Credit Valley Conservation

Terrestrial Monitoring Program Report

2002 - 2006

Monitoring Forest Integrity within the Credit River Watershed
Chapter 1: Forest Soil Chemistry

CVC
CREDIT VALLEY CONSERVATION

Monitoring Forest Integrity within the Credit River Watershed

Chapter 1: Soil Chemistry
2002 & 2006

Prepared by:

Kata Bavrlic[1]
Pauline Quesnelle

Credit Valley Conservation
1255 Derry Road West
Meadowvale ON L5N 6R4
August, 2010

---

[1] Terrestrial Monitoring, KBavrlic@creditvalleyca.ca

To be cited as:

Credit Valley Conservation. 2010. Monitoring Forest Integrity within the Credit River Watershed. Chapter 1: Forest Soil Chemistry 2002 - 2006. Credit Valley Conservation. vi + 31p.

ABSTRACT

Forest Soil Chemistry in the Credit River Watershed: Summary of Monitoring Results 2002 & 2006

Temporal Trends: Sodium and potassium concentrations declined from 2002 to 2006. All other nutrients and pH remained stable between the two sampling years.

Spatial Trends: Iron and potassium concentrations were higher in the Lower than the Upper Watershed. Magnesium concentrations were higher in the Middle than the Lower Watershed. Concentrations of cobalt, chromium, copper and nickel were higher in the Lower than the Upper Watershed.

Threshold Analyses: Heavy metal concentrations did not exceed guidelines Watershed-wide. However, lead and zinc concentrations exceeded in two forest plots within the Middle Watershed.

Recommendations: Additional years of soil chemistry monitoring data are required to determine whether observed patterns are in fact reflective of long-term trends. Future soil chemistry trends and results will be related to tree species composition, soil type (texture and organic matter content), pH, soil temperature, moisture and land-use practices. Sampling of microbial communities and earth worms may provide further insight into some of the observed trends in 2002 and 2006.

Monitoring Forest Integrity within the Credit River Watershed
Chapter 1: Forest Soil Chemistry 2002 - 2006

Forest soil chemistry was sampled at 4 year intervals between 2002 and 2006 in 26 forest plots as part of Credit Valley Conservation Authority's (CVC's) Terrestrial Monitoring Program. This report summarizes the 4-year review and statistical analysis of soil nutrient status, pH and heavy metal contamination data collected in 2002 and 2006 in forest plots Watershed-wide.

A total of six nutrients (calcium, iron, magnesium, phosphorus, potassium and sodium) and pH were measured in 2002. In 2006, two additional nutrients were measured: carbon and nitrogen. Nutrient levels generally remained stable from 2002 to 2006. However, soil sodium and potassium concentrations declined from one sampling year to the next. Soil pH was close to neutral at forest sites and remained stable between the two sampling years.

In 2006, eight heavy metal concentrations (cadmium, chromium, cobalt, copper, lead, molybdenum, nickel and zinc) were measured in the Credit River Watershed and compared to soil contamination limits listed by the Ministry of Environment (Ontario Ministry of the Environment 2004). Watershed-wide, heavy metal concentrations in monitored forests were below the posted MOE limits. However, soil zinc concentrations did exceed MOE guidelines at two sites within the Middle Watershed, with soil lead concentrations also exceeding posted guidelines at one of those locations.

Trend analysis could not be performed on soil nutrient status and contamination because there were too few years of data, however, soil chemistry data were spatially analyzed among the three Physiographic Zones within the Credit Watershed. Iron and potassium concentrations were significantly higher in the Lower than the Upper Watershed, while magnesium concentrations were significantly higher in the Middle than the Lower Watershed zones. As well, the Lower Watershed had significantly higher concentrations of cobalt, chromium, copper and nickel than the Upper Watershed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

1.1 BACKGROUND

Ontario has undergone dramatic change since the arrival of European settlers. A landscape that was historically dominated by forest cover has experienced rapid removal of wildlife habitat and fragmentation of remaining natural areas by agriculture, residential development and roads (Larson et al. 1999).

The amount of natural forest cover in a landscape often dictates what forest dependent wildlife species can be supported. Although this is especially evident with the disappearance of large mammals such as the gray wolf (*Canis lupus*) and black bear (*Ursus americanus*) from the highly developed landscapes of southern Ontario, this is also true for smaller organisms such as birds and plants. Forest habitat loss, and therefore reductions in overall natural cover, can negatively affect a species in many ways; some species disappear from the landscape, some species decline in abundance, while others fail to reproduce (Noss and Cooperrider 1994). Forest-dwelling species requiring large habitat patches or specialized habitat conditions are most sensitive to reduced forest cover. While other species, such as urban associates or generalist species may benefit and flourish in disturbed landscapes. Recent studies have revealed that total forest cover may be a better predictor of species richness, diversity and occupancy than forest size, shape and spatial configuration alone, especially once regional cover exceeds 30% (Andren and Nurnberger 1994; McGarigal and McComb 1995; Fahrig 1997; Trzinski et al. 1991; Villard et al. 1999; Fahrig 2002). Research therefore emphasizes the importance of retaining and enhancing existing forest cover within the landscape.

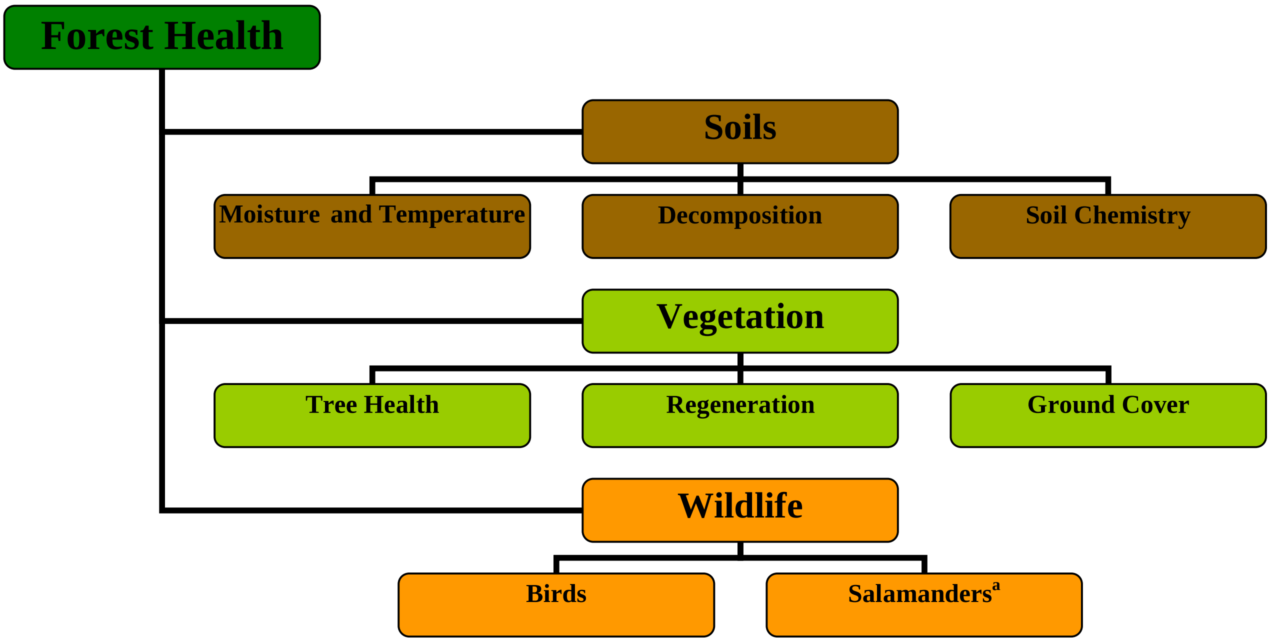
Fragmentation generally results in the reduction of total habitat available, the isolation of remaining patches, decreases in patch size and often an increase in total patch number (Noss and Cooperrider 1994; Fahrig 2002). Plant and wildlife species that are adapted to living in well-connected landscapes now face the challenge of acquiring all resources crucial to survival and reproduction from isolated habitat patches (Beier and Noss 1998). This is especially difficult for species that are poor dispersers or require large home ranges to fulfill their foraging and breeding needs (Andren and Nurnberger 1994). Isolation from other patches can result in reduced ability to secure required resources, reduced gene flow and ultimately extirpation of a species (Fleury and Brown 1997). Habitat loss and fragmentation can therefore have serious implications for populations, biodiversity and ecosystem functioning (Hess and Fischer 2001; Noss and Cooperrider 1994).

Forest cover levels are lower in southern Ontario than anywhere else in the province. The Carolinian zone has dropped from an estimated pre-settlement value of 80% forest cover to 11% (Larson et al. 1999). In 2002, the dominant land use in the Credit Watershed was agricultural at 34%, followed by urban development at 31%, natural cover at 19% and successional community cover at sixteen percent. Remaining forest cover in the Credit River Watershed is at 12%, much below Environment Canada’s recommended minimum value of 30% forest cover in a watershed to sustain stable and ‘healthy’ populations of wildlife species (Environment Canada, 2004).

1.2 THE IMPORTANCE OF LONG-TERM MONITORING

There is an increasing demand for better accounting of the condition 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 and processes of a given ecosystem. A superior monitoring program should address both biotic and abiotic components, as well as function across multiple scales. Monitoring is useful in providing managers with information which can be used for long-term planning, because trends over time can be used 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).

In 2002 the Terrestrial Monitoring Program was initiated at Credit Valley Conservation (CVC) to examine the integrity of biotic and abiotic indicators in forest, wetland and riparian ecosystems throughout the watershed. The main goals of the Terrestrial Monitoring Program are to (1) measure indicators of the structure, composition and function of terrestrial ecosystems, to assess the ecosystem integrity of the Credit River Watershed, (2) identify status and trends in the integrity of terrestrial communities at the watershed scale, and link to overall watershed integrity, (3) identify spatial patterns in terrestrial community integrity and (4) provide meaningful data on which watershed management decisions can be based (Credit Valley Conservation 2010). Within the watershed several forest monitoring stations have been established in which soil, vegetation and wildlife parameters are measured to describe forest conditions in the watershed and to monitor trends over a 25 year period (Fig. 1 & 2).



[a]monitoring to begin in 2011

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

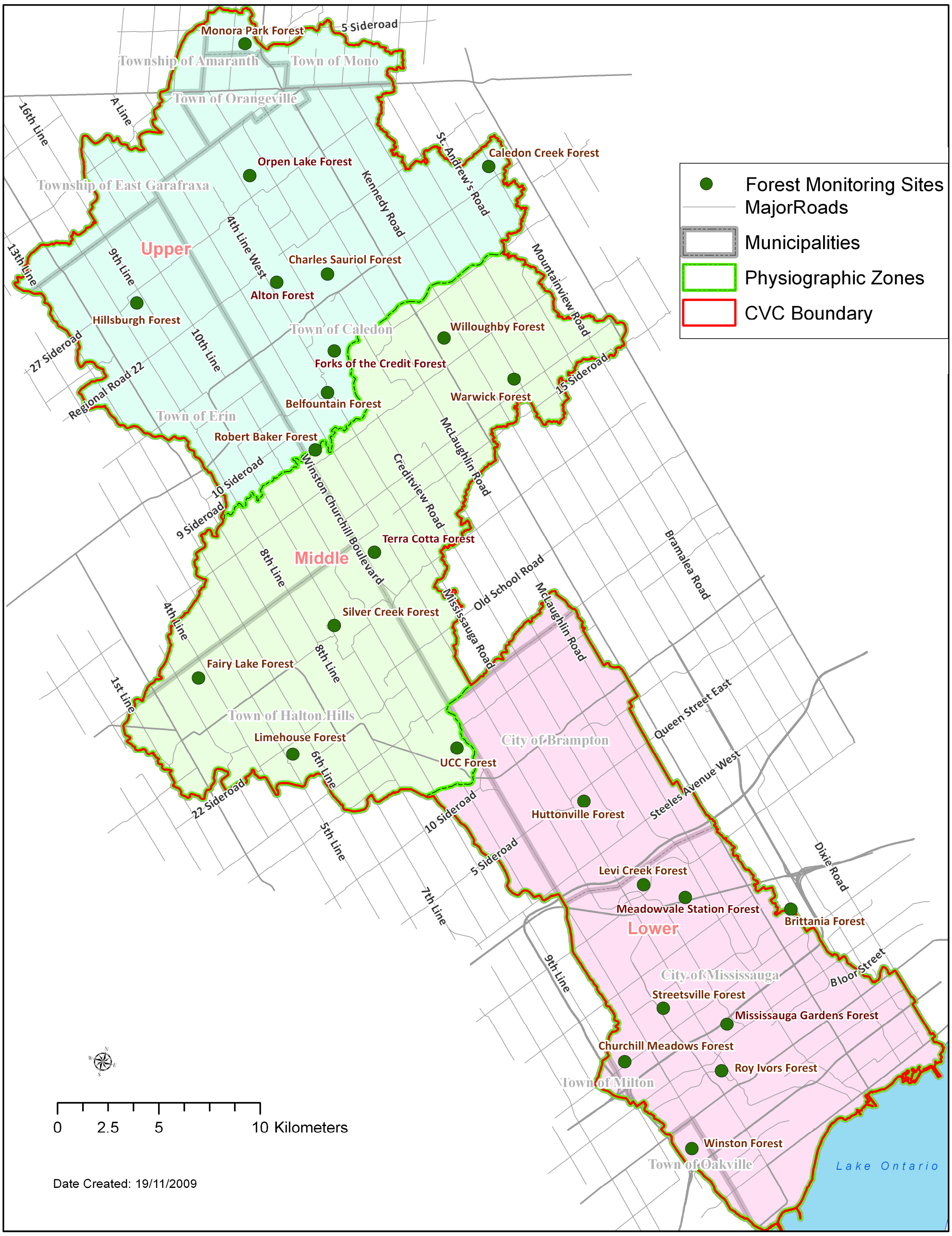


Figure 2. Forest monitoring sites in the Credit River Watershed.

1.3 WHY MONITOR SOIL CHEMISTRY?

Soil chemistry is a direct measure of the pH, nutrient status and heavy metal contamination of forest soils. The chemical composition of forest soils can regulate plant growth, influence ecosystem processes such as nutrient cycling, and affect rates of organic matter decomposition, all of which ultimately affect primary productivity and ecosystem health. Soil chemistry is naturally variable due to influences of soil texture and plant species composition. For example, soils with high clay and/or organic matter content hold nutrients more tightly than sandy soils, resulting in nutrient accumulation and a reduced likelihood of leaching from these soils (Brady and Weil 1996). It is well documented that soil beneath coniferous tree species are more acidic (McGee et al. 2007), but there is also evidence that deciduous species influence soil acidity and nutrient content through mechanisms such as nitrogen fixation, production of organic-rich litter, simulation of mineral weathering and interspecific differences in uptake and accumulation of soil nutrients (Finzi et al. 1998). Worldwide, soils have been depleted, contaminated and degraded due to a variety of anthropogenic and natural processes. These threats, including pollution and climate change are described in greater detail below.

1.4 SOIL CHEMISTRY RESPONSES TO A CHANGING LANDSCAPE

1.4.1 Declining Soil Nutrients and Acidification

There is a growing concern in North America that nutrients in forest soils are declining due to the combined effects of pollution (*e.g.*, acid rain deposition and heavy metals) and tree harvesting (Watmough and Dillon 2003). Watmough and Dillon (2003) predicted that reported losses of calcium (Ca) in south-central Ontario soils would result in the serious depletion of plant-available Ca reserves in the upper soil horizon within the next few decades. Substantial loss of this primary plant nutrient would directly impair forest health through decreased plant productivity and reduced tolerance to other stresses, such as drought, freezing and disease. Soils have also become more acidic in forests of south-central Ontario, which is of great concern as soil pH influences the availability of nutrients to plant species (Lambers et al. 1998, Watmough and Dillion 2003). For example, as soil acidity increases, macronutrients such as nitrogen, phosphorus, potassium, calcium and magnesium become insoluble and unavailable for plant uptake, while heavy metals such as aluminum become mobilized, potentially resulting in metal accumulation and ultimately toxicities that reduce a plants capacity to the uptake essential nutrients (Brady and Weil 1996).

Soil acidification is the primary cause of soil nutrient loss through the process of nutrient leaching (Brady and Weil 1996). Acidification of soil occurs through the deposition of acidifying nitrogen-oxide (NOx) and/or sulphur-oxide (SOx) compounds in the form of acid rain or fertilizers (Brady and Weil 1996). Although SOx deposition has decreased significantly over the past few decades, NOx has remained stable or even increased in certain regions of eastern Canada, resulting in excess levels of nitrogen (N), otherwise known as ‘nitrogen saturation’ (Aber et al. 1989; Watmough and Dillon 2003).

The excess nitrogen in saturated soils can lead to reductions in primary productivity and result in forest decline, as it is released as NO3, an anion that leaches base cations such as vital potassium, calcium and magnesium, from the rooting zone (Aber et al. 1989). Furthermore, these soils become net sources of nitrogen, with runoff of nitrates into surface waters causing growth or algal blooms and reduced water quality, leaching of nitrogen into local groundwater and nitrous oxide release into the atmosphere (Aber et al. 1989; Brady and Weil 1996).

1.4.2 Soil Carbon Loss and Climate Change

Soil is the largest carbon store globally, storing twice as much carbon as vegetation or the atmosphere (Bellamy et al. 2005). Concerns over recent carbon losses from all soil types in the U.K. have been linked to climate change (Bellamy et al. 2005). Climate change affects soil carbon turnover as increases in temperature increase rates of organic matter decomposition. Furthermore, as decomposition naturally releases CO_2 (Lambers et al. 1998), climate change is further exacerbated, creating a positive feedback loop. As an increasingly important source of carbon emissions, it is important to monitor soil carbon levels to both determine the impacts of climate change on soil chemistry and decomposition, as well as to elucidate the potential contributions of soils to greenhouse gas emissions.

1.4.3 Heavy Metal Contamination

Heavy metals such as cobalt, copper, nickel and zinc are essential plant nutrients that are necessary in small amounts (micronutrients), however, they become toxic to plants at higher concentrations (Brady and Weil 1996). Of particular concern are highly toxic, non-nutrient metals such as lead, cadmium, chromium and mercury. Although elevated, toxic levels of heavy metals may result from natural soil conditions, anthropogenic inputs such as car exhaust, road dust, waste leachate, refineries and manufacturing facilities are important sources of heavy metal contamination (Brady and Weil 1996; Li et al. 2001). In both plants and animals, heavy metal toxicity causes oxidative damage to tissues and alters physiological processes by inactivating proteins and enzymes (Brady and Weil 1996). In plants, contamination also reduces photosynthetic and water uptake capacity (Lambers et al. 1998). Elevated levels of heavy metals have been detected in both urban and rural forests, raising concerns over biological toxicity, and groundwater and surface water contamination (Pouyat and McDonnell 1991; Pouyet et al. 1997; Watmough and Hutchinson 2004).

1.5 FORESTS IN A CHANGING WATERSHED

The Credit River Watershed encompasses approximately 950 square kilometres of land in southern Ontario, Canada (Credit Valley Conservation, 2003). The River flows southeast for nearly 100 kilometres from its headwaters in Orangeville to its drainage point at Lake Ontario. There are 21 sub-watersheds within the main Watershed boundaries, as well as zones which drain directly into Lake Ontario. These sub-watersheds contain almost 1500 kilometres of streams and creeks that empty into the Credit River (Credit Valley Conservation 2003). As of 2007, the Watershed was composed of 23% natural communities, 11% successional communities (*i.e.* cultural savannah, thicket and meadow), 37% agricultural land use, and 29% urban area (Credit Valley Conservation 2007a). Approximately 6% of the Watershed is classified as wetland, while forests make up 12% of the Credit River Watershed Landscape. Communities that are dominated by trees, but do not fall within the formal 'Ecological Land Classification' definition for forest, make up an additional 30% (4% treed swamps, 5% successional and 21% woodland; , Lee et al. 1998, Credit Valley Conservation 2007a).

Though encompassing many unique landscape formations, the Watershed can be divided into three main Physiographic Zones based on topography, morphology, geologic origins, and the boundaries of the individual sub-watersheds (Credit Valley Conservation 2007b). The Lower Physiographic Zone is highly urbanized, containing over 85% of the Watershed population. The soils in the Lower Watershed are primarily clay, resulting in poor surface water infiltration (Credit Valley Conservation 2007b). The topography of this area is relatively flat and has, in places, been significantly altered by human development. The amount of both wetland and forest cover in the Lower Watershed has been classified as poor when applying proposed government guidelines (Environment Canada 2004). The Middle Zone contains the Niagara Escarpment, a region of steep slopes, rocky outcrops, and thin soil (Credit Valley Conservation 2005). Much of this zone is protected under the Greenbelt Plan (OMMAH 2005). Due to topographic factors, lower levels of urbanization, and protective legislation, the Middle Zone contains the greatest proportion of natural cover in the Watershed. The Upper Physiographic Zone lies above the escarpment and is characterized by hilly moraines, glacial spillways, and permeable loamy soils (Credit Valley Conservation 2005; Credit Valley Conservation 2007b). Agricultural land use dominates portions of the Upper Watershed, though it also contains several large wetland complexes and numerous headwater streams.

The majority of the Credit River Watershed is located in the Great Lakes – St. Lawrence Forest Region. The climax forest type for this area is dominated by Sugar Maple (*Acer saccharum ssp. saccharum*) and American Beech (*Fagus grandifolia*), in association with American Basswood (*Tilia americana*), White Elm (*Ulmus americana*), Yellow Birch (*Betula alleghaniensis*), White Ash (*Fraxinus americana*), Eastern Hemlock (*Tsuga canadensis*) and Eastern White Pine (*Pinus strobus*) (Credit Valley Conservation 1956; Fig. 1). The "Deciduous Forest" Region extends only a few kilometers into the Watershed from the mouth of the river. Characteristic associations in this region include Black and White Oak (*Quercus alba* and *Q. velutina* respectively), Sassafras (*Sassafras albidum*) and Shagbark Hickory (*Carya ovata*) (Credit Valley Conservation 1956). In 1851, it was estimated that forests covered approximately 67% of the Credit River Watershed (Fig. 3). However, in the following 50 years this number decreased substantially, to below 10%, as settlement increased (Fig.4; Credit Valley Conservation 1956). For the last 100 years, forest cover in the Credit River Watershed has lingered between 9% and 16%. When last reported in 2007, forests as formally defined by Ecological Land Classification (Lee et al. 1998) accounted for 12% of land use in the Watershed (Credit Valley Conservation 2007b). This is well below the 30%

forest cover recommended by the Canadian Wildlife Service (Environment Canada 2004) for adequate wildlife habitat.

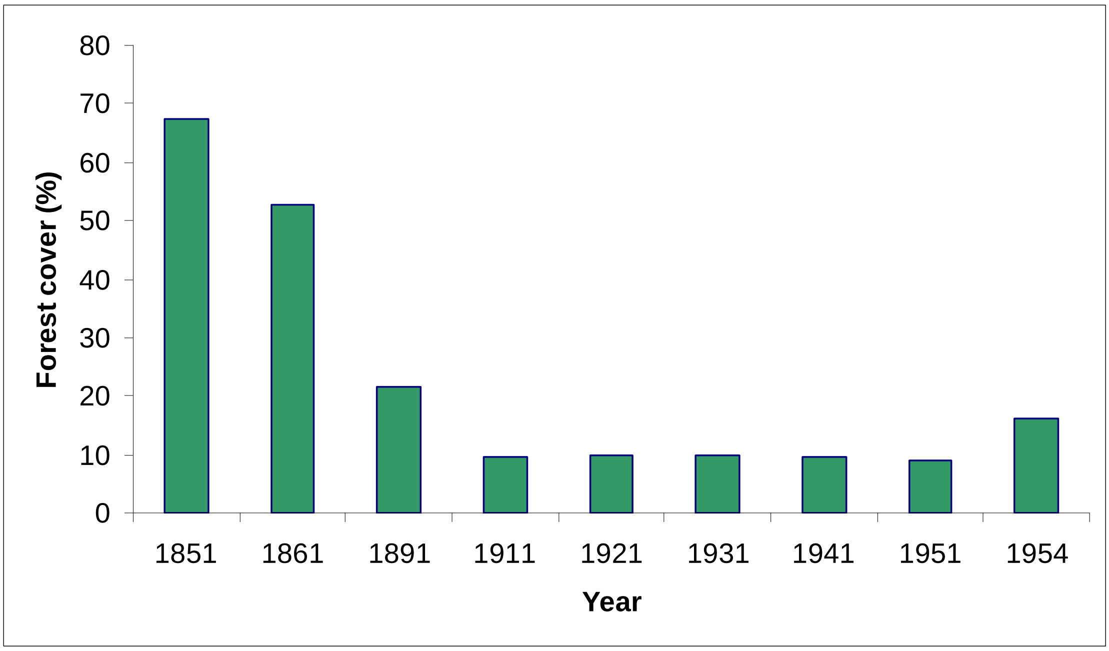


Figure 3. Estimated forest coverage in the Credit River Watershed from 1851-1954 (Credit Valley Conservation, 1956).

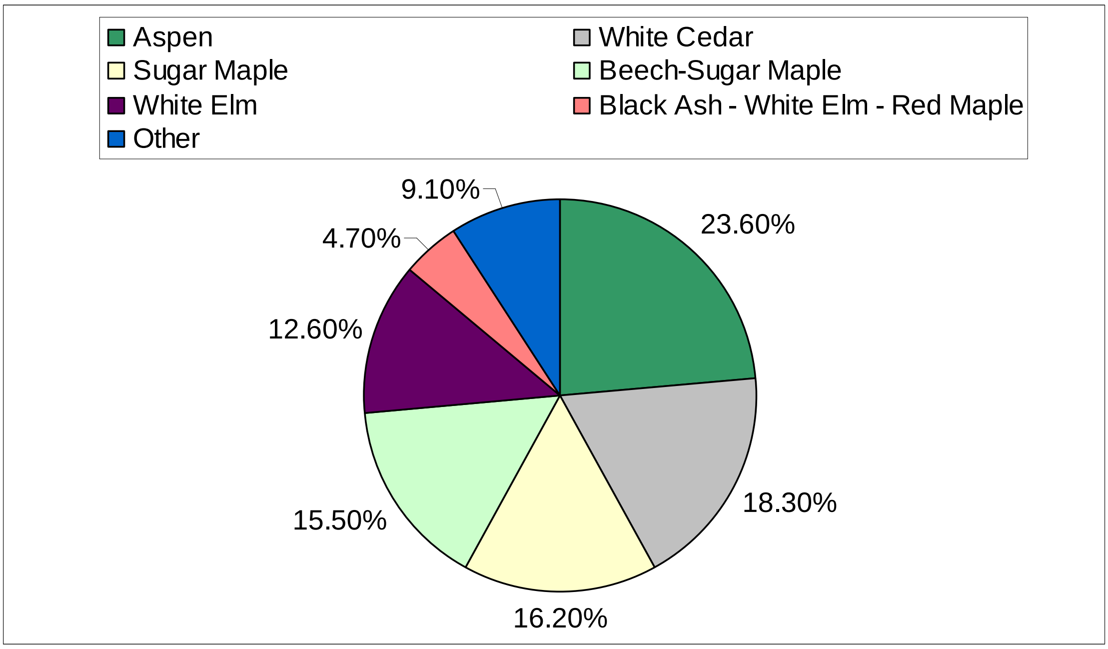


Figure 4. Forest cover types in the Credit River Watershed in 1954 (Credit Valley Conservation, 1956).

1.6 OBJECTIVE: MONITORING QUESTION

Concerns about local soil condition and how it relates to watershed health prompted forest soil chemistry monitoring in the Credit Watershed in 2002 to answer the question:

ARE FOREST SOILS IN THE CREDIT WATERSHED HEALTHY?

More specifically, 1) are soil nutrient status and heavy metal concentrations changing through time; and 2) do soil nutrient and heavy metal concentrations differ spatially throughout the Credit Watershed (Table 1).

Table 1. Credit River Watershed Soil Chemistry Monitoring Framework.

Monitoring Question [a]	Monitoring Variable	Unit of Measurement	Threshold or Target	Analysis Method
Temporal Analyses				
Is the nutrient status of forest soils changing in the Credit River Watershed?	-pH, total nitrogen (N), phosphorus (P), potassium (K), Total carbon (C), iron (Fe), sodium (Na), calcium (Ca), copper (Cu), magnesium (Mg)	Concentration (mg/L soil or % dry)	n/a	-paired t-test for parametric nutrients, Wilcoxon signed-ranks test for non-parametric nutrients
Spatial Analysis				
Are there spatial differences in nutrient status of forest soils in the Credit River Watershed?	-pH, total nitrogen (N), phosphorus (P), potassium (K), Total carbon (C), iron (Fe), sodium (Na), calcium (Ca), copper (Cu), magnesium (Mg)	Concentration (mg/L soil or % dry)	n/a	**-1 year data set:**-Univariate ANOVA for parametric parameters and Kruskal Wallis for non-parametric parameters. **-1 year data set:** Repeated Measures ANOVA for parametric parameters and Friedman test for non-parametric parameters
Are there spatial differences in heavy metal concentrations of forest soils of the Credit River Watershed?	- cobalt (Co), chromium (Cr), copper (Cu), molybdenum (Mo), nickel (Ni), lead (Pb), zinc (Zn)	Concentration (mg/kg)	n/a	-Univariate ANOVA
Threshold Analysis				
Do heavy metal concentrations in forest soils of Credit River Watershed exceed MOE limits?	- cobalt (Co), chromium (Cr), copper (Cu), molybdenum (Mo), nickel (Ni), lead (Pb), zinc (Zn)	Concentration (mg/kg)	Thresholds established by MOE are heavy metal specific	-t-test

[a] The upper panel describes primary monitoring questions the program is mandated to answer; the lower panel describes additional questions that can be obtained from the monitoring data but do not reflect the purpose of the monitoring program.

2.0 METHODS

2.1 SOIL SAMPLING AND CHEMICAL ANALYSIS

Every 5 years, a 300g sample of surface mineral soil (top 10cm of A horizon- rooting zone) was collected from each of the 26 forest monitoring plots. Sampling stations were at least 5m from EMAN forest plot perimeters, in areas free of disturbance and at least 1 m away from the following:

1) large objects (*i.e.* trees, rocks)
2) saturated areas (*i.e.* vernal pools)
3) metal objects
4) changing topography (*i.e.* slopes, depressions, mounds)
5) full sun exposure
6) miscellaneous chemical/nutrient sources (*i.e.* garbage)
7) previous soil sampling locations.

These samples were sent to the University of Guelph Soil and Nutrient Laboratory (Guelph, Ontario) to determine soil pH and concentrations of a suite of essential plant nutrients (Table 2). In 2006, a suite of heavy metals was included in soil analysis, in addition to total Nitrogen and total Carbon concentrations.

Table 2. Soil nutrients and heavy metal concentrations analyzed in soil samples collected every 5 years from each of the 25 forest monitoring plots.

Parameter	2002	2006
Soil Nutrient Status		
Calcium (Ca)	✓	✓
Carbon (total C)		✓
Iron (Fe)	✓	✓
Magnesium (Mg)	✓	✓
Nitrogen (total N)		✓
Phosphorus (P)	✓	✓
Potassium (K)	✓	✓
Sodium (Na)	✓	✓
pH value	✓	✓
Heavy Metal Contamination		
Cadmium (Cd)		✓
Chromium (Cr)		✓
Cobalt (Co)		✓
Copper (Cu)		✓
Lead (Pb)		✓
Molybdenum (Mo)		✓
Nickel (Ni)		✓
Zinc (Zn)		✓

2.2 ANALYSIS OF HEAVY METAL CONTAMINATION

To determine if forest soils were contaminated with heavy metals, results were assessed following the Ontario Ministry of the Environment (MOE) soil standards (Ontario Ministry of the Environment 2004). Data were analyzed with STATISTICA 7.0 (Statsoft Inc.), with results considered significant when $P<0.05$ (Zar 1999). Data were tested for normality and homoscedasticity using Shapiro-Wilks and Levene's test for homogeneity of variance, respectively. A One Sample *t*-Test was used to test the difference between observed heavy metal concentrations in forest plots with MOE limits.

MOE soil standards represent background heavy metal concentrations that are expected in uncontaminated Ontario soils. Soils that exceed heavy metal concentrations listed by the MOE may be toxic to plants and animals, having the potential to negatively impact forest, aquatic and human health.

2.3 STATISTICAL ANALYSIS

2.3.1 Trend and Temporal Analyses

Trend analysis and statistical process control could not be conducted with only one to two years worth of data. These analyses will be implemented in the future when data sets are sufficient to make statistically robust conclusions.

Parameters with two years of data were however analyzed to compare nutrient concentrations between the two sampling years. Data were analyzed with STATISTICA 7.0 (Statsoft Inc.), with results considered significant when $P<0.05$ (Zar 1999). Data were tested for normality and homoscedasticity using Shapiro-Wilks and Levene's test for homogeneity of variance, respectively. A paired *t*-Test was used for parametric parameters; a Wilcoxon Signed-Ranks test was used for non-parametric parameters (Sodium, Phosphorus and Potassium). Tukey's HSD tests for unequal sample sizes were used for post-hoc comparisons. Bonferroni corrections were not used to reduce the likelihood of a Type II Error (Moran 2003, Nakagawa 2004).

Pearson Produce-Moment Correlation was used to test correlations between soil pH and soil nutrient concentrations for parametric data. Spearman Rank-Order Correlation was used to test correlations between non-normal data.

2.3.2 Spatial Trends

To examine spatial patterns of forest soil chemistry in the Credit Watershed, monitoring sites were grouped into three Physiographic Zones; Upper, Middle and Lower Watershed. It is hypothesized that differences in land-use cover among the three zones are likely to influence forest health parameters, including soil chemistry. The Lower Watershed is dominated by urban cover at 57%, compared to 15% in the Upper and Middle Watershed zones. The Upper Watershed contains the greatest proportion of agricultural and semi-natural (successional) communities (56% combined) relative to the Middle (51%) and Lower Watersheds (34%). The Middle Watershed has the greatest proportion of natural cover at 33%, with the Upper Watershed containing 27% and Lower zone containing 7% natural cover. In addition to land-use, the configuration and overall character of existing natural cover also differs among the three Physiographic Zones. The dominant forest types in the Middle and Lower zones are deciduous and mixed-deciduous, compared to the Upper Watershed where forests are represented equally by coniferous and deciduous habitat types. On average, woodland units, composed of forest, plantation, cultural woodland and treed swamp communities (Lee et al. 1998), are larger in the Middle than the Lower and Upper Physiographic Zones. Fifty percent of all patches greater than 20 ha in size are found in the Middle Physiographic Zone, including the only two patches within Credit River Watershed boundaries that are greater than 200 ha in size (Credit Valley Conservation 2007a).

Data were analyzed with STATISTICA 7.0 (Statsoft Inc.), with results considered significant when $P<0.05$ (Zar 1999). Data were tested for normality and homoscedasticity using Shapiro-Wilks and Levene's test for homogeneity of variance, respectively.

One-way ANOVA was used to compare soil chemistry parameters among the three Physiographic Zones with only one year of data, including heavy metal concentrations, total carbon and total nitrogen concentrations. Kruskal-Wallis Test was used for non-parametric data. Repeated –measures ANOVA was used to compare soil nutrient concentrations among the three Physiographic Zones, for the remainder of the soil nutrients, for which two years of data were collected. Friedman Test was used for non-parametric data. Tukey's HSD tests for unequal sample sizes were used for post-hoc comparisons. Bonferroni corrections were not used to reduce the likelihood of a Type II Error (Moran 2003; Nakagawa 2004).

Percent composition of natural, agricultural and urban land-use within a 2km radius from the edge of each sampled forest patch was calculated with GIS mapping for years 2005-2007, at a scale of 1:10, 000. For parametric data, Pearson Product-Moment Correlation was used to test correlations between soil nutrient concentrations and percent land use composition (natural, agricultural and urban). Correlations for non-parametric data were tested with Spearman Rank-Order Correlation.

2.3.3 Power Analysis

Power analyses were conducted in PASS (NCSS Inc.) to determine the number of monitoring sites required in order to detect significant levels of change in various soil chemistry parameters. Power analysis also assessed the ability of the current monitoring program to detect statistical differences in forest soil parameters among physiographic zones and among years, given the number of established monitoring sites. Power analysis uses baseline monitoring data to determine if additional monitoring sites are required to detect significant trends.

Confidence and power levels are also subjectively, but not arbitrarily, selected. Although research standards typically set confidence to 95% and power to 80%, this may not be appropriate for ecological monitoring (Dobbie et al. 2006). Confidence refers to the probability of not committing a Type I statistical error. In ecological monitoring, this may be considered a "false alarm". Power refers to the probability of not making a Type II error, which may be considered a "missed signal". In ecological monitoring, missing a signal has more severe management implications than raising a false alarm. For that reason, power is usually set higher than confidence in this type of monitoring (Dobbie et al. 2006).

2.3.4 Comparison to Established Thresholds

To determine if forest soils were contaminated with heavy metals, results were assessed following the Ontario Ministry of the Environment (MOE) soil standards (Ontario Ministry of the Environment 2004). Data were analyzed with STATISTICA 7.0 (Statsoft Inc.), with results considered significant when $P<0.05$ (Zar 1999). Data were tested for normality and homoscedasticity using Shapiro-Wilks and Levene's test for homogeneity of variance, respectively. A One Sample *t*-Test was used to test the difference between observed heavy metal concentrations in forest plots with MOE limits.

MOE soil standards represent background heavy metal concentrations that are expected in uncontaminated Ontario soils. Soils that exceed heavy metal concentrations listed by the MOE may be toxic to plants and animals, having the potential to negatively impact forest, aquatic and human health.

3.0 RESULTS AND DISCUSSION

3.1 TEMPORAL ANALYSES

3.1.1 Nutrient Status

Monitoring Question: Is the nutrient status of forest soils changing in the Credit Watershed?

- Soil sodium and potassium concentrations declined between 2002 and 2006 in the Credit Watershed.
-Soil pH was neutral and remained stable from year to year.

Although two years worth of soil chemistry data (2002 and 2006) were insufficient to perform a trend analysis, temporal trends were analysed between the two monitoring years.

Overall, nutrient concentrations were within ranges expected in deciduous forests of Eastern North America (Watmough and Dillon 2003). Based on snap-shot comparisons between the two sampling years, potassium and sodium declined from 2002 to 2006, however, they still remained within ranges detected in eastern soils (potassium: Wilcoxon Signed-Ranks Test $Z = 2.02$, $p= 0.04$, sodium: Wilcoxon Signed-Ranks Test $Z = 5.32$, $p= <0.0001$; Table 3; Watmough and Dillon 2003, Evans et al. 2005). Additional years of data are required to determine whether these are in fact long-term trends that are of potential concern or just natural variability expected to occur over short periods of time.

Watershed-wide, the carbon to nitrogen ratio (C:N) was 14.6 (SE ± 0.5), which is much lower than the value at which nutrient disorders become apparent in plants (C:N ratio > 25; Spurr and Barnes 1980). Although carbon to phosphorus and carbon to potassium ratios are also important indicators of the nutritional health of Watershed soils, we were unable to calculate these ratios with the concentrations provided by the Guelph Laboratory.

Typical of deciduous forests of southern Ontario, soils had a neutral pH. Although deciduous tree species found in southern Ontario can tolerate a range of soil pH values, many prefer neutral or slightly acidic soils (OMNR 2000). This is likely due to the fact that most soil nutrients are available at higher concentrations in near neutral soils (5.75-7.75; Londo et al. 2006).

Lastly, to develop soil nutrient thresholds, standard levels or background concentrations in soils of the two ecoregions (7E and 6E) within the CVC jurisdiction are being investigated.

Table 3. Nutrient status of forest soils in the Credit Watershed in 2002 and 2006.

Soil Parameter	**2002 Concentration (mg/L)** [a] **Mean (±SE)**	**2006 Concentration (mg/L)** [a] **Mean (±SE)**	**Time Effect**		**Observed Trend**
			t /Z df= 24	***p***	
Calcium (Ca)	1990.8 (±255.1)	1839.0 (±152.1)	0.93	0.36	None
Carbon (total % C) [b]	n/a	4.6% (±0.5)	n/a	n/a	n/a
Iron (Fe)	86.3 (±9.6)	72.8 (±8.3)	1.33	0.20	None
Magnesium (Mg)	230.9 (±35.8)	236.8 (±35.2)	-0.41	0.69	None
Nitrogen (total % N)[b]	n/a	0.31% (±0.03)	n/a	n/a	n/a
Phosphorus (P) [c]	9.2 (±2.0)	9.7 (±2.1)	1.66	0.10	None
Potassium (K) [c]	68.2 (±6.8)	57.8 (±5.1)	2.02	0.04	2002>2006
Sodium (Na) [c]	40.5 (±2.7)	26.7 (±1.3)	5.32	<0.0001	2002>2006
pH value	6.3 (±0.2)	6.4 (±0.2)	-0.32	0.75	None

[a] Concentrations represent the mean values from all forest monitoring plots.
[b] Element was a new parameter added in 2006
[c] Wilcoxon Signed-Ranks Test for which *Z* was reported

3.1.2 Heavy Metal Concentrations

Monitoring Question: Is the concentration of heavy metals in forest soils increasing in the Credit Watershed?

-UNKNOWN due to insufficient data.

Temporal analyses could not be performed on the heavy metal data due to the fact that it was collected in only one year (2006). Temporal analyses will be conducted on heavy metal concentrations once sufficient years of data have been collected.

3.2 SPATIAL ANALYSIS

3.2.1 Nutrient Status

Monitoring Question: Are there spatial differences in nutrient status of forest soils in the Credit Watershed?

- Iron and potassium concentrations were significantly higher in the Lower than the Upper Watershed.
-Magnesium concentrations were higher in the Middle than the Lower Watershed.

Concentrations of two soil nutrients, iron and potassium, were significantly higher in the Lower than the Upper Watershed (Table 4; Fig. 5). However, the Middle Watershed had higher concentrations of soil magnesium than the Lower Watershed.

Table 4. Comparison of forest soil nutrient concentrations at forest plots in three physiographic zones of the Credit River Watershed.

Soil Parameter	Concentration (mg/L) Mean (± SE)			Time Effect		Physiographic Effect		Observed Trend
	Upper	**Middle**	**Lower**	***F***	***P***	***F***	***P***	
Calcium (Ca)	1777.8 (±249.4)	2297.8 (±331.1)	1675.1 (±165.2)	0.89	0.35	1.02	0.38	None
Carbon (% C) [a]	4.1 (±0.4)	5.7 (±1.4)	3.9 (±0.4)	n/a	n/a	1.45	0.25	None
Iron (Fe)	61.9 (±8.7)	71.5 (±11.5)	214.4 (±111.8)	1.71	0.20	3.71	0.04	Lower> Upper
Magnesium (Mg)	167.3 (±27.7)	383.1 (±55.2)	153.4 (±15.3)	0.24	0.63	3.92	0.03	Middle> Lower
Nitrogen (% N) [a]	0.28 (±0.02)	0.39 (±0.09)	0.27 (±0.03)	n/a	n/a	1.48	0.25	None
Phosphorus (P)	6.9 (±1.7)	5.6 (±1.0)	15.5 (±3.2)	0.50	0.49	3.02	0.07	None
Potassium (K)	43.8 (±5.1)	61.8 (±5.8)	81.2 (±7.8)	4.30	0.04	5.51	0.01	2002>2006 Lower> Upper
Sodium (Na)	30.6 (±2.6)	33.8 (±3.5)	36.1 (±3.1)	28.30	<0.001	0.94	0.41	2002>2006
pH value	6.58 (±0.2)	6.67 (±0.2)	5.97 (±0.2)	0.08	0.77	2.68	0.09	None

[a] One-way ANOVA for parameters sampled in 2006 only.

[b] Significant differences between physiographic regions were determined using ANOVA (univariate or repeated measures).

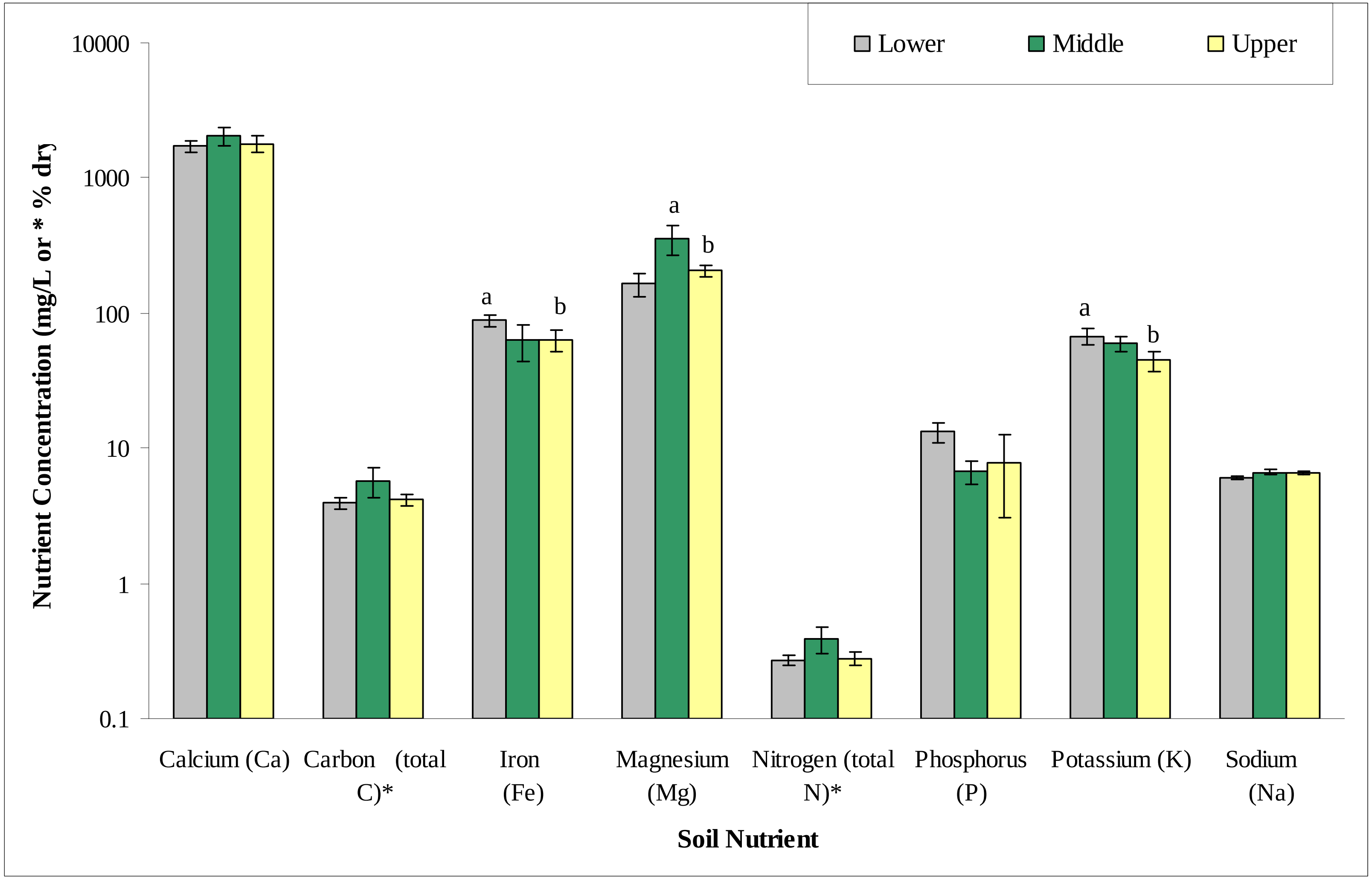


Figure 5. Soil nutrient concentrations (mean ± standard error) observed in 26 forest plots in three Physiographic Zones of the Credit River Watershed.

Soil nutrient concentration can be influenced by plant species composition at a site, soil pH and surrounding land-use practices. Tree species in particular change the chemistry of soil substrates by influencing soil acidity and exchangeable cations through interspecific differences in the uptake of cations and anions, nitrogen fixation and nitrification, the production of higher organic matter in litter and by stimulating mineral weathering (Finzi et al. 1998). Herbaceous plant species such as the non-native Garlic Mustard (*Alliaria petiolata*) negatively influence the availability of nutrients in soils and therefore to native plant species by producing phytochemicals that harm important services provided by mycorrhizal fungi (Stinson et al. 2006). Soil pH has also been shown to be positively correlated with the availability of calcium and magnesium, and negatively associated with nutrients such as aluminum and iron (Finzi et al. 1998). Of important note is the influence of land-use practices on the concentration of soil nutrients. Nutrient concentrations in forest soils may increase with the over-application of fertilizers in adjacent agricultural fields, or inputs from sewage treatment and industrial activities (Brady and Weil 1996). Nutrient depletions or losses can result from timber harvest practices, intensive livestock grazing and soil tillage (Brady and Weil 1996).

Higher soil iron concentrations in the Lower than the Upper Watershed may be attributed to two factors; soil texture and pH. Sites in the Lower Watershed have clay soils, which are known to bind strongly to positively charged ions such as iron and aluminum (Brady and Weil 1996). The sandy loam soils of the Upper Watershed do not have this strong binding capability. Although some of the sites in the Middle Watershed are classified as clay, most are loams, which may explain the intermediate soil iron concentrations detected in the Middle Watershed relative to the other two zones. Soil pH is also known to be negatively correlated with iron concentrations (Finzi et al. 1998), which was confirmed in our study (Pearson Product-moment Correlation r=-0.66, P<0.0001). Although not statistically significant, there was a trend towards higher pH values in the Upper and Middle Watersheds than the Lower Watershed, which could therefore explain the higher iron concentrations in forest soils of the Lower Physiographic Zone.

Higher soil magnesium concentrations in the Middle Watershed than the Lower Watershed may be attributed to three factors; tree species composition, soil pH and surrounding land-use. Finzi et al. (1998) reported that magnesium levels were significantly higher under Sugar Maple (*Acer saccharum*) and White Ash (*Fraxinus americana*) than other tree species found in eastern deciduous forests. Although Sugar Maple and White Ash are found in all three physiographic zones, they accounted for 58% of all trees in the Middle Watershed relative to only 38% in the Lower Watershed. Soil calcium concentrations are also positively correlated with soil pH (Finzi et al. 1998), which was further confirmed by our study (Pearson Product-moment Correlation r=0.63, P=0.001). As mentioned earlier, there is a trend towards higher soil pH in the Middle than the Lower Watershed. Magnesium concentrations were also positively correlated with percent natural cover in our study (Pearson Product-moment Correlation r=0.39, P=0.04; Table 5). The Middle Watershed is characterized by higher percent natural cover than the heavily urbanized Lower Watershed. It is possible that surrounding land-use practices in the Lower Watershed are resulting in magnesium leaching from the forest soils.

It is unclear why potassium concentrations are higher in the Lower than the Upper Watershed. Potassium is found in much higher concentrations in mineral soils than other nutrients, except in quartz sands (Brady and Weil 1996). The sandy character of the Upper Watershed may therefore account for the lower observed concentrations relative to the Lower Watershed. In our study, potassium was positively correlated with percent urban cover (Pearson Product-moment Correlation r=0.52, P<0.008; Table 5), which may indicate that urban activities are increasing potassium concentrations either through increased inputs or through the reduction of potassium cycling. Further research is needed to elucidate this observed relationship. It is important to note that there was a trend towards higher concentrations of phosphorus in the Lower than the Middle Watershed. Soil concentrations of phosphorus were also positively associated with percent urban cover (Pearson Product-moment Correlation r=0.46, P<0.02; Table 5). Urban activities such as over application of fertilizers, sewage treatment and industrial outputs may explain why higher phosphorus concentrations were observed in the Lower than the Middle Watershed (Brady and Weil 1996).

Table 5. Pearson Product Moment correlations between forest soil parameters with % Agriculture, Natural and Urban cover.

Soil Chemistry Parameter	**% Agriculture**		**% Natural**		**% Urban**	
	Pearson R	***P* value** [a]	**Pearson R**	***P* value** [a]	**Pearson R**	***P* value** [a]
Nutrients						
Calcium (Ca)	-0.129	0.540	0.371	0.068	-0.121	0.565
Carbon (% C)	-0.142	0.499	**0.462**	**0.020**	-0.144	0.492
Iron (Fe)	-0.095	0.653	0.232	0.256	-0.098	0.642
Magnesium (Mg)	0.119	0.571	**0.398**	**0.049**	-0.330	0.107
Nitrogen (% N)	-0.082	0.697	**0.389**	**0.054**	-0.165	0.431
Phosphorus (P)	**-0.391**	**0.053**	-0.337	0.100	**0.461**	**0.020**
Potassium (K)	**-0.0425**	**0.034**	-0.096	0.648	0.325	0.113
Sodium (Na)	-0.313	0.128	**-0.542**	**0.005**	**0.527**	**0.007**
pH	0.174	0.404	0.363	0.075	-0.344	0.092
Heavy Metals						
Chromium (Cr)	**-0.400**	**0.047**	-0.299	0.146	**0.442**	**0.027**
Cobalt (Co)	**-0.512**	**0.009**	-0.171	0.412	**0.436**	**0.027**
Copper (Cu)	-0.159	0.445	0.056	0.789	0.074	0.724
Lead (Pb)	-0.095	0.653	0.236	0.256	-0.098	0.642
Nickel (Ni)	**-0.464**	**0.019**	-0.228	0.274	**0.438**	**0.029**
Zinc (Zn)	-0.051	0.810	0.325	0.113	-0.171	0.414

[a] Results considered significant when $p<0.05$ and are reported in bold.

3.2.2 Power Analysis

According to the power analysis, the sample size of 26 forest plots was sufficient to detect a significant difference in soil nutrient concentrations among physiographic regions and within the two sampling periods with power ranging between 97-99%, at a confidence level of 80%.

3.2.3 Heavy Metal Concentrations

Monitoring Question: Are there spatial differences in heavy metal concentrations of forest soils in the Credit Watershed?

- The Lower Watershed had significantly higher concentrations of cobalt, chromium, copper and nickel than the Upper Watershed.

Concentrations of four heavy metals, cobalt, chromium, copper and nickel, were significantly higher in Lower Watershed soils than in Upper Watershed forest plots (Table 6). The significantly higher concentrations of four heavy metals in the Lower Watershed relative to the Upper Watershed can be explained by surrounding land use, as there was a positive correlation between percent urban cover and concentrations of three of the four heavy metals (Pearson Product-moment Correlation Cr: r=0.46, P=0.03; Co: r=0.44, P=0.03; Ni: r=0.44, P=0.03). This is not surprising as chromium, cobalt and nickel are associated with urban activities; chromium is produced during brick manufacture and leather tanning, cobalt is produced during fossil fuel combustion and industrial activities involving the heavy metal, while nickel is produced in the combustion of fossil fuels, alloy manufacture and electroplating, and aggregate extraction (Brady and Weil 1996). Copper concentrations are not correlated with percent urban cover, likely due to the fact that sources of copper can be found Watershed-wide including mine tailings, fly ash and fertilizers (Brady and Weil 1996). The elevated heavy metal concentrations in Credit River Watershed urban forests are similar to those found in studies conducted in Ontario, New York and Hong Kong (Pouyat and McDonnell 1991; Li et al. 2001). Lead concentrations were four times higher, while copper and nickel concentrations were two times higher in urban compared to rural forests (Pouyat and McDonnell 1991). Overall, the main routes of heavy metal contamination are associated with urban land use, such as road dust, exhaust, landfill sites, refineries and manufacturing facilities.

It is important to note that lead concentrations were not elevated in the heavily urbanized Lower Watershed compared to the Middle and Upper Physiographic Zones. This is consistent with observed continent wide reductions in lead pollution since the early 1970’s, which have been attributed to activities such as the production of lead-free gasoline (Friedland et al. 1992; Watmough and Hutchinson 2004; Evans et al. 2005). Despite the absence of an association between lead concentrations and percent urban cover, there was a trend towards higher lead concentrations in the Middle than the Upper Watershed. It is unclear why Middle Watershed forest soils have higher lead concentrations than other forests, and further investigation is necessary to determine whether this is an outcome of soil properties, historical land-use or unknown sources such as illegal dumping of lead containing products in the vicinity of forests.

Table 6. Physiographic difference in heavy metal concentrations in forests soil in the Credit River Watershed.

Soil Parameter*	Concentration (mg/kg) Mean (± SE)			Physiographic Effect[b]		Observed Trend
	Upper	Middle	Lower	*H*	*P*	
Chromium (Cr)	18.1 (±1.3)	20.1 (±1.4)	25.6 (±2.6)	6.1	0.05	Lower>Upper
Cobalt (Co)	5.0 (±0.9)	6.4 (±0.9)	8.7 (±1.0)	6.4	0.04	Lower>Upper
Copper (Cu)	7.7 (±1.2)	13.1 (±1.6)	16.4 (±3.7)	7.1	0.03	Lower>Upper
Lead (Pb)	19.3 (±2.6)	38.8 (±9.9)	26.6 (±1.9)	5.5	0.06	None
Nickel (Ni)	11.9 (±2.0)	13.9 (±1.4)	18.8 (±1.8)	7.4	0.02	Lower>Upper
Zinc (Zn)	55.5 (±8.3)	112.1 (±33.3)	68.5 (±5.8)	3.4	0.2	None

[a] exact values for chromium and molybdenum were not provided by lab therefore spatial analyses could not be conducted.
[b] Significant differences between physiographic zones were determined using Kruskal-Wallis.

3.2.4 Power Analysis

According to the power analysis, the sample size of 26 forest plots was sufficient to detect a significant difference in soil nutrient concentrations among Physiographic Regions and within the two sampling periods, with power ranging between 97-99%, at a confidence level of 80%. Sample size was also sufficient to detect a significant difference in heavy metal concentrations among Physiographic Regions, with power ranging between 93-99%, with a confidence level of 80%.

3.3 HEAVY METAL THRESHOLDS

Monitoring Question: Do heavy metal concentrations in forest soils exceed MOE limits in the Credit Watershed?

-On a Watershed basis, metal concentrations are below posted limits.
- However, at a site level, zinc concentrations exceeded guidelines at two sites in the Middle Watershed, with concentrations of lead also exceeding guidelines at one of those sites.

At the Watershed scale, heavy metal concentrations in forest soils were significantly lower than limits posted by the Ontario Ministry of the Environment (Ontario Ministry of the Environment 2004; Table 7, Fig. 6), and within ranges documented for Southern Ontario (Watmough et al. 2005) and New York State (Pouyat et al. 1997).

Table 7. Heavy metal concentrations in forests soils in the Credit River Watershed in 2006.

Soil Parameter	**MOE Limit** [a] **(mg/kg)**	**CVC Concentration (mg/kg)** [b] **Mean (±SE)**	**Comparison to Limits** [c]	
			t **df=25**	***P***
Cadmium (Cd)	1.0	<1.0	--	--
Chromium (Cr)	67	21.6 (±1.3)	-35.04	<0.0001
Cobalt (Co)	19	6.9 (±0.6)	-19.29	<0.0001
Copper (Cu)	56	12.4 (±1.5)	-29.67	<0.0001
Lead (Pb)	55	28.1 (±3.5)	-7.75	<0.0001
Molybdenum (Mo)	2.5	<2.5	--	--
Nickel (Ni)	43	15.2 (±1.2)	-24.10	<0.0001
Zinc (Zn)	150	77.9 (±11.3)	-6.36	<0.0001

[a] Ontario Ministry of the Environment standards for soils (2004)

[b] Concentrations represent mean values across all forest monitoring plots.

[c] No concentrations exceeded MOE standards at the Watershed scale.

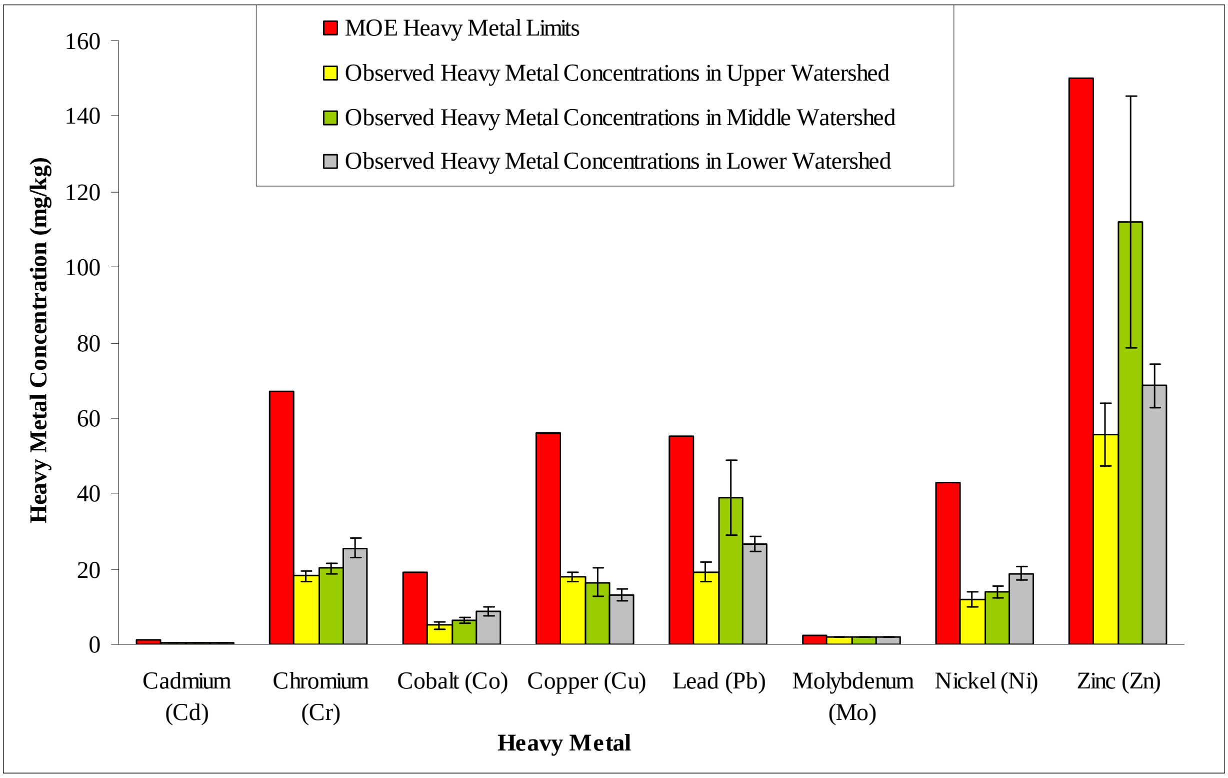


Figure 6. Soil heavy metal concentrations (mean ± standard error) observed in 26 forest plots within three physiographic zones in the Credit Watershed compared to Ministry of Environment guidelines

At the forest plot level, MOE limits were exceeded at two forest plots within the Middle Watershed. At Robert Baker CA Forest lead and zinc concentrations exceeded MOE guidelines (Appendix A). Zinc limits were also exceeded at Silver Creek Forest. However, concentrations at these two sites were still well below those reported by Friedland et al. (1986) that are necessary to negatively effect microbial respiration and soil organism populations. Further investigation involving multiple samples over time at these forest monitoring plots is required to confirm these high heavy metal concentrations.

Sources of lead include combustion of fossil fuels and the production of iron and steel (McGee et al. 2007). Lead concentrations in forest mineral soils of the Eastern United States typically range from 8-35mg/kg, depending on distance from transportation corridors and elevation (Friedland et al. 1992). Watmough and Hutchinson (2004) reported higher lead concentrations closest to roads, with average concentrations in Peterborough forest soils of 24 mg/kg. Strong relationships of soil lead concentrations with soil organic matter content, soil texture and pH have also been reported (Watmough and Hutchinson 2004; Watmough et al. 2005). The highest lead concentrations are often found in the most acidic soils, due to the reduced rates of decomposition and organic matter turnover observed in those soils (Watmough et al. 2005). Soils with a high clay content bind strongly with lead, preventing leaching and mobility of the heavy metal through the soil (Brady and Weil 1996). Lead also has a strong affinity for soil organic matter and can be extremely elevated in organic forest floor horizons (Brady and Weil 1996; Watmough and Hutchinson 2004; Watmough et al. 2005). Therefore, differences in soil lead concentrations among sites can be a result of differences in lead cycling due to the above mentioned variables, rather than different inputs (Watmough et al. 2005). This might be especially true for sites such as Robert Baker CA where there is no obvious proximate point source that would result in such elevated concentrations of lead. The monitoring plot from which the soil samples are collected is at least 0.5 km from a road which does not experience high volumes of traffic (unlike some of the other sites). In fact, this plot is farther from the road than 81% of the remaining forest plots, therefore proximity to road is an unlikely explanation for elevated lead levels at Robert Baker Ca forest. Soil pH at this site was just above neutral (7.3), therefore pH would not explain high lead concentrations. Soil at the site has been classified as a loam, which has relatively low proportions of clay to bind with the lead. However, organic matter content has not been measured at forest plots, and can therefore be a possible explanation. Watmough and Hutchinson (2004) found that 65% of lead in surface mineral soils (top of A horizon) of rural Southern Ontario forests was from pollution (atmospheric deposition). Therefore, it is also possible that past land use (*e.g.,* old farming machinery) or atmospheric deposition of pollution resulted in the observed elevated lead concentrations. Future soil chemistry tests that include sampling of soil organic matter content will provide further insight into elevated lead concentrations at Robert Baker CA Forest.

Sources of zinc are varied including non-ferrous metal smelting, combustion of fossil fuels, street dust, galvanized iron and steel, alloys, batteries, brass, rubber manufacturing, mining, old tires and geologic deposits (Brady and Weil 1996; Li et al. 2001; McGee et al. 2007). McGee et al. (2007) reported that birch and aspen tree species bio-accumulate zinc, resulting in higher soil zinc concentrations beneath birch trees than those associated with soil beneath maple species. Zinc concentrations are also positively correlated with soil pH (Watmough et al. 2005). Although neither of the two plots had birch or aspen species that could result in bio-accumulation of zinc, both sites had soil pHs at the upper range of values observed in the Watershed (7.3). Both sites also have active aggregate extraction within a 5 km radius of patch edge, which could potentially contribute to elevated zinc concentrations. Future sampling will be necessary to determine whether the above mentioned variables are sufficient explanations for the observed zinc concentrations or whether alternate point sources are responsible.

4.0 CONCLUSIONS

It is difficult to draw any solid conclusions about forest soil chemistry based on only one or two years worth of sampling data, however, these preliminary results suggest that Watershed-wide heavy metal concentrations do not exceed MOE guidelines, and that some important spatial differences exist. Detected differences in soil nutrient status of the Lower Watershed compared to the Middle and Upper zones will be further investigated with an attempt to uncover the underlying mechanisms. The observed differences are likely influenced by a number of factors including plant species composition, pH and local land-use practices. To what degree each of these factors explains the observed variability may become more evident with additional years of sampling and possibly some modeling exercises relating them to the predictor variables. Further monitoring of heavy metal concentrations will also provide insight into whether higher levels in the Lower Watershed are temporary in nature or long-term patterns resulting from urban pressures in the southern part of the Watershed. Elevated levels of zinc and lead concentrations at one and two sites within the Middle Watershed, respectively, will be further monitored to determine whether these were simply due to a temporary point source or if local activities are resulting in patch-wide heavy metal accumulation.

Although soil chemistry alone contributes to an understanding of forest integrity in the Credit River Watershed, ultimately these results should be related to other biotic indicators to determine whether observed levels are having any positive or detrimental effects on higher level organisms in the Watershed. Expanding the program to monitoring worms and or soil micro-organisms will likely elucidate some direct links between soil and soil fauna, but exploring relationships between vegetation and soil chemistry will also be of great value.

5.0 REFERENCES

Aber, J.D., Nadelhoffer, K.J., Steudler, P., Melillo, J.M. 1989. Nitrogen saturation in northern forest ecosystems. Bioscience 39: 378-386.

Andren, F.R. and Nurnberger, B. 1994. Persistence in patchy irregular landscapes with different proportions of suitable habitat: A review. Oikos 71: 355-366.

Bellamy, P.H., Loveland, P.J., Bradley, I., Lark, R.M., Kirk, G.J.D. 2005. Carbon losses from all soils across England and Wales 1978-2003. Nature. 437: 245-248.

Brady, N.C. and Weil. R.R. 1996. The nature and properties of soils. Prentice Hall Inc., Upper Saddle River, New Jersey, United States.

Beier, P. and Noss, R.F.1998. Do habitat corridors provide connectivity? Conservation Biology 12: 1241-1252.

Credit Valley Conservation. 1956. Credit Valley Conservation Report 1956. 709 p.

Credit Valley Conservation. 2003. Integrated watershed monitoring program: 2003 summary report. Technical report, 104 p.

Credit Valley Conservation. 2005. Credit Valley Conservation watershed report card. Technical report, 23 p.

Credit Valley Conservation. 2007a. Ecological Land Classification. Unpublished Data.

Credit Valley Conservation. 2007b. Interim watershed characterization report for the Credit River watershed. Technical Report, 177 p.

Credit Valley Conservation. 2010. Terrestrial Monitoring program overview. Credit Valley Conservation. 42 p.

Dobbie, T., Keitel, J., Zorn, P. 2006. State of the park report: Point Pelee National Park. Draft Technical Compendium. 106 p.

Environment Canada. 2004. How much habitat is enough? 2nd edition. Technical report, 80 p.

Evans, G.C., Nortons, S.A., Fernandez, I.J., Kahl, J.S., Hanson, D. 2005. Changes in concentrations of major elements and trace metals in Northeastern U.S. – Canadian sub-alpine forest floors. Water, Air and Soil Pollution 163: 245-267.

Fahrig, L. 1997. Relative effects of habitat loss and fragmentation on population extinction. Journal of Wildlife Management 61: 603-610.

Fahrig, L. 2002. Effect of habitat fragmentation on the extinction threshold: A synthesis. Ecological Applications 12: 346-353.

Finzi, A., Canham, C., Van Breemen, N. 1998. Canopy tree-soil interations within temperate forests: Species effects on pH and cations. Ecological Applications 8: 447-454.

Fleury, A.M. and Brown R.D.1997. A framework for the design of wildlife conservation corridors-with specific application to Southwestern Ontario. Landscape and Urban Planning 37: 163-186.

Friedland, A.J., Craig, B.W., Miller, E.K. Herrick, G.T., Siccama, T.G., Johnson, A.H. 1992. Decreasing lead levels in the forest floor of Northeastern USA. Ambio 21: 400-402.

Friedland, A.J., Johnson, A.H., Siccama, T.G. 1986. Coniferous litter decomposition in Camels Hump, Vermont: A review. Canadian Journal of Botany 64: 1349-1354.

Hess, G.R. and Fisher, R.A. 2001. Communicating clearly about conservation corridors. Landscape and Urban Planning 55: 195-208.

Lambers, H., Pons, T.L., Chapin, F.S. 1998. Plant Physiological Ecology. Springer-Verlag Inc. New York, NY, United States.

Larson, B.M., Riley, J.L., Snell, E.A., Godschalk, H.G. 1999. The woodland heritage of southern Ontario: A study of ecological change, distribution and significance. Federation of Ontario Naturalists, Ontario, Canada.

Lee, H.T., Bakowsky, W.D., Riley, J., Bowles, J., Puddister, M., Uhlig, P., McMurray, S. 1998. Ecological Land Classification for Southern Ontario: First Approximation and Its Application. Ontario Ministry of Natural Resources, Southcentral Science Section, Science Development and Transfer Branch. SCSS Field Guide FG-02.

Li, X., Poon, C.S., Liu, P.S. 2001. Heavy metal contamination of urban soils and street dusts in Hong Kong. Applied Geochemistry 16: 1361-1368.

Londo, A.J., Kushla, J.D., Carter, R.C. 2006. Soil pH and tree species suitability in the south. A Regional Peer Reviewed Technology Bulleting from Southern Region Extension of Forestry, SREF-FM-002.

McGarigal, K. and McComb, W.C. 1995. Relationship between landscape structure and breeding birds in the Oregon Coast Range. Ecological Monographs 65: 235-260.

McGee, C.J., Fernandez, I.J., Norton, S.A., Stubbs, C.S. 2007. Cd, Ni, Pb, and Zn concentrations in forest vegetation soils in Maine. Water, Air and Soil Pollution. 180: 141-153.

Moran, M.D. 2003. Arguments for rejecting the sequential Bonferroni in ecological studies. Oikos 100: 403-405.

Niemi, G.F. and McDonald, M.E. 2004. Application of ecological indicators. Annual Revue of Ecology and Evolutions Systematics 35: 89-111.

Nakawaga, S. 2004. A farewell to Bonferroni: The problems of low statistical power and publication bias. Behavioural Ecology 15: 1044-1045.

Noss, R.F. and Cooperrider, A.Y. 1994. Saving natures legacy: Protecting and restoring biodiversity. Island Press, Washington D.C, USA.

Ontario Ministry of Municipal Affairs and Housing (OMMAH). 2005. Greenbelt Plan. 57p. http://www.mah.gov.on.ca/Page189.aspx#greenbelt. (accessed January 28 2009).

Ontario Ministry of Natural Resources (OMNR). 2000. A silvicultural guide to managing southern Ontario forests. Queen’s Printer for Ontario, Toronto, Ontario, Canada.

Ontario Ministry of the Environment. 2004. Soil, ground water and sediment standards for use under part XV.1 of the Environmental Protection Act. Ontario Ministry of the Environment. PIBS# 4697e.

Pouyat, R.V. and McDonnell, M.J. 1991. Heavy-metal accumulation in forest soils along an urban-rural gradient in southeastern New York, USA. Water, Air and Soil Pollution 57-58: 797-807.

Pouyat, R.V., McDonnell, M.J., Pickett, S.T. 1997. Litter decomposition and nitrogen mineralization in oak stands along an urban-rural land use gradient. Urban Ecosystems 1: 117-131.

Reeves, G.H., Hohler, D.B., Larsen, D.P., Busch, D.E., Kratz, K., Reynolds, K., Stein, K.F., Atzet, T., Hays, P., Tehan, M. 2004. Effectiveness monitoring for the aquatic and riparian component of the Northwest forest plan: Conceptual framework and options. USDA Forest Service, general technical report, 84 p.

Spurr, S.H. and Barnes, B.V. 1980. Forest Ecology. John Wiley and Sons, New York, New York, United States.

Stinson, K.A., Campbell, S.A., Powell, J.R., Wolfe, B.E., Callaway, R.M., Thelen, G.C., Hallett, S.G., Prati, D., Klironomos, J.N. 2006. Invasive plant suppresses the growth of native tree seedlings by disrupting belowground mutualisms. PLoS Biology 4: 727-731.

Trzinski, M.K., Fahrig, L., Merriam, G. 1991. Independent effects of forest cover and fragmentation on the distribution of forest breeding birds. Ecological Applications 9: 586-593.

Villard, M.A., Trzcinski, M.K., Merriam, G. 1999. Fragmentation effects on forest birds: Relative influence of woodland cover and configuration on landscape occupancy. Conservation Biology 13: 774-783.

Watmough, S.A. and Dillon, P.J. 2003. Base cation and nitrogen budgets for seven forested catchments in central Ontario, 1983-1999. Forest Ecology and Management 177 :155-177.

Watmough, S.A. and Hutchinson, T.C. 2004. The quantification and distribution of pollution Pb at a woodland in rural south central Ontario, Canada. Environmental Pollution 128: 419-428.

Watmough, S.A., Dillon, P.J., Epova, E.N. 2005. Metal partitioning and uptake in central Ontario forests. Environmental Pollution 134: 493-502.

Zar, J.H. 1999. Biostatistical Analysis: Fourth Edition. Prentice Hall. Upper Saddle River, New Jersey, USA. 663p.

APPENDIX A: A COMPARISON OF MINISTRY OF ENVIRONMENT (MOE) HEAVY METAL CONCENTRATION GUIDELINES TO HEAVY METAL CONCENTRATIONS AT 26 FOREST PLOTS IN THE CREDIT RIVER WATERSHED.

Site Name	Site #	Township	County	Physiographic Zone	Heavy Metal Concentration (mg/kg)							
					Co	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**	**Cd**	**Mo**
MOE GUIDELINES	**NA**	**NA**	**NA**	**NA**	**19**	**67**	**56**	**43**	**55**	**150**	**1**	**2.5**
Brampton Property	F-17	Brampton	Peel	Lower	11.00	27	18	21	23	66	<1.0	<2.5
Brittania Woods	F-16	Mississauga	Peel	Lower	9.40	20	10	15	21	58	<1.0	<2.5
Churchill Meadows Property	F-13	Mississauga	Peel	Lower	8.30	23	10	16	19	67	<1.0	<2.5
Huttonville Property	F-10	Brampton	Peel	Lower	5.80	21	6.2	15	20	45	<1.0	<2.5
Levi Creek Property	F-11	Mississauga	Peel	Lower	4.90	19	12	13	24	60	<1.0	<2.5
Meadowvale Station	I-05	Mississauga	Peel	Lower	8.90	45	15	29	32	73	<1.0	<2.5
Mississauga Gardens	I-01	Mississauga	Peel	Lower	14.00	25	22	21	28	91	<1.0	<2.5
Roy Ivors Woods	F-14	Mississauga	Peel	Lower	3.70	16	7.6	11	36	43	<1.0	<2.5
Streetsville Woods Property	F-12	Mississauga	Peel	Lower	12.00	30	12	25	35	98	<1.0	<2.5
Winston Woods	F-15	Oakville	Halton	Lower	9.40	30	18	22	28	84	<1.0	<2.5
Fairy Lake Property	F-18	Halton Hills	Halton Hills	Middle	4.20	15	12	9.3	17	53	<1.0	<2.5
FON Willoughby Reserve	F-20	Caledon	Peel	Middle	4.50	22	15	13	17	74	<1.0	<2.5
Limehouse Property	F-08	Halton Hills	Halton Hills	Middle	9.30	22	36	19	41	80	<1.0	<2.5
Robert Baker Forest	F-05	Caledon	Peel	Middle	7.70	26	13	17	100	320	<1.0	<2.5
Silver Creek Property	F-07	Halton Hills	Halton Hills	Middle	5.90	20	11	13	43	160	<1.0	<2.5
Terra Cotta Forest	I-06	Caledon	Peel	Middle	11.00	23	29	18	51	130	<1.0	<2.5
Upper Canada Property	F-09	Halton Hills	Halton Hills	Middle	5.30	19	11	14	23	46	<1.0	<2.5
Warwick Property	F-06	Caledon	Peel	Middle	2.90	14	4.3	7.8	18	34	<1.0	<2.5
Alton Forest	I-03	Caledon	Peel	Upper	3.70	17	7	8.5	17	46	<1.0	<2.5
Belfountain Property	F-19	Caledon	Peel	Upper	11.00	22	15	25	24	91	<1.0	<2.5
Caledon Creek Forest (TRCA)	F-04	Caledon	Peel	Upper	4.30	17	5.8	10	15	43	<1.0	<2.5
Charles Sauriol Property	F-03	Caledon	Peel	Upper	3.20	14	6.1	8.4	13	43	<1.0	<2.5
Forks of the Credit	I-04	Caledon	Peel	Upper	4.00	17	8.4	10	14	45	<1.0	<2.5
Hillsburgh Property	F-02	Erin	Wellington	Upper	4.40	25	7.6	15	27	94	<1.0	<2.5
Monora Park Property	F-01	Mono	Dufferin	Upper	3.50	16	3.5	7.6	12	31	<1.0	<2.5
Orpen Lake	I-02	Caledon	Peel	Upper	5.90	17	8.1	11	32	51	<1.0	<2.5