Credit Valley Conservation

Terrestrial Monitoring Program Report

2006 - 2008

Monitoring Wetland Integrity within the Credit River Watershed
Chapter 1: Wetland Hydrology and Water Quality

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Monitoring Wetland Integrity within the Credit River Watershed

Chapter 1: Wetland Hydrology and Water Quality 2006-2008

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ABSTRACT

Wetland Hydrology and Water Quality in the Credit River Watershed Summary of Monitoring Results 2006-2008
Water Quality: Currently, it is not feasible to compare water quality between sites or draw conclusions about quality of water at each site. The preliminary summary assessed water quality results in terms of the Ontario Provincial Water Quality Objectives (PWQO's) and Ontario Drinking Water Standards (ODWS's) for each site to provide some basis for presenting water quality information, although these guidelines were not developed specifically for wetlands. In groundwater samples, only uranium concentrations at Speersville exceeded the ODWS'S. Therefore, the groundwater at all other sites was in compliance with drinking water standards. The PWQO's were exceeded at all three sites where surface water was sampled. One parameter only was exceed at both Belfountain (total phosphorus) and Speersville (zinc), while aluminum, iron and total phosphorus guidelines were all exceeded at Warwick.
Hydrology: Four of the seven hydroperiod classes were represented by monitored wetlands, with Saturated wetlands being the most common. Wetlands fed through surface water inputs appeared more dominant that groundwater fed wetlands. Monitored wetlands tended to be wettest in the spring and early summer, which is consistent with snow melt and high rainfall during these times. Wetlands were driest in late summer and fall due to higher temperatures and lower rainfall. As more data become available with additional years of monitoring, hydrological classifications of the monitored wetlands will be refined and significant trends may be elucidated.
Recommendations: To measure water quality, the use of a Water Quality Index (WQI) developed specifically for inland wetland surface waters would allow both temporal and spatial comparison of wetland water quality within the watershed. Budget and time constraints need to be examined closely in order to determine if a WQI is a feasible indicator to add to wetland monitoring. Before piezometer installation occurs it is recommended that a detailed methodology for the hydrology component be developed. This will ensure that resources are used in the most optimal fashion to acquire high quality data and that hydrological monitoring will be performed consistently into the future.

Wetland hydrology and water quality monitoring was conducted as part of the terrestrial component of an overall Integrated Watershed Monitoring Program established at Credit Valley Conservation. Eighteen permanent wetland monitoring sites were established in 2002 throughout the Credit River Watershed for the initial purpose of monitoring changes in vegetation. In 2006, piezometers were installed to monitor surface and groundwater levels and water quality at a select group of monitored wetlands to develop an understanding of site hydrology.

Currently, it is not feasible to compare water quality between sites or even draw conclusions about the state of the quality of water at each individual site. The preliminary summary of the water quality results are presented in terms of the Ontario Provincial Water Quality Objectives (PWQO's) and Ontario Drinking Water Standards (ODWS's) for each individual site to provide some basis for presenting water quality information, even though these guidelines are not developed specifically for wetlands. In groundwater samples, only uranium concentrations at Speersville exceeded the ODWS'S. Therefore, the groundwater at all other sites was in compliance with drinking water standards. PWQO's were exceeded at all three sites where surface water was sampled. One parameter only was exceed at both Belfountain (total phosphorus) and Speersville (zinc), while aluminum, iron and total phosphorus guidelines were all exceeded at Warwick.

Four of the seven hydroperiod classes (Mitsch and Gosselink 2007) were represented in the watershed, with Saturated wetlands being the most common. All four of the groundwater flow patterns (Mitsch and Gosselink 2007) were represented in monitored wetlands; however, wetlands fed through surface water inputs appear to be more common than groundwater fed wetlands. Monitored sites tended to be wettest in the spring and early summer, which is consistent with snow melt and high rainfall during these times. Wetlands were driest in late summer and fall due to higher temperatures and lower rainfall. As more data become available with additional years of monitoring, hydrological classifications of the monitored wetlands will be refined and significant trends regarding changes in hydrology will be better elucidated.

In order to examine temporal and spatial trends in wetland surface water quality, the use of a Water Quality Index (WQI) developed specifically for this application would be ideal. There are a variety of options for developing a water quality monitoring program around this WQI; however, it must fist be confirmed that this coastal wetland WQI is applicable in inland wetlands as well. In addition, budget and time constraints need to be examined closely in order to determine if the addition of the WQI is feasible for the program. Plans have already been made to expand the hydrology portion of the wetland monitoring program through the planned installation of 3 piezometers at each wetland site. The addition of these piezometers will assist in confirming the preliminary hydrological classifications in this report as well as complementing data already collected on flora and fauna indicators at the permanent wetland plots. This will allow the program to link observed trends to understand the relationships between water quality, wetland hydrology, plant and animal communities more holistically.

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1.0 INTRODUCTION

1.1 BACKGROUND

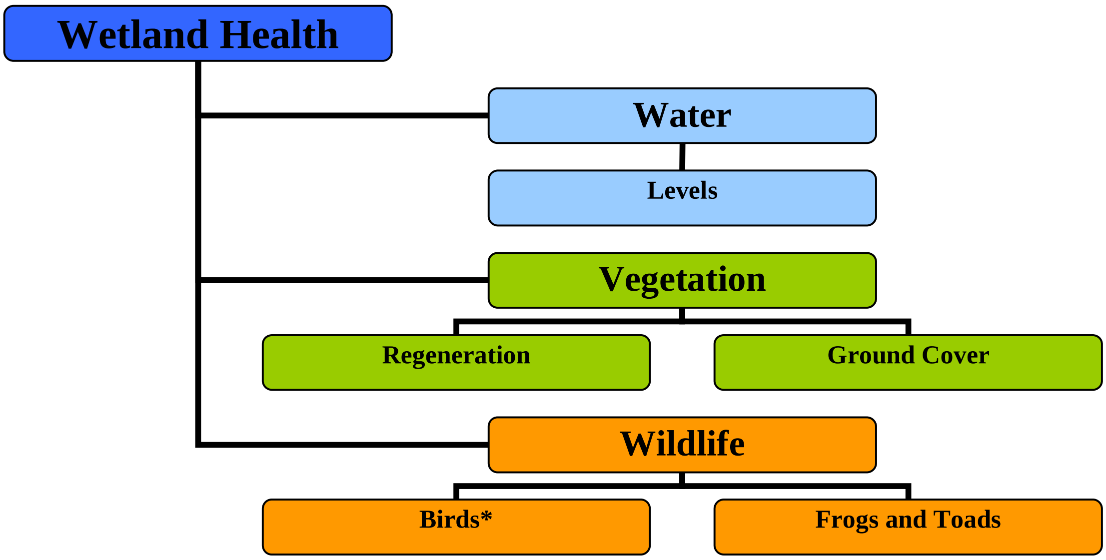
Wetlands provide numerous, irreplaceable hydrological and ecological functions, including stabilization of water supplies, flood abatement, water purification, erosion control, recharge of groundwater aquifers and carbon sequestration (Zedler and Kercher 2005; Mitsch and Gosselink 2007). Despite these benefits, wetlands have historically been viewed as unsightly waste areas and were often drained and filled to accommodate agriculture (Grand River Conservation Authority 2003). Approximately 70% of original wetland area within southern Ontario is estimated to have been drained for agricultural purposes, with the proportion increasing to over 80% near major urban centres (Natural Resources Canada 2009).

The types of alterations which lead to wetland degradation can be grouped into four categories, including: a) geomorphic and hydrologic, b) nutrient and contaminant, c) harvest, extinction and invasion, and d) climate change (Brinson and Malvarez 2002; Zedler and Kercher 2005). Current stressors specific to wetlands within the Credit River Watershed include habitat removal, nutrient enrichment, organic loading, contaminants (e.g. road salts), sedimentation, turbidity, thermal changes, dehydration, inundation, exotic species, habitat fragmentation, climate change and unsustainable use (e.g. species harvesting) (Dougan and Associates 2009). The relative impact of each of these processes on wetland health within the watershed is still unknown. Through monitoring wetlands as part of the Terrestrial Monitoring Program, it is hoped that a deeper insight into the impact of each of these processes will be gained. This will help to guide future adaptive management and restoration efforts within the Credit River Watershed.

1.2 THE IMPORTANCE OF LONG-TERM MONITORING

There is an increasing demand for better accounting of the state and health of the environment to determine whether conditions are improving or deteriorating (Niemi and McDonald 2004). An ecological monitoring program increases understanding of the trends, processes, structure and composition of a given ecosystem. A superior monitoring program should address both biotic and abiotic components across multiple scales. Monitoring is useful in providing managers with information that can be used for long-term planning because temporal trends can be employed to infer future conditions. From an ecological perspective, a monitoring program can also provide insight into cause and effect relationships between environmental stressors and ecosystem responses (Reeves et al. 2004).

Within the Credit River Watershed, 18 wetland monitoring stations have been established in which soil and vegetation parameters are measured to describe wetland conditions in the watershed and to monitor trends over a 25 year period (Fig. 1). Information gathered over time will enable the detection of changes in ecosystem structure and function and will be used to guide watershed-level management decisions.



* monitoring will begin in 2009

Figure 1. Wetland health parameters in the Credit River Watershed.

1.3 WHY MONITOR WETLAND HYDROLOGY AND WATER QUALITY?

Hydrology is possibly the most important factor for the establishment and maintenance of specific wetland types and processes (Mitsch and Gosselink 2007). It is an important component of the cycle that determines the conditions and biota within a wetland (Fig. 2). Hydrologic conditions affect many abiotic factors (e.g. soil anaerobiosis and nutrient availability) which are, in turn, responsible for the development of the biota within the wetland. This, consequently, can actively alter the wetland hydrology and physiochemical features (Mitsch and Gosselink 2007). Improved understanding of wetland function can be gained through the study of hydroperiod, water budget and water turnover time. In wetlands, hydrology can affect species composition and richness, primary productivity, organic accumulation and nutrient cycling (Mitsch and Gosselink 2007). Monitoring wetland hydrology also allows for detection of the impacts of climate change. As the climate becomes warmer, it is expected that wetland communities will transition to drier habitat types: marsh, fen and bog communities changing to swamp communities and swamps to non-wetland communities (Dougan and Associates 2009). By monitoring yearly wetland hydroperiods, detection of long-term changes to wetland hydrology should be possible.

Although wetlands are known to have the ability to cleanse contaminated water flowing into them, this contamination may negatively affect wetland biota. Wetlands may be damaged through high levels of sediment, nutrients, metals and toxic compounds (Albert and Minc 2004; Mitsch and Gosselink 2007). Sedimentation may result in high turbidity, which can lead to inadequate conditions for many aquatic macrophytes and algae to photosynthesize and survive (Albert and Minc 2004). In addition, seed germination of both emergent and submergent aquatic plants can be lost due to the deposition of thick sediments. This deposition can lead to a severe decline in plant diversity in the submergent zone. Aggressive colonizers such as Dock-leaf Smartweed

(*Polygonum lapathafolium*), Nodding Beggar-ticks (*Bidens cernua*), Spotted Touch-me-not (*Impatiens capensis*), Rice Cutgrass (*Leersia orizoides*), Bog Yellow-cress (*Rorippa palustris*), Purple Loosestrife (*Lythrum salicaria*), Common Reed (*Phragmites australis*) and Reed Canary Grass (*Phalaris arundinacea*) may take the place of other less aggressive emergent species (Albert and Minc 2004). Nutrient loading may be caused by sewage effluent or fertilizers from agricultural activities. Water carrying high levels of nutrients can result in eutrophication and associated increases in productivity, followed by increased decay rates and higher community respiration rates (Mitsch and Gosselink 2007). Nutrient enrichment can also lead to high production of blue-green algae and several species of floating-leaved plants including Duckweed (*Lemna spp.* and *Spirodela spp.*) and Watermeal (*Wolfia spp.*). Dense growth of these plants can limit available light for submergent aquatic flora (Albert and Minc 2004). Therefore, monitoring wetland water quality can identify areas where urbanization and agricultural practices are impairing water quality and if changes in water quality are occurring over time.

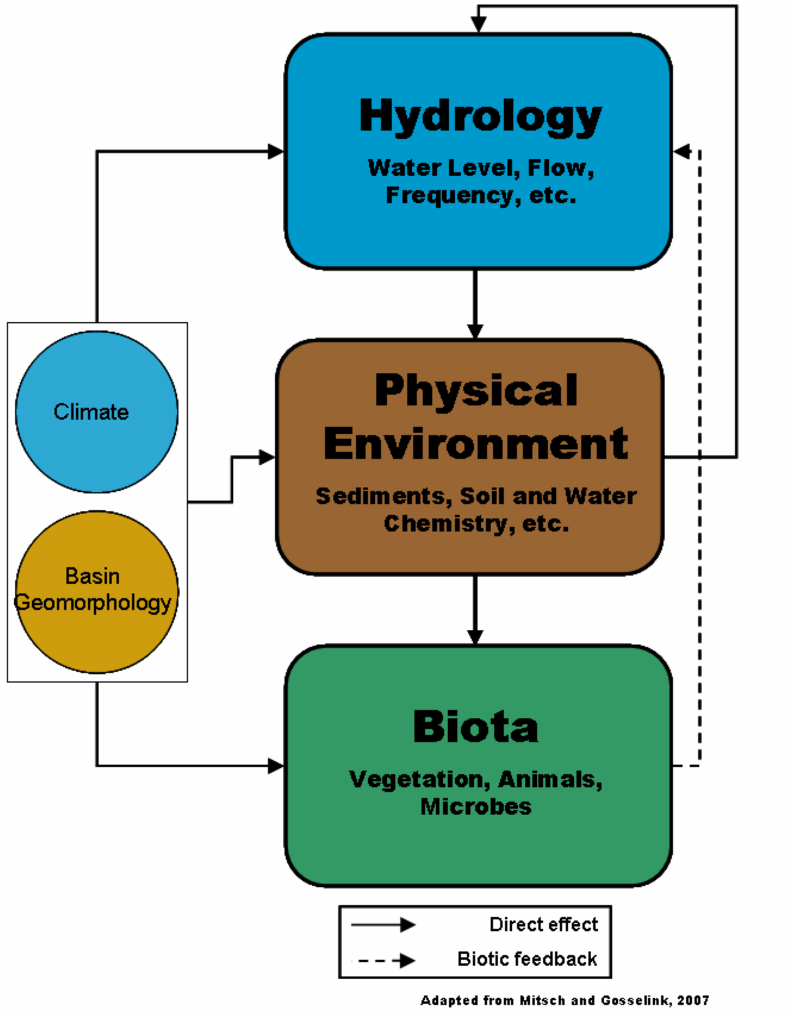


Figure 2. Conceptual diagram illustrating the effects of hydrology on wetland function and the biotic feedbacks that affect wetland hydrology (Adapted from Mitsch and Gosselink 2007).

1.4 WETLAND HYDROLOGY AND WATER QUALITY IN A CHANGING LANDSCAPE

The Credit River Watershed encompasses 950 square kilometres of land in southern Ontario, Canada (Credit Valley Conservation 2003). The Credit River flows southeast for nearly 100 km from its headwaters in Orangeville to its drainage point at Lake Ontario. It has been estimated that 33% of wetlands in the watershed have been lost (Dougan and Associates 2009). Most of this loss has occurred in areas where urban development has been most prominent. The watershed is comprised of 23% natural communities, 11% successional communities, 37% agricultural land use, and 29% urban area (Credit Valley Conservation 2007a).

Though encompassing many unique landscape formations, the Credit River Watershed can be divided into three main physiographic zones based on topography, physiographic regions and subwatershed boundaries (Fig. 3) (Credit Valley Conservation 2007b). The Lower physiographic zone is highly urbanized, containing over 85% of the population of the watershed. The topography of this area is relatively flat with a gentle slope towards Lake Ontario and it has been significantly altered by human development. The Lower watershed is comprised of lower permeability sediments, such as silt and clay till, lying on top of Georgian Bay and Queenston shales (Credit Valley Conservation 2007b). The soils in the Lower zone are comprised of clay loams associated with the Peel Plain and the South Slope physiographic regions (Credit Valley Conservation 2007b). These soils have low permeability in relation to the rest of the watershed; however, localized pockets of sand and gravel exist. When compared against government standards (Environment Canada 2004), the amount of both wetland and forest cover in the Lower watershed is classified as poor.

The Middle zone contains the Niagara Escarpment, a landform comprised of steep slopes, rocky outcrops, and thin soil (Credit Valley Conservation 2005); much of this zone is protected under the Greenbelt Plan (OMMAH 2005). The steep topography of this area leads to relatively high runoff volumes and velocities; however, the high forest cover slows runoff and increases infiltration. Soils in this zone are variable as a result of the changing physiography between the Upper and Lower zones (Credit Valley Conservation 2007b). The east portion of this zone is underlain by Queenston Shale, whereas the west portion is underlain by dolomite of the Amabel/Lockport Formation. Surface geology is dominated by silt to clay tills and silty sand to sandy silt, with pockets of ice-contract stratified drift and bedrock or bedrock drift (Credit Valley Conservation 2007b). Due to topographic factors, lower levels of urbanization and protective legislation, the Middle zone contains the greatest proportion of natural cover in the watershed.

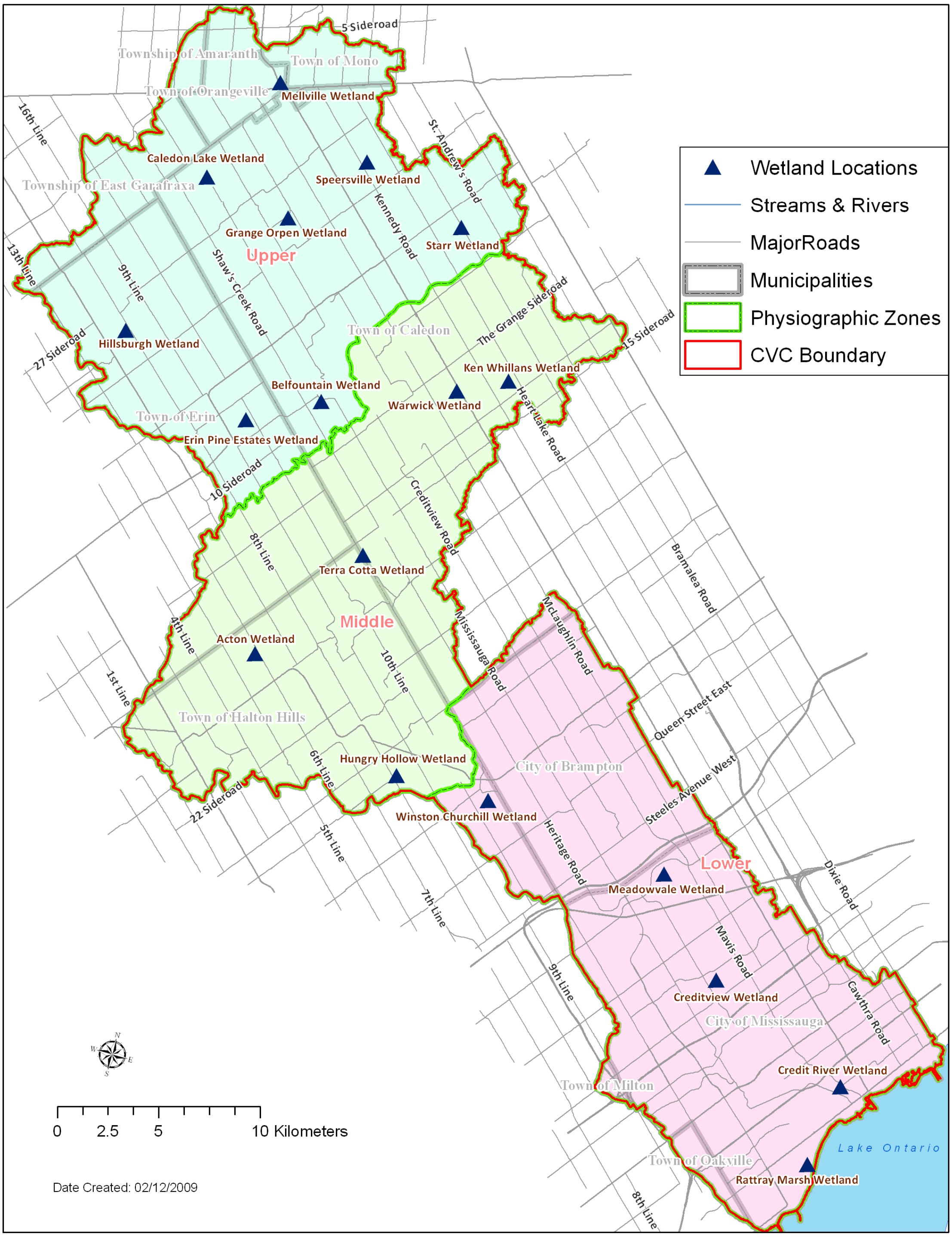


Figure 3. Wetland monitoring site locations in the Credit River Watershed.

The Upper physiographic zone lies above the escarpment and is characterized by till plains, moraines and glacial spillways (Credit Valley Conservation 2007b). This area is dominated by sandy loam soils that are associated with the Guelph drumlin field and the Hillsburgh Sandhills (Credit Valley Conservation 2007b). The high groundwater recharge rates in the Upper watershed are supported by the relatively high permeability rates of these soils. The Amabel/Lockport Formation is the dominant bedrock type in this area with pockets of the Guelph and Manitoulin dolostones (Credit Valley Conservation 2007b). Surficial geology is dominated by ice-contact stratified drift, silty sand to sandy silt and glaciofluvial gravel. Agricultural land use dominates portions of the Upper watershed, though it also contains several large wetland complexes and numerous headwater streams (Credit Valley Conservation 2007b).

Scientific research in Ontario has demonstrated that in order for good water quality to be maintained, the proportion of undeveloped land in a watershed should remain above 50% (Chow-Fraser 2006). Watersheds with predominantly agricultural land use tend to have the lowest water quality, followed closely by those watersheds dominated by urban uses (Chow-Fraser 2006). Overall, changes in landscape metrics have the ability to alter ecosystem processes, nutrient availability and water availability. All of these changes can alter wetland water quality in the watershed. Therefore, observed trends will be considered in the context of the changing landscape of the Credit River Watershed.

1.5 OBJECTIVE: MONITORING QUESTIONS

WHAT IS THE CURRENT STATE OF WETLAND WATER QUALITY AND HYRDOLOGY IN THE WATERSHED?

HOW CAN WETLAND WATER QUALITY AND HYRDOLOGY MONITORING IN THE WATERSHED BE IMPROVED?

More specifically, 1) in 2006, what was the level of groundwater and surface water quality at wetland monitoring sites?; 2) what were the apparent trends in hydrology at wetland monitoring sites between 2006 and 2008?; 3) what improvements can be made to the water quality and hydrology portion of the wetland monitoring program (Table 1)?

Table 1. Wetland water quality and hydrology monitoring framework for the Credit River Watershed between 2006 and 2008.

Monitoring Question	Monitoring Variable	Unit of Measurement	Analysis Method
Did any tested water quality parameters exceed PQWO and ODWS guidelines?	Inorganics and Metals	various	Comparison with PWQO and ODWS Guidelines
What were the apparent trends in hydrology at wetland monitoring sites?	Water Depth	meters	Descriptive

2.0 METHODS

2.1 WETLAND HEALTH MONITORING

Eighteen permanent wetland monitoring sites were established in 2002 throughout the Credit River Watershed. These sites were monitored for changes in vegetation from 2005 to 2010. The wetland sites represent 6 swamp and 12 marsh communities (Appendix A). The monitored wetlands represent 11 Provincially Significant Wetlands (PSW's), 11 Environmentally Sensitive Areas (ESA's) and six Life Science Areas of Natural and Scientific Interest (ANSI). Wetland monitoring sites consisted of 12 paired sub-plots spaced ten metres apart, established along a 50 m linear transect, which ran along the wetland's hydrological gradient (from dry to wet).

In 2006, 12 Solinst Drive-Point shielded piezometers were manually installed to the depths specified in Table 2 at 11 of the 18 wetland monitoring sites (a nest of two piezometers was installed at Erin Pines Estate Wetland). In 2008, a thirteenth piezometer was added to Rattray Marsh. These piezometers were installed to monitor surface and groundwater levels at each wetland to develop an understanding of site hydrology. Sites were selected to accommodate various types of wetlands (i.e. groundwater fed versus surface water fed). Piezometers were installed at sites where there was typically standing water for 6 months of the year. At sites where standing water is typically present for shorter periods, a two piezometer nest was installed in order to obtain more accurate information about the site.

A piezometer is a small diameter well or pipe that is only partially screened and is designed to measure groundwater conditions at a single point within an aquifer (Fig. 4) (Commonwealth of Australia 2006; Mitsch and Gosselink 2007). Individual piezometers may be installed at a site in order to measure groundwater levels or a nest of piezometers may be installed, where each piezometer is installed to a different depth. Nested piezometers provide information regarding the vertical hydraulic gradient at any of the depths to which the piezometers are installed (Commonwealth of Australia 2006).

The piezometers used by CVC have a pointed shield at the end of the piezometer to allow direct installation into the ground without having to pre-drill a hole (Fig. 4). This shield must be removed from the end of the piezometer after installation to reveal the screening. In order to do this, after the piezometer has been installed to the desired depth, it must be pulled slightly back out of the hole to release the shield. This shield cannot be recovered if the piezometer is removed and needs to be reinstalled. Therefore, it is important that no rocks or impenetrable objects are present in the subsurface layer that would prevent the piezometer from reaching its desired depth. Therefore, the piezometer installation process is as follows (Fig. 5):

Table 2. Water quality analyses and water level measurements completed at wetland monitoring sites throughout the Credit River Watershed.

Site #	Site Name	Physiographic Zone	Wetland Type	Approximate Distance from Transect to Piezometer	Piezometer Depth (mbgs)	Ground and Surface Water Levels	Inorganics and Metals		Temperature, Dissolved Oxygen, Conductivity, pH	
							Groundwater	Surface Water	Groundwater	Surface Water
W-01	Rattray Marsh Wetland	Lower	Marsh	< 40m	2.75	X				
W-02	Credit River Wetland	Lower	Marsh	-- [a]	--					
W-03	Creditview Wetland	Lower	Marsh	--	--					
W-04	Meadowvale Wetland	Lower	Marsh	>50m	0.98	X			X	X
W-12	Winston Churchill Wetland	Lower	Marsh	--	--					
W-06	Hungry Hollow Wetland	Middle	Swamp	--	--					
W-07	Acton Wetland	Middle	Swamp	<15m	1.62	X	X		X	
W-08	Terra Cotta Wetland	Middle	Swamp	--	--					
W-09	Ken Whillans Wetland	Middle	Swamp	<15m	1.94	X	X		X	
W-10	Warwick Wetland	Middle	Marsh	<5m	1.85	X	X	X	X	X
W-11	Erin Pine Estates Wetland [b]	Upper	Marsh	<35m	1.01 Shallow 2.35 Deep	X	X		X	
W-13	Hillsburgh Wetland	Upper	Marsh	<15m	2.34	X	X		X	
W-15	Grange Orpen Wetland	Upper	Swamp	<5m	2.41	X	X		X	
W-16	Starr Wetland	Upper	Marsh	<30m	2.33	X	X		X	X
W-17	Speersville Wetland	Upper	Marsh	<5m	1.99	X	X	X	X	X
W-18	Caledon Lake Wetland	Upper	Swamp	--	--					
W-19	Melville Wetland	Upper	Marsh	<5m	2.2	X	X		X	
W-20	Belfountain Wetland	Upper	Marsh	<5m	1.79	X	X	X	X	X

[a] Indicates that a piezometer is not currently installed at the wetland monitoring site.
[b] Two piezometers installed at this site.

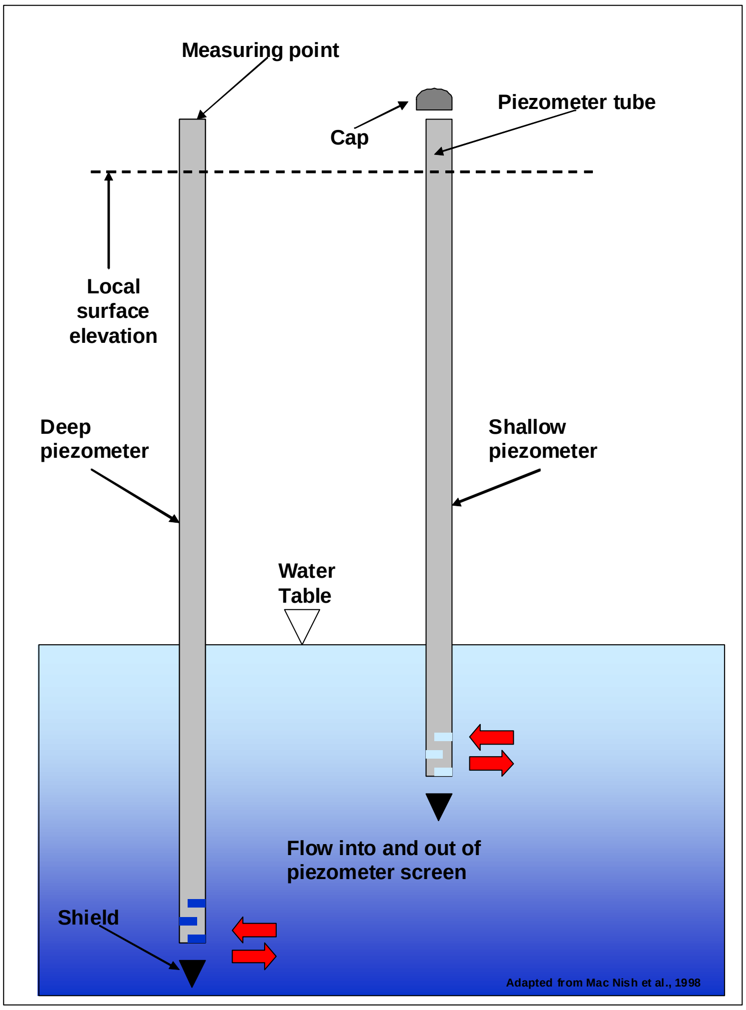


Figure 4. Example schematic of a piezometer nest (Adapted from Mac Nish et al. 1998).

1. A steel rod (A) may be hammered into the substrate using a manual slide hammer (B) previous to installing the piezometer to ensure that no impenetrable objects are present in the subsurface layer.
2. The steel rod is removed once it is determined that it is safe to install the piezometer.
3. The piezometer (C) is then hammered into the resulting hole using the manual slide hammer to the desired depth.
4. The piezometer is then pulled slightly back out of the hole to release the shield (D) located at the bottom of the piezometer.

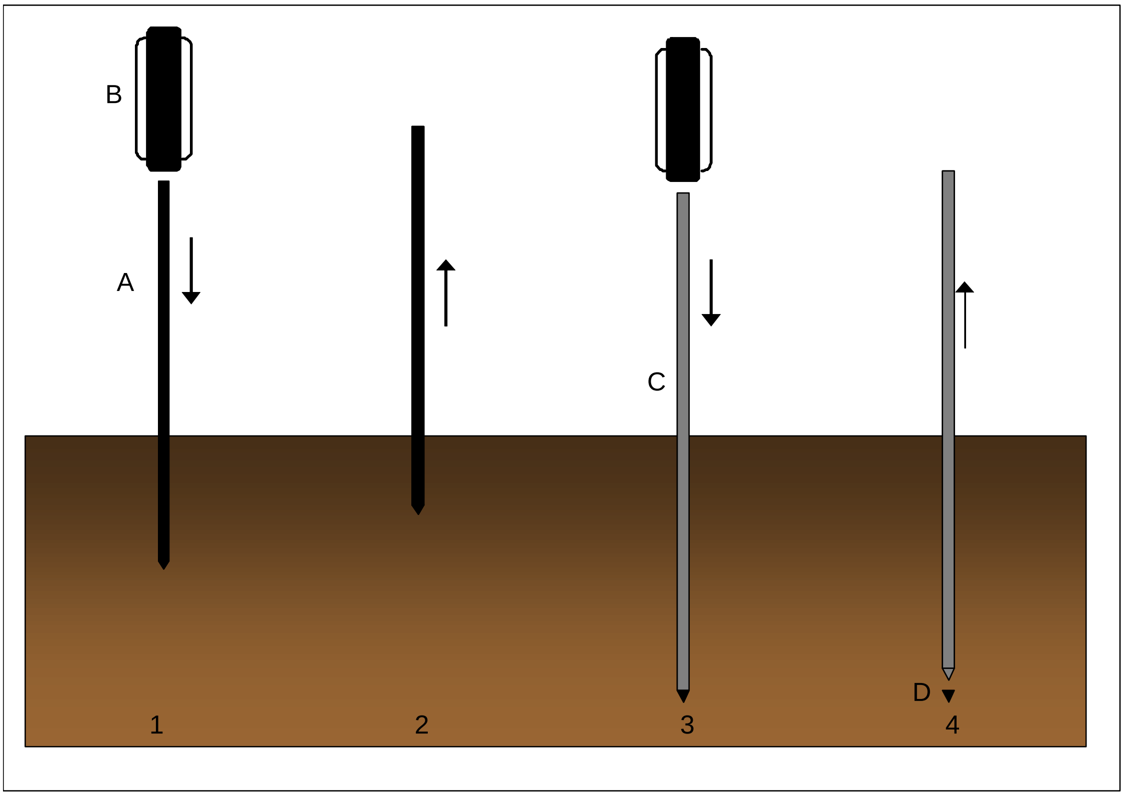


Figure 5. Piezometer installation process.

Groundwater depth is measured using a water level meter, which is a narrow measuring tape with a probe at the end. The tape is lowered into the piezometer and when the probe comes into contact with water, it activates a buzzer and light. The measurement is then taken from the specified measuring point at the top of the piezometer. The same water level meter can be used to measure surface water depth. This is done by measuring from the measuring point to the surface water and to the ground surface. Piezometers can also be used to sample groundwater quality using the water lift method as follows (CH2M Hill 2009):

1) A one-way check valve is installed in a length of Teflon or plastic tubing long enough to reach the bottom of the piezometer and facilitate easy dispensing of water into sample bottles.
2) The tubing is inserted into the piezometer.
3) The piezometer is purged by quickly raising and lowering the tubing in the piezometer to lift water past the check valve.
4) The piezometer should be purged once prior to taking a sample to ensure that the water is representative of *in situ* groundwater.
5) After the water in the piezometer has recharged, the piezometer is purged to acquire a groundwater sample. Piezometer recharge time will vary by site.
6) Sample water should be dispensed into labelled sample bottles and placed in a cooler until relinquished for analysis.

Water depth of both ground and surface water was measured at all piezometers approximately every 2 weeks from May until freeze (approximately October to December) from 2006 to 2008. In June 2006, at the time of piezometer instalment, water quality was sampled for the analysis of a suite of parameters, including inorganics and metals. Groundwater was sampled via the method described above. Surface water was sampled by obtaining a grab sample from standing water at the location of each piezometer, where water depth allowed. At Starr Wetland, a sample was also taken from the spring nearby the piezometer. Water samples were then sent to Maxxam Analytics Inc. for analysis. Field measurements including temperature, dissolved oxygen (DO), conductivity and pH were also measured for both ground and surface water. This was completed by placing the appropriate HydroLab probe into each water sample and recording stabilized values. Field measurements were taken between 8:00am and 3:00pm. Surface water samples were taken to confirm that surface water was not directly leaking into the groundwater in the piezometer, as groundwater is expected to be more pristine than wetland surface water. Unfortunately, water quality sampling was not completed at all sites. Table 2 outlines analyses and measurements taken at each site.

3.0 PRELIMINARY RESULTS

3.1 WATER QUALITY

Currently, it is not feasible to compare water quality between sites or even draw conclusions about the state of quality of water at each individual site. This is because water quality was analyzed only once in three years and not all parameters were measured at all sites. Comparing water quality between sites is easiest when employing a water quality index (WQI). Although a WQI has been developed specifically for use in coastal wetlands (Chow-Fraser 2006), the parameters tested in 2006 are not consistent with those used in the index, nor is there confirmation that this WQI is reliable in inland wetland systems. In addition, the current samples provide only a brief “snap-shot” of water quality at each site. This may not be reflective of the long-term pattern of water quality at the sites that may affect biogeochemical cycles and wetland biota (U.S. EPA 2008). More frequent sampling is required in order to develop reasonable estimates of water quality to account for changes in water quality during and between seasons. In order to overcome these limitations, suggestions for program improvement are provided in Section 5.

The preliminary summary of the water quality results will instead be discussed in terms of the Ontario Provincial Water Quality Objectives (PWQO’s) and Ontario Drinking Water Standards (ODWS’s) for each individual site to provide some basis for presenting water quality information. Neither set of guidelines were designed for wetland systems; The PWQO’s are surface water guidelines developed to protect aquatic life, while the ODWS’s were developed to provide safe drinking water to the public. Although groundwater and surface water are interconnected, the properties of these two water sources can be very different. In general, surface water has lower mineral content but higher toxin contaminate concentrations (bacteria, pesticides, industrial waste) than groundwater. Surface water is also generally faster moving, with higher dissolved oxygen concentrations and greater risk of point source pollution. Groundwater is slower moving with lower oxygen contents. Because of the percolation of water through the soil column and its long stay in underground aquifers, groundwater tends to have less contamination and higher mineral contents. Due to these differences, the PWQO’s may be more applicable to the measured surface water samples, while the ODWS’s may be more applicable to the groundwater samples. Therefore, although comparisons are provided for reference for both set of guidelines for surface and groundwater the ODWS’s will be used to determine the level of water quality for groundwater samples and the PWQO’s will be used to determine the level of water quality for surface water samples.

Laboratory analysis was completed for a suite of over 45 water quality parameters including inorganics and metals; five additional parameters were measured in the field (Appendix B). Table 3 lists the parameters analyzed for which PWQO and/or ODWS guidelines are associated. The guidelines listed in Table 3 indicate maximum allowable concentrations for all parameters except pH, which indicates a range within which pH should fall. Although PWQO guidelines are available for pH and DO, these guidelines were not used for comparisons in this report because they are not applicable in wetland ecosystems. Many of the parameters in Table 3 were not detected at any of the monitoring sites and will not be discussed further.

Table 3. Provincial Water Quality Objectives (PWQO's) and Ontario Drinking Water Standards (ODWS's) for parameters tested in wetland ground and surface water in the Credit River Watershed.

Parameter	Unit	PWQO [b]	ODWS [b]
Metals			
Aluminum (Al)	µg/L	75	N/A
Antimony (Sb)	µg/L	20	6
Arsenic (As)	µg/L	5	25
Barium (Ba)	µg/L	N/A	1000
Beryllium (Be) [a]	µg/L	11 or 1100 [e]	N/A
Boron (B)	µg/L	200	5000
Cadmium (Cd) [a]	µg/L	0.2	5
Chromium (Cr) [a]	µg/L	1	50
Cobalt (Co)	µg/L	0.9	N/A
Copper (Cu)	µg/L	5	N/A
Iron (Fe)	µg/L	300	N/A
Lead (Pb)	µg/L	5	10
Molybdenum (Mo)	µg/L	40	N/A
Nickel (Ni)	µg/L	25	N/A
Selenium (Se) [a]	µg/L	100	10
Silver (Ag)	µg/L	0.1	N/A
Thallium (Tl) [a]	µg/L	0.3	N/A
Tungsten (W) [a]	µg/L	30	N/A
Uranium (U)	µg/L	5	20
Vanadium (V)	µg/L	6	N/A
Zinc (Zn)	µg/L	20	N/A
Zirconium (Zr) [a]	µg/L	4	N/A
Inorganics			
Total Phosphorus (TP)	µg/L	20 - 30 [d]	N/A
Nitrite (N)	mg/L	N/A	1
Nitrate (N)	mg/L	N/A	10
Nitrite + Nitrate	mg/L	N/A	10
Other			
pH [c]	N/A	6.5-8.5	N/A
Dissolved Oxygen (DO) [c]	mg/L	Temperature dependant	N/A

[a] Parameters not detected at any monitored wetland.
[b] Indicates the maximum allowable concentrations for all parameters except pH, which indicates a range within which pH should fall.
[c] Although PWQO guidelines are available, these guidelines were not used for comparisons because they are not applicable in wetland ecosystems.
[d] 20mg/L is the guideline for lakes, whereas 30mg/L is the guideline for rivers
[e] 11µg/L when Hardness as $CaCO_3$ (mg/L) <75; 1100µg/L when Hardness as $CaCO_3$ (mg/L) >75

All metals were analysed using dissolved concentrations for groundwater and total concentrations for surface water. Phosphorus is present in aquatic systems in three forms: inorganic phosphorus, particulate organic phosphorus, and dissolved (soluble) organic phosphorus (Canadian Council of Ministers of the Environment 2004). Phosphate, the most dominant type of inorganic phosphorus, is required by aquatic biota for nutrition. However, due to the relative difficultly in estimating phosphate, total phosphorus (TP) (the sum of all three forms) is typically used for measuring phosphorus in surface waters (Canadian Council of Ministers of the Environment 2004).

3.1.1 Groundwater

3.1.1.1 Laboratory Analyses: Aluminum, antimony and zinc were each detected at only two wetlands: aluminum and antimony at Acton and Erin Pine Estates and zinc at Belfountain and Speersville. Observed levels of these parameters were well below the PWQO and/or ODWS guidelines. Barium, boron, molybdenum, nickel and nitrogen compounds (nitrite, nitrate and nitrite + nitrate) were detected at the majority of the locations, but concentrations always fell below prescribed guidelines (Appendix B).

At Speersville, the uranium concentrations reached 35 µg/L, exceeding both the PWQO guideline and the 25 µg/L ODWS guideline (Fig. 6). The 5 µg/L PWQO guideline for uranium was also exceeded at Acton and Erin Pine Estates Wetlands. It is unclear why concentrations were so high at this site. Although uranium is a radionuclide, studies show that chemical toxicity is of higher concern than radiological toxicity (Sheppard et al. 2005). Uranium toxicity can lead to malfunctioning of several mammalian organs, most notably the kidneys. Invertebrates and aquatic plants appear to be the most sensitive to uranium toxicity, and may be negatively affected by the uranium concentrations found at the three aforementioned sites; however, these levels are well below toxicity levels for fish (Sheppard et al. 2005).

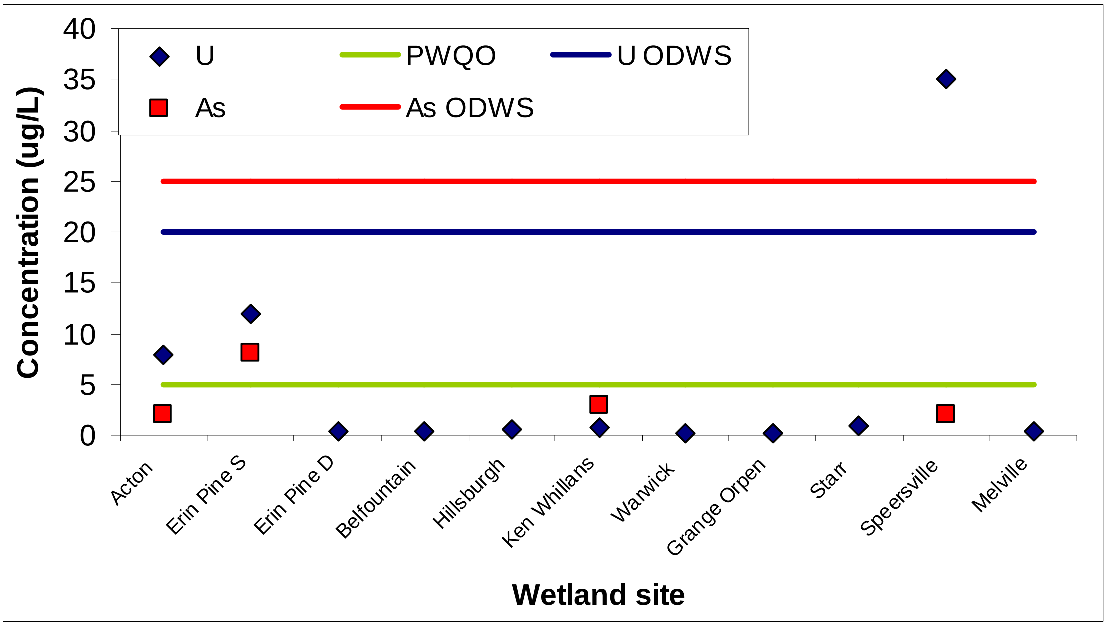


Figure 6. Arsenic (As) and Uranium (U) groundwater concentrations (points) at monitored wetlands compared to PWQO and ODWS guidelines (solid lines). Erin Pine S, Erin Pine Estates shallow piezometer; Erin Pine D, Erin Pine Estates deep piezometer. Parameter was not detected at a given site if no point is present on the graph.

The 25 µg/L ODWS guideline for arsenic was not exceeded at any site (Fig. 6). However, the 5 µg/L PWQO guideline was exceeded at Erin Pine Estates Wetland. Arsenic is an ecotoxic metal that enters water through the natural weathering of rocks and soils and through smelting and refining industries. Though arsenic does not appear to be biomagnified within the food chain, some species of aquatic plants appear to be the most sensitive aquatic biota to arsenic toxicity (Canadian Council of Ministers of the Environment 2001).

No ODWS guidelines exist for copper, vanadium, silver or cobalt. However, the PWQO guideline for each of these metals was exceeded at one or more sites. The 5 µg/L PWQO guideline for copper was exceeded at Ken Whillans Wetland and the 6 µg/L PWQO guideline for vanadium was exceeded at Starr and Erin Pine Estates Wetlands (Fig. 7). Microorganisms such as algae and plankton are the most sensitive to copper, while macrophytes are the least (Nor 1987). Anthropogenic sources of elevated copper levels include mining, industrial discharges, sewage sludge disposal and fertilizer and pesticide applications (Nor 1987). Similar to other metals, a large portion of the vanadium in water originates from erosion of rock and soil. However, concentrations can be elevated through acid rain and contaminated fall-out from the combustion of coal and crude oil (Beusen and Neven 1987). Vanadium has been found to be toxic to both aquatic invertebrates and several species of fish and appears to result in mortality rather than reproduction inhibition (Beusen and Neven 1987).

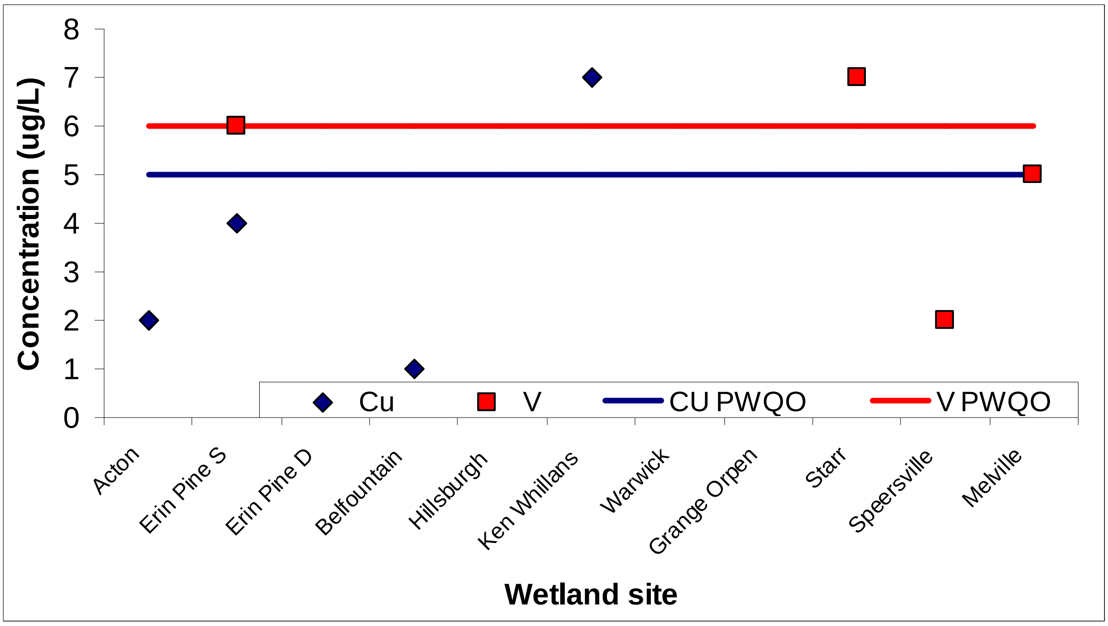


Figure 7. Copper (Cu) and Vanadium (V) groundwater concentrations (points) at monitored wetlands compared to PWQO guidelines (solid lines). Erin Pine S, Erin Pine Estates shallow piezometer; Erin Pine D, Erin Pine Estates deep piezometer. Parameter was not detected at a given site it no point is present on the graph.

The cobalt PWQO guideline was exceeded at Acton Wetland, while the PWQO guideline for silver was exceed at Starr, Acton and Speersville Wetlands (Fig. 8). Negative toxic effects of cobalt on aquatic organisms may include mortality, bioaccumulation and changes to biota physiology, biochemistry, growth, development, populations and behaviour. Cobalt has been found to be highly toxic to fish, amphibians and zooplankton (Kegley et al. 2009). The concentration of silver in water is usually caused by natural sources; however, mining and photographic processing are the main anthropogenic factors which may increase these concentrations. In fish and crustaceans, the toxic mechanism of silver involves an interference with ionic uptake at the gill surface; therefore, acute silver toxicity is higher in smaller organisms than larger ones because gill area is inversely related to body mass (Bianchini et al. 2002).

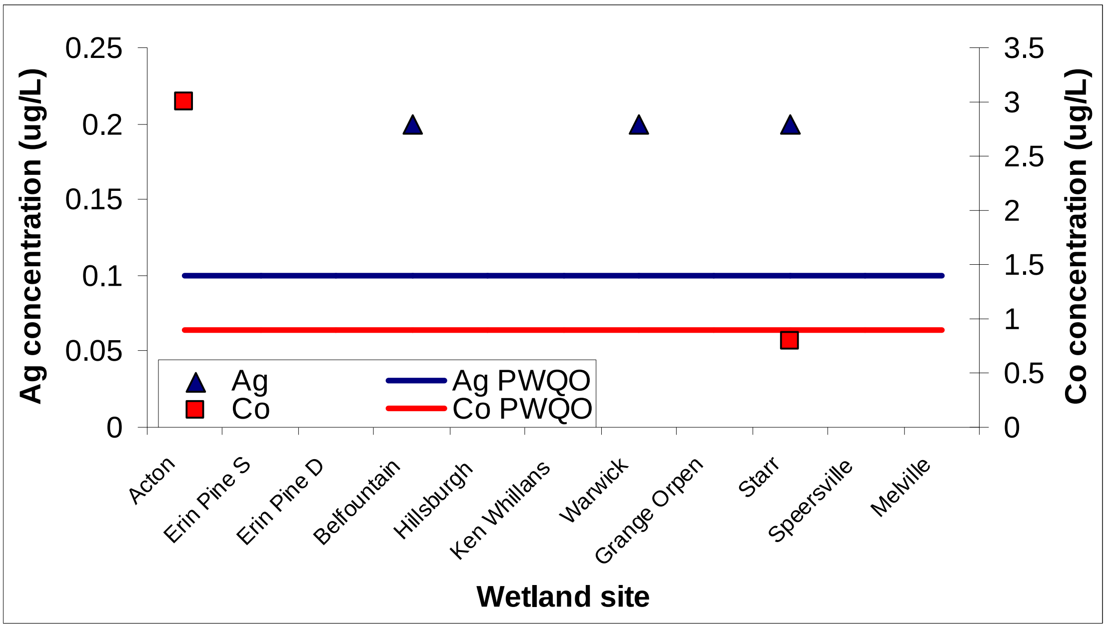


Figure 8. Silver (Ag) and Cobalt (Co) groundwater concentrations (points) at monitored wetlands compared to the PWQO guidelines (solid lines). Erin Pine S, Erin Pine Estates shallow piezometer; Erin Pine D, Erin Pine Estates deep piezometer. Parameter was not detected at a given site it no point is present on the graph.

There is also no ODWS guideline for total phosphorus (TP), but these concentrations met or exceeded both the 20 µg/L and 30 µg/L PWQO guidelines at all sites (Fig. 9). Phosphorus is a key macronutrient required by biota for biological metabolism. It tends to be the least abundant macronutrient, and therefore, is most often the limiting factor for biological productivity (Canadian Council of Ministers of the Environment 2004). Water with low P concentrations tends to support relatively diverse aquatic life. However, high P concentrations can lead to adverse effects on aquatic ecosystems, such as decreased biodiversity, anoxic conditions, increased turbidity, increased plant and animal biomass, a decline in ecologically sensitive species and an increase in nutrient tolerant species (Canadian Council of Ministers of the Environment 2004).

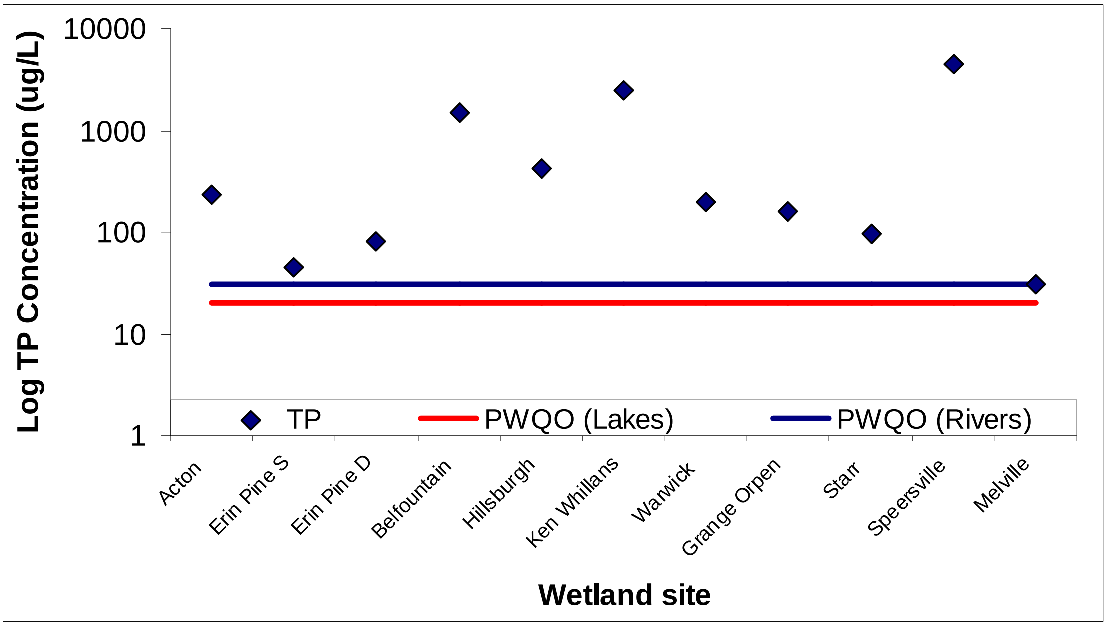


Figure 9. Total Phosphorus (TP) groundwater concentrations (points) at monitored wetlands compared to the PWQO guidelines (solid lines). Erin Pine S, Erin Pine Estates shallow piezometer; Erin Pine D, Erin Pine Estates deep piezometer. Parameter was not detected at a given site if no point is present on the graph.

3.1.1.2 Field Analyses: Provincial Water Quality Objective guidelines for flowing water for pH range from 6.5-8.5. The deviation of pH from this recommended range can be lethal for fish and invertebrates, such as caddis flies. In addition, the toxicity of other water components (e.g. trace metals and carbon dioxide) may increase with changes in pH (Ministry of the Environment 1979). These guidelines, however, are not applicable in wetland systems. No standards for pH exist in the ODWS. Mean pH in the Upper and Middle zones was 7.37and 7.75, respectively (Fig. 10). At Meadowvale Wetland, the only site sampled in the Lower zone, pH was 7.04. The lowest pH was detected at Belfountain (6.70), while the highest pH was detected at Speersville (8.68).

Similarly, no standards for DO exist in the ODWS. In flowing waters with temperatures ranging from 10-25°C, PWQO's suggest that the minimum DO requirements for aquatic life ranges from 4 to 8 mg/L depending on temperature and biota type (warm vs. cold water). The absence of DO leads to anaerobic decomposition and the production of noxious gases. Low levels of DO cause fish to expend high amounts of energy to continue breathing. This reduces energy available for other essential activities, may increase lethal effect of other toxins and can eventually lead to death (Ministry of the Environment 1979). However, these standards do not apply to groundwater due to the inherent difference in the properties of groundwater. Mean DO concentrations in the Upper and Middle zones were 6.49 mg/L and 7.15 mg/L, respectively (Fig. 11). At Meadowvale Wetland, the only site sampled in the Lower zone, the DO concentration was 5.52 mg/L.

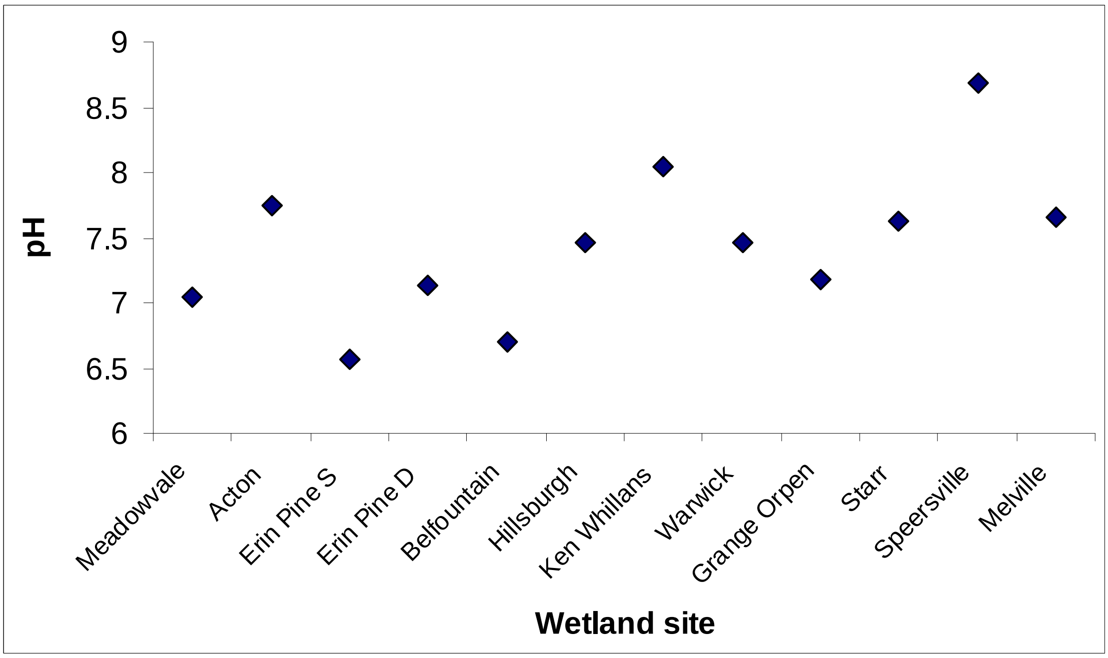


Figure 10. Groundwater pH at monitored wetlands. Erin Pine S, Erin Pine Estates shallow piezometer; Erin Pine D, Erin Pine Estates deep piezometer.

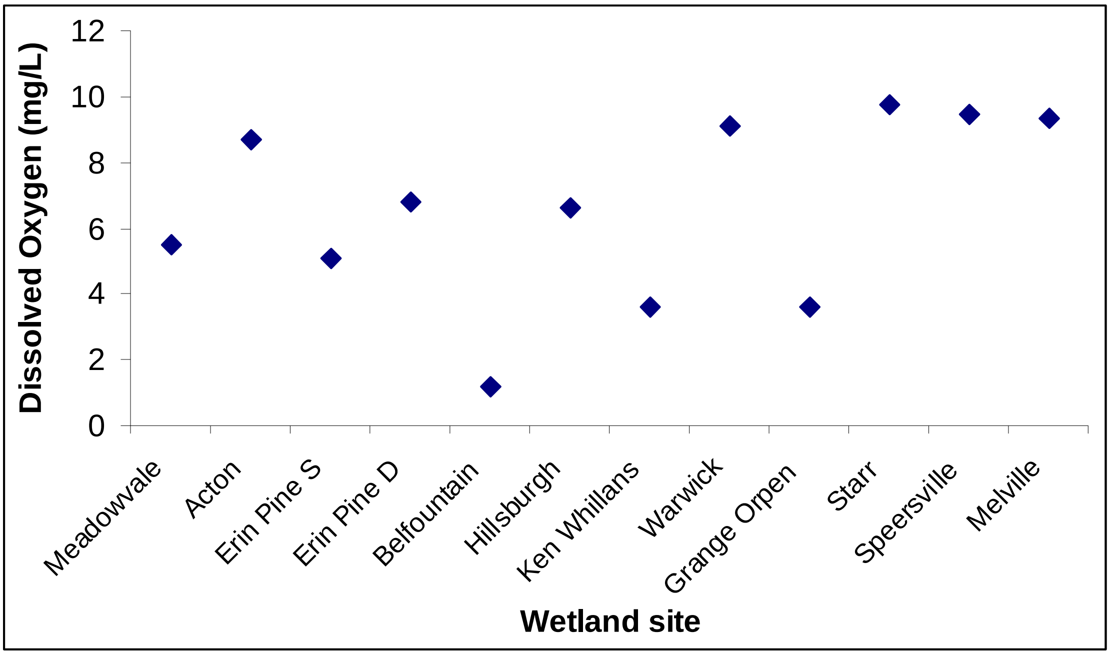


Figure 11. Groundwater dissolved oxygen (DO) concentrations at monitored wetlands. Erin Pine S, Erin Pine Estates shallow piezometer; Erin Pine D, Erin Pine Estates deep piezometer.

Neither the ODWS or the PWQO guidelines set specific recommended ranges for water temperature. Instead, the ODWS set an aesthetic objective of 15°C to enhance drinking water taste, ordor and colour. In the PWQO guidelines it is stated that “the natural thermal regime of any body of water shall not be altered so as to impair the quality of the natural environment. In particular, the diversity, distribution and abundance of plant and animal life shall not be significantly changed" (Ministry of Environment and Energy 1995). Mean temperature in the Upper and Middle zones was 14.5 ^{o}C and16.8^{o}C, respectively (Fig. 12). At Meadowvale Wetland, the only site sampled in the Lower zone, temperature was 24.5^{o}C. The dramatically higher temperature in the Lower watershed is likely the result of sampling at only one site.

Electrical conductivity refers to the ability of water to pass an electrical current (U.S. EPA 1997). This is affected by the concentrations of inorganic dissolved solids such as chloride, nitrate, sulphate, and phosphate anions and sodium, magnesium, calcium, iron, and aluminum cations in the water. Conductivity increases with increasing water temperature and is therefore reported as conductivity at 25^{o}C (U.S. EPA 1997). The ODWS's and PWQO's do not set guidelines for electrical conductivity. Harter (2003) indicates that, in the U.S., water with conductivity above 0.83 microSiemens per centimetre cubed (mS/cm) is not recommended for drinking water and water with conductivity above 2.5 - 4 mS/cm is problematic for irrigation. This is because at high levels of conductivity water becomes saline, which is undesirable for drinking and stressful for plants with low to medium salt tolerance. These limits are indicated in Fig. 10 to provide a reference point for the conductivity measured at wetland sites. Conductivity generally ranged from 0-1 mS/cm (Fig. 13). The very high conductivity reading at Meadowvale, 12.2 mS/cm, may have been caused by measurement error in the field or due to pollution from road salting, as the piezometer is located in close proximity to residential roads. Unfortunately, laboratory analyses were not completed at Meadowvale. This would have provided information on the chloride concentration of the water which could be used to confirm if road salt pollution was an issue at this site.

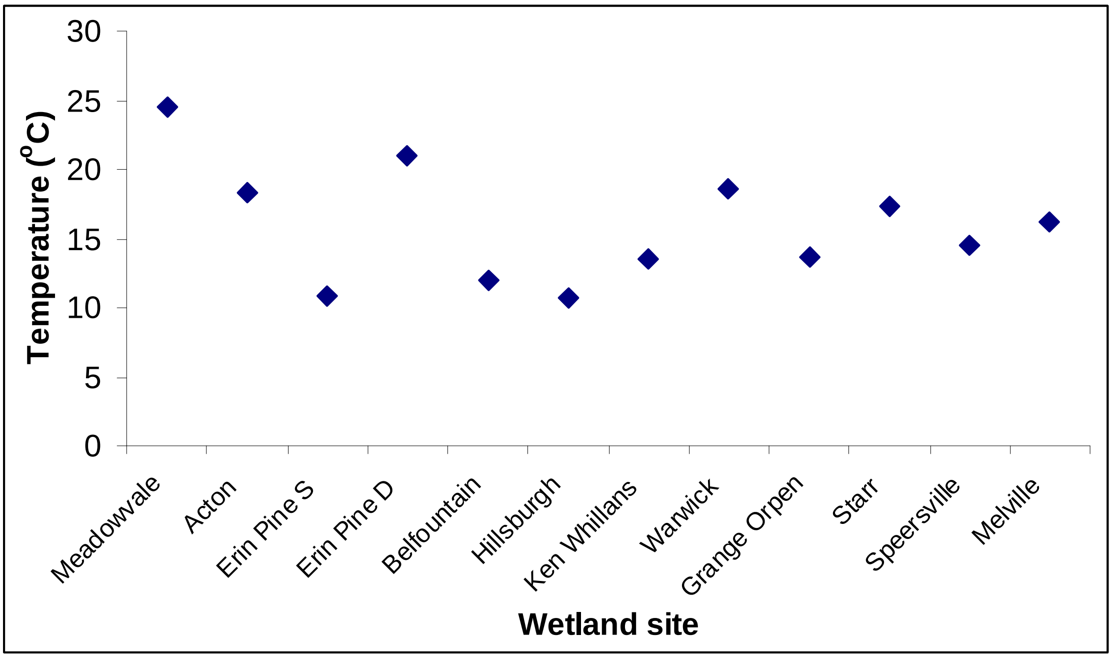


Figure 12. Groundwater temperature at monitored wetlands. Erin Pine S, Erin Pine Estates shallow piezometer; Erin Pine D, Erin Pine Estates deep piezometer.

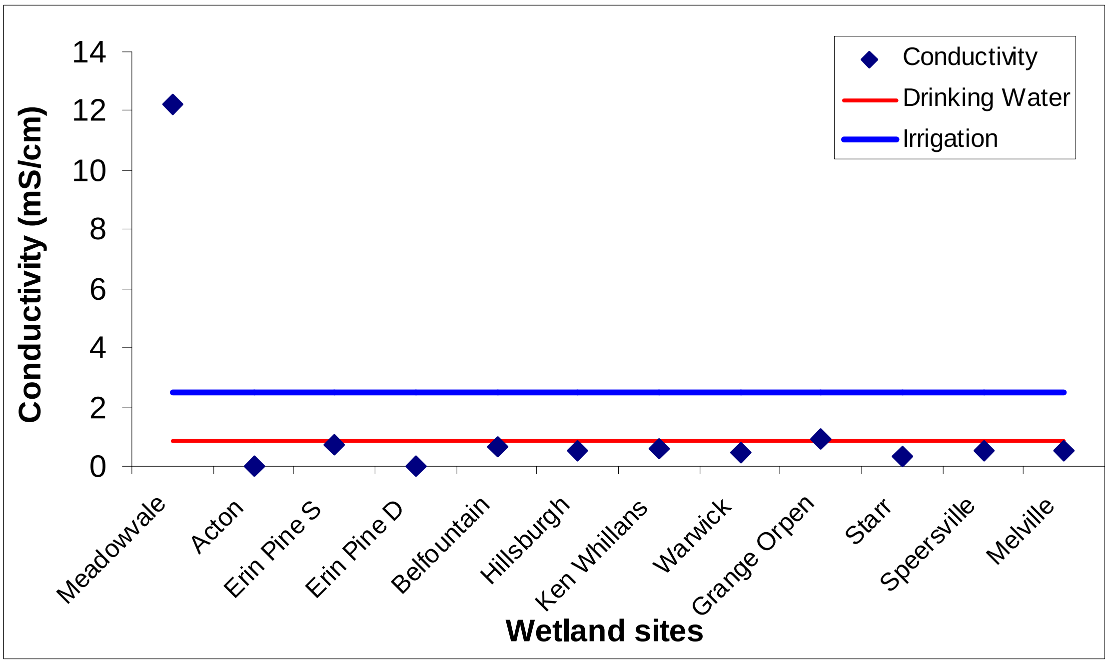


Figure 13. Groundwater conductivity at monitored wetlands. Erin Pine S, Erin Pine Estates shallow piezometer; Erin Pine D, Erin Pine Estates deep piezometer.

3.1.2 Surface Water

3.1.2.1 Laboratory Analyses: Laboratory analyses were completed for surface water at Belfountain, Warwick and Speersville Wetlands. The majority of the parameters in Table 3 were not detected (Appendix B). None of the ODWS guidelines were exceeded in sampled surface water. The PWQO guidelines were equalled or exceeded for four parameters – zinc, iron, aluminum and total phosphorus. The 75 μg/L guideline for aluminum was met at Warwick. Although aluminum is the third most abundant crustal element, it serves little purpose in the functioning of biotic systems (Gensemer and Playle 1999). In aquatic systems, aluminum toxicity increases as water becomes more acidic. Aluminum is toxic to all forms of aquatic life, from macrophytes to invertebrates. Therefore, it can be responsible for the demise of aquatic communities, especially in acidic conditions (Gensemer and Playle 1999). Also at Warwick, iron was present in concentrations over three times the 300 μg/L guideline. Similar to other metals, iron concentrations in water are elevated from natural levels through anthropogenic factors (e.g. mining and processing iron and metal fabricating). Iron is an essential element to all organisms and is used in a variety of biological processes (Ministry of the Environment 1979). Iron is moderately toxic to plants and only minimally toxic to mammals. Iron can lead to a decrease in water pH and an increase in turbidity through the formation of flocs (small, loose masses of fine particles suspended in a solution). This can smother bottom fauna, reduce primary productivity and affect species which rely on visual cues (Ministry of the Environment 1979). Zinc exceeded the 20 μg/L limit at Speersville by 18 μg/L. Zinc is also an essential nutrient for plants and animals in that it is necessary for formation of DNA and RNA, growth and reproduction. Fish appear to be the most sensitive aquatic organisms to zinc, high levels of which can lead to reduced egg production and mortality (Ministry of the Environment 1979). Total phosphorus exceeded both the 20 and 30 μg/L guidelines at Belfountain and Warwick Wetlands.

3.1.2.2 Field Analyses: In surface water samples, pH ranged from 6.6 to 8.2 (Fig. 14). Surface water DO concentrations ranged from 1.98 to 10.69 mg/L (Fig. 15), while temperature ranged from 10.8oC to 23.2oC (Fig. 16).Conductivity was typically below 1 mS/cm (Fig. 17). At Meadowvale conductivity reached nearly 3.5 mS/cm, although this may have been elevated for similar reasons as mentioned for groundwater. The PWQO guidelines are also not applicable in wetland surface waters as they may be inappropriately high for wetland systems, which tend to have naturally low DO concentrations (U.S. EPA 2009; Minnesota Pollution Control Agency 2009). In order to deal with these naturally anoxic conditions, wetland biota, ranging from unicellular organisms to plants and animals, have adapted to deal with the low levels of oxygen (Mitsch and Gosselink 2007). These adaptations include biochemical, physiological, structural and behavioural changes. For example, fauna may modify respiratory pigments to improve oxygen carrying capacity in order to control gas exchange in anoxic conditions (Mitsch and Gosselink 2007). It is important to note that DO and temperature were sampled as *insitu* spot measurements. Dissolved oxygen is highly affected by temperature and season. In addition, in areas with aquatic macrophytes oxygen levels are also affected by photosynthesis with higher DO levels during the day and lower levels at night during respiration. Macrophytes can also affect DO levels in a diel cycle, with higher oxygen levels during the growing season and low levels later in the season during vegetation dieback and decomposition (Canadian Council of Ministers of the Environment 1999). Temperature is also highly variable over the duration of a day and throughout seasons. Although, all measurements were taken within 4 days of each other, time of day varied and could significantly affect the measured values of both parameters.

It is important to remember that currently, no guidelines exist for wetland water quality. The PWQO guidelines were developed in order to ensure water quality levels that protect all forms of aquatic life during all aquatic life cycles for surface waters (e.g. lakes and rivers) (Ministry of Environment and Energy 1995). The ODWS guidelines were developed to protect public health through the provision of safe drinking water (Ontario Ministry of the Environment, 2003). Therefore, neither set of guidelines are explicitly applicable to a wetland ecosystem, however, the ODWS's will be used for groundwater samples and the PWQO's will be used for surface water samples to provide an initial approximation of site water quality (Table 4).

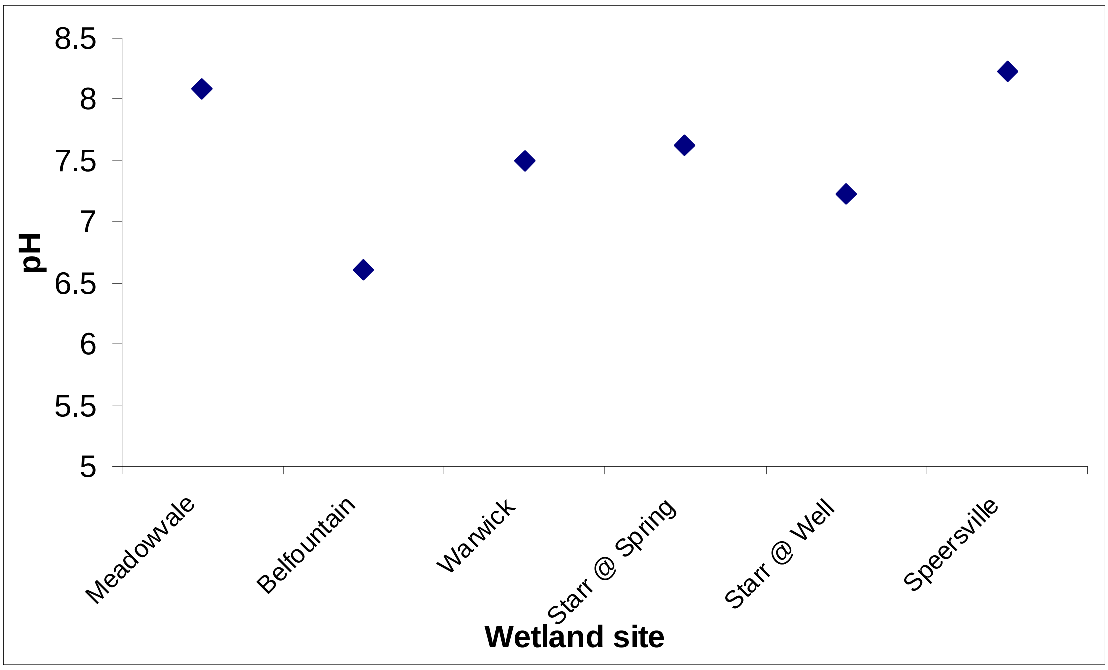


Figure 14. Surface water pH at monitored wetlands. Starr @ Spring, Starr Wetland sampled at flowing spring; Starr @ Well, Starr Wetland sampled at piezometer.

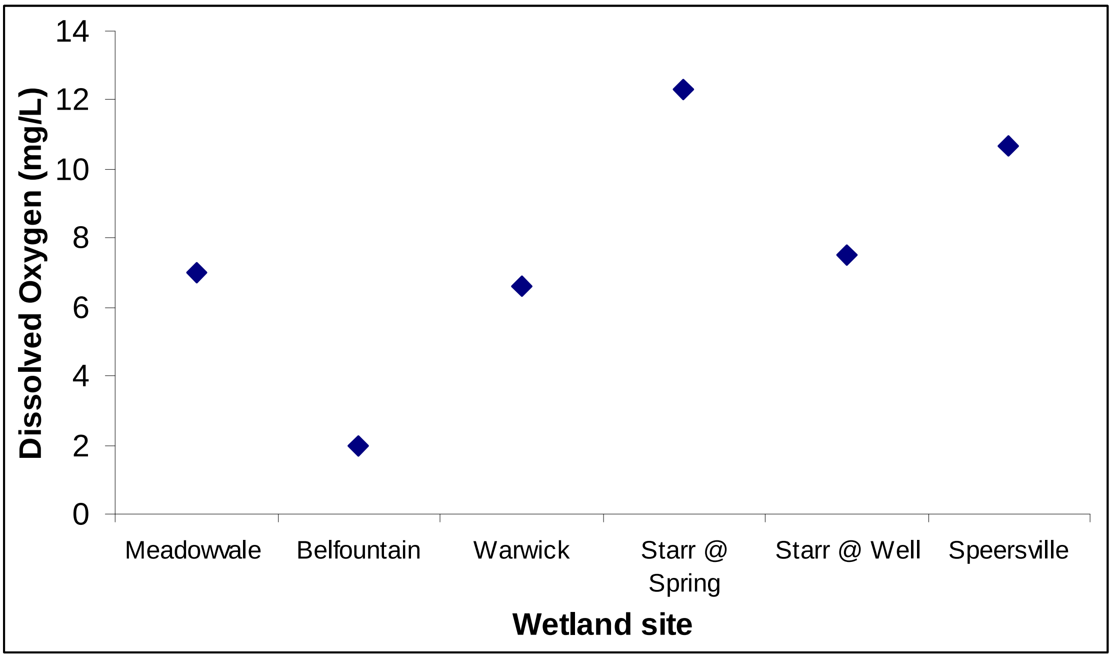


Figure 15. Surface water Dissolved Oxygen (DO)concentrations at monitored wetlands. Starr @ Spring, Starr Wetland sampled at flowing spring; Starr @ Well, Starr Wetland sampled at piezometer.

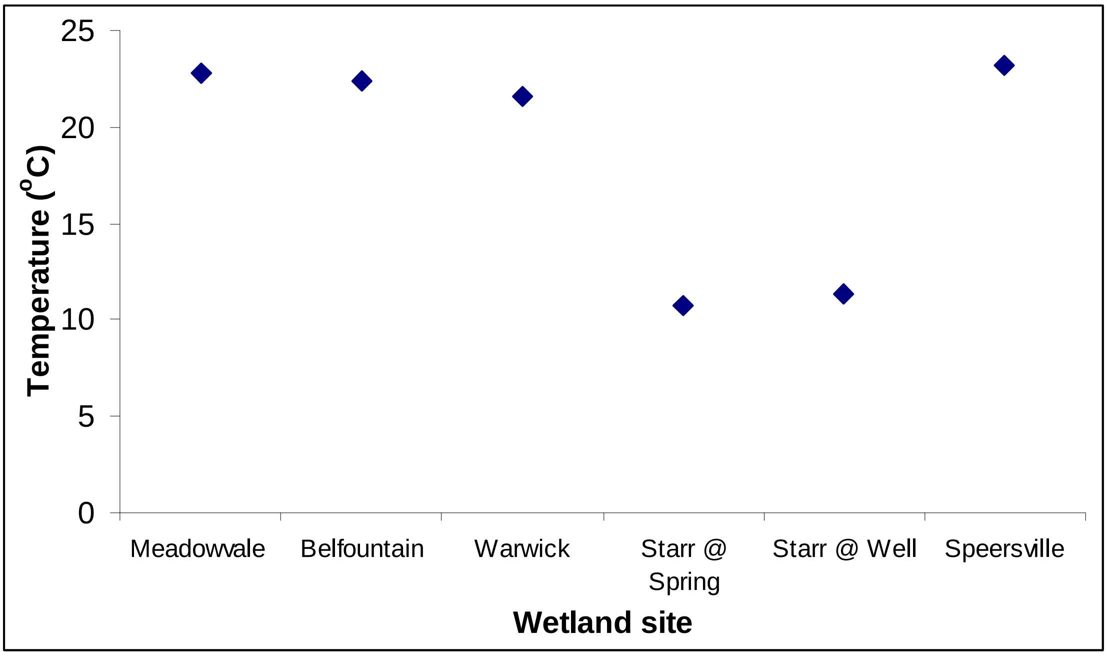


Figure 16. Surface water temperature at monitored wetlands. Starr @ Spring, Starr Wetland sampled at flowing spring; Starr @ Well, Starr Wetland sampled at piezometer.

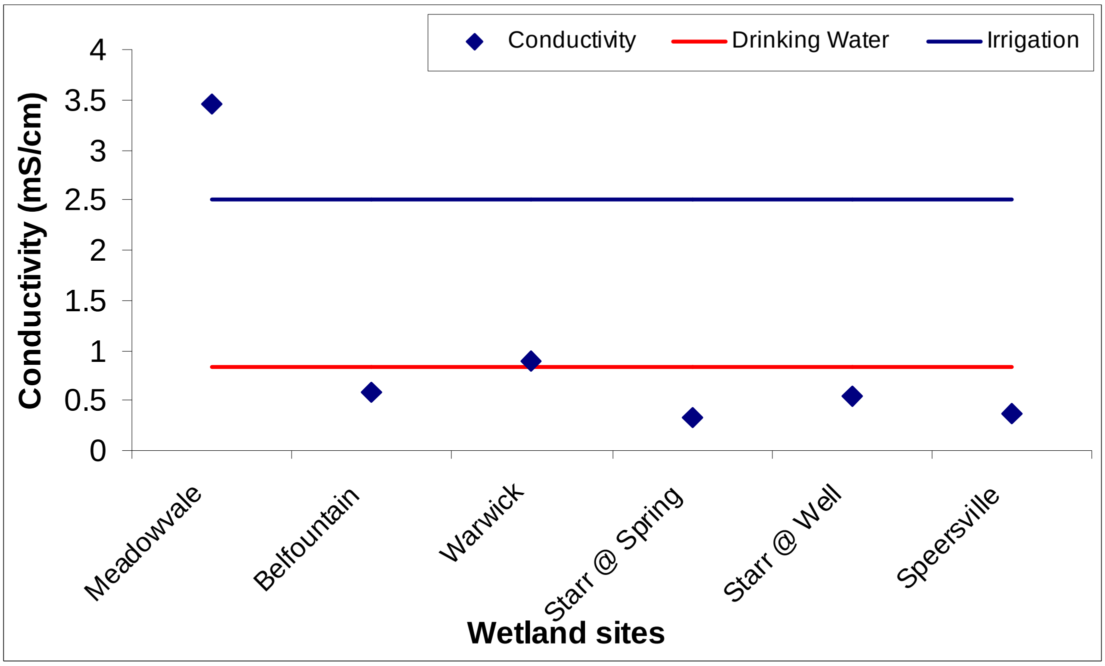


Figure 17. Surface water conductivity at monitored wetlands. Starr @ Spring, Starr Wetland sampled at flowing spring; Starr @ Well, Starr Wetland sampled at piezometer.

Table 4. Exceedance of PWQO and ODWS Guidelines for inorganics and metals in ground and surface water at wetland sites in the Credit River Watershed.

Site #	Site Name	Physiographic Region	Guidelines Not Met					
			Groundwater		Surface Water		Total	
			PWQO	ODWS [a]	PWQO	ODWS	PWQO	ODWS
W-04	Meadowvale Wetland	Lower	TP				1	0
W-13	Hillsburgh Wetland	Upper	TP				1	0
W-19	Melville Wetland	Upper	TP				1	0
W-15	Grange Orpen Wetland	Upper	TP				1	0
W-20	Belfountain Wetland	Upper	TP		TP		2	0
W-09	Ken Whillans Wetland	Middle	Cu, TP				2	0
W-16	Starr Wetland	Upper	V, Ag, TP				3	0
W-07	Acton Wetland	Middle	U, Co, Ag, TP				4	0
W-10	Warwick Wetland	Middle	TP		Al, Fe, TP		4	0
W-11	Erin Pine Estates Wetland	Upper	U, As, V, TP				4	0
W-17	Speersville Wetland	Upper	U, Ag, TP	U	Zn		4	1

[a] Blue shaded cells indicate the guideline upon which an initial approximation of site water quality should be based.

3.2 HYDROLOGY

3.2.1 Wetland Hydrologic Classification

Wetlands can be classified in many different ways including by vegetation, geographical location and hydrology. Hydroperiod describes the seasonal water level patterns of a wetland. This can be used as a broad classification tool, grouping wetlands with similar flooding regimes. Non-tidal wetlands may be placed into one of the seven hydroperiod categories listed in Table 5. Hydroperiod is important because it directly modifies the physiochemical environment of a wetland, altering aspects such as oxygen availability, soil and water chemistry, nutrients, toxicity and sedimentation. These alterations then directly impact wetland biota (Fig. 2) through changes in species composition, richness and ecosystem productivity (Mitsch and Gosselink 2007). For example, significant changes to water levels in a wetland may affect the ability of submergent or emergent vegetation to survive. If water levels drop significantly, it may be impossible for submergent aquatic vegetation to persist.

Table 5. Hydroperiod categories for freshwater wetlands (Mitsch and Gosselink 2007).

Hydroperiod Category	Description
Permanently Flooded	- flooded throughout the year in all years
Intermittently Exposed	- flooded throughout the year except in years of extreme drought
Semipermanently Flooded	- flooded during the growing season in most years
Seasonally Flooded	- flooded for extended periods during the growing season, but usually no surface water by the end of the growing season
Saturated	- substrate is saturated for extended periods during the growing season, but standing water is rarely present
Temporarily Flooded	- flooded for brief periods during the growing season, but water table is otherwise well below surface
Intermittently Flooded	- surface is usually exposed with surface water present for variable periods without detectable seasonal pattern

Wetlands can also be classified according to their groundwater patterns (Mitsch and Gosselink 2007). In some wetlands, groundwater plays an important role in regulating water levels. In others, surface water is the major contributor to the wetland. Wetland groundwater interactions can occur in two ways: discharge and recharge. Groundwater discharge occurs when the groundwater feeds the wetland; this usually takes place when the wetland is hydrologically lower than the groundwater table. Recharge occurs when water from wetlands is released into the groundwater (Mitsch and Gosselink 2007). Freshwater wetlands may be classified as one of the four wetland types described in Table 6.

Table 6. Groundwater flow pattern classification for freshwater wetlands (Mitsch and Gosselink 2007).

Groundwater Flow Pattern Classification	Characteristics
Surface Water Depression Wetland	- Dominated by surface runoff and precipitation - Little groundwater outflow due to low-permeability soils - Limited groundwater recharge possible - Water table usually below wetland
Surface Water Slope Wetland	- Generally found adjacent to a lake or stream - Fed predominantly by overbank flooding from adjacent water body - Some inflow from runoff and precipitation - Some groundwater recharge possible, but this usually discharges shortly back to water body - Water table usually below wetland
Groundwater Depression Wetland	- Wetland in depression low enough to intercept the groundwater table - Water-level fluctuations relatively less dramatic than surface fed wetlands due to the relative stability of groundwater levels
Groundwater Slope Wetland	- Located on slopes where groundwater discharges to surface through seeps or springs - Groundwater discharge to wetland can be continuous or seasonal depending on geohydrology and evapotranspiration rates

3.2.2 Site-specific Wetland Hydrological Classifications

According to the three years of data acquired through measurement of surface and groundwater levels, the studied wetlands were tentatively classified by hydroperiod and groundwater flow pattern (Table 7). However, these classifications are used with caution because of limited data and piezometer placement. Only three years of water level data are currently available. Within that time frame, there were both relatively hot-dry and cool years, which may skew results from the typical hydrological patterns of the sites (Fig. 18). In addition, piezometers were not consistently placed within the wetland hydrological gradient (e.g. at the wettest position in the wetland) or along the sampling transect. Consequently, it becomes very difficult to accurately assign a hydroperiod classification and compare between wetlands. As more data become available, these classifications will be updated. Annual piezometer water levels at each monitored wetland are displayed graphically in Appendix C and summarized in Appendix D, while Appendix E contains maps and photos of each site.

Table 7. Hydroperiod classifications of wetland monitoring sites in the Credit River Watershed.

Site #	Site Name	Hydroperiod Classification	Groundwater Flow Pattern
W-01	Rattray Marsh Wetland	Seasonally Flooded	Surface Water Slope
W-04	Meadowvale Wetland	Permanently Flooded	Surface Water Slope
W-07	Acton Wetland	Seasonally Flooded	Groundwater Depression
W-09	Ken Whillans Wetland	Temporarily Flooded	Surface Water Depression
W-10	Warwick Wetland	Permanently Flooded	Surface Water Slope
W-11	Erin Pine Estates Wetland	Saturated	Surface Water Slope
W-13	Hillsburgh Wetland	Saturated	Surface Water Slope
W-15	Grange Orpen Wetland	Saturated	Surface or Groundwater Slope
W-16	Starr Wetland	Saturated	Groundwater Slope
W-17	Speersville Wetland	Seasonally Flooded	Surface Depression
W-19	Melville Wetland	Saturated	Surface Water Slope
W-20	Belfountain Wetland	Seasonally Flooded	Surface Water Depression

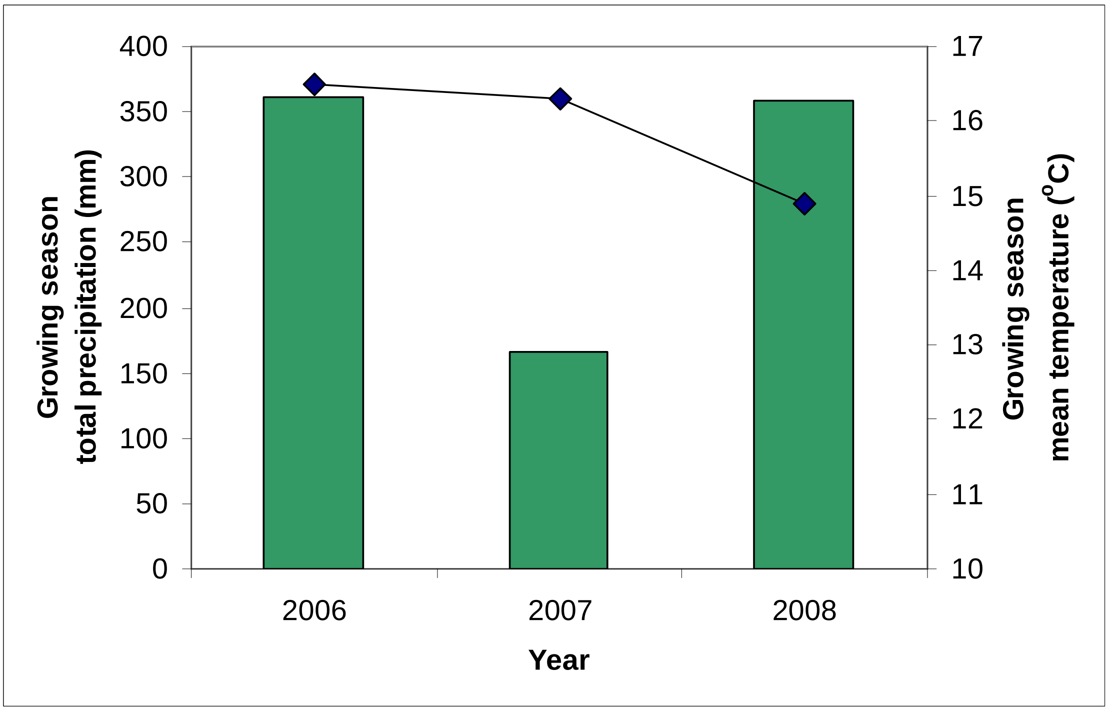


Figure 18. Total monthly precipitation (bars) and mean monthly temperature (points) from 2006 to 2008 in Georgetown, ON during the growing season (April – September). Mean temperature and precipitation over the growing season were 16.5°C and 360.7 mm, 16.3°C and 166.5 mm, 14.9°C and 358.0 mm in 2006, 2007 and 2008, respectively.

3.2.2.1 <u>Lower Watershed:</u> The Rattray Marsh Wetland is classified as a Surface Water Slope Wetland, as it is located on the shore of Lake Ontario. Although the hydrograph indicates groundwater discharge throughout the 2008 season, this may not be characteristic of the flow pattern of the marsh. Groundwater discharge in 2008 may have been due to high groundwater levels observed throughout the watershed during that year (Appendix C). However, it is not uncommon for some groundwater discharge to occur in

Surface Water Slope Wetlands (Table 7). Therefore, additional years of data are required to confirm the groundwater flow pattern classification at this site. Although a large portion of Rattray Marsh Wetland is permanently flooded, the monitoring site is located on the edge of the wetland were standing water is typically absent in late summer. It has been classified as Seasonally Flooded until more data are available to confirm these visual observations.

Meadowvale Wetland is also deemed a Surface Water Slope Wetland because it is located in the floodplain of the Credit River. Certain parts of this wetland have standing water throughout the year; therefore, it is classified as a Permanently Flooded wetland.

3.2.2.2 Middle Watershed: Acton Wetland is a swamp that is classified as Seasonally Flooded. There is an ephemeral stream running through the site during the early growing season, but by late summer and fall, standing water is usually absent. It appears from the hydrograph that Acton Wetland is fed by groundwater (Appendix C) and is therefore classified as a Groundwater Depression Wetland.

Ken Whillans Wetland is also a swamp located in the Middle watershed. This swamp has standing water for short periods during the growing season and is classified as Temporarily Flooded. In contrast to Acton Wetland, this swamp appears to be fed by surface water inflow, such as overland flow and precipitation, and is deemed a Surface Water Depression Wetland.

Warwick Wetland is flooded throughout the year, even in dry years such as 2007. Accordingly, it is classified as a Permanently Flooded wetland. The piezometer at this site was not functioning properly, possibly because a tight seal was not formed around the piezometer due to the high level of organics at the site. Therefore, accurate groundwater levels were not obtained at this wetland and, currently, it is not possible to determine the groundwater flow patterns at this site. However, this wetland is adjacent to a large lake and, as such, is tentatively classified as a Surface Water Slope Wetland. Reinstallation of the piezometer at Warwick Wetland is planned, and future data will be used to confirm this initial groundwater flow pattern classification.

3.2.2.3 Upper Watershed: Erin Pine Estates, Hillsburgh, Grange Orpen and Melville Wetlands all have similar hydroperiods and groundwater flow patterns. Standing water is rarely present at these four sites, but the substrate is usually saturated (Appendix C). Accordingly, all four wetlands were classified as Saturated. Standing water in 2006 and 2007 at Melville was due to a beaver dam that was altering water levels from their normal patterns. The dam was removed, however 2008 was an exceptionally wet year and a representation of the wetland’s natural condition may not be observed until future years. Future data will assist in confirming this. In addition, Erin Pine Estates, Hillsburgh and Melville are all adjacent to water bodies, which influence the water levels of the wetlands. These wetlands are classified as Surface Water Slope Wetlands. Grange Orpen is also situated near a water body; however, it is not clear if this wetland is fed by ground or surface water. More information is needed to confirm if groundwater discharge plays an important role in the hydrology of this site.

At Starr Wetland, groundwater seeps are the major inflow of water, clearly indentifying it as a Groundwater Slope Wetland. Similar to the other previously mentioned wetlands in this region, the ground at Starr tends to be Saturated with little standing water (Appendix C).

It was difficult to assign classifications to Speersville Wetland because, similar to Warwick Wetland, the piezometer was not working properly. The site is situated on land that was previously an airport with engineered filled. This engineered fill may have been affecting piezometer readings. Despite the fact that the hydrograph indicates that the wetland is seasonally flooded (Appendix C), visual observations indicate that the wetland is permanently flooded. The wetland was classified as Seasonally Flooded until more reliable data are available. For these same reasons, it was not possible to determine groundwater discharge to the wetland. Visual observations indicated that Speersville Wetland may be a Surface Depression wetland. It is hoped that new data from the piezometer in subsequent years will allow more accurate classification of this site.

Finally, Belfountain is a Seasonally Flooded wetland. It is classified as a Surface Depression wetland because groundwater does not appear to play an important role of the hydrology at this site.

3.2.2.4 Watershed-wide: Four of the seven hydroperiod classes (Table 5) appear to be represented in the watershed, with Saturated wetlands being the most common. All four of the groundwater flow patterns (Table 6) are represented in monitored wetlands; however, wetlands fed through surface water inputs appear more dominant than groundwater fed wetlands. It is unclear whether surface water wetlands are more dominant in the watershed or if surface water wetlands are disproportionately represented in monitored wetlands.

From examining the hydrographs in Appendix C it appears that Belfountain, Meadowvale and Speersville Wetlands consistently had the most surface water, while Erin Pine Estates, Hillsburgh and Grange Orpen Wetlands tended to be the driest sites. Monitored wetlands tended to be wettest in the spring and early summer (typically April – June), which is consistent with snow melt and high rainfall during these times. Wetlands were driest in late summer and fall (July – August or September) due to higher temperatures and lower rainfall. It is important to note that 2007 was a relatively dry year and 2008 was a relatively cool year (Fig. 18). This was reflected in piezometer measurements. Groundwater levels tended to be lower in 2007 compared to 2006, especially in the late summer. This is likely due to reduced recharge resulting from low rainfall. Throughout the 2008 growing season, groundwater levels tended to be higher than the previous two years. Although 2008 was not wetter than normal, it was relatively cooler, which may have led to a decrease in evapotranspiration. As more data become available with additional years of monitoring, hydrological classifications of the monitored wetlands will be refined and significant trends in changes in hydrology will be elucidated.

4.0 CURRENT PROGRAM ADVANCEMENTS

Preliminary results based on analysis of three years of existing groundwater data make it clear that in order to better understand the hydrology of the Credit River watershed, and its large influence on shaping plant and animal communities across the landscape, this component of the program would have to be expanded. Proposed expansions to the program include the following:

- Establishment of eleven additional permanent plots to achieve a more representative sample of wetland communities (marsh versus swamp) in the watershed.
- Elevation mapping of all monitored wetlands (required in order to determine optimal placement of hydrological monitoring equipment).
- Characterization of monitored wetland communities according to Ecological Land Classification principles.
- Installation of three piezometers at all wetland monitoring plots to monitor groundwater levels and movement throughout the site.
- A staff gauge will be installed at all wetland sites to measure surface water depth and assist in the determination of hydroperiod.
- Data loggers will accompany installation of piezometers and staff gauges to increase sampling frequency and accuracy without increasing disturbance to the sensitive wetland communities.
- Commitment to long-term monitoring and analysis of wetland hydrology to ensure that extreme weather years are not used to establish baseline levels.

The above proposed changes to monitoring protocols focus on increasing understanding of wetland hydrology. Additional information collected from wetland hydrology monitoring will complement data already collected on flora and fauna indicators at the permanent wetland plots. This will allow the program to link observed trends to understand the relationships between water quality, wetland hydrology, plant and animal communities more holistically.

The proposed Wetland Hydrology component of the Terrestrial Monitoring Program has been broken up into 4 phases to ensure the workload and cost is reasonable over time. The phases are as follows:

<u>Phase 1</u> (August 2010-December 2010)

1. Selection of new wetland plots to ensure adequate representation of wetland types across the watershed, and adequate statistical power (11 additional sites)
2. Development and refinement of wetland hydrology methodology with water department
3. Completion of ELC at all established and proposed wetland plots
4. Purchase of hydrology monitoring equipment for 9 wetland plots

Phase 2 (January 2011-December 2011)

1. Completion of elevation surveys at all established and proposed wetland sites (to be completed in Phase 1 if possible)
2. Selection of 9 permanent wetland plots for piezometer and staff gauge installation
3. Installation of piezometers and staff gauges and accompanying data loggers at 9 wetland sites based on elevation survey results

Phase 3 – optional expansion of program to all wetland plots (August 2011-August 2012)

1. Selection of 10 additional permanent wetland plots for piezometers and staff gauge installation
2. Installation of piezometers and staff gauges at 10 wetland sites based on elevation survey results

Phase 4 - optional expansion of program to all wetland plots (August 2012-August 2013)

1. Installation of piezometers and staff gauges at 11 remaining permanent wetland monitoring sites based in elevation survey results
2. Wetland water quality surveys will be conducted at all permanent plots (TBD)

5.0 PROGRAM RECOMMENDATIONS

5.1 WATER QUALITY

5.1.1 Water Quality Index

If wetland water quality is to be monitored in the Credit River Watershed, it is essential that a suite of parameters be selected for monitoring that will not only provide a comprehensive assessment of water quality, but also be economically and operationally feasible and allow for the comparison of water quality between sites and over time. Chow-Fraser (2006) developed a WQI for coastal wetland surface waters as an environmental indicator of wetland health in response to degradation of costal marshes in the Great Lakes due to land use changes.

This WQI was originally developed using 12 water quality parameters (Table 8). These parameters were chosen for ease of measurement and their potential for indicating unique information (Chow-Fraser 2006). Results of analyses of these parameters are entered into a predictive equation which provides the WQI score. This 12-parameter model (Eq. 1, Table 9) describes the total variation in WQI scores and can be replaced instead with a number of other equations which use some combination of four to seven of the parameters in Table 8. Equations 2-6 (Table 9) have uniformly high r^2-values and should generate comparable WQI scores. Equations 7 -9 have lower r^2-values, but are included because they may be more feasible for some monitoring programs because they include only four or five very commonly measured parameters. Water Quality Index scores calculated with one of the equations in Table 9 are interpreted according the WQI score descriptions (Table 10). Water Quality Index scores range from -3 to +3 with positive scores indicating good water quality and negative scores indicating degraded water (Chow-Fraser 2006).

This WQI has been used to track the improved health of Cootes Paradise Marsh over the course of a marsh-wide carp exclusion program as part of the Hamilton Harbour Remediation Action Plan (Chow-Fraser 2006). Improvements in the WQI score over the course of this program were consistent with improvements in the health of zooplankton, plant and fish communities observed over the same time. The WQI was also effective at ranking wetlands according to water quality across the entire Great Lakes Basin, producing results that were comparable to published biotic indicators (Chow-Fraser 2006). This WQI was also significantly related to a wetland fish index and a wetland zooplankton index, both of which were also developed to determine the quality of coastal wetlands (Lougheed and Chow-Fraser 2002; Seilheimer and Chow-Fraser 2004). This indicates that the WQI provides a good approximation of wetland health in relation to other estimators.

Table 8. Summary of water quality variables included in the original Water Quality Index (WQI) (Chow-Fraser 2006).

Variable	Acronym	Unit	Analysis Method
Turbidity	TURB	NTU	*in situ*
Temperature	TEMP	^oC	*in situ*
pH	pH	N/A	*in situ*
Conductivity	COND	µS/cm	*in situ*
Chlorophyll-a	CHL	µg/L	Laboratory
Total suspended solids	TSS	mg/L	Laboratory
Total inorganic suspended solids [a]	TISS	mg/L	Laboratory
Total phosphorus	TP	µg/L	Laboratory
Soluble reactive phosphorus	SRP	µg/L	Laboratory
Total ammonium nitrogen	TAN	µg/L	Laboratory
Total nitrate nitrogen	TNN	µg/L	Laboratory
Total nitrogen [b]	TN	µg/L	Laboratory

[a] This is a calculated parameter. Volatile suspended solids test is needed for TISS calculation.
[b] This is a calculated parameter. Total Kjehldahl nitrogen (TKN) test needed for TN calculation.

Table 9. Summary of regression equations to predict WQI scores (Chow-Fraser 2006).

Eq. #	Variables in model	Associated r^2 value	Predictive Equation
1	TURB, TSS, TISS, TP, SRP, TAN, TNN, TN, COND, TEMP, pH, CHL	1.00	+10.0239684 - 0.3154965 * log TURB -0.3656606 * logTSS -0.3554498 * log ISS -0.3760789 * log TP -0.1876029 * log SRP -0.0732574 * log TAN -0.2016657 * log TNN -0.2276255 * log TN -0.5711395 * log COND -1.1659027 * log TEMP -4.3562126 * log pH -0.2287166 * log CHL
2	TURB, TSS, TP, COND, TN	0.965	+5.2427978 -0.298509 * log TURB -0.865436 * log TSS -0.626229 * log TP -0.818190 * log COND -0.330760 * log TN

Eq. #	Variables in model	Associated r^2 value	Predictive Equation
3	TURB, COND, TEMP, PH, TP, TN, CHL	0.964	+10.753047 -0.946098* log TURB -0.837294 * log COND -1.319621 * log TEMP -4.604864 * log pH -0.387189 * log TP -0.353713 * log TN -0.337888 * log CHL
4	TP, TN, SRP, TNN, TAN, TSS, CHL	0.963	+3.8311461 -0.629834 * log TP -0.271059 * log TN -0.083724 * log SRP -0.211261 * log TNN -0.119190 * log TAN -0.995406 * log TSS -0.243290 * log CHL
5	TURB, COND, TEMP, PH, SRP, TNN, TAN	0.947	+11.88597 -1.147966 * log TURB -1.048255 * log COND -2.308968 * log TEMP -4.653771 * log pH -0.278112 * log SRP -0.324002 * log TNN -0.116383 * log TAN
6	TURB, COND, TEMP, PH, TP, TN	0.947	+11.590154 -1.073765 * log TURB -0.916011 * log COND -1.684796 * log TEMP -4.677050 * log pH -0.599127 * log TP -0.306512 * log TN
7	TURB, COND, TEMP, PH	0.898	+9.2663224 -1.367148 * log TURB -1.577380 * log COND -1.628048 * log TEMP -2.371337 * log pH
8	TP, TN, COND, CHL	0.867	+5.2333056 -0.832012 * log TP -0.313032 * log TN -0.982628 * log COND -0.583014 * log CHL
9	TP, TAN, TNN, TN, CHL	0.853	+3.5161294 -0.985870 * log TP -0.195332 * log TAN -0.261192 * log TNN -0.171508 * log TN -0.599259 * log CHL

Table 10. Water Quality Index score descriptions (Chow-Fraser 2006).

WQI Score	Category
+3 to +2	Excellent
+2 to +1	Very Good
+1 to 0	Good
0 to -1	Moderately Degraded
-1 to -2	Very Degraded
-2 to -3	Highly Degraded

5.1.2 Recommendations

When adding a new component to a monitoring program it is important to ensure that the component is consistent with the goals of the monitoring program and that it functions as an effective monitoring indicator. The main goals of the Terrestrial Monitoring Program are as follows:

1. Identify status and trends in the health of terrestrial communities at the watershed scale and link to watershed health.
2. Identify spatial patterns in terrestrial community health parameters.
3. Provide meaningful data on which watershed management decisions can be based.

Water quality, using the WQI, may be a beneficial wetland monitoring indicator to add to the wetland monitoring program. The WQI will allow both temporal and spatial trends to be identified that may be useful in developing watershed management strategies. Water Quality Index component metrics are easy to measure and understand and do not require a high level of technical or biological expertise to monitor. The WQI provides key information about the structure, function and/or composition of the ecosystem, is quantifiable in a manner that is suitable for statistical analysis and is known to have relationships with other terrestrial variables. In addition, as shown by Chow-Fraser (2006) the WQI is sensitive to change and anthropogenic stresses. The use of this WQI would allow CVC to not only track changes in water quality at monitored wetland sites over time, but also compare water quality among sites. This would allow for comparisons between physiographic zones within the watershed and identify sites where water quality is of concern. This information would be complementary to the current data on wetland vegetation already being collected to asses the health of wetlands in the watershed. Unfortunately, this WQI was designed using coastal wetland ecosystems. It must first be determined if this is system is scientifically valid for inland, non-costal wetlands, before it can be used in this monitoring program.

With the consideration that the majority of wetlands monitored by the program are surface water fed and that the WQI was developed for wetland surface water, it seems reasonable to suggest that water quality sampling be completed for surface water only. This would be more costs effective for the program than completing both ground and surface water sampling.

Using the 12-parameter model for determining WQI would theoretically be ideal, as it provides the most accurate WQI estimations. However, this may not be practical due to the number of parameters being analyzed which would not only increase costs, but also the time to process samples. For the 12-parameter model, it would cost approximately $188.60 per sample in lab fees, not including the costs of the four *in situ* parameters that need to be analyzed (Table 11). Therefore, using one of the alternative models may be more practical. There are different benefits and drawbacks of using of each of the remaining equations. For example, Equation 7 uses only four parameters, all of which can be obtained by field measurements using portable equipment. This would eliminate sample processing and laboratory fees. Costs would include only those required to purchase (or borrow) the field equipment and required reagents/supplies. Purchasing equipment to take the four required *in situ* measurements would range in cost. The purchase of a Quanta T system, which would allow the measurement of all four *in situ* parameters using one device, is estimated at approximately $6000 (Appendix F); however, other options at lower costs ($1000-$2000) are also available (Appendix F). In contrast, Equations 4 and 9 both require no in situ measurements, with only laboratory samples required. Laboratory fees would range from $147.65 to $173.10 per sample for these equations. Although laboratory costs are high for these equations, no additional equipment would be needed to be purchased or borrowed for *in situ* analysis. The remaining equations use a combination of laboratory and *in situ* parameters. Budget and time constraints would need to be examined closely in order to determine which equation would be most suitable for the program's needs.

Table 11. Estimated laboratory costs for each WQI equation. Prices do not include cost of measuring *in situ* parameters. [a]

Equation	Number of Laboratory Parameters	Number of *in situ* parameters	Cost per sample	Annual sampling program	Biannual sampling program	Bimonthly sampling program
1	10	4	$188.60	$3017.60	$6,035.20	$36,211.20
2	3	2	$39.20	$627.20	$1,254.40	$7526.40
3	3	4	$130.95	$2095.20	$4,190.40	$25,142.40
4	7	0	$173.10	$2769.60	$5,539.20	$33,235.20
5	3	4	$33.90	$542.40	$1,084.80	$6,508.80
6	2	4	$30.95	$495.20	$990.40	$5,942.20
7	0	4	$0.00	$0.00	$0.00	$0.00
8	3	1	$130.95	$2095.20	$4,190.40	$25,142.40
9	5	0	$157.65	$2522.40	$5,044.80	$30,268.80

[a] Costs estimated from individual analyses cost as per Appendix F.

Although purchasing *in situ* equipment has a high up-front cost, the initial investment may be cheaper than annual laboratory costs over the life of the program. However, the expected lifespan and replacement costs of the equipment must be considered. Also, the possibility of sharing equipment with other CVC departments may decrease costs if required equipment is available. It is imperative that the most appropriate equation is chosen and that the same equation is consistently applied spatially and temporally.

Although a WQI has been developed for monitoring wetland water quality, no protocols have been specifically developed for wetland water quality sampling. Bimonthly sampling has been recommended to obtain relatively accurate readings (Jen Dougherty, pers. comm.).This may not be feasible for wetland monitoring due to time and budgetary constraints. A more feasible option may be annual or bi-annual sampling carried out at the time of wetland vegetation monitoring visits. Water quality is difficult to quantify due to the ever changing state of the water. Annual sampling would provide merely a “snapshot” in time. In addition, standard procedures relating to the timing of sampling (e.g. during storm events, etc.) will need to be developed. Estimated laboratory costs for annual, biannual and bimonthly sampling programs are presented in Table 11. Additional information regarding options for water quality monitoring costs is available in Appendix F.

In addition to water quality monitoring within the wetland, future projects may also involve monitoring the hydrological and chemical ecosystem services that wetlands offer. Wetlands provide both water quality and quantity services by capturing overland flow, reducing flow velocity and providing the opportunity for water to infiltrate and evapotranspire. As a result, pollutants transported by the overland water are deposited or filtered in the wetlands. This provides sustainable flows and improved water quality down stream of the wetlands. In order to monitor these ecosystem services the following two objectives would need to be met:

1. Monitor the water quality and quantity services provided by the wetlands
2. Monitor how quality of water received by the wetlands impact their ecosystem

To meet both the objectives it would be important to monitor water quality and quantity upstream of the wetlands, in the wetlands, and down stream of the wetlands.

Although valuable information is sure to be gained from such a project, this is a very large undertaking and would require the collaborative effort of several CVC groups, including Terrestrial Monitoring, Water and Restoration. A partnership among these groups would be essential to the success of such an undertaking as the program would demand highly of funds and man hours.

5.2 HYDROLOGY

Studying the hydrology of all monitored wetlands in the watershed is beneficial because it assists in correctly classifying wetlands according to their hydrology, leading to a better understanding of each individual wetland system. The piezometers will also provide data to assist in the determination of temporal changes in wetland hydrology, as concerns exist that wetlands are becoming dryer with climate change and increasing urbanization. In addition, it is hoped that this information will provide a better understand the hydrology of the Credit River watershed, and its large influence on shaping plant and animal communities across the landscape.

It is believed that the current proposed expansions to the hydrology component of the monitoring program will generate the information needed to answer the many questions that exist surrounding the hydrology of wetlands within the Credit River

Watershed. However, before piezometer installation occurs in 2011 it is recommended that a detailed methodology for the hydrology component be developed. This would include the rationale for the program, methodology for piezometer placement and installation as well as detailed monitoring methods. This will ensure that resources are used in the most optimal fashion to acquire high quality data and that hydrological monitoring will be performed consistently into the future.

6.0 CONCLUSIONS

Under the current monitoring configuration and the available data based thereon, few conclusive results can be drawn regarding the water quality or hydrology of wetlands in the watershed. Speersville and Warwick Wetlands appear to have the worst water quality of sampled wetlands. However, this was determined using the ODWS and PWQO guidelines which are not designed specifically for wetland water quality. If wetland water quality is a desired component for addition to the wetland monitoring program, it is suggested that a WQI developed for wetland surface water be employed in order to determine spatial and temporal changes in wetland water quality. However, this may be a costly addition to the program.

Wetland hydrology data provided enough information to begin preliminary hydrological classifications of each wetland. However, additional years of data under the new proposed wetland hydrology monitoring program will be required for definitive classifications. These data will also assist in discerning temporal changes in wetland moisture regime. Monitoring of wetland hydrology and water quality may provide information that is useful for determining temporal and spatial trends in wetland health in the Credit River Watershed. However, it is important that detailed goals and objectives be developed for hydrology monitoring (and water quality monitoring if adopted by the program) in order to use program resources in the most efficient manner, producing the highest-quality and most pertinent results.

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APPENDIX A: WETLAND MONITORING SITES

Table 1. Wetland Health Monitoring Sites established throughout the Credit River Watershed.

Site #	Site Name	Township	County	Wetland type	Physiographic zone	PSW, ESA and/or ANSI designation [a]	Habitat patch size (ha)
W-01	Rattray Marsh Wetland	Mississauga	Regional Municipality of Peel	Marsh	Lower	PSW, ESA, ANSI	92.27
W-02	Credit River Wetland	Mississauga	Regional Municipality of Peel	Marsh	Lower	ESA, ANSI	0.26
W-03	Creditview Wetland	Mississauga	Regional Municipality of Peel	Marsh	Lower	PSW, ANSI	5.38
W-04	Meadowvale Wetland	Mississauga	Regional Municipality of Peel	Marsh	Lower	ESA	42.29
W-12	Winston Churchill Wetland	Halton Hills	Regional Municipality of Peel	Marsh	Lower		114.06
W-06	Hungry Hollow Wetland	Halton Hills	Regional Municipality of Peel	Swamp	Middle	PSW, ESA	127.86
W-07	Acton Wetland	Halton Hills	Regional Municipality of Peel	Swamp	Middle	PSW, ESA	753.26
W-08	Terra Cotta Wetland	Caledon	Regional Municipality of Peel	Swamp	Middle	ESA, ANSI	165.92
W-09	Ken Whillans Wetland	Caledon	Regional Municipality of Peel	Swamp	Middle		191.18
W-10	Warwick Wetland	Caledon	Regional Municipality of Peel	Marsh	Middle	PSW, ESA, ANSI	93.12
W-11	Erin Pine Estates Wetland	Erin	Wellington County	Marsh	Upper	PSW	24.66
W-13	Hillsburgh Wetland	Erin	Wellington County	Marsh	Upper	PSW, ESA	14.37
W-15	Grange Orpen Wetland	Caledon	Regional Municipality of Peel	Swamp	Upper	PSW, ESA	137.59
W-16	Starr Wetland	Caledon	Regional Municipality of Peel	Marsh	Upper		291.34
W-17	Speersville Wetland	Caledon	Regional Municipality of Peel	Marsh	Upper	PSW, ESA	218.85
W-18	Caledon Lake Wetland	Caledon	Regional Municipality of Peel	Swamp	Upper	PSW, ESA, ANSI	554.82
W-19	Melville Wetland	Orangeville	County of Dufferin	Marsh	Upper	PSW	5.53
W-20	Belfountain Wetland	Caledon	Regional Municipality of Peel	Marsh	Upper		30.86

[a] PSW, Provincially Significant Wetland; ESA, Environmentally Sensitive Area; ANSI, Area of Natural and Scientific Interest.

APPENDIX B: WETLAND WATER QUALITY TESTING

Table 1. Water quality parameters tested at selected wetlands in the Credit River Watershed in June 2006.

Parameter	Unit	Parameter	Unit
Metals [a]		**Inorganics**	
Aluminum (Al)	ug/L	Dissolved Inorganic Carbon	mg/L
Antimony (Sb)	ug/L	Total Ammonia-N	mg/L
Arsenic (As)	ug/L	Total Carbonaceous BOD	mg/L
Barium (Ba)	ug/L	Total Chemical Oxygen Demand (COD)	mg/L
Beryllium (Be)	ug/L	Conductivity	umho/cm
Boron (B)	ug/L	Total Dissolved Solids	mg/L
Cadmium (Cd)	ug/L	Fluoride (F-)	mg/L
Chromium (Cr)	ug/L	Hardness (CaCO3)	mg/L
Cobalt (Co)	ug/L	Total Kjeldahl Nitrogen (TKN)	mg/L
Copper (Cu)	ug/L	Dissolved Organic Carbon	mg/L
Iron (Fe)	ug/L	Orthophosphate (P)	mg/L
Lead (Pb)	ug/L	pH	pH
Molybdenum (Mo)	ug/L	Total Phosphorus	mg/L
Nickel (Ni)	ug/L	Total Suspended Solids	mg/L
Selenium (Se)	ug/L	Sulphide	mg/L
Silver (Ag)	ug/L	Alkalinity (Total as CaCO3)	mg/L
Thallium (Tl)	ug/L	Nitrite (N)	mg/L
Tungsten (W)	ug/L	Chloride (Cl)	mg/L
Uranium (U)	ug/L	Nitrate (N)	mg/L
Vanadium (V)	ug/L	Nitrate + Nitrite	mg/L
Zinc (Zn)	ug/L	Sulphate (SO4)	mg/L
Zirconium (Zr)	ug/L	**RCAP Calculations** [b]	
Field Measurements		Bicarb. Alkalinity	mg/L
pH	pH	Carb. Alkalinity	mg/L
Conductivity	µS/cm	Hydrox. Alkalinity	mg/L
Dissolved Oxygen	mg/L	**Nutrients**	
Dissolved Oxygen	%	Dissolved Phosphorus (P)	ug/L
Temperature	^{o}C		

[a] Dissolved metal concentrations were analyzed for groundwater samples, while total metal concentrations were analyzed for surface water samples.
[b] Calculated as CaCO3

APPENDIX B: WETLAND WATER QUALITY TESTING (Cont'd)

Table 2. Wetland groundwater quality results for tested parameters with PWQO and/or ODWS guidelines [a].

Parameter	Units	ODWS Guideline	PWQO Guideline	W-07	W-09	W-10	W-11 S [b]	W-11 D [b]	W-13	W-15	W-16	W-17	W-19	W-20
Total Phosphorus	ug/L	N/A	20 – 30 [c]	**230**	**2500**	**200**	**44**	**81**	**420**	**160**	**94**	**4400**	**30**	**1500**
Dissolved Aluminum	ug/L	N/A	75	6	ND	ND	9	ND	ND	ND	ND	ND	ND	ND
Dissolved Antimony	ug/L	6	20	2	ND	ND	1	ND	ND	ND	ND	ND	ND	ND
Dissolved Arsenic	ug/L	25	5	2	3	ND	**8**	ND	ND	ND	ND	2	ND	ND
Dissolved Barium	ug/L	1000	1000	66	150	63	280	120	31	150	58	32	150	200
Dissolved Beryllium	ug/L	N/A	11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dissolved Boron	ug/L	5000	200	ND	27	24	15	17	ND	20	16	ND	48	10
Dissolved Cadmium	ug/L	5	0.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dissolved Chromium	ug/L	50	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dissolved Cobalt	ug/L	N/A	0.9	**3**	ND	ND	ND	ND	ND	ND	0.8	ND	ND	ND
Dissolved Copper	ug/L	N/A	5	2	**7**	ND	4	ND	ND	ND	ND	ND	ND	1
Dissolved Iron	ug/L	N/A	300	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dissolved Lead	ug/L	10	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dissolved Molybdenum	ug/L	N/A	40	30	ND	2	8	ND	2	1	2	1	2	1
Dissolved Nickel	ug/L	N/A	25	8	ND	3	2	ND	ND	1	9	2	2	2
Dissolved Selenium	ug/L	10	100	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dissolved Silver	ug/L	N/A	0.1	ND	ND	**0.2**	ND	ND	ND	ND	**0.2**	0.1	ND	**0.2**
Dissolved Thallium	ug/L	N/A	0.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dissolved Tungsten	ug/L	N/A	30	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dissolved Uranium	ug/L	20	5	**7.8**	0.8	0.1	**12**	0.3	0.6	0.2	0.9	**35**	0.3	0.4
Dissolved Vanadium	ug/L	N/A	6	ND	ND	ND	**6**	ND	ND	ND	**7**	2	5	ND
Dissolved Zinc	ug/L	N/A	20	ND	ND	ND	ND	ND	ND	ND	ND	12	ND	12
Dissolved Zirconium	ug/L	N/A	4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Nitrite	mg/L	1	N/A	ND	ND	ND	0.01	ND	ND	0.01	ND	ND	ND	0.01
Nitrate	mg/L	10	N/A	ND	ND	ND	72	56	ND	99	21	ND	ND	13
Nitrite + Nitrate	mg/L	10	N/A	ND	ND	ND	ND	2.7	ND	ND	4.6	ND	ND	0.2
pH	N/A	N/A	6.5-8.5	7.74	8.05	7.46	6.56	7.13	7.46	7.18	7.63	8.68	7.65	6.7
Dissolved Oxygen	mg/L	N/A	Temp. dependant	8.69	3.63	9.12	5.09	6.78	6.65	3.62	9.73	9.48	9.34	1.21

[a] ND, Not detected; Grey text indicates guidelines which are not applicable to wetlands; Values exceeding applicable guidelines are highlighted in bold.
[b] S, shallow well; D, deep well.
[c] 20mg/L is the guidelines for lakes, whereas 30mg/L is the guideline for rivers

APPENDIX B: WETLAND WATER QUALITY TESTING (Cont'd)

Table 3. Wetland surface water quality results for tested parameters with PWQO and/or ODWS guidelines [a].

Parameter	Units	ODWS Guideline	PWQO Guideline	W-04	W-10	W-16 S [b]	W-16 W [b]	W-17	W-20
Total Phosphorus	ug/L	N/A	20 – 30 [c]		**100**			16	**2300**
Total Aluminum	ug/L	N/A	75		**75**			18	22
Total Antimony	ug/L	6	20		ND			ND	ND
Total Arsenic	ug/L	25	5		2			1	ND
Total Barium	ug/L	1000	1000		110			26	69
Total Beryllium	ug/L	N/A	11		ND			ND	ND
Total Boron	ug/L	5000	200		16			14	10
Total Cadmium	ug/L	5	0.2		ND			ND	ND
Total Chromium	ug/L	50	1		ND			ND	ND
Total Cobalt	ug/L	N/A	0.9		ND			ND	ND
Total Copper	ug/L	N/A	5		ND			ND	1
Total Iron	ug/L	N/A	300		**970**			260	64
Total Lead	ug/L	10	5		0.5			ND	ND
Total Molybdenum	ug/L	N/A	40		ND			ND	ND
Total Nickel	ug/L	N/A	25		ND			ND	ND
Total Selenium	ug/L	10	100		ND			ND	ND
Total Silver	ug/L	N/A	0.1		ND			ND	ND
Total Thallium	ug/L	N/A	0.3		ND			ND	ND
Total Tungsten	ug/L	N/A	30		ND			ND	ND
Total Uranium	ug/L	20	5		0.2			0.9	ND
Total Vanadium	ug/L	N/A	6		ND			ND	ND
Total Zinc	ug/L	N/A	20		6			**38**	12
Total Zirconium	ug/L	N/A	4		ND			ND	ND
Nitrite	mg/L	1	N/A		ND			ND	ND
Nitrate	mg/L	10	N/A		ND			ND	ND
Nitrite + Nitrate	mg/L	10	N/A		ND			ND	ND
pH	N/A	N/A	6.5-8.5	8.08	7.5	7.62	7.22	8.23	6.6
Dissolved Oxygen	mg/L	N/A	Temp. dependant	6.9983.1	6.59	12.3	7.52	10.69	1.98

[a] ND, Not detected; Grey text indicates guidelines which are not applicable to wetlands; Values exceeding applicable guidelines are highlighted in bold; shaded cells indicate that analysis was not completed for that parameter.
[b] S, at spring; W, at piezometer.
[c] 20mg/L is the guidelines for lakes, whereas 30mg/L is the guideline for rivers

APPENDIX C: HYDROGRAPHS AT SELECTED WETLAND MONITORING SITES IN THE CREDIT RIVER WATERSHED

For hydrographs in this appendix, depth indicates the depth of water in relation to the ground surface. Therefore, positive numbers represent the depth of water above the ground and negative numbers represent the distance from the ground surface to water below. Surface water levels are determined from the depth of water on the ground surface directly outside of the piezometers. Groundwater levels are determined by the depth of water within the piezometers and may be either above or below the ground surface. Groundwater being higher than the surface water may be an indication of groundwater discharge into the wetland; however more in-depth hydrological studies are required to confirm these estimations. Two sampling dates occurred in May 2006 at each site, once in mid-May and once in late May. A dramatic difference between the measurements was observed only at Meadowvale Wetland. This difference could be attributed to either measurement error in the field or the effect of the Credit River on the water table in the spring, as this is a riparian wetland to the Credit River.

APPENDIX C: HYDROGRAPHS AT SELECTED WETLAND MONITORING SITES IN THE CREDIT RIVER WATERSHED (Cont'd)

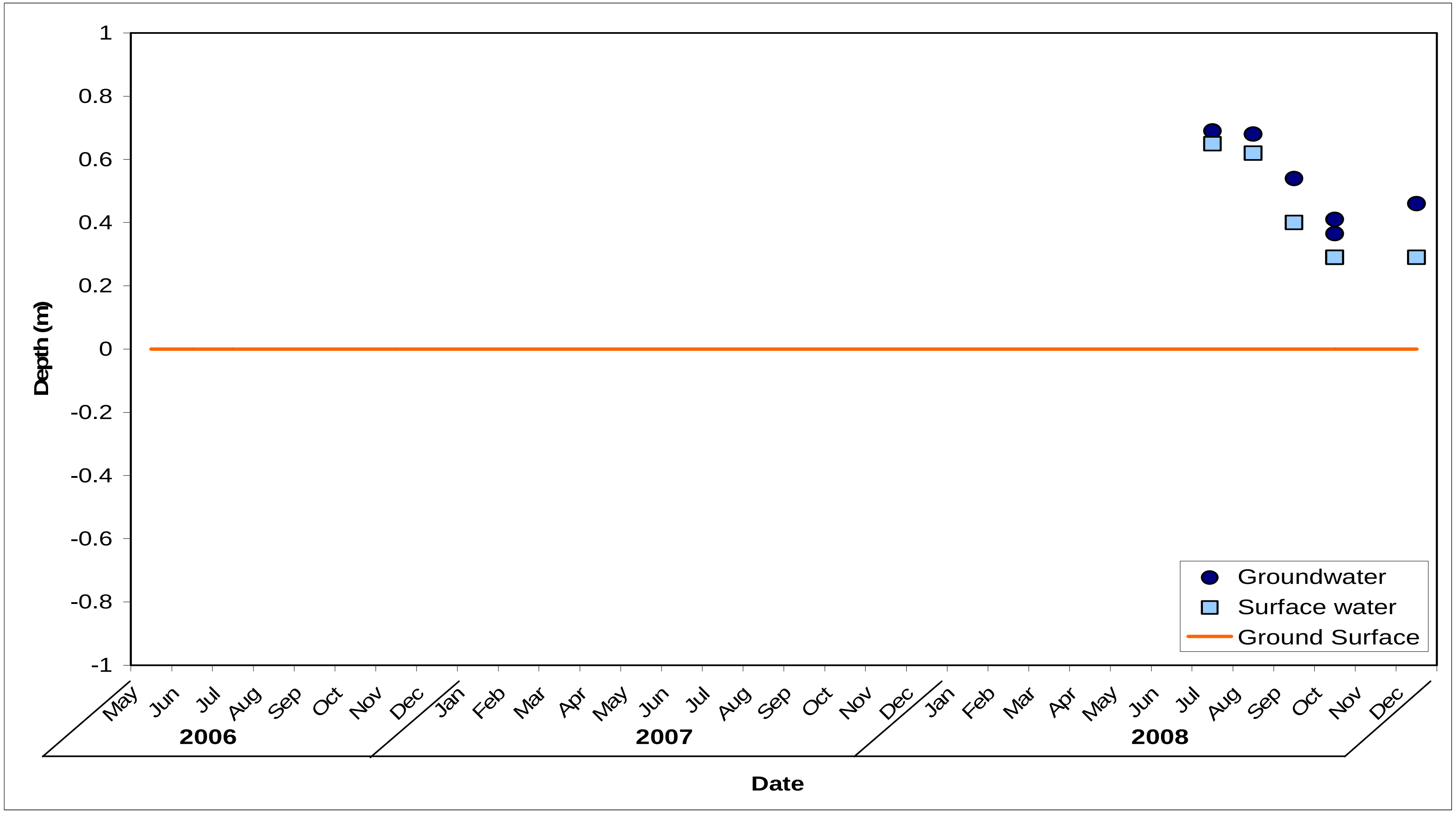

Figure 1. Hydrograph for Rattray Marsh Wetland (W-01) from Summer 2008 to Fall 2008. Depth (m) indicates the depth of water in relation to the ground surface. Therefore, positive numbers represent the depth of water above the ground and negative numbers represent the distance from the ground surface to water below.

APPENDIX C: HYDROGRAPHS AT SELECTED WETLAND MONITORING SITES IN THE CREDIT RIVER WATERSHED (Cont'd)

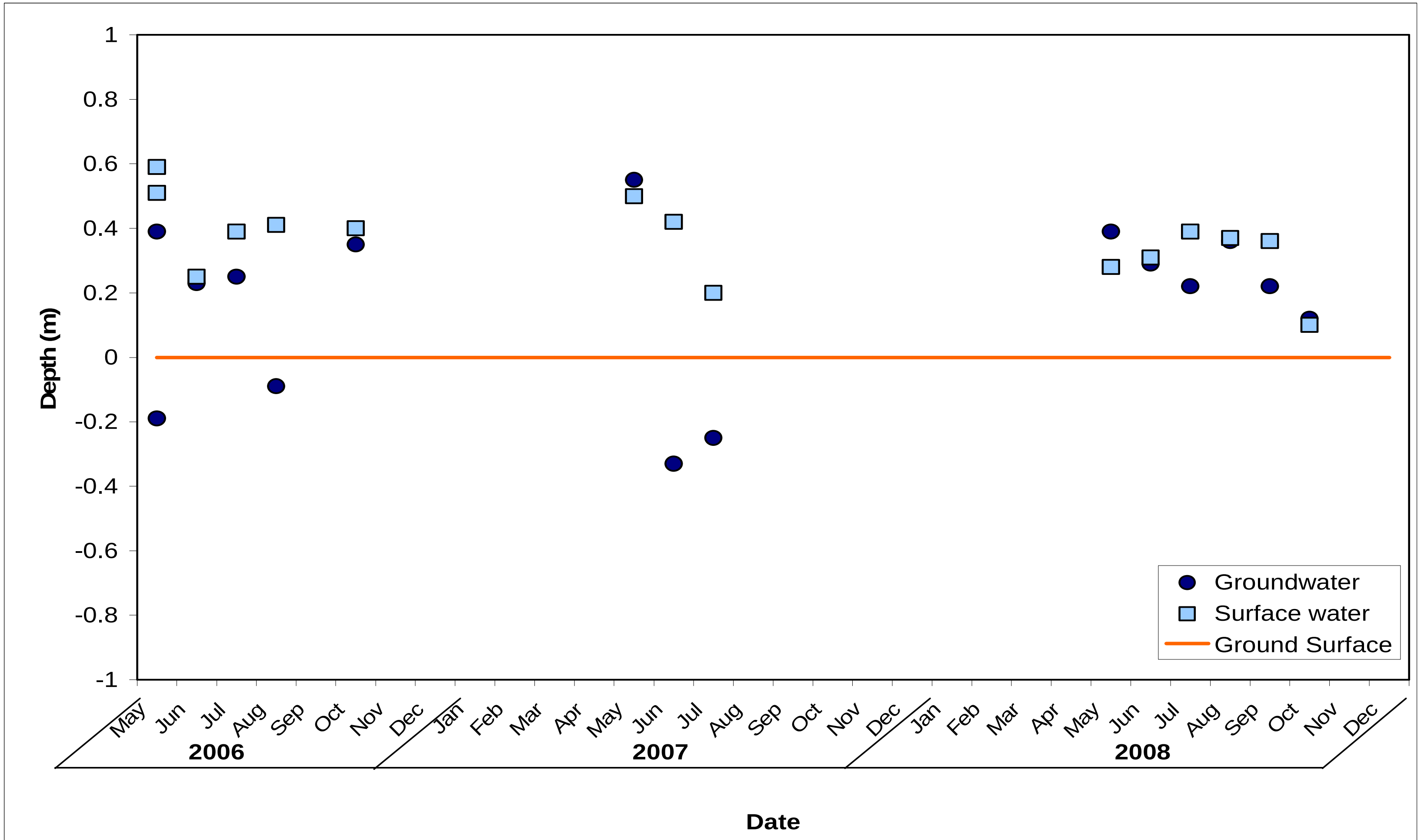

Figure 2. Hydrograph for Meadowvale Wetland (W-04) from Spring 2006 to Fall 2008. Depth (m) indicates the depth of water in relation to the ground surface. Therefore, positive numbers represent the depth of water above the ground and negative numbers represent the distance from the ground surface to water below.

APPENDIX C: HYDROGRAPHS AT SELECTED WETLAND MONITORING SITES IN THE CREDIT RIVER WATERSHED (Cont'd)

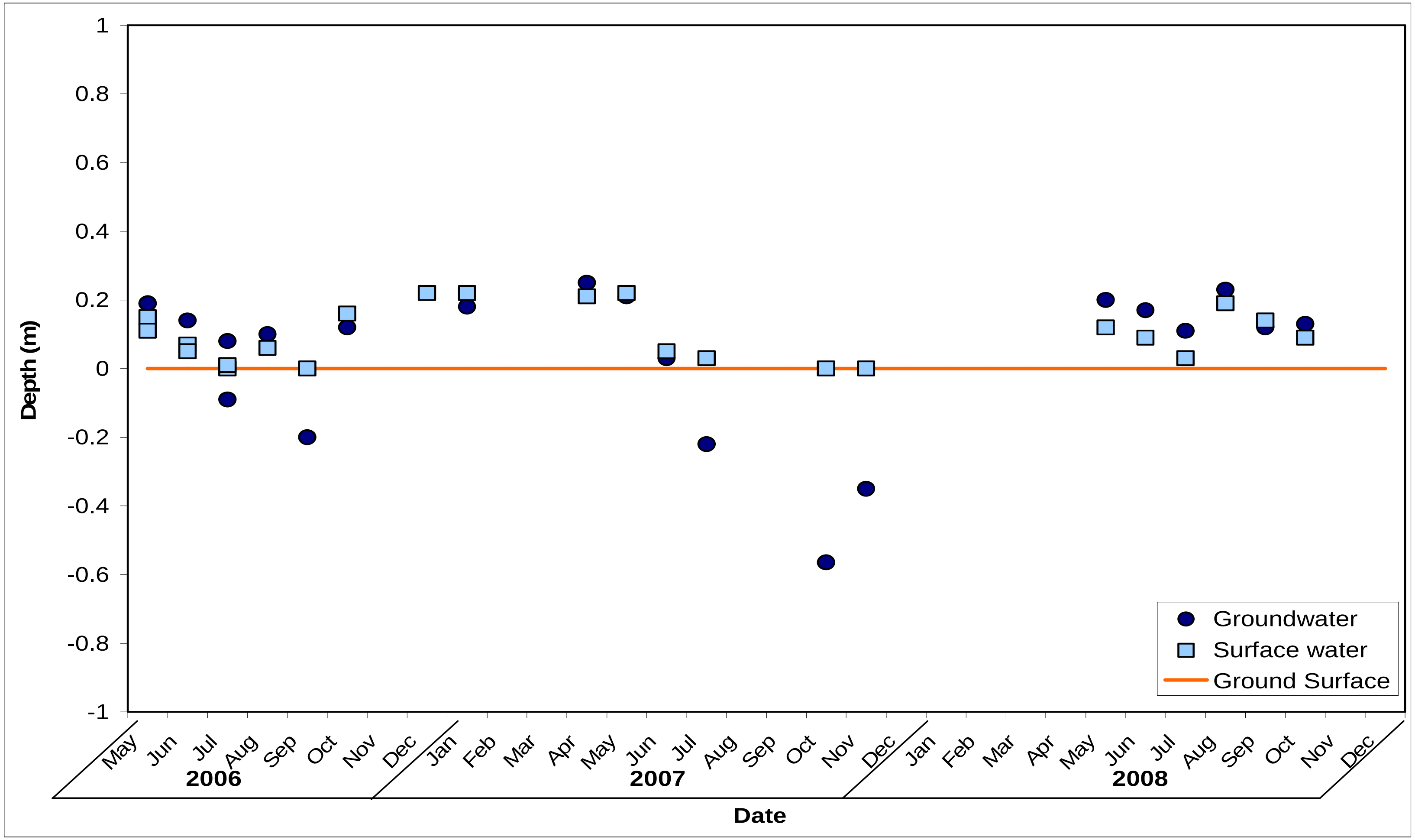

Figure 3. Hydrograph for Acton Wetland (W-07) from Spring 2006 to Fall 2008. Depth (m) indicates the depth of water in relation to the ground surface. Therefore, positive numbers represent the depth of water above the ground and negative numbers represent the distance from the ground surface to water below.

APPENDIX C: HYDROGRAPHS AT SELECTED WETLAND MONITORING SITES IN THE CREDIT RIVER WATERSHED (Cont'd)

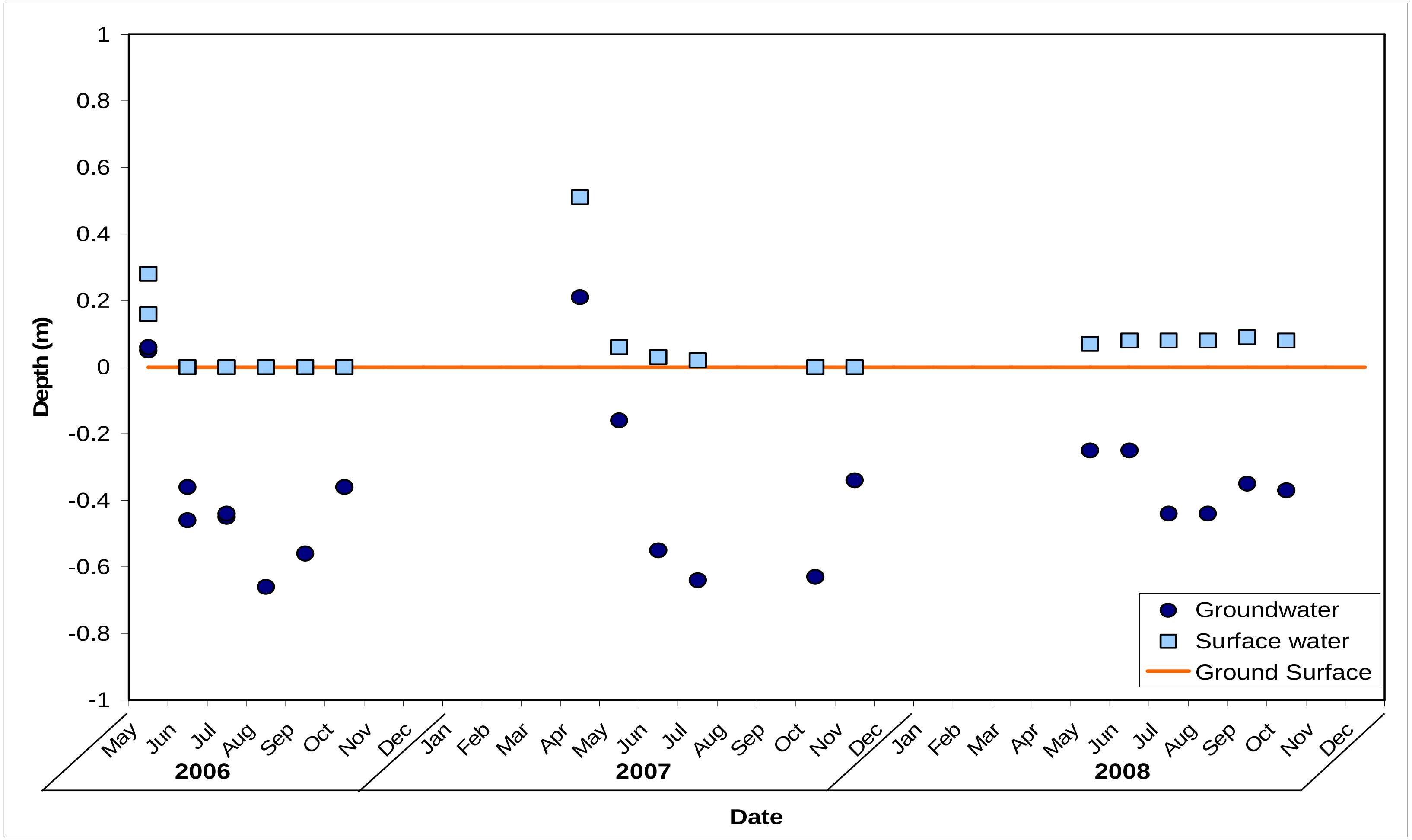

Figure 4. Hydrograph for Ken Whillans Wetland (W-09) from Spring 2006 to Fall 2008. Depth (m) indicates the depth of water in relation to the ground surface. Therefore, positive numbers represent the depth of water above the ground and negative numbers represent the distance from the ground surface to water below.

APPENDIX C: HYDROGRAPHS AT SELECTED WETLAND MONITORING SITES IN THE CREDIT RIVER WATERSHED (Cont'd)

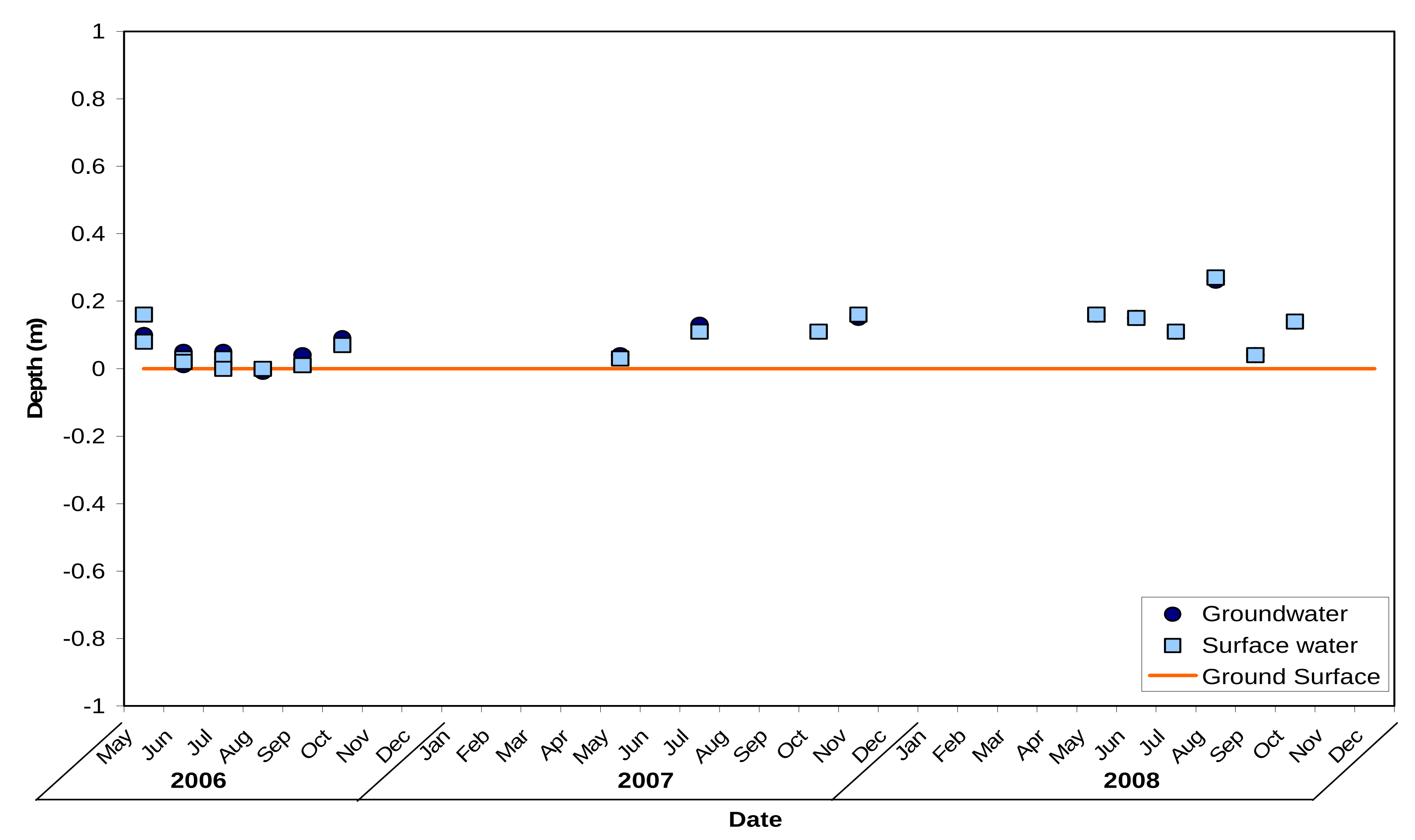

Figure 5. Hydrograph for Warwick Wetland (W-10) from Spring 2006 to Fall 2008. Depth (m) indicates the depth of water in relation to the ground surface. Therefore, positive numbers represent the depth of water above the ground and negative numbers represent the distance from the ground surface to water below.

APPENDIX C: HYDROGRAPHS AT SELECTED WETLAND MONITORING SITES IN THE CREDIT RIVER WATERSHED (Cont'd)

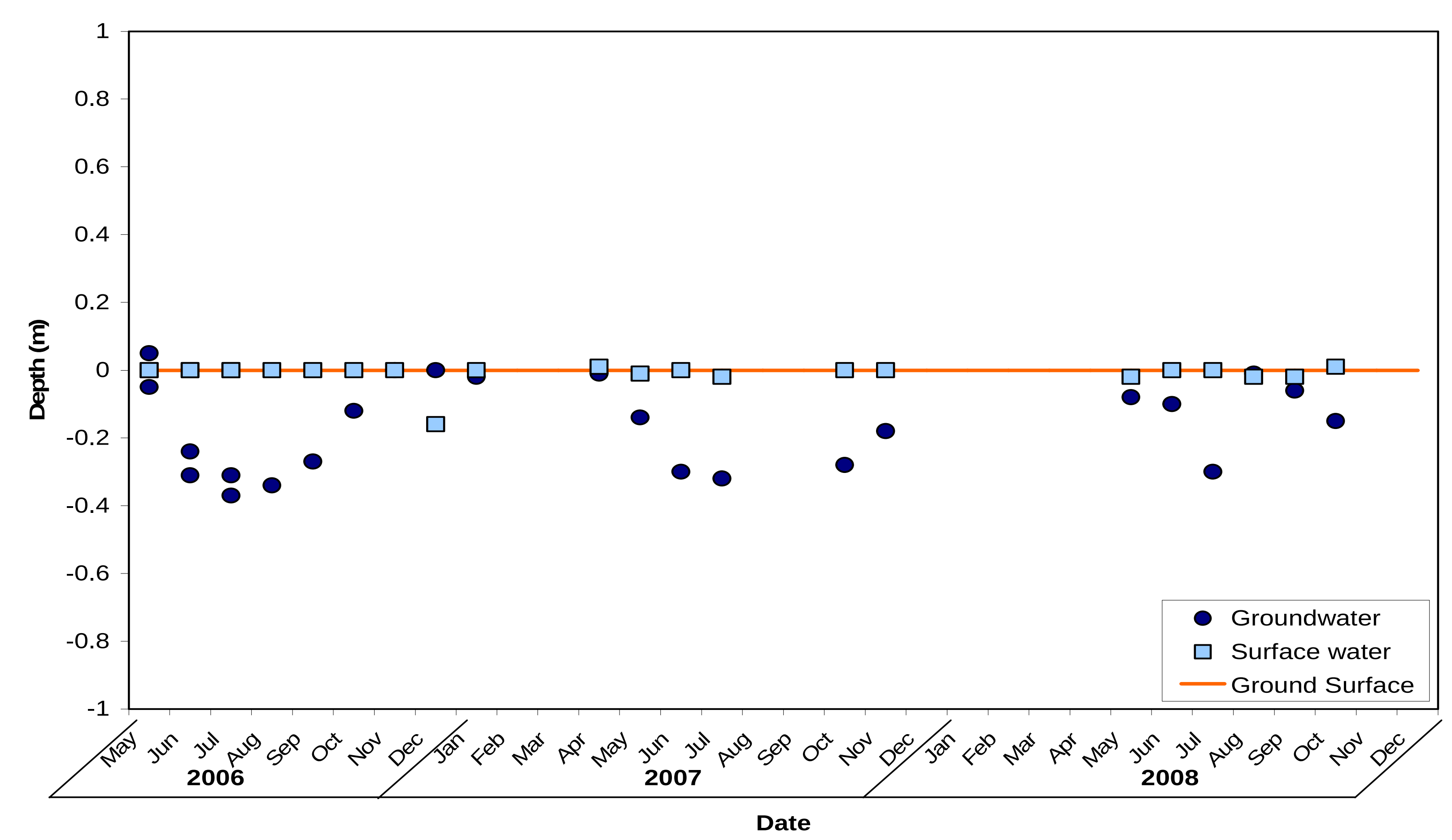

Figure 6. Hydrograph for Erin Pine Estates Wetland (Deep Piezometer) (W-11) from Spring 2006 to Fall 2008. Depth (m) indicates the depth of water in relation to the ground surface. Therefore, positive numbers represent the depth of water above the ground and negative numbers represent the distance from the ground surface to water below.

APPENDIX C: HYDROGRAPHS AT SELECTED WETLAND MONITORING SITES IN THE CREDIT RIVER WATERSHED (Cont'd)

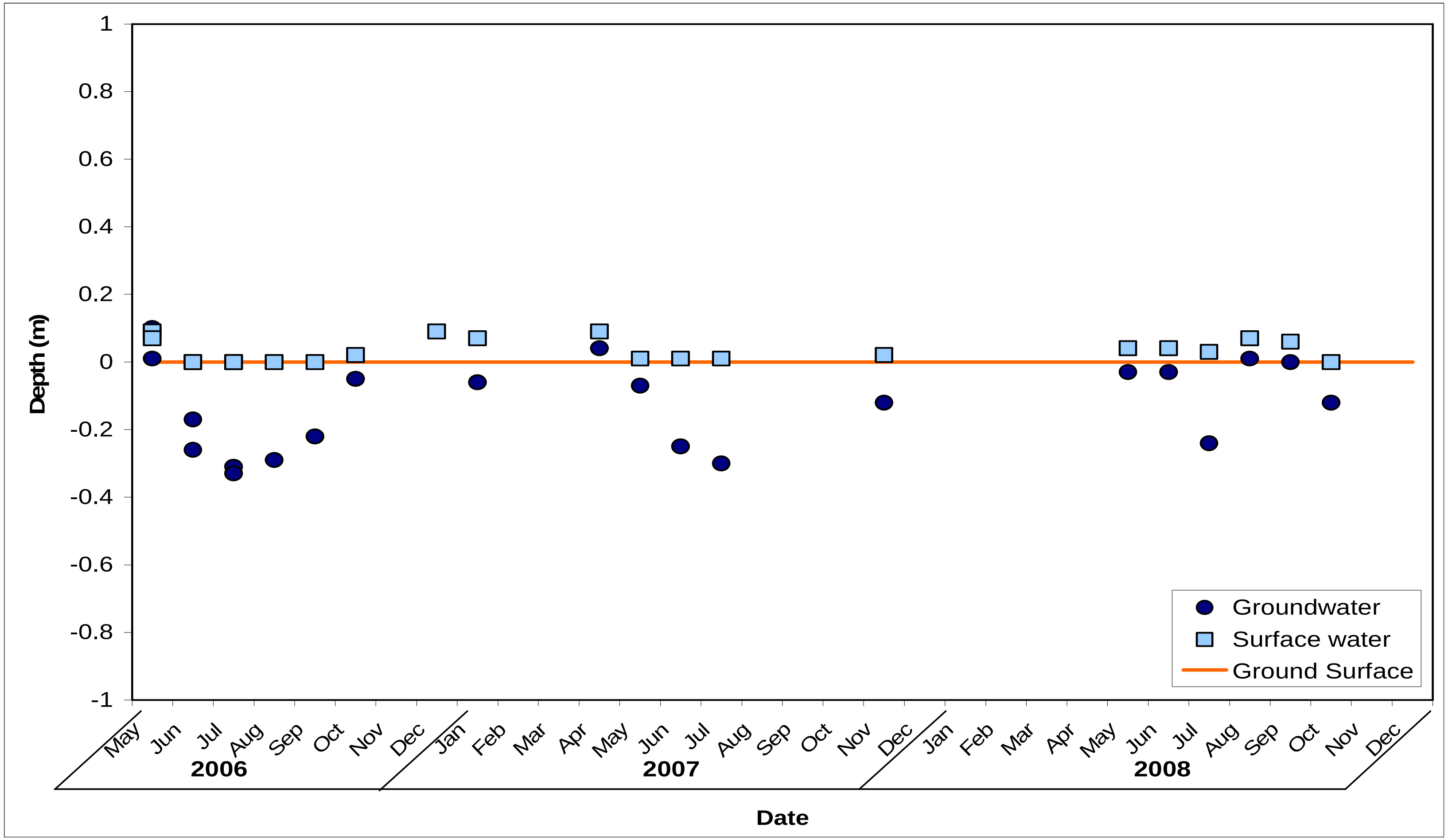

Figure 7. Hydrograph for Erin Pine Estates Wetland (Shallow Piezometer) (W-11) from Spring 2006 to Fall 2008. Depth (m) indicates the depth of water in relation to the ground surface. Therefore, positive numbers represent the depth of water above the ground and negative numbers represent the distance from the ground surface to water below.

APPENDIX C: HYDROGRAPHS AT SELECTED WETLAND MONITORING SITES IN THE CREDIT RIVER WATERSHED (Cont'd)

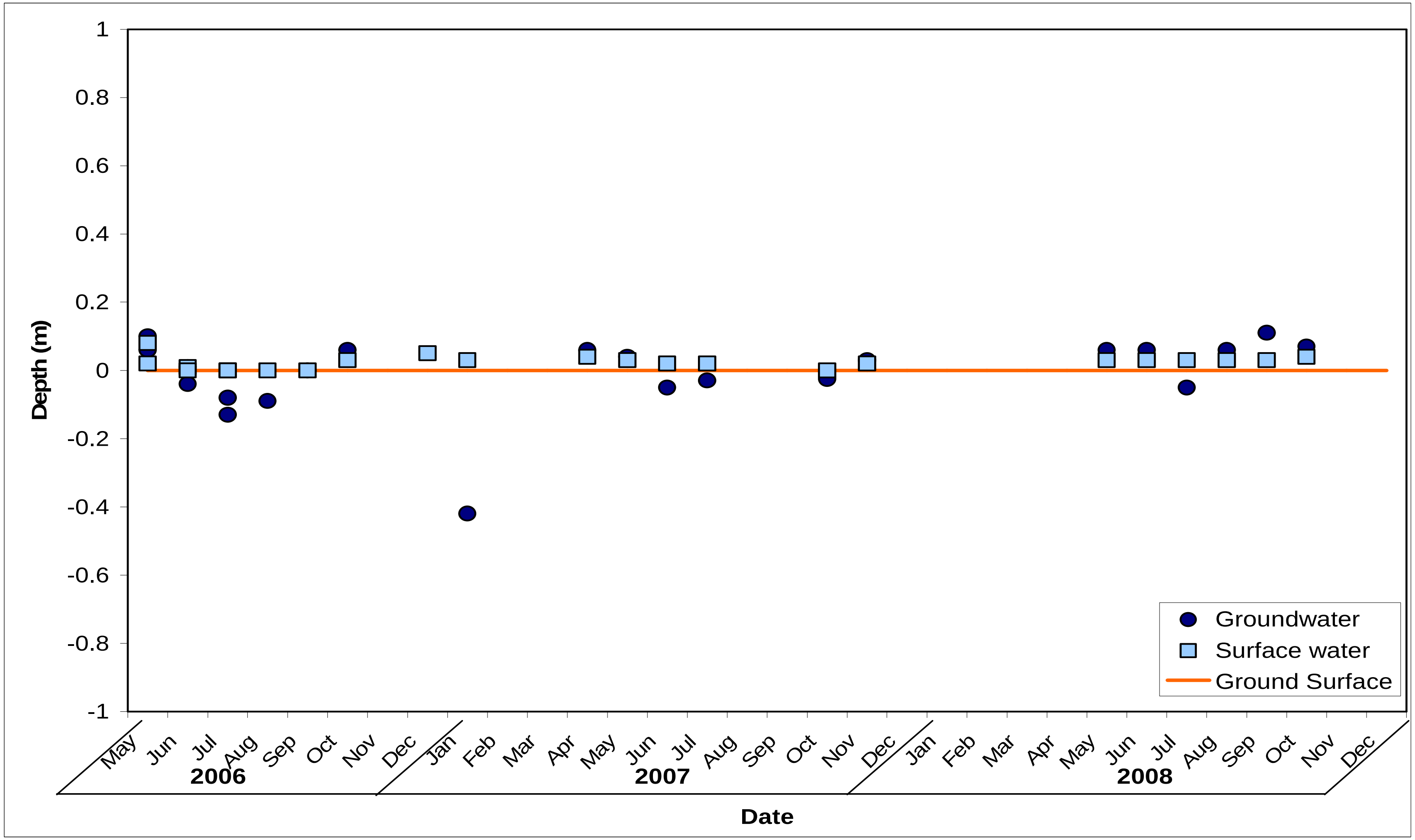

Figure 8. Hydrograph for Hillsburgh Wetland (W-13) from Spring 2006 to Fall 2008. Depth (m) indicates the depth of water in relation to the ground surface. Therefore, positive numbers represent the depth of water above the ground and negative numbers represent the distance from the ground surface to water below.

APPENDIX C: HYDROGRAPHS AT SELECTED WETLAND MONITORING SITES IN THE CREDIT RIVER WATERSHED (Cont'd)

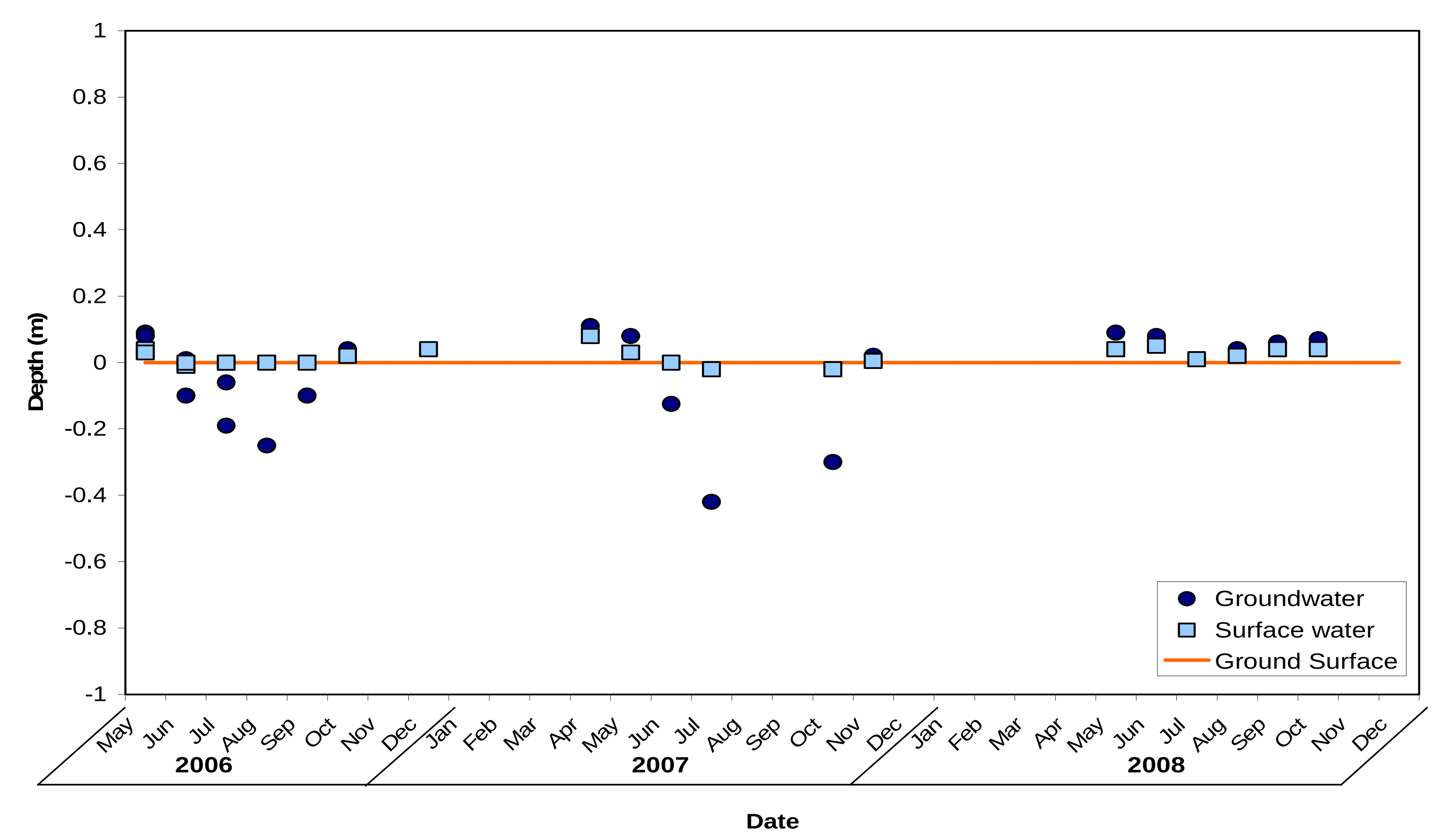

Figure 9. Hydrograph for Grange Orpen Wetland (W-15) from Spring 2006 to Fall 2008. Depth (m) indicates the depth of water in relation to the ground surface. Therefore, positive numbers represent the depth of water above the ground and negative numbers represent the distance from the ground surface to water below.

APPENDIX C: HYDROGRAPHS AT SELECTED WETLAND MONITORING SITES IN THE CREDIT RIVER WATERSHED (Cont'd)

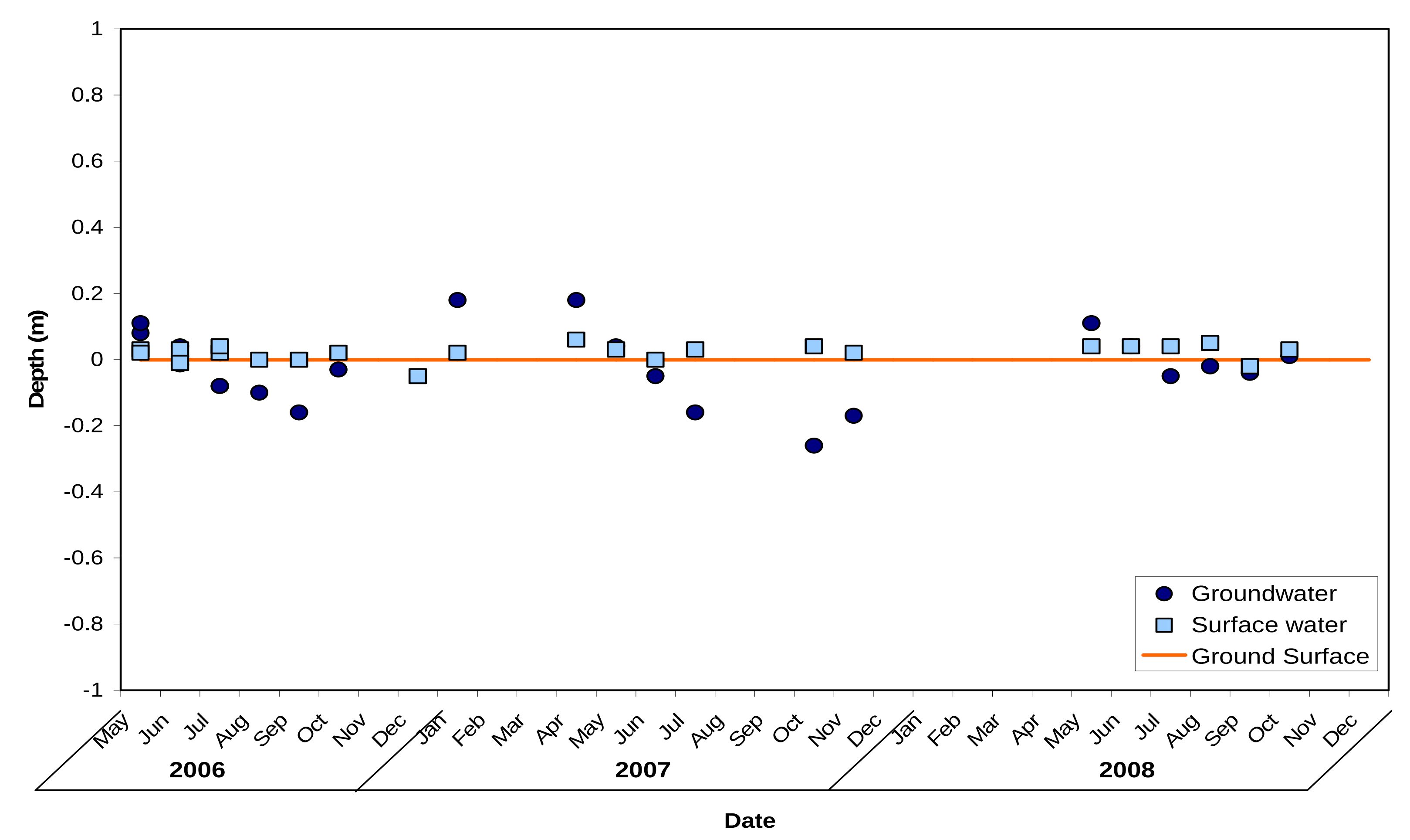

Figure 10. Hydrograph for Starr Wetland (W-16) from Spring 2006 to Fall 2008. Depth (m) indicates the depth of water in relation to the ground surface. Therefore, positive numbers represent the depth of water above the ground and negative numbers represent the distance from the ground surface to water below.

APPENDIX C: HYDROGRAPHS AT SELECTED WETLAND MONITORING SITES IN THE CREDIT RIVER WATERSHED (Cont'd)

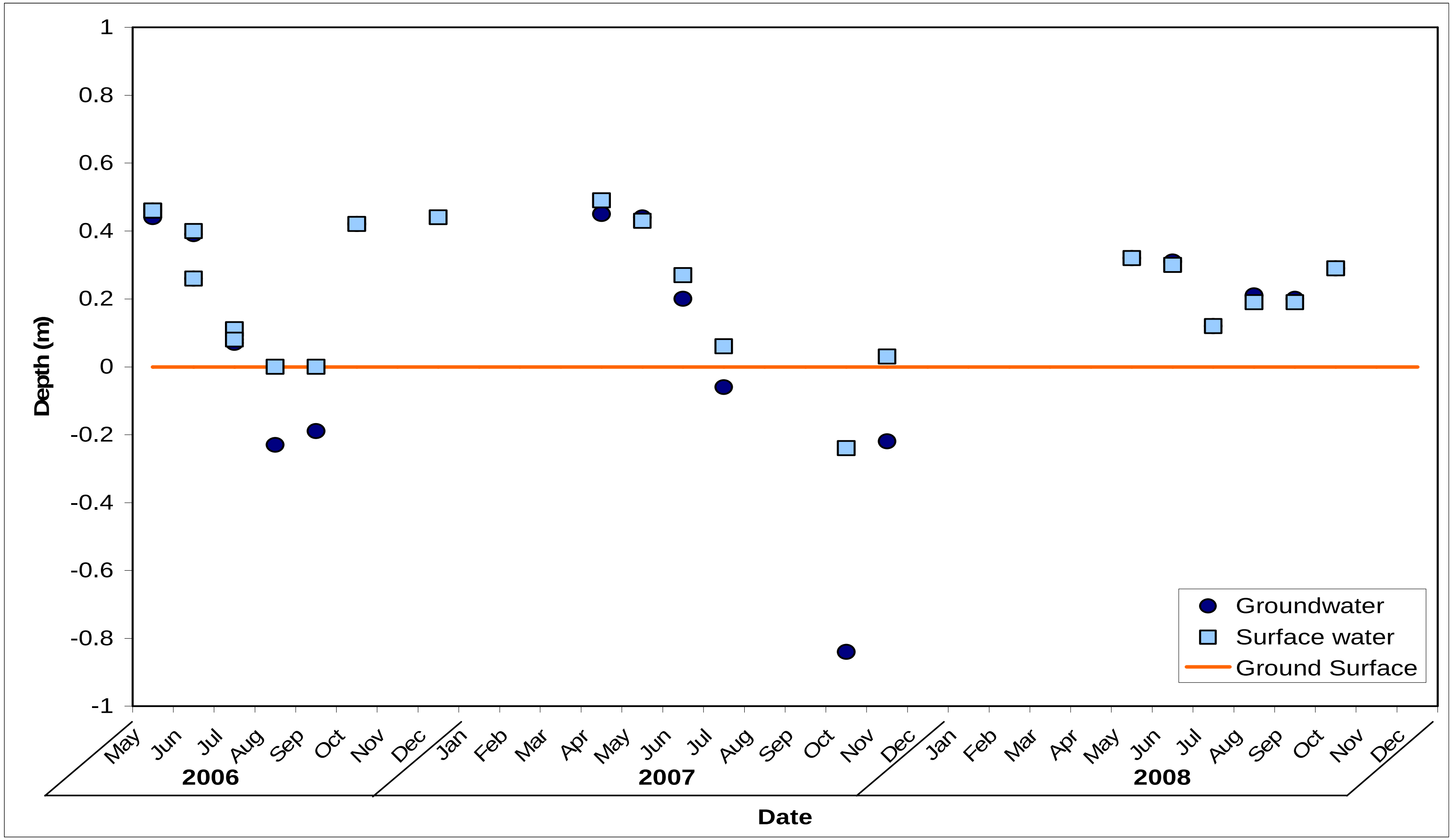

Figure 11. Hydrograph for Speersville Wetland W-17) from Spring 2006 to Fall 2008. Depth (m) indicates the depth of water in relation to the ground surface. Therefore, positive numbers represent the depth of water above the ground and negative numbers represent the distance from the ground surface to water below.

APPENDIX C: HYDROGRAPHS AT SELECTED WETLAND MONITORING SITES IN THE CREDIT RIVER WATERSHED (Cont'd)

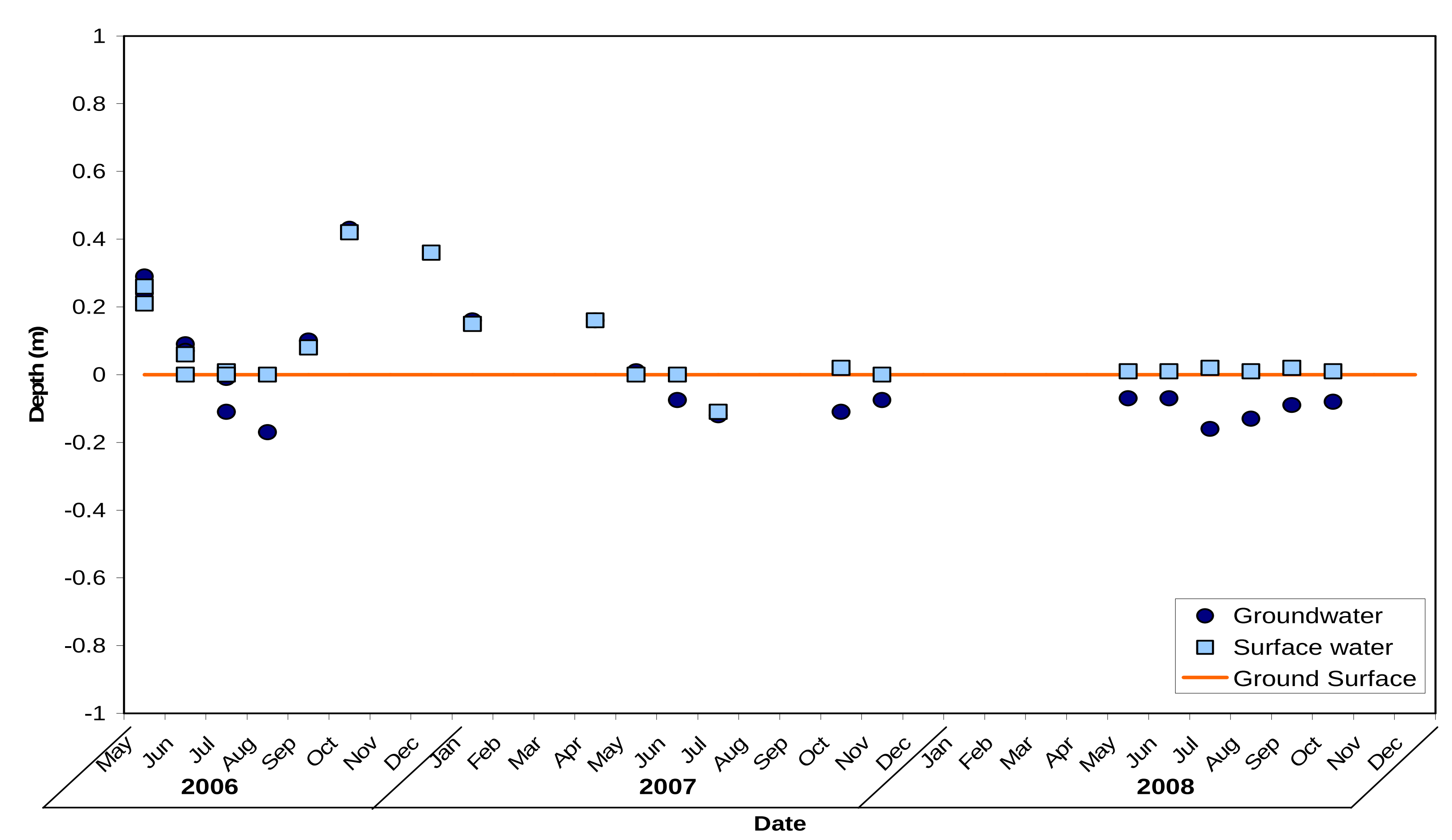

Figure 12. Hydrograph for Melville Wetland (W-19) from Spring 2006 to Fall 2008. Depth (m) indicates the depth of water in relation to the ground surface. Therefore, positive numbers represent the depth of water above the ground and negative numbers represent the distance from the ground surface to water below.

APPENDIX C: HYDROGRAPHS AT SELECTED WETLAND MONITORING SITES IN THE CREDIT RIVER WATERSHED (Cont'd)

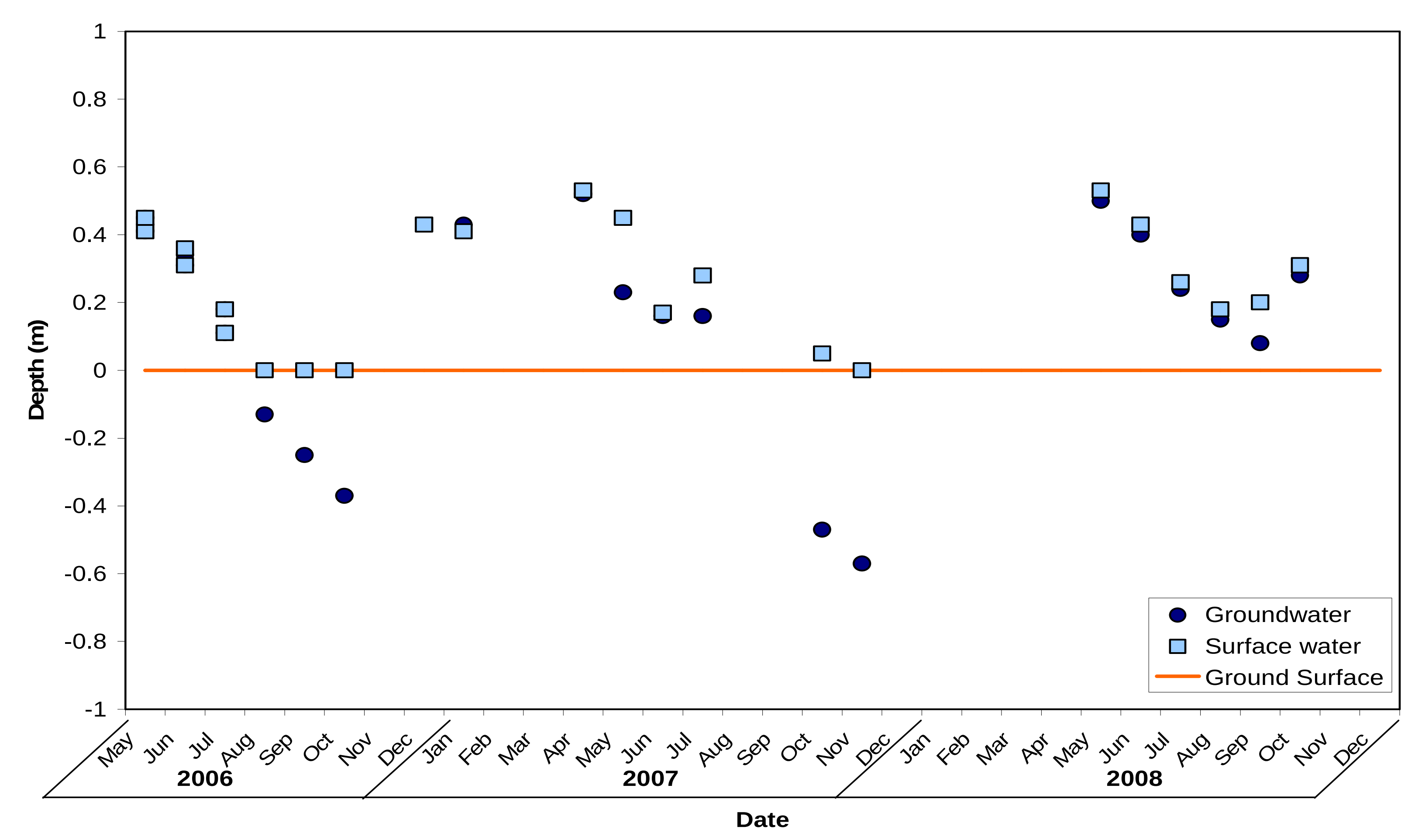

Figure 13. Hydrograph for Belfountain Wetland (W-20) from Spring 2006 to Fall 2008. Depth (m) indicates the depth of water in relation to the ground surface. Therefore, positive numbers represent the depth of water above the ground and negative numbers represent the distance from the ground surface to water below.

APPENDIX D: WETLAND SITE HYDROLOGY SUMMARIES

Table 1. Summary of local hydrology at selected wetland monitoring sites in the Credit River Watershed based on piezometer water levels.

Wetland Site	2006	2007	2008	Combined
Meadowvale Wetland	•During dryer periods, groundwater drops below ground surface •No periods of groundwater discharge to wetland •Surface water always present (0.25-0.59m above ground surface)	•During dryer periods, groundwater drops below ground surface •Groundwater discharge into wetland in May •Surface water always present (0.2-0.5m above ground surface)	•Groundwater does not drop below ground surface – 2008 not as dry as 2007 •Groundwater discharge entire season •Surface water always present (0.3-0.65m above ground surface)	•Limited groundwater discharge to wetland •Typical groundwater drops in dry periods •Generally wet
Rattray Marsh Wetland			•Groundwater discharge into wetland in May and October •Surface water always present (0.1-0.39m above ground surface) Ground and surface water levels decrease during dryer periods	•Moderate amounts groundwater discharge to wetland •Typical groundwater drops in dry periods •Generally wet
Acton Wetland	•During dryer periods (July & September), groundwater drops below ground surface •Groundwater discharge to wetland from May – June, and in late summer •Surface water absent at dry time with average of 0.1m above ground surface	•During dryer periods (July – Nov), groundwater drops below ground surface (up to 0.57m below) •Groundwater discharge into wetland in Apr •Surface water always present (0.03-0.22m above ground surface)	•Groundwater does not drop below ground surface – 2008 not as dry as 2007 •Groundwater discharge into wetland over the majority of the season •Surface water always present (0.03-0.19m above ground surface)	•Moderate amounts groundwater discharge to wetland •Typical groundwater drops in dry periods •Generally moist
Warwick Wetland				•Surface water almost always present, sometimes dry during dry season, seems to fluctuate over season •Organics likely not providing a compact enough seal, resulting in surface water monitoring only, well may be more suitable
Ken Whillans Wetland	•Groundwater drops below ground surface for the majority of the season (except May) (mean 0.47m) •No groundwater discharge to wetland •Surface water present in May, absent for remainder of season	•Groundwater drops below ground surface for the majority of the season (except Apr) (mean 0.46m) •No groundwater discharge to wetland •Surface water at 0.5m in May but drops to mean of 0.04m into May and June, absent later in season	•Groundwater drops below ground surface for entire season (mean 0.35m) •No groundwater discharge to wetland •Surface water always present (mean 0.08m)	•No groundwater discharge to wetland •Groundwater below surface for majority of season •Generally dry •Groundwater not a large contributor to wetland hydrology
Erin Pine Estates Wetland	•Groundwater drops below ground surface for the majority of the season •Groundwater discharge to wetland only in May •Surface water generally absent, present in shallow early and late in season	•Groundwater drops below ground surface for the majority of the season •No groundwater discharge to wetland •Surface water generally absent or minimal after April	•Groundwater drops below ground surface for entire season •No groundwater discharge to wetland •Surface water absent from deep well, minimal at shallow well	•No groundwater discharge to wetland •Groundwater below surface for majority of season

Wetland Site	2006	2007	2008	Combined
Hillsburgh Wetland	•Groundwater drops below ground surface during dry periods •Groundwater discharge to wetland early and late in season •Surface water absent during summer season	•Groundwater drops below ground surface during dry periods •Minimal groundwater discharge to wetland early and late in season •Surface water minimal (mean 0.03m) and stable	•Groundwater drops below ground surface only in July •Potential groundwater discharge to wetland for majority of season •Surface water minimal (mean 0.03m) and stable	•Limited potential groundwater discharge to wetland, depending on till •Groundwater below surface only in dry times •Minimal surface water and stable •Creek may moderate surface water levels
Grange Orpen Wetland	•Groundwater drops below ground surface from June-Sept •Groundwater discharge to wetland in spring and fall •Surface water dry from June - Sept	•Groundwater drops below ground surface from June-Oct •Groundwater discharge to wetland in spring and fall •Surface water dry from June - Oct	•Groundwater does not drops below ground surface for entire season •Groundwater discharge to wetland for majority of season •Surface water always present (mean 0.03m)	•Potential groundwater discharge to wetland •Groundwater below surface during dry events •Generally moist
Starr Wetland	•During dryer periods (June – Oct.), groundwater drops below ground surface •Groundwater discharge to wetland from May – June •Surface water absent in Aug, with average of 0.03m above ground surface	•During dryer periods (June – Nov), groundwater drops below ground surface •Groundwater discharge into wetland Jan- May •Surface water always present (mean 0.03m above ground surface)	•Groundwater drops below surface but by no more than 0.05m from July-Sept. •Groundwater discharge into wetland only in May •Surface normally present (mean 0.04m)	•Moderate amount of groundwater discharge to wetland •Typical groundwater drops in dry periods •Generally moist •Annual spring flow at site
Speersville Wetland	•Groundwater drops below ground surface during dry periods •No groundwater discharge to wetland •Surface water absent Aug – Sept, decreases from spring to summer and then increases in fall	•Groundwater drops below ground surface during dry periods •Essentially no groundwater discharge to wetland •Surface water absent Aug – Oct, decreases from spring to summer and then increases in fall	•Groundwater never drops below ground surface •Essentially no groundwater discharge to wetland •Surface water always present (mean 0.24m)	•Piezometer may be leaking, may just be monitoring surface was, as groundwater follows similar trends, may also be result of engineered fill which is why groundwater falls below surface during dry periods •Essentially no groundwater discharge to wetland •Groundwater below surface during dry periods •Usually standing water
Melville Wetland	•Groundwater drops below ground surface in summer •Minimal groundwater discharge in spring and fall •Surface water present for entire season, but fluctuates greatly due to beaver dam	•Groundwater drops below ground surface in summer and fall •Essentially no groundwater discharge to wetland •Surface water variable, higher in spring and fall, also affected by dam?	•Groundwater drops below ground surface for entire season (mean 0.10m) •No groundwater discharge to wetland •Surface water always present (mean 0.01m)	•2006 and 2007 surface data affected by beaver dam •Very limited groundwater discharge to wetland •Groundwater below surface for large portions of season •Generally dry after removal of dam
Belfountain Wetland	•Groundwater drops below ground surface in dry season (Aug – Oct) •No groundwater discharge to wetland •Surface water present until Aug, absent for remainder of season until Dec	•Groundwater drops below ground surface in fall •Groundwater discharge to wetland only in Jan •Surface water present until Nov. (mean 0.32m)	•Groundwater does not drop below ground surface •No groundwater discharge to wetland •Surface water always present (mean 0.29m)	•Groundwater has very little input in wetland, surface water more important, outflow location from wetland •Surface water depth decreases throughout the season •Groundwater below surface during dry spells

APPENDIX E: WETLAND MONITORING SITE MAPS AND PHOTOS

Figure 1. Rattray Marsh Wetland (W-01) site map and photograph.

APPENDIX E: WETLAND MONITORING SITE MAPS AND PHOTOS (Con't)

Figure 2. Meadowvale Wetland (W-04) site map and photograph.

APPENDIX E: WETLAND MONITORING SITE MAPS AND PHOTOS (Con't)

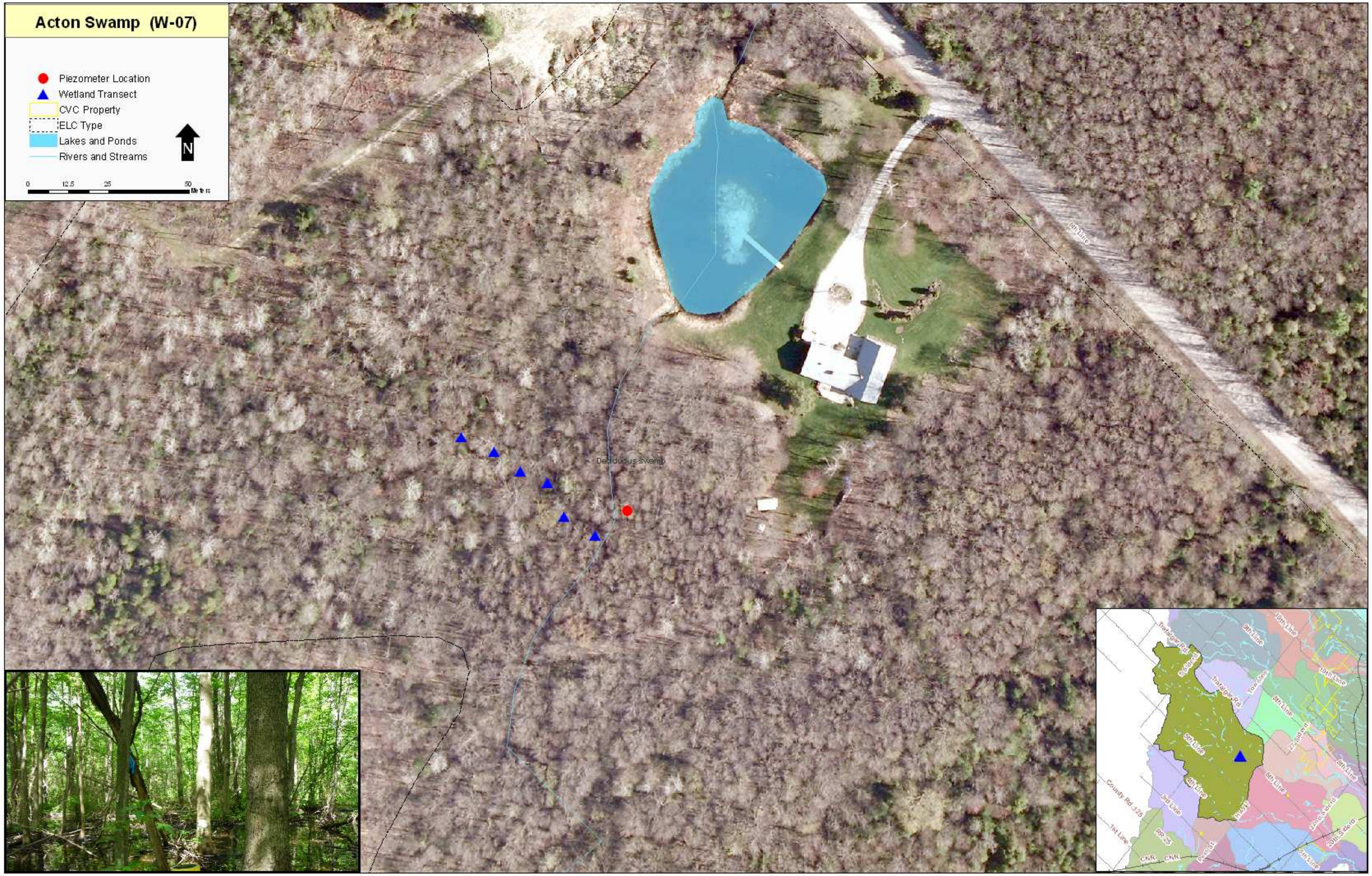

Figure 3. Action Wetland (W-07) site map and photograph.

APPENDIX E: WETLAND MONITORING SITE MAPS AND PHOTOS (Con't)

Figure 4. Ken Whillans Wetland (W-09) site map and photograph.

APPENDIX E: WETLAND MONITORING SITE MAPS AND PHOTOS (Con't)

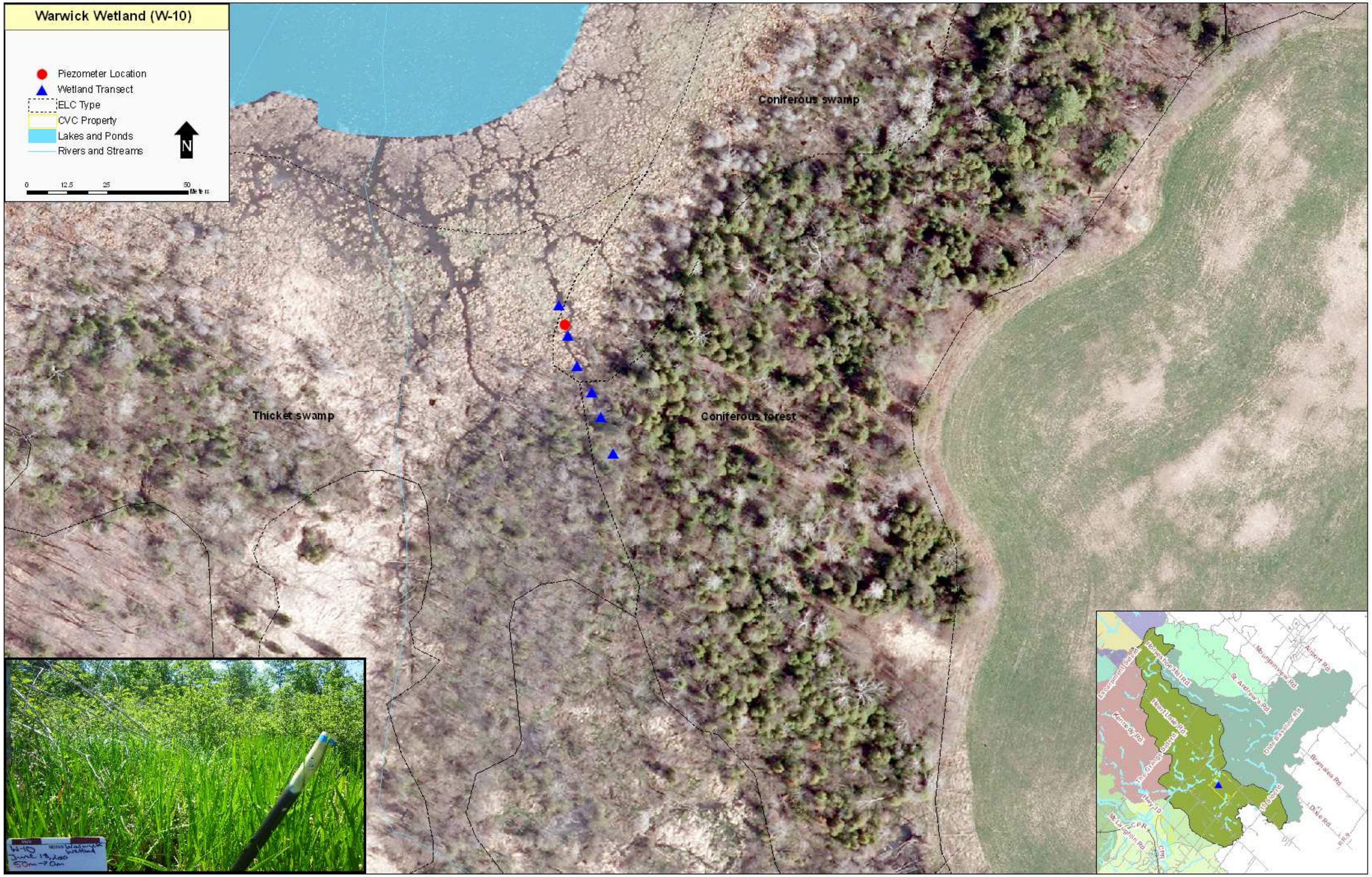

Figure 5. Warwick Wetland (W-10) site map and photograph.

APPENDIX E: WETLAND MONITORING SITE MAPS AND PHOTOS (Con't)

Figure 6. Erin Pine Estates Wetland (W-11) site map and photograph.

APPENDIX E: WETLAND MONITORING SITE MAPS AND PHOTOS (Con't)

Figure 7. Hillsburgh Wetland (W-13) site map and photograph.

APPENDIX E: WETLAND MONITORING SITE MAPS AND PHOTOS (Con't)

Figure 8. Grange Orpen Wetland (W-15) site map and photograph.

APPENDIX E: WETLAND MONITORING SITE MAPS AND PHOTOS (Con't)

Figure 9. Starr Wetland (W-15) site map and photograph.

APPENDIX E: WETLAND MONITORING SITE MAPS AND PHOTOS (Con't)

Figure 10. Speersville Wetland (W-17) site map and photograph.

APPENDIX E: WETLAND MONITORING SITE MAPS AND PHOTOS (Con't)

Figure 11. Melville Wetland (W-19) site map and photograph.

APPENDIX E: WETLAND MONITORING SITE MAPS AND PHOTOS (Con't)

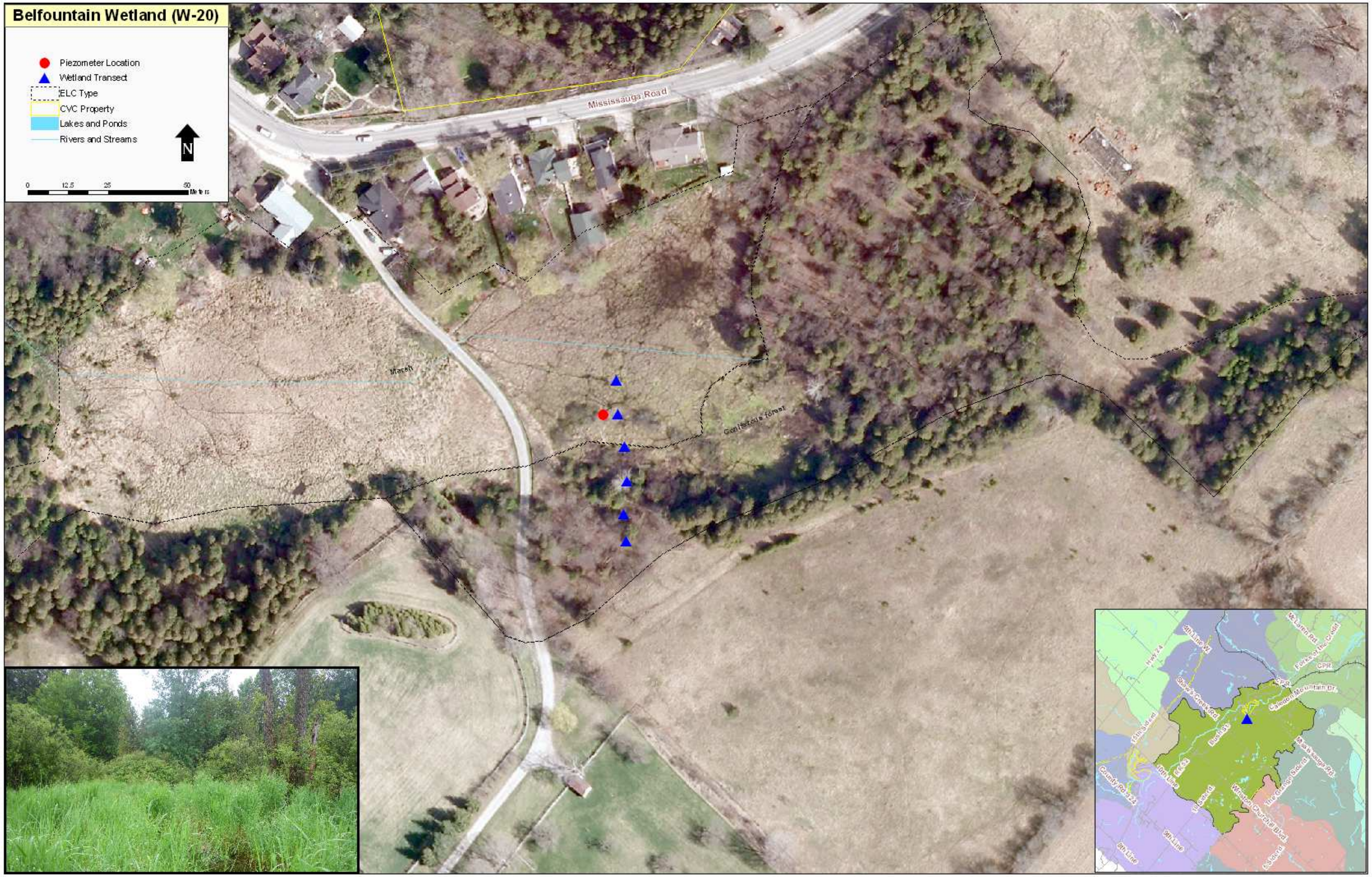

Figure 12. Belfountain Wetland (W-20) site map and photograph.

APPENDIX F: ADDITIONAL LABORATORY AND EQUIPMENT COSTS

LABORATORY COSTS

Table 1. Laboratory costs for each parameter in the WQI (excludes *in situ* parameters) as quoted from Maxxam Analytics. [a]

Parameter	Cost per Sample	Notes
Chlorophyll-a	$100	
Total suspended solids	$8.25	
Total inorganic suspended solids	$15.50	Cost for Volatile suspended solids test, needed for TISS calculation (TISS=TSS-VSS)
Total phosphorus	$15.50	
Soluble reactive phosphorus	$7.20	
Total ammonium nitrogen	$12.30	
Total nitrate nitrogen	$14.40	
Total nitrogen	$15.45	Cost for TKN test, needed for TN calculation

[a] Displayed costs are on a per sample basis. Lower costs may be available for mass sample submissions.

IN SITU EQUIPMENT COSTS

Quanta T System

The Quanta T system is a complete water quality monitoring system capable of monitoring multiple water quality parameters simultaneously. The system is comprised of three components: the Quanta transmitter, the Quanta display, and a connecting cable. The system can be custom configured to monitor your desired parameters (it will measure all four *in situ* parameters required for the WQI). More detailed information regarding this equipment can be found at the following website: http://www.campbellsci.ca/Catalogue/QUANTAT.html. The purchase cost before taxes for this system is estimated at under $6000.00 (Table 2). Please note that this estimate was generated from the 2009 Campbell Scientific Hydrolab Products price list. Additional supplies, such as reagents or carrying case, may need to be purchased. A quote from Campbell Scientific should be requested prior to purchase.

Table 2. Estimated purchase costs of a Quanta T transmitter unit as estimated from Campbell Scientific Price List.

Product #	Description	Cost
Quanta T	Basic Quanta Transmitter [a]	$1730.00
Quanta D	Quanta Display	$1110.00
H8047	Specific Conductance Sensor	$520.00
H8041	pH Sensor	$690.00
H8060	4Beam Turbidity Sensor	$1850.00
Total Estimate		$5630.00

[a] Includes temperature sensor, SDI-12 Format and 5 m cable.

APPENDIX F: ADDITIONAL LABORATORY AND EQUIPMENT COSTS (Cont'd)

Other Options

Portable testers for individual parameters can also be purchased (Table 3). There is a broad range of portable testers available for each parameter. The Pocket Pal testers are at the low end of the cost scale, while other equipment can cost over $1000.00. Range and accuracy of the Pocket Pal testers are comparable to that of the Quanta (Table 4); however, the Pocket Pal testers are not as convenient as the Quanta because they do not provide the ease of measuring all parameters at once and they do not store data within the device. More information on portable testers can be found at the following website: http://www.fondriest.com/waterquality.htm.

Table 3. Estimated purchase costs of individual portable testers.

Product	Cost [a]
Hach Pocket Pal Conductivity Tester	$64.50
Hach Pocket Pal pH Tester	$56.67
Hach Pocket Pal Temperature Tester	$53.06
Hach 2100P Portable Turbidity Meter	$815.00
Total Estimate	$989.23

[a] Prices in US dollars and do not include the cost of reagents.

Table 4. Comparison of range and accuracy between the Quanta system and portable meters.

Parameter	Range	Accuracy
Temperature		
Quanta T	-5 °C to 50 °C	+/-0.20°C
Pocket Pal	-15 °C to 170 °C	+/-1.0 °C
Conductivity		
Quanta T	0 to 100 mS/cm	+/-1% of reading +/- 1 count
Pocket Pal	10 to 1990 uS/cm	+/-2% of reading
pH		
Quanta T	0 to 14 units	+/-0.2 units
Pocket Pal	0 to 14 units	+/-0.1 units
Turbidity		
Quanta T	0 - 1000 NTU	± 5% of reading ±1 NTU
Portable Turbidity Meter	0 - 1000 NTU	± 2% of reading or ± 1 least significant digit from 0-500 NTU ± 3% of reading between 500-1000 NTU