Quantification of the Long-Term Effects from Nutrient Reductions on Groundwater Nitrate Concentrations in an Agricultural Setting

by

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A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Master of Science
in
Earth Sciences

Waterloo, Ontario, Canada, 2008

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Jason Cole

Abstract

The Ontario Nutrient Management Act (2002) recommends agricultural Beneficial Management Practices (BMPs) that involve reductions in nutrient applications of nitrogen (N) to fields to improve underlying groundwater quality, but little is known regarding how to best evaluate their success, and how quickly and to what extent groundwater quality will be improved. This study focuses on a 54 ha hog farm located on the southern flank of the Oak Ridges Moraine near Port Hope, Ontario, where, beginning in 1997, the farm operator reduced nutrient application of N by 46% (from 286 kg-N/ha to 153 kg-N/ha). This site provided a unique opportunity to study the long-term effects of reducing nutrient loading of N because of the availability of historical groundwater quality data and records of yearly, field-by-field applications of N (as liquid swine manure and commercial fertilizers such as urea and ammonium sulphate), crop types (corn and soybeans), and crop yields. The objective of this study was to determine how the reduction in nutrients has altered the nitrate loading to the subsurface and its effect on groundwater quality. It was hypothesized that analysis of unsaturated zone soil and the shallow groundwater following 10 years of nutrient reductions should provide insight into the long-term effects of BMPs.

A multifaceted characterization of the site was undertaken that included yearly N-budget calculations for four individual fields on the farm to determine the potentially leachable N and the hydrogeological characterization of flow and transport of N through the unsaturated zone and underlying groundwater. Field investigations included: installation of new monitoring wells (9); datalogging of water levels (12 wells); water quality monitoring (32 wells); multiple soil coring events; analysis of nitrate isotopes for characterization of N sources in soil and groundwater using $\delta^{15}N$ and $\delta^{18}O$ isotopic ratios; bromide tracer tests (3 sites); soil moisture profiles measured in 5 neutron access tubes; and installation of a meteorological station. Investigations focused on a surficial aquitard unit, which was a ~10 m thick, stony, sandy, silty, till (Newmarket Till), and an underlying aquifer unit, which was a ~7m thick, semi-confined sand and gravel aquifer. These two units make up the local flow system at the site and are underlain by another aquitard and a deeper aquifer. The study concentrated on Field B where the 1997 change in nutrient application coincided with a change from swine manure to commercial fertilizer, and the area upgradient of it. This change meant that the isotopic signature of the nitrate could be used as an additional "tracer" to distinguish "BMP applied N" from previous or upgradient applications. A comparison between 1997 and present groundwater nitrate concentrations in the shallow aquifer and aquitard show that farm wide concentrations have decreased by an average of 35% from an average of ~32 mg/L to and average of ~21 mg/L. The most significant improvements were observed in wells screened at or near the watertable, where concentrations below 10 mg/L were observed. The recharge rate was estimated from bromide tracer tests and water balance calculations to be 160 mm/yr, which suggests that water infiltrating in 1997 should have reached the watertable (~6 m deep) prior to the start of this study in 2005. Isotopic values $\delta^{15}N$ and $\delta^{18}O$ in NO_3^- further confirm this result. Estimations of the groundwater nitrate concentrations from N-budget calculations provided reasonable estimates of changes in groundwater quality over time, but were very sensitive to site-specific groundwater recharge rates. Nitrate loading beneath the site were estimated to have decreased by 43% since 1997. This decrease in nitrate loading has significantly decreased the concentration of nitrate exiting the farm property. These results suggest that historical applications of N likely exceeded crop nutrient requirements and therefore a reduction in N applications to the land surface have the capacity to reduce nitrate loading to the groundwater. To date, crop yields have not been significantly altered from the changes in land-use practices. If N application rates at the Allin Farm are maintained, it is likely that further improvements will be observed in the groundwater, although the full extent of these improvements may not be observed for many years. The fact that the improvements in groundwater nitrate concentrations can be achieved at a local scale within a larger flow system may provide encouragement for more widespread adoption of agricultural BMPs.

Acknowledgements

I would first like to thank my supervisors Dr. Dave Rudolph and Dr. Brewster Conant Jr. for all of their help, guidance, patience and hard work, in helping me complete my thesis. Without their knowledgeable inputs at all stages of this project, the outcome would not have been so positive. I just wish that I could have seen “Rudy the Rudolph” more than once during my tenure at UW. I am also indebted to Dr. Ramon Aravena for being on my committee and for providing insights on isotopes.

I would also like to thank Loren Bekeris, who generously provided me assistance, and because her thesis and methodologies developed during completion of her thesis, saved me considerable time and effort in completing this study. I am furthermore indebted to her for introducing me to the many valuable field methods she developed at the Woodstock study site that I used to help complete my study.

A very special thanks is given to Sue Fisher, Patty Forester, Lorraine Albrecht, Jane Lang and Chris Hanton-Fong for all of their help. I have no idea how the department would function without these ladies. Thanks are also given to Bob Ingleton and Paul Johnson for their help at my field site and for coming up with creative solutions to problems.

I gratefully acknowledge the generous financial support of Ontario Pork and the Canadian Water Network (CWN). I would like to thank Mr. Keith Allin for his co-operation with this project, allowing us access to his property. I would like to thank Mr. Bill Adams for not getting upset we when destroyed some of his crops during well installations.

I would finally like to thank all the students who helped drag around equipment at my field site in -40°C conditions just to collect a couple of water samples and the students who spend long hours in the lab collecting and analyzing samples on my behalf. The list is almost too long to mention, but here it goes: Colby Steelman, Kate Critchley, Zsolt Molnar, John Priamo, Andrew Wiebe, Marilla Murry, Geoff Moroz, Jacqueline Kreller, Julia Charlton, Xiaotong Chi, Jeff Melchin, Xin Xu, and Cailey McCutcheon. An extra special thanks goes out to Odum Idika for all his help with day-to-day operations of the project and for knowing everything that goes on with the Rudolph Research Group.

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1. Introduction

1.1 Agricultural Nitrate Contamination

In many areas of the world, decades of agricultural activities have led to extensive groundwater contamination. Nitrate nitrogen (NO_3^--N), derived from nutrient applications of commercial fertilizers and animal manures to facilitate crop growth, is the most common pollutant derived from agricultural practices (Spalding and Exner, 1993; Goss et al., 1998; Burkart and Stoner, 2002; Tomer and Burkart, 2003; Almasri and Kaluarachchi, 2004). A study by Hamilton and Helsel (1995) of five regions of the United States found that between 12 and 46 percent of wells sampled in agricultural regions had nitrate concentrations exceeding the maximum contaminant level (MCL) established at 10 mg nitrate as N per L (mgNO_3^--N/L) by the U.S. Environmental Protection Agency (EPA). In Ontario, a study by Goss et al. (1998) found that 14 percent of farm wells exceeded the maximum allowable concentration (MAC) of 10 mgNO_3^--N /L, as established by the Ontario Ministry of the Environment (MOE). Although agricultural nitrate contamination can originate from point sources (e.g., waste lagoons and storage tanks), it is thought that diffuse or non-point sources of nitrogen (N) such as fertilizer and manure spreading have a greater influence on groundwater quality (Rudolph et al., 1998).

1.2 Management Strategies for Reducing Nitrate Contamination from Agricultural Lands

In response to the widespread contamination of aquifers with nitrate, agricultural nutrient management programs have been developed and implemented with the goal of reducing the environmental impact of agricultural activities. Nutrient management regulations in the Province of Ontario are designed to regulate the storage, handling, and land application of nutrients (Nutrient Management Act, 2002). As part of the Nutrient Management Act, farmers are encouraged to implement additional beneficial management practices (BMPs) that include: a protocol for matching fertilizer applications to crop nutrient requirements; crop rotations to minimize leaching of excess N; properly timed fertilizer applications to match crop uptake and to reduce leaching of N; and the use of cover crops during the non-growing season to uptake excess N (OMAF, 1994). The objective of the BMPs is to strike a balance between minimizing land application of nutrients, meeting crop growth requirements, eliminating leachable nitrate, and providing economic benefits for farmers (Turpin et al., 2005; Almasri and Kaluarachchi, 2005). This study is specifically aimed towards determining the long-term effects of reducing land application of nitrogen-based fertilizers as part of an agricultural BMP.

1.3 The Use of BMPs to Reduce Nitrate Impacts to Groundwater

BMPs are often promoted as a method to reduce nitrate contamination primarily through the optimized management of nitrogen inputs of both commercial fertilizers and animal manures (Wassenaar et al., 2006). Although the implementation of BMPs is becoming a widespread practice by producers, there are relatively few studies that demonstrate to demonstrate that reducing the land application of nutrients improves the groundwater quality in an aquifer historically contaminated by nitrate. One fundamental problem with determining the effects of BMPs is that changes to groundwater quality may substantially lag behind changes in management practices (Tomer and Burkart, 2002). Results from Meissner et al. (2002) showed that a 50% reduction in mineral fertilizers on an agricultural field brought about a significant reduction in N-leaching, but only after 13 years. The lag time for groundwater to respond to changes in nutrient applications of N depends on the area being monitored (plot, farm, or regional scale), unsaturated zone thickness, soil hydraulic properties, spatial and temporal variability in N applications, and groundwater monitoring strategy employed. In a study of the large regional Abbotsford-Sumas aquifer in British Columbia (Canada) and Washington State (USA), Wassenaar et al. (2006) presented evidence that nitrate concentrations were unchanged after a decade of voluntary BMP implementation. It was speculated that the lack of observable change was a result of non-compliance with the fertilizer application requirements by farm operators and/or because a change to inorganic chemical fertilizers from manure resulted in increased leaching of N from the soil. Boumans et al. (1999) showed that by minimizing nutrient surpluses at a farm in the Netherlands, groundwater nitrate concentrations decreased in the shallow sandy aquifer, underlying the site. McMahon et al. (2006) suggests that determining a link between changes in nutrient management and improvements to groundwater quality as a result of these changes is complicated by the presence of large subsurface reservoirs of nitrate from historical nutrient applications and long transit times to the watertable. For this reason many studies aimed at quantifying the effects of reducing nutrient applications focus on water quality obtained with lysimeters in the unsaturated zone (Meissner et al, 2002; Burr and Goss, 2003). Other studies have shown rapid decreases in root zone nitrate leaching below the root zone after changes in surface N loading, but suggested that it may take years or decades for these changes to be observed in the groundwater quality due to long transit times to the watertable (Honisch et al., 2002; Tomer and Burkart, 2003).

1.4 Objectives

Long-term studies where management practices changes are documented and detailed groundwater chemistry is known prior to changes in land management are needed better to understand the effects and timing of water quality responses to BMPs. Studies where the objective has been to evaluate the consequences of implementing an agricultural BMP to reduce nitrate concentrations in groundwater have mainly focused on unconfined, sandy aquifers (e.g., Meissner et al., 2002; Wassenaar et al., 2006), as it is reasonable to assume that these geologic conditions will show the effects in a shorter time period. However, many regions and municipalities that are interested in BMPs to help manage their water supply are located in glacial environments, where low permeability sediments are present and it is thought that transit times to the watertable will be long (e.g., southern Ontario). Only a few studies have focused on evaluating the effectiveness of BMPs in these conditions (e.g., Honisch et al., 2002; Haslauer, 2006; Bekeris, 2007). Both farmers and policy makers in Ontario are interested in understanding the long-term effects of implementing BMPs in a local geologic setting and using this information to make critical future decisions. Also of concern is the potentially high cost in terms of agricultural productivity that may be associated with implementation of BMPs.

This study examines the relationship between nutrient management practices and groundwater nitrate concentrations at the farm scale, prior to and following a decade of significant changes in nutrient applications of N fertilizers. It was hypothesized that reducing nutrient applications of N to better match crop requirements as part of a BMP would have the capacity to reduce the nitrate concentrations in shallow groundwater contaminated with nitrate without causing a loss in agricultural productivity. With this goal in mind, the objectives of the study were to:

- To provide a quantitative assessment of the effects of reducing surface applications of N as part of an agricultural BMP in a complex glacial environment in terms of the amount of leachable N, the N loading to the watertable, and the groundwater nitrate concentrations, both before and following nutrient reductions.
- To develop a field scale methodology that can be used to quantitatively assess the effects of applying a BMP to farms and/or watersheds with the intention of improving groundwater quality.
- To determine if a reduction in nutrient applications of N at the Allin Farm resulted in a decrease in grain yield or agricultural productivity from the cropped land over the last decade.
- To evaluate the time period required to observe the effects of reducing nutrient applications of N in an aquifer that has historical nitrate impacts.

2. Background

2.1 The Nitrogen Cycle

This study focuses on the transport of nitrate in the subsurface, so it is useful to understand the nitrogen cycle and the various forms of nitrogen (N) present in the soil and groundwater. Knowledge of the nitrogen cycle can assist in determining and understanding N-balance calculations for the various fields and crops. N is one of the essential nutrients for plant growth and often its availability is the primary limitation to plant development (Donahue, 1983). Although the atmosphere is made up of 79% nitrogen (by volume) as stable N_2 gas, this form is most often not available to plants for growth functions (Foth, 1984). Nitrogen is available to plants in the form of either the ammonium cation (NH_4^+) or nitrate anion (NO_3^-). Specialized bacteria in soils and algae in water are able to convert N_2 gas into usable forms of nitrogen by a process called nitrogen fixation. This study does not focus on nitrogen dynamics in the zone of root growth and biological activity, but is concerned with what leaches from this zone and can impact the water quality of the saturated soils below.

The nitrogen cycle in the zone of root growth is a complex balance between nitrogen inputs and outputs. Nitrogen fixation is a process when bacteria present in the soil convert N_2 gas from the atmosphere into usable forms of nitrogen (Donahue, 1983). Symbiotic nitrogen fixation is the process in which bacteria cause the formation of root nodules in legume plants (soybeans). Symbiotic fixation of N_2 by legume bacteria can add 50 – 280 kg/ha/yr of usable nitrogen for their host plants. Nonsymbiotic nitrogen fixation is carried out by specific groups of bacteria present in soil, but living independently of higher plants, that have the ability to use atmospheric N_2 for metabolic functions (Foth, 1984). This process, on average, adds 5 – 8 kg/ha/yr of nitrogen to the soil.

Mineralization, which is also called ammoniafication, is the process where nitrogen as soil organic matter is converted to the ammonia ion (NH_4^+). Ammonia is oxidized to NO_2^- by *Nitrosomonas,* and then to NO_3^- by *Nitrobacter* by nitrification. It is fortunate that nitrogen in the form of NO_2^- does not accumulate in the soil and is rapidly converted to NO_3^- since NO_2^- is toxic to living organisms, including plants (Donahue, 1983; Addiscott, 2004).

Immobile nitrogen or organic nitrogen is found in plant residue and in animal manure, and can add a significant source of N to the soil, although it is not immediately available for plant use

(Donahue, 1983). Immobilization is the process where microorganisms convert available forms of nitrogen (NH_4^+ and NO_3^-) back to organic nitrogen. Available nitrogen is also lost as the result of denitrification. Denitrification is carried out by anaerobic bacteria, which are able to use nitrate as a substitute for oxygen in respiration, where there are sufficient electron donors such as organic carbon present (Foth, 1984). This chemical reaction produces N_2 gas, which is lost to the atmosphere.

Nitrate is very soluble in water, and exhibits little to no retardation in when transported though soil (Freeze and Cherry, 1979). Excess nitrate that is leached from the root zone to the deeper unsaturated zone below is the focus of this study. Since the movement of nitrate is not retarded, the hydraulic properties of the soil, the soil water content, hydraulic gradients, and groundwater recharge rates control its movement.

2.2 $\delta^{15}N$ and $\delta^{18}O$ in NO_3^- and Tracing Nitrogen Sources

In order to develop a management strategy to preserve water quality or to remediate a site already contaminated with nitrate, an understanding of the sources of nitrate involved and the pattern affecting these sources is useful (Kendall, 1998). To assess the impacts to water supplies, contaminant sources and flowpaths need to be identified, and isotopes can be helpful in providing this information. In this study, isotopic signatures will be used to discriminate between nitrogen sources and to evaluate if denitrification is responsible for reductions in nitrate concentrations. The use of stable isotopic ratios of nitrogen ($\delta^{15}N/\delta^{14}N$) and oxygen ($\delta^{18}O/\delta^{16}O$) have been shown to be an effective tool for identifying different sources of nitrate. Fractionation (i.e., discrimination between light and heavy isotopes of N and O during transformation processes) of nitrogen and oxygen in nitrate is a complex process that involves many physical, geochemical, and biogeochemical processes that alter the isotopic signature of nitrate. Typical $\delta^{15}N$ values for various sources of nitrate N range from -2‰ to 4‰ for commercial fertilizers, +3‰ to +8‰ for soil organic nitrogen nitrate, and +10‰ to +20‰ for human and animal wastes (Gormly and Spalding, 1979; Heaton, 1986; Kendall, 1998). For synthetic nitrate based commercial fertilizers ($NH_4^+ - NO_3^-$) have very enriched $\delta^{18}O$ ranging from +18‰ to +22‰, since the source of the oxygen is atmospheric oxygen. Nitrate derived from soil organic N, ammonium based fertilizers (e.g., urea and ammonium sulphate), and human and animal wastes are much more depleted in $\delta^{18}O$ and range from -0.1‰ to +5‰ (Aravena et al, 1993). For a complete and detailed review of this topic, the reader is referred to Kendall (1998). A large number of studies have shown that the use of nitrogen and oxygen isotopes in nitrate to be effective at distinguishing nitrate sources in groundwater (e.g., Spalding et al., 1982; Aravena et al., 1993; Herbel and Spalding, 1993; Wassenaar, 1995; Aravena and Robertson, 1998; Fogg et al., 1998; Chang et al., 2002). Each of these studies has effectively used the differences in the isotopic ratios of $\delta^{15}N$ and $\delta^{18}O$ in NO_3^- to positively identify the source of nitrate in groundwater, surface water or unsaturated zone soil water.

The process of nitrification of manure N or inorganic chemical N (commercial fertilizer N) involves many steps, each capable of causing fractionations in $\delta^{15}N$ ratios (Kendall, 1998). Generally, it is the "rate-determining" step or the slowest step that causes the greatest fractionation, which at the Allin Farm would be the oxidation of the fertilizer or manure nitrogen to nitrate. Spreading of liquid swine manure by broadcast methods causes large isotopic enrichments of the nitrogen source. In a survey of fertilized soils in Texas, Kreitler (1975) attributed a +2 to +3‰ increase in $\delta^{15}N$ values in underlying groundwater relative to the initially applied fertilizer, although this amount could be much larger under different environmental conditions. In general, the $\delta^{15}N$ found in soil and groundwater nitrate produced from commercial fertilizers averages +4.7‰ ± 5.4‰ and the nitrate produced from animal wastes averages +14.0‰ ± 8.8‰ (Kendall, 1998). This large difference makes the two sources isotopically distinguishable in natural systems.

The process of microbial denitrification causes enrichment of both the $\delta^{15}N$ and $\delta^{18}O$ in NO_3, as bacteria preferentially use the lighter ^{14}N and ^{16}O from NO_3^- for metabolic functions, which causes enrichment in the heavier isotopes in the $\delta^{15}N/\delta^{14}N$ and $\delta^{18}O/\delta^{16}O$ isotopic rations (Aravena and Robertson, 1998; Kendall, 1998). Denitrification can be identified by a linear isotopic enrichment factor of 2.1:1 on a plot of $\delta^{15}N$ and $\delta^{18}O$ in NO_3^- away from the typical fertilizer and manure ranges (Bottcher et al., 1990; Aravena and Robertson, 1998).

2.3 Environmental and Health Risks Associated with Nitrate

The driving force behind the study of nitrate in groundwater is based upon the environmental and human health risks associated with the chemical. Bekeris (2007) previously summarized the health effects associated with nitrate and the following overview is based on that previous work Studies by Addiscott (2004) and Manassaram et al. (2006) outline the two primary human health concerns associated with nitrate, which are methaemoglobinaemia (blue baby syndrome) and cancer. Health Canada has established a Maximum Acceptable Concentration (MAC), which has been adopted by the Ministry of the Environment (MOE), of 10 mgNO_3^--N/L for nitrate in drinking water (Health Canada, 2006). Nitrate is also known to cause eutrophication of surface water bodies (Addiscott, 2004). Environmental risks area not the main concern at the study site, it is the high concentrations of nitrate detected in nearby drinking water wells that first brought attention to this particular site.

2.4 Study Site Selection

The difficulty of assessing the long-term effects of reducing nutrient applications of N as part of a BMP is locating a suitable study site. To meet the study objectives, it was desirable to have a site that was geologically "typical" of southern Ontario, contains an aquifer with historical nitrate contamination, and an implemented BMP aimed at reducing groundwater nitrate concentrations that had been in place for a decade or more. The Allin Farm study site (herein referred to as the Allin Farm or the study site), located east of the City of Toronto, near Port Hope Ontario (Fig. 2.1) met the above criteria. In addition to the above criteria, the Allin Farm was instrumented with numerous multi-level monitoring well nests and groundwater samples had been collected during the year of BMP implementation. This provided baseline groundwater nitrate concentrations for pre-BMP conditions. Following the implementation of the BMP, the farmer kept detailed records outlining all agricultural activities on the farm, including fertilizer and manure application rates and crop yields. Also of scientific interest is the fact the nutrient inputs of N on Field B (Fig. 2.1) were changed from manure to commercial fertilizer at the same time the BMP was implemented. It was thought that the "commercial fertilizer" nitrate would be isotopically distinct from the "manure" nitrate and, therefore could be used as a "tracer" for following the effects of the BMP.

2.5 The Allin Farm

Mr. Allin purchased the farm in 1978 and prior to this the farm was used as a cow-calf operation. From 1978 to 1996 the property was been used as a sow and finishing hog farm with the ~54 hectares (ha) of surrounding farmland being cropped with corn. Liquid swine manure was typically spread on the fields in the late fall as a nutrient source for the spring planted crops. The land-use in the area is predominantly agricultural with small residential areas. There are a number of residences located west of the Allin Farm, in Perrytown, Ontario (Fig. 2.1).

2.5.1 Site History and Previous Studies

In March 1993, the Ministry of the Environment (MOE) was contacted due to an accidental discharge of several thousand gallons of liquid hog manure to the ground surface (Hodgins, 1993). Because the ground was frozen at the time and the Allin farm was located at a higher elevation than the surrounding area, the manure flowed down onto a neighbouring property. The MOE collected samples from a number of private water wells near the Allin farm and found that many of them had nitrate concentrations in excess of 10 mg NO_3^--N/L. In April 1995, Mr. Frank Crossley of the MOE re-sampled the neighbouring wells and found that some of the nitrate concentrations had increased (Crossley, 1995). In that report, it was suggested that the nitrate contamination originated solely from the application of nutrients on the Allin Farm property. In 1995 the Ontario Federation of Agriculture (OFA) and the Ontario Farm Environmental Coalition (OFEC) became involved at the site after a discussion with Mr. Allin. In 1996, after 2 public hearings, Mr. Allin changed his operation from a sow and finishing program to strictly a sow program to reduce the smell and volume of manure produced. Mr. Allin was also ordered to pay for deep replacement wells for the effected neighbours screened in a deeper aquifer that had not been impacted by nitrates.

In 1997, Mr. Allin reduced the amount of N based fertilizers applied to the farm fields under the direction of the MOE. Also at this time, nutrient applications of N on the southwest field of his farm (Field B; Fig. 2.1) from liquid swine manure to commercial fertilizer to reduce the potential for bacteriological contamination in the manure to reach the neighbouring wells. In 2001 Stratford Agri Analysis (Stratford Agri Analysis, 2001) was hired to conduct an Environmental Production Plan (EPP) on his farm, and to specifically determine the relationship between nutrient requirements of his intended crops and the application rate of manure. A nutrient management plan was prepared for the farm to ensure the proper storage, transferring, and spreading of nutrients. Both commercial fertilizer and liquid swine manure were applied at a rate, as deemed appropriate by the EPP, to meet crop nutrient requirements and would theoretically reduce nitrate leaching from the root zone to the watertable.

In 1997, Dr. Dave Rudolph and Mr. Rick Gibson of the University of Waterloo conducted a study to better understand the groundwater flow patterns and the nitrate distribution in the area (Gibson and Rudolph, 1997). Selected data from their study are presented in Appendix A. The site was revisited in 2000 by the MOE (Crossley, 2000) and the nitrate concentrations in the private wells were found to have either increased or remained constant. Since the nitrogen load was decreased on the field adjacent to the private wells, and no observable, beneficial effects were seen, it was hypothesized by Mr. Crossley that the most likely source of the nitrate was point source contamination from the manure tank. A subsequent geophysical survey of the area down gradient of the tank indicated that a large nitrate plume originating from the tank does not exist (Pagulayan and Rudolph, 2001) and that the tank was not the source of the nitrate in the private wells.

The Environmental Consulting Firm, Gibson Associates (Gibson Associates, 2001) was hired in 2001 to continue site monitoring, perform a structural test on the liquid manure storage tanks, and to dig deep test pits to search for evidence of fracture flow. Hydraulic testing of the tank indicates that it was structurally sound and tests pits did not reveal any major fractures in the upper till that would focus vertical flow of surface applied nitrate to the watertable (Gibson Associates, 2001). Although a final report for this work was never produced, the results of the well sampling event are presented in Appendix A.

In 2003, an electrical fire destroyed the primary barn at the Allin Farm. As a result of the fire, the total capacity was lowered from 2000 to 500 hogs, and the pumping rate of the on-site water supply well was reduced from approximately 19,000 L/day (5000 gal/day) to 9,700 L/day (1000 gal/day).

2.6 Physical and Hydrogeological Characteristics of the Allin Farm

2.6.1 Topography

The site is situated on the southern flank of the Oak Ridges Moraine (Fig. 2.1a), which is a large interlobate moraine formed during the Wisconsin glacial period that is a very important source of potable groundwater for many towns and cities stretching from East of Rice Lake to Bolton, Ontario. The topography of the area surrounding the study site can be described as rolling and hummocky (Gorrell and Brennand, 1997). The local topographic high of 262 meters above sea level (masl) is located approximately 400 m east of the Allin farm (Fig. 4.3). The topographic low of 160 masl is the North Ganaraska River, located approximately 2 km west of the study area.

2.6.2 Geology

The bedrock in the area is the Ordovician aged Lindsay Formation, which is light to medium grey and blue-grey, sublithographic to fine grained, nodular, limestone, with shaly partings (Carson, 1980). This unit is found approximately 90 m below ground surface (mbgs). The surficial deposits consist of Newmarket Till, which is described as a sandy silt to sand till, with >3% stones, and stratified interbeds that often forms upland areas (Gorrell and Brennand, 1997). Cores taken at the study site by Gibson and Rudolph (1997) show that the underlying material consists mainly of fine silty, sand interspersed with coarser sand lenses and cobbles (Appendix A; Table A.1) and ranges in thickness from approximately 6 – 14 m. Grain size analysis from grab samples and intact core indicates that the surficial geology is consistent across the site. The top of the topographic high at the southeast side of the farm, is a small drumlin made of Newmarket Till. Local water well records obtained from the MOE show a complex, multi aquifer/aquitard system under the site. The geological descriptions from the well logs are somewhat inconsistent and perhaps not representative of actual site conditions, but do provide an estimate of depths and thicknesses of the main units at the site.

2.6.2.1 Newmarket Till

The Newmarket Till is the primary aquitard of the Oak Ridges Moraine because of its regional extent, thickness and texture and it confines the several underlying overburden aquifers (Gerber and Howard, 1996; Howard et al, 1997; Gerber and Howard, 2000; Gerber et al., 2001). The Newmarket Till is characterized as a consistent stony, sandy, silt lithology that forms drumlinized upland areas (Sharpe et al., 1997). It ranges in thickness from 0 – 50 m thick. Sharpe et al. (1997) provides a complete sedimentological description of the till unit as: a massive, overconsolidated diamict with a sandy, silt matrix lithology with 5 – 15% pebbles and cobbles which are a mixture of granitic, gneissic and carbonate clasts, and a high density (high p-wave velocity).

In areas where the Newmarket Till is greater than 50 m in thickness, groundwater flow through it is attributed mainly to heterogeneities such as sandy interbeds and fractures, which enhance the bulk vertical hydraulic conductivity (K_v) to ~ 10^{-9} m/s (Gerber et al., 2001). Matrix flow is likely minor as K_v measured on cores range from ~10^{-11} to 10^{-10} m/s. Vertical hydraulic gradients are variable and vertical groundwater recharge through the aquitard has been measured at < 35 mm/yr (Gerber and Howard, 2000). However, Gerber et al., 2001 estimated groundwater flow velocities through this till unit to exceed 1m/yr due to the presence of fractures and other heterogeneities. According to these studies, the Newmarket Till acts as a semi-confining unit, vertical flow is dominated by fracture flow, windows or breaches in the till unit, and by preferential flow though sandy interbeds. However, studies by Gibson and Rudolph (1997) and by Gibson Associates (2001) show that significant vertical fractures do not exist within the Newmarket Till at the Allin Farm and therefore, the mechanism responsible for vertical transport of nitrate remained largely unknown in 2001.

2.6.3 Hydrogeology

Gibson and Rudolph (1997) conducted a study titled “groundwater resource evaluation of the property of Mr. Allin, Perrytown, Ontario”. This study was the first to characterize groundwater flow at the farm and to evaluate the distribution of nitrate in shallow groundwater. Six nests of four monitoring wells each where installed at the farm (Fig. 2.1). The wells in each nest where named KA-*-1 for the shallowest well in the nest and KA-*-4 for the deepest. The wells were installed using a CME 150 auger rig operated by All-Terrain Drilling of Waterloo, Ontario. The wells were constructed using two inch ID (5.08 cm) schedule 40 flush joint threaded PVC pipe with a 2 foot (60 cm) long screened interval. The screened interval of the shallowest well was placed at the watertable, and all subsequent wells in a nest were placed one meter below the previous. This provides four sampling points at each nest ranging from the watertable to 3 meters below the watertable. The wells were completed with a sand pack that extended from the base of the screen to 15 cm above the screen. A 40 to 60 cm thick layer of bentonite chips was placed above the sand pack. The remainder of the wells was sealed using a water/bentonite slurry. Wells located near the roadways and near the barn were completed with a protective casing. All wells were developed using a 3.8 cm diameter by 1-meter long bailer. The wells where then further developed using a Grundfos submersible pump.

Shallow groundwater flow was found to follow the topography at the site. Flow was found to be approximately east to west from the topographic high near KA1 to the topographic lows near KA5 and KA6. Slug tests were performed on each well by pumping each well down to the pump intake, then measuring the recovery over time. Analysis of the tests was conducted using Aquifer Test software program (Waterloo Hydrogeologic, 1997). The values for hydraulic conductivity (K) ranged from a high of 1.9 x 10^{-6} m/s for well KA5-4 to a low of 2.9 x 10^{-9} m/s for well KA2-1 (Appendix A; Table A.2). The mean value was 5.0x10^{-7} m/s, which corresponds to a silty sand (Freeze and Cherry, 1979). The estimated average linear groundwater velocity at the site ranged from a high of 1.11 cm/d between the nest at KA3 and KA5 to a low of 0.08 cm/d between the nest at KA2 and KA3. The average linear groundwater velocity was 0.58 cm/d. The porosity (n) was assumed to be 0.30. Groundwater velocities are highest on the west side of the farm owing to steeper vertical gradients between well nest and greater hydraulic conductivities (K). Vertical gradients between wells in a single nest are downward at all well nest except KA6, which has a strong upward gradient. All wells in the KA6 nest are flowing artesian. Appendix A contains results of the slug tests and the velocity calculations.

2.6.4 Groundwater Chemistry

Groundwater samples were first collected from the six monitoring well nests and the on-site pumping well in 1997 as part of the work conducted by Gibson and Rudolph (1997). Wells were sampled for nitrate, chloride, Eh, pH, dissolved oxygen (DO), and conductivity. Samples for nitrate and chloride were collected in 20ml vials and stored on ice, until submitted for laboratory analysis at the Analytical Services Lab at the Department of Land Resources Sciences, University of Guelph, Guelph, ON. Based upon the results for DO, Eh, pH, and nitrate, it appeared that the conditions required for denitrification were not present in the groundwater. In 2001, groundwater samples were collected by Gibson Associates (2001) from a portion of the monitoring wells installed by Gibson and Rudolph (1997), for dissolved metals, anions, and general groundwater parameters. Selected results are included in Appendix A.

2.6.5 Isotopic Source Evaluation of Nitrate

In 2001, Dr. Will Robertson of the University of Waterloo conducted an isotopic study of nitrate sources at the Allin Farm (Robertson, 2001). The results are presented in Appendix A. Wells KA3-3, KA5-4, and four private wells were sampled for nitrate and, $\delta^{15}N$ in NO_3^-. It was concluded that there were several sources of nitrate present in the area. These sources include commercial fertilizers, manure, and septic wastes. This sampling showed that the use of isotope data of $\delta^{15}N$ in NO_3^- could successfully distinguish between nitrate sources in the groundwater at the Allin Farm. KA3-3 and KA5-4 were the only on-site well sampled for isotopes and the $\delta^{15}N$ in NO_3^- for these wells were +10.77‰ and +10.40‰, and both signatures are indicative of a manure and/or sewage source.

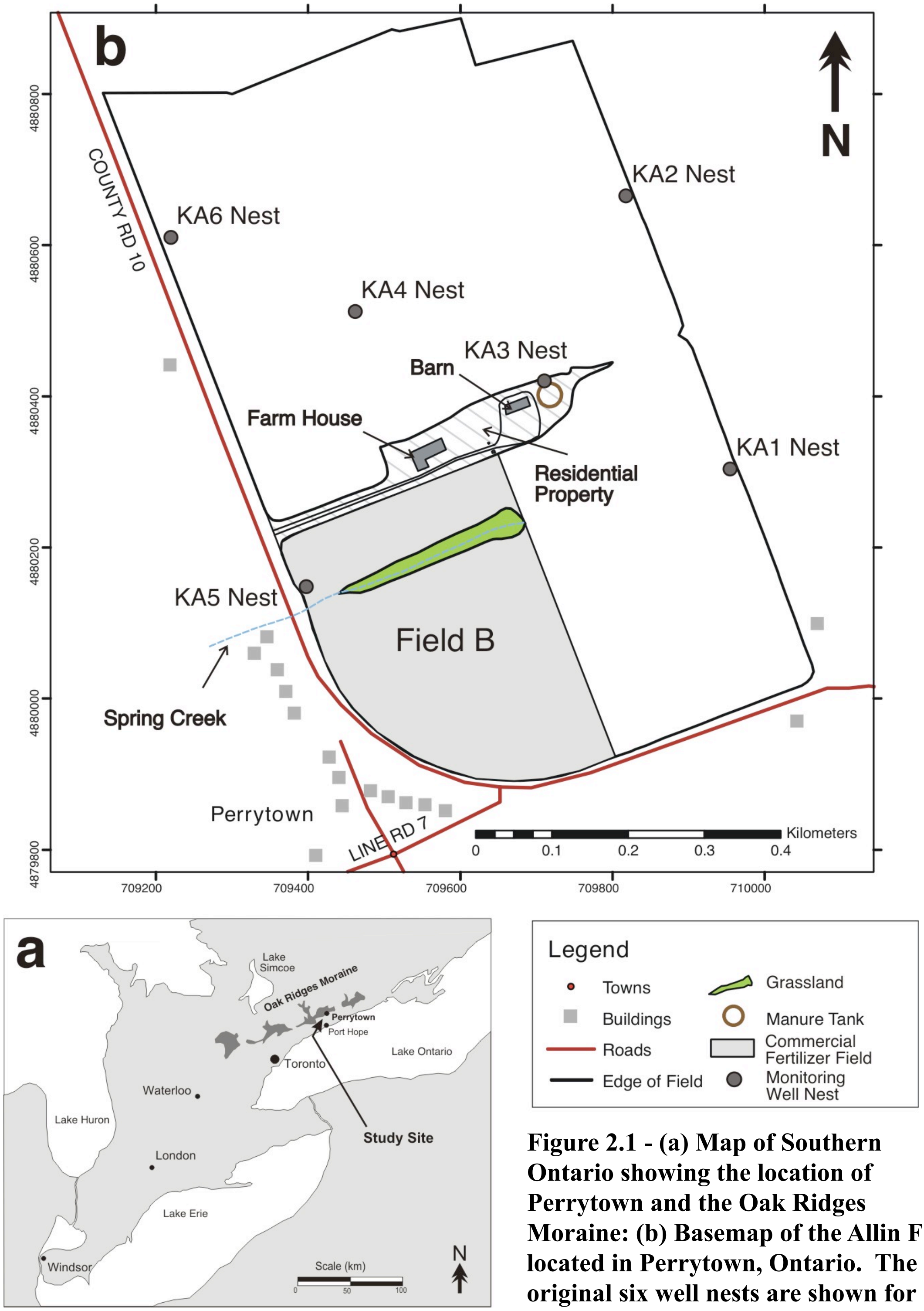

Figure 2.1 - (a) Map of Southern Ontario showing the location of Perrytown and the Oak Ridges Moraine: (b) Basemap of the Allin Farm located in Perrytown, Ontario. The original six well nests are shown for reference.

3. Methods

3.1 Redevelopment of Existing Wells

Twenty-four monitoring wells existed at the study site, which were installed as part of a study by Gibson and Rudolph (1997). Details about the installation and properties of these wells are provided in Section 2.6.3. The ”original” wells had not been purged or sampled since 2001 (Gibson Associates, 2001) and required redevelopment. As part of this study, each well was pumped at a rate of approximately 1L/min using a Geopump peristaltic pump until either 5 casing volumes were extracted or the well became dry. Wells that became dry were allowed to recover and were pumped dry again before any samples were collected.

3.2 Installation of New Monitoring Wells

To meet the objectives of the current study, nine wells were installed in Fields A and B (Fig. 4.4) to obtain data relating to groundwater nitrate distribution, depth to groundwater, stratigraphy, and unsaturated zone nitrate concentrations.

Wells KA7 and KA8 were installed during an investigatory drilling and well installation program in October 2006. These two wells were installed using the University of Waterloo’s track mounted CME 35 auger rig, equipped with 11.4 cm OD (4.5 inch) hollow stem augers to a depth of 8.0 mbgs for KA7 and 12.0 mbgs for KA8. Soil samples were taken every 0.8 m (2.5 ft) using a split spoon sampler. Due to the compact, dry and stony nature of the material, core recoveries were extremely poor and were typically < 5%. Grab samples from auger flights were taken at various depths to determine the geology, but due to the necessary addition of deionized (DI) water to facilitate drilling, natural moisture contents were not preserved. A 3.2 cm ID (1.25 inch) schedule 40 PVC monitoring well was installed in each borehole. KA7 is screened over the bottom 1.5 m (5 ft) and due to the soil formation collapsing around the screen; a proper sand pack could not be installed. Bentonite chips were then added above the collapsed formation to the ground surface. KA8 had a 3 m (10 ft) long screen and the sandpack ended 0.6 m (2 ft) above the screen, and bentonite chips were placed above the sandpack to ground surface.

Seven additional wells KA5-5, 6, KA9-1,2,3, and KA10-1,2 were installed on January 17th to 20th, 2007 by SDS Drilling (Boart Longyear Inc.) using a Mini-Sonic track mounted rig with 4 x 6-inch continuous coring system. For shallow core samples (i.e., 0 to 3.05 m), a split core barrel was used to collect continuous relatively undisturbed core of 10 cm (4 inch) diameter, in 1.5 m (5 ft) long Lexan tubes. When tubes were retrieved, the ends were sealed to preserve soil moisture. Due to the compact, dry and stony nature of the upper geologic strata, the Lexan coring was only successful at shallow depths. For the remaining geological core samples, the core was collected in a 3.05 m (10ft) long, by 10 cm ID (4 inch) core barrel. Water was used to maintain downwards pressure on the intact core and a plastic "core catcher" was used to prevent the loss of core out the end of the barrel during recovery. On surface, the recovered core was vibrated out of the core barrel and into a long plastic sample bag. The top 17 cm (6 inches) of core was not collected because it may have been impacted by drilling water. Drilling water did not appear to have impacted the remaining portion of the sample. This method provided close to complete core recovery and allowed for very detailed core logging. The sample was immediately logged, double bagged, wound tightly with tape, and left outside, under a tarp to freeze. The average outside temperature during the drilling was -8.9^{o}C as measured by a local meteorological station (Blackstock weather station - Environment Canada, 2007) and the temperature never rose above the freezing mark. These conditions meant the samples were well preserved and could be analyzed for nitrate, chloride and moisture content. Cores were collected and bagged along the entire length of each borehole to the bottom of the well screen.

Three monitoring wells were installed at the KA9 well nest. KA9-3 was drilled and continuously cored to a depth of 30.5 mbgs (100 feet). A 5 cm ID (2 inch), schedule 40 PVC monitoring well was installed and screened from 29.7 mbgs (97 ft) to 25.0 mbgs (82 ft). The bottom 0.8m (2.6 ft) of the well was allowed to naturally collapse and then a sandpack was installed around the well screen to 0.6 m (2 ft) above the well screen. The remainder of the hole was filled with bentonite chips or slurry from the top of the sandpack to ground surface. A separate hole was drilled for KA9-2 and KA9-1. This hole was drilled approximately 2 m (6 ft) east of KA9-3, to a depth of 15.3 mbgs (51 ft), and was not continuously sampled, although the drill cuttings from the core tubes were periodically sampled to confirm geology for well installation purposes. Monitoring wells KA9-1 and KA9-2 were completed in a single borehole. KA9-2 consists of a 5 cm ID (2 inch), schedule 40 PVC, and was screened from 15.3 m (51ft) to 12.3 m (41 ft), with a sand pack installed around the well screen and ending 0.6 m (2 ft) above the well screen. From 11.7 mbgs (38.4 ft) to 9.6 mbgs (31.6 ft) Peltinite bentonite pellets were used to seal the borehole between the two monitoring wells. KA9-1 consists of a 3.2 cm ID (1.25 inch), schedule 40 PVC, screened from 9.0 mbgs (29.6 ft) to 6.0 mbgs (19.6 ft), with

0.6 m (2 ft) of sandpack below the well screen and 0.6 m of sandpack above the well screen. A mixture of bentonite chips and slurry was used to seal the well from the top of the upper sandpack to the ground surface.

Monitoring well installations for the KA10-1,2 well pair and KA5-5,6 well pair were very similar to the single borehole installation method for the KA9-1,2 well pair, so the details will not be repeated. Continuous core samples were taken at each of the two locations and samples were preserved using the technique outlined above.

3.3 Bromide Tracer Applications

In order to quantify vertical solute transport rates in the unsaturated zone and directly measure groundwater recharge rates, a potassium bromide (KBr) conservative tracer was applied on the ground surface of Fields A and B, at three locations, BT1, BT2, and BT3 (Fig. 4.4). Each location was selected to represent a different land surface condition. The bromide tracer was applied on December 1, 2005. Although the tracer was applied during the late fall, the ground surface was not frozen and the average temperature for the day was 2.3^{o}C. At each site, five kg of KBr was dissolved in 18L of deionized (DI) water and the solution was applied across the application area of 9 m^2 in 1.5 m^2 increments using a watering can. This application was equivalent to an aqueous concentration of 186.1 g Br/L in the tracer solution, or an applied concentration of 0.41 kg Br/m^2. The tracer solution was spread as evenly as possible on the ground surface and only minimal plant cover was present as residue at the time of application. Cores were later taken at each Br tracer location to track the movement of the surface applied Br pulse.

3.4 EM31 Geophysical Survey of Bromide Tracer Locations

In an attempt to better delineate the possible horizontal movement of the bromide solution applied at the bromide tracer sites, a geophysical survey was conducted in August 2007 using an EM31 Conductivity Meter (EM31-MK2, Geonics Ltd) with a resolution of ±0.1% of full range (range equals 10,100 mS/m) and an accuracy of ±5.0% at 20 mS/m. Measurements were taken with the transmitter and receiver coils in the vertical position to collect data to a maximum depth of 3.5m and have the optimum signal strength at 1.75m. A brief analysis of the results indicated that the bromide pulse was not detected by the EM31, possibly due to low moisture content of the soil or ionic concentration lower than the limits of the tool. Although these results will not be used as part of the present study, it can be concluded that using the EM31 is not a viable method to delineate a high concentration solute plume in soils with low moisture contents (i.e., the unsaturated zone).

3.5 Neutron Access Tube Installations and Moisture Content Measurements

3.5.1 Neutron Access Tube Installations

In order to detect seasonal changes in soil water content and to obtain information on the vertical movement of water in Aquitard 1, five neutron probe access tubes were installed at the site. Neutron probe access tubes NA1, NA2, and NA3 were installed on April 2 and 3, 2006 and access tubes NA4 and NA5 were installed on February 2, 2007. Each access tube was installed by the University of Waterloo using an Enviro-Core® direct push rig, equipped with the Vibra-Push® sampling system. The Vibra-Push® sampling system advanced the core barrel in 0.9 m (3 ft) intervals and collects a 3.8 cm (1.5 inch) core in Lexan tubes, while creating a 5 cm open borehole. The 0.9 m long core tubes were sealed in the field to preserve moisture content and then refrigerated at the University of Waterloo until analyzed. Each access tube consisted of a 5 cm ID (2 inch) schedule 40 PVC threaded riser pipe with a solid threaded coupling on the bottom was installed in the open borehole. The riser pipe fit snugly in each borehole and it was in direct contact with the surrounding undisturbed geologic material. The only exception to this installation method was NA3. In an effort to obtain deeper core samples and to install a deep access tube, a 7.6 cm OD (3 inch) borehole was first drilled to a depth of 3 m (10 ft) to reduce sidewall friction for a deeper 5 cm ID (2 inch) diameter borehole to be drilled. A 5 cm OD (2 inch) borehole was completed within the 7.6 cm diameter borehole to a depth of 4.8 m (15.8 ft). The access tube was completed with a 5 cm ID (2 inch) schedule 40 PVC riser to a depth of 4.8 m. To prevent surface water movement down along the space between the PVC riser and the borehole wall, the upper 3 m was backfilled with bentonite pellets. Because of the bentonite seal, the NA3 access tube was not used for any moisture content calculations.

3.5.2 Neutron Moisture Probe Measurements

Bekeris (2007) describes in detail a method used to collect soil moisture content values using a Neutron Moisture Probe and was used as part of this study. A Model 503 DR Hydroprobe Neutron Moisture Probe (CPN International Inc.) was used inside neutron access tubes to measure the soil water content along the outside of the access tubes. The Probe uses a 50mCi Americium-241/Beryllium as a source of fast neutrons, and measures the ratio of emitted fast neutrons that are expelled from the device, to the number that are reflected back to the probe as slow neutrons after colliding with hydrogen atoms in water molecules in the surrounding soil. Moisture content is determined from the neutron probe count ratio (CR), which is defined as the raw neutron count divided by the neutron count in a standard medium. By using a linear calibration equation developed specifically for the particular soils at the study site (see discussion below), the CR can be converted into moisture contents.

To collect data in the form of CRs, the neutron moisture probe was lowered down the access tubes at a depth interval of 0.15m. At each measurement depth, the CR was determined from an average of neutron reflection and emission over a 16-second time interval. Data was collected 6 times between May 2006 and August 2007 for the neutron probe access tubes that were installed in April 2006. Data was collected 3 times between February 2007 and August 2007 for the access tubes installed in February 2007.

The 503 DR Hydroprobe Neutron Moisture Probe comes with a manufacturer suggested calibration for measurement in 2 inch, PVC wells, but studies have shown accuracy can be improved with site and soil specific calibrations (e.g., Greacen et al., 1981; Yao et al., 2004). Soil cores were collected during the February 2007 installation of the neutron probe access tubes and were immediately sealed to preserve moisture content. Probe measurements were taken within 4 hours after access tube installation. Once back in the laboratory, cores were immediately opened and sub-sampled using a 0.15 m interval for volumetric moisture content and bulk density. The results of the February 2007 neutron probe measurements and the soil moisture measurements were compared to create a site and soil specific calibration (i.e., linear equation) for the neutron probe results using the methodology described by Bekeris (2007). The details of this calibration are provided in Appendix B. The calibration was then used to convert all CR data collected at the site to moisture content data.

3.6 Shallow Soil Cores

To characterize the nitrate concentrations and geological conditions at the site, six boreholes (BH 1 to BH 6) were drilled between April 2 and 3, 2006. Each borehole was installed by the University of Waterloo using an Enviro-Core® direct push rig, equipped with the Vibra-Push® sampling system. The Vibra-Push® sampling system is advanced in 0.9 m (3 ft) intervals and collects a 5 cm ID (2 inch) core in Lexan tubes, while creating a 5 cm open borehole. The 0.9 m long core tubes were sealed in the field to preserve moisture content and then refrigerated at the University of Waterloo until analyzed. The boreholes were not completed with any instrumentation and were backfilled with bentonite pellets to ground surface. Geologic logs are presented in the Results Section of the text.

3.7 Soil Core Analysis

3.7.1 Geologic Logging of soils

Continuous geologic cores were collected during soil coring in April 2006 and during monitoring well installations in January 2007 as described in section 3.2. The purpose of continuous core collection was to determine stratigraphy, soil water content, and soil nitrate and bromide concentrations. Additional cores were collected in February 2007 as part of coring the bromide tracer locations, which would correspond to 416 days since tracer application. Soil from the cores was classified using the ISSS (International Soil Sci. Soc.) classification system.

3.7.2 Physical Properties of Soils *(θ, ρ_b, n)*

Geologic cores collected in April 2006 were analyzed in the laboratory at the University of Waterloo in April and May 2006 for gravimetric moisture content (θ_g), volumetric moisture content (θ_v), dry bulk density (ρ_b), and porosity (n). Cores collected in January and February 2007 were analyzed in February and March 2007 for the same parameters as above.

Each core was stored either refrigerated or frozen until analysis could be performed. Frozen cores were thawed prior to analysis. Each core was opened and immediately sampled at approximately 0.3 m intervals from materials that were collected from the center of the core that was deemed to not be impacted by drilling, storage, or opening. For the cores from April 2006 (3.8 cm core collected with the EnviroCore rig), a 5 cm (2 inch) long segment was extracted from the core, and then split in half along the long axis. Half of the sample was oven-dried at 100^{o}C for 24 hours and reweighed (ASTM, 2006) and the other half was air dried for approximately 24 to 48 hours and put into a glass jar for later analysis. For the cores from January 2007 (10 cm core collected with the RotoSonic rig), the outer 1 to 3 cm of the soil core was removed using a knife, because this material was deemed to possibly be contaminated with drilling water and was disturbed while opening the core, A metal ring with a volume of 60 cm^3 and weighing 168 g was then pushed into the core to collect a sample with a known volume. The top and the bottom of the sampling ring were trimmed to remove any excess soil. Large pieces of gravel caused difficulties in trimming the soil sample to the exact volume of the metal sample ring. Due to the dry, compact, and stony nature of much of the soil at the study site, it was difficult at times to ensure that the sample ring was completely filled with sample and that no voids existed. There is likely a significant amount of subsequent error associated with ρ_b and θ_v in the driest and stoniest stratigraphic layers. The sample was then weighed, removed from the ring and oven-dried at 100^{o}C for

24 hours, then reweighed (ASTM, 2006). Gravimetric water content (θ_g) was calculated using the equation:

$$\theta_g = \frac{W_w}{W_s} \tag{3.1}$$

where W_w is the mass of water in the sample, and W_s is the mass of the solid particles in the soil sample. Volumetric water content (θ_v) was calculated using the equation:

$$\theta_v = \frac{V_w}{V_{sample}} = \frac{\left(\frac{W_w}{\rho_w}\right)}{V_{sample}} \tag{3.2}$$

where, V_{sample} is the volume of the sample (60 cm^3), V_w is the volume of water in the sample, and ρ_w is the density of water (1.0 g/cm^3).

Dry bulk density of the soil (ρ_b) was calculated using the equation:

$$\rho_b = \frac{W_s}{V_{sample}} \tag{3.3}$$

Porosity (n) of the soil was calculated by the following equation:

$$n = 1 - \left(\frac{\rho_b}{\rho_p}\right) \tag{3.4}$$

where ρ_p is particle density, and assumed it to equal 2.65 g/cm^3. Although, both the n and the θ_v of a particular sample are based upon the assumption that sample ring was completely full of sample at the time weighing, a comparison between the two can provide insight into the accuracy of each measurement, because the θ_v should never be greater than the n of the soil sample.

3.7.3 Grain Size Analysis and Hydrometer Testing

Grain size analysis and hydrometer testing was conducted on sample collected from cores obtain during the April 2006 drilling event to determine the particle size distribution of the soil at the study site. Typically, 2 samples per core were collected for grain size analysis. A total of 20 samples were collected for particle size analysis. Samples were selected from each core to be representative of the stratigraphic units encountered. Methods for grain size analysis and hydrometer testing of soil from the study site followed ASTM procedure D 422-63, Standard Test Method of Particle-Size Analysis of Soil (ASTM, 2006). A brief explanation of the ASTM method follows. Approximately 50 g samples of soil were collected from the April 2006 cores. The soil was broken apart using a mortar and pistil, placed into a column of 9 sieves [sieve sizes ranged from 2mm (or # 10) to 0.063 mm (or # 230) and underlain by a pan], and was shaken for 15 minutes. The amount of soil collected in each sieve was weighted, the cumulative weight was calculated, and was plotted on a semi-log plot of percent (%) soil passing though a sieve, against sieve diameter. All of the soil was then combined (excluding particle sizes ≥1.0 mm) and prepared for hydrometer testing. Hydrometer testing involved measuring the rate of gravimetric settling of soil in a column of water mixed with a Dispersing Agent Solution (Calgon®) over a period of 24 h. The results of the hydrometer testing were combined with the results of the grain size analysis to develop a complete particle size distribution for the soil at the study site. The results of the particle size analysis are presented graphically in Appendix F.

3.7.4 Organic Carbon and Nitrogen Content of Solid Samples

Three soil samples from each core collected during the April 2006 drilling event (24 samples in total) were analyzed for % Organic Carbon (TOC), $\delta^{13}C$, % total N, and $\delta^{15}N$. Analysis was conducted at the Environmental Isotope Laboratory at the University of Waterloo on an Isochrom Continuous Flow Stable Isotope Mass Spectrometer (GVInstruments / Micromass-UK) coupled to a Carlo Erba Elemental Analyzer (CHNS-O EA1108-Italy). Samples were selected to determine the organic carbon and nitrogen content of the topsoil and within the upper till unit to help determine if denitrification had occurred in the surficial soils at the study site. To remove carbon derived from carbonate rocks (inorganic carbon) each sample was acidified with a 10% HCl solution and heated at 60°C for 24 hours. The pH was checked after this time and if the acid had been completely neutralized, the procedure was repeated. Acidified samples were dried overnight at 80°C prior to analysis. These data were not used to meet any of the objectives of this study and are therefore not included in the results or discussion sections.

3.7.5 Porewater Nitrate, Chloride, and Bromide Analysis

For each sample collected and analyzed for soil water content, the second half of the sub-sample was analyzed for bulk soil nitrate and chloride (mg/kg soil). Cores collected at the bromide tracer locations, were analyzed for bromide rather than chloride concentrations due to analysis limitations. Bulk soil chemical analysis was performed on samples that had been air dried at room temperature for between 24 and 48 hours, ground using a mortar and pestle, and sieved to remove particles of gravel greater than 1 mm in diameter. The University of Guelph Laboratory Services analyzed the samples collected April 2006 using the colorimetric method as described by Tel and Heseltine (1990). Samples collected February and March 2007 were analyzed for nitrate and Br or Cl, at the University of Waterloo using a Dionex ICS 3000 ion chromatograph equipped with a Dionex Ionpac AS 4 x 250 mm analytical column and a KOH eluent, with a detection limit of 0.1 mg/L for each compound. In this analysis, 5 g of air-dried sample is shaken in 50 ml of DI water for 24 h, after which the soil is either settled or centrifuged out of solution, and the extract solution analyzed. By washing 5 g of soil with 50 ml of DI water, a ten times dilution factor was introduced between the concentration in the recovered supernatant and the bulk soil concentration (C_{soil} mg /kg soil). Assuming no sorption of ions to the soil particles, aqueous nitrate, chloride, and bromide concentrations in the porewater of each sample (C_{aq} mg N/L porewater) are calculated as,

$$C_{aq} = \frac{C_{soil}}{\theta_g} \rho_w \qquad (3.5)$$

assuming again that ρ_w equals 1.0 g/cm^3.

Ten duplicate samples that were originally analyzed using the University of Waterloo Dionex ICS 3000 IC, were submitted to the University of Guelph Laboratory for analytical comparison. The sample results from the University of Guelph varied by an average of approximately 10% from the University of Waterloo results, which was deemed to be a reasonable degree of error (results not presented).

3.7.6 Porewater δ^{15}N in NO_3^- Isotope Analysis

Porewater isotopes of δ^{15}N in NO_3^- were collected to obtain a vertical isotopic profile of the nitrate present in soil at the study site. The method of porewater isotope sampling was based upon a technique outlined in Fogg et al. (1998). The method required a minimum aqueous nitrate (as N) concentration of 2.0 mg/L to obtain a large enough mass of nitrate to run the analyses. The mass of soil and the volume of water used to extract the NO_3^- for δ^{15}N analysis depended upon the moisture content, the unsaturated zone nitrate concentrations and the analysis method used for δ^{15}N. Because of these limitations, approximately 1 kg of soil was required to be processed to obtain the necessary mass of nitrate for the δ^{15}N analysis. One kg samples of soil typically represented approximately 0.5 to 1.5 m of core that was not impacted by drilling water. Approximately 350 g sub-samples of soil were placed in a 1L High Density Polyethylene (HDPE) bottle. The following steps were repeated 3 times per sample. Seven hundred ml of DI water was used as an extractant for nitrate (e.g., Herbel and Spalding, 1993) and was added to the 1L HDPE bottle with the soil. The samples were shaken on a radial shaker for between 20 and 24 hours at a speed sufficient to keep the soil in motion. The samples were placed in a refrigerator overnight and the soil was allowed to settle to the bottom of the HDPE bottles. The clear water on the top of the sample was carefully poured off the top of the sample into a 1.5L Low Density Polyethylene (LDPE) sample bottle. The remaining mixture of soil and water was poured into a 500ml HDPE bottle and spun on a centrifuge for 15 minutes at 2200 rpm to separate any remaining water from the soil. This water was carefully poured off the top of the sample into the 1.5 LDPE sample bottle. After the entire 1 kg of sample had been used and the water collected, samples were then analyzed for nitrate concentration using a HACH (Model # DR/2400 Portable Spectrophotometer and the Cadmium Reduction Method #8039 for nitrate-N analysis that had a measurement range of 0.3 to 30.0 mg/L). For samples where greater than 1.5 L of water was extracted and/or for samples that had low nitrate concentrations (i.e., less than 2 mg/L), the samples were concentrated. Excess water from the samples was evaporated from a 600 ml beaker that was placed in an oven at between 60°C and 80°C. The samples were then stored in a refrigerator until they could be analyzed. Samples were analyzed by the Environmental Isotope Laboratory at the University of Waterloo for $\delta^{15}N$ using a modified version of the Ion Exchange Method by Silva et al. (2000). The accuracy of this method for analysis of $\delta^{15}N$ was ±0.05‰.

3.8 Manure and Commercial Fertilizer Sample Collection and Analysis

Manure and commercial fertilizer samples were collected to obtain a pre-application value of $\delta^{15}N$ of the nitrogen applied to the farm fields. A sample of liquid swine manure was collected on August 9th 2007 from the underground manure storage tank located beneath the primary barn at the study site (Fig. 2.1). The sample was collected using a disposable bailer that was lowered approximately halfway to the bottom of the manure tank. The sample was transferred to a large plastic sample jug and stored on ice until it was placed in the freezer at the University of Waterloo. The commercial fertilizer samples of urea (CH_4N_2O) and ammonium sulphate ($H_8N_2O_4S$) were collected from Northumberland Grain Co., located in Cobourg, ON, where the farmer at the study site had obtained fertilizer from for the last two decades. It is not known if the supplier of the fertilizer to Northumberland Grain Co. remained constant over the same time period.

To prepare the liquid swine manure sample for analysis, a sample was thawed and thoroughly mixed. Two hundred ml was transferred to a 600 ml beaker, which was placed in an oven at 80°C for approximately 24 hours to evaporate all water from the sample leaving only solid materials behind (Drimmie 2007, personal comm.). Three separate analyses were conducted on the commercial fertilizer samples: urea only, ammonium sulphate only, and 50%50% mixture by weight of urea and ammonium sulphate. The latter is considered representative of the commercial fertilizer applied to the study site because the farmer's records show that a 50%50% mixture by weight of urea and ammonium sulphate was used. The commercial fertilizer samples of urea and ammonium sulphate and the solid manure sample were ground to a powder using a mortar and pestle prior to analysis. Both the manure and fertilizers were analyzed at the Environmental Isotope Laboratory at the University of Waterloo using an Isochrom Continuous Flow Stable Isotope Mass Spectrometer (GVInstruments / Micromass-UK) couples to a Carlo Erba Elemental Analyzer (CHNS-O EA1108-Italy) and is considered accurate to within ±0.05‰.

3.9 Groundwater Monitoring

3.9.1 Water level measurements and Levelogger Installations

Watertable elevations were monitored manually and with dataloggers as part of this study to determine local groundwater flow patterns. Manual groundwater level monitoring events typically only occurred during groundwater sampling events. The 24 pre-existing on-site wells were monitored six times during the study period: June 2005, January 2006, May 2006, September 2006, March 2007 and August 2007. Wells KA7 and KA8 were monitored shortly after installation (October 2006) and also in March and August 2007. Wells KA9-1, 2, 3, KA5-5, 6, and KA10-1, 2, were monitored shortly after installation (February 2007) and also in March and August 2007. Well KA10-1 was found to be dry during initial monitoring and no water level data has been able to be collected from it.

In May 2006, a total of 12 model 3001 LT 5m Levelogger Gold pressure transducers and 2 Barologger Gold pressure loggers were installed at the study site to continuously monitor water level elevations and barometric pressure. The loggers were programmed to record water level elevations every 2 hours to provide a continual measurement of water levels to assess seasonal, daily, and precipitation event water level changes. The leveloggers are accurate to ± 1% of full range . Two Solinst model 3001 F5/M1-5 Barometric pressure loggers were installed at the site in wells KA5-3 and KA Well to monitor changes in atmospheric pressure. The barologgers were set to record at the same interval as the leveloggers. The barometric pressure data was used to correct to the levelogger measured water level data since they were non-vented pressure transducers. Manual water level measurements were used to check and validate the results of the leveloggers. Leveloggers were installed at each well nest in the second deepest well (KA*-3) for the older existing wells, and in each newly installed well. The second deepest well in each nest was selected because historical records indicated that this well never became dry in any of the well nests at any time of the year. The exception to this installation was at the KA6 well nest where the logger was installed in KA6-1, because flowing artesian conditions caused the water in the other wells to overflow their stick-up casings and would not have provided accurate readings. Another exception was that a second levelogger was installed at the KA5 well nest in KA5-4 to assist in determining in the vertical hydraulic gradients. The on-site supply well (KA Well) was also instrumented with a levelogger.

3.9.2 Location Survey of Wells and Other Site Features

A site survey was conducted in March 2007 using a Z-Max real time kinetic (RTK) global positioning system (GPS) surveying system (Thales Navigation, Santa Clara California). All wells, neutron access tubes, borehole locations, bromide tracer plots and other field installations, were surveyed for both global position (i.e., latitude and longitude in UTM Zone 17 coordinates) and elevation in meters above sea level (masl). The survey was conducted to obtain accurate water level elevations to calculate vertical and horizontal flow gradients and groundwater flow directions. A temporary benchmark was installed at the site and the GPS used in static mode to collect data and establish a new and accurate benchmark for further surveying. The new GPS survey was conducted to replace an elevation survey conducted as part of the Gibson and Rudolph (1997) study, which required updating. The horizontal and vertical RMS errors for all installed equipment (monitoring wells, etc.) were less than 1 cm and 1.7 cm respectively. The data from this survey is presented in Appendix C. An on-site, temporary benchmark was used as a reference.

3.9.3 Water Quality Sampling and Analysis

Water quality monitoring was performed as part of this study to determine water quality distribution and trends over time. A detailed list of the specific wells and parameters sampled during each sampling event are presented in Table 3.1. The 24 pre-existing wells were sampled six times during the study period: June 2005, January 2006, May 2006, September 2006, March 2007 and August 2007. Well KA3-1 was destroyed sometime between 2001 and 2005 and was not sampled as part of this study. Wells KA7 and KA8 were sampled shortly after installation (October 2006) as well as in March and August 2007. KA7 was not sampled in August 2007 due to concerns that surface water had entered the well. Wells KA9-1,2,3, KA5-5,6, and KA10-1,2, were sampled shortly after installation (February 2007) as well as in March and August 2007. Well KA10-1 was found to be dry during initial monitoring and has never been sampled due to a lack of water. Samples from the May 2005 sampling were submitted to Maxxam Analytics Inc. (Mississauga, ON) for analysis of anions and cations. Samples from the January 2006, May 2006, September 2006, and October 2006 sampling events, were submitted to Environmental Testing Laboratories Inc. (ETL; Waterloo, ON) for analysis of nitrate and chloride. Samples from the February 2007, March 2007 and August 2007 sampling events were analyzed at the University of Waterloo using a Dionex ICS 3000 ion chromatograph equipped with a Dionex Ionpac AS 4 x 250 mm analytical column and using a KOH eluent. The detection limit for nitrate and chloride from each of the three labs is 0.1 mg/L. Field Blanks and equipment blanks were collected at the study site from DI water and submitted for analysis for each sampling event with the exception of October 2006. Chemical analysis of all parameters analyzed for the blanks were non-detectable (nd) by the laboratory analytical methods. Duplicate groundwater samples were collected at each sampling event (except October 2006) and were submitted to the laboratory under a different sample name. Chemical analysis of all duplicate samples collected matched their original samples within 5% for all parameters, indicating that laboratory methods are reproducible.

On-site field analysis of Iron (Fe), and ammonia (NH_4^+) was conducted on the May 2006 samples using the HACH Model # DR/2400 Portable Spectrophotometer and the FerroVer® Method #8008 test for iron, (range of 0.02 – 3.0 mg/L) and the Salicylate Method #8155 test for ammonia (range of 0.01 – 0.5 mg/L). Standard field parameter data was collected at each well during each sampling event for some or all of the following parameters as listed in **Table 3.1**: pH and temperature using a Theremo Electron Corp. Orion 250A+ advanced pH/mV/RnV/ORP digital meter with Thermo-Orion 9107BN pH Triode probe, Eh using a Theremo Electron Corp. Orion 250A+ advanced pH/mV/RnV/ORP digital meter with Thermo-Orion 9180BN ORP Triode probe, Electrical Conductivity using a Oakton Con 10 Series TDS/Cond/^{o}C conductivity probe and meter, and Dissolved Oxygen using a probe and meter made by VWR SympHony SP70D meter with a VWR SympHony DO probe with a range of 0.01 to 10 mg/L and/or a VacuVials kit made by CHEMetrics V-2000 meter with Oxygen 2 VacuVials with a range of 0.1 to 10 mg/L and/or colourmetrics kit made by CHEMets® DO K-7512. When possible, each of these parameters was measured using a Flow-Though Cell designed by the University of Waterloo.

DO measurements can be difficult to conduct accurately in the field, so multiple methods were employed to ensure accuracy and reproducibility. All samples were collected using a Geopump peristaltic pump with the flow rate set to approximately 0.25 L/min and measured using a DO Probe in a flow through cell or using VacuVials. Care was taken to not introduce any atmospheric oxygen into the sample. In cases where both methods were employed, the results were averaged as long as they were reasonably similar. When the depth to water exceeded 9.8 mbgs, the Geopump could not be used for sampling and Waterra tubing (Solinst Inc., Georgetown, ON) or a stainless steel bailer was used. Due to the high potential for the addition of atmospheric oxygen into the samples from these collection methods, DO samples were not preformed when the Geopump could not be used.

Well sampling protocols varied on a well-by-well basis, based upon depth to water, well diameter, and hydraulic conductivity of the material surrounding the well screen. In general, the well sampling protocol was as follows. The static water level and depth of the well were measured prior to purging three well casing volumes of water from the well. Purging and sampling was conducted with a Geopump Series II peristaltic pump (Geotech Environmental Equipment Inc., Denver, Colorado) with 1/4" OD (0.32 cm) HDPE tubing. The pump had a maximum flow rate of approximately 1L/min. A single length of HDPE tubing was used to sample each well. Where there was a large difference in groundwater nitrate concentrations (as known from the results of previous sampling results), wells at each well nest were sampled in order of "lowest" nitrate concentration to "highest" nitrate concentration. Three well casing volumes of water were pumped though the HDPE tubing prior to sample collection and the tubing was rinsed with DI water between well nests. All probes used to measure field parameters were rinsed with DI water between measurements. The results from the equipment blanks showed that these procedures were sufficient to avoid any cross contamination between samples. To purge and sample wells where the watertable was found below the suction limit of the peristaltic pump (~9.8 m), either a 3.8 cm diameter by 1m long bailer or a submersible pump (Grundfos Rediflow 2 submersible pump, Model 1A107603) was used, depending upon flow rate of the well. The bailer was rinsed with DI water between well nests. The sample collected from the on-site supply well was obtained from a tap in the pump house and was located between the pump and the holding tank. The tap was allowed to flow for 2 minutes prior to sample collection. Samples collected for analysis of cations were field filtered through 100μm and 0.45μm filters into 200 ml bottles and acidified to a pH of 2 with 1.0M HCl. All remaining samples were collected unfiltered and were not acidified. Samples were stored in coolers and packed with ice in the field, and then transferred to the refrigerator at the University of Waterloo until samples were submitted for analysis.

3.10 Hydraulic Testing of Monitoring Wells

Hydraulic tests (i.e., slug tests) were performed on all wells on August 8th and 9th, 2007 to determine hydraulic conductivity of the geologic material surrounding the well screen. For most 2-inch ID (5cm) wells that were not flowing artesian, both a rising head and a falling head slug test were performed on the well using a 3.8 cm by 1 m long slug. For the wells KA8, KA9-1 and KA5-5, where the casing ID was 1.25-inches (3.2 cm), two slug tests were performed using a 1.9 cm by 1 m long slug. Hydraulic conductivity values could not be estimated for wells KA8 and KA5-5 because the slug used did not displace enough water to obtain sufficient data to calculate hydraulic parameters before the well fully recovered. For the flowing artesian wells, KA6-1,2,3,4 and KA5-6, a 3.8 cm by 1 m long slug was first lowered into the well casing displacing its volume of water over the top of the casing. The overflow was allowed to stabilize, then the slug was removed and the recovery measured. For the flowing artesian wells, the true static head was determined prior to the test. Watertable recovery for all tests was measured at 0.5-second intervals using a Solinst Levelogger Gold, Model 3001 5M positioned 2 m below the initial watertable depth in each well. The Bower and Rice method for analysis of single well hydraulic tests was used to estimate hydraulic conductivities. Analysis of the data was completed using the AQTESOLV software program (AQTESOLV Pro 4.0, HydroSOLVE Inc., 2005). These results were then compared to literature values by Freeze and Cherry (1979) and found to match the expected ranges based upon the geological nature of the surrounding well material.

3.11 Groundwater Flow Direction and Velocity

The groundwater flow direction was estimated at the site from the water level elevations measured at the May and August 2007 monitoring events, for the watertable elevation and the potentiometric surface for wells screened in Aquifer 1. These two dates were selected to represent the yearly high and low water level elevations at the site. The watertable elevations were determined from the shallowest well at each well nest that was not dry at the time of monitoring. The potentiometric surface elevations of Aquifer 1 were derived from wells KA5-4, KA8, KA9-2, and KA10-2. The water level elevations were contoured using the Surfer 8© version 8.05 contouring program (Golden Software Inc., 2004).

Horizontal average linear groundwater flow velocities (V_{gw}) were calculated between wells within Aquifer 1 that lie on the same groundwater flow path, by the following equation:

$$v_{gw} = \frac{-K\dfrac{dh}{dl}}{n} \tag{3.6}$$

where, K is the average hydraulic conductivity between the two wells, dh is the difference in head between the two wells, dl is the separation distance between the wells and n is the average porosity.

The vertical average linear groundwater flow velocity ($v_{v,gw}$) was also calculated for water movement through Aquitard 1 (through the saturated zone). Saturated vertical flow velocity through Aquitard 1 was calculated using equation 3.6 (above), where dl is the vertical distance between the midpoints of the well screens of two wells at each nest. In this instance dh is replaced by dv, which is the vertical hydraulic difference (*dv*) that was calculated from the average *dv* between each well pair in each individual well nest since monitoring began in 1997.

The average recharge velocity for vertical groundwater flow through the unsaturated zone was calculated from the following equation,

$$v_R = \frac{R}{\theta_{v,avg}} \tag{3.7}$$

where R is the study site recharge rate and θ_v is the average volumetric moisture content in Aquitard 1.

3.12 Groundwater Flux Calculation

Using the results of the groundwater flow direction contours, the groundwater flux was calculated for water entering Aquifer 1 from below the footprint of the Allin Farm Property along Cross Section A-A' in Fields A and B (Fig. 4.4). The groundwater flux leaving the Allin Farm property horizontally through Aquifer 1 along the western site boundary (Cross Section B-B') was also calculated. This was completed to get a sense of what percentage of the water that left the Allin Farm through Aquifer 1 actually originated from the Allin Farm Property. If all of the water that enters Aquifer 1 below Fields A and B can be accounted for in the water that leaves the property, then the influence of upgradient water flow and contaminant transport onto the site from upgradient properties is minimal. The groundwater flux (L/s) vertically into Aquifer 1 ($q_{v,aquifer\ 1}$)was calculated from the following,

$$q_{v.Aquifer1} = A * K * i_v + A_{aqt2} * K_{aqt2} * i_{v,aqt2} \tag{3.8}$$

where, *A* is the plan view area (m^2) of Fields A and B, *K* is the hydraulic conductivity (m/s) of Aquitard 1 obtained from slug testing results, and *i* (m/m) is the average vertical gradient between pairs of wells screened in Aquitard 1 and Aquifer 1 or Aquitard 1 and Aquitard 1, in Fields A and B. Also included in this calculation is the input of water into Aquifer 1 from discharge out of Aquitard 2, where, A_{aqt2} is the plan view area (m^2) of the extent of Aquitard 2 beneath Fields A and B, K_{aqt2} is the hydraulic conductivity (m/s) of Aquitard 2 obtained from slug testing results, and i_{aqt2} (m/m) is the average vertical gradient between pairs of wells screened in Aquitard 2 and Aquifer 1, in Fields A and B

Calculation of the horizontal groundwater flux out of Aquifer 1 along the western site boundary was calculated from the following,

$$q_{h.Aquifer1} = A * K * i_h \tag{3.9}$$

where, A is the cross-sectional area of Aquifer 1 along the B-B' cross section (measured to be 3199 m^2), K is the hydraulic conductivity of Aquifer 1, and i_h is the average horizontal gradient between well pairs KA9-2 and KA5-4, and KA8 and KA10-2 . The groundwater flux will be used to calculate the nitrate loading to Aquifer 1 for both pre- and post-BMP conditions.

3.13 Meteorological Station Installation and Monitoring

For the period of October 16, 2006 to February 2, 2007, a temporary tipping bucket rain gauge with a mini HOBO data logger (Onset Computer Corp., Pacassett, Massachusetts) was installed to collect precipitation data prior to installation of a complete meteorological station. A meteorological station was installed at the study site on February 2, 2007, to provide detailed and accurate climatic data for the site for the purpose of calculating a site water balance. The location of the meteorological station was selected because of its flat topography, the absence of nearby tall trees or buildings, and it was off the producing agricultural fields (Fig. 4.4). The meteorological station was equipped with a Campbell Scientific (CSI) CRX10 data logger set to collect and record information at hourly intervals. The station was also equipped with an array of meteorological sensors for measurement of the following parameters: precipitation (rainfall measurement with a Texas Electronics 525WS tipping bucket rain gauge, equipped with a Campbell Scientific CS 705 snowfall adaptor to measure frozen precipitation), temperature and relative humidity (Vaisala HMP43C temperature and relative humidity sensor), wind speed and wind direction (RM Young wind monitor 05103-10), and solar radiation (SP LITE silicon pynarometer sensor). Three time domain reflectometry (TRD) probes were installed in May 2007 (CS616-L50 water content reflectometer) near the station at depths of 0.10, 0.35, and 0.72 mbgs to measure changes in the soil water content with depth. Probes were installed by manually pushing the probes horizontally into the sidewall of a vertically dug hole. All data recorded at the meteorological station is provided in Appendix D.

3.14 Recharge Estimation Methods

The following section describes the methods used to determine the groundwater recharge at the study site. Recharge (R) was estimated using a variety of methods and can be estimated using site-specific data between December 2005 to December 2007. Outside of this time window, data from off-site meteorological stations needed to be used to estimate groundwater recharge.

3.14.1 Tracer Velocity Calculation Method

A bromide tracer was applied at the ground surface in December 2005 (Section 3.3) to obtain a direct measurement of groundwater recharge through the unsaturated zone at three locations at the study site. The tracer velocity method of estimating the recharge rate is calculated from the product of a conservative tracer's vertical velocity (v_{tr}) and the average volumetric moisture content of the unsaturated zone soil (θ_v) in the area of tracer migration. The tracer recharge rate (R_{Tr}) can be calculated as follows,

$$R_{Tr} = v_{tr}\theta_v = \frac{\Delta z_{tr}}{\Delta t}\theta_v \tag{3.10}$$

where Δz_{tr} represents the distance traveled by the center of the mass or peak concentration of a tracer that was applied at ground surface, and Δt represented the time of travel (Scanlon et al., 2002). The value of θ_v was determined by volumetric moisture content measurements conducted in the laboratory (equation 3.2) and compared to field measurements of moisture content as measured by the neutron probe to ensure accuracy. The center of mass (z_{center}) of a controlled tracer pulse is expressed as;

$$z_{center} = \frac{\sum_{i-1}^{n} C_{soil,i} l_i z_i}{\sum_{i-1}^{n} C_{soil,i} l_i} \tag{3.11}$$

where $C_{soil,\mathrm{i}}$ is the bulk soil bromide concentration (mg Br/kg soil) of a geologic core sample, l_i is the length of the core represented by $C_{soil,i}$, z_i is the depth of a core sample, and n is the number of samples within a profile.

A mass balance of the bromide tracer was calculated by assuming that the bromide concentration profile was consistent beneath the entire tracer plot area. Calculation of the total recovered bromide mass (M_{Br}) provides a quantitative assessment of the heterogeneities associates with vertical transport. The total recovered bromide mass at a tracer location during a coring event was calculated from

$$M_{Br} = \left(\sum_{i-1}^{n} C_{soil,i} l_i\right)\rho_{b,avg} A_{Br} \tag{3.12}$$

where $\rho_{b,avg}$ is the average dry soil bulk density (g/cm^3) of the soil, and A_{Br} is the area of bromide tracer application. All tracer velocity recharge rate estimations assume uniform horizontal distribution of the bromide tracer, conservative transport, and no lateral flow of the tracer outside of the application area.

The downward migration of nitrate concentration peaks in soil profile can also be used to estimate recharge rates assuming that nitrate is conservative. This methods was also used to estimate the recharge rate at core location BT1, which was cored twice during the study period in April 2006 and February 2007. The depth of the peak nitrate concentration measured in the April 2006 core was compared to the peak nitrate concentration in the February 2007 core, and the difference in depth was used in the tracer velocity method to estimate recharge.

3.14.2 Water Balance Method

A basic water balance equates water inputs (precipitation, irrigation, and run-on) on a parcel of land to the water outputs (evaporation, transpiration, infiltration, and run-off) and the change in storage (Scanlon et al., 2002) in the following simplified equation:

$$Inputs = Outputs + \Delta Storage \tag{3.13}$$

Assuming no change in storage of either surface water or groundwater, and that surface run-on equals surface run-off, the equation for the recharge rate (R_{WB}) becomes,

$$R_{WB} = P - ET \tag{3.14}$$

where, R_{WB} is the rate of groundwater recharge (or infiltration) as calculated by subtracting the total annual precipitation (P) by the total annual evapotranspiration (ET). The assumption that surface run-on equals surface run-off is judged to be reasonable, because both surface run-on and surface run-off were observed during major rainfall events and during the spring snow melt at the study site. However, neither of these parameters was directly measured as part of this study.

Groundwater recharge at the study site was estimated for each year between 1996 and 2007 using a combination of on-site meteorological data and data obtained from local Environment Canada Meteorological Stations. The average yearly precipitation rate was calculated for each year between 1996 and 2001using the average of meteorological station records from Cobourg and Peterborough, ON (Environment Canada, 2007). The average between these two stations were used because they are the two closest operational stations to the study site. By spatially averaging the results from these two stations, the conditions representative of the Allin Farm can be estimated. Data recording at these two meteorological stations was stopped in 2002. Between 2002 and 2006, precipitation data was obtained from the Blackstock Meteorological station located approximately 25 km west of the study site in geographic and topographic conditions similar to the Allin Farm (Environment Canada, 2007). On October 17, 2006, a tipping bucket rain gauge was installed at the Allin Farm. This gauge provided precipitation data from the time of installation until January 17, 2007, when the first snowfall of the season fell. Due to warm and rainy conditions between October 2006 and January 2007, the tipping bucket rain gauge provided reliable information. Between Jan 17, 2007 and February 21, 2007,when a complete meteorological station was installed at the study site, precipitation data from the Blackstock meteorological station was used.

3.14.2.1 Evapotranspiration Calculation

Evapotranspiration (ET) was estimated using a method described by the Food and Agriculture Organization of the United Nations Publication 056 (Allin et al., 1998). This method was further refined by Bekeris (2007), for conditions representative of southern Ontario. The method of Bekeris (2007) was further modified and applied to this study, to account for various crop types, the length of the growing season and type of groundcover present during different times of the year (e.g.,, bare soil or snow-covered). A daily reference ET value (ET_o) was calculated using a combination of local and regional measured meteorological data, as well as standard reference values for crops found in Allin et al. (1998). An explanation of ET calculations is presented in Appendix E and for additional insights into the calculation of ET, see Bekeris (2007). The parameters used for calculation of ET included: solar radiation, air temperature, wind speed, relative humidity, barometric pressure, and precipitation. Calculations were performed to estimate the daily ET value across the study site in 2005, 2006, and 2007. Calculations incorporated crop growth data, meteorological parameters, obtained from meteorological data and literature values from Allin et al. (1998), and land-use data obtained from farming records. Between January 1, 2005 and February 21, 2007, meteorological parameters used to calculate ET were obtained from the Blackstock meteorological station. Between Feb 21, 2007 and December 2007, the on-site meteorological station provided the data required to calculate ET.

3.15 Nitrate Mass Loading Calculations from Agricultural Data

3.15.1 Historical Nitrogen Application Rates

In 1997, the operator at the Allin Farm implemented an agricultural BMP aimed at reducing the nitrogen loading to the land-surface and groundwater beneath the farm. Beginning in 1997, the farmer kept detailed records of nutrient applications, application timing, crop yields, and manure analysis on a field-by-field basis. These data are a record of the amount that nitrogen loading to the land-surface changed following implementation of the BMP. Pre-1997 or pre-BMP (i.e., prior to changing nutrient applications and conforming to an EPP) data was obtained through personal communications with the farmer and property owner. The nitrogen application rate or nitrogen loading was calculated on a field-by-field basis by summing the amount of liquid swine manure spread in the fall, and the amount of manure, commercial fertilizer, and starter fertilizer spread in the spring. The nitrogen content of the manure was calculated on a yearly basis by the farmer. The nitrogen content of the manure (lbs/ 1000 gal) was then used to calculate the manure application rate (gal/ac). This nitrogen application rate was then converted to total manure nitrogen loading for each field in kg N/ac. The total nitrogen application rate then equals:

$$\textit{Nutrient Applied N (kg/ha)} = \textit{Manure N (kg/ha)} + \textit{Fertilizer N (kg/ha)} + \textit{Starter N (kg/ha)} \qquad (3.15)$$

Records for the nitrogen content of manure were not available for every year between 1997 and 2007, so for these years, nitrogen content was estimated from the average nitrogen content of the manure from the seven years with manure data (1997, 1998, 1999, 2001, 2002, 2003, 2004), which was 26.09 lbs N/ 1000 gal of manure. Since the range of nitrogen content measured in the manure is small (24.1 – 30 lbs/1000 gal) and no significant changes were made to the management of the hogs such as altering feed type, it is assumed that the average value is reasonable for those years.

3.15.2 Potentially Leachable Nitrogen (N_{pl})

The budget method of Meisinger and Randall (1991) calculates the long-term potentially leachable nitrogen (N_{pl}) over a known time period, based upon the general conservation of mass equation for any soil-crop system. The equation for calculating N_{pl} is:

$$N_{pl} = N_{input} - N_{output} - \Delta N_{st} \qquad (3.16)$$

where N_{input} is the total amount of N added to the fields from either anthropogenic sources (e.g., manure spreading) or from natural deposition (e.g., atmospheric deposition), N_{output} is the total N leaving the field (e.g., crop uptake), and ΔN_{st} is the change in stored N (e.g., remobilization of immobilized N). N_{pl} is used as the budget-derived estimate of total nitrate-N loading to the groundwater for a given crop year. Nitrogen inputs considered as part of this study are: liquid swine manure, commercial fertilizer, crop seed, crop residue, and N_2 fixation (both symbiotic and nonsymbiotic). Nitrogen outputs considered as part of this study are: crop uptake, volatilization losses (during spreading and prior to incorporation into the soil), and denitrification. The amount of N removed each season from crop uptake was estimated from grain yields. Changes in ΔN_{st} have two potential components: soil inorganic N (ΔN_{si}) and soil organic N (ΔN_{so}). ΔN_{si} is dominated by the change in soil nitrate - N because soil ammonia - N levels are typically low and remain constant over the long term (Meisinger and Randall, 1991). Changes in ΔN_{so} can be difficult to quantify and consist of two primary sources: crop residue organic N and manure/fertilizer organic N. Both of these sources can be large and can contribute N by slowly decomposing.

3.15.3 Estimation of Groundwater Nitrate Concentration from N_{pl}

It is assumed that all N present at the study site, when mobile, will be found in the form of nitrate-N, which is nonsorbing and has the potential to leach rapidly to groundwater. The nitrogen budget approach was used successfully by Barry et al. (1993) in a study of N budgets in Southern Ontario to estimate groundwater nitrate concentrations from leachable N, and by Kraft and Stites (2003) to measure and predict N-loading to groundwater. Leaching losses (N_{pl}) are described in units of mass per unit area per unit time ($\mathrm{kgNha^{-1}yr^{-1}}$), where ha refers to hectares. To convert this mass flux of nitrate-N to a groundwater concentration, the flux of water or the recharge rate passing through the root zone must be known. The following equation describes the method used to obtain the average concentration of N in the drainage water leaving the root zone and migrating towards the watertable:

$$NO_{3(potential)}(mgL^{-1}) = \frac{N_{pl}(kgNha^{-1}yr^{-1})}{R(mmyr^{-1})} \times 100 \qquad (3.17)$$

where R is best estimate of the recharge rate for a particular area of the study site based upon the results of all recharge estimation techniques. Units and a conversion factor is included in equation 3.17. $NO_{3(potential)}$ was estimated for each field and/or region of the study site so that a direct comparison could be made between the potential groundwater concentration and the measured groundwater concentration both before and after nutrient reductions. Since no groundwater nitrate concentrations were available in some locations it was necessary to estimate the groundwater concentrations.

3.16 Nitrate Mass Flux Estimations

3.16.1 Mass Flux From Soil Core Nitrate Concentrations

Bekeris (2007) described in detail the methodology behind estimating the nitrate mass flux through the unsaturated zone at a study site where nutrient applications of N had been reduced as part of an agricultural BMP. By determining the maximum depth attained by BMP influenced recharge water, Bekeris (2007) was able to calculate the pre-BMP and post-BMP nitrate concentrations in the porewater of the unsaturated zone soil and hence the pre-BMP and post-BMP unsaturated zone nitrate mass flux. Kraft and Stites (2003) also present a "water-year" method of measuring the nitrate mass loading at and below the watertable. For the present study, the nitrate mass flux was calculated for nitrate moving through the soil profile below Fields A and B within Aquitard 1. The average porewater nitrate concentrations were calculated based upon a distance-weighted average of the concentrations ($C_{aq,avg}$),

$$C_{aq,avg} = \frac{\sum_{i-1}^{n} C_{aq,i} \cdot l_i}{\sum_{i-1}^{n} l_i} \tag{3.18}$$

where $C_{aq,i}$ is the aqueous nitrate concentration of in a geologic core sample, l_i is the vertical core interval length corresponding to $C_{aq,i}$ sample, and n represents the total number of core samples within Aquitard 1. The average porewater nitrate concentration is then multiplied by the recharge rate (R) that is representative of the spatial area of the geologic core, to obtain the nitrate mass flux (ton NO_3/yr) from soil core nitrate concentrations ($N\text{-}Flux_{Soil}$) as follows,

$$N - Flux_{Soil} = C_{aq,avg} \cdot R \tag{3.19}$$

3.16.2 Nitrate Mass Flux From Groundwater Nitrate Concentrations

The mass flux of nitrate was also calculated from groundwater nitrate concentrations. In order to estimate this value, vertical or near vertical solute transport and groundwater flow was assumed for the upper aquitard. Rather than using aqueous porewater nitrate concentrations from soil core samples, groundwater nitrate concentrations were used to calculate the nitrate flux. It was assumed that the average groundwater nitrate concentration measured in wells located in a particular field, represents the average groundwater nitrate concentration over the entire area of the field. To calculate the mass flux ($N\text{-}Flux_{GW}$; t NO_3/yr) at each well nest, the vertical water flux q_v (L/s) is multiplied by the average groundwater nitrate concentration (mg NO_3/L) below the field (C_{avg}) to give the following equation:

$$N - Flux_{GW} = C_{avg} \cdot q_v \tag{3.20}$$

This calculation was performed for pre- and post-BMP groundwater nitrate concentrations as obtained from measured values and from estimates made from N-Budgeting. This will not only give a comparison between the pre- and post-BMP conditions, but it will serve as an independent check on $N\text{-}Flux_{soil}$ and of the estimated groundwater nitrate concentrations.

Table 3.1 - Summary of groundwater sampling events

Date	28-Jun-05												20-Jan-06											
Laboratory	Maxxam						On-Site						ETL						On-Site					
Sample Type	Groundwater Chemistry						Field Parameters						Groundwater Chemistry						Field Parameters					
Parameter	Cations	Anions	Nitrate	Chloride	^{15}N and ^{18}O in NO_3	Dissolved Carbon	HACH Parameters	Eh	pH	Conductivity	Dissolved Oxygen	Temperature	Cations	Anions	Nitrate	Chloride	^{15}N and ^{18}O in NO_3	Dissolved Carbon	HACH Parameters	Eh	pH	Conductivity	Dissolved Oxygen	Temperature
KA1-1	X	X	X	X				X	X	X	X				X'	X'					X	X	X	
KA1-2	X	X	X	X				X	X	X	X				X	X					X	X		
KA1-3	X	X	X	X				X	X	X	X				X	X					X	X		
KA1-4	X	X	X	X				X	X	X	X				X	X					X	X	X	
KA2-1	X	X	X	X				X	X	X	X				X	X					X	X		
KA2-2	X	X	X	X				X	X	X	X				X	X					X	X	X	
KA2-3	X	X	X	X				X	X	X	X				X	X					X	X		
KA2-4	X	X	X	X				X	X	X	X				X	X					X	X		
KA3-2	X	X	X	X				X	X	X	X				X	X					X	X	X	
KA3-3	X	X	X	X				X	X	X	X				X	X					X	X	X	
KA3-4	X'	X'	X'	X'				X	X	X	X				X	X					X	X	X	
KA4-1	X	X	X	X				X	X	X	X				X	X					X	X	X	
KA4-2	X	X	X	X				X	X	X	X				X	X					X	X		
KA4-3	X	X	X	X				X	X	X	X				X	X					X	X		
KA4-4	X	X	X	X				X	X	X	X				X	X					X	X		
KA5-1	X	X	X	X				X	X	X	X													
KA5-2	X	X	X	X				X	X	X	X													
KA5-3	X'	X'	X'	X'				X	X	X	X				X	X					X	X	X	
KA5-4	X	X	X	X				X	X	X	X				X	X					X	X	X	
KA5-5																								
KA5-6																								
KA6-1	X	X	X	X				X	X	X	X				X	X					X	X	X	
KA6-2	X	X	X	X				X	X	X	X				X	X					X	X	X	
KA6-3	X	X	X	X				X	X	X	X				X	X					X	X	X	
KA6-4	X	X	X	X				X	X	X	X				X'	X'					X	X	X	
KA7																								
KA8																								
KA9-1																								
KA9-2																								
KA9-3																								
KA10-2																								
KA Well	X	X	X	X											X	X								
Field Blank			X	X											X	X								
Equipment Blank			X	X											X	X								

Date	24-May-06												12-Sep-06											
Laboratory	ETL						On-Site						ETL						On-Site					
Sample Type	Groundwater Chemistry						Field Parameters						Groundwater Chemistry						Field Parameters					
Parameter	Cations	Anions	Nitrate	Chloride	^{15}N and ^{18}O in NO_3[1]	Dissolved Carbon[1]	HACH Parameters	Eh	pH	Conductivity	Dissolved Oxygen	Temperature	Cations	Anions	Nitrate	Chloride	^{15}N and ^{18}O in NO_3	Dissolved Carbon	HACH Parameters	Eh	pH	Conductivity	Dissolved Oxygen	Temperature
KA1-1			X	X	X	X	X		X	X	X				X	X					X	X		X
KA1-2			X	X		X			X	X	X				X	X					X	X		X
KA1-3			X	X		X	X		X	X	X				X'	X'					X	X		X
KA1-4			X	X	X	X	X		X	X	X				X	X					X	X		X
KA2-1			X	X	X	X	X		X	X	X				X	X					X	X		
KA2-2			X	X		X			X	X	X				X	X					X	X		X
KA2-3			X	X		X	X		X	X	X				X	X					X	X		X
KA2-4			X	X	X	X	X		X	X	X				X	X					X	X		X
KA3-2			X'	X'	X	X	X		X	X	X				X	X					X	X	X	X
KA3-3			X	X		X			X	X	X				X	X					X	X	X	X
KA3-4			X	X	X	X	X		X	X	X				X	X					X	X	X	X
KA4-1			X	X	X	X	X		X	X	X				X	X					X	X	X	X
KA4-2			X	X		X			X	X	X				X	X					X	X	X	X
KA4-3			X	X	X	X			X	X	X				X	X					X	X	X	X
KA4-4			X	X		X	X		X	X	X				X	X					X	X	X	X
KA5-1			X	X	X	X	X		X	X	X													
KA5-2			X'	X'		X			X	X	X													
KA5-3			X	X		X			X	X	X				X	X					X	X	X	X
KA5-4			X	X	X	X	X		X	X	X				X'	X'					X	X	X	X
KA5-5																								
KA5-6																								
KA6-1			X	X	X	X	X		X	X	X				X	X					X	X	X	X
KA6-2			X	X		X			X	X	X				X	X					X	X	X	X
KA6-3			X	X		X			X	X	X				X	X					X	X	X	X
KA6-4			X	X	X	X	X		X	X	X				X	X					X	X	X	X
KA7																								
KA8																								
KA9-1																								
KA9-2																								
KA9-3																								
KA10-2																								
KA Well			X'	X'	X	X	X		X	X	X	X			X	X					X	X	X	X
Field Blank			X	X											X	X								
Equipment Blank			X	X											X	X								

Date	16-Oct-06												20-Feb-07											
Laboratory	ETL						On-Site						University of Waterloo						On-Site					
Sample Type	Groundwater Chemistry						Field Parameters						Groundwater Chemistry						Field Parameters					
Parameter	Cations	Anions	Nitrate	Chloride	^{15}N and ^{18}O in NO_3	Dissolved Carbon	HACH Parameters	Eh	pH	Conductivity	Dissolved Oxygen	Temperature	Cations	Anions	Nitrate	Chloride	^{15}N and ^{18}O in NO_3	Dissolved Carbon	HACH Parameters	Eh	pH	Conductivity	Dissolved Oxygen	Temperature
KA1-1																								
KA1-2																								
KA1-3																								
KA1-4																								
KA2-1																								
KA2-2																								
KA2-3																								
KA2-4																								
KA3-2																								
KA3-3																								
KA3-4																								
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KA4-2																								
KA4-3																								
KA4-4																								
KA5-1																								
KA5-2																								
KA5-3																								
KA5-4																								
KA5-5															X	X	X				X	X	X	
KA5-6															X	X	X				X	X	X	
KA6-1																								
KA6-2																								
KA6-3																								
KA6-4																								
KA7			X	X					X	X														
KA8			X	X					X	X														
KA9-1															X'	X'	X				X	X	X	
KA9-2															X	X	X				X	X	X	
KA9-3															X	X	X				X	X	X	
KA10-2															X	X	X				X	X		
KA Well																								
Field Blank															X	X								
Equipment Blank																								

Date	13-Mar-07												8-Aug-07											
Laboratory	University of Waterloo						On-Site						University of Waterloo						On-Site					
Sample Type	Groundwater Chemistry						Field Parameters						Groundwater Chemistry						Field Parameters					
Parameter	Cations	Anions	Nitrate	Chloride	^{15}N and ^{18}O in NO_3	Dissolved Carbon	HACH Parameters	Eh	pH	Conductivity	Dissolved Oxygen	Temperature	Cations	Anions	Nitrate	Chloride	^{15}N and ^{18}O in NO_3	Dissolved Carbon	HACH Parameters	Eh	pH	Conductivity	Dissolved Oxygen	Temperature
KA1-1			X'	X'					X	X	X	X			X	X	X				X	X		
KA1-2			X	X					X	X					X	X					X	X		
KA1-3			X	X					X	X					X	X					X	X		
KA1-4			X	X					X	X	X	X			X	X	X				X	X		
KA2-1			X	X					X	X					X	X					X	X		
KA2-2			X	X					X	X	X				X	X	X				X	X		
KA2-3			X	X					X	X	X				X	X					X	X		
KA2-4			X	X					X	X					X	X	X				X	X		
KA3-2			X	X					X	X		X			X	X	X				X	X	X	
KA3-3			X	X					X	X	X	X			X	X					X	X	X	
KA3-4			X	X					X	X	X	X			X	X	X				X	X	X	
KA4-1			X	X					X	X	X	X			X	X	X				X	X	X	
KA4-2			X	X					X	X	X	X			X	X					X	X	X	
KA4-3			X	X					X	X	X	X			X	X	X				X	X	X	
KA4-4			X	X					X	X	X	X			X	X					X	X	X	
KA5-1			X'	X'					X	X	X	X											
KA5-2			X	X					X	X	X	X			X	X	X				X	X	X	
KA5-3			X	X					X	X	X	X			X'	X'	X				X	X	X	
KA5-4			X	X					X	X	X	X			X	X	X				X	X	X	
KA5-5			X	X					X	X	X	X			X	X	X				X	X	X	
KA5-6			X	X					X	X	X	X			X	X					X	X	X	
KA6-1			X	X					X	X	X	X			X	X	X				X	X	X	
KA6-2			X	X					X	X	X	X			X	X					X	X	X	
KA6-3			X	X					X	X	X	X			X'	X'					X	X	X	
KA6-4			X	X					X	X	X	X			X	X	X				X	X	X	
KA7			X	X					X	X	X	X			X	X					X	X	X	
KA8			X	X					X	X	X	X			X	X	X				X	X	X	
KA9-1			X	X					X	X	X	X			X	X	X				X	X	X	
KA9-2			X	X					X	X	X	X			X	X	X				X	X	X	
KA9-3			X	X					X	X	X	X			X	X	X				X	X	X	
KA10-2			X	X					X	X		X			X	X					X	X	X	
KA Well			X	X					X	X	X	X			X	X	X				X	X	X	
Field Blank			X	X											X	X								
Equipment Blank			X	X											X	X								

Notes:

1 - Analysis completed at the University of Waterloo

' - Duplicate sample collected and analyzed

4. Results

Much of the new information collected as part of this study focused on the effects of nutrient reductions on the groundwater quality beneath Fields A and B. Previous studies had shown that a small aquifer unit (Aquifer 1) was present beneath Fields A and B, but may not have extended other areas of the farm (Fields C and D). A significant portion of this work is focused on evaluating the changes to groundwater quality within the aquitard and aquifer beneath Fields A and B.

4.1 Land-Use Practices

4.1.1 Nutrient Applications of Nitrogen

This section describes the nitrogen (N) sources that were applied to the farm fields each year over the time period of 1996 – 2007. Detailed records provided information on yearly crop type, yield, nutrient application rate, timing of nutrient applications, and manure N test records. Prior to 1997 no written records are available. However, according to the property owner and operator routine historic practices involved the broadcast application of approximately 200 kg/ha of nitrogen in the form of liquid swine manure on Fields A, B, C, and D (Fig. 4.1) in the late fall (Keith Allin, personal comm., 2007). A further 84 kg/ha of nitrogen was spread on the fields each spring prior to planting in the form of a 50/50% mixture of urea and ammonium sulphate. An additional 3.4 kg/ha of nitrogen was added in the spring with the application of liquid pop-up® starter fertilizer. Based on the values, the estimated average total amount of nitrogen added to the fields in the years prior to the land-use change in 1997 was 286 kg/ha. The pre-1997 land-use activities are assumed to be typical of the agricultural practices since 1971 when Mr. Allin purchased the Farm.

In 1997, Mr. Allin agreed to voluntarily reduce nutrient applications of nitrogen to all farm fields until a study could be conducted to determine the optimal fertilization rate to match crop nutrient requirements (Keith Allin, personal Comm., 2007). In 2001, an Environmental Production Plan (EPP) was completed for the Allin farm property by Stratford Agri Analysis (Stratford Agri Analysis, 2001). Soil samples were collected from each field and were analyzed for nitrogen, phosphorous, potash, pH, organic matter, and potassium (data not presented). This study recommended the application of nitrogen (from all nitrogen sources) be reduced to 129 kg/ha for all fields to meet the nutrient requirements of an expected grain yield for corn of 6.9 t/ha. The EPP accounted for an estimated ammonium loss of 66% of N between the measured N content of the manure prior to application and nutrients available to crops the following growing season after a fall application. No loss was of N was applied to spring applied commercial fertilizers. Operational records show that the application of nitrogen (on average from 1997 to the present) was 153 kg/ha of N and if a 66% loss of manure N is taken into account, 101 kg/ha was considered to be available for crop growth from all N sources. Therefore, N was under applied relative to the recommendations made by the EPP. The value of 153 kg/ha will be used for further calculations and analysis, because volatilization rates of N are variable and we are specifically concerned with the amount that was applied.

By averaging the total N applications between 1997 and present, it was found that nutrient applications of N on Fields A, B, C, and D, received 46%, 64%, 40%, 35% less N, respectively, compared to pre-1997 N applications. During this period, Fields A, C, and D still received a combination of fall-spread manure, and spring-spread starter fertilizer and commercial fertilizer, with the occasional spring manure application. Herein, the above listed type of N application will be referred to as a "manure" application of N. Field B, with the exception of a small spring application of manure in 2004, has only received spring applied commercial fertilizer as a source of N for the crops since 1997. This type of application of N will be referred to as a "commercial fertilizer" N application. Table 4.1 summarizes the crop type, crop yield, applied nitrogen sources, and overall nitrogen application rate for each of the fields for each year from 1996 to 2007.

4.1.2 Isotopic Composition of Nutrients

The isotopic composition of different nutrient sources can be quite distinct and can be used to identify their individual presence in the subsurface (Kendall, 1998). With the conversion of the main nutrient source on Field B to commercial fertilizer from liquid swine manure, the potential to track the movement of the different nutrient sources based on isotopic analysis was of interest in the study. In March 2007, samples were collected to assess the chemical isotopes of $\delta^{15}N$ in the various sources of N (liquid swine manure, urea, and ammonium sulphate) applied at the Allin Farm. Historical manure and commercial fertilizer isotopic samples were not collected as part of any previous study. The $\delta^{15}N$ of the liquid swine manure collected in March 2007, was measured to be 9.42‰ and the $\delta^{15}N$ of the commercial fertilizer was measured to be -0.85‰. Kendall (1998) and Clark and Fritz (1997) reported that animal manure $\delta^{15}N$ values generally range from +10 to +25‰. Samples collected from a liquid swine manure pit by Krapac et al. (2002) were +9.14 and +11.40‰, respectively. Commercial fertilizers typically have $\delta^{15}N$ values that are low reflecting their atmospheric source and are generally in the range of -4 to +4‰ (Kendall, 1998). Mean values for urea are +0.18 ±1.27‰ and ammonium are -0.91 ±1.88‰. The 50/50% by weight mixture of urea and ammonium sulphate fertilizer used by the farmer at the Allin Farm, with a $\delta^{15}N$ measured to be -0.85‰, falls within the range given by Kendall (1998) and would be isotopically distinguishable from swine manure.

4.1.3 Crop Rotation

A typical crop rotation for a field where corn is grown in southern Ontario is a corn-soybean rotation (Goss and Goorahoo, 1995). Often two or three years of corn are followed by one year of soybeans (e.g., corn-corn-soybeans). Other rotations incorporate wheat into the rotation (e.g., corn-soybeans-wheat). No formal crop rotation was implemented at the study site, but soybeans were planted in 1999, 2005, and 2006, because corn prices were low (Table 4.1). During years where soybeans were grown, only starter fertilizer was applied in the spring prior to planting, with the exception of 2004 on Field B, where manure was applied. Planting soybeans helped decrease the amount of N that would need to be applied to the fields both in the year of planting and in the following year due to the large amount of N left behind by the soybean crop residue and symbiotic N fixation.

4.1.4 Tillage Practices

For at least the last two decades, the farmer has employed no-till cultivation practices on all fields for both corn and soybean crops. This method was employed to increase the amount of crop residue left on the fields to improve soil structure by adding organic matter, to reduce water run-off, and to reduce soil erosion. Tillage systems can affect the N mineralization rate and soil organic N level. It was found that the long-term combination of no-till and manure application resulted in significantly more soil N, when compared to other tillage systems and fertilizer types (Mikha et al., 2006). By increasing the organic matter left on the fields, the amount of organic N added to the soil from the plant residue increased and would likely contribute a small but significant source of N to the soil. The Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA) estimates the residue will be equal to adding 14 kg N/ha when sweet corn residue is present and 30 kg N/ha when soybean residue remains (OMAFRA, 2002).

4.1.5 Crop Yields

Crop yields were derived from farm records kept following the land-use change. These records show large variations in crop yields for the study site on a year-by-year basis, but not on a field-by-field basis (**Table 4.1**). This result suggests that the farmer kept a cumulative crop yield record and not a field specific yield record. Harvest yields for a corn crop prior to nutrient reductions typically ranged between 5.0 and 7.8 t/ha and were primarily affected by weather conditions during the growing season (Keith Allin, Personal Comm., 2007). After nutrient reductions of N, the crop yield for corn ranged from 3.6 to 7.8 t/ha and the soybean yield ranged from 4.0 to 4.4 t/ha. The average corn yield between 1997 and 2007 was 6.4 t/ha, which is a decrease of 7% from the expected yield for a corn crop at the study site (6.9 t/ha) projected by the EPP. If the yield of 3.6 t/ha in 2001 is removed from the average, as this was an exceptionally dry year, there is no observable decrease in grain yield. It can therefore be stated that the reduction in nutrient applications of N, did not have a negative effect on the crop yield at the farm as a whole, but lower yields may have been experienced on individual fields over the course of the study. It cannot be stated conclusively that yields on Field B, where only commercial fertilizer was applied as a source of N, were less than or greater than the yields experienced by the other fields. Cumulative grain yields were maintained over the entire study site following nutrient reductions occurred, suggesting that the crops still receive sufficient N fertilizer to facilitate growth and produce the expected yields. However, it is recognized that a large amount of N is stored in the root zone from decades of N fertilization and is being released annually, which may be contributing significantly to the available N for the field crops. This pool of stored N is likely being depleted by the reduced N applications at the Allin Farm and therefore, it is not known at this time whether crop yield will decrease in the future as a result of the land-use changes.

4.2 Nitrogen Budget

In order to assess the impact that reducing nutrient applications of N at the study site has had on the groundwater quality, the amount of N that is potentially available to leach below the root zone (N_{pl}) was estimated (Section 3.15.2). The depth of the zone of root growth varies from one site to another, but for the Allin Farm site it was determined that the root zone typically extends to 0.70 mbgs, based upon soil core descriptions. To get a complete picture of the total inputs and outputs of N, a nitrogen budget for the farm was conducted. Barry et al. (1993) successfully used this method to calculate the total excess N at both a research farm plot and an active farm, in southern Ontario. Their approach was similar to a method by Meisinger and Randall (1991), which is used to calculate the long-term potentially leachable N (N_{pl}). The methods of Meisinger and Randall (1991) and by Barry et al. (1993) have been tested by Kraft and Stites (2003), Watson and Atkinson (1999) and by Goss and Goorahoo (1995). Watson and Atkinson (1999) determined that the more complex the estimation method is (i.e.,, the more sources and sinks of N that are taken into account), the more accurate the estimation of the total nitrogen budget is and that it will provide the most accurate estimation of leachable N. Several of the values used in calculating the N-budget as part of this study where not measured at the study site and were obtained as best estimates from literature values. This adds a degree of uncertainty in the calculations as will be discussed further below.

Yearly nitrogen inputs (N_{input}) considered as part of this study are: liquid swine manure, commercial fertilizer, crop residue, N_2 fixation (both symbiotic and nonsymbiotic), and crop seed (Table 4.2). The farmer at the study site supplied data on manure and commercial fertilizer inputs (Table 4.1). Sweet corn seed supplied 0.3 kg N/ha (Meisinger and Randall, 1991; Barry et al., 1993) and soybean seed supplied 5 kg N/ha (Barry et al., 1993). N derived from crop residue is considered to add 14 kg N/ha when sweet corn reside is present and 30 kg N/ha when soybean residue remains (OMAFRA, 2002). Atmospheric nitrogen inputs were estimated to be 18.4 kg N/ha, and nonsymbiotic N_2 fixation inputs were estimated to equal 5.0 kg N/ha, based upon estimates provided by Barry et al., (1993). Symbiotic N_2 fixation inputs for soybeans were calculated from a linear regression ($P < 0.001$) of symbiotically fixed N plotted against grain yield derived by Barry et al. (1993) from soybean grown on plots between 1987 and 1989 in southern Ontario. The amount of N fixed by soybeans at the study site varied seasonally, but for yields between 4.0 and 4.4 t/ha, the N fixed ranged from 225 to 260 kg-N/ha.

Nitrogen outputs (N_{output}) considered as part of this study are: crop uptake, volatilization losses (during spreading and prior to incorporation into the soil), N run-off, and denitrification (Table 4.2). The amount of N removed by a cash crop for a given year was based upon the crop yield. OMAFRA (2002) determined that the average nutrient removal of N for corn is 14.9 kg/ha per 1 t/ha yield and for soybeans; the average N removal is 72.3 kg/ha per 1 t/ha yield. OMAFRA (2002) provides estimates of total N available to crops for the upcoming growing season based upon volatilization losses and the percentage of organic N that is unavailable to the subsequent crops. For fall applied, liquid manure, 52% is lost or unavailable. For spring applied liquid manure, 48% is lost or unavailable. For urea based fertilizer, it is estimated that 5% is lost or unavailable. The annual loss of nitrate by denitrification in the root zone for Ontario soils planted with continuous silage corn was estimated to range from 15 – 53 kg NO3/ ha (Cully et al., 1981; Phillips et al., 1981; Patni and Cully, 1989). Goss and Goorahoo (1995) estimated the potential denitrification from within the root zone on fields from a hog farm averaged 14.5 kg/ha. This value was applied to the N-budget at the Allin Farm.

Changes in stored N (ΔN_{st}) have two potential components: soil inorganic N (ΔN_{si}) and soil organic N (ΔN_{so}). ΔN_{si} is dominated by the change in soil nitrate, and because soil ammonia (N) levels are typically low and remain constant over the long term (Meisinger and Randall, 1991) they are therefore assumed to be zero. The source of ΔN_{so} is primarily immobilized organic N derived from crop residue and/or the organic N component of manure. Prior to changes in nutrient applications in 1997, it is assumed that ΔN_{st} was approximately at steady state, as decades of continuous corn cropping and similar applications of N would balance the additions and losses of soil inorganic N and organic N for a net change of 0%. Following reductions in nutrient applications, it is likely that the ΔN_{st} will no longer be at steady state because N inputs have been reduced, while N outputs have been maintained. It was beyond the scope of this study to determine the changes in N mineralization following a reduction in applied N at the Allin Farm. It was conservatively assumed that the net change in ΔN_{st} was 0%, although it is likely that since 1997, the pool of stored N has decreased and therefore caused ΔN_{st} to decrease on all fields at the Allin Farm, with the largest decrease observed on Field B, where manure spreading stopped.

The results of the nitrogen budget indicate that prior to nutrient reductions in 1997, the total potentially leachable N (N_{pl}) for each field was 88 ha/ha (Table 4.2). Following a reduction in nutrient applications, the average N_{pl} for Fields A, B, C, and D are 45, 39, 52, and 57 ha/ha respectively. This represents a 50%, 56%, 41%, and 35% reduction in leachable N on the four fields. On the same fields, the total average application of N decreased by 46%, 64%, 40%, and 35%, which suggests that the amount of leachable N will be reduced by approximately the same amount that the overall nutrient applications of N are reduced. Prior to 1997, the percentage of N estimated to be lost to leaching was 31% of the total applied N. It is interesting to note that even after significant reductions in N applications, the percentage of N estimated to be lost to leaching for the years between 1997 and 2007 was 32%. This suggests that the percentage of N lost to leaching is not related to the amount of N applied, but rather to N use efficiency by the field crops and possibly to the timing of nutrient applications.

4.3 Soil Analytical Results

4.3.1 Physical and Chemical Properties

Soil cores were collected in the field and preserved using the methods outlined in Section 3.1.2 prior to being sampled in the laboratory. Bulk soil nitrate, porewater nitrate, porewater chloride, volumetric moisture content (θ_v), porosity (n), and porewater δ^{15}N isotopes are presented graphically for KA5-5, KA9, KA10, BT1 (no porewater chloride), and BH1 (no porewater chloride) in Figs. 4.12 to 4.16. Also included on these figures is the core log associated with the borehole. The location of each borehole is presented in Fig. 4.4. Graphical representations of the soil core profiles for the remaining boreholes are presented in Appendix G, Figs. G.1 to G.8. All additional laboratory measured and/or calculated results including dry bulk density and chloride concentrations, from the soil core analysis are included in Appendix G, Tables G.1 and G.2. Trends observed for each hydrostratigraphic unit (root zone, Aquitard 1, Aquifer 1, Aquitard 2, and Aquifer 2), are discussed below with specific details stated on a core-by-core basis.

4.3.1.1 Bulk Density, Porosity, and Moisture Content

The each of the five stratigraphic units at the Allin Farm has significantly different physical properties. Aquitard 1 is an over-consolidated, stony, sandy, silty, till, which makes subsurface investigations and the measurement of physical properties difficult. Every effort was made to accurately measure the physical characteristics of gravimetric moisture content (θ_g), volumetric moisture content (θ_v), dry bulk density (ρ_b), and porosity (n) of the Aquitard 1 soil, but there is likely a degree of uncertainty associated with these measurements. Analysis of samples from the other four stratigraphic units was less problematic. The source of these sampling errors is discussed in detail in Appendix G. Any sample where the θ_v exceeded n by a factor that is greater than reasonable by typical sample variability, it was assumed that the n value was correct and that the θ_v is erroneous. These values were excluded from later calculations of porewater nitrate concentrations. Table 4.4 summarizes the minimum, maximum and average values for θ_g, θ_v, ρ_b and n as obtained from the average values measured in each core from each of the five stratigraphic units. All raw data related to the measurement of the physical properties of the geological units are presented in Appendix G, Tables G.1 and G.2.

The upper 0.7 m is considered part of the root zone. The ρ_b ranged from 1.8 g/cm^3 to 2.1 g/cm^3, and averaged 2.0 g/cm^3. This ρ_b reflects the silty loamy nature of the topsoil and the high organics content. The θ_v ranged from 17.6 to 56.6, and averaged 34.6. The n ranged from 20.8 to 44.9, and averaged 28.2. It is not physically possible for θ_v to exceed n, unless the soil is oversaturated. The ground was wet during the April 2006 drilling event and there was snow on the ground during the January 2007 drilling event, which may caused the soil samples to be mixed with excess water and snow. It is likely that the upper topsoil was disturbed and altered during the two drilling events in April 2006 and January 2007 causing θ_v to exceed n for samples in the root zone.

Generally, the physical properties of Aquitard 1 were observed to be similar between cores taken in Field A and cores taken in Field B. Samples obtained from sandy interbeds from within the till of Aquitard 1, generally had higher moisture contents and porosities than the surrounding till. For Field A, the ρ_b ranged from 2.2 g/cm^3 to 2.3 g/cm^3 and averaged 2.3 g/cm^3. The value obtained for ρ_b is reflective of the compact nature of the till that makes up Aquitard 1. The θ_v ranged from 10.9 to 19.2 and averaged 16.0. The n values ranged from 13.8 to 17.3 and averaged 15.2. The average n value of 15.2 corresponds to the value suggested by Gerber et al. (2001) for Newmarket Till on the Oak Ridges Moraine. Although the θ_v is low throughout Field A, the similarity between θ_v and n suggests that much of Aquitard 1 is saturated, which corresponds to water level records (Fig. 4.13). For Field B the ρ_b ranged from 1.9 g/cm^3 to 2.2 g/cm^3 and averaged 2.0 g/cm^3. The θ_v ranged from 13.0 to 15.0 and averaged 13.9. The n ranged from 15.2 to 27.2 and averaged 21.8. The separation between the θ_v and n values suggest that most of Aquitard 1 is unsaturated in Field B, which corresponds to water level records (Figs. 4.12 and 4.14). The lower ρ_b and the larger n in Field B compared to Field A suggest that the till unit in this field is less compact and more highly weathered, which may result in an increased ability to transmit water. It is important to note that based upon core logging and field observations Aquitard 1 appears homogeneous regardless of the area of the farm where samples are collected. It would be very difficult to detect any differences in the physical properties in Aquitard 1 sediments between Fields A and B, without the detailed sedimentological analysis performed as part of this study.

The physical properties of Aquifer 1 were consistent between Fields A and B. The ρ_b averaged 2.0 g/cm^3, the θ_v averaged 21.6 and the n averaged 24.1. This unit was fully saturated at KA9 and at KA5-5 (Figs. 4.12 and 4.13), but the upper 1.0 – 2.0 m of Aquifer 1 at KA10 was typically unsaturated (Fig. 4.14), leading the overall average θ_v to be slightly less that the n. Gravelly layers were difficult to obtain an accurate θ_v in and may have also caused some error.

In Aquitard 2, the ρ_b averaged 2.2 g/cm^3, the θ_v averaged 19.7 and the n averaged 18.6. The small difference between θ_v and n in this fully saturated material is considered a reasonable degree of error.

Only KA9 penetrated Aquifer 2 and from that core, the ρ_b averaged 2.0 g/cm^3, the θ_v averaged 25.6 and the n averaged 24.9. Again, the small variation between θ_v and n in this fully saturated material is considered a reasonable degree of error.

The core KA3-5 was not included in any calculations or averages of the physical properties of the soil at the Allin Farm (Fig. G.8). This borehole was drilled through construction fill (Fig. 4.6) put in place for construction of the outdoor liquid manure storage tank and is not considered representative of geologic conditions.

The general trends in the vertical profiles of physical soil properties between Fields A and B show that each hydrostratigraphic unit is locally heterogeneous, but is generally homogeneous between the two fields. θ_v for Aquitard 1 is similar between Fields A and B, but the difference in n, suggests a thick unsaturated zone in Field B (6 – 12m) and a thin unsaturated zone in Field A (2 – 4m). This difference may cause groundwater flow and contaminant transport between the two fields to differ, which may affect how the implementation of the BMP will be observed in the groundwater. Beneath Field A, most of the vertical transport of nitrate will be within the saturated zone as the watertable elevation is high. Beneath Field B, most of the vertical transport of nitrate will be within the unsaturated zone as the watertable elevation is low.

4.3.1.2 Soil and Porewater Nitrate

Spatial variability of soil nitrate concentrations can be very large, and is highly dependent upon the yearly nutrient applications of nitrogen fertilizer and the timing of sample collection. Uneven spreading of manure and/or commercial fertilizer in combination with micro scale differences in infiltration rates and soil chemistry is thought to add a large degree of spatial variability to soil nitrate concentrations from a single field (Onsoy et al., 2005). For this reason, the results from soil nitrate sampling will be described for each of the five stratigraphic units within Fields A and B, rather than on an individual core basis. Table 4.5 summarizes the minimum, maximum and average concentrations for bulk soil nitrate and porewater nitrate as obtained from the average values measured in each core from each of the five stratigraphic units.. Figures 4.12 to 4.16 display the individual core results of bulk soil nitrate and porewater nitrate concentrations. Additional core logs are provided in Appendix G. All contaminant concentrations of nitrate are presented in nitrate (as N).

In many core samples, the highest bulk soil nitrate concentrations were observed in the zone of root growth. For Field A, bulk soil nitrate concentrations in the root zone ranged from 0.4 to 16.4 mg/kg and averaged 6.5 mg/kg. By following equation 3.5, an average porewater nitrate concentration in the root zone of 27.9 mg/L is calculated. For Field B, bulk soil nitrate concentrations in the root zone ranged from 1.8 to 8.3 mg/kg and averaged 4.6 mg/kg. This gives an average porewater nitrate concentration in the root zone of 22.7 mg/L. The lower nitrate concentrations observed in the root zone of Field B compared to Field A is consistent with the nutrient application history which shows that less N has been applied to Field B than Field A since 1997. The difference may suggest that the application of commercial fertilizers rather than manure may decrease the nitrogen in the topsoil, which is logical because manure applications also add organic N to the topsoil, than can mineralize at a later time and add to the N pool. Although there were observed correlations between land-use practices and average root zone nitrate concentrations, on an individual core basis, spatial variability in geology and seasonal nitrogen distribution may control root zone nitrate concentrations more than nutrient application amount or type. This hypothesis is highlighted in the large difference between the root zone nitrate concentrations between KA5-5 of 3.0 mg/kg (Fig. 4.12) and BT1 of 19.0 mg/kg (Fig. 4.16), which are located approximately 40m apart within Field B.

The till sediments of Aquitard 1 contain an archive of the nitrogen application and leaching history at the farm, and the porewater nitrate concentrations within this unit can provide insight regarding the future effects of nutrient reductions resulting from an agricultural BMP. For Field A, the average bulk soil nitrate concentration from within Aquitard 1 is 1.8 mg/kg, which translates into an average porewater nitrate concentration of 19.1 mg/L. For Field B, the average bulk soil nitrate concentration is 1.2 mg/kg and the average porewater nitrate concentration is 17.6 mg /L. These data suggests that there is little difference between the N leaching between the two fields even though Field B has received less N than Field A since 1997 and that the source of the N was changed from manure to commercial fertilizers. However, the average nitrate concentration in Field B was heavily influenced by very high nitrate concentrations found in BH4 (Fig. G.3), and by very low porewater nitrate concentrations measured in KA5-5 (Fig. 4.12) and KA10 (Fig. 4.14). It appears that the nitrate profiles at KA5-5 and KA10 have flushed out much of the nitrate that would have historically been present in Aquitard 1, likely due to the change in nutrient loading on Field B. The nitrate profile at BH4 does not appear to have been affected by a reduction in N loading. This difference again highlights the importance of spatial variability controlling nitrate distribution even at the scale of a single field that is only 8 ha in area. In the KA9 core, (Fig. 4.13) the bulk soil nitrate concentrations increase to a depth of 7.7 mbgs at a concentration of 3.1 mg/kg or 60.9 mg/L. This suggests that N applied in previous years and that leached below the root zone is still present in the subsurface and will influence the groundwater chemistry in Aquifer 1 in the years to come. This shows that the recharging water now contains less nitrate than it may have historically, which can be attributed to reductions in surface N loading. Nitrate concentrations continue to increase into Aquifer 1 but the source of this nitrate may be related to upgradient land-use activities and not from nutrient applications on Field A.

Borehole KA9 provided soil core samples from Aquifer 1 beneath Field A and boreholes KA10 and KA5-5 provided soil core samples from Aquifer 1, from beneath Field B (Figs. 4.12 to 4.14). Because samples from Aquifer 1 and below are fully saturated, the porewater nitrate concentrations are believed to be representative of groundwater nitrate concentrations. For Field A, the average porewater nitrate concentration is 19.1 mg /L. For Field B, the average porewater nitrate concentration is 8.7 mg/L. This fits with our conceptual model of nitrate leaching though Aquitard 1 and influencing the groundwater chemistry below. The average porewater nitrate concentration beneath Field A is nearly identical between Aquitard 1 and Aquifer 1, assuming vertical flow, this suggests that the nitrate is derived from the same source. The significantly reduced nitrate concentration beneath Field B suggests that changes in nutrient loading have already flushed much of the nitrate out of Aquitard 1 and now recharge of relatively nitrate free water is entering Aquifer 1 under Field B and reducing the nitrate concentration by dilution.

Aquitard 2 sediments were collected from boreholes KA9 and KA5-5. For Field A, the average porewater nitrate concentration is 2.1 mg/L. For Field B, the average porewater nitrate concentration is 2.4 mg/L. These values may be slightly elevated relative to natural background values, but do suggest that Aquitard 2 is not significantly affected by land-use activities above and is not providing significant nitrate mass to Aquifer 1.

Only KA9 was drilled deep enough to collect soil samples from Aquifer 2 from beneath Field A (Fig. 4.13). No samples were collected for Aquifer 2 from beneath Field B. The average porewater nitrate concentration in Aquifer 2 is 1.8 mg/L. This value may be slightly elevated, but suggests that Aquifer 2 is not significantly affected by land-use activities above.

Two cores were collected from the BT1 location in Field B (Fig. 4.16), with the first collected in April 2006 (BT1) and the second collected in February 2007 (BT1-2). The collection of these cores provides an opportunity to study the movement of the soil nitrate profile over one year. Trends in n and θ_v were similar between the cores from the two coring events. Below the zone of root growth (0.7 mbgs) to the bottom of the core, BT1 shows a consistent porewater nitrate concentration of approximately 27.0 mg/L. BT1-2 from 0.7 mbgs to 2.2 mbgs shows porewater nitrate concentrations that range from 0.0 to 6.0 mg/L. Below 2.2m, the porewater nitrate concentrations tend to match the porewater nitrate concentrations of BT1 and average 22.0 mg/L. The porewater contained in the upper 2.2 m of core in BT1-2 may be low nitrate recharge water attributed to reduced N leaching from the soybean crop planted the year before. The different times of year these cores were collected may also explain this variation in soil nitrate profile. The core sample collected in April 2006 was collected following the spring recharge event but prior to spring application of fertilizer. The core sample collected in February 2007 was drilled prior to the spring melt and because of a very rainy fall 2006 and winter 2007 (Fig. 4.2), advection of low nitrate recharge water may have been present in the soil profile.

The core KA3-5 (Fig. G.8) was drilled near KA3 (Fig. 4.4) through construction fill near the outdoor manure storage tank. Only the lower portion of the core provided information pertaining to the stored nitrate in Aquitard 1 and the physical properties of the upper till. The θ_v decreased after 2.3 mbgs from an average of 33.0 to 19.0, corresponding to the change from construction fill to native till. The porewater nitrate content in all but the deepest core sample (5.2 mbgs) is low and averages 3.9 mg/L. The deepest sample has a porewater nitrate concentration of 19.9 mg/L, which is consistent with nitrate concentrations in Aquitard 1.

4.3.1.3 Porewater Chloride

Chloride (Cl) concentrations were measured in the porewater of KA5-5, KA9 and KA10 (Figs. 4.12 to 4.14). In Aquitard 1, beneath Field A, the Cl concentration averaged 6.8 mg/L and increased with depth. In Aquitard 1, beneath Field B, the Cl concentration averaged 9.7 mg/L and also increased with depth. In Aquifer 1 for Fields A and B, the Cl concentration averaged 17.4 mg/L and 12.1 mg/L respectively. In Aquitard 2 for Fields A and B, the Cl concentration averaged 14.5 mg/L and 5.1 mg/L respectively. In Aquifer 2, beneath Field A, the Cl concentration was 12.3 mg/L. Porewater Cl concentrations were generally consistent within Aquitard 1 and Aquifer 1 between Fields A and B. This result was unexpected as the urea and ammonium sulphate commercial fertilizers used at the farm are not a source of Cl, whereas manure is a source. Fig. 4.12 shows a sharp decrease in Cl concentration between Aquifer 1 and Aquitard 2 at KA5-5, indicating that water in Aquifer 1 is derived from recharge from above and that the two aquifers are not hydraulically connected. This similarity between the Cl concentrations in all hydrostratigraphic units at KA9 (Fig. 4.13) suggests that there may be some mixing between the two aquifer systems and that Aquitard 2 may provide less of a hydraulic barrier here than at KA5-5.

4.3.2 Porewater $\delta^{15}N$ in NO_3^-

Isotopic analysis of the porewater contained within five of the soil cores was performed to determine the source of the nitrogen in the nitrate (either manure or commercial fertilizer or a mixture of the two) in the porewater of the soil cores. Because the BMP implementation on Field B involved changing nutrient applications of N from a fertilizer/manure mixture to only commercial fertilizer, it was believed that isotopic differences of $\delta^{15}N$ in NO_3^- in the nutrient sources could be used as a "tracer" to track the movement of the different sources in the subsurface. The differences in isotopic signature within the soil profile can provide evidence of the depth of influence of the changes in nutrient source within the subsurface environment. A full review of differentiating nitrate sources from isotope data is presented in Section 2.2. Data from cores KA9, KA10, KA5-5, BH1, and BT1 for porewater isotopes is presented in vertical profile in Figs 4.12 to 4.14, as well as in Table 4.6.

Porewater isotopes for $\delta^{15}N$ in NO_3^- were collected from two cores drilled in Field A, where the nitrogen source of fall applied manure and spring applied commercial fertilizer had remained relatively constant since 1997. BH1 was drilled in April 2006 (Fig. 4.15) and KA9 (Fig. 4.13) was drilled in January 2007. Due to large volume of soil required to obtain a sufficient mass of nitrate to complete the porewater isotopic analysis, only 2 samples could be analyzed from BH1. The $\delta^{15}N$ isotopic signature of 5.97‰ in sample BH1-1 represents either a commercial fertilizer N source or a symbiotically fixed N source from a legume plant. Because soybeans were planted on Field A during the previous growing season and the farm records do not show any applications of commercial fertilizer, the result suggest a symbiotically fixed N source from soybeans. Analysis of both $\delta^{15}N$ in NO_3^- and $\delta^{18}O$ in NO_3^- would help distinguish between symbiotically fixed N and commercial fertilizer N, but a large enough mass of nitrate could not be collected from the soil cores to permit the analysis of both parameters. The $\delta^{15}N$ signature of BH1-2 of 12.12‰ is indicative of a manure N source. Sample BH1-2 was obtained from deeper in the soil profile, where manure derived nitrate was still present from the 2004 application.

The core from KA9 provided a detailed stratigraphic analysis of porewater isotopes of nitrate. The samples from 0 – 2.12 mbgs typically show a mixed signature between manure and either commercial fertilizer or symbiotically fixed N and have an average $\delta^{15}N$ in NO_3^- of 7.77‰ and range from 4.4‰ to 9.4‰. From 2.12 - 8.80 mbgs (excluding sample KA9 – 13 from 6.50 to 6.95 mbgs) show a signature indicative of manure averaging 11.95‰ and range from 10.3‰ to 13.4‰. This suggests that the growing soybeans for the past two growing seasons has influenced the chemistry of the shallow subsurface and that the manure spread the seasons prior to soybean growth is still present at depth in the Aquitard 1 sediments. The enriched $\delta^{15}N$ value at KA9-13 of 21.8‰ suggests that denitrification may be occurring in this isolated pocket of soil.

Porewater isotopes for $\delta^{15}N$ in NO_3^- were collected from three cores within Field B, where the nitrogen source since 1997 had been only commercial fertilizer. Soybeans have been planted on this field between 2004 and 2007. BT1 was drilled in April 2006 (Fig. 4.16) and, KA10 (Fig. 4.14) and KA5-5 (Fig. 4.12) were drilled in January 2007. Samples BT1-1, BT1-2 and BT1-3 (Table 4.6) had $\delta^{15}N$ signatures of 4.30‰, 7.77‰, and 5.69‰ respectively, suggestive of commercial fertilizer or symbiotically fixed N source, which would be expected given the historical land-use practices on this field. The core from KA5-5 provided composite porewater isotope samples over approximately 1 m intervals. The sample KA5-5-1 was collected from the topsoil or root zone between 0 – 0.86 mbgs, and had a $\delta^{15}N$ signature of 13.90‰, suggesting a manure source. Samples collected between 0.86 – 7.22 mbgs show a $\delta^{15}N$ signature that averages 6.70‰, suggesting a commercial fertilizer or symbiotic N source. Based upon the depth below ground surface, it can be concluded that majority of the isotopic signature of the samples between 2.0 and 7.22 mbgs are representative of commercial fertilizer, which is consistent with the nutrient application history since 1997. Between 7.22 – 9.50 mbgs, the average $\delta^{15}N$ result is 13.51‰, indicative of a manure source. The core KA10 shows a similar trend to that of KA5-5. Sample KA10-1 from the root zone has an isotopic signature of 10.22‰, signifying a manure $\delta^{15}N$ source. Samples from 0.85 – 10.35 mbgs have a $\delta^{15}N$ signature that averages 5.70‰, suggesting a commercial fertilizer or a symbiotically fixed N source. Again, based upon the depth below the ground surface, it is thought that the majority of the isotopic signatures indicate a commercial fertilizer source. The sample KA10-8 from between 10.35 and 11.65 mbgs has a $\delta^{15}N$ signature of 9.39‰, which suggests a manure source.

Results from porewater isotope analysis indicate that nitrate derived from manure has been completely flushed out of the unsaturated zone beneath the root zone of Field B and been replaced with nitrate derived from commercial fertilizers. This suggests that the effects land-use change have successfully migrated from the surface to the watertable. Beneath Field A, nitrate derived from manure is still present, but nitrate derived from symbiotically fixed N is present in the upper portions of the soil profile, which corresponds to known farming activities.

4.4 Soil Moisture in the Unsaturated Zone

To provide additional information on the moisture content of the unsaturated zone regular measurements were taken using a neutron moisture probe at the five neutron access tubes installed at the site (Fig. 4.4). Three time domain reflectometry (TDR) probes were installed near the meteorological station to obtain a continual record of seasonal soil water content changes in the shallow subsurface.

4.4.1 Neutron Moisture Probe

In order to obtain the best relationship between neutron probe count ratios (CR) and the soil moisture content, CR measurements were converted to volumetric water content (θ_v) values using site-specific calibration equations developed in Appendix B. A single calibration equation was derived from a linear regression of the results of neutron probe CR measurements taken shortly after the installation of NA4 and NA5 and the soil moisture content measurements conducted in the laboratory on soil cores BT2 and BT3 (which correspond to NA4 and NA5), in February 2007. Three neutron access tubes (NA1, NA2, and NA3) were installed at the site in August 2006 and two others (NA4 and NA5) were installed in February 2007. The seasonal variation of θ_v measurements from the neutron moisture probe, including the laboratory-measured θ_v from the soil core collected is presented in Figs. 4.17 – 4.21. The data collected from NA3 (Fig. 4.19) will not be evaluated as part of this study because a 3 cm thick bentonite seal was installed around the access tube. The measurements taken in NA3 with the neutron moisture probe reflect the high moisture content of the bentonite and are not representative of the native material as evident by the large difference between the laboratory measured and the neutron probe measured moisture content. Measurements taken in August 2007 of the upper 1.0 m of soil often yielded negative moisture content values after calibration, indicating that the CR to θ_v calibration equation is not robust enough to accurately estimate the θ_v of a soil with essentially no soil moisture. Measurements taken in NA 1 (Fig. 4.17) had the highest average moisture content of approximately 20%, compared to the other access tubes installed across the study site, which may reflect saturated conditions of the soil present below much of Field A. The moisture content of NA4 (Fig. 4.20) averaged approximately 17% and may also reflect saturated soil conditions. NA2 (Fig. 4.18) consistently had the lowest moisture contents and averaged approximately 12%. This access tube was not installed deep enough to intercept the watertable and it therefore reflective of unsaturated zone moisture content values beneath Field B. The moisture content of NA5 averaged approximately 15% and reflects unsaturated conditions in Field A near the KA1 well nest. θ_v profiles over the upper 1 m of the soil profile exhibited the greatest amount of variation and are likely dependent upon recent rainfall events and the state of the field (i.e.,, cropped or bare, frozen or wet), which all relate to the ET rate. Below 1 mbgs, the θ_v each of the moisture content profiles varied annually by approximately 4% (volume %). Measurements taken during in May 2006 and March 2007, while the fields were still bare, resulted in the highest average θ_v for each profile, while measurements taken in September and October 2007, resulted in the lowest average θ_v for each profile. There are θ_v peaks in NA1 between 2.25 and 2.55 mbgs for measurements taken in May 2006 and July 2006 suggest that additional water was present at this depth during these times. A similar trend is observed in NA2 between 2.85 and 3.60 mbgs for the May 2006 measurement. The very low θ_v values in NA2 at the depth of 4.05 mbgs are likely due to the presence of a large boulder, which was encountered during the drilling. Overall, the θ_v profiles measured at the site are relatively consistent with depth and spatial location of the access tube, and show little seasonal variability, which is consistent with gravity-driven quasi-steady state flow below the root zone. This suggests that the stored mass of water in the unsaturated zone and saturated zone in Aquitard 1 remains relatively constant on a yearly basis.

4.4.1.1 Relationship Between Field and Laboratory Measured Moisture Content Values

The θ_v measured in the laboratory generally correlate well with the θ_v measured by the neutron moisture probe in the field as both peaks and troughs in θ_v were captured by both methods. The neutron moisture probe was able to measure seasonal peaks in moisture content from locations and times where no core data was available. Neutron probe moisture measurements at each location were generally higher than the laboratory-measured value at the same location by an average of approximately 4% (volume %). This suggests that the moisture content values may have been slightly underestimated from the soil cores but in general the difference is not significant. And both methods provided reasonable moisture content results. Moisture content values measured at NA2 reflect the unsaturated conditions in Field B and show that the soil above the watertable is approximately 55% saturated.

4.4.2 TDR Probes from Meteorological Station

Three TDR probes were installed in a horizontal orientation at 0.14 mbgs (shallow), 0.39 mbgs (middle) and 0.73 mbgs (deep), in May 2007 near the meteorological station (Fig. 4.4). These probes were connected to the CRX10 data logger and soil moisture measurements (θ_v) were collected on an hourly basis. The daily average soil moisture content value for each of the three TDR probes is presented in Fig. 4.22.

The shallowest TDR probe recorded the widest range of θ_v values ranging from 23% to 5% and responded quickly to rainfall events. θ_v declined significantly over the growing season between May and August and peaked during periods of sustained recharge (October to December and May). The middle TDR probe responded quickly to changes in θ_v during the periods of October to December and May. This response was greatly subdued during the summer months suggesting the recharge was not percolating deep enough to be measured by this probe. The θ_v measured with the deep TDR probe was consistently low (less than 10%) and only responded during recharge events in the late fall (mid November to December). This suggests that recharge water was only able to reach 0.73 mbgs during times of no crop growth and heavy precipitation. Because no wetting front is observed in the vertical soil profile below 0.73m using the neutron moisture probe during other major recharge events, this spike in water content may be evidence for a lateral interflow of infiltrating water, although vertical flow still appears to dominate.

4.5 Groundwater

4.5.1 Groundwater Levels

Groundwater levels have been manually measured between 1997 and 2007 at the six original well nests KA1 to KA6 (Fig. 4.23). Beginning in 2007, leveloggers were installed at each well nest and in each newly installed well to obtain a continuous record of water level fluctuations (Fig. 4.24). Much of the detail in seasonal water level elevations is lost when all of the on-site wells are plotted together. For this reason, both manual and levelogger piezometric data are plotted for each individual well in Appendix H, Figs H.1 to H.17. Water level data is also presented in Table H.1 for additional reference. Table 4.3 summarizes all well data and provides a range of yearly depths to the watertable. Hydraulic conductivity measurements, calculation of horizontal and vertical gradients and estimates of the groundwater flow direction are presented and discussed in Sections 4.8.2 through 4.8.4. As stated previously, a GPS survey was conducted as part of this study and all water level elevation information was derived from these data (Appendix C).

Detailed water level monitoring in 2001, 2005, 2006 and 2007 indicate that most wells at the Allin Farm experience large yearly and potentially seasonal fluctuations in watertable elevation. Water levels at the KA1 well nest, which is located at the highest elevation at the farm, can fluctuate by more than 7.5 m over the course of a year (Fig. 4.23). The seasonal low water level at KA1 occurs in August through October (~10 mbgs), and the seasonal high water level occurs in November through January and again in April through May (~3.5 mbgs). KA1 tends to respond quickly to recharge events (Fig. H.8), even though the watertable is on average located 6.0 mbgs. The hydraulic properties of KA1 are consistent for a recharge area at the top of a groundwater flow system. Water levels at the KA2 well nest can fluctuate by approximately 4 m over the course of a year (Fig. 4.23). The seasonal low water level at KA2 occurs in October (11.5 mbgs), and the seasonal high water level in April through May (5.9 mbgs). KA2-1 is often dry during periods of low water levels. The response of KA2 to recharge events (Fig. H.9) ranges from rapid during the spring melt (April) and slow during the fall rains (October through January), suggesting that given the right circumstances, recharge can occur rapidly. Water levels at the KA3 well nest can fluctuate by approximately 6 m over the course of a year (Fig. 4.23). The seasonal low water level at KA3 occurs in October (~9.3 mbgs), and the seasonal high water level occurs in November through January and again in April through May (~ 3.3 mbgs). The response of KA3 to recharge events (Fig. H.10) is rapid during both the spring melt (March) and during the fall rains (October through January), suggesting that KA3 is hydraulically connected to the ground surface. Water levels at the KA4 well nest can fluctuate by approximately 3 m over the course of a year (Fig. 4.23). The seasonal low water level at KA4 occurs in August through October (~3.6 mbgs), and the seasonal high water level occurs in November through January and again in April through May (~ 0.6 mbgs). The response of KA4 to recharge events (Fig. H.11) is very rapid, suggesting that KA3 is hydraulically connected to the ground surface. Water levels at the KA5 well nest can fluctuate by approximately 5 m over the course of a year (Fig. 4.23). The seasonal low water level at KA5 occurs in October (~9.0 mbgs), and the seasonal high water level occurs in November through January (~ 3.8 mbgs). Both KA5-1 and KA5-2 can become dry during periods of low water levels. KA5-6 is flowing artesian with a water level measured to be approximately 2 m above ground surface (mags) and is screened in Aquitard 2. The amount of fluctuation in this well is unknown as only one reliable measurement was taken over the course of this study. The response of KA5 to recharge events (Figs. H.12 to H.14) is slightly subdued compared to other well nests, but is still generally suggestive that KA5 is hydraulically connected to the ground surface. Water levels at the KA6 well nest are all flowing artesian and can fluctuate by approximately 2 m over the course of a year (Fig. H.6), but generally maintain a constant level (Fig, 4.23). KA6 shows small responses to recharge events (Fig. H.15), but generally does not fluctuate seasonally, suggesting that KA6 is not as hydraulically influenced by ground surface events and is connected to a deeper flow system.

Wells KA7 and KA8 experience seasonal low water levels in October and seasonal high water levels in April, and fluctuate seasonally by approximately 4 m (Fig. H.7). The KA9 well nest measures three different hydraulic systems (Figs. H.7 and H.16). KA9-1 is screened in Aquitard 1 and responded quickly to the spring 2007 recharge, where the water level rose by approximately 3.5 m over the month of March. KA9-2 is screened in Aquifer 1, and showed a subdued response to the spring 2007 recharge event. The water levels in KA9-2, KA5-3, KA5-4, and KA5-5, each responded similarly to the spring 2007 melt suggesting that they are part of the same flow system as predicted by the geological correlation between the wells. KA9-3 is screened in Aquifer 2, and showed a subdued response to the spring 2007 recharge event. This suggests that it is not well connected to the ground surface, but may be connected to the Aquifer 1 flow system, as the hydraulic response was similar. Water levels in KA10-2 at the KA10 well nest (Fig. H.17), which is screened in Aquifer 1, showed a subdued response to the spring recharge event, in a similar manor to the other wells known to be screened in Aquifer 1.

Water level measurements indicate that there are at least three distinct groundwater flow systems present at the Allin Farm. The first flow system is characterized by a shallow water level and/or a rapid response to seasonal recharge events and is shown at well nests KA1, KA2, KA3, KA4, KA9-1 and possibly KA7 and KA8. Each of these wells is screened in Aquitard 1. The second flow system is characterized by a subdued response to recharge events and is screened in Aquifer 1. This flow system includes wells and well nests KA5, KA9-2, and KA10-2. The third flow system is characterized by no significant response to recharge events and flowing artesian conditions. The KA6 well nest is part of this flow system. It is not clear from water level measurements which flow system KA9-3 belongs to, but based upon its depth (30 mbgs), it is likely part of a fourth deeper flow system.

4.5.2 Slug Tests

Slug tests were conducted on each well to determine the hydraulic conductivity (K) of the geological material surrounding the well screen (Table 4.7). The hydraulic conductivities ranged from $4.5\text{x}10^{-5}$ m/s (KA6-4) to $3.1\text{x}10^{-9}$ m/s (KA5-6). Many of the hydraulic conductivities measured as part of this study are approximately one order of magnitude greater than the conductivity measured by Gibson and Rudolph (1997), which are included in Table 4.7 for reference. Smearing effects on the side of the boreholes from the auger drill rig used to install the wells may have caused the lower K values measured in 1997. This effect on the soils may have been lessened since that time and K values measured as part of this study better reflect the natural site conditions.

The K for Aquitard 1 ranges from $1.2\text{x}10^{-6}$ m/s (KA3-4) to $1.7\text{x}10^{-8}$ m/s (KA2-4). Geological logs show that Aquitard 1 contains many sandy and gravelly interbeds. These beds may provide an additional horizontal hydraulic pathway that increases the horizontal hydraulic conductivity of the unit as measured by the slug tests. The hydraulic conductivity for Aquifer 1 ranges from $4.5\text{x}10^{-5}$ m/s (KA6-4) to $3.6\text{x}10^{-6}$ m/s (KA5-2). The K values for Aquifer 1 are relatively uniform, even though the unit contains many different aquifer type sediments including silty sands, coarse sands as well as interbeds of glacial till and silty clay. Well KA5-6 was the only well screened in Aquitard 2 and the K value derived from slug testing was $3.1\text{x}10^{-9}$ m/s. Well KA9-3 was the only well deep enough to be screened in Aquifer 2 and its K value was found to be 5.9x10^{-7} m/s, which is representative of a silty sand aquifer unit (Freeze and Cherry, 1979).

A hydraulic conductivity value was selected to be representative for each geological and hydrological unit based upon 2007 slug testing data. The value of 1.6x10^{-5} m/s was assigned to Aquifer 1 and was obtained by averaging the results from each slug test performed in this unit. The value of 5.2x10^{-8} m/s was selected as the representative K for Aquitard 1. The presence of sandy interbeds in this geological unit may have caused the large range of K values obtained from slug testing and may have resulted in increased K compared to homogeneous till (Gerber and Howard, 1996). The value of 5.2x10^{-8} m/s was specifically calculated by averaging the K values from wells were no apparent heterogeneities were present (KA2-1,2,3,4 and KA5-1). Gerber and Howard (2000) used the water balance approach to derive a bulk K for the Newmarket Till of 5.0x10^{-9} m/s. Slug test estimates of K, also from Gerber and Howard (2000) show a range of K values from 10^{-12} to 10^{-5} m/s for the Newmarket Till. Hydraulic conductivity values assigned to Aquitard 2 of 3.1x10^{-9} m/s and Aquifer 2 of 5.9x10^{-7} m/s are the results of the only slug tests performed in each of these units (KA5-6 and KA9-3, respectively).

4.5.3 Hydraulic Gradients

Figs. H.1 to H.7 show the water levels for each individual well in each well nest, and provide diagrammatic evidence of the direction of vertical groundwater flow between individual wells and each hydrostratigraphic unit. Table 4.8 provides a summary of the calculated average vertical hydraulic gradient at each well nest and between each hydrostratigraphic unit.

From 1997 to 2007, within groups of wells completed exclusively in Aquitard 1, on average the vertical hydraulic gradient ranged from -0.04 m/m (KA4 nest) to -0.31 m/m (KA2 nest), indicating downwards flow or recharging conditions (Table 4.8). Between wells completed in Aquitard 1 and wells completed in Aquifer 1, on average the vertical hydraulic gradient ranges from -0.26 m/m (KA9-1 and KA9-2) to-0.29 m/m (KA5-1 and KA5-2), and indicates a downward flow of water. The hydraulic gradient between Aquifer 1 and Aquitard 2 was measured to be 0.63 m/m between the wells KA5-6 and KA5-1 and indicates an upward flow of water. The hydraulic gradient between Aquifer 2 and Aquifer 1 was measured to be 0.09 m/m between wells KA9-3 and KA9-2. The KA6 well nest is flowing artesian and has an upward gradient of 0.47 m/m.

Although, on average flow was downward in Aquitard 1, many of the well nests experience periods of upwards groundwater flow directions. The range of vertical gradients at well nests KA1, KA2, KA 3 and KA4, shows that during some monitoring events, the groundwater flow direction switched from the typical downwards gradient to an upwards one.

Horizontal hydraulic gradients at the site are small relative to the vertical gradients (Table 4.9). The horizontal gradients range from 0.03 m/m between wells KA4-1 and KA6-1, to 0.06 m/m between wells KA3-1 and KA5-1. The horizontal gradients between well nests are typically one order of magnitude smaller than the vertical gradients experienced at each well nest within Aquitard 1, which suggests that vertical groundwater flow is dominant within the study area. The addition of any anisotropic geological units such as higher K interbeds within the low K Aquitard 1 would cause these features to dominate flow direction and velocity.

4.5.4 Groundwater Flow Direction

Water level elevations were contoured using the Surfer 8® software program (Golden Software, 2007) for May 2007 and August 2007 water level data. Two contour maps were created for both the May and August 2007 monitoring events. The first represents the piezometric surface elevation in Aquitard 1 and draws data from wells KA1-1, KA2-1, KA3-2, KA4-1, KA5-1, KA6-1, KA9-1, and KA10-2 (Figs. 4.25 and 4.26). KA10-2 is not screened in Aquitard 1, but at this well nest, the piezometric surface elevation is found within Aquifer 1. The second set of contour maps show the piezometric surface elevations for Aquifer 1 and draws data from KA5-4, KA8, KA9-2, and KA10-2 (Figs. 4.27 and 4.28). Overall, watertable elevations in Aquitard 1 tend follow surface elevation patterns (Fig. 4.3) and decline from east to west across the site. Insufficient data was available to contour water level elevations in Aquitard 2 or Aquifer 2. The groundwater elevation contours presented in Figs. 4.25 through 4.28 are thought to be representative of typical groundwater flow directions between 1997 and 2007, at the Allin Farm study site, but do not represent the very highest levels (April) or the very lowest (October).

Due to the large difference in K between Aquitard 1 and Aquifer 1, and the large vertical hydraulic gradient relative to the horizontal gradient, it is thought that Aquifer 1 acts like a drain and captures all water moving vertically downward through Aquitard 1. Fig. 4.29 presents a conceptual groundwater flow model along the A – A’ transect (Fig. 4.4) and is based upon all available groundwater data including hydraulic responses, hydraulic head values, K values, vertical gradients, horizontal gradients, and site geology. All conceptual groundwater flow and contaminant transport models between Fields A and B at the Allin Farm are based upon the groundwater flow net depicted in Fig. 4.29. The hydraulic head difference between Aquifer 1 and Aquifer 2 suggests that flow is upwards and that Aquitard 2 restricts groundwater movement between the aquifer units and may be effective at confining Aquifer 2 at specific locations. This causes Aquifer 2 to be part of a separate, deeper flow system below Aquifer 1. The groundwater flow system in Fig 4.29 suggests that changes in nutrient loading to Field A will affect the groundwater beneath Field A and also the groundwater deeper in Aquifer 1 beneath Field B. Changes to nutrient loading to Field B, will affect only the shallow groundwater in Aquitard 1 and Aquifer 1 under Field B within the limits if the study site.

4.5.5 Groundwater Flux Estimation

The groundwater flux into Aquifer 1 from vertical flow through Fields A and B, and the horizontal groundwater flux out of Aquifer 1 along the western property boundary at County Rd. 10, was calculated (Table 4.10a and 4.10b). These calculations should account for all groundwater into and out of Aquifer 1 within Fields A and B. Because Aquifer 1 is thought to terminate beneath Field A (Fig. 4.8) groundwater inputs to the aquifer from upgradient of KA1 should be small relative to inputs from the Allin Farm area. The area of Fields A and B were obtained from farm records.

Because of the large degree of spatial heterogeneity and the small amount of data relative to the size of the farm, the groundwater flux to Aquifer 1 beneath Fields A and B was estimated using two different methods. The first method involved estimating the groundwater flux at each well nest in Fields A and B, then applying the flux at each well nest over an area believed to be representative of the conditions at the well nest. This method uses well specific K (Table 4.7) and vertical gradient values (i_v; Table 4.8), and then applies them to a larger area. The calculations for this method are presented in Table 10a. The second method involves determining an average set of values for K and i_v for Field A, and an average set of values for K (Section 4.8.2) and i_v for Field B. K values for each of the hydrostratigraphic units are determined from the site-wide average values and the i_v values are determined for Fields A and B individually. This method uses spatially averaged K and iv values and then applies them to the area of the field. The calculations for this method are presented in Table 10b.

4.5.5.1 Groundwater Flux Discussion

Using well specific values is the most common method used to calculate groundwater flux because it utilizes physically measured point source data and applies the results over a spatially representative area (Table 10a). The average K and i_v measured at KA1 was applied over the eastern half of Field A, and the average K and i_v at KA9 was applied over the western half of Fields A. The contribution from Aquitard 2 from below was calculated at KA9 and KA5, using well nest specific i_v values and the K value measured at well KA5-6. It was assumed that the aerial extent of Aquitard 2 covered all of Field B and half of Field A, as the geological core logs suggest is the case. The sum of the groundwater flux into Aquifer 1 from Fields A and B was 37.3 L/s. The groundwater flux was then estimated for all the water leaving Aquifer 1 through the western property boundary along the B-B' transect (Fig. 4.4). The thickness of Aquifer 1 was estimated from borehole logs to average 6.57m and the length was measured to be 487m, which gives an area of 3200 m^2. The average K and horizontal gradient (i_h) was calculated between well nest pairs KA9 and KA5, and KA8 and KA10, using well specific values. The sum of the groundwater flux out of Aquifer 1 along the western property boundary was estimated to be 2.5 L/s. These results suggest that less than 7% of the water that enters Aquifer 1 through the foot print of the Allin Farm leaves the Allin Farm by flowing from east to west (the direction of groundwater flow) through Aquifer 1. This result is not considered to be representative of actual site conditions because strong upwards-vertical gradients prevent groundwater from flowing below Aquifer 1 into Aquitard 2 or Aquifer 2, and the groundwater flow directions are stable throughout the year and clearly show that the area between KA5 and KA10 is main area where groundwater exits the Allin Farm property. The geological boundary conditions at the site provided a "relatively" confined flow system. It is believed that the groundwater flux calculated to be leaving Aquifer 1 is accurate as all lengths and distances are well constrained, K values from slug testing results in Aquifer 1 are reasonable for the aquifer material, and i_h is a much less sensitive parameter to measure than i_v. As discussed in Section in 4.8.2, it is believed that the K values measured at KA1 and KA9 using slug testing that range from 10^{-6} to 10^{-7} m/s are not representative of the vertical K (K_v) through Aquitard 1. Slug testing provides a horizontal K value (K_h) for the area around the well screen, and the presence of discontinuous sandy interbeds or lenses may have enhanced K_H compared to a homogeneous till. A value of 10^{-8} m/s is considered more representative of the actual Kv. Slug testing results at well nest KA2 and well KA5-1 show that Aquitard 1 sediments at these locations have Kh values of 10^{-8}, which is similar to literature values (e.g., Gerber and Howard, 2000). Due to the inability for the well specific value method to provide an accurate representation of groundwater flux to Aquifer 1, a spatially averaged method was utilized.

The spatially averaged groundwater flux estimation results are presented in Table 10b. The K values used were the values selected to be representative of each hydrostratigraphic unit in Section 4.8.2. The vertical gradient through Aquitard 1 in Field A was calculated to be 0.16 m/m from the average vertical gradient between the KA1 and KA9 well nests. The vertical gradient through Aquitard 1 in Field B was calculated to be 0.28 m/m from the average between the vertical gradient at

KA9 and KA5. The vertical upwards gradient between Aquifer 2/Aquitard 2 and Aquifer 1 was calculated from the average hydraulic gradient at the KA5 well nest and the KA9 well nest. It was assumed that the aerial extent of Aquitard 2 covered all of Field B and half of Field A, as the geological core logs suggest is the case. The sum of the groundwater inputs from vertical flow through Aquitard 1 from Fields A and B is 1.32 L/s and 1.13 L/s respectively. The amount of water entering Aquifer 1 from Aquitard 2 below was calculated to be 0.18 L/s. The total groundwater inputs to Aquifer 1 are estimated to be 2.63 L/s. The groundwater flux out of Aquifer 1 along the western edge of the site is estimated to be 2.48 L/s. It is not clear where the water in Aquifer 2 or Aquitard 2 originates from, but based upon the site geology and groundwater flow pattern (Fig. 4.29), it likely originated from upgradient of KA1. This result is considered reasonable considering the large number of assumptions that needed to be made to provide accurate values to this calculation. The fact that a spatially average K_v value was able to more accurately represent the groundwater flow through Aquitard 1 highlights the fact that significant spatial heterogeneities exist across the study site and that the groundwater flow regime at the farm is very complicated.

Using the spatially averaged groundwater flux results, it appears that all the water that enters Aquifer 1 from Fields A and B, leaves Aquifer 1 along the western property boundary of Field B. The fact that all water that leaves the Allin Farm in Aquifer 1 can be accounted for by all the water the enters Aquifer 1 from the Allin Farm property has significant implications in terms of down gradient water quality and land management. This implies that any N that leaches below the root zone on Fields A and B, should ultimately impact the water quality in Aquifer 1. Alternatively, any changes in surface nutrient management on Fields A and B should also have a significant impact on the water quality of Aquifer 1. Although, the reader is reminded that a large degree of averaging was used to derive this result and therefore it should be used with caution.

4.6 Groundwater Sampling Results

4.6.1 Nitrate Concentrations and Inorganic Water Quality

Nitrate has always been the contaminant of concern at the Allin Farm property and has been sampled during eleven sampling events at the site since 1997. All changes in nutrient management at the farm were implemented with the intention of reducing the amount of nitrate that leaches below the root zone and ultimately to reduce the nitrate concentrations in the groundwater. The first two sampling events were conducted by Gibson and Rudolph (1997) in 1997, followed by a series of samplings by Gibson Associates (2001) in 2001. The 1997 sampling events are herein referred to as the “baseline” sampling events to which most data collected as part of this study will be compared. As part of this present study, groundwater sampling resumed in June 2005. During this sampling event, samples were collected for anions and cations from the six original well nests and from the farm pumping well (Appendix I; Table I.1). The anion results for all parameters were similar to the results obtained from Gibson Associates from 2001 (Table A.5). Groundwater samples were collected and analyzed specifically for nitrate and chloride, six more times between 2005 and 2007. All groundwater nitrate concentrations are presented as mg/L nitrate as N. Groundwater chloride results are presented as mg/L chloride.

The results of all sampling events conducted between 1997 and 2007 are presented graphically for each monitoring well in each well nest in Figs. 4.30 to 4.45, with the corresponding data sets shown in Table I.3 in Appendix I. The calculated average groundwater nitrate concentrations on an individual well and well nest basis for 1997, 2000 – 2001, and 2005 – 2007 is presented in Table I.7.

The nitrate concentrations at the KA1 well nest (Fig. 4.30), which is screened in Aquitard 1, have increased 140% from the 1997 baseline average to the 2005 – 2007 average, from 6.9 mg/L to 16.5 mg/L. All samples collected in 1997 were below the 10 mg/L MAC drinking water limit and all samples collected from 2001 to 2007 were higher than the drinking water limit (note: only KA1-4 was sampled in 2001). All wells in the nest show a similar pattern of increasing nitrate concentrations. In contrast to the nitrate concentrations, the groundwater chloride concentrations (Fig. 4.31) in the wells at this nest have remained relatively constant or have declined. Since the KA1 well nest is located at the top of the groundwater flow system at the Allin Farm, any water that enters this well originated from upgradient and off-site. This increase in nitrate concentration at the well nest may be caused by increased nutrient applications at the upgradient agricultural property or may reflect high nitrate recharge water that has finally migrated to the well screens at KA1.

The KA2 well nest nitrate concentrations (Fig. 4.32) have increased significantly since 1997, with KA2-3 and KA2-4 showing about a 2000% increases from concentrations <1.0 mg/L to concentrations of 14.2 mg/L for KA2-3, and 9.2 mg/L for KA2-4. Each well at KA2 is screened in Aquitard 1. KA2-1 and KA2-2 have shown less dramatic increases of 230% and 85%, respectively. Like the KA1 well nest, the KA2 well nest is located at the top of the groundwater flow system at the Allin Farm, and any water that enters these wells must have originated from upgradient and off-site. This increase in nitrate concentration at the well nest may be caused by increased nutrient applications at the upgradient property or may reflect high nitrate recharge water that has finally migrated to KA2. The chloride concentrations in all wells at the KA2 well nest have decreased since 1997 (Fig. 4.33), but are generally still low and indicative of a commercial fertilizer source. These results may suggest that the influence of slowly infiltrating commercial fertilizer N has reached the well screens and begun to influence groundwater chemistry.

The KA3 well nest (Fig. 4.34) is located directly beside the outdoor liquid manure storage tank for the farm and is screened in Aquitard 1. The groundwater nitrate concentrations measured in 1997 ranged from 45.0 mg/L in KA3-1 to 76.3 mg/L for KA3-4. The concentrations remained high for the results of the 2001 sampling. The results of nitrate sampling from 2005 to 2007 show significant decreases in nitrate concentrations for all wells in the nest. KA3-1 has not been sampled since 1997 as is was destroyed sometime between 2001 and 2005. The nitrate concentration in KA3-2 decreased from 59.0 mg/L in May 1997 to 28.0 mg/L in August 2007. Similar decreases were observed in each well in this nest. Overall, the decrease in nitrate concentration at the well nest from the 1997 baseline average to the 2005 – 2007 average is 45%. The chloride concentration has generally decreased since 1997 (Fig. 4.35), coinciding with the decrease in nitrate concentration. The chloride concentration is still high enough to suggest that the source of nitrate and chloride is manure. The decrease in groundwater nitrate, without a change in source type suggests that surface loading of N decreased between 1997 and 2007 in this area. As part of the EPP for the Allin Farm, recommendations to reduce spillage during manure transfers were made. The large decrease in nitrate concentration at this well nest may be due to both reduced nutrient applications of N on the farm fields and reduced spillage of manure near the tank.

The nitrate concentrations at the KA4 well nest (Fig. 4.36) have either decreased or remained constant since 1997. Each well at this nest is screened in Aquitard 1. The nitrate concentration in KA4-1 has decreased from 46.5 mg/L in the 1997 baseline average to 29.8 mg/L in the 2005 - 2007 average. KA4-2 has shown similar decreases in nitrate concentration from 60.4 mg/L in the 1997 baseline average to 40.6 mg/L in the 2005 - 2007 average. KA4-3 has maintained a high nitrate concentration of 49.9 mg/L in the 1997 baseline average to 52.2 mg/L in the 2005 - 2007 average. In contrast to the other wells in the KA4 well nest, nitrate concentrations at KA4-4 are very low and have decreased slightly from 1.7 mg/L in the 1997 baseline average to 0.5 mg/L in the 2005 - 2007 average. The nitrate concentrations at this well may be affected by denitrification as nitrate is low, sulphate is high (171 mg/L), DO ranges from 8.23 to 0.48 mg/L, and Mn was detected (0.034 mg/L). The hydraulic conductivity of the surrounding geologic material is typical for Aquitard 1 and it is likely that it is screened in this unit, but because no geological log exists for this well, this explanation cannot be confirmed. In general, the groundwater nitrate data from this well nest is scattered and exhibits large differences in nitrate concentration between sampling events. The large degree of variability may be related to yearly pulses of groundwater nitrate that enter the wells and reflect nitrate that historically leached into the groundwater. The chloride concentrations have remained constant since 1997 (Fig. 4.37), which suggests that the source of the chloride and possible nitrate, have also remained constant. This result would imply that groundwater nitrate concentrations at KA4-1 and KA4-2 have decreased since changes to nutrient loading were implemented in 1997 without a change in nitrogen source. The presence of detectable Mn concentrations at this well nest suggest that conditions may be reducing for at least part of the year.

Data from the KA5 well nest (Fig. 4.38) shows decreasing groundwater nitrate concentrations for each well in the nest. This well nest is located at the edge of Field B, where in 1997 the nutrient applications of N were changed from a mix of manure and commercial fertilizer to commercial fertilizer only. KA5-1 is screened in Aquitard 1, where as the other wells are each screened progressively deeper in Aquifer 1. The reader is referred back to Fig. 4.29 for a diagrammatic representation of the conceptual model of the groundwater flow system beneath Fields A and B. It is believed that changes in groundwater chemistry at this well nest may reflect the decrease in nutrient loading on Fields A and B and that the pattern of the observed changes may relate to both the nutrient application history and the groundwater flow system. The most significant decrease in nitrate concentration is observed in KA5-1. The nitrate concentration in the 1997 baseline average was 32.1 mg/L, which has decreased to 11.2 mg/L in the 2005 – 2007 average. The May 2007 sample had a nitrate concentration of 9.7 mg/L, which meets the MOE MAC criteria for nitrate of 10 mg/L. This represents a 65% decrease in groundwater nitrate concentration at the top of the watertable. The nitrate concentration at KA5-1 has progressively decreased over the course of the current study from 13.2 mg/L in June 2005 to 9.7 mg/L in May 2007. The nitrate concentration at KA5-2 has decreased from 16.9 mg/L in the 1997 average to 13.7 mg/L in the 2005 – 2007 average, a 19% reduction in concentration. KA5-3 decreased from 30.7 mg/L in the 1997 average to 21.5 mg/L in the 2005 – 2007 average. KA5-4 decreased from 31.2 mg/L in the 1997 average to 21.9 mg/L in the 2005 - 2007 average. Overall, the nitrate concentrations at the well nest have decreased by an average of 38% since 1997 and the groundwater nitrate concentrations have decreased from an average of 27.7 mg/L in 1997 to 17.1 mg/L in the 2005 – 2007 average. The chloride concentrations at well KA5-1 have decreased from 23.0 mg/L in 1997 to 4.8 mg/L in March 2007 (Fig. 4.39). This large decrease in chloride concentration may be related to the decrease in nutrient loading to Field B. Chloride concentrations in KA5-2 have decreased slightly from 1997 to the present. The chloride concentrations in KA5-3 and KA5-4 have increased between 1997 and the present, but the data is highly scattered and which makes it difficult to draw a conclusion. Overall, groundwater nitrate results are consistent with the conceptual model of regional groundwater flow and changes to nutrient loading. The shallow groundwater at KA5, which is though to be representative of the shallow groundwater beneath Field B in both Aquitard 1 (KA5-1) and Aquifer 1 (KA5-2), has shown a significant decrease in nitrate concentration. This decrease is likely related to decreases in nutrient loading to Field B. The deeper groundwater at KA5, is represented by KA5-3 and KA5-4, which are both screened in Aquifer 1, show decreases in nitrate concentration. This decrease is thought to be a result of combined reductions in nutrient loading to Fields A and B.

The nitrate concentrations at the KA6 well nest (Fig. 4.40) have increased since 1997. It is not clear exactly what hydrostratigraphic unit is represented by these wells, although it is permeable and confined. All wells in the nest show a similar pattern of increasing nitrate concentrations from an average nitrate concentration at the well nest of 30.5 mg/L in the 1997 baseline to an average nitrate concentration of 40.9 mg/L from 2005 to 2007. This represents a 34% increase in nitrate concentrations at the well nest. The chloride concentrations have decreased in all wells at this nest since 1997 (Fig. 4.41). The increase in nitrate concentration and the decrease in chloride concentration may suggests that there has been a change in nitrate source since 1997. Because these well are flowing artesian and the hydraulic gradients are strongly upwards, the source of water and nitrate at KA6 is at least partially derived from a deeper flow system and may reflect land-use practices on fields that are beyond the study area. This suggests that there is a regional flow system originating from upgradient of the Allin Farm, where reductions to nutrient loadings have not been made and a regional nitrate plume still exists. Nitrate concentrations observed today may be a result of nutrient applications that occurred many years ago on an upgradient field and have finally reached the area below the Allin Farm.

The supply well at the Allin Farm (KA Well) is screened in Aquifer 2, and has been monitored for nitrate since 1997. The average nitrate concentration in the well in 1997 was 34.7 mg/L (Fig. 4.42) and the average chloride concentration in 1997 was 23.4 mg/L (Fig. 4.43). The nitrate concentration was essentially unchanged during the 2001 sampling that averaged 38.1 mg/L. Chloride was not analyzed in 2001. In 2003 a fire destroyed the primary barn at the site and the capacity for raising hogs decreased from 2000 to 500 head. The pumping rate of the well decreased from approximately 18.93 m^3/day (5000 gal/day) to 3.79 m^3/day (1000 gal/day). The results from the

2005 to 2007 sampling events show that nitrate concentrations have decreased to an average of 6.9 mg/L, which represents an 80% decrease in nitrate concentration, and chloride concentrations have decreased to an average of 10.3 mg/L, which represents a 56% decrease in concentration. It is speculated that the decrease in both nitrate and chloride concentrations are related to the reduced pumping rate of the well. It is possible the vertical hydraulic gradients caused by pumping introduced water with high nitrate and chloride concentrations to enter Aquifer 2 near the well and resulted in higher pumped concentrations than are currently being observed. The well KA9-3 is also screened in Aquifer 2 and is located approximately 200 m to the south of KA Well in Field A. The nitrate concentration has not exceeded 0.1 mg/L for the three sampling events conducted between February 2007 and August 2007. The chloride concentration averaged 3.8 mg/L over the same sampling events. The difference between the nitrate and chloride concentrations at the KA Well and KA9-3 suggests that nitrate and chloride are entering Aquifer 2 near KA Well, but not near KA9-3. This result leads to questions about the competency of the construction of KA Well, as it is possible that leakage along the well casing of high nitrate water is what caused historical nitrate impacts to this well.

Wells KA7 and KA8 were installed in October 2006 along the border between Fields A and B. KA7 is screened within Aquitard 1 in field B and KA8 is screened within Aquifer 1 in Field A. KA7 (Fig. 4.44) was sampled in October 2006 and March 2007 for nitrate, with measured concentrations of 0.3 and 2.6 mg/L, respectively for the two sampling events. The chloride concentrations for sampling events in October 2006 and March 2007 were 55.0 mg/L and 27.1 mg/L respectively (Fig. 4.45). These nitrate data do not correlate to the measured soil nitrate porewater concentrations. Due to problems installing the sand pack around the screened interval during well installations and sampling, these data are considered questionable and will not be used further. KA8 (Fig. 4.44) was sampled in October 2006 and, March and August of 2007. The October 2006 nitrate sample containing 18.0 mg/L may be artificially low because deionized water (DI) was used during drilling that was not properly purged prior to sampling. The groundwater nitrate concentrations of 30.6 mg/L measured in March 2007 and 31.2 mg/L measured in August 2007 are considered more representative of the actual groundwater conditions around the well. The chloride analytical results ranged from 26.0 mg/L for the October 2006 sampling to 18.8 mg/L for the August 2007 sampling (Fig. 4.45), which is consistent with other groundwater samples collected from Aquifer 1.

The well nest KA5-5, located near well nest KA5 in Field B, contains two wells, KA5-5, which is screened in Aquifer 1 and KA5-6, which is screened in Aquitard 2. Each well was sampled in February, March and August 2007 for nitrate. The average nitrate concentration measured in KA5-5 is 18.10 mg/L and in KA5-6 each sample has been <0.1 mg/L (Fig. 4.44). The chloride concentration measured in KA5-5 of 23.0 mg/L (Fig. 4.45) is similar to the range of values measured in KA5-3 and KA5-4 (25 mg/L). The chloride concentration in KA5-6 was substantially lower and was measured to range between 15.6 mg/L and 15.9 mg/L over three sampling events. KA5-5 is screened across Aquifer 1 at a similar depth to KA5-3 and KA5-4. This similarity is evident in the similarity between the groundwater chemistry for both chloride and nitrate. KA5-6 is flowing artesian and shows a strong upwards-vertical gradient between Aquitard 2 and Aquifer 1. This suggests that water from Aquitard 2 discharges into Aquifer 1 and that nitrate present in Aquifer 1 is disconnected from the deeper groundwater flow system as shown in Fig. 4.29. Aquitard 2 provides an effective barrier to downwards flow between Aquifer 1 and Aquifer 2 near KA5.

Well nest KA9 was installed in January 2007 and contains three wells: KA9-1, which is screened in Aquitard 1, KA9-2, which is screened in Aquifer 1, and KA9-3, which is screened in Aquifer 2 (Fig. 4.5). Each well was sampled in February, March and August 2007 for nitrate (Fig. 4.44). The average nitrate concentration measured in KA9-1 was 22.5 mg/L, in KA9-2 was 19.4 mg/L, and in KA9-3 was 0.1 mg/L. The chloride concentrations for wells KA9-1 and KA9-2 were similar and ranged from 21.8 mg/L in KA9-2 in February 2007 to 17.6 in KA9-2 in August 2007 (Fig. 4.45). The similarity between the chloride concentrations from wells in Aquitard 1 and Aquifer 1, suggests that the water could be from the same source, which further supports the conclusion that water travels vertically through Aquitard 1 and drains into Aquifer 1. The chloride concentration is similar between KA8 and KA9-2 (19 mg/L), which are both screened in Aquifer 1 and located in Field A. This suggests that the chloride in Aquifer 1, even at different locations within Field A, is derived from the same source. The chloride analytical results from KA9-3, which is screened in Aquifer 2, averaged 4.0 mg/L and are significantly lower than the other wells at this well nest, suggesting that at this location Aquifer 2 has not been impacted by agricultural activities.

The well nest KA10 is located in the southwest corner of Field B and contains two wells, KA10-1, which is constantly dry, and KA10-2, which is screened in Aquifer 1. KA10-2 has been sampled in February, March and August 2007 for nitrate (Fig. 4.44). The average nitrate concentration measured in KA10-2 for the three sampling events is 14.4 mg/L. The average chloride concentration is 5.1 mg/L over the same three sampling events (Fig. 4.45). The chloride concentration measured at KA10-2, in Aquifer 1, is similar to the concentration measured in KA5-1 and KA5-2 (8 mg/L), which may suggest that they are from the same source.

The geochemical parameters indicative of reducing conditions, such as elevated iron (Fe) and manganese (Mn) were observed in wells KA2-4, KA3-2, KA3-3, KA3-4, KA4-3, KA4-4 and KA Well. For this group of wells, Mn ranged from 0.02 to 0.034 mg/L and Fe ranged from <0.05 to 0.57 mg/L (Table I.1). These results suggest that some of the geochemical conditions required for reducing conditions are present in the aforementioned well. Each of the other wells at the Allin Farm had Mn and Fe concentrations at or below the detection limit of 0.05 mg/L and 0.002 mg/L, respectively, suggesting that the groundwater is not reducing and that denitrification is not likely to be responsible for the attenuation of nitrate in the groundwater at these locations. Nitrate reduction is still likely occurring in the root zone and removing quantities of nitrate in that zone. Nitrite and phosphate concentrations were non-detectable in all groundwater samples at all wells. In 2006, groundwater was sampled from the deepest well at each of the six original well nests for ammonia and Fe using a Hack© DREL 2400 field analysis kit (Table I.2; Appendix I). The results for ammonia showed that ammonia concentrations were very low across the study site, with minor concentrations above the detection limit (0.01 mg/L) at wells KA5-1 (0.05 mg/L) and KA6-1 (0.03 mg/L). The results from the Fe testing showed that Fe detectable above the detection limit of 0.02 mg/L in wells KA Well (0.09 mg/L) and KA3-3 (0.03 mg/L).

4.6.2 Field Parameters

The field parameters of pH, Eh, dissolved oxygen (DO), temperature and conductivity where measured in the field in the groundwater sampled taken from each well during most sampling events from 2005 to 2007 as part of this study (Table I.4). These parameters were measured to determine the redox condition at the study site to provide evidence for loss of nitrate concentration by denitrification. Gibson and Rudolph (1997) measured the same field parameters in the original 24 monitoring wells and the on-site pumping well in 1997. Their results are presented in Table A.4.

The pH measured in the groundwater at each well was neutral to slightly alkaline, except at wells KA3-3 and KA3-4, where the pH was consistently below neutral and ranged from 6.50 to 7.80. The conductivity was consistently measured between 300 μS and 600 μS, except for at the KA3 well nest, and wells KA4-3 and KA4-4, where conductivities ranged from approximately 500 1300 μS. Eh measurements were made only during the June 2005 sampling event. Eh values typically fall in the range of +100 to +300 mV relative to the standard hydrogen electrode, indicating oxidizing conditions. This result varies from the Eh measurements of Gibson and Rudolph (1997), which were typically between -70 and -100 mV, however, it is unclear if their result is presented relative to the standard hydrogen electrode. The groundwater temperature was measured in September 2006 and in March 2007 and the results reflect the seasonal changes in groundwater temperature, with the September 2006 average being approximately 11°C and the March 2007 average being approximately 8.5°C.

The DO concentrations measured at the KA1 well nest ranged from 8.0 mg/L to more than10.0 mg/L. At the KA2 well nest the depth to water was typically > 9.8 m and a bailer was used for sampling so accurate DO measurements were not attempted. In May 2006, the depth to water at the KA2 well nest was shallow enough to permit sampling using the Geopump, and during this event the DO concentrations measured ranged from 6.3 mg/L to >10.0 mg/L. At KA3, lower DO concentrations were encountered that ranged from 0.1 mg/L to 8.9 mg/L, with concentrations typically averaging 1.0 mg/L. DO concentrations at KA4 were typically >5.0 mg/L, with the exception of the August 2007 sampling event where concentrations in KA4-2,3,4 were all <1.0 mg/L. The KA5 well nest had DO concentrations ranging from 5.0 mg/L to >10.0 mg/L. Well KA5-6, which is screened in Aquitard 2, had low DO concentrations for the two sampling events that averaged 0.6 mg/L. The DO concentrations at KA6 ranged from 1.3 mg/L to 9.6 mg/L. The farm pumping well (KA Well), which is screened in Aquifer 2, had low DO concentrations ranging from 0.1 mg/L to 2.1 mg/L. KA9-3, which is screened in Aquifer 2, had DO values that averaged 2.0 mg/L, KA9-2, which is screened in Aquifer 1, had DO values that averaged 7.0 mg/L, and KA9-1, which is screened in Aquitard 1, had DO concentrations that averaged 2.5 mg/L. Due to the use of Waterra tubing to sample at KA10-2, no DO samples were collected.

Conditions that promote denitrification, such as low DO and negative Eh, generally are not present in the shallow groundwater at the Allin Farm. Generally, a DO concentration less than 2.0 mg/L is necessary for denitrification to occur (Appelo and Postma, 1999). DO concentrations measured at the Allin Farm are typically much greater than 2.0 mg/L, which suggests that the process of denitrification is not responsible for reducing the amount of nitrate present in the groundwater. Some wells show are wide range of variability in DO concentrations which may be related to seasonal changes in oxygen transport though the unsaturated zone, and may experience conditions conducive to denitrification during specific times of the year. At the KA3 well nest, low DO concentrations, elevated conductivity, detectable concentrations of Fe and Mn, and slightly acidic pH values, suggest that denitrification is occurring at this location and is likely responsible for removal of nitrate. Well KA4-4 has a lower than average DO concentration, elevated sulphate concentration, detectable concentrations of Fe and Mn, and elevated conductivity, which suggests that denitrification may be occurring at this well. Deep groundwater in Aquitard 2 (KA5-6) and in Aquifer 2 (KA9-3 and KA

Well), have low DO concentrations, which may indicate reducing conditions and possible denitrification at those locations.

4.6.3 Dissolved Organic Carbon

Dissolved organic carbon (DOC) was analyzed for each of the original monitoring wells and the pumping well at the study site to further determine if the conditions required for denitrification existed at the Allin Farm (Table I.5). DOC is an important electron donor for the reduction of nitrate (Appelo and Postma, 1999). DOC concentrations ranged from 1.84 mg/L in KA6-1 to 5.84 mg/L in KA3-3. The DOC values at the KA3 well nest were slightly elevated compared to the other well nests at the site. The range of DOC concentrations at the site are sufficient to help promote denitrification, however the presence of DO may limit nitrate from being reduced through denitrification at most locations at the Allin Farm.

4.6.4 Groundwater Isotopes of $\delta^{15}N$ and $\delta^{18}O$ in NO_3^-

The stable isotopic composition of nitrate (^{15}N and ^{18}O in NO_3^-) was analyzed to help determine the source of the nitrate in the groundwater at the Allin Farm (i.e., manure or commercial fertilizer), as well as to assess the possible occurrence of denitrification as a means to reduce the nitrate concentration in the groundwater. Because the BMP implementation on Field B involved changing nutrient applications of N from a fertilizer/manure mixture to only commercial fertilizer, it was believed that isotopic differences of $\delta^{15}N$ in NO_3^- in the nutrient sources could be used as a "tracer" to track the movement of the different sources in the subsurface, and to determine if post-BMP water had migrated to the saturated zone. Section 2.2 provides a detailed outline of identifying nitrogen sources using the $\delta^{15}N$ and $\delta^{18}O$ values in NO_3^-. As part of this study, the shallowest (KA*-1) and the deepest (KA*-4) wells at each original well nest and each of the new wells were sampled for $\delta^{15}N$ and $\delta^{18}O$ in NO_3^- on two separate sampling events during the study period (Table 4.11). This pattern was altered if at the time of sampling, the shallowest well was dry and/or if a well did not contain a high enough concentration of nitrate to perform the analysis.

4.6.4.1 $\delta^{15}N$ in Nitrate

The $\delta^{15}N$ of commercial fertilizer used at the Allin Farm was measured to be -0.9‰ and the manure was measured to be +9.4‰. In general, the $\delta^{15}N$ found in soil and groundwater nitrate produced from commercial fertilizers (ammonia based) averages +4.7‰ ± 5.4‰ and from animal wastes the nitrate produced averages +14.0‰ ± 8.8‰ (Kendall, 1998). This difference makes the two sources isotopically distinguishable in natural systems.

Wells KA3-3 and KA5-4 were previously sampled by Gibson Associates (2001) and analyzed for $\delta^{15}N$ in 2001 (Robertson, 2001). This does not provide a 1997 baseline result, but it does provide a historical reference. The $\delta^{15}N$ in KA3-3 was +10.8‰, and in KA5-4 was +10.4, which suggests a manure source of nitrate N in groundwater for both wells.

Figures 4.46 to 4.48 show a wide range of $\delta^{15}N$ values that vary between +2.7‰ and +23.2‰, which indicates that there are multiple sources of N at the study site responsible for nitrate in the groundwater. When these samples are separated into the typical commercial fertilizer and manure ranges, a distinct $\delta^{15}N$ isotopic separation between the different wells and fields emerges. The $\delta^{15}N$ values that were determined to be representative of commercial fertilizer derived from urea and/or ammonium sulphate ranged from +2.7‰ to +7.2‰ with a mean of +4.2‰ ± 1.1‰ (n = 11) and was found in groundwater in wells KA1-1, KA1-4, KA2-1, KA2-2, KA2-3, KA5-1, KA5-2, and KA10-2. The $\delta^{15}N$ values that were determined to be representative of animal manure derived from spreading of liquid swine manure ranged from +8.7‰ to+23.2‰, with a mean of +12.1‰ ± 3.0‰ (n = 22) and were found in groundwater in wells KA3-2, KA3-4, KA4-1, KA4-3, KA5-3, KA5-4, KA5-5, KA6-1, KA6-4, KA8, KA9-1, KA9-2, and KA Well. The relationship between which wells derived their source of nitrate from commercial fertilizers and which derived their source from manure is a function of both the land application of N and the groundwater flow system at the site.

Analysis of the groundwater flow patterns at the Allin Farm (Fig. 4.29) show that well nests KA1 and KA2 derive their water and presumably nitrate, from upgradient of the study site. The groundwater at both of these wells nests contain $\delta^{15}N$ from a commercial fertilizer source (+2.7‰ to +5.8‰) which suggests that the upgradient farmer(s) use commercial fertilizers as a source of N for their crops. Visual observations of fertilization practices from the upgradient farm near KA1, confirm that in 2006, urea was spread as a source of N. The groundwater flow pattern in Fig. 4.29 suggests that shallow groundwater beneath Field B (wells KA5-1, KA5-2, KA10-2) is derived from water that infiltrated through Field B, where commercial fertilizers have been spread since 1997. Deeper groundwater beneath Field B (wells KA5-3, KA5-4, KA5-5) is thought to originate from infiltration through Field A, where manure is spread as a source of N. The presence of $\delta^{15}N$ from a commercial fertilizer source in wells KA5-1, KA5-2, and KA10-2 (+3.5‰ to +7.2‰) confirm that nitrate in the shallow groundwater beneath Field B is derived from commercial fertilizer. This also correlates with the results of the porewater $\delta^{15}N$ isotopes and confirms that the time period between 1997 and 2006 was sufficiently long enough for water that recharged in 1997 to reach the watertable and that all traces of manure N (from manure spreading prior to 1997) have been flushed from the unsaturated zone beneath Field B. The presence of manure δ^{15}N in the deep groundwater in Aquifer 1 beneath Field B, in wells KA5-3, KA5-4, and KA5-5 (+9.6‰ to +11.3‰) adds an additional line of evidence that supports the groundwater flow system proposed in Fig. 4.29. The remaining wells and well nests contain nitrate N that was derived from a manure source (δ^{15}N ranges from +9.7‰ to +23.2‰). This result is consistent with nutrient applications of manure N as conducted on all areas of the farm except Field B.

4.6.4.2 δ^{18}O in Nitrate

The original nitrogen source for both the manure and the commercial fertilizers used at the Allin Farm is ammonia, which does not contain any oxygen. During nitrification three oxygen atoms (O) are added to the N atoms to produce nitrate (NO_3^-). Two of the oxygen atoms are obtained from water molecules, where the δ^{18}O is typically -10‰, and one of the oxygen atoms is obtained from atmospheric oxygen, where the δ^{18}O is typically +22‰. This results in an initial δ^{18}O value for nitrate at the study site of approximately 0‰. The δ^{18}O values in the groundwater at the study site ranged from -2.5‰ to +13.2‰. Isotopically δ^{18}O derived from wells where commercial fertilizer was the source of N (δ^{18}O ranged from -2.5‰ to +1.7‰, mean = +0.2‰ ± 0.9‰, n = 11) was isotopically distinct from δ^{18}O derived from wells where manure was the source of N (δ^{18}O ranged from -0.4‰ to +13.2‰, mean = +3.2‰ ± 2.4‰, n = 22). The enrichment of δ^{18}O is likely due to denitrification of nitrate at specific locations (discussed in Section 4.9.4.3).

Groundwater at well nests KA1 and KA2 have δ^{18}O values indicative of commercial fertilizer (-2.52‰ to +1.69‰), which is consistent with the δ^{15}N results. Statistically, δ^{18}O values in groundwater beneath Field B (wells KA5-1, KA5-2, KA5-3, KA5-4, KA5-5, and KA10-2) are not isotopically distinguishable as δ^{18}O from commercial fertilizer ranges from -1.31‰ to +0.82‰ and δ^{18}O from manure ranges from +0.88‰ to +2.74‰, although the manure source may be slightly enriched. Groundwater at the remaining wells and well nests are consistent with the typical range of δ^{18}O values assumed for manure N of approximately 0‰.

4.6.4.3 Enrichment of δ^{15}N and δ^{18}O in Nitrate by Denitrification

Groundwater nitrate concentrations at most well nests that derive their source of water and nitrate from the Allin Farm property have either shown improvements (i.e., decreases in groundwater nitrate concentration) or have remained stable since BMPs were implemented in 1997. Wells KA4-1, KA4-2, KA5-1, KA5-2, KA5-3, and KA5-4 show substantial decreases in groundwater nitrate concentration with no enrichment of either $\delta^{15}N$ or $\delta^{18}O$ isotopes (Figs. 4.46 to 4.48). This result suggests that denitrification is not occurring at these well locations, which is consistent with the groundwater field parameter chemistry especially DO concentrations, and that denitrification is likely not responsible for decreasing groundwater nitrate concentrations. In contrast, wells KA3-2, KA3-4, KA4-3, and KA Well show isotopic enrichment of $\delta^{15}N$ and $\delta^{18}O$ by a factor of approximately 2.1 and decreasing or stable nitrate concentrations. These results suggest that denitrification is occurring at these well locations and that it is likely responsible for removal of nitrate. The amount of nitrate potentially removed by denitrification was not estimated as part of this study.

4.6.4.4 Relationship Between $\delta^{15}N$ and Groundwater Nitrate Concentration

Figures I.1 to I.7 show that vertical changes in $\delta^{15}N$ isotopes and groundwater nitrate concentrations are directly related. The general trend is that higher nitrate concentrations are related to more enriched $\delta^{15}N$ isotopes and that nitrate concentration increases with depth. This suggests that manure N is associated with higher nitrate concentrations and that improvement to groundwater quality as a result of changing nutrient applications practices are most evident in the shallow groundwater.

4.7 Field Recharge Estimates

Due to uncertainties associated with estimating recharge (R), multiple techniques were employed at the Allin Farm study site. A bromide (Br) chemical tracer was applied at the soil surface at three locations in December 2005 and was later cored in April 2006 and February 2007 to determine the subsurface distribution of the Br pulse. A water budget method was used, whereby all the variables in the water-budget equation (Equation 3.14) were calculated or estimated and the residual is then an estimation of R. Run-off (RO) was not accounted for in the water balance R estimation so R is equal to R-RO. During most of the year, RO is considered to be small, with the exception of the spring melt, and therefore the error associated with excluding RO is considered minimal. A major limitation to the water balance method is the accuracy of the recharge estimate is a function of the accuracy of which the other components are measured, with the most critical often being evapotranspiration (ET; Scanlon et al. 2002). A daily reference ET value (ETo) was calculated using a combination of local and regional measured values, as well as standard reference values found in Allin et al. (1998). An explanation behind calculation of ET and ETo is presented in Appendix E. Daily precipitation was measured in a tipping bucket rain gauge at the study site from October 2006 to December 2007. All other precipitation data were obtained from local meteorological stations. Historical tracers of nitrate and $\delta^{15}N$ in NO_3^- were used to estimate recharge rates. Due to uncertainties in the application timing, application concentration, as well as the likely non-conservative behaviour of the chemicals, recharge estimations for nitrate and $\delta^{15}N$ in NO_3^- are employed qualitatively. Table 4.12 presents estimates of groundwater recharge rates from 1996 to 2007 using the three methods described above and displays the results on a yearly basis.

4.7.1 Meteorological Data

Meteorological data for the study site were collected from various local and on-site sources during the course of study (see Section 3.13 and 3.14.2). The average daily temperature and yearly precipitation for the city of Port Hope, located approximately 18 km south of the study site along the shore of lake Ontario (Fig. 2.1), from 1971 to 2000 as recorded by Environment Canada (Environment Canada, 2007) were 7.4°C and 832 mm respectively. The average daily temperature and precipitation measured for the study site from Jan. 1, 2005 to Dec. 5, 2007, are shown in Fig. 4.2. The annual precipitation at the study site for 2005, 2006, and 2007 was, 888.6 mm, 1033.7 mm, and 617.0 mm, respectively. The mean daily temperature at the study site for 2005, 2006, and 2007 was, 8.2°C, 8.4°C, and 8.0°C, respectively. The Allin Farm study site had average daily temperatures from 2005 to 2007 that were warmer than the historic average from the Port Hope meteorological station. This may be due to geographic differences between the study site, which is located 18 km inland from lake Ontario, and Port Hope, which is located directly on the shore of the lake. The data show that 2006 was an exceptionally wet year having approximately 20% more rainfall than average, and 2007 was an exceptionally dry year having approximately 26% less rainfall than average. Additional meteorological data are provided in Appendix D.

4.7.2 Bromide Tracer

Figs. 4.49 to 4.51 show vertical profiles of bulk bromide (Br) concentration in soil, with the calculated center of mass determined from core data for the three-bromide tracer sites applied to Fields A and B (BT1, BT2, and BT3). The BT1 location is situated near KA5 well nest on flat ground, the BT2 tracer location is on a hill that slopes to the west near the KA1 well nest, and BT3 is located on flat ground in between KA9 nest and KA8 (Fig. 4.4). The BT1 tracer location was cored in April 2006 and again in February 2007. The BT2 and BT3 locations were only cored in February 2007. Each core was drilled deep enough to capture the anticipated lower extent of the applied bromide tracer pulse.

The center of Br mass for the April 2006 and February 2007 coring events at the BT1 tracer location were 0.56 mbgs and 2.59 mbgs respectively (Fig. 4.49). This translates to yearly recharge rates for the two coring events of 217 mm/yr and 375 mm/yr (Table 4.12). For the April 2006 core, 0.98 kg Br or 20% of the total mass applied was estimated to have been recovered from the soil below the applied area. This assumes that the observed concentration of Br was the same everywhere beneath the area of the tracer application. For the February 2007 core, 2.19 kg Br or 44% of the total Br mass applied was estimated to be below the applied area. About 90% of the recovered Br mass was found between 1.72 mbgs and 3.11 mbgs, with less than 4% of the Br present in the upper 1.72 m of core. The shape of the concentration versus depth curve suggests that the Br tracer movement was conservative and moved by matrix dominated piston flow through the till of Aquitard 1 at this location. Heterogeneities in the soil profile and in the infiltration of water likely caused the difference in recharge rates from the two coring events and the loss of Br mass.

The bromide tracer sites BT2 and BT3 were cored in February 2007, and the center of Br mass at each location was measured to be 0.25 mbgs and 0.30 mbgs respectively (Figs. 4.50 and 4.51). These values equate to yearly recharge rates of 41 mm/yr and 44 mm/yr. These results differ greatly from the results of the two coring events at BT1 by almost one order of magnitude. For BT2, 0.06 kg Br or 1% of the total Br mass applied was estimated to be below the applied area. For BT3, 0.04 kg Br or 1% of the total Br mass applied was estimated to be below the applied area. No Br was recovered from below 0.92 mbgs at either tracer location. Possible reasons why the Br did not move deep in the soil column includes: (1) the bromide was washed off of the top of the soil and away from the tracer location prior to infiltration; (2) there is a large horizontal component of interflow type transport that caused the bromide to move laterally beyond the tracer location; and (3) an impermeable soil layer exists at approx. 0.92 mbgs that prevented vertical infiltration and promoted horizontal flow. Coring records show that the soil becomes denser below the zone of root growth (0.70 m) at the BT2 and BT3 locations, but not at the BT1 location. The BT2 location is situated on a hill slope that may have enhanced horizontal flow and reduced vertical infiltration.

Despite the underestimation of Br mass at each Br tracer site, the Br tracer test is considered robust, because it is a direct measurement of the movement of solutes as a result of groundwater recharge over the area of Br application. The peaks of Br mass were easily identifiable in the BT1 core, indicating that it had adequately captured the movement of the tracer. The results of BT2 and BT3 should be treated with caution, as an explanation for the lack of Br mass below 0.92 mbgs or the complete loss of Br mass, has yet to be determined. Overall, the results from these tests highlight the large amount of heterogeneity beneath the agricultural fields within a soil that geologically speaking would be considered homogeneous. By taking the mean recharge rate from each of the four-recharge estimates from the three Br tracer sites, a "site wide" Br recharge rate can be estimated. The recharge rates as estimated for the Allin Farm from the Br tracer results is 170 mm/yr. The values of recharge measured may be quite accurate of "realistic" site conditions, however one should only use the qualitative location of the center of mass for recharge estimates.

4.7.3 Water Balance

In the water balance method, data from the study site meteorological station and from local meteorological stations (explained in Section 3.11.2.2) were used to estimate the evapotranspiration rate (ET), which was then subtracted from the observed precipitation to obtain a recharge (R) estimate. Change in soil water storage was considered to be negligible, as was the difference in groundwater flow into and out of the study site. Run-off (RO) was not considered as part of the water balance, but observations made the Allin Farm suggest that it may only affect R estimates during the spring melt and is considered negligible the rest of the year. Detailed ET and water balance calculations and raw data are included in Appendix E.

Precipitation was assumed to vary over time but not space at the study site. The four fields were typically planted with the same crop type during each growing season during the study period. Calculation of ET was based upon a method by Bekeris (2007), which was adapted from Allen et al. (1998) to be representative of conditions present in southern Ontario. For time periods where ET is less than precipitation, it is thought that there is a surplus of water at the site and therefore, recharge occurs (Fig. E.1). The time period between early fall (Late September) and the winter freeze (December) have the greatest difference between ET and precipitation, and it is thought that much of the years total recharge occurs during this period, when the fields are bare and precipitation is heavy.

The water balance method was used to estimate R for each year between 1996 and 2007 (Table 4.12) and provided R estimates that ranged from -153 mm/yr in 2007 to 367 mm/yr in 1996. The mean R as estimated from the water balance, assuming R = 0 for years where R was calculated to be negative, was 111 mm/yr. Precipitation rates varied significantly between 1996 and 2007 and ranged from 1136 mm (1996) to 617 mm (2007), with a mean value of 864 mm. Environment Canada measured an average yearly precipitation rate between 1971 and 1999 at a weather station in Peterborough Ontario to be 900.5 mm. Although soybeans were planted in 2005 and 2006, and corn was planted in 2007, the ET was similar for each of the three years (764, 774, and 770 mm) and averaged 769 mm/yr. Bekeris (2007) estimated ET at a farm near Woodstock Ontario under cropping practices and similar geology to be approximately 826 mm during 2005. Overall, ET is based on empirical crop coefficients and numerous other field parameters including crop height, root depth, growth stage lengths and soil water availability, which due to the lack of detailed field observations, are also estimated from the literature (Section 3.14.2.1). The assumptions required to calculate actual ET limit the accuracy of water balance method for the estimation of recharge.

4.7.4 Historical NO_3^- as a Qualitative Tracer in the Unsaturated Zone

Historical tracers occur as a result of human activities or past events, where the input history of a particular chemical is known (Scanlon et al., 2002). Samples from soil cores collected overtime can be used to estimate R from changes in peak soil nitrate profiles. This method is considered qualitative, rather than quantitative because of the uncertainty in the exact timing and amount of N application and because nitrate may not act conservatively in the subsurface.

Cores were collected at the BT1 location twice during the study period and sampled for nitrate (Fig. 4.15). The peak nitrate concentration in the April 2006 soil profile was centered at 1.52 mbgs. Downwards migration of soil water that has a low concentration of nitrate can be observed in the February 2007 soil profile between 0.77 and 2.62 m, when compared to the April 2006 profile. The peak nitrate concentration is the February 2007 core is at 2.53 mbgs. Assuming that the peak concentration of nitrate has moved conservatively between April 2006 and February 2007, the groundwater recharge rate is calculated to be 138 mm/yr, using the tracer velocity method (Equation 3.10; Section 3.14.1).

4.7.5 Estimation of Recharge Rate

The results from three methods of estimating recharge all confirm that there is a large degree of spatial and temporal heterogeneities associated with estimating the groundwater recharge rate at the study site. A minimum boundary condition for recharge can be established at the site by using the presence of commercial fertilizer inferred from the $\delta^{15}N$ isotopes that were initially applied in 1997 in the groundwater in wells KA5-1 and KA10-2, which are screened to a depth of 5.37 and 9.48 mbgs respectively. This provides a minimum R boundary condition for the site of approximately 0.95 mm/yr. Results from the Br tracer tests estimate recharge to be 170 mm/yr. This recharge rate is considered the most accurate as it is to only test robust enough to account for site heterogeneity. Movement of nitrate through the unsaturated zone provided a recharge estimation of 140 mm/yr.

Even with all of the inherent problems associated with estimating recharge using a water balance, this method provided an estimate of 111mm/yr by averaging each of the recharge estimates between 1996 and 2007. This is likely an underestimation of recharge as the calculation of ET is very theoretical and may be much lower due to poor access to stored soil water during times of lower than average precipitation. By weighting the three-recharge rates by the accuracy of the method (the bromide tracer was considered to be the most accurate and the water balance the least accurate) the site wide recharge rate was estimated to be 160 mm/yr. This recharge rate is the same as the value typically used in the literature as the standard R for southern Ontario (e.g., Barry et al. 1993).

4.8 Average Linear Groundwater Flow Velocity and Travel Times

To determine the time it will take to observe changes to the groundwater quality at the western property boundary near KA5 or KA10, the total travel time of a hypothetical water particle from the ground surface to the edge of the Allin Farm property must be calculated. Significant topographical elevation changes are present at the study site. Horizontal average linear groundwater flow velocities (Section 3.10) were calculated between wells that lie on the same groundwater flow path for the May and August 2007 monitoring events (Figs. 4.27 and 4.28). The average *n* for Aquitard 1 and Aquifer 1 within Fields A and B were estimated to be 0.19 and 0.26, respectively, from the porosity measured in all soil cores, for the specific units (Appendix G). The K values for each well pair were calculated from the average K value from 2007 slug testing results. At KA8, no K value was calculated from slug testing, so the estimated K value for Aquifer 1 of 1.55×10^{-5} m/s was used. The average linear horizontal groundwater flow velocities between corresponding wells, in both Aquitard 1 and Aquifer 1 are presented in Table 4.13. These velocities range from 2.4 to 9.0 m/yr between wells screened in Aquitard 1. The average linear groundwater flow velocity in Aquifer 1 between well pairs KA9-2 and KA5-4, and KA8 and KA10-2 is 93.5 and 83.2 m/yr respectively. This indicates that horizontal flow though Aquifer 1 dominates the movement of groundwater laterally at the study site.

The vertical average linear groundwater flow velocity was calculated for water movement through Aquitard 1 to obtain the recharge velocity through the unsaturated zone (equation 3.7) and for the vertical darcy velocity through the saturated zone (equation 3.6). The vertical groundwater flow velocities through Aquitard 1 or between Aquitard 1 and Aquifer 1 for each well nest are presented in Table 4.14. The velocity of vertical groundwater flow through the unsaturated zone was estimated to range between 0.88 to 1.30 m/yr based upon differences in soil moisture content. The vertical flow velocities through the saturated sediments of Aquitard 1 were estimated to range from 2.18 to 3.21 m/yr. Gerber et al. (2001) used the presence of tritiated porewater and hydraulic head profiles to estimate the vertical groundwater flow velocity through the Newmarket Till to be > 1.0 m/yr. This fits the range of vertical flow velocities measured as part of this study. The two orders of magnitude difference in K between Aquitard 1 and Aquifer 1 suggest that vertical flow will dominate in Aquitard 1 and horizontal flow will dominate in Aquifer 1.

4.8.1 Travel Time

The travel time for a particle at ground surface to reach the western property boundary in Field B was calculated using the average linear groundwater flow velocities determined in the previous section (Table 4.13 and 4.14). Physical properties of the various stratigraphic units were obtained from Table 4.4. The travel times were calculated along the A-A’ and D-D’ cross-sections for travel between well nests KA9 and KA5, and wells KA8 and KA10-2 (Table 4.15). From ground surface at KA5 to Aquifer 1 beneath KA5, the total travel time was calculated to be 6.0 yr, which indicates that the effects of reducing nutrient applications of N near KA5 would have reached Aquifer 1 by the time the study began in 2005. The presence of commercial fertilizer $\delta^{15}N$ in the unsaturated zone porewater and in the shallow watertable at KA5-1 and KA5-2, further substantiate this finding. From ground surface at KA9 to Aquifer 1 beneath KA5, the total travel time is 10.9 yr. This result suggests that only samples collected in 2007 would reflect the change in nutrient applications. Groundwater nitrate samples collected in 2005 and 2006 from wells KA5-3 and KA5-4 show the same trends in nitrate and chloride concentrations as the 2007 samples. This indicates that the estimates of groundwater travel time have overestimated the amount of time it would take a particle at ground surface near KA9 to reach Aquifer 1 beneath KA5. From the ground surface at KA10, it was calculated that it would take a particle at ground surface 8.7 yr to reach Aquifer 1. This well was not installed and sampled until February 2007, and by that time the influence of changing land-use practices would have reached the watertable. $\delta^{15}N$ isotopes indicative of commercial fertilizer in the porewater of the unsaturated zone and in the groundwater at KA10-2 further indicate that the over the last 8.7 yrs the effects of reducing N fertilizer applications and changing from manure to commercial fertilizer have migrated through the unsaturated zone and have begin to affect the groundwater chemistry. From the ground surface at KA8 to Aquifer 1 beneath KA10, the total travel time is 8.3 yr. The vertical gradient, the θ_v, and n were assumed to be equal to the values obtained at KA9 as no vertical hydraulic information was collected from KA8. The averaged K of Aquifer 1 (1.55×10^{-5} m/s) was assumed to be representative K at KA8.

Based upon the groundwater travel times, it would appear that by the time this study began in 2005, all water at the surface of Field B in 1997, and therefore the effects of implementing a BMP in

1997, have reached the watertable. All of the groundwater sampled as part of this study at KA5, KA9, KA8 and KA10 is representative of post-BMP conditions. Due to a lack of detailed geological information from beneath Fields C and D, no groundwater travel times could be calculated for a particle on the surface in 1997 and leaving the property to the west in Aquifer 1. Vertical travel times from the surface to the mid-point of the well screens for each well in Fields C and D can be estimated with the exception of KA6 (Table 4.15). The results show that vertical groundwater velocities at well nests KA1, KA2 and KA4are not fast enough to observe the effects of changing land use practices in 1997 at the watertable today. The vertical groundwater velocity is fast enough at KA3 so that the effects from changing land-use practices in 1997 have had the time to migrate to the watertable and influence groundwater chemistry.

Generally, the estimated groundwater travel time fits with the conceptual model of groundwater flow and contaminate transport following nutrient reductions in 1997. Based upon a recharge rate of 160 mm/yr, water that recharged in 1997 has migrated to the watertable at each well nest confirming that samples collected as part of this study reflect groundwater that has been influenced by the BMP. This result further substantiates the results of the $\delta^{15}N$ or $\delta^{18}O$ isotopes and shows that the improvements to groundwater quality beneath the Allin Farm are directly related to the change in nutrient management practices and occurred within the expected time period, based upon the estimated groundwater travel times. It would appear that the time period between 1997 and 2005 was sufficient to flush most nitrates derived from manure from Aquitard 1 and the upper portion of Aquifer 1 beneath Field B, and replace it with a lower concentration of nitrate derived from commercial fertilizers. Along the A-A' and D-D' transect, water the infiltrated near the western edge of Field A has had sufficient time to migrate through the subsurface to be presently located along the western boundary of Field B. The calculated groundwater travel times fit the conceptual model of groundwater flow as proposed in Fig. 4.29. If vertical groundwater flow did not dominate transport through Aquitard 1, it is unlikely that any of the effects of implementing a BMP in 1997 would be able to presently influence groundwater chemistry.

It must be noted that a large number of assumptions were made to reduce the heterogeneities associated with many of the values used to calculate groundwater flow velocities and ultimately travel times. In the opinion of the authors, parameters such as the groundwater recharge rate, the hydraulic conductivity of Aquitard 1, and the porosity and moisture content of the soil in Aquitard 1, contain large degrees of uncertainty, which leads to an overall uncertainty for groundwater transport calculations.

4.9 Estimation of Groundwater Nitrate Concentrations from Nitrogen Budget

An objective of this project has been to determine the effects of reducing nutrient applications using an agricultural BMP to help reduce nitrate loading to groundwater. As part of this objective, historical and yearly effects of reduced nutrient applications of N were compared to the groundwater quality. Historical records of groundwater quality allow a direct comparison between the nitrogen loading to groundwater (N_{pl}) as predicted by the N-budget method (Section 4.2; Table 4.2) and the measured groundwater nitrate concentrations (Table I.3). The N-budget approach for estimating groundwater nitrate concentrations are most useful at farms that have been under cultivation for a long enough period of time that they are at or very near equilibrium in terms of changes in organic matter and soil N (Fried et al., 1976; Barry et al. 1993). An established farm that has been practicing one particular management and cropping strategy for decades, such as the Allin Farm, would likely be at a state of equilibrium prior to nutrient reductions in 1997. If the predicted nitrogen (as nitrate – NO_3^--N) loading closely matches the observed groundwater nitrate concentration trends at the study site, this would suggest that all nitrate present in the groundwater can be accounted for by nutrient leaching at the site. It will also give confidence to the accuracy of the historical farming records, as well as the assumptions and literature values selected when calculating the farm N-budget.

Section 3.15.3 describes the theory and equations behind predicting the nitrate concentration in groundwater from N-budgeting. The complete results of this comparison are presented graphically in Fig. 4.52 and listed in Table 4.16. A recharge rate of 160 mm/yr was applied to all fields. Prior to reducing nutrient applications (pre-1997), the N_{pl} was calculated to be 88.3 kg N/ha for all fields (Table 4.2), and therefore the predicted groundwater concentration under Fields A, B, C, and D, is 55.2 mg/L. Because groundwater nitrate concentration data were not available prior to1997 (pre-BMP) the groundwater nitrate concentrations beneath each field at the study site were estimated from the average of the two sampling events in 1997 from the wells at each well nest that were assumed to best represent the groundwater chemistry at the time. Under Field A, the groundwater nitrate concentrations for the pre-BMP conditions were obtained by averaging the 1997 nitrate concentrations from KA3-1, KA5-3 and KA5-4 (37.39 mg/L). As shown by the groundwater flow path (Fig. 4.29), the water found in KA5-3 and KA5-4 is likely derived from Field A. Assuming no changes to groundwater flow between 1997 and the present, the water found in KA5-3 and KA5-4 in 1997 was derived from Field A and can therefore be used as a surrogate for the expected groundwater concentrations under that field. The current groundwater nitrate concentrations beneath Field A were calculated from the 2005 – 2007 (post-BMP) average of KA9-1, KA8, and KA3-2 (26.38 mg/L). For Field B, the nitrate concentration at KA5-1 measured in 1997 (32.09 mg/L) was thought to represent the pre-BMP groundwater conditions and the 2005 – 2007 average between KA5-1 and KA10-2 (12.83 mg/L) was used to represent the post-BMP groundwater conditions. For Field C, the groundwater nitrate concentration for pre-BMP conditions were estimated from the 1997 concentration at KA4-1 and KA3-1 (47.38 mg/L). For post-BMP conditions, the groundwater nitrate concentration was estimated from the 2005 – 2007 average at KA4-1 and KA3-2 (29.04 mg/L). For Field D, the groundwater nitrate concentration for both the pre- and post-BMP conditions were estimated from the nitrate concentration at KA6-1 of 32.25 mg/L and 39.75 mg/L respectively.

The N-Budget provided a reasonable estimate of both the Pre- and Post-BMP groundwater nitrate concentrations at the Allin Farm. Utilization of this method can provide a quick, non-invasive estimation of the expected effects of reducing N applications as art of a BMP. They also provide a quick method for determining how far along the BMP effects are at a particular site. This result could be further refined by measuring many of the parameters of the N-Budget on-site rather than relying on literature values.

4.10 Nitrate Mass Balance

4.10.1 Nitrate Mass Flux and Mass Loading from Soil Cores

The nitrate mass flux was calculated from the porewater nitrate concentration (Section 4.7.1) and the recharge estimate (Section 4.10.4), for each soil core drilled at the study site. This methodology closely follows the technique of Bekeris (2007) in calculating the post- and pre-BMP conditions at a farm near Woodstock, ON. The mass flux was determined at different locations for Fields A and B (Table 4.17). Average porewater nitrate concentrations were determined for the soil below the zone of root growth (i.e., below 0.70 m) because Bekeris (2007) suggests that variability in nitrate concentrations in the root zone can lead to an overestimation of the nitrate mass flux. The average porewater nitrate concentration from the soil cores within Aquitard 1 was slightly less under Field B (17.6 mg/L) than Field A (19.1 mg/L). The total N mass loading to the watertable as estimated from soil cores is 0.70 t NO_3/yr. The calculated mass load from Field A was determined to be 0.48 t NO_3/yr, and from Field B was determined to be 0.22 t NO_3/yr (Table 4.17). This suggests that Field A, is responsible for approximately twice as much nitrate loading to the watertable than Field B, which is consistent with the difference in area between the two fields.

The small difference between the soil core nitrate concentrations within Fields A and B are not consistent with the large difference in groundwater nitrate concentration observed between the two fields. Especially in Field B, the reductions in groundwater nitrate concentration suggest that Aquitard 1 would be significantly flushed of Pre-BMP nitrate, thus leading to lower groundwater nitrate concentrations. The limited spatial data obtained from soil cores were likely not able to accurately capture the effects of the BMP. The groundwater nitrate concentrations, especially the samples collected at KA5 at the base of the flow system, are a mixture of all water and nitrate that infiltrated though Fields A and B. The groundwater samples do not contain any spatial bias like the soil cores may.

4.10.2 Nitrate Mass Balance - Aquifer 1

The results of the groundwater flux estimation into and out of Aquifer 1 (Section 4.8.5; Table 4.10) indicates that most of the groundwater that enters Aquifer 1, enters through infiltration beneath the footprint of Fields A and B. Groundwater migrates vertically through Aquitard 1 and upon reaching Aquifer 1, travels horizontally to the west within the aquifer and exits the site along the western property boundary. A small percentage of groundwater enters from vertically upwards discharge from Aquitard 2. It was shown that most of the nitrogen that is leached below the root zone on Fields A and B should eventually enter Aquifer 1 and be transported to the west and move off site. A comparison was be made between the nitrate mass loading to Aquifer 1 for Fields A and B, for pre- and post-1997 nutrient reductions based upon measured groundwater nitrate concentrations (Table 4.18). No nitrate mass flux was calculated for upward inputs from Aquitard 2, because no nitrate is present in the groundwater in this hydrostratigraphic unit. Prior to implementing a BMP in 1997, the sum of the nitrate entering Aquifer 1 was estimated to be 2.73 t NO_3/yr and the sum of the nitrate exiting Aquifer 1 was estimated to be 2.71 t NO_3/yr. Following the implementation of a BMP in 1997, the sum of the nitrate entering Aquifer 1 was estimated to be 1.56 t NO_3/yr and the sum of the nitrate exiting Aquifer was estimated to be 1.55 t NO_3/yr. Although these results match exceptionally well, there still a large amount of temporal and spatial variability associated with groundwater nitrate concentrations and mass loading calculations. These results suggest that as a result of decreasing nutrient loading to the land surface in 1997, the total mass load of nitrate exiting the Allin Farm property has decreased by 43%. The mass of nitrate present in Aquifer 1 can be accounted for from nitrate derived from nutrient applications at the Allin Farm, entering the aquifer from the leaching below Fields A and B. Nitrate inputs into Aquifer 1 from upgradient sources are small because Aquifer 1 is believed to pinch out beneath Field A.

The post-BMP N loading to Aquifer 1 predicted from groundwater nitrate concentrations (1.56t/yr) varies considerably from the N loading as predicted from the soil cores (0.70 t/yr). The N loading estimated from the groundwater nitrate concentrations provides an average value that represents all of the nitrate that leaches through the unsaturated zone and reaches the watertable, as such, local heterogeneities such as differences in recharge rate, soil type, and N application rate are all taken into account. N-loading estimates from soil cores are only representative of the location were the core was collected and is variable based upon local heterogeneities. N loading calculated from groundwater nitrate concentrations are considered to be more representative of the site in general and therefore soil core N loading will not be considered in any further discussion.

Table 4.1 - Crop history, crop yield, and total nitrogen applications on each field at the Allin Farm between 1996 and 2007

Field	Nutrient Application (kg N/ha) and crop history	Pre-BMP	Post-BMP											
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Average
A (Area = 15.9 ha)	Crop type	corn	corn	corn	soybeans	corn	corn	corn	corn	corn	soybeans	soybeans	corn	-
	Yield (t/ha)	5.0 - 7.8	5.6	5.9	4.2	7.1	3.6	7.8	7.8	6.9	4.0	4.4	6.9	-
	Fall Manure (previous year)	199	117	131	135	0	146	168	0	44	0	0	0	67
	Spring Manure	0	0	0	0	0	0	0	89	98	0	0	0	17
	Starter Fertilizer	3	3	3	0	3	3	3	3	3	3	3	3	3
	Commercial Fertilizer[1]	84	90	67	0	129	78	78	78	84	0	0	129	67
	Total Application Rate	286	210	202	135	132	228	250	170	230	3	3	132	154
B (Area = 7.9 ha)	Crop type	corn	corn	corn	soybeans	corn	corn	corn	corn	soybeans	soybeans	soybeans	corn	-
	Yield (t/ha)	5.0 - 7.8	5.6	5.9	4.2	7.1	3.6	7.8	7.8	4.2	4.0	4.4	6.9	-
	Fall Manure (previous year)	199	0	0	0	0	0	0	0	0	0	0	0	0
	Spring Manure	0	0	0	0	0	0	0	0	29	0	0	0	3
	Starter Fertilizer	3	3	3	0	3	3	3	3	3	3	3	3	3
	Commercial Fertilizer[1]	84	140	224	0	129	146	134	157	0	0	0	146	98
	Total Application Rate	286	143	227	0	132	149	138	160	33	3	3	149	103
C (Area = 19.1 ha)	Crop type	corn	corn	corn	corn	corn	corn	corn	corn	corn	soybeans	soybeans	corn	-
	Yield (t/ha)	5.0 - 7.8	5.6	5.9	4.2	7.1	3.6	7.8	7.8	6.9	4.0	4.4	6.9	-
	Fall Manure (previous year)	199	0	131	135	116	146	168	71	89	0	0	0	78
	Spring Manure	0	108	0	0	0	0	0	44	85	0	0	0	22
	Starter Fertilizer	3	3	3	3	3	3	3	3	3	3	3	3	3
	Commercial Fertilizer[1]	84	90	67	62	67	78	78	78	84	0	0	146	68
	Total Application Rate	286	201	202	200	186	228	250	197	261	3	3	149	171
D (Area = 10.7 ha)	Crop type	corn	corn	corn	corn	corn	corn	corn	corn	corn	soybeans	soybeans	corn	-
	Yield (t/ha)	5.0 - 7.8	5.6	5.9	4.2	7.1	3.6	7.8	7.8	6.9	4.0	4.4	6.9	-
	Fall Manure (previous year)	199	117	131	135	110	131	134	85	103	0	0	0	86
	Spring Manure	0	0	0	117	171	0	0	0	82	0	0	0	34
	Starter Fertilizer	3	3	3	3	3	3	3	3	3	3	3	3	3
	Commercial Fertilizer[1]	84	90	67	62	0	78	78	78	84	0	0	146	62
	Total Application Rate	286	210	202	317	285	213	216	167	272	3	3	149	185

Notes:

1 - 50/50% mixture of Urea and Ammonium Sulphate

Table 4.2 - Nitrogen Budget (N-Budget) at the Allin Farm for the years between 1996 and 2007

Field	N Budget	Nitrogen Source/Sink (kg-N/ha)	Pre-BMP	Post-BMP											
			1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Average
A	N_{inputs}	Fall Manure	198.7	116.9	131.5	135.0	0.0	146.1	168.0	0.0	44.3	0.0	0.0	0.0	*67.4*
		Spring Manure	0.0	0.0	0.0	0.0	0.0	0.0	0.0	88.5	97.9	0.0	0.0	0.0	*16.9*
		Starter Fertilizer	3.4	3.4	3.4	0.0	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	*3.1*
		Broadcast Fertilizer	84.0	89.6	67.2	0.0	128.8	78.4	78.4	78.4	84.0	0.0	0.0	128.8	*66.7*
		Crop Residue	14.0	14.0	14.0	14.0	30.0	14.0	14.0	14.0	14.0	14.0	30.0	30.0	*18.4*
		Atm deposition	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	*18.4*
		Seed	0.3	0.3	0.3	5.0	0.3	0.3	0.3	0.3	0.3	5.0	5.0	0.3	*1.6*
		Symbiotic N_2 Fixation	0.0	0.0	0.0	243.9	0.0	0.0	0.0	0.0	0.0	225.9	261.9	0.0	*66.5*
		Non-Symbiotic N_2 Fixation	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	*5.0*
		Total N Inputs	*323.8*	*247.5*	*239.8*	*421.3*	*185.9*	*265.6*	*287.5*	*208.0*	*267.2*	*271.7*	*323.7*	*185.9*	264.0
	$N_{outputs}$	Crop Uptake	107.3	82.9	87.5	305.4	105.2	54.0	116.4	115.5	102.4	289.3	321.5	102.8	*153.0*
		Volatilization	107.7	65.4	71.9	70.2	6.6	80.1	91.4	43.0	70.5	0.2	0.2	6.6	*46.0*
		Run-Off	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	*6.0*
		Denitrification	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5
		Total N Outputs	*235.5*	*168.8*	*179.9*	*396.1*	*132.3*	*154.6*	*228.4*	*179.0*	*193.4*	*310.0*	*342.1*	*129.9*	219.5
	N_{pl}	*Total Potentially Leachable N*	*88.3*	*78.7*	*59.8*	*25.2*	*53.5*	*111.0*	*59.1*	*29.0*	*73.8*	*-38.3*	*-18.4*	*55.9*	44.5
B	N_{inputs}	Fall Manure	198.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	*0.0*
		Spring Manure	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.2	0.0	0.0	0.0	*2.7*
		Starter Fertilizer	3.4	3.4	3.4	0.0	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	*3.1*
		Broadcast Fertilizer	84.0	140.0	224.0	0.0	128.8	145.6	134.4	156.8	0.0	0.0	0.0	145.6	*97.7*
		Crop Residue	14.0	14.0	14.0	14.0	30.0	14.0	14.0	14.0	14.0	30.0	30.0	30.0	*19.8*
		Atm deposition	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	*18.4*
		Seed	0.3	0.3	0.3	5.0	0.3	0.3	0.3	0.3	5.0	5.0	5.0	0.3	*2.0*
		Symbiotic N_2 Fixation	0.0	0.0	0.0	243.9	0.0	0.0	0.0	0.0	242.1	225.9	261.9	0.0	*88.5*
		Non-Symbiotic N_2 Fixation	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	*5.0*
		Total N Inputs	*323.8*	*181.1*	*265.1*	*286.3*	*185.9*	*186.7*	*175.5*	*197.9*	*317.1*	*287.7*	*323.7*	*202.7*	237.2
	$N_{outputs}$	Crop Uptake	107.3	82.9	87.5	305.4	105.2	54.0	116.4	115.5	303.7	289.3	321.5	102.8	*171.3*
		Volatilization	107.7	7.2	11.4	0.0	6.6	7.4	6.9	8.0	13.0	0.2	0.2	7.4	*6.2*
		Run-Off	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	*6.0*
		Denitrification	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5
		Total N Outputs	*235.5*	*110.5*	*119.4*	*325.9*	*132.3*	*82.0*	*143.8*	*144.0*	*337.2*	*310.0*	*342.1*	*130.8*	198.0
	N_{pl}	*Total Potentially Leachable N*	*88.3*	*70.5*	*145.7*	*-39.6*	*53.5*	*104.7*	*31.7*	*53.9*	*-20.1*	*-22.3*	*-18.4*	*71.9*	39.2
C	N_{inputs}	Fall Manure	198.7	0.0	131.5	135.0	115.7	146.1	168.0	71.1	88.5	0.0	0.0	0.0	*77.8*
		Spring Manure	0.0	108.0	0.0	0.0	0.0	0.0	0.0	43.8	84.7	0.0	0.0	0.0	*21.5*
		Starter Fertilizer	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	*3.4*
		Broadcast Fertilizer	84.0	89.6	67.2	61.6	67.2	78.4	78.4	78.4	84.0	0.0	0.0	145.6	*68.2*
		Crop Residue	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	30.0	30.0	*16.9*
		Atm deposition	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	*18.4*
		Seed	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	5.0	5.0	0.3	*1.2*
		Symbiotic N_2 Fixation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	225.9	261.9	0.0	*44.3*
		Non-Symbiotic N_2 Fixation	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	*5.0*
		Total N Inputs	*323.8*	*238.6*	*239.8*	*237.6*	*224.0*	*265.6*	*287.5*	*234.4*	*298.3*	*271.7*	*323.7*	*202.7*	256.7
	$N_{outputs}$	Crop Uptake	107.3	82.9	87.5	62.9	105.2	54.0	116.4	115.5	102.4	289.3	321.5	102.8	*131.0*
		Volatilization	107.7	52.2	71.9	73.4	63.7	80.1	91.4	60.4	87.7	0.2	0.2	7.4	*53.5*
		Run-Off	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	*6.0*
		Denitrification	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5
		Total N Outputs	*235.5*	*155.5*	*179.9*	*156.8*	*189.4*	*154.6*	*228.4*	*196.3*	*210.6*	*310.0*	*342.1*	*130.8*	205.0
	N_{pl}	*Total Potentially Leachable N*	*88.3*	*83.1*	*59.8*	*80.8*	*34.5*	*111.0*	*59.1*	*38.1*	*87.7*	*-38.3*	*-18.4*	*71.9*	51.8
D	N_{inputs}	Fall Manure	198.7	116.9	131.5	135.0	110.2	131.5	134.4	85.3	103.3	0.0	0.0	0.0	*86.2*
		Spring Manure	0.0	0.0	0.0	116.9	171.4	0.0	0.0	0.0	81.8	0.0	0.0	0.0	*33.6*
		Starter Fertilizer	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	*3.4*
		Broadcast Fertilizer	84.0	89.6	67.2	61.6	0.0	78.4	78.4	78.4	84.0	0.0	0.0	145.6	*62.1*
		Crop Residue	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	30.0	30.0	*16.9*
		Atm deposition	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	*18.4*
		Seed	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	5.0	5.0	0.3	*1.2*
		Symbiotic N_2 Fixation	0.0	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	225.9	261.9	0.3	*44.6*
		Non-Symbiotic N_2 Fixation	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	*5.0*
		Total N Inputs	*323.8*	*247.8*	*240.1*	*354.8*	*322.9*	*251.3*	*254.2*	*205.1*	*310.5*	*271.7*	*323.7*	*203.0*	271.4
	$N_{outputs}$	Crop Uptake	107.3	82.9	87.5	62.9	105.2	54.0	116.4	115.5	102.4	289.3	321.5	102.8	*131.0*
		Volatilization	107.7	65.4	71.9	124.9	132.9	72.5	74.0	48.5	94.1	0.2	0.2	7.4	*62.9*
		Run-Off	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	*6.0*
		Denitrification	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5
		Total N Outputs	*235.5*	*168.8*	*179.9*	*208.3*	*258.6*	*147.0*	*210.9*	*184.4*	*217.0*	*310.0*	*342.1*	*130.8*	*214.3*
	N_{pl}	*Total Potentially Leachable N*	*88.3*	*79.0*	*60.1*	*146.5*	*64.3*	*104.3*	*43.3*	*20.7*	*93.5*	*-38.3*	*-18.4*	*72.2*	57.0

Table 4.3 - Well details for all wells at the Allin Farm

Well	TOC elevation (masl)	Ground elevation (masl)	stick-up (m)	depth (mbtoc)	depth (mbgs)	Screen Length (m)	Screened Interval (m)	Low Water Level (mbgs)	High Water Level (mbgs)	Stratigraphic Unit
KA1-1	255.25	254.27	0.98	11.89	10.91	0.61	10.30 - 10.91	10.79	3.03	Aquitard 1
KA1-2	255.25	254.23	1.02	12.94	11.92	0.61	11.31 - 11.92	10.38	3.17	Aquitard 1
KA1-3	255.21	254.35	0.86	13.84	12.98	0.61	12.37 - 12.98	10.58	3.42	Aquitard 1
KA1-4	255.26	254.40	0.85	14.46	13.61	0.61	13.00 - 13.61	10.61	3.46	Aquitard 1
KA2-1	248.30	247.26	1.04	9.71	8.73	0.61	8.12 - 8.73	8.67	5.89	Aquitard 1
KA2-2	248.37	247.41	0.96	10.64	9.64	0.61	9.03 - 9.64	9.67	6.12	Aquitard 1
KA2-3	248.57	247.52	1.05	11.63	10.61	0.61	10.00 - 10.61	10.58	6.29	Aquitard 1
KA2-4	248.68	247.70	0.97	12.56	11.48	0.61	10.87 - 11.48	11.59	7.02	Aquitard 1
KA3-1	242.73	242.36	0.37	5.47	5.12	0.61	4.51 - 5.12	7.82	5.10	Aquitard 1
KA3-2	242.69	242.32	0.37	7.76	7.89	0.61	7.28 - 7.89	8.86	4.07	Aquitard 1
KA3-3	242.70	242.18	0.52	9.45	8.91	0.61	8.30 - 8.91	9.68	3.84	Aquitard 1
KA3-4	242.66	241.77	0.89	10.57	10.09	0.61	9.48 - 10.09	9.31	3.39	Aquitard 1
KA4-1	238.06	236.93	1.13	7.18	6.07	0.61	5.46 - 6.07	3.65	0.57	Aquitard 1
KA4-2	238.05	236.85	1.20	8.83	7.70	0.61	7.09 - 7.70	3.60	0.55	Aquitard 1
KA4-3	238.08	236.93	1.15	9.75	8.62	0.61	8.01 - 8.62	3.63	0.64	Aquitard 1
KA4-4	238.00	236.86	1.14	10.88	9.81	0.61	9.20 - 9.81	3.61	0.97	Aquitard 1
KA5-1	225.46	224.57	0.89	6.87	5.98	0.61	5.37 - 5.98	5.98	3.96	Aquitard 1
KA5-2	225.31	224.41	0.90	7.66	6.78	0.61	6.17 - 6.78	6.76	3.89	Aquifer 1
KA5-3	225.32	224.49	0.83	9.01	8.20	0.61	7.59 - 8.20	8.18	3.97	Aquifer 1
KA5-4	225.15	224.38	0.77	9.85	9.07	0.61	8.46 - 9.07	9.08	4.00	Aquifer 1
KA5-5	225.39	224.55	0.84	10.16	9.32	3.10	6.22 - 9.32	0.25	-0.85	Aquifer 1
KA5-6	225.39	224.55	0.84	18.84	17.99	1.55	16.44 - 17.99	-0.77	-2.33	Aquitard 2
KA6-1	222.20	221.34	0.86	5.44	4.58	0.61	3.97 - 4.58	-0.89	-2.42	Aquifer 1 ?
KA6-2	222.28	221.21	1.07	6.87	5.80	0.61	5.19 - 5.80	-1.35	-3.04	Aquifer 1 ?
KA6-3	222.18	221.19	1.00	8.00	7.00	0.61	6.39 - 7.00	6.46	4.01	Aquifer 1 ?
KA6-4	221.93	221.14	0.79	8.81	8.02	0.61	7.41 - 8.02	0.00	0.00	Aquifer 1 ?
KA7	239.99	239.48	0.51	7.96	7.45	1.55	5.90 - 7.45	4.54	2.51	Aquitard 1
KA8	240.60	240.56	0.04	12.10	12.06	3.10	8.96 - 12.06	5.57	4.16	Aquifer 1
KA9-1	240.13	239.68	0.44	9.47	9.03	1.55	7.48 - 9.03	4.14	1.50	Aquitard 1
KA9-2	240.13	239.68	0.45	15.82	15.37	3.10	12.27 - 15.37	7.66	7.66	Aquifer 1
KA9-3	239.93	239.68	0.24	29.67	29.43	4.57	24.86 - 29.43	12.10	9.91	Aquifer 2
KA10-1	230.89	229.95	0.94	8.60	7.66	1.55	6.11 - 7.66	5.80	1.66	Aquitard 1 (Dry)
KA10-2	230.91	229.95	0.95	13.54	12.58	3.10	9.48 - 12.58	3.76	1.28	Aquifer 1
KA Well	238.52	240.47	-2.07	30.00	32.07	6.10	25.97 - 32.07	4.86	0.72	Aquifer 2

Notes:
mbtoc - meters below top of well casing
mbgs - meters below ground surface
TOC - top of casing
masl - meters above mean sea level

Table 4.4 - Averaged soil physical properties for each stratigraphic unit from within Fields A and B

Physical Property	Root Zone			Aquitard 1						Aquifer 1			Aquitard 2			Aquifer 2
				Field A			Field B									
	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Average
Gravimetric Moisture Content (%)	8.8	27.0	17.7	4.9	8.5	7.1	6.1	7.7	6.9	8.1	13.2	11.0	6.3	12.4	9.3	12.9
Volumetric Moisture Content (%)	17.6	56.6	34.6	10.9	19.2	16.0	13.0	16.9	14.3	16.3	25.5	21.6	14.5	24.9	19.7	25.6
Dry Bulk Density (g/cm^3)	1.8	2.1	2.0	2.2	2.3	2.3	1.9	2.3	2.1	2.0	2.1	2.0	2.0	2.3	2.2	2.0
Porosity	20.8	44.9	28.2	13.8	17.3	15.2	15.2	27.2	21.8	21.0	26.2	24.1	13.3	24.0	18.6	24.9

Table 4.5 - Average bulk soil nitrate and porewater nitrate concentrations for each stratigraphic unit within Fields A and B

Stratigraphic Unit	Field	Value	Bulk Soil Nitrate ($mgNO_3$-N/kg)	Porewater Nitrate Concentration ($mgNO_3$-N/L)
Root Zone	Field A	Min	0.4	4.1
		Max	16.4	56.7
		Average	6.5	27.9
	Field B	Min	1.8	4.4
		Max	8.3	40.3
		Average	4.6	22.7
Aquitard 1	Field A	Min	0.9	7.2
		Max	3.2	29.2
		Average	1.8	19.1
	Field B	Min	0.2	1.2
		Max	3.0	41.0
		Average	1.2	17.6
Aquifer 1	Field A	Average	2.7	19.1
	Field B	Min	1.0	8.3
		Max	1.3	9.0
		Average	1.2	8.7
Aquitard 2	Field A	Average	0.2	2.1
	Field B	Average	0.3	2.4
Aquifer 2	Field A	Average	0.2	1.8

Table 4.6 - Porewater Isotopes from soil cores collected within Fields A and B

Field	Sample	Depth Interval (m)	Depth (m)	^{15}N in NO$_3$	Description
A	BH1-1	0 - 2.13	1.07	5.97	fertilizer
	BH1-2	2.13 - 3.96	3.05	12.12	manure
	KA9-1	0 - 0.33	0.15	9.46	mixed
	KA9-2	0.33 - 0.81	0.51	4.42	fertilizer/soybeans
	KA9-3	0.81 - 1.44	1.11	8.64	mixed
	KA9-4	1.44 - 2.12	1.77	8.54	mixed
	KA9-5	2.12 - 2.96	2.47	11.33	manure
	KA9-6	2.96 - 3.74	3.45	13.47	manure
	KA9-7	3.74 - 4.35	4.02	12.08	manure
	KA9-8	4.35 - 4.92	4.67	12.04	manure
	KA9-9	4.92 - 5.35	5.17	10.94	manure
	KA9-10	5.35 - 5.77	5.52	10.92	manure
	KA9-11	5.77 - 6.14	6.02	10.33	manure
	KA9-12	6.14 - 6.50	6.25	12.27	manure
	KA9-13	6.50 - 6.95	6.75	21.83	manure
	KA9-14	6.95 - 7.41	7.15	13.06	manure
	KA9-15	7.41 - 8.24	7.67	13.56	manure
	KA9-16	8.24 - 9.45	8.80	11.47	manure
B	BT1-1	0 - 2.13	1.07	4.30	fertilizer / soil
	BT1-2	2.13 - 3.96	3.05	7.77	mixed
	BT1-3	3.96 - 4.88	4.42	5.69	fertilizer
	KA5-5-1	0 - 0.86	0.41	13.90	manure
	KA5-5-2	0.86 - 1.85	1.31	3.77	fertilizer/soybeans
	KA5-5-3	1.85 - 2.87	2.38	9.02	mixed
	KA5-5-4	2.87 - 4.04	3.37	7.26	fertilizer
	KA5-5-5	4.04 - 5.22	4.71	7.53	fertilizer
	KA5-5-6	5.22 - 6.11	5.73	6.31	fertilizer
	KA5-5-7	6.11 - 7.21	6.48	6.33	fertilizer
	KA5-5-8	7.21 - 8.35	7.95	12.87	manure
	KA5-5-9	8.35 - 9.13	8.75	12.75	manure
	KA5-5-10	9.13 - 9.87	9.50	14.92	manure
	KA10-1	0 - 0.85	0.55	10.22	manure
	KA10-2	0.85 - 1.50	1.15	3.36	fertilizer/soybeans
	KA10-3	1.50 - 2.82	1.85	7.44	mixed
	KA10-4	2.82 - 5.01	3.78	4.34	fertilizer
	KA10-5	5.01 - 7.24	6.37	7.29	fertilizer
	KA10-6	7.24 - 8.91	8.11	5.60	fertilizer
	KA10-7	8.91 - 10.35	9.71	6.17	fertilizer
	KA10-8	10.35 - 11.65	10.99	9.39	mixed

Notes:
mixed - mixture between manure and fertilizer or fertilzier/soybean N

Table 4.7 - Hydraulic conductivity (K) from slug tests

Well	Test 1 (falling head) K (m/s)	Test 2 (rising head) K (m/s)	Avg K Value[a] (m/s)	Gibson and Rudolph 1997 (m/s)	Stratigraphic Unit
KA1-1	9.41E-07	9.05E-07	9.23E-07	4.05E-07	Aquitard 1
KA1-2	1.02E-06	9.88E-07	1.00E-06	6.23E-07	Aquitard 1
KA1-3	9.66E-07	1.24E-06	1.10E-06	3.35E-08	Aquitard 1
KA1-4	1.16E-06	1.10E-06	1.13E-06	7.55E-07	Aquitard 1
KA2-1	3.41E-08	na	3.41E-08	3.43E-09	Aquitard 1
KA2-2	2.16E-08	na	2.16E-08	3.80E-08	Aquitard 1
KA2-3	1.19E-07	na	1.19E-07	3.68E-08	Aquitard 1
KA2-4	1.66E-08	na	1.66E-08	6.29E-08	Aquitard 1
KA3-2	9.67E-07	7.50E-07	8.59E-07	1.86E-07	Aquitard 1
KA3-3	9.27E-07	9.33E-07	9.30E-07	9.81E-07	Aquitard 1
KA3-4	1.53E-06	9.53E-07	1.24E-06	7.03E-07	Aquitard 1
KA4-1	8.72E-07	8.61E-07	8.67E-07	6.82E-07	Aquitard 1
KA4-2	1.01E-06	9.24E-07	9.69E-07	4.41E-07	Aquitard 1
KA4-3	8.92E-07	1.17E-06	1.03E-06	1.52E-07	Aquitard 1
KA4-4	4.30E-08	na	4.30E-08	5.19E-08	Aquitard 1
KA5-1	1.20E-07	1.72E-08	6.85E-08	4.56E-08	Aquitard 1
KA5-2	3.54E-06	3.66E-06	3.60E-06	2.89E-07	Aquifer 1
KA5-3	3.52E-05	2.96E-05	3.24E-05	1.09E-06	Aquifer 1
KA5-4	2.52E-05	1.67E-05	2.09E-05	1.83E-06	Aquifer 1
KA5-5	poor data	poor data	na	na	Aquifer 1
KA5-6	3.13E-09	na	3.13E-09	na	Aquitard 2
KA6-1	3.51E-06	na	3.51E-06	5.30E-07	Aquifer 1
KA6-2	1.93E-06	na	1.93E-06	8.89E-07	Aquifer 1
KA6-3	3.60E-05	na	3.60E-05	6.52E-07	Aquifer 1
KA6-4	4.46E-05	na	4.46E-05	8.98E-07	Aquifer 1
KA8	poor data	poor data	na	na	Aquitard 1
KA9-1	9.58E-07	1.02E-06	9.87E-07	na	Aquitard 1
KA9-2	9.00E-06	6.78E-06	7.89E-06	na	Aquifer 1
KA9-3	6.84E-07	5.00E-07	5.92E-07	na	Aquifer 2
KA10-2	1.33E-05	1.21E-05	1.27E-05	na	Aquifer 1

Notes:
a - average of Test 1 and Test 2 data
na - data not available or well not tested
poor data - well tested but data not useful for calculating K

Table 4.8 - Min, Max, and Average vertical hydraulic gradients measured since 1997

Nest	Wells	Stratigraphic Unit	1997 - 2007[a]			Average Flow Direction
			Min	Max	Average	
KA1	1,2,3,4	Aquitard 1	-0.13	0.11	-0.07	Downwards
KA2	1,2,3,4	Aquitard 1	-0.74	0.001	-0.31	Downwards
KA3	2,3,4	Aquitard 1	-0.49	0.05	-0.16	Downwards
KA4	1,2,3,4	Aquitard 1	-0.42	0.14	-0.04	Downwards
KA5	1,2	Aquitard 1 - Aquifer 1	-1.20	-0.07	-0.29	Downwards
KA5	2,3,4	Aquifer 1	-0.62	-0.05	-0.14	Downwards
KA5	1,6	Aquifer 1 - Aquitard 2	0.54	0.76	0.63	Upwards
KA6	1,2,3,4	Unknown (Aquifer 1?)	0.39	0.66	0.47	Upwards
KA9	1,2	Aquitard 1 - Aquifer 1	-0.34	-0.22	-0.26	Downwards
KA9	2,3	Aquifer 1 - Aquifer 2	0.08	0.12	0.09	Upwards

Notes:

a - min, max, and average vertical gradient since manual waterlevel monitoring began in 1997

Table 4.9 - Average horizontal gradients between different wells in Aquitard 1 and Aquifer 1

Well Pairs	Stratigraphic Unit	Horrizontal Separation dl (m)	1997				2007				Average Gradient (m/m)
			April		August		May		August		
			Head Difference dh (m)	Gradient (m/m)	Head Difference dh (m)	Gradient (m/m)	Head Difference dh (m)	Gradient (m/m)	Head Difference dh (m)	Gradient (m/m)	
KA1-1 - KA9-1	Aquitard 1	246	--	--	--	--	12.48	0.05	10.15	0.04	0.05
KA1-1 - KA3-2	Aquitard 1	269	9.65	0.04	10.09	0.04	12.41	0.05	9.45	0.04	0.04
KA9-1 - KA5-1	Aquitard 1	337	--	--	--	--	17.57	0.05	17.49	0.05	0.05
KA3-2 - KA5-1	Aquitard 1	417	17.39	0.04	17.57	0.04	19.23	0.07	18.94	0.07	0.06
KA2-1 - KA4-1	Aquitard 1	423	3.11	0.01	5.31	0.01	17.64	0.04	18.19	0.04	0.03
KA4-1 - KA6-1	Aquitard 1 - Aquifer 1(?)	251	13.76	0.05	12.58	0.05	5.71	0.01	6.02	0.01	0.03
KA9-2 - KA5-4	Aquifer 1	337	--	--	--	--	13.74	0.05	11.74	0.05	0.05
KA8 - KA10-2	Aquifer 1	269	--	--	--	--	14.95	0.04	16.14	0.05	0.05

Notes:
-- well(s) not installed

Table 4.10a - Groundwater Flux (Aquifer 1) using spatially weighted values

Field/Aquifer	Well Nest	Area (m^2)	Hydraulic Conductivity (m/s)	Hydraulic Gradient[b] (m/m)	Flow Direction	Water Flux (L/s)
A	KA1	79500	1.0E-06	0.07	vertical (downwards)	5.8
	KA9	79500	9.9E-07	0.26	vertical (downwards)	20.4
	KA9[a]	79500	3.1E-09	0.09	vertical (upwards)	0.02
					SUM	*26.2*
B	KA9	39500	9.9E-07	0.26	vertical (downwards)	10.1
	KA5	39500	6.8E-08	0.29	vertical (downwards)	0.8
	KA5[a]	79000	3.1E-09	0.63	vertical (upwards)	0.2
					SUM	*11.1*
Total Input to Aquifer 1 = 37.3 L/s						
Aquifer 1	KA5	1600	1.9E-05	0.05	horizontal (east to west)	1.5
	KA10	1600	1.3E-05	0.05	horizontal (east to west)	1.0
Total Output from Aquifer 1 = 2.5 L/s						

Notes:
a - input from Aquitard 2 below Aquifer 1

Table 4.10b - Groundwater Flux (Aquifer 1) using averaged values

Field/Aquifer	Area (m^2)	Hydraulic Conductivity (m/s)	Hydraulic Gradient[b] (m/m)	Flow Direction	Water Flux (L/s)
A[a]	158,800	5.20E-08	0.16	vertical (downwards)	1.32
B[b]	78,900	5.20E-08	0.28	vertical (downwards)	1.13
Aquitard 2[c]	158,300	3.13E-09	0.36	vertical (upwards)	0.18
Aquifer 1[d]	4200	1.55E-05	0.05	horizontal (east to west)	2.48

Notes:
a - hydraulic gradient = average gradient at KA1 and KA9 well nest between 1997 and 2007 (Table 4.8)
b - hydraulic gradient = average gradient at KA5 and KA9 well nest between 1997 and 2007 (Table 4.8)
c - hydraulic gradient = average gradient at KA5-6 and KA9 nest between 1997 and 2007 (Table 4.8)
d - Area = average Aquifer 1 thickness (6.57m) * distance along western site boundary (487m)

Table 4.11 - Groundwater Isotopes of ^{15}N and ^{18}O in NO_3

Sample Date	5/24/06		2/20/07		8/8/07	
Well	^{15}N	^{18}O	^{15}N	^{18}O	^{15}N	^{18}O
KA1-1	3.81	0.07	--	--	2.88	-2.52
KA1-4	3.21	0.29	--	--	3.03	-0.52
KA2-1	2.72	0.66	--	--	--	--
KA2-2	--	--	--	--	4.73	1.42
KA2-4	5.8	1.69	--	--	4.99	0.8
KA3-2	16.29	6.22	--	--	13.14	13.16
KA3-4	13.14	3.95	--	--	9.63	0.9
KA4-1	11.62	3.34	--	--	10.05	1.02
KA4-3	17.51	6.92	--	--	23.23	9.52
KA5-1	3.49	-1.31	--	--	--	---
KA5-2	--	--	--	--	7.19	0.61
KA5-3	--	--	--	--	9.63	0.88
KA5-4	11.33	2.74	--	--	9.57	1.33
KA6-1	9.4	3.4	--	--	9.82	1.75
KA6-4	9.45	3.64	--	--	8.71	2.43
KA8	--	--	10.02	0.45	9.51	-0.43
KA9-2	--	--	12.82	1.15	10.08	0.86
KA9-1	--	--	10.01	0.87	9.97	-0.21
KA5-5	--	--	9.72	1.52	9.84	0.92
KA10-2	--	--	4.44	0.82	--	--
KA Well	21.42	6.66	--	--	13.62	3.96

Notes:

-- no sample collected

Table 4.12 - Summary of groundwater recharge estimations between 1996 and 2007

Year	Method	Measured Time Period	Precipitation (mm/yr)	Evapotranspiration[d] (mm/yr)	Recharge (mm/yr)
1996[a]	Water Balance	Jan 1, 1996 - Dec. 31, 1996	1136	769	367
1997[a]	Water Balance	Jan 1, 1997 - Dec. 31, 1997	798	769	29
1998[a]	Water Balance	Jan 1, 1998 - Dec. 31, 1998	915	769	146
1999[a]	Water Balance	Jan 1, 1999 - Dec. 31, 1999	758	769	0 (-11.6)
2000[a]	Water Balance	Jan 1, 2000 - Dec. 31, 2000	827	769	58
2001[a]	Water Balance	Jan 1, 2001 - Dec. 31, 2001	746	769	0 (-22.9)
2002[b]	Water Balance	Jan 1, 2002 - Dec. 31, 2002	874	769	105
2003[b]	Water Balance	Jan 1, 2003 - Dec. 31, 2003	778	769	9
2004[b]	Water Balance	Jan 1, 2004 - Dec. 31, 2004	998	769	229
2005[b]	Water Balance	Jan 1, 2005 - Dec. 31, 2005	889	764	125
2006[b,c]	Water Balance	Jan 1, 2006 - Dec. 31, 2006	1034	774	260
	Bromide Tracer (BT1)	Dec 1, 2005 - Apr 4, 2006	Recharge = 217 mm/yr		
	Bromide Tracer (BT1-2)	Dec 1, 2005 - Feb 21, 2007	Recharge = 375 mm/yr		
	Bromide Tracer (BT2)	Dec 1, 2005 - Feb 21, 2007	Recharge = 41 mm/yr		
	Bromide Tracer (BT3)	Dec 1, 2005 - Feb 21, 2007	Recharge = 44 mm/yr		
	Nitrate Pulse	Apr 4, 2006 - Feb 21, 2007	Recharge = 138 mm/yr		
2007[c]	Water Balance	Jan 1, 2007 - Dec. 5, 2007	617	770	0 (-153.1)

Notes:
a - precipitation data derived from the average measured at Peterborough and Cobourg Meteorological Stations
b - precipitation data derived from Blackstock Meteorological Stations
c - precipitation and ET data derived from Allin Farm Meteorological Station
d - ET value is the average value from 2005 to 2007 as measured at the Allin Farm

Table 4.13 - Average linear horizontal groundwater flow velocities between sets of wells in Aquitard 1 and Aquifer 1

Well Pairs	Stratigraphic Unit	Average Porosity	Average K (m/s)	1997				2007				Average Linear GW Flow Velocity (m/yr)
				April		August		May		August		
				Gradient (m/m)	Velocity (m/year)	Gradient (m/m)	Velocity (m/year)	Gradient (m/m)	Velocity (m/year)	Gradient (m/m)	Velocity (m/year)	
KA1-1 - KA9-1	Aquitard 1	0.15	9.6E-07	--	--	--	--	0.05	9.9	0.04	8.1	9.0
KA1-1 - KA3-2	Aquitard 1	0.15	8.9E-07	0.04	6.6	0.04	6.9	0.05	8.4	0.04	6.4	7.1
KA9-1 - KA5-1	Aquitard 1	0.18	5.3E-07	--	--	--	--	0.05	4.7	0.05	4.7	4.7
KA3-2 - KA5-1	Aquitard 1	0.18	4.6E-07	0.04	3.3	0.04	3.3	0.07	5.7	0.07	5.6	4.5
KA2-1 - KA4-1	Aquitard 1	0.15	4.5E-07	0.01	0.7	0.01	1.2	0.04	3.9	0.04	4.0	2.4
KA4-1 - KA6-1	Aquitard 1 - Aquifer 1(?)	0.18	2.2E-06	0.05	20.5	0.05	18.7	0.01	5.0	0.01	5.3	12.4
KA9-2 - KA5-4	Aquifer 1	0.24	1.4E-05	--	--	--	--	0.05	100.9	0.05	86.2	93.5
KA8 - KA10-2	Aquifer 1	0.24	1.4E-05	--	--	--	--	0.04	80.0	0.05	86.4	83.2

Notes:

-- well(s) not installed

Table 4.14 - Average linear vertical groundwater flow velocities

Well	Well Pairs	Vertical gradient[a] (m/m)	Flow Direction	Stratigraphic Unit	K - Aquitard 1 (m/s)	Porosity - Aquitard 1	Average Linear Vertical GW Velocity (m/yr)
KA1	KA1-1 - KA1-4	0.07	downwards	Aquitard 1	5.2E-08	0.15	0.8
KA2	KA2-1 - KA2-4	0.31	downwards	Aquitard 1	5.2E-08	0.15	3.4
KA3	KA3-2 - KA3-4	0.16	downwards	Aquitard 1	5.2E-08	0.15	1.7
KA4	KA4-1 - KA4-4	0.04	downwards	Aquitard 1	5.2E-08	0.15	0.5
KA5	KA5-1 - KA5-2	0.29	downwards	Aquitard 1 - Aquifer 1	5.2E-08	0.22	2.2
KA6	KA6-1 - KA6-4	0.47	upwards	Aquifer 1	5.2E-08	0.18	4.3
KA9	KA9-1 - KA9-2	0.28	downwards	Aquitard 1 - Aquifer 1	5.2E-08	0.19	2.4

Notes:

a - average since manual waterlevel monitoring began in 1997

Table 4.15 - Calculated groundwater travel times from the ground surface to Aquifer 1 along the western property boundary

Starting Point[a]	Ending Point[b]	Stratigraphic Unit	Unsaturated Depth[c] (m)	Saturated Depth[c] (m)	Horizontal Distance in Aquifer 1 (m)	Recharge Velocity in Aquitard 1 (m/yr)	Average Linear Vertical GW Flow Velocity in Aquitard 1 (m/yr)	Average Linear Horizontal GW Flow Velocity in Aquifer 1 (m/yr)	Travel Time (yr)
KA5	KA5	Aquitard 1 - Aquifer 1	5.4	1.0	--	1.12	2.18	--	5.3
KA9	KA5	Aquitard 1 - Aquifer 1	2.9	9.1	353	1.00	3.02	89.24	9.9
KA10	KA10	Aquitard 1 - Aquifer 1	11.3	0.0	---	1.12	--	--	10.0
KA8	KA10	Aquitard 1 - Aquifer 1	2.5	5.4	261	1.12	3.21	89.24	6.9

Notes:
a - starting point considered the ground surface above the specified well nest
b - ending point considered is Aquifer 1 along western site boundary in Field B
c - average yearly depth since manual waterlevel monitoring began

Table 4.16 - Comparison between measured and predicted groundwater nitrate concentrations

Field	Recharge Rate (mm/yr)	Pre-BMP			Post-BMP		
		N_{pl} (kgN/ha)	Measured Groundwater Nitrate Concentration (mg/L)	Predicted Groundwater Nitrate Concentration (mg/L)	N_{pl} (kgN/ha)	Measured Groundwater Nitrate Concentration (mg/L)	Predicted Groundwater Nitrate Concentration (mg/L)
A	160	88.3	37.39[a]	55.20	44.5	26.38[e]	27.80
B	160	88.3	32.90[b]	55.20	39.2	12.83[f]	24.50
C	160	88.3	48.37[c]	55.20	51.8	29.03[g]	31.10
D	160	88.3	32.23[d]	55.20	57.0	39.75[h]	35.60

Notes:
a - average of 1997 concentrations of KA3-1 and KA5-3,4
b - 1997 concentration of KA5-1
c - averageof 1997 concentrations of KA4-1 and KA3-1
d - average of 1997 concentrations of KA6-1
e - average of 2005 - 2007 concentrations of KA9-3 and KA3-2
f - average of 2005 - 2007 concentrations of KA5-1,2 and KA10-2
g - average of 2005 - 2007 concentrations of KA4-1 and KA3-2
h - average of 2005 - 2007 concentrations of KA6-1

Table 4.17 - Nitrate mass flux to the watertable estimated from soil core data

Field	Core	Average Porewater Nitrate Concentration C_{aq} (mg/L)	Recharge Rate (m/yr)	Mass Flux (mgNO3-N/m^2/yr)	Total Field Mass Load (t/yr)
A	BH1	16.18	0.16	2.59	0.48
	BH2	19.93		3.19	
	BH3	29.17		4.67	
	KA9	26.42		4.23	
	BT2	15.45		2.47	
	BT3	7.23		1.16	
B	BH4	41.00	0.16	6.56	0.22
	BH5	17.63		2.82	
	BH6	17.35		2.78	
	KA5-5	1.18		0.19	
	KA10	4.30		0.69	
	BT1	27.00		4.32	
	BT1-2	14.73		2.36	
Field A Average	--	19.06	--	3.05	--
Field B Average	--	17.60	--	2.82	--

Table 4.18 - Nitrate mass load entering and exiting Aquifer 1 beneath Fields A and B

Field/Aquifer		Water Flux (L/s)	Pre-BMP		Post-BMP	
			Average Nitrate Concentration (mg/L)	Nitrate Mass Load (t/yr)	Average Nitrate Concentration (mg/L)	Nitrate Mass Load (t/yr)
Nitrate Entering Aquifer 1	A	1.32	37.39[a]	1.56	26.38[d]	1.10
	B	1.13	32.90[b]	1.17	12.83[e]	0.46
	Sum A + B	2.45	--	2.73	--	1.56
Nitrate Exiting Aquifer 1	Aquifer 1	2.48	34.66[c]	2.71	19.86[f]	1.55

Notes:

a - average of 1997 concentrations of KA3-1 and KA5-3,4
b - 1997 concentration of KA5-1
c - averageof 1997 concentrations of KA5-3,4
d - average of 2005 - 2007 concentrations of KA8 and KA9-1
e - average of 2005 - 2007 concentrations of KA5-1,2 and KA10-2
f - average of 2005 - 2007 concentrations of KA5-3,4,5 and KA10-2

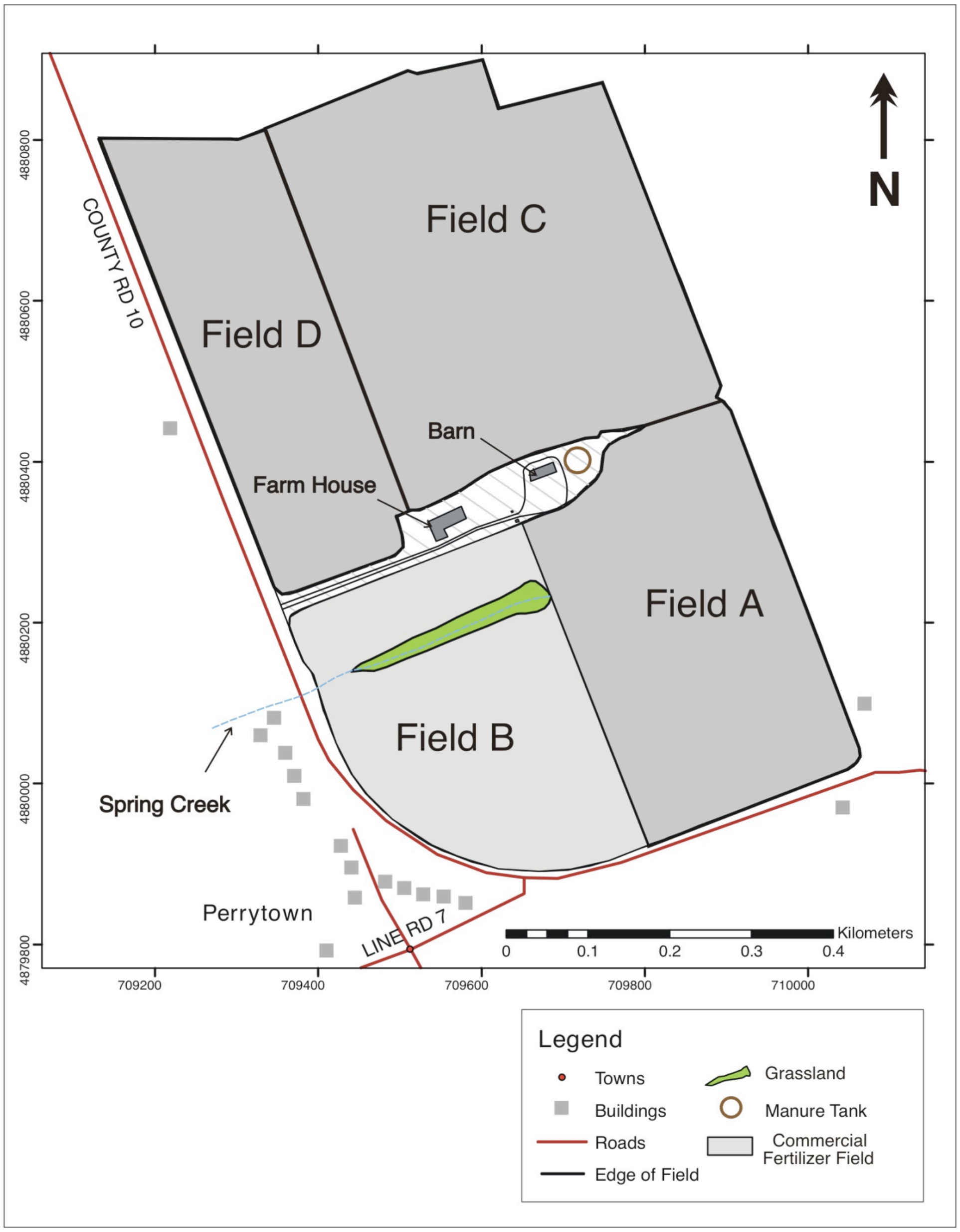

Figure 4.1 - Site map of Allin Farm showing Fields A, B, C, and D. Since 1997, only commercial fertilizers have been spread on Field B as a source of nitrogen for the field crops. The other fields continued to be fertilized using a mixture of manure and commercial fertilizers.

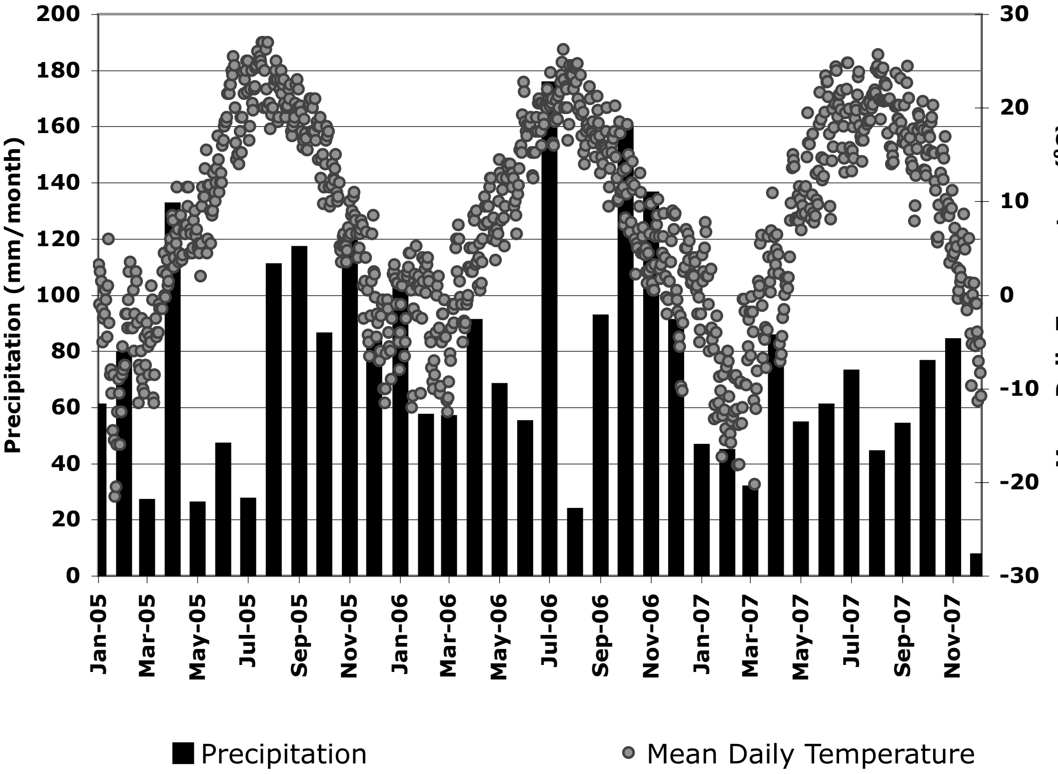

Figure 4.2 - Mean daily temperature and monthly precipitation as measured at the Allin Farm since 2005. Data derived from a combination of local meteorological stations managed by Environment Canada (Jan. 2005 - October 2005; Blackstock Meterological Station, Environment Canada, 2007) and from an on-site meteorological station.

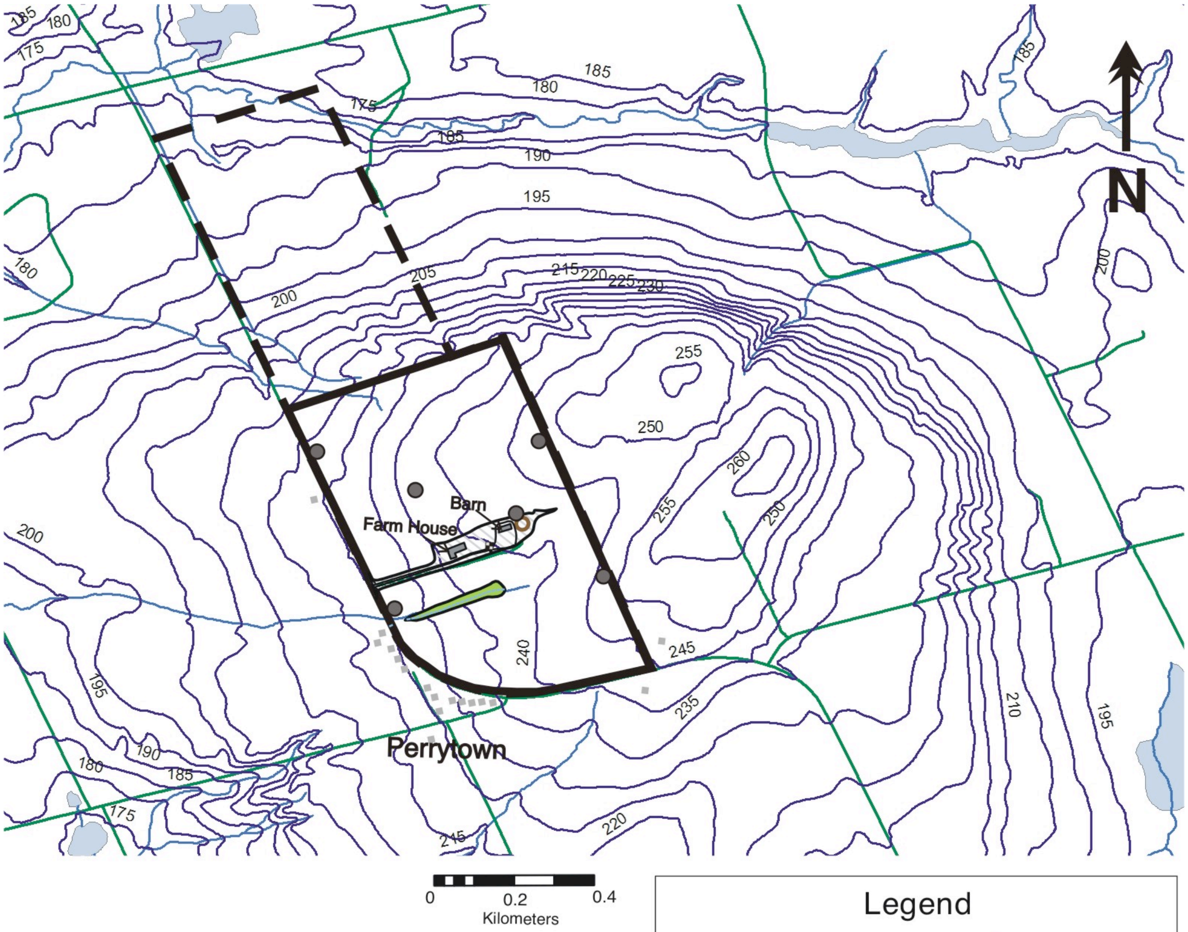

Figure 4.3 - Topographic map of the area surrounding the Allin Farm. The regional topographic high occurs approximately 400m east of the study site. Basemap modified from MNR (2008).

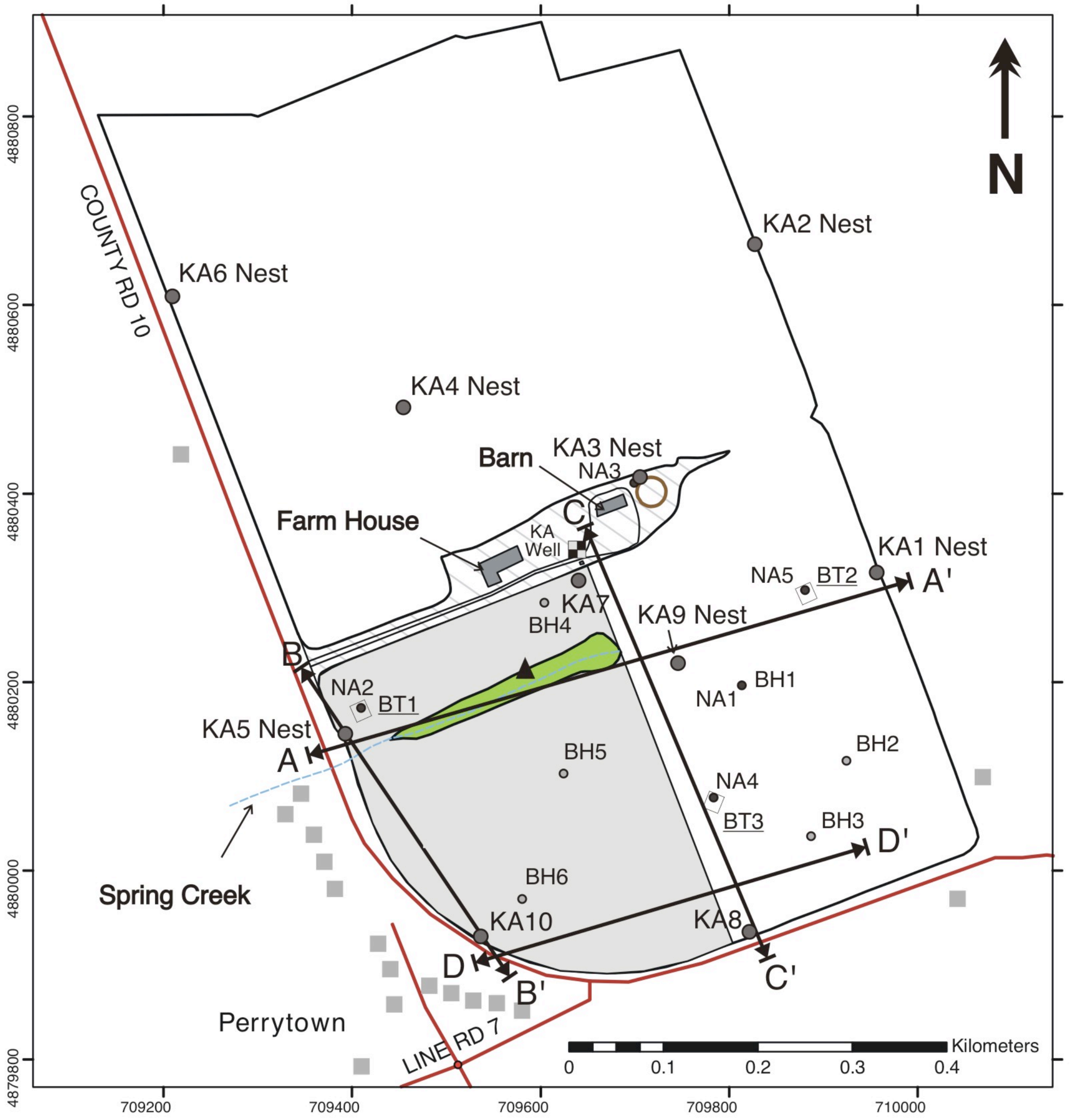

Figure 4.4 - Site map of the Allin Farm showing all instrumentation including: monitoring wells nests, neutron access tubes, soil core locations, bromide tracer plots, meteorological station, and house pumping well.

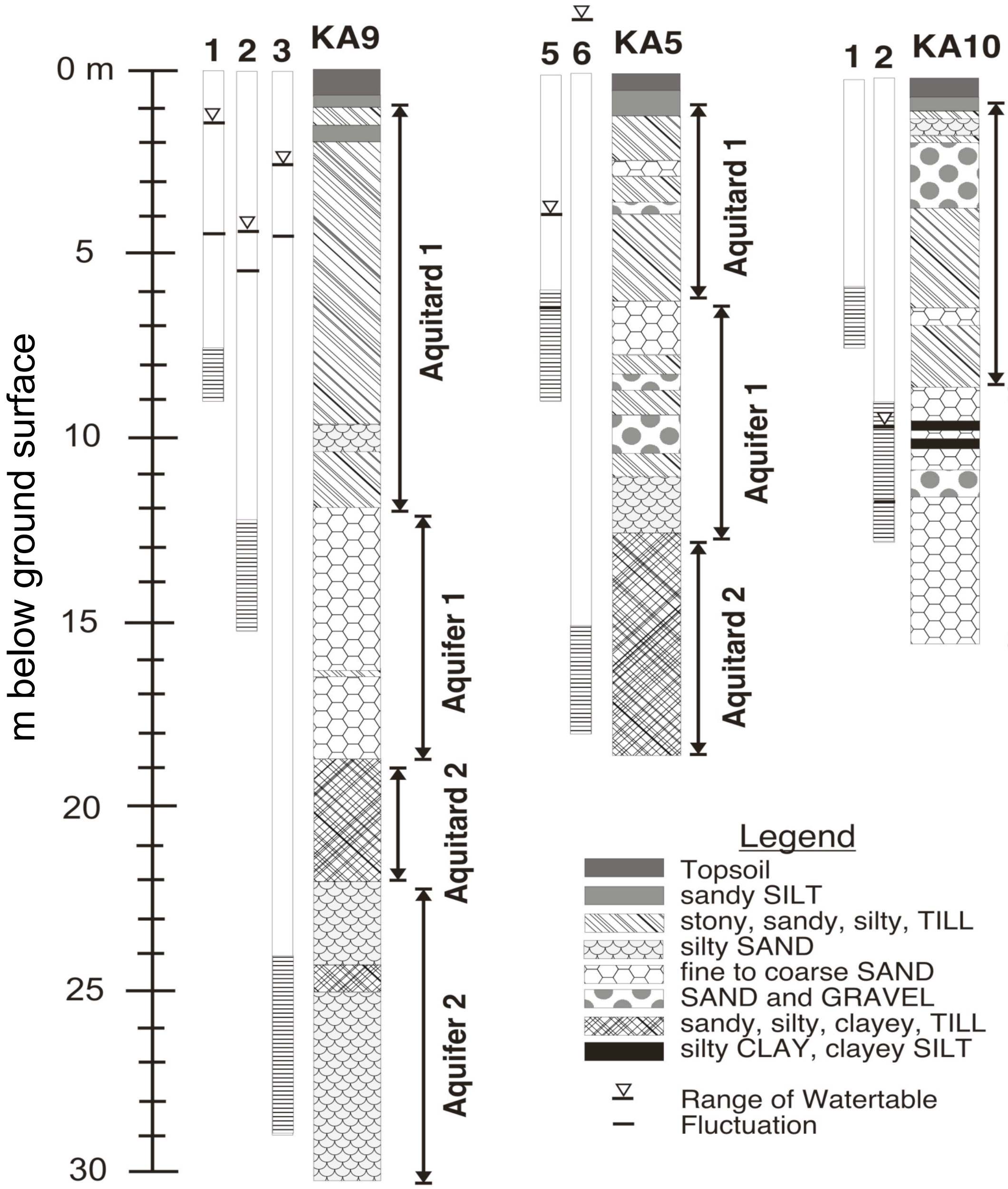

Figure 4.5 - Borehole logs of KA5-5, KA9, and KA10 drilled in February 2007. The interpreted hydrostratigraphic units of Aquitard 1, Aquifer 1, Aquitard 2, and Aquifer 2, are presented for reference. Monitoring wells installed in or near the boreholes are shown as are the minimum and maximum watertable elevations as measured in 2007.

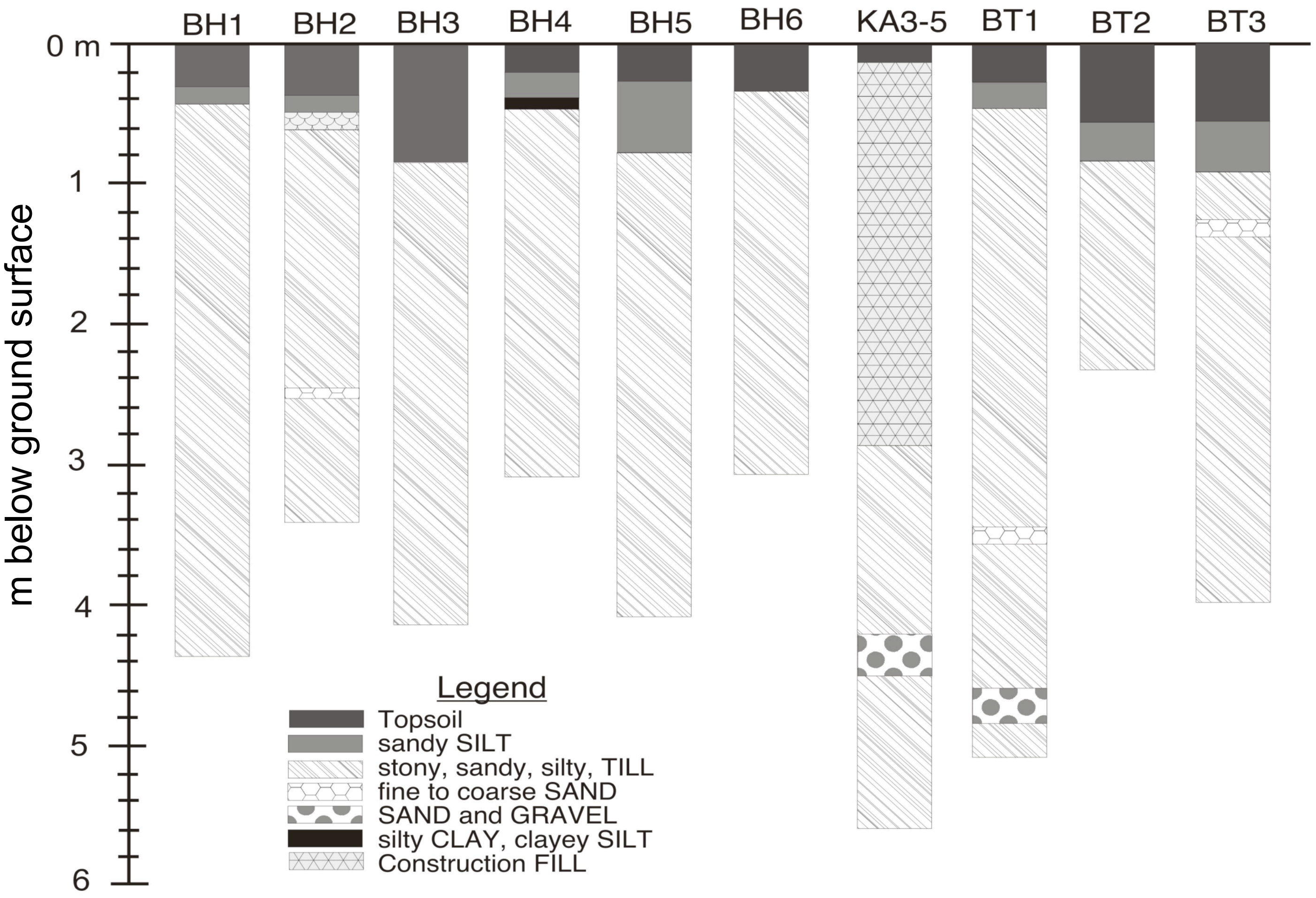

Figure 4.6 - Core logs for BH1 to BH 6 and KA3-5, drilled in April 2006. BT1 to BT3 were drilled in February 2007. All boreholes were ended within Aquitard 1.

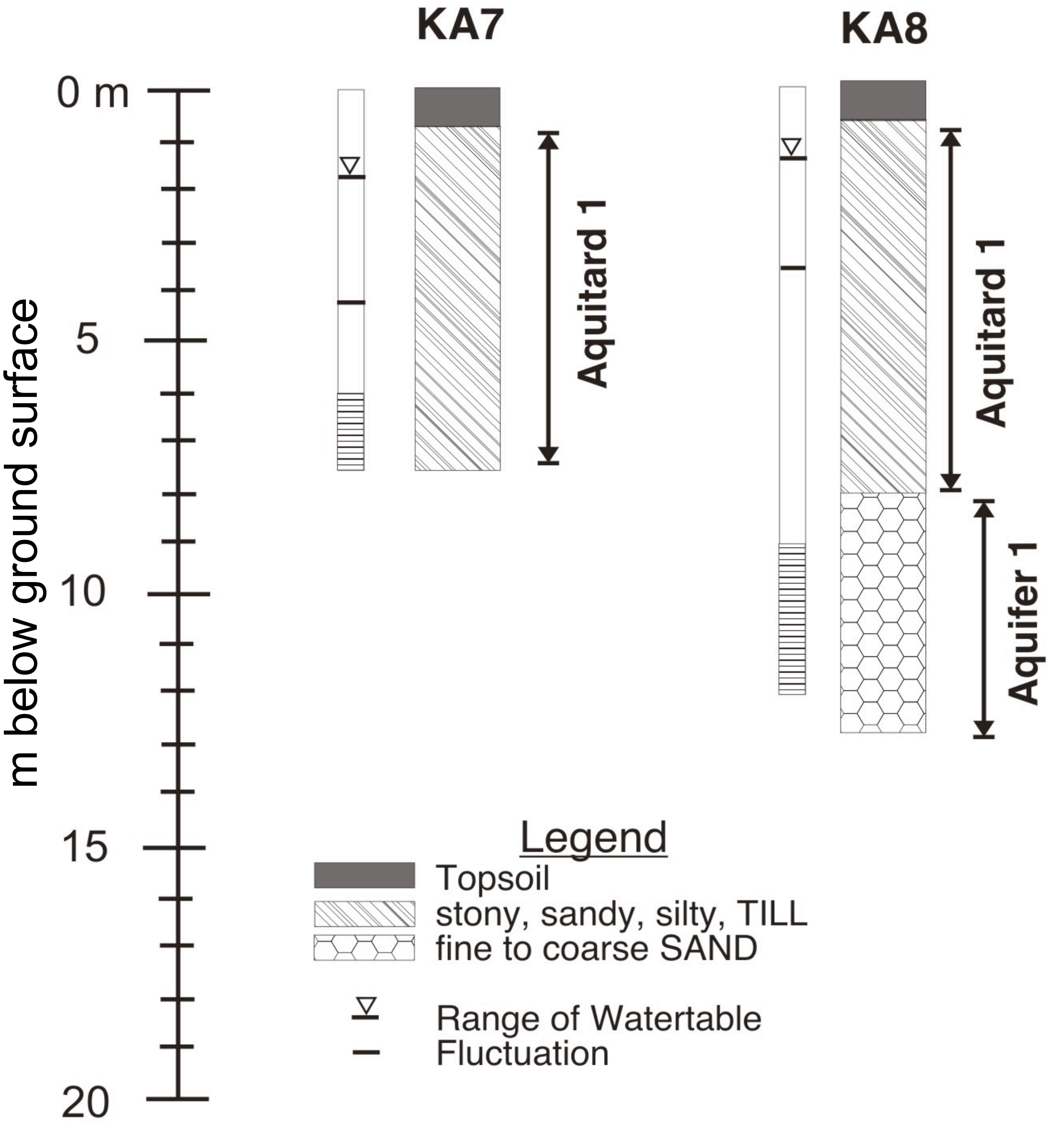

Figure 4.7 - Borehole logs for KA7 and KA8 drilled in September 2006. Geological interpretations were made from drill cutting samples rather than complete core samples.

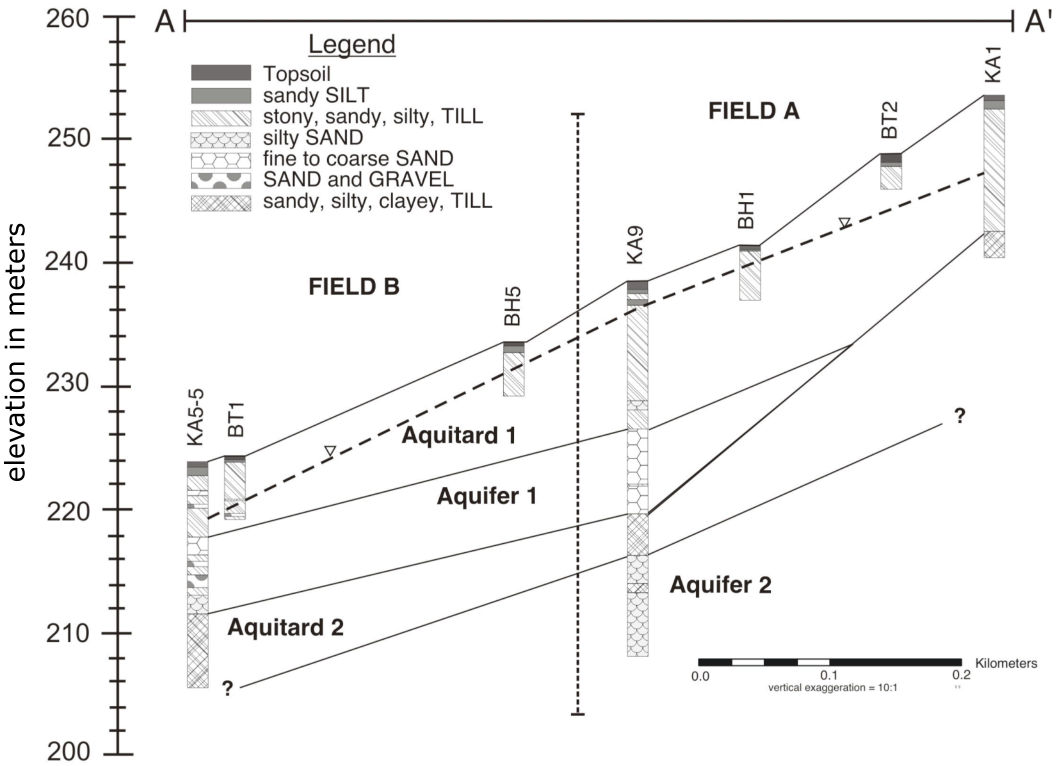

Figure 4.8 - Cross-Section A - A' from KA1 to KA5 showing all hydrostratigraphic units.

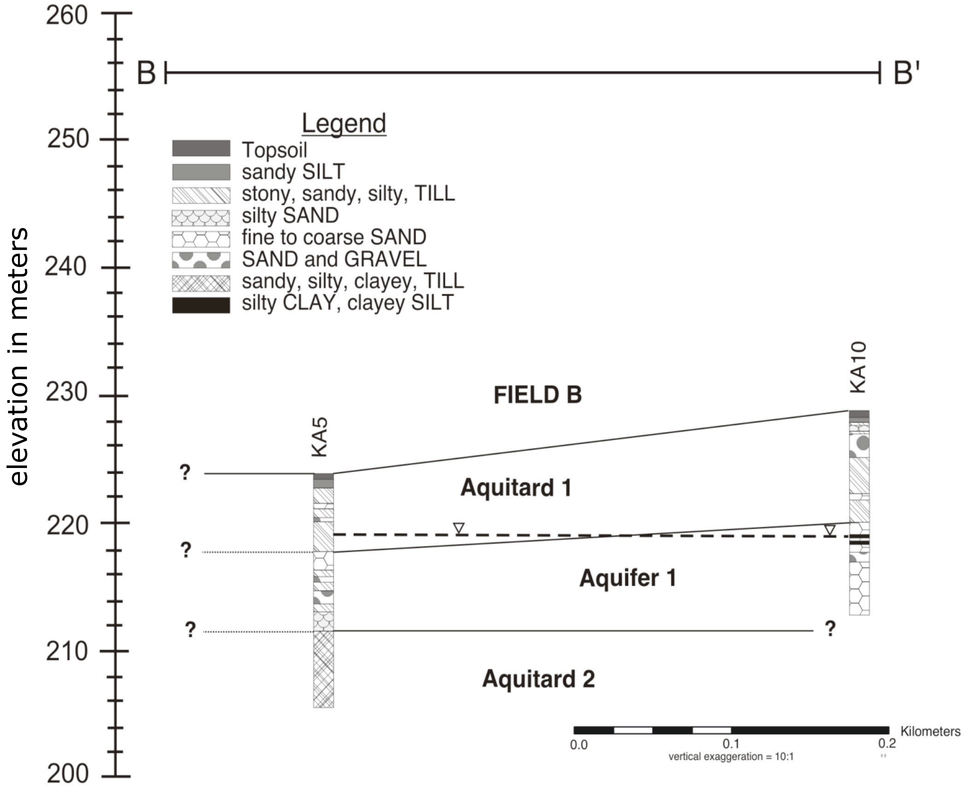

Figure 4.9 - Cross-Section B - B' from KA5 to KA10.

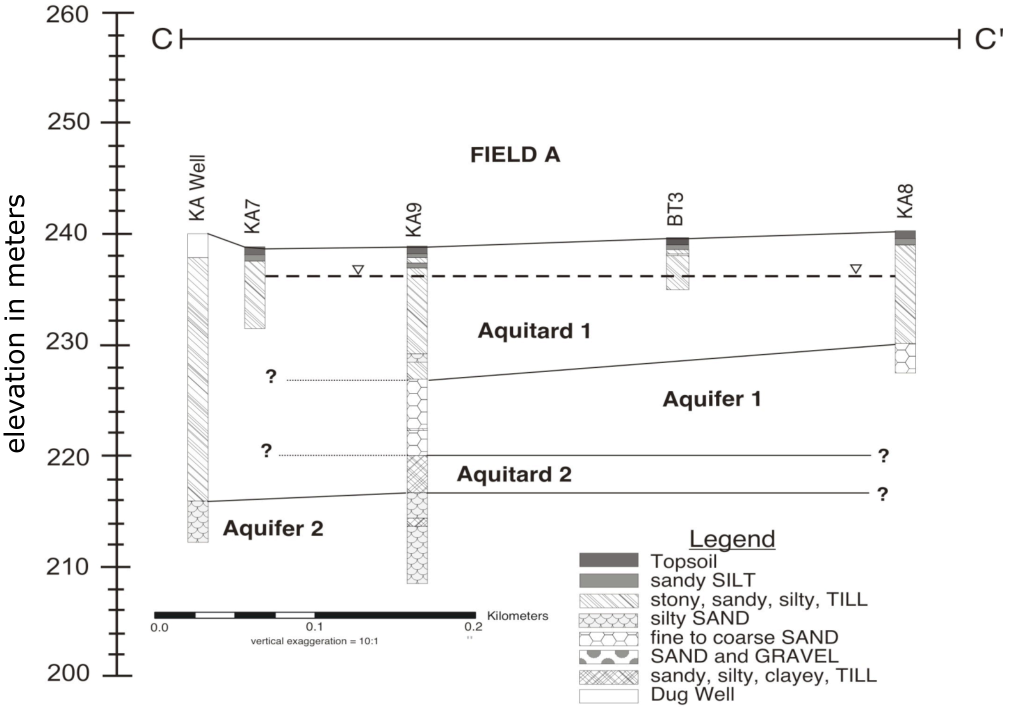

Figure 4.10 - Cross-Section C - C' from KA Well to KA8.

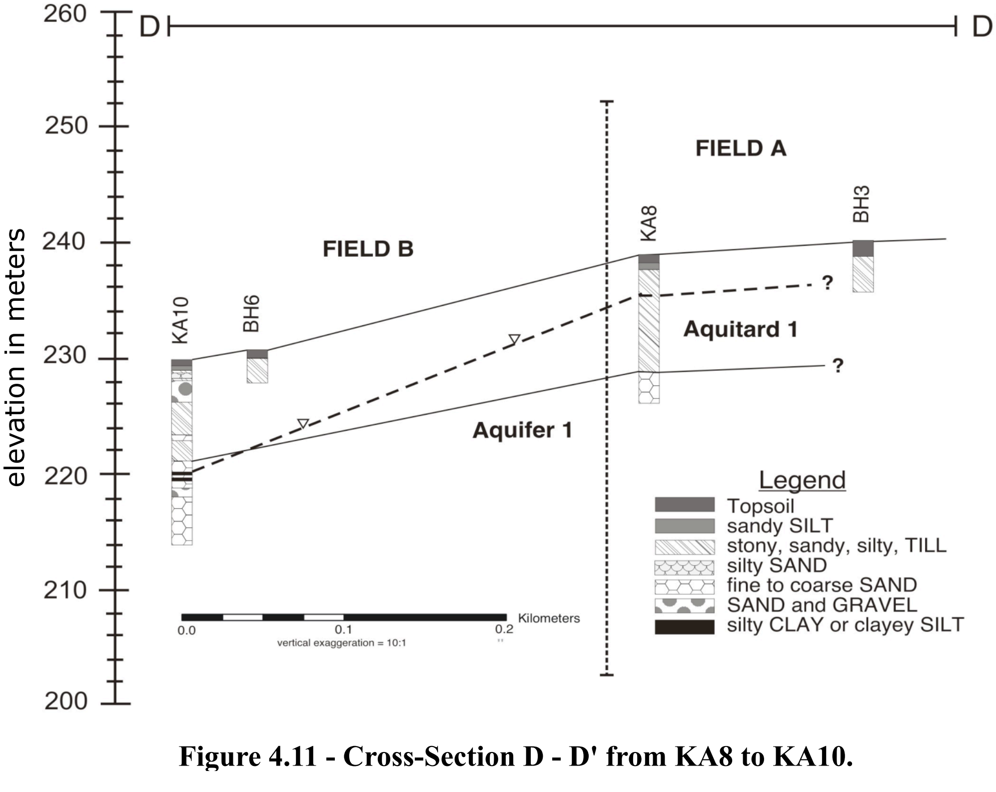

Figure 4.11 - Cross-Section D - D' from KA8 to KA10.

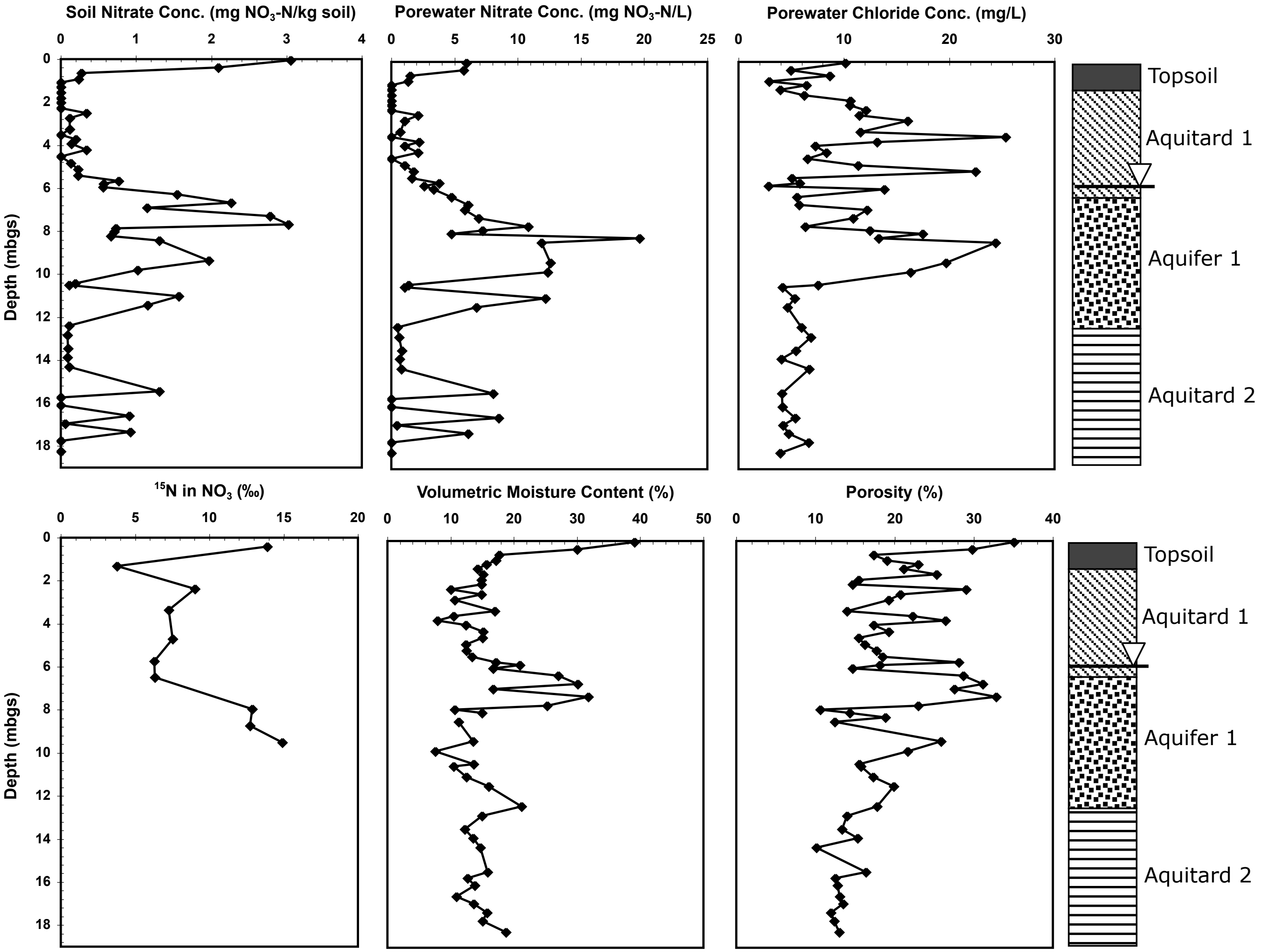

Figure 4.12 - KA5-5 soil core profiles of bulk soil nitrate, porewater nitrate, porewater chloride, δ^{15}N in NO_3^- isotopes, volumetric moisture content, and porosity from core collected in January 2007. Average watertable elevation is shown.

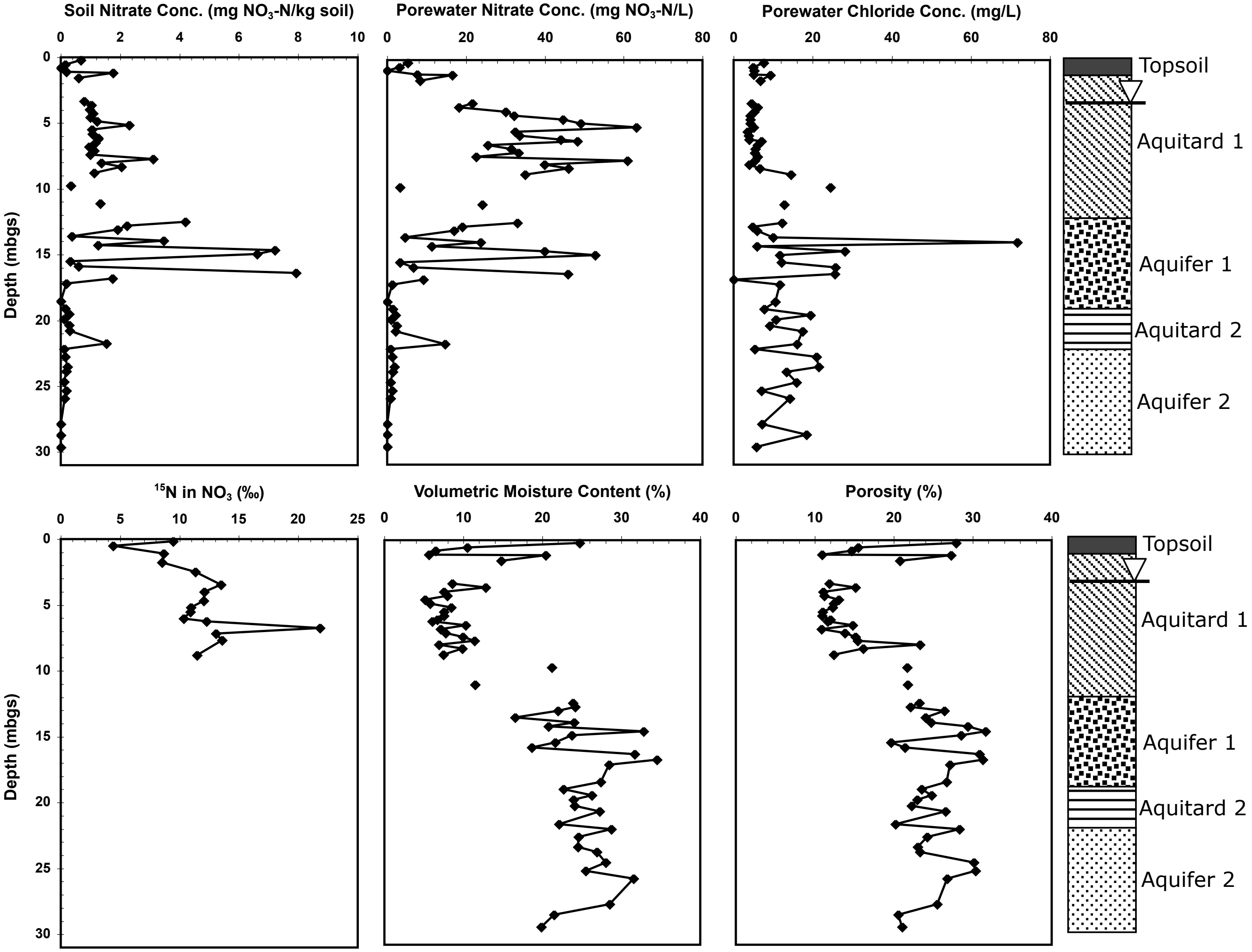

Figure 4.13 - KA9 soil core profiles of bulk soil nitrate, porewater nitrate, porewater chloride, $\delta^{15}N$ in NO_3^- isotopes, volumetric moisture content, and porosity from core collected in January 2007. Average watertable elevation is shown.

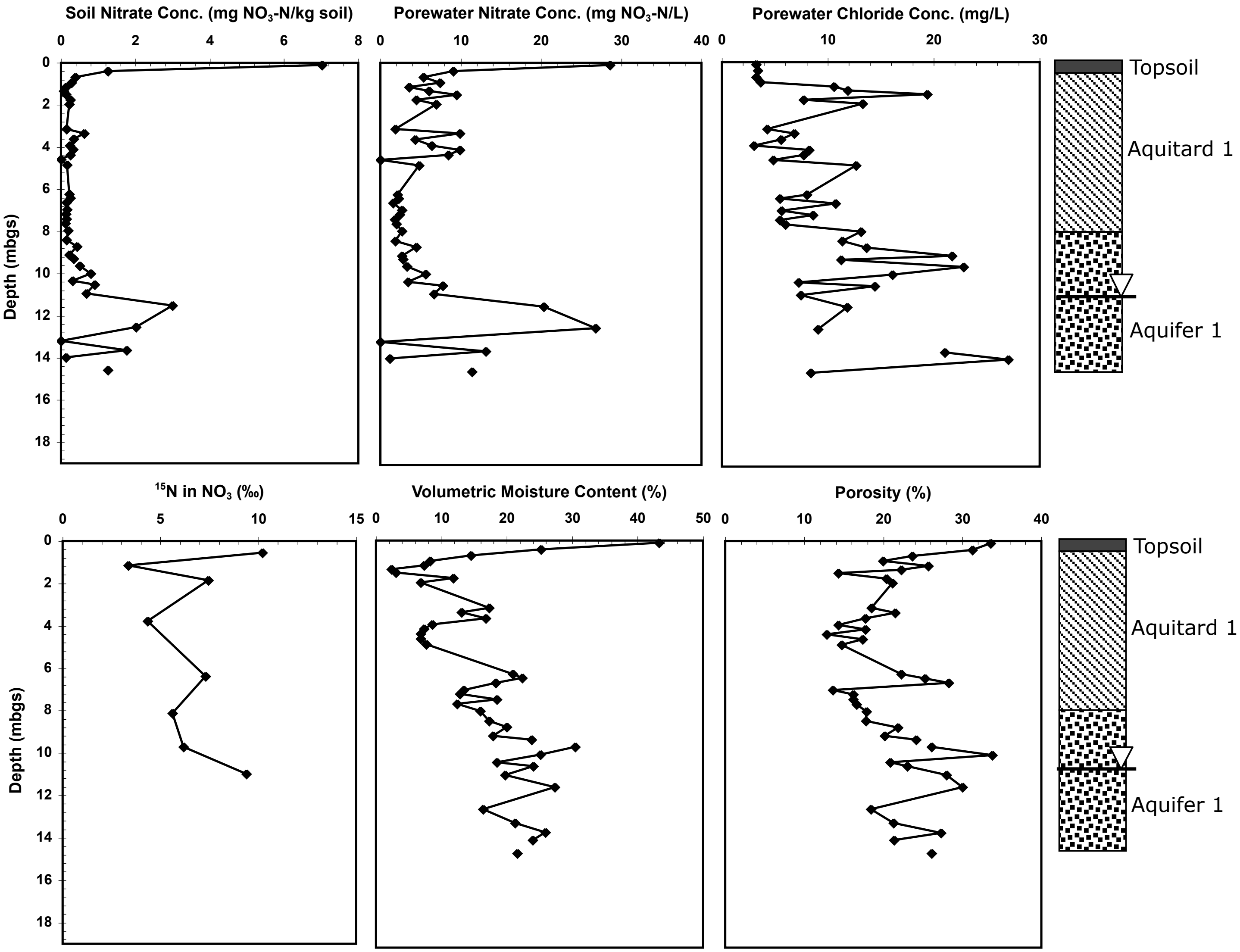

Figure 4.14 - KA10 soil core profiles of bulk soil nitrate, porewater nitrate, porewater chloride, $\delta^{15}N$ in NO_3^- isotopes, volumetric moisture content, and porosity from core collected in January 2007. Average watertable elevation is shown.

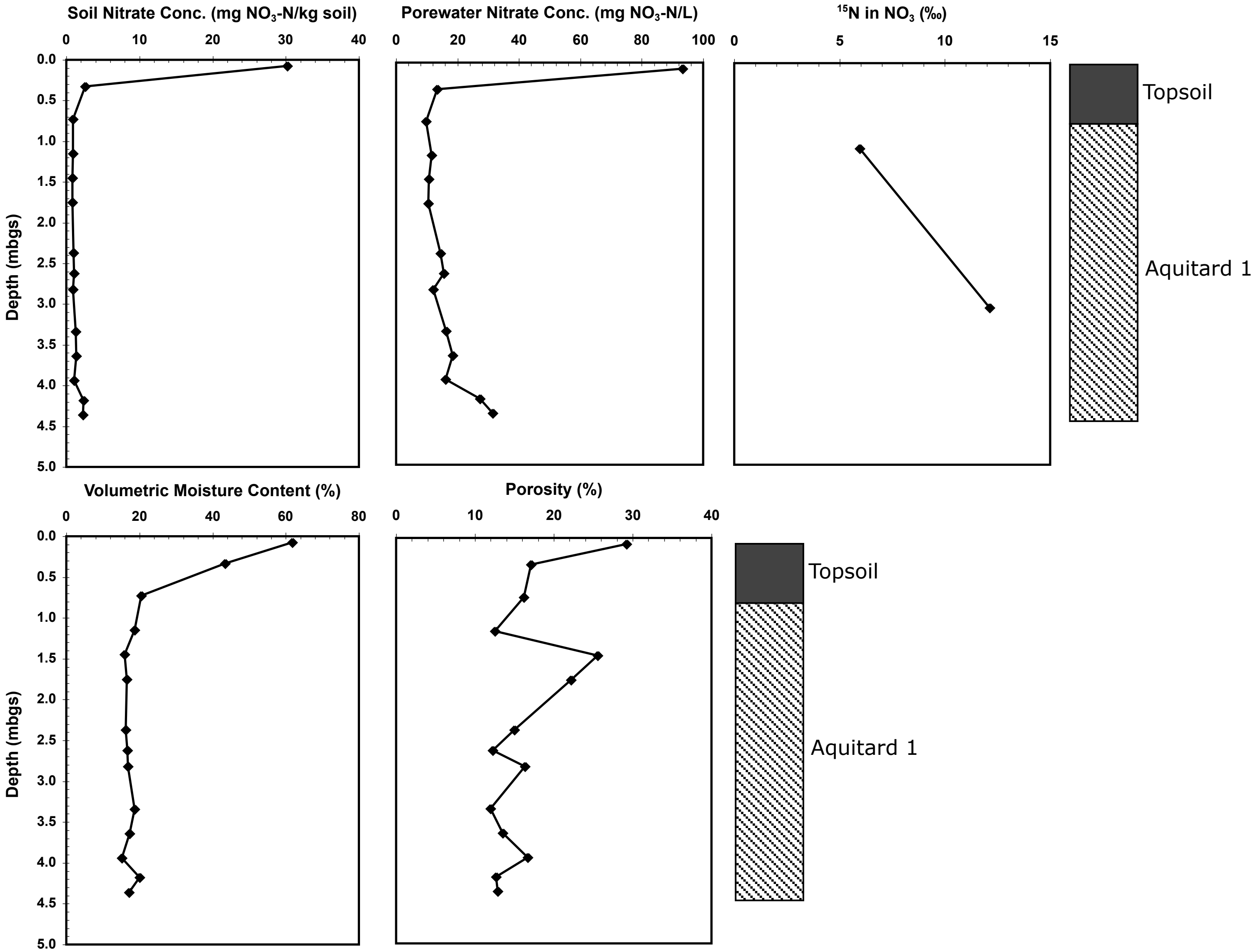

Figure 4.15 - **BH1 soil core profiles of bulk soil nitrate, porewater nitrate, $\delta^{15}N$ in NO_3^- isotopes, volumetric moisture content, and porosity from core collected in April 2006.**

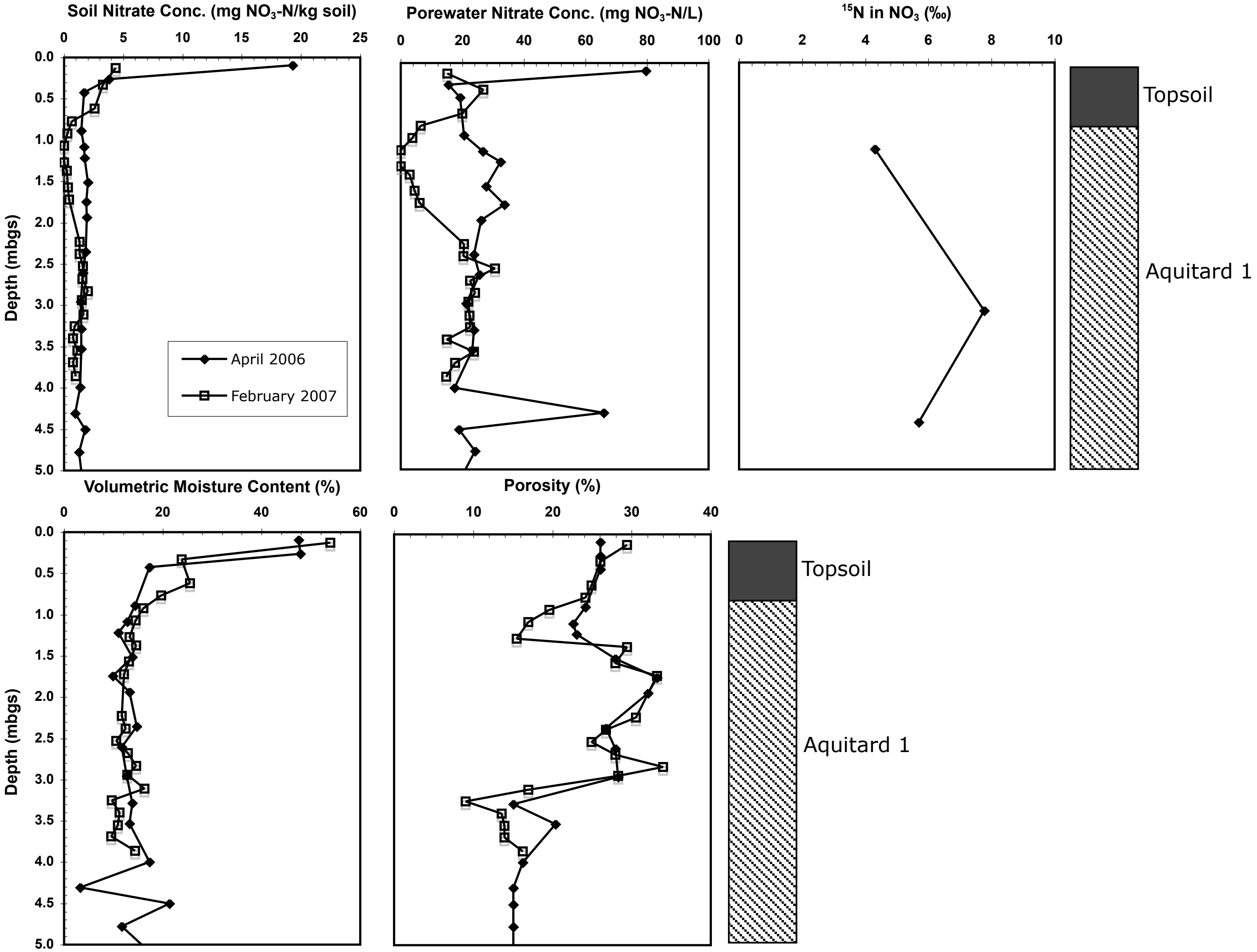

Figure 4.16 - BT1 and BT1-2 soil core profiles of bulk soil nitrate, porewater nitrate, $\delta^{15}N$ in NO_3^- isotopes, volumetric moisture content, and porosity from core collected in April 2006 (BT1) and February 2007 (BT1-2).

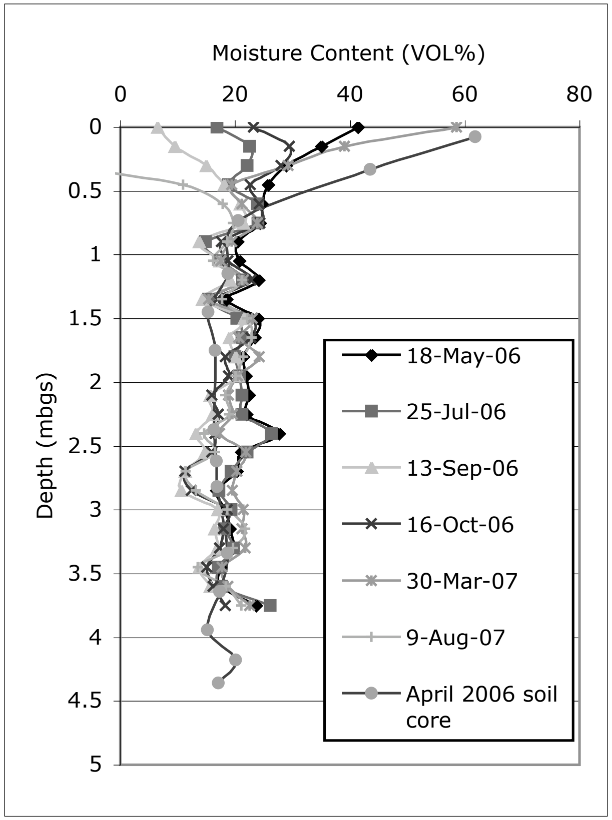

Figure 4.17 - NA1 neutron probe measured soil moisture profile. Laboratory measured soil moisture profile of the BH1 core is included for reference.

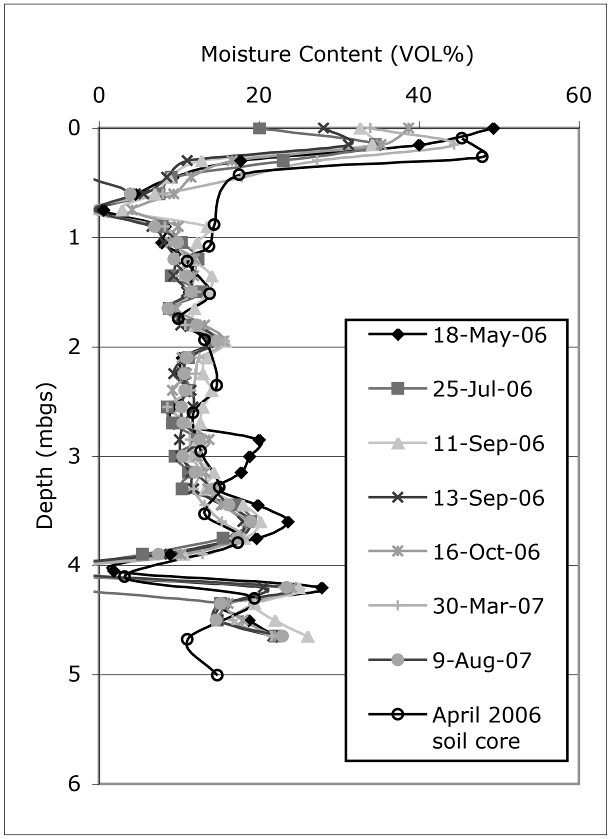

Figure 4.18 - NA2 neutron probe measured soil moisture profile. Laboratory measured soil moisture profile of the BT1 core is included for reference.

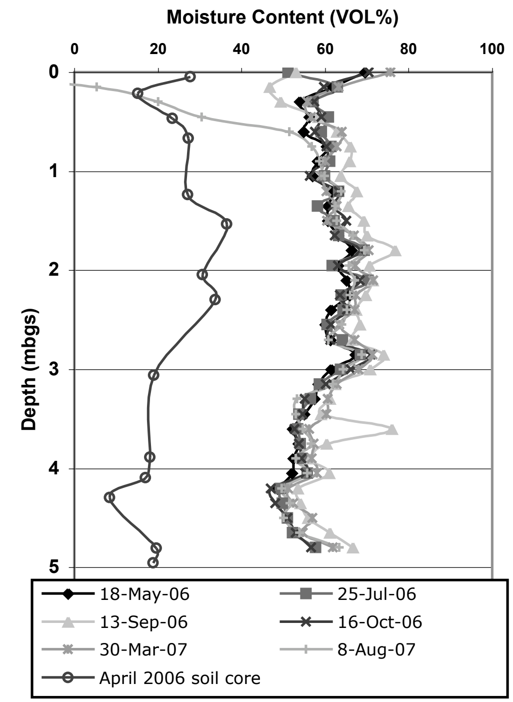

Figure 4.19 - NA3 neutron probe measured soil moisture profile. Laboratory measured soil moisture profile of the KA3-5 core is included for reference.

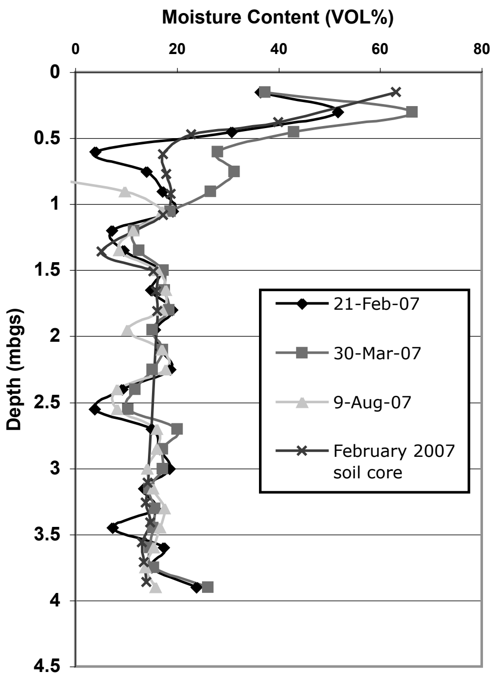

Figure 4.20 - NA4 neutron probe measured soil moisture profile. Laboratory measured soil moisture profile of the BT3 core is included for reference.

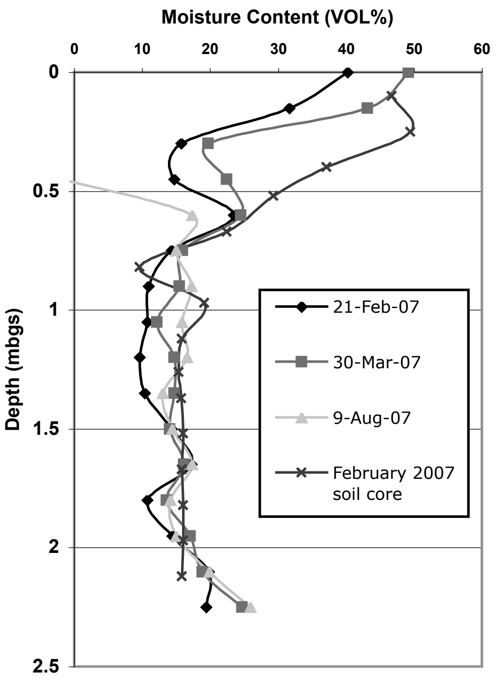

Figure 4.21 - NA5 neutron probe measured soil moisture profile. Laboratory measured soil moisture profile of the BT2 core is included for reference.

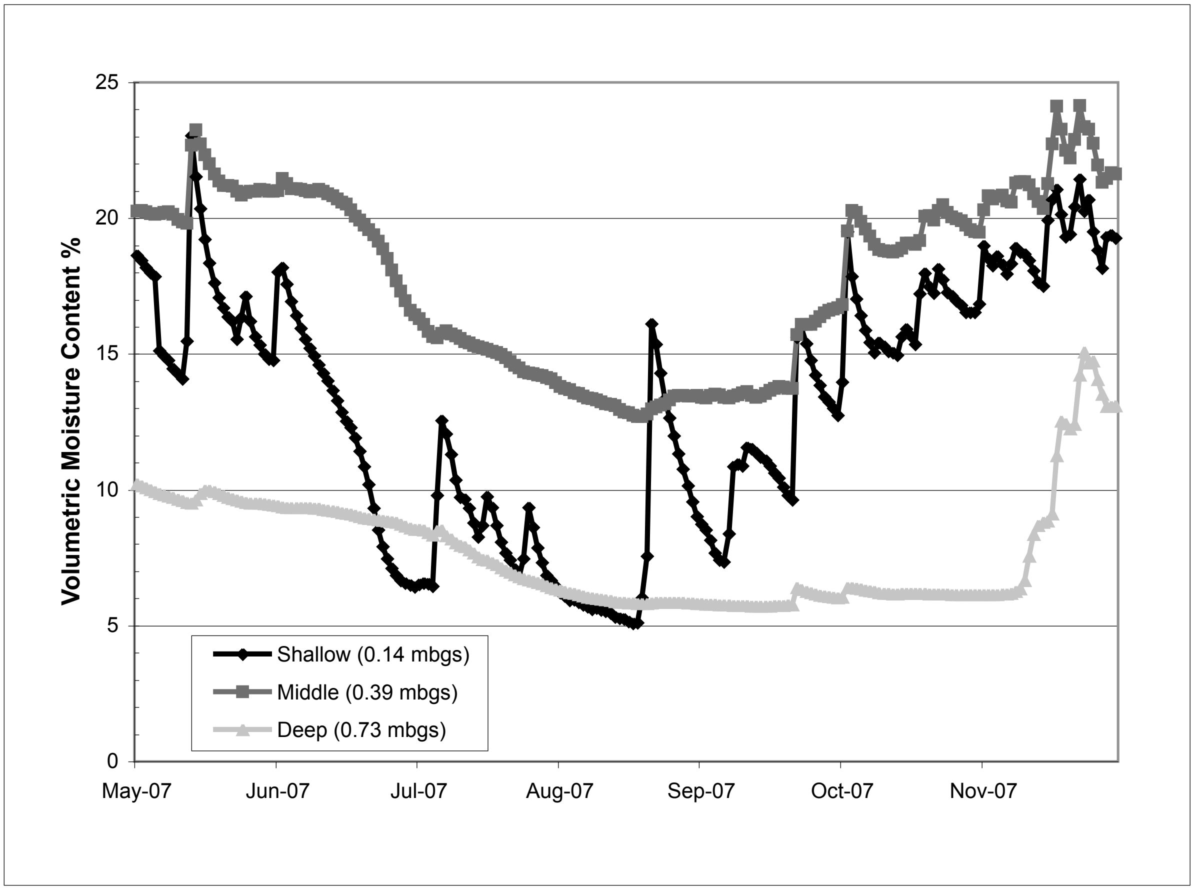

Figure 4.22 - Volumetric soil moisture content as measured by three TDR probes installed at progressively deeper depths below ground surface. Probes were installed in May 2007 approximately 2m north of the met station in Field B.

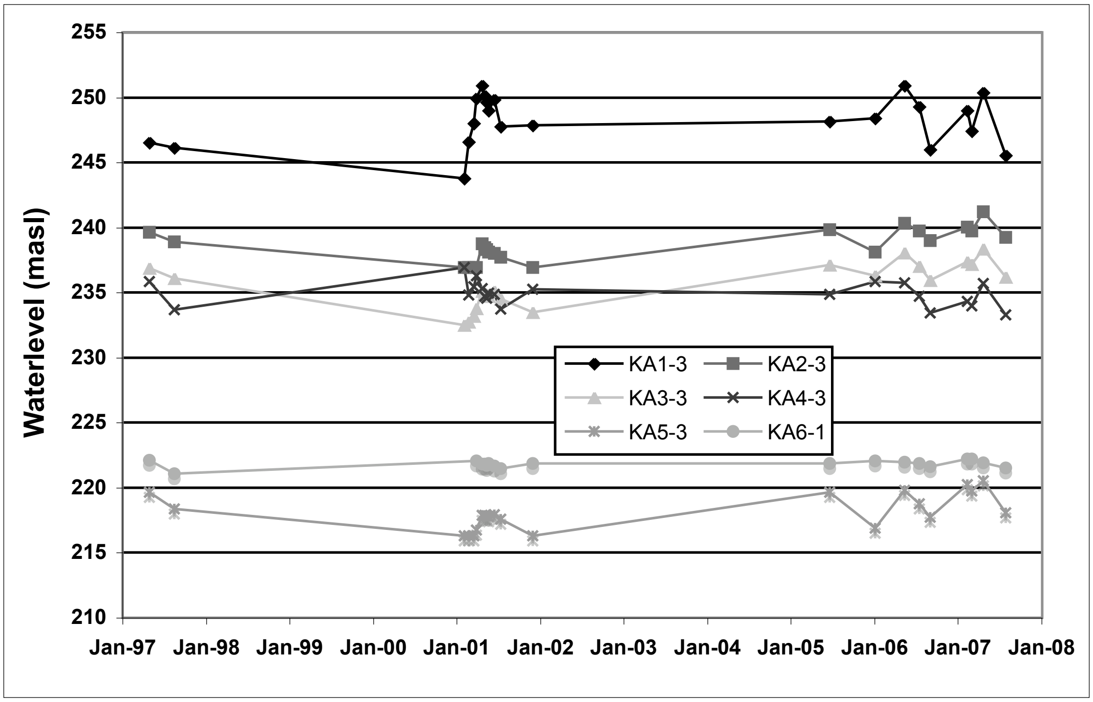

Figure 4.23 - Manual water level measurements at well nests KA1 to KA6 taken between 1997 and 2007. Water level elevations show that the general groundwater flow direction is from KA1 (east) to KA5 (west).

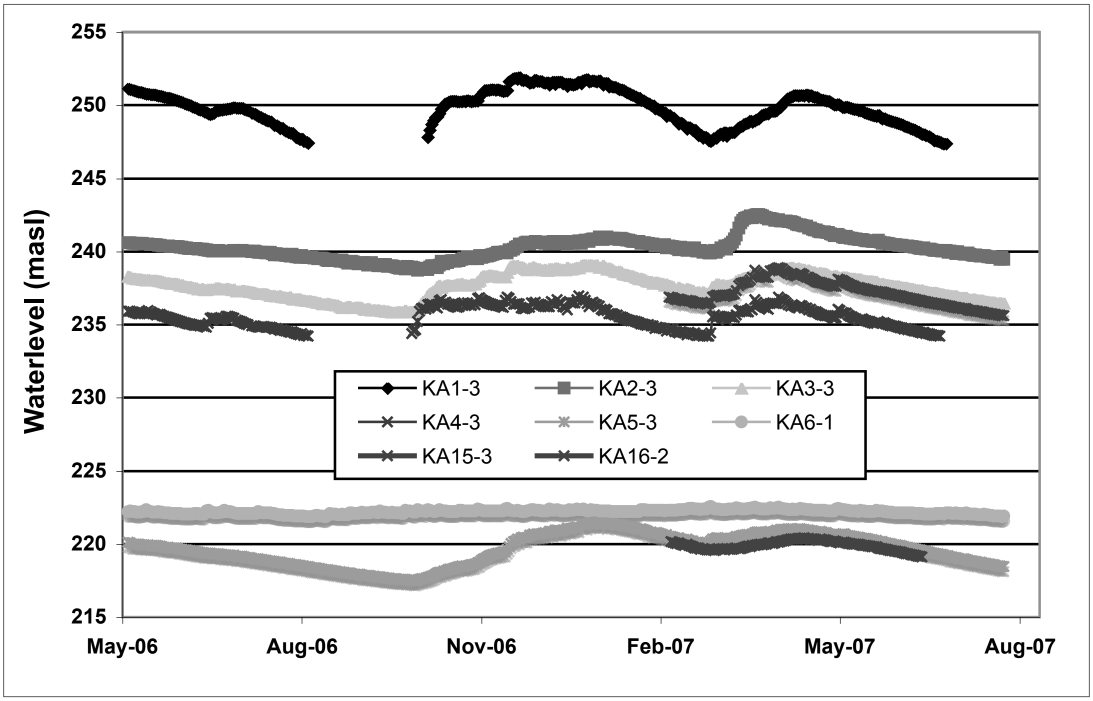

Figure 4.24 - Levelogger water level measurements at well nests KA1 to KA6, KA9 and KA10 taken between May 2006 and August 2007.

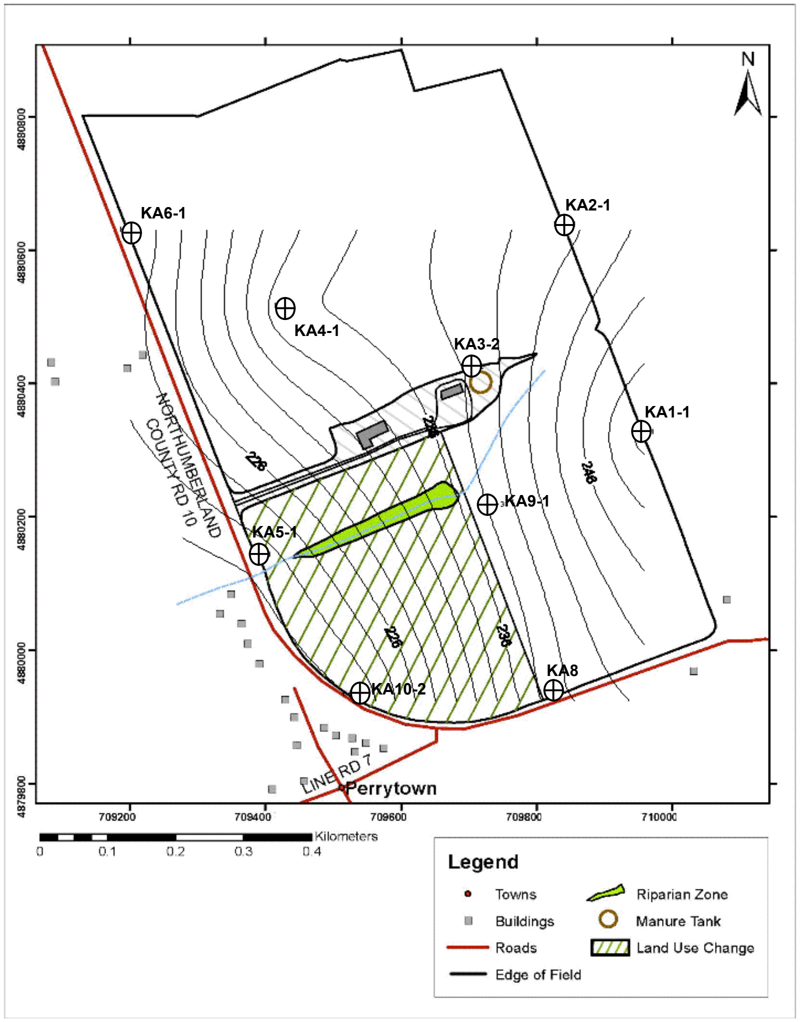

Figure 4.25 - May 2007 piezometric surface elevation contours from wells screened in Aquitard 1. General groundwater flow direction is from east to west. Contour interval = 2m.

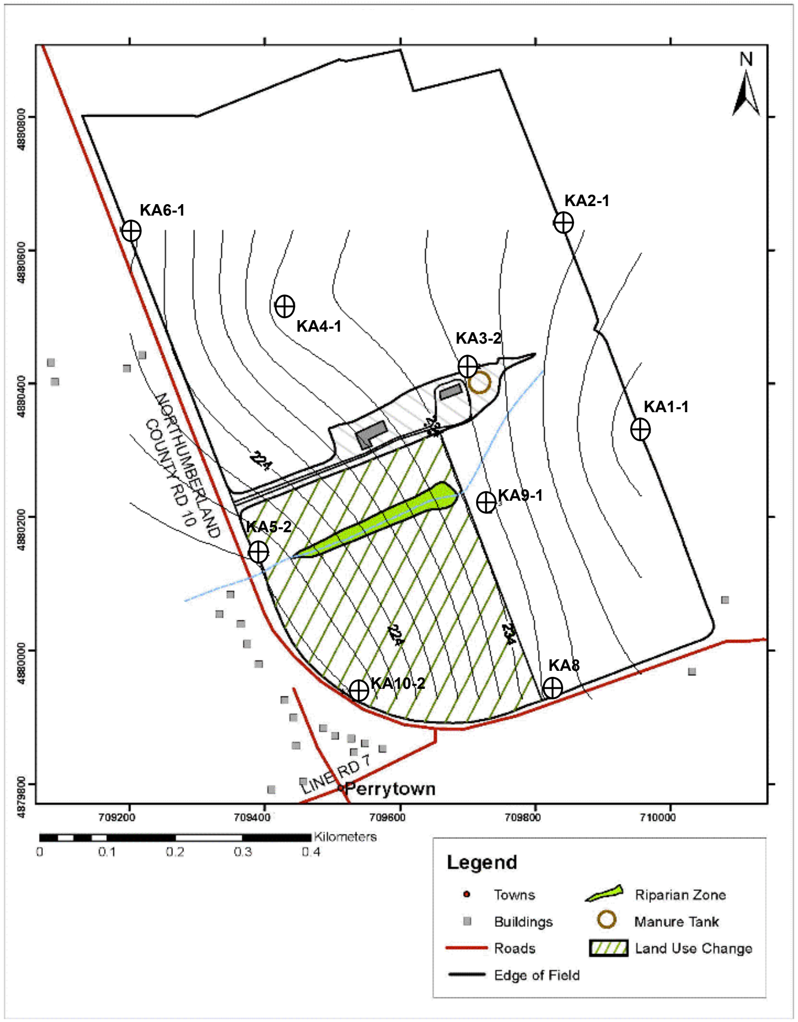

Figure 4.26 - August 2007 piezometric surface elevation contours from wells screened in Aquitard 1. General groundwater flow direction is from east to west. Contour interval = 2m.

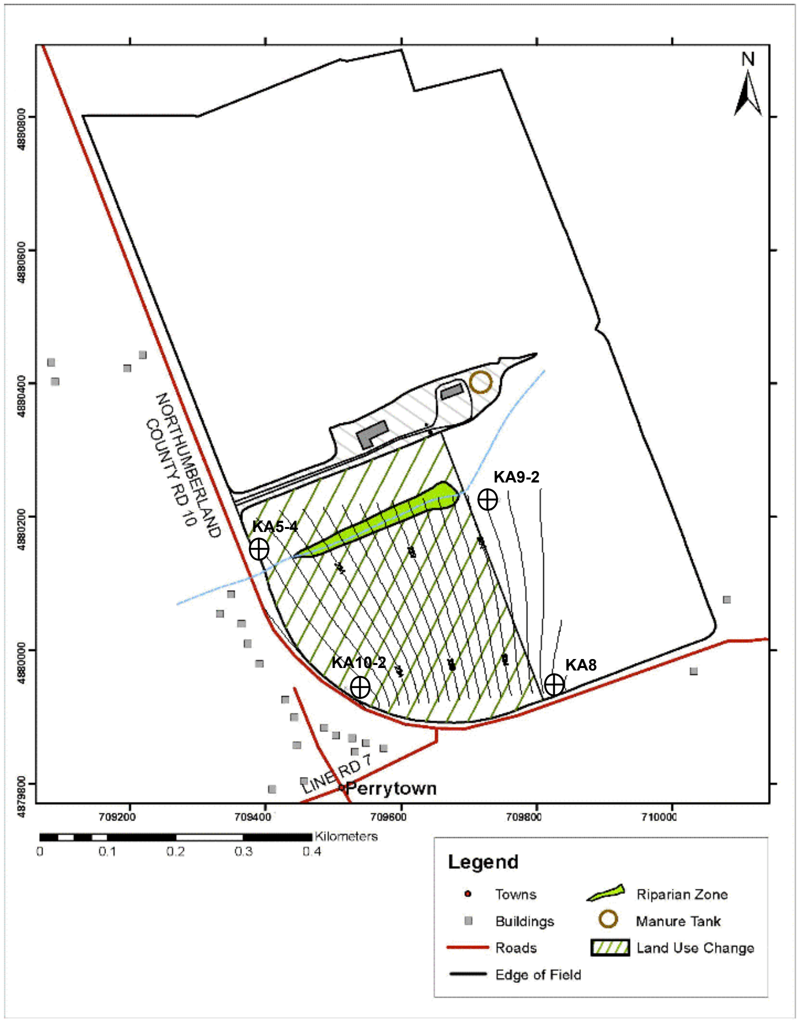

Figure 4.27 - May 2007 piezometric surface elevation contours from wells screened in Aquifer 1. General groundwater flow direction is from east to west. Contour interval = 2m.

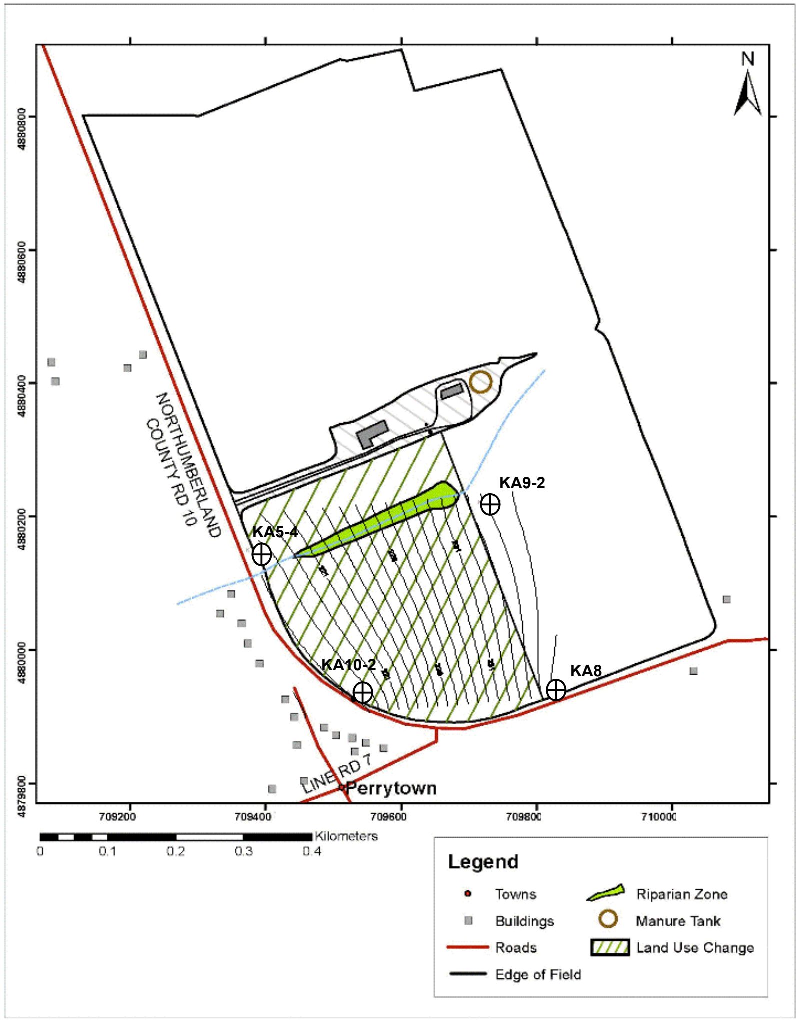

Figure 4.28 - August 2007 piezometric surface elevation contours from wells screened in Aquifer 1. General groundwater flow direction is from east to west. Contour interval = 2m.

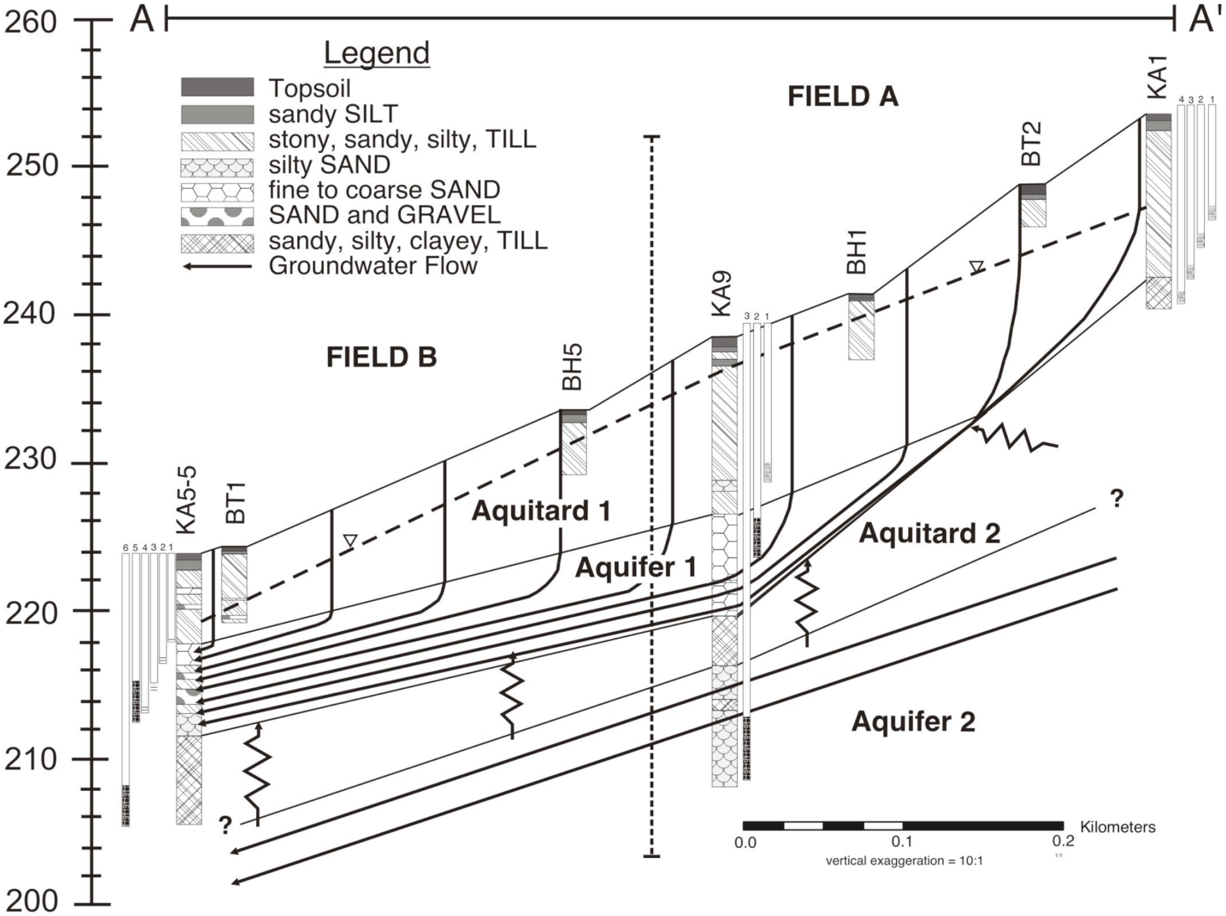

Figure 4.29 - Conceptual model of groundwater flow along transect A - A' beneath Fields A and B. Groundwater flow is vertical through Aquitard 1, until Aquifer 1 is reached where the groundwater flow direction is horizontal from east to west. The upwards vertical gradient between Aquifer 2 and Aquifer 1, suggests that groundwater enters Aquifer 1 from below. Generally, groundwater flow in Aquifer 2 is from east to west and is separated from Aquifer 1.

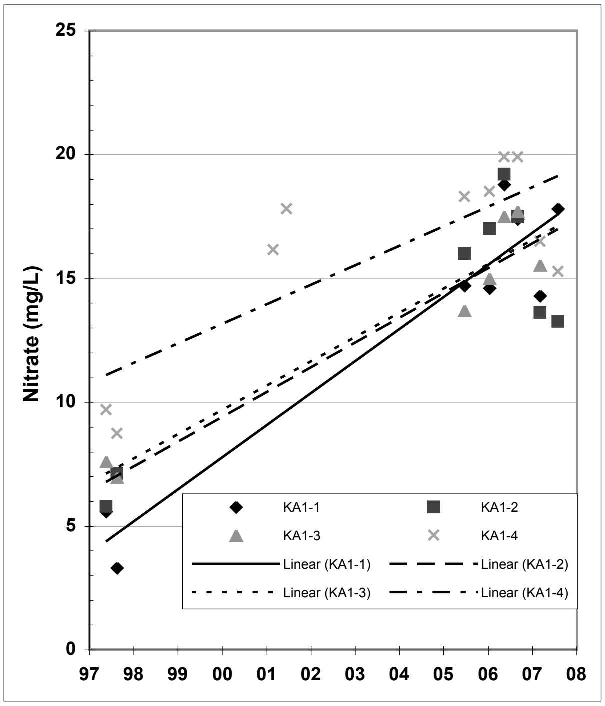

Figure 4.30 - KA1 groundwater nitrate concentrations (1997 to 2007).

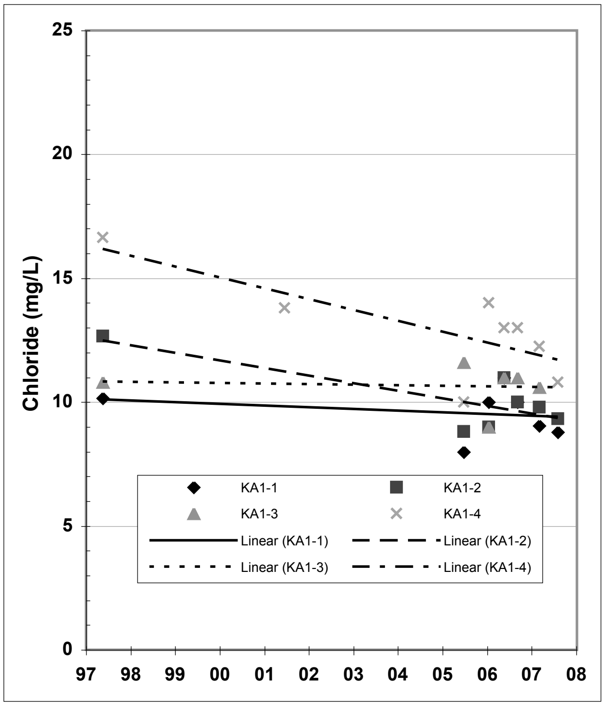

Figure 4.31 - KA1 groundwater chloride concentrations (1997 to 2007).

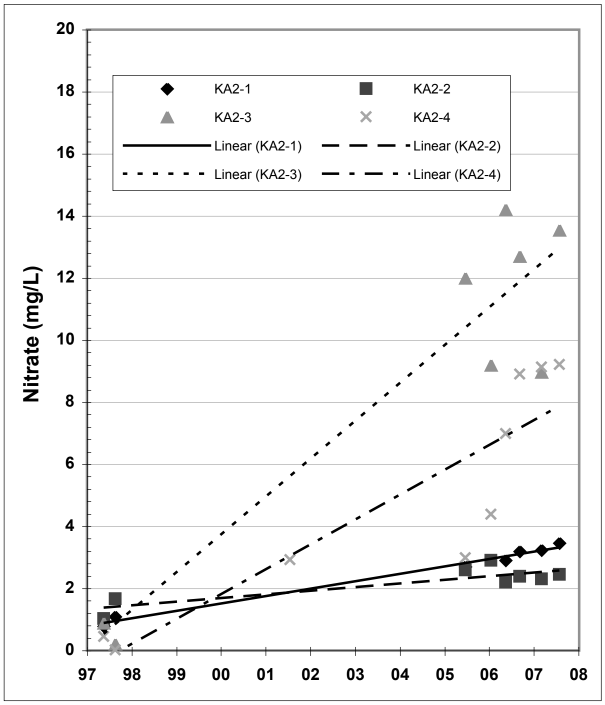

Figure 4.32 - KA2 groundwater nitrate concentrations (1997 to 2007).

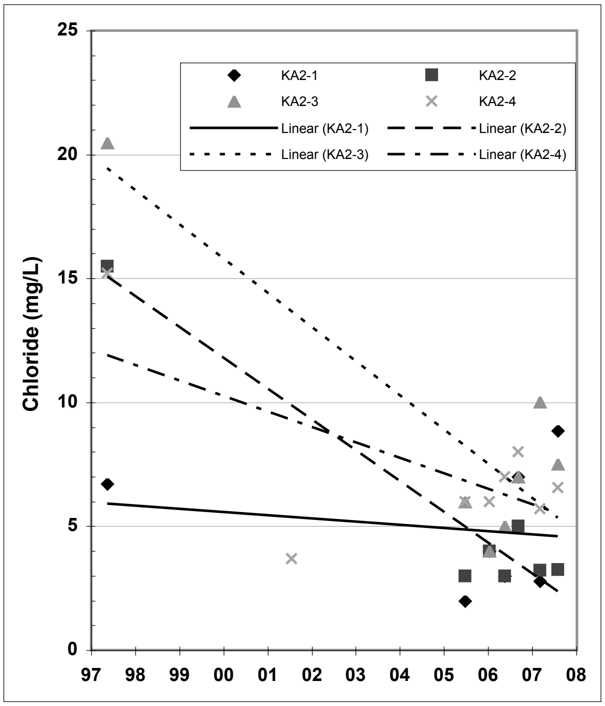

Figure 4.33 - KA2 groundwater chloride concentrations (1997 to 2007).

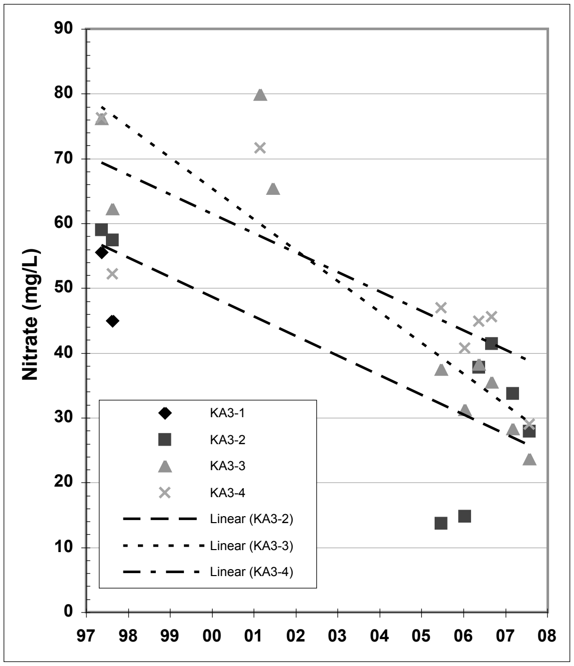

Figure 4.34 - KA3 groundwater nitrate concentrations (1997 to 2007).

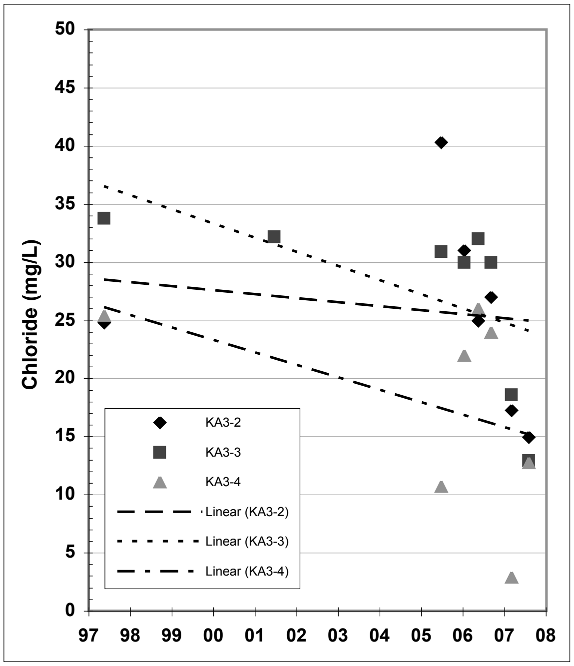

Figure 4.35 - KA3 groundwater chloride concentrations (1997 to 2007).

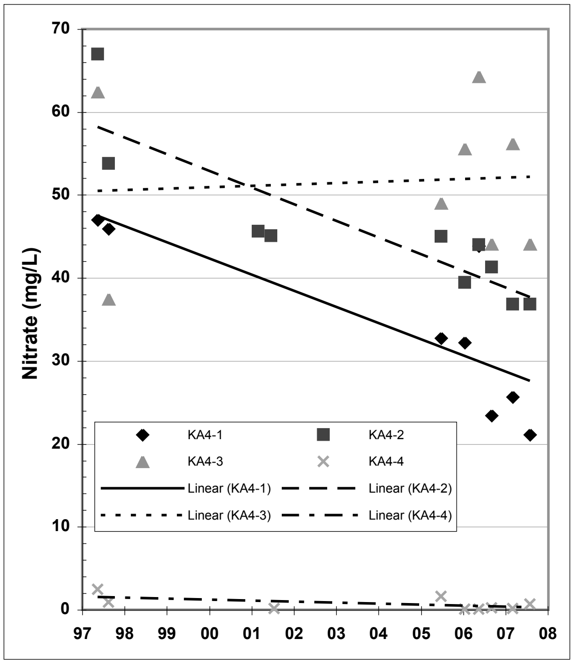

Figure 4.36 - KA4 groundwater nitrate concentrations (1997 to 2007).

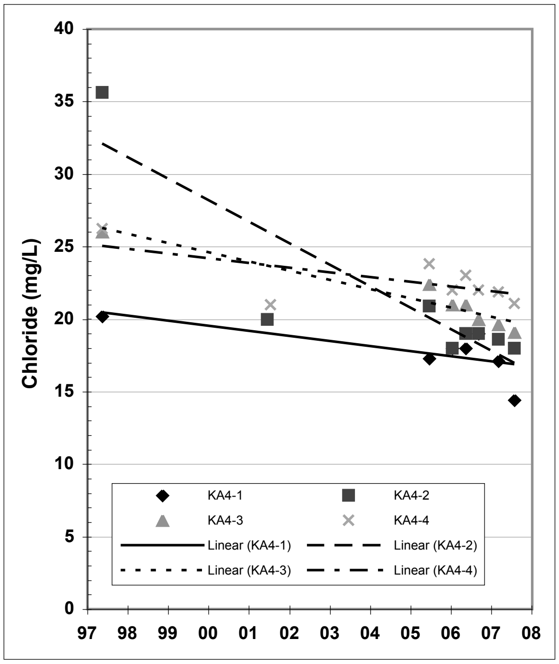

Figure 4.37 - KA4 groundwater chloride concentrations (1997 to 2007).

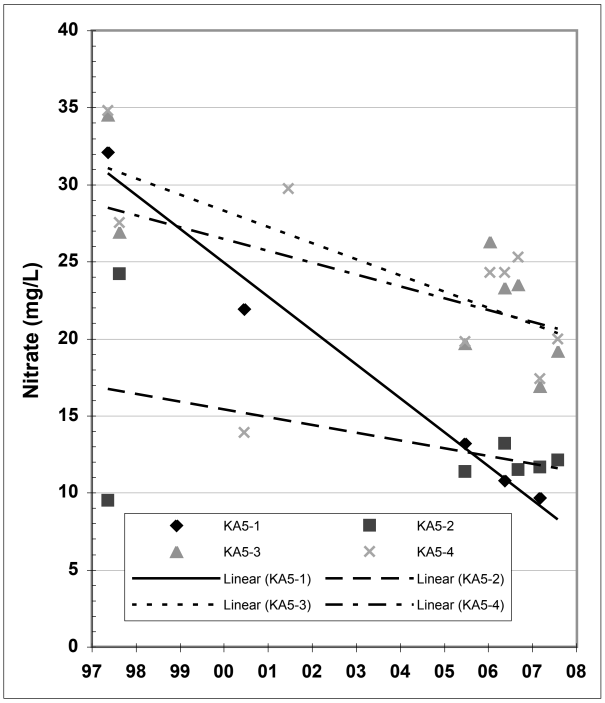

Figure 4.38 - KA5 groundwater nitrate concentrations (1997 to 2007).

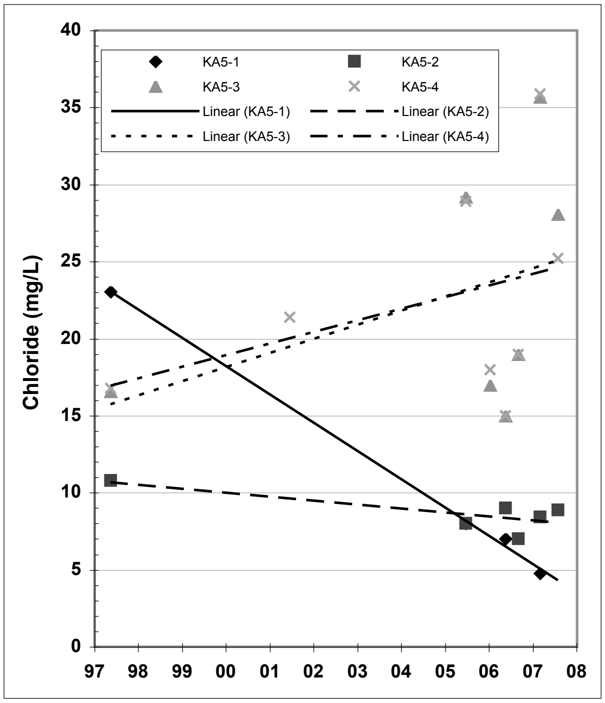

Figure 4.39 - KA5 groundwater chloride concentrations (1997 to 2007).

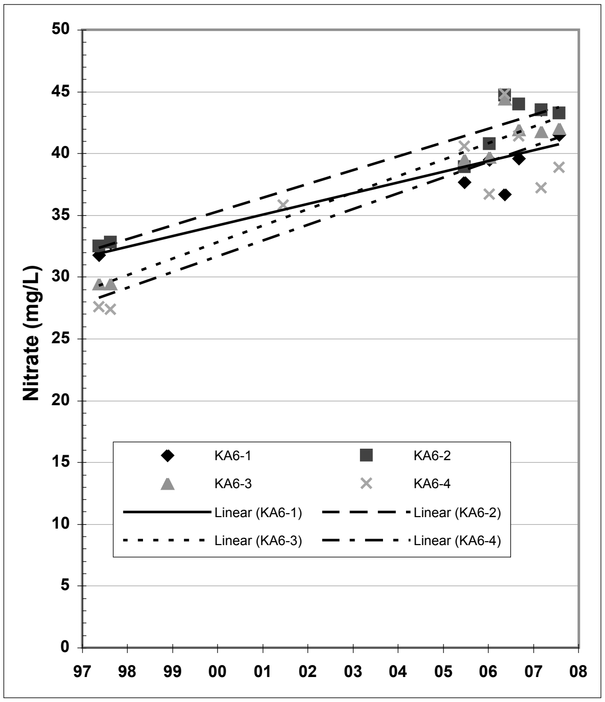

Figure 4.40 - KA6 groundwater nitrate concentrations (1997 to 2007).

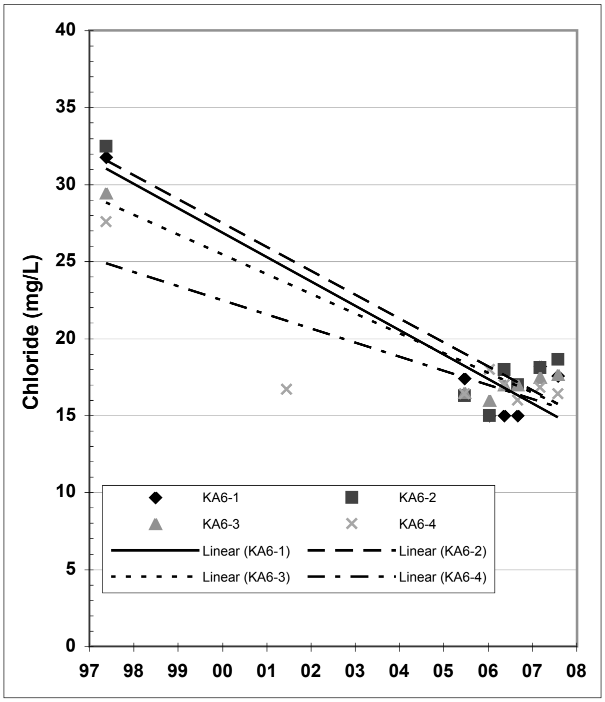

Figure 4.41 - KA6 groundwater chloride concentrations (1997 to 2007).

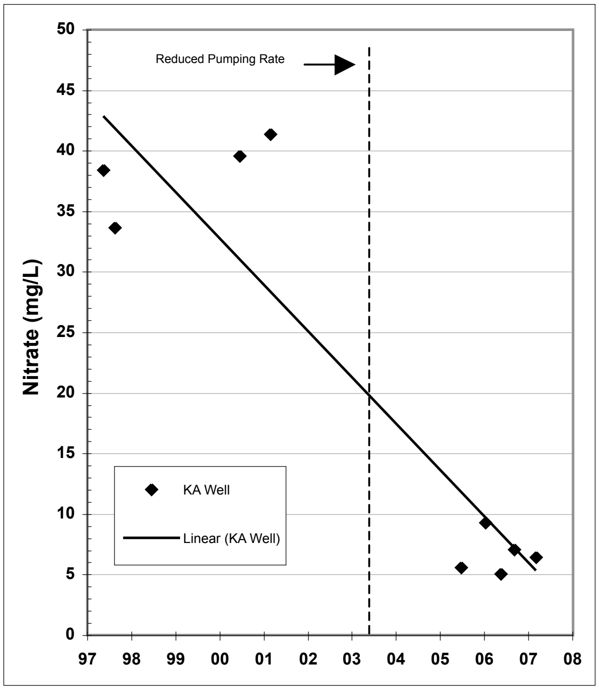

Figure 4.42 - Allin Farm pumping well (KA Well) groundwater nitrate concentrations (1997 to 2007). Pumping rate was reduced from 5000 gal/day to 1000 gal/day in 2003.

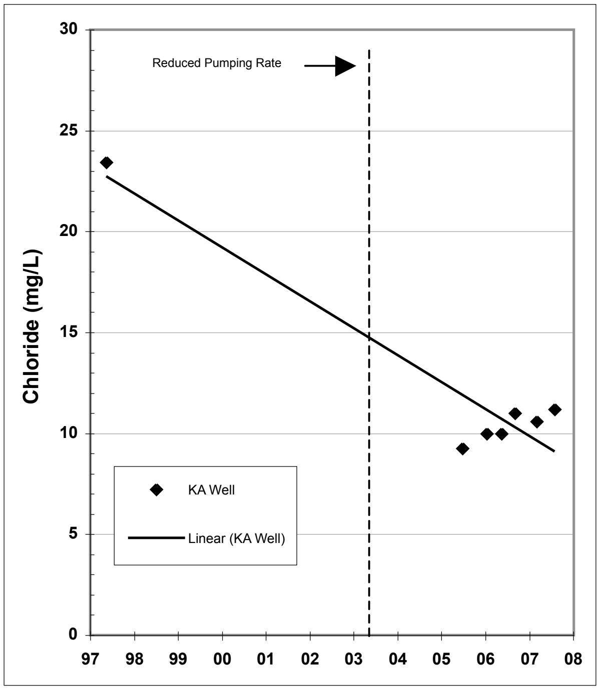

Figure 4.43 - Allin Farm pumping well (KA Well) groundwater chloride concentrations (1997 to 2007). Pumping rate was reduced from 5000 gal/day to 1000 gal/day in 2003.

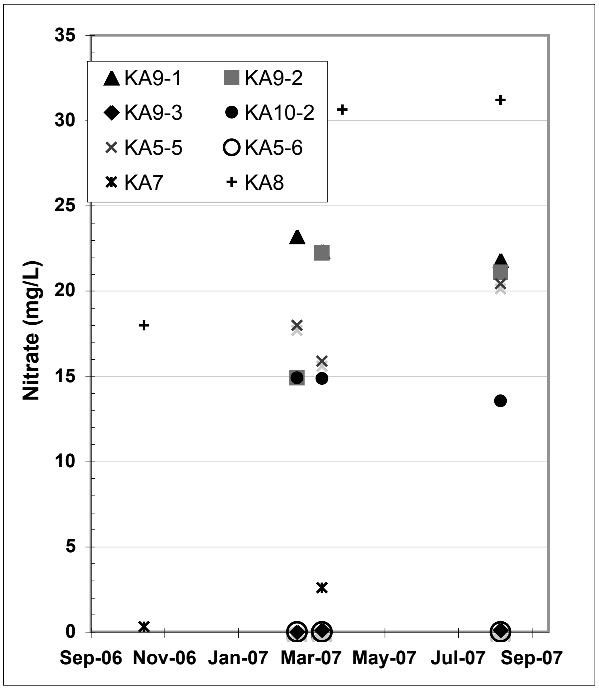

Figure 4.44 - Groundwater nitrate concentrations at wells installed in 2006 and 2007 as part of the present study.

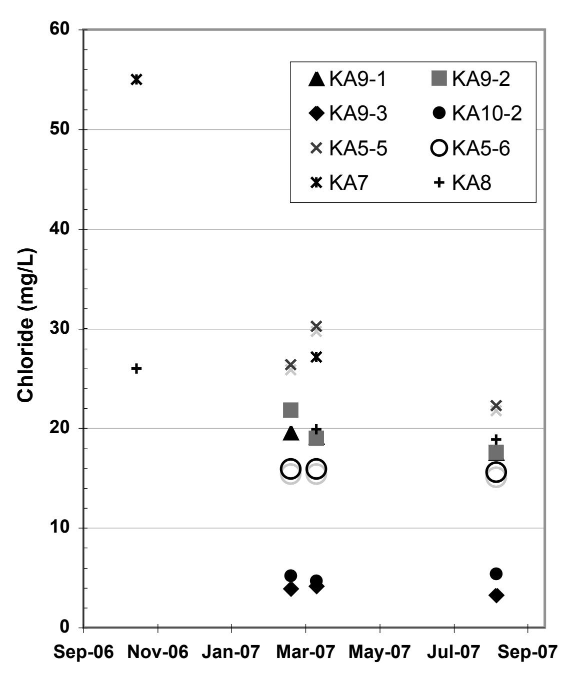

Figure 4.45 - Groundwater chloride concentrations at wells installed in 2006 and 2007 as part of the present study.

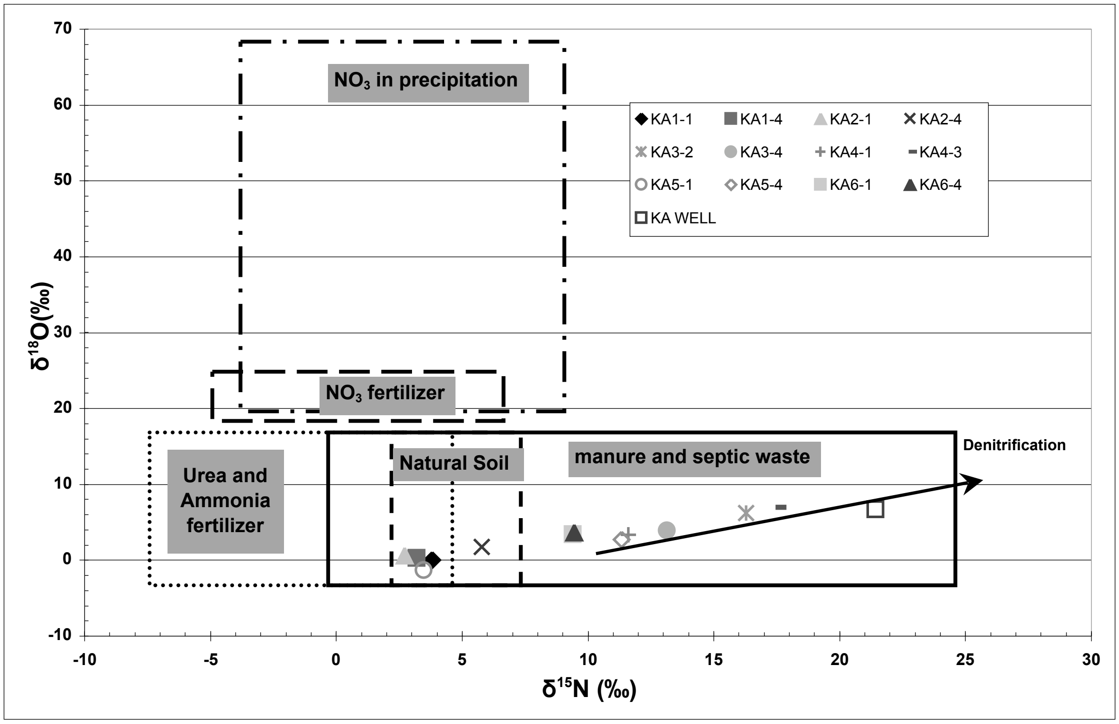

Figure 4.46 - Groundwater δ^{15}N and δ^{18}O in NO$_3^-$ Isotopes (May 2006). Background modified from Kendall (1998).

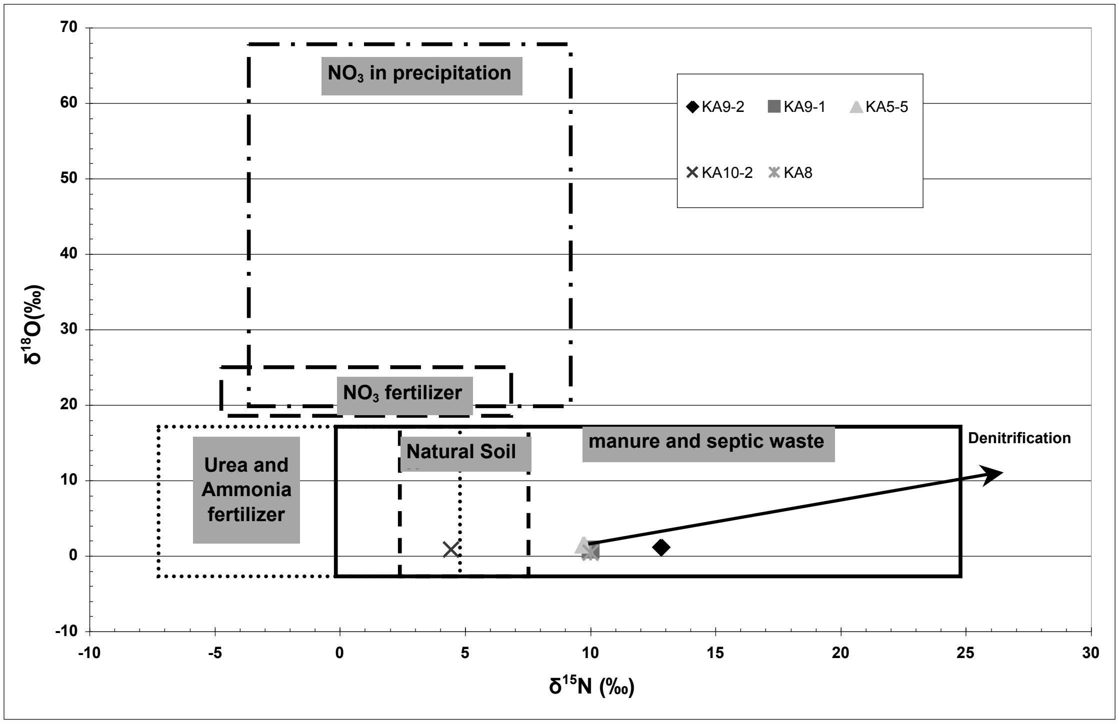

Figure 4.47 - Groundwater δ^{15}N and δ^{18}O in NO$_3^-$ Isotopes (February 2007). Background modified from Kendall (1998).

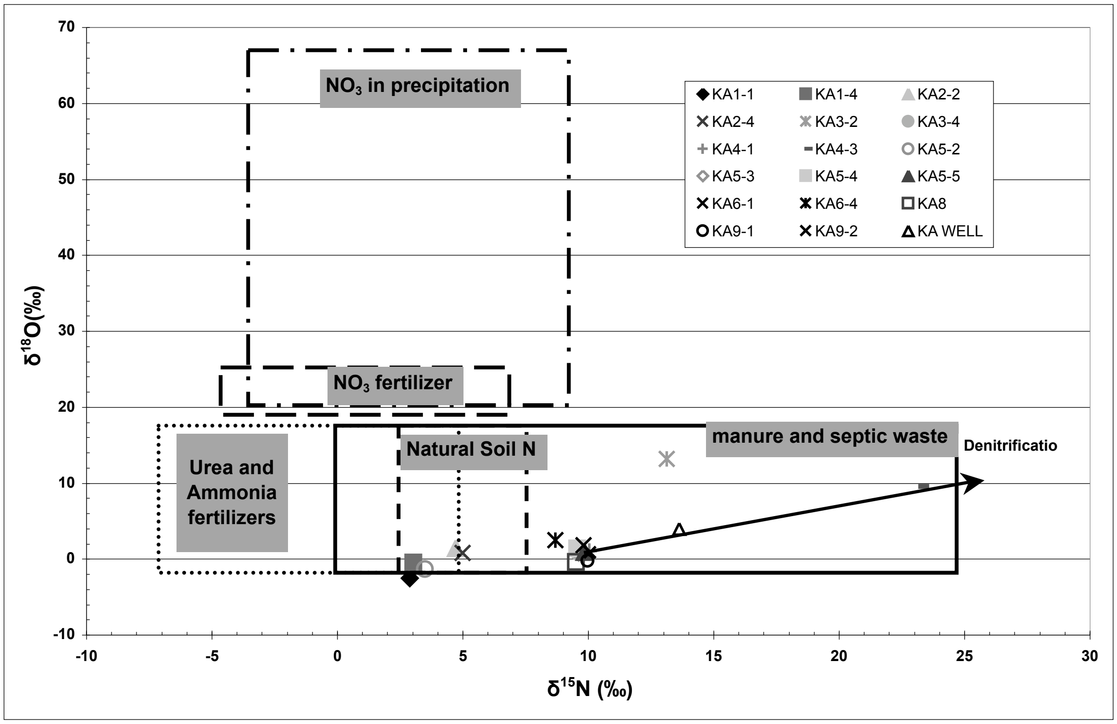

Figure 4.48 - Groundwater δ^{15}N and δ^{18}O in NO_3^- Isotopes (August 2007). Background modified from Kendall (1998).

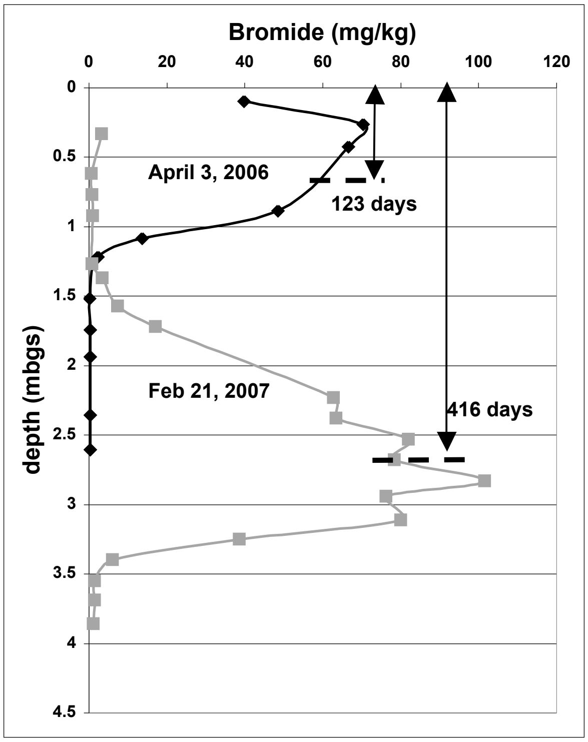

Figure 4.49 - Soil bromide concentrations at the BT1 bromide tracer site. Cores collected in April 2006 and February 2007.

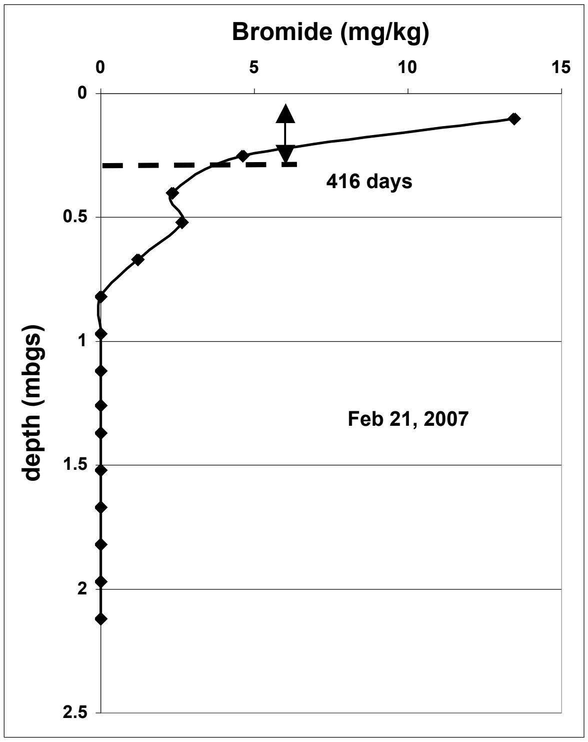

Figure 4.50 - Soil bromide concentrations at the BT2 bromide tracer site. Core collected in February 2007.

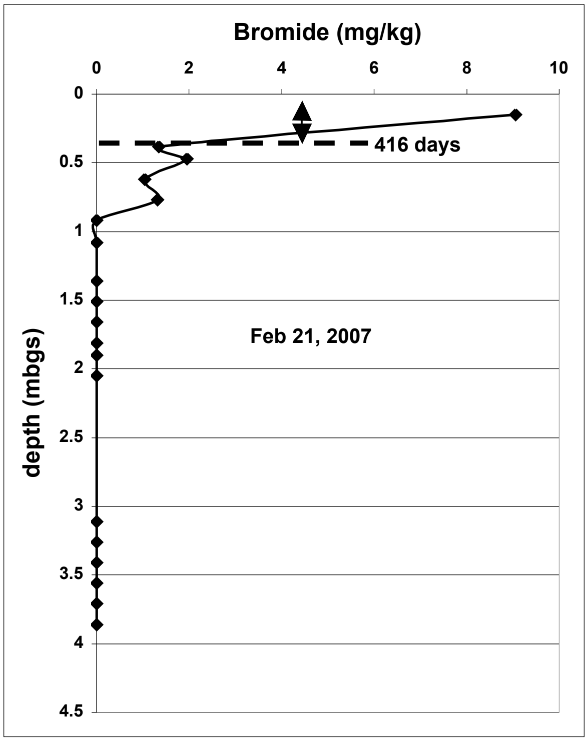

Figure 4.51 - Soil bromide concentrations at the BT3 bromide tracer site. Core collected in February 2007.

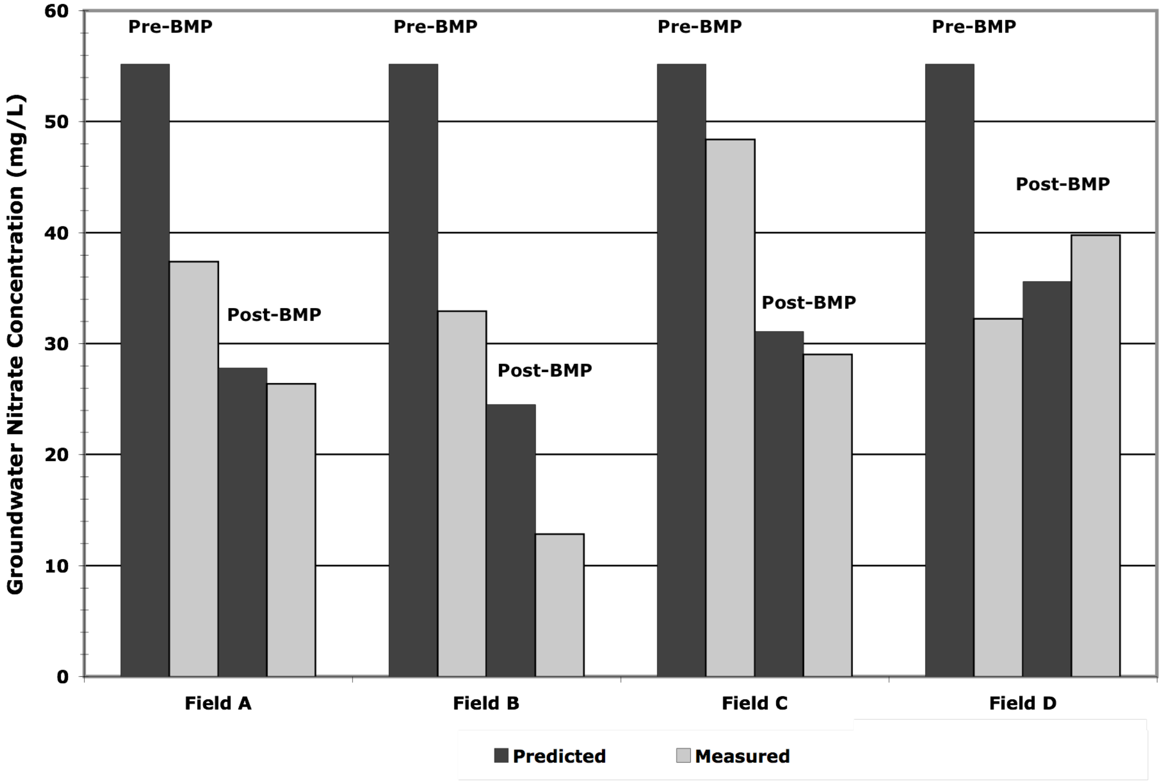

Figure 4.52 - Predicted groundwater nitrate concentrations from N-Budget plotted with measured groundwater nitrate concentrations for Fields A, B, C, and D, for both pre-BMP and post-BMP nutrient loading.

5. Discussion

5.1 Groundwater Flow

The groundwater flow system at the Allin Farm consists of a multi-aquifer/ aquitard system characterized by a shallow, local scale flow system within a larger regional setting (Fig. 4.29). Accurate characterization of the groundwater flow patterned at the study site aids in the interpretation of trends observed in the groundwater chemistry and can help evaluate the performance of the BMP. The groundwater flow direction generally follows topography and trends from east to west or from high surface elevation to low surface elevation. The hydrostratigraphic sequence consists of five main units. Aquitard 1 is the upper most unit and consists of the well-documented Newmarket till, which is one of the primary aquitard units within the Oak Ridges Moraine (e.g., Gerber and Howard, 2000). Groundwater flow through Aquitard 1 is primarily vertically downwards towards Aquifer 1 at an average velocity of approximately 3.0 m/yr, based upon field-measured data. Previous studies by show that fracture flow though Aquitard 1 does not contribute to the overall movement of water at the site. Watertable depth varies seasonally, ranges in depth from approximately 2.0 to 11.0 mbgs across the study site, and at many locations responds quickly to recharge events especially in the fall (September to December) and spring (March to May). The average annual groundwater recharge rate through this unit was estimated to be 160 mm/yr based upon bromide tracer profiles and water balance calculations. Aquifer 1, which underlies the surficial aquitard, is a localized, sand and gravel unit that is found beneath Fields A and B, and was a source of potable water for local residences prior to 1997. The maximum thickness of Aquifer 1 is approximately 7.0 m but it is believed to be discontinuous towards the eastern edge of the study site below Field A. As such, it does not likely receive much lateral groundwater inputs from upgradient of the site. This observation was important as it creates a boundary condition for flow into Aquifer 1 and suggests that nitrate present in the unit is from the Allin Farm. Groundwater flow in this unit trends from east to west at an average velocity of approximately 90.0 m/yr. Aquitard 2 is located below Aquifer 1 and is a silty, clayey till unit that separates the localized flow system in Aquifer 1, from a deeper, more regional flow system in Aquifer 2. Groundwater flow in Aquitard 2 is primarily upwards towards Aquifer 1. Aquifer 2 is a continuous silty sand aquifer unit that is the source of water for the on-site farm supply well. Aquifer 2 is confined beneath Aquitard 2 and the measured gradients between Aquifer 2 and Aquifer 1, suggests that groundwater discharges into Aquifer 1 across its lower boundary. Groundwater withdrawal from the farm supply well, however creates a local capture zone in the vicinity of the well, decreasing the magnitude of the upward hydraulic gradient between the two aquifers. The extent of both Aquifer 1 and Aquifer 2 past the boundary of Fields A and B is unknown.

Estimation of the groundwater flux entering and exiting Aquifer 1 indicates that the aquifer is obtains recharge from infiltration though the footprint of Fields A and B, and to a lesser extent from groundwater inflow from Aquitard 2 below. Because the groundwater flow within Fields A and B are part of a small, contained flow system all inputs and outputs can be estimated with reasonable precision, providing boundary conditions for nitrate mass loading and mass flux calculations to the aquifer. Hydrogeologic evidence suggests that KA6 derives its water from a deeper, more regional flow system that originates from upgradient of the Allin Farm. Fig. 4.3 shows that the regional topographic high is located approximately 400 m east of the study site and would likely represent the beginning of the regional groundwater flow system. At KA6, the strong upward gradient and the flowing artesian conditions, provides evidence for a regional groundwater flow system that originates beyond the limits of the study site.

5.2 Changes in Nutrient Applications Following BMP Implementation

Detailed agricultural land use records from 1997 to the present show that nutrient applications of nitrogen (N) at the entire Allin Farm study site was reduced by 46% compared to the pre-1997 application rates. Fertilizer applications on Field B were changed from fall applied liquid swine manure and spring applied commercial fertilizer (urea and ammonium sulphate mix), to only spring applied commercial fertilizer. Soybeans were planted in 1999, 2004, 2005, and 2006, which helped to reduce the amount of N applied, but a crop rotation in the strict sense, was not implemented. The transfer of liquid manure into the outdoor storage tank was conducted with greater care following a manure spill in 1993. Other farming practices such as tillage method and timing of nutrient applications were unchanged from methods employed prior to nutrient reductions in 1997.

Although there was a decrease in total applied N by 46%, the farm operator reported no significant decrease in grain yields for either corn or soybean crops. Corn production was maintained near the expected yield of 6.9 t/ha at an average yield between 1997 and 2007 of 6.4 t/ha. The crop yields were conducted on a farm wide basis and therefore differences may exist between the crop yields of each individual field. The stability of the grain yields at the farm as a whole suggests that the crops were receiving a sufficient supply of N following significant reductions in applied N and that the historical rate of N application was in excess of crop nutrient demands. The two most likely explanations for the maintenance of grain yields are: (1) Historical applications of N were in excess of crop nutrient requirements and decreasing the nutrient application rate only brought them inline with these demands. (2) Decades of manure spreading created a large reserve of immobile or “legacy” organic N that has built up in the soil. This legacy N has been slowly mineralizing adding to the total N available to facilitate plant growth and is responsible for maintaining crop yields even though N applications have been less than the crop nutrient requirements as determined by the EPP. Soil core samples from the root zone on all fields have high concentrations of nitrate N and isotopically, the N appears to be derived from manure even on Field B. The presence of manure N on Field B were commercial fertilizers have been applied since 1997, suggests that some of the manure N is still present from prior to 1997 or that the single application of manure in the spring of 2004 is dominating the N present in the topsoil. Below the root zone in Field B, commercial fertilizer nitrate dominates suggesting that legacy N derived from manure has been flushed from the unsaturated zone. Overall, it is still unclear how long crop yields can be maintained under the current N application rates. It is likely that mineralization of stored organic N is contributing to the overall N pool used by crops as a nutrient source. It was beyond the scope of this study to determine the length of time that the stored N will contribute to the overall soil N. In the long term, the current N application rates may not be large enough to sustain crop growth at the historical rate.

A comparison between the total application rate of N prior to 1997 (Table 4.1) and the predicted leachable N (Table 4.2) suggests that 31% of total N applied had the potential to leach below the root zone. For the period between 1997 and 2007, the percentage of the total N applied that had the potential to leach below the root zone was estimated to be 29%, 38%, 30%, and 31% for fields A, B, C and D respectively, which is an overall leachable N of 32%. This result suggests that although total nutrient applications of N were reduced (from 286 to 153 ha/ha), approximately one third of the applied N still has the potential to leach below the root zone and impact groundwater.

5.3 Usefulness of Nitrogen Budgeting for Estimating Groundwater Nitrate Concentrations

The equilibrium established at the Allin prior to 1997, allowed an estimation of the groundwater nitrate concentrations based upon the potentially leachable N and the groundwater recharge rate. The predicted groundwater concentrations from N-budgeting overestimated the groundwater concentrations for all fields for the pre-BMP data. Goss and Goorahoo (1995) showed that N-budget commonly overestimates groundwater nitrate concentrations by about 33%, because it fails to account for the portion of groundwater sampled that is not connected to the worked land and has a low nitrate concentration. Because the shallow groundwater flow system is well understood at the Allin Farm and the measured groundwater nitrate concentrations were derived from wells that are screened at or near the watertable, uncertainties from sampling water not connected to the worked land have been minimized. It is not clear where the groundwater at KA6 is derived, so this uncertainty exists at this particular well nest. The groundwater nitrate concentration beneath Fields A, B, C, and D were overestimated by 32%, 40%, 12%, and 42% respectively. The predicted groundwater nitrate concentrations for the post-BMP data more closely matched the observed groundwater nitrate concentrations than pre-BMP estimates, with the exception of Field B. Estimates from N-budgeting overestimated the groundwater nitrate concentrations beneath Fields A, B, and C, by 5%, 48%, and 7%, and underestimated the concentration beneath Field D by 12%. The pre-1997 overestimation of groundwater nitrate concentrations for all fields suggest that either less N was applied to the fields than was shown in the records or that less N was available to leach from these fields than was predicted by the N-Budget. Because no physical records of nutrient applications were kept until 1997, there is more uncertainty in the pre-1997 values for N applications than for the post-BMP values. The clearer understanding of the N applications after 1997 may have improved the accuracy of the N-budget. The measured groundwater nitrate concentrations beneath Field C corresponded well to the predicted concentrations by the N-budgeting for both the pre- and post-BMP conditions. The shallow watertable and relatively flat ground in Field C may have helped to eliminate some spatial variability in N distribution and increased the ability of the N-Budget to predict the shallow groundwater nitrate concentration. Significant overestimation of the groundwater nitrate concentration beneath Field B remained following the BMP. The change from manure to commercial fertilizer may have significantly altered the N dynamics in the topsoil, which would drastically change the balance between immobilization and the mineralization of organic N.

Although there is some discrepancy between the predicted and measured groundwater nitrate concentrations, the N-Budget method provided a reasonable estimation of the groundwater nitrate concentration under two different N management strategies. For example, on Field A, the predicted pre-BMP groundwater nitrate concentration was 55.2 mg/L, where as the measured concentration was 37.4 mg/L. The predicted post-BMP groundwater nitrate concentration was 27.8 mg/L, where as the measured concentration was 26.4 mg/L. The N-Budget was able to capture the considerable reduction in groundwater nitrate concentration under Fields A, B, and C, following reductions in N loading to the ground surface. The most accurate results were obtained from the average the potentially leachable N (N_{pl}) calculated at the study site between 1997 and 2007. By using the average yearly variations in crop uptake, nutrient application rate, nutrient application timing, and other heterogeneities where minimized. The ability to reasonably estimate the potential impacts to groundwater using information commonly available to farm operators and regulators such as N application amounts, is a valuable tool to help predict the future effects of reducing N applications as part on an agricultural BMP.

The most significant limitation to using the N-Budget Method to predict groundwater nitrate concentrations is accurately measuring groundwater recharge. Many authors simply assume a recharge rate that is typical of the study area (e.g., Barry et al., 1993). Using base flow analysis and computer modeling of the Great Lakes Watershed, Neff et al. (2005), estimated that recharge rates range from 100 to 400 mm/yr in the Great Lakes Region, where the study area is situated. On the area that specifically contains the Allin Farm, the recharge rate was estimated to be between 100 and 200 mm/yr, which matches closely with the rate estimated as part of this study of 160 mm/yr from bromide tracer data and water balance estimations. The surficial soil at the Allin Farm is Newmarket till. An average estimated recharge rate of 35 mm/yr as suggested by Gerber and Howard (2000) for this unit across the Oak Ridges Moraine, is significantly lower than the recharge rate estimated as part of the current study, which demonstrates the significance of site specific conditions in controlling recharge. Had this average value been used, the accuracy of the N-budget would have been greatly reduced. This points to the importance of calculating a site-specific recharge rate when applying the N-budget method for estimating groundwater nitrate concentrations, although this may not be feasible in all situations.

5.4 Changes in Groundwater Nitrate Concentrations Following Nutrient Reductions

5.4.1 Local Flow System at the Allin Farm

Groundwater nitrate concentrations within the shallow flow system at the Allin Farm have decreased since implementing an agricultural BMP in 1997 and reducing N loading to the land surface. Nitrate concentrations at well nests KA3, KA4, and KA5 have decreased by an average of 35% between 1997 and 2007. Fig. 5.1 shows a conceptual model of how BMPs at the Allin Farm have over time improved the groundwater quality. The conceptual model is based upon the groundwater flow pattern suggested in Fig. 4.29, as well as field observations of groundwater nitrate concentrations, $\delta^{15}N$ values, and soil core profiles.

Based upon the location of the KA5 well nest and the land-use history associated with Field B, it is believed that any changes at this well nest reflect the results of reducing N loading in 1997 at the Allin Farm as a whole. Four independent lines of evidence support the conclusion that the decrease in nitrate concentration in the shallow groundwater at well nest KA5 (KA5-1 and KA5-2) was a direct result of reducing N applications in 1997 as part of an agricultural BMP. (1) The groundwater nitrate concentrations have decreased on average at the well nest by 38%, especially in the shallowest well (KA5-1), where the decrease was 65%. (2) The presence of $\delta^{15}N$ and $\delta^{18}O$ values in NO_3^- in the groundwater indicative of commercial fertilizer suggests that water that infiltrated along with nitrate derived from anthropogenic N in 1997 has reached the watertable. Therefore, the surficial effects of changing fertilizer type along with reducing N applications have reached the groundwater and begun to influence its chemistry. The minimum age for the water that was sampled in May 2006 at KA5-1 would have to be < 10 yrs. (3) Groundwater recharge travel time estimates predict that it will take approximately 6 yrs for water that infiltrates at the surface at near the KA5 nest to reach the watertable at KA5-1. Because this calculated travel time falls within the range as set by the isotope data of 10 years, this value is considered reasonable. This is also consistent with the fact that groundwater had not shown any change in nitrate concentration during a sampling event in 2000 by the MOE (Crossley, 2000) following 3 years of reduced N applications. (4) Analysis of soil cores for nitrate and porewater $\delta^{15}N$ values in NO_3^-, show that the soil nitrate concentrations are low and that only nitrate derived from commercial fertilizer is present in the soil profile at KA5 above the KA5-1 well. This suggests that the unsaturated zone above KA5 has been flushed of the majority of the historical manure N, and been replaced by new commercial fertilizer N, although the topsoil still contains remnants of legacy manure applications. The recharge water that is present in the unsaturated zone soil profile, that has not yet reached the watertable, has a low concentration of nitrate that is derived from commercial fertilizer N or soybean N. We would therefore expect the groundwater nitrate concentrations at KA5-1 to continue to decrease in the future as groundwater with progressively lower nitrate concentration migrates to the watertable. Although not directly related to nutrient reductions, high concentrations of DO averaging 8.27 mg/L for the KA5 well nest, indicates that denitrification is not an important mechanism for reducing nitrate concentrations at this well nest. Because of this, the only mechanism that could have reduced the nitrate concentration in the groundwater at KA5 was dilution by the recharge of water containing low concentrations of nitrate. The low nitrate concentration in recharging water is a direct result of reducing N loading Field B and by applying N at a rate that better matches crop requirements. These efforts were effective at reducing the amount of N that leached below the root zone, which provided low nitrate recharge water to enter the watertable and decrease the nitrate concentration in the groundwater by dilution.

The deeper wells at the KA5 well nest (KA5-3, KA5-4) show significant decreases in nitrate concentration, which are believed to be related to reduced N applications on Field A, upgradient of the well nest. Fig. 5.1 shows how nitrate present in wells KA5-3 and KA5-4 originated from Field A. The isotope data indicate manure N rather than commercial fertilizer N in the two wells, which is consistent with the groundwater flow model for the farm. Groundwater travel time estimates predict that water that infiltrates near KA9 would take approximately 10 years to reach the screens at wells KA5-3 and KA5-4, which fits the timeline of this study. Each of these lines of evidence suggest that nitrate present in the deep wells at KA5, is derived from Field A and that reductions in groundwater nitrate concentration have occurred without a change to mineral fertilizers.

Decreases in groundwater nitrate concentration at the KA4 well nest are likely due to reducing the N loading to Field C. Nitrate concentrations at the well nest have decreased by an average of 22%, with KA4-1 and KA4-2 showing the greatest reductions of 36% and 33%. Nitrate concentrations at KA4-3 and KA4-4 have remained constant since 1997. The source of the applied N was not altered on Field C as it was on Field B, and the practice of applying liquid swine manure in the fall and augmenting with commercial fertilizer in the spring was maintained. Isotope data of $\delta^{15}N$ and $\delta^{18}O$ confirm that the nitrate present in the KA4 well nest was derived from manure and that well KA4-3 may be affected by denitrification, although no loss of nitrate concentration has been observed. KA4-4 is also likely affected by denitrification. Overall, the results from this well nest suggest that a decade of reducing the amount of manure N applied to Field C, has significantly reduced the groundwater nitrate concentration in the shallowest two wells at the KA4 well nest. This also indicates that significant reductions in groundwater nitrate concentrations can be achieved without switching to mineral fertilizers.

The KA3 well nest has experienced an overall reduction of 44% in groundwater nitrate concentration since 1997. The shallowest well shows the greatest reduction of approximately 52%. KA3 is located adjacent to the outdoor manure storage tank and it is believed that increased diligence in handling and transferring manure to avoid spillage in combination with reducing applications of N on the upgradient field (Field C), is responsible for the substantial decrease in nitrate concentration at the well nest. Isotopic data indicate that the nitrate in the groundwater at KA3 is derived from manure and therefore decreases in nitrate concentrations have occurred without a change in N source type.

Denitrification may also be responsible for removal of some of the nitrate mass, as DO concentrations average 2.9 mg/L (range from 0.1 to 6.4 mg/L), Mn is present in detectable concentrations, and the $\delta^{15}N$ and $\delta^{18}O$ in NO_3^- are more enriched than the other manure values.

5.4.2 Regional and Upgradient Flow System

Land-use practices were altered at the Allin Farm, but there is no evidence to suggest land management practices have changed upgradient of the farm or at a regional scale. Wells representative of groundwater originating from the Allin Farm have shown an improvement in water quality, whereas along the up gradient property line at KA1 and KA2, it appears that water quality is degrading. The groundwater nitrate concentration at well nests KA1 and KA2 have increased since the implementation an agricultural BMP at the Allin Farm in 1997. The nitrate concentration in the KA1 well nest has increased from an average of 6.85 mg/L in 1997 to 16.50 mg/L in 2007, an increase of 140%. The nitrate concentration in the KA2 well nest has increased from an average of 0.77 mg/L in 1997 to 6.07 mg/L in 2007, an increase of 690%. The nitrate present in the groundwater in these two well nests is derived from commercial fertilizers ($\delta^{15}N$ in NO_3^-, of less than 5‰), which makes it isotopically distinguishable from the nitrate derived from manure spread on the adjacent fields on the Allin Farm Property. No written records exist describing the nutrient spreading history of the upgradient farms, but the field observation and isotopic data suggest that commercial fertilizer is used as the source of N for those field crops and that the application rate of N or the N_{pl} has increased at those farms since 1997. It is not clear at this time how an increase in groundwater nitrate entering the Allin Farm property will influence the future groundwater nitrate concentrations in Aquifer 1, as it is suspected that Aquifer 1 does not extend as far as the eastern boundary of Field A. The influence of upgradient nitrate on the groundwater at the Allin Farm can be traced, because the $\delta^{15}N$ signature of the nitrate entering the Allin Farm is isotopically distinguishable from the groundwater collected at well nests KA3, KA4 and KA9, although the contributions to Aquifer 1 from upgradient sources will likely be small.

Groundwater at the KA6 well nest is the only other well nest where concentrations have increased. Nitrate concentrations have increased from an average of 30.46 mg/L in 1997 to 40.94 mg/L in 2007, an increase of 34%. No borehole logs exist for KA6, which creates difficulties in interpreting the results of groundwater sampling at this well nest. The strong upwards-vertical gradients and the flowing artesian conditions suggest that the groundwater collected from KA6 is derived from an upgradient, regional source with a deeper, longer flow path and is not influenced by land-use activities at the Allin Farm. It is possible that the water and therefore nitrate in KA6 could be derived from Field C or D, as the potentiometric surface is lower here than at KA4, and that groundwater related to the land-use changes has not yet reached the well screen. However, a seasonally stable water level, as measured by the levelogger in KA6-1, that does not react to recharge events like the other wells at the site, suggests that the groundwater is from a regional source. Overall, the groundwater in KA6 is believed to reflect the regional nature of excess N loading in the area as there have been no indications that historical nutrient applications have decreased anywhere in the area besides the Allin Farm.

Nitrate concentration at the farm supply well (KA Well) has decreased by 80% since 1977. Most of this reduction is likely related to a change in the capture zone of the well caused by a significant reduction in the pumping rate of the well, and not likely due to changes in land-management practices.

5.4.3 Implications for the Adoption of BMPs

The identification of a local and a regional groundwater flow system at the Allin Farm provides insights into the broader adoption of BMPs. At the local scale, or at a single farm (the Allin Farm for example), a reduction in N loading to the land surface has resulted in a decrease in groundwater nitrate concentrations, both at the watertable and within a small glaciofluvial aquifer. The time lag between implementing the BMP and observing improvements to groundwater quality was estimated to range between 4.0 and 10.0 years. This value is highly dependent upon the geologic conditions, hydrogeologic conditions, and the depth of the watertable at a particular location, but suggests that it may take up to a decade for changes to be observed in groundwater under conditions similar to those encountered at the Allin Farm. At the regional scale and at the up gradient farm from the Allin Farm, it appears that nitrate concentrations are increasing and groundwater quality is degrading due to regional influences. This reinforces the need to adopt nutrient management strategies at the large scale, but improvements seen at the Allin Farm show that BMPs are clearly valuable for individual farms.

This result differs from the results of a study of the Abbotsford-Sumas Aquifer by Wassenaar et al. (2006), where a decade of voluntary nutrient reductions yielded no observable change in groundwater nitrate concentrations in an unconfined sand and gravel aquifer. Although the Abbotsford-Suma Aquifer is regional in extent and the aquifer at the Allin Farm is local in extent the effects of reducing surface nutrient loading should have a similar observable effect on the nitrate concentrations at the watertable. Wassenaar et al. (2006) suggests that non-compliance of farm operators participating in voluntary BMPs and the application of commercial fertilizers during groundwater recharge events in the fall, may be responsible for maintaining high nitrate concentrations in the aquifer. At the Allin Farm, the farm operator complied with the established nutrient management plan for the farm and commercial fertilizers were applied in the spring prior to planting, rather then in the fall. The shallow subsurface (i.e., the unsaturated zone and the watertable) should be further studied at the Abbotsford-Sumas Aquifer before BMPs are judged to be ineffective. The large scale of the Abbotsford-Sumas Aquifer may significantly increase the time scale required to observe changes in the groundwater chemistry as a result of BMPs, past what would be initially expected.

5.5 Changes in Nitrate Loading Following Nutrient Reductions

By decreasing the amount of N applied to the fields, the N loading to the ground surface at the entire site was decreased on average by 46%, based upon nutrient application records (Table 4.1). If volatilization of N during initial spreading is taken into account, N loading was decreased by 35%. On Field A, N applications decreased on average by 46% from 286 yr/ha/yr to 154 yr/ha/yr, based upon nutrient application records, and nitrate loading to the watertable below the field decreased 29% from 1.56 t/yr to 1.10 t/yr, based upon the estimated groundwater flux and groundwater nitrate concentrations. On Field B, N applications decreased by 64% from 286 ha/ha to 103 ha/ha, and nitrate loading to the watertable below the field decreased 61% from 1.17 t/yr to 0.46 t/yr. The nitrate mass flowing out of Aquifer 1 along the western property boundary decreased from 2.71 t /yr to 1.55 t/yr, which represents a 43% reduction in nitrate mass flux. Therefore, the groundwater exiting the Allin Farm property contains on average, 43% less nitrate than it did prior to 1997. The original purpose for decreasing nitrate loading to the land surface was to improve groundwater quality, not only beneath the Allin Farm, but also in the private wells downgradient of farm. Although none of the private wells were sampled as part of this study, it is likely that they would show a reduction in groundwater nitrate concentration compared to the pre-1997 concentrations. If improvements in water quality are not observed in these well, then it is likely that the source of the nitrate is not the Allin Farm and other options should be explored.

5.6 Effectiveness of Reducing Nutrient Applications of N as Part of a BMP Aimed at Reducing Groundwater Nitrate Concentrations

Between 1997 and the present the amount of N applied to the land surface at the Allin Farm has decreased by 46%, without a decrease in crop production, suggesting that the application rate of N prior to 1997 was in excess of crop nutrient requirements and that N was being over applied. The amount of N potentially lost below the root zone due to leaching (N_{pl}) decreased from 88 ha/ha to an average of 48 ha/ha, which is a 46% decrease. This result indicates that water that infiltrates through the root zone in 2007 will contain less mass of N or a lower concentration of nitrate than in 1997. Core samples collected at KA5 and KA10 show that nitrate concentrations in the unsaturated zone porewater beneath Field B typically less than 5 mg/L. Because the nitrate present in the groundwater is derived from nitrate that leached though the root zone and migrated to the groundwater, by reducing the concentration of nitrate in the recharge water, the concentration of nitrate entering the groundwater is also reduced. Tomer and Burkart (2003), Meissner et al. (2002) and Honisch et al. (2002) suggest that in small watersheds, it may take several years or decades for changes in agricultural practices to fully effect and potentially show improvements in groundwater quality. At the Allin Farm it took between 4.0 and 10.0 yrs for water at surface to reach the watertable. It would therefore, take at least that time for the groundwater to show any changes as a result of reducing N applications as part of a BMP. It has been suggested that the only way to reduce nitrate concentrations in groundwater beneath historically contaminated farms is by dilution with low nitrate recharge water (Spalding et al., 2001). By reducing the amount of N applied to the fields to an amount that better matched crop nutrient requirements, the amount of leachable N was reduced, and therefore the concentration of nitrate in the recharge water was reduced. After a decade of recharge with reduced nitrate concentrations in the water, the legacy N present in the soil has begun to decrease and the unsaturated zone has been partially flushed of high nitrate concentration porewater. Considerable legacy N is still present in the topsoil, but unsaturated zone soil cores show that little is present below the zone of root growth. These effects have migrated to the watertable and have begun to lower the groundwater nitrate concentrations beneath the Allin Farm. Groundwater nitrate concentrations in Aquifer 1 have been positively affected by reduced N applications at the surface and the concentration of nitrate in the aquifer that is exiting the study site to the west has decreased considerably since 1997. The groundwater nitrate concentrations at the entire farm decreased by an average of 35% since 1997.

It is not clear from the result of this study, if the land-use changes at the Allin Farm have the capacity to reduce groundwater nitrate concentrations beneath the farm to below the 10 mg/L drinking water limit, without causing negative effects on crop yields. The May 2007 sample from KA5-1 had a concentration of 9.7 mg/L, which meets drinking water criteria and represents a reduction of 70% compared to the 1997 concentration of 32.1 mg/L. This sample provides some hope for using BMPs to reduce groundwater nitrate concentrations to levels below the drinking water limit. It is reasonable to assume that given sufficient time, the nitrate concentration in Aquitard 1 and

Aquifer 1 should be the same based upon the conceptual models of groundwater flow and nitrate transport. Currently, the groundwater chemistry and the soil porewater chemistry at KA5 and KA10 are similar, suggesting that over the last decade, these locations have been completely flushed of the Pre-BMP groundwater and replaced with Post-BMP water. It is therefore unlikely that further improvements will be seen at the watertable at these locations. The soil porewater nitrate concentration above KA9 still has high concentrations of nitrate in it, suggesting that a decade has not been long enough to completely flush high nitrate water from the Aquitard 1 soil at this location. Based upon groundwater travel time estimates and the conceptual model of groundwater flow at the Allin Farm, it is estimated that it may take between 10 and 20 more years to completely flush the water beneath Fields A and B of the pre-BMP water. The long-term effects of implementing an agricultural BMP at the Allin Farm will not be realized for at least another decade. However, the results of this study suggest that the improvements to groundwater will be significant as long as we all exercise a little patience.

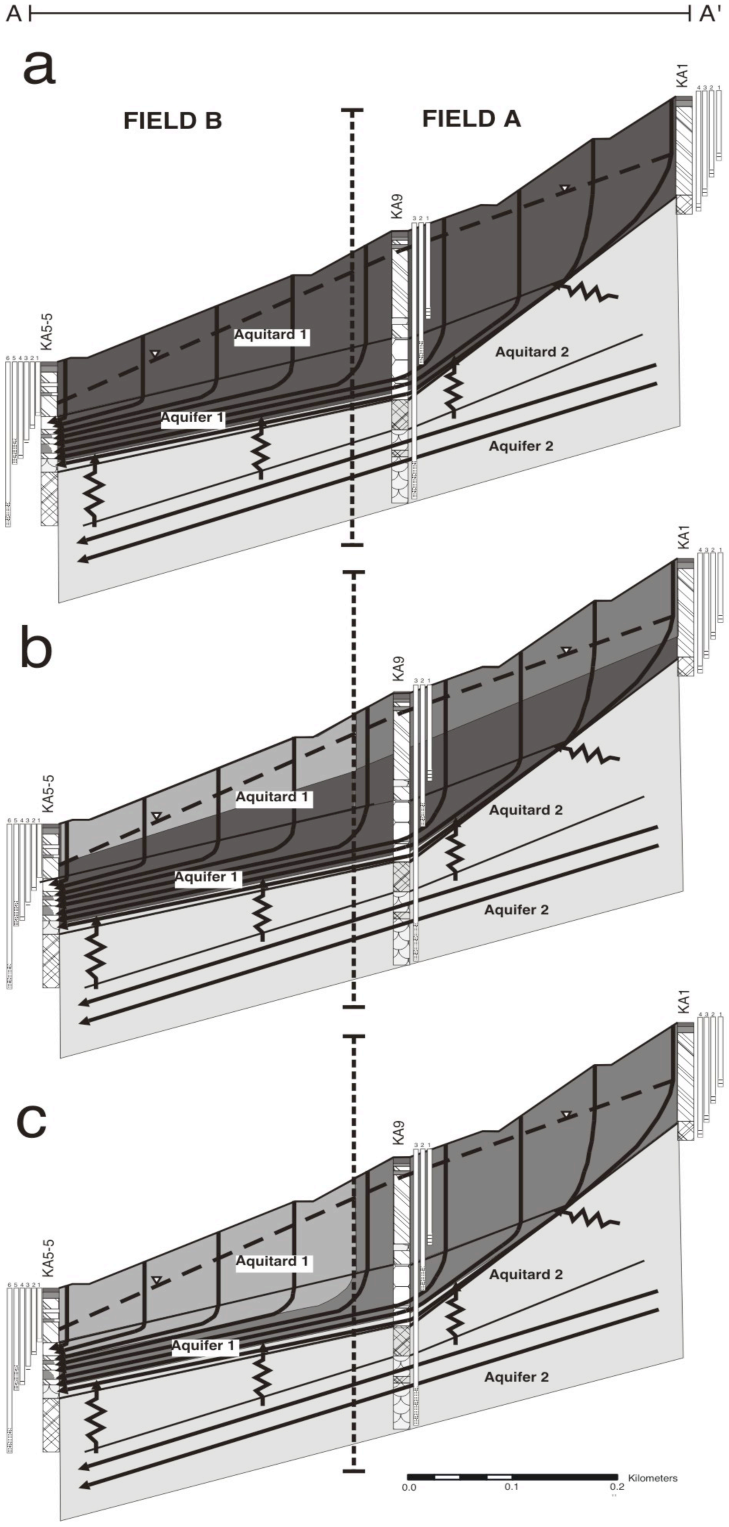

Figure 5.1 - Conceptual model of changes to groundwater chemistry at the Allin Farm following implementation of a BMP.
(a) Pre-BMP groundwater nitrate distribution. Both Fields A and B are affected by excess N loading and the groundwater beneath both fields contains high concentrations of manure derived nitrate based upon isotopic data. Nitrate free water is entering Aquifer 1 from below.
(b) Post-BMP effects following 2-3 years of implimentation. N loading has been reduced on both fields and the shallow groundwater beneath both fields contain lower nitrate concentrations than the pre-BMP concentrations. Recharge water beneath Field B contains commercial fertilizer derived nitrate reflecting the change in N source type.
(c) Post-BMP effects after a decade of nutrient reductions. Aquitard 1 has been mostly flushed of pre-BMP manure nitrate. The shallow groundwater in Aquifer 1 contains nitrate that reflects the commercial fertilizer from Field B. The deeper groundwater in Aquifer 1 derives it source from Field A and the manure nitrate reflects this.

6. Conclusions and Recommendations

6.1 Conclusions

The Allin Farm study site provided a unique opportunity to study the effects of a decade of reduced land application of N fertilizers as part of agricultural BMPs on groundwater nitrate concentrations. A field scale study involving seasonal groundwater sampling, detailed water level monitoring, soil coring, and hydraulic testing, integrated with agricultural records was successful at recognizing changes to groundwater quality as a result of nutrient reductions. Following more than a decade of applying N fertilizers at the Allin Farm at a rate slightly less than the recommended application rate, the nitrate concentrations in the historically contaminated groundwater beneath the farm have decreased by an overall average of 35%. According to records maintained by the farm operator, farm wide grain yields for corn were not affected by the 46% reduction in surface applied N. This suggests that historical applications were in excess of crop nutrient demands and that the nutrient reductions had a minimal effect on the productivity of the farmland.

The $\delta^{15}N$ and $\delta^{18}O$ in NO_3^- data in the groundwater at KA5 and KA10-2 in Field B are indicative of a commercial fertilizer source. Surface to watertable groundwater travel time calculations, in combination with isotopic results suggest that sufficient time has past since land-use changes were implemented for water that recharged following nutrient reductions in 1997 to have reached the watertable. High DO concentrations present in the groundwater suggest no significant losses of nitrate from denitrification have occurred at most locations at the study site. Denitrification effects may be significant at well nest KA3 and wells KA4-4 and KA Well. Overall, the primary mechanism responsible for lowering groundwater nitrate concentrations is a reduction in the amount of N that is leached below the root zone caused by the less N loading at the ground surface. Since 1997, recharging groundwater with low nitrate concentration has mostly flushed the unsaturated zone of Field B of historical manure related nitrate and lowered the nitrate concentration in the groundwater by dilution. Field A still shows some remnant Pre-BMP nitrate and requires a longer time period to be flushed. Estimates of the groundwater recharge and flow velocity suggest that it would take between 4 and 10 years to observe the effects of reduced surface applications of N at the watertable. This indicates that monitoring strategies aimed at observing the effects of BMPs on groundwater should focus on the shallow (not deep) groundwater and may need to be in place for a decade to observe changes.

Decreases in the surface loading of N were responsible for improvements to groundwater quality rather than changes to the fertilizer source type. At the KA5 well nest, reductions in groundwater nitrate concentrations coincided with an isotopic change from manure N to commercial fertilizer N. However, at well nests KA3 and KA4, reductions in groundwater nitrate concentration were observed with continued application of manure.

Nitrate loading to Aquifer 1, beneath Fields A and B decreased by 46% following reductions in surface N applications. Not only did N loading beneath the agricultural fields decrease, but the nitrate load leaving the Allin Farm to the west near KA5 and moving towards the private wells, has also decreased. It is likely that the downgradient private wells will show a significant improvement in groundwater quality if re-sampled.

Improvements to the groundwater quality at the Allin Farm have occurred despite the fact that groundwater nitrate concentrations in the water entering the Allin Farm property from the east, near KA1 and KA2 have increased considerably, since monitoring began in 1997. This groundwater is influenced by up-gradient land-use activities and does not reflect the groundwater chemistry resulting from activities at the Allin Farm. Increases in nitrate concentration were also observed in the flowing artesian well, KA6, which is believed to be a discharge location for a deeper flow system. The fact that the Allin Farm is showing improvements although the surrounding groundwater quality is degrading provides validation for implementing local BMPs within larger flow systems that have widespread nitrate contamination.

The use of N-Budgets to calculate N_{pl} allowed for a quantitative analysis of how N leaching had changed following nutrient reductions. Approximately one third of applied N is potentially available to leach below the root zone regardless of the application rate. Although, with less N applied, less N is able to leach. By multiplying the N_{pl} by the estimated recharge rate, estimates of the groundwater nitrate concentration in the shallow groundwater were calculated for pre-BMP and post-BMP conditions. The N-Budget typically over estimated the groundwater nitrate concentrations, but overall provided a reasonable estimate of the groundwater nitrate concentration for both the pre- and post-BMP conditions. The accuracy of the N-budget is highly dependent upon a site-specific recharge rate that may limit its widespread usefulness.

Overall, the results of this study indicate that reducing N applications as part of an agricultural BMP has the capability to improve groundwater quality beneath a farm, where historical nitrate contamination exists. Crop yields have not suffered over the last decade of reduced N applications, but it is not known if this trend will continue in the future. It is unclear at this time if this method has the capacity to reduce nitrate concentrations in a large regional aquifer as opposed to a small local one, but if these results are transferred to many farms within a large watershed, the possibility may exist. Reductions in nitrate below the drinking water limit of 10 mg/L can potentially be achieved using nutrient reductions, as observed at KA5-1, but the long-term effect on crops yields is unknown. This site should be revisited over the next 5 to 10 years to determine if further reductions in groundwater nitrate concentration have occurred.

6.2 Recommendations

In light of the positive results observed at the Allin Farm, the following recommendations should be considered for designing a monitoring program to test the effectiveness of reducing the application of N as part of an agricultural BMP.

- The first and most significant change in nitrate concentration occurred at the watertable. A monitoring well that is screened across the seasonal high and low watertable should be installed.
- The calculation of a N-budget and a site specific estimation of groundwater recharge, provided a baseline estimate of the amount of possible reduction in nitrate concentration that can be achieved under a new management strategy, without spending funds to conduct subsurface investigations. Averaging the N-budget over many years should improve its accuracy by eliminating heterogeneities.
- Monitoring the nitrate concentration in deep farm wells may provide inaccurate information about the changes in groundwater chemistry following BMP implementation.
- By taking continuous soil cores and calculating the porewater nitrate concentration, the current groundwater nitrate concentration can be estimated as well as the future groundwater nitrate concentration. Low nitrate recharge water present in the unsaturated zone may suggest that nutrient reductions have been effective at reducing N leaching.
- Monitoring programs need to be carried out for many years to allow recharge water that infiltrated at the time of the land-use change to reach the watertable and begin to influence the groundwater chemistry. This time is highly dependent upon local geology

and flow conditions, but it is likely that even in sandy soil, it could take more than a decade to observe results.

- Multilevel monitoring, although significantly more expensive, provides excellent information on the effect of nutrient reductions on the groundwater, both at and below the watertable.

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Appendix A

Previous Studies at the Allin Farm

Gibson and Rudolph (1997)

Gibson Associates (2001)

Robertson (2001)

Table A.1 - Geological log from KA1-4 completed by Gibson and Rudolph (1997)

Depth	Description
0 - 0.40m	Dark brown organic soil with roots
0.40 - 0.70m	Rusty coloured fine silt with roots
0.70 - 1.52m	Very fine silty sand TILL
	Cobbles and pebbles max size 3", granite and limestone
	Calcite precipitation on limestone
1.52 - 3.05m	Very fine silty sand TILL
	Cobbles and pebbles max size 5", granite and limestone
	Calcite precipitation on limestone
3.05 - 4.58m	Very fine silty sand TILL
	Cobbles and pebbles max size 3", granite and limestone
	Calcite precipitation on limestone
4.58 - 6.10m	Very fine silty sand TILL
	Cobbles and pebbles max size 2", granite and limestone
	Calcite precipitation on limestone
6.10 - 7.68m	Core not recovered
7.86 - 9.15m	Core not recovered
9.15 - 10.68m	Very fine silty sand TILL
	Cobbles and pebbles max size 5", granite and limestone
	Calcite precipitation on limestone
10.68 - 12.20m	Sandy clayey silt
	Few pebbles or cobbles
	Mud cracks on the sides of the core
12.20 - 13.10m	Sandy clayey silt
	Few pebbles or cobbles
	Mud cracks on the sides of the core

Table A.2 - Hydaulic conductivities from slug testing of the wells completed by Gibson and Rudolph (1997)

Well	Hydraulic Conductivity K (m/s)
KA1-1	4.05E-07
KA1-2	6.23E-07
KA1-3	3.35E-08
KA1-4	7.55E-07
KA2-1	3.43E-09
KA2-2	3.80E-08
KA2-3	3.68E-08
KA2-4	6.29E-08
KA3-1	5.31E-07
KA3-2	1.86E-07
KA3-3	9.81E-07
KA3-4	7.03E-07
KA4-1	6.82E-07
KA4-2	4.41E-07
KA4-3	1.52E-07
KA4-4	5.19E-08
KA5-1	4.56E-08
KA5-2	2.89E-07
KA5-3	1.09E-06
KA5-4	1.83E-06
KA6-1	5.30E-07
KA6-2	8.89E-07
KA6-3	6.52E-07
KA6-4	8.98E-07

Table A.3 - Calculated average linear groundwater velocities by Gibson and Rudolph (1997)

Transect Section		Average K (m/s)	Gradient (m/m)	Velocity (cm/day)
From	To			
KA2 Nest	KA3 Nest	3.97E-07	6.79E-03	0.08
KA3 Nest	KA5 Nest	8.79E-07	4.39E-02	1.11
KA1 Nest	KA3 Nest	6.59E-07	3.41E-02	0.65
KA3 Nest	KA4 Nest	5.84E-07	6.29E-03	0.11
KA4 Nest	KA6 Nest	4.69E-02	4.69E-02	0.91

Table A.4 - Groundwater chemistry from 1997 sampling event by Gibson and Rudolph (1997)

Well	Eh (mV)	pH	Cond. (uS)	D.O. (mg/L)	Temp. °C	Chloride (mg/L)	Nitrate (mg/L)
KA1-1	-76.7	7.3	565	8.8	6.0	10.16	5.59
KA1-2	-71.6	7.2	563	10.7	7.2	12.67	5.80
KA1-3	-72.4	7.3	585	9.4	7.2	10.80	7.61
KA1-4	-71.8	7.2	628	10.2	7.1	16.65	9.69
KA2-1	-75.2	7.6	493	9.5	6.0	6.71	0.78
KA2-2	-70.4	7.4	493	8.1	6.2	15.49	1.03
KA2-3	-89.4	8.2	492	2.5	--	20.47	0.88
KA2-4	-91.4	8.1	577	4.5	7.2	15.22	0.45
KA3-1	-92.8	7.1	1031	3.4	7.7	22.19	55.58
KA3-2	-97.6	7.2	1104	3.3	8.6	24.84	59.02
KA3-3	-94	7.1	1271	0.9	9.4	33.76	76.17
KA3-4	-76.5	7.0	1307	5.4	8.4	25.41	76.28
KA4-1	-77.3	7.3	878	11.3	8.6	20.20	46.99
KA4-2	73.5	7.3	1081	8.2	--	35.64	66.96
KA4-3	-85.4	7.4	1079	5.8	--	26.01	62.41
KA4-4	-92	7.5	778	4.1	--	26.26	2.43
KA5-1	-72.5	7.3	886	7.6	9.7	62.17	32.09
KA5-2	-64.8	7.3	658	10.3	8.3	10.22	9.52
KA5-3	-54.9	7.2	915	8.5	7.5	16.96	34.53
KA5-4	-51.1	7.2	913	8.1	7.6	16.55	34.79
KA6-1	-72.3	7.4	773	9.3	Air Temp (8.8)	15.43	31.77
KA6-2	-63.7	7.4	779	9.5	Air Temp (8.8)	15.30	32.48
KA6-3	-78.5	7.4	758	8.2	Air Temp (8.8)	15.37	29.45
KA6-4	-75.7	7.2	746	8.0	Air Temp (8.8)	14.56	27.57
KA Well	--	--	--	--	--	23.43	38.43

Table A.5 - Selected groundwater chemistry from 2001 sampling event by Gibson Associates (2001)

Well	Sulphate (mg/L)	Chloride (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	Iron (mg/L)	pH	Cond. (uS)
KA1-4	21.30	13.80	17.81	<0.015	<0.02	<0.1	7.9	617
KA2-4	23.70	3.68	2.93	<0.015	<0.02	<0.1	7.9	536
KA3-3	41.70	32.20	65.40	0.76	<0.02	<0.1	7.6	1053
KA4-2	46.50	20.00	45.13	<0.015	<0.02	<0.1	7.8	841
KA4-4	172.60	21.00	0.16	<0.015	0.03	<0.1	7.9	723
KA5-4	37.20	21.40	29.73	<0.015	<0.02	<0.1	7.7	761
KA6-4	37.60	16.70	35.81	<0.015	<0.02	<0.1	7.8	692

Table A.6 - Groundwater ^{15}N isotopes in NO_3 collected in 2001 (Gibson, 2001) and interpreted by Robertson (2001)

Well	^{15}N Isotopes	Nitrate (mg/L)	Interpreted Nitrogen Source
KA3-3	10.77	65	Sewage/manure
KA5-4	10.40	30	Sewage/manure
7007 Cty Rd. 10	13.21	13	Sewage/manure
7021 Cty Rd. 10	11.21	20	Sewage/manure
7102 Cty Rd. 10	4.00	10	Commercial Fertilizer
4182 7th Line	7.60	14	Mixed fertilizer and sewage/manure

Note: No map is included for off site properties

Appendix B

Neutron Moisture Probe Calibration

Figure B.1 – Neutron Moisture Probe Calibration Curve

A site-specific neutron probe calibration was conducted at the Allin Farm study site, using a method similar to the one described by Bekeris (2007), with the intention of obtaining more accurate and representative values of volumetric moisture content (θ_v) for the soils at the site. Greacen et al. (1981) and Yao et al. (2004) each suggest that calibrating a neutron probe using soils collected and laboratory analyzed from the study site will provide more reliable values than the factory calibration curve. Therefore, a field calibration program was conducted at the study area following the installation of neutron access tubes NA4 and NA5 on February 2, 2007. The calibration was based on the comparison of probe measurements in NA4 and NA5 access tubes with the volumetric water content measured in the laboratory of the core collected during tube installation. The soil water content was measured using a Model 503 DR Hydroprobe Neutron Moisture Probe (CPN International Inc.). Moisture content of the surrounding soil is presented as the neutron probe count ratio (CR). The count ratio refers to the difference between the number of fast neutrons emitted (the Model 503 DR Hydroprobe uses a 50mCi Americium 241/Beryllium as a source of fast neutrons) to the number that are returned to the probe as slow neutrons after colliding with hydrogen atoms in the porewater and surrounding material.

In a manner similar to Bekeris (2007), the volumetric moisture content of the soil measured in the laboratory was regressed against the CR data collected by the neutron moisture probe (Fig. B.1). The volumetric moisture content (θ_v) and CR data were obtained from cores BT2 and BT3, which correspond to neutron access tubes NA5 and NA4 respectively. The calibration equation ($r^2 = 0.6071$) obtained for the conversion of CR to VWC was,

$$\theta_v = 117.14x - 82.068 \qquad \text{(B.1)}$$

where VWC is the volumetric water content (percentage) and CR is the count ratio (raw neutron count/standard count). Given the similar geological soil conditions at each neutron access borehole, applying any further corrections to account for differences in soil type, clay content, and density was not considered necessary.

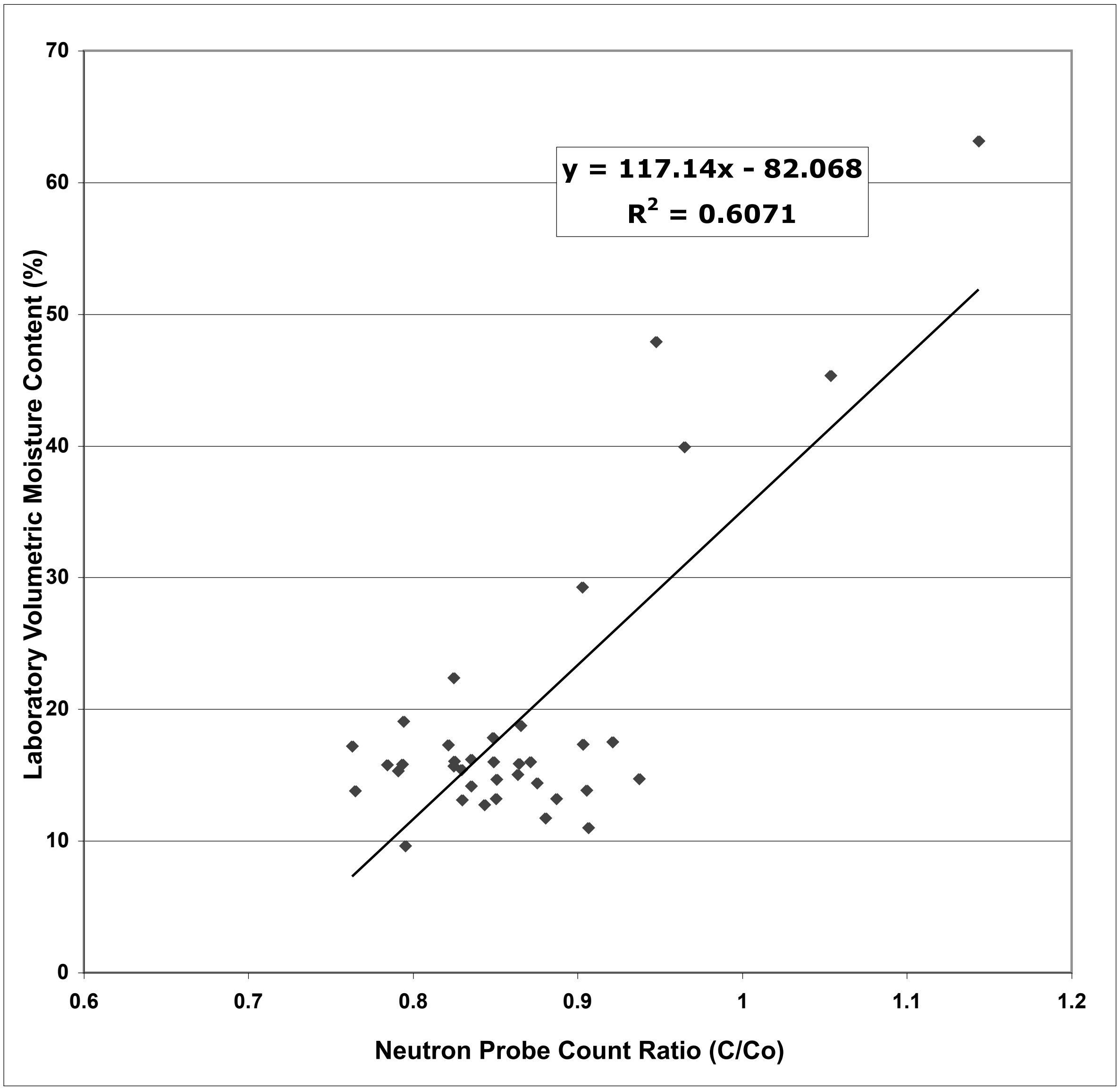

Figure B.1 - Neutron Probe calibration based upon a linear regression between laboratory measured volumetric moisture content values at BT2 and BT3 and neutron moisutre probe measured count ratios (CR) at NA5 and NA4.

Appendix C

Survey Data

Table C.1 – Allin Farm GPS Survey Results

A Z-Max RTK (Real-Time Kinetic) GPS Surveying System (Thales Navigation Inc., Santa Clara California) was used to provide centimeter level accuracy of surveyed locations. A temporary benchmark (TBM1) was installed at the site and consisted of a 4-foot long 1-inch diameters solid steel rod driven into the ground. To determine the Universal Transverse Mercator (UTM) coordinates of this benchmark and elevation in NAD83 the GPS system was used in a static mode. On March 30, 2007, the GPS base station receiver was set up over the benchmark and allowed to remain stationary (i.e., be static) and record raw satellite data over approximately 9 hours. This data was then combined with raw satellite data acquired at provincially and federally maintained receivers located at Port Weller, Kingston and Parry Sound Ontario to calculate the actual location and elevation of the KTMB1 benchmark. The post processing of these data sets was performed using GNSS Solutions version 2.00.03 software (Thales Navigation Inc) and the calculated benchmark coordinates were determined to have a 95% accuracy of 0.015 m horizontally and 0.020 m vertically.

Using the new known coordinates of the permanent benchmark, the GPS system was then used in RTK mode to obtain UTM Zone 17N coordinates and NAD83 elevations for site features. The accuracy of GPS measurements are not constant over time and space (depending on the constellation of the satellites at the time of measurements and local obstructions that block the view of the sky), but the average accuracy of the points surveyed was 0.009 m horizontally and 0.012 m vertically (relative to TBM1).

Table C.1 - Allin Farm GPS Survey Data.

Description	North (m)	East (m)	Elevation NAD83 (m)	Comment
Benchmark				
TBM1 Allin Farm	4880211.400	709647.140	235.637	Top of 1-inch diameter steel rod temporary bench mark - corrected to 3 30 07 PP
Wells				
KA1-1	4880321.458	709958.616	255.247	KA1-1 top of 2-inch ID PVC. Has gray top
Grnd	4880321.425	709958.565	254.266	Grnd at KA1-1
KA1-2	4880319.910	709958.958	255.250	KA1-2 top of 2-inch ID PVC. Has gray top
Grnd	4880319.933	709958.883	254.234	Grnd at KA1-2
KA1-3	4880318.058	709959.477	255.210	KA1-3 top of 2-inch ID PVC. Has gray top
Grnd	4880318.005	709959.500	254.354	Grnd at KA1-3
KA1-4	4880316.795	709960.200	255.259	KA1-4 top of 2-inch ID PVC. Has gray top
Grnd	4880316.846	709960.186	254.404	Grnd at KA1-4
KA2-1	4880633.248	709842.201	248.295	KA2-1 top of 2-inch ID PVC. Has gray top
Grnd	4880633.191	709842.214	247.256	Grnd at KA2-1
KA2-2	4880635.507	709841.325	248.372	KA2-2 top of 2-inch ID PVC. Has gray top
Grnd	4880635.478	709841.294	247.411	Grnd at KA2-2
KA2-3	4880637.691	709840.685	248.569	KA2-3 top of 2-inch ID PVC. Has gray top
Grnd	4880637.713	709840.580	247.518	Grnd at KA2-3
KA2-4	4880639.933	709839.965	248.678	KA2-4 top of 2-inch ID PVC. Has gray top. N end of set
Grnd	4880639.940	709839.927	247.703	Grnd at KA2-4
KA3-1	4880418.551	709706.277	242.733	KA3-1 top of 2-inch ID PVC
Grnd	4880418.514	709706.368	242.363	Grnd at KA3-1
KA3-2	4880418.012	709704.946	242.692	KA3-2 top of 2-inch ID PVC
Grnd	4880417.959	709704.968	242.323	Grnd at KA3-2
KA3-3	4880417.904	709703.671	242.704	KA3-3 top of 2-inch ID PVC. logger in it
Grnd	4880417.857	709703.751	242.179	Grnd at KA3-3
KA3-4	4880417.412	709702.300	242.661	KA3-4 top of 2-inch ID PVC. no protective casing
Grnd	4880417.463	709702.370	241.775	Grnd at KA3-4. in hole
KA4-1	4880510.593	709428.756	238.059	KA4-1 top of 2-inch ID PVC. Has gray top
Grnd	4880510.606	709428.775	236.931	Grnd at KA4-1
KA4-2	4880506.909	709429.812	238.046	KA4-2 top of 2-inch ID PVC Has gray top. S well of the set
Grnd	4880506.828	709429.766	236.851	Grnd at KA4-2. There is a small depression at well.
KA4-3	4880508.824	709429.223	238.079	KA4-3 top of 2-inch ID PVC. Has gray top
Grnd	4880508.959	709429.152	236.930	Grnd at KA4-3
KA4-4	4880512.591	709427.976	237.997	KA4-4 top of 2-inch ID PVC. Has gray top. N well of the set.
Grnd	4880512.578	709428.020	236.860	Grnd at KA4-4
KA5-1	4880136.808	709391.376	225.464	KA5-1 top of 2-inch ID PVC. Has gray top.
Grnd	4880136.784	709391.305	224.574	Grnd at KA5-1
KA5-2	4880135.495	709389.450	225.307	KA5-2 top of 2 inch ID PVC. Has gray top
Grnd	4880135.460	709389.392	224.406	Grnd at KA5-2
KA5-3	4880135.489	709391.838	225.318	KA5-3 top of 2-inch ID PVC gray
Grnd	4880135.467	709391.784	224.492	Grnd at KA5-3
KA5-4	4880134.083	709390.510	225.146	KA5-4 top of 2-inch ID PVC. Has gray top
Grnd	4880134.098	709390.453	224.376	Grnd at KA5-4
KA5-5	4880139.105	709390.671	225.388	KA5-5 top of 1.25-inch ID PVC (white)
KA5-6	4880139.092	709390.593	225.389	KA5-6 top of 2-inch ID PVC (white)
Grnd	4880139.180	709390.710	224.545	Grnd at KA5-5 and 6
KA6-1	4880624.335	709199.195	222.203	KA6-1 top of 2-inch ID PVC. Has gray top
Grnd	4880624.386	709199.135	221.345	Grnd at KA6-1
KA6-2	4880625.920	709198.580	222.279	KA6-2 top of 2-inch ID PVC. Has gray top
Grnd	4880625.989	709198.518	221.209	Grnd at KA6-2
KA6-3	4880627.837	709197.983	222.182	KA6-3 top of 2-inch ID PVC. Has gray top
Grnd	4880627.857	709197.923	221.186	Grnd at KA6-3
KA6-4	4880629.243	709197.651	221.927	KA6-4 top of 2-inch ID PVC. Has gray top like rest. N well of set. Moss growing on top of pipe. Flowing
Grnd	4880629.142	709197.666	221.139	Grnd at KA6-4
KA13	4880314.022	709637.305	239.166	KA13 top of 1.25-inch ID PVC (white). Dug up, but no extension on it yet.
KA13	4880313.997	709637.296	239.991	KA13 top of 1.25 inch ID PVC (white). Jay has added new stick up to be above ground
Grnd	4880314.051	709637.346	239.476	Grnd at KA13
KA14	4879932.951	709825.870	240.600	KA14 top of 1.25 inch ID PVC (white). New stickup, extended to ve level with ground minutes before surveyed
Grnd	4879932.930	709825.880	240.559	Grnd at KA14. Approximate
KA15-1	4880210.681	709731.528	239.926	KA15-1 top of 2-inch ID PVC (white). Top of PVC is cut at a slant, surveyed highest part

Description	North (m)	East (m)	Elevation NAD83 (m)	Comment
Grnd	4880210.683	709731.504	239.684	Grnd at KA15-1
KA15-2	4880210.969	709732.832	240.127	KA15-2 top of 2-inch ID PVC (white)
KA15-3	4880210.935	709732.769	240.126	KA15-3 top of 1.25 in ID PVC (white)
Grnd	4880210.856	709732.922	239.682	Grnd at KA15-2 and 3
KA16-1	4879927.280	709532.924	230.891	KA16-1 top of 1.25-inch ID PVC. (white)
KA16-2	4879927.217	709532.890	230.907	KA16-2 top of 2-inch ID PVC. (white)
Grnd	4879927.163	709532.898	229.953	Grnd at KA16-1 and 2
Bromide Tracer Locations and Neutron Access Tubes				
BT1-SE	4880153.705	709405.129	225.790	BT1-SE ground at SE corner of Bromide tracer patch
BT1-SW	4880152.710	709402.462	225.660	BT1-SW ground at SW corner
BT1-NW	4880155.650	709401.475	225.610	BT1-NW ground at NW corner
BT1-NE	4880156.391	709404.369	225.768	BT1-NE ground at NE corner
NA2	4880155.378	709403.751	226.156	NA2 top of 2-inch ID PVC access tube
Grnd	4880155.396	709403.769	225.706	Grnd at NA2
Core	4880153.705	709402.979	225.697	Core ground elevation (shallow 3 ft deep failed one to S) in BT1 area
Core	4880154.431	709402.502	225.680	Core ground elevation. The "good" core hole. In BT1 area
BT2-SE	4880299.651	--	250.247	BT2-SE ground at SE corner
BT2-SW	4880298.739	709909.227	249.922	BT2-SW ground at SW corner
BT2-NW	4880301.546	709908.259	249.840	BT2-NW ground at NW corner
BT2-NE	4880302.584	709910.977	250.089	BT2-NE ground at NE corner
Core	4880300.132	709910.759	250.087	Core ground elevation. In BT2 area
NA5	4880301.068	709910.295	250.679	NA5 top of 2-inch ID PVC in BT2 area
Grnd	4880301.080	709910.254	250.024	Grnd at NA5
BT3-S	4880091.235	709782.896	242.308	BT3-S ground at S corner
BT3-W	4880092.781	709780.004	242.116	BT3-W ground at W corner
BT3-N	4880095.487	709781.380	242.260	BT3-N ground at N corner
BT3-E	4880093.812	709784.289	242.361	BT3-E ground at E corner
NA4	4880092.699	709782.528	242.860	NA4 top of 2-inch ID PVC in BT3 area
Grnd	4880092.729	709782.524	242.286	Grnd at NA4
NA1	4880190.137	709795.261	243.218	NA1 top of 2-inch ID PVC (alone)
Grnd	4880190.084	709795.278	242.809	NA1 grnd
NA3	4880417.000	709699.448	243.103	NA3 top of 2-inch ID PVC. tall stickup near KA3 wells
Grnd	4880417.012	709699.513	241.931	Grnd at NA3
Tile Drains				
TD1	4880228.118	709678.672	236.766	TD1. Tile Drain. Invert of 6 inch ID corrugated steel pipe. Enters east end of center grassy island. Is flowing
Hole	4880280.512	709705.444	237.333	Hole. Ground at lowest point of hole dug by backhole at previous tile drain break. ~25 m east of TD1
TD2A	4880215.566	709654.064	235.077	TD2A Tile drain. Invert of 6 inch ID steel corrugated pipe. Enters swale from N side, just up stream of TD2 cassion
TD2 cassion	4880214.575	709652.447	234.963	TD2 cassion. Top of the steel on east side of 3 ft dia. vertical corrugated steel pipe
TD2 cassion	4880214.446	709651.842	235.103	TD2 cassion. Top of the steel on west side of 3 ft dia. vertical corrugated steel pipe
TD2 cassion Invert	4880214.447	709651.924	234.060	TD2 cassion invert. This is elevation of invert of ~12 inch-diameter black pipe exiting W side of cassion. Water flowing
Gully (a.k.a. TD3)	4880114.309	709394.660	222.918	Gully (a.k.a. TD3) where goes under wire fence, off of W end of field. See 1-inch deep flowing water at time
Hole	4880190.361	709603.120	232.083	Hole. West of TD2 by about 50 m. Circular vertical sided 2 ft dia collapse hole in field. Elevation of bottom of hole
Hole	4880190.390	709603.388	232.849	Ground surface elevation of field at hole
Buildings and Structures				
Met Station	4880218.310	709604.929	236.444	Ground at meteorological station. Measured at SE corner of logger box near center of tripod
House	4880300.879	709544.846	237.616	House. Ground at SW corner of brick house
Well house	4880337.387	709638.628	240.621	Well house SE corner
Well House	4880336.791	709636.904	240.110	Well house SW corner
Well House	4880338.310	709636.329	239.996	Well house NW corner
Well House	4880338.989	709638.069	240.509	Well house NE corner
Well stake	4880336.542	709637.734	240.469	Top of wooden stake about 1 ft in front of well house door
Bolt	4880335.825	709640.317	240.949	Top of 3/8-inch steel bolt sticking up on SW corner of cement footing. About 7 ft SE of pump house
Barn	4880387.319	709691.991	242.193	Barn SE corner of existing barn. Tough to get fix
Barn	4880375.561	709660.212	241.191	Barn SW corner. Note this is at small extension which is offset by about 3 ft N from wall of main barn.
Barn	4880399.463	709687.459	242.160	Barn NE corner
Barn	4880387.943	709658.912	243.322	Barn NW corner. Tough, unable to get fix. About 1 m error

Description	North (m)	East (m)	Elevation NAD83 (m)	Comment
Shed	4880325.632	709645.861	240.049	Shed near KA13, ground at SE corner
Shed	4880324.429	709642.366	239.862	Shed ground at SW corner
Shed	4880328.354	709644.824	240.196	Shed ground at NE corner of shed, but at least 1 ft from actual corner
Shed	4880327.108	709641.396	239.987	Shed ground at NW corner
Manure tank	4880390.015	709707.704	242.222	Manure tank. Elevation of ground next to cement wall
Manure tank	4880396.009	709703.370	242.446	Grnd next to wall
Manure tank	4880403.074	709702.201	242.551	Grnd next to wall
Manure tank	4880410.237	709704.736	242.613	Grnd next to wall
Manure tank	4880415.307	709710.081	242.388	Grnd next to wall
Manure tank	4880417.269	709716.843	242.359	Grnd next to wall
Manure tank	4880416.008	709723.867	242.415	Grnd next to wall
Manure tank	4880411.681	709729.614	242.869	Grnd next to wall
Manure tank	4880402.904	709733.029	242.532	Grnd next to wall
Manure tank	4880395.337	709731.606	242.410	Grnd next to wall
Manure tank	4880389.761	709727.286	242.232	Grnd next to wall
Manure tank	4880386.653	709720.241	242.186	Grnd next to wall
Manure tank	4880387.565	709711.785	242.182	Grnd next to wall
Manure tank	4880391.362	709706.314	242.333	End of manure tank ground next to wall elevations
Manure tank	4880391.896	709705.901	242.956	Top of cement wall of manure tank. West side
Driveway	4880216.348	709354.820	224.435	Driveway. Ground at edge of driveway at fence line near road. S side
Driveway	4880221.055	709352.714	224.470	Driveway. Ground at edge of driveway at fence line near road. N side
Driveway	4880315.106	709594.576	238.501	Driveway ground on S side of drive where barway is
Driveway	4880318.058	709593.193	238.488	Driveway ground on N side of drive where barway is
Driveway	4880291.545	709548.393	237.237	S side of driveway where in line with W side of house
Driveway	4880294.859	709547.027	237.196	N side of driveway where in line with W side of house
Gate post	4879929.240	709824.914	240.588	Gate post near KA14. Grnd at wooden gate post. W one of pair
Gate post	4879930.996	709829.470	240.532	Gate post near KA14. Grnd at wooden gate post. E one of pair
Culvert	4879935.387	709856.513	240.034	Top of 2 ft dia culvert SE of KA14 that goes under the road, North end of culvert
Culvert	4879935.920	709856.352	239.467	Invert of 2 ft dia culvert SE of KA14 that goes under the road, North end of culvert
Edge of Farm Field				
Field Edge	4880251.395	709343.000	224.630	Field edge. Start at location N of driveway entrance and on west edge of field nearest main road
Field Edge	4880241.974	709347.802	224.649	
Field Edge	4880236.660	709353.897	224.632	
Field Edge	4880235.302	709362.361	225.035	
Field Edge	4880237.168	709370.422	225.569	
Field Edge	4880246.521	709396.359	227.040	
Field Edge	4880256.187	709421.490	228.940	
Field Edge	4880265.920	709446.022	231.110	
Field Edge	4880275.602	709471.573	232.890	
Field Edge	4880282.555	709490.253	234.048	
Field Edge	4880288.288	709498.994	234.666	
Field Edge	4880296.052	709504.428	235.194	
Field Edge	4880304.745	709504.023	235.349	
Field Edge	4880326.199	709497.039	235.223	In line with E-W cedar hedge behind house
Field Edge	4880336.826	709493.575	235.250	
Field Edge	4880349.631	709489.379	235.601	
Field Edge	4880373.093	709480.831	235.747	West edge of grassy strip that extends to KA4. Stop segment. Strip continues N though
Field Edge	4880374.319	709483.702	236.501	East edge of grassy strip that extends to KA4. Start segment
Field Edge	4880351.617	709493.885	236.469	
Field Edge	4880343.888	709500.343	236.435	
Field Edge	4880339.812	709507.684	236.597	
Field Edge	4880340.921	709522.452	236.930	
Field Edge	4880350.095	709545.329	237.978	
Field Edge	4880360.551	709565.934	238.639	
Field Edge	4880372.154	709586.982	239.293	
Field Edge	4880385.962	709608.104	240.294	
Field Edge	4880396.342	709631.231	240.584	At N end of horizontal (fallen) silo
Field Edge	4880405.109	709651.994	241.119	In line with W end of barn
Field Edge	4880414.268	709681.871	241.527	In line with E end of barn
Field Edge	4880422.188	709705.436	242.001	
Field Edge	4880429.656	709731.449	242.094	

Description	North (m)	East (m)	Elevation NAD83 (m)	Comment
Field Edge	4880432.137	709744.488	242.219	
Field Edge	4880437.665	709746.308	242.312	Edge of bone pile
Field Edge	4880438.132	709756.164	242.284	
Field Edge	4880438.075	709771.682	242.303	
Field Edge	4880443.448	709792.691	242.315	
Field Edge	4880444.795	709799.893	242.282	E end of rocky point
Field Edge	4880440.619	709796.254	241.707	
Field Edge	4880436.219	709787.211	241.279	At gully that cuts across rocky point
Field Edge	4880425.810	709764.221	241.820	
Field Edge	4880419.138	709754.585	241.916	
Field Edge	4880409.781	709749.356	241.620	
Field Edge	4880384.198	709744.303	240.791	
Field Edge	4880362.502	709723.726	240.010	
Field Edge	4880344.238	709702.516	240.077	
Field Edge	4880334.296	709676.638	240.371	
Field Edge	4880327.493	709658.179	240.056	Back near shed. Done with line segment
Field Edge	4880322.853	709646.889	239.933	Field edge S of shed. Start of the buildings island
Field Edge	4880309.138	709614.919	238.935	
Field Edge	4880298.150	709588.032	238.233	
Field Edge	4880287.249	709561.004	237.179	South of the porch part of house
Field Edge	4880276.505	709534.259	235.809	
Field Edge	4880266.092	709506.530	234.446	
Field Edge	4880255.463	709478.344	232.398	
Field Edge	4880243.808	709449.154	230.338	
Field Edge	4880232.795	709420.653	228.331	
Field Edge	4880221.328	709391.439	225.880	
Field Edge	4880213.709	709374.085	224.620	
Field Edge	4880207.566	709366.349	224.415	
Field Edge	4880199.447	709365.001	224.349	
Field Edge	4880190.675	709365.940	224.299	
Field Edge	4880174.764	709371.992	224.399	End of this segment, ends near tree N of KA5
Field edge	4880152.290	709381.357	224.672	Field edge, ground. Start N of KA5 on east side of field
Field edge	4880147.763	709384.749	224.676	
Field edge	4880142.666	709388.871	224.644	
Field edge	4880139.593	709391.295	224.597	
Field edge	4880136.682	709392.865	224.499	
Field edge	4880129.808	709395.364	224.292	
Field edge	4880117.346	709399.875	224.062	Gully that exits field toward road. Near TD3
Field edge	4880091.626	709406.625	224.628	
Field edge	4880084.556	709409.599	224.547	Location of small gully exiting field
Field edge	4880066.459	709416.084	224.771	
Field edge	4880040.182	709426.753	225.114	
Field edge	4880013.276	709440.776	225.675	
Field edge	4879988.169	709458.034	226.280	
Field edge	4879966.136	709479.725	226.826	
Field edge	4879947.849	709501.603	228.037	
Field edge	4879932.618	709523.830	229.497	
Field edge	4879929.425	709529.003	229.740	
Field edge	4879927.758	709531.370	229.870	
Field edge	4879926.935	709532.759	229.941	
Field edge	4879925.804	709534.781	229.980	Near KA16 wells
Field edge	4879916.296	709553.219	230.218	At center of 20 ft wide gully fan exiting the field
Field edge	4879913.240	709561.320	230.458	
Field edge	4879902.715	709588.431	232.154	
Field edge	4879895.595	709618.781	233.396	
Field edge	4879892.399	709648.491	234.351	
Field edge	4879891.461	709678.528	235.778	
Field edge	4879893.034	709706.037	237.068	
Field edge	4879898.162	709733.273	238.103	
Field edge	4879906.055	709759.939	239.166	
Field edge	4879918.202	709788.338	240.357	
Field edge	4879927.548	709816.051	240.632	
Field edge	4879930.592	709824.553	240.558	
Field edge	4879932.524	709829.167	240.553	Near KA14
Field Edge	4879937.920	709844.102	240.558	In wide wash out area, near W edge
Field Edge	4879941.617	709854.068	240.578	
Field edge	4879947.227	709867.197	240.552	Still within washed out area

Description	North (m)	East (m)	Elevation NAD83 (m)	Comment
Field edge	4879956.900	709891.478	240.760	Edge of wash out low area. East side of that wide fan
Field edge	4879966.820	709917.143	241.679	
Field edge	4879977.809	709944.989	242.607	
Field edge	4879987.815	709971.280	243.773	
Field edge	4879997.824	709997.083	245.243	
Field edge	4880007.760	710022.921	246.293	About across street from church sign
Field edge	4880017.541	710048.569	246.631	
Field edge	4880017.547	710048.565	246.627	
Field edge	4880021.853	710055.781	246.668	
Field edge	4880027.878	710060.968	246.820	SE corner of field
Field edge	4880035.096	710063.660	247.096	
Field edge	4880044.525	710062.107	247.318	
Field edge	4880071.549	710051.798	248.091	
Field edge	4880105.385	710039.674	249.119	
Field edge	4880131.630	710029.994	249.672	
Field edge	4880157.590	710020.386	249.797	South edge of wet seep from east, upgradient property
Field edge	4880168.162	710016.796	249.571	Center of wet seep from east. in line with the line of E-W trending spruce trees
Field edge	4880189.800	710008.805	250.087	N edge of wet area to E
Field edge	4880215.808	709998.646	251.110	
Field edge	4880241.709	709989.007	252.463	
Field edge	4880267.478	709978.880	253.427	
Field edge	4880292.445	709968.986	254.092	
Field edge	4880311.707	709960.972	254.213	
Field edge	4880318.338	709957.983	254.025	End near KA1
Field edge	4880347.038	709947.933	252.956	Resume survey of field edge near KA1 (East end of field)
Field edge	4880370.728	709938.872	251.756	
Field edge	4880395.814	709930.220	250.234	
Field edge	4880420.816	709920.888	248.441	
Field edge	4880446.509	709911.467	246.807	
Field edge	4880463.720	709904.802	246.076	
Field edge	4880473.873	709897.697	245.388	Tree fallen down onto field and also there is a rock pile
Field edge	4880481.320	709887.298	244.663	
Field edge	4880493.248	709892.890	245.147	
Field edge	4880506.493	709889.144	244.949	
Field edge	4880531.890	709879.835	244.515	
Field edge	4880555.597	709870.532	244.341	
Field edge	4880579.888	709861.119	244.717	
Field edge	4880603.416	709852.425	245.674	
Field edge	4880626.920	709843.432	246.862	
Field edge	4880635.794	709839.572	247.335	
Field edge	4880666.361	709827.524	249.085	End of segment. N end of E edge of field
Field edge	4880231.152	709685.373	237.963	Field edge Ground elevations. East end of center grassy island. At field elevation at gully S edge
Field edge	4880232.928	709684.417	237.354	in gully
Field edge	4880237.123	709682.404	237.497	in gully
Field edge	4880237.091	709681.878	237.872	N edge of gully
Field edge	4880245.366	709674.035	237.983	
Field edge	4880251.401	709666.217	237.918	
Field edge	4880252.019	709659.953	238.155	
Field edge	4880248.866	709652.726	238.295	
Field edge	4880244.258	709647.169	237.868	
Field edge	4880229.829	709622.447	237.126	
Field edge	4880218.082	709594.901	236.142	
Field edge	4880206.670	709570.173	235.229	
Field edge	4880192.513	709544.257	233.815	
Field edge	4880180.824	709515.846	232.071	5 ft N of telephone pole
Field edge	4880167.229	709490.916	230.058	
Field edge	4880154.024	709463.996	228.192	
Field edge	4880148.581	709452.141	227.158	3 ft N of telephone pole
Field edge	4880144.555	709447.254	226.432	
Field edge	4880138.820	709440.802	225.531	Western end of grassy island
Field edge	4880210.651	709647.164	235.637	
Field edge	4880211.051	709654.105	236.581	
Field edge	4880213.563	709668.556	237.330	
Field edge	4880217.334	709677.477	237.546	
Field edge	4880224.097	709682.448	238.231	End of field edge for center grassy island. Back near gully

Appendix D

Meteorological Station Data

Table D.1 - Meteorological Station Data

Table D.1 - Meteorological Station Data.

░ Cobourg Env Canada Met Station Data
▒ Blackstock Env Canada Met station Data
▓ Allin Farm Rain Gauge
□ Allin Farm Met Station Data
nd no data available
-- equipment not installed

Date	Day	Air Temp °C (Max Daily)	Air Temp °C (Min Daily)	Air Temp °C (Avg Daily)	Relative Humidity (Max Daily)	Relative Humidity (Min Daily)	Relative Humidity (Avg Daily)	Wind Speed (m/s)	Wind Direction (Degrees)	Precipitation (mm/Day)	Solar Radiation (MJ/m²/day)	Soil Moisture Content % (0.73m bgs)	Soil Moisture Content % (0.39m bgs)	Soil Moisture Content % (0.14m bgs)
1/1/05	1	3.5	3.0	3.3	80.0	51.0	nd	nd	nd	0.0	1.4	--	--	--
1/2/05	2	5.0	-7.0	-1.0	100.0	51.0	nd	nd	nd	12.0	6.7	--	--	--
1/3/05	3	4.0	1.0	2.5	99.0	81.0	nd	nd	nd	0.0	3.4	--	--	--
1/4/05	4	3.0	0.0	1.5	100.0	67.0	nd	nd	nd	0.0	3.4	--	--	--
1/5/05	5	-1.0	-2.0	-1.5	79.0	54.0	nd	nd	nd	0.0	2.0	--	--	--
1/6/05	6	0.0	-10.0	-5.0	98.0	54.0	nd	nd	nd	2.0	6.3	--	--	--
1/7/05	7	1.0	-6.0	-2.5	80.0	67.0	nd	nd	nd	0.0	5.3	--	--	--
1/8/05	8	1.0	-5.0	-2.0	98.0	70.0	nd	nd	nd	2.0	4.9	--	--	--
1/9/05	9	3.0	-2.0	0.5	97.0	79.0	nd	nd	nd	0.0	4.5	--	--	--
1/10/05	10	2.0	-3.0	-0.5	94.0	61.0	nd	nd	nd	0.0	4.6	--	--	--
1/11/05	11	-2.0	-7.0	-4.5	68.0	53.0	nd	nd	nd	0.0	4.6	--	--	--
1/12/05	12	9.0	-7.0	1.0	100.0	67.0	nd	nd	nd	11.6	8.3	--	--	--
1/13/05	13	11.0	1.0	6.0	100.0	78.0	nd	nd	nd	5.0	6.6	--	--	--
1/14/05	14	-1.0	-5.0	-3.0	97.0	50.0	nd	nd	nd	0.0	4.2	--	--	--
1/15/05	15	-5.0	-12.0	-8.5	78.0	53.0	nd	nd	nd	0.0	5.6	--	--	--
1/16/05	16	-6.0	-10.0	-8.0	78.0	48.0	nd	nd	nd	0.0	4.3	--	--	--
1/17/05	17	-8.0	-13.0	-10.5	78.0	37.0	nd	nd	nd	0.0	4.9	--	--	--
1/18/05	18	-5.0	-24.0	-14.5	100.0	42.0	nd	nd	nd	0.0	9.6	--	--	--
1/19/05	19	-2.0	-15.0	-8.5	100.0	53.0	nd	nd	nd	13.0	8.0	--	--	--
1/20/05	20	-13.0	-18.0	-15.5	70.0	43.0	nd	nd	nd	0.0	5.0	--	--	--
1/21/05	21	-18.0	-25.0	-21.5	68.0	43.0	nd	nd	nd	0.0	6.0	--	--	--
1/22/05	22	-17.0	-24.0	-20.5	81.0	51.0	nd	nd	nd	3.0	6.0	--	--	--
1/23/05	23	-11.0	-21.0	-16.0	69.0	38.0	nd	nd	nd	0.0	7.3	--	--	--
1/24/05	24	-4.0	-21.0	-12.5	91.0	57.0	nd	nd	nd	2.0	9.6	--	--	--
1/25/05	25	-7.0	-11.0	-9.0	86.0	40.0	nd	nd	nd	8.0	4.7	--	--	--
1/26/05	26	-9.0	-12.0	-10.5	86.0	41.0	nd	nd	nd	0.0	4.1	--	--	--
1/27/05	27	-11.0	-21.0	-16.0	68.0	38.0	nd	nd	nd	0.0	7.6	--	--	--
1/28/05	28	-4.0	-21.0	-12.5	90.0	47.0	nd	nd	nd	0.0	10.1	--	--	--
1/29/05	29	0.0	-17.0	-8.5	90.0	64.0	nd	nd	nd	0.0	10.2	--	--	--
1/30/05	30	2.0	-13.0	-5.5	86.0	43.0	nd	nd	nd	0.0	9.7	--	--	--
1/31/05	31	-1.0	-15.0	-8.0	79.0	44.0	nd	nd	nd	0.0	9.5	--	--	--
2/1/05	32	0.0	-15.0	-7.5	87.0	59.0	nd	nd	nd	0.0	9.9	--	--	--
2/2/05	33	0.0	-15.0	-7.5	89.0	54.0	nd	nd	nd	0.0	10.1	--	--	--
2/3/05	34	2.0	-6.0	-2.0	91.0	56.0	nd	nd	nd	0.0	7.4	--	--	--
2/4/05	35	4.0	-8.0	-2.0	97.0	68.0	nd	nd	nd	0.0	9.2	--	--	--
2/5/05	36	2.0	-9.0	-3.5	100.0	93.0	nd	nd	nd	0.0	8.9	--	--	--
2/6/05	37	5.0	-6.0	-0.5	100.0	58.0	nd	nd	nd	0.0	9.1	--	--	--
2/7/05	38	7.0	-2.0	2.5	88.0	58.0	nd	nd	nd	3.0	8.3	--	--	--
2/8/05	39	5.0	2.0	3.5	100.0	73.0	nd	nd	nd	3.0	4.9	--	--	--
2/9/05	40	-1.0	-6.0	-3.5	90.0	81.0	nd	nd	nd	6.0	6.3	--	--	--
2/10/05	41	-1.0	-6.0	-3.5	88.0	40.0	nd	nd	nd	0.0	6.4	--	--	--
2/11/05	42	1.0	-8.0	-3.5	84.0	46.0	nd	nd	nd	1.0	8.7	--	--	--
2/12/05	43	3.0	-2.0	0.5	95.0	55.0	nd	nd	nd	0.0	6.6	--	--	--
2/13/05	44	0.0	-12.0	-6.0	73.0	55.0	nd	nd	nd	0.0	10.4	--	--	--
2/14/05	45	4.0	-8.0	-2.0	100.0	72.0	nd	nd	nd	24.2	10.5	--	--	--
2/15/05	46	5.0	0.0	2.5	100.0	94.0	nd	nd	nd	17.0	6.9	--	--	--
2/16/05	47	3.0	0.0	1.5	100.0	65.0	nd	nd	nd	1.8	5.4	--	--	--
2/17/05	48	1.0	-7.0	-3.0	91.0	61.0	nd	nd	nd	0.0	8.9	--	--	--
2/18/05	49	-8.0	-15.0	-11.5	81.0	48.0	nd	nd	nd	0.0	8.4	--	--	--
2/19/05	50	-1.0	-14.0	-7.5	83.0	58.0	nd	nd	nd	0.0	11.6	--	--	--
2/20/05	51	-4.0	-12.0	-8.0	88.0	54.0	nd	nd	nd	6.0	9.2	--	--	--
2/21/05	52	-1.0	-11.0	-6.0	95.0	78.0	nd	nd	nd	0.0	10.5	--	--	--
2/22/05	53	1.0	-6.0	-2.5	94.0	61.0	nd	nd	nd	0.0	8.9	--	--	--
2/23/05	54	-4.0	-14.0	-9.0	80.0	43.0	nd	nd	nd	0.0	10.7	--	--	--
2/24/05	55	-5.0	-15.0	-10.0	74.0	40.0	nd	nd	nd	0.0	10.9	--	--	--
2/25/05	56	-5.0	-16.0	-10.5	91.0	47.0	nd	nd	nd	5.0	11.5	--	--	--
2/26/05	57	-1.0	-8.0	-4.5	93.0	56.0	nd	nd	nd	0.0	9.3	--	--	--
2/27/05	58	-3.0	-12.0	-7.5	78.0	51.0	nd	nd	nd	0.0	10.7	--	--	--
2/28/05	59	1.0	-7.0	-3.0	97.0	65.0	nd	nd	nd	6.0	10.2	--	--	--
3/1/05	60	-2.0	-6.0	-4.0	91.0	73.0	nd	nd	nd	4.0	7.3	--	--	--
3/2/05	61	-4.0	-7.0	-5.5	85.0	46.0	nd	nd	nd	0.0	6.4	--	--	--
3/3/05	62	-5.0	-12.0	-8.5	65.0	35.0	nd	nd	nd	0.0	9.9	--	--	--
3/4/05	63	1.0	-10.0	-4.5	77.0	61.0	nd	nd	nd	0.0	12.6	--	--	--
3/5/05	64	2.0	-12.0	-5.0	85.0	61.0	nd	nd	nd	0.0	14.4	--	--	--
3/6/05	65	4.0	-2.0	1.0	99.0	65.0	nd	nd	nd	0.0	9.5	--	--	--
3/7/05	66	5.0	-6.0	-0.5	99.0	79.0	nd	nd	nd	10.0	13.0	--	--	--
3/8/05	67	-8.0	-14.0	-11.0	72.0	44.0	nd	nd	nd	0.0	9.7	--	--	--
3/9/05	68	-7.0	-16.0	-11.5	74.0	37.0	nd	nd	nd	0.0	12.1	--	--	--
3/10/05	69	-2.0	-15.0	-8.5	74.0	45.0	nd	nd	nd	0.0	14.7	--	--	--
3/11/05	70	0.0	-5.0	-2.5	93.0	60.0	nd	nd	nd	0.0	9.2	--	--	--
3/12/05	71	1.0	-10.0	-4.5	96.0	61.0	nd	nd	nd	0.0	13.8	--	--	--
3/13/05	72	0.0	-8.0	-4.0	80.0	45.0	nd	nd	nd	0.0	11.9	--	--	--
3/14/05	73	2.0	-10.0	-4.0	75.0	39.0	nd	nd	nd	0.0	14.8	--	--	--
3/15/05	74	4.5	-6.5	-1.0	73.0	45.0	nd	nd	nd	0.0	14.3	--	--	--
3/16/05	75	3.0	-6.0	-1.5	81.0	35.0	nd	nd	nd	0.0	13.1	--	--	--
3/17/05	76	3.0	-6.0	-1.5	95.0	67.0	nd	nd	nd	0.0	13.2	--	--	--
3/18/05	77	3.0	-6.0	-1.5	94.0	61.0	nd	nd	nd	0.0	13.3	--	--	--
3/19/05	78	3.0	-6.0	-1.5	81.0	46.0	nd	nd	nd	0.0	13.5	--	--	--
3/20/05	79	6.0	-1.0	2.5	89.0	41.0	nd	nd	nd	0.0	12.0	--	--	--
3/21/05	80	9.0	0.0	4.5	94.0	40.0	nd	nd	nd	0.0	13.8	--	--	--
3/22/05	81	4.5	-4.5	0.0	79.0	51.0	nd	nd	nd	0.0	13.9	--	--	--
3/23/05	82	2.5	-3.0	-0.3	69.0	40.0	nd	nd	nd	0.0	11.0	--	--	--
3/24/05	83	6.0	-1.5	2.3	90.0	53.0	nd	nd	nd	0.0	12.9	--	--	--
3/25/05	84	7.0	0.5	3.8	90.0	37.0	nd	nd	nd	0.0	12.2	--	--	--
3/26/05	85	5.0	-3.0	1.0	76.0	54.0	nd	nd	nd	0.0	13.6	--	--	--
3/27/05	86	8.0	-5.0	1.5	86.0	63.0	nd	nd	nd	0.0	17.5	--	--	--
3/28/05	87	8.0	2.0	5.0	95.0	77.0	nd	nd	nd	0.0	12.0	--	--	--

Date	Day	Air Temp ^{o}C (Max Daily)	Air Temp ^{o}C (Min Daily)	Air Temp ^{o}C (Avg Daily)	Relative Humidity (Max Daily)	Relative Humidity (Min Daily)	Relative Humidity (Avg Daily)	Wind Speed (m/s)	Wind Direction (Degrees)	Precipitation (mm/Day)	Solar Radiation (MJ/m^2/day)	Soil Moisture Content % (0.73m bgs)	Soil Moisture Content % (0.39m bgs)	Soil Moisture Content % (0.14m bgs)
3/29/05	88	9.0	3.0	6.0	94.0	74.0	nd	nd	nd	0.0	12.1	--	--	--
3/30/05	89	12.0	-2.0	5.0	98.0	51.0	nd	nd	nd	0.0	18.7	--	--	--
3/31/05	90	11.0	6.0	8.5	87.0	53.0	nd	nd	nd	10.6	11.3	--	--	--
4/1/05	91	12.0	4.0	8.0	90.0	50.0	nd	nd	nd	9.4	14.4	--	--	--
4/2/05	92	5.0	1.0	3.0	93.0	63.0	nd	nd	nd	36.0	10.3	--	--	--
4/3/05	93	7.0	1.0	4.0	94.0	77.0	nd	nd	nd	4.0	12.7	--	--	--
4/4/05	94	11.0	2.0	6.5	89.0	35.0	nd	nd	nd	0.0	15.7	--	--	--
4/5/05	95	12.0	-1.0	5.5	82.0	16.0	nd	nd	nd	0.0	19.0	--	--	--
4/6/05	96	17.0	6.0	11.5	76.0	35.0	nd	nd	nd	0.0	17.6	--	--	--
4/7/05	97	10.0	4.0	7.0	95.0	61.0	nd	nd	nd	1.0	13.1	--	--	--
4/8/05	98	9.0	-2.0	3.5	96.0	37.0	nd	nd	nd	0.0	17.9	--	--	--
4/9/05	99	13.0	-4.0	4.5	85.0	40.0	nd	nd	nd	0.0	22.5	--	--	--
4/10/05	100	18.0	-1.0	8.5	73.0	26.0	nd	nd	nd	0.0	23.9	--	--	--
4/11/05	101	6.5	1.0	3.8	70.0	26.0	nd	nd	nd	0.0	13.0	--	--	--
4/12/05	102	7.5	0.0	3.8	73.0	35.0	nd	nd	nd	0.0	15.3	--	--	--
4/13/05	103	10.0	-1.5	4.3	68.0	28.0	nd	nd	nd	0.0	19.0	--	--	--
4/14/05	104	13.0	0.5	6.8	72.0	31.0	nd	nd	nd	0.0	20.0	--	--	--
4/15/05	105	12.0	3.0	7.5	65.0	32.0	nd	nd	nd	0.0	17.1	--	--	--
4/16/05	106	15.0	-2.0	6.5	72.0	34.0	nd	nd	nd	0.0	23.7	--	--	--
4/17/05	107	16.0	-1.0	7.5	80.0	48.0	nd	nd	nd	0.0	23.8	--	--	--
4/18/05	108	16.0	7.0	11.5	73.0	34.0	nd	nd	nd	0.0	17.5	--	--	--
4/19/05	109	16.0	3.0	9.5	80.0	60.0	nd	nd	nd	0.0	21.1	--	--	--
4/20/05	110	15.0	8.0	11.5	95.0	64.0	nd	nd	nd	22.0	15.6	--	--	--
4/21/05	111	9.0	0.0	4.5	84.0	40.0	nd	nd	nd	0.0	17.8	--	--	--
4/22/05	112	14.0	0.0	7.0	96.0	33.0	nd	nd	nd	12.0	22.3	--	--	--
4/23/05	113	8.0	5.0	6.5	97.0	88.0	nd	nd	nd	33.0	10.4	--	--	--
4/24/05	114	6.0	3.0	4.5	99.0	82.0	nd	nd	nd	1.0	10.5	--	--	--
4/25/05	115	8.0	2.0	5.0	94.0	82.0	nd	nd	nd	2.0	14.9	--	--	--
4/26/05	116	15.0	1.0	8.0	94.0	59.0	nd	nd	nd	3.0	22.9	--	--	--
4/27/05	117	12.0	6.0	9.0	95.0	72.0	nd	nd	nd	0.0	15.1	--	--	--
4/28/05	118	9.0	4.0	6.5	91.0	43.0	nd	nd	nd	0.0	13.8	--	--	--
4/29/05	119	10.5	2.0	6.3	83.0	59.0	nd	nd	nd	2.6	18.1	--	--	--
4/30/05	120	10.0	4.0	7.0	87.0	63.0	nd	nd	nd	4.2	15.3	--	--	--
5/1/05	121	10.0	0.0	5.0	91.0	62.0	nd	nd	nd	0.0	19.9	--	--	--
5/2/05	122	8.0	3.0	5.5	91.0	74.0	nd	nd	nd	5.0	14.1	--	--	--
5/3/05	123	7.0	2.0	4.5	96.0	64.0	nd	nd	nd	0.0	14.2	--	--	--
5/4/05	124	8.0	-4.0	2.0	97.0	70.0	nd	nd	nd	0.0	22.1	--	--	--
5/5/05	125	13.0	-2.0	5.5	93.0	54.0	nd	nd	nd	0.0	24.8	--	--	--
5/6/05	126	17.0	2.0	9.5	74.0	44.0	nd	nd	nd	0.0	24.9	--	--	--
5/7/05	127	16.0	7.0	11.5	86.0	48.0	nd	nd	nd	0.0	19.4	--	--	--
5/8/05	128	18.0	3.0	10.5	81.0	50.0	nd	nd	nd	0.0	25.2	--	--	--
5/9/05	129	17.0	4.0	10.5	85.0	69.0	nd	nd	nd	0.0	23.5	--	--	--
5/10/05	130	21.0	6.0	13.5	82.0	56.0	nd	nd	nd	0.0	25.4	--	--	--
5/11/05	131	22.0	9.0	15.5	93.0	57.0	nd	nd	nd	0.0	23.7	--	--	--
5/12/05	132	9.0	0.0	4.5	66.0	27.0	nd	nd	nd	0.0	19.8	--	--	--
5/13/05	133	13.0	-1.0	6.0	76.0	29.0	nd	nd	nd	4.3	24.8	--	--	--
5/14/05	134	18.5	5.0	11.8	97.0	63.0	nd	nd	nd	8.2	24.5	--	--	--
5/15/05	135	14.0	9.5	11.8	100.0	75.0	nd	nd	nd	0.0	14.2	--	--	--
5/16/05	136	13.0	5.0	9.0	93.0	45.0	nd	nd	nd	0.0	19.0	--	--	--
5/17/05	137	11.0	0.0	5.5	87.0	69.0	nd	nd	nd	0.0	22.3	--	--	--
5/18/05	138	15.0	2.0	8.5	84.0	43.0	nd	nd	nd	0.0	24.4	--	--	--
5/19/05	139	15.0	3.0	9.0	92.0	46.0	nd	nd	nd	0.0	23.5	--	--	--
5/20/05	140	19.0	7.0	13.0	75.0	32.0	nd	nd	nd	0.0	23.5	--	--	--
5/21/05	141	16.0	6.0	11.0	94.0	53.0	nd	nd	nd	0.0	21.6	--	--	--
5/22/05	142	14.0	6.0	10.0	90.0	64.0	nd	nd	nd	2.0	19.3	--	--	--
5/23/05	143	16.0	8.0	12.0	92.0	61.0	nd	nd	nd	1.0	19.4	--	--	--
5/24/05	144	17.0	10.0	13.5	87.0	57.0	nd	nd	nd	0.0	18.2	--	--	--
5/25/05	145	24.0	10.0	17.0	78.0	28.0	nd	nd	nd	0.0	25.8	--	--	--
5/26/05	146	21.0	8.0	14.5	89.0	45.0	nd	nd	nd	0.0	24.9	--	--	--
5/27/05	147	15.0	7.0	11.0	92.0	78.0	nd	nd	nd	1.2	19.6	--	--	--
5/28/05	148	16.0	8.0	12.0	89.0	68.0	nd	nd	nd	0.0	19.6	--	--	--
5/29/05	149	17.0	9.0	13.0	91.0	60.0	nd	nd	nd	2.0	19.7	--	--	--
5/30/05	150	19.0	5.0	12.0	91.0	65.0	nd	nd	nd	0.0	26.1	--	--	--
5/31/05	151	21.0	11.0	16.0	90.0	54.0	nd	nd	nd	0.0	22.1	--	--	--
6/1/05	152	22.0	11.0	16.5	91.0	68.0	nd	nd	nd	0.0	23.2	--	--	--
6/2/05	153	25.0	11.0	18.0	89.0	60.0	nd	nd	nd	0.0	26.2	--	--	--
6/3/05	154	23.0	14.0	18.5	80.0	59.0	nd	nd	nd	0.0	21.1	--	--	--
6/4/05	155	21.0	16.0	18.5	95.0	81.0	nd	nd	nd	0.0	15.7	--	--	--
6/5/05	156	24.0	14.0	19.0	94.0	76.0	nd	nd	nd	0.0	22.3	--	--	--
6/6/05	157	25.0	18.0	21.5	90.0	73.0	nd	nd	nd	0.0	18.7	--	--	--
6/7/05	158	29.0	14.0	21.5	90.0	31.0	nd	nd	nd	0.0	27.4	--	--	--
6/8/05	159	28.0	15.0	21.5	85.0	65.0	nd	nd	nd	0.0	25.5	--	--	--
6/9/05	160	27.0	18.0	22.5	88.0	77.0	nd	nd	nd	0.0	21.3	--	--	--
6/10/05	161	26.0	19.0	22.5	94.0	82.0	nd	nd	nd	0.0	18.8	--	--	--
6/11/05	162	29.0	19.0	24.0	95.0	73.0	nd	nd	nd	0.0	22.4	--	--	--
6/12/05	163	28.0	19.0	23.5	94.0	74.0	nd	nd	nd	0.0	21.3	--	--	--
6/13/05	164	30.0	21.0	25.5	100.0	81.0	nd	nd	nd	0.0	21.3	--	--	--
6/14/05	165	28.0	21.0	24.5	100.0	67.0	nd	nd	nd	22.0	18.8	--	--	--
6/15/05	166	22.0	18.0	20.0	100.0	84.0	nd	nd	nd	7.0	14.2	--	--	--
6/16/05	167	18.0	14.5	16.3	100.0	74.0	nd	nd	nd	12.0	13.3	--	--	--
6/17/05	168	18.0	11.0	14.5	100.0	76.0	nd	nd	nd	2.0	18.8	--	--	--
6/18/05	169	17.0	13.0	15.0	100.0	71.0	nd	nd	nd	0.0	14.3	--	--	--
6/19/05	170	17.0	13.0	15.0	93.0	70.0	nd	nd	nd	0.0	14.3	--	--	--
6/20/05	171	19.0	9.0	14.0	94.0	81.0	nd	nd	nd	0.0	22.5	--	--	--
6/21/05	172	24.0	11.0	17.5	100.0	73.0	nd	nd	nd	1.6	25.7	--	--	--
6/22/05	173	24.0	14.0	19.0	100.0	34.0	nd	nd	nd	0.0	22.5	--	--	--
6/23/05	174	22.0	8.5	15.3	88.0	71.0	nd	nd	nd	0.0	26.2	--	--	--
6/24/05	175	26.0	12.0	19.0	94.0	63.0	nd	nd	nd	0.0	26.6	--	--	--
6/25/05	176	31.5	16.0	23.8	85.0	28.0	nd	nd	nd	0.0	28.0	--	--	--
6/26/05	177	27.0	16.0	21.5	73.0	40.0	nd	nd	nd	0.0	23.6	--	--	--
6/27/05	178	30.0	16.0	23.0	83.0	54.0	nd	nd	nd	0.0	26.6	--	--	--
6/28/05	179	29.0	19.0	24.0	88.0	71.0	nd	nd	nd	0.0	22.5	--	--	--
6/29/05	180	29.0	21.0	25.0	93.0	65.0	nd	nd	nd	0.0	20.1	--	--	--
6/30/05	181	25.5	18.0	21.8	91.0	76.0	nd	nd	nd	0.0	19.4	--	--	--
7/1/05	182	29.0	21.0	25.0	93.0	43.0	nd	nd	nd	0.0	20.0	--	--	--
7/2/05	183	22.0	11.0	16.5	86.0	44.0	nd	nd	nd	0.0	23.5	--	--	--
7/3/05	184	26.0	10.0	18.0	89.0	53.0	nd	nd	nd	0.0	28.3	--	--	--
7/4/05	185	27.0	17.0	22.0	91.0	73.0	nd	nd	nd	4.0	22.3	--	--	--
7/5/05	186	28.0	20.0	24.0	93.0	65.0	nd	nd	nd	0.0	19.9	--	--	--

Date	Day	Air Temp °C (Max Daily)	Air Temp °C (Min Daily)	Air Temp °C (Avg Daily)	Relative Humidity (Max Daily)	Relative Humidity (Min Daily)	Relative Humidity (Avg Daily)	Wind Speed (m/s)	Wind Direction (Degrees)	Precipitation (mm/Day)	Solar Radiation ($MJ/m^2/day$)	Soil Moisture Content % (0.73m bgs)	Soil Moisture Content % (0.39m bgs)	Soil Moisture Content % (0.14m bgs)
7/6/05	187	24.0	17.0	20.5	82.0	61.0	nd	nd	nd	0.0	18.6	--	--	--
7/7/05	188	25.0	14.5	19.8	83.0	47.0	nd	nd	nd	0.0	22.8	--	--	--
7/8/05	189	25.0	19.0	22.0	93.0	69.0	nd	nd	nd	2.0	17.2	--	--	--
7/9/05	190	27.5	17.0	22.3	94.0	45.0	nd	nd	nd	0.0	22.7	--	--	--
7/10/05	191	29.0	19.5	24.3	73.0	36.0	nd	nd	nd	0.0	21.5	--	--	--
7/11/05	192	31.0	18.0	24.5	79.0	59.0	nd	nd	nd	0.0	25.1	--	--	--
7/12/05	193	31.0	21.0	26.0	84.0	58.0	nd	nd	nd	0.0	22.0	--	--	--
7/13/05	194	30.0	20.0	25.0	82.0	62.0	nd	nd	nd	1.0	22.0	--	--	--
7/14/05	195	28.0	22.0	25.0	90.0	67.0	nd	nd	nd	0.0	17.0	--	--	--
7/15/05	196	29.0	22.0	25.5	79.0	57.0	nd	nd	nd	0.0	18.3	--	--	--
7/16/05	197	29.0	21.0	25.0	91.0	60.0	nd	nd	nd	3.0	19.5	--	--	--
7/17/05	198	28.0	21.0	24.5	95.0	89.0	nd	nd	nd	0.0	18.2	--	--	--
7/18/05	199	30.0	24.0	27.0	94.0	76.0	nd	nd	nd	0.0	16.8	--	--	--
7/19/05	200	30.0	24.0	27.0	90.0	46.0	nd	nd	nd	0.0	16.8	--	--	--
7/20/05	201	26.0	14.0	20.0	83.0	68.0	nd	nd	nd	0.0	23.6	--	--	--
7/21/05	202	29.0	19.0	24.0	94.0	69.0	nd	nd	nd	0.0	21.5	--	--	--
7/22/05	203	30.5	22.0	26.3	81.0	37.0	nd	nd	nd	0.0	19.8	--	--	--
7/23/05	204	29.0	15.0	22.0	84.0	35.0	nd	nd	nd	0.0	25.3	--	--	--
7/24/05	205	26.0	14.0	20.0	86.0	71.0	nd	nd	nd	0.0	23.3	--	--	--
7/25/05	206	35.0	19.0	27.0	92.0	16.0	nd	nd	nd	0.0	26.8	--	--	--
7/26/05	207	26.0	15.0	20.5	100.0	54.0	nd	nd	nd	12.0	22.2	--	--	--
7/27/05	208	23.0	18.0	20.5	100.0	52.0	nd	nd	nd	0.0	14.9	--	--	--
7/28/05	209	24.5	11.0	17.8	88.0	65.0	nd	nd	nd	0.0	24.4	--	--	--
7/29/05	210	25.5	13.0	19.3	92.0	59.0	nd	nd	nd	0.0	23.4	--	--	--
7/30/05	211	25.0	15.0	20.0	82.0	43.0	nd	nd	nd	0.0	20.8	--	--	--
7/31/05	212	25.0	15.0	20.0	83.0	62.0	nd	nd	nd	3.0	20.7	--	--	--
8/1/05	213	27.0	18.0	22.5	91.0	70.0	nd	nd	nd	8.0	19.6	--	--	--
8/2/05	214	27.0	19.0	23.0	93.0	71.0	nd	nd	nd	0.0	18.4	--	--	--
8/3/05	215	30.0	18.0	24.0	99.0	70.0	nd	nd	nd	0.0	22.4	--	--	--
8/4/05	216	31.0	19.0	25.0	98.0	76.0	nd	nd	nd	6.0	22.3	--	--	--
8/5/05	217	28.0	18.0	23.0	92.0	34.0	nd	nd	nd	0.0	20.3	--	--	--
8/6/05	218	24.0	13.0	18.5	91.0	58.0	nd	nd	nd	0.0	21.2	--	--	--
8/7/05	219	25.0	13.0	19.0	90.0	74.0	nd	nd	nd	0.0	22.0	--	--	--
8/8/05	220	29.0	15.0	22.0	88.0	58.0	nd	nd	nd	0.0	23.7	--	--	--
8/9/05	221	29.0	17.0	23.0	99.0	68.0	nd	nd	nd	0.0	21.8	--	--	--
8/10/05	222	29.0	19.0	24.0	97.0	77.0	nd	nd	nd	5.0	19.8	--	--	--
8/11/05	223	25.5	17.5	21.5	97.0	64.0	nd	nd	nd	0.0	17.6	--	--	--
8/12/05	224	25.0	20.0	22.5	100.0	61.0	nd	nd	nd	5.2	13.9	--	--	--
8/13/05	225	27.0	19.0	23.0	98.0	44.0	nd	nd	nd	0.0	17.4	--	--	--
8/14/05	226	22.0	19.0	20.5	89.0	61.0	nd	nd	nd	2.0	10.6	--	--	--
8/15/05	227	25.0	13.0	19.0	96.0	55.0	nd	nd	nd	0.0	21.1	--	--	--
8/16/05	228	26.0	14.0	20.0	75.0	46.0	nd	nd	nd	0.0	21.0	--	--	--
8/17/05	229	26.5	13.5	20.0	80.0	32.0	nd	nd	nd	0.0	21.7	--	--	--
8/18/05	230	24.0	16.5	20.3	67.0	50.0	nd	nd	nd	0.0	16.4	--	--	--
8/19/05	231	26.0	18.0	22.0	100.0	57.0	nd	nd	nd	31.0	16.8	--	--	--
8/20/05	232	24.0	18.0	21.0	92.0	74.0	nd	nd	nd	0.0	14.5	--	--	--
8/21/05	233	26.0	19.0	22.5	98.0	46.0	nd	nd	nd	0.0	15.5	--	--	--
8/22/05	234	21.0	14.0	17.5	84.0	58.0	nd	nd	nd	1.0	15.4	--	--	--
8/23/05	235	23.0	11.0	17.0	97.0	50.0	nd	nd	nd	0.0	20.1	--	--	--
8/24/05	236	24.0	12.0	18.0	85.0	45.0	nd	nd	nd	0.0	19.9	--	--	--
8/25/05	237	24.0	13.0	18.5	88.0	61.0	nd	nd	nd	0.0	19.0	--	--	--
8/26/05	238	25.0	13.0	19.0	89.0	54.0	nd	nd	nd	0.4	19.7	--	--	--
8/27/05	239	26.0	15.0	20.5	94.0	69.0	nd	nd	nd	1.0	18.7	--	--	--
8/28/05	240	25.0	20.0	22.5	96.0	71.0	nd	nd	nd	0.0	12.5	--	--	--
8/29/05	241	29.0	17.0	23.0	98.0	63.0	nd	nd	nd	0.0	19.2	--	--	--
8/30/05	242	25.0	15.0	20.0	99.0	75.0	nd	nd	nd	47.0	17.4	--	--	--
8/31/05	243	26.0	18.0	22.0	100.0	61.0	nd	nd	nd	2.0	15.5	--	--	--
9/1/05	244	25.0	15.0	20.0	90.0	73.0	nd	nd	nd	0.0	17.2	--	--	--
9/2/05	245	26.0	14.5	20.3	95.0	47.0	nd	nd	nd	0.4	18.3	--	--	--
9/3/05	246	25.0	14.0	19.5	88.0	50.0	nd	nd	nd	0.0	17.7	--	--	--
9/4/05	247	20.0	15.0	17.5	89.0	59.0	nd	nd	nd	0.2	11.9	--	--	--
9/5/05	248	21.5	10.0	15.8	95.0	65.0	nd	nd	nd	0.0	17.8	--	--	--
9/6/05	249	21.5	11.5	16.5	100.0	75.0	nd	nd	nd	0.0	16.5	--	--	--
9/7/05	250	24.0	13.5	18.8	100.0	79.0	nd	nd	nd	0.0	16.7	--	--	--
9/8/05	251	21.0	13.5	17.3	98.0	69.0	nd	nd	nd	6.0	14.0	--	--	--
9/9/05	252	22.0	11.5	16.8	99.0	56.0	nd	nd	nd	0.0	16.5	--	--	--
9/10/05	253	20.0	11.0	15.5	85.0	54.0	nd	nd	nd	0.0	15.1	--	--	--
9/11/05	254	22.0	9.0	15.5	91.0	53.0	nd	nd	nd	0.0	18.0	--	--	--
9/12/05	255	26.5	14.0	20.3	90.0	62.0	nd	nd	nd	0.0	17.5	--	--	--
9/13/05	256	26.0	15.0	20.5	99.0	75.0	nd	nd	nd	0.0	16.3	--	--	--
9/14/05	257	27.0	15.0	21.0	99.0	69.0	nd	nd	nd	7.0	16.8	--	--	--
9/15/05	258	26.0	16.0	21.0	100.0	61.0	nd	nd	nd	0.0	15.2	--	--	--
9/16/05	259	19.0	16.0	17.5	99.0	78.0	nd	nd	nd	24.0	8.3	--	--	--
9/17/05	260	24.0	16.0	20.0	95.0	60.0	nd	nd	nd	0.0	13.3	--	--	--
9/18/05	261	22.5	12.0	17.3	99.0	65.0	nd	nd	nd	0.0	15.1	--	--	--
9/19/05	262	23.0	12.0	17.5	91.0	73.0	nd	nd	nd	0.0	15.3	--	--	--
9/20/05	263	24.0	18.0	21.0	90.0	53.0	nd	nd	nd	0.0	11.2	--	--	--
9/21/05	264	23.0	10.0	16.5	89.0	62.0	nd	nd	nd	0.0	16.3	--	--	--
9/22/05	265	22.0	15.0	18.5	100.0	77.0	nd	nd	nd	2.0	11.9	--	--	--
9/23/05	266	21.0	15.0	18.0	100.0	32.0	nd	nd	nd	0.0	10.9	--	--	--
9/24/05	267	19.0	10.0	14.5	77.0	58.0	nd	nd	nd	12.0	13.2	--	--	--
9/25/05	268	21.0	15.0	18.0	100.0	80.0	nd	nd	nd	37.0	10.6	--	--	--
9/26/05	269	20.0	18.0	19.0	100.0	74.0	nd	nd	nd	10.0	6.1	--	--	--
9/27/05	270	18.0	7.0	12.5	92.0	62.0	nd	nd	nd	0.0	14.1	--	--	--
9/28/05	271	21.0	8.0	14.5	100.0	75.0	nd	nd	nd	13.0	15.2	--	--	--
9/29/05	272	18.0	12.0	15.0	95.0	31.0	nd	nd	nd	3.0	10.2	--	--	--
9/30/05	273	16.0	3.5	9.8	93.0	61.0	nd	nd	nd	0.0	14.6	--	--	--
10/1/05	274	19.0	4.0	11.5	100.0	69.0	nd	nd	nd	0.0	15.8	--	--	--
10/2/05	275	20.0	8.0	14.0	99.0	63.0	nd	nd	nd	0.0	13.9	--	--	--
10/3/05	276	22.0	11.0	16.5	99.0	78.0	nd	nd	nd	0.0	13.2	--	--	--
10/4/05	277	22.0	14.0	18.0	100.0	75.0	nd	nd	nd	0.0	11.1	--	--	--
10/5/05	278	21.0	13.0	17.0	100.0	77.0	nd	nd	nd	0.0	11.0	--	--	--
10/6/05	279	23.0	12.0	17.5	100.0	90.0	nd	nd	nd	0.0	12.7	--	--	--
10/7/05	280	13.0	10.0	11.5	99.0	81.0	nd	nd	nd	45.0	6.6	--	--	--
10/8/05	281	13.0	6.0	9.5	82.0	49.0	nd	nd	nd	0.0	9.9	--	--	--
10/9/05	282	15.0	5.0	10.0	81.0	62.0	nd	nd	nd	0.0	11.7	--	--	--
10/10/05	283	14.5	9.0	11.8	92.0	80.0	nd	nd	nd	0.0	8.6	--	--	--
10/11/05	284	17.0	11.0	14.0	90.0	76.0	nd	nd	nd	0.0	8.9	--	--	--
10/12/05	285	15.0	10.0	12.5	100.0	70.0	nd	nd	nd	0.0	8.0	--	--	--

Date	Day	Air Temp °C (Max Daily)	Air Temp °C (Min Daily)	Air Temp °C (Avg Daily)	Relative Humidity (Max Daily)	Relative Humidity (Min Daily)	Relative Humidity (Avg Daily)	Wind Speed (m/s)	Wind Direction (Degrees)	Precipitation (mm/Day)	Solar Radiation (MJ/m^2/day)	Soil Moisture Content % (0.73m bgs)	Soil Moisture Content % (0.39m bgs)	Soil Moisture Content % (0.14m bgs)
10/13/05	286	14.5	10.0	12.3	100.0	92.0	nd	nd	nd	0.0	7.5	--	--	--
10/14/05	287	15.0	12.0	13.5	100.0	81.0	nd	nd	nd	9.0	6.0	--	--	--
10/15/05	288	18.0	12.0	15.0	100.0	50.0	nd	nd	nd	5.0	8.4	--	--	--
10/16/05	289	14.0	8.0	11.0	92.0	57.0	nd	nd	nd	0.0	8.3	--	--	--
10/17/05	290	15.0	5.0	10.0	86.0	57.0	nd	nd	nd	0.0	10.6	--	--	--
10/18/05	291	14.5	6.5	10.5	94.0	60.0	nd	nd	nd	0.0	9.4	--	--	--
10/19/05	292	17.5	6.5	12.0	91.0	59.0	nd	nd	nd	0.0	10.9	--	--	--
10/20/05	293	11.0	-0.5	5.3	88.0	70.0	nd	nd	nd	0.0	11.0	--	--	--
10/21/05	294	10.0	-0.5	4.8	92.0	61.0	nd	nd	nd	0.0	10.4	--	--	--
10/22/05	295	7.0	0.0	3.5	90.0	70.0	nd	nd	nd	15.2	8.3	--	--	--
10/23/05	296	7.5	3.0	5.3	94.0	86.0	nd	nd	nd	5.0	6.6	--	--	--
10/24/05	297	8.5	4.0	6.3	93.0	75.0	nd	nd	nd	3.2	6.5	--	--	--
10/25/05	298	8.0	5.0	6.5	89.0	77.0	nd	nd	nd	1.0	5.3	--	--	--
10/26/05	299	7.0	3.5	5.3	86.0	53.0	nd	nd	nd	0.2	5.6	--	--	--
10/27/05	300	8.0	2.5	5.3	89.0	57.0	nd	nd	nd	0.4	6.9	--	--	--
10/28/05	301	8.0	-1.0	3.5	95.0	59.0	nd	nd	nd	0.0	8.8	--	--	--
10/29/05	302	10.5	-1.0	4.8	86.0	56.0	nd	nd	nd	0.0	9.8	--	--	--
10/30/05	303	13.0	1.5	7.3	86.0	70.0	nd	nd	nd	0.0	9.7	--	--	--
10/31/05	304	11.0	1.5	6.3	100.0	89.0	nd	nd	nd	0.0	8.7	--	--	--
11/1/05	305	12.0	8.0	10.0	100.0	74.0	nd	nd	nd	4.0	5.6	--	--	--
11/2/05	306	12.0	1.0	6.5	98.0	68.0	nd	nd	nd	0.0	9.1	--	--	--
11/3/05	307	15.0	2.0	8.5	99.0	72.0	nd	nd	nd	0.0	9.8	--	--	--
11/4/05	308	14.0	4.0	9.0	88.0	75.0	nd	nd	nd	0.0	8.5	--	--	--
11/5/05	309	16.0	5.0	10.5	100.0	76.0	nd	nd	nd	11.0	8.8	--	--	--
11/6/05	310	15.0	7.0	11.0	99.0	72.0	nd	nd	nd	4.2	7.4	--	--	--
11/7/05	311	11.0	6.0	8.5	86.0	62.0	nd	nd	nd	0.0	5.8	--	--	--
11/8/05	312	12.0	4.0	8.0	95.0	60.0	nd	nd	nd	0.0	7.2	--	--	--
11/9/05	313	12.0	1.0	6.5	100.0	66.0	nd	nd	nd	23.0	8.3	--	--	--
11/10/05	314	6.0	2.0	4.0	74.0	50.0	nd	nd	nd	0.0	5.0	--	--	--
11/11/05	315	8.0	0.0	4.0	94.0	53.0	nd	nd	nd	0.0	7.0	--	--	--
11/12/05	316	12.0	-2.0	5.0	100.0	60.0	nd	nd	nd	0.0	9.1	--	--	--
11/13/05	317	13.0	0.0	6.5	84.0	55.0	nd	nd	nd	0.0	8.7	--	--	--
11/14/05	318	10.0	4.0	7.0	81.0	54.0	nd	nd	nd	4.0	5.8	--	--	--
11/15/05	319	14.0	2.0	8.0	100.0	68.0	nd	nd	nd	21.0	8.1	--	--	--
11/16/05	320	10.0	5.0	7.5	99.0	69.0	nd	nd	nd	0.0	5.2	--	--	--
11/17/05	321	2.0	0.0	1.0	84.0	62.0	nd	nd	nd	0.0	3.2	--	--	--
11/18/05	322	2.0	-7.0	-2.5	94.0	59.0	nd	nd	nd	2.0	6.8	--	--	--
11/19/05	323	7.0	-4.0	1.5	99.0	67.0	nd	nd	nd	0.0	7.5	--	--	--
11/20/05	324	9.0	-1.0	4.0	93.0	72.0	nd	nd	nd	0.0	7.0	--	--	--
11/21/05	325	8.5	5.0	6.8	94.0	75.0	nd	nd	nd	0.0	4.1	--	--	--
11/22/05	326	3.0	-2.0	0.5	92.0	58.0	nd	nd	nd	0.0	4.9	--	--	--
11/23/05	327	1.5	-10.0	-4.3	83.0	50.0	nd	nd	nd	6.0	7.3	--	--	--
11/24/05	328	-3.0	-7.0	-5.0	100.0	46.0	nd	nd	nd	0.0	4.3	--	--	--
11/25/05	329	0.0	-13.0	-6.5	95.0	65.0	nd	nd	nd	0.0	7.6	--	--	--
11/26/05	330	1.5	-6.0	-2.3	93.0	70.0	nd	nd	nd	9.0	5.8	--	--	--
11/27/05	331	8.0	-5.0	1.5	91.0	75.0	nd	nd	nd	0.0	7.5	--	--	--
11/28/05	332	14.5	-1.5	6.5	93.0	82.0	nd	nd	nd	12.0	8.3	--	--	--
11/29/05	333	10.0	7.0	8.5	100.0	81.0	nd	nd	nd	23.8	3.5	--	--	--
11/30/05	334	3.5	1.5	2.5	84.0	68.0	nd	nd	nd	0.0	2.9	--	--	--
12/1/05	335	4.0	0.5	2.3	87.0	74.0	nd	nd	nd	1.0	3.8	--	--	--
12/2/05	336	1.5	-2.0	-0.3	99.0	56.0	nd	nd	nd	1.0	3.7	--	--	--
12/3/05	337	-1.0	-8.0	-4.5	84.0	55.0	nd	nd	nd	0.0	5.3	--	--	--
12/4/05	338	1.0	-5.0	-2.0	82.0	61.0	nd	nd	nd	0.0	4.8	--	--	--
12/5/05	339	-1.0	-5.0	-3.0	67.0	51.0	nd	nd	nd	0.0	3.9	--	--	--
12/6/05	340	-3.0	-11.0	-7.0	85.0	47.0	nd	nd	nd	0.0	5.5	--	--	--
12/7/05	341	-4.0	-10.0	-7.0	80.0	40.0	nd	nd	nd	0.0	4.8	--	--	--
12/8/05	342	0.0	-12.0	-6.0	84.0	49.0	nd	nd	nd	10.0	6.7	--	--	--
12/9/05	343	1.0	-5.5	-2.3	100.0	67.0	nd	nd	nd	0.0	4.9	--	--	--
12/10/05	344	1.0	-3.0	-1.0	84.0	71.0	nd	nd	nd	0.0	3.8	--	--	--
12/11/05	345	0.0	-1.0	-0.5	93.0	69.0	nd	nd	nd	11.0	1.9	--	--	--
12/12/05	346	-7.0	-13.0	-10.0	77.0	43.0	nd	nd	nd	0.0	4.7	--	--	--
12/13/05	347	-5.0	-18.0	-11.5	71.0	45.0	nd	nd	nd	0.0	6.8	--	--	--
12/14/05	348	-5.0	-15.0	-10.0	78.0	51.0	nd	nd	nd	0.0	6.0	--	--	--
12/15/05	349	-0.5	-12.0	-6.3	100.0	70.0	nd	nd	nd	25.0	6.4	--	--	--
12/16/05	350	3.0	-4.0	-0.5	100.0	69.0	nd	nd	nd	0.0	5.0	--	--	--
12/17/05	351	0.0	-3.0	-1.5	77.0	65.0	nd	nd	nd	0.0	3.3	--	--	--
12/18/05	352	-3.0	-5.0	-4.0	76.0	66.0	nd	nd	nd	0.0	2.7	--	--	--
12/19/05	353	-2.0	-9.0	-5.5	82.0	63.0	nd	nd	nd	0.0	5.0	--	--	--
12/20/05	354	-2.0	-10.0	-6.0	86.0	60.0	nd	nd	nd	0.0	5.3	--	--	--
12/21/05	355	-1.0	-17.0	-9.0	88.0	67.0	nd	nd	nd	0.0	7.5	--	--	--
12/22/05	356	4.0	-9.0	-2.5	86.0	72.0	nd	nd	nd	0.0	6.8	--	--	--
12/23/05	357	5.5	-1.0	2.3	94.0	80.0	nd	nd	nd	16.3	4.8	--	--	--
12/24/05	358	4.5	0.5	2.5	99.0	86.0	nd	nd	nd	0.0	3.8	--	--	--
12/25/05	359	5.0	1.5	3.3	94.0	68.0	nd	nd	nd	6.3	3.5	--	--	--
12/26/05	360	2.5	1.0	1.8	98.0	80.0	nd	nd	nd	0.0	2.3	--	--	--
12/27/05	361	3.0	-5.0	-1.0	89.0	75.0	nd	nd	nd	0.2	5.4	--	--	--
12/28/05	362	3.5	-1.0	1.3	99.0	82.0	nd	nd	nd	5.9	4.0	--	--	--
12/29/05	363	2.0	0.5	1.3	100.0	82.0	nd	nd	nd	0.0	2.3	--	--	--
12/30/05	364	-3.0	-7.0	-5.0	84.0	77.0	nd	nd	nd	0.0	3.8	--	--	--
12/31/05	365	-6.0	-10.0	-8.0	90.0	76.0	nd	nd	nd	5.0	3.8	--	--	--
1/1/06	1	1.0	-9.0	-4.0	95.0	81.0	nd	nd	nd	0.0	6.1	--	--	--
1/2/06	2	3.0	-5.0	-1.0	100.0	82.0	nd	nd	nd	0.0	5.5	--	--	--
1/3/06	3	3.0	-1.0	1.0	86.0	71.0	nd	nd	nd	0.0	3.9	--	--	--
1/4/06	4	5.0	-1.0	2.0	100.0	81.0	nd	nd	nd	11.0	4.8	--	--	--
1/5/06	5	3.0	1.0	2.0	100.0	71.0	nd	nd	nd	1.0	2.8	--	--	--
1/6/06	6	-5.0	-8.0	-6.5	79.0	59.0	nd	nd	nd	0.0	3.4	--	--	--
1/7/06	7	0.0	-10.0	-5.0	99.0	77.0	nd	nd	nd	2.0	6.3	--	--	--
1/8/06	8	3.0	-8.0	-2.5	100.0	83.0	nd	nd	nd	3.0	6.7	--	--	--
1/9/06	9	5.0	-1.0	2.0	90.0	70.0	nd	nd	nd	0.0	5.0	--	--	--
1/10/06	10	5.0	0.0	2.5	88.0	56.0	nd	nd	nd	2.0	4.6	--	--	--
1/11/06	11	8.0	-2.0	3.0	100.0	80.0	nd	nd	nd	6.0	6.5	--	--	--
1/12/06	12	6.0	3.0	4.5	100.0	82.0	nd	nd	nd	0.0	3.6	--	--	--
1/13/06	13	10.0	-1.0	4.5	100.0	64.0	nd	nd	nd	10.0	6.9	--	--	--
1/14/06	14	3.0	-2.0	0.5	100.0	57.0	nd	nd	nd	0.0	4.7	--	--	--
1/15/06	15	-10.0	-14.0	-12.0	67.0	43.0	nd	nd	nd	0.0	4.3	--	--	--
1/16/06	16	-5.5	-16.0	-10.8	70.0	56.0	nd	nd	nd	0.0	7.0	--	--	--
1/17/06	17	5.0	-8.0	-1.5	100.0	61.0	nd	nd	nd	35.0	7.8	--	--	--
1/18/06	18	5.0	-2.0	1.5	100.0	66.0	nd	nd	nd	0.0	5.8	--	--	--
1/19/06	19	7.5	-3.0	2.3	85.0	67.0	nd	nd	nd	0.0	7.2	--	--	--

Date	Day	Air Temp °C (Max Daily)	Air Temp °C (Min Daily)	Air Temp °C (Avg Daily)	Relative Humidity (Max Daily)	Relative Humidity (Min Daily)	Relative Humidity (Avg Daily)	Wind Speed (m/s)	Wind Direction (Degrees)	Precipitation (mm/Day)	Solar Radiation (MJ/m^2/day)	Soil Moisture Content % (0.73m bgs)	Soil Moisture Content % (0.39m bgs)	Soil Moisture Content % (0.14m bgs)
1/20/06	20	10.0	0.5	5.3	88.0	70.0	nd	nd	nd	10.0	6.9	--	--	--
1/21/06	21	2.0	0.0	1.0	100.0	66.0	nd	nd	nd	0.0	3.2	--	--	--
1/22/06	22	2.5	-7.0	-2.3	92.0	71.0	nd	nd	nd	0.0	7.0	--	--	--
1/23/06	23	5.0	-1.0	2.0	86.0	54.0	nd	nd	nd	0.0	5.7	--	--	--
1/24/06	24	5.0	-3.0	1.0	94.0	65.0	nd	nd	nd	5.0	6.6	--	--	--
1/25/06	25	3.5	-2.5	0.5	98.0	71.0	nd	nd	nd	0.0	5.8	--	--	--
1/26/06	26	-6.0	-15.0	-10.5	75.0	54.0	nd	nd	nd	0.0	7.2	--	--	--
1/27/06	27	5.0	-10.0	-2.5	87.0	75.0	nd	nd	nd	0.0	9.4	--	--	--
1/28/06	28	6.0	2.0	4.0	90.0	69.0	nd	nd	nd	1.6	4.9	--	--	--
1/29/06	29	5.0	-2.0	1.5	100.0	72.0	nd	nd	nd	14.0	6.6	--	--	--
1/30/06	30	6.5	1.0	3.8	100.0	77.0	nd	nd	nd	0.0	5.9	--	--	--
1/31/06	31	4.0	1.5	2.8	100.0	64.0	nd	nd	nd	0.0	4.0	--	--	--
2/1/06	32	3.0	-2.5	0.3	85.0	75.0	nd	nd	nd	0.0	6.0	--	--	--
2/2/06	33	7.0	-0.5	3.3	94.0	65.0	nd	nd	nd	4.0	7.1	--	--	--
2/3/06	34	5.0	3.0	4.0	100.0	81.0	nd	nd	nd	2.0	3.7	--	--	--
2/4/06	35	6.0	-2.0	2.0	99.0	72.0	nd	nd	nd	22.0	7.5	--	--	--
2/5/06	36	3.0	0.0	1.5	100.0	70.0	nd	nd	nd	0.0	4.7	--	--	--
2/6/06	37	-2.0	-7.0	-4.5	87.0	67.0	nd	nd	nd	0.0	6.1	--	--	--
2/7/06	38	-2.0	-8.0	-5.0	77.0	58.0	nd	nd	nd	0.0	6.8	--	--	--
2/8/06	39	-4.5	-11.0	-7.8	86.0	53.0	nd	nd	nd	0.0	7.1	--	--	--
2/9/06	40	-6.0	-12.5	-9.3	85.0	44.0	nd	nd	nd	0.0	7.2	--	--	--
2/10/06	41	-5.0	-15.0	-10.0	86.0	67.0	nd	nd	nd	1.0	9.1	--	--	--
2/11/06	42	-2.0	-12.0	-7.0	86.0	62.0	nd	nd	nd	0.0	9.2	--	--	--
2/12/06	43	-3.0	-14.0	-8.5	64.0	33.0	nd	nd	nd	0.0	9.8	--	--	--
2/13/06	44	0.0	-8.0	-4.0	99.0	53.0	nd	nd	nd	0.0	8.5	--	--	--
2/14/06	45	5.0	-5.0	0.0	94.0	71.0	nd	nd	nd	0.0	9.6	--	--	--
2/15/06	46	6.0	-4.0	1.0	98.0	69.0	nd	nd	nd	4.0	9.7	--	--	--
2/16/06	47	7.0	-3.0	2.0	100.0	60.0	nd	nd	nd	15.0	9.8	--	--	--
2/17/06	48	-2.0	-5.0	-3.5	100.0	57.0	nd	nd	nd	2.0	5.4	--	--	--
2/18/06	49	-7.0	-14.0	-10.5	87.0	43.0	nd	nd	nd	0.0	8.4	--	--	--
2/19/06	50	-6.0	-13.5	-9.8	71.0	56.0	nd	nd	nd	0.0	8.8	--	--	--
2/20/06	51	-2.0	-8.0	-5.0	72.0	57.0	nd	nd	nd	0.0	8.0	--	--	--
2/21/06	52	3.0	-7.0	-2.0	85.0	46.0	nd	nd	nd	0.0	10.5	--	--	--
2/22/06	53	4.0	-8.0	-2.0	99.0	70.0	nd	nd	nd	0.0	11.6	--	--	--
2/23/06	54	4.0	-5.0	-0.5	99.0	61.0	nd	nd	nd	0.0	10.2	--	--	--
2/24/06	55	-1.0	-8.0	-4.5	72.0	30.0	nd	nd	nd	2.0	9.1	--	--	--
2/25/06	56	-1.0	-8.0	-4.5	98.0	59.0	nd	nd	nd	3.0	9.2	--	--	--
2/26/06	57	-7.5	-15.0	-11.3	91.0	39.0	nd	nd	nd	0.0	9.7	--	--	--
2/27/06	58	-5.0	-20.0	-12.5	84.0	40.0	nd	nd	nd	0.0	13.8	--	--	--
2/28/06	59	-5.5	-16.5	-11.0	92.0	49.0	nd	nd	nd	0.0	12.0	--	--	--
3/1/06	60	-2.0	-16.5	-9.3	78.0	39.0	nd	nd	nd	0.0	13.9	--	--	--
3/2/06	61	-0.5	-12.0	-6.3	87.0	45.0	nd	nd	nd	0.0	12.6	--	--	--
3/3/06	62	-2.0	-12.0	-7.0	64.0	38.0	nd	nd	nd	0.0	11.9	--	--	--
3/4/06	63	1.0	-8.0	-3.5	62.0	40.0	nd	nd	nd	0.0	11.4	--	--	--
3/5/06	64	3.0	-5.0	-1.0	57.0	30.0	nd	nd	nd	0.0	10.9	--	--	--
3/6/06	65	2.0	-5.0	-1.5	72.0	36.0	nd	nd	nd	0.0	10.3	--	--	--
3/7/06	66	2.0	-8.0	-3.0	66.0	33.0	nd	nd	nd	0.0	12.4	--	--	--
3/8/06	67	6.0	-8.0	-1.0	80.0	63.0	nd	nd	nd	10.0	14.9	--	--	--
3/9/06	68	10.0	0.0	5.0	100.0	65.0	nd	nd	nd	8.2	12.7	--	--	--
3/10/06	69	10.0	2.0	6.0	100.0	68.0	nd	nd	nd	2.0	11.5	--	--	--
3/11/06	70	9.0	-4.0	2.5	96.0	60.0	nd	nd	nd	0.0	14.8	--	--	--
3/12/06	71	12.0	3.0	7.5	99.0	62.0	nd	nd	nd	8.0	12.5	--	--	--
3/13/06	72	10.0	2.0	6.0	100.0	63.0	nd	nd	nd	14.3	11.9	--	--	--
3/14/06	73	3.0	0.0	1.5	100.0	50.0	nd	nd	nd	2.0	7.4	--	--	--
3/15/06	74	2.5	-3.0	-0.3	98.0	39.0	nd	nd	nd	0.0	10.1	--	--	--
3/16/06	75	3.0	-5.0	-1.0	70.0	44.0	nd	nd	nd	0.0	12.3	--	--	--
3/17/06	76	2.0	-8.0	-3.0	63.0	30.0	nd	nd	nd	0.0	13.9	--	--	--
3/18/06	77	-2.0	-8.0	-5.0	74.0	34.0	nd	nd	nd	0.0	10.9	--	--	--
3/19/06	78	1.5	-7.0	-2.8	88.0	46.0	nd	nd	nd	0.0	13.1	--	--	--
3/20/06	79	0.0	-7.0	-3.5	65.0	37.0	nd	nd	nd	0.0	12.0	--	--	--
3/21/06	80	3.0	-9.0	-3.0	73.0	43.0	nd	nd	nd	0.0	15.9	--	--	--
3/22/06	81	2.0	-4.0	-1.0	87.0	53.0	nd	nd	nd	0.0	11.4	--	--	--
3/23/06	82	4.0	-5.0	-0.5	82.0	66.0	nd	nd	nd	0.0	14.0	--	--	--
3/24/06	83	5.5	-5.5	0.0	87.0	67.0	nd	nd	nd	2.0	15.7	--	--	--
3/25/06	84	6.0	0.0	3.0	98.0	77.0	nd	nd	nd	0.0	11.7	--	--	--
3/26/06	85	9.0	1.0	5.0	90.0	32.0	nd	nd	nd	0.0	13.6	--	--	--
3/27/06	86	8.0	-2.0	3.0	79.0	37.0	nd	nd	nd	0.0	15.4	--	--	--
3/28/06	87	9.0	-4.0	2.5	83.0	45.0	nd	nd	nd	0.0	17.7	--	--	--
3/29/06	88	9.0	-4.0	2.5	81.0	61.0	nd	nd	nd	0.0	17.9	--	--	--
3/30/06	89	13.0	-3.0	5.0	86.0	68.0	nd	nd	nd	0.0	20.0	--	--	--
3/31/06	90	17.0	0.0	8.5	100.0	61.0	nd	nd	nd	8.0	20.8	--	--	--
4/1/06	91	10.0	6.0	8.0	100.0	73.0	nd	nd	nd	0.0	10.2	--	--	--
4/2/06	92	8.0	-1.5	3.3	80.0	39.0	nd	nd	nd	1.0	15.8	--	--	--
4/3/06	93	15.0	3.0	9.0	98.0	46.0	nd	nd	nd	25.0	18.0	--	--	--
4/4/06	94	7.0	0.0	3.5	90.0	40.0	nd	nd	nd	0.0	13.8	--	--	--
4/5/06	95	6.0	-4.0	1.0	89.0	62.0	nd	nd	nd	0.0	16.7	--	--	--
4/6/06	96	8.0	0.0	4.0	88.0	65.0	nd	nd	nd	0.0	15.0	--	--	--
4/7/06	97	8.0	3.0	5.5	91.0	75.0	nd	nd	nd	9.8	12.0	--	--	--
4/8/06	98	6.0	-5.0	0.5	74.0	42.0	nd	nd	nd	0.0	17.9	--	--	--
4/9/06	99	6.5	-4.0	1.3	80.0	50.0	nd	nd	nd	0.0	17.7	--	--	--
4/10/06	100	10.0	-3.0	3.5	86.0	65.0	nd	nd	nd	0.0	19.8	--	--	--
4/11/06	101	13.0	-1.0	6.0	83.0	52.0	nd	nd	nd	0.0	20.7	--	--	--
4/12/06	102	12.0	3.0	7.5	95.0	43.0	nd	nd	nd	7.0	16.7	--	--	--
4/13/06	103	15.0	6.0	10.5	95.0	75.0	nd	nd	nd	1.0	16.8	--	--	--
4/14/06	104	14.5	4.5	9.5	100.0	83.0	nd	nd	nd	5.8	17.9	--	--	--
4/15/06	105	13.0	6.0	9.5	100.0	52.0	nd	nd	nd	0.0	15.1	--	--	--
4/16/06	106	12.5	3.0	7.8	78.0	48.0	nd	nd	nd	0.0	17.7	--	--	--
4/17/06	107	12.5	3.0	7.8	89.0	54.0	nd	nd	nd	0.0	17.8	--	--	--
4/18/06	108	14.0	5.0	9.5	88.0	53.0	nd	nd	nd	0.0	17.5	--	--	--
4/19/06	109	16.5	6.5	11.5	81.0	43.0	nd	nd	nd	0.0	18.5	--	--	--
4/20/06	110	19.0	6.0	12.5	77.0	24.0	nd	nd	nd	0.0	21.3	--	--	--
4/21/06	111	21.0	4.0	12.5	74.0	32.0	nd	nd	nd	15.0	24.5	--	--	--
4/22/06	112	7.0	5.0	6.0	98.0	76.0	nd	nd	nd	4.0	8.4	--	--	--
4/23/06	113	7.5	4.5	6.0	100.0	87.0	nd	nd	nd	18.0	10.4	--	--	--
4/24/06	114	13.5	3.0	8.3	99.0	63.0	nd	nd	nd	2.0	19.6	--	--	--
4/25/06	115	9.5	4.0	6.8	96.0	34.0	nd	nd	nd	0.0	14.3	--	--	--
4/26/06	116	10.0	-2.5	3.8	77.0	61.0	nd	nd	nd	0.0	21.6	--	--	--
4/27/06	117	10.5	1.0	5.8	79.0	41.0	nd	nd	nd	0.0	19.0	--	--	--
4/28/06	118	13.0	1.0	7.0	71.0	39.0	nd	nd	nd	0.0	21.4	--	--	--

Date	Day	Air Temp °C (Max Daily)	Air Temp °C (Min Daily)	Air Temp °C (Avg Daily)	Relative Humidity (Max Daily)	Relative Humidity (Min Daily)	Relative Humidity (Avg Daily)	Wind Speed (m/s)	Wind Direction (Degrees)	Precipitation (mm/Day)	Solar Radiation (MJ/m^2/day)	Soil Moisture Content % (0.73m bgs)	Soil Moisture Content % (0.39m bgs)	Soil Moisture Content % (0.14m bgs)
4/29/06	119	15.0	-2.0	6.5	79.0	24.0	nd	nd	nd	0.0	25.6	--	--	--
4/30/06	120	19.0	1.0	10.0	76.0	22.0	nd	nd	nd	0.0	26.5	--	--	--
5/1/06	121	21.0	8.0	14.5	66.0	21.0	nd	nd	nd	0.0	22.7	--	--	--
5/2/06	122	18.0	8.0	13.0	73.0	30.0	nd	nd	nd	0.0	20.0	--	--	--
5/3/06	123	13.0	3.0	8.0	89.0	77.0	nd	nd	nd	0.0	20.1	--	--	--
5/4/06	124	20.0	5.0	12.5	88.0	35.0	nd	nd	nd	0.0	24.7	--	--	--
5/5/06	125	16.5	6.0	11.3	78.0	48.0	nd	nd	nd	4.0	20.8	--	--	--
5/6/06	126	12.5	4.0	8.3	88.0	32.0	nd	nd	nd	0.0	18.8	--	--	--
5/7/06	127	11.0	-0.5	5.3	82.0	54.0	nd	nd	nd	0.0	21.9	--	--	--
5/8/06	128	17.0	2.0	9.5	83.0	52.0	nd	nd	nd	0.0	25.2	--	--	--
5/9/06	129	20.0	5.0	12.5	86.0	37.0	nd	nd	nd	0.0	25.3	--	--	--
5/10/06	130	21.0	7.0	14.0	88.0	39.0	nd	nd	nd	0.0	24.5	--	--	--
5/11/06	131	16.0	12.0	14.0	97.0	57.0	nd	nd	nd	36.0	13.2	--	--	--
5/12/06	132	18.0	9.0	13.5	100.0	74.0	nd	nd	nd	4.0	19.8	--	--	--
5/13/06	133	19.0	9.0	14.0	100.0	80.0	nd	nd	nd	0.0	21.0	--	--	--
5/14/06	134	17.0	11.0	14.0	84.0	73.0	nd	nd	nd	0.0	16.3	--	--	--
5/15/06	135	15.0	11.0	13.0	95.0	75.0	nd	nd	nd	7.0	13.4	--	--	--
5/16/06	136	14.0	9.0	11.5	100.0	92.0	nd	nd	nd	0.0	15.0	--	--	--
5/17/06	137	17.0	9.0	13.0	100.0	85.0	nd	nd	nd	0.0	19.0	--	--	--
5/18/06	138	17.0	8.0	12.5	100.0	88.0	nd	nd	nd	2.0	20.3	--	--	--
5/19/06	139	14.0	5.0	9.5	100.0	76.0	nd	nd	nd	0.0	20.3	--	--	--
5/20/06	140	13.0	7.0	10.0	90.0	54.0	nd	nd	nd	2.0	16.7	--	--	--
5/21/06	141	12.0	5.0	8.5	90.0	58.0	nd	nd	nd	4.8	18.0	--	--	--
5/22/06	142	10.0	3.0	6.5	81.0	49.0	nd	nd	nd	0.0	18.1	--	--	--
5/23/06	143	18.5	3.0	10.8	76.0	40.0	nd	nd	nd	0.0	27.0	--	--	--
5/24/06	144	19.0	4.5	11.8	86.0	41.0	nd	nd	nd	0.0	26.2	--	--	--
5/25/06	145	18.0	9.0	13.5	88.0	60.0	nd	nd	nd	1.0	20.7	--	--	--
5/26/06	146	20.0	11.0	15.5	100.0	70.0	nd	nd	nd	3.0	20.7	--	--	--
5/27/06	147	21.5	10.5	16.0	100.0	66.0	nd	nd	nd	0.0	23.0	--	--	--
5/28/06	148	21.0	9.5	15.3	98.0	70.0	nd	nd	nd	0.0	23.6	--	--	--
5/29/06	149	27.5	11.0	19.3	94.0	66.0	nd	nd	nd	0.0	28.3	--	--	--
5/30/06	150	28.5	17.0	22.8	100.0	78.0	nd	nd	nd	0.0	23.7	--	--	--
5/31/06	151	26.5	17.0	21.8	99.0	65.0	nd	nd	nd	2.0	21.5	--	--	--
6/1/06	152	21.0	16.0	18.5	100.0	80.0	nd	nd	nd	1.6	15.7	--	--	--
6/2/06	153	21.0	14.0	17.5	100.0	63.0	nd	nd	nd	3.5	18.6	--	--	--
6/3/06	154	19.0	15.0	17.0	96.0	79.0	nd	nd	nd	16.0	14.1	--	--	--
6/4/06	155	23.0	13.5	18.3	92.0	34.0	nd	nd	nd	0.0	21.7	--	--	--
6/5/06	156	25.0	11.0	18.0	89.0	52.0	nd	nd	nd	0.0	26.4	--	--	--
6/6/06	157	24.0	12.0	18.0	87.0	38.0	nd	nd	nd	0.0	24.5	--	--	--
6/7/06	158	25.5	11.0	18.3	80.0	59.0	nd	nd	nd	0.0	26.9	--	--	--
6/8/06	159	22.0	16.0	19.0	94.0	60.0	nd	nd	nd	0.0	17.3	--	--	--
6/9/06	160	16.5	14.0	15.3	94.0	72.0	nd	nd	nd	6.0	11.2	--	--	--
6/10/06	161	17.0	8.5	12.8	78.0	40.0	nd	nd	nd	0.0	20.7	--	--	--
6/11/06	162	18.0	7.0	12.5	77.0	60.0	nd	nd	nd	0.0	23.5	--	--	--
6/12/06	163	20.0	10.5	15.3	87.0	58.0	nd	nd	nd	0.0	21.9	--	--	--
6/13/06	164	18.0	12.5	15.3	89.0	63.0	nd	nd	nd	0.0	16.7	--	--	--
6/14/06	165	23.0	12.0	17.5	89.0	51.0	nd	nd	nd	0.0	23.6	--	--	--
6/15/06	166	25.0	13.0	19.0	77.0	33.0	nd	nd	nd	0.0	24.7	--	--	--
6/16/06	167	25.0	10.0	17.5	87.0	55.0	nd	nd	nd	0.0	27.6	--	--	--
6/17/06	168	26.0	15.0	20.5	81.0	55.0	nd	nd	nd	0.0	23.6	--	--	--
6/18/06	169	26.0	16.0	21.0	89.0	71.0	nd	nd	nd	0.0	22.5	--	--	--
6/19/06	170	26.0	15.0	20.5	100.0	78.0	nd	nd	nd	3.4	23.6	--	--	--
6/20/06	171	24.0	11.0	17.5	100.0	46.0	nd	nd	nd	0.0	25.7	--	--	--
6/21/06	172	21.0	11.0	16.0	85.0	72.0	nd	nd	nd	0.0	22.5	--	--	--
6/22/06	173	26.0	15.0	20.5	91.0	42.0	nd	nd	nd	0.0	23.6	--	--	--
6/23/06	174	23.0	15.0	19.0	88.0	71.0	nd	nd	nd	0.0	20.1	--	--	--
6/24/06	175	23.0	13.5	18.3	90.0	63.0	nd	nd	nd	0.0	21.9	--	--	--
6/25/06	176	26.5	14.0	20.3	88.0	49.0	nd	nd	nd	0.0	25.2	--	--	--
6/26/06	177	24.0	17.0	20.5	92.0	65.0	nd	nd	nd	1.0	18.8	--	--	--
6/27/06	178	21.0	19.0	20.0	100.0	89.0	nd	nd	nd	18.0	10.1	--	--	--
6/28/06	179	26.0	18.0	22.0	100.0	82.0	nd	nd	nd	0.0	20.1	--	--	--
6/29/06	180	23.5	18.0	20.8	95.0	64.0	nd	nd	nd	0.0	16.6	--	--	--
6/30/06	181	26.0	15.0	20.5	90.0	31.0	nd	nd	nd	0.0	23.5	--	--	--
7/1/06	182	27.0	13.5	20.3	94.0	70.0	nd	nd	nd	3.2	26.0	--	--	--
7/2/06	183	28.5	19.0	23.8	86.0	46.0	nd	nd	nd	0.0	21.8	--	--	--
7/3/06	184	28.0	13.0	20.5	100.0	79.0	nd	nd	nd	30.4	27.4	--	--	--
7/4/06	185	25.0	17.0	21.0	100.0	46.0	nd	nd	nd	12.0	20.0	--	--	--
7/5/06	186	20.5	12.0	16.3	88.0	46.0	nd	nd	nd	0.0	20.5	--	--	--
7/6/06	187	22.0	10.0	16.0	93.0	74.0	nd	nd	nd	0.0	24.4	--	--	--
7/7/06	188	26.0	11.0	18.5	88.0	51.0	nd	nd	nd	0.0	27.2	--	--	--
7/8/06	189	26.0	12.0	19.0	92.0	74.0	nd	nd	nd	0.0	26.2	--	--	--
7/9/06	190	26.0	15.5	20.8	95.0	69.0	nd	nd	nd	1.6	22.7	--	--	--
7/10/06	191	21.5	16.0	18.8	100.0	77.0	nd	nd	nd	25.2	16.4	--	--	--
7/11/06	192	25.5	17.0	21.3	100.0	67.0	nd	nd	nd	3.8	20.3	--	--	--
7/12/06	193	22.0	18.0	20.0	96.0	78.0	nd	nd	nd	6.6	13.9	--	--	--
7/13/06	194	29.0	14.5	21.8	96.0	76.0	nd	nd	nd	0.0	26.4	--	--	--
7/14/06	195	29.0	16.5	22.8	93.0	74.0	nd	nd	nd	1.5	24.5	--	--	--
7/15/06	196	28.0	19.0	23.5	96.0	44.0	nd	nd	nd	0.0	20.7	--	--	--
7/16/06	197	29.8	20.0	24.9	89.0	70.0	nd	nd	nd	0.0	21.5	--	--	--
7/17/06	198	31.5	21.0	26.3	91.0	67.0	nd	nd	nd	3.6	22.3	--	--	--
7/18/06	199	28.0	18.0	23.0	89.0	64.0	nd	nd	nd	0.0	21.7	--	--	--
7/19/06	200	27.0	13.0	20.0	82.0	57.0	nd	nd	nd	0.0	25.6	--	--	--
7/20/06	201	27.0	17.5	22.3	89.0	70.0	nd	nd	nd	0.7	21.0	--	--	--
7/21/06	202	25.0	19.0	22.0	92.0	61.0	nd	nd	nd	0.0	16.7	--	--	--
7/22/06	203	23.0	17.0	20.0	87.0	62.0	nd	nd	nd	0.0	16.6	--	--	--
7/23/06	204	23.0	10.0	16.5	88.0	60.0	nd	nd	nd	2.3	24.4	--	--	--
7/24/06	205	26.0	10.5	18.3	91.0	70.0	nd	nd	nd	0.0	26.5	--	--	--
7/25/06	206	29.0	20.0	24.5	90.0	75.0	nd	nd	nd	58.2	20.1	--	--	--
7/26/06	207	28.0	19.0	23.5	96.0	74.0	nd	nd	nd	2.4	20.1	--	--	--
7/27/06	208	28.0	19.0	23.5	96.0	79.0	nd	nd	nd	0.5	20.0	--	--	--
7/28/06	209	28.5	18.5	23.5	95.0	83.0	nd	nd	nd	0.0	21.0	--	--	--
7/29/06	210	30.0	19.0	24.5	100.0	84.0	nd	nd	nd	21.3	21.9	--	--	--
7/30/06	211	26.0	18.0	22.0	100.0	70.0	nd	nd	nd	0.0	18.6	--	--	--
7/31/06	212	30.5	18.0	24.3	96.0	77.0	nd	nd	nd	0.0	23.2	--	--	--
8/1/06	213	30.0	19.0	24.5	92.0	77.0	nd	nd	nd	0.0	21.7	--	--	--
8/2/06	214	28.3	17.3	22.8	100.0	82.0	nd	nd	nd	0.0	21.6	--	--	--
8/3/06	215	29.5	20.0	24.8	100.0	78.0	nd	nd	nd	5.2	20.0	--	--	--
8/4/06	216	26.5	15.5	21.0	96.0	33.0	nd	nd	nd	0.0	21.4	--	--	--
8/5/06	217	25.5	14.0	19.8	82.0	65.0	nd	nd	nd	0.0	21.8	--	--	--

Date	Day	Air Temp °C (Max Daily)	Air Temp °C (Min Daily)	Air Temp °C (Avg Daily)	Relative Humidity (Max Daily)	Relative Humidity (Min Daily)	Relative Humidity (Avg Daily)	Wind Speed (m/s)	Wind Direction (Degrees)	Precipitation (mm/Day)	Solar Radiation (MJ/m^2/day)	Soil Moisture Content % (0.73m bgs)	Soil Moisture Content % (0.39m bgs)	Soil Moisture Content % (0.14m bgs)
8/6/06	218	25.5	15.0	20.3	84.0	70.0	nd	nd	nd	0.0	20.7	--	--	--
8/7/06	219	28.0	19.0	23.5	91.0	46.0	nd	nd	nd	0.0	19.1	--	--	--
8/8/06	220	23.5	15.0	19.3	80.0	33.0	nd	nd	nd	0.0	18.4	--	--	--
8/9/06	221	25.0	9.0	17.0	90.0	55.0	nd	nd	nd	0.0	25.2	--	--	--
8/10/06	222	25.0	14.0	19.5	84.0	49.0	nd	nd	nd	0.0	20.8	--	--	--
8/11/06	223	21.5	9.0	15.3	80.0	45.0	nd	nd	nd	0.0	22.0	--	--	--
8/12/06	224	22.0	6.0	14.0	69.0	38.0	nd	nd	nd	0.0	24.8	--	--	--
8/13/06	225	24.0	8.0	16.0	80.0	48.0	nd	nd	nd	0.0	24.6	--	--	--
8/14/06	226	25.0	10.0	17.5	95.0	75.0	nd	nd	nd	2.9	23.7	--	--	--
8/15/06	227	23.5	13.0	18.3	86.0	40.0	nd	nd	nd	0.0	19.7	--	--	--
8/16/06	228	25.0	11.5	18.3	90.0	49.0	nd	nd	nd	0.0	22.2	--	--	--
8/17/06	229	25.5	10.0	17.8	92.0	61.0	nd	nd	nd	0.0	23.7	--	--	--
8/18/06	230	28.5	16.0	22.3	92.0	73.0	nd	nd	nd	0.0	21.2	--	--	--
8/19/06	231	26.0	16.0	21.0	93.0	71.0	nd	nd	nd	0.0	18.8	--	--	--
8/20/06	232	19.0	16.0	17.5	93.0	77.0	nd	nd	nd	0.0	10.2	--	--	--
8/21/06	233	25.0	9.5	17.3	96.0	58.0	nd	nd	nd	0.0	23.1	--	--	--
8/22/06	234	25.0	12.0	18.5	86.0	31.0	nd	nd	nd	0.0	21.0	--	--	--
8/23/06	235	23.5	9.0	16.3	85.0	59.0	nd	nd	nd	1.0	22.1	--	--	--
8/24/06	236	22.0	12.0	17.0	86.0	67.0	nd	nd	nd	0.4	18.2	--	--	--
8/25/06	237	16.0	13.5	14.8	87.0	60.0	nd	nd	nd	5.4	9.0	--	--	--
8/26/06	238	23.5	10.0	16.8	88.0	65.0	nd	nd	nd	3.7	20.9	--	--	--
8/27/06	239	23.5	19.0	21.3	97.0	89.0	nd	nd	nd	0.8	12.0	--	--	--
8/28/06	240	24.5	15.0	19.8	92.0	55.0	nd	nd	nd	2.0	17.2	--	--	--
8/29/06	241	23.3	13.5	18.4	94.0	67.0	nd	nd	nd	0.0	17.3	--	--	--
8/30/06	242	22.0	12.0	17.0	74.0	46.0	nd	nd	nd	0.0	17.4	--	--	--
8/31/06	243	22.0	4.0	13.0	82.0	52.0	nd	nd	nd	0.0	23.2	--	--	--
9/1/06	244	24.0	8.0	16.0	78.0	60.0	nd	nd	nd	0.0	21.7	--	--	--
9/2/06	245	16.0	13.5	14.8	93.0	64.0	nd	nd	nd	20.5	8.5	--	--	--
9/3/06	246	16.5	11.5	14.0	94.0	77.0	nd	nd	nd	2.0	11.9	--	--	--
9/4/06	247	19.0	13.0	16.0	90.0	62.0	nd	nd	nd	0.0	13.0	--	--	--
9/5/06	248	19.0	12.5	15.8	93.0	73.0	nd	nd	nd	0.0	13.4	--	--	--
9/6/06	249	21.0	10.0	15.5	93.0	67.0	nd	nd	nd	0.0	17.3	--	--	--
9/7/06	250	23.0	12.0	17.5	91.0	69.0	nd	nd	nd	0.0	17.1	--	--	--
9/8/06	251	25.5	14.5	20.0	97.0	76.0	nd	nd	nd	8.5	17.0	--	--	--
9/9/06	252	16.5	14.0	15.3	95.0	68.0	nd	nd	nd	1.1	8.0	--	--	--
9/10/06	253	17.0	2.0	9.5	75.0	48.0	nd	nd	nd	0.0	19.5	--	--	--
9/11/06	254	18.0	5.0	11.5	70.0	50.0	nd	nd	nd	0.0	18.0	--	--	--
9/12/06	255	18.0	9.0	13.5	92.0	64.0	nd	nd	nd	6.5	14.8	--	--	--
9/13/06	256	18.0	14.0	16.0	96.0	87.0	nd	nd	nd	3.3	9.8	--	--	--
9/14/06	257	16.5	14.0	15.3	96.0	88.0	nd	nd	nd	1.9	7.7	--	--	--
9/15/06	258	20.0	14.0	17.0	96.0	80.0	nd	nd	nd	0.3	11.8	--	--	--
9/16/06	259	22.0	11.5	16.8	97.0	82.0	nd	nd	nd	0.0	15.4	--	--	--
9/17/06	260	22.0	13.0	17.5	100.0	83.0	nd	nd	nd	0.0	14.2	--	--	--
9/18/06	261	24.0	16.5	20.3	99.0	77.0	nd	nd	nd	18.0	12.8	--	--	--
9/19/06	262	18.5	11.0	14.8	95.0	53.0	nd	nd	nd	0.5	12.7	--	--	--
9/20/06	263	14.5	10.5	12.5	82.0	53.0	nd	nd	nd	1.2	9.2	--	--	--
9/21/06	264	17.0	3.0	10.0	92.0	67.0	nd	nd	nd	0.0	17.0	--	--	--
9/22/06	265	17.5	3.0	10.3	93.0	73.0	nd	nd	nd	2.6	17.1	--	--	--
9/23/06	266	23.0	14.0	18.5	100.0	88.0	nd	nd	nd	5.6	13.3	--	--	--
9/24/06	267	19.5	15.0	17.3	100.0	78.0	nd	nd	nd	1.0	9.3	--	--	--
9/25/06	268	16.0	6.0	11.0	96.0	74.0	nd	nd	nd	3.7	13.7	--	--	--
9/26/06	269	17.5	5.0	11.3	95.0	77.0	nd	nd	nd	0.0	15.2	--	--	--
9/27/06	270	20.5	6.0	13.3	99.0	76.0	nd	nd	nd	9.5	16.2	--	--	--
9/28/06	271	12.0	11.0	11.5	100.0	81.0	nd	nd	nd	1.0	4.2	--	--	--
9/29/06	272	12.5	2.5	7.5	89.0	37.0	nd	nd	nd	0.5	13.2	--	--	--
9/30/06	273	15.0	1.5	8.3	91.0	66.0	nd	nd	nd	2.6	15.1	--	--	--
10/1/06	274	17.5	9.5	13.5	95.0	75.0	nd	nd	nd	0.0	11.5	--	--	--
10/2/06	275	17.0	4.5	10.8	97.0	67.0	nd	nd	nd	0.0	14.2	--	--	--
10/3/06	276	25.0	11.5	18.3	100.0	86.0	nd	nd	nd	3.5	14.6	--	--	--
10/4/06	277	18.0	12.0	15.0	100.0	65.0	nd	nd	nd	2.4	9.6	--	--	--
10/5/06	278	12.0	1.5	6.8	89.0	45.0	nd	nd	nd	0.0	12.6	--	--	--
10/6/06	279	15.0	-1.5	6.8	88.0	54.0	nd	nd	nd	0.0	15.6	--	--	--
10/7/06	280	16.5	-1.0	7.8	91.0	64.0	nd	nd	nd	0.0	15.9	--	--	--
10/8/06	281	20.0	4.0	12.0	100.0	71.0	nd	nd	nd	0.0	15.0	--	--	--
10/9/06	282	20.5	8.0	14.3	100.0	46.0	nd	nd	nd	0.0	13.1	--	--	--
10/10/06	283	14.5	8.0	11.3	63.0	48.0	nd	nd	nd	7.5	9.3	--	--	--
10/11/06	284	15.5	8.0	11.8	100.0	65.0	nd	nd	nd	34.1	9.9	--	--	--
10/12/06	285	7.5	4.5	6.0	97.0	49.0	nd	nd	nd	0.0	6.2	--	--	--
10/13/06	286	6.5	-2.0	2.3	88.0	57.0	nd	nd	nd	0.4	10.3	--	--	--
10/14/06	287	9.0	2.0	5.5	81.0	54.0	nd	nd	nd	1.2	9.2	--	--	--
10/15/06	288	11.0	-1.0	5.0	87.0	67.0	nd	nd	nd	0.0	11.9	--	--	--
10/16/06	289	14.0	0.0	7.0	94.0	65.0	nd	nd	nd	0.0	12.7	--	--	--
10/17/06	290	13.0	6.0	9.5	100.0	75.0	nd	nd	nd	57.8	8.9	--	--	--
10/18/06	291	16.0	10.0	13.0	99.0	85.0	nd	nd	nd	0.2	8.1	--	--	--
10/19/06	292	13.0	9.0	11.0	100.0	71.0	nd	nd	nd	3.0	6.6	--	--	--
10/20/06	293	6.0	3.0	4.5	90.0	71.0	nd	nd	nd	2.2	5.6	--	--	--
10/21/06	294	11.0	1.5	6.3	86.0	56.0	nd	nd	nd	0.0	9.8	--	--	--
10/22/06	295	9.0	5.5	7.3	94.0	80.0	nd	nd	nd	21.0	5.9	--	--	--
10/23/06	296	6.0	3.0	4.5	92.0	55.0	nd	nd	nd	0.2	5.4	--	--	--
10/24/06	297	6.5	2.0	4.3	86.0	61.0	nd	nd	nd	0.0	6.5	--	--	--
10/25/06	298	8.0	2.0	5.0	79.0	50.0	nd	nd	nd	0.0	7.4	--	--	--
10/26/06	299	7.0	-2.0	2.5	83.0	53.0	nd	nd	nd	0.0	9.0	--	--	--
10/27/06	300	6.0	-3.5	1.3	91.0	71.0	nd	nd	nd	3.8	9.1	--	--	--
10/28/06	301	6.0	3.0	4.5	97.0	74.0	nd	nd	nd	15.8	5.1	--	--	--
10/29/06	302	5.0	0.0	2.5	89.0	47.0	nd	nd	nd	4.6	6.5	--	--	--
10/30/06	303	12.0	1.0	6.5	80.0	60.0	nd	nd	nd	0.0	9.5	--	--	--
10/31/06	304	14.5	5.0	9.8	93.0	70.0	nd	nd	nd	0.2	8.7	--	--	--
11/1/06	305	7.0	-1.0	3.0	81.0	52.0	nd	nd	nd	0.0	7.9	--	--	--
11/2/06	306	4.5	-2.0	1.3	80.0	52.0	nd	nd	nd	0.0	7.0	--	--	--
11/3/06	307	4.0	-3.0	0.5	90.0	62.0	nd	nd	nd	0.0	7.2	--	--	--
11/4/06	308	4.0	-3.0	0.5	87.0	60.0	nd	nd	nd	0.2	7.1	--	--	--
11/5/06	309	7.0	-0.5	3.3	93.0	74.0	nd	nd	nd	0.2	7.2	--	--	--
11/6/06	310	13.0	-0.5	6.3	95.0	76.0	nd	nd	nd	0.0	9.6	--	--	--
11/7/06	311	11.0	4.0	7.5	97.0	73.0	nd	nd	nd	8.8	6.8	--	--	--
11/8/06	312	10.5	6.5	8.5	100.0	95.0	nd	nd	nd	3.0	5.1	--	--	--
11/9/06	313	12.5	8.0	10.3	100.0	72.0	nd	nd	nd	0.2	5.3	--	--	--
11/10/06	314	9.5	3.0	6.3	92.0	65.0	nd	nd	nd	0.0	6.3	--	--	--
11/11/06	315	4.5	1.0	2.8	95.0	78.0	nd	nd	nd	5.2	4.6	--	--	--
11/12/06	316	4.0	-0.5	1.8	80.0	66.0	nd	nd	nd	0.0	5.2	--	--	--

Date	Day	Air Temp °C (Max Daily)	Air Temp °C (Min Daily)	Air Temp °C (Avg Daily)	Relative Humidity (Max Daily)	Relative Humidity (Min Daily)	Relative Humidity (Avg Daily)	Wind Speed (m/s)	Wind Direction (Degrees)	Precipitation (mm/Day)	Solar Radiation (MJ/m^2/day)	Soil Moisture Content % (0.73m bgs)	Soil Moisture Content % (0.39m bgs)	Soil Moisture Content % (0.14m bgs)
11/13/06	317	4.5	2.0	3.3	100.0	82.0	nd	nd	nd	1.6	3.8	--	--	--
11/14/06	318	5.5	3.5	4.5	100.0	83.0	nd	nd	nd	3.2	3.4	--	--	--
11/15/06	319	12.0	0.5	6.3	98.0	70.0	nd	nd	nd	0.8	8.0	--	--	--
11/16/06	320	14.5	3.0	8.8	100.0	93.0	nd	nd	nd	35.2	7.9	--	--	--
11/17/06	321	5.0	3.0	4.0	100.0	66.0	nd	nd	nd	5.2	3.2	--	--	--
11/18/06	322	4.0	0.0	2.0	86.0	69.0	nd	nd	nd	0.2	4.5	--	--	--
11/19/06	323	0.5	-1.0	-0.3	80.0	66.0	nd	nd	nd	0.0	2.8	--	--	--
11/20/06	324	0.0	-4.0	-2.0	90.0	59.0	nd	nd	nd	0.0	4.4	--	--	--
11/21/06	325	3.5	-4.5	-0.5	72.0	63.0	nd	nd	nd	0.0	6.2	--	--	--
11/22/06	326	8.0	-5.0	1.5	94.0	72.0	nd	nd	nd	0.0	7.9	--	--	--
11/23/06	327	9.0	-6.0	1.5	95.0	62.0	nd	nd	nd	0.2	8.4	--	--	--
11/24/06	328	10.0	-3.0	3.5	93.0	53.0	nd	nd	nd	0.0	7.7	--	--	--
11/25/06	329	11.5	0.0	5.8	94.0	73.0	nd	nd	nd	0.0	7.2	--	--	--
11/26/06	330	13.5	4.0	8.8	94.0	82.0	nd	nd	nd	0.0	6.5	--	--	--
11/27/06	331	12.5	5.5	9.0	100.0	86.0	nd	nd	nd	0.0	5.5	--	--	--
11/28/06	332	9.5	4.5	7.0	100.0	86.0	nd	nd	nd	0.4	4.6	--	--	--
11/29/06	333	14.0	3.0	8.5	100.0	73.0	nd	nd	nd	0.0	6.8	--	--	--
11/30/06	334	13.5	4.0	8.8	100.0	84.0	nd	nd	nd	23.6	6.3	--	--	--
12/1/06	335	1.0	0.0	0.5	98.0	64.0	nd	nd	nd	46.0	2.0	--	--	--
12/2/06	336	1.0	-2.0	-0.5	71.0	53.0	nd	nd	nd	0.0	3.5	--	--	--
12/3/06	337	0.0	-3.5	-1.8	81.0	53.0	nd	nd	nd	0.0	3.7	--	--	--
12/4/06	338	-2.5	-6.5	-4.5	96.0	35.0	nd	nd	nd	0.0	4.0	--	--	--
12/5/06	339	1.0	-12.0	-5.5	96.0	59.0	nd	nd	nd	2.4	7.1	--	--	--
12/6/06	340	2.0	-6.5	-2.3	83.0	64.0	nd	nd	nd	2.2	5.7	--	--	--
12/7/06	341	-7.5	-12.0	-9.8	90.0	45.0	nd	nd	nd	0.4	4.1	--	--	--
12/8/06	342	-4.0	-16.5	-10.3	75.0	55.0	nd	nd	nd	0.0	6.8	--	--	--
12/9/06	343	1.0	-7.0	-3.0	73.0	57.0	nd	nd	nd	0.0	5.4	--	--	--
12/10/06	344	6.0	-1.0	2.5	84.0	65.0	nd	nd	nd	0.0	5.1	--	--	--
12/11/06	345	6.0	0.0	3.0	96.0	74.0	nd	nd	nd	3.6	4.7	--	--	--
12/12/06	346	8.0	2.0	5.0	99.0	77.0	nd	nd	nd	0.2	4.7	--	--	--
12/13/06	347	8.0	6.0	7.0	100.0	78.0	nd	nd	nd	4.4	2.7	--	--	--
12/14/06	348	9.0	1.0	5.0	100.0	77.0	nd	nd	nd	0.0	5.4	--	--	--
12/15/06	349	9.0	4.0	6.5	90.0	75.0	nd	nd	nd	1.0	4.2	--	--	--
12/16/06	350	8.5	-1.0	3.8	88.0	66.0	nd	nd	nd	0.0	5.8	--	--	--
12/17/06	351	10.5	1.0	5.8	93.0	74.0	nd	nd	nd	0.0	5.8	--	--	--
12/18/06	352	4.0	0.0	2.0	84.0	51.0	nd	nd	nd	0.0	3.8	--	--	--
12/19/06	353	3.0	-0.5	1.3	84.0	47.0	nd	nd	nd	0.0	3.5	--	--	--
12/20/06	354	6.0	-3.0	1.5	86.0	67.0	nd	nd	nd	0.0	5.6	--	--	--
12/21/06	355	5.5	-1.0	2.3	85.0	47.0	nd	nd	nd	0.0	4.8	--	--	--
12/22/06	356	7.0	-3.0	2.0	100.0	61.0	nd	nd	nd	14.6	5.9	--	--	--
12/23/06	357	5.0	3.0	4.0	100.0	80.0	nd	nd	nd	2.2	2.7	--	--	--
12/24/06	358	6.0	1.0	3.5	85.0	76.0	nd	nd	nd	0.2	4.2	--	--	--
12/25/06	359	4.0	-3.0	0.5	100.0	73.0	nd	nd	nd	4.2	5.0	--	--	--
12/26/06	360	2.0	0.0	1.0	100.0	73.0	nd	nd	nd	4.0	2.7	--	--	--
12/27/06	361	0.5	-4.5	-2.0	86.0	65.0	nd	nd	nd	0.2	4.2	--	--	--
12/28/06	362	3.0	-3.5	-0.3	88.0	72.0	nd	nd	nd	0.0	4.8	--	--	--
12/29/06	363	-1.0	-9.0	-5.0	79.0	44.0	nd	nd	nd	0.0	5.4	--	--	--
12/30/06	364	0.5	-8.0	-3.8	91.0	61.0	nd	nd	nd	1.0	5.6	--	--	--
12/31/06	365	5.0	-9.0	-2.0	97.0	76.0	nd	nd	nd	2.2	7.2	--	--	--
1/1/07	1	8.5	0.0	4.3	100.0	73.0	nd	nd	nd	9.2	5.6	--	--	--
1/2/07	2	5.0	-2.0	1.5	87.0	58.0	nd	nd	nd	0.0	5.1	--	--	--
1/3/07	3	6.0	-1.0	2.5	85.0	76.0	nd	nd	nd	0.0	5.2	--	--	--
1/4/07	4	8.0	2.0	5.0	91.0	76.0	nd	nd	nd	1.0	4.8	--	--	--
1/5/07	5	9.5	6.0	7.8	100.0	91.0	nd	nd	nd	8.2	3.7	--	--	--
1/6/07	6	9.5	4.0	6.8	100.0	65.0	nd	nd	nd	8.0	4.7	--	--	--
1/7/07	7	3.0	1.0	2.0	91.0	55.0	nd	nd	nd	0.8	2.8	--	--	--
1/8/07	8	3.5	0.5	2.0	100.0	65.0	nd	nd	nd	7.2	3.5	--	--	--
1/9/07	9	1.0	-3.0	-1.0	78.0	53.0	nd	nd	nd	0.0	4.1	--	--	--
1/10/07	10	-3.0	-9.0	-6.0	82.0	50.0	nd	nd	nd	0.0	5.0	--	--	--
1/11/07	11	5.0	-12.5	-3.8	84.0	65.0	nd	nd	nd	0.0	8.6	--	--	--
1/12/07	12	4.5	1.0	2.8	100.0	67.0	nd	nd	nd	5.0	3.9	--	--	--
1/13/07	13	-3.0	-4.0	-3.5	100.0	57.0	nd	nd	nd	0.6	2.1	--	--	--
1/14/07	14	-3.0	-6.5	-4.8	91.0	69.0	nd	nd	nd	0.0	4.0	--	--	--
1/15/07	15	-5.0	-6.5	-5.8	91.0	56.0	nd	nd	nd	0.0	2.6	--	--	--
1/16/07	16	-11.0	-15.5	-13.3	82.0	46.0	nd	nd	nd	0.0	4.6	--	--	--
1/17/07	17	-4.0	-19.5	-11.8	88.0	58.0	nd	nd	nd	0.4	8.5	--	--	--
1/18/07	18	0.0	-8.0	-4.0	78.0	66.0	nd	nd	nd	0.0	6.2	--	--	--
1/19/07	19	-0.5	-4.0	-2.3	100.0	57.0	nd	nd	nd	3.2	4.1	--	--	--
1/20/07	20	-10.0	-16.0	-13.0	76.0	49.0	nd	nd	nd	0.0	5.5	--	--	--
1/21/07	21	-4.0	-19.0	-11.5	80.0	61.0	nd	nd	nd	0.0	8.8	--	--	--
1/22/07	22	-5.0	-12.5	-8.8	83.0	56.0	nd	nd	nd	0.2	6.3	--	--	--
1/23/07	23	-2.0	-11.5	-6.8	94.0	73.0	nd	nd	nd	0.0	7.1	--	--	--
1/24/07	24	-7.0	-13.5	-10.3	78.0	35.0	nd	nd	nd	0.0	6.0	--	--	--
1/25/07	25	-15.0	-19.5	-17.3	66.0	49.0	nd	nd	nd	0.0	5.0	--	--	--
1/26/07	26	-10.0	-15.8	-12.9	86.0	37.0	nd	nd	nd	0.0	5.7	--	--	--
1/27/07	27	-5.0	-12.0	-8.5	93.0	82.0	nd	nd	nd	0.0	6.4	--	--	--
1/28/07	28	-10.0	-14.5	-12.3	88.0	61.0	nd	nd	nd	0.0	5.2	--	--	--
1/29/07	29	-8.0	-23.0	-15.5	77.0	52.0	nd	nd	nd	0.4	9.6	--	--	--
1/30/07	30	-9.5	-19.0	-14.3	84.0	62.0	nd	nd	nd	0.0	7.7	--	--	--
1/31/07	31	-4.2	-8.4	-6.7	96.9	53.4	76.5	4.2	177.5	0.0	6.2	-0.9	-0.5	-0.6
2/1/07	32	-3.6	-8.4	-5.6	96.9	53.4	81.5	4.1	177.5	0.6	6.2	-0.9	-0.6	-0.6
2/2/07	33	-3.7	-10.5	-5.4	96.5	62.4	85.7	3.3	177.5	0.0	5.0	-0.9	2.8	-0.6
2/3/07	34	-8.4	-13.3	-11.2	92.9	47.0	70.3	6.7	177.5	0.0	10.0	-1.1	9.5	-0.6
2/4/07	35	-13.0	-16.6	-15.3	70.5	55.0	62.2	8.0	177.5	1.2	8.1	-1.1	8.9	-0.7
2/5/07	36	-12.3	-19.2	-15.3	88.3	58.6	73.6	5.6	177.5	2.2	10.4	-1.1	18.2	-0.7
2/6/07	37	-10.0	-17.1	-13.1	90.1	54.3	74.3	4.1	177.5	0.0	8.8	-1.1	15.9	-0.7
2/7/07	38	-8.6	-17.3	-12.6	91.4	72.4	80.4	4.9	177.5	4.0	8.5	-1.1	7.3	-0.7
2/8/07	39	-7.0	-10.4	-9.0	91.4	52.8	72.4	6.2	177.5	5.6	11.6	-1.0	1.3	-0.6
2/9/07	40	-7.1	-17.7	-11.8	82.7	62.3	70.2	4.1	177.5	0.0	10.8	-1.1	0.9	-0.6
2/10/07	41	-6.2	-11.4	-8.8	87.4	57.9	75.1	4.3	177.5	2.2	10.4	-1.0	1.5	-0.6
2/11/07	42	-6.5	-10.7	-8.4	77.2	55.7	69.2	5.7	177.5	0.0	10.0	-1.0	2.3	-0.6
2/12/07	43	-7.7	-16.7	-10.4	87.0	35.3	61.1	3.2	177.5	0.0	9.4	-1.0	7.6	-0.6
2/13/07	44	-15.5	-20.8	-18.1	82.9	46.0	56.3	4.9	177.5	7.3	7.9	-1.1	2.4	-0.7
2/14/07	45	-9.9	-17.8	-14.9	83.8	59.1	75.3	5.4	177.5	0.0	6.8	-1.1	2.7	-0.6
2/15/07	46	-13.5	-22.7	-17.4	89.7	49.9	63.2	4.3	177.5	1.0	14.0	-1.1	1.3	-0.7
2/16/07	47	-4.5	-14.3	-9.7	90.5	54.5	73.8	5.2	177.5	0.0	10.9	-1.0	1.1	-0.6
2/17/07	48	-5.9	-12.7	-8.9	94.2	59.1	73.8	4.3	177.5	0.0	9.6	-1.0	8.2	-0.6
2/18/07	49	-8.7	-18.8	-12.9	92.2	52.0	69.1	3.5	177.5	0.0	14.5	-1.0	1.9	-0.7
2/19/07	50	-3.7	-20.3	-12.3	90.1	44.1	69.7	3.5	177.5	0.0	10.5	-1.0	0.8	-0.6

Date	Day	Air Temp °C (Max Daily)	Air Temp °C (Min Daily)	Air Temp °C (Avg Daily)	Relative Humidity (Max Daily)	Relative Humidity (Min Daily)	Relative Humidity (Avg Daily)	Wind Speed (m/s)	Wind Direction (Degrees)	Precipitation (mm/Day)	Solar Radiation (MJ/m^2/day)	Soil Moisture Content % (0.73m bgs)	Soil Moisture Content % (0.39m bgs)	Soil Moisture Content % (0.14m bgs)
2/20/07	51	3.1	-3.9	0.4	86.5	66.3	76.6	2.4	177.4	0.0	5.2	-0.8	0.8	-0.4
2/21/07	52	5.1	-5.9	-1.7	95.9	48.1	75.4	1.8	126.0	0.0	14.8	-0.8	0.8	-0.4
2/22/07	53	1.2	-4.7	-1.0	99.8	82.7	94.2	3.8	99.4	0.0	4.5	-0.7	1.7	-0.3
2/23/07	54	-5.6	-13.5	-10.8	90.6	55.2	69.2	3.4	135.6	0.3	15.7	-0.9	0.9	-0.5
2/24/07	55	-3.7	-15.5	-10.1	71.0	49.9	63.3	2.5	110.3	1.5	15.9	-0.8	0.6	-0.6
2/25/07	56	-2.2	-11.7	-6.5	89.1	45.2	64.6	4.8	31.8	0.3	11.6	-0.8	0.7	-0.5
2/26/07	57	-4.0	-7.0	-5.4	95.8	53.7	78.3	3.8	41.9	0.0	4.3	-0.7	0.7	-0.4
2/27/07	58	2.2	-7.4	-3.7	97.5	38.0	72.4	1.6	67.8	0.0	7.4	-0.7	0.8	-0.4
2/28/07	59	3.5	-7.1	-3.5	78.4	31.1	54.0	2.1	47.0	1.0	16.8	-0.7	0.7	-0.3
3/1/07	60	-2.7	-10.2	-6.1	96.8	39.6	66.6	5.1	33.1	0.0	7.8	-0.7	0.8	-0.4
3/2/07	61	1.9	-2.3	0.0	99.8	73.1	89.5	3.5	88.9	15.2	8.7	0.3	1.9	0.1
3/3/07	62	-0.4	-3.2	-1.5	94.0	63.4	76.8	6.0	122.0	0.0	10.9	-0.5	3.7	-0.5
3/4/07	63	-2.4	-5.5	-4.3	90.7	50.3	74.0	5.8	139.4	0.0	14.4	-0.5	0.9	-0.5
3/5/07	64	-3.7	-18.8	-9.0	92.5	52.5	67.4	6.4	148.2	0.3	16.3	-0.3	0.9	-0.6
3/6/07	65	-15.6	-24.8	-19.7	59.6	30.4	46.6	2.9	150.0	0.0	18.2	-0.5	0.2	-0.8
3/7/07	66	-7.8	-16.5	-11.9	85.9	50.0	67.8	2.8	123.3	0.0	16.4	0.9	0.6	-0.6
3/8/07	67	-7.3	-12.8	-9.7	84.4	35.2	58.7	2.7	79.9	0.0	17.4	0.1	0.6	-0.6
3/9/07	68	-2.6	-13.6	-7.7	85.7	54.7	69.8	4.1	49.5	0.0	17.1	-0.2	0.6	-0.4
3/10/07	69	5.1	-2.2	1.6	95.7	73.5	86.2	4.2	102.9	0.0	7.2	3.6	1.2	-0.2
3/11/07	70	3.1	-2.7	0.0	98.4	47.8	76.5	3.3	142.5	1.8	19.1	4.5	0.9	-0.3
3/12/07	71	4.4	-2.4	0.9	99.0	57.2	79.7	3.1	112.3	0.0	10.6	6.4	0.8	-0.3
3/13/07	72	9.3	1.7	5.9	89.1	54.9	74.1	4.0	105.4	0.0	12.9	4.7	0.6	-0.3
3/14/07	73	8.7	4.1	7.4	99.7	55.9	88.8	3.2	128.7	0.3	2.9	2.6	1.1	-0.2
3/15/07	74	3.3	-5.5	-0.3	60.6	39.7	49.8	3.2	79.9	0.0	11.0	0.9	0.5	-0.3
3/16/07	75	-5.1	-8.4	-7.1	91.7	35.7	56.8	6.1	26.3	0.0	6.7	-0.3	0.6	-0.4
3/17/07	76	-0.8	-8.4	-4.9	93.2	42.7	69.2	3.2	87.8	0.5	14.0	-0.7	1.1	-0.4
3/18/07	77	-1.6	-7.9	-4.6	57.7	32.5	41.4	4.3	154.0	0.0	20.2	-0.6	0.7	-0.4
3/19/07	78	0.4	-7.3	-2.6	99.3	51.1	81.4	4.0	109.3	0.0	4.2	-0.5	1.3	-0.4
3/20/07	79	-2.4	-13.2	-7.7	72.9	37.9	56.9	3.2	123.0	0.0	21.1	-0.4	0.7	-0.5
3/21/07	80	1.9	-9.5	-2.8	87.0	50.5	68.4	4.6	62.1	0.0	13.8	-0.4	1.0	-0.4
3/22/07	81	10.3	2.2	5.6	95.9	68.0	81.0	4.9	126.7	0.8	4.6	-0.2	4.1	-0.3
3/23/07	82	9.1	-0.9	4.1	84.8	34.1	55.8	2.4	128.0	1.5	20.9	-0.2	0.9	-0.4
3/24/07	83	3.1	-0.3	1.5	99.3	59.7	81.2	3.1	36.3	0.0	2.9	-0.2	1.5	-0.3
3/25/07	84	1.8	-1.2	0.2	101.7	93.8	98.9	2.4	49.6	0.8	6.2	-0.3	1.9	-0.2
3/26/07	85	11.7	2.0	7.3	98.0	85.7	92.8	2.7	99.7	8.4	6.2	-0.1	1.6	-0.2
3/27/07	86	15.6	6.2	10.5	98.0	71.2	87.5	2.1	112.0	0.0	18.1	-0.1	1.2	-0.2
3/28/07	87	8.5	-0.5	3.7	84.3	20.6	47.3	4.2	23.6	0.0	22.1	-0.2	0.6	-0.3
3/29/07	88	7.6	-2.9	1.8	42.1	22.4	33.5	2.8	59.3	0.0	22.7	-0.3	0.5	-0.3
3/30/07	89	11.5	0.9	5.1	66.8	26.8	39.4	1.7	81.7	0.0	11.3	-0.2	0.5	-0.3
3/31/07	90	8.6	-2.1	2.8	55.5	22.6	36.8	3.2	49.6	0.0	20.8	-0.2	0.5	-0.3
4/1/07	91	6.2	3.6	4.5	98.4	29.8	72.5	5.0	58.7	2.0	3.8	-0.1	7.1	-0.1
4/2/07	92	9.6	3.4	6.2	100.4	70.9	87.3	4.1	119.4	4.1	6.5	0.0	1.6	-0.1
4/3/07	93	7.8	0.9	4.3	96.5	66.8	86.9	2.6	85.8	7.9	8.6	-0.1	1.3	-0.2
4/4/07	94	6.8	-2.2	3.7	100.2	78.6	93.5	5.4	97.6	17.0	3.3	0.1	2.1	-0.1
4/5/07	95	-2.8	-7.7	-5.3	86.0	59.6	72.8	5.0	139.8	0.0	14.7	-0.3	0.6	-0.4
4/6/07	96	-5.3	-8.9	-7.3	93.5	70.8	82.9	3.6	142.8	2.2	11.7	-0.3	0.5	-0.5
4/7/07	97	-3.6	-9.1	-6.5	94.4	66.1	82.8	3.1	141.5	0.6	12.6	-0.3	1.5	-0.4
4/8/07	98	-1.2	-7.6	-4.1	94.5	65.4	79.6	4.6	143.5	0.0	13.4	-0.3	0.6	-0.4
4/9/07	99	0.1	-4.9	-2.2	86.0	60.2	72.8	3.3	144.2	0.0	9.2	-0.3	0.6	-0.4
4/10/07	100	2.0	-5.1	-1.3	88.6	44.4	62.6	2.5	136.4	0.0	17.8	-0.3	0.6	-0.4
4/11/07	101	3.4	-3.4	0.4	99.9	47.9	65.7	4.2	41.2	1.0	11.6	-0.1	0.9	-0.2
4/12/07	102	3.7	-0.1	1.5	100.9	94.1	99.7	5.6	76.3	16.3	2.9	0.3	2.5	0.1
4/13/07	103	2.8	-0.6	1.0	100.8	76.9	88.2	4.9	140.7	0.3	7.1	-0.1	1.2	-0.2
4/14/07	104	4.9	-1.1	1.9	90.6	55.7	74.0	2.5	117.3	0.0	14.4	-0.2	0.3	-0.3
4/15/07	105	2.4	-0.9	1.0	97.8	79.1	93.3	4.0	21.1	3.3	3.5	-0.2	0.9	-0.2
4/16/07	106	3.5	0.3	2.2	96.6	89.3	93.1	3.7	45.9	14.5	6.8	0.1	2.0	-0.2
4/17/07	107	6.0	2.1	4.3	91.5	70.6	81.9	3.2	16.5	0.0	11.0	-0.2	0.7	-0.2
4/18/07	108	12.3	3.6	6.8	90.7	57.7	72.7	3.8	35.9	0.0	18.6	-0.2	0.8	-0.2
4/19/07	109	16.2	3.4	9.6	77.4	28.5	47.8	3.5	37.5	0.0	26.0	-0.1	0.8	-0.2
4/20/07	110	19.4	7.8	13.4	30.5	20.2	26.5	2.7	69.0	0.0	26.4	-0.1	0.6	-0.2
4/21/07	111	21.2	8.8	14.9	36.7	17.8	26.8	2.8	85.2	0.0	25.9	-0.1	0.7	-0.1
4/22/07	112	20.4	8.4	14.3	50.3	22.1	36.3	2.9	97.1	0.0	24.3	-0.1	1.2	-0.2
4/23/07	113	19.3	8.2	13.5	93.5	41.1	63.3	4.6	124.9	4.6	14.1	-0.1	1.1	-0.2
4/24/07	114	12.8	3.3	8.2	82.3	34.7	57.5	2.1	110.9	0.0	25.7	-0.1	0.1	-0.3
4/25/07	115	12.2	4.3	7.2	86.2	41.1	63.3	1.9	72.6	0.0	13.9	-0.2	0.1	-0.3
4/26/07	116	12.3	3.7	7.3	95.0	43.4	79.4	3.9	65.8	4.3	9.9	-0.1	0.8	-0.3
4/27/07	117	14.1	7.2	10.0	99.4	84.3	93.8	4.3	92.1	3.6	8.5	0.1	1.3	-0.2
4/28/07	118	9.1	6.7	7.8	98.4	78.4	91.1	2.9	137.3	0.3	4.7	0.2	1.1	-0.2
4/29/07	119	18.0	5.2	11.7	91.7	28.9	66.2	3.0	117.4	0.5	25.4	-0.1	0.9	-0.2
4/30/07	120	13.4	7.1	10.2	78.8	45.1	58.4	4.1	147.1	0.5	25.9	-0.1	0.5	-0.3
5/1/07	121	9.7	4.2	7.1	87.0	50.7	66.2	2.6	43.4	0.5	7.5	-0.1	1.0	-0.3
5/2/07	122	13.8	3.5	9.0	92.8	32.2	57.5	2.8	57.3	0.0	17.3	-0.1	0.3	-0.3
5/3/07	123	14.9	4.2	9.5	50.3	24.0	36.0	2.8	58.0	0.0	28.8	6.5	12.9	11.8
5/4/07	124	17.0	5.5	11.7	63.9	24.7	37.1	2.8	75.7	0.0	28.2	10.2	20.3	18.6
5/5/07	125	15.7	6.5	11.2	61.1	16.5	33.0	4.3	48.9	0.0	27.0	10.2	20.3	18.4
5/6/07	126	13.7	3.7	8.5	45.1	30.8	37.3	2.9	72.3	0.0	29.1	10.1	20.2	18.2
5/7/07	127	17.9	5.2	11.1	53.0	25.1	37.1	2.7	84.0	0.0	28.9	10.0	20.2	18.0
5/8/07	128	22.4	7.0	15.1	68.5	27.0	43.5	3.6	109.0	0.0	25.5	9.9	20.1	17.9
5/9/07	129	25.4	13.6	18.4	78.2	41.7	64.2	2.0	64.0	0.0	16.1	9.9	20.2	15.1
5/10/07	130	21.6	10.9	17.4	95.8	56.4	73.5	2.5	69.8	0.0	21.5	9.8	20.2	14.9
5/11/07	131	21.7	10.5	15.8	97.8	43.9	70.1	2.3	59.7	0.0	24.3	9.8	20.2	14.8
5/12/07	132	13.4	5.0	9.0	60.7	29.0	48.2	3.4	42.8	0.0	21.1	9.7	20.2	14.5
5/13/07	133	13.1	3.3	8.5	48.1	23.4	34.9	2.5	72.2	0.0	29.3	9.7	20.0	14.3
5/14/07	134	16.2	5.3	10.9	76.0	25.4	45.4	3.1	99.8	0.5	23.5	9.6	19.9	14.1
5/15/07	135	23.3	11.1	16.5	98.3	50.0	72.0	3.5	95.1	32.8	18.2	9.6	19.8	15.5
5/16/07	136	12.5	5.1	8.7	99.6	84.7	92.2	3.8	27.3	7.1	4.3	9.5	22.7	23.1
5/17/07	137	11.5	4.1	7.3	92.3	48.5	75.6	1.8	54.1	0.0	21.7	9.6	23.3	21.5
5/18/07	138	13.4	3.5	8.5	90.7	55.7	71.5	2.2	70.2	0.0	28.6	9.9	22.7	20.4
5/19/07	139	19.8	6.1	14.1	78.2	30.8	47.2	2.3	131.6	0.0	29.6	10.0	22.3	19.2
5/20/07	140	14.5	5.9	11.7	87.9	53.6	68.7	2.1	102.4	0.0	18.2	10.0	22.0	18.3
5/21/07	141	15.4	4.0	10.0	80.5	35.2	51.9	2.2	95.2	0.0	29.2	9.9	21.6	17.6
5/22/07	142	18.8	7.6	13.7	62.5	25.6	39.5	2.2	68.1	0.0	21.9	9.9	21.4	17.1
5/23/07	143	25.3	11.2	17.9	60.1	32.6	45.3	2.4	68.7	0.0	28.2	9.8	21.2	16.7
5/24/07	144	28.3	15.0	21.5	65.9	41.1	57.0	2.4	99.1	0.0	26.9	9.7	21.2	16.4
5/25/07	145	24.8	12.8	19.2	77.6	57.1	67.0	2.6	127.8	2.0	20.8	9.7	21.2	16.2
5/26/07	146	19.7	9.7	14.5	73.9	32.3	55.5	1.5	91.2	0.0	22.4	9.6	21.0	15.5
5/27/07	147	16.4	8.2	12.6	98.9	46.6	88.7	2.4	91.6	9.4	6.8	9.6	20.8	16.4
5/28/07	148	18.0	7.4	13.2	90.1	52.2	69.0	2.5	135.1	0.0	24.8	9.5	21.0	17.1
5/29/07	149	19.7	9.2	15.0	82.6	38.9	61.8	2.5	75.6	0.0	30.0	9.5	21.0	16.2

Date	Day	Air Temp ^{o}C (Max Daily)	Air Temp ^{o}C (Min Daily)	Air Temp ^{o}C (Avg Daily)	Relative Humidity (Max Daily)	Relative Humidity (Min Daily)	Relative Humidity (Avg Daily)	Wind Speed (m/s)	Wind Direction (Degrees)	Precipitation (mm/Day)	Solar Radiation (MJ/m^2/day)	Soil Moisture Content % (0.73m bgs)	Soil Moisture Content % (0.39m bgs)	Soil Moisture Content % (0.14m bgs)
5/30/07	150	26.2	12.9	20.5	65.1	32.6	50.2	2.2	115.3	0.0	28.0	9.5	21.0	15.7
5/31/07	151	28.4	18.4	22.4	78.8	47.5	67.2	1.8	109.2	0.0	21.1	9.5	21.1	15.3
6/1/07	152	27.2	18.3	22.0	85.6	48.0	67.7	1.9	111.2	0.0	19.9	9.5	21.0	15.0
6/2/07	153	28.3	17.2	22.9	88.2	45.6	66.4	1.9	84.3	0.0	27.2	9.5	21.0	14.8
6/3/07	154	27.0	15.4	19.8	98.5	57.7	81.7	3.0	74.2	7.6	17.6	9.5	21.0	14.8
6/4/07	155	20.7	13.8	16.2	98.9	78.8	93.5	2.6	94.4	10.4	11.6	9.4	21.0	18.0
6/5/07	156	15.4	3.5	10.5	99.3	76.8	90.4	2.8	131.6	0.8	6.2	9.4	21.5	18.2
6/6/07	157	13.7	2.5	9.0	97.1	51.7	71.7	1.8	120.5	0.0	18.9	9.4	21.3	17.6
6/7/07	158	21.8	6.8	14.5	88.1	54.3	69.5	3.6	66.5	0.0	24.6	9.3	21.1	16.9
6/8/07	159	27.9	11.9	20.7	81.3	58.9	69.4	4.1	126.0	0.5	25.0	9.3	21.1	16.4
6/9/07	160	21.9	9.8	15.7	83.7	41.0	62.7	1.6	81.5	0.0	31.4	9.4	21.1	15.9
6/10/07	161	23.7	12.0	18.2	61.8	36.3	50.2	1.9	70.1	0.0	29.1	9.4	21.0	15.5
6/11/07	162	26.7	14.2	21.0	66.6	33.1	51.4	1.7	67.0	0.0	29.2	9.4	21.0	15.2
6/12/07	163	31.1	17.7	24.7	71.0	26.0	47.9	2.0	32.6	0.0	28.8	9.3	21.0	14.9
6/13/07	164	29.1	18.9	23.6	75.4	41.3	56.2	2.1	72.5	0.0	25.3	9.3	21.1	14.6
6/14/07	165	23.4	14.6	18.8	83.8	42.1	61.4	2.7	64.9	0.0	30.0	9.3	21.0	14.3
6/15/07	166	26.1	14.6	20.4	75.4	41.0	57.2	1.9	92.4	0.0	29.2	9.3	20.9	14.0
6/16/07	167	26.8	16.0	21.4	70.1	42.4	57.2	1.9	148.5	0.0	25.4	9.2	20.8	13.7
6/17/07	168	27.2	15.7	21.7	82.7	42.6	63.0	1.2	149.9	0.0	21.9	9.2	20.7	13.3
6/18/07	169	25.0	14.7	20.5	83.1	47.6	61.8	2.7	117.1	1.6	24.4	9.2	20.6	12.9
6/19/07	170	27.6	16.2	21.3	96.5	55.0	74.0	3.3	177.5	37.5	19.3	9.1	20.5	12.5
6/20/07	171	19.8	11.5	16.0	87.8	49.0	63.4	2.7	165.6	0.0	25.3	9.1	20.3	12.3
6/21/07	172	24.1	11.9	17.6	84.3	44.7	62.5	2.3	146.1	0.0	26.8	9.1	20.1	11.9
6/22/07	173	18.9	10.3	14.7	79.6	35.8	56.1	1.4	155.0	0.0	28.1	9.0	19.9	11.4
6/23/07	174	19.8	6.5	13.9	76.0	32.8	52.3	1.4	162.5	0.0	27.5	9.0	19.8	10.9
6/24/07	175	25.4	13.5	19.7	66.7	38.1	52.8	2.0	158.6	0.0	27.9	8.9	19.6	10.2
6/25/07	176	28.5	15.5	23.0	74.6	37.3	53.2	2.0	177.5	0.0	28.4	8.9	19.4	9.3
6/26/07	177	30.4	19.2	25.0	78.7	44.4	62.3	2.2	177.5	0.0	27.6	8.9	19.2	8.5
6/27/07	178	30.1	19.6	24.3	90.5	49.1	71.9	3.4	177.5	0.3	25.5	8.9	18.9	7.9
6/28/07	179	24.3	15.5	20.9	76.8	44.6	56.6	1.8	177.5	0.0	24.6	8.9	18.5	7.5
6/29/07	180	21.1	10.4	16.6	77.0	35.4	53.9	2.0	154.6	0.0	30.6	8.8	18.1	7.1
6/30/07	181	19.7	10.7	15.5	80.2	51.4	64.0	1.4	156.1	0.0	20.2	8.8	17.7	6.8
7/1/07	182	18.0	8.5	13.4	90.6	42.5	65.2	1.2	174.2	0.0	21.4	8.7	17.3	6.7
7/2/07	183	22.4	8.5	15.8	87.5	37.3	59.8	1.1	177.5	0.0	24.3	8.7	17.0	6.6
7/3/07	184	23.9	12.1	18.1	71.7	25.6	50.1	1.8	174.2	0.0	26.8	8.6	16.6	6.5
7/4/07	185	16.0	13.2	15.1	98.5	62.7	86.6	1.3	134.1	4.3	3.5	8.6	16.4	6.4
7/5/07	186	23.2	14.5	17.7	99.2	67.3	90.9	1.5	163.9	1.2	12.8	8.6	16.3	6.5
7/6/07	187	25.0	15.2	19.4	92.7	45.8	73.8	1.1	177.5	0.0	22.1	8.5	16.1	6.6
7/7/07	188	26.1	13.4	20.5	88.1	45.3	63.6	1.9	177.5	0.0	19.7	8.4	15.8	6.5
7/8/07	189	25.8	17.0	21.0	94.6	67.8	77.4	2.1	177.5	18.5	14.1	8.3	15.6	6.5
7/9/07	190	28.7	18.0	23.0	98.0	57.5	81.9	2.2	162.0	0.0	23.6	8.5	15.6	9.8
7/10/07	191	28.9	18.8	23.4	90.7	61.5	76.1	2.1	131.1	0.0	25.9	8.5	15.8	12.6
7/11/07	192	23.0	13.3	19.8	91.2	52.1	75.5	2.7	171.9	0.0	21.1	8.3	15.9	12.1
7/12/07	193	23.5	10.4	17.2	83.7	36.1	62.1	2.7	157.7	0.3	28.5	8.2	15.7	11.3
7/13/07	194	20.6	12.4	16.2	92.5	40.3	67.7	1.9	163.4	0.0	23.4	8.1	15.7	10.4
7/14/07	195	17.3	11.2	14.5	94.6	67.3	84.5	1.8	177.5	7.1	7.3	8.0	15.6	9.7
7/15/07	196	19.9	13.1	15.9	97.7	63.1	84.2	2.3	162.4	5.4	21.1	7.9	15.4	9.7
7/16/07	197	22.4	12.9	17.4	89.8	45.6	70.5	1.4	174.1	0.0	24.1	7.8	15.4	9.3
7/17/07	198	25.3	14.2	19.7	90.0	48.4	69.0	1.4	176.7	0.0	25.3	7.7	15.3	8.8
7/18/07	199	24.7	15.1	19.8	96.1	60.8	80.5	1.7	177.5	23.5	25.1	7.5	15.3	8.3
7/19/07	200	24.0	16.6	18.4	96.9	72.1	90.6	1.2	177.5	8.1	12.6	7.5	15.2	8.7
7/20/07	201	22.6	13.8	17.6	94.9	43.7	70.2	1.3	150.6	0.0	25.5	7.4	15.2	9.8
7/21/07	202	24.4	12.8	18.5	76.7	36.4	58.1	1.1	133.7	0.0	28.2	7.3	15.1	9.3
7/22/07	203	27.2	14.3	20.1	70.0	33.6	57.6	1.3	177.5	0.0	26.7	7.2	15.1	8.7
7/23/07	204	26.3	14.8	19.9	75.5	37.5	59.0	1.0	177.5	2.3	21.3	7.1	15.0	8.1
7/24/07	205	22.6	14.8	18.2	95.0	67.3	80.4	1.9	177.5	0.0	15.8	7.1	14.9	7.7
7/25/07	206	25.5	14.3	20.4	95.8	53.2	75.2	1.6	153.5	0.0	27.4	7.0	14.7	7.4
7/26/07	207	26.8	15.9	21.6	94.8	49.3	74.2	1.9	106.8	0.0	25.8	6.9	14.6	7.1
7/27/07	208	23.6	17.0	19.9	98.3	64.4	85.0	1.3	92.7	0.0	17.0	6.8	14.5	6.8
7/28/07	209	26.2	17.0	21.2	97.3	62.2	83.6	0.8	111.2	0.0	18.0	6.7	14.4	7.5
7/29/07	210	27.2	16.7	21.2	91.8	38.4	68.8	1.5	91.0	0.0	26.8	6.7	14.3	9.4
7/30/07	211	27.4	15.7	21.8	85.6	39.9	58.6	1.3	92.3	0.0	25.6	6.7	14.3	8.6
7/31/07	212	29.8	18.4	24.2	72.3	42.1	54.8	0.9	129.2	0.0	22.6	6.6	14.2	7.9
8/1/07	213	30.2	18.8	25.0	84.2	40.6	60.1	1.6	107.0	0.0	25.7	6.5	14.2	7.3
8/2/07	214	31.5	19.8	25.6	86.1	35.6	62.2	1.7	172.5	0.4	25.0	6.5	14.1	6.8
8/3/07	215	29.6	18.0	24.3	93.6	32.3	66.0	1.6	172.6	0.0	22.9	6.4	14.1	6.7
8/4/07	216	26.4	15.4	20.8	82.1	29.5	53.5	1.1	174.9	0.0	28.4	6.4	13.9	6.5
8/5/07	217	25.8	11.8	20.1	89.6	37.3	59.8	2.0	142.1	0.0	26.2	6.3	13.8	6.2
8/6/07	218	28.4	19.3	23.0	94.6	50.3	71.7	1.5	158.9	0.0	21.2	6.3	13.7	6.1
8/7/07	219	24.6	17.0	20.6	97.5	59.3	82.3	1.3	136.6	2.7	9.6	6.2	13.7	5.9
8/8/07	220	28.6	19.8	23.7	98.4	46.8	73.8	1.8	173.9	0.0	24.4	6.2	13.6	6.0
8/9/07	221	25.5	15.9	20.2	77.9	45.7	61.8	2.1	166.4	0.0	16.8	6.1	13.6	5.9
8/10/07	222	27.8	13.7	20.0	76.9	31.9	58.0	1.5	171.1	0.0	26.7	6.1	13.4	5.8
8/11/07	223	29.6	15.8	22.4	78.0	29.3	50.3	1.6	160.1	0.0	26.1	6.1	13.4	5.7
8/12/07	224	27.8	17.0	21.1	97.2	39.1	67.4	1.9	177.5	2.2	15.8	6.0	13.4	5.6
8/13/07	225	25.4	16.1	20.3	97.8	29.5	59.0	1.6	176.9	0.0	27.1	6.0	13.3	5.6
8/14/07	226	22.6	11.9	17.9	83.2	50.2	66.0	1.9	177.5	0.0	23.3	6.0	13.2	5.6
8/15/07	227	25.2	16.5	20.7	87.5	33.2	59.3	2.1	145.9	0.0	22.5	6.0	13.2	5.5
8/16/07	228	27.6	14.4	20.6	87.8	19.4	58.1	2.3	124.9	0.0	20.9	5.9	13.1	5.5
8/17/07	229	22.6	9.1	15.4	79.3	25.4	58.4	1.9	150.1	2.2	16.1	5.9	13.1	5.3
8/18/07	230	20.7	7.2	13.6	94.4	32.3	64.8	1.1	155.1	0.0	25.1	5.9	12.9	5.3
8/19/07	231	21.6	9.8	15.3	82.0	37.9	62.8	1.4	124.0	0.0	20.9	5.9	12.9	5.2
8/20/07	232	18.4	11.4	14.4	81.2	39.1	59.8	1.9	169.6	0.0	8.3	5.9	12.8	5.2
8/21/07	233	16.9	11.6	14.8	93.7	73.4	83.0	2.9	177.5	0.0	6.0	5.8	12.7	5.1
8/22/07	234	21.2	14.4	17.0	97.6	68.9	88.1	1.5	177.5	1.2	8.5	5.8	12.7	5.1
8/23/07	235	23.2	17.1	19.9	97.6	79.7	91.3	2.2	177.5	5.4	9.1	5.8	12.7	6.0
8/24/07	236	28.1	19.4	22.8	97.2	58.8	83.7	2.5	156.1	27.2	18.1	5.8	12.8	7.6
8/25/07	237	23.2	17.4	20.2	98.5	82.9	92.3	2.8	177.5	0.6	8.4	5.9	13.0	16.1
8/26/07	238	22.8	14.8	18.4	94.4	60.6	79.4	1.1	170.6	0.0	15.2	5.9	13.1	15.4
8/27/07	239	24.8	12.9	18.8	95.4	48.9	74.2	1.5	155.9	0.0	24.2	5.9	13.1	14.3
8/28/07	240	26.7	13.9	20.0	90.9	49.1	71.8	1.6	129.9	0.0	22.0	5.9	13.2	13.4
8/29/07	241	29.0	17.4	22.6	95.1	52.6	74.7	2.2	169.7	0.0	20.6	5.9	13.3	12.7
8/30/07	242	23.5	13.3	19.1	95.4	42.6	74.7	1.0	121.6	0.0	18.3	5.9	13.5	12.0
8/31/07	243	24.6	10.3	17.1	90.3	32.1	65.4	1.2	120.0	0.0	22.5	5.9	13.5	11.3
9/1/07	244	21.7	11.0	15.8	89.9	35.4	66.5	1.4	170.6	0.0	23.0	5.9	13.5	10.8
9/2/07	245	22.8	10.8	16.3	90.6	36.9	66.7	1.3	175.9	0.0	23.1	5.8	13.4	10.2
9/3/07	246	27.5	13.1	19.0	94.2	30.3	63.6	1.8	174.9	0.0	20.2	5.8	13.4	9.6
9/4/07	247	19.4	12.9	15.9	89.3	51.7	69.0	1.0	122.1	2.2	9.8	5.8	13.5	9.0
9/5/07	248	21.1	13.3	16.4	91.4	46.5	72.6	1.9	177.5	1.8	12.6	5.8	13.4	8.7

Appendix E

Evapotranspiration Parameters and Calculation

Table E.1 – Monthly precipitation and Evapotranspiration (ET)

The following calculation is based on a method described in Allen et al. (1998) and is a modified version of text excerpted from Appendix C of Bekeris (2007). Bekeris (2007) also provided the author with a Microsoft Excel (MS Excel) spreadsheet containing the formulas listed below (unpublished). This spreadsheet was subsequently modified to represent the site-specific conditions at the Allin Farm.

Reference evapotranspiration is expressed as

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}$$

where,

ET_o	reference evapotranspiration [mm day^{-1}]
R_n	net radiation at the crop surface [MJ m^{-2} day^{-1}]
G	soil heat flux density [MJ m^{-2} day^{-1}]
T	air temperature at 2 m height [^{o}C]
u_2	wind speed at 2 m height [m s^{-1}]
e_s	saturation vapour pressure [kPa]
e_a	actual vapour pressure [kPa]
e_s – ea	saturation vapour pressure deficit [kPa]
Δ	slope vapour pressure curve (kPa^{o}C^{-1})
γ	psychrometric constant (kPa^{o}C^{-1})

Saturation vapour pressure is expressed as

$$e_s = 0.3054\left[\exp\left(\frac{17.27T_{\max}}{T_{\max} + 237.3}\right) + \exp\left(\frac{17.27T_{\min}}{T_{\min} + 237.3}\right)\right]$$

where

e_s	saturation vapour pressure [kPa]
T_{max}	maximum temperature in daily period [^{o}C]
T_{min}	minimum temperature in daily period [^{o}C]

Slope of vapour pressure curve is expressed as

$$\Delta = \frac{4098\left[0.6108\exp\left(\frac{17.27T}{T+237.3}\right)\right]}{\left(T+237.3\right)^2}$$

where

Δ	slope vapour pressure curve (kPa^{o}C^{-1})
T	mean air temperature [^{o}C]

Actual vapour pressure is expressed as

$$e_a = \frac{\exp\left(\frac{17.27T_{\min}}{T_{\min}+237.3}\right)\frac{RH_{\max}}{100} + \exp\left(\frac{17.27T_{\max}}{T_{\max}+237.3}\right)\frac{RH_{\min}}{100}}{2}$$

where

e_a	actual vapour pressure [kPa]
T_{max}	maximum temperature in daily period [^{o}C]
T_{min}	minimum temperature in daily period [^{o}C]
RH_{max}	maximum relative humidity in daily period [%]
RH_{min}	minimum relative humidity in daily period [%]

Psychrometric constant is expressed as

$$\gamma = 0.665 \cdot 10^{-3} P$$

where

γ	psychrometric constant (kPa^{o}C^{-1})
P	atmospheric pressure [kPa]

Net radiation is expressed as

$$R_n = R_{ns} - R_{nl}$$

where

R_n	net radiation [MJ m^{-2} day^{-1}]
R_{ns}	incoming net shortwave radiation [MJ m^{-2} day^{-1}]
R_{nl}	outgoing net longwave radiation [MJ m^{-2} day^{-1}]

Net outgoing longwave radiation is expressed as

$$R_{nl} = \sigma\left[\frac{T_{\max,K}{}^4 + T_{\min,K}{}^4}{2}\right]\left(0.34 - 0.14\sqrt{e_a}\right)\left[1.35\frac{R_s}{R_{so}} - 0.35\right]$$

where

R_{nl}	net outgoing longwave radiation [MJ m^{-2} day^{-1}]
σ	Stefan-Boltzmann constant (4.903×10^{-9} MJ K^{-4} m^{-2} day^{-1})
$T_{max,K}$	maximum absolute temperature during the 24-hour period [K]
$T_{min,K}$	minimum absolute temperature during the 24-hour period [K]
e_a	actual vapour pressure [kPa]
R_s	measured or calculated solar radiation [MJ m^{-2} day^{-1}]
R_{so}	calculated clear-sky radiation [MJ m^{-2} day^{-1}]

Calculated clear-sky radiation is expressed as

$$R_{so} = \left(0.75 + 2 \cdot 10^{-5} z\right) R_a$$

where
z station elevation above sea level [m]
R_a extraterrestrial radiation [MJ m^{-2} day^{-1}]

Extraterrestrial radiation is expressed as

$$R_a = \frac{24 \cdot 60}{\pi} G_{sc} d_r \left[\omega_s \sin\varphi \sin\delta + \cos\varphi \cos\delta \sin\omega_s\right]$$

where

R_a	extraterrestrial radiation [MJ m^{-2} day^{-1}]
G_{sc}	solar constant [0.0820 MJ m^{-2} day^{-1}]
d_r	inverse relative distance Earth-Sun
ω_s	sunset hour angle (rad)
φ	latitude (rad)
δ	solar declination (rad)

Inverse relative distance Earth-Sun and solar declination are expressed as

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi}{365} J\right)$$

$$\delta = 0.409 \sin\left(\frac{2\pi}{365} J - 1.39\right)$$

where

J	number of the day in the year

Sunset hour angle is expressed as

$$\omega_s = \arccos[-\tan\varphi \tan\delta]$$

The calculation of the crop specific evapotranspiration (ET_{cadj}) was derived from the following equation,

$$ET_{cadj} = (K_s K_{cb} + K_e) ET_o$$

where

$ET_{c\ adj}$	crop evapotranspiration adjusted for soil water stress
K_s	water stress coefficient
K_{cb}	basal crop coefficient
K_e	soil evaporatation coefficient

Three values for K_{cb} are required to describe and construct the crop coefficient curve: those during the initial stage ($K_{cb\ ini}$), the mid-season stage ($K_{cb\ mid}$) and at the end of the late season stage ($K_{c\ end}$).

The following is a sample calculation based upon and partially excerpted from Bekeris (2007):

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
	Day	ET_o	P-RO	I/fw	h	K_{cmax}	f_c	f_w	f_{ew}	K_{cb}	$D_{e,istart}$	K_r	K_e	E
1	135	1.35	0	0	0.261	1.186	0.01	1	0.99	0.15	0	1	1.036	1.398
2	136	1.812	0	0	0.261	1.183	0.01	1	0.99	0.15	1.41	1	1.033	1.873

	O	P	Q	R	S	T	U	V	W	X	Y	Z
	DP_e	$De_{,i\ end}$	K_c	ET_c	Root depth	Ending D	Irr.	Drain	K_s	$K_{c\ adj}$	Corr Ending D	$Et_{c\ adj}$
1	0	1.41	1.19	1.60	0	1.600	0	0	1	1.186	1.60	1.60
2	0	3.30	1.18	2.14	0	3.744	0	0	1	1.183	3.74	2.14

Columns:

A	day of year
B	reference evapotranspiration [mm]
C	precipitation minus runoff [mm]
D	net irrigation depth [mm]
E	plant height [m]
F	maximum Kc immediately following wetting [-]
G	effective fraction of soil surface covered by vegetation [-]
H	fraction of soil surface wetted by irrigation or precipitation [-]
I	exposed and wetted soil fraction [-]
J	basal crop coefficient [-]
K	initial depth of evaporation (depletion) [mm]
L	dimensionless evaporation reduction coefficient [-]
M	soil evaporation coefficient [-]
N	evaporation on day i [mm]
O	deep percolation from evaporating layer [mm]
P	depth of evaporation (depletion) at end of day [mm]
Q	dual crop coefficient [-]
R	crop evapotranspiration, uncorrected for soil water stress [mm]
S	root depth [m]
T	root zone depletion at end of day i (soil water stress correction) [mm]
U	net irrigation depth on day i (soil water stress correction) [mm]
V	deep percolation (soil water stress correction) [mm]
W	dimensionless transpiration reduction factor [-]
X	evapotranspiration coefficient [-]
Y	corrected root zone depletion at end of day i [mm]
Z	final crop evapotranspiration value [mm]

Equations for Row 2:

A	day of year
B	ET$_o$
C	P - RO
D	Irrigation on day 1/H1
E	max ((J2/K$_{cb}$ mid) x max height, E1)
F	max ((1.2+(0.04*(u$_2$-2)-0.004*(RH$_{min}$-45))*(E2/3)^0.3),(J2+0.05))
G	max ((((J2-K$_{c\ min}$)/(K$_{c\ max}$ – K$_{c\ min}$))^(1*0.5E2)), 0.01)
H	1 (no irrigation)
I	min (1-G2, H2)
J	basal crop coefficient, varies with crop growth stage
K	max (P1-C2-D2,0)
L	max (if(K2<REW,1,((TEW-K2)/(TEW-REW))),0)
M	min (L2*(F2-J2),I2*F2)
N	M2 x B2
O	max (C2+D2-P1,0)
P	min (K2-C2-D2+N2/I2+O2,0)
Q	M2 + J2
R	Q2 x B2
S	max (min.root+(max.root-min.root)*(J2-K$_{cb\ ini}$)/(K$_{cb\ mid}$ – K$_{cb\ ini}$),0)
T	Y1-C2-U2+R2

U	0 (no irrigation)
V	max (C2+U1-R2-Y1,0)
W	if (T2>RAW,(TAW-T2)/(TAW-RAW),1)
X	W2 x J2 + M2
Y	Y1-C2-U2+X2*B2+V2
Z	X2 x B2

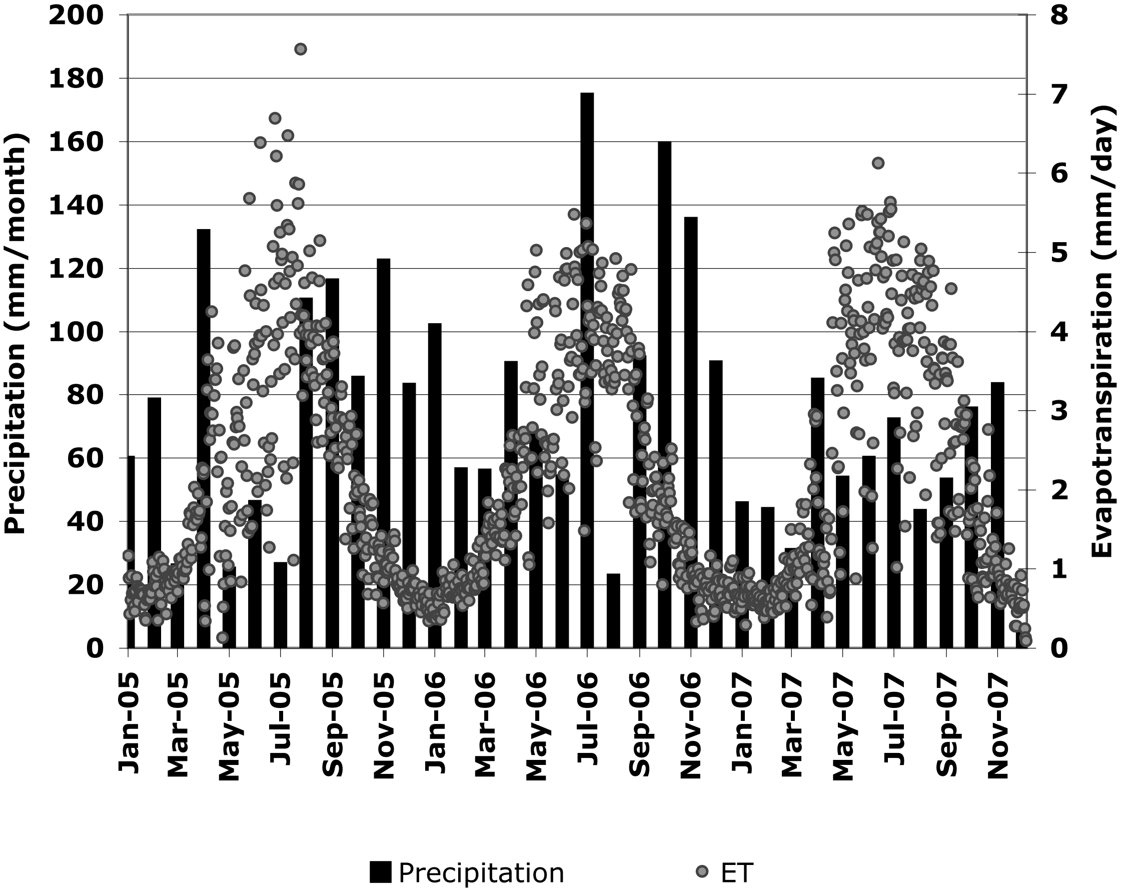

Figure E.1 - Monthly precipitation and daily evapotranspiration (ET) at the Allin Farm between January 2005 and December 2007.

Appendix F

Grain Size Analysis

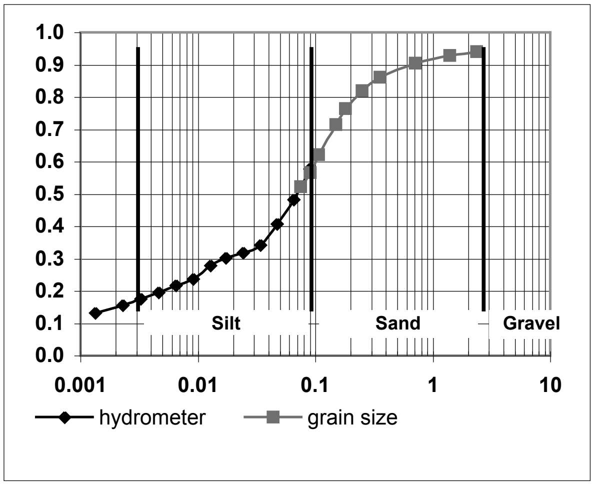

Figure F.1 - Grain size distribution at BH1 at a depth of 3.80m.

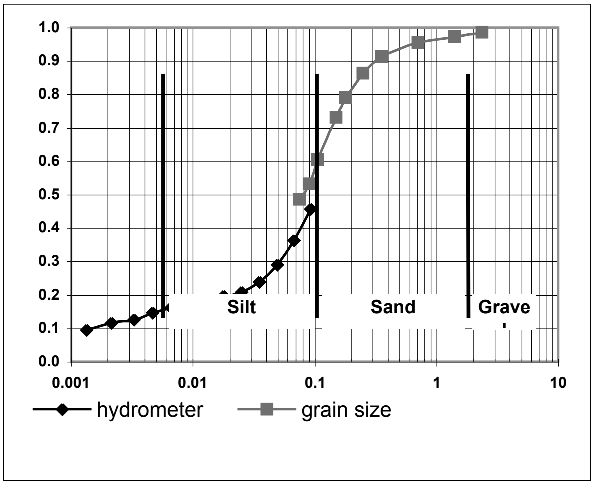

Figure F.2 - Grain size distribution at BH2 at a depth of 2.15m.

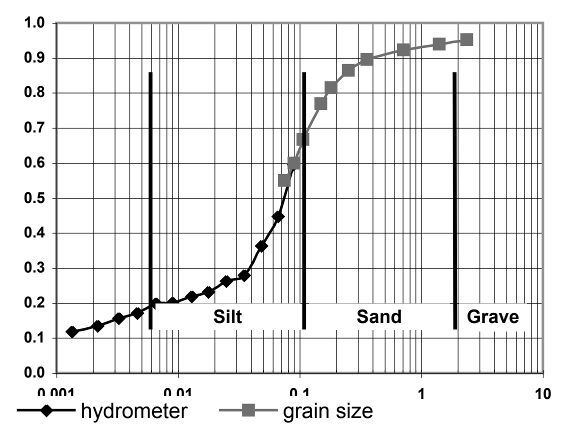

Figure F.3 - Grain size distribution at BH2 at a depth of 3.05m.

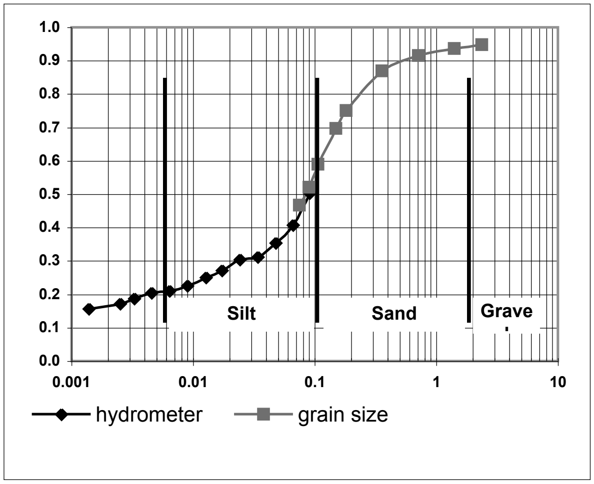

Figure F.4 - Grain size distribution at BH3 at a depth of 2.85m.

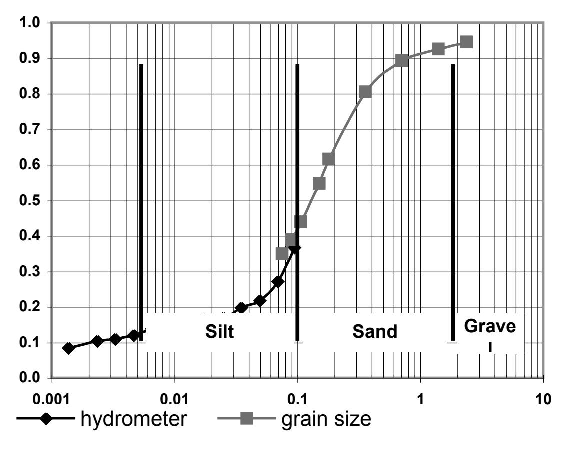

Figure F.5 - Grain size distribution at BH4 at a depth of 2.75m.

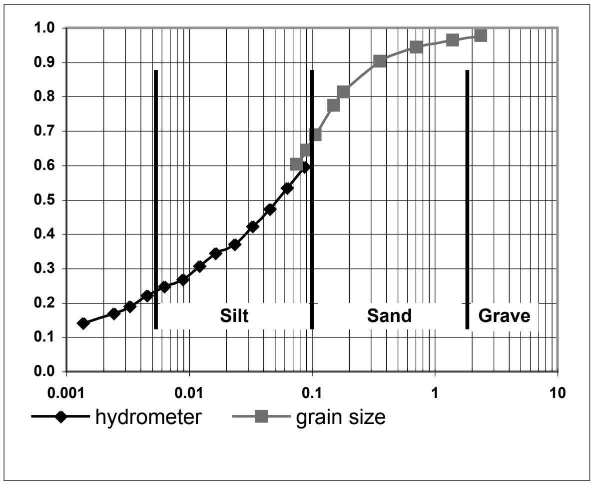

Figure F.6 - Grain size distribution at BH5 at a depth of 1.85m.

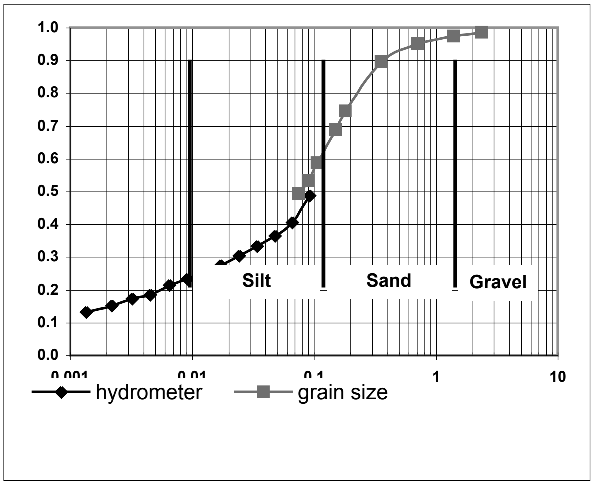

Figure F.7 - Grain size distribution at BH6 at a depth of 2.05m.

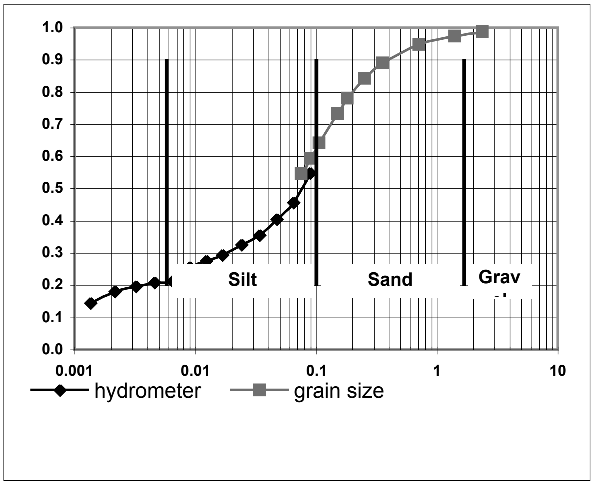

Figure F.8 - Grain size distribution at BH6 at a depth of 2.85m.

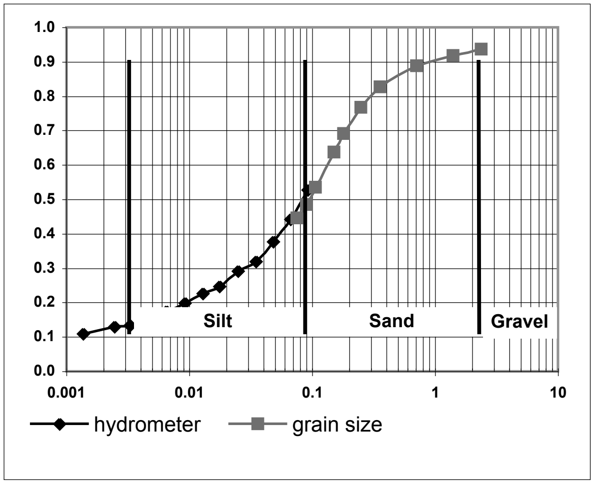

Figure F.9 - Grain size distribution at BT1 at a depth of 2.55m.

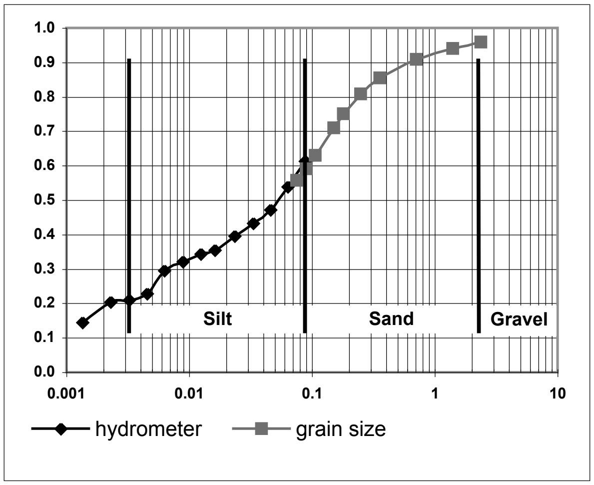

Figure F.10 - Grain size distribution at BT1 at a depth of 4.10m.

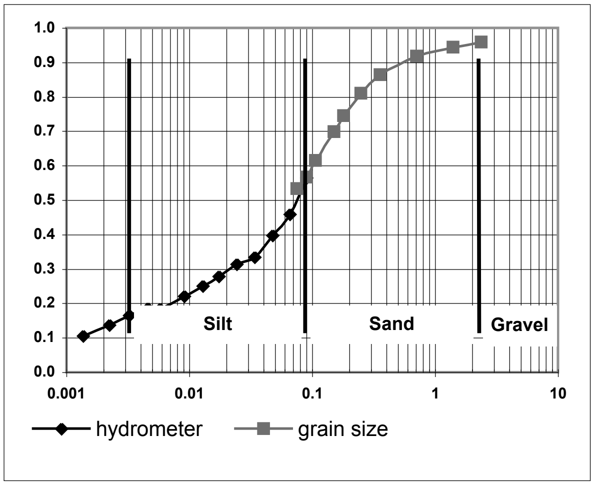

Figure F.11 - Grain size distribution at KA3-5 at a depth of 1.75m.

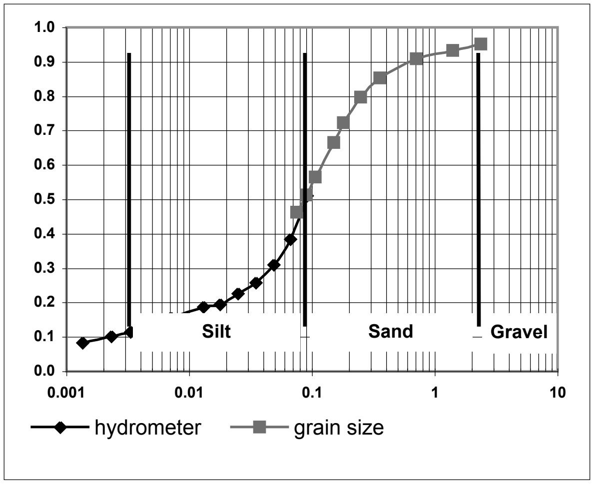

Figure F.12 - Grain size distribution at KA3-5 at a depth of 4.95m.

Appendix G

Additional Soil Analytical Results

Table G.1 - Additional Soil Core Data

DEPTH (mbgs)	MOISTURE CONTENT (Weight %)	MOISTURE CONTENT (Volume %)	Dry Bulk Density (g/cm^3)	Porosity %	SOIL NITATE CONCENTRATION (mg NO_3-N/kg soil)	SOIL CHLORIDE CONCENTRATION (mg Cl/L)
KA9 - January 2007						
0.22	12.95	24.75	1.91	27.89	0.67	7.62
0.55	4.69	10.50	2.24	15.52	0.14	4.94
0.82	2.87	6.50	2.26	14.62	0.00	5.24
1.1	2.39	5.63	2.36	10.90	0.18	5.07
1.17	10.61	20.45	1.93	27.23	1.75	9.29
1.57	7.04	14.78	2.10	20.74	0.59	6.78
1.67	7.16	16.43	2.30	13.38	0.49	6.11
1.92	5.84	13.83	2.37	10.58	0.50	4.70
2.22	7.58	17.13	2.26	14.75	0.50	4.33
2.52	6.80	16.17	2.38	10.31	0.75	4.67
3.34	3.68	8.60	2.34	11.86	0.79	4.51
3.64	5.69	12.80	2.25	15.14	1.04	6.08
3.96	3.21	7.57	2.36	11.06	0.97	5.23
4.26	3.39	7.98	2.35	11.23	1.09	4.18
4.56	2.24	5.17	2.31	13.02	1.00	4.19
4.86	2.48	5.75	2.32	12.40	1.22	4.25
5.16	3.64	8.47	2.33	12.26	2.30	5.07
5.51	3.21	7.57	2.36	10.97	1.04	3.49
5.81	3.20	7.55	2.36	10.94	1.07	3.80
6.11	2.87	6.70	2.33	11.99	1.26	3.97
6.2	2.60	6.08	2.34	11.60	1.25	6.98
6.5	4.54	10.25	2.26	14.77	1.16	6.09
6.8	3.01	7.10	2.36	10.86	0.95	5.41
7.1	3.38	7.72	2.29	13.77	1.13	5.34
7.41	4.40	9.90	2.25	15.13	0.99	6.07
7.71	5.09	11.42	2.24	15.40	3.10	5.37
8.01	3.41	6.93	2.03	23.32	1.36	3.89
8.31	4.43	9.85	2.22	16.13	2.04	6.67
8.79	3.21	7.45	2.32	12.36	1.12	14.43
9.44	5.38	12.73	2.37	10.69	0.78	8.70
9.74	10.21	21.20	2.08	21.67	0.34	24.53
10.24	7.61	17.20	2.26	14.74	0.81	5.70
10.74	6.28	14.82	2.36	10.98	1.33	8.76
11.09	5.53	11.47	2.07	21.79	1.34	12.74
11.51	7.83	18.05	2.31	13.00	1.60	11.97
12.49	12.73	25.88	2.03	23.26	4.20	12.17
12.79	11.70	24.15	2.06	22.13	2.23	4.81
13.09	11.25	21.95	1.95	26.40	1.90	5.85
13.58	8.23	16.58	2.01	24.01	0.37	10.00
13.95	14.58	29.10	2.00	24.70	3.47	71.74
14.26	11.10	20.77	1.87	29.40	1.25	5.96
14.64	18.09	32.78	1.81	31.62	7.21	28.10
14.94	12.53	23.73	1.89	28.50	6.61	11.64
15.49	10.15	21.62	2.13	19.64	0.32	12.11
15.89	8.95	18.63	2.08	21.40	0.60	25.78
16.4	17.29	31.67	1.83	30.87	7.92	25.59
16.81	18.94	34.52	1.82	31.24	1.73	11.69
17.21	14.72	28.45	1.93	27.08	0.19	10.54
18.54	14.11	27.40	1.94	26.70	0.00	7.69

DEPTH (mbgs)	MOISTURE CONTENT (Weight %)	MOISTURE CONTENT (Volume %)	Dry Bulk Density (g/cm^3)	Porosity %	SOIL NITATE CONCENTRATION (mg NO_3-N/kg soil)	SOIL CHLORIDE CONCENTRATION (mg Cl/L)
19.08	11.18	22.65	2.03	23.54	0.16	19.35
19.53	13.19	26.30	1.99	24.78	0.28	10.75
19.88	11.74	23.97	2.04	22.94	0.11	9.09
20.34	11.69	24.08	2.06	22.23	0.29	17.46
20.79	14.02	27.28	1.95	26.54	0.30	15.98
21.77	10.46	22.12	2.11	20.23	1.54	5.30
22.16	15.11	28.70	1.90	28.30	0.12	20.97
22.76	12.25	24.60	2.01	24.19	0.15	21.54
23.51	12.01	24.48	2.04	23.04	0.22	13.40
23.88	13.22	26.87	2.03	23.29	0.18	15.85
24.68	15.15	28.05	1.85	30.11	0.12	7.08
25.34	13.82	25.52	1.85	30.33	0.18	14.23
25.94	16.24	31.52	1.94	26.76	0.13	7.20
27.88	14.46	28.55	1.97	25.48	0.00	18.42
28.7	10.19	21.45	2.11	20.57	0.00	5.81
29.64	9.49	19.85	2.09	21.08	0.00	5.53
KA10 - January 2007						
0.1	24.6	43.25	1.76	33.58	7.02	3.23
0.4	13.9	25.24	1.82	31.28	1.26	3.39
0.69	7.2	14.52	2.02	23.65	0.39	3.24
0.94	3.9	8.22	2.12	20.00	0.29	3.63
1.15	3.7	7.31	1.97	25.66	0.13	10.59
1.33	1.2	2.39	2.06	22.26	0.07	11.90
1.5	1.4	3.07	2.27	14.34	0.13	19.36
1.75	5.6	11.84	2.11	20.38	0.25	7.70
1.95	3.3	6.82	2.09	21.13	0.23	13.29
3.13	8.0	17.25	2.16	18.49	0.15	4.25
3.34	6.3	13.11	2.08	21.51	0.62	6.81
3.62	7.7	16.76	2.18	17.74	0.33	5.58
3.92	3.8	8.57	2.27	14.34	0.24	3.00
4.12	3.3	7.30	2.18	17.74	0.33	8.22
4.36	2.9	6.81	2.31	12.83	0.25	7.72
4.58	3.1	6.80	2.19	17.36	0.00	4.85
4.84	3.4	7.66	2.26	14.72	0.16	12.68
6.22	10.1	20.89	2.06	22.26	0.22	8.00
6.41	11.3	22.33	1.98	25.28	0.26	5.45
6.63	9.6	18.32	1.90	28.30	0.15	10.73
6.97	5.8	13.38	2.29	13.58	0.16	5.61
7.17	5.8	12.85	2.22	16.23	0.14	8.58
7.41	8.3	18.44	2.22	16.23	0.15	5.46
7.62	5.6	12.40	2.21	16.60	0.11	6.00
7.96	7.3	15.92	2.18	17.87	0.20	13.15
8.41	7.9	17.30	2.18	17.83	0.15	11.38
8.71	9.6	19.98	2.07	21.83	0.43	13.67
9.11	8.5	17.88	2.12	20.17	0.23	21.70
9.29	11.9	23.82	2.01	24.18	0.34	11.25
9.62	15.6	30.45	1.96	26.13	0.51	22.84
9.99	14.3	25.12	1.76	33.77	0.81	16.09
10.34	8.8	18.48	2.10	20.87	0.30	7.22
10.53	11.8	24.02	2.04	23.06	0.91	14.43
10.93	10.3	19.72	1.91	28.02	0.69	7.46
11.51	14.7	27.28	1.85	30.04	2.99	11.80
12.54	7.6	16.35	2.16	18.42	2.02	9.05

DEPTH (mbgs)	MOISTURE CONTENT (Weight %)	MOISTURE CONTENT (Volume %)	Dry Bulk Density (g/cm^3)	Porosity %	SOIL NITATE CONCENTRATION (mg NO$_3$-N/kg soil)	SOIL CHLORIDE CONCENTRATION (mg Cl/L)
13.18	10.2	21.22	2.09	21.28	0.00	---
13.63	13.4	25.85	1.93	27.28	1.76	21.02
13.98	11.5	23.97	2.08	21.39	0.13	27.03
14.59	11.0	21.57	1.96	26.13	1.26	8.40
KA5-5 - January 2007						
0.05	22.73	39.09	1.72	35.09	3.05	10.13
0.40	16.14	30.02	1.86	29.81	2.09	4.99
0.65	8.07	17.66	2.19	17.36	0.27	8.64
0.92	8.02	17.20	2.15	19.03	0.24	2.92
1.10	7.68	15.66	2.04	23.02	0.00	6.45
1.30	6.81	14.24	2.09	21.13	0.00	3.95
1.55	7.66	15.17	1.98	25.28	0.00	6.22
1.81	6.63	14.85	2.24	15.47	0.00	10.60
2.03	6.59	14.89	2.26	14.72	0.00	10.55
2.27	5.35	10.05	1.88	29.06	0.00	12.09
2.50	7.08	14.87	2.10	20.75	0.34	11.46
2.75	4.97	10.63	2.14	19.25	0.12	16.04
3.27	7.47	17.03	2.28	13.96	0.12	11.56
3.51	5.09	10.48	2.06	22.26	0.00	25.33
3.73	4.05	7.89	1.95	26.42	0.20	13.15
3.93	5.65	12.38	2.19	17.36	0.14	7.29
4.23	7.08	15.16	2.14	19.25	0.34	8.33
4.53	6.71	15.02	2.24	15.47	0.00	6.54
4.83	5.58	12.39	2.22	16.23	0.13	11.35
5.12	5.73	12.50	2.18	17.74	0.23	22.50
5.42	6.18	13.35	2.16	18.49	0.23	5.07
5.66	9.00	17.13	1.90	28.15	0.77	5.79
5.80	9.65	20.95	2.17	18.11	0.57	2.88
5.95	7.38	16.69	2.26	14.72	0.56	13.86
6.30	14.32	27.06	1.89	28.68	1.55	5.55
6.68	16.49	30.09	1.83	31.12	2.26	5.77
6.91	8.72	16.74	1.92	27.55	1.14	12.20
7.29	17.83	31.74	1.78	32.83	2.78	10.85
7.69	12.38	25.25	2.04	23.02	3.03	6.35
7.87	4.48	10.62	2.37	10.63	0.73	12.49
8.03	6.58	14.94	2.27	14.34	0.71	17.47
8.23	1.49	3.21	2.15	18.87	0.66	13.31
8.45	4.88	11.31	2.32	12.45	1.31	24.40
9.37	6.91	13.57	1.96	25.86	1.97	19.72
9.82	3.64	7.57	2.08	21.66	1.02	16.32
10.42	6.11	13.67	2.24	15.55	0.19	7.54
10.52	4.67	10.43	2.23	15.74	0.11	4.15
11.02	5.70	12.48	2.19	17.29	1.57	5.34
11.45	7.56	16.05	2.12	19.91	1.15	4.67
12.39	9.75	21.25	2.18	17.79	0.11	5.95
12.84	6.57	14.97	2.28	14.00	0.09	6.85
13.47	5.33	12.23	2.30	13.35	0.10	5.45
13.87	6.05	13.57	2.24	15.36	0.09	4.06
14.32	6.17	14.70	2.38	10.15	0.11	6.71
15.46	7.16	15.87	2.22	16.40	1.31	4.13
15.74	5.97	12.63	2.32	12.53	0.00	3.76
16.09	4.73	13.78	2.31	12.81	0.00	4.19
16.60	5.95	10.90	2.30	13.08	0.91	5.40

DEPTH (mbgs)	MOISTURE CONTENT (Weight %)	MOISTURE CONTENT (Volume %)	Dry Bulk Density (g/cm^3)	Porosity %	SOIL NITATE CONCENTRATION (mg NO$_3$-N/kg soil)	SOIL CHLORIDE CONCENTRATION (mg Cl/L)
16.95	6.74	13.63	2.29	13.49	0.06	4.25
17.35	6.47	15.73	2.33	11.97	0.92	4.74
17.76	8.12	15.02	2.32	12.39	0.00	6.65
18.26		18.72	2.30	13.04	0.00	3.97
BH1 - April 2006						
0.08	0.32	61.82	1.91	29.22	30.20	---
0.33	0.19	43.47	2.24	17.09	2.60	---
0.73	0.09	20.50	2.26	16.20	0.88	---
1.15	0.08	18.74	2.36	12.55	0.92	---
1.45	0.08	15.93	2.01	25.56	0.84	---
1.75	0.08	16.49	2.10	22.21	0.83	---
2.37	0.07	16.28	2.30	14.98	1.02	---
2.62	0.07	16.73	2.37	12.23	1.10	---
2.82	0.07	16.88	2.26	16.33	0.90	---
3.34	0.08	18.67	2.38	11.98	1.28	---
3.64	0.07	17.27	2.34	13.49	1.37	---
3.94	0.07	15.18	2.25	16.71	1.09	---
4.18	0.08	20.03	2.36	12.71	2.32	---
4.36	0.07	17.08	2.35	12.87	2.28	---
BH2 - April 2006						
0.08	0.26	49.36	1.91	29.22	14.40	---
0.29	0.15	29.53	1.91	29.22	1.28	---
0.47	0.15	34.67	2.24	17.09	3.03	---
0.84	0.10	22.07	2.26	16.20	1.22	---
1.49	0.08	16.29	2.10	22.21	1.10	---
1.86	0.08	19.33	2.37	12.23	1.68	---
2.14	0.08	18.37	2.26	16.33	1.87	---
2.34	0.09	21.10	2.38	11.98	1.45	---
2.68	0.09	21.95	2.34	13.49	1.86	---
3.15	0.07	15.30	2.34	13.49	2.17	---
BH3 - April 2006						
0.16	0.23	44.79	1.91	29.22	2.82	---
0.70	0.31	68.45	2.24	17.09	5.66	---
0.90	0.14	32.01	2.26	16.20	3.22	---
1.23	0.08	15.92	1.93	28.58	2.04	---
1.52	0.08	17.51	2.10	22.21	3.17	---
1.82	0.07	16.93	2.37	12.23	3.23	---
2.12	0.06	14.50	2.26	16.33	2.20	---
2.39	0.08	17.57	2.24	17.12	2.34	---
2.69	0.08	17.20	2.24	17.12	2.00	---
2.94	0.11	22.56	2.14	20.83	2.37	---
3.04	0.08	19.41	2.32	14.07	1.85	---
3.23	0.08	18.31	2.34	13.49	2.24	---
3.59	0.08	17.89	2.25	16.71	2.24	---
3.96	0.08	18.40	2.36	12.71	2.18	---
BH4 - April 2006						
0.12	0.26	50.03	1.91	29.22	17.30	---
0.42	0.18	40.47	2.24	17.09	3.68	---
0.64	0.11	24.55	2.26	16.20	3.74	---
0.86	0.07	15.90	2.26	16.20	2.31	---
1.40	0.07	15.52	2.10	22.21	3.68	---
1.62	0.09	19.75	2.30	14.98	3.69	---

DEPTH (mbgs)	MOISTURE CONTENT (Weight %)	MOISTURE CONTENT (Volume %)	Dry Bulk Density (g/cm^3)	Porosity %	SOIL NITATE CONCENTRATION (mg NO_3-N/kg soil)	SOIL CHLORIDE CONCENTRATION (mg Cl/L)
1.80	0.07	17.62	2.37	12.23	3.74	---
2.03	0.09	21.31	2.26	16.33	2.83	---
2.39	0.06	15.38	2.38	11.98	2.98	---
2.70	0.06	13.32	2.34	13.49	2.88	---
2.89	0.07	16.13	2.32	14.07	1.78	---
BH5 - April 2006						
0.09	0.29	56.19	1.96	26.04	2.57	---
0.39	0.13	25.18	1.96	26.04	2.59	---
0.69	0.17	34.16	1.96	26.04	3.61	---
0.96	0.09	18.28	2.01	24.15	2.32	---
1.29	0.09	17.75	2.05	22.64	2.01	---
1.53	0.08	16.27	2.04	23.02	1.57	---
1.83	0.07	13.78	1.91	27.92	1.42	---
2.35	0.07	12.55	1.77	33.21	1.38	---
2.64	0.07	12.64	1.80	32.08	1.37	---
3.05	0.08	15.71	1.94	26.79	1.23	---
3.33	0.07	12.56	1.91	27.92	0.91	---
3.67	0.07	13.39	1.90	28.30	0.73	---
3.95	0.08	17.19	2.22	16.23	0.76	---
BH6 - April 2006						
0.08	0.25	49.37	1.96	26.04	11.30	---
0.30	0.10	19.47	1.91	27.92	2.30	---
0.45	0.09	17.57	1.93	27.17	0.51	---
0.83	0.08	16.10	2.01	24.15	1.45	---
1.18	0.08	15.96	2.05	22.64	1.56	---
1.42	0.07	14.85	2.04	23.02	1.22	---
1.72	0.07	13.47	1.91	27.92	1.61	---
2.01	0.07	12.72	1.77	33.21	1.56	---
2.28	0.08	13.75	1.80	32.08	1.08	---
2.58	0.08	15.14	1.94	26.79	1.16	---
3.00	0.08	15.08	1.91	27.92	0.82	---
KA3-5 - April 2006						
0.05	0.16	27.67	1.78	32.83	1.04	---
0.22	0.09	15.23	1.71	35.47	0.73	---
0.47	0.13	23.40	1.81	31.70	0.47	---
0.67	0.15	27.23	1.82	31.32	0.84	---
1.24	0.15	27.15	1.82	31.32	0.53	---
1.54	0.19	36.52	1.91	27.92	0.75	---
2.05	0.16	30.66	1.92	27.55	0.33	---
2.30	0.18	33.70	1.92	27.47	0.71	---
3.06	0.10	18.96	1.95	26.42	0.39	---
3.89	0.09	18.07	1.99	24.91	0.21	---
4.10	0.08	17.03	2.04	23.02	0.19	---
4.30	0.04	8.36	2.11	20.38	0.13	---
4.81	0.09	19.54	2.23	15.85	0.14	---
4.96	0.08	18.79	2.28	13.96	0.27	---
5.15	0.07	15.96	2.25	15.09	1.41	---

Notes:

--- Not analyzed

Table G.2 - Additional Bromide Tracer Site Core Data

DEPTH (mbgs)	MOISTURE CONTENT (Weight %)	MOISTURE CONTENT (Volume %)	Dry Bulk Density (g/cm^3)	Porosity %	SOIL NITATE CONCENTRATION (mg NO_3-N/kg soil)	SOIL BROMIDE CONCENTRATION (mg Br/kg soil)
BT1 - April 2006						
0.10	0.24	47.53	1.96	26.04	19.30	39.74
0.27	0.24	47.90	1.96	26.04	3.77	70.41
0.43	0.09	17.27	1.96	26.04	1.70	66.50
0.89	0.07	14.42	2.01	24.15	1.47	48.44
1.09	0.06	12.80	2.05	22.64	1.67	13.60
1.22	0.05	11.01	2.04	23.02	1.75	2.23
1.52	0.07	13.87	1.91	27.92	2.02	0.24
1.75	0.06	9.88	1.77	33.21	1.88	0.39
1.94	0.07	13.23	1.80	32.08	1.92	0.26
2.36	0.08	14.74	1.94	26.79	1.81	0.30
2.61	0.06	11.74	1.91	27.92	1.57	0.26
2.96	0.07	12.74	1.90	28.30	1.42	---
3.29	0.06	13.82	2.25	15.09	1.46	---
3.53	0.06	13.21	2.11	20.38	1.45	---
4.00	0.08	17.34	2.22	16.23	1.36	---
4.31	0.01	3.27	2.25	15.09	0.96	---
4.51	0.09	21.30	2.25	15.09	1.79	---
4.78	0.05	11.65	2.25	15.09	1.25	---
5.01	0.07	15.85	2.25	15.09	1.47	---
BT1-2 - February 2007						
0.13	28.82	53.89	1.87	29.43	4.37	3.35
0.33	12.17	23.86	1.96	26.04	3.26	0.64
0.62	12.83	25.54	1.99	24.91	2.56	0.81
0.77	9.81	19.71	2.01	24.15	0.64	0.91
0.92	7.56	16.11	2.13	19.62	0.28	0.76
1.07	6.59	14.51	2.20	16.98	0.00	3.51
1.27	5.91	13.24	2.24	15.47	0.00	7.44
1.37	7.81	14.61	1.87	29.43	0.23	17.05
1.57	6.86	13.10	1.91	27.92	0.31	62.78
1.72	6.87	12.15	1.77	33.21	0.42	63.40
2.23	6.38	11.74	1.84	30.57	1.32	82.00
2.38	6.45	12.51	1.94	26.79	1.31	78.34
2.53	5.28	10.51	1.99	24.91	1.61	101.51
2.68	6.79	12.98	1.91	27.92	1.52	76.20
2.83	8.33	14.57	1.75	33.96	2.01	80.01
2.94	6.71	12.76	1.90	28.30	1.48	38.60
3.11	7.39	16.26	2.20	16.98	1.64	6.12
3.25	4.01	9.66	2.41	9.06	0.90	1.42
3.40	4.89	11.21	2.29	13.58	0.73	1.44
3.55	4.80	10.93	2.28	13.96	1.14	1.15
3.69	4.20	9.59	2.28	13.96	0.74	---
3.86	6.49	14.41	2.22	16.23	0.96	---
BT2 - February 2007						
0.10	26.25	46.72	1.78	32.83	14.58	13.47
0.25	12.35	22.73	1.84	30.57	11.77	4.62
0.40	10.51	19.03	1.81	31.70	5.29	2.34
0.52	10.26	19.40	1.89	28.68	2.76	2.64
0.67	8.32	16.72	2.01	24.15	4.60	1.21
0.82	4.12	9.63	2.34	11.70	2.46	0.00
0.97	5.79	12.85	2.22	16.23	1.11	0.00

DEPTH (mbgs)	MOISTURE CONTENT (Weight %)	MOISTURE CONTENT (Volume %)	Dry Bulk Density (g/cm^3)	Porosity %	SOIL NITATE CONCENTRATION (mg NO_3-N/kg soil)	SOIL BROMIDE CONCENTRATION (mg Br/kg soil)
1.12	7.05	15.79	2.24	15.47	0.64	0.00
1.26	6.64	15.33	2.31	12.83	0.46	0.00
1.37	6.77	15.03	2.22	16.23	0.45	0.00
1.52	6.99	16.00	2.29	13.58	0.90	0.00
1.67	6.86	15.85	2.31	12.83	0.71	0.00
1.82	7.07	16.04	2.27	14.34	0.70	0.00
1.97	7.00	16.04	2.29	13.58	0.62	0.00
2.12	6.55	15.46	2.36	10.94	0.71	0.00
BT3 - February 2007						
0.15	18.96	32.04	1.69	36.23	4.81	9.06
0.38	18.07	30.91	1.71	35.47	6.39	1.35
0.47	13.86	22.86	1.65	37.74	2.00	1.95
0.62	8.20	17.30	2.11	20.38	1.29	1.03
0.77	8.55	17.88	2.09	21.13	1.76	1.31
0.92	8.73	18.78	2.15	18.87	0.74	0.00
1.08	7.86	17.20	2.19	17.36	0.71	0.00
1.36	2.54	5.13	2.02	23.77	0.14	0.00
1.51	7.20	15.40	2.14	19.25	0.82	0.00
1.66	6.91	15.90	2.30	13.21	0.82	0.00
1.81	6.71	14.84	2.21	16.60	0.96	0.00
1.90	6.58	15.66	2.38	10.19	0.88	0.00
2.05	7.12	16.58	2.33	12.08	0.62	0.00
3.11	6.14	13.57	2.21	16.60	1.79	0.00
3.26	5.64	13.26	2.35	11.32	0.99	0.00
3.41	6.44	14.68	2.28	13.96	1.51	0.00
3.56	5.30	12.61	2.38	10.19	1.29	0.00
3.71	5.88	13.47	2.29	13.58	1.36	0.00
3.86	5.90	13.39	2.27	14.34	1.44	0.00

Notes:
--- Not analyzed

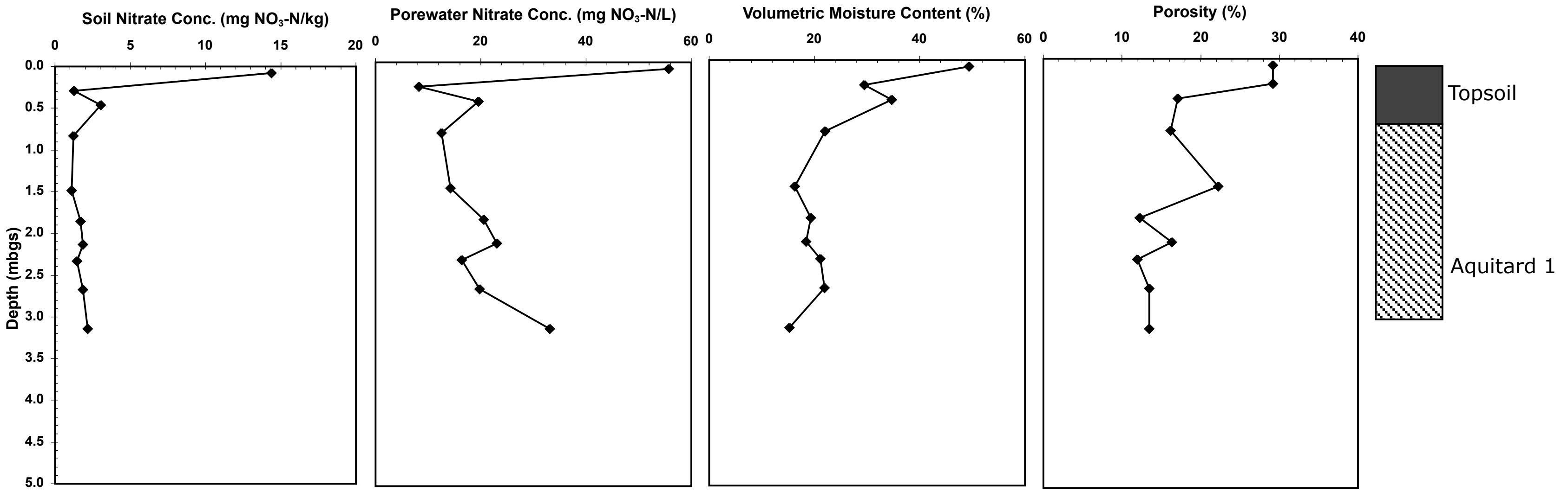

Figure G.1 - BH2 soil core profiles of bulk soil nitrate, porewater nitrate, volumetric moisture content, and porosity from core collected April 2006.

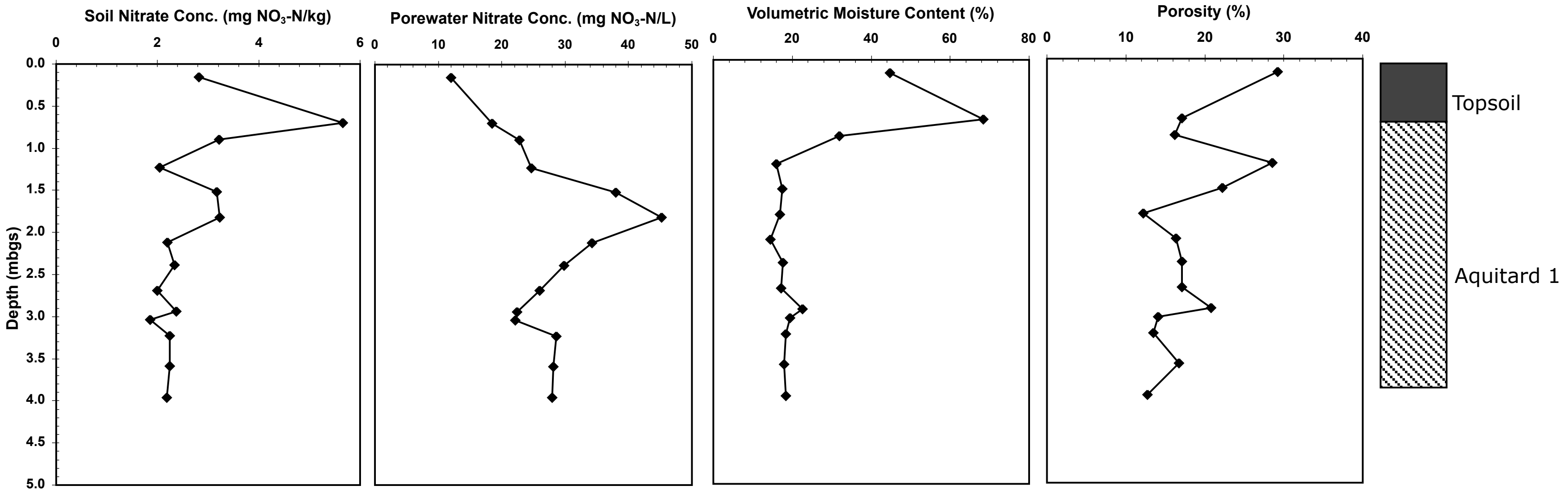

Figure G.2 - BH3 soil core profiles of bulk soil nitrate, porewater nitrate, volumetric moisture content, and porosity from core collected April 2006.

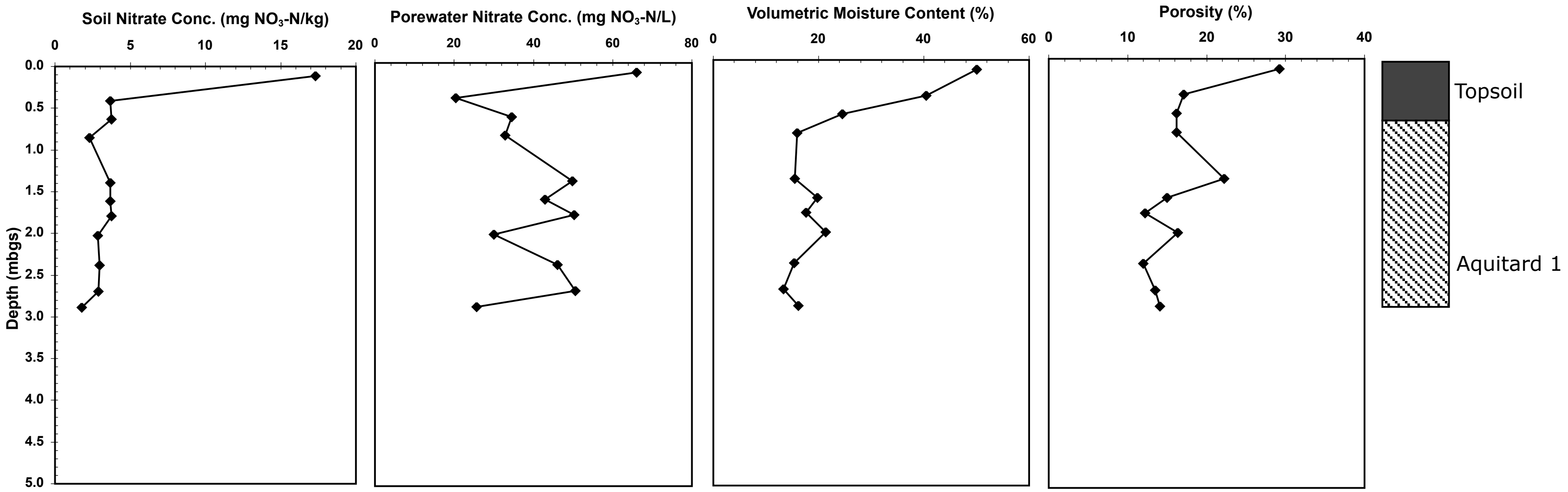

Figure G.3 - BH4 soil core profiles of bulk soil nitrate, porewater nitrate, volumetric moisture content, and porosity from core collected April 2006.

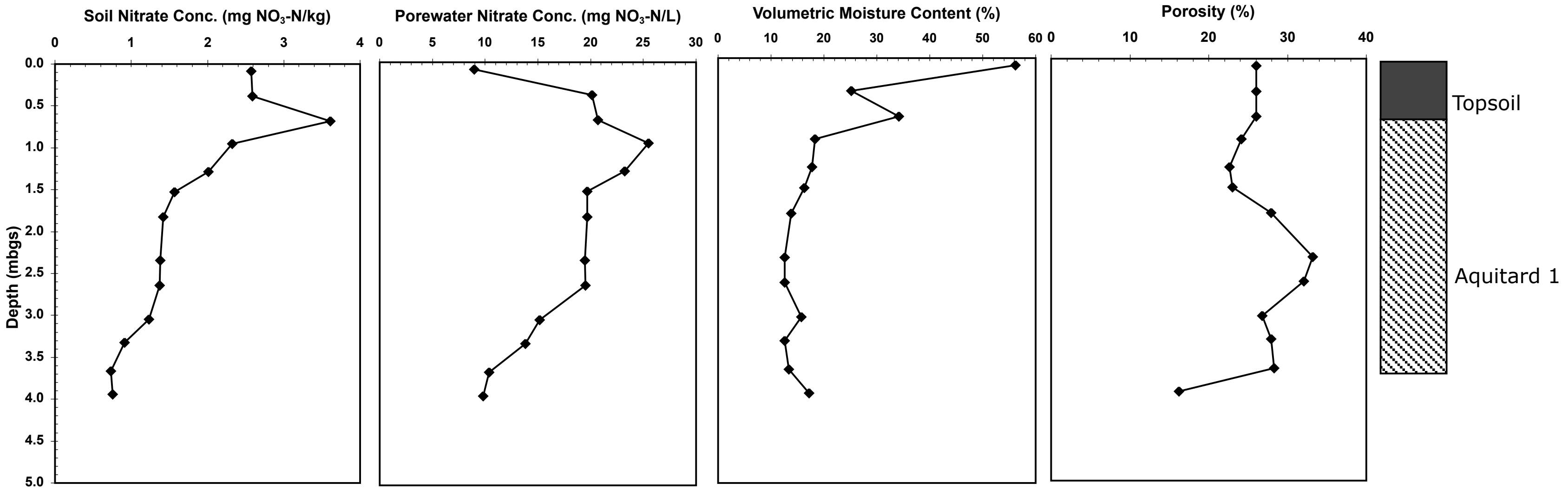

Figure G.4 - BH5 soil core profiles of bulk soil nitrate, porewater nitrate, volumetric moisture content, and porosity from core collected April 2006.

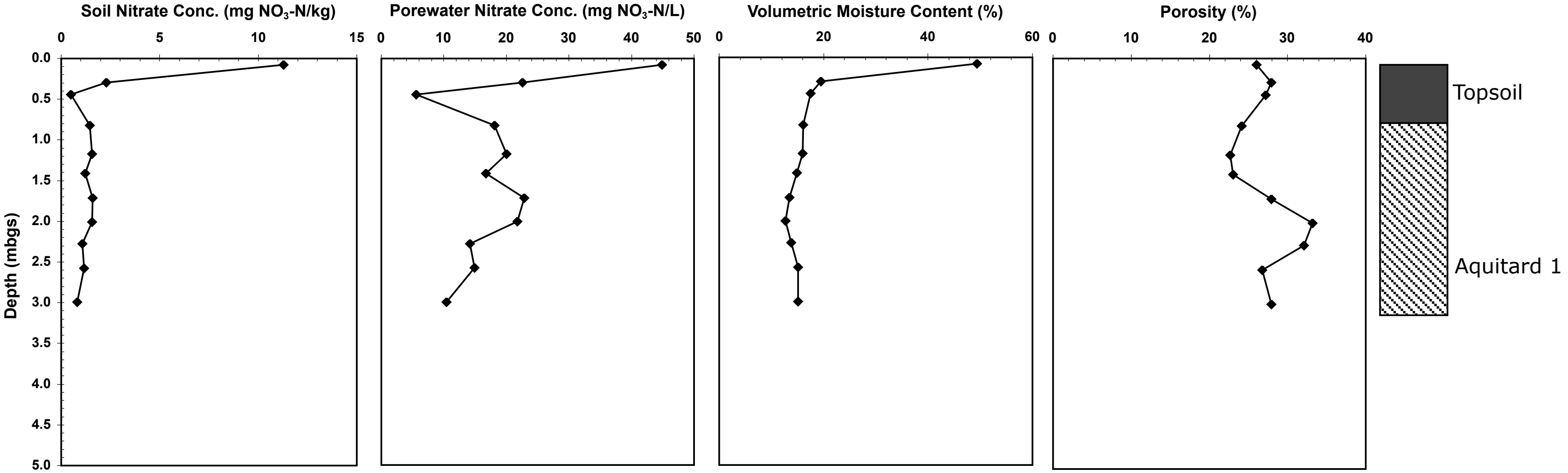

Figure G.5 - BH6 soil core profiles of bulk soil nitrate, porewater nitrate, volumetric moisture content, and porosity from core collected April 2006.

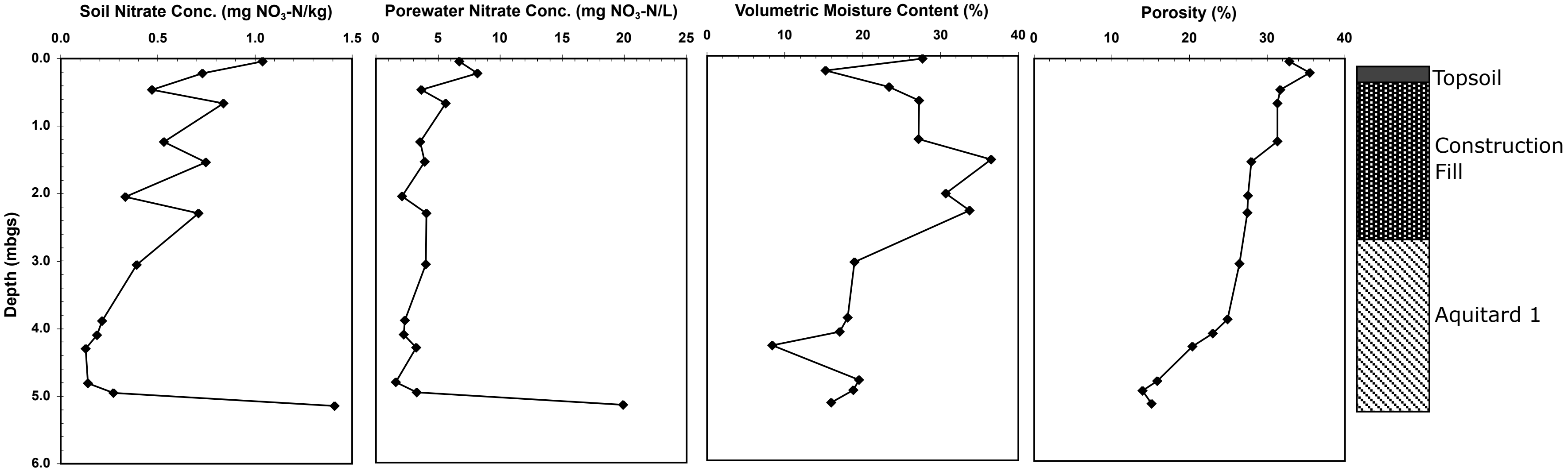

Figure G.6 - KA3-5 soil core profiles of bulk soil nitrate, porewater nitrate, volumetric moisture content, and porosity from core collected April 2006.

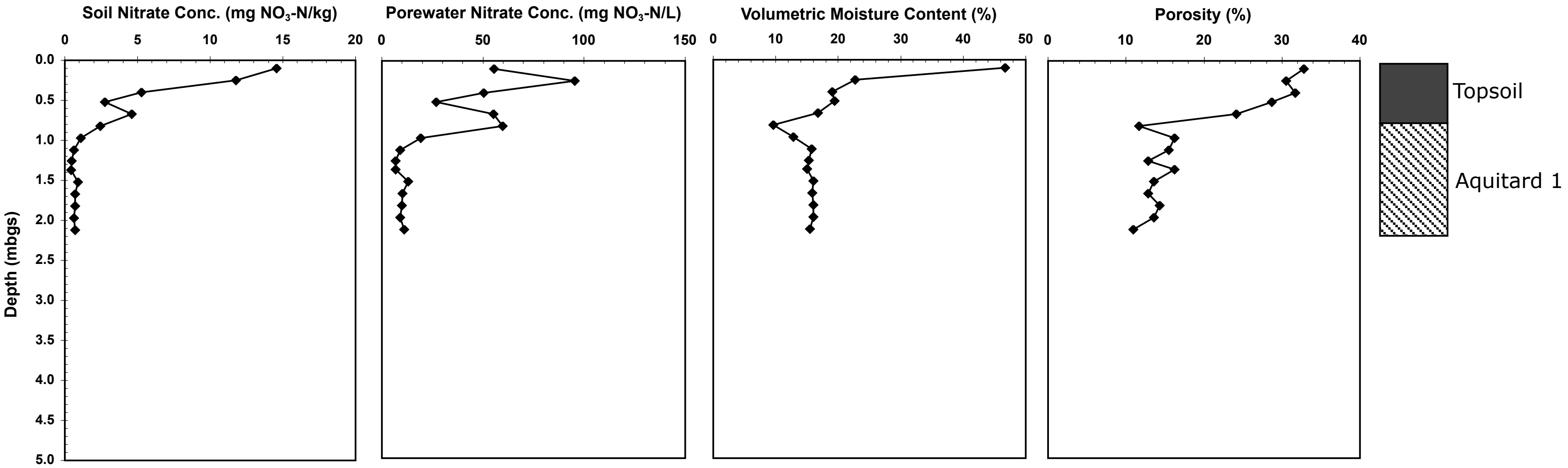

Figure G.7 - BT2 soil core profiles of bulk soil nitrate, porewater nitrate, volumetric moisture content, and porosity from core collected February 2007.

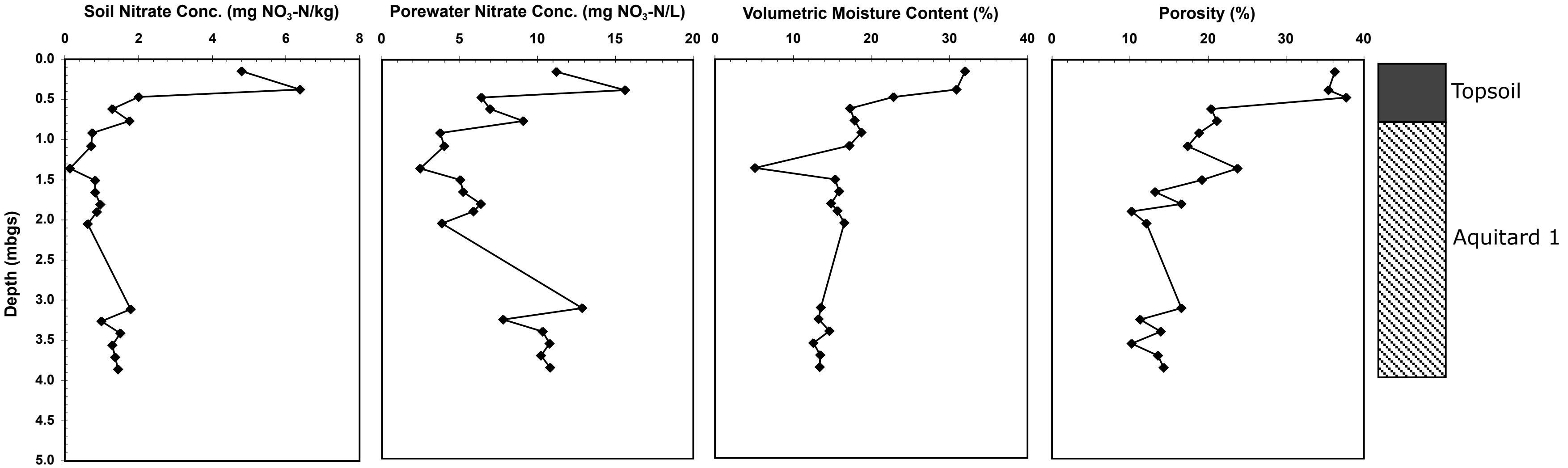

Figure G.8 - BT3 soil core profiles of bulk soil nitrate, porewater nitrate, volumetric moisture content, and porosity from core collected February 2007.

Appendix H

Additional Waterlevel Figures and Raw Data

Table H.1 - Manually measured water level data from 1997 to 2007.

Water Table Depth Below Ground Surface (mbgs)

Well	4/30/97	8/18/97	2/8/01	2/26/01	3/23/01	4/3/01	4/26/01	5/9/01	5/16/01	5/25/01	6/19/01	7/18/01	12/5/01	6/28/05	1/12/06	5/23/06	7/25/06	9/12/06	9/29/06	10/16/06	2/20/07	3/13/07	3/30/07	5/2/07	8/8/07
KA1-1	7.51	7.95	10.79	7.33	5.84	3.83	3.09	3.89	4.38	5.00	4.17	6.32	6.05	5.85	5.52	3.03	4.67	8.19	--	--	--	6.61	--	3.61	8.57
KA1-2	7.59	8.00	10.38	7.51	6.00	4.04	3.21	4.01	4.50	5.11	4.28	6.42	6.20	5.96	5.65	3.17	4.83	8.16	--	--	--	6.65	--	3.74	8.63
KA1-3	7.82	8.21	10.58	7.80	6.33	4.42	3.46	4.23	4.73	5.35	4.51	6.61	6.51	6.20	5.97	3.42	5.07	8.35	--	--	5.37	6.95	--	3.99	8.80
KA1-4	7.86	8.26	10.61	7.83	6.34	4.40	3.50	4.27	4.77	5.38	4.54	6.67	6.53	6.25	5.96	3.46	5.10	8.39	--	--	--	6.99	--	4.03	8.86
KA2-1	8.30	8.28	--	--	--	--	7.96	8.36	8.59	--	--	--	--	7.37	7.69	6.84	7.44	8.17	--	--	--	7.47	--	5.89	7.96
KA2-2	7.74	8.50	--	--	--	--	8.59	8.89	9.05	9.26	9.32	9.63	--	7.64	9.23	7.05	7.63	8.36	--	--	--	7.66	--	6.12	8.15
KA2-3	7.89	8.62	--	--	--	--	8.77	9.06	9.21	9.42	9.49	9.79	--	7.68	9.40	7.20	7.76	8.50	--	--	7.47	7.79	--	6.29	8.27
KA2-4	8.73	9.25	--	--	--	--	10.37	10.05	10.10	10.25	10.32	10.51	--	8.23	9.88	7.89	8.36	9.03	--	--	--	8.27	--	7.02	8.76
KA3-1	5.26	6.14	--	--	--	--	7.05	7.21	7.30	7.49	7.13	7.82	--	np	np	np	np	np	np	np	np	np	np	np	np
KA3-2	5.37	6.22	--	--	--	8.63	7.15	7.33	7.42	7.57	7.18	7.84	8.86	4.38	5.23	4.19	5.23	6.33	--	--	--	4.96	--	4.07	6.08
KA3-3	5.30	6.10	9.68	9.45	9.01	8.41	7.05	7.23	7.32	7.46	7.05	7.65	8.72	5.05	5.90	4.12	5.16	6.26	--	--	4.82	5.02	--	3.84	6.00
KA3-4	4.91	5.63	9.31	8.81	8.68	8.14	6.91	6.96	7.01	7.14	6.80	7.18	8.36	4.72	5.59	3.82	4.84	5.91	--	--	--	4.77	--	3.39	5.68
KA4-1	1.08	3.26	--	2.09	1.43	0.57	1.58	2.18	2.34	1.92	2.08	3.22	1.69	2.13	1.08	1.22	2.28	3.52	--	--	--	2.96	--	1.27	3.65
KA4-2	1.03	3.21	--	2.06	1.40	0.55	1.57	2.16	2.32	1.90	2.06	3.20	1.66	2.08	1.02	1.16	2.21	3.47	--	--	--	3.04	--	1.18	3.60
KA4-3	1.07	3.23	--	2.13	1.47	0.64	1.60	2.19	2.35	1.95	2.08	3.22	1.69	2.09	1.06	1.19	2.24	3.50	--	--	2.59	2.97	--	1.23	3.63
KA4-4	2.56	2.81	--	2.55	1.98	1.14	1.87	2.36	2.50	2.22	2.19	3.19	1.98	1.76	1.20	0.97	1.89	3.61	--	--	--	2.44	--	0.99	3.12
KA5-1	4.86	5.92	--	--	--	--	--	--	--	--	--	--	--	4.86	5.09	4.70	5.72		--	--	--	--	--	3.96	--
KA5-2	4.76	6.05	--	--	--	--	6.56	6.54	6.58	6.65	6.50	--	--	4.75	5.88	4.61	5.63	6.68	--	--	--	4.66	--	3.89	6.35
KA5-3	4.82	6.12	--	--	--	7.75	6.64	6.62	6.66	6.73	6.58	6.93	--	4.82	7.59	4.69	5.71	6.76	--	--	4.26	4.74	--	3.97	6.42
KA5-4	4.86	6.12	--	--	8.66	7.95	6.84	6.76	6.78	6.83	6.69	7.00	8.56	4.85	7.55	4.72	5.71	6.74	--	--	4.25	4.73	--	4.00	6.40
KA5-5	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	--	--	4.07	6.37	--	4.01	6.46
KA5-6	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	--	--	--	--	--	--	--
KA6-1	-0.75	0.25	--	--	--	-0.71	-0.49	-0.45	-0.39	-0.52	-0.34	-0.14	-0.51	-0.54	-0.71	-0.62	-0.50	-0.28	--	--	--	-0.85	--	-0.58	-0.20
KA6-2	-1.79	-0.77	--	--	--	--	--	--	--	--	--	-0.83	--	-2.33	-1.64	-1.71	-1.39	-1.01	--	--	--	-1.62	--	-1.68	-0.92
KA6-3	-2.03	-0.99	--	--	--	--	--	--	--	--	--	--	--	-2.42	-1.71	-1.72	-1.45	-1.02	--	--	--	-1.55	--	-1.79	-0.89
KA6-4	-2.68	-1.35	--	--	--	--	--	--	--	--	--	--	--	-3.04	-2.50	-2.55	-2.24	-1.82	--	--	--	-2.50	--	-2.63	-1.70
KA7	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	5.80	4.12	--	--	2.20	1.66	--
KA8	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	--	3.31	--	--	2.20	1.28	3.76
KA9-1	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	--	--	2.78	3.25	--	1.50	4.14
KA9-2	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	--	--	4.16	4.74	--	4.35	5.57
KA9-3	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	--	--	3.10	3.41	--	2.51	4.54
KA10-1	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	--	--	--	--	--	--	--
KA10-2	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	--	--	9.95	10.51	--	9.91	12.10
KA Well	--	--	--	--	--	--	--	--	--	--	--	--	--	4.86	--	--	0.72	--	--	--	--	--	--	3.80	2.07

Notes:
-- Waterlevel not measured
np - well not present at the time of monitoring

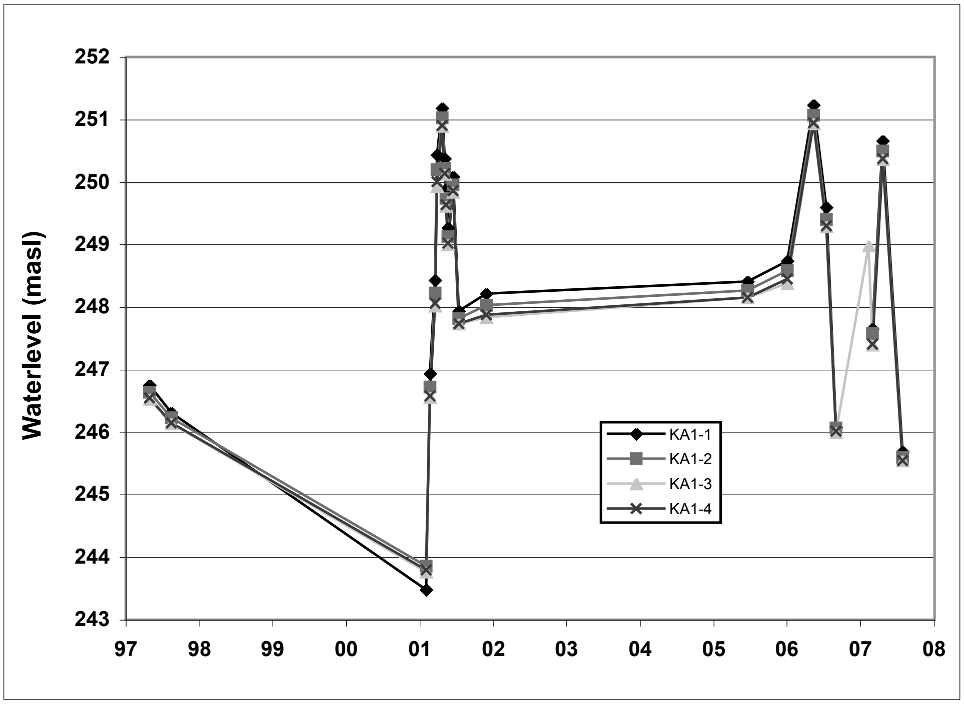

Figure H.1 - KA1 well nest manually measured water levels (1997 - 2007)

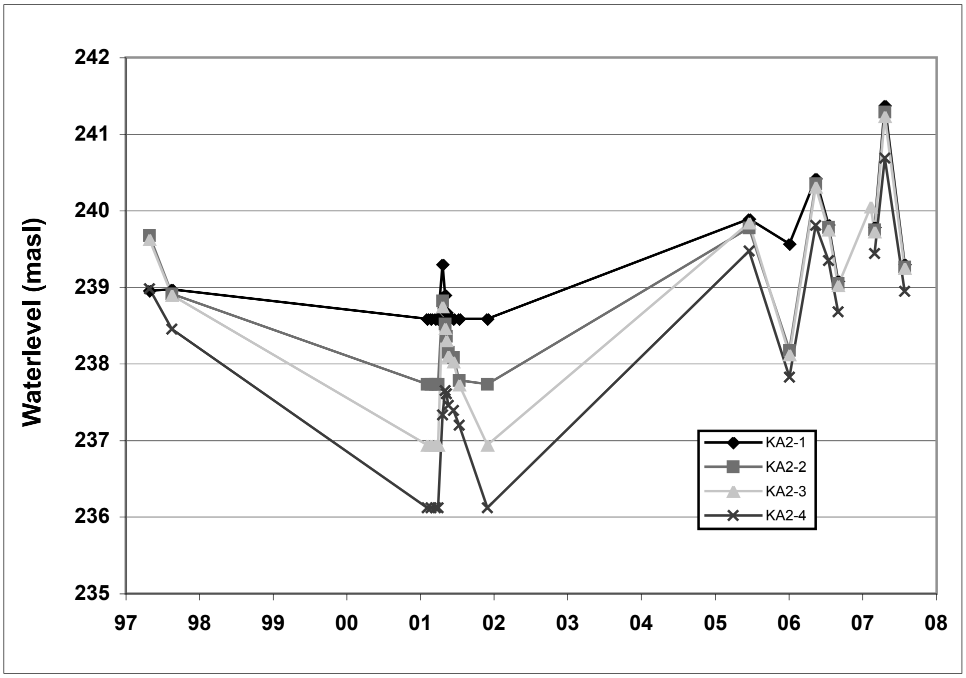

Figure H.2 - KA2 well nest manually measured water levels (1997 - 2007)

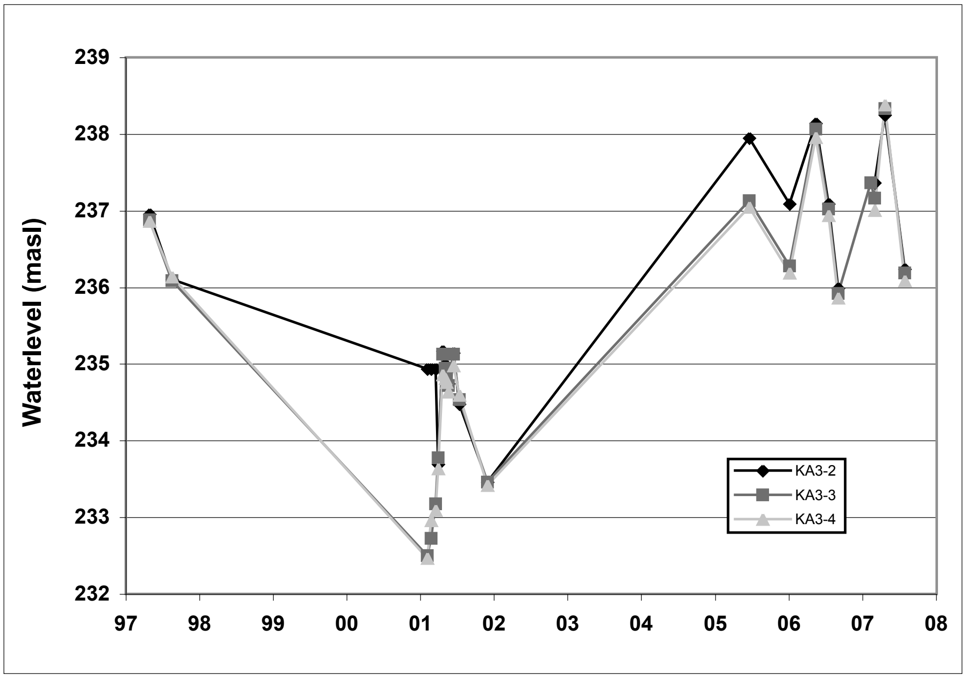

Figure H.3 - KA3 well nest manually measured water levels (1997 - 2007)

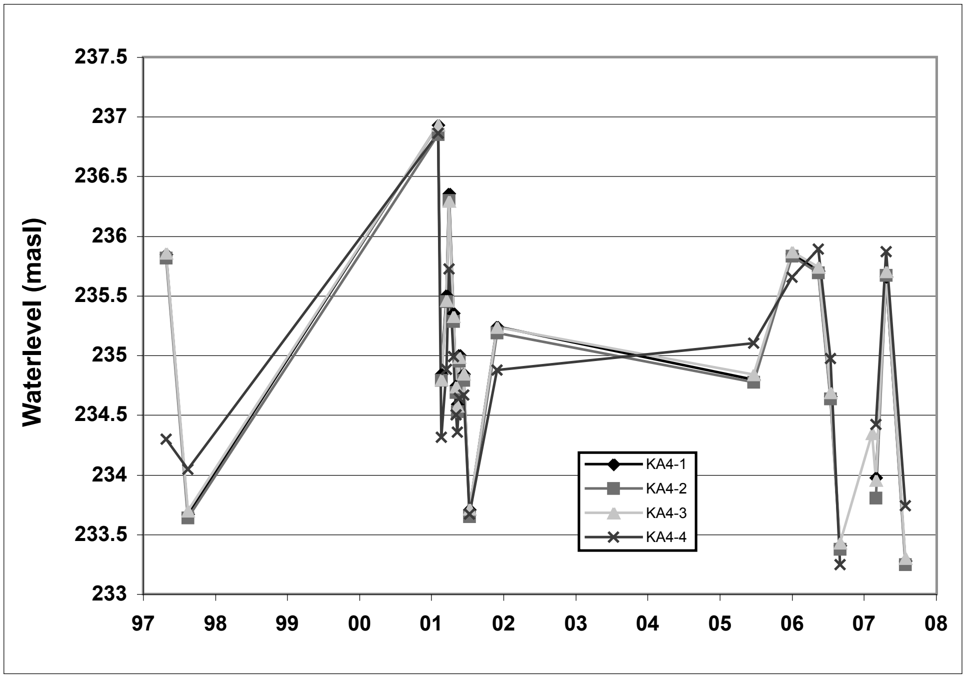

Figure H.4 - KA4 well nest manually measured water levels (1997 - 2007)

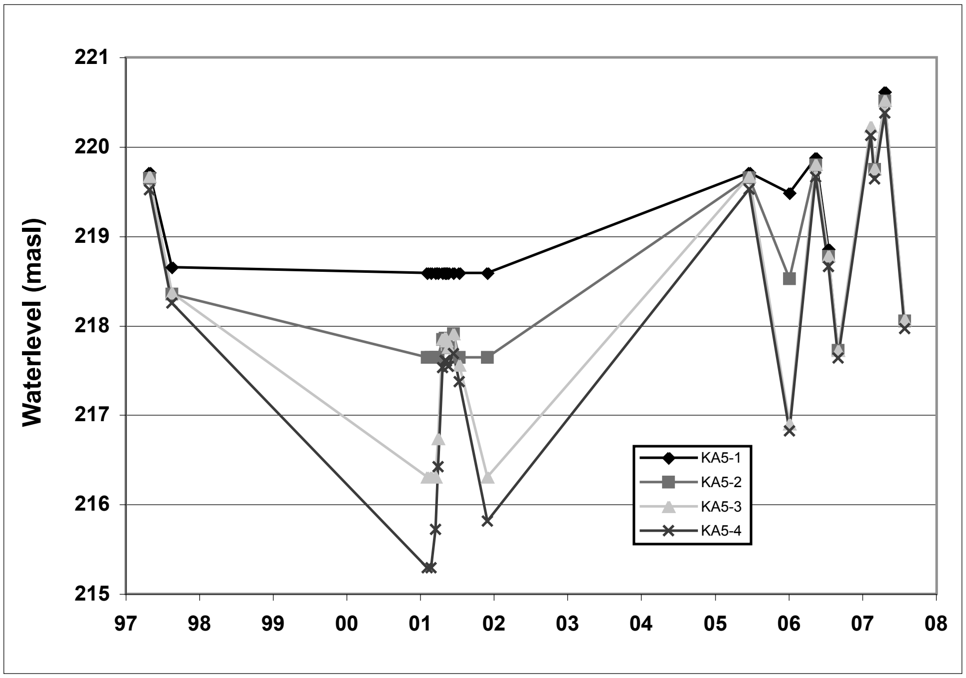

Figure H.5 - KA5 well nest manually measured water levels (1997 - 2007)

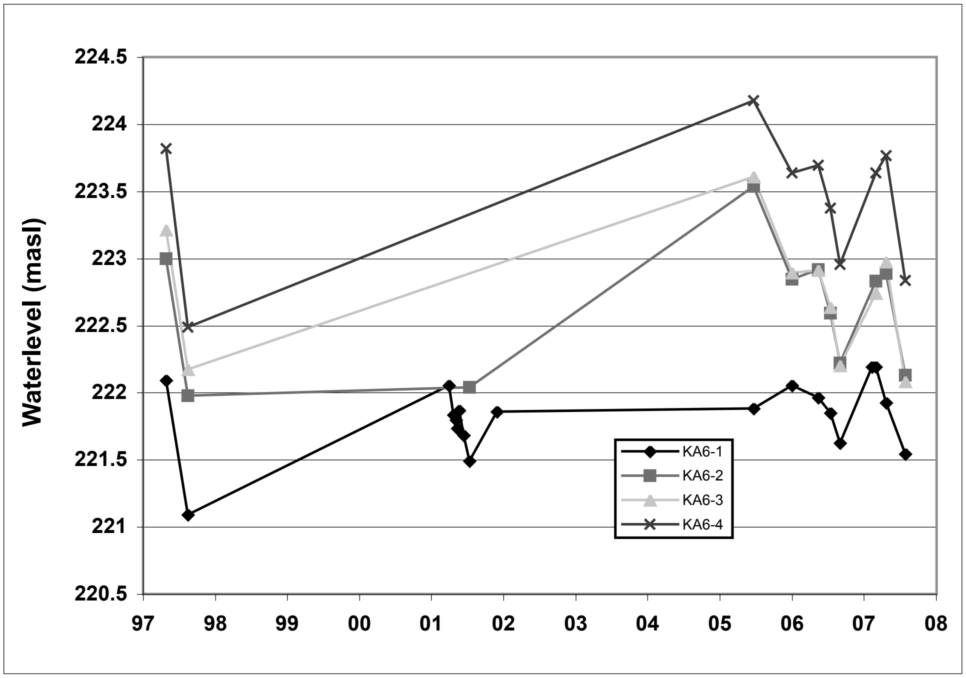

Figure H.6 - KA6 well nest manually measured water levels (1997 - 2007)

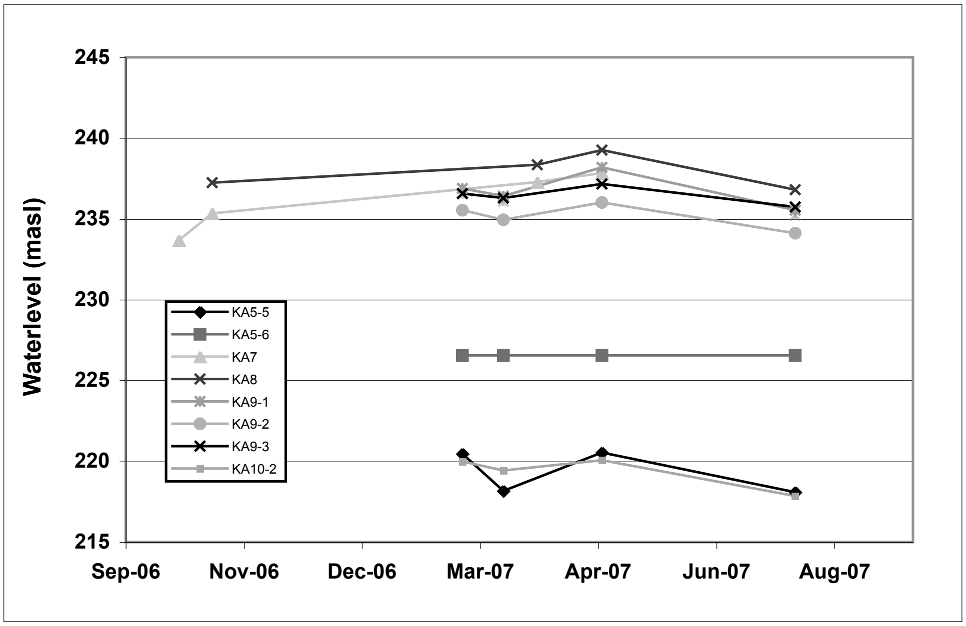

Figure H.7 - Manually measured water levels for wells: KA7, KA8 (September 2006 - August 2007); KA5-5, KA5-6, KA9-1, KA9-2, KA9-3, KA10-2 (February - August 2007).

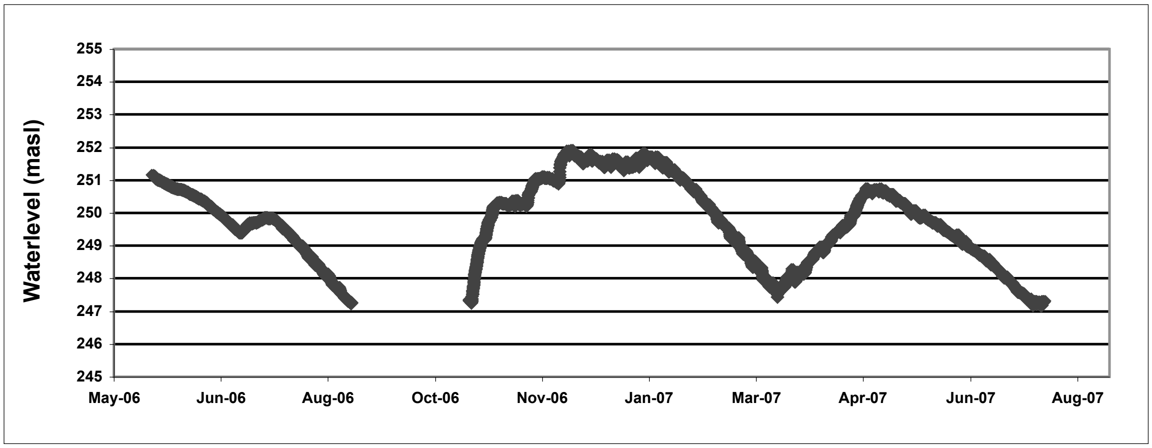

Figure H.8 - KA1-3 Levelogger Data (May 2006 - August 2007)

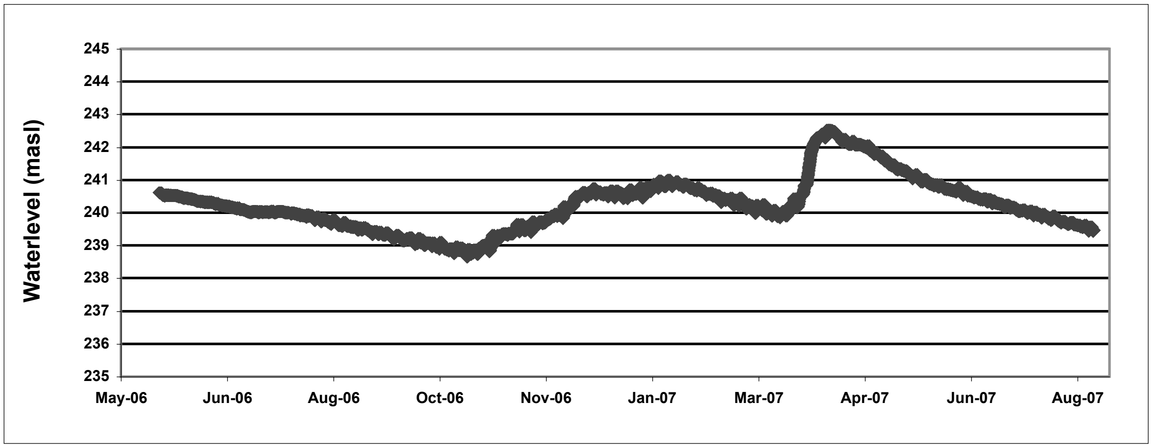

Figure H.9 - KA2-3 Levelogger Data (May 2006 - August 2007)

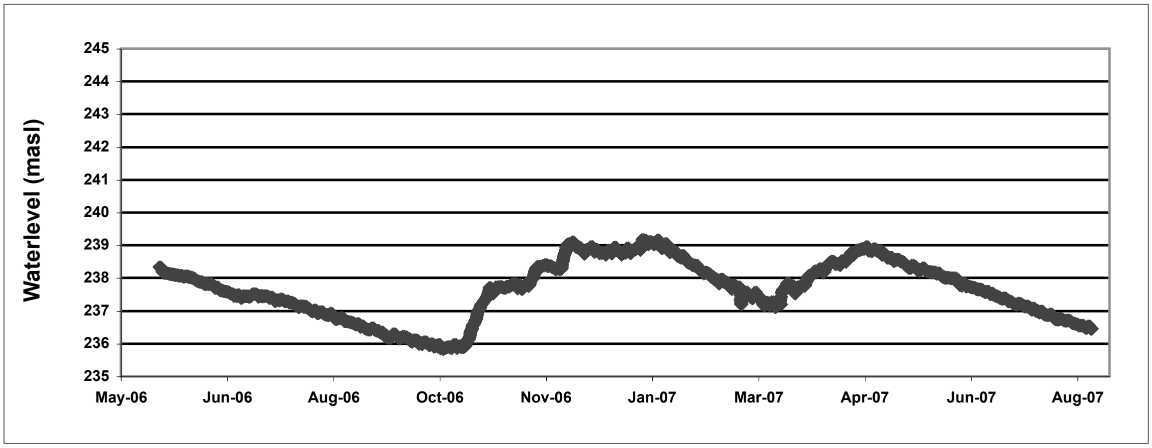

Figure H.10 - KA3-3 Levelogger Data (May 2006 - August 2007)

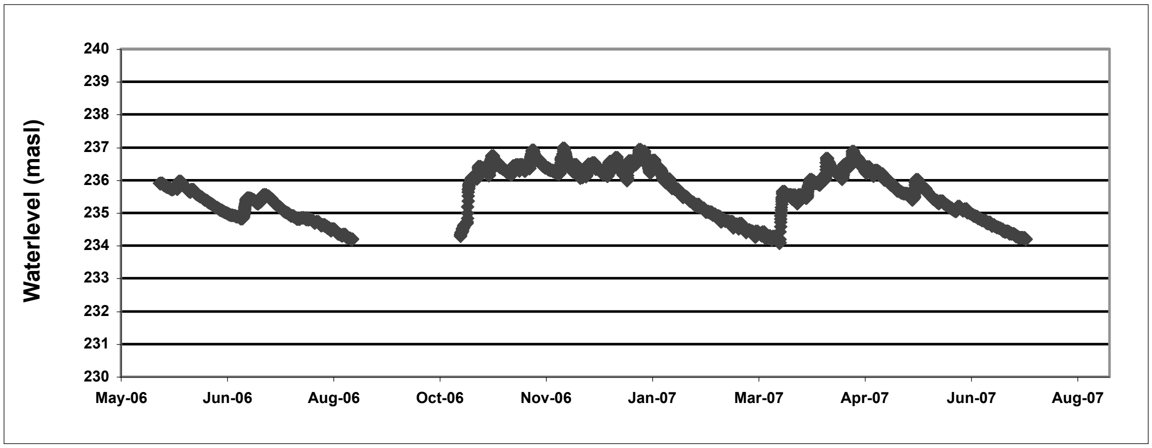

Figure H.11 - KA4-3 Levelogger Data (May 2006 - August 2007)

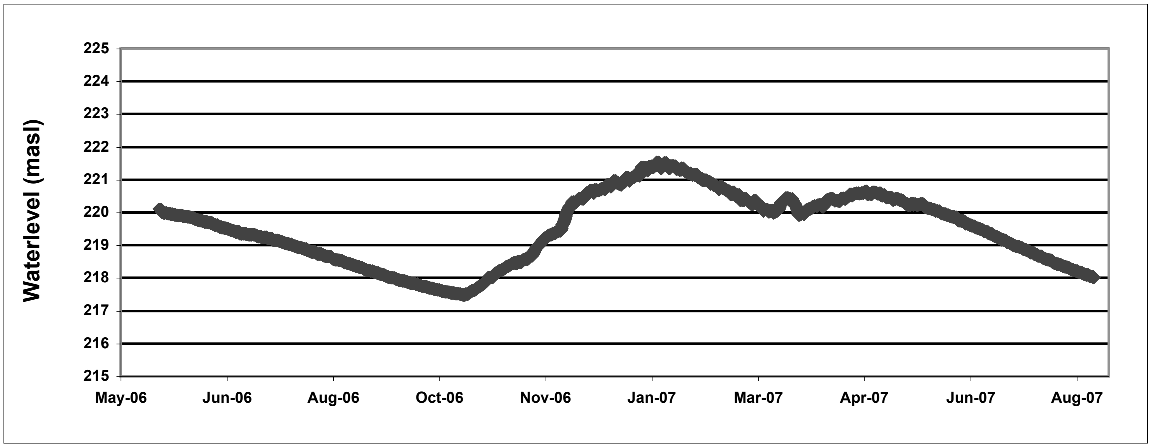

Figure H.12 - KA5-3 Levelogger Data (May 2006 - August 2007)

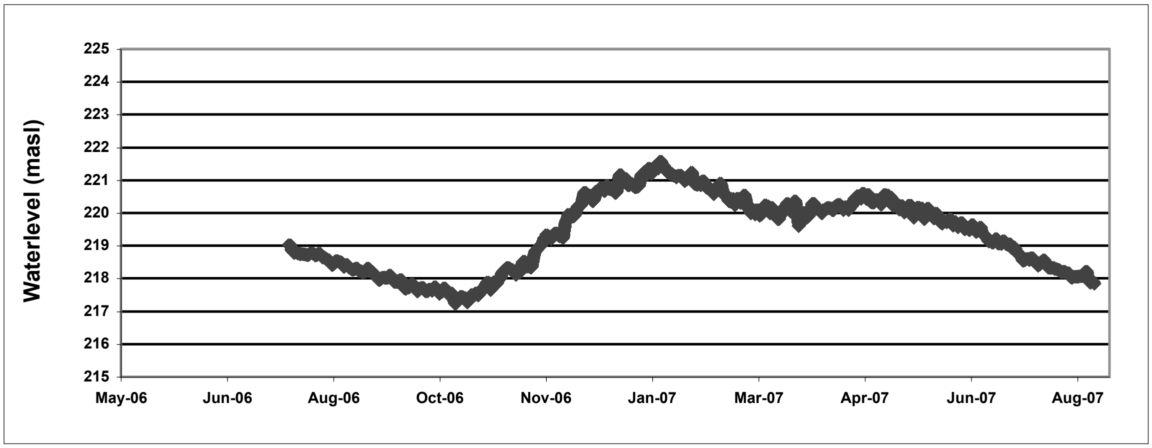

Figure H.13 - KA5-4 Levelogger Data (June 2006 - August 2007)

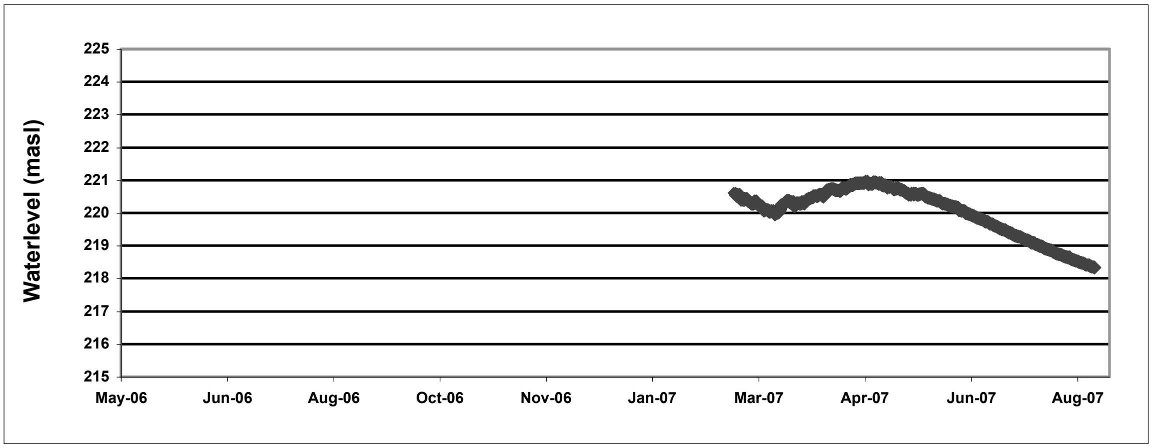

Figure H.14 - KA5-5 Levelogger Data (February - August 2007)

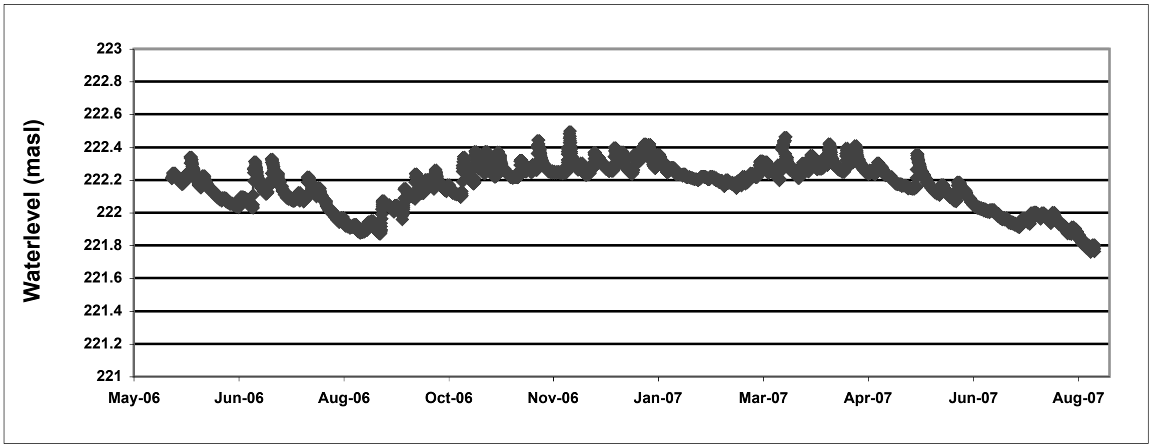

Figure H.15 - KA6-1 Levelogger Data (May 2006 - August 2007)

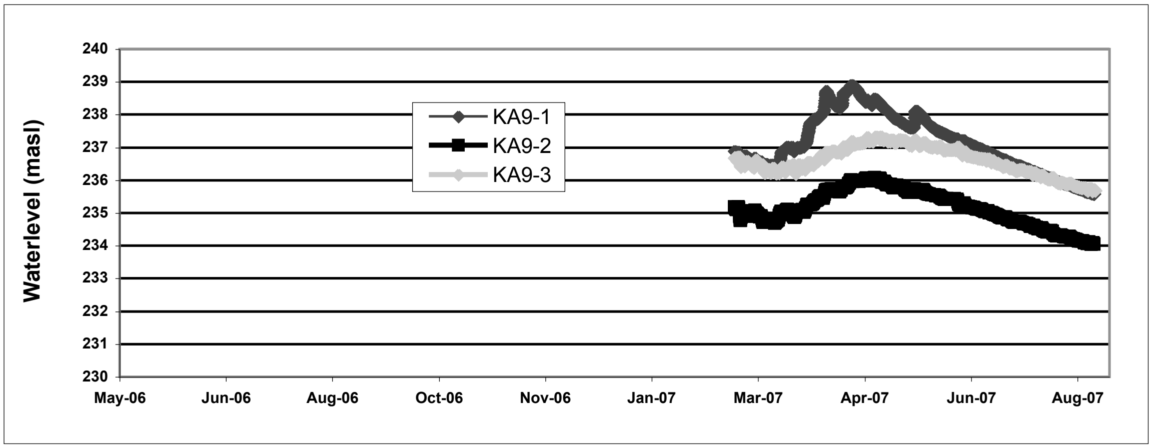

Figure H.16 - KA9-1, KA9-2, and KA9-3 Levelogger Data (February - August 2007)

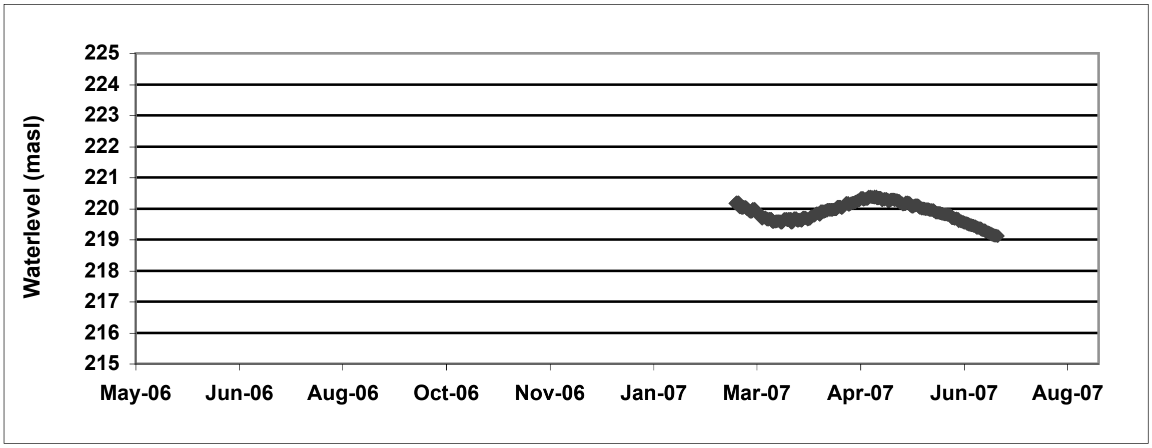

Figure H.17 - KA10-2 Levelogger Data (February - August 2007)

Appendix I

Additional Groundwater Analytical Results

Table I.1 - Groundwater Sampling - Anions and Cations (June 2005)

Parameter	Well	KA1				KA2				KA3				KA4				KA5					KA6				KA Well
	units	1	2	3	4	1	2	3	4	2	3	4	4A	1	2	3	4	1	2	3	3A	4	1	2	3	4	
Depth (mbgs)	mbgs	10.93	11.96	13	13.54	8.73	9.64	10.61	11.48	8.65	9.75	10.48	10.48	6.04	7.74	8.61	9.76	5.85	6.74	8.12	8.12	8.85	4.58	5.8	7	8.02	29.4
ANIONS																											
Total Alkalinity	mg/L	241	243	208	250	221	228	197	278	587	411	309	334	254	240	210	208	240	262	262	262	262	201	202	203	198	199
Chloride	mg/L	8	8.81	11.6	10	2	3	6	6	40.3	30.9	10.7	15.3	17.3	20.9	22.4	23.8	8	8	29.2	29.3	28.9	17.4	16.3	16.5	16.4	9.26
Nitrite	mg/L	<0.3	<0.1	<0.1	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.1	<0.3	<0.1	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.1	<0.3	<0.1	<0.3	<0.3	<0.3	<0.1	<0.1
Nitrate	mg/L	14.7	16	13.7	18.3	2.7	2.6	12	3	37.5	47	13.7	16.4	49	45	32.8	1.6	13.2	11.4	19.7	20.0	19.8	37.7	38.9	39.5	40.6	5.6
Phosphate	mg/L	<1	<0.3	<0.3	<1	<1	<1	<1	<1	<1	<0.3	<1	<0.3	<1	<1	<1	<1	<1	<1	<0.3	<1	<0.3	<1	<1	<1	<0.3	<0.3
Sulphate	mg/L	10	18.6	27.4	19.1	10.3	14.2	1	7	38.8	47	8	10.2	42.3	43.7	67.6	171	20.9	26.1	40.7	32.3	40.7	28.7	27.6	25.1	37.1	55.3
CATIONS																											
Aluminum	mg/L	<0.005	0.02	<0.005	0.006	<0.005	<0.005	0.008	0.399	<0.005	<0.005	0.005	<0.005	0.007	0.006	0.022	0.005	0.006	<0.005	0.012	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Antimony	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<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	<0.001	<0.001	<0.001	<0.001
Arsenic	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	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Barium	mg/L	0.056	0.049	0.064	0.068	0.046	0.057	0.07	0.145	0.259	0.17	0.117	0.122	0.154	0.156	0.092	0.038	0.062	0.088	0.119	0.119	0.141	0.166	0.125	0.117	0.126	0.104
Beryllium	mg/L	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<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	<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	0.03	0.08	0.18	0.03	0.08	0.05	0.06	0.54	0.31	0.21	0.06		0.03	0.03	0.03		0.04	0.03	0.03		0.03	0.02	0.002	0.02	0.02	0.02
Cadmium	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0007	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Calcium	mg/L	98.7	97.4	73.8	100	50.7	56.4	78.4	60.3	207	192	117		151	126	99.1		84.6	107	119		116	102	103	101	105	64.5
Chromium	mg/L	<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	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cobalt	mg/L	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0015	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Copper	mg/L	0.004	0.006	0.006	0.005	0.005	0.005	0.005	0.028	0.01	0.0008	0.007	0.007	0.006	0.005	0.009	0.005	0.005	0.009	0.005	0.009	0.008	0.005	0.006	0.021	0.006	0.007
Iron	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.57	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.09	<0.05	0.06
Lead	mg/L	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0049	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0033	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Lithium	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.005	0.007	<0.005	<0.005	<0.005	<0.005	0.006	0.011	0.01	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.008
Magnesium	mg/L	17	16.6	20.2	18.6	12.6	9.91	9.06	6.45	32.7	24.9	14.4		22.9	31.8	36.7		11.4	9.01	19.7		19.2	26.9	26.4	26.2	26.9	22.5
Manganese	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.099	0.015	0.016	0.034	0.034	<0.002	<0.002	0.002	0.008	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.011
Molybdenum	mg/L	<0.001	<0.001	0.004	<0.001	0.0009	0.005	<0.001	0.003	<0.001	<0.001	0.002	0.002	<0.001	<0.001	<0.001	0.009	0.004	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Nickel	mg/L	<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	<0.001	0.007	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001
Phosphorus	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.16	<0.05	<0.05	0.2	0.18	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Potassium	mg/L	0.8	0.7	2.1	0.7	0.9	0.8	0.7	4.6	1.9	1.5	13.7		3.2	1.3	2.8		1.1	0.6	2.1		2.1	1.3	1.4	1.3	1.2	1.7
Selenium	mg/L	0.003	<0.002	<0.002	<0.002	<0.002	0.006	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.005	<0.002	<0.002	<0.002	<0.002	<0.002	0.003	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.004
Silicon	mg/L	7.08	7.1	7.04	7.09	6.48	5.96	5.67	87.9	10.2	7.95	6.44	6.28	6.79	7.92	5.18	6.96	5.75	4.79	6.54	6.57	6.51	7.34	7.05	7.57	7.29	8.33
Silver	mg/L	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.235	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Sodium	mg/L	8.7	12.1	22.6	5.7	30.6	36.9	4.4	<0.1	66.2	23.7	16.1		12	8.4	8.6		33.5	14.8	12		12.5	6.9	7	6.9	6.9	4.9
Strontium	mg/L	0.178	0.169	0.18	0.183	0.123	0.109	0.285	<0.001	0.566	0.433	0.231	0.23	0.379	0.264	0.24	0.244	0.158	0.166	0.233	0.237	0.241	0.23	0.237	0.222	0.232	0.187
Tellurium	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	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Thallium	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Thorium	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	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Tin	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	<0.001	<0.001	<0.001	<0.001	<0.001	<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	<0.005	<0.005	0.009	<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	<0.005	<0.005	<0.005	<0.005	<0.005
Tungsten	mg/L	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	0.002	<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	<0.001	<0.001	<0.001	<0.001
Uranium	mg/L	0.0004	0.0003	0.0019	0.0004	0.0011	0.001	0.0003	0.0031	0.0011	0.0007	0.0007	0.0006	0.0004	0.0011	0.0056	0.0025	0.0008	0.0003	0.0008	0.0008	0.0008	0.001	0.0006	0.0005	0.0006	0.0012
Vanadium	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<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	<0.001	<0.001	<0.001	<0.001
Zinc	mg/L	<0.005	<0.005	0.007	0.02	0.012	0.008	0.015	0.023	0.007	0.031	<0.005	<0.005	0.041	0.018	0.024	0.014	<0.005	0.021	<0.005	0.005	0.021	0.016	0.015	0.018	0.017	0.019
Zirconium	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	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table I.2 - Groundwater Chemical Analysis (HACK Field Kit)

Parameter	Ammonia (mg/L)	Iron (mg/L)
KA1-1	0.04	<0.02
KA1-3	--	0.02
KA1-4	<0.01	<0.02
KA2-1	<0.01	--
KA2-3	<0.01	--
KA2-4	<0.01	<0.02
KA3-2	0.02	--
KA3-3	0.02	0.03
KA3-4	0.01	--
KA4-1	<0.01	--
KA4-4	<0.01	0.02
KA5-1	0.05	--
KA5-4	<0.01	<0.02
KA6-1	0.03	--
KA6-4	<0.01	<0.02
KA Well	<0.01	0.09

Notes:
-- parameter not tested for

Table I.3 - Groundwater Nitrate and Chloride Data (1997 to 2007)

Sampled by:	Gibson and Rudolph (1997)		Gibson and Rudolph (1997)		MOE (2000)		Gibson Associates (2001)		Gibson Associates (2001)		Gibson Associates (2001)		Cole (2008)		Cole (2008)		Cole (2008)		Cole (2008)		Cole (2008)		Cole (2008)		Cole (2008)		Cole (2008)	
Dates Sampled	16-May-97		18-Aug-97		20-Jun-00		28-Feb-01		19-Jun-01		19-Jul-01		28-Jun-05		20-Jan-06		24-May-06		12-Sep-06		16-Oct-06		20-Feb-07		13-Mar-07		8-Aug-07	
Well	Nitrate	Chloride	Nitrate	Chloride	Nitrate	Chloride	Nitrate	Chloride	Nitrate	Chloride	Nitrate	Chloride	Nitrate	Chloride	Nitrate	Chloride	Nitrate	Chloride	Nitrate	Chloride	Nitrate	Chloride	Nitrate	Chloride	Nitrate	Chloride	Nitrate	Chloride
KA1-1	5.6	10.2	3.3	--	--	--	--	--	--	--	--	--	14.7	8.0	14.6	10.0	18.8	11.0	17.4	10.0	--	--	--	--	14.3	9.1	17.8	8.8
KA1-2	5.8	12.7	7.1	--	--	--	--	--	--	--	--	--	16.0	8.8	17.0	9.0	19.2	11.0	17.5	10.0	--	--	--	--	13.6	9.8	13.3	9.3
KA1-3	7.6	10.8	7.0	--	--	--	--	--	--	--	--	--	13.7	11.6	15.0	9.0	17.5	11.0	17.7	11.0	--	--	--	--	15.5	10.6	--	--
KA1-4	9.7	16.7	8.8	--	--	--	16.2	--	17.8	13.8	--	--	18.3	10.0	18.5	14.0	19.9	13.0	19.9	13.0	--	--	--	--	16.5	12.2	15.3	10.8
KA2-1	0.8	6.7	1.1	--	--	--	--	--	--	--	--	--	2.7	2.0	--	4.0	2.9	3.0	3.2	7.0	--	--	--	--	3.2	2.8	3.5	8.8
KA2-2	1.0	15.5	1.7	--	--	--	--	--	--	--	--	--	2.6	3.0	2.9	4.0	2.2	3.0	2.4	5.0	--	--	--	--	2.3	3.2	2.5	3.3
KA2-3	0.9	20.5	0.2	--	--	--	--	--	--	--	--	--	12.0	6.0	9.2	4.0	14.2	5.0	12.7	7.0	--	--	--	--	9.0	10.0	13.5	7.5
KA2-4	0.5	15.2	0.0	--	--	--	--	--	--	--	2.9	3.7	3.0	6.0	4.4	6.0	7.0	7.0	8.9	8.0	--	--	--	--	9.1	5.7	9.2	6.6
KA3-1	55.6	22.2	45.0	--	--	--	--	--	--	--	--	--	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np
KA3-2	59.0	24.8	57.4	--	--	--	--	--	--	--	--	--	13.7	40.3	14.8	31.0	37.8	25.0	41.4	27.0	--	--	--	--	33.7	17.3	27.9	15.0
KA3-3	76.2	33.8	62.3	--	79.9	--	--	--	65.4	32.2	--	--	37.5	30.9	31.3	30.0	38.3	32.0	35.5	30.0	--	--	--	--	28.4	18.6	23.7	12.9
KA3-4	76.3	25.4	52.2	--	71.6	--	--	--	--	--	--	--	47.0	10.7	40.8	22.0	44.9	26.0	45.6	24.0	--	--	--	--	--	2.9	29.0	12.7
KA4-1	47.0	20.2	46.0	--	--	--	--	--	--	--	--	--	32.8	17.3	32.2	18.0	43.9	18.0	23.4	19.0	--	--	--	--	25.6	17.1	21.1	14.4
KA4-2	67.0	35.6	53.8	--	--	--	45.7	--	45.1	20.0	--	--	45.0	20.9	39.5	18.0	44.0	19.0	41.3	19.0	--	--	--	--	36.8	18.6	36.8	18.0
KA4-3	62.4	26.0	37.5	--	--	--	--	--	--	--	--	--	49.0	22.4	55.6	21.0	64.3	21.0	44.1	20.0	--	--	--	--	56.2	19.6	44.1	19.1
KA4-4	2.4	26.3	0.9	--	--	--	--	--	--	--	0.2	21.0	1.6	23.8	0.1	22.0	0.1	23.0	0.2	22.0	--	--	--	--	0.2	21.9	0.7	21.1
KA5-1	32.1	23.0	--	--	--	--	--	--	--	--	--	--	13.2	8.0	--		10.8	7.0	--	--	--	--	--	--	9.7	4.8	--	--
KA5-2	9.5	10.8	24.2	--	--	--	--	--	--	--	--	--	11.4	8.0	--		13.2	9.0	11.5	7.0	--	--	--	--	11.7	8.4	12.1	8.9
KA5-3	34.5	16.6	26.9	--	--	--	--	--	--	--	--	--	19.7	29.2	26.3	17.0	23.3	15.0	23.5	19.0	--	--	--	--	16.9	35.7	19.2	28.1
KA5-4	34.8	16.8	27.5	--	13.9	--	--	--	29.7	21.4	--	--	19.8	28.9	24.3	18.0	24.3	15.0	25.3	19.0	--	--	--	--	17.4	35.9	20.0	25.2
KA5-5	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	18.0	26.4	15.9	30.2	20.4	22.2
KA5-6	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	<0.1	15.9	<0.1	15.9	<0.1	15.6
KA6-1	31.8	15.4	32.7	--	--	--	--	--	--	--	--	--	37.7	17.4	39.5	15.0	36.7	15.0	39.6	15.0	--	--	--	--	43.5	18.2	41.5	17.6
KA6-2	32.5	15.3	32.8	--	--	--	--	--	--	--	--	--	38.9	16.3	40.8	15.0	44.7	18.0	44.0	17.0	--	--	--	--	43.5	18.1	43.3	18.7
KA6-3	29.5	15.4	29.5	--	--	--	--	--	--	--	--	--	39.5	16.5	39.7	16.0	44.4	17.0	41.9	17.0	--	--	--	--	41.8	17.5	42.0	17.6
KA6-4	27.6	14.6	27.4	--	--	--	--	--	35.8	16.7	--	--	40.6	16.4	36.7	18.0	44.8	17.0	41.4	16.0	--	--	--	--	37.2	16.8	38.9	16.4
KA7	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	0.3	55.0	--	--	2.6	27.1	--	--
KA8	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	18.0	26.0	--	--	30.6	19.9	31.2	18.8
KA9-1	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	23.2	19.6	22.3	19.1	21.8	17.5
KA9-2	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	14.9	21.8	22.2	19.0	21.1	17.6
KA9-3	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	<0.1	3.9	0.1	4.2	0.1	3.3
KA10-2	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	np	14.9	5.2	14.9	4.7	13.6	5.4
KA WELL	38.4	23.4	33.7	--	39.6	--	41.4	--	--	--	--	--	5.6	9.26	9.3	10.0	5.1	10.0	7.1	11.0	--	--	--	--	6.5	10.6	7.8	11.2

Notes
-- parameter not tested for
np - well not installed at time of sampling

Table I.4 - Field Parameters

Well	Parameter	6/27/2005[1]	1/12/2006[2]	5/23/2006[1]	9/12/2006[1]	2/20/2007[1,3]	3/13/2007[1,3]	8/8/2007[1,3]
KA1-1	Cond (uS)	65	579	489	569	--	459	534
	pH	7.53	7.57	8.21	7.85	--	7.14	7.33
	Eh (mV)	221.80	--	--	--	--	--	--
	DO (mg/L)	11.77	10.00	10.67	--	--	8.40	--
	Temp (°C)	--	--	--	10.00	--	8.60	--
KA1-2	Cond (uS)	101	585	475	582	--	511	601
	pH	7.52	7.48	7.74	7.86	--	7.26	7.67
	Eh (mV)	186.70	--	--	--	--	--	--
	DO (mg/L)	11.02	--	10.31	--	--	--	--
	Temp (°C)	--	--	--	10.30	--	--	--
KA1-3	Cond (uS)	557	618	560	579	--	507	589
	pH	7.88	7.64	7.73	7.80	--	7.43	7.39
	Eh (mV)	202.80	--	--	--	--	--	--
	DO (mg/L)	--	--	8.29	--	--	--	--
	Temp (°C)	--	--	--	11.40	--	--	--
KA1-4	Cond (uS)	336	646	513	515	--	433	492
	pH	7.38	7.43	7.69	7.82	--	7.31	7.54
	Eh (mV)	194.10	--	--	--	--	--	--
	DO (mg/L)	11.33	9.00	10.75	--	--	7.98	--
	Temp (°C)	--	--	--	10.20	--	8.40	--
KA2-1	Cond (uS)	329	--	382	370	--	356	387
	pH	7.94	--	7.77	8.06	--	7.89	8.01
	Eh (mV)	262.50	--	--	--	--	--	--
	DO (mg/L)	--	--	6.30	--	--	--	--
	Temp (°C)	--	--	--	--	--	--	--
KA2-2	Cond (uS)	415	428	507	444	--	494	522
	pH	7.96	7.78	7.90	8.18	--	7.98	7.88
	Eh (mV)	232.80	--	--	--	--	--	--
	DO (mg/L)	--	10.00	>10	--	--	9.06	--
	Temp (°C)	--	--	--	12.70	--	--	--
KA2-3	Cond (uS)	473	533	438	468	--	485	435
	pH	7.89	7.77	7.98	7.98	--	7.85	7.59
	Eh (mV)	208.60	--	--	--	--	--	--
	DO (mg/L)	--	--	>10	--	--	--	--
	Temp (°C)	--	--	--	11.50	--	--	--
KA2-4	Cond (uS)	471	558	570	457	--	503	479
	pH	8.12	7.88	8.31	8.07	--	8.21	7.94
	Eh (mV)	-9.62	--	--	--	--	--	--
	DO (mg/L)	--	--	>10	--	--	--	--
	Temp (°C)	--	--	--	15.40	--	--	--
KA3-2	Cond (uS)	488	758	978	776	--	360	622
	pH	7.08	7.10	7.14	7.10	--	7.80	7.45
	Eh (mV)	207.80	--	--	--	--	--	--
	DO (mg/L)	4.87	1.80	0.14	1.11	--	--	1.48
	Temp (°C)	--	--	--	12.80	--	8.40	--
KA3-3	Cond (uS)	851	1270	1131	803	--	750	675
	pH	6.87	6.78	6.73	6.50	--	7.35	7.02
	Eh (mV)	211.80	--	--	--	--	--	--
	DO (mg/L)	0.54	1.00	6.36	0.95	--	8.78	0.78
	Temp (°C)	--	--	--	14.50	--	8.80	--
KA3-4	Cond (uS)	371	1144	958	790	--	750	477
	pH	6.69	6.90	6.82	7.07	--	7.31	7.09
	Eh (mV)	419.60	--	--	--	--	--	--
	DO (mg/L)	5.74	2.00	1.85	5.34	--	2.54	3.21
	Temp (°C)	--	--	--	12.70	--	8.50	--

Well	Parameter	6/27/2005[1]	1/12/2006[2]	5/23/2006[1]	9/12/2006[1]	2/20/2007[1,3]	3/13/2007[1,3]	8/8/2007[1,3]
KA4-1	Cond (uS)	719	734	801	781	--	273	405
	pH	7.22	7.34	7.24	7.45	--	7.40	7.34
	Eh (mV)	325.40	--	--	--	--	--	--
	DO (mg/L)	--	9.00	10.54	9.69	--	8.77	4.71
	Temp (°C)	--	--	--	11.40	--	11.20	--
KA4-2	Cond (uS)	347	883	742	617	--	396	583
	pH	7.41	7.36	7.33	7.58	--	7.30	7.53
	Eh (mV)	348.10	--	--	--	--	--	--
	DO (mg/L)	--	--	6.80	3.30	--	5.43	0.39
	Temp (°C)	--	--	--	11.80	--	12.70	--
KA4-3	Cond (uS)	380	857	693	618	--	419	552
	pH	7.68	7.42	7.48	7.89	--	7.34	7.29
	Eh (mV)	324.20	--	--	--	--	--	--
	DO (mg/L)	--	--	5.10	8.52	--	8.09	0.7
	Temp (°C)	--	--	--	13.30	--	12.80	--
KA4-4	Cond (uS)	478	716	731	659	--	280	474
	pH	7.45	7.66	7.77	8.05	--	7.56	7.66
	Eh (mV)	323.80	--	--	--	--	--	--
	DO (mg/L)	--	--	8.23	--	--	6.31	0.48
	Temp (°C)	--	--	--	13.70	--	11.90	--
KA5-1	Cond (uS)	385	--	549	--	--	361	--
	pH	7.46	--	7.77	--	--	6.77	--
	Eh (mV)	233.80	--	--	--	--	--	--
	DO (mg/L)	10.88	--	9.36	--	--	9.41	--
	Temp (°C)	--	--	--	--	--	9.90	--
KA5-2	Cond (uS)	359	--	481	--	--	325	369
	pH	7.38	--	7.49	--	--	7.32	7.48
	Eh (mV)	293.60	--	--	--	--	--	--
	DO (mg/L)	9.76	--	11.44	--	--	8.47	8
	Temp (°C)	--	--	--	--	--	11.70	--
KA5-3	Cond (uS)	473	679	614	365	--	455	486
	pH	7.30	7.45	7.32	7.52	--	7.05	7.19
	Eh (mV)	232.80	--	--	--	--	--	--
	DO (mg/L)	9.81	6.00	10.90	7.65	--	6.72	4.99
	Temp (°C)	--	--	--	9.70	--	11.00	--
KA5-4	Cond (uS)	429	580	618	574	--	366	471
	pH	7.24	7.51	7.31	7.50	--	7.17	7.54
	Eh (mV)	239.80	--	--	--	--	--	--
	DO (mg/L)	8.42	7.00	10.10	7.36	--	5.39	5.49
	Temp (°C)	--	--	--	9.60	--	11.50	--
KA5-5	Cond (uS)	np	np	np	np		390	466
	pH	np	np	np	np		7.29	7.48
	Eh (mV)	np	np	np	np		--	--
	DO (mg/L)	np	np	np	np		6.58	4.67
	Temp (°C)	np	np	np	np		11.20	--
KA5-6	Cond (uS)	np	np	np	np		359	389
	pH	np	np	np	np		7.78	7.98
	Eh (mV)	np	np	np	np		--	--
	DO (mg/L)	np	np	np	np		0.83	0.26
	Temp (°C)	np	np	np	np		12.30	--

Well	Parameter	6/27/2005[1]	1/12/2006[2]	5/23/2006[1]	9/12/2006[1]	2/20/2007[1,3]	3/13/2007[1,3]	8/8/2007[1,3]
KA6-1	Cond (uS)	636	363	662	276	--	693	520
	pH	7.37	7.63	7.46	6.98	--	7.97	7.63
	Eh (mV)	211.20	--	--	--	--	--	--
	DO (mg/L)	8.25	7.00	9.21	9.35	--	3.96	2.74
	Temp (°C)	--	--	--	14.00	--	6.40	--
KA6-2	Cond (uS)	739	692	689	392	--	739	562
	pH	7.34	7.70	7.47	7.53	--	7.95	7.43
	Eh (mV)	212.20	--	--	--	--	--	--
	DO (mg/L)	8.72	7.00	8.84	8.64	--	5.98	2.06
	Temp (°C)	--	--	--	12.20	--	5.60	--
KA6-3	Cond (uS)	740	680	671	537	--	733	529
	pH	7.40	7.65	7.45	7.47	--	7.92	7.66
	Eh (mV)	215.70	--	--	--	--	--	--
	DO (mg/L)	7.22	7.00	8.88	9.57	--	4.40	1.69
	Temp (°C)	--	--	--	13.30	--	7.00	--
KA6-4	Cond (uS)	463	712	632	585	--	714	518
	pH	7.45	7.63	7.56	7.54	--	7.90	7.29
	Eh (mV)	195.20	--	--	--	--	--	--
	DO (mg/L)	7.94	7.00	9.54	8.80	--	1.34	1.55
	Temp (°C)	--	--	--	12.10	--	6.90	--
KA7	Cond (uS)	np	np	np	534	--	--	--
	pH	np	np	np	8.01	--	--	--
	Eh (mV)	np	np	np	--	--	--	--
	DO (mg/L)	np	np	np	--	--	--	--
	Temp (°C)	np	np	np	9.89	--	--	--
KA8	Cond (uS)	np	np	np	356	--	--	427
	pH	np	np	np	7.93	--	--	7.81
	Eh (mV)	np	np	np	--	--	--	--
	DO (mg/L)	np	np	np	--	--	--	--
	Temp (°C)	np	np	np	12.60	--	--	--
K9-1	Cond (uS)	np	np	np	np	639	--	418
	pH	np	np	np	np	7.56	--	7.76
	Eh (mV)	np	np	np	np	--	--	--
	DO (mg/L)	np	np	np	np	1.98	--	3.08
	Temp (°C)	np	np	np	np	8.40	--	--
KA9-2	Cond (uS)	np	np	np	np	605	--	371
	pH	np	np	np	np	7.74	--	7.54
	Eh (mV)	np	np	np	np	--	--	--
	DO (mg/L)	np	np	np	np	3.99	--	9.94
	Temp (°C)	np	np	np	np	8.60	--	--
KA9-3	Cond (uS)	np	np	np	np	383	--	287
	pH	np	np	np	np	7.97	--	7.86
	Eh (mV)	np	np	np	np	--	--	--
	DO (mg/L)	np	np	np	np	0.53	--	3.47
	Temp (°C)	np	np	np	np	8.60	--	--
KA10-2	Cond (uS)	np	np	np	np	400	--	439
	pH	np	np	np	np	7.72	--	7.53
	Eh (mV)	np	np	np	np	--	--	--
	DO (mg/L)	np	np	np	np	--	--	--
	Temp (°C)	np	np	np	np	11.00	--	--
KA Well	Cond (uS)	--	--	542	398	388	--	456
	pH	--	--	8.02	7.82	7.74	--	7.98
	Eh (mV)	--	--	--	--	--	--	--
	DO (mg/L)	--	--	2.10	0.18	1.07	--	0.09
	Temp (°C)	--	--	11.50	11.10	9.84	--	--

-- parameter not analyzed for
np - well not present at time of sampling
1 - DO samples collected using Vacu-vials
2 - DO sample collected using the colourmetric kit
3 - DO samples collected using the Symphony DO Probe

Table I.5 - Dissolved Carbon Results

Well	DC mg/L	DIC mg/L	DOC mg/L
KA Well	42.60	40.60	2.05
KA1-1	41.00	38.10	2.83
KA1-2	41.00	38.10	2.90
KA1-3	40.00	37.90	2.07
KA1-4	42.20	39.30	2.90
KA2-1	41.50	38.50	3.09
KA2-2	43.10	40.90	2.25
KA2-3	37.90	35.80	2.09
KA2-4	59.30	58.00	1.34
KA3-2	60.10	57.00	3.13
KA3-3	83.90	78.00	5.84
KA3-4	63.40	59.00	4.34
KA4-1	37.90	35.70	2.16
KA4-2	40.60	38.30	2.27
KA4-3	40.00	37.60	2.41
KA5-1	42.10	38.90	3.11
KA5-2	45.90	43.90	2.07
KA5-3	44.00	41.30	2.67
KA5-4	40.70	37.50	3.20
KA6-1	29.60	27.80	1.84
KA6-2	36.00	33.20	2.81
KA6-3	36.30	33.50	2.80
KA6-4	39.80	37.30	2.52

Table I.6 - Averaged groundwater nitrate concentrations and % change

Well	1997 Average Nitrate (mg/L)	2000 - 2001 Average Nitrate (mg/L)	2005 - 2007 Average Nitrate (mg/L)	Average Change %	Well Nest Average 1997 Nitrate (mg/L)	Well Nest Average 2005 - 2007 Nitrate (mg/L)	% change
KA1-1	4.45	--	15.96	-259	6.85	16.50	-141
KA1-2	6.46	--	16.10	-149			
KA1-3	7.29	--	15.89	-118			
KA1-4	9.22	16.98	18.06	-96			
KA2-1	0.94	--	3.10	-232	0.77	6.07	-692
KA2-2	1.35	--	2.48	-84			
KA2-3	0.55	--	11.77	-2059			
KA2-4	0.24	2.93	6.94	-2854			
KA3-1	50.28	--	np	--	60.49	34.05	44
KA3-2	58.21	--	28.23	52			
KA3-3	69.23	72.65	32.44	53			
KA3-4	64.23	71.60	41.47	35			
KA4-1	46.48	--	29.84	36	39.63	30.78	22
KA4-2	60.40	45.40	40.58	33			
KA4-3	49.95	--	52.21	-5			
KA4-4	1.68	0.16	0.48	72			
KA5-1	32.09	--	11.22	65	27.71	17.07	38
KA5-2	16.86	--	13.72	19			
KA5-3	30.73	--	21.49	30			
KA5-4	31.17	21.82	21.85	30			
KA5-5	np	np	18.10	--	--	--	--
KA5-6	np	np	< 0.1	--	--	--	--
KA6-1	32.26	--	39.76	-23	30.46	40.94	-34
KA6-2	32.66	--	42.53	-30			
KA6-3	29.45	--	41.55	-41			
KA6-4	27.47	--	39.94	-45			
KA7	np	np	1.45	--	--	--	--
KA8	np	np	26.62	--	--	--	--
KA9-1	np	np	22.46	--	--	--	--
KA9-2	np	np	19.42	--	--	--	--
KA9-3	np	np	< 0.1	--	--	--	--
KA10-2	np	np	14.44	--	--	--	--
KA Well	34.71	38.13	6.90	80	--	--	--

Notes
-- no information available to calculate
negative sign indicates an increase in concentration

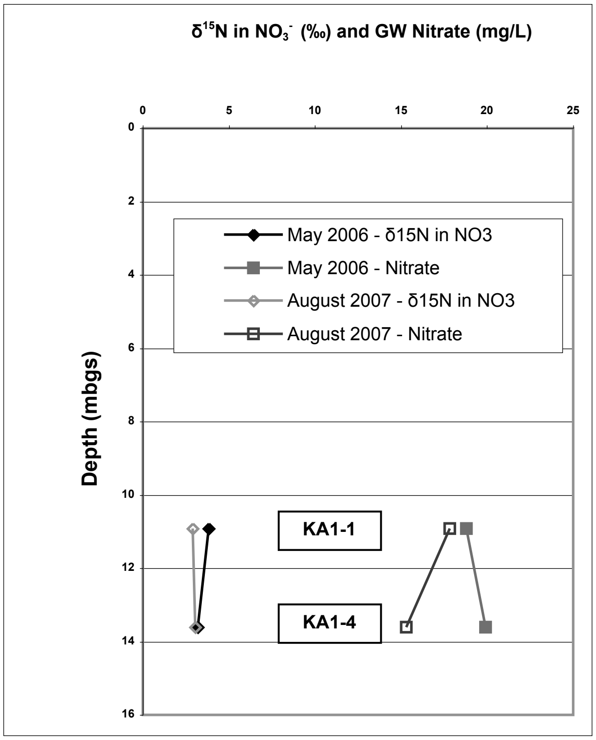

Figure I.1 - Groundwater nitrate and δ^{15}N in NO_3^- Isotopes at the KA1 well nest.

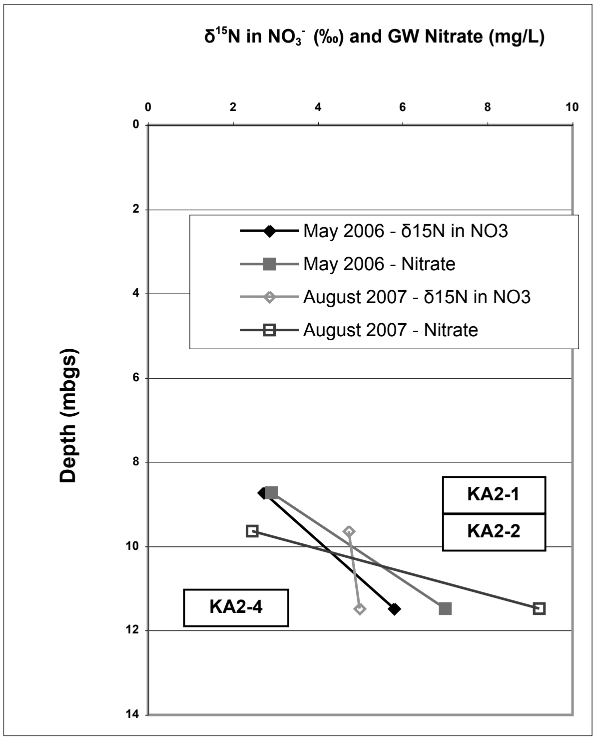

Figure I.2 - Groundwater nitrate and δ^{15}N in NO_3^- Isotopes at the KA2 well nest.

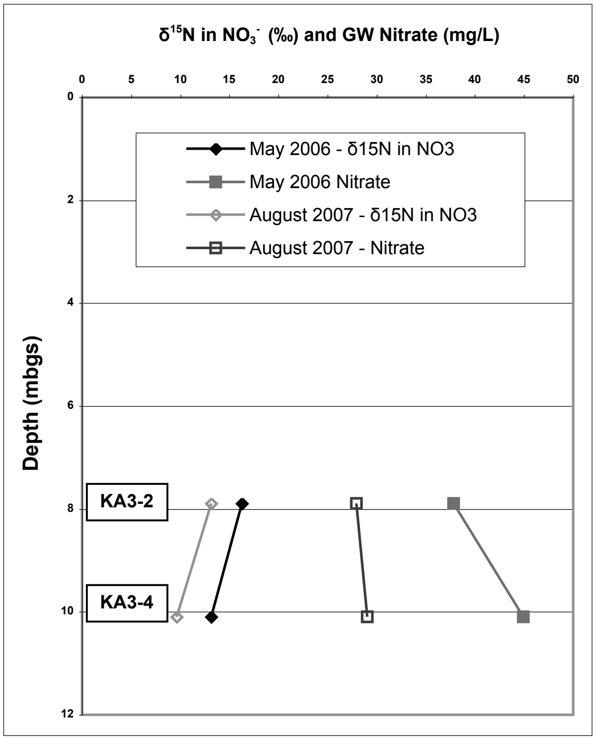

Figure I.3 - Groundwater nitrate and δ^{15}N in NO_3^- Isotopes at the KA3 well nest.

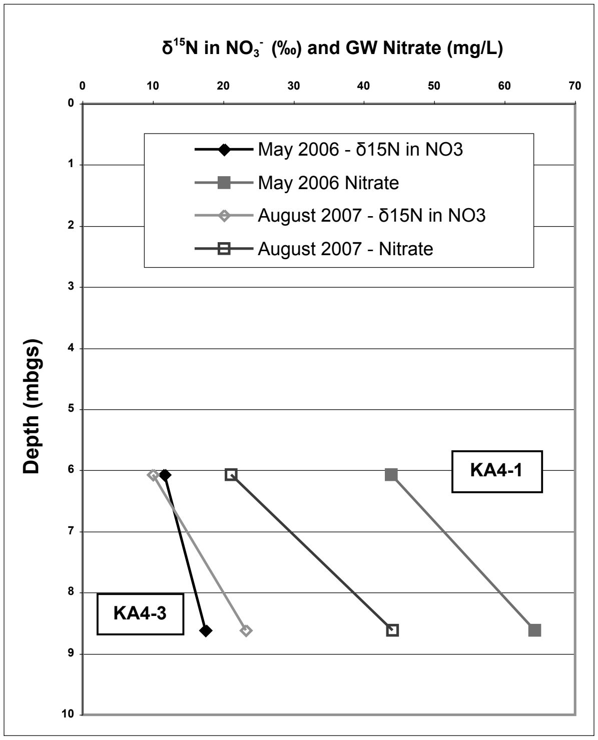

Figure I.4 - Groundwater nitrate and δ^{15}N in NO_3^- Isotopes at the KA4 well nest.

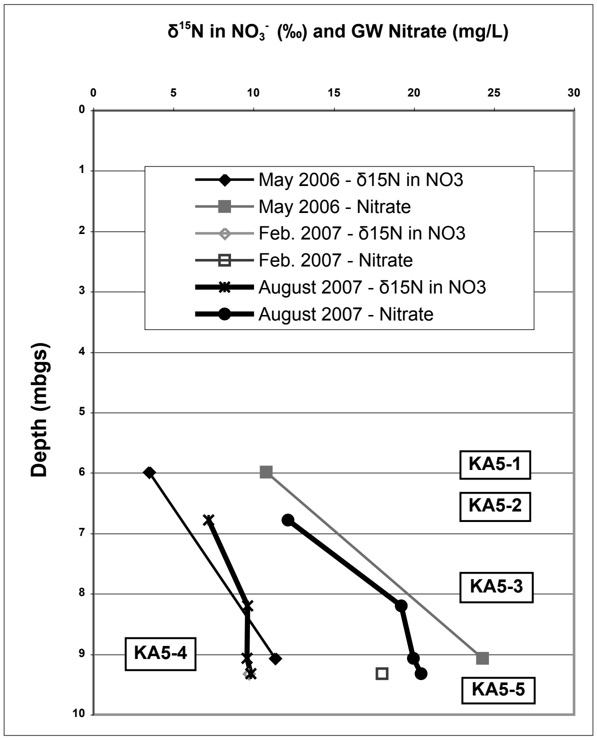

Figure I.5 - Groundwater nitrate and $\delta^{15}N$ in NO_3^- Isotopes at the KA5 well nest.

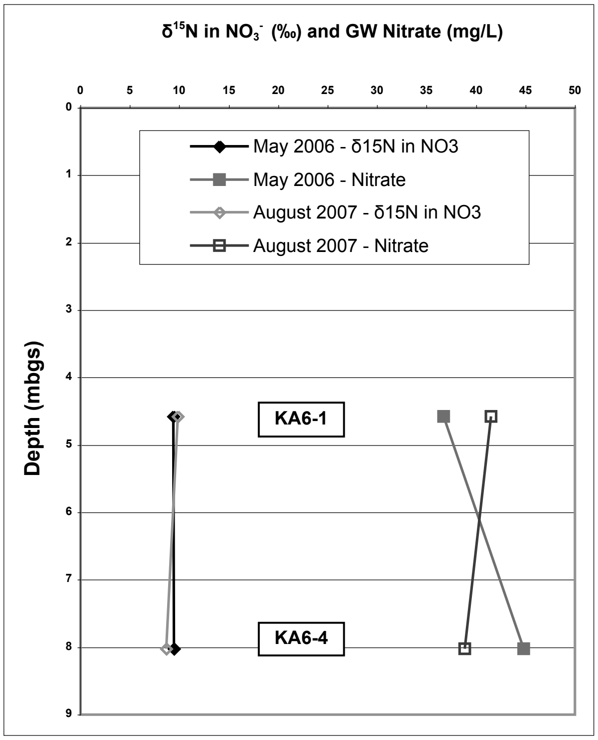

Figure I.6 - Groundwater nitrate and $\delta^{15}N$ in NO_3^- Isotopes at the KA6 well nest.

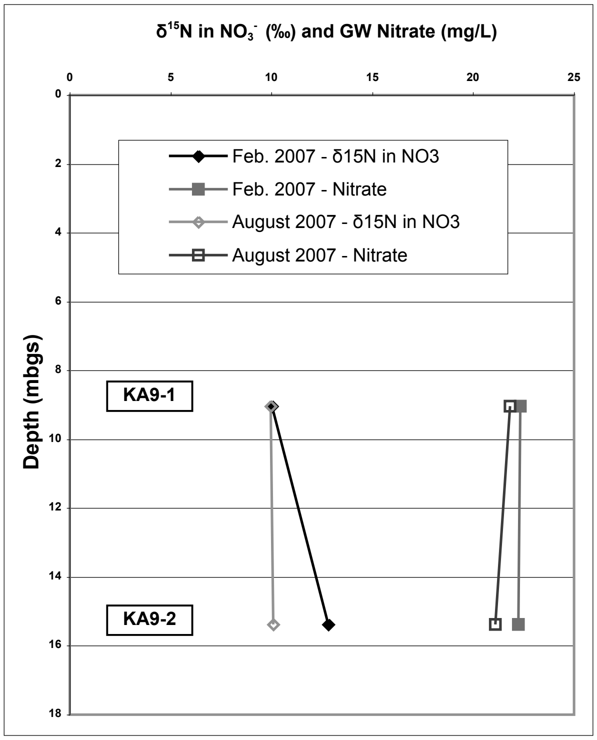

Figure I.7 - Groundwater nitrate and $\delta^{15}N$ in NO_3^- Isotopes at the KA9 well nest.