Fate and Transport of Land Applied Waste Greenhouse Feed Water During Field Infiltration Experiments

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, 2016

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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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Abstract

Because of the high concentration of greenhouses in Essex County, greenhouse feed water discharges are considered as a potential contributor to nuisance and harmful algal blooms and hypoxia in western Lake Erie. Waste greenhouse nutrient feed waters (GNF) are comparable to other nutrient sources used in agriculture. Land application of greenhouse nutrient feed water to adjacent crop land is regarded as a potentially suitable alternative to in-house wastewater treatment systems both in cost and ease of adoption. Therefore, the land application of the feed water can be an appropriate management response to the nutrient load issues in such water courses. Compared to other non-agricultural source materials, such as biosolids, GNF are under studied and much less used as sources of alternative fertilizers. In an effort to assess the potential environmental impacts of this land application option, a collaborative monitoring program was established at partner greenhouse operations near Leamington, ON. We hypothesized that the nutrients and other dissolved constituents of concern in feed water applied to active crop lands would be absorbed and attenuated to an acceptable level within the soil profile before reaching the local ground water table. Investigations of this hypothesis involved the controlled land application of GNF on active cropland managed by greenhouse operators in the vicinity of Leamington, ON. Four field trial sites were established and characterized for controlled plot size experiments. Field installations included porous cup lysimeters for the collection of soil water samples and groundwater monitoring wells above and below water table to monitor long term groundwater quality and water table fluctuations; composite soil samples taken at randomized locations within the field plots. Local precipitation was also measured using on-site rain gauge station. At two of the field sites, feed water from the greenhouses was applied to the monitored plots in the fall as a pilot infiltration experiment. In the second year, feed water was applied together with a conservative tracer at all four field sites in the spring. Composite soil samples and water samples including soil water from lysimeters, shallow groundwater from monitor wells and surface water from tile outlets were collected both before and after the land application events. Geochemical analysis was focused on target species including nutrients, heavy metals and applied conservative tracer. By comparing the field data sets, high variability in fate and transport of land applied GNF was observed under different soil conditions. Surficial soil permeability and the potential presence of macropore features are highly related to the land application performance. However, the results demonstrated that the majority of the GNF applied at highest permissible rates over a variety of different soil types and agricultural land use practices, typical of the Leamington

Area, remained within the vadose zone and at low concentrations over the course of the monitoring period. Based on the results obtained from all of the controlled GNF land application experiments, it was observed that nutrients and other dissolved constituents of concern in the applied are significantly attenuated in vadose zone and remain at very low concentrations. No evidence of significant environmental impact from the land application of GNF was observed. Overall, the results of the study suggest that the land application GNF under Ontario’s regulations could be considered as a feasible and environmentally reasonable alternative to other waste water treatment option for managing GNF. Additional insight could be derived from monitored field-scale land applications of GNF on various geographical settings and agricultural land use practices within the Leamington area.

Acknowledgements

First and foremost, I would like to thank my supervisor Dr. David Rudolph for the opportunity to carry out this challenging and interesting project and his invaluable guidance and support over the years. His kindness and encouragement gave me great motivation to move forward along this tremendous journey.

I would also like to thank Don King and Ann Huber for their assistance in fields as well as their advice and comments during the whole project. Their suggestions and help are critical for the completion of this thesis.

My grateful acknowledgements are extended to Dr. William Robertson for his role as advisor on my defense committee and taking the time to provide comments and suggestions.

I am also grateful to Bob Ingleton and Paul Johnson for their careful work in the field drilling soil cores and useful helps in the lab. Their in depth knowledge and experience helped me a lot in this work presented. I would like to thank Andrew Wiebe for helping me set up on-site data logger stations and his valuable suggestions on data analysis.

I appreciate the help of Niki Long, Elliot Pai, Kristen Blowes and Ian Mercer for their hard work and kind helps in the field as co-op students.

Finally, I would like to thank my parents for their unconditional support.

Financial assistance was provided by the University of Waterloo, Natural Sciences and Engineering Research Council of Canada, Soil Resource Group, Guelph, ON and the Ontario Ministry of the Environment and Climate Change.

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1 Introduction

1.1 Eutrophication in Lake Erie

Eutrophication in Lake Erie has been a historical problem for more than a half century. Excess nutrient loading, particularly phosphorus from point and agricultural non-point sources is regarded as the primary cause of Lake Erie eutrophication (Dolan and Chapra, 2012, Scavua et al., 2014). By the late 1960s, an agreement for limiting phosphorus inputs to the Great Lakes was implemented through the Great Lakes Water Quality Agreement as a response (GLWQA) (DePinto et al., 1986). Because of the load reduction, a rapid and unprecedented success in water quality recovery was achieved during 1970s and 1980s (Bertram, 1993). Despite the early success, however, Lake Erie appears to be returning to eutrophic conditions since mid-1990s (Bridgeman et al., 2013, Zhou et al., 2013). In 2011, a record-breaking magnitude of harmful algal blooms (HABS) occurred in Lake Erie (Michalak et al., 2013). Over the past several years, HABS have been continuously forming in Lake Erie (Figure 1.1). The great impact on both local ecosystem and human health has once again become a topic of considerable concern (Gilbert et al., 2014).

1.2 Nutrient Contributions from Greenhouses

In recent years, the greenhouse industry has been expanding in Essex County, particularly in the Leamington area and elsewhere in southern Ontario (The Ontario Greenhouse Alliance, 2009) (Figure 1.2). Greenhouses routinely produce variable quantities of waste nutrient feed water over the course of a year that has to be disposed of. Greenhouse Nutrient Feedwater (GNF) is a nutrient solution removed from a closed circulation system at a greenhouse operation that still retains significant nutrients for plant growth. Intensive horticultural operations may lead to groundwater pollution resulting from the inappropriate management of GNF (Thompson et al., 2007). According to the Greenhouse Wastewater Monitoring Project report prepared by The Ministry of the Environment and Climate Change (MOECC) in 2012, 65 per cent of the greenhouse operations sampled in the Leamington area discharged waste water with high nutrient levels either directly or indirectly into watercourses, much of which is anticipated to flow eventually into Lake Erie. Phosphorus from sampled from ponds, outfalls and surface water from drains and tributaries etc. was measured up to 2,000 times the Provincial Water Quality Objective (1994) (0.03 mg/L) and nitrate concentrations in discharges were measured up to 70 times the Canadian Council of Ministers of the Environment criteria for protection of aquatic life in streams (2012) (13 mg/L). Because excess phosphorus loading is implicated as a potential contributing source to abiotic conditions in western Lake Erie, the Ontario Ministry of the Environment and Climate Change (MOECC) concluded that waste greenhouse nutrient feed water may be a contributor to nutrient loadings into Lake Erie. In Leamington area, the mean annual feedwater yield per hectare greenhouse is 357.7 m^3 (Soil Resource Group, 2012). Based on the total area of greenhouses in Essex County provided by Statistics Canada (2011) and typical greenhouse leachate information presented in Greenhouse Process Water Quality and Quantity Characterization Analysis Final Report (Soil Resource Group, 2012), an estimate for unused greenhouse leachate total phosphorus is derived to be approximately 20 metric tons per year (Appendix H). Compared to the annual Thames River total phosphorus loading reported by Nürnberg and Lazerte (2015), which is 342 metric tons per year, an estimate of 20 metric tons of total phosphorus per year from greenhouse leachate is quite significant. Although the actual nutrient loading from GNF to Lake Erie is not well known and is likely lower than this estimated amount, it is still potentially a significant amount that should be taken into consideration when assessing total phosphorous loading to western Lake Erie. Therefore, an effective and feasible solution for managing GNF is desired.

1.3 Solutions and Current Studies

Although a significant portion of nutrients applied as fertilizer within greenhouse operations are taken up by the greenhouse plants from feed waters, waste GNF derived from the fertilization process still has significant amounts of nutrients and other dissolved constituents left in the solution (Table 1.1). Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA, 2013) has completed an analysis of various greenhouse nutrient feed waters and deemed the feed waters discharged from many greenhouses to be comparable to other nutrient sources used in agriculture practices. Land application of greenhouse feed water to adjacent crop land is regarded as a potential alternative to in-house wastewater treatment systems both economically and for ease of adoption. Therefore, land application of GNF may be an appropriate management response.

In 2015, the Province of Ontario released a Greenhouse Nutrient Feed Water (GNF) regulation (Ontario Regulation 300/14, 2015) designed to regulate and permit the land application of greenhouse nutrient feed waters to agricultural lands. However, there have been very few studies conducted on the potential environmental impacts of land applying greenhouse nutrient feed water. As a comparison, land application of biosolids has been evaluated in detail from an environmental perspective and is currently a routine practice within southern Ontario and elsewhere. It has proven a cost effective practice for recycling nutrients and improving soil quality, and the environmental impacts are deemed to be minimal (Hébert, 2008 and McFarland et al., 2012). Compared to the well-studied land application of biosolids, the fate and transport behavior of dissolved constituents from GNF application to agriculture land is not well understood.

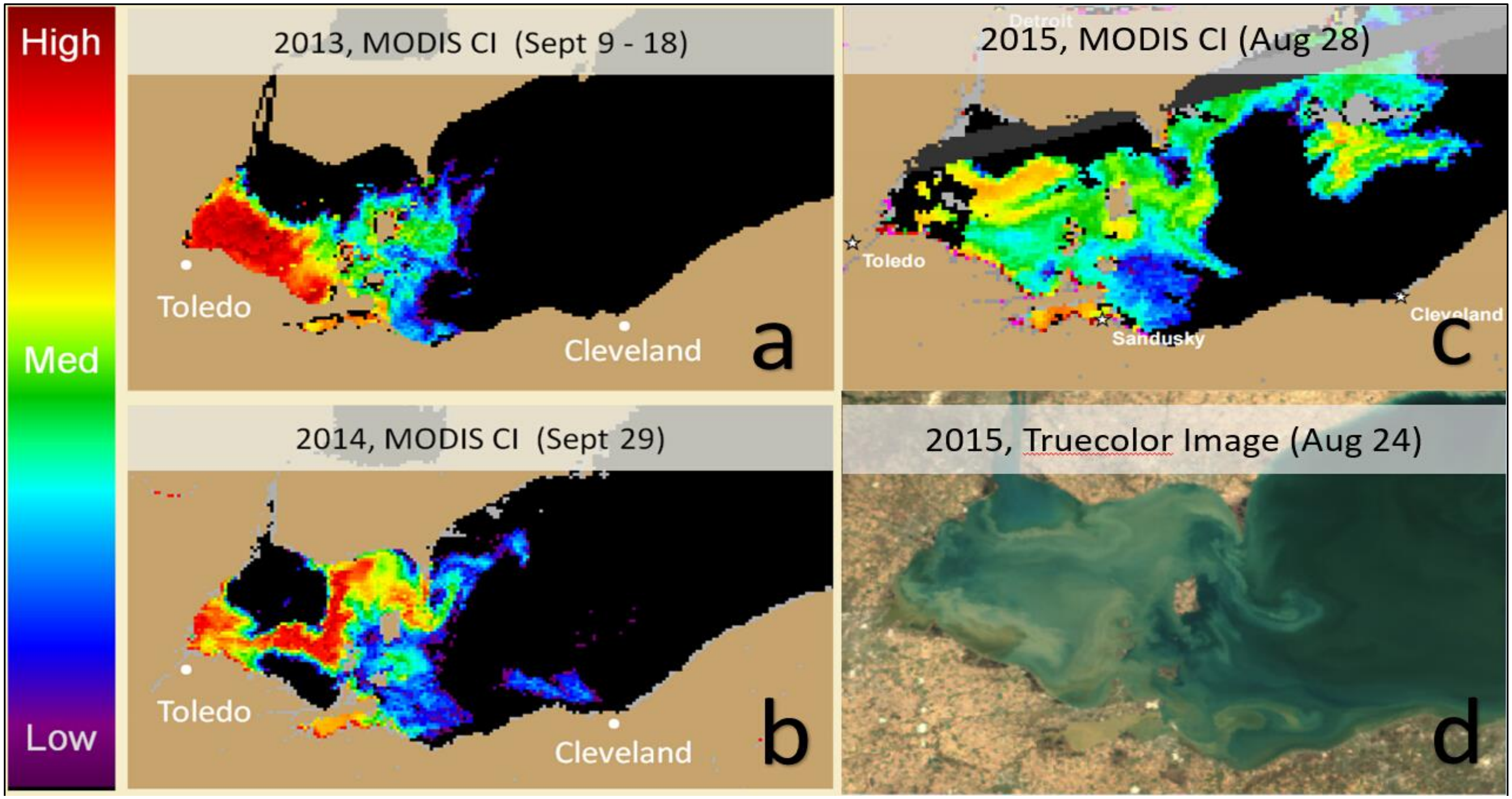


Figure 1.1 a), b), c) Cyanobacterial Index from NASA's MODIS-Aqua data collected in 2013, 2014 and 2015. d): A truecolor image taken from NASA's Aqua satellite in 2015 (Source: NOAA)

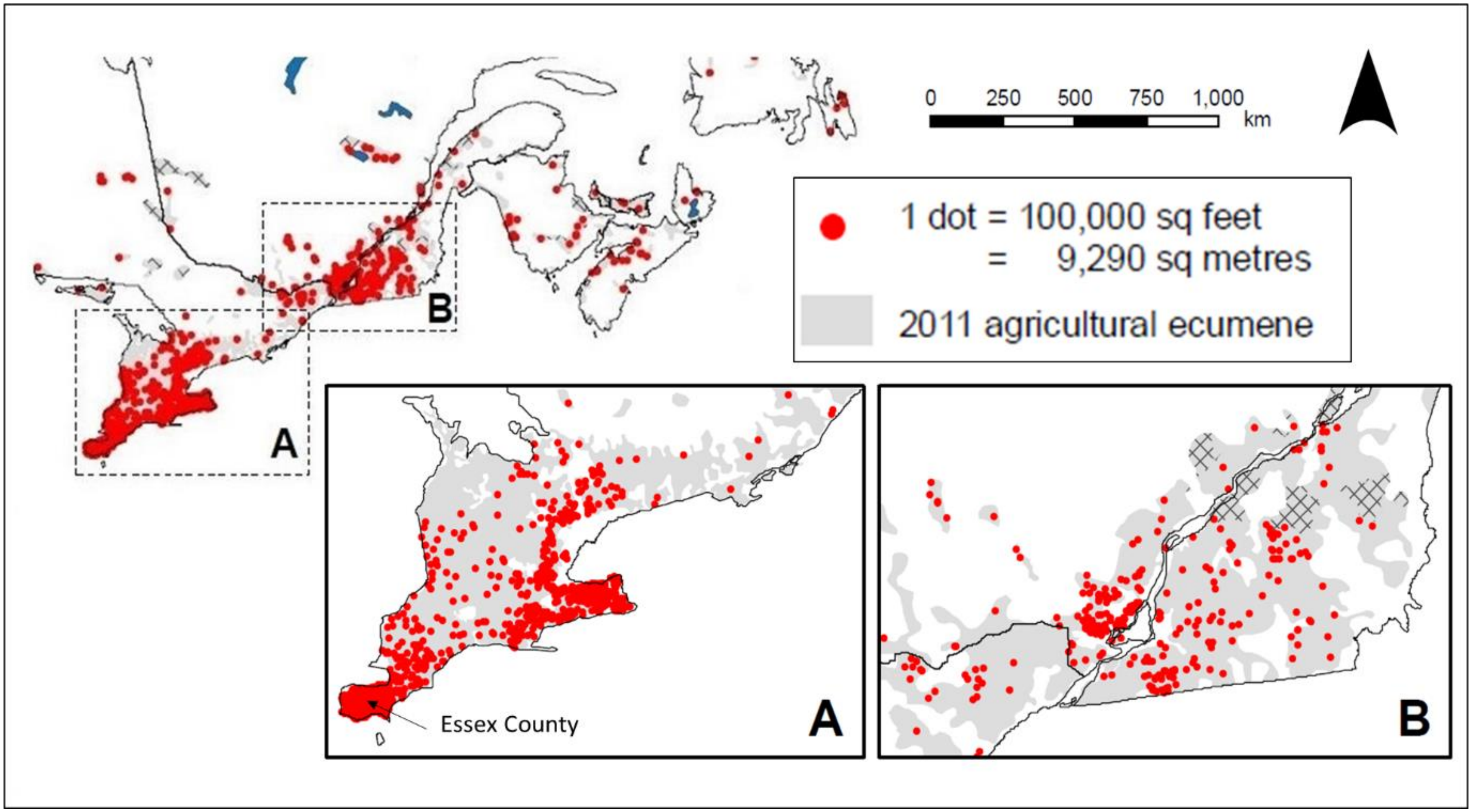


Figure 1.2 Illustration of total greenhouse area in central and eastern Canada, modified from Statistics Canada, 2011. Total greenhouse area in Essex County: 6,215,010 m^2

Table 1.1 Chemical analysis of waste greenhouse nutrient feed water sampled from each of the field sites in spring 2015

	Prism	Cecelia	Lakeview	Warkentin	Guidelines
Nitrate Nitrogen (ppm)	381	266	38.3	283	10[1,2]
Total Phosphorus (ppm)	21.8	37.3	8.73	59.3	0.03[2]
Potassium (ppm)	189	307	43.7	396	N/L*
Calcium (ppm)	341	213	88.2	253	N/L*
Magnesium (ppm)	90.8	45.3	23.8	55.2	N/L*
Chloride (ppm)	51.8	63.5	20.7	30.1	250[1]
Sulphates (ppm)	288	221	96.1	248	500[1]
Sodium (ppm)	81.9	210	11.8	14.1	200[1]
Zinc (ppm)	0.611	0.136	0.123	0.316	0.02[2]
Manganese (ppm)	0.288	0.602	0.0344	0.596	0.05[1]
Copper (ppm)	0.116	0.078	0.0826	0.052	1[1]
Iron (ppm)	1.58	1.37	0.147	1.45	0.3[1,2,3]
Boron (ppm)	0.85	0.5	0.056	0.35	5[1]
Molybdenum (ppm)	0.105	0.0594	0.0188	0.0618	0.040[2]
Aluminum (ppm)	<0.1	<0.10	0.046	<0.10	0.1[1]
Arsenic (ppm)	<0.01	<0.010	0.0023	<0.010	0.025[1]
Cadmium (ppm)	<0.0009	<0.00090	0.000252	<0.00090	0.005[1]
Chromium (ppm)	<0.0050	<0.0050	0.00233	<0.0050	0.05[1]
Cobalt (ppm)	<0.0050	<0.0050	0.0173	<0.0050	0.009[2]
Lead (ppm)	<0.0050	<0.0050	0.00155	<0.0050	0.005[2]
Mercury (ppm)	0.000025	<0.000010	<0.000010	<0.000010	0.001[1]
Nickel (ppm)	0.039	<0.010	0.0106	<0.010	0.025[2]
Selenium (ppm)	N/L*	<0.0040	<0.00040	<0.0040	0.01[1]

*These parameters are not specifically regulated in any Ontario water standards.

[1] Technical support document for Ontario drinking water standards, objectives and guidelines, 2006.

[2] Ontario Ministry of the Environment and Energy (1994) Water management policies, guidelines, provincial water quality objectives.

[3] Canadian Council of Ministers of the Environment (2007) Canadian Environmental Quality Guidelines

1.4 Objectives and Hypothesis

The primary objective was to determine whether the land application of greenhouse nutrient feed water is protective of the environment.

Specific objectives of this research were as follows:

1. Select representative and collaborative greenhouse operations as field sites within the vicinity of Leamington, ON. Design, conduct and assess the approach to controlled plot-size GNF infiltration experiments on well characterized soil at selected active greenhouse sites.
2. Assess and document the fate and transport behavior of the dissolved constituents within the greenhouse nutrient feed water (GNF) after the land application in different field settings.
3. Evaluate the potential environmental impacts of the land application of GNF in these field settings through field monitoring.
4. Provide advice and recommendations to policy makers and farmers for the land application of GNF as part of nutrient management plans for different greenhouse operations.

The hypothesis of this study is that the nutrients and other dissolved constituents of concern in GNF applied to active crop lands under worst case scenarios would be absorbed and attenuated to an acceptable level within the soil profile before entering the local groundwater system.

1.5 Study Site

A group of four field study sites were selected after consultation with the respective greenhouse operators near the towns of Leamington, Kingsville and Cedar Spring in south-western Ontario, Canada (Figure 1.3). Each of the operations has been in operation for many years and has vegetable greenhouses on site as well as cropland adjacent to them. Each of the sites has a unique combination of greenhouse produce, other crops, and soils that are typical of the region and represents a large range of greenhouse nutrient management practices and soil conditions. Soils at these sites range overall from fine gravel to sandy loam and clay, representing typical well drained and poorly drained soils within the region (Morwick et al., 1949). Detailed background information and site characterization information for each site is contained in Appendix A, and briefly summarized below (Table 1.2).

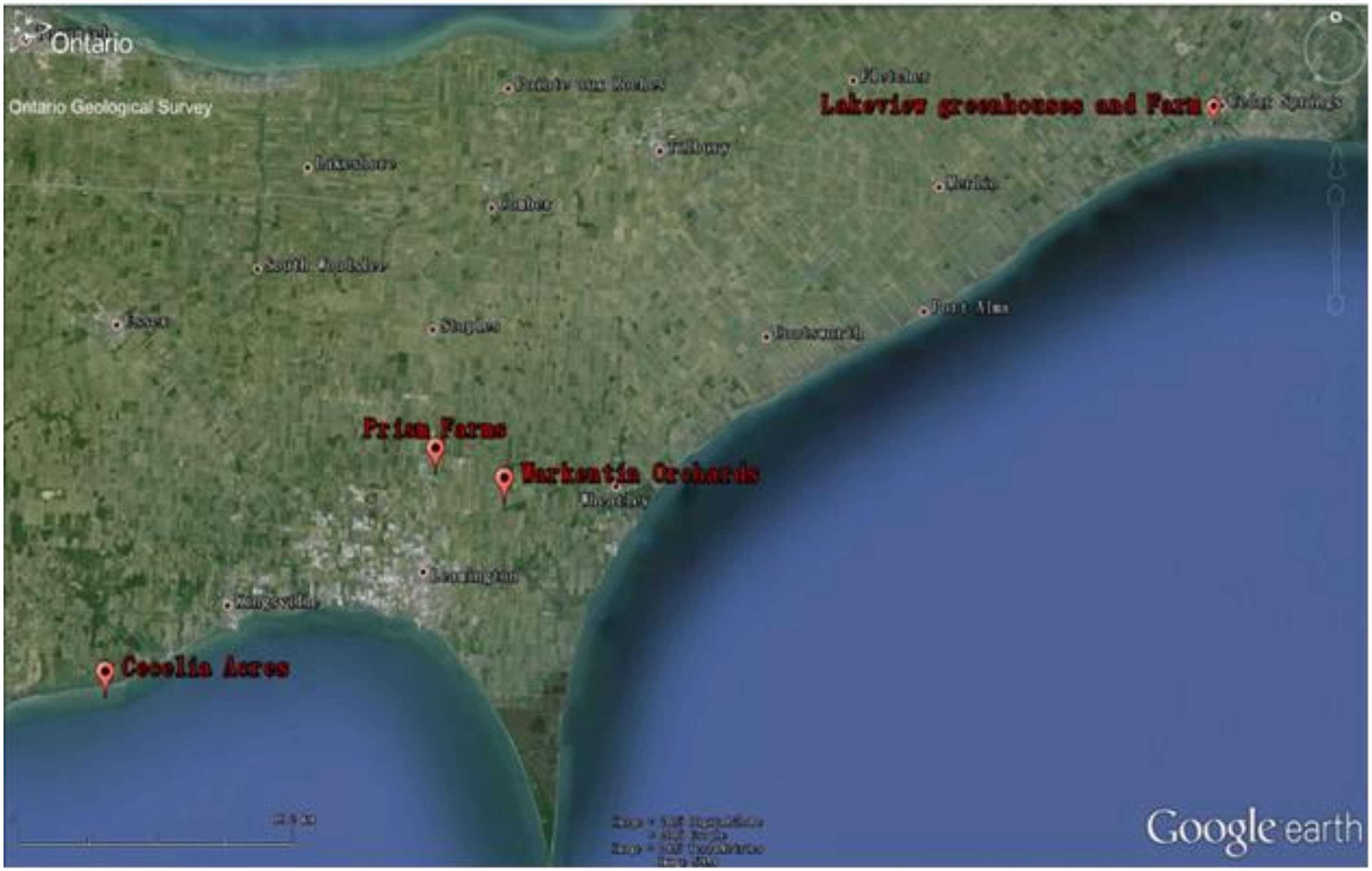


Figure 1.3 Study site locations of the four selected greenhouse operations. Retrieved from Google Earth, Ontario Geological Survey 2010.

Table 1.2 Summary of Study Sites Infirmation

	Field crop	**Greenhouse crop**	**Soil description**
Prism	Miscanthus	Tomatoes	30 cm of sandy silt topsoil overlying silts and stiff clay with occasional thin sand interbeds
Cecelia	Soybean	Tomatoes	25 cm of sandy silt top soil and another 75 cm of sand and silt layer overlying stiff clay
Warkentin	Orchard	Cucumbers	30 cm of clayey silt overlying 40 cm of compacted silty material and stiff clay
Lakeview	Soybean, Tobacco	Mixed vegetable transplants, cucumbers	Coarse and loose sandy gravel overlying clay

2 Materials and Methodologies

2.1 Site Selection

One of the critical components of the study was to establish a series of field sites where the on-farm field activities could be carried out for the entire duration of the project. Different agricultural practices and soil conditions can have a significant influence on the results. Thus, selection of the field sites was an essential component of this study. In order to have good representation of conditions typical to the region, the selection process was based primarily on:

1. Characteristics of both the greenhouse operation and associated field cropping practices to be representative of typical conditions encountered in the region.
2. Nature of the geographical setting and soil conditions as being representative of typical conditions encountered in the region.
3. The greenhouse operator was interested and committed to support on-farm field investigations over the course of the study.

Several tools were involved in the site selection including soils and surficial geology maps, aerial photography from the Ontario Geological Survey, drainage and topographic maps and on-site field investigations. Several on-site discussions with each of the greenhouse operators were also conducted as part of the site selection process, which provided invaluable insight for the design and implementation of the field activities. The four collaborating greenhouse operations that were selected for the study including Prism Farms, Cecelia Acres, Warkentin Orchards and Lakeview Greenhouses are described briefly in the Results section below with more detailed information contained in Appendix A.

2.2 Baseline Characterization

A baseline monitoring program was developed and carried out at the four sites. Included in the baseline monitoring was physical soil characterization through the analysis of soil cores, soil water chemistry based on lysimeter samples, soil chemistry analysis from soil core samples and groundwater quality on samples collected from the monitoring well network and tile drain samples. The soil and water samples were analyzed for a selected series of compounds associated with GNF in advance of its land application on the selected fields as described below. These combined data sets provided initial reference levels of the selected compounds, which could then be compared to data collected during subsequent sampling events following the future controlled land application of the GNF. The comparative analysis would provide insight into the nutrient value of the feed water applications, potential environmental impacts and inform the development of effective nutrient management practices. Studies were also completed to understand historical agricultural land use practices and to collect any additional site investigations or relevant data that could provide additional background information. The results of the detailed baseline site characterization are described in Appendix A.

2.3 Plot-scale Infiltration Experiments

2.3.1 Field Instrumentation

Field installations were initiated at each of the four selected field sites in June, 2014 to facilitate the collection of baseline data for the plot areas prior to the land application of the GNF. The instrumentation included porous ceramic cup lysimeters installed at depths of 30cm, 60cm and 90cm within root zone for the collection of soil water samples and at least two groundwater monitoring wells above and below water table. Lysimeters were installed manually with a hand auger system at an angle of 30 degrees from the vertical in order to minimize the incidence of preferential flow (Mitchell et al., 2001). Once augered to the specified depth, sediment from the last portion of augered hole where the ceramic cup would be placed was collected and mixed with silica flour and water to make a slurry. The slurry was then replaced to the base of the augered hole to enhance the hydraulic connection between soil and ceramic materials. The lysimeter was then installed and the annulus was sealed with bentonite powder to prevent downward flow from surface around the lysimeters. To help the ceramic cup remain hydrophilic so that the capillary tension in soil could be maintained (Lajtha et al., 1999), all ceramic cups were saturated in the laboratory and kept in water before field installation. All components were acid washed with 5% HCl before laboratory saturation to remove any influence of the construction and handling of the cups.

The monitoring wells and the deep soil cores were installed and collected respectively with a track mounted GeoProbe drill rig. The rig is designed to collect continuous 3 cm core samples using a vibratory and pushing action. At each site core samples were taken both to collect samples for soil chemistry analysis and also to permit stratigraphic logging of the near surface sediments. Prior to the installation of the monitoring well screens and casing, the pilot core holes were reamed to a diameter of 5 cm with an auger to permit the installation of 3 cm diameter flush joint PVD well screens and casings. The extra space around the screen and casing was backfilled with permeable sand to just above the screen to form a permeable filter pack and bentonite pellets were backfilled to ground surface to form a seal between the casing and the soil to prevent vertical movement of water. For each of the installations, 30 cm long, 10 slot PVC well screens were used. Both lysimeters and groundwater monitoring wells were developed by extracting water and allowing them to recover with in situ soil water and groundwater.

Anticipating annual fluctuations and potential level changes during irrigation, the wells were instrumented with continuous pressure and temperature recording equipment. All the instruments were carefully protected anticipating their use over the entire time frame of the project. Each site is designed to have two adjacent experimental plots. One labeled as application plot, which received the controlled GNF application and the other only receive normal agricultural land management and thus was labeled as the control plot. These plots have identical field instrumentation installed. Details on plot designs are described in the section below.

Composite soil cores were collected at random locations throughout the agricultural fields using standard hand held soil corer (2.5cm diameter).The soil samples were sent for chemical analysis to develop an idea of the existing distribution of key soil parameters that would be of interest during the land application of the GNF. Additional detail on the soil sampling and composite sample process is provided below.

During the first year of the study, there were sufficient resources and time to fully instrument and conduct the initial controlled GNF land application trials on two of the field sites. Basic installations were implemented on the other two field sites including groundwater monitoring wells and 2 sets of three lysimeters so that baseline characterization can be conducted. As this study carried into the second year, full instrumentation was completed at the other two field sites. In order to enhance the volume of soil water that could be collected and to obtain a more representative sample of the average concentrations of the target species in the soil water, each site has 6 clusters of porous ceramic cup lysimeters, each cluster has 3 lysimeters installed at the three designated depths (noted above) and at least two ground water monitoring wells beneath both the application and control plots The field plot designs are described in next section. In addition, a rain gauge station powered by solar panels was also deployed to collect precipitation data in the Leamington area and was located centrally near one field sites (Warkentin Orchards). The combined field instrumentation is summarized in Table 2.1 and an illustration of the configuration is provided in Figure 2.2.

2.3.2 Experimental Design

2.3.2.1 Plot Design

Experimental plots at each selected site were located within active farm fields adjacent to greenhouses. The plots were designed to have two treatment options referred to as the control plot and the application plot located directly adjacent to each other. Both the application and control plots received the same agricultural management as the surrounding fields during the course of the year; however, only the application plot received the controlled land application of GNF. Each of the two test plots is 3 m by 3 m in aerial extent and is divided into 9 equal sections to assist with the nutrient feed water application process and to aid in the detailed mapping of sampling locations. The two adjacent plots are separated by a 1 meter buffer zone (Figure 2.2). The lysimeter clusters were installed at three depths: 30 cm, 60 cm and 90 cm within the control and application plots and were replicated in three randomized positions within each of the plots. Groundwater monitoring wells were installed at approximately 0.5 m above and below the water table within both plots (Figure 2.2). Feed water provided by the greenhouse operators was applied manually on the entire surface of the application plots through the use of large watering cans on each of the 9 equally divided subsections of the plot to ensure accuracy in application rate and distribution.

2.3.2.2 Sampling Protocol

Soil samples were collected from random locations representative of the study area using a standard hand held soil corer (2.5cm diameter). As part of the baseline study for the initial infiltration experiment at two of the field sites, the samples were collected from the upper 15 cm of the soil profile at locations throughout the field where the plots were located to represent the background soil conditions over the test field. Within the application and control plots both before and after the initial GNF experiments, subsamples were collected to a depth up to 45 cm. However, the results of the year 1 study showed limitations of soil water samples and coarse soil sampling. It also suggested a potential of deep infiltration within a short time after application. A more detailed soil sampling was desired to help identify the GNF movements. As the study carried into the second year, a more detailed soil sample procedure was adapted based on the results and experience gained during the first year. In both the background study and GNF land application experiments, soils were cored down to 90 cm below ground surface and subsamples were taken at 10 cm increments along the core. Composite samples were constructed of a blend of the subsamples from each of the different depths from all of the cores. Once thoroughly mixed, a subsample of the composite soil mixture was packaged and submitted to an accredited laboratory for analysis. The corer was washed between samples to avoid cross contamination. Powdered bentonite was used to backfill the augered holes.

Samples of soil water collected from the shallow vadose zone were obtained using porous cup lysimeters installed at several different depths at the field sites. The soil water samplers or lysimeters used in this project consisted of four main components: the porous ceramic cup, PVC pipe, rubber sealed top with openings for plastic access tubes and the access tubes connected to a vacutainer or other sealed container and a vacuum pump (Figure 2.1). The ceramic cup functions as the filtering membrane for soil water (Lajtha et al., 1999), and is cemented to a 1 inch diameter PVC pipe using water proof epoxy which is a great bonder for ceramic and plastic and provides a good seal. The upper opening of the PVC pipe is sealed by a rubber stopper with two pin holes letting access tubes penetrating through. Silicone is used to seal between the pinhole and tubes. The access tubes are made from Teflon and extended above ground surface. One of the tubes is installed to the base of the ceramic cup and connected to a sealed vacutainer as a collection vessel. The other tube is positioned just below the rubber stopper and connected to a vacuum pump as a vacuum source. When sampling, suction is generated by vacuum pump to impose negative pressure throughout the system so that water in soil will be drawn into the ceramic cup. After the vacuum is maintained for a period of time, the vacuum pump was disconnected from the lysimeter, allowing air at atmospheric pressure to enter the lysimeter chamber and pushing the collected soil water solution into vacutainer.

Groundwater samples were collected using a Geopump (peristaltic pump) and a Teflon tube reaching to the bottom of the well. The monitoring wells were always purged prior to sampling so that the collected samples are representative of local groundwater. An amount equivalent to three well volumes was recommended removed to reach a complete purging process (USEPA 2004). However, the seasonal groundwater table fluctuations and low permeable materials surround the well screen can make sample availability and the recovery of the well extremely slow. In this case, only one well volume of water was purged before sample collection.

All water samples were sealed in 250ml plastic sampling bottles and immediately stored in a cooler with an icepack. Water samples were then sent to the commercial SGS Agri-food laboratory for chemical analysis within 48 hrs.

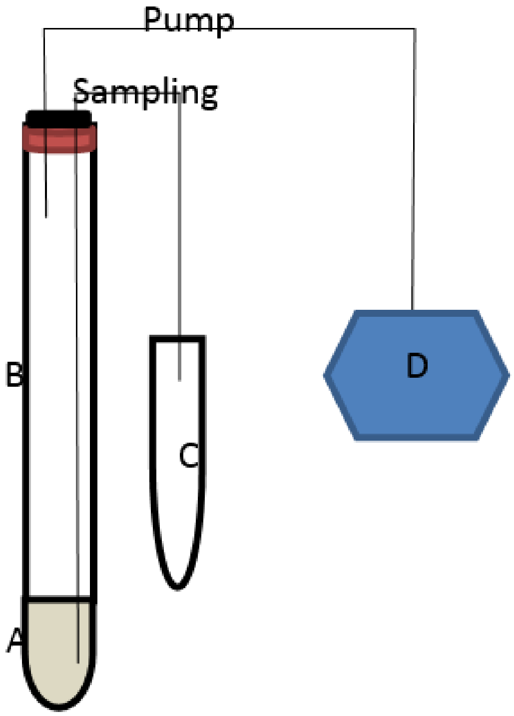


Figure 2.1 Demonstration of lysimeter design

(A) Ceramic cup, (B) PVC pipe, (C) Vacutainer, (D) Vacuum pump

2.3.2.3 Preliminary Plot-scale Infiltration Experiment

On December 4th 2014, the initial plot-scale infiltration experiments were established at two of the selected field sites: Prism Farms and Cecelia Acres (Figure 1.3). These initial controlled GNF land application trials were used to evaluate the field experimental protocol and also to investigate the case of a fall application. The two sites were anticipated to be the first ones to be receiving large-scale land application of GNF as initial trials. The unused GNF was taken directly from the farms' storage tanks following treatment with their UV+O3 systems. Overall, the applied feed waters contained low concentrations of nutrients and other solute species compared to other crop nutrient sources typically used in field application (Table 1.1). According to OMAFRA (Interim Protocol for the Utilization of Greenhouse Nutrient Feed water as a Nutrient on Agricultural Land, June 6, 2013), the maximum application rate that would be recommended at the time of these initial trials for the actual land application of the nutrient feed water within a 24hr period was 75m3/ha (7.5L/m2). This maximum amount (7.5L/m2) was applied during two applications (two separate days) to achieve the total recommended load based on the composition of the feed waters tested. To simulate a worst case scenario, this maximum rate was used to apply the feed water on the 3 m by 3 m application plot. Thus, a total of 67.5L greenhouse nutrient feed water was applied on each application plot per day for two consecutive days. For all of the GNF land application experiments, it was assumed that a one-time application at the maximum permissible rate would be used by the greenhouse operator over a land area that would be sufficient to use all of the waste GNF that the operation produced on an annual basis.

Prior to the GNF application, initial background soil water, soil and groundwater samples were collected from within both application and control plots. Soil water was collected from the lysimeters at all three depths (noted above) and composite soil samples (procedure described above) were collected from 8 to 12 randomized locations within the control and application plots at depth ranges from 0 to 15 cm, 15 cm to 30 cm and 30 cm to 45 cm to track a relatively continuous vertical profile of GNF movement. Groundwater samples were collected from the monitoring wells using a Geopump. In order to track the target species after the application, soil and water samples from both the lysimeter clusters and the monitoring wells were collected both in the short term (forty-eight hours after application) and in the longer term, 3 months later. Soil and water samples were sent to SGS Agri-Food Laboratory and analyzed for nutrients and heavy metals.

2.3.2.4 Second Year Plot-scale Infiltration Experiment

On June 30 2015, controlled land application experiments were designed and implemented at all four of the field sites. Experience gained through the Year 1 field tests was used to modify the field activities for these second GNF application tests. The field tests were conducted during this time period to evaluate the fate and transport behavior of GNF during a spring application event. Subsequent to the completion of the initial Year 1 trials, new maximum application rates were published in Ontario's regulation 300/14 on greenhouse nutrient feed water (2015), which permit higher application rates of GNF. This new maximum allowable application rate is 130m^3/ha (13.5L/m^2) within twenty-four hours, which is nearly twice that used during the initial tests (7.5L/m^2). At one of the sites (Cecelia Acres), application water ponded on the surface for the first 8 hours because of the high application rate and low permeability of the surface material. A barrier was constructed around the plot to prevent surface runoff. During the second day of application, feed water infiltrated at a slightly higher rate.

In addition to the GNF solution, another tracer species was added along with the feed water to help quantify the vertical GNF movement during the Year 2 tests. Sodium bromide was chosen because it is conservative tracer, environmentally friendly and bromide is not naturally present in the soil profile. A total of 5.5kg of solid sodium bromide was dissolved in 18L of application water making an aqueous concentration of 237g Br/L solution. It was applied evenly on the 3m by 3m plot at all four sites along with the nutrient feed water and the application was equivalent to a surface concentration of 0.47kg Br/m^2. Additional detail on the use of the bromide tracer is included below. Prior to the application of the feed water/tracer solution, excess vegetative stubble on each plot was cut and removed from the soil surface to ensure consistent soil surface application. It should be noted that following both GNF application in fall and spring, each site received routine agricultural management between the sampling periods.

A similar sampling protocol was followed as in the initial, Year 1 experiments. Prior to the application event, soil water, soil and groundwater samples were collected from within both application and control plots to document background concentrations of the key target species and distinguish possible previous legacy nutrients should they still be in the soil profile. Forty eight hours and three months after the application, a second and third full sampling round was completed as well. The experience gained in initial plot-scale infiltration trials indicated that sampling the soil water using the ceramic cup lysimeters proved to be inconsistent due to the differences in soil permeability at several locations. This was especially problematic during dry soil conditions. In some cases, very limited soil water sample volumes were acquired even over extended sampling cycles, which limited or prevented the chemical analysis of water samples. Also, considering the fairly large separation distances between the individual solution samplers (approximately 30 cm), it is possible that some of the infiltration front could be situated between the samplers making the precise interpretation of infiltration depth difficult. In order to enhance the monitoring of the land applied feed water and tracer solutes in the subsurface soil, soil cores were taken from both the application and control plots at each site (See result section). To ensure a more continuous data record throughout the entire vertical profile, the soil was cored from ground surface to a depth of 90cm and subsamples were collected every 10cm for analysis using the composite sample approach. These data sets permitted a more explicit evaluation of the mobility of the target tracer species.

During shallow excavation activities at several of the sites, macropore features including worm holes and old root holes were observed in the soil profile. To further investigate macropore characteristics, an 80cm deep test pit was excavated and mapped at one of the field sites. The potential role of the macroporosity on the mobility of the land applied nutrient feed waters is discussed in a subsequent section with reference to the observed tracer and feed water species distributions.

Table 2.1 Overview of Field Instrumentation at each of the Field Study Site.

	Prism Farms	Cecelia Acres	Warkentin Orchards	Lakeview Greenhouse
Groundwater Wells w/ transducer	6	2	4	7
Lysimeters	18	18	18	18
Soil Cores	√	√	√	√
Rain gauge Station			√	

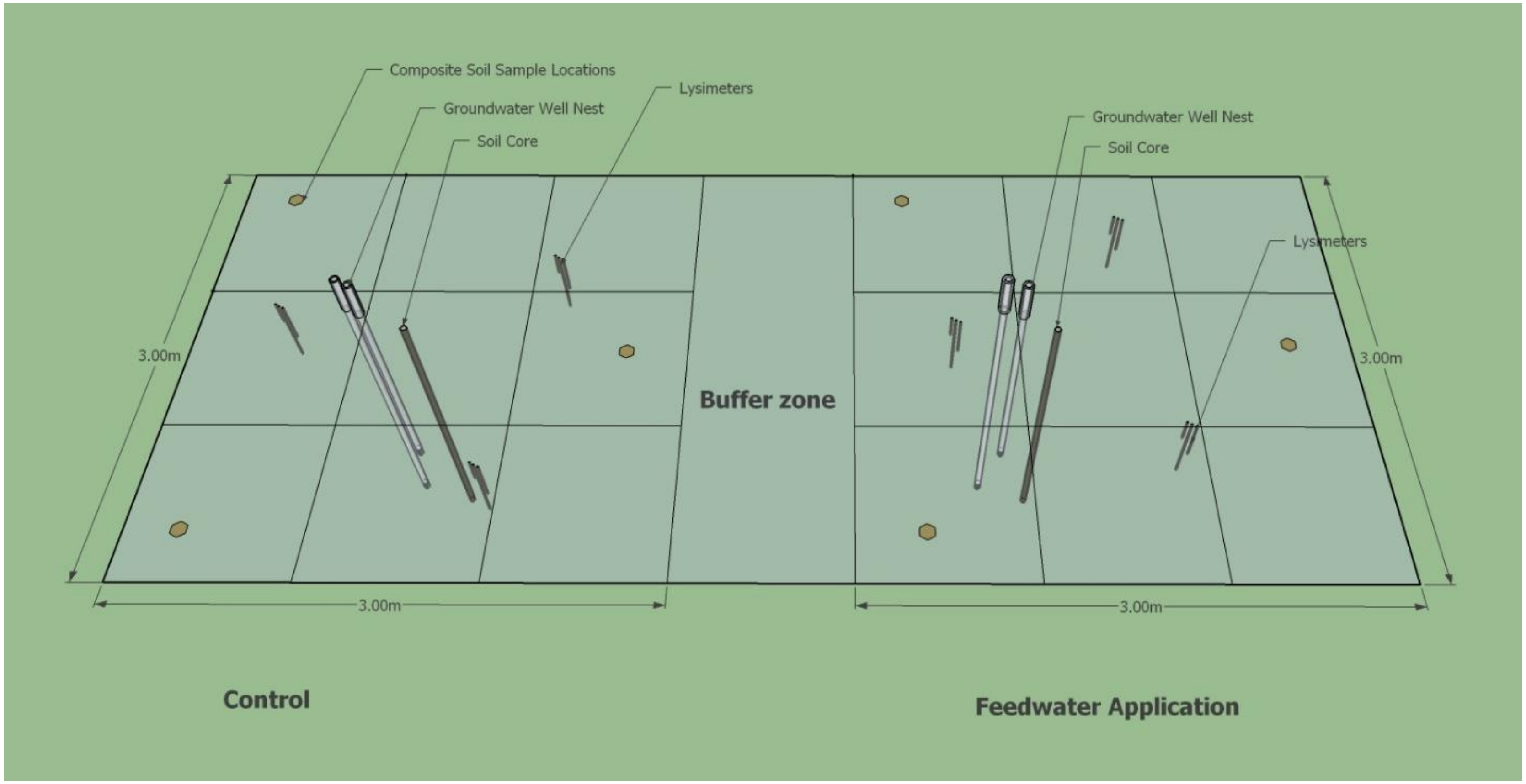


Figure 2.2 Illustration of plot design and instrumentation

2.4 Geochemical Analysis

To facilitate consistency in the chemical analysis of all samples, the same analytical laboratory (SGS Agri-Food Laboratories) was used during both fall and spring experiments (Years 1 and 2). The same set of solute species were tracked in the soil and water samples during all of the sampling campaigns as outlined in Table 2.2 and Table 2.3. The only difference was the inclusion of bromide in second year analysis. For the soil samples, general chemistry and nutrients analyses were accomplished through a series of extraction methods. Bromide and heavy metals analyses were conducted at SGS Lakeview Laboratories using microwave extraction and ICP analysis. For the water samples, electrode, colorimeter, ICP and titration techniques were used to analyze general chemistry and nutrients. A portion of the water samples were sent to SGS Lakeview Laboratories for dissolved heavy metal analysis using the MTH-SPEC-6 and ICP-AES method. The lists of the analysis methods are summarized in Appendix C in Table C.1 and Table C.2.

Table 2.2 Water parameter analysis

Analysis Group	Laboratory analysis parameter
General Chemistry	Conductivity, pH, Alkalinity, Hardness, TDS
Macronutrients	Total Phosphorus, Calcium, Nitrate Nitrogen, Potassium
Micronutrients	Boron, Magnesium, Molybdenum, Copper, Iron, Zinc, Nickel
Other Metals	Manganese, Aluminum, Arsenic, Cadmium, Chromium, Cobalt, Lead, Mercury, Selenium
Limiters	Chloride, Sulphate, Carbonate, Sodium
Conservative Tracer	Bromide

Table 2.3 Soil chemical parameter analysis

Analysis Group	Laboratory analysis parameter
Fertility	Phosphorus, Potassium, Calcium, pH, Organic Matter
Micronutrients	Boron, Magnesium, Molybdenum, Copper, Iron, Zinc, Nickel
Other Metals	Manganese, Arsenic, Cadmium, Chromium, Cobalt, Lead, Mercury, Selenium

2.5 Methodologies Used to Interpret Target Species Movements

Using the chemical analysis results of the soil and soil water samples, the vertical movement of the applied GNF species and the bromide tracer were directly tracked over time. The vertical profiles of concentration of the main target species were related to the background/pre application profiles as a reference and compared between control and application plots to elucidate the vertical movement of target species during the monitoring time period.

2.5.1 Relationship to Background Data

The primary reason for collecting background data beneath each of the test plots prior to the application of the feed water solutions was to have initial concentrations of the main target species in the subsurface. Once the background data was collected and compiled, a point of comparison was established to assess the data collected after the application of the GNF/tracer solution. As such, prior to an application event, background data sets were collected from all of the available instrumentation and from the soil profile beneath both the application and control plots. These data were then tabulated and plotted for direct comparison to the profiles collected following the application events as discussed in Section 4 below.

2.5.2 Comparison between Control and Application Plot Profiles

As demonstrated in plot design (Figure 2.2), control plots were established adjacent to the application plot where the feed water and tracers were applied. The duplicate plots had the same instrumentation and the sampling protocols were identical on both. As noted above, both the application and control plots received the same agricultural management as the surrounding fields; however, the application plots received the extra additional GNF/tracer application. With this type of plot experimental design, target species in the vertical soil profile can be compared side by side so that the effects from other variables are minimized when interpreting data results making data assessment more credible and straightforward. The control plot profiles collected following the irrigation event on the adjacent application plot were compared to the background data first to identify any potential changes in concentrations in the vertical profiles or to highlight potential errors in the data. The target species concentration profiles from the application plot were then compared to both the background data and control plot data. This combined series of profile comparison steps provided a more consistent approach to detecting any changes in concentration of the key target species that may have resulted from the land application of the GNF.

2.5.3 Use and Interpretation of the Bromide Tracer

Many of the feed water target species such as potassium, calcium and phosphorus, are abundant in agricultural soil reserves. Because the concentration of some of these target species in the applied GNF solutions may be much lower than the naturally occurring concentrations, it may be potentially difficult to detect a change in their presence in the soil profile. Although this may be a positive result from an environmental impact point of view, a clear contrasting concentration profile between plots is required to quantify the downward migration of the applied feed water solution. In order to address this problem, a fairly high concentration of bromide was added to the feed water solution. Bromide concentrations were low in these soils so it was considered a useful tracer to help monitor the potential movement of applied GNF. Bromide is also a common analyte in chemical laboratory analyses, and it can be easily added to the list of requested species. The bromide concentration profile is a surrogate for the vertical distribution of the conservative species within the nutrient feed water. In this way, the assumption was made that locations within the subsurface environment where measurable bromide was detected were also locations where a conservative species within the feed water would be, even if the feed water concentrations were too low to measure. This provided a separate estimate of the maximum depth of infiltration of the GNF following land application, a critical metric within the current study.

2.5.4 Long Term Monitoring in the Groundwater, Tile Drains and Surface Water

Groundwater samples collected from the monitoring wells located beneath the infiltration plots have the potential to indicate the arrival of the surface applied tracers. Samples were collected at various times during the monitoring period and evaluated for the occurrence of the key target species including the bromide tracer. The water levels in the monitoring wells were also monitored continuously with transducers in order to track fluctuations in the water table depth that could be the result of the irrigation event. Monitoring the groundwater table fluctuations can help demonstrate the vulnerability of groundwater in respect to surface contamination. Meanwhile, an understanding of local groundwater levels in different seasons can provide insights into the best application period during the annual cycle for land applying GNF when potential impacts on shallow groundwater quality is minimum.

In addition to the groundwater sampling that occurred following the land application events at each of the field sites, samples were also collected from the complete groundwater monitoring network over the course of the entire year during discrete sampling episodes. These measurements include analyses of samples from groundwater monitoring wells, tile water monitoring points and surface water samples collected occasionally from streams and drainage ditches near experimental sites. In addition, continuous groundwater levels and temperatures were recorded in a subset of the monitoring wells throughout the different sites using pressure transducer and thermistor devices installed in the wells. In addition to their use in monitoring the groundwater conditions during the infiltration tests, all of these data are intended to augment the baseline and regional data sets that will prove useful in the longer term as more extensive land application of GNF is adopted in the Leamington area.

2.6 Comparison with Biosolids

Biosolids are one of the common non-agricultural source materials (NASM) in Ontario. Although GNF is an agricultural source material (ASM), they both contain nutrients that field crops can use and are considered to have value as fertilizers. The land application of biosolids is strictly regulated in Ontario within the Environmental Protection Act (1990) and the Nutrient Management Act (2002). Because biosolids are widely land applied and well controlled in Ontario, it may be of value to compare GNF to biosolids relative to their potential environmental impacts. In the current study, the total mass loadings of key target species within the regulated limits of GNF land application are compared to those permitted for biosolids as a method of interpreting the comparable, potential environmental impacts of both alternative fertilizer source materials.

3 Results

3.1 Site Characterization

Based on principles listed in previous section, four collaborating greenhouse operations were selected including Prism Farms, Cecelia Acres, Warkentin Orchards and Lakeview Greenhouses. These four farms cover a wide geographical area within the region (Figure 1.3); include many of the typical types of greenhouse operations encountered in the area and involve a variety of different cropping types and practices on a range of typical field soils and conditions. Details of the site conditions at each of the collaborating farms is included in Appendix A and a brief summary of some of the most relevant information is presented below.

Prism Farms is located within Essex County north to northeast of the city of Leamington, Ontario. It has approximately 18 acres of greenhouse tomatoes and 6 acres of miscanthus as primary crop. On an annual basis, between 5% and 10% of the nutrient feed water used within the greenhouse operation is produced as waste water. The miscanthus field is the site of the plot experiments and is systematically tiled from north to south and connected to with a main tile drain header that drains toward the south into a shallow surface water drain. There is an access point at the outfall of the tile header that permits water sampling. The surficial soils on this site consist mostly of Brookston Clay with a thin, intermittent layer of fine to medium grained sand overlying parts of the cultivated fields on site. As presented in Appendix A, the surficial topography is very flat with a gentle slope of the ground surface from north to south. Soil cores taken on the experimental plots showed a soil profile of 30 cm of silty clay topsoil overlying stiff clays with occasional thin sand interbeds. Water samples including groundwater, soil water and tile water collected at this site during the initial baseline monitoring showed very low levels of all inorganic and metal species measured, which were all well below the Ontario Drinking Water Objectives (2016) (Table 3.1). A unique aspect of the miscanthus crop is that it is annually harvested but the plants remain viable to regrow the following year and are not tilled under at the end of the growing season and replanted the subsequent year.

Cecelia Acres is located within Essex County southwest of Kingsville, Ontario and less than 1000 m from the Lake Erie shoreline. Tomatoes are the main greenhouse product in the 20 acres glass greenhouses and 18 acres of soybean has been their primary field crop. Approximately 5% of the total feed water is collected as unused leachate on this site annually. The field selected for the plot-scale experiments is randomly tiled and connected to a surface water drain. Surface water features on this site include surface drains to both sides of the field. The surficial soils are mostly comprised of Fox Silt Loam and the topography is almost flat. According to the near surface core log data, there is approximately 25 cm of sandy silt top soil and another 75 cm of sand and silt overlying stiff clay. Generally, the shallow sediments at this site are similar to those encountered at the Prism site but the near surface materials appear to be less permeable in nature. Groundwater samples were unavailable during the baseline characterization. Soil water analyses showed similar low concentrations in target species as those measured at the Prism site except for slightly higher nitrate concentrations. Analysis of the soil samples indicated only higher nitrate, magnesium and calcium values than in Prism (Appendix A.2, Table A.9). Some spatial geochemical differences in the soil water and soil samples were observed in the data illustrating the potential for minor variability across the field site. Additional details on chemical analysis and soil conditions are contained in Appendix A

The Warkentin Orchards operation is located within Essex County northeast of the city of Leamington, Ontario. There were approximately 3 acres of greenhouse cucumbers as the major greenhouse crop and there are approximately 35 acres of orchards dominated by two species of apple trees in the field. Similar to the Prism Farms site, the surficial soils are mostly composed of Brookston Clay with an intermittent layer of fine to medium grained sand overlying parts of the orchard field on site. The greenhouse irrigation system does not recirculate the GNF and it is directly discharged into a lined pond. The orchard field is systematically tiled from north to south on 14 feet centers to match the orchard row width with all headers converging into a single drainage box (AgriDrain). As described in Appendix A, the continuous core samples suggests a soil profile of a thin layer of sandy material overlying thick and stiff clay. At the time of background investigation, not enough groundwater and soil water was collected for chemical analysis due the dry condition. Tile water samples were collected through drainage box, chemical analysis on these samples suggests similar results as Prism with an exception of slightly elevated manganese concentration. Soil analysis at this sites shows noticeably higher concentrations of target species than those in Prism and Cecelia, indicating a very high fertility level.

Lakeview Greenhouse and farm is located southwest of Cedar Springs, Ontario adjacent to Lake Erie. Operations in the Lakeview greenhouses include 8 acres of mixed vegetable transplants followed by cucumbers. The field crops have included corn and tobacco in recent years. During the course of this study, soybean has been the major field crop. According to the operators, greenhouse nutrient feed water is only recirculated 95% when growing cucumbers. The remaining 5% is mixed with storm water in a holding pond adjacent to the greenhouse structures. Based on data derived from regional soils maps (weblink for Ag Canada map) the surficial soils at this site are comprised of Highgate Sandy Loam and Gobles Loam. The topography across the land is again quite flat and lateral surface water drainage ditches are present between some of the fields. The soil core samples indicate loose sandy gravel in the upper 2 m to 3 m overlying clay with the gravel layer thickening towards the south part of the selected test field. Overall, the underlying sediments at this site are the most permeable among the four selected trial sites and are not completely consistent with the regional soils map designations. The composition of the groundwater is very similar to that observed at the other three sites although the concentrations are more dilute for many of the analytes (Table A.10 in Appendix A). Similar to the dry conditions in Warkentin, no soil water was initially obtained from the lysimeters during the baseline study. Analysis of the soil samples shows similar conclusions as in Warkentin with all target species concentrations below the Ontario Drinking Water Objectives (2016) (Table 3.1). However, the soil pH at this site is slightly acidic unlike the neutral to slightly alkaline soils at the other sites. More details on the baseline characterization and site investigation data are presented in Appendix A.

3.2 Results from Fall Application (Year 1)

The background data for fall application were collected at the Prism Farms and Cecelia Acres sites in November, 2014. The concentrations of the target species in both the soil and the soil water between application and control plots are nearly identical (See Appendix A, Table A.1, Table A. 3, Table A. 4, Table A.7, Table A.8 and Table A. 9). GNF sources from both sites were also sampled for chemical analysis. As presented in Table B.1, the GNF from two operations were very similar in chemical composition although the GNF from Cecelia was significantly more dilute for most species than Prism.

The plot-scale infiltration experiments began on December 2, 2014. Feed water provided by the greenhouse operators was manually applied on the 3m by 3m application plot at a rate of 7.5L/m^2 each day for two consecutive days. The soil surface was not frozen at the time of the application.

3.2.1 Fate and Transport of Target Species in the Soil Water Profiles

Soil water samples were collected from the ceramic cup lysimeters forty-eight hours and 5 months after the application events. Nitrate nitrogen, potassium, calcium and chloride were used as the indicators of the fate and transport mobility of applied GNF in the soil water profiles. These species were selected because they are relatively conservative during transport in the soil and occur at relatively high concentrations in the GNF. In contrast the heavy metals in the applied GNF were generally below detection limits.

Because of the relative fine surficial soil material at both sites, infiltration rates were expected to be rather slow. Forty-eight hours after the initial application, soil water samples were collected from the 30 cm deep lysimeters from the control and applications plots at both sites. Infiltration deeper than 30 cm below ground surface within 48 hours was not initially expected and as such the deeper lysimeters were not sampled. Comparison of the soil water samples before and after GNF application shows a noticeable increase in several of the chemical parameters including potassium, calcium, magnesium, at Prism and copper at Cecelia (Figure 3.1). Based on this limited soil water data from the lysimeter clusters, it would appear that the GNF infiltrated at least to a depth of 30 cm. Additional insight can be derived from the soil sample analysis discussed below.

Five months later in May 2015, the lysimeters within both plots at the Prism Farms and Cecelia Acres were sampled again and a sufficient amount of water was obtained from all three depths except 30cm at Cecelia application plot. The soil water data collected from both the application and control plots at both sites were first compared to the background collected in the fall of 2014. Increases in concentration of multiple target species were observed at both control and application plots at all three depth relative to the fall background data (Table A. 5, Table A. 6, Table A.7, Table A.8, Table A. 9 and Table A.10 in Appendix D). These changes in chemical concentrations in the soil water over the course of the 5 month period may have been due to natural processes. In order to evaluate the influence of the applied GNF on the concentration distributions, the data between the application plot and control plot were also compared. This comparison indicated only small increases in iron at Prism and very minor difference in most of the species (Figure 3.2 and Figure 3.3).

Overall, the changes in concentrations of target species detected in soil water either forty-eight hours or 5 months after the application were very low. It is difficult to attribute these change to the presence of the applied GNF in the soil profile due to the very low concentrations detected and the potential for natural heterogeneity. The elevated species concentration observed in the 30 cm lysimeters forty-eight hours after the application were no longer observed 5 months later, which is inferred to be due to attenuation or redistributed within the soil profile. Based on the results from the soil water samples, it would appear that the land application GNF did not significantly increase the concentrations of any of the constituents of interest in this study. As a result of the difficulty in collecting sufficient soil water samples from the lysimeters and the awareness of the potential soil heterogeneity, duplicate clusters or lysimeters were installed in advance of the Year 2 application trails.

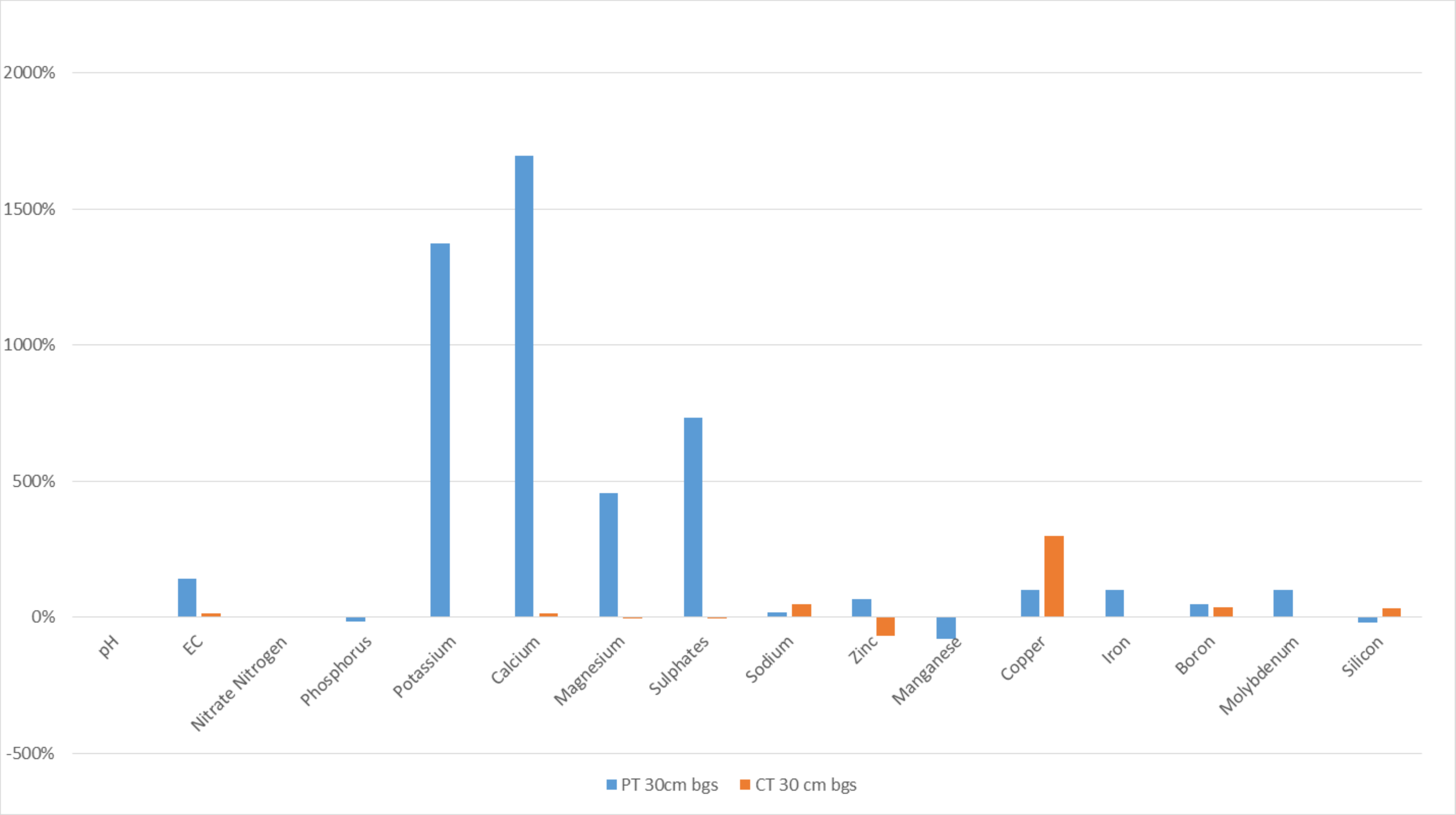


Figure 3.1 Percentage change in target species concentration relative to background in 30 cm deep soil water samples collected from Prism (PT) and Cecelia (CT) sites 48 hours after fall application of GNF

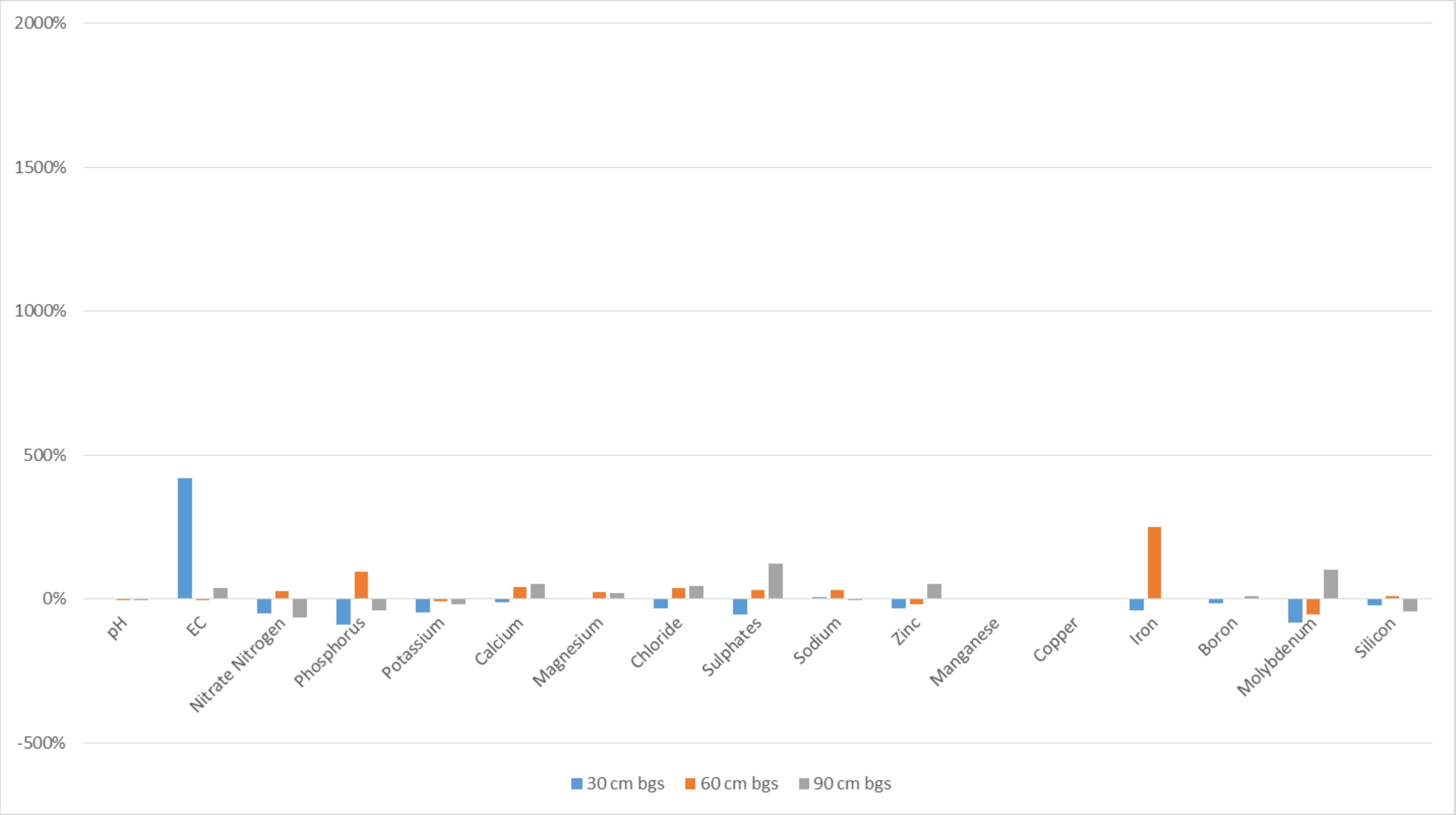


Figure 3.2 Percentage difference of target species between soil water samples collected from application plot and control plot at Prism 5 months (Jan, Feb, Mar, April, May) after fall application of GNF

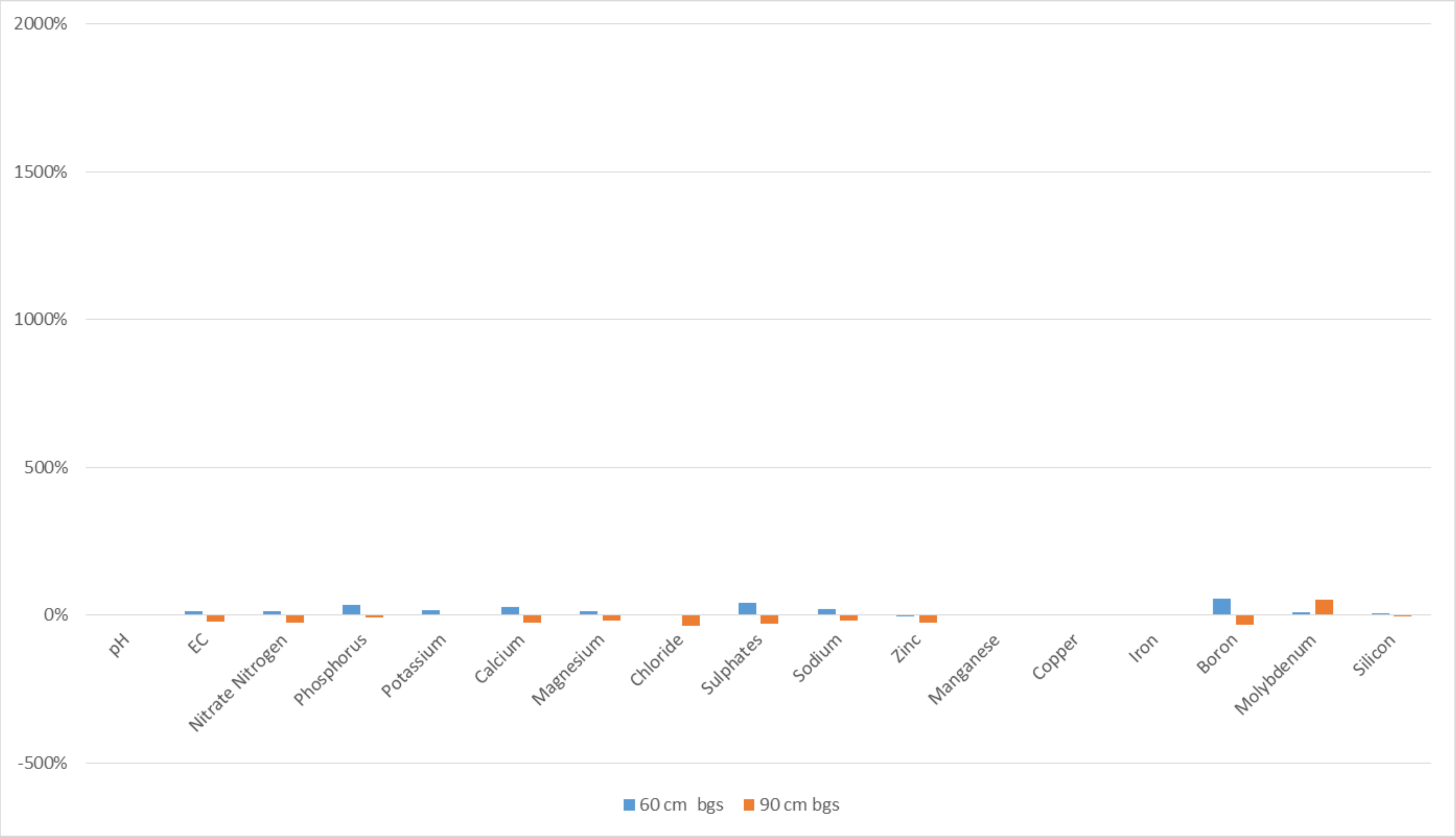


Figure 3.3 Percentage difference of target species between soil water samples collected from application plot and control plot at Cecelia Acres 5 months (Jan, Feb, Mar, April, May) after fall application of GNF

3.2.2 Fate and Transport of Target Species in the Soil Sample Profiles

Composite soil cores were collected forty-eight hours and 5 months after the application events. Potassium, calcium and zinc were selected as the key indicators of the fate and transport of applied GNF in soil profiles primarily because they are relatively conservative during transport and abundant in the applied GNF making them relatively easy to distinguish and detect in the soil. Nitrogen was not chosen here because of the extreme variability of this parameter in the shallow subsurface. In addition, both the heavy metal and the phosphorus concentrations in the applied GNF were too low relative to the soil solid phase concentrations to effectively influence the soil concentrations of these species in the profiles.

Twenty four hours after the last GNF application, soil was collected from both plots using the approach outlined in the methodology with soil sampling completed to a depth of 45 cm at Prism Farms and 30 cm at Cecelia Acres. The cores were only taken from these relatively shallow depths because a very slow infiltration rate was anticipated initially. However, species such as potassium, calcium and zinc were detected all the way down to 45 cm at Prism and 30 cm at Cecelia (Figure 3.6). The results from soil water and soil samples showed a potential of deeper infiltration than originally expected, possibly due to the presence of macropore features (Figure 3.4 and Figure 3.5).

Five months later, soil was again collected from both plots to a depth of 90cm at the two sites. The soil analysis data again showed no significant increases in concentration of any of the target analytes that could be detected through the standard soil analysis approach (Figure 3.7, Table D. 9 and Table D. 10). This may be the combined result of the inability to detect such small changes in soil concentrations that might result from the GNF application, the shallow overall infiltration depth and the potential for significant dilution and attenuation of the target species in the soil profile. This result may also reflect the fact that the total mass of many of the constituents added to the subsurface through the application of the GNF is relatively small. As a result of these initial results, it was decided that an additional, dissolved tracer (bromide) would be added to the GNF solution for the subsequent land application trials to aid in tracking the vertical infiltration of the GNF.

When considering the results of both the soil water and soil concentration data, the fact that there was evidence of the GNF solution at a depth of 30 cm immediately following application suggests the potential existence of a preferred transport pathway. Some of the applied GNF may have infiltrated faster through macropore flow and was partially captured by the lysimeters. This illustrates the importance of sampling both soil and soil water during the future infiltration experiments and broader scale land applications. The role of macroporosity is examined further below.

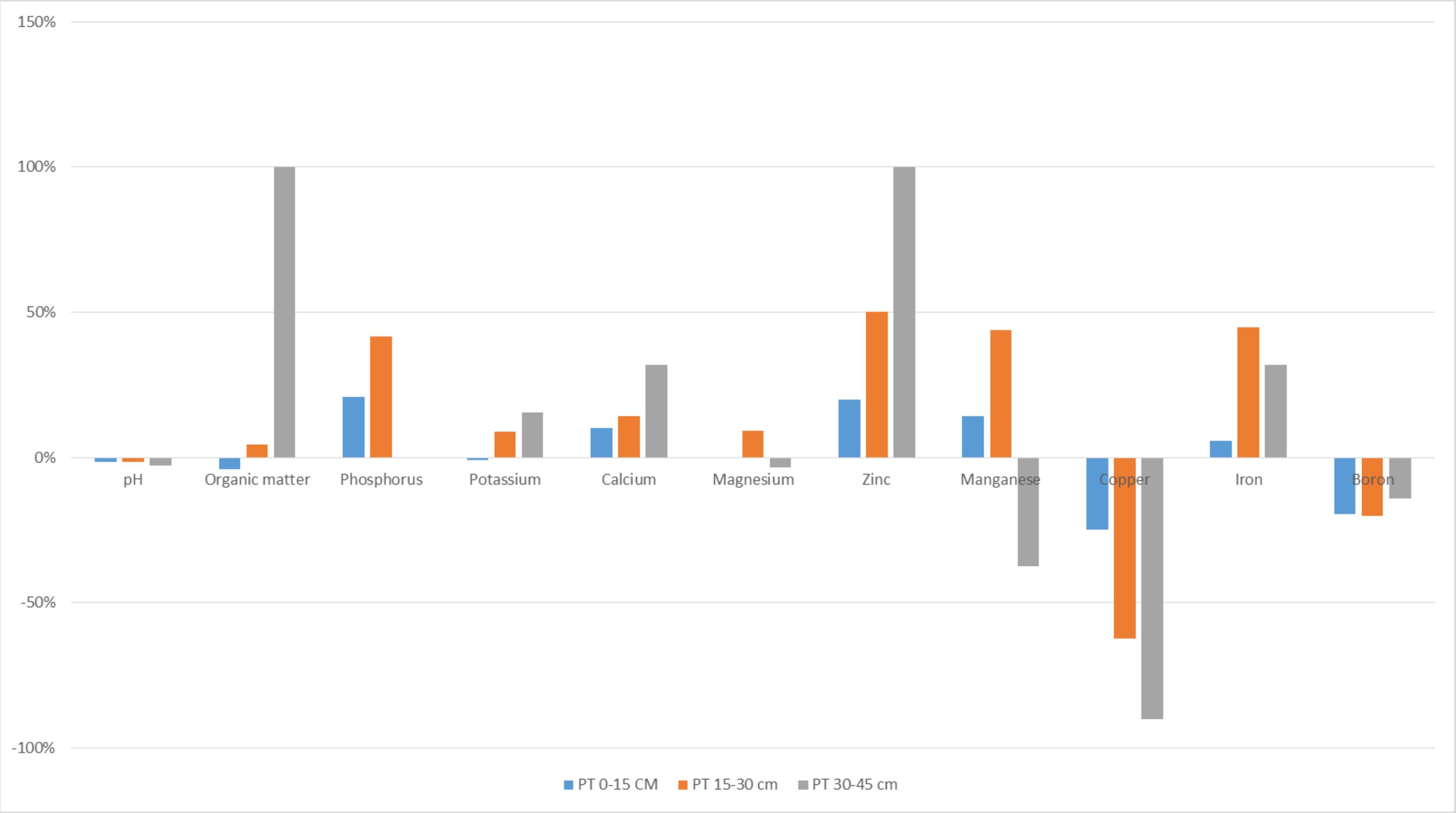


Figure 3.4 Percentage increase on target species in soil samples collected from Prism Farms 48 hours after fall application

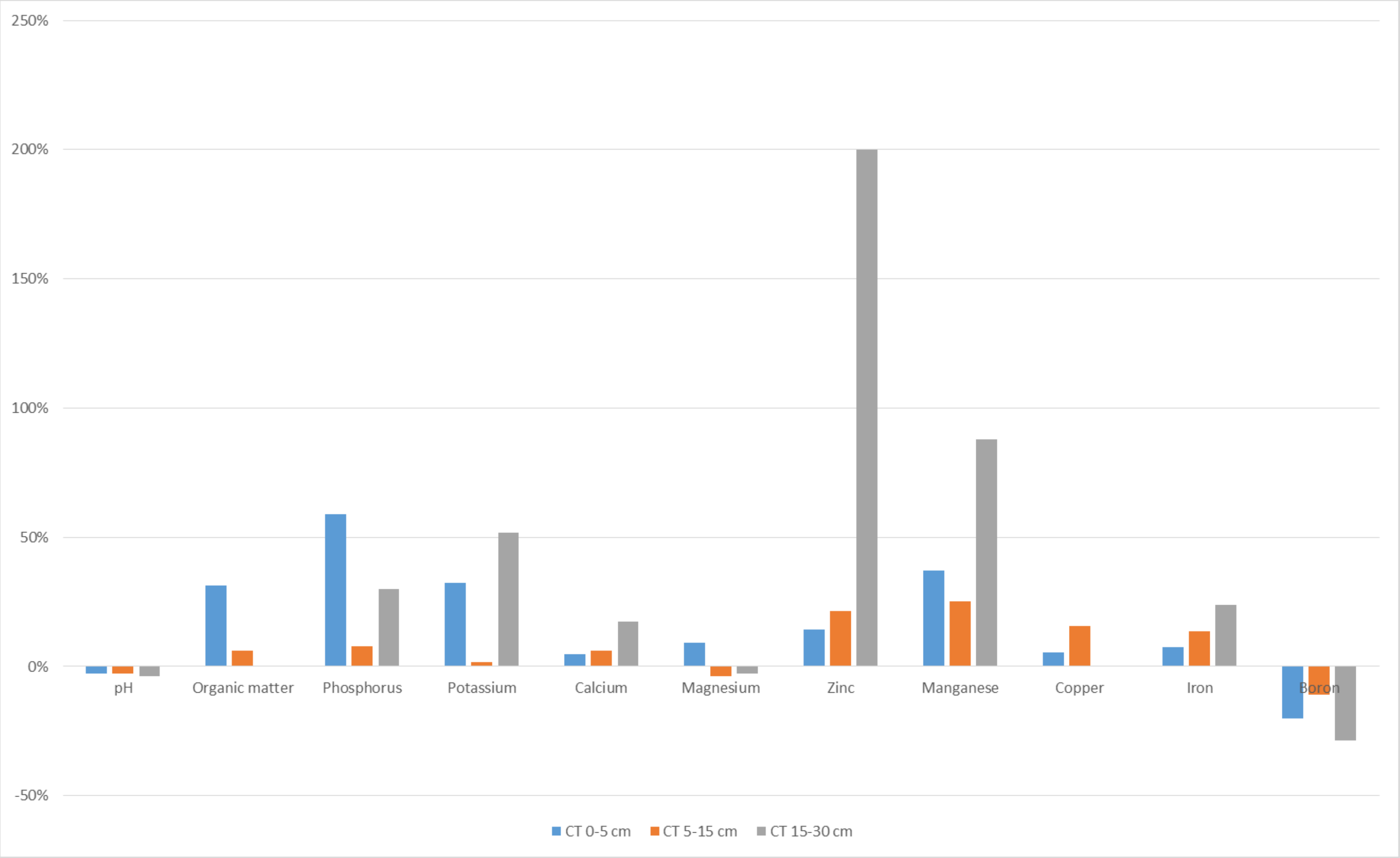


Figure 3.5 Percentage increase on target species in soil samples collected from Cecelia Acres 48 hours after fall application

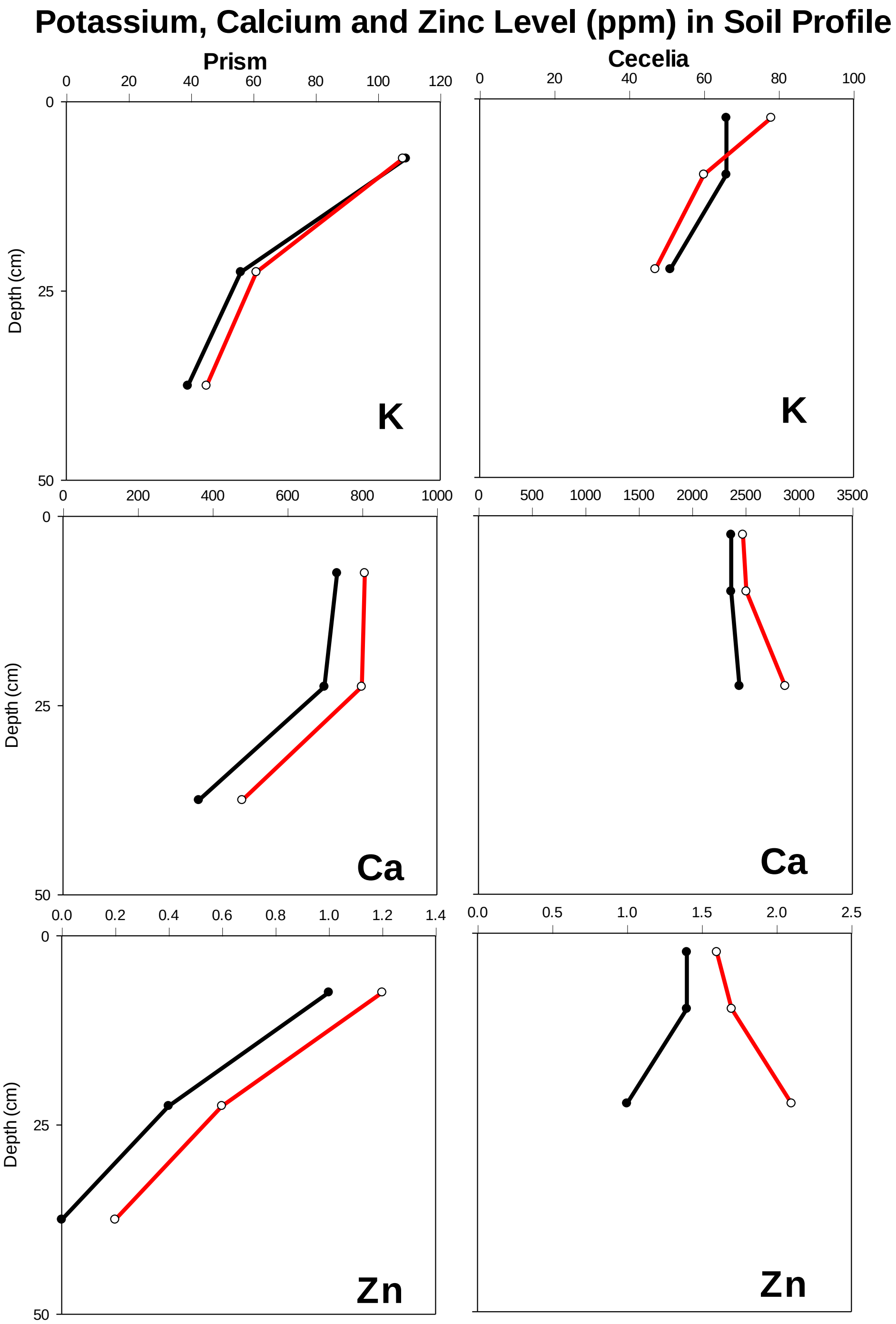

Potassium, Calcium and Zinc Level (ppm) in Soil Profile

Figure 3.6 Comparison of Selected Species between Application Plot and Control Plot at Prism and Cecelia 48 Hours after Fall Application

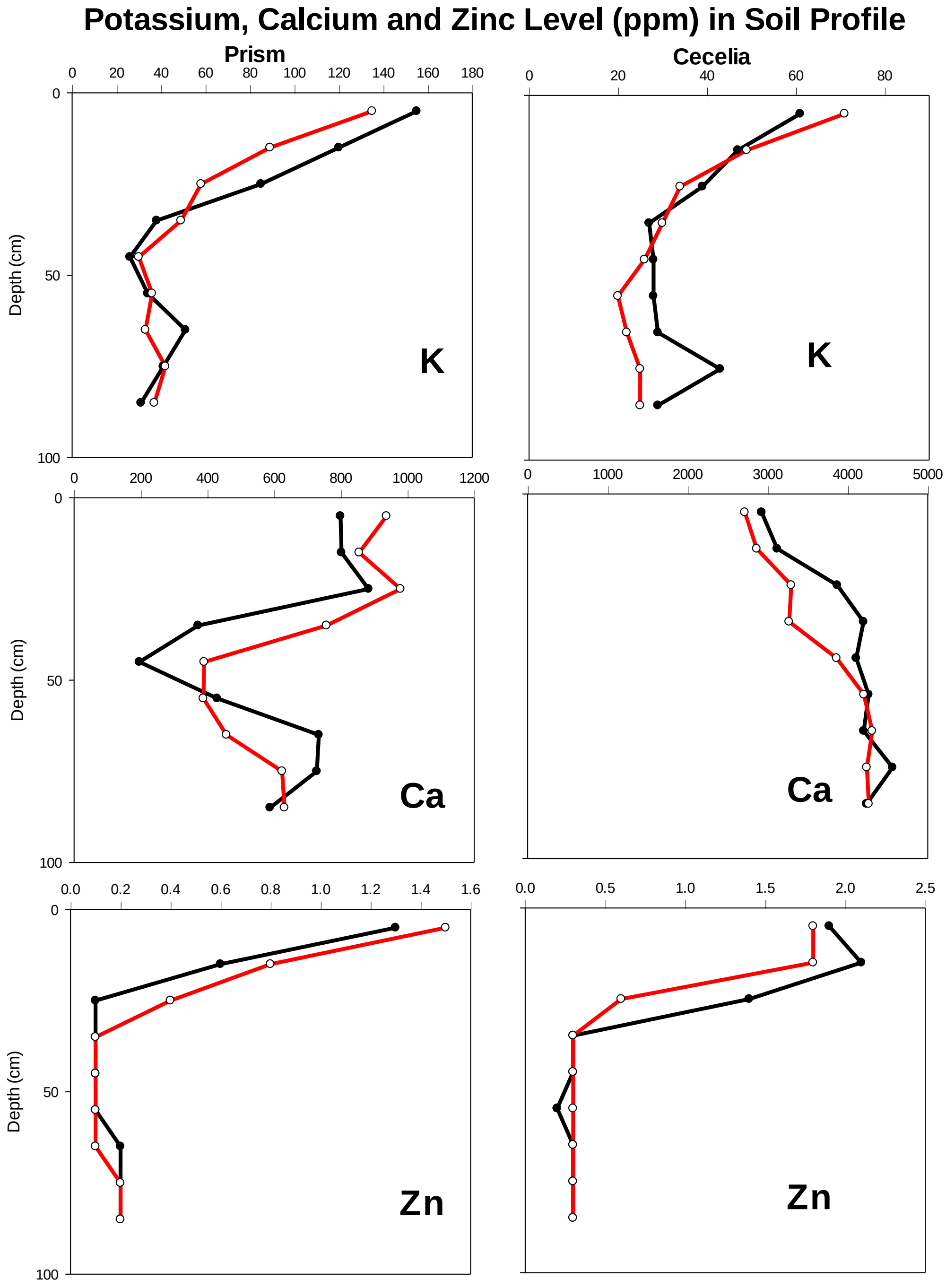


Figure 3.7 Comparison of Selected Species between Application Plot and Control Plot at Prism and Cecelia 5 Months (Jan, Feb, Mar, April, May) after Application

3.3 Results from Spring Application (Year 2)

Before Year 2 applications in the spring of 2015, GNF from all 4 sites was sampled once again for chemical analysis. As presented in Table B.2, the GNF from these sites still shared similar chemical composition. It was observed that the GNF provided by Lakeview Greenhouses was much more diluted because it was pumped from the storm water pond where GNF and rain water was mixed together.

The soil and soil water samples that were collected in May, 2015 at the Prism Farms and Cecelia Acres sites as part of the assessment of the Year 1 land application experiments were used as pre-application background data. This was based on the fact that no significant differences were observed in the concentrations of any of the target species in either the soil or the soil water between application and control plots after the Year 1 applications and that the Year 2 applications were planned to occur shortly after the May soil sampling campaign (See Appendix E Table E.1, Table E.2, Table E.3 and Table E.4). The slight variations in concentrations of several of the species may be either a legacy effect from the earlier applications or the result of the normal agricultural land use practices on site.

The pre-application data were collected at the Warkentin Orchards and Lakeview Greenhouses in July, 2015. Target species concentrations in both the soil water and soil profiles are very similar under the control and application plots (See Appendix E Table E.5, Table E.6, Table E.7 and Table E.8). Unfortunately, during the collection of soil water at Warkentin site, lysimeters at 60 cm were not able to provide enough sample volume for chemical analysis. As a result, Warkentin site does not have background data for soil water at 60 cm depth.

The plot-scale infiltration experiments began in July, 2015. As described in the methodology, GNF provided by the greenhouse operators was blended with a bromide tracer and carefully applied on the application plot area at a rate of 13.5L/m^2 each day for two consecutive days. Because of the high application rate and low permeability of the surficial soils at Cecelia Acres, an earth dam was built to prevent surface run-off during infiltration. The temporary dam was not required at any of the other sites. This insured that equal volumes of GNF infiltrated at each of the field sites.

3.3.1 Fate and Transport of Target Species in the Soil Water Profiles

3.3.1.1 Nutrients

Soil water samples were collected from the ceramic cup lysimeters both forty-eight hours and 3 months after the application events. The target species used to indicate the fate and transport mobility of applied GNF in the soil water profiles included nitrate nitrogen, potassium, and chloride along with bromide. Bromide results are discussed in separate section below. The other metals such copper, iron, boron etc. are not discussed here because of their extremely low concentration in soil water. Concentrations detected near detection limits are often considered to be inaccurate and unreliable when comparing between soil profiles.

By comparing data from application and control plots at forty-eight hours after the application, several target species noted above were found at 30cm and 60cm depth (Figure 3.8, Figure 3.9, Figure 3.10, Figure 3.11 and Table E. 9, Table E. 10, Table E. 11, Table E. 12 in Appendix E). Potassium, calcium and magnesium were detected to be elevated at Prism while at Cecelia there were only minor differences between control and application plots. It is noted that this observation is similar to Year 1 results. Some of the species such as potassium and nitrate nitrogen appeared to infiltrate at least as deep as 90cm as indicated by the elevated concentration levels observed in one of the lysimeters installed at the Warkentin and Lakeview site. It is hypothesized that this may be indicative of preferential flow through macropores at this site.

After a period of 3 months, when the sites were resampled, two of the sites (Warkentin Orchards and Lakeview Greenhouses) were not able to provide enough soil water from the lysimeters for chemical analysis due to the dry soil conditions. However, elevated levels of several of the target species were found at all three depths (30cm, 60cm, and 90cm) at the other two sites (Figure 3.12 and Figure 3.13). In addition, the concentrations of the target species detected at these depths after the 3 month time period are higher than those detected immediately after application suggesting the continued downward migration of the applied feed waters during this time period. Although the differences in target species concentration observed are not significant, it was not observed in Year 1 study. The main reason for this is considered to be caused by the different application rates and sampling time between the two application experiment. A much higher application rate and shorter time gap between application events and sampling in Year 2 could result in higher concentrations of target species remaining in soil. It should be noted that in all cases, none of the concentrations of any of the target species exceeded the Ontario drinking water limits (Table 3.1) except for iron. The increase in soil water iron is still under evaluation.

Table 3.1 Ontario Drinking Water Standards

	Ontario drinking water objectives and guidelines
pH	6.5-8.5
Total Dissolved Solids(ppm)	500
Total Hardness(ppm)	Unacceptable over 500
Nitrate Nitrogen (ppm)	10
Total Phosphorus (ppm)	N/L*
Potassium (ppm)	N/L*
Calcium (ppm)	N/L*
Magnesium (ppm)	N/L*
Chloride (ppm)	250
Sulphates (ppm)	500
Sodium (ppm)	200
Zinc (ppm)	5
Manganese (ppm)	0.05
Copper (ppm)	1
Iron (ppm)	0.3
Boron (ppm)	5
Molybdenum (ppm)	N/L*
Aluminum	0.1

*These parameters are not specifically regulated in Ontario drinking water standard.

Source: Technical support document for Ontario drinking water standards, objectives and guidelines, 2006.

3.3.1.2 Bromide

The objective of mixing a relatively high concentration of bromide tracer in the feed water solution was to ensure that there was at least one controlled tracer species (Br) that would persist at a high enough concentration to be detected even in small sample volumes. The concentration of bromide in soil water samples collected from the application and control plots were compared to determine the relative vertical transport during the experiments at each site. No significant bromide was detected in the soil water or soil beneath any of the control plots.

Forty-eight hours after the application, bromide was detected in the lysimeter clusters to a maximum depth of 30 cm beneath the application plots at two of the sites (Prism Farms and Ceclia Acres) (Figure 3.14). Both of these sites are characterized by relatively low permeability surficial soils. At Warkentin Orchards, however, bromide was captured at all depths (30cm, 60cm, and 90cm) (Figure 3.14), although only one out of three of the 60cm and 90cm lysimeters detected a measurable bromide concentration (Table E. 11 and Table E. 12). This suggests the potential occurrence of preferential flow. The surficial soils at this site are very fine grained and cohesive (see Appendix A), which supports the preservation of macropore features. The bromide tracer detected at the 90 cm depth in one of the lysimeters may have migrated through an open macropore located close to the lysimeter cup.

To investigate the potential occurrence of macropores at the Warkentin site, a test pit was excavated to a depth of approximately 80 cm. As illustrated in Figure 3.16, macropore features were clearly recognizable to a depth of at least 80 cm and they likely continue deeper into the profile. The macroporosity likely influences a component of downward mass flux of the applied feed water. The detection of the tracer migrating down the macropores depends on the relative location of the lysimeters which may explain why only one of the deeper lysimeters detected the bromide tracer. At Lakeview Greenhouses, two of the 30cm lysimeters captured bromide and only one of the three 90cm lysimeters had traces of the bromide. The soil on this site is coarse grained with a relatively high hydraulic conductivity. It would be anticipated that the applied feed water solution could migrate reasonably deep in a short time period in this type of material although preferential flow paths would likely develop as zones of higher infiltration rates following the most permeable pathway through the heterogeneous material.

When the lysimeter clusters were resampled after 3 months, only the lysimeters at the Prism Farms and Cecelia Acres sites produced sufficient water sample volumes for analysis due to the fairly dry soil conditions. The soil water data indicated reasonably high bromide concentrations at all three depths at the Prism Farms and Cecelia Acres sites (Figure 3.15). However, bromide captured by lysimeters at similar depths had variable concentrations (Appendix E, Table E. 13 and Table E. 14), which would be anticipated in natural soil profiles. The data also suggest that after 3 months of infiltration, the majority of the applied GNF mass has likely redistributed within the soil matrix and appears to still be contained in the shallow vadose zone although some of the mass may have migrated deeper and was undetectable due to the limited extent of the instrumentation arrays.

These data illustrate the utility of the bromide tracer in representing the transport behavior of the applied feed water solution that was not as obvious based on the much lower concentration species in the feed water. Adding the sodium bromide to the feed water solution increases the density of the infiltrating fluid and as such the mixture has the potential to infiltrate deeper than would be the case for the dilute feed water on its own. As such, the depths at which the bromide was detected in these experiments may represent an exaggerated infiltration depth for the feed water components.

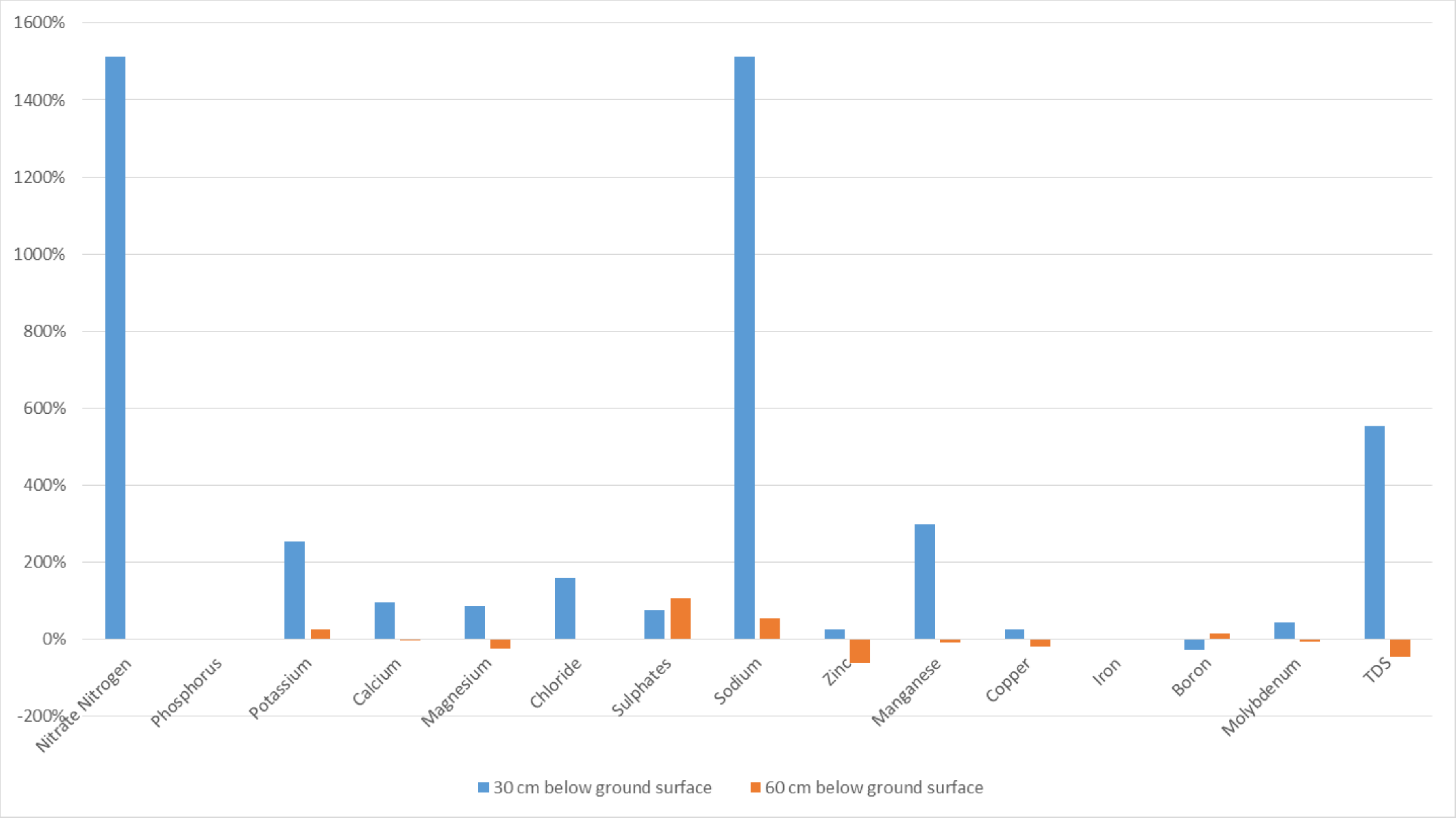


Figure 3.8 Percentage difference of target species between soil water samples collected from application plot and control plot 48 hours after spring application at Prism

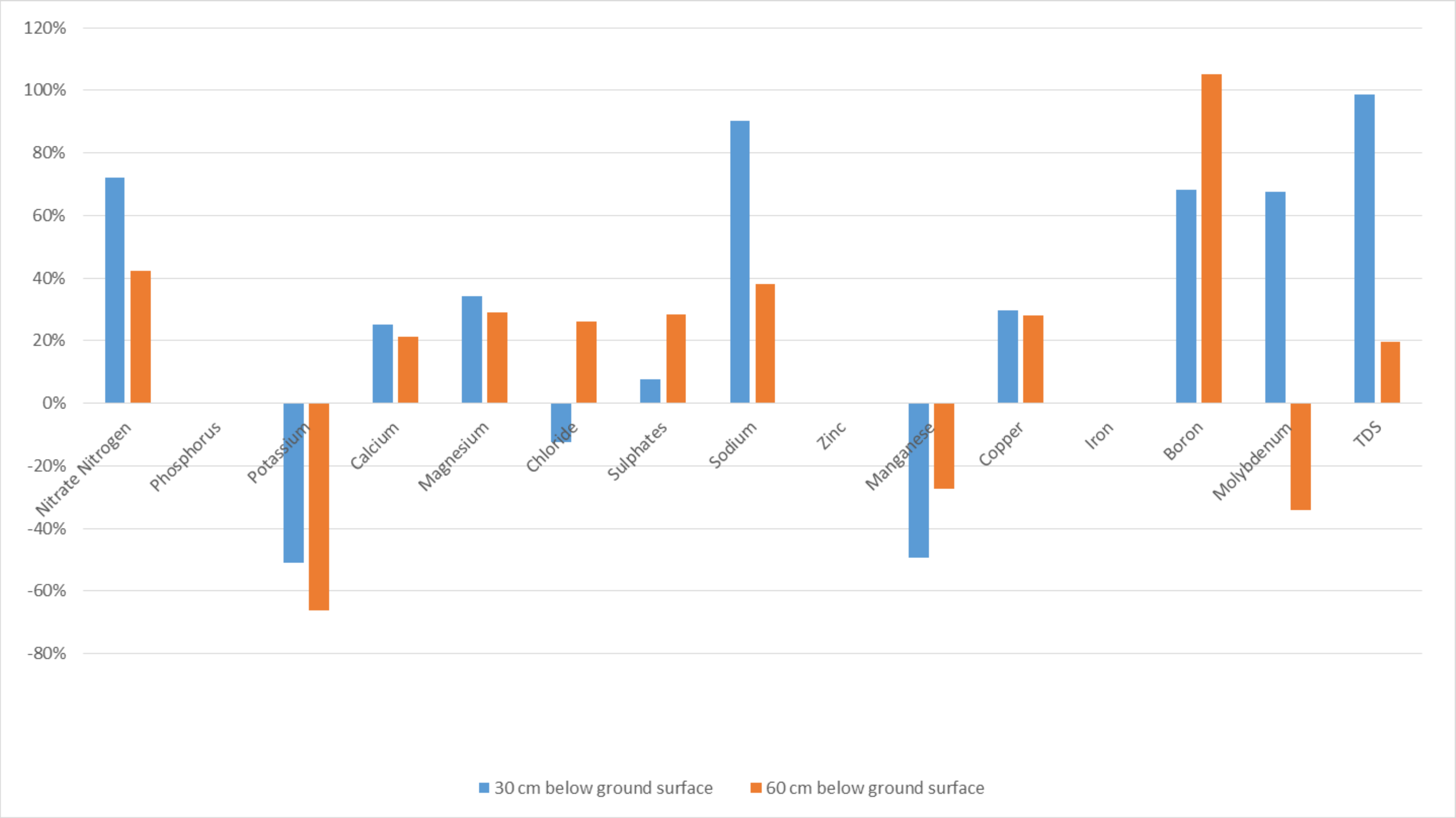


Figure 3.9 Percentage difference of target species between soil water samples collected from application plot and control plot 48 hours after spring application at Cecelia

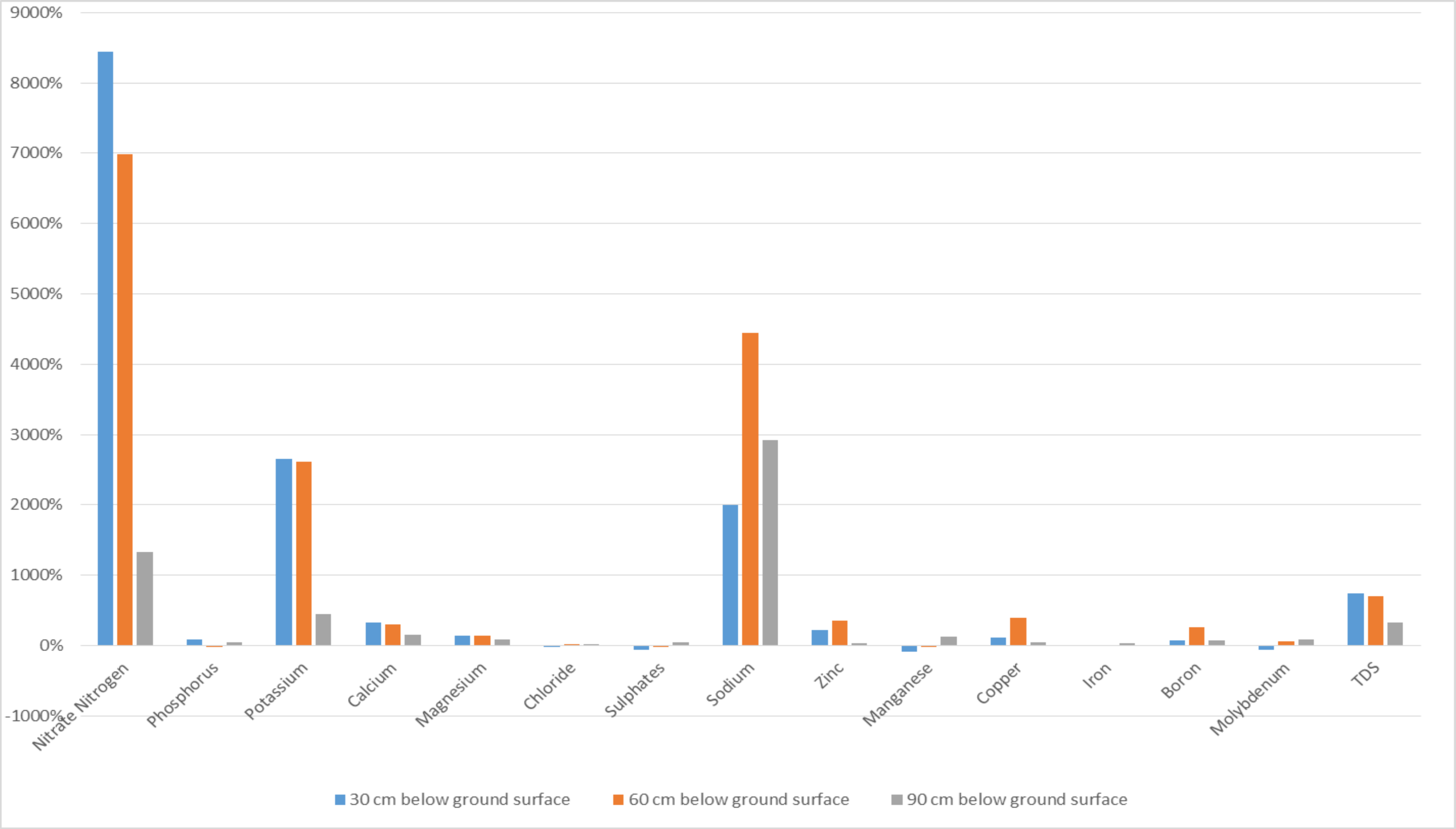


Figure 3.10 Percentage difference of target species between soil water samples collected from application plot and control plot 48 hours after spring application at Warkentin

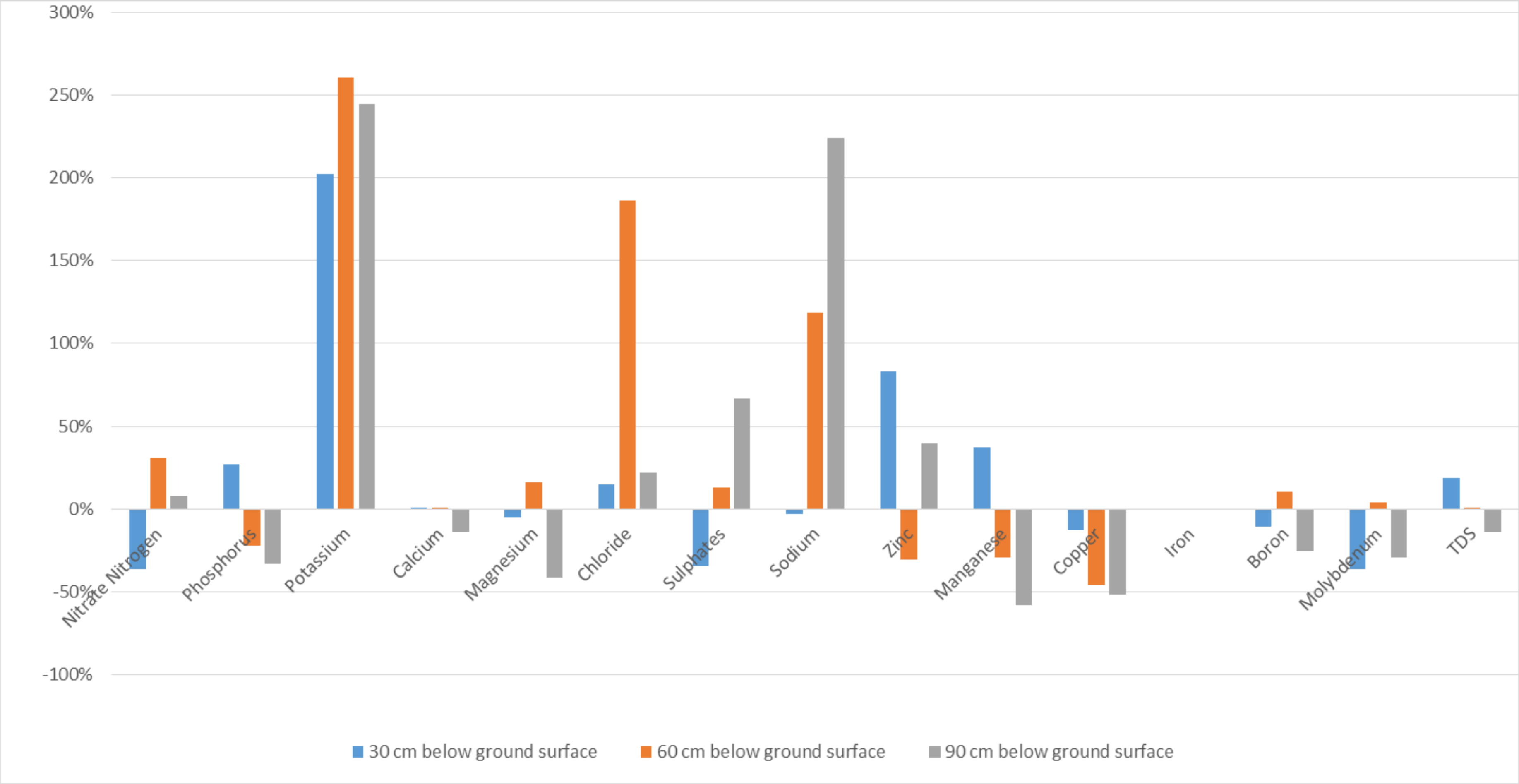


Figure 3.11 Percentage difference of target species between soil water samples collected from application plot and control plot 48 hours after spring application at Lakeview

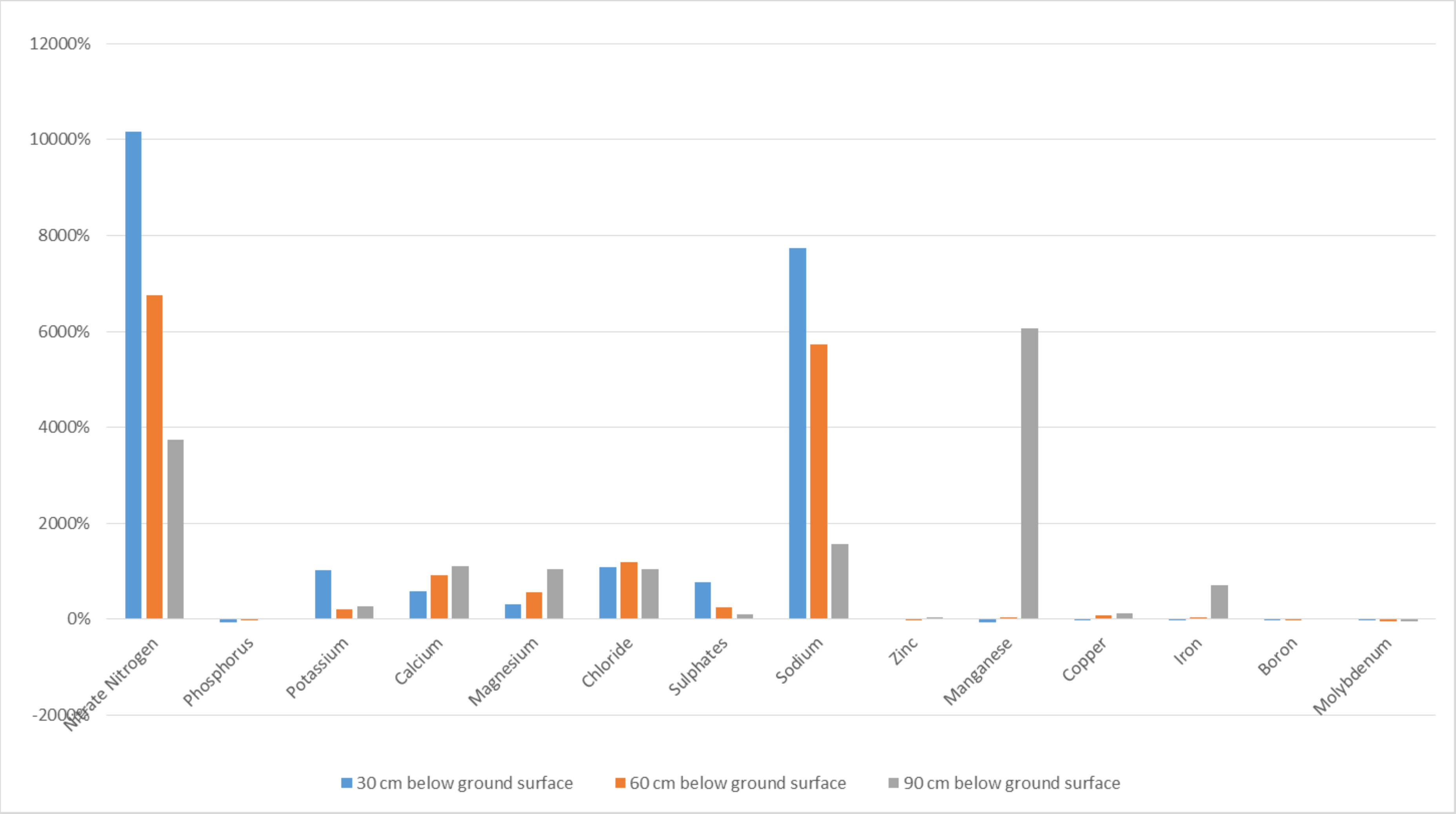


Figure 3.12 Percentage difference of target species between soil water samples collected from application plot and control plot at Prism 3 months (July, Aug, Sept, Oct) after spring application

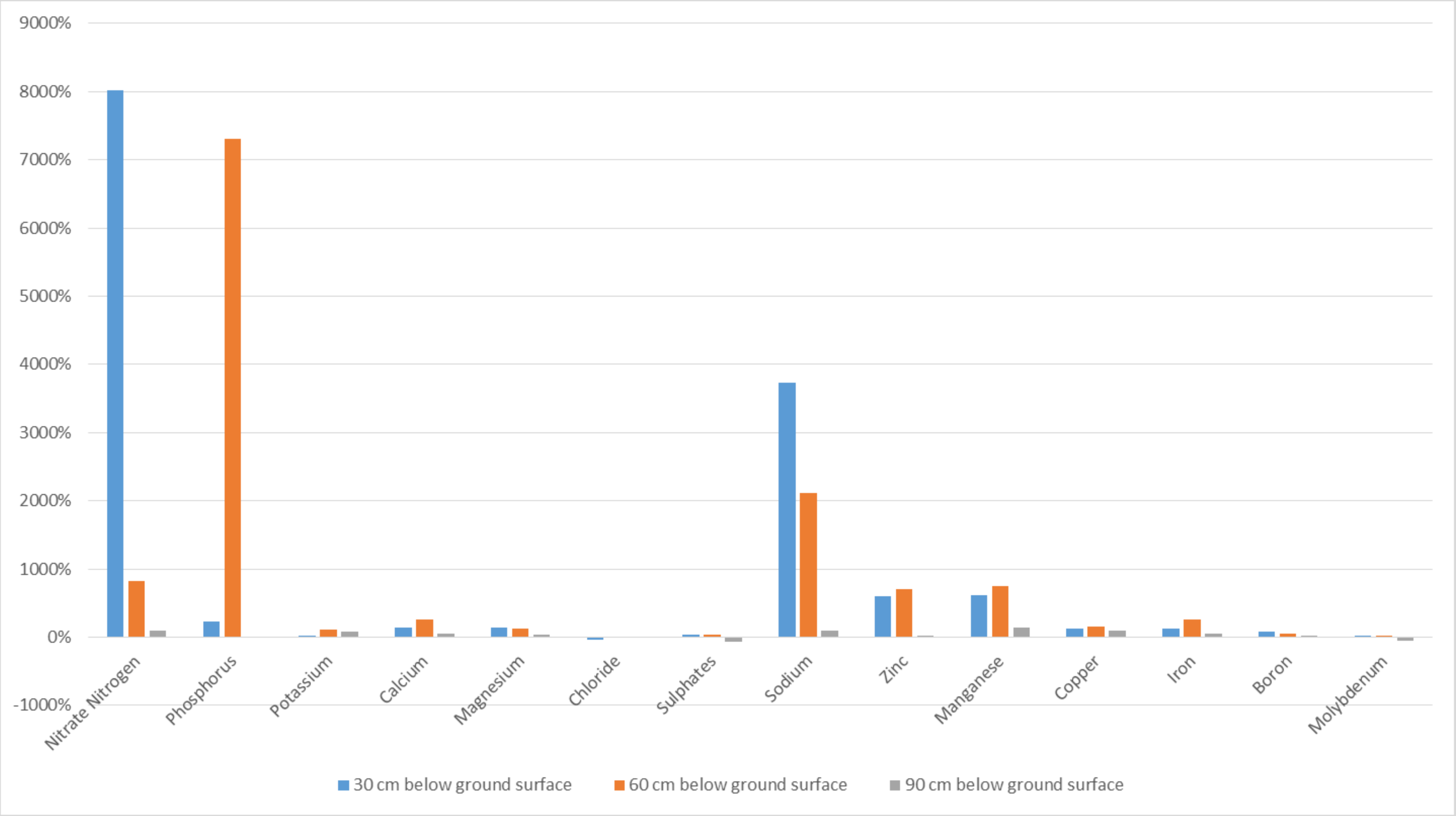


Figure 3.13 Percentage difference of target species between soil water samples collected from application plot and control plot at Cecelia 3 months (July, Aug, Sept, Oct) after spring application

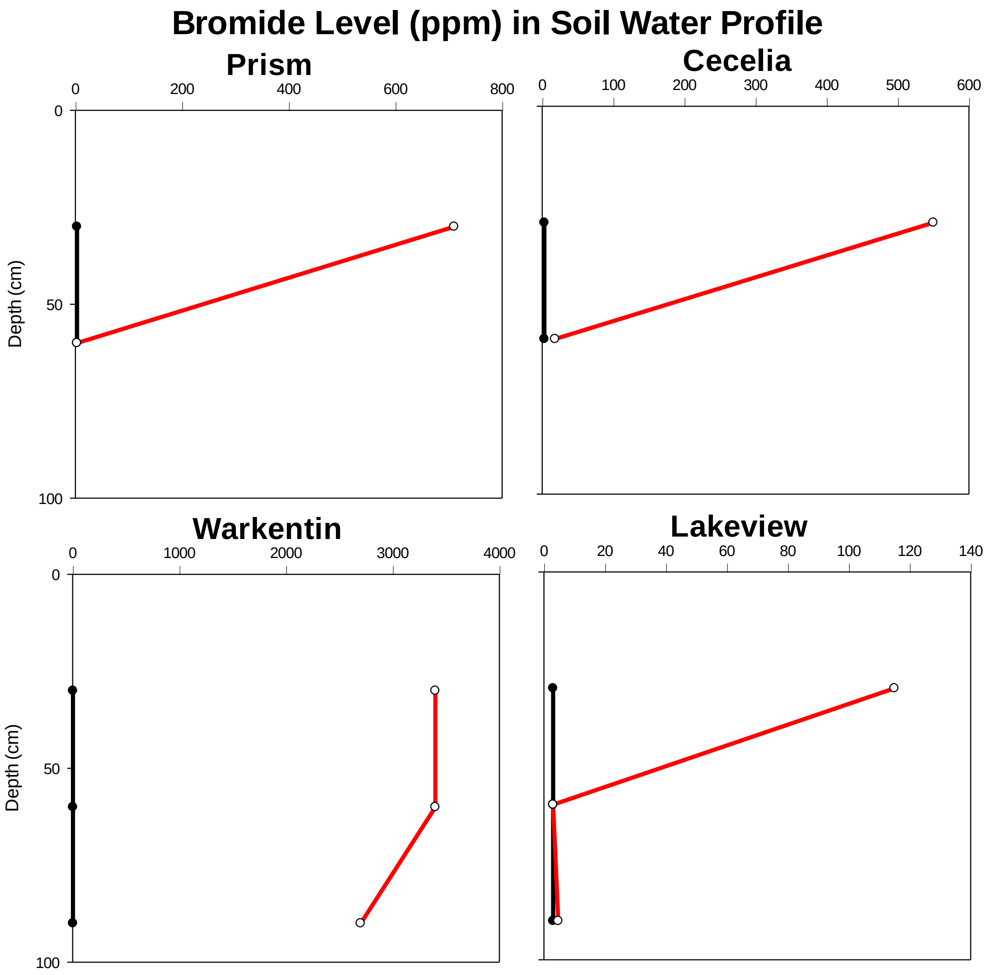


Figure 3.14 Comparison of bromide concentration in soil water samples collected between application plot and control plot 48 hours after application

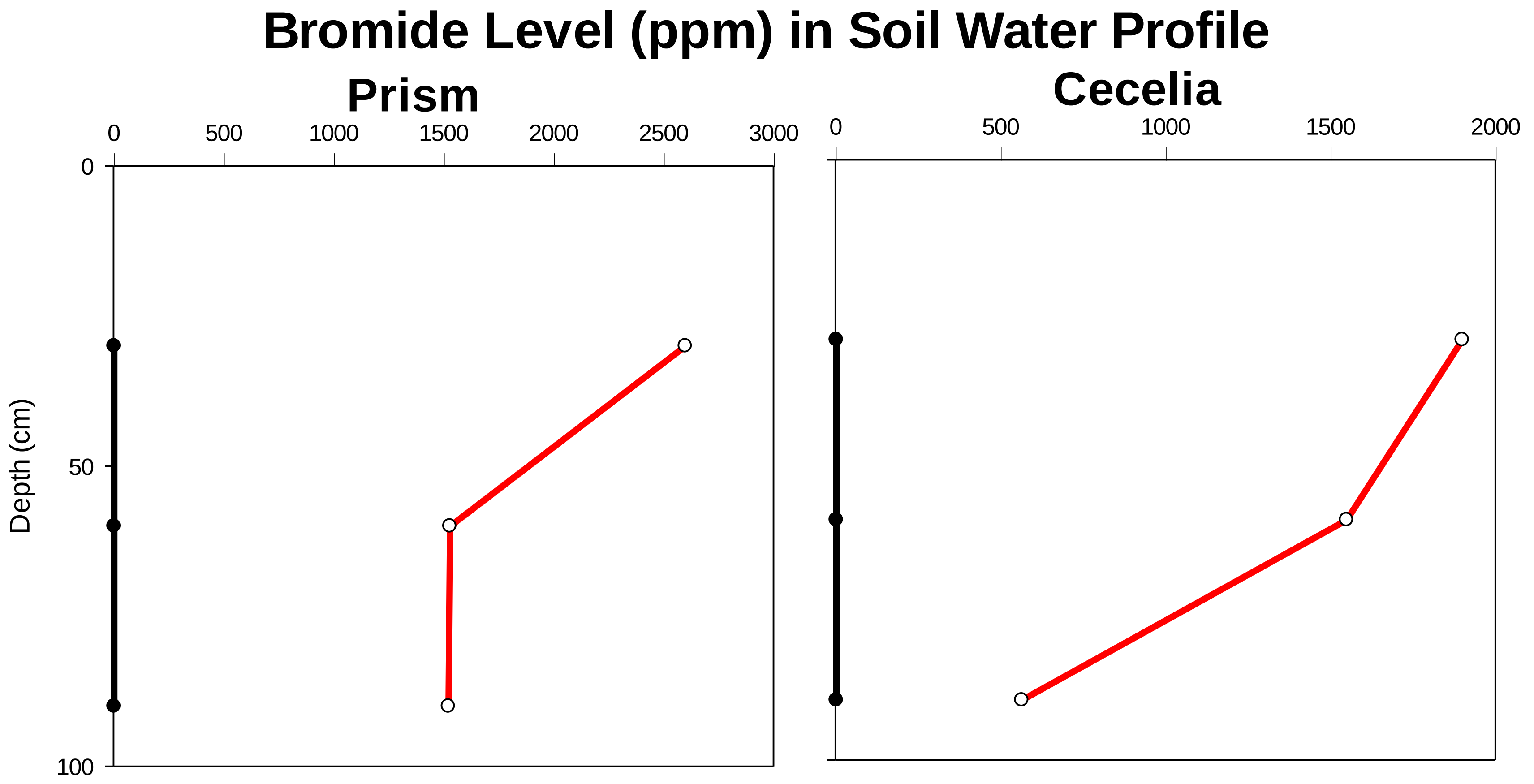


Figure 3.15 Comparison of bromide concentration in soil water samples collected between application plot and control plot 3 months (July, Aug, Sept, Oct) after application

Figure 3.16 Test pit at the Warkentin site indicating the presence of macropore features.

3.3.2 Fate and Transport of Target Species in the Soil Sample Profiles

3.3.2.1 Nutrients

Random soil sampling was conducted with a soil probe forty-eight hours and 3 months after the application events to a depth of 90cm. Composite samples were constructed for every 10cm of depth through the soil profile and these samples were submitted for extraction and analysis. Potassium and calcium were selected as the key indicators of the fate and transport of applied GNF in soil profiles. Most of the metals are not compared because of the low concentrations in soil. The result can be easily interfered with heterogeneity.

As indicated in Figure 3.17 and Figure 3.18 (also in Table E.15, Table E.16, Table E.17, Table E.18, Table E.19, Table E.20, Table E.21 and Table E.22 in Appendix E), there were no observable increases in the concentrations of any of the species that were included in the analyses including the specific target species selected above after either the first 48 hour time period or the subsequent 3 month time frame at any of the field plot sites. Based on the standard soil analysis procedures, there was no evidence that the land application of greenhouse nutrient feed waters at the highest permissible application rate resulted in measurable increases in any of the key potential dissolved constituents of concern within the GNF. This is in contrast with the data collected from the porous cup lysimeters as presented above and also the soil water results from fall application. Acknowledging the presence of macropore features on these sites, the variations in results are possibly due to the different transport pathways that the lysimeters and coarse soil cores captured in previous study.

3.3.2.2 Bromide

In order to examine the infiltration characteristics of the feed water solution in more spatial detail, the continuous soil core samples were divided into 10 cm segments for analysis. With the higher data density, the information can more effectively be presented in figures that depict the vertical distribution of bromide. Both the application and control plots were cored and analyzed. There was no indication of bromide within the control plots at any of the field sites. Forty-eight hours after the application, all four sites show a similar pattern of bromide concentration versus depths based on soil analysis (Figure 3.19). Within the first 30cm of the surface soil, the bromide concentration remained fairly high due to the short infiltration time period. Concentrations were observed to reduce significantly with depth.

The data suggest that the GNF infiltrated to less than 60cm within forty-eight hours at Prism Farms and Cecelia Acres. At Warkentin Orchards, bromide tracer was detected at low concentrations in the composite soil samples to the maximum depth of 90cm, which corresponds to the analytical results of the soil water under the application plot. Although traces of bromide can be found fairly deep in the soil profile, the concentration is very low compared to the upper 30 cm of soil, again suggesting that there may be an influence of preferential macropore flow at this site. At Lakeview Greenhouses site, bromide was detected through the entire profile to the maximum depth of 90 cm. This can be explained by the coarse nature of the gravely soil at this site. Similar observations were noted in soil water profile discussed above (Appendix A).

When the soil profiles were resampled 3 months later in October, data from all four sites indicated a slight downward migration of the bromide concentration profile (Figure 3.20). The majority of the bromide mass was still located in the upper 50cm of the soil profile suggesting that most of the applied GNF remained in the shallow vadose zone even after 3 months of redistribution and progressive infiltration. By comparing the figures of bromide concentrations in soil at forty-eight hours and 3 months (Figure 3.21), the vertical profiles do not appear to have changed significantly indicating a very slow downward migration of the feed water solution over the summer and early fall time period. The combined data suggest that the applied feed water did not likely migrate deeper than approximately 1 m over the 3 month time period with the majority of the mass remaining within the root zone. Again, it is hypothesised that the bromide distribution is a reasonable surrogate for the other, conservative feed water target species of interest.

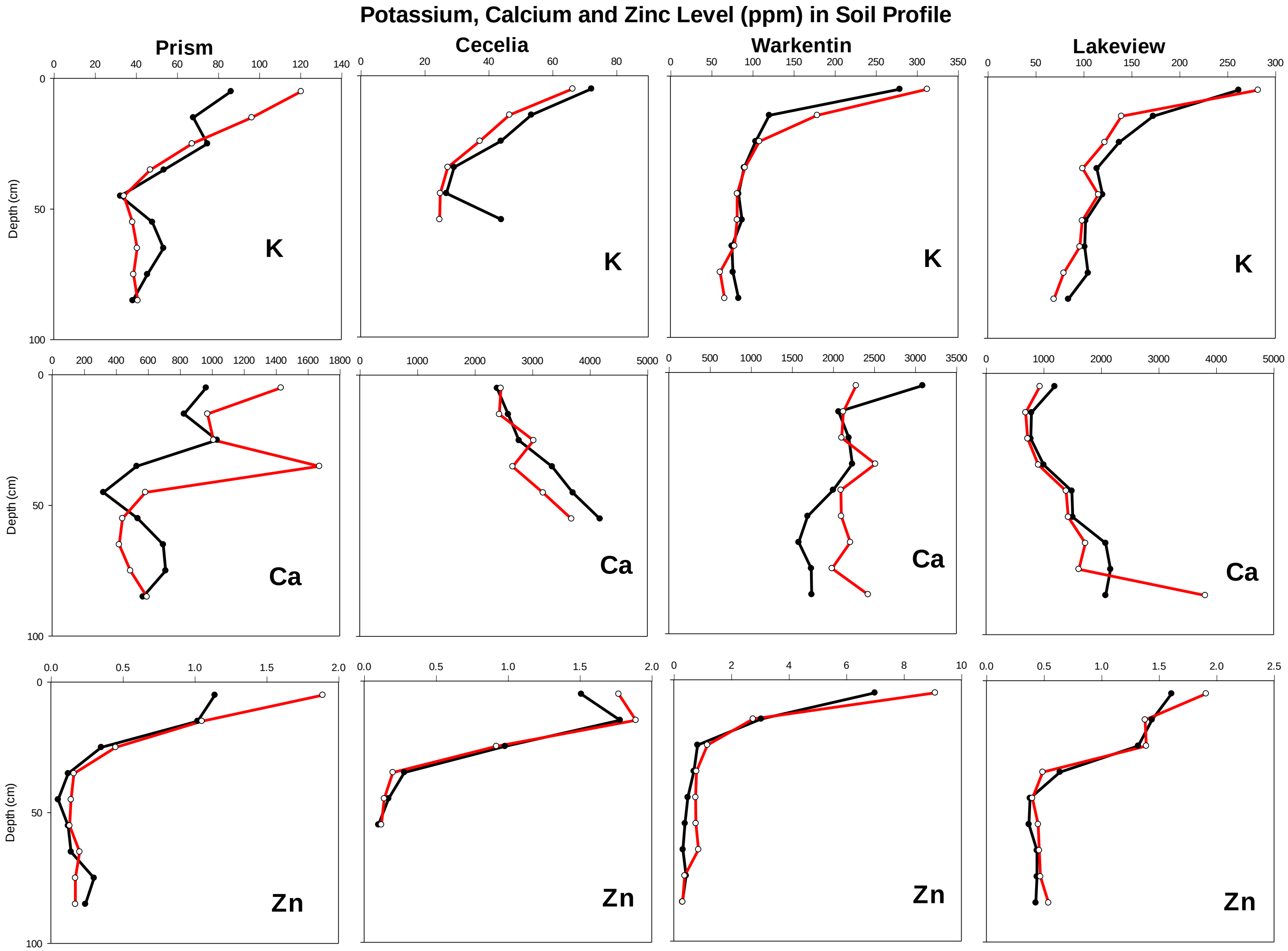


Figure 3.17 Concentration of selected species in soil samples collected 48 hours after application

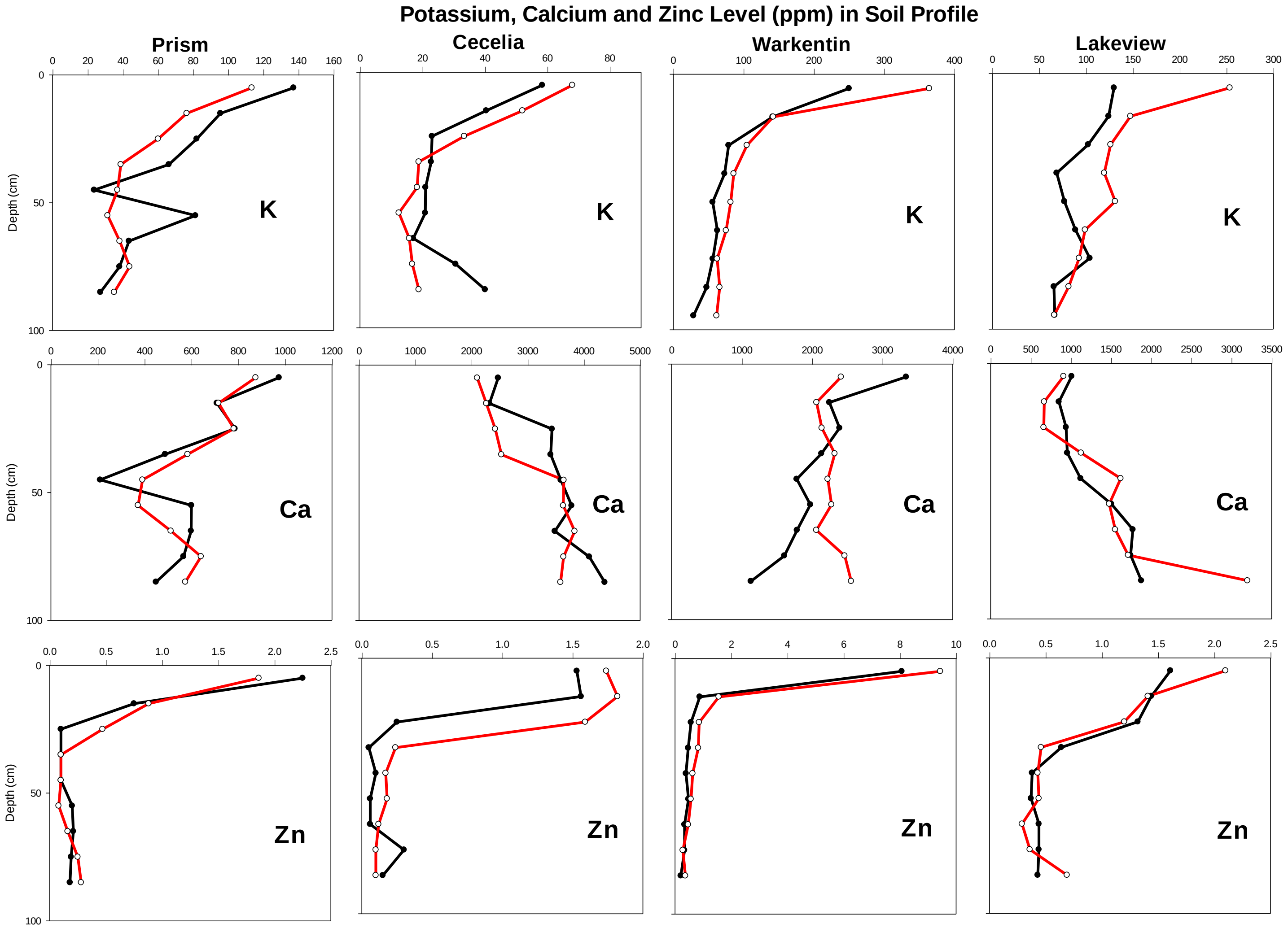


Figure 3.18 Concentration of selected species in soil samples collected 3 months (July, Aug, Sept, Oct) after application

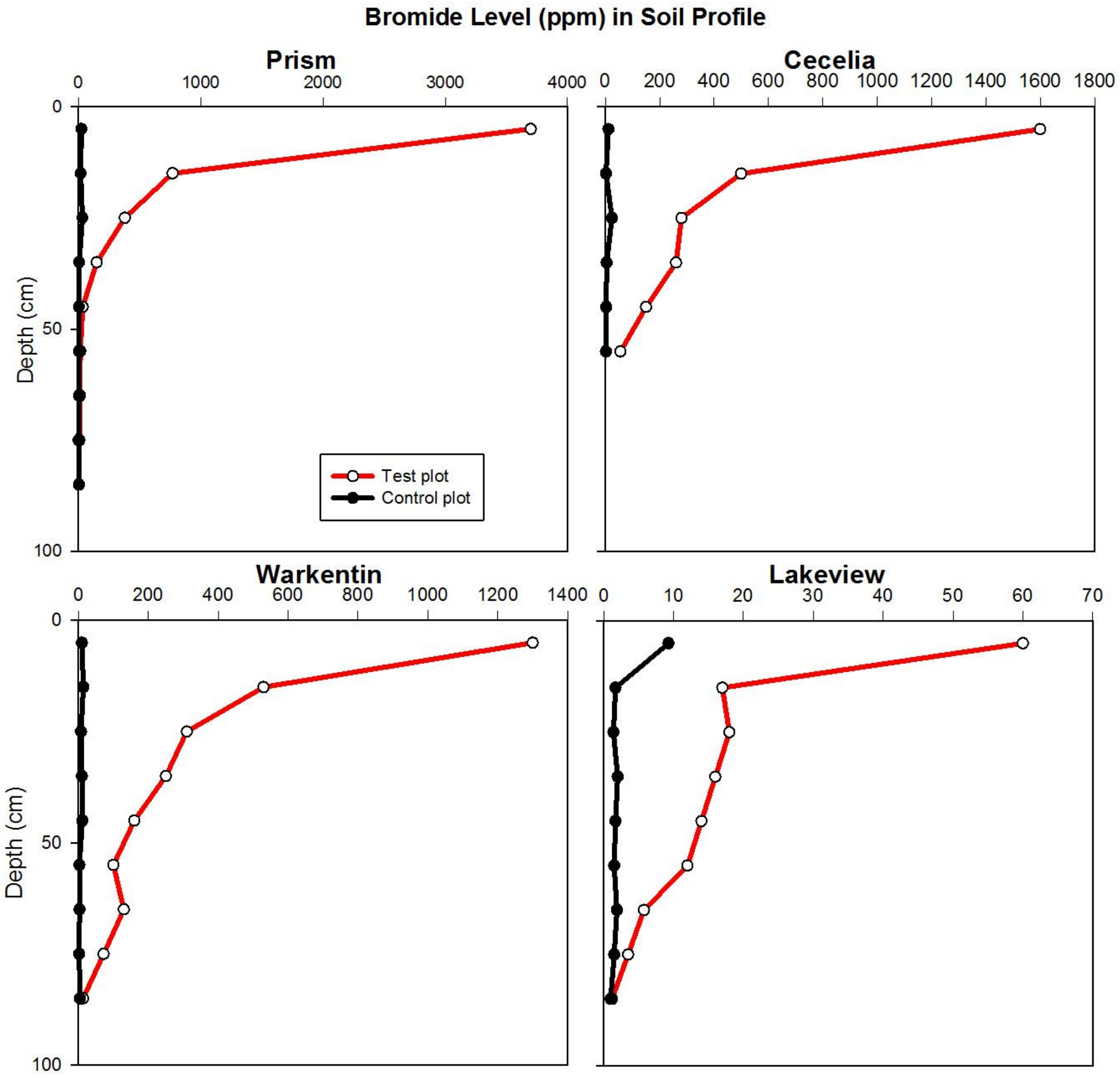


Figure 3.19 Bromide concentrations in soil at 48 hours after application

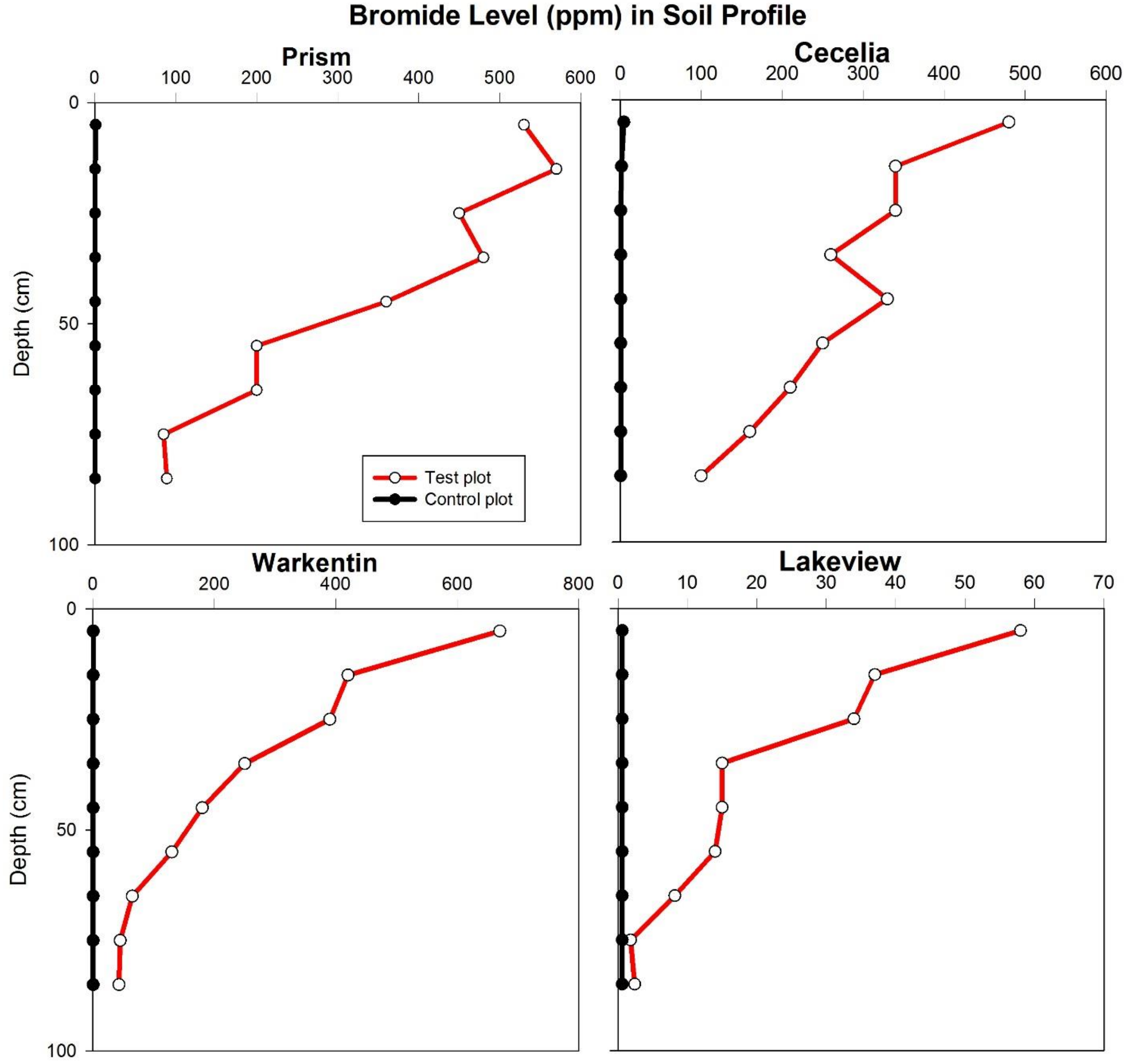


Figure 3.20 Bromide concentrations in soil at 3 months (July, Aug, Sept, Oct) after application

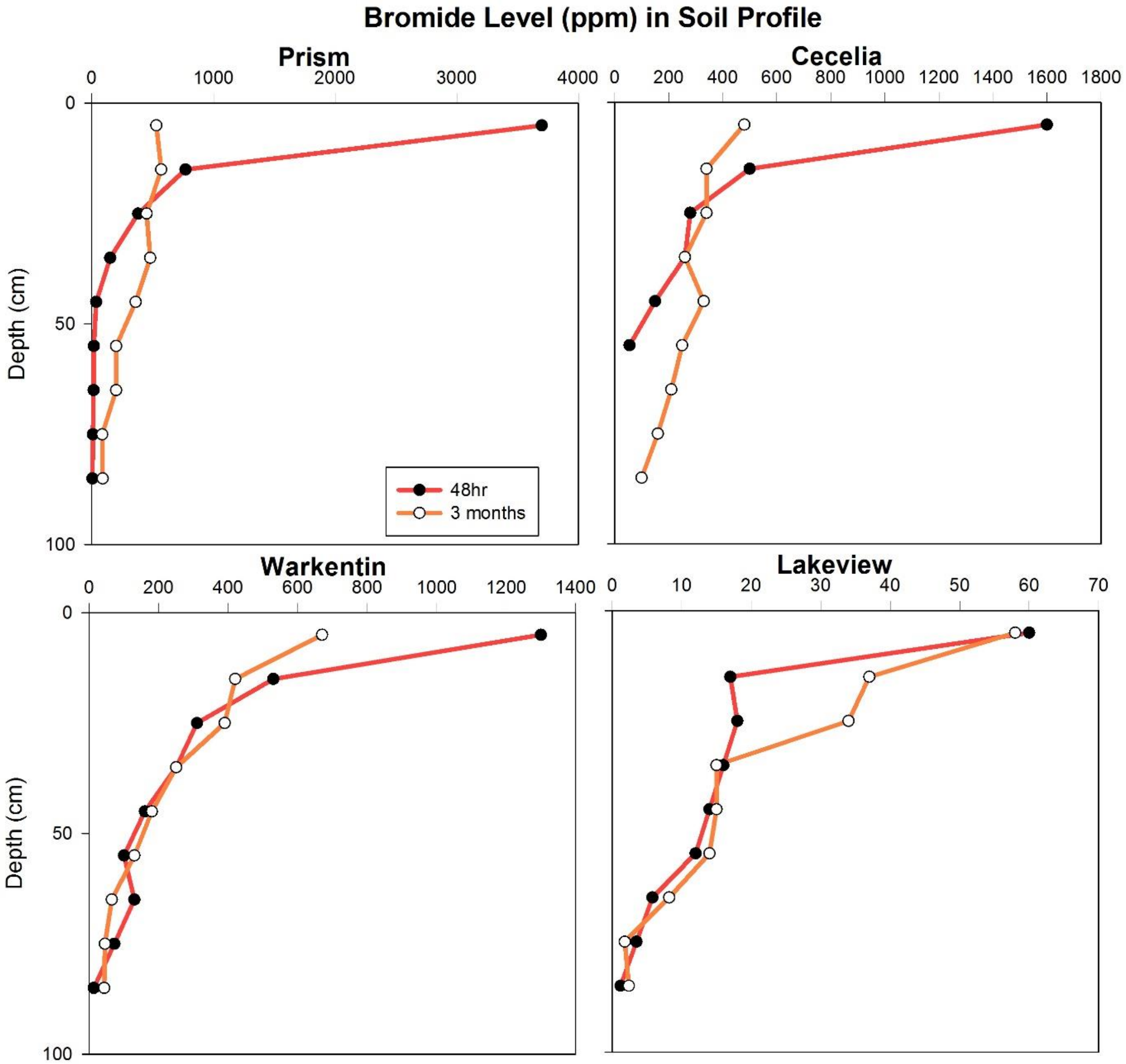


Figure 3.21 Comparison of Bromide concentrations in soil between 48 hours and 3 months (July, Aug, Sept, Oct) after application

3.4 Results from the Long Term Monitoring Well, Tile drains and Surface Water

Groundwater and surface water samples were collected at various times during the monitoring period and evaluated for the occurrence of the key target species including the bromide tracer. However, surface water features were usually restricted by location or availability depending on weather. Groundwater sampling is also dependent on seasonal groundwater table fluctuations. As a result, a full set of groundwater and surface water samples were extremely difficult to achieve. Based on available data sets (Appendix F), there is no evidence of target species originating from the land applied GNF in groundwater, tile drains or surface water at any of the sites. The only time that high level of nutrients were detected in Cecelia Acres' East Ditch is explained to be direct GNF discharge from greenhouse at that time (Appendix F, Table F.8).

Fluctuations in the water table depth were monitored at three of the sites continuously. As shown in Appendix F, water tables at these sites were below the lowest sampling point (90 cm deep) for the most of the time. It should be noted that the quick drawdown and recovery patterns were caused by groundwater sampling events. At the Prism Farms site, water levels in the deep well (6.0 mbgs) did not fluctuate very much during the course of the monitoring period and remained below the water levels recorded in shallow wells (2.5 mbgs and 1.4 mbgs). This indicated to persistence of a downward hydraulic gradient at this site. At Prism Farms and Cecelia Acres, several rapid fluctuations in groundwater levels were observed in shallow (1.5 mbgs) groundwater wells. These rapid changes correlated well with sampling events, local extreme precipitation events and with the land application events. This suggests a fairly rapid hydraulic connection within the shallow soil profile. The magnitude of these fluctuations was significantly smaller with depth. The rapid response may again illustrate the presence of secondary permeability in the shallow soil profile.

Generally, the groundwater table remains relatively low during the summer and early fall months and slowly rises during the winter. Groundwater levels are the highest in the spring following the snow melt period. The groundwater levels at the field sites selected for this study tend to remain approximately 1 m below ground surface for most of the year.

3.5 Climate Conditions during the Course of the Field Experiments

Apart from gravity, vertical hydraulic gradient caused by infiltrating precipitation is the main driving force that results in downward migration of soil water in vadose zone (Jacob &Hermance, 2005). Therefore, the climatic conditions, especially precipitation, during the experimental period is one of the critical factors controlling the vertical movements of applied GNF. The rain gauge station installed at Warkentin Orchards recorded precipitation from the beginning of May 2015 until the final field monitoring campaign in October 2015 (Appendix G, Table G.2). Data were collected on Oct 7, 2015 and compared to average historical data obtained from Environmental Canada data base (Appendix G, Table G.2 and Table G.3). The historical monthly data were collected from Environment Canada weather station at Harrow, Ontario, which was the closet one to the current study sites. The data indicate that the monthly rainfall during the course of the field monitoring program (May, 2015 to October 2015) was very similar to the average annual values for this region of Ontario. This suggests that the information obtained regarding the fate and transport of GNF during the current study is likely typical of what would be expected in an average climatic year.

3.6 Comparison with the Land Application of Biosolids

Since the early 1970's, Ontario has been land applying biosolids as a crop amendment under provincial regulations. A detailed explanation of these regulations and guidelines can be found in O. Reg. 267/03 under Nutrient Management Act, 2002. As a new potential crop nutrient source, it is useful to compare the characteristics of GNF to those of typical biosolids when considering GNF for regulated land application. Compared to the fully developed legislation on biosolids management, (the new guidelines for GNF land application are somewhat stricter) (Table 3.2), typically the concentration of nutrients and other potential pollutants are much lower in GNF than biosolids (Table 3.3). Besides the high concentrated heavy metals, other toxic substance typically found in biosolids includes pharmaceuticals, hormones, steroids, pathogen, and other organic compounds (Hydromantis, 2010). The biosolids, however, tend to have higher viscosity than GNF which reduces their capacity for rapid downward migration in the shallow soil profile. On the other hand, there is a higher potential for surface runoff losses in the case of the biosolids as they may remain closer to the ground surface after application. Overall, the total mass of applied nutrients and other target solutes of interest are much lower with the GNF and considering the successful management of biosolids land application over such a long time frame, it would appear logical that GNF could also be appropriately managed as a soil amendment.

Table 3.2 A comparison of standards for target species in GNF and Biosolids in Ontario (mg/kg*)

	GNF[1]	Biosolids[2]
Nitrogen	based on agronomic application rate	based on agronomic application rate
Phosphorus	based on agronomic application rate	based on agronomic application rate
Potassium	based on agronomic application rate	based on agronomic application rate
Calcium	not specified	not specified
Zinc	42	100.8
Copper	17	40.8
Molybdenum	0.94	2.256
Arsenic	1.7	4.08
Cadmium	0.34	0.816
Chromium	28	67.2
Cobalt	3.4	8.16
Lead	11	26.4
Mercury	0.11	0.264
Nickel	4.2	10.08
Selenium	0.34	0.816
Boron	based on maximum application rate of 1kg/ha/yr	based on maximum application rate of 1kg/ha/yr

Source:

[1] Ontario regulation 300/14 under Nutrient Management Act, 2002, A Review of the Current

[2] Canadian Legislative Framework for Wastewater Biosolids from CCME.

* Concentrations all converted to mg/kg on total weight basis.

Table 3.3 A comparison of target species concentrations in typical GNF and biosolids in mg/kg*

	GNF	BIOSOLIDS
Nitrate-Nitrogen	266	1560
Total Phosphorus	37	864
Potassium	307	96
Calcium	213	1200
Zinc	0.136	12.144
Copper	0.078	13.2
Molybdenum	0.0594	0.156
Arsenic	<0.010	0.1032
Cadmium	<0.00090	0.0816
Chromium	<0.0050	1.92
Cobalt	<0.0050	0.156
Lead	<0.0050	1.152
Mercury	<0.000010	0.0336
Nickel	<0.010	0.288
Selenium	<0.0040	0.0648

Source: 2002 Survey of Municipal Sewage Biosolids Quality from OMAFRA; Guidance document for the beneficial use of municipal biosolids, municipal sludge and treated septage (2012) from CCME.

* Concentrations all converted to mg/kg on total weight basis.

4 Discussion

4.1 Field Monitoring

Evaluating the feasibility of the land application of greenhouse nutrient feed water as a crop nutrient source and assessing its characteristics relative to potential environmental impacts requires on-farm testing conducted under a range of typical conditions over an extended time period. The selection of the specific four field sites has provided the opportunity to evaluate land application of GNF in a wide range of representative soil types, field cropping practices and greenhouse operations typical of the Leamington Area. The plot-scale experimental design appears to be functioning reasonably well following a series of protocol modifications after the Year 1 trials.

Although the chemical analyses of the different sources of GNF used in this study show similar chemical composition and relatively low concentrations of the main constituents of concern, they may still differ depending on the different greenhouse growing seasons and greenhouse crop types. A chemical analysis of the local GNF prior to the land application is recommended. As mentioned earlier, the new Ontario Regulation 300/14 on Greenhouse nutrient feed water was published in January 2015, where a much higher maximum GNF application rate is now permitted compared to that included in the interim guidelines. At one of the sites where the pore space and natural drainage might have been reduced by past management and the surficial soils had low hydraulic conductivity (permeability) the potential for surface runoff at the maximum application rates was observed in the field. This should be considered within the new regulations at sites where similar conditions exist that limit rapid infiltration of land applied GNF.

The porous cup lysimeter system used in this study proved challenging to install, maintain and to collect soil water samples from. Collecting a complete set of soil water samples can be very difficult in dry conditions. Although this instrument was still able to provide valuable information in this study, modifications or substitutions with a more efficient device may help to improve both precision and cost of time. Considering the fairly large separation distances between each individual lysimeter, sometimes the infiltration could be bypass flow and possibly fall between sampling points making the interpretation of infiltration depth difficult. In order to increase the sampling resolution, a denser coverage of lysimeters within the monitored soil profile is recommended.

The more detailed vertical soil core sampling also helped improve sampling resolution and provided valuable additional insight into the fate and mobility of the land applied GNF. Despite the advantages of using soil samples, the main challenge in the soil core analysis procedure is the very low concentrations of many of the main target species of interest within the GNF compared to the large soil reserves. This makes it somewhat difficult to detect concentration variations in the soil following the land application of the GNF but also confirms that overall the applied GNF solution does not result in an increase in any of the species of interest within the shallow soil profile, based on conventional soil testing procedures. However, a conservative tracer such as bromide in this study can be easily captured by soil analysis thus providing valuable additional insight into the fate and transport behavior of other conservative GNF species. Bromide does not easily react with other species or become absorbed by typical soil horizons (Levy &Chambers, 2006). Its distribution can be considered as an excellent indicator of maximum potential migration of GNF dissolved constituents.

Besides the surficial soil and soil water samples, samples from a groundwater monitoring well network and continuous water level measurements can be used to indicate the arrival of applied species and provide an indication of the nature of the hydraulic connection between the ground surface and the water table.

4.2 Overall Movement of the Target Species in this Experiment

The results from the plot-scale land application trials suggest very low mobility and transport of applied GNF in the short term even under conditions that may be considered the worst case scenario with high, undiluted loading of the feed water applied in fall when there is expected to be minimum plant uptake. During the Year 2 application experiments, a new maximum permitted application rate which is almost twice as much as the rate applied in Year 1 was used, which possibly caused deeper infiltration and higher concentrations of target species remained in soil profile. It also appeared that some GNF likely infiltrated faster through macropore features instead of the soil matrix in the first forty-eight hours after the application. It is anticipated, however, that the total GNF mass moving within the macroporosity was very low compared to the total applied mass and that most of the GNF remained within the upper 30cm of soil. After 3 months, the majority of the applied GNF appeared to migrate vertically less than 50cm with most of the GNF remaining in the upper 90cm of the soil profiles at each site. Overall, there was no evidence of the presence of any of the GNF target species in the groundwater and tile monitoring network following the land application of GNF at any of the sites. Even if any of the GNF migrated though the soil profile and into groundwater, the low concentrations of these target species after soil attenuation and plant take up will make the contamination a minimal environmental threat.

Combining results from the two land application experiments, a high degree of variability in the fate, transport and mobility of the land applied GNF was observed between the four different field sites. This appeared to be directly related to the natural permeability of the surficial soils and the potential presence of secondary permeability associated with macropore features. However, the majority of the GNF applied at the highest permissible rates over a variety of soil types and agricultural land use practices, typical of the Leamington area, remained within the shallow vadose zone and at very low concentrations both immediately following application and 3-5 months later. In addition, because the majority of the land applied GNF mass appears to have remained within the shallow soil environment above the water table, the nutrients would have been available for plant uptake within the root zone.

4.3 Agricultural Applications

As a potential liquid source of nutrients, greenhouse feed water could be applied on agriculture land as an alternative irrigation source. Before land application, the potential transport and fate of land applied species need to be considered relative to the local conditions. There were several factors influencing the movement of applied GNF found in this study. First of all, concentrations of different species of interest can be very different. This illustrates a significant degree of variability in the GNF that may be used for land application. An appropriate chemical analysis on GNF before land application is required. Secondly, the soil conditions and climate need to be considered as well.

As observed in this study, soils that have low hydraulic conductivity (permeability) can greatly slow the vertical movement of most of the target species, but also can cause surface runoff at high application rates. On the other hand, soils with high hydraulic conductivity (permeability) will permit applied soluble constituents to travel faster through the vadose zone potentially reaching groundwater at locations where the water table is shallow. Because the vertical hydraulic gradient caused by infiltrating precipitation is the main driving force that results in downward migration of soil water in vadose zone (Jacob &Hermance, 2005), climate conditions are one of the critical factors controlling the vertical movements of applied GNF. Meanwhile, local hydrology is important in respect to groundwater levels. Shallow groundwater is obviously more vulnerable from surface application and may involve more active tile flow, which could be a potential transport pathway for some of the infiltrating GNF mass. According to the local groundwater table monitoring data derived from the current study, it is suggested the land application of GNF in the early summer when the plants are viable and early fall when groundwater table is low are likely the time periods during the annual cycle when the potential for impacts on shallow water quality would be the lowest.

Finally, the presence of macropores in soil is an important factor of GNF infiltration. During the course of this study, evidence indicated the presence of secondary permeability associated with macropore features at three of the sites. Macropore features generated from the processes of desiccation, growth and decay of roots, mycelia, and burrowing animals are very common in soils (Coppola et al., 2009 and Bachmair & Weiler, 2011). This suggests there maybe macroporosity in the near surface soils at other locations throughout the Leamington area that will influence the downward migration of land applied GNF to some degree, particularly immediately following high rates of surface application. According to the review paper by Beven and Germann (2013), although further studies are still needed, it is widely agreed that macropore flow can play a significant role in soil water infiltration processes. Unlike matrix flow, preferential flow in macropores are quite independent from soil moisture and capillary flow (Beven &Germann, 2013). In the field study of macropores conducted by Cey and Rudolph (2009), macropore flow can be significant at very low pressure heads, making the infiltration potential of the macroporous soils to be high. However, it is also noted that although preferential flow through macropores contributes to infiltration rates and distance, soil matrix flow will quickly take over the flow system once an infiltration source is removed. The macropore-matrix interaction will significantly influence the downward migration of water. The bromide profile in this study also implicates the matrix flow as a contributing process.

5 Summary and Conclusions

The main objective of this study was to determine whether the land application of greenhouse nutrient feed water is protective of the environment. In order to address this objective, several steps were taken to accomplish this research. As a cornerstone of this study, four representative and collaborative greenhouse operations were selected and characterized as field sites, which cover a wide geographical area within the region and include many of the typical types of greenhouse operations encountered in the area. The sites also involved a variety of different cropping types and practices on a range of typical field soils and conditions. Experiment plots were established and instrumented at each of the sites. By conducting two land application experiments in fall and spring both followed by routine monitoring programs, the fate and transport behavior of the dissolved constituents within the greenhouse nutrient feed water (GNF) after the land application in different field settings were investigated. It is concluded that the majority of the target species in GNF applied at the daily highest permissible rates over a variety of soil types and agricultural land use practices, typical of the Leamington area, was significantly retarded within the shallow vadose zone and kept at very low concentrations both immediately following application and 3-5 months later. The majority of the nutrient mass would have been available for plant uptake during the monitored time period. No evidence of potential environmental impacts of land applying GNF in these field settings was observed. Therefore, land application of GNF under Ontario’s regulations would appear to be a feasible and environmentally reasonable alternative to other possible waste water treatment options, such as in-house waste water treatment plants (WWTPs) for managing GNF. As the major cause of eutrophication problem in Lake Erie, phosphorus particularly is much diluted in GNF and significantly attenuated in vadose zone after land application of unused GNF. Thus the land application of GNF may also have the potential of being a GNF management response to Lake Erie Nutrient loading issues.

6 Future Research

The plot-scale experimental design adapted from Year 1 trials appears to be functioning reasonably well although some challenges remain relative to effective soil water sampling and overall interpretation of the soil chemistry data. Although enough information was obtained through the combination of current soil and soil water sampling procedures to develop an understanding of the fate and transport on GNF in the shallow agricultural soil environment, a denser coverage of lysimeters within the monitored soil profile and more efficient soil water sampling method are is recommended during the subsequent phase of the current study. In order to achieve further understanding of the transport and fate of GNF and assess the environmental impacts of larger scale land application, field-scale field infiltration experiments would be highly recommended and anticipated for subsequent investigations.

This research is primarily focused on the transport and fate of applied GNF in the vadose zone. It showed that the majority of GNF, which was applied to the test plots at the highest recommended rates, remained within the unsaturated soil profile between 3 and 5 months following the time of application. However, further studies on the mobility of target species in saturated conditions would be of value and may require much longer monitoring time frames.

The presence of macropores in soil was found to potentially influence the vertical mobility of GNF within the vadose zone. Further investigations and modelling is recommended to estimate the influence from macropore features. Accessible codes such as HYDRUS (Šimůnek and van Genuchten, 2008) or HydroGeosSphere (HGS) can provide different dual porosity and dual permeability models to understand the influence from preferential flow at different soil settings.

The concentration of nutrients in GNF is generally quite low compared to commonly used fertilizer. Although the Nutrient Management Computer Program (NMAN) was used in this study to ensure the land will retain the nutrients applied thought GNF, the plant uptake of nutrients and crop yield were not considered. A comprehensive knowledge of crop productivity impacts from GNF land application should be of interest.

During the future large-scale infiltration experiments, winter or early spring are considered to be the best time of the year to land apply GNF in order to simulate the worst case scenario when groundwater level is relatively high and following snow melting can push land applied GNF further. Plant uptake is also minimum during this time of the year. However, for best management practice, GNF should be applied on the field between late spring to summer when groundwater level is low and plant up take is high. There are several points require extra consideration during the future experiments. In this study, low permeability surficial soil can cause surface run-off. A much slower application or other technique such as constructed barrier should be applied to prevent run-off. However, if the soil has high hydraulic conductivity, a rapid infiltration will be expected. Although a stiff clay layer underlying the shallow soils is typical around the Leamington area, a lower application rate is recommended for highly permeable soils.

Appendix A

Detailed Site Physical Information and Characterization

A.1 Prism Farms

A.1.1 Site Background

The Prism Farms operation is located within Essex County north to northeast of the city of Leamington, Ontario (Figure 1.3) and includes approximately 18 acres of greenhouse tomatoes. The surficial soils consist mostly of Brookston Clay with a thin, intermittent layer of fine to medium grained sand overlying parts of the cultivated fields on site. The surficial topography is very flat with a gentle slope of the ground surface from north to south.

The greenhouse irrigation system recirculates between 90% and 95% of the greenhouse GNF with the remaining GNF stored in two 40000 gallon tanks. A primary crop grown on site is Miscanthus which is intended for use as a biofuel both for energy production on site and as a commercial crop. At the time of the site investigations, 6 acres of Miscanthus were in production and an additional 15 acres remained to be planted. Operators of the Prism Farms enterprise are considering land applying residual greenhouse nutrient feed water as a nutrient source to the Miscanthus crop and have established a test application field directly west and adjacent to the main greenhouse structure (Figure A.1). This field (6 acres) is systematically tiled from north to south with a main tile draining toward the south into a shallow surface drain.

A.1.2 Detailed Site Investigation

In order to evaluate the characteristics of the subsurface sediments at the site, continuous core samples were collected during the installation of the groundwater monitoring wells. A 5.98 m core was collected at the southwest corner of the test field (location PG in Figure A.1) and the stratigraphic log is demonstrated in Figure A.3. The soil profile at this location consists of 30 cm of silty clay topsoil overlying stiff silty clay and clay with occasional thin sand interbeds. A second core was collected at the northwest corner of the field to a depth of 3 m (location P TW/PCW in Figure A.1). At this location, a 0.5 m thick silty sand unit overlies the stiff clay sediments. Overall, the sediments underlying this site are low permeability materials typical of a large portion of the Essex County region.

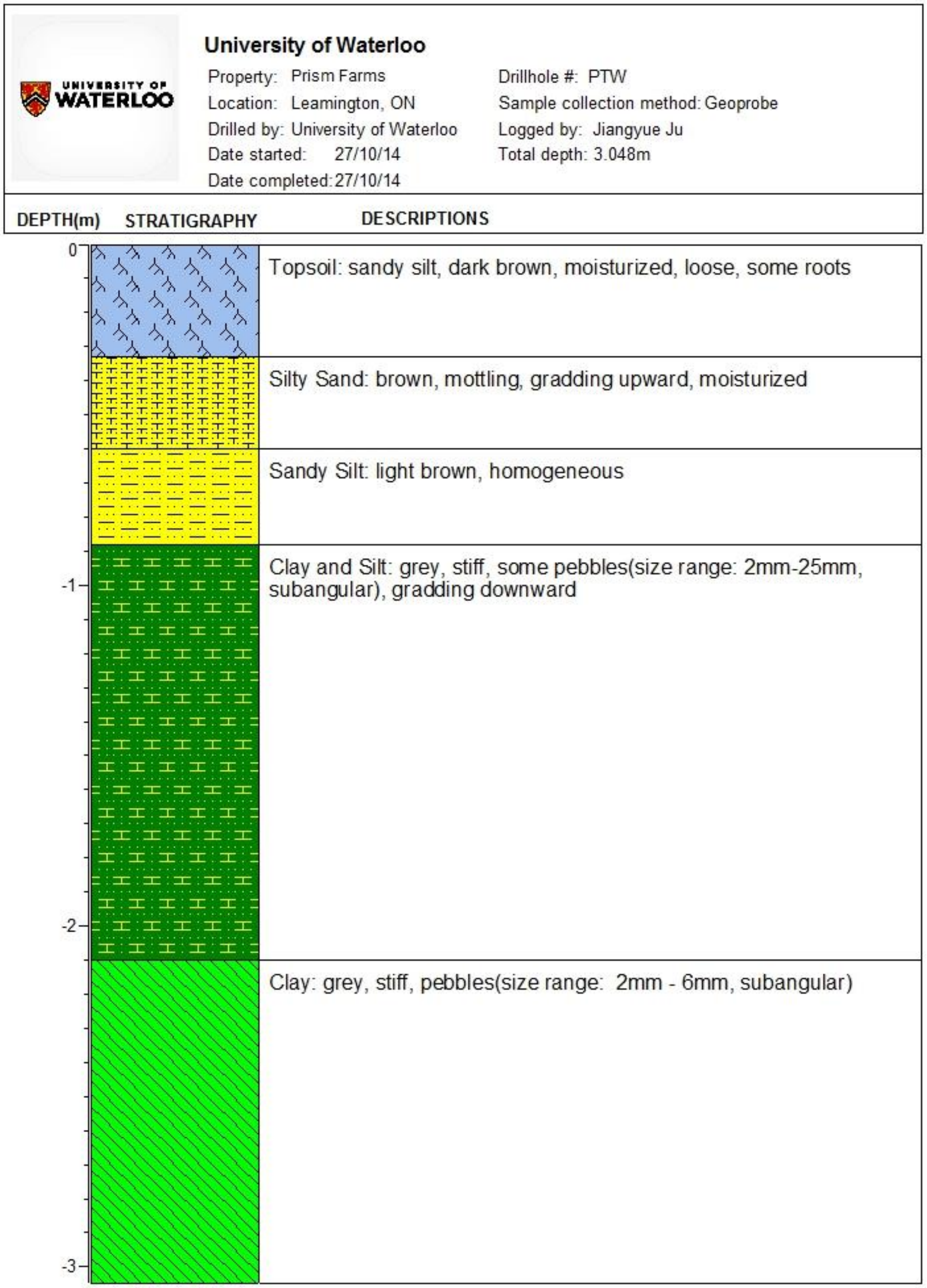
At the PG site, groundwater monitoring wells were installed to depths of 2.2 m and 5.98 m anticipating that these depths would capture the annual fluctuation in the water table. Two sets of monitoring wells were also installed at the PTW/PCW site to depths of 1.5 m and 2.5 m. These wells are intended to be used during the controlled infiltration experiments (discussed below) and to provide regional groundwater flow gradient information and background groundwater samples. Recording pressure transducers were installed in all of the wells to monitor seasonal changes in groundwater levels at the site.

Background water samples were collected from all of the groundwater wells at the Prism site and the data are presented in Table A.1 and Table A.10. All inorganic and metal species measured occurred at very low levels in all of the groundwater samples with the exception of sulphate, magnesium and calcium, which tended to be somewhat higher in concentration but still well below the Ontario Drinking Water Objectives. There is a general trend of increasing concentrations of many of the inorganic analytes with depth below the water table although the metal concentrations remained relatively consistent with depth.

A total of 6 sets of three lysimeters each were installed at the Prism site within the designated infiltration plot (Figure 2.2). Soil water samples were collected from each of the lysimeters and analysis indicated that all of the inorganic and metal species were at concentrations well below the Ontario Drinking Water Objectives and lower than the groundwater concentrations (Table A.1). The only exception to this was the silicon concentration of all the samples collected from the lysimeters. These high concentrations may be an artifact of the soil water passing through the silica flour slurry/ceramic porous cups and leaching some of the silicon. A water sample collected from a tile drain (Table A. 6) on site showed very similar chemical characteristics to the soil water, however with silicon concentrations much closer to those measured in the groundwater samples again suggesting some influence of the lysimeters itself.

Randomized soil samples were collected from the upper 15 cm of the soil profile in order to provide a composite sample representative of background conditions over the test field (Table A. 5). Soil samples were also collected from upper 15cm, 15 cm to 30 cm and 30 cm to 45 cm from experimental plots as monitoring reference (Table A. 3). This sample was analyzed for the standard agricultural nutrient suites which were found to be at moderate fertility levels. The concentrations of most inorganic species when compared to that observed in the soil water or groundwater samples were much higher, which would be anticipated for a soil analysis. In addition, random composite samples were also collected from three different depths within the infiltration experiment plots. These samples were analyzed for both the nutrient suite and heavy metals (Table A. 4). Overall assessment of the chemical analysis of the composite soil samples revealed that the concentrations of essentially all inorganic and metal species decrease in concentration in the soil with depth below the ground surface (Table A. 3 and Table A. 5). Compared to the Ontario Guidelines for soil, all concentrations of species where guideline values exist are below the recommended limits with the exception of several nickel values from samples collected at depths greater than 30 cm beneath the infiltration plots.

Figure A.1 Detailed site plan of the Prism Farms site showing the location of the greenhouse, the potential nutrient feed water land application site, infiltration test plot sites and relevant instrumentation and field characteristics

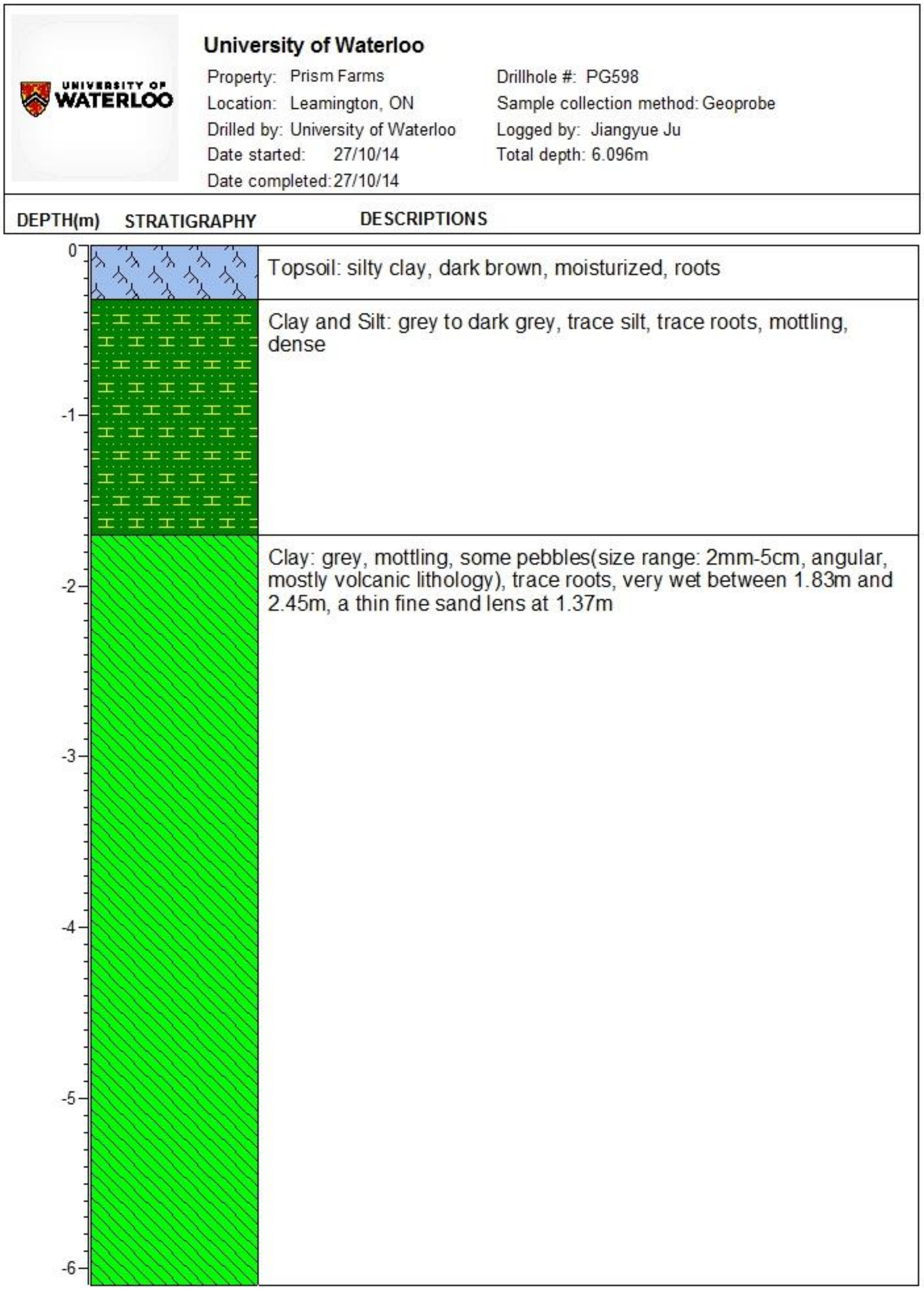


University of Waterloo

Property: Prism Farms
Location: Leamington, ON
Drilled by: University of Waterloo
Date started: 27/10/14
Date completed: 27/10/14
Drillhole #: PTW
Sample collection method: Geoprobe
Logged by: Jiangyue Ju
Total depth: 3.048m

DEPTH(m)	STRATIGRAPHY	DESCRIPTIONS
0		Topsoil: sandy silt, dark brown, moisturized, loose, some roots
		Silty Sand: brown, mottling, gradding upward, moisturized
		Sandy Silt: light brown, homogeneous
-1		Clay and Silt: grey, stiff, some pebbles(size range: 2mm-25mm, subangular), gradding downward
-2		Clay: grey, stiff, pebbles(size range: 2mm - 6mm, subangular)
-3		

Figure A.2 Stratigraphic log for drill hole PTW



University of Waterloo

Property: Prism Farms
Location: Leamington, ON
Drilled by: University of Waterloo
Date started: 27/10/14
Date completed: 27/10/14

Drillhole #: PG598
Sample collection method: Geoprobe
Logged by: Jiangyue Ju
Total depth: 6.096m

Topsoil: silty clay, dark brown, moisturized, roots

Clay and Silt: grey to dark grey, trace silt, trace roots, mottling, dense

Clay: grey, mottling, some pebbles(size range: 2mm-5cm, angular, mostly volcanic lithology), trace roots, very wet between 1.83m and 2.45m, a thin fine sand lens at 1.37m

Figure A.3 Stratigraphic log for drill hole PG598

Table A.1 Background nutrient concentrations in soil water at Prism Farms experiment plot

Background Soil Water	Ontario Drinking Water standard	PT230	PT330	PT260	PT360	PT190	PT390	PC130/ 230	PC360	PC190	PC390
Dilution Factor		3	1.5	3				3			
pH	6.5-8.5	7.32	7.32	7.4	7.01	7.32	7.33	7.33	7.48	7.56	7.59
EC (mmhos/cm)		0.05	0.09	0.07	0.1	0.18	0.17	0.07	0.12	0.17	0.14
Nitrate Nitrogen (ppm)	10	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Phosphorus (ppm)	N/L	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Potassium (ppm)	N/L	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Calcium (ppm)	N/L	<1.00	6.015	4.89	4.18	17.44	17.35	9.09	9.2	15.62	9.59
Magnesium (ppm)	N/L	<1.00	3.795	8.82	5.78	7.01	7.4	<1.00	3.99	7.73	7.82
Chloride (ppm)	250	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sulphates (ppm)	500	<1.00	3.105	<1.00	3.57	14.05	21.55	22.68	4.88	6.29	7.81
Sodium (ppm)	200	4.8	2.895	<1.00	<1.00	3.04	1.25	<1.00	3.57	3.91	2.62
Zinc (ppm)	5	0.03	0.03	0.03	0.03	0.03	0.04	0.06	0.04	0.05	0.05
Manganese (ppm)	0.05	0.09	0.045	0.03	0.03	0.02	0.02	<0.01	<0.01	0.05	0.02
Copper (ppm)	1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Iron (ppm)	0.3	0.06	0.075	0.03	0.03	0.09	0.07	<0.01	<0.01	<0.01	0.01
Boron (ppm)	5	0.06	0.03	0.09	0.06	0.08	0.07	0.06	0.05	0.07	0.06
Molybdenum (ppm)	N/L	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01
Silicon (ppm)	N/L	39.36	32.205	45.75	14.23	25.3	15.2	41.73	18.44	29.28	32.31
Aluminon	0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

*PT: Prism test/application plot
PC: Prism control plot
3 digit numbers were labeled as: cluster number-depth below ground surface. eg: PT230 means the 30 cm deep lysimeter in lysimeter cluster 1 at Prism test plot.

Table A. 2 Background nutrient concentrations in groundwater at Prism Farms and Lakeview sites

Background Groundwater	Ontario Drinking Water standard	**PTW141**	**PTW251**	**PCW139**	**PCW249**	**PG220**	**PG598**	**Lakeview GW**
Dilution Factor								
pH	6.5–8.5	7.44	7.49	7.62	7.59	7.33	7.26	7.81
EC (mmhos/cm)		0.53	0.59	0.37	0.5	1	1.47	0.45
Nitrate Nitrogen (ppm)	10	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	
Phosphorus (ppm)	N/L	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	0.22
Potassium (ppm)	N/L	2.7	< 1.00	< 1.00	< 1.00	< 1.00	4.73	3.26
Calcium (ppm)	N/L	83.98	76.88	56.12	69.44	143.18	171.05	97.27
Magnesium (ppm)	N/L	14.56	17.93	9.77	14.82	42.7	81.75	7.24
Chloride (ppm)	250							
Sulphates (ppm)	500	108.12	102.97	24.15	62.98	109.95	542.45	12.8
Sodium (ppm)	200	5.67	22.38	6.79	10.38	15.01	57.91	2.4
Zinc (ppm)	5	0.03	0.02	0.02	0.02	0.05	0.04	0.01
Manganese (ppm)	0.05	0.16	0.2	0.1	0.78	0.03	0.08	0
Copper (ppm)	1	< 0.01	< 0.01	< 0.01	< 0.01	0.08	< 0.01	0.01
Iron (ppm)	0.3	0.43	0.03	0.41	0.04	0.04	0.06	0.17
Boron (ppm)	5	0.08	0.14	0.08	0.08	0.07	0.76	0.07
Molybdenum (ppm)	N/L	< 0.01	0.08	< 0.01	0.04	0.02	0.04	0.01
Silicon (ppm)	N/L	5.06	4.97	5.27	6.81	7.22	7.42	3.12

Table A. 3 Background nutrient levels in soil at Prism Farms experiment plot

Plot Background Soil(Nutrients)	PT 0-15cm	PT15-30cm	PT30-45cm	PC0-15cm	PC15-30cm	PC30-45cm
pH	6.8	6.8	7.1	6.9	7.1	7.3
EC (mmhos/cm)						
Organic matter	2.4	2.2	0.4	2.4	1.8	0.2
Nitrate Nitrogen (ppm)						
Phosphorus (ppm)	29	12	5	27	10	5
Potassium (ppm)	109	56	39	71	51	42
Calcium (ppm)	733	699	363	731	655	333
Magnesium (ppm)	109	75	60	101	75	62
Zinc (ppm)	1	0.4	0	0.8	0.1	0
Manganese (ppm)	14.7	9.6	3.2	16.9	4.4	3.8
Copper (ppm)	0.4	0.8	2	0.5	0.9	1.1
Iron (ppm)	24.5	23.6	10.7	21.6	14.6	7.3
Boron (ppm)	0.46	0.45	0.28	0.47	0.43	0.25

*PT: Prism test/application plot
PC: Prism control plot

Table A. 4 Background heavy metal levels in soil at Prism Farms experiment plots

Plot Background Soil(Metals)	Guideline*	Mean Ontario*	PT0-15cm	PT15-30cm	PT30-45cm	PC0-15cm	PC15-30cm	PC30-45cm
Zinc (ppm)	220	55	24	22	15	22	20	17
Copper (ppm)	100	25	4.1	6	7.7	4	5.2	6.5
Molybdenum (ppm)	4	2	1.2	1.4	1.2	1.1	1.3	0.9
Cobalt (ppm)	20	5	1.3	1.4	2.3	1.4	1.5	2.2
Cadmium (ppm)	1.6	0.8	0.17	0.19	0.07	0.15	0.14	0.07
Lead (ppm)	60	15	8.1	8.2	4.9	7.2	7.6	5.7
Nickel (ppm)	32	16	6.7	32	47	5.3	11	19
Selenium (ppm)	1.6	0.4	< 0.70	< 0.70	< 0.70	< 0.78	0.7	< 0.70
Arsenic (ppm)	14	7	2.6	2.9	3.7	2.5	2.9	3
Chromium (ppm)	120	15	5.8	5.5	6.5	5.9	5.8	7
Mercury (ppm)	0.5	0.1	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

* Retrieved from table "Criteria for Metal Content in Soils table" from Guidelines for the utilization of biosolids and other waste on agricultural land, 1996.

Table A. 5 Background nutrient levels in top 15 cm soil collected from study sites during baseline characterization

	Prism	**Cecelia***	**Warkentin**	**Lakeview**
pH	6.7	7.8	7.4	7
EC (mmhos/cm)				
Organic matter	3.3	1.3	3.9	3.7
Nitrate Nitrogen (ppm)				
Phosphorus (ppm)	31	29.5	64	25
Potassium (ppm)	106	45	262	159
Calcium (ppm)	760	2405.5	2668	2870
Magnesium (ppm)	82	123.5	261	182
Zinc (ppm)	2	1.05	4.2	1.5
Manganese (ppm)	4.8	10.85	20.2	17.7
Copper (ppm)	1	1.7	1.6	1.8
Iron (ppm)	49.8	27.3	42.8	15.5
Boron (ppm)	0.45	0.605	2.07	0.64

*mean value from plot background data

Table A. 6 Background nutrient concentrations in tile water from Prism Farms site and Warkentin Orchard site

	Ontario Drinking Water standard	**Prism Tile**	**Warkentin Tile**
pH	6.5-8.5	7.97	7.77
EC (mmhos/cm)		0.63	0.73
Nitrate Nitrogen (ppm)	10		< 0.50
Phosphorus (ppm)	N/L	0	< 1.00
Potassium (ppm)	N/L	8.15	8.7
Calcium (ppm)	N/L	112.61	105.97
Magnesium (ppm)	N/L	29.5	27.98
Chloride (ppm)	250	N/L	N/L
Sulphates (ppm)	500	78.13	146.11
Sodium (ppm)	200	7.48	6.99
Zinc (ppm)	5	0	0.03
Manganese (ppm)	0.05	0.01	0.06
Copper (ppm)	1	0.04	< 0.01
Iron (ppm)	0.3	0.07	0.02
Boron (ppm)	5	0.08	0.2
Molybdenum (ppm)	N/L		< 0.01
Silicon (ppm)	N/L	4.1	4.28

A.2 Cecelia Acres

A.2.1 Site Background

Cecelia Acres is located within Essex County southwest of Kingsville, Ontario and less than 1000m from the lake shore (Figure 1.3). The surficial soils are mostly comprised of fox silt loam and the topography is almost flat. The field is randomly tiled from west to east and connected to a surface water drain. The locations of all tiles are not precisely known by the operator and outfall locations to the surface drain were modified by the operator during the course of the study.

About 95% of the greenhouse leachate is recirculated through the internal irrigation system and stored in tanks inside the greenhouse. The farm operation includes 20 acres of greenhouse tomatoes and 18 acres of field soybeans, which was the planted field crop at the time of the investigation. Operators of the farm are interested in land application of nutrient feedwater as a crop nutrient. As an initial step towards assessing the feasibility of land application, the operators agreed to permit the establishment of a test application plot on the north side of the greenhouse (Figure A.4).

A.2.2 Detailed Site Investigation

Characteristics of the subsurface sediments were evaluated in the same approach as outlined above for the Prism Farms location. As part of the process of installing the groundwater monitoring wells, a 4.57m continuous core was collected within the infiltration plot area (Figure A.4, between CW151 and CW220). According to the stratigraphic log (Figure A. 5), there is approximately 25 cm of sandy silt top soil and another 75 cm of sand and silt layer overlying stiff clay. Generally, the shallow sediments at this site are similar to those encountered at the Prism site but the near surface materials appear to be less permeable in nature.

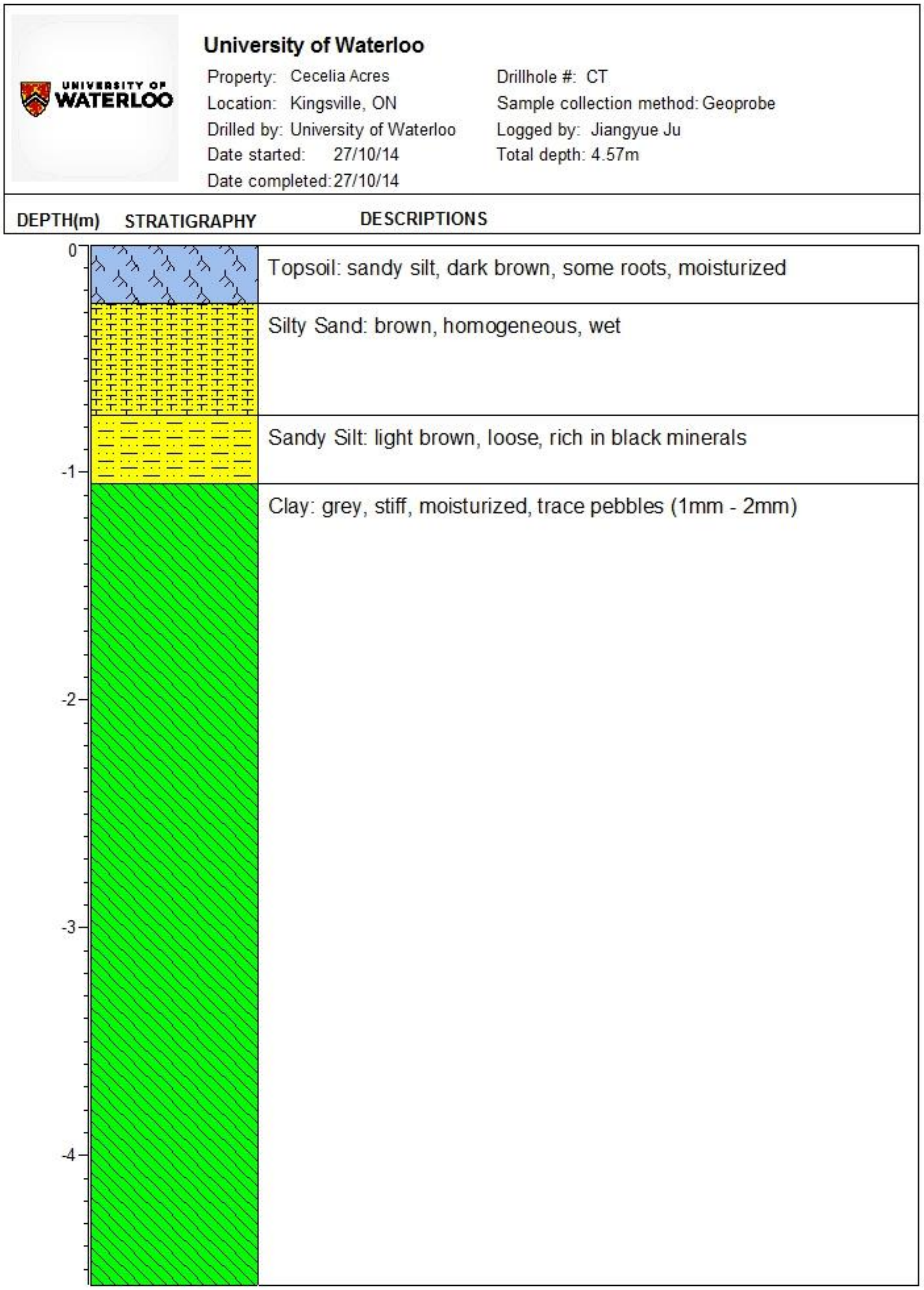
Two sets of monitoring wells were installed within the infiltration test plots to depths of 1.51 m and 1.20 m. They are used to provide groundwater samples and monitor groundwater table fluctuation during the controlled infiltration experiments and the future, larger scale land applications. The wells were placed just below the anticipated tile drainage depth in order to intercept the water table fluctuation during the course of the year. At the time of installation, the tiles were not flowing and the wells were dry. Samples could not be collected from them prior to full freeze up. All of the wells were buried half meter below ground surface and 3M^{TM} near-surface markers were used to mark the well location, which can be located using 3M^{TM} Dynatel^{TM} electronic locator at a later date. Background water samples were collected from the soil profile with the lysimeters installed on site.

As implemented within the infiltration plots established at the Prism Farms site, 6 sets of three lysimeters each were installed at the Cecelia site within the designated infiltration plot (Figure 2.1) and soil water samples were collected from each of the lysimeters. Analysis of those samples indicated that all of the inorganic and metal species were at concentrations well below the Ontario Drinking Water Objectives (Table 3.1) other than nitrate and silicon. The nitrate value in Cecelia site's soil water is about 130% to 180% of the guided value. The chemical composition of the nutrient feedwater is discussed below in context with the plot infiltration tests. The silicon concentrations may be an artifact influence of the lysimeters as discussed above.

Composite soil samples were collected from the upper 15 cm of the soil profile to represent the background soil conditions over the test field. Soil samples were also collected from upper 15 cm, 15 cm to 30 cm and 30 cm to 45 cm at experimental plots as background reference for later monitoring. The samples were sent to lab and analyzed for the standard agricultural nutrient suite and heavy metals. The concentrations of most inorganic species were much higher than that observed in the soil water samples although still below the Ontario Guidelines for soil (Table A.7 and Table A. 5). Overall assessment of the chemical analysis of the composite soil samples shows that the concentrations of essentially all inorganic and metal species decrease in concentration in soil with depth below ground surface with the exception of calcium, which tends to increase with depth (Table A.8 and Table A. 9).There are several geochemical differences that illustrate the potential for minor variability across the field site. In comparing variability with depth, soil water in the test plot had higher nitrate concentrations at 30 cm depth and in the control plot, higher sulphate concentrations were observed at 90 cm depth. Soil samples at 30 cm to 45 cm depth in control plot shows a relatively high concentration of molybdenum, which is above the mean molybdenum content in uncontaminated soil in Ontario but still below the maximum permissible metal content according to Ontario's criteria for metal in soil (MOE, 1996). Compared to the Prism Farms site, nitrate, magnesium and calcium values are much higher at the Cecelia site.

As noted, the tile drainage system was not flowing during any of the site visits and the lateral surface water drain was dry so that no water samples could be collected during the baseline characterization.

Figure A.4 Detailed site plan of the Cecelia Acres site showing the location of the greenhouse, the potential nutrient feedwater land application site, infiltration test plot sites and relevant instrumentation and field characteristics



University of Waterloo

Property: Cecelia Acres
Location: Kingsville, ON
Drilled by: University of Waterloo
Date started: 27/10/14
Date completed: 27/10/14

Drillhole #: CT
Sample collection method: Geoprobe
Logged by: Jiangyue Ju
Total depth: 4.57m

DEPTH(m)	STRATIGRAPHY	DESCRIPTIONS
0		Topsoil: sandy silt, dark brown, some roots, moisturized
		Silty Sand: brown, homogeneous, wet
		Sandy Silt: light brown, loose, rich in black minerals
-1		Clay: grey, stiff, moisturized, trace pebbles (1mm - 2mm)

Figure A. 5 Stratigraphic log for drill hole CT

Table A.7 Background nutrient concentrations in soil water at Cecelia acres experiment plot

Background Soil Water	Ontario Drinking Water standard	CT130	CT230	CT160	CT290	CC130/230	CC160	CC260	CC190	CC290
Dilution Factor			3			5				
pH	6.5-8.5	7.95	7.71	7.79	7.88	7.46	7.91	7.77	7.85	7.82
EC (mmhos/cm)		0.77	0.28	0.88	10.2	0.12	0.75	0.8	1.34	1.02
Nitrate Nitrogen (ppm)	10	31.00	39.00	17.00	17.00	15.00	18.00	17.00	8.00	13.00
Phosphorus (ppm)	N/L	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Potassium (ppm)	N/L	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Calcium (ppm)	N/L	140.17	103.5	159.73	207.87	36.75	135.93	143.17	278.78	196.43
Magnesium (ppm)	N/L	19.28	16.92	28.56	33.46	14.6	23.6	24.38	43.44	34.46
Chloride (ppm)	250									
Sulphates (ppm)	500	49.71	89.43	52.99	81.58	63.25	45.48	59.18	338.89	112.92
Sodium (ppm)	200	4.28	25.53	3.53	6.57	26.35	4.34	4.33	9.75	6.97
Zinc (ppm)	5	0.06	0.06	0.06	0.07	0.05	0.05	0.06	0.07	0.08
Manganese (ppm)	0.05	0.01	<0.01	0.01	0.04	<0.01	0.02	0.01	0.02	0.01
Copper (ppm)	1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Iron (ppm)	0.3	<0.01	<0.01	<0.01	0.02	0.05	<0.01	0.01	0.02	<0.01
Boron (ppm)	5	0.08	0.06	0.09	0.18	<0.01	0.07	0.07	0.17	0.19
Molybdenum (ppm)	N/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Silicon (ppm)	N/L	24.82	33.24	40.3	33.33	37.8	31.77	36.45	38.31	42.08
Aluminon	0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Table A.8 Background heavy metal levels in soil at Cecelia Acres experiment plots

	Guideline*	Mean Ontario*	CT0-15cm	CT15-30cm	CT30-45cm	CC0-15cm	CC15-30cm	CC30-45cm
Zinc (ppm)	220	55	27	23	18	30	22	18
Copper (ppm)	100	25	13	9.6	8.2	14	9.3	8.2
Molybdenum (ppm)	4	2	0.8	0.9	1.4	0.8	1	2.7
Cobalt (ppm)	20	5	2.5	2.4	2.5	2.7	2.6	3
Cadmium (ppm)	1.6	0.8	0.22	0.2	0.16	0.23	0.16	0.12
Lead (ppm)	60	15	6.7	5.8	4.3	7.1	4.9	3.4
Nickel (ppm)	32	16	7.5	8	11	8.3	9	12
Selenium (ppm)	1.6	0.4	< 0.70	< 0.70	< 0.70	< 0.70	< 0.70	< 0.70
Arsenic (ppm)	14	7	2.2	2.3	2.3	2.3	2.1	2.7
Chromium (ppm)	120	15	7.2	7	6.5	7.7	5.9	5.9
Mercury (ppm)	0.5	0.1	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

* Retrieved from table “Criteria for Metal Content in Soils table” from Guidelines for the utilization of biosolids and other waste on agricultural land, 1996.

Table A. 9 Background nutrient levels in soil at Cecelia experiment plot

	CT0-15cm	CT15-30cm	CT30-45cm	CC0-15cm	CC15-30cm	CC30-45cm
pH	7.7	7.9	8.1	7.8	8	8.2
EC (mmhos/cm)						
Organic matter	1.6	1	0.4	1.6	0.8	0
Nitrate Nitrogen (ppm)						
Phosphorus (ppm)	39	20	6	37	16	5
Potassium (ppm)	59	31	16	57	31	22
Calcium (ppm)	2367	2444	3674	2308	3307	3554
Magnesium (ppm)	131	116	107	126	91	81
Zinc (ppm)	1.4	0.7	0.1	1.3	0.6	0
Manganese (ppm)	12.7	9	11	12.8	10.5	11.4
Copper (ppm)	1.9	1.5	0.7	1.8	1.1	0.5
Iron (ppm)	31.1	23.5	24	19.6	13.5	7.1
Boron (ppm)	0.65	0.56	0.35	0.55	0.37	0.22

A.3 Warkentin Acres

A.3.1 Site Background

The Warkentin Orchards operation is located within Essex County northeast of the city of Leamington, Ontario (Figure 1.3). Similar to the Prism Farms site, the surficial soils are mostly composed of Brookston Clay with an intermittent layer of fine to medium grained sand overlying parts of the orchard field on site. The topography is relatively flat at this site and the orchard is dominated by two species of apple trees (Figure A.6). There were approximately 3 acres of greenhouse cucumbers as the major greenhouse crop at the time of investigation.

The greenhouse irrigation system does not recirculate the leachate and it is directly discharged into a lined pond. A second pond is currently under construction (Figure A.6).The apple orchards are irrigated by a surface drip system. Operators of the farm are considering land applying unused greenhouse nutrient feedwater as an alternative nutrient source for the orchards. They are anticipating the land application to occur on a newly established orchard area located north east of the green house (Figure A.6). The orchard field is systematically tiled from north to south on 14 feet centers to match the orchard row width with all headers converging into a single drainage box (AgriDrain).

A.3.2 Detailed Site Investigation

Continuous core samples were collected during the installation of the groundwater monitoring wells at the location of WW 220 site (Figure A.6). The soil profile at this location shows a thin layer of sandy material overlying thick and stiff clay, which is quite similar with the soil profile at Prism (Figure A. 7).

Groundwater monitoring wells were installed at two adjacent locations to depths of 1.49 m and 2.20 m, just beneath the tile depth to capture fluctuations in the water table over the annual cycle. Although the soil core samples indicated relatively wet soil conditions at the depths of the screens, not enough water entered the wells during the monitoring period to provide sufficient sample volume for analysis so no samples were collected from the wells during the fall sampling campaign. This is likely primarily due to the very low permeability of the underlying clay sediments at the site. Samples will be collected from the wells during the spring sampling event.

Background water samples were collected from the drainage box northeast of the field for the agricultural nutrient suite analysis and the data are presented in Table A. 6. Overall the nutrient concentrations were very low in the tile water as were most of the metal species. The manganese concentration was the only one that exceeded the Ontario Drinking Water Objectives, with all other species being well below those objectives. There was no surface water available for sampling on the farm property near the field investigations.

Sets of two lysimeters each were installed to depths of 30 cm and 60 cm at both monitoring points on the Warkentin site before the baseline characterization. The lysimeters and monitoring wells are positioned in anticipation of future infiltration experiments at this site. Due to the dry conditions of the soil and low permeability, it was not possible to extract soil water from these lysimeters during the fall sampling event. Additional lysimeters were installed in the second year study to provide more detailed soil water information during the anticipated infiltration tests.

Soil samples were collected at random locations throughout the test field from the upper 15 cm of the soil profile. They were mixed as a composite sample representative of background conditions and analyzed for the standard agricultural nutrient suite. For most of the chemical species in the nutrient suite, concentrations at the Warkentin site were noticeably higher than those observed at either the Prism or Cecelia sites and indicated a very high fertility level. In addition, the soil nutrient levels were much higher than those observed in the tile water (Table A. 5), which would be anticipated for a soil analysis. Soil texture analysis was completed from composite soil samples collected in the two adjacent monitoring areas for the upper 15 cm, 15 cm to 30 cm and 30 cm to 45 cm of the soil profile. Greater silt and clay content was consistently found than Prism and Cecelia sites and was characterized as a loam soil to silty clay loam. Surface soil bulk density was as a result greater than the coarser soil sites where the control and application plots averaged 1.45 and 1.48 g/cu.cm, respectively.

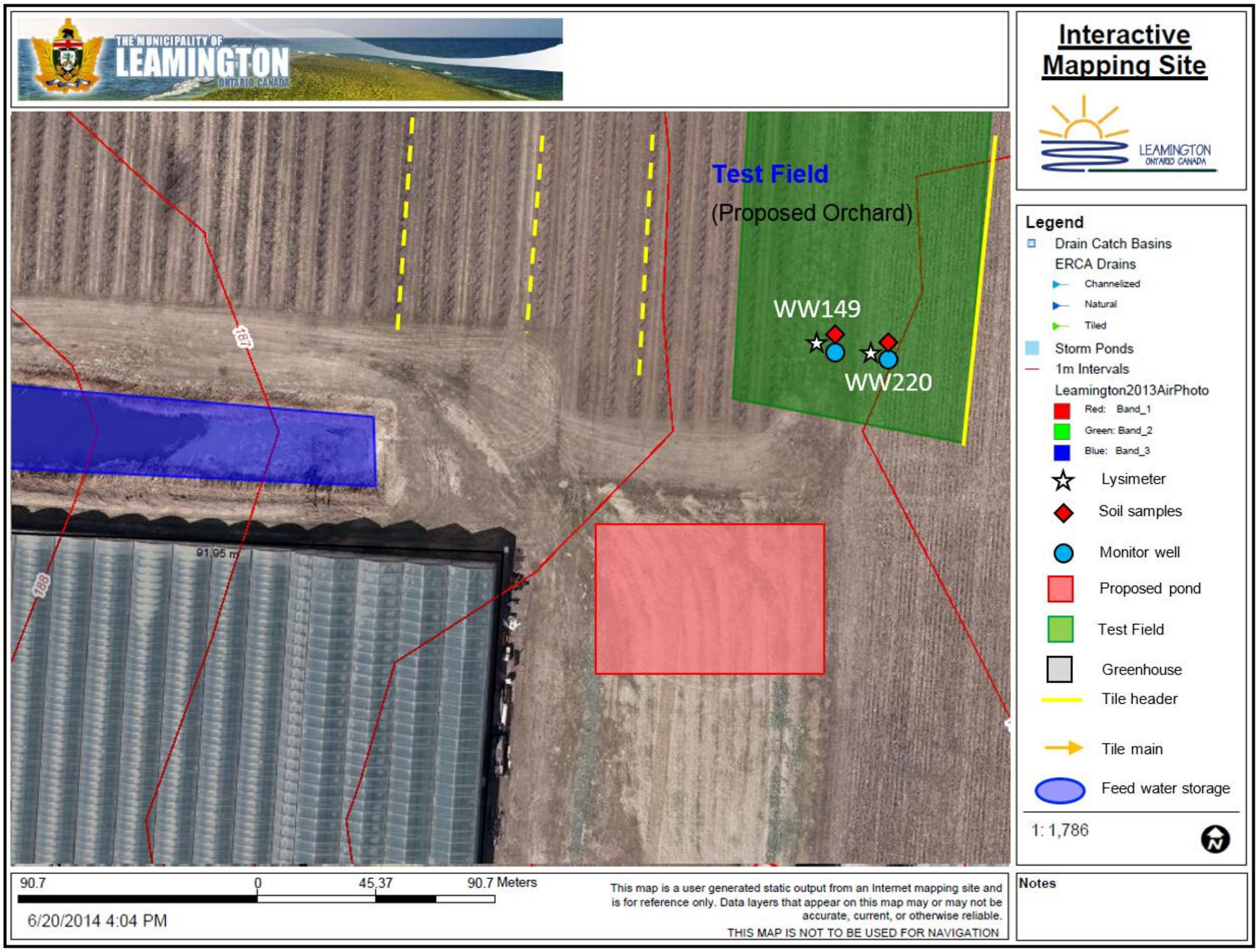
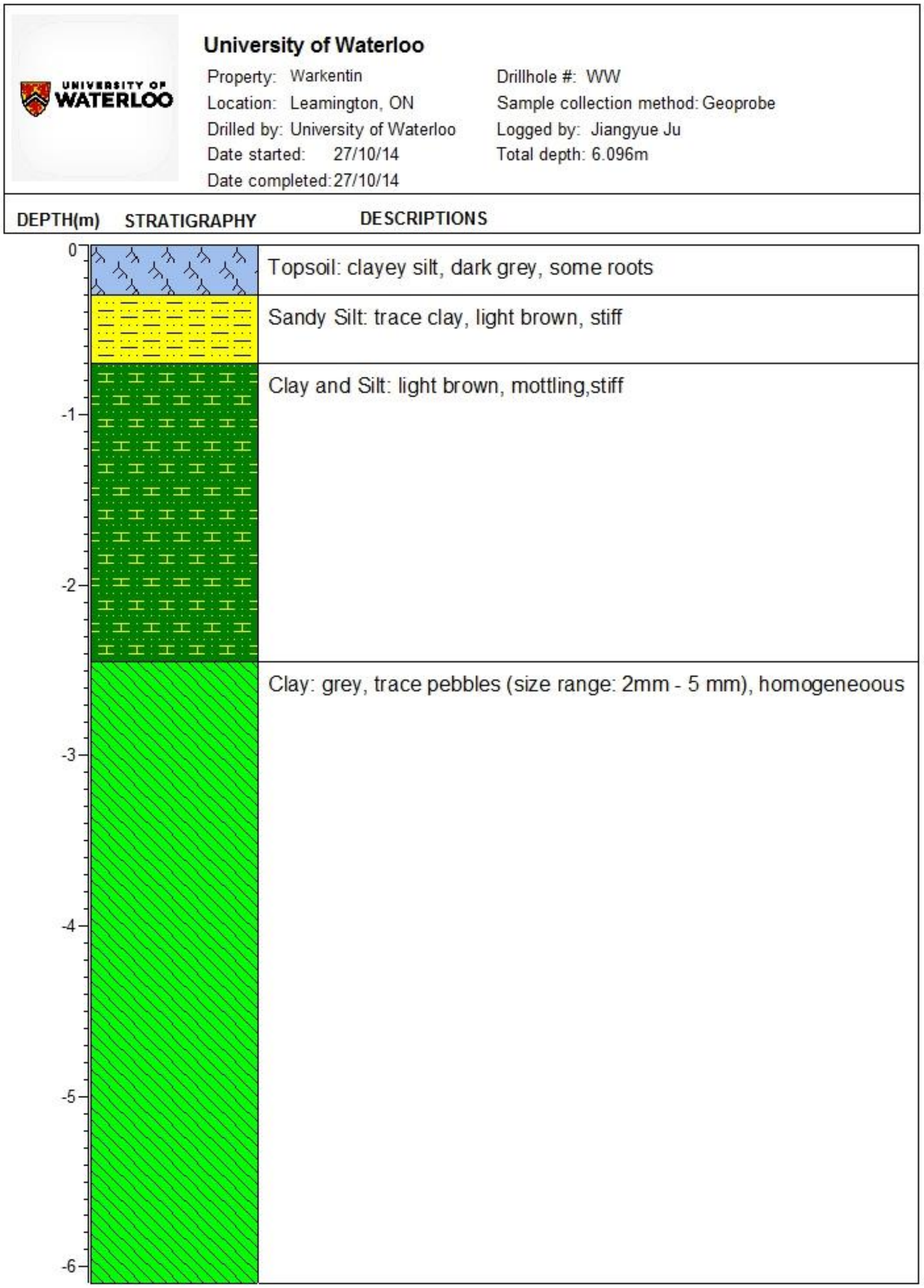


Figure A.6 Detailed site plan of the Warkentin Orchards site showing the location of the greenhouse, the potential nutrient feedwater land application site, infiltration test plot sites and relevant instrumentation and field characteristics



University of Waterloo

Property: Warkentin

Location: Leamington, ON

Drilled by: University of Waterloo

Date started: 27/10/14

Date completed: 27/10/14

Drillhole #: WW

Sample collection method: Geoprobe

Logged by: Jiangyue Ju

Total depth: 6.096m

DEPTH(m)	STRATIGRAPHY	DESCRIPTIONS
0		Topsoil: clayey silt, dark grey, some roots
		Sandy Silt: trace clay, light brown, stiff
		Clay and Silt: light brown, mottling,stiff
		Clay: grey, trace pebbles (size range: 2mm - 5 mm), homogeneoous

Figure A. 7 Stratigraphic log for drill hole WW

A.4 Lakeview Greenhouses

A.4.1 Site Background

Lakeview Greenhouse and Farm is located southwest of Cedar Springs, Ontario and is adjacent to Lake Erie (Figure 1.3). Surficial soils at this site are comprised of Highgate Sandy Loam and Gobles Loam. The topography across the land is again quite flat and lateral surface water drainage ditches are present between some of the fields (Figure A. 8). The fields are not tile drained.

The operation in the Lakeview greenhouse is mixed vegetable transplants, followed by cucumbers. According to the operators, greenhouse nutrient feedwater is only recirculated when growing cucumbers. Unused nutrient feedwater is collected in two lined ponds that have enough capacity for a full year's storage. The field crops have included corn and tobacco in recent years. During the course of this study, soybean has been the major field crop.

A.4.2 Detailed Site Investigation

Two continuous cores were collected beside a groundwater well nest installed at the LG 245 site in the north west corner of the field and the location of the future infiltration plot site to the south east (LT and LC) (Figure A. 9 and Figure A. 10) to evaluate the characteristics of the subsurface sediments. The soil profiles indicate a coarse and loose sandy gravel overlying clay with the south part of the test field containing more gravel than the north part. Overall, the underlying sediments at this site are the most permeable among the four selected trial sites.

At the LG site (location see Figure A. 8), groundwater monitoring wells were installed to depths of 3.49 m anticipating that these depths would capture the annual fluctuation in the water table and provide baseline groundwater samples. In addition, two sets of groundwater monitoring wells were installed at the application and control plots to depths of approximately 2.5 m, 3.0 m and 3.5 m. These wells were used as monitoring wells providing regional groundwater flow gradient information and groundwater samples as part of future infiltration tests.

A background groundwater sample was collected from the 3.49 m deep monitoring well at LG site and the analysis is included in Table A.10. Overall, the composition of the groundwater is very similar to that observed at the other three sites although the concentrations are more dilute for many of the analytes. All inorganic and metal species measured occurred at very low levels in all of the groundwater samples, well below Ontario Drinking Water Objectives. No surface water was available for sampling during the course of the field investigations.

As at the Warkentin site, sets of two lysimeters were installed to depths of 30 cm and 60 cm at both application and test plots on the Lakeview site. These lysimeters and the monitoring wells were installed in anticipation of future infiltration experiments at this site. Due to the course nature of the sediment at this site and the fairly dry conditions in the soil profile at the time of sampling, no soil water was obtained from the lysimeters. Additional lysimeters were installed during the second year study for infiltration tests.

Soil samples were randomly collected from the upper 15 cm of the soil profile in order to provide a composite sample representative of background conditions over the test field. Soil samples analyzed for the standard agricultural nutrient suite were similar to the Warkentin site as concentrations of most analytes are somewhat higher than those measured at the Prism and Cecelia sites. As observed at several other sites, the soil nutrient levels were higher than that observed in the ground water sample (Table A. 5). The soil pH at Lakefield unlike the neutral to slightly alkaline surface soils of the other sites was slightly acidic. The considerable gravel content of the surface soil reduced the bulk density measurement to around 1.0g/cu.cm.

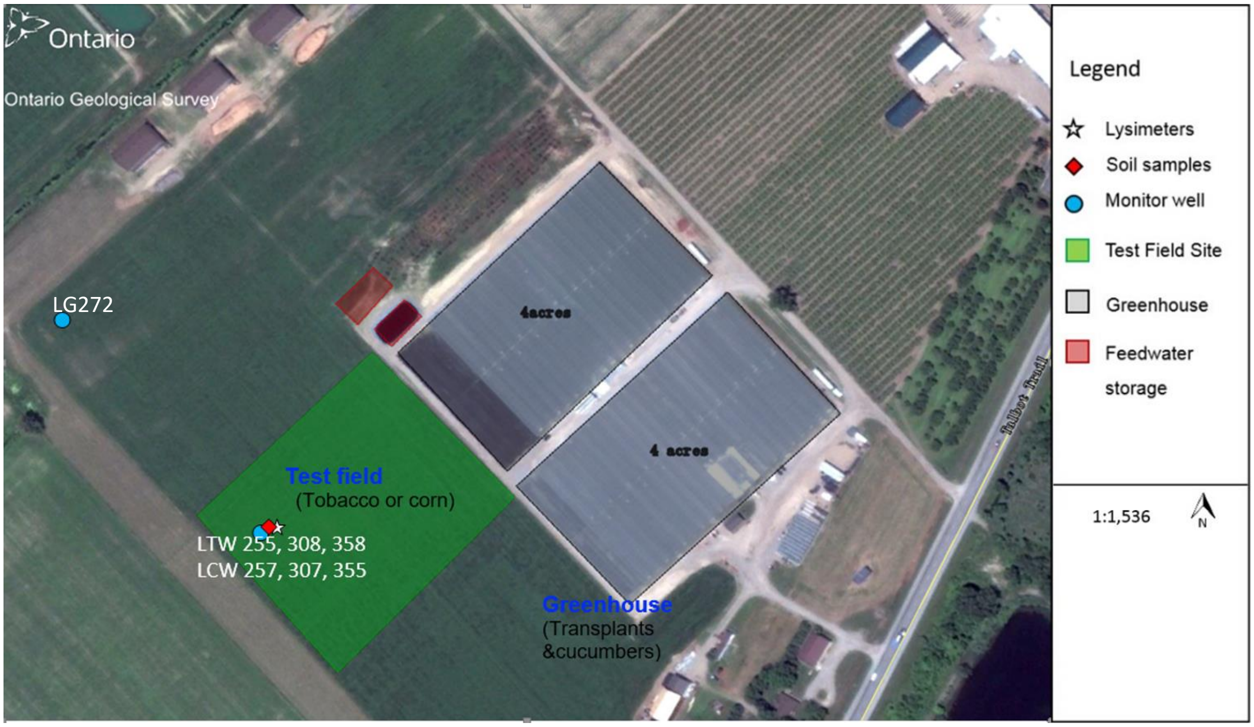
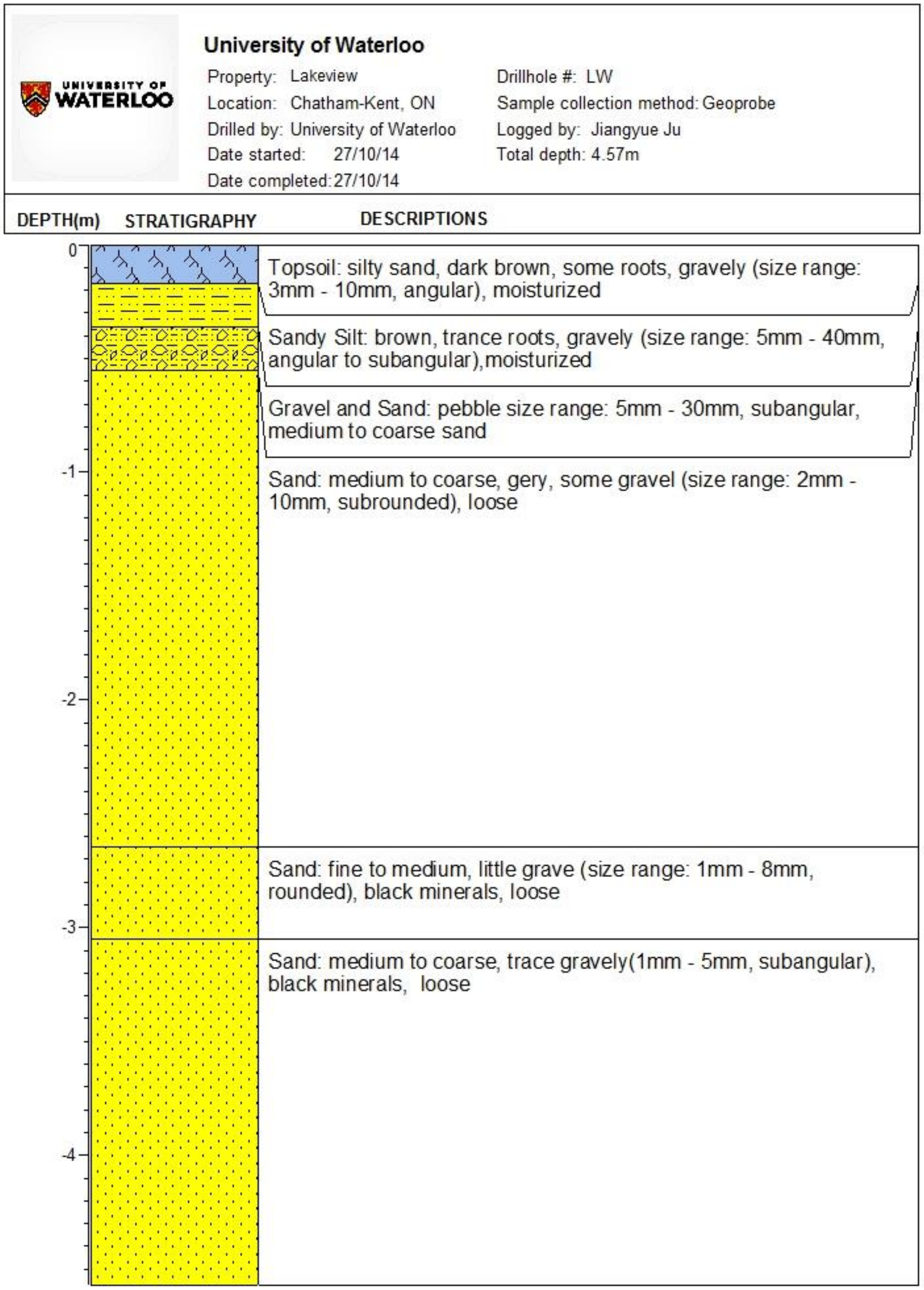


Figure A. 8 Detailed site plan of the Lakeview Greenhouse and Farm site showing the location of the greenhouse, the potential nutrient feedwater land application site, infiltration test plot sites and relevant instrumentation and field characteristics.



University of Waterloo

Property: Lakeview
Location: Chatham-Kent, ON
Drilled by: University of Waterloo
Date started: 27/10/14
Date completed: 27/10/14

Drillhole #: LW
Sample collection method: Geoprobe
Logged by: Jiangyue Ju
Total depth: 4.57m

DEPTH(m) STRATIGRAPHY DESCRIPTIONS

Topsoil: silty sand, dark brown, some roots, gravely (size range: 3mm - 10mm, angular), moisturized

Sandy Silt: brown, trance roots, gravely (size range: 5mm - 40mm, angular to subangular),moisturized

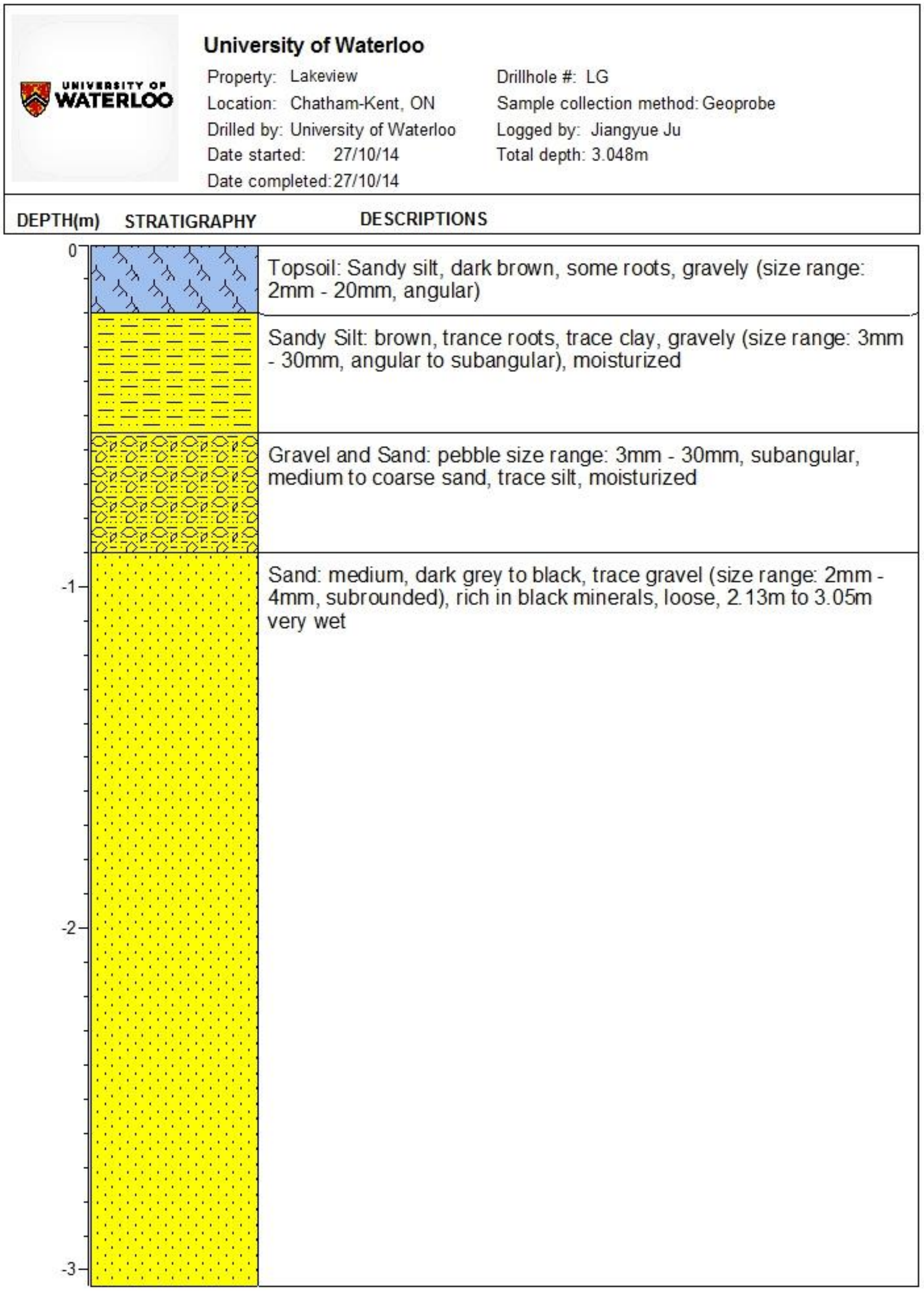
Gravel and Sand: pebble size range: 5mm - 30mm, subangular, medium to coarse sand

Sand: medium to coarse, gery, some gravel (size range: 2mm - 10mm, subrounded), loose

Sand: fine to medium, little grave (size range: 1mm - 8mm, rounded), black minerals, loose

Sand: medium to coarse, trace gravely(1mm - 5mm, subangular), black minerals, loose

Figure A. 9 Stratigraphic log for drill hole LW



University of Waterloo

Property: Lakeview

Location: Chatham-Kent, ON

Drilled by: University of Waterloo

Date started: 27/10/14

Date completed: 27/10/14

Drillhole #: LG

Sample collection method: Geoprobe

Logged by: Jiangyue Ju

Total depth: 3.048m

DEPTH(m)	STRATIGRAPHY	DESCRIPTIONS
0		Topsoil: Sandy silt, dark brown, some roots, gravely (size range: 2mm - 20mm, angular)
		Sandy Silt: brown, trance roots, trace clay, gravely (size range: 3mm - 30mm, angular to subangular), moisturized
		Gravel and Sand: pebble size range: 3mm - 30mm, subangular, medium to coarse sand, trace silt, moisturized
-1		Sand: medium, dark grey to black, trace gravel (size range: 2mm - 4mm, subrounded), rich in black minerals, loose, 2.13m to 3.05m very wet

Figure A. 10 Stratigraphic log for drill hole LG

Table A.10 Background nutrient concentrations in groundwater at Prism Farms and Lakeview sites

	Ontario Drinking Water standard	**PTW141**	**PTW251**	**PCW139**	**PCW249**	**PG220**	**PG598**	**LG248**
Dilution Factor								
pH	6.5–8.5	7.44	7.49	7.62	7.59	7.33	7.26	7.81
EC (mmhos/cm)		0.53	0.59	0.37	0.5	1	1.47	0.45
Nitrate Nitrogen (ppm)	10	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	
Phosphorus (ppm)	N/L	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	0.22
Potassium (ppm)	N/L	2.7	< 1.00	< 1.00	< 1.00	< 1.00	4.73	3.26
Calcium (ppm)	N/L	83.98	76.88	56.12	69.44	143.18	171.05	97.27
Magnesium (ppm)	N/L	14.56	17.93	9.77	14.82	42.7	81.75	7.24
Chloride (ppm)	250							
Sulphates (ppm)	500	108.12	102.97	24.15	62.98	109.95	542.45	12.8
Sodium (ppm)	200	5.67	22.38	6.79	10.38	15.01	57.91	2.4
Zinc (ppm)	5	0.03	0.02	0.02	0.02	0.05	0.04	0.01
Manganese (ppm)	0.05	0.16	0.2	0.1	0.78	0.03	0.08	0
Copper (ppm)	1	< 0.01	< 0.01	< 0.01	< 0.01	0.08	< 0.01	0.01
Iron (ppm)	0.3	0.43	0.03	0.41	0.04	0.04	0.06	0.17
Boron (ppm)	5	0.08	0.14	0.08	0.08	0.07	0.76	0.07
Molybdenum (ppm)	N/L	< 0.01	0.08	< 0.01	0.04	0.02	0.04	0.01
Silicon (ppm)	N/L	5.06	4.97	5.27	6.81	7.22	7.42	3.12

Appendix B

Chemical Analysis on Greenhouse Nutrient Feed Water

Table B. 1 Chemical analysis on greenhouse nutrient feed water applied in fall 2014

Feed water	Ontario Drinking Water standard	Prism GNF	Cecelia GNF
Dilution Factor			
pH	6.5-8.5	6.91	6.88
EC (mmhos/cm)		2.72	0.94
Nitrate Nitrogen (ppm)	10	222	NA
Phosphorus (ppm)	N/L	27.98	16.17
Potassium (ppm)	N/L	235.4	97.52
Calcium (ppm)	N/L	261.31	103.75
Magnesium (ppm)	N/L	47.14	31.69
Chloride (ppm)	250		
Sulphates (ppm)	500	226.08	205.17
Sodium (ppm)	200	56.78	14.34
Zinc (ppm)	5	0.31	0.14
Manganese (ppm)	0.05	1.37	0.05
Copper (ppm)	1	0.16	0.06
Iron (ppm)	0.3	0.37	0.09
Boron (ppm)	5	0.67	0.25
Molybdenum (ppm)	N/L	0.07	0.03
Silicon (ppm)	N/L	6.75	1.8

Table B. 2 Chemical analysis on greenhouse nutrient feed water applied in spring 2015.

Leachate Sampled in July, 2015	Prism	Cecelia	Lakeview	Warkentin
Nitrate Nitrogen (ppm)	381	266	38.3	283
Phosphorus (ppm)	21.8	37.3	8.73	59.3
Potassium (ppm)	189	307	43.7	396
Calcium (ppm)	341	213	88.2	253
Magnesium (ppm)	90.8	45.3	23.8	55.2
Chloride (ppm)	51.8	63.5	20.7	30.1
Sulphates (ppm)	288	221	96.1	248
Sodium (ppm)	81.9	210	11.8	14.1
Zinc (ppm)	0.611	0.136	0.123	0.316
Manganese (ppm)	0.288	0.602	0.0344	0.596
Copper (ppm)	0.116	0.078	0.0826	0.052
Iron (ppm)	1.58	1.37	0.147	1.45
Boron (ppm)	0.85	0.5	0.056	0.35
Molybdenum (ppm)	0.105	0.0594	0.0188	0.0618
Silicon (ppm)	19	<10	5.8	<10
Aluminum (ppm)	<0.1	<0.10	0.046	<0.10
Arsenic (ppm)	<0.01	<0.010	0.0023	<0.010
Cadmium (ppm)	<0.0009	<0.00090	0.000252	<0.00090
Chromium (ppm)	<0.0050	<0.0050	0.00233	<0.0050
Cobalt (ppm)	<0.0050	<0.0050	0.0173	<0.0050
Lead (ppm)	<0.0050	<0.0050	0.00155	<0.0050
Mercury (ppm)	0.000025	<0.000010	<0.000010	<0.000010
Nickel (ppm)	0.039	<0.010	0.0106	<0.010
Selenium (ppm)		<0.0040	<0.00040	<0.0040

Appendix C

Geochemical Analysis Set and Analytical Methods

Table C.1 Water analysis species and analytical methods.

Target Species	Analytical methods
pH	electrode
EC (mmhos/cm)	electrode
Bromide (ppm)	<0.5
Bicarbonate	titration
Nitrate Nitrogen (ppm)	colorimeter
Phosphorus (ppm)	ICP
Potassium (ppm)	ICP
Calcium (ppm)	ICP
Magnesium (ppm)	ICP
Bicarbonate(ppm)	ICP
Chloride (ppm)	specific ion electrode
Sulphates (ppm)	ICP
Sodium (ppm)	ICP
Zinc (ppm)	ICP
Manganese (ppm)	ICP
Copper (ppm)	ICP
Iron (ppm)	ICP
Boron (ppm)	ICP
Molybdenum (ppm)	ICP
Silicon (ppm)	ICP
Aluminum (ppm)	ICP
Arsenic (ppm)	ICP
Cadmium (ppm)	ICP
Chromium (ppm)	ICP
Cobalt (ppm)	ICP
Lead (ppm)	ICP
Mercury (ppm)	ICP
Nickel (ppm)	ICP
Selenium (ppm)	ICP
Heavy metals (MOE package)	MTH-SPEC-6; modified from SM3030B EPA 200.7

Table C.2 Soil sample chemical analytical methods

Target Species	Analytical methods
pH	SMP Buffer
Organic matter	2.1
Bromide (ppm)	58
Phosphorus (ppm)	Olson P method
Potassium (ppm)	Ammonium Acetate extraction/ ICP analysis
Calcium (ppm)	Ammonium Acetate extraction/ ICP analysis
Magnesium (ppm)	Ammonium Acetate extraction/ ICP analysis
Zinc (ppm)	DTPA extraction/ ICP analysis
Manganese (ppm)	Phosphoric acid extraction/ ICP analysis
Copper (ppm)	DTPA extraction/ ICP analysis
Iron (ppm)	DTPA extraction/ ICP analysis
Heavy metals (MOE package)	Microwave extraction/ ICP analysis

Appendix D

Chemical Analysis on Soil and Soil Water Samples in First Year Experiments

*Tables for background nutrient concentrations in soil, soil water are presented in corresponding sections in Appendix A.

Table D.1 Comparison of nutrient concentrations in soil water at Prism Farms experiment plot before and 48 hrs after application

	PT230	PT230*	%increase	**Prism Leachate**
Dilution Factor	3			
pH	7.32	7.67	5%	6.91
EC (mmhos/cm)	0.05	0.12	140%	2.72
Nitrate Nitrogen (ppm)	<0.50			222
Phosphorus (ppm)	<1.00	0.83	-17%	27.98
Potassium (ppm)	<1.00	14.72	1372%	235.4
Calcium (ppm)	<1.00	17.95	1695%	261.31
Magnesium (ppm)	<1.00	5.55	455%	47.14
Sulphates (ppm)	<1.00	8.34	734%	226.08
Sodium (ppm)	4.8	5.72	19%	56.78
Zinc (ppm)	0.03	0.05	67%	0.31
Manganese (ppm)	0.09	0.02	-78%	1.37
Copper (ppm)	<0.01	0.02	100%	0.16
Iron (ppm)	0.06	0.12	100%	0.37
Boron (ppm)	0.06	0.09	50%	0.67
Molybdenum (ppm)	<0.01	0.02	100%	0.07
Silicon (ppm)	39.36	31.77	-19%	6.75
Aluminon	<0.05			

* Collected 48 hours after the application event on December 6.

Table D. 2 Comparison of nutrient concentrations in soil at Prism Farms experiment plot before and 48 hours after application

	PT1	PT 0-15*	PT2	PT 15-30*	PT3	PT 30-45*	PC1	PC 0-15*	PC2	PC 15-30*	PC3
pH	6.8	6.7	6.8	6.7	7.1	6.9	6.9	7	7.1	6.9	7.3
Organic matter	2.4	2.3	2.2	2.3	0.4	0.8	2.4	2.3	1.8	1.7	0.2
Phosphorus (ppm)	29	35	12	17	5	5	27	39	10	13	5
Potassium (ppm)	109	108	56	61	39	45	71	77	51	57	42
Calcium (ppm)	733	807	699	799	363	479	731	852	655	745	333
Magnesium (ppm)	109	109	75	82	60	58	101	115	75	77	62
Zinc (ppm)	1	1.2	0.4	0.6	0	0.2	0.8	1.2	0.1	0.3	0
Manganese (ppm)	14.7	16.8	9.6	13.8	3.2	2	16.9	16	4.4	12.7	3.8
Copper (ppm)	0.4	0.3	0.8	0.3	2	0.2	0.5	0.3	0.9	0.2	1.1
Iron (ppm)	24.5	25.9	23.6	34.2	10.7	14.1	21.6	21	14.6	19.3	7.3
Boron (ppm)	0.46	0.37	0.45	0.36	0.28	0.24	0.47	0.39	0.43	0.34	0.25

* Collected 48 hours after the application event on December 6.

Table D. 3 Comparison of nutrient concentrations in soil water at Cecelia Acres experiment plot before and 48 hrs after application

	CT130	CT130*	%increase	**Cecelia Leachate**
Dilution Factor				
pH	7.95	8.29	4%	6.88
EC (mmhos/cm)	0.77	0.88	14%	0.94
Nitrate Nitrogen (ppm)	31.00			
Phosphorus (ppm)	<1.00	<1.00		16.17
Potassium (ppm)	<1.00	<1.00		97.52
Calcium (ppm)	140.17	161.11	15%	103.75
Magnesium (ppm)	19.28	18.49	-4%	31.69
Sulphates (ppm)	49.71	49.22	-1%	205.17
Sodium (ppm)	4.28	6.39	49%	14.34
Zinc (ppm)	0.06	0.02	-67%	0.14
Manganese (ppm)	0.01	0.01	0%	0.05
Copper (ppm)	<0.01	0.04	300%	0.06
Iron (ppm)	<0.01	0.01	0%	0.09
Boron (ppm)	0.08	0.11	38%	0.25
Molybdenum (ppm)	<0.01	0.01	0%	0.03
Silicon (ppm)	24.82	33.1	33%	1.8
Aluminon	<0.05			

Collected 48 hours after the application event on December 7.

Table D. 4 Comparison of nutrient concentrations in soil water at Cecelia Acres experiment plot before and 48 hours after application

	CT1	CT 0-5*	CT 5-15*	CT2	CT 15-30*	CT3	CC1	CC 0-15*	CC2	CC 15-30*	CC3
pH	7.7	7.5	7.5	7.9	7.6	8.1	7.8	7.7	8	7.7	8.2
Organic matter	1.6	2.1	1.7	1	1	0.4	1.6	2.1	0.8	1	0
Phosphorus (ppm)	39	62	42	20	26	6	37	40	16	20	5
Potassium (ppm)	59	78	60	31	47	16	57	66	31	51	22
Calcium (ppm)	2367	2477	2509	2444	2872	3674	2308	4128	3307	3555	3554
Magnesium (ppm)	131	143	126	116	113	107	126	132	91	114	81
Zinc (ppm)	1.4	1.6	1.7	0.7	2.1	0.1	1.3	1.4	0.6	1	0
Manganese (ppm)	12.7	17.4	15.9	9	16.9	11	12.8	17.7	10.5	17.7	11.4
Copper (ppm)	1.9	2	2.2	1.5	1.5	0.7	1.8	1.7	1.1	1.4	0.5
Iron (ppm)	31.1	33.4	35.3	23.5	29.1	24	19.6	36.2	13.5	21.7	7.1
Boron (ppm)	0.65	0.52	0.58	0.56	0.4	0.35	0.55	0.39	0.37	0.35	0.22

*Collected 48 hours after the application event on December 7.

Table D. 5 Comparison of nutrient concentrations in soil water at Prism Farms application plot before and 5 months after application

Target Species	PT230	PT 230*	PT 260	PT360	PT 160*	PT 360*	PT 190	PT 390	PT 290*	PT 390*
pH	7.32	7.87	7.68	7.01	7.72	7.59	7.6	7.33	7.43	7.51
EC (mmhos/cm)	0.05	0.26	0.18	0.1	0.16	0.19	0.18	0.17	0.23	0.26
Nitrate Nitrogen (ppm)	<0.50	3	2	<0.50	3	2	3	<0.50	1	1
Phosphorus (ppm)	<1.00	0.22	0.19	<1.00	0.42	0.32	0.39	<1.00	0.25	0.21
Potassium (ppm)	<1.00	10.36	7.16	<1.00	6.51	6.71	6.4	<1.00	6.4	3.92
Calcium (ppm)	<1.00	15.44	17.18	4.18	26.055	21.84	19.95	17.35	25.07	34.98
Magnesium (ppm)	<1.00	3.8	6.07	5.78	9.54	5.19	6.14	7.4	8.18	6.68
Chloride (ppm)		16	12		19.5	13	9		14	12
Sulphates (ppm)	<1.00	36.21	18.26	3.57	28.53	18.41	20.82	21.55	33.13	58.86
Sodium (ppm)	4.8	28.37	4.31	<1.00	5.475	5.66	5.19	1.25	4.49	5.74
Zinc (ppm)	0.03	0.04	0.05	0.03	0.06	0.02	0.02	0.04	0.03	0.03
Manganese (ppm)	0.09	<1.00	<1.00	0.03	<1.00	<1.00	<1.00	0.02	<1.00	<1.00
Copper (ppm)	<0.01	0.01	<1.00	<0.01	<1.00	<1.00	<1.00	<0.01	<1.00	<1.00
Iron (ppm)	0.06	0.22	0.01	0.03	0.06	0.01	<1.00	0.07	<1.00	0.01
Boron (ppm)	0.06	0.05	0.07	0.06	0.075	0.07	0.07	0.07	0.08	0.07
Molybdenum (ppm)	<0.01	0.01	0.04	<0.01	0.015	0.02	0.01	0.02	0.02	0.02
Silicon (ppm)	39.36	24.2	29.3	14.23	45.525	18.65	29.77	15.2	21.48	12.67
Total Dissolved Solids (ppm)		166.4	115.2		102.4	121.6	115.2		147.2	166.4
Total Hardness (ppm)		54.65	67.96		69.67	75.96	75.13		96.32	114.89

*Collected 5 months after the application event on May 6, 2015.

Table D. 6 Comparison of nutrient concentrations in soil water at Prism Farms control plot before and 5 months after application

Target Species	PC 130	PC 130*	PC 360	PC 160*	PC 190	PC 290*
pH	7.33	7.79	7.48	7.68	7.56	7.6
EC (mmhos/cm)	0.07	0.05	0.12	0.18	0.17	0.18
Nitrate Nitrogen (ppm)	<0.50	6	<0.50	2	<0.50	3
Phosphorus (ppm)	<1.00	2.28	<1.00	0.19	<1.00	0.39
Potassium (ppm)	<1.00	20.16	<1.00	7.16	<1.00	6.4
Calcium (ppm)	9.09	17.46	9.2	17.18	15.62	19.95
Magnesium (ppm)	<1.00		3.99	6.07	7.73	6.14
Chloride (ppm)		24		12		9
Sulphates (ppm)	22.68	81.36	4.88	18.26	6.29	20.82
Sodium (ppm)	<1.00	27.24	3.57	4.31	3.91	5.19
Zinc (ppm)	0.06	0.06	0.04	0.05	0.05	0.02
Manganese (ppm)	<0.01	<1.00	<0.01	<1.00	0.05	<1.00
Copper (ppm)	<0.01	<1.00	<0.01	<1.00	<0.01	<1.00
Iron (ppm)	<0.01	0.36	<0.01	0.01	<0.01	<1.00
Boron (ppm)	0.06	0.06	0.05	0.07	0.07	0.07
Molybdenum (ppm)	<0.01	0.06	<0.01	0.04	<0.01	0.01
Silicon (ppm)	41.73	31.44	18.44	29.3	29.28	29.77
Total Dissolved Solids(ppm)		192		115. 2		115. 2
Total Hardness(ppm)		44. 46		67. 96		75. 13

*Collected 5 months after the application event on May 6, 2015.

Table D. 7 Comparison of nutrient concentrations in soil water at Cecelia Acres application plot before and 5 months after application

Target Species	CT160	CT 160*	CT 260*	CT290	CT 190*	CT 290*
pH	7.79	8.19	8.03	7.88	8.13	8.02
EC (mmhos/cm)	0.88	1	1.11	10.2	0.79	1.06
Nitrate Nitrogen (ppm)	17.00	27.6	36	17.00	13	20
Phosphorus (ppm)	<1.00	0.3	0.34	<1.00	0.19	0.32
Potassium (ppm)	<1.00	3.66	4.24	<1.00	3.08	2.92
Calcium (ppm)	159.73	240.744	217.32	207.87	144.4	204.65
Magnesium (ppm)	28.56	24.756	23.36	33.46	22.44	29.34
Chloride (ppm)		72	43		32	40
Sulphates (ppm)	52.99	80.712	59.03	81.58	95.68	82.55
Sodium (ppm)	3.53	7.656	6.05	6.57	6.9	7.85
Zinc (ppm)	0.06	0.072	0.06	0.07	0.05	0.06
Manganese (ppm)	0.01	<1.00	<1.00	0.04	<1.00	<1.00
Copper (ppm)	<0.01	<1.00	<1.00	<0.01	<1.00	<1.00
Iron (ppm)	<0.01	<1.00	<1.00	0.02	<1.00	<1.00
Boron (ppm)	0.09	0.24	0.19	0.18	0.11	0.19
Molybdenum (ppm)	<0.01	0.024	0.02	<0.01	0.01	0.02
Silicon (ppm)	40.3	32.592	23.73	33.33	19.7	28.23
Total Dissolved Solids(ppm)	646.4	768	710.4		505.6	678.4
Total Hardness(ppm)	559.72	703.128	638.89		453.01	631.87

*Collected 5 months after the application event on May 7, 2015.

Table D. 8 Comparison of nutrient concentrations in soil water at Cecelia Acres control plot before and 5 months after application

Target Species	CC230	CC130*	CC160	CC260	CC 260*	CC 360*	CC 190	CC 290	CC 290*	CC 390*
pH	7.46	8.19	7.91	7.77	8.04	7.96	7.85	7.82	7.86	8.04
EC (mmhos/cm)	0.12	1.01	0.75	0.8	0.95	1.33	1.34	1.02	1.25	1.14
Nitrate Nitrogen (ppm)	15.00	35	18.00	17.00	28	33	8.00	13.00	16	28
Phosphorus (ppm)	<1.00	0.26	<1.00	<1.00	0.24	0.17	<1.00	<1.00	0.19	0.36
Potassium (ppm)	<1.00	4.01	<1.00	<1.00	3.38	3.03	<1.00	<1.00	2.9	3.03
Calcium (ppm)	36.75	190.4	135.93	143.17	180.33	268.34	278.78	196.43	242.96	229.61
Magnesium (ppm)	14.6	20.45	23.6	24.38	21.22	30.14	43.44	34.46	34.34	30.41
Chloride (ppm)		66			56	70			61	53
Sulphates (ppm)	63.25	60.99	45.48	59.18	49.38	69.82	338.89	112.92	182.27	74.54
Sodium (ppm)	26.35	10.38	4.34	4.33	5.78	8.39	9.75	6.97	11.25	6.84
Zinc (ppm)	0.05	0.08	0.05	0.06	0.07	0.07	0.07	0.08	0.08	0.07
Manganese (ppm)	<0.01	<1.00	0.02	0.01	<1.00	<1.00	0.02	0.01	<1.00	<1.00
Copper (ppm)	<0.01	<1.00	<0.01	<0.01	<1.00	<1.00	<0.01	<0.01	<1.00	<1.00
Iron (ppm)	0.05	<1.00	<0.01	0.01	<1.00	<1.00	0.02	<0.01	<1.00	<1.00
Boron (ppm)	<0.01	0.11	0.07	0.07	0.14	0.29	0.17	0.19	0.25	0.21
Molybdenum (ppm)	<0.01	<1.00	<0.01	<0.01	0.02	0.02	<0.01	<0.01	0.01	0.01
Silicon (ppm)	37.8	30	31.77	36.45	26.71	20.73	38.31	42.08	27.63	23.68
Total Dissolved Solids (ppm)		646.4			608	851.2			800	729.6
Total Hardness (ppm)		559.72			537.74	794.2			748.12	698.64

*Collected 5 months after the application event on May 7, 2015.

Table D. 9 Comparison of nutrient concentrations in soil samples between application plot and control plot at Prism Farms 5 months after application

	PC 0-10cm	PC 10-20cm	PC 20-30cm	PC 30-40cm	PC 40-50cm	PC 50-60cm	PC 60-70cm	PC 70-80cm	PC 80-90cm
pH	6.7	6.6	6.9	6.9	7	7	7	7.1	7.3
Organic matter	2.5	1.9	1.5	0.3	0.1	0.1	0.1	0.1	0.1
Phosphorus (ppm)	44	21	6	4	6	4	5	6	5
Potassium (ppm)	155	120	85	38	26	34	51	41	31
Calcium (ppm)	799	802	883	372	196	429	734	728	588
Magnesium (ppm)	117	94	80	41	30	90	160	129	93
Zinc (ppm)	1.3	0.6	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Manganese (ppm)	23.8	6.4	1.5	0.5	0.7	1	1.1	1.5	3
Copper (ppm)	0.3	0.3	0.2	0.2	0.1	0.2	0.3	0.5	0.7
Iron (ppm)	22.5	23.5	18.3	12.9	8.3	8.6	8.7	7.7	6.6
Boron (ppm)	0.37	0.32	0.31	0.23	0.11	0.1	0.14	0.12	0.1
	PT 0-10cm	PT 10-20cm	PT 20-30cm	PT 30-40cm	PT 40-50cm	PT 50-60cm	PT 60-70cm	PT 70-80cm	PT 80-90cm
pH	6.9	6.5	6.7	6.8	7	7	7	7	7.1
Organic matter	2.5	2.3	2.3	1.7	0.5	0.1	0.1	0.1	0.1
Phosphorus (ppm)	41	26	15	6	5	4	3	3	4
Potassium (ppm)	135	89	58	49	30	36	33	42	37
Calcium (ppm)	937	855	979	757	390	388	457	624	631
Magnesium (ppm)	125	100	91	71	44	64	86	122	107
Zinc (ppm)	1.5	0.8	0.4	0.1	0.1	0.1	0.1	0.2	0.2
Manganese (ppm)	24.1	13.2	5.8	1.8	1	1.9	2.7	3.6	3.7
Copper (ppm)	0.3	0.4	0.3	0.2	0.1	0.1	0.2	0.4	0.5
Iron (ppm)	27.5	30.3	32.1	23.7	15.3	14.3	11.4	10.9	9.6
Boron (ppm)	0.42	0.39	0.43	0.32	0.2	0.16	0.14	0.15	0.15

Table D. 10 Comparison of nutrient concentrations in soil samples between application plot and control plot at Cecelia 5 months after application

	CC 0-10cm	CC 10-20cm	CC 20-30cm	CC 30-40cm	CC 40-50cm	CC 50-60cm	CC 60-70cm	CC 70-80cm	CC 80-90cm
pH	7.8	7.8	8	8	8.1	8	8.1	8.1	8.1
Organic matter	1.5	1.3	1.1	0.1	0.1	0.3	0.3	0.5	0.5
Phosphorus (ppm)	48	46	32	4	3	3	3	2	2
Potassium (ppm)	61	47	39	27	28	28	29	43	29
Calcium (ppm)	2925	3120	3870	4198	4107	4262	4200	4561	4236
Magnesium (ppm)	133	115	106	81	82	94	98	145	117
Zinc (ppm)	1.9	2.1	1.4	0.3	0.3	0.2	0.3	0.3	0.3
Manganese (ppm)	18.3	15.6	13.7	9.4	11.4	10.4	12.6	13.8	16.5
Copper (ppm)	2.3	2.4	1.8	0.4	0.4	0.4	0.3	0.4	0.2
Iron (ppm)	26.1	25.7	20.8	8.1	8.8	8.6	8.5	11.8	12.1
Boron (ppm)	0.52	0.58	0.42	0.15	0.16	0.19	0.2	0.27	0.21
	CT 0-10cm	CT 10-20cm	CT 20-30cm	CT 30-40cm	CT 40-50cm	CT 50-60cm	CT 60-70cm	CT 70-80cm	CT 80-90cm
pH	7.6	7.8	7.8	7.9	7.9	7.9	8	8	8
Organic matter	1.7	1.5	0.9	0.9	0.9	0.3	0.3	0.5	0.5
Phosphorus (ppm)	58	39	12	6	5	10	6	8	4
Potassium (ppm)	71	49	34	30	26	20	22	25	25
Calcium (ppm)	2715	2863	3295	3269	3862	4203	4307	4240	4263
Magnesium (ppm)	148	119	119	122	117	97	99	103	101
Zinc (ppm)	1.8	1.8	0.6	0.3	0.3	0.3	0.3	0.3	0.3
Manganese (ppm)	20.9	13.6	12.2	11.1	11.2	10.6	13.5	13.6	15.5
Copper (ppm)	0.2	2.3	1.1	0.8	0.7	0.4	0.4	0.5	0.4
Iron (ppm)	34.1	34.4	22.1	21.4	23.6	14.7	14	15.7	11.2
Boron (ppm)	0.55	0.53	0.38	0.38	0.38	0.29	0.26	0.28	0.23

Appendix E

Chemical Analysis on Soil and Soil Water Samples in Second Year Experiments

Table E. 1 Concentrations of target species in soil water from control and application plots at Prism Farms in May, 2015 as background.

Target Species	PC 130	PT 230	PC 160	PT 160	PT 360	PC 290	PT 290	PT 390
pH	7.79	7.87	7.68	7.72	7.59	7.6	7.43	7.51
EC (mmhos/cm)	0.05	0.26	0.18	0.16	0.19	0.18	0.23	0.26
Nitrate Nitrogen (ppm)	6	3	2	3	2	3	1	1
Phosphorus (ppm)	2.28	0.22	0.19	0.42	0.32	0.39	0.25	0.21
Potassium (ppm)	20.16	10.36	7.16	6.51	6.71	6.4	6.4	3.92
Calcium (ppm)	17.46	15.44	17.18	26.055	21.84	19.95	25.07	34.98
Magnesium (ppm)		3.8	6.07	9.54	5.19	6.14	8.18	6.68
Chloride (ppm)	24	16	12	19.5	13	9	14	12
Sulphates (ppm)	81.36	36.21	18.26	28.53	18.41	20.82	33.13	58.86
Sodium (ppm)	27.24	28.37	4.31	5.475	5.66	5.19	4.49	5.74
Zinc (ppm)	0.06	0.04	0.05	0.06	0.02	0.02	0.03	0.03
Manganese (ppm)	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Copper (ppm)	<1.00	0.01	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Iron (ppm)	0.36	0.22	0.01	0.06	0.01	<1.00	<1.00	0.01
Boron (ppm)	0.06	0.05	0.07	0.075	0.07	0.07	0.08	0.07
Molybdenum (ppm)	0.06	0.01	0.04	0.015	0.02	0.01	0.02	0.02
Silicon (ppm)	31.44	24.2	29.3	45.525	18.65	29.77	21.48	12.67
Total Dissolved Solids(ppm)	192	166.4	115.2	102.4	121.6	115.2	147.2	166.4
Total Hardness(ppm)	44.46	54.65	67.96	69.67	75.96	75.13	96.32	114.89

Table E. 2 Concentrations of target species in soil water between control and application plots at Cecelia Acres in May, 2015 as background.

Target Species	CC130	CC 260	CC 360	CC 160	CC 260	CC 290	CC 190	CC 290
pH	8.19	8.04	7.96	8.19	8.03	7.86	8.13	8.02
EC (mmhos/cm)	1.01	0.95	1.33	1	1.11	1.25	0.79	1.06
Nitrate Nitrogen (ppm)	35	28	33	27.6	36	16	13	20
Phosphorus (ppm)	0.26	0.24	0.17	0.3	0.34	0.19	0.19	0.32
Potassium (ppm)	4.01	3.38	3.03	3.66	4.24	2.9	3.08	2.92
Calcium (ppm)	190.4	180.33	268.34	240.744	217.32	242.96	144.4	204.65
Magnesium (ppm)	20.45	21.22	30.14	24.756	23.36	34.34	22.44	29.34
Chloride (ppm)	66	56	70	72	43	61	32	40
Sulphates (ppm)	60.99	49.38	69.82	80.712	59.03	182.27	95.68	82.55
Sodium (ppm)	10.38	5.78	8.39	7.656	6.05	11.25	6.9	7.85
Zinc (ppm)	0.08	0.07	0.07	0.072	0.06	0.08	0.05	0.06
Manganese (ppm)	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Copper (ppm)	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Iron (ppm)	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Boron (ppm)	0.11	0.14	0.29	0.24	0.19	0.25	0.11	0.19
Molybdenum (ppm)	<1.00	0.02	0.02	0.024	0.02	0.01	0.01	0.02
Silicon (ppm)	30	26.71	20.73	32.592	23.73	27.63	19.7	28.23
Total Dissolved Solids(ppm)	646.4	608	851.2	768	710.4	800	505.6	678.4
Total Hardness(ppm)	559.72	537.74	794.2	703.128	638.89	748.12	453.01	631.87

Table E. 3 Concentrations of target species in soil samples between control and application plots at Prism Farms in May, 2015 as background.

	PC 0-10cm	PC 10-20cm	PC 20-30cm	PC 30-40cm	PC 40-50cm	PC 50-60cm	PC 60-70cm	PC 70-80cm	PC 80-90cm
pH	6.7	6.6	6.9	6.9	7	7	7	7.1	7.3
Organic matter	2.5	1.9	1.5	0.3	0.1	0.1	0.1	0.1	0.1
Phosphorus (ppm)	44	21	6	4	6	4	5	6	5
Potassium (ppm)	155	120	85	38	26	34	51	41	31
Calcium (ppm)	799	802	883	372	196	429	734	728	588
Magnesium (ppm)	117	94	80	41	30	90	160	129	93
Zinc (ppm)	1.3	0.6	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Manganese (ppm)	23.8	6.4	1.5	0.5	0.7	1	1.1	1.5	3
Copper (ppm)	0.3	0.3	0.2	0.2	0.1	0.2	0.3	0.5	0.7
Iron (ppm)	22.5	23.5	18.3	12.9	8.3	8.6	8.7	7.7	6.6
Boron (ppm)	0.37	0.32	0.31	0.23	0.11	0.1	0.14	0.12	0.1
	PT 0-10cm	PT 10-20cm	PT 20-30cm	PT 30-40cm	PT 40-50cm	PT 50-60cm	PT 60-70cm	PT 70-80cm	PT 80-90cm
pH	6.9	6.5	6.7	6.8	7	7	7	7	7.1
Organic matter	2.5	2.3	2.3	1.7	0.5	0.1	0.1	0.1	0.1
Phosphorus (ppm)	41	26	15	6	5	4	3	3	4
Potassium (ppm)	135	89	58	49	30	36	33	42	37
Calcium (ppm)	937	855	979	757	390	388	457	624	631
Magnesium (ppm)	125	100	91	71	44	64	86	122	107
Zinc (ppm)	1.5	0.8	0.4	0.1	0.1	0.1	0.1	0.2	0.2
Manganese (ppm)	24.1	13.2	5.8	1.8	1	1.9	2.7	3.6	3.7
Copper (ppm)	0.3	0.4	0.3	0.2	0.1	0.1	0.2	0.4	0.5
Iron (ppm)	27.5	30.3	32.1	23.7	15.3	14.3	11.4	10.9	9.6
Boron (ppm)	0.42	0.39	0.43	0.32	0.2	0.16	0.14	0.15	0.15

Table E. 4 Concentrations of target species in soil samples between control and application plots at Cecelia Acres in May, 2015 as background.

	CC 0-10cm	CC 10-20cm	CC 20-30cm	CC 30-40cm	CC 40-50cm	CC 50-60cm	CC 60-70cm	CC 70-80cm	CC 80-90cm
pH	7.8	7.8	8	8	8.1	8	8.1	8.1	8.1
Organic matter	1.5	1.3	1.1	0.1	0.1	0.3	0.3	0.5	0.5
Phosphorus (ppm)	48	46	32	4	3	3	3	2	2
Potassium (ppm)	61	47	39	27	28	28	29	43	29
Calcium (ppm)	2925	3120	3870	4198	4107	4262	4200	4561	4236
Magnesium (ppm)	133	115	106	81	82	94	98	145	117
Zinc (ppm)	1.9	2.1	1.4	0.3	0.3	0.2	0.3	0.3	0.3
Manganese (ppm)	18.3	15.6	13.7	9.4	11.4	10.4	12.6	13.8	16.5
Copper (ppm)	2.3	2.4	1.8	0.4	0.4	0.4	0.3	0.4	0.2
Iron (ppm)	26.1	25.7	20.8	8.1	8.8	8.6	8.5	11.8	12.1
Boron (ppm)	0.52	0.58	0.42	0.15	0.16	0.19	0.2	0.27	0.21
	CT 0-10cm	CT 10-20cm	CT 20-30cm	CT 30-40cm	CT 40-50cm	CT 50-60cm	CT 60-70cm	CT 70-80cm	CT 80-90cm
pH	7.6	7.8	7.8	7.9	7.9	7.9	8	8	8
Organic matter	1.7	1.5	0.9	0.9	0.9	0.3	0.3	0.5	0.5
Phosphorus (ppm)	58	39	12	6	5	10	6	8	4
Potassium (ppm)	71	49	34	30	26	20	22	25	25
Calcium (ppm)	2715	2863	3295	3269	3862	4203	4307	4240	4263
Magnesium (ppm)	148	119	119	122	117	97	99	103	101
Zinc (ppm)	1.8	1.8	0.6	0.3	0.3	0.3	0.3	0.3	0.3
Manganese (ppm)	20.9	13.6	12.2	11.1	11.2	10.6	13.5	13.6	15.5
Copper (ppm)	0.2	2.3	1.1	0.8	0.7	0.4	0.4	0.5	0.4
Iron (ppm)	34.1	34.4	22.1	21.4	23.6	14.7	14	15.7	11.2
Boron (ppm)	0.55	0.53	0.38	0.38	0.38	0.29	0.26	0.28	0.23

Table E. 5 Concentrations of target species in soil water between control and application plots at Warkentin Orchards in July, 2015 as background.

Target Species	WC230	WT130	WC260	WC190	WC290	WT290
pH	8.47	8.50	7.80	8.09	8.47	7.90
Bromide (ppm)	< 3	< 3	< 3	< 3	< 3	< 3
Nitrate Nitrogen (ppm)	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
Phosphorus (ppm)	0.19	0.33	0.05	< 0.03	0.05	0.39
Potassium (ppm)	1.45	10.7	0.71	0.26	0.31	0.58
Calcium (ppm)	98.7	63.2	95.5	71.9	121	109
Magnesium (ppm)	38.3	33.4	38.9	27.9	47.1	49.4
Chloride (ppm)	28	21	32	23	86	47
Sulphates (ppm)	180	83	190	75	150	120
Sodium (ppm)	24.3	11.6	13.4	7.2	8.2	9.5
Zinc (ppm)	<0.02	< 0.02	< 0.02	<0.02	0.07	0.10
Manganese (ppm)	0.528	0.0104	0.0857	0.0576	0.0544	0.0748
Copper (ppm)	0.0079	0.0086	0.0035	0.0070	0.0096	0.0282
Iron (ppm)	< 0.07	< 0.07	< 0.07	< 0.07	< 0.07	< 0.07
Boron (ppm)	0.269	0.490	0.163	0.096	0.109	0.130
Molybdenum (ppm)	0.0171	0.0164	0.0050	0.0048	0.0065	0.0114
Total Dissolved Solids(ppm)	607	525	650	434	731	757

Table E. 6 Concentrations of target species in soil water between control and application plots at Lakeview Greenhouses in July, 2015 as background.

Target Species	LC130	LT130	LC260	LT260	LC290	LT190
pH	8.04	8.15	8.13	7.97	8.56	8.41
Bromide (ppm)	< 3	< 3	< 3	< 3	< 3	< 3
Nitrate Nitrogen (ppm)	34.5	13.9	19.9	24.1	25.3	25.2
Phosphorus (ppm)	0.11	0.08	0.09	< 0.03	0.06	0.12
Potassium (ppm)	3.68	7.92	2.29	7.40	0.72	2.55
Calcium (ppm)	47.7	29.7	42.7	38.9	103	74.8
Magnesium (ppm)	31.4	26.6	16.6	15.8	23.3	23.1
Chloride (ppm)	7.8	14	2.2	7.5	3.7	6.9
Sulphates (ppm)	38	40	23	33	12	16
Sodium (ppm)	25.5	15.0	5.5	15.9	4.2	6.9
Zinc (ppm)	0.06	< 0.02	0.13	0.06	0.05	0.03
Manganese (ppm)	0.0142	0.0165	0.0112	0.0082	0.0131	0.0036
Copper (ppm)	0.0072	0.0052	0.0039	0.0028	0.0031	0.0021
Iron (ppm)	< 0.07	< 0.07	< 0.07	< 0.07	< 0.07	< 0.07
Boron (ppm)	0.109	0.104	0.066	0.070	0.075	0.068
Molybdenum (ppm)	0.0051	0.0050	0.0026	0.0025	0.0058	0.0071
Total Dissolved Solids(ppm)	471	360	360	352	500	438

Table E. 7 Concentrations of target species in soil samples between control and application plots at Warkentin Orchards in July, 2015 as background.

	WC 0-10	WC 10-20	WC 20-30	WC 30-40	WC 40-50	WC 50-60	WC 60-70	WC 70-80	WC 80-90
pH	7.54	7.24	6.95	7.03	7.23	7.33	7.47	7.53	7.53
Organic matter	4.2	2.9	2.9	2.1	1.3	0.9	0.7	0.7	0.5
Phosphorus (ppm)	81.26	29.66	19.49	8.42	2.65	1.85	1.24	1.26	0.97
Potassium (ppm)	274.34	156.1	98.52	85.2	72.41	65.6	60.74	60.63	58.37
Calcium (ppm)	3089.07	2068.07	2191.94	2234.24	2001.65	1690.13	1581.88	1734.36	1739.62
Magnesium (ppm)	223	262.82	297.08	320.66	290.1	259.4	251.02	270.11	278.84
Zinc (ppm)	5.97	2.12	0.76	0.96	0.41	0.31	0.21	0.25	0.17
Manganese (ppm)	32.1	9.3	3.5	4	2.9	2.7	3.6	4.2	3.3
Copper (ppm)	2.18	1.88	1.85	1.01	0.83	0.77	0.67	0.74	0.75
Iron (ppm)	61.11	68.78	82.41	48.09	26.1	19.05	10.22	11.62	6.49
Boron (ppm)	1.18	0.89	0.86	0.67	0.42	0.27	0.23	0.19	0.16
	WT 0-10	**WT 10-20**	**WT 20-30**	**WT 30-40**	**WT 40-50**	**WT 50-60**	**WT 60-70**	**WT 70-80**	**WT 80-90**
pH	7.25	7.11	6.95	6.94	6.98	7.1	7.51	7.45	7.42
Organic matter	4	2.7	2.7	1.9	1.7	1.3	0.9	0.9	0.9
Phosphorus (ppm)	71.85	32.23	13.62	6.95	3.99	3.55	4.23	3.28	3.36
Potassium (ppm)	279.07	120.32	103.71	89.68	82.85	87.1	74.79	76.1	82.91
Calcium (ppm)	2370.09	1812.48	2436.42	2512.96	2258.86	2270.74	3818.72	2556.59	2643.25
Magnesium (ppm)	239.71	256.21	351.68	380.08	334.23	348.77	319.84	358.1	422.59
Zinc (ppm)	6.99	3.04	0.83	0.7	0.49	0.39	0.32	0.43	0.3
Manganese (ppm)	32.5	7.1	3.7	3.8	3.5	4	10.2	7.8	7.2
Copper (ppm)	2.06	1.89	1.56	1.05	1.06	1.05	0.83	0.96	0.96
Iron (ppm)	48.98	65.07	61.15	35.03	30.68	23.88	14.5	12.04	10.61
Boron (ppm)	1.12	1	0.87	0.65	0.53	0.42	0.33	0.3	0.26

Table E. 8 Concentrations of target species in soil samples between control and application plots at Lakeview Greenhouses in July, 2015 as background.

	LC 0-10	LC 10-20	LC 20-30	LC 30-40	LC 40-50	LC 50-60	LC 60-70	LC 70-80	LC 80-90
pH	6.49	6.11	6.08	6.16	6.21	6.32	6.5	6.7	7.55
Organic matter	2.5	2.3	1.9	1.3	1.3	1.3	1.3	1.1	1.3
Phosphorus (ppm)	43.96	45.87	34.36	8.98	7.59	7.18	9.16	8.46	4.28
Potassium (ppm)	182.93	132.59	103.91	77.12	71.78	82.23	71.17	74.36	61.89
Calcium (ppm)	1996.95	1163.29	1209.25	1246.72	1238.7	1553.72	1542.9	1617.64	2123.16
Magnesium (ppm)	149.85	179.94	217.6	217.63	199.25	193.06	147.2	125.42	93.22
Zinc (ppm)	1.38	1.44	0.83	0.35	0.41	0.55	0.45	0.43	0.45
Manganese (ppm)	31	19.8	14.9	11.5	12	12.8	9.3	7.7	14.5
Copper (ppm)	1.16	1.3	1.6	5.22	3.55	4.62	3.2	2.43	2.36
Iron (ppm)	38.72	41.26	35.71	26.26	29.07	30.42	25.57	18.8	14.32
Boron (ppm)	0.2	0.21	0.24	0.19	0.19	0.18	0.18	0.17	0.17
	LT 0-10	**LT 10-20**	**LT 20-30**	**LT 30-40**	**LT 40-50**	**LT 50-60**	**LT 60-70**	**LT 70-80**	**LT 80-90**
pH	5.95	5.37	5.4	5.55	5.56	5.61	6.11	6.28	6.58
Organic matter	2.5	2.1	1.9	1.5	1.3	1.1	1.3	1.3	1.7
Phosphorus (ppm)	44.72	55.25	58.44	21.35	9.97	10.08	10.54	7.62	5.62
Potassium (ppm)	261.71	172.67	137.16	113.89	119.84	102.14	101.23	104.73	84.09
Calcium (ppm)	1194.64	790.61	778.7	1003.75	1493.57	1507.9	2080.46	2164.78	2080.22
Magnesium (ppm)	139.48	128.29	141.14	184.98	186.41	161.3	153.73	139.38	118.92
Zinc (ppm)	1.61	1.44	1.32	0.64	0.38	0.37	0.44	0.44	0.43
Manganese (ppm)	21.9	15.3	13	9.9	6.2	5.5	6.7	5.9	6.6
Copper (ppm)	1.08	1.15	1.16	1.89	2.52	2.26	2.37	2.52	2.28
Iron (ppm)	45.25	52.34	48.02	37.44	35.31	32.8	24.29	21.18	16.51
Boron (ppm)	0.26	0.25	0.36	0.2	0.21	0.19	0.19	0.22	0.22

Table E. 9 Concentrations of target species in soil water collected 48 hours after application at Prism Farms.

Target Species	PC230	PT330	PC360	PT360
pH	8.31	8.05	8.20	8.28
Bromide (ppm)	< 3	710	< 3	< 3
Nitrate Nitrogen (ppm)	< 0.6	9.67	< 0.6	< 0.6
Phosphorus (ppm)	< 0.03	< 0.03	< 0.03	< 0.03
Potassium (ppm)	5.18	18.4	4.92	6.17
Calcium (ppm)	31.0	61.1	28.3	28.0
Magnesium (ppm)	9.20	17.1	8.82	6.68
Chloride (ppm)	< 2	5.2	< 2	< 2
Sulphates (ppm)	7.4	13	4.8	10
Sodium (ppm)	10.3	166	7.0	10.8
Zinc (ppm)	0.04	0.05	0.05	0.02
Manganese (ppm)	0.0013	0.0052	0.0013	0.0012
Copper (ppm)	0.0045	0.0056	0.0033	0.0027
Iron (ppm)	< 0.07	< 0.07	0.07	< 0.07
Boron (ppm)	0.107	0.079	0.099	0.115
Molybdenum (ppm)	0.0029	0.0042	0.0028	0.0026
Total Dissolved Solids (ppm)	1210	121	185	222

Table E. 10 Concentrations of target species in soil water collected 48 hours after application at Cecelia Acres.

Target Species	CC230	CC330	CT230	CT330	CC160	CC260	CT360
pH	8.24	8.18	8.17	8.35	8.07	8.11	8.07
Bromide (ppm)	< 3	< 3	550	18	< 3	< 3	< 3
Nitrate Nitrogen (ppm)	9.55	2.23	9.16	11.1	12.3	12.3	17.5
Phosphorus (ppm)	0.08	< 0.03	0.08	< 0.03	< 0.03	0.04	< 0.03
Potassium (ppm)	1.16	3.79	1.67	0.75	1.19	1.24	0.41
Calcium (ppm)	172	162	281	137	136	166	183
Magnesium (ppm)	22.9	22.6	33.0	28.0	24.5	23.9	31.2
Chloride (ppm)	60	68	53	59	44	48	58
Sulphates (ppm)	54	39	50	50	48	47	61
Sodium (ppm)	5.9	8.6	20.6	7.0	6.2	6.4	8.7
Zinc (ppm)	< 0.02	0.05	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Manganese (ppm)	0.0005	0.0060	0.0030	0.0003	0.0004	0.0007	0.0004
Copper (ppm)	0.0052	0.0046	0.0064	0.0063	0.0032	0.0032	0.0041
Iron (ppm)	< 0.07	< 0.07	< 0.07	< 0.07	< 0.07	< 0.07	< 0.07
Boron (ppm)	0.189	0.244	0.363	0.366	0.213	0.219	0.443
Molybdenum (ppm)	0.0028	0.0046	0.0053	0.0071	0.0049	0.0051	0.0033
Total Dissolved Solids (ppm)	731	311	1466	603	494	457	569

Table E. 11 Concentrations of target species in soil water collected 48 hours after application at Warkentin Orchards.

Target Species	WC230	WT230	WT330	WT130	WC260	WT360	WC190	WC290	WT190	WT390
pH	8.47	8.12	8.07	7.98	7.80	8.21	8.09	8.47	8.09	8.25
Bromide (ppm)	< 3	4400	3800	2000	< 3	3400	< 3	< 3	2700	14.7
Nitrate Nitrogen (ppm)	< 0.6	48.3	69.5	35.9	< 0.6	42.5	< 0.6	< 0.6	16.5	< 0.6
Phosphorus (ppm)	0.19	0.31	0.37	0.42	0.05	0.04	< 0.03	0.05	0.03	0.12
Potassium (ppm)	1.45	73.2	31.5	15.2	0.71	19.3	0.26	0.31	2.80	0.30
Calcium (ppm)	98.7	575	433	248	95.5	383	71.9	121	392	95.6
Magnesium (ppm)	38.3	125	94.7	63.5	38.9	94.0	27.9	47.1	94.1	41.3
Chloride (ppm)	28	20	25	35	32	39	23	86	88	41
Sulphates (ppm)	180	52	110	89	190	140	75	150	210	110
Sodium (ppm)	24.3	532	649	349	13.4	609	7.2	8.2	458	7.2
Zinc (ppm)	0.02	0.06	0.07	0.06	< 0.02	0.09	0.02	0.07	0.06	0.06
Manganese (ppm)	0.528	0.0556	0.207	0.0508	0.0857	0.0682	0.0576	0.0544	0.138	0.118
Copper (ppm)	0.0079	0.0116	0.0189	0.0199	0.0035	0.0174	0.0070	0.0096	0.0147	0.0102
Iron (ppm)	< 0.07	< 0.07	0.12	< 0.07	< 0.07	< 0.07	< 0.07	< 0.07	< 0.07	0.11
Boron (ppm)	0.269	0.340	0.342	0.701	0.163	0.598	0.096	0.109	0.230	0.130
Molybdenum (ppm)	0.0171	0.0069	0.0082	0.0084	0.0050	0.0077	0.0048	0.0065	0.0082	0.0125
Total Dissolved Solids (ppm)	607	6530	5640	3230	650	5250	434	731	4340	630

Table E. 12 Concentrations of target species in soil water collected 48 hours after application at Lakeview Greenhouses.

Target Species	LC130	LT130	LT230	LC260	LT160	LC290	LT190
pH	8.04	8.02	8.20	8.13	8.03	8.56	8.44
Bromide (ppm)	< 3	10.1	220	< 3	< 3	< 3	4.7
Nitrate Nitrogen (ppm)	34.5	18.5	25.5	19.9	26.0	25.3	27.2
Phosphorus (ppm)	0.11	0.10	0.18	0.09	0.07	0.06	0.04
Potassium (ppm)	3.68	8.97	13.3	2.29	8.25	0.72	2.48
Calcium (ppm)	47.7	35.1	60.8	42.7	42.8	103	88.3
Magnesium (ppm)	31.4	23.6	36.0	16.6	19.3	23.3	13.6
Chloride (ppm)	7.8	5.9	12	2.2	6.3	3.7	4.5
Sulphates (ppm)	38	19	31	23	26	12	20
Sodium (ppm)	25.5	5.1	44.4	5.5	12.0	4.2	13.6
Zinc (ppm)	0.06	0.04	0.18	0.13	0.09	0.05	0.07
Manganese (ppm)	0.0142	0.0205	0.0185	0.0112	0.0079	0.0131	0.0055
Copper (ppm)	0.0072	0.0062	0.0064	0.0039	0.0021	0.0031	0.0015
Iron (ppm)	< 0.07	< 0.07	< 0.07	< 0.07	< 0.07	< 0.07	< 0.07
Boron (ppm)	0.109	0.093	0.102	0.066	0.073	0.075	0.056
Molybdenum (ppm)	0.0051	0.0029	0.0036	0.0026	0.0027	0.0058	0.0041
Total Dissolved Solids (ppm)	471	450	670	360	362	500	429

Table E. 13 Concentrations of target species in soil water collected 3 months after application at Prism Farms.

Target Species	PC 130	PT 130	PT 230	PC 160	PT 160	PT 360	PC 190	PT 190	PT 290	PT 390
Bromide (ppm)	< 3	1400	3800	< 3	2700	360	< 3	270	3000	1300
Nitrate Nitrogen (ppm)	< 0.6	17.2	106	< 0.6	78.7	3.64	< 0.6	2.80	40.6	25.8
Phosphorus (ppm)	0.010	0.004	< 0.003	0.022	< 0.003	0.018	0.027	< 0.003	< 0.003	< 0.003
Potassium (ppm)	2.48	20.3	35.5	4.85	20.6	8.71	4.40	3.93	23.4	20.0
Calcium (ppm)	13.4	42.4	140	14.5	254	42.7	20.5	85.5	455	202
Magnesium (ppm)	5.24	12.2	30.2	5.84	54.4	22.2	6.40	18.1	135	66.7
Chloride (ppm)	< 2	25	22	< 2	47	4.3	< 2	40	19	9.6
Sulphates (ppm)	6.0	69	35	9.0	21	42	8.7	36	7.9	11
Sodium (ppm)	9.49	407	1080	4.66	476	68.1	4.63	16.5	139	74.6
Zinc (ppm)	0.037	0.045	0.047	0.039	0.051	0.019	0.025	0.014	0.051	0.032
Manganese (ppm)	0.01612	0.00157	0.00779	0.00175	0.00343	0.00168	0.00034	0.00112	0.0557	0.00607
Copper (ppm)	0.00494	0.00537	0.00274	0.00254	0.00270	0.00616	0.00117	0.00082	0.00411	0.00247
Iron (ppm)	0.295	0.177	0.352	0.269	0.601	0.115	0.072	0.210	1.04	0.491
Boron (ppm)	0.0737	0.0611	0.0716	0.0913	0.0785	0.0887	0.116	0.140	0.120	0.117
Molybdenum (ppm)	0.00391	0.00617	0.00149	0.00733	0.00206	0.00145	0.00297	0.00067	0.00183	0.00391

Table E. 14 Concentrations of target species in soil water collected 3 months after application at Cecelia Acres.

Target Species	CC 130	CT 130	CC 260	CT 260	CT 360	CC 390	CT290	CT190
Bromide (ppm)	62.2	1900	< 3	2000	1100	< 3	980	150
Nitrate Nitrogen (ppm)	< 0.6	48.7	4.95	56.2	34.8	10.3	25.6	15.2
Phosphorus (ppm)	< 0.003	0.010	< 0.003	0.222	< 0.003	< 0.003	< 0.003	< 0.003
Potassium (ppm)	1.53	1.65	0.997	3.06	1.25	0.413	0.748	0.690
Calcium (ppm)	148	358	107	439	315	164	284	199
Magnesium (ppm)	17.2	40.3	17.4	44.8	35.7	32.0	50.8	34.6
Chloride (ppm)	73	43	53	42	54	52	39	54
Sulphates (ppm)	54	71	48	61	63	160	45	71
Sodium (ppm)	7.57	290	5.27	156	76.7	8.83	23.4	12.3
Zinc (ppm)	0.003	0.021	< 0.002	0.026	0.006	< 0.002	0.003	0.002
Manganese (ppm)	0.00024	0.00173	0.00046	0.00707	0.00067	0.00005	0.00015	0.00009
Copper (ppm)	0.00312	0.00707	0.00253	0.00778	0.00509	0.00164	0.00316	0.00300
Iron (ppm)	0.366	0.843	0.259	1.05	0.787	0.401	0.699	0.500
Boron (ppm)	0.133	0.249	0.164	0.217	0.287	0.327	0.339	0.376
Molybdenum (ppm)	0.00717	0.00736	0.00806	0.00694	0.0102	0.0105	0.00400	0.00695

Table E. 15 Concentrations of target species in soil samples collected 48 hours after application at Prism Farms in July, 2015.

	PC 0-10	PC 10-20	PC 20-30	PC 30-40	PC 40-50	PC 50-60	PC 60-70	PC 70-80	PC 80-90
pH	7.13	7.09	7.12	7.24	7.18	7.23	7.17	7.16	7.16
Organic matter	2.7	2.7	2.9	1.1	0.3	0.3	0.1	0.3	0.3
Bromide (ppm)	25	19	33	6.2	4.9	4.9	5.1	1.3	5.4
Phosphorus (ppm)	43.77	36.66	10.68	2.42	5.29	5.86	5.52	5.05	5.18
Potassium (ppm)	86.26	67.89	74.77	53.56	32.38	47.94	53.39	45.55	38.42
Calcium (ppm)	963.42	825.77	1032.29	529.64	321.03	536.23	695.2	710.48	568.29
Magnesium (ppm)	126.83	113.08	108.95	59.71	41.7	104.37	151.18	147.7	109.9
Zinc (ppm)	1.14	1.02	0.35	0.12	0.05	0.12	0.14	0.3	0.24
Manganese (ppm)	29.2	21.6	4.1	0.8	0.9	1.7	1	1.9	2
Copper (ppm)	0.44	0.44	0.33	0.17	0.13	0.28	0.49	0.68	0.75
Iron (ppm)	21.66	23.58	22.98	10.15	9.13	7.43	7.54	7.47	6.73
Boron (ppm)	0.38	0.39	0.49	0.31	0.2	0.15	0.15	0.15	0.15
	PT 0-10	PT 10-20	PT 20-30	PT 30-40	PT 40-50	PT 50-60	PT 60-70	PT 70-80	PT 80-90
pH	6.9	6.62	6.98	7.14	7.28	7.36	7.35	7.37	7.46
Organic matter	3.2	2.7	2.9	1.9	0.7	0.5	0.3	0.3	0.3
Bromide (ppm)	3700	770	380	150	35	16	14	9.1	4.4
Phosphorus (ppm)	44.58	27.51	18.38	5.86	4.47	2.61	2.88	2.68	2.7
Potassium (ppm)	120.33	96.35	67.3	46.98	34.15	38.3	40.6	38.77	40.86
Calcium (ppm)	1432.51	972.64	1010.06	1672.93	584.27	440.44	419.65	489.71	593.35
Magnesium (ppm)	122.72	122.02	97.92	86.38	53.96	68.47	81.18	100.87	108.3
Zinc (ppm)	1.89	1.05	0.45	0.16	0.14	0.13	0.2	0.17	0.17
Manganese (ppm)	23.3	11.7	7.1	2.8	1.7	2	2.2	3.4	6
Copper (ppm)	0.41	0.43	0.39	0.22	0.16	0.22	0.29	0.42	0.64
Iron (ppm)	21.55	24.02	27.37	19.88	11.52	10.84	10.09	8.59	8
Boron (ppm)	0.39	0.37	0.4	0.29	0.22	0.18	0.15	0.15	0.16

Table E. 16 Concentrations of target species in soil samples collected 48 hours after application at Cecelia Acres in July, 2015.

	CC 0-10	CC 10-20	CC 20-30	CC 30-40	CC 40-50	CC 50-60
pH	7.51	7.72	7.83	7.89	8.08	8.08
Organic matter	1.9	1.9	1.3	0.5	0.5	0.5
Bromide (ppm)	11	2.1	24	4.3	3	1.4
Phosphorus (ppm)	45.75	37.35	22.69	5.82	3.41	3.31
Potassium (ppm)	72.2	53.4	43.88	29.23	26.81	43.97
Calcium (ppm)	2386.04	2579.52	2766.71	3344.41	3703.93	4175.56
Magnesium (ppm)	138.64	122.23	117.82	106.76	92.89	148.38
Zinc (ppm)	1.51	1.78	0.98	0.28	0.17	0.1
Manganese (ppm)	19.1	15.5	14.6	8.6	10	7.7
Copper (ppm)	2.42	2.58	1.48	0.45	0.47	0.55
Iron (ppm)	30.84	25.15	18.03	10.17	8.24	9.01
Boron (ppm)	0.56	0.56	0.4	0.24	0.21	0.26
	CT 0-10	CT 10-20	CT 20-30	CT 30-40	CT 40-50	CT 50-60
pH	7.36	7.62	7.67	7.73	7.85	8.06
Organic matter	1.7	1.9	1.3	1.1	1.1	0.5
Bromide (ppm)	1600	500	280	260	150	55
Phosphorus (ppm)	59.52	45.66	23.09	4.13	3.96	3.21
Potassium (ppm)	66.32	46.56	37.28	27.24	24.89	24.69
Calcium (ppm)	2453.31	2425.89	3021.58	2658.25	3185.93	3680.66
Magnesium (ppm)	150.66	127.97	129.12	124.19	117.95	109.37
Zinc (ppm)	1.77	1.89	0.92	0.2	0.14	0.12
Manganese (ppm)	20.4	13.7	12.2	8.9	10.3	9.7
Copper (ppm)	2.3	2.45	1.67	0.99	0.78	0.51
Iron (ppm)	30.99	32.84	29.74	16.57	13.88	9.77
Boron (ppm)	0.61	0.67	0.46	0.37	0.4	0.3

Table E. 17 Concentrations of target species in soil samples collected 48 hours after application at Warkentin Orchards in July, 2015.

	WC 0-10	WC 10-20	WC 20-30	WC 30-40	WC 40-50	WC 50-60	WC 60-70	WC 70-80	WC 80-90
pH	7.54	7.24	6.95	7.03	7.23	7.33	7.47	7.53	7.53
Organic matter	4.2	2.9	2.9	2.1	1.3	0.9	0.7	0.7	0.5
Bromide (ppm)	10	14	7.3	10	11	2.8	3.1	2	4
Phosphorus (ppm)	81.26	29.66	19.49	8.42	2.65	1.85	1.24	1.26	0.97
Potassium (ppm)	274.34	156.1	98.52	85.2	72.41	65.6	60.74	60.63	58.37
Calcium (ppm)	3089.07	2068.07	2191.94	2234.24	2001.65	1690.13	1581.88	1734.36	1739.62
Magnesium (ppm)	223	262.82	297.08	320.66	290.1	259.4	251.02	270.11	278.84
Zinc (ppm)	5.97	2.12	0.76	0.96	0.41	0.31	0.21	0.25	0.17
Manganese (ppm)	32.1	9.3	3.5	4	2.9	2.7	3.6	4.2	3.3
Copper (ppm)	2.18	1.88	1.85	1.01	0.83	0.77	0.67	0.74	0.75
Iron (ppm)	61.11	68.78	82.41	48.09	26.1	19.05	10.22	11.62	6.49
Boron (ppm)	1.18	0.89	0.86	0.67	0.42	0.27	0.23	0.19	0.16
	WT 0-10	WT 10-20	WT 20-30	WT 30-40	WT 40-50	WT 50-60	WT 60-70	WT 70-80	WT 80-90
pH	7.18	6.82	6.84	6.89	7.05	7.06	7.3	7.45	7.54
Organic matter	4	3.3	2.5	1.8	1.3	1.3	1.3	0.6	0.6
Bromide (ppm)	1300	530	310	250	160	100	130	72	13
Phosphorus (ppm)	70.94	36.61	17.12	7.15	6.31	10.02	12	2.75	2.71
Potassium (ppm)	312.48	178.65	108.3	90.71	81.29	81.18	77.9	60.48	65.92
Calcium (ppm)	2280.5	2124.24	2104.7	2514.66	2094.78	2100	2210.04	1987.24	2425.93
Magnesium (ppm)	242.51	289.59	326.83	374.08	335.08	332.46	344.58	344.3	438.27
Zinc (ppm)	9.09	2.76	1.17	0.79	0.76	0.77	0.86	0.38	0.31
Manganese (ppm)	36.7	7.3	4.4	5.2	3.7	5.2	6.1	4.9	4.5
Copper (ppm)	2.26	2.33	1.54	1.08	0.79	1	1.16	0.79	1.04
Iron (ppm)	52.63	75.56	63.71	46.17	30.66	32.74	34.42	13.6	13.45
Boron (ppm)	1.29	1.17	1.06	0.77	0.57	0.55	0.43	0.24	0.2

Table E. 18 Concentrations of target species in soil samples collected 48 hours after application at Lakeview Greenhouses in July, 2015.

	LC 0-10	LC 10-20	LC 20-30	LC 30-40	LC 40-50	LC 50-60	LC 60-70	LC 70-80	LC 80-90
pH	6.49	6.11	6.08	6.16	6.21	6.32	6.5	6.7	7.55
Organic matter	2.5	2.3	1.9	1.3	1.3	1.3	1.3	1.1	1.3
Bromide (ppm)	9.3	1.7	1.4	2	1.7	1.5	1.9	1.5	1
Phosphorus (ppm)	43.96	45.87	34.36	8.98	7.59	7.18	9.16	8.46	4.28
Potassium (ppm)	182.93	132.59	103.91	77.12	71.78	82.23	71.17	74.36	61.89
Calcium (ppm)	1996.95	1163.29	1209.25	1246.72	1238.7	1553.72	1542.9	1617.64	2123.16
Magnesium (ppm)	149.85	179.94	217.6	217.63	199.25	193.06	147.2	125.42	93.22
Zinc (ppm)	1.38	1.44	0.83	0.35	0.41	0.55	0.45	0.43	0.45
Manganese (ppm)	31	19.8	14.9	11.5	12	12.8	9.3	7.7	14.5
Copper (ppm)	1.16	1.3	1.6	5.22	3.55	4.62	3.2	2.43	2.36
Iron (ppm)	38.72	41.26	35.71	26.26	29.07	30.42	25.57	18.8	14.32
Boron (ppm)	0.2	0.21	0.24	0.19	0.19	0.18	0.18	0.17	0.17
	LT 0-10cm	LT 10-20cm	LT 20-30cm	LT 30-40cm	LT 40-50cm	LT 50-60cm	LT 60-70cm	LT 70-80cm	LT 80-90cm
pH	5.56	5.23	5.3	5.59	6.04	6.45	6.55	6.73	7.34
Organic matter	2.5	1.8	1.6	1.3	1.1	1.1	1.1	1.1	1.6
Bromide (ppm)	60	17	18	16	14	12	5.8	3.5	1.2
Phosphorus (ppm)	51.65	53.48	56.91	16.8	6.73	7.11	5.73	8.37	6.4
Potassium (ppm)	282.04	139.51	122.02	99	115.48	98.6	96.08	79.33	69.1
Calcium (ppm)	937.13	688.49	725.26	911.15	1393.24	1429.88	1727.73	1614.92	3810.82
Magnesium (ppm)	139.68	120.99	145.11	174.48	192.06	127.45	119.47	97.66	98.14
Zinc (ppm)	1.91	1.38	1.39	0.49	0.4	0.45	0.46	0.47	0.54
Manganese (ppm)	21.5	15.3	13.5	9.5	7.3	5.5	4.4	5.4	11.7
Copper (ppm)	1.13	1.01	1.22	1.64	2.09	2.15	2.19	1.96	2.07
Iron (ppm)	49.97	45.52	50.14	33.28	29.33	23.42	20.42	20.7	19.18
Boron (ppm)	0.27	0.2	0.22	0.22	0.21	0.2	0.18	0.19	0.21

Table E. 19 Concentrations of target species in soil samples collected 3 months after application at Prism Farms in October, 2015.

	PC 0-10cm	PC 10-20cm	PC 20-30cm	PC 30-40cm	PC 40-50cm	PC 50-60cm	PC 60-70cm	PC 70-80cm	PC 80-90cm
pH	6.56	6.37	6.56	6.67	6.76	6.83	6.98	7.01	7.05
Organic matter	4.1	2.6	2.6	1.6	0.7	0.4	0.4	0.4	0.7
Bromide (ppm)	1.2	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Phosphorus (ppm)	41.21	31.26	10.2	5.69	5.35	4.88	4.89	2.74	3.67
Potassium (ppm)	137.19	95.59	82.06	66.23	23.71	81.37	43.49	38.14	27.27
Calcium (ppm)	973.79	708.7	785.73	487.87	210.46	599.94	598.7	566.44	448.67
Magnesium (ppm)	158.22	97.97	67.78	51.51	30.52	136.64	129.33	121.66	87.78
Zinc (ppm)	2.25	0.75	0.1	0.1	0.1	0.2	0.21	0.19	0.18
Manganese (ppm)	21	10.7	1.7	0.5	0.5	1.1	1	0.9	1.4
Copper (ppm)	0.34	0.34	0.16	0.09	0.08	0.17	0.25	0.49	0.57
Iron (ppm)	22.93	21.81	20.45	9.83	7.62	8.84	8.25	5.92	5.62
Boron (ppm)	0.38	0.3	0.23	0.2	0.11	0.12	0.1	0.09	0.09
	PT 0-10	PT 10-20	PT 20-30	PT 30-40	PT 40-50	PT 50-60	PT 60-70	PT 70-80	PT 80-90
pH	6.69	6.31	6.33	6.33	6.51	6.51	6.64	6.76	6.87
Organic matter	3.1	2.6	2.6	1.6	0.9	0.4	0.4	0.7	0.7
Bromide (ppm)	530		450	480	360	200	200	85	89
Phosphorus (ppm)	33.52	25.32	16.54	7.32	6.58	4.91	4.17	6	4.4
Potassium (ppm)	113.43	76.42	60.07	38.88	36.98	31.37	38.2	43.88	35.09
Calcium (ppm)	874.44	715.95	781.05	583.76	391.33	372.05	512.07	641.21	574.08
Magnesium (ppm)	111.33	90.09	88.9	58.53	47.54	66.45	107.38	132.79	102.93
Zinc (ppm)	1.86	0.88	0.47	0.1	0.1	0.08	0.16	0.25	0.28
Manganese (ppm)	19.9	8.5	4.8	1	1.4	1.1	1.3	1.8	2.5
Copper (ppm)	0.35	0.31	0.3	0.12	0.09	0.1	0.16	0.33	0.5
Iron (ppm)	27.45	29.13	33.93	16.76	14.5	12.16	8.95	9.87	7.17
Boron (ppm)	0.45	0.38	0.36	0.28	0.19	0.12	0.11	0.13	0.12

Table E. 20 Concentrations of target species in soil samples collected 3 months after application at Cecelia Acres in October, 2015.

	CC 0-10	CC 10-20	CC 20-30	CC 30-40	CC 40-50	CC 50-60	CC 60-70	CC 70-80	CC 80-90
pH	7.69	7.73	8.07	8.15	8.12	8.1	8.24	8.06	8.04
Organic matter	1.6	1.4	0.4	0.4	0.4	0.4	0.4	0.4	0.7
Bromide (ppm)	4.4	1.4	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Phosphorus (ppm)	47.76	37.9	9.99	4	2.98	3.81	2.64	3.47	3.06
Potassium (ppm)	58.37	40.39	23.06	22.79	20.99	20.89	17.04	30.61	40.06
Calcium (ppm)	2473.71	2318.68	3431.83	3408.97	3589.24	3781.36	3482.15	4094	4370.75
Magnesium (ppm)	138.57	102.87	74.08	78.39	83.63	86.03	68.81	134.92	189.67
Zinc (ppm)	1.53	1.56	0.25	0.05	0.1	0.06	0.06	0.3	0.15
Manganese (ppm)	13.3	11.7	9	10.4	7.7	6.2	12	12.1	10.7
Copper (ppm)	2.19	2.16	0.5	0.39	0.3	0.29	0.22	0.55	0.29
Iron (ppm)	25.35	23.1	6.94	4.74	6.44	7.32	4.44	13.97	13.72
Boron (ppm)	0.53	0.42	0.15	0.1	0.11	0.16	0.11	0.31	0.25
	CT 0-10	CT 10-20	CT 20-30	CT 30-40	CT 40-50	CT 50-60	CT 60-70	CT 70-80	CT 80-90
pH	7.54	7.63	7.61	7.68	7.74	8.01	8.03	8.11	8.13
Organic matter	1.9	1.6	1.2	0.9	0.7	0.4	0.4	0.4	0.4
Bromide (ppm)	480	340	340	260	330	250	210	160	100
Phosphorus (ppm)	56.72	37.03	24.49	7.89	6.48	4.26	3.49	3.16	2.69
Potassium (ppm)	68	52.02	33.37	18.82	18.3	12.46	15.77	16.75	18.82
Calcium (ppm)	2102.56	2263.37	2422.41	2532.95	3641.9	3632.37	3835.69	3638.37	3584.08
Magnesium (ppm)	129.44	122.52	112.67	106.58	116.87	85.88	90.51	80.39	77.04
Zinc (ppm)	1.74	1.82	1.59	0.24	0.17	0.18	0.12	0.1	0.1
Manganese (ppm)	14.5	10.5	9.6	9.6	9.3	10.7	12	14	16.4
Copper (ppm)	1.91	2.05	1.76	0.78	0.66	0.33	0.42	0.32	0.36
Iron (ppm)	32.32	32.46	39.14	19.44	19.73	8.28	7.59	5.93	5.88
Boron (ppm)	0.55	0.54	0.46	0.32	0.29	0.19	0.19	0.16	0.16

Table E. 21 Concentrations of target species in soil samples collected 3 months after application at Warkentin Orchards in October, 2015.

	WC 0-10	WC 10-20	WC 20-30	WC 30-40	WC 40-50	WC 50-60	WC 60-70	WC 70-80	WC 80-90
pH	7.54	7.17	7.05	7.13	7.2	7.27	7.37	7.44	7.44
Organic matter	4.5	3.1	2.4	1.2	0.9	0.7	0.7	0.4	0.4
Bromide (ppm)	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Phosphorus (ppm)	81.21	28.53	14.08	5.36	4.46	4.34	3.04	2.87	3.39
Potassium (ppm)	250.09	141.51	78.85	73.09	56.11	62.84	56.41	47.51	28.83
Calcium (ppm)	3338.05	2245.54	2390.04	2132.57	1781.34	1975.21	1785.62	1604.63	1128.77
Magnesium (ppm)	206.29	280.12	351.61	322.27	269.51	307.59	284.63	264.02	186.22
Zinc (ppm)	8.07	0.88	0.57	0.47	0.39	0.48	0.34	0.34	0.21
Manganese (ppm)	26.6	2.7	1.7	1.8	1.9	2.4	2.1	1.7	2.8
Copper (ppm)	1.97	1.78	1.08	0.67	0.57	0.63	0.67	0.68	0.67
Iron (ppm)	46.9	78.46	63.34	28.09	24.61	26.02	19.28	14.1	11.4
Boron (ppm)	0.89	0.8	0.63	0.44	0.35	0.3	0.2	0.16	0.16
	WT 0-10	WT 10-20	WT 20-30	WT 30-40	WT 40-50	WT 50-60	WT 60-70	WT 70-80	WT 80-90
pH	7.09	6.84	6.71	6.67	6.76	6.96	7.14	7.26	7.39
Organic matter	4.1	2.6	2.4	1.9	1.4	1.4	0.7	0.7	0.7
Bromide (ppm)	670	420	390	250	180	130	65	45	43
Phosphorus (ppm)	73.86	31.26	15.12	8.58	5.94	5.98	4.93	3.59	3.32
Potassium (ppm)	364.34	142.29	104.92	86.06	81.79	75.28	62.55	66.14	61.73
Calcium (ppm)	2411.85	2062.86	2137.44	2322.88	2223.48	2276.84	2061.31	2463.92	2556.25
Magnesium (ppm)	265.11	285.41	323.21	361.59	346.78	364.86	351.77	438.23	466.11
Zinc (ppm)	9.44	1.56	0.86	0.83	0.63	0.57	0.47	0.28	0.37
Manganese (ppm)	33	4.7	2.8	3.1	2.2	2.7	4.6	3.3	4.9
Copper (ppm)	2.2	2.4	1.64	1.21	1.21	1.16	1.12	0.98	0.96
Iron (ppm)	47.48	77.47	58.78	44.95	31.28	30.53	17.32	14.03	11.12
Boron (ppm)	0.99	1.05	0.97	0.76	0.64	0.54	0.31	0.24	0.2

Table E. 22 Concentrations of target species in soil samples collected 3 months after application at Lakeview Greenhouses in October, 2015

	LC 0-10	LC 10-20	LC 20-30	LC 30-40	LC 40-50	LC 50-60	LC 60-70	LC 70-80	LC 80-90
pH	5.68	5.52	5.84	5.96	6.17	6.35	6.37	6.61	6.71
Organic matter	2.1	1.9	1.6	1.2	0.9	1.2	1.2	1.2	1.6
Bromide (ppm)	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Phosphorus (ppm)	35.91	39.2	40.92	18.59	8.82	8.82	9.27	6.9	6.99
Potassium (ppm)	129.99	124.21	102.33	68.84	77	88.83	104.1	65.77	66.76
Calcium (ppm)	1010.5	851.07	940.16	955.2	1121.04	1504.93	1770.74	1743.61	1877.15
Magnesium (ppm)	157.34	161.89	181.53	196.77	198.22	200.13	178.04	108.88	103.59
Zinc (ppm)	1.92	1.67	1.17	0.62	0.37	0.45	0.52	0.87	0.89
Manganese (ppm)	17.9	14.5	12	10	8.7	6.9	6.7	6	9.1
Copper (ppm)	1.23	1.14	1.16	1.75	2.5	2.93	2.28	1.89	2.17
Iron (ppm)	49.85	43.68	36.48	28.77	22.19	22.47	22.33	16.64	17.85
Boron (ppm)	0.18	0.18	0.21	0.2	0.16	0.2	0.23	0.21	0.23
	LT 0-10	LT 10-20	LT 20-30	LT 30-40	LT 40-50	LT 50-60	LT 60-70	LT 70-80	LT 80-90
pH	5.75	5.2	5.23	5.74	6.31	6.41	6.61	6.77	7.39
Organic matter	2.1	1.9	1.6	1.2	1.2	0.9	0.7	1.2	1.4
Bromide (ppm)	58	37	34	15	15	14	8.2	1.8	2.4
Phosphorus (ppm)	53.55	51	48.48	12.8	7.36	6.65	5.42	6.17	6.81
Potassium (ppm)	253.58	147.61	126.35	119.57	131.25	99.08	92.72	81.66	66.28
Calcium (ppm)	909.51	668.44	661.6	1126.83	1620.35	1477.42	1552.11	1713.8	3198.63
Magnesium (ppm)	139.79	112.4	123.95	190.62	189.3	114.81	102.86	92.84	88.12
Zinc (ppm)	2.1	1.41	1.2	0.46	0.43	0.44	0.29	0.36	0.69
Manganese (ppm)	19.1	17.7	14.3	8.5	7.1	5.2	4.3	5.2	14.5
Copper (ppm)	1.04	1.01	1.15	2.48	2.94	2.03	1.81	1.94	1.74
Iron (ppm)	55.01	59.27	59.35	30.88	27.01	19.76	16.76	16.03	15.1
Boron (ppm)	0.21	0.2	0.19	0.18	0.22	0.17	0.16	0.17	0.16

Appendix F

Long Term Groundwater, Tile Drain and Surface Water Monitoring

Table of background groundwater, tile drains chemical analyses was presented in Appendix A.

Table F. 1 Concentrations of target species in groundwater sampled at Prism Farms and Cecelia on May 6, 2015

	PTW 141	PTW 251	PCW 139	PG 220	PG 598	CCW	CTW
pH	7.78	7.57	7.77	7.21	7.35	7.53	7.29
EC (mmhos/cm)	0.46	0.55	0.36	0.95	1.41	1.78	1.26
Nitrate Nitrogen (ppm)	2	2	2	2	2	14	17
Phosphorus (ppm)	0.19	0.25	0.32	0.15	0.16	0.3	0.3
Potassium (ppm)	5.84	4.83	6.74	4.46	6.57	4.45	3.71
Calcium (ppm)	70.76	73.21	50.5	145.49	168.8	331.98	236.88
Magnesium (ppm)	11.76	17.4	10.39	48.11	80.29	73.38	42.18
Chloride (ppm)	24	20	10	26	6	62	41
Sulphates (ppm)	87.73	91.99	66.21	105.13	477.87	573.87	193.21
Sodium (ppm)	9.41	20.74	9.76	12.54	54.7	35.95	21.47
Zinc (ppm)	0.05	0.04	0.04	0.05	0.06	0.08	0.06
Manganese (ppm)	0.03	0.2	0.05	0.19	0.03	2.45	0.69
Copper (ppm)	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
Iron (ppm)	3.64	0.55	6.7	0.1	0.07	1.26	0.17
Boron (ppm)	0.11	0.12	0.12	0.06	0.73	0.15	0.19
Molybdenum (ppm)	<0.01	0.07	<0.01	0.03	0.05	0.01	<0.01
Silicon (ppm)	11.62	4.83	12.45	6.42	6.86	7.4	4.94
Bicarbonate(ppm)	159	238	156	506	381		534
Total Dissolved Solids(ppm)	294.4	352	230.4	608	902.4	1139.2	806.4
Total Hardness(ppm)	231.75	255.81	181.03	561.92	752.23	1137.83	766.77

Table F. 2 Concentrations of target species in groundwater sampled at Warkentin and Lakeview on May 6, 2015

	LTW 308	LTW 358	LCW 308	LCW 355	LG 245	WWE 150	WWW 150	WWW 089	WWE 089
EC (mmhos/cm)	7.68	8.23	7.78	7.9	8.68	8	7.82	8.13	8.26
Nitrate Nitrogen (ppm)	0.44	0.47	0.48	0.7	0.46	1.05	0.89	0.85	0.98
Phosphorus (ppm)	11	19	14	2	3	2	4	4	4
Potassium (ppm)	0.03	0.22	0.27	0.39	0.14	0.52	0.45	0.26	0.25
Calcium (ppm)	3.85	4.8	3.75	5.67	3.36	6.74	5.02	4.42	5.56
Magnesium (ppm)	84.46	86.33	91.29	33.35	91.93	100.29	143.94	129.4	119.62
Chloride (ppm)	5.98	5.89	6.01	3.48	5.9	26.91	37.86	32.49	29.81
Sulphates (ppm)	19	18	16	16	2	59	41	36	71
Sodium (ppm)	26.73	27.61	24.07	14.94	16.33	211.53	140.96	148.58	225.64
Zinc (ppm)	2.56	3.61	2.36	126.18	3.17	105.2	10.15	12.12	47.13
Manganese (ppm)	0.04	0.05	0.04	0.02	0.03	0.05	0.05	0.07	0.06
Copper (ppm)	0.01	0	0.01	0.41	0.09	0.15	0.64	0.52	0.16
Iron (ppm)	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01
Boron (ppm)	0.27	0.03	0.38	3.93	0.36	1.24	1.37	1.68	0.07
Molybdenum (ppm)	0.02	0.02	0.02	0.09	0.03	0.09	0.03	0.03	0.06
Silicon (ppm)	0.02	0.01	0	0.13	<0.01	0.01	0.01	0.02	0.02
Bicarbonate(ppm)	3.92	3.47	4.18	5.4	3.44	9.18	5.62	7.62	3.76
Total Dissolved Solids(ppm)	214	204	226	415	302				
Total Hardness(ppm)	281.6	300.8	307.2	448	294.4	672	569.6	544	627.2

Table F. 3 Concentrations of target species in groundwater sampled at Prism and Cecelia on July 11, 2015 before application

	PG598	PG 249	PTW 141	PTW 251	PCW 249	PCW 139	CTW 120	CTW 123
pH		7.79	8.05		8.16	8.11	7.78	7.9
Bromide (ppm)	<0.50	<0.50	<0.50		1.79	<0.50	94.8	8.12
NO3-N (ppm)	0.17	<0.10	<0.10	<0.10	<0.10	<0.10	8.81	2.97
Phosphorus (ppm)	0.128	0.044	0.047		0.051	0.03	0.252	0.186
Potassium (ppm)	4.2	2.4	2.7	2.9	1.8	2.6	2.8	2.3
Calcium (ppm)	175	156	70.4	75.2	58.6	56.4	164	330
Magnesium (ppm)	83.2	47.6	12.6	14	14.1	10.7	27.5	77.5
Chloride (ppm)	5.7	25.5	29.1		12.8	14.5	41.1	61.8
Sulphates (ppm)	528	111	82.2		51.3	58	177	725
Sodium (ppm)	54.2	13.3	11.4	10.2	9.12	9.17	71.7	32
Zinc (ppm)	0.0211	0.0084	0.009	0.0137	0.0106	0.0105	0.003	0.0156
Manganese (ppm)	0.196	0.169	0.0322	0.0724	0.501	0.0368	0.26	1.25
Copper (ppm)	0.0055	0.008	0.0017	0.0032	0.0027	0.0033	0.0086	0.0048
Iron (ppm)	2.43	1.69	0.946	2.2	0.343	1.8	2.69	1.76
Boron (ppm)	0.796	0.075	0.159	0.153	0.073	0.142	0.286	0.243
Molybdenum (ppm)	0.0241	0.0258	0.00236	0.0054	0.0208	0.00238	0.0151	0.0146
Silicon (ppm)	11	9	4.9	6.3	6.9	7.4	9.7	9.8
Aluminum (ppm)	1.64	0.37	0.613	1.49	0.212	1.97	2.18	1.2
Arsenic (ppm)	0.002	0.0035	<0.0010	0.0016	0.002	0.0016	0.0022	0.0019
Cadmium (ppm)	0.000208	0.000101	<0.000090	0.000095	<0.000090	<0.000090	0.000156	0.000156
Chromium (ppm)	0.00334	0.00121	0.00107	0.00236	0.00057	0.0025	0.0033	0.00206
Cobalt (ppm)	0.00265	0.00148	0.00053	0.00118	0.00052	0.0007	0.00185	0.00187
Lead (ppm)	0.00149	0.00085	0.00066	0.0016	0.00052	0.00109	0.00213	0.0012
Mercury (ppm)	<0.000010	<0.000010	<0.000010	0.000023	<0.000010	<0.000010	<0.000010	<0.000010
Nickel (ppm)	0.0082	0.0044	0.0019	0.0036	0.0021	0.0036	0.0115	0.008
Selenium (ppm)	<0.00040	<0.00040	<0.00040	<0.00040	<0.00040	<0.00040	0.00854	0.00838

Table F. 4 Concentrations of target species in groundwater sampled at Warkentin and Lakeview on July 11, 2015 before application

	WCW 150	LCW 307	LCW 355	LTW 308	LTW358
pH	8.16	8.09	8.26	8.12	8.35
Bromide (ppm)	5.28	<0.50	<0.50	<0.50	<0.50
NO3-N (ppm)	0.154	6.55	8.91	9.18	12.2
Phosphorus (ppm)	0.41	<0.030	0.152	0.038	0.064
Potassium (ppm)	2.2	1.3	2.8	2	2
Calcium (ppm)	139	81.6	71.4	89.7	85.2
Magnesium (ppm)	37	6.73	7.95	7.67	7.15
Chloride (ppm)	39	12.5	8.9	18.7	15.5
Sulphates (ppm)	125	12.3	22	17.5	16.4
Sodium (ppm)	18.7	1.99	14.3	2.62	3.38
Zinc (ppm)	0.0436	<0.0030	0.0105	0.0124	0.0095
Manganese (ppm)	1.12	0.0038	0.341	0.0437	0.0104
Copper (ppm)	0.0116	<0.0010	0.0039	0.0048	0.0023
Iron (ppm)	6	0.195	2.94	2.93	0.167
Boron (ppm)	0.062	0.026	0.038	0.025	0.027
Molybdenum (ppm)	0.014	0.00105	0.0169	0.00283	0.00227
Silicon (ppm)	13.5	4.1	4.8	5.8	4
Aluminum (ppm)	5.05	0.124	0.653	1.47	0.094
Arsenic (ppm)	0.0042	<0.0010	0.0029	0.0026	<0.0010
Cadmium (ppm)	0.000165	<0.000090	0.00015	<0.000090	<0.000090
Chromium (ppm)	0.0144	<0.00050	0.00193	0.00226	<0.00050
Cobalt (ppm)	0.00329	<0.00050	0.00213	0.00141	<0.00050
Lead (ppm)	0.00423	<0.00050	0.00202	0.00188	<0.00050
Mercury (ppm)	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Nickel (ppm)	0.0295	<0.0010	0.0051	0.0052	0.0019
Selenium (ppm)	0.0004	<0.00040	<0.00040	<0.00040	<0.00040

Table F. 5 Concentrations of target species in groundwater sampled at study sites from July 13-15, 2015 48 hrs after application

	PTW 141	PTW 251	PCW 249	PCW139	CTW 120	CTW 123	LTW 308	LTW 358	LCW 307	LCW 355
pH	8.04	7.97	8.09	8.11	7.78	7.9	8.04	8.04	8.02	8.1
Bromide (ppm)	<0.10	4.48	0.67	<0.10	94.8	8.12	<0.10	<0.10	<0.10	0.51
NO3-N (ppm)	<0.020	0.134	0.02	0.029	8.81	2.97	8.94	10.7	7.57	10.9
Phosphorus (ppm)	0.139	0.093	<0.030	<0.030	0.252	0.186	<0.030	<0.030	<0.030	0.284
Potassium (ppm)	3.8	2.7	5	2.6	2.8	2.3	1.5	2	1.3	2.9
Calcium (ppm)	93.7	71.3	82.8	65.6	164	330	94.5	87.9	90	86.4
Magnesium (ppm)	18	19.1	25.5	13.3	27.5	77.5	8.41	7.81	7.74	9.7
Chloride (ppm)	47.1	16.4	12.5	18.9	41.1	61.8	18.1	13.9	14.1	9.05
Sulphates (ppm)	110	92.5	52.1	74.7	177	725	16.9	16.4	12	30.1
Sodium (ppm)	13.1	29.7	9.91	11.2	71.7	32	4.55	4.48	2.14	9.74
Zinc (ppm)	0.0232	0.08	0.0854	0.0052	0.003	0.0156	<0.0030	0.0035	<0.0030	0.0189
Manganese (ppm)	0.13	0.12	0.768	0.047	0.26	1.25	0.0014	0.0085	0.0043	0.321
Copper (ppm)	0.0048	0.0083	0.027	0.0017	0.0086	0.0048	<0.0010	<0.0010	<0.0010	0.0021
Iron (ppm)	3.5	1.09	20.5	1.16	2.69	1.76	0.088	0.071	0.269	0.811
Boron (ppm)	0.177	0.135	0.09	0.17	0.286	0.243	0.025	0.028	0.024	0.033
Molybdenum (ppm)	0.0025	0.0771	0.0307	0.00174	0.0151	0.0146	0.00186	0.00303	0.00126	0.0121
Silicon (ppm)	7.6	6.7	33	6.2	9.7	9.8	4	4.2	4.3	4.2
Aluminum (ppm)	2.15	0.819	15.6	1.13	2.18	1.2	0.076	0.035	0.141	0.221
Arsenic (ppm)	0.0028	0.0015	0.0121	0.0012	0.0022	0.0019	<0.0010	<0.0010	<0.0010	0.0015
Cadmium (ppm)	0.000093	0.000186	0.000373	<0.000090	0.000156	0.000156	<0.000090	<0.000090	<0.000090	<0.000090
Chromium (ppm)	0.00332	0.00165	0.0207	0.00129	0.0033	0.00206	<0.00050	<0.00050	<0.00050	0.0007
Cobalt (ppm)	0.00162	0.00083	0.00843	0.00057	0.00185	0.00187	<0.00050	<0.00050	<0.00050	0.00171
Lead (ppm)	0.00237	0.00181	0.0121	0.00097	0.00213	0.0012	<0.00050	<0.00050	<0.00050	0.00061
Mercury (ppm)	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Nickel (ppm)	0.0051	0.0065	0.0278	0.0021	0.0115	0.008	0.0011	0.0011	0.0011	0.0056
Selenium (ppm)	<0.00040	0.00068	0.00045	<0.00040	0.00854	0.00838	<0.00040	<0.00040	<0.00040	<0.00040

Table F. 6 Concentrations of target species in groundwater sampled at study sites on October 6, 2015

	PG 249	PG 598	PTW251	PCW249	LT 358	LC 355	LG 272
pH	7.4	7.67	7.63	7.81	7.92	7.74	7.67
Total Hardness(ppm)	560.51	721.4	258.52	237.67	256.56	209.53	304.36
Bromide (ppm)	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Nitrate Nitrogen (ppm)	3	4	2	<0.5	20	10	13
Phosphorus (ppm)	<1	<1	<1	<1	<1	<1	<1
Potassium (ppm)	<1	3.13	<1	<1	<1	2.53	<1
Calcium (ppm)	149.31	160.46	74.07	68.26	91.49	71.72	109.65
Magnesium (ppm)	45.52	77.53	17.76	16.03	6.72	7.22	7.37
Chloride (ppm)	21	6	15	12	15	12	2
Sulphates (ppm)	103.71	502.73	102.82	44.02	15.65	13.1	5.02
Sodium (ppm)	13.42	51.46	27.86	9.68	5.89	28.72	2.19
Zinc (ppm)	0.04	0.05	0.03	0.02	0.03	0.03	0.03
Manganese (ppm)	0.07	0.01	0.09	0.45	0.06	0.18	0.03
Copper (ppm)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Iron (ppm)	0.08	0.85	0.16	0.22	0.16	0.2	0.08
Boron (ppm)	0.09	0.69	0.17	0.09	0.03	0.04	0.05
Molybdenum (ppm)	0.02	0.03	0.11	0.04	<0.01	0.02	0.01
Silicon (ppm)	8.02	8.81	5.6	8.1	4.41	4.45	3.78
Aluminum (ppm)	< 0.001	0.031	0.002	0.003	0.003	< 0.001	< 0.001
Arsenic (ppm)	0.0015	0.0009	0.0011	0.0018	0.0003	0.0008	0.0002
Cadmium (ppm)	0.000009	0.000010	0.000031	0.000010	< 0.000003	0.000019	< 0.000003
Chromium (ppm)	0.00004	0.00011	0.00006	< 0.00003	0.00006	0.00004	0.00005
Cobalt (ppm)	0.000059	0.000071	0.000164	0.000168	0.000098	0.000331	0.000028
Lead (ppm)	0.00003	0.00005	0.00004	0.00003	0.00004	0.00002	0.00002
Mercury (ppm)	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Nickel (ppm)	0.0024	0.0074	0.0017	0.0012	0.0011	0.0031	0.0004
Selenium (ppm)	0.00020	0.00222	0.00116	0.00005	0.00013	0.00060	0.00112

Table F. 7 Concentrations of target species in tile drains and surface waters sampled at study sites in May, 2015

	Prism Front Ditch	Prism Tile	Cecelia east ditch	Cecelia west ditch	Lakeview northeast Pond
pH	7.46	7.03	7.42	7.63	8
EC (mmhos/cm)	0.17	0.48	5.24	0.87	0.65
Total Dissolved Solids(ppm)	108.8	307.2	3353.6	556.8	416
Total Hardness(ppm)	61.46	268.7	977.47	445.66	279.69
Nitrate Nitrogen (ppm)	1	1	12	16	3
Phosphorus (ppm)	0.29	0.24	0.25	0.26	0.2
Potassium (ppm)	6.76	5.29	7.18	6.53	4.65
Calcium (ppm)	17.92	76.92	312.05	136.64	95.22
Magnesium (ppm)	3.9	18.41	47.89	25.35	10.04
Bicarbonate(ppm)	104	268	497	345	259
Chloride (ppm)	9	5	1460	56	61
Sulphates (ppm)	20.51	49.47	84.81	80.1	57.08
Sodium (ppm)	8.79	5.26	719.99	20.14	27.72
Zinc (ppm)	0.02	0.03	0.07	0.05	0.04
Manganese (ppm)	<0.01	<0.01	0.22	0.02	0.1
Copper (ppm)	<0.01	<0.01	<0.01	<0.01	<0.01
Iron (ppm)	0.37	0.44	0.35	0.02	0.21
Boron (ppm)	0.03	0.06	0.05	0.08	0.04
Molybdenum (ppm)	0.02	0.01	0.01	0.03	<0.01

Table F. 8 Concentrations of target species in tile drains and surface waters sampled at study sites in July, 2015

	Prism Tile	Cecelia East Pond	Warkentin South Ditch	Warkentin Tile Box	Warkentin Tile BOX (after application)
pH	7.44	6.88	7.87	7.67	7.87
Bromide (ppm)	<0.50	<0.50	<0.10	<0.10	<0.10
Nitrate Nitrogen (ppm)	0.56	188	31.4	6.31	5.32
Phosphorus (ppm)	0.168	28.5	0.1	<0.030	<0.030
Potassium (ppm)	8	198	22.9	13	17.1
Calcium (ppm)	80	195	96.2	85.9	81.4
Magnesium (ppm)	20.3	50	21.5	23.9	23.8
Chloride (ppm)	12	22.1	51.9	49	49.4
Sulphates (ppm)	40.1	232	81.6	68.8	79.4
Sodium (ppm)	9.46	24.8	18.2	5.59	5.99
Zinc (ppm)	<0.0030	0.16	0.0086	0.0042	<0.0030
Manganese (ppm)	0.04	0.095	0.0172	0.0292	0.0084
Copper (ppm)	0.0023	0.062	0.0037	0.001	0.0025
Iron (ppm)	0.28	0.5	0.057	0.05	<0.050
Boron (ppm)	0.11	0.53	0.096	0.277	0.272
Molybdenum (ppm)	0.00586	0.0484	0.00453	0.00334	0.00473
Silicon (ppm)	5.3	<10	4.8	5.2	4.7
Aluminum (ppm)	0.18	0.13	0.053	0.092	0.035
Arsenic (ppm)	0.0027	<0.010	<0.0010	<0.0010	<0.0010
Cadmium (ppm)	<0.000090	<0.00090	<0.000090	0.000091	<0.000090
Chromium (ppm)	0.00052	<0.0050	<0.00050	0.0005	<0.00050
Cobalt (ppm)	<0.00050	<0.0050	<0.00050	0.0005	<0.00050
Lead (ppm)	<0.00050	<0.0050	<0.00050	0.0005	<0.00050
Mercury (ppm)	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Nickel (ppm)	0.0029	<0.010	0.0032	0.0029	0.0013
Selenium (ppm)	<0.00040	<0.00040	0.00082	<0.00040	<0.00040

Table F. 9 Concentrations of target species in tile drains and surface waters sampled at study sites in July 12, 2015 48 hrs after application

	Prism Tile (Not Running)
pH	7.29
Bromide (ppm)	< 3
Nitrate Nitrogen (ppm)	11
Phosphorus (ppm)	<1
Potassium (ppm)	43.34
Calcium (ppm)	89
Magnesium (ppm)	24.79
Chloride (ppm)	29
Sulphates (ppm)	175.05
Sodium (ppm)	29.13
Zinc (ppm)	0.04
Manganese (ppm)	0.03
Copper (ppm)	0.01
Iron (ppm)	1.29
Boron (ppm)	0.21
Molybdenum (ppm)	0.05
Silicon (ppm)	6.08
Aluminum (ppm)	0.017
Arsenic (ppm)	0.0021
Cadmium (ppm)	0.000028
Chromium (ppm)	0.00027
Cobalt (ppm)	0.000308
Lead (ppm)	0.00008
Mercury (ppm)	< 0.01
Nickel (ppm)	0.0091
Selenium (ppm)	0.00070

Figure F. 1 Groundwater level fluctuations recorded in PG598

*Dash line: Estimate of overall trend of groundwater levels without anthropogenic influences such as water sampling.

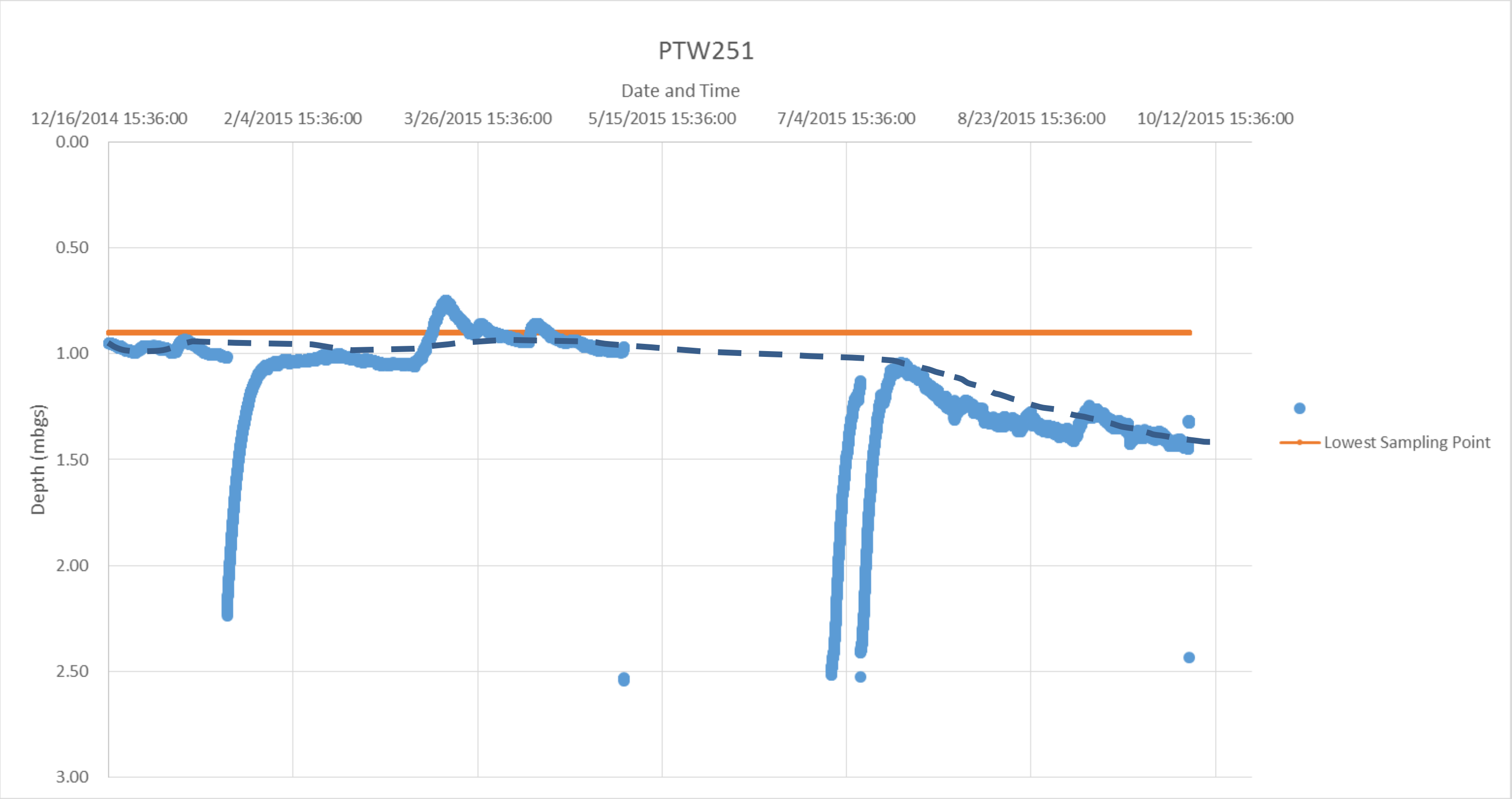


Figure F. 2 Groundwater level fluctuations recorded in PTW251

*Dash line: Estimate of overall trend of groundwater levels without anthropogenic influences such as water sampling.

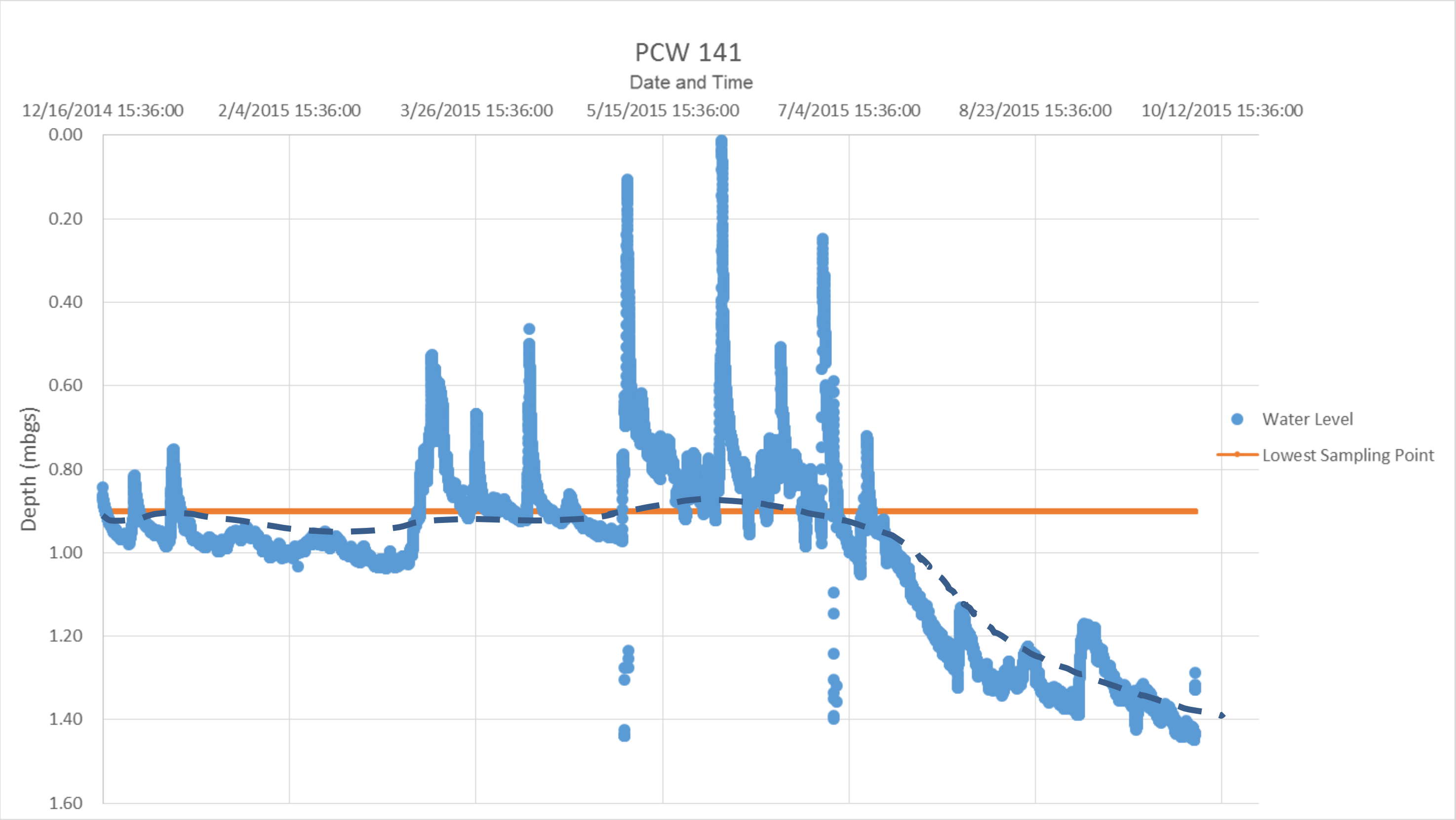


Figure F. 3 Groundwater level fluctuations recorded in PCW251

*Dash line: Estimate of overall trend of groundwater levels without anthropogenic influences such as water sampling.

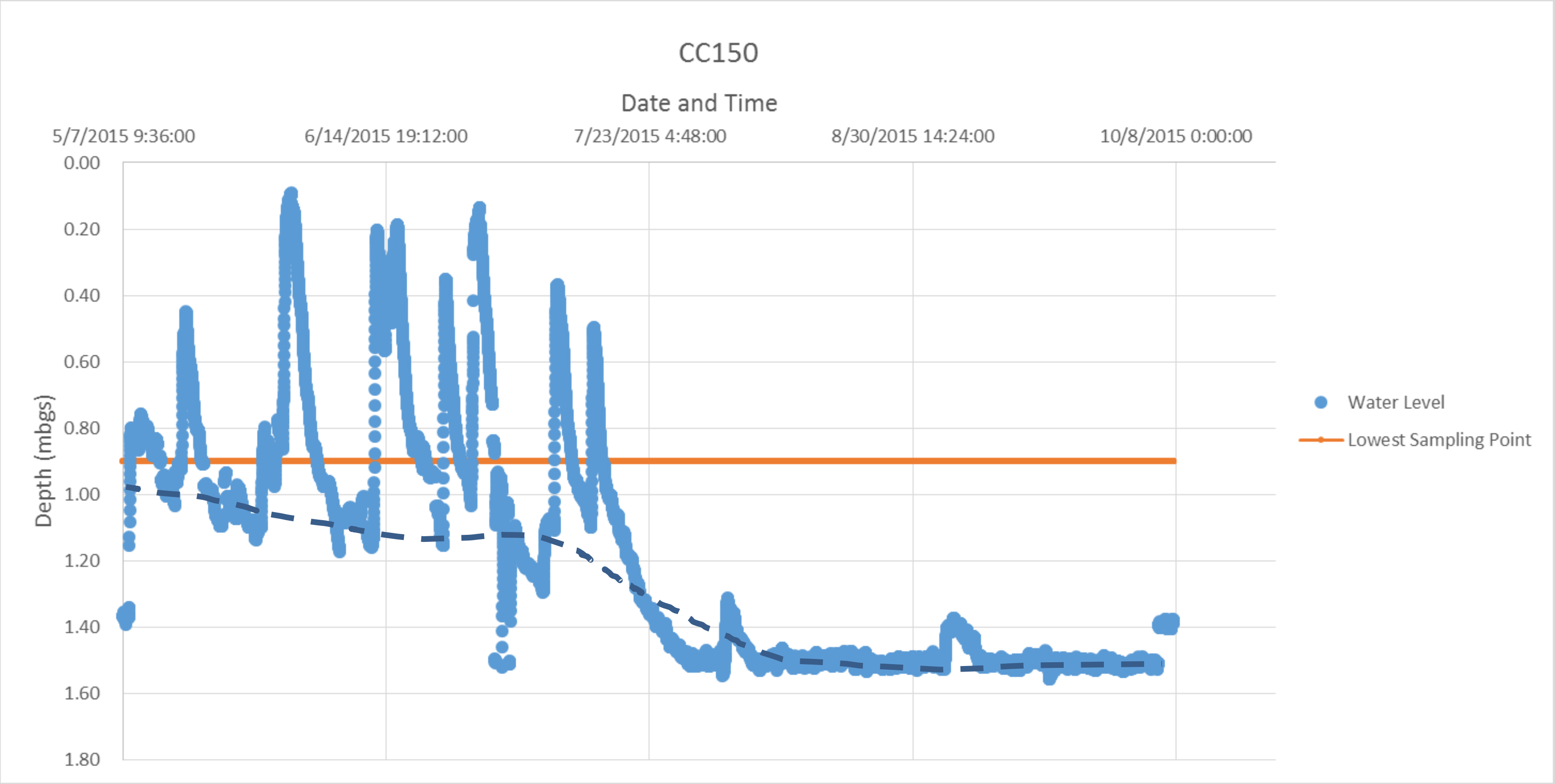


Figure F. 4 Groundwater level fluctuations recorded in CC150

*Dash line: Estimate of overall trend of groundwater levels without anthropogenic influences such as water sampling.

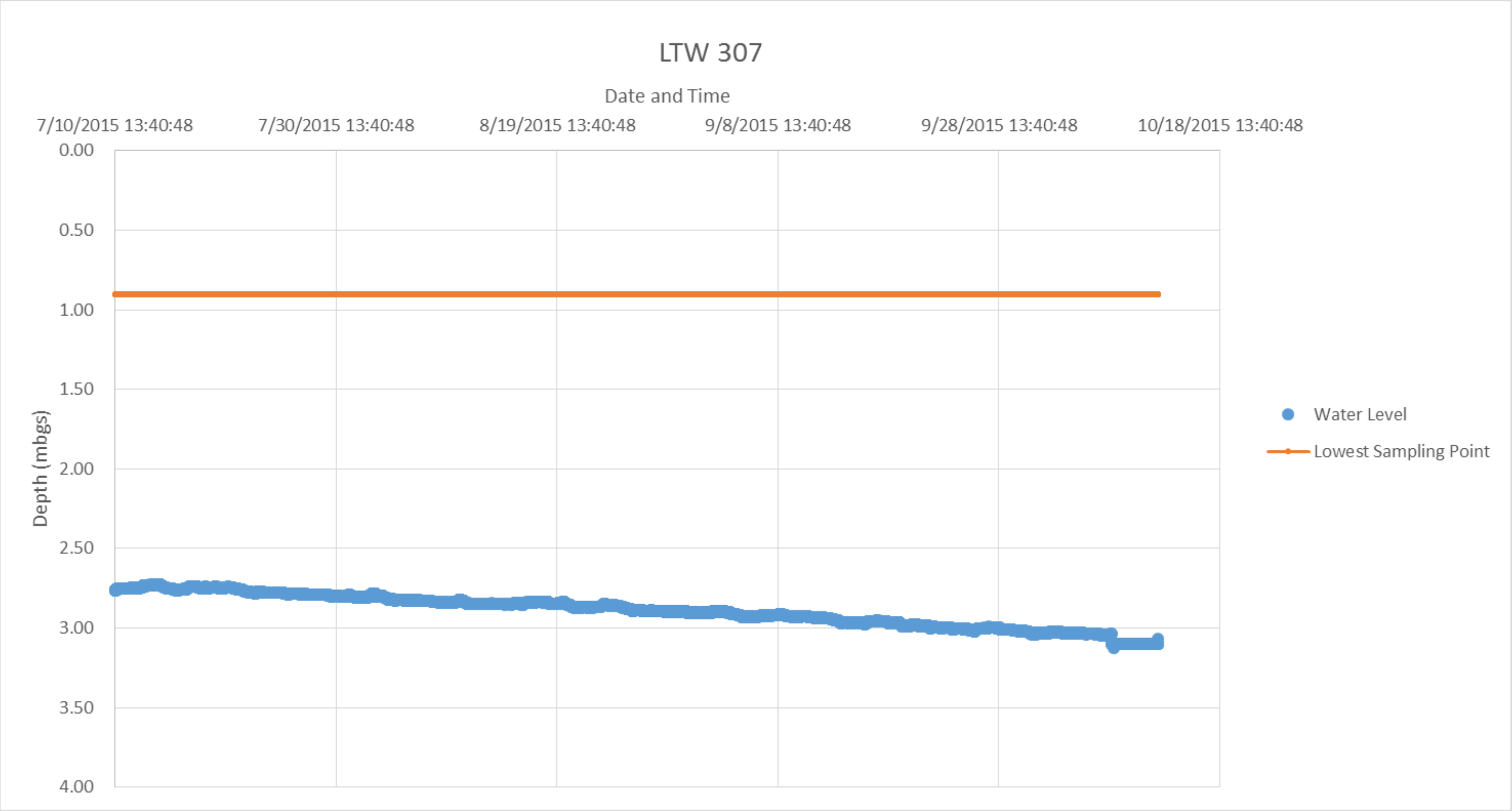


Figure F. 5 Groundwater level fluctuations recorded in LTW 307

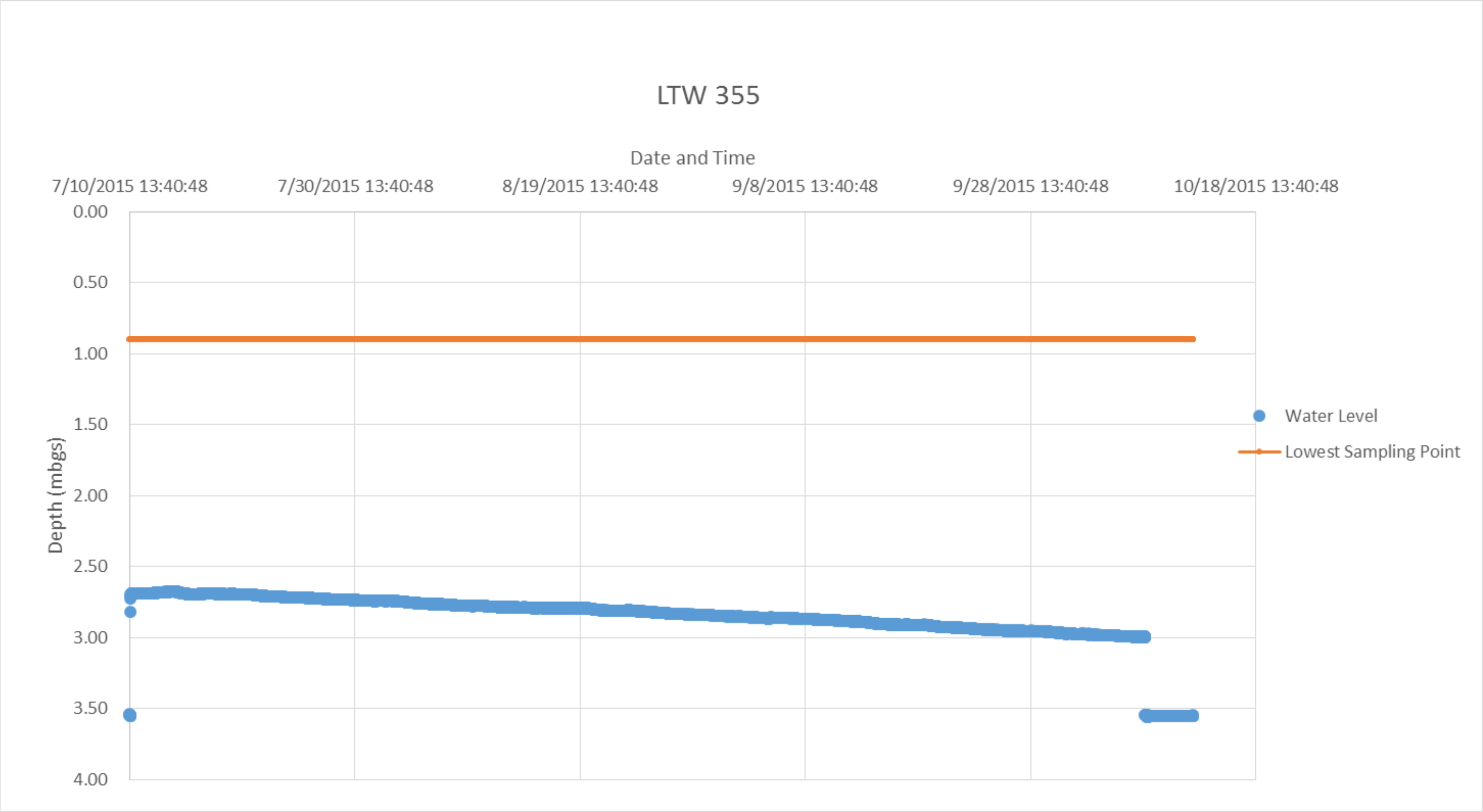


Figure F. 6 Groundwater level fluctuations recorded in LTW 355

Appendix G

Precipitation Data Recorded During the Experiments

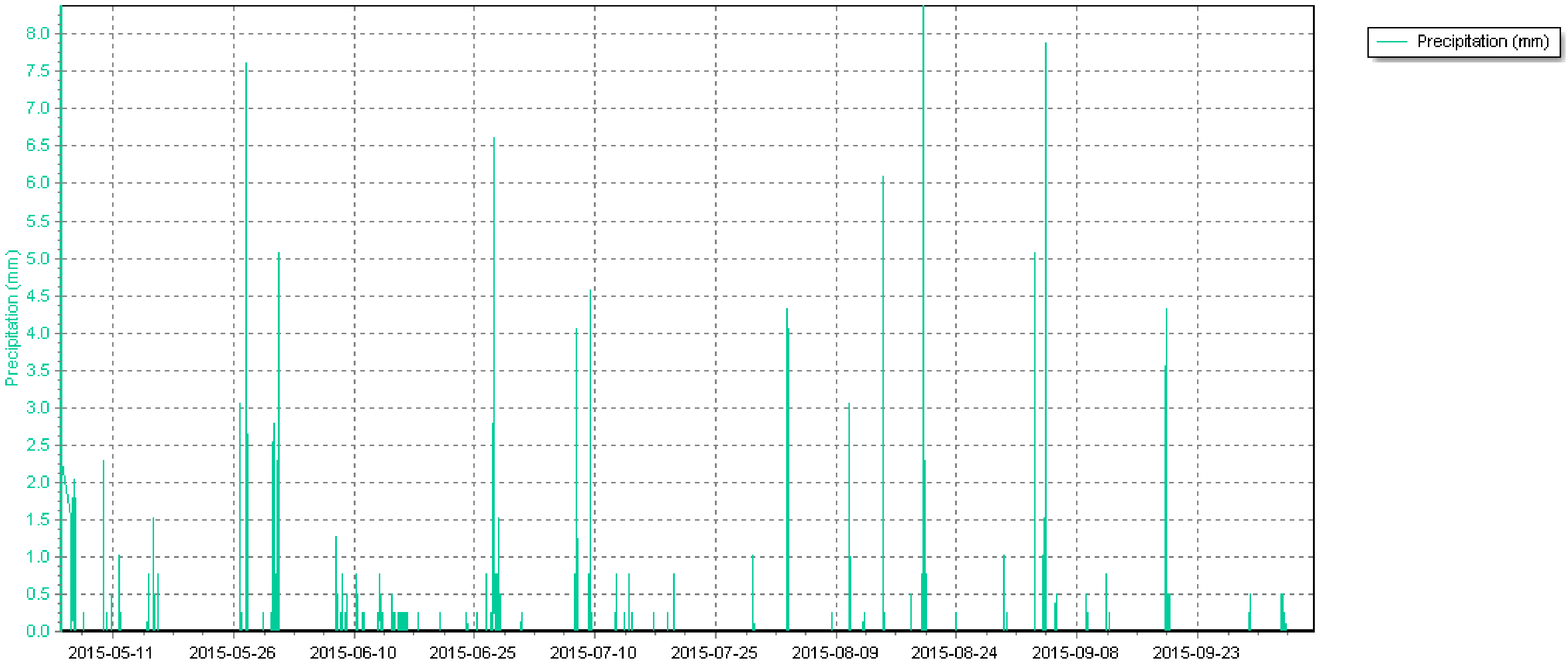


Figure G. 1 Precipitation (mm) data collected every 15 min in Leamington Area

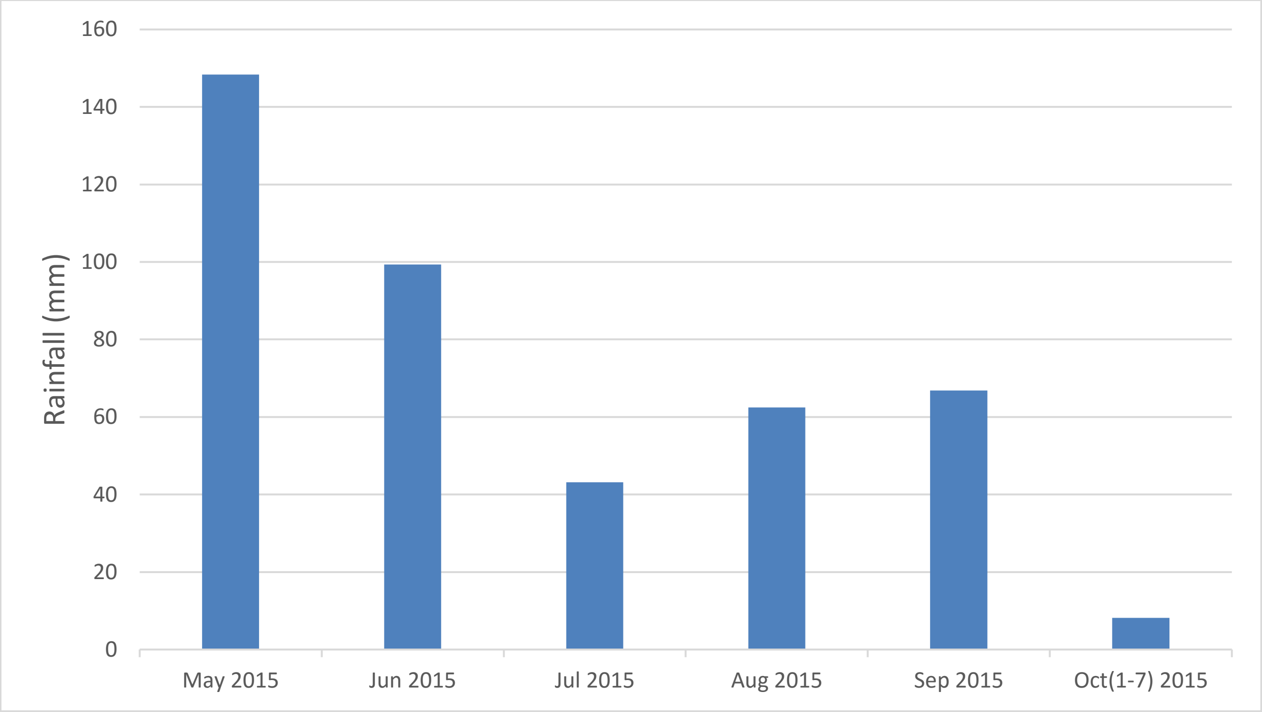


Figure G. 2 Monthly Rainfall (mm) data collected at Study Area (Total rainfall: 428.24mm)

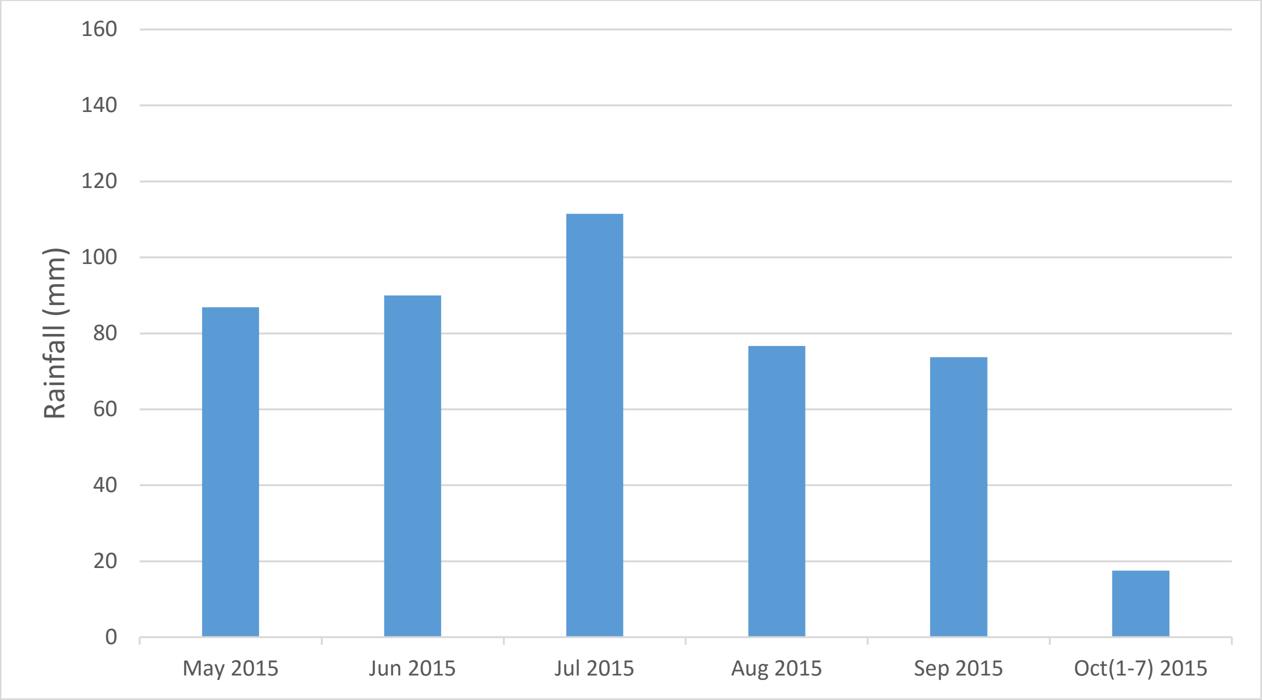


Figure G. 3 Average Monthly Rainfall (mm) in Study Area (2009-2014) (Total rainfall: 456.28mm)

Source: Historical climate data derived from Environmental Canada data base: http://climate.weather.gc.ca/index_e.html

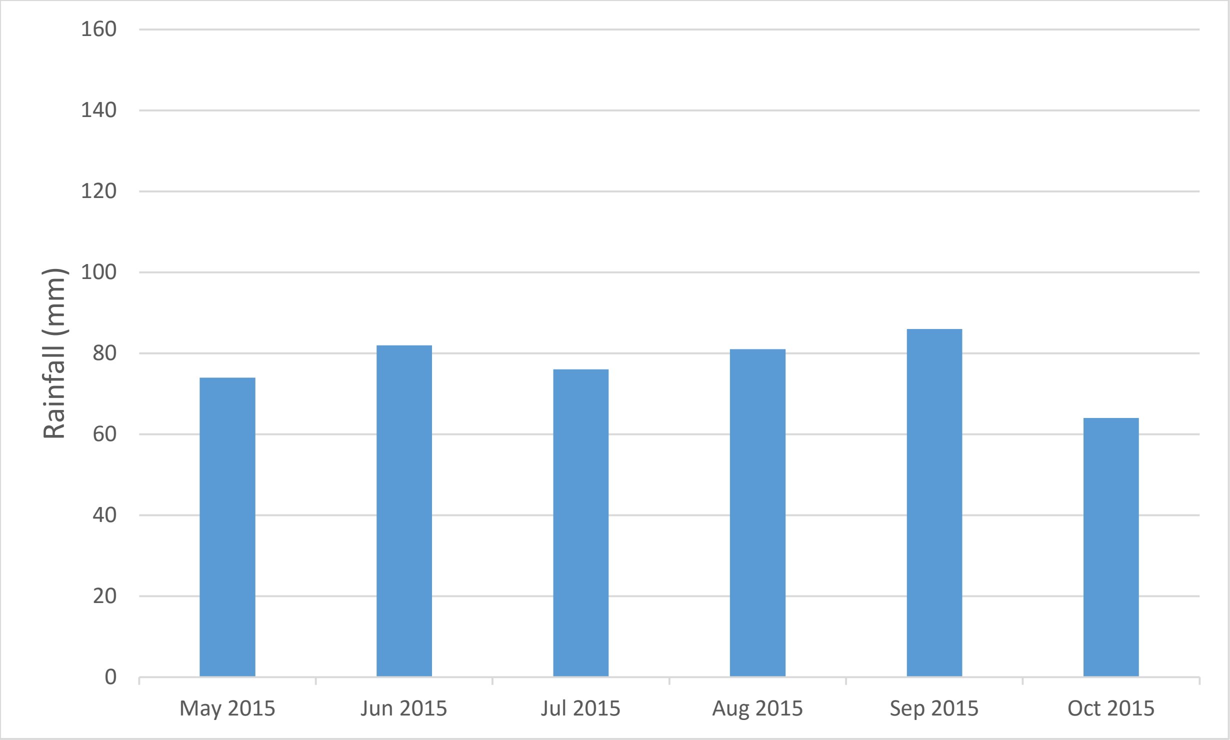


Figure G. 4 Average Monthly Rainfall (mm) in Study Area (30 years coverage) (Total rainfall: 463mm)

Source: Historical climate data derived from The Weather Network: http://www.theweathernetwork.com/forecasts/statistics/summary/cl6134190/caon0350

Appendix H

Calculations on Annual Total Nutrient Loading from Greenhouses

According to the information provided by Soil Resource Group in Greenhouse Process Water Quality and Quantity Characterization Analysis Final report (2012), the most common greenhouse vegetable types in this region are tomato, peppers and cucumbers. It also assumed that the percentages of these vegetable types of all greenhouse operations are 40%, 40% and 20% respectively. As presented in Table H.1 and Table H.2, each type of greenhouse vegetables have unique leach volume and different chemical concentrations of nutrients in unused greenhouse feed water. The annual mass of nutrients in unused greenhouse feed water for specific vegetable type is derived by the equation given as follows:

$$\begin{aligned}\text{Annual Nutrient Flux} &\\ &= \text{Total Greenhouse Area(A)} \times \text{Vegetable Type Percentage}(\alpha) \\ &\times \text{Annual Leach Volume by crop(V)} \times \text{Nutrient Concentration by crop}(C_n)\end{aligned}$$

According to the census of agriculture conducted by Statistics Canada (2011), the total greenhouse area in Essex is counted to be 6215010 square meters. Therefore, the annual mass loading of nutrients from greenhouses is presented in Table H.3.

Table H.1 Annual Leach Volume of Different Greenhouse Vegetable Types

Crop type:	Percentage of Total Greenhouse	Average fraction not recycled	Leach volume (L/sq ft/yr)*
Tomato (n=5)	40	5%	2.223
Peppers (n=4)	40	5%	4.995
Cucumbers (n=3)	20	6.7%	2.920

***** Leach volume by crop calculated using the sum of seasonal leach volumes.

$$\textbf{seasonal leach volume} = \textbf{seasonal feed water yield} \times \textbf{seasonal leach out persent} \times \textbf{fraction of leach not recycled} \times \textbf{time (90days)}$$

Source: Greenhouse Process Water Quality and Quantity Characterization Analysis Final report, 2012

Table H. 2 Average Nutrient Concentrations* in Different Greenhouse Operations

	pH	EC(mmhos/cm)	NO3-N(ppm)	P(ppm)	K(ppm)
Tomato	5.7	4.4	328.1	101	492.2
Peppers	6	2.9	232.4	83.4	322.4
Cucumbers	5.3	3	244.3	74	210.3
Transplant	NA	3.1	230.6	23.9	NA

Source: Greenhouse Process Water Quality and Quantity Characterization Analysis Final report, 2012.

* Average concentrations of leachate from spring, summer and fall.

Table H. 3 Annual Effluent from Greenhouses in Essex Region (metric tonnes)

	NO3-N	P	K
Tomato	20.75	6.38	31.12
Peppers	33.01	11.84	45.80
Cucumbers	10.14	3.07	8.73
Total	63.90	21.30	85.66

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