008	0.015	0.021
Total Phosphorus	mg/L				0.013	0.013	<1																	
Selenium	mg/L	0.1	<0.002	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.002	<0.002	<0.002	<0.002	<0.0004	0.0006	0.001	<0.0004	<0.0004	<0.002	<0.002	<0.002	<0.002
Silicon	mg/L			2	1.7	2.17									2.1	1.4	2.6		1.7	1.7	2	1.7	1.8	2.1
Silver	mg/L	0.0001	<0.0001	<0.005	<0.005	0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.0001	<0.0001	<0.0001	<0.0005	<0.0001	<0.0001	**0.0004**	<0.0001	<0.0001	**0.0002**	<0.0001	<0.0001	<0.0001
Strontium	mg/L			0.023	0.023	0.023	0.024	0.019	0.02	0.023	0.021	0.02	0.024	0.23	0.022	0.025	0.021	0.023	0.026	0.026	0.017	0.023		0.025
Sulphur	mg/L			0.9	0.9	1	1.0	1.0	0.9	1.0	1.0	0.9												
Thallium	mg/L	0.0003	<0.002	<0.005	<0.005	<0.005									<0.00005	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.00005	<0.00005	<0.00005	<0.00005
Tin	mg/L			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001		<0.001
Titanium	mg/L	0.0003					<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	**0.032**	<0.002	**0.002**	<0.002	<0.002	<0.002	<0.005	<0.005		0.013
Tungsten	mg/L	0.03													<0.001	<0.01	<0.01		<0.01	<0.01			<0.001	<0.001
Uranium	mg/L	0.005													0.0002	<0.005	<0.006	<0.006	<0.005	<0.005	0.0001	0.0001	0.0001	0.0002
Vanadium	mg/L	0.006	<0.003	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.0005	<0.0005	<0.0005	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc	mg/L	0.03	<0.003	**0.093**	<0.005	<0.005	**0.073**	<0.005	0.027	<0.005	**0.039**	<0.005	0.012	<0.005	<0.005	0.004	<0.003	0.006	<0.003	<0.003	0.006	<0.005	<0.005	<0.005
Zirconium	mg/L	0.004														<0.004	<0.004	<0.004	<0.004	<0.004			<0.001	<0.001

Notes:
Table to be read in conjunction with accompanying report.
PWQO - Provincial Water Quality Objectives.
PWQO exceedances shown highlighted in bold text.

Summary of Surface Water Results

Parameters	Units	PWQO	SW2 (Downstream)								
			5/24/2001	8/28/2001	10/17/2001	12/6/2002	8/22/2002	5/28/2007	9/19/2007	6/4/2008	10/9/2008
Field Testing Results											
pH	units							7.9	8.1	8.28	7.97
Temperature	C					11.5	18	12.3	16.6	11.8	12.2
Specific Conductance 25°C	uS/cm			151	162	142	148	121	150	1135	140
Dissolved Oxygen	mg/L						8.63				
General Chemistry											
pH	units	6.5-8.5		7.08	7.69	8	7.98	7.00	8.00	8	7.7
Specific Conductance 25°C	uS/cm							118	150	127	145
Colour	TCU		60	35	40	46	47	47	37	47	36
Total Dissolved Solids	mg/L			124	148	82	90	80		90	
Total Kjeldahl Nitrogen (TKN)	mg/L		0.3	0.35	0.25	0.37	0.33	0.4	0.4		
Hardness (as CaCO3)	mg/L			76.6	80.1	71	73.7	62.0	75.0	67	73
Chemical Oxygen Demand	mg/L			24	24	24	23	27	20		
Dissolved Organic Carbon	mg/L		7.7	8.6	8	8.7	8.3	7.9	8.3		7.7
Biological Oxygen Demand	mg/L			<0.6	<0.5	<0.5	0.7	<2	<2		
Phenols	mg/L	0.001			<0.001	<0.001	<0.001				
Tannins and Lignins	mg/L			0.75	0.6	0.94	0.72	0.90	0.70		
Ammonia (as N)	mg/L		<0.05	<0.03	<0.03	<0.03	<0.03	<0.06	<0.05	<0.05	<0.06
Anions											
Alkalinity (as CaCO3)	mg/L		56	75	72	65		63	72	60	71
Bicarbonate	mg/L							63	71	60	70
Chloride	mg/L			1.6	1.6	1.2	1.3	2	3	2	2
Sulphate	mg/L		13	2.9	2.7	2.4	2.8	3	2	<1	2
Nitrate	mg/L		1	<0.2	0.2	<0.2	<0.2	0.2	<0.1	<0.1	0.4
Nitrite	mg/L		<0.1	<0.2	<0.2	<0.2	<0.2	<0.01	<0.01	<0.01	<0.01
Orthophosphate (as P)	mg/L							<0.01	<0.01	<0.001	
Cations											
Calcium	mg/L			23.2	24.2	21	22.8	18	24	20	23
Magnesium	mg/L			4.46	4.73	4.17	4.64	3.3	5	4	4.7
Potassium	mg/L		<1	<1.0	<1	2	<1	0.7	0.7	0.6	1.6
Sodium	mg/L		1.09	1.4	1.5	1.2	1.3	1.5	1.6	1.3	0.7
Metals											
Aluminum	mg/L	0.075		<0.03	<0.03	0.06	0.04	0.048	0.062	0.046	0.034
Antimony	mg/L	0.02	<0.001	<0.2	<0.2	<0.2	<0.2	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic	mg/L	0.1	0.002	<0.2	<0.2	<0.2	<0.2	0.002	0.003	0.002	0.003
Barium	mg/L		0.008	0.009	0.01	0.008	0.008	0.009	0.008	0.008	0.009
Beryllium	mg/L	1.1	<0.0001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Bismuth	mg/L			<0.2	<0.2	<0.2	<0.2	<0.001	<0.001		
Boron	mg/L	0.2	0.006	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
Cadmium	mg/L	0.0002	**0.0003**	<0.005	<0.005	<0.005	<0.005	<0.0001	<0.0001	<0.0001	<0.0001
Chromium	mg/L	0.0089	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cobalt	mg/L	0.0009	<0.005	<0.005	<0.005	<0.005	<0.005	<0.0005	<0.0005	<0.0005	<0.0005
Copper	mg/L	0.005	<0.0002	<0.005	<0.005	<0.005	<0.005	0.002	0.001	<0.001	<0.001
Iron	mg/L	0.3		0.02	0.09	0.06	0.04	0.08	0.12	<0.1	<0.1
Lead	mg/L	0.005	<0.002	<0.05	<0.05	<0.05	<0.05	<0.0005	<0.0005	<0.0005	<0.0005
Lithium	mg/L										
Manganese	mg/L			0.006	0.049	<0.005	0.008	0.011	0.026	0.004	0.019
Molybdenum	mg/L	0.04	<0.006	<0.02	<0.02	<0.02	<0.02	<0.001	<0.001	<0.001	<0.001
Mercury	mg/L	0.0002	<0.0001							<0.0001	
Nickel	mg/L	0.025	<0.1	<0.02	<0.02	<0.02	<0.02	<0.001	<0.001	<0.001	<0.001
Phosphorous	mg/L	0.02		<0.1	**0.1**	<0.1	<0.1			0.012	0.01
Total Phosphorus	mg/L		0.03	0.015	0.011	0.008	<1				
Selenium	mg/L	0.1	<0.002	<0.2	<0.2	<0.2	<0.2	<0.002	<0.002	<0.002	<0.002
Silicon	mg/L			1.54	1.74	1.7		1.8	1.8	1.8	2
Silver	mg/L	0.0001	<0.0001	<0.005	<0.005	**0.005**	**0.007**	<0.0001	<0.0001	<0.0001	<0.0001
Strontium	mg/L			0.022	0.023	0.019	0.021	0.019	0.023		0.021
Sulphur	mg/L			1	1	1	1.0				
Thallium	mg/L	0.0003	<0.002	<0.005	<0.005	<0.005		<0.00005	<0.00005	<0.00005	<0.00005
Tin	mg/L			<0.05	<0.05	<0.05	<0.05	<0.001	<0.001		<0.001
Titanium	mg/L	0.0003					<0.005	<0.005	<0.005		<0.005
Tungsten	mg/L	0.03									
Uranium	mg/L	0.005						0.0002	0.0001	0.0001	0.0001
Vanadium	mg/L	0.006	<0.003	<0.005	<0.005	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001
Zinc	mg/L	0.03	<0.003	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Zirconium	mg/L	0.004								<0.001	

Notes:
Table to be read in conjunction with accompanying report.
PWQO - Provincial Water Quality Objectives.
PWQO exceedances shown highlighted in bold text.

Summary of Surface Water Results