Water Quality (2014) in the Muskrat Lake Watershed

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Summary

Excessive inputs of the nutrients phosphorus and nitrogen from agriculture, urban and industrial activities may lead to eutrophication. Eutrophication is characterized by excessive growth of algae and aquatic plants and can led to negative effects such as toxic algal blooms, oxygen depletion and fish kills. Concern regarding eutrophication in Muskrat Lake (Township of Whitewater Region, Canada) has led to efforts to assess water quality issues in the surrounding watershed in relation to land use activities. Water samples were collected from 27 field sites in the Muskrat Lake watershed monthly from April to October 2014 and were analyzed for a number of parameters including reactive phosphorus, total phosphorus, nitrate, total nitrogen and total suspended solids. Overall, the Muskrat Lake watershed had high average concentrations of nitrogen and phosphorus and moderate concentrations of total suspended sediments. High concentrations persisted throughout the sampling period and frequently exceeded thresholds for impairment of streams. Several tributaries were identified as being highly enriched in nitrogen, phosphorus or both nutrients including: the Cobden Wetland, Upper Harris Drain, North Tributary, O'Gorman Agnew Drain, Stoqua Creek and Unnamed Creek (SC-02). Portions of Mink Creek and Snake River were also nutrient enriched, whereas the Muskrat River generally did not exceed threshold values for impairment. At the watershed scale, nutrients and total suspended sediments increased with increasing annual crop land and pasture/forage land and decreased with increasing natural habitat. The relationship between nitrate enrichment and annual crop land was particularly strong. Efforts to improve water quality in the Muskrat Lake watershed should focus on reducing inputs of nutrients and total suspended sediments from annual crop land. Several beneficial management practices may be effective. In particular, controlled tile drainage can be effective in reducing exports of nitrogen and phosphorus. A reduction in nutrient loads to Muskrat Lake is essential to improving its water quality.

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1.0 Introduction

1.1 Effects of nutrient enrichment and total suspended solids

Nutrients such as nitrogen and phosphorus are essential to life in general and to the natural growth of plants and algae in particular. Nitrogen gas comprises approximately 78% of the atmosphere but is unavailable for uptake by most organisms. Processes such as lightning and nitrogen fixation by bacteria and algal species are essential to transform nitrogen gas to usable forms of nitrogen such as nitrate and ammonium. Human activities have dramatically altered the nitrogen cycle through the production of synthetic fertilizers, the intensification of agriculture and industrial activities and these activities have increased the amount of available nitrogen in terrestrial and aquatic ecosystems. Unlike nitrogen, phosphorus is scarce in the atmosphere but relatively abundant in the lithosphere (Earth's crust and upper mantle). Weathering of rocks represents the major natural source of phosphorus. Phosphorus typically occurs naturally in low concentrations in surface waters and bioavailable forms such as reactive phosphorus are often quickly incorporated into organic tissues. Anthropogenic sources of phosphorus include agricultural sources such as synthetic fertilizers and manure and urban sources such as wastewater effluent, septic tank leakages, runoff from lawns, golf courses and urban development (Dubrovsky et al., 2010).

Excessive inputs of phosphorus and nitrogen from agriculture, urban and industrial activities are a major threat to water quality in many parts of the world. Nutrient enrichment may lead to eutrophication which is characterized by undesirable increases in the growth of algae and aquatic plants. Subsequent negative effects of eutrophication can include the formation of toxic algal blooms, oxygen depletion, fish kills and a loss of biodiversity (Carpenter et al., 1998). The consequences of eutrophication can be severe, resulting in a decline in the health and functioning of aquatic ecosystems and the impairment of water for drinking as well as industrial, agricultural and recreational activities. Point (direct) sources of nutrient pollution (e.g. municipal sewage treatment effluent) are relatively easy to identify. Non-point (diffuse) sources of nutrient pollution (e.g. runoff from agricultural fields) are much more difficult to identify and control because concentrations occur in pulses and sources often originate from across large areas of land.

Total suspended solids may also impair water bodies and are often linked to nutrient pollution. Total suspended solids in water refer to any material retained on a filter (2 μm) and include silt and clay particles, algae and decomposing matter. There is a close relationship between total suspended sediments and phosphorus. Total suspended solids may contain phosphorus adsorbed to fine soil particles. Sources of total suspended solids include soil erosion and runoff from agricultural fields, roads, industrial activities and sewage effluent. In excess, total suspended solids may absorb heat from sunlight, increase water temperatures, increase decomposition and reduce oxygen concentrations. Particles that eventually settle out of the water column can clog fish gills and have adverse effects on benthic organisms.

1.2 Muskrat Lake and its surrounding watershed

Muskrat Lake (1201 ha) is located within the Township of Whitewater Region of eastern Ontario. It is the drinking water source for the nearby town of Cobden. Water and sewage treatment facilities for the town of Cobden are located adjacent to the lake. Muskrat Lake is also used recreationally for swimming, boating and fishing by both permanent and seasonal residents as well as visitors. The lake has a maximum depth of 64 m and average depth of 17.9 m (OMNRF, 2015). Muskrat Lake supports a number of fish species including: blue gill, brown bullhead, lake trout, largemouth bass, muskellunge, northern pike, pumpkinseed, rainbow smelt, rock bass, smallmouth bass, walleye, white sucker and yellow perch (OMNRF, 2015). It is stocked annually with yearling lake trout (OMNRF, 2015). Muskrat Lake is highly nutrient enriched and concerns have arisen over its water quality, particularly the formation of blue-green algal (cyanobacteria) blooms.

Land use activities surrounding Muskrat Lake are likely having a negative effect on water quality. Muskrat Lake is part of the larger Muskrat River watershed (114 458 ha) which commences near Renfrew, Ontario and flows into a chain of lakes, including

Muskrat Lake, and eventually discharges into the Ottawa River near Pembroke, Ontario. The total area of land draining into Muskrat Lake is 51 072 ha and is referred to here as the Muskrat Lake watershed. This watershed includes: tributaries to the north of Muskrat Lake (5072 ha), the south eastern portion of the Muskrat River watershed (6647 ha) and the Snake River watershed (39 353 ha) (Fig. 1). The Snake River watershed represents 77% of the land draining into Muskrat Lake. The headwaters of the Snake River begin in the mainly forested Boreal Shield Ecozone where Black Creek flows into Lake Dore (1516 ha) with the main branch of the Snake River commencing at the lake's outlet. Snake River flows through wetland and agriculture areas in the Mixedwood Plains Ecozone before discharging into Muskrat Lake. Overall land use of the three areas draining into Muskrat Lake and forming the Muskrat Lake watershed is classified as forest and pasture but agricultural activities may be having a negative impact on the water quality of Muskrat Lake.

1.3 Report scope and objectives

Data from the Ontario Ministry of the Environment and Climate Change (MOECC) from 2005 and 2012 indicated that nutrient concentrations were elevated in the Muskrat Lake watershed, particularly in the Snake River watershed. Unlike most parts of southern Ontario, the Muskrat Lake watershed lacks a Conservation Authority to provide a coordinated approach to nutrient management and water quality initiatives vis-à-vis farming practices, although local organizations are working in these areas. In 2014, a comprehensive effort was made to assess water quality issues in the Muskrat Lake watershed in relation to land use activities. The project was led by Algonquin College (Pembroke) and the Muskrat Watershed Council. It was funded through Farm & Food Care Ontario's Water Adaptation Management and Quality Initiative (WAMQI). As part of this project, water quality parameters were analyzed at sites located throughout the Muskrat Lake watershed.

The scope of this report was the analysis of water quality monitoring data from water samples collected at 27 field sites located in the Muskrat Lake watershed from April to October 2014. The analysis focused on key nutrients involved in eutrophication as well as total suspended solids. The main objectives were 1) to prepare a report that reviews, summarizes, analyzes and interprets water quality monitoring data from the Muskrat Lake watershed and 2) to provide recommendations for future analysis and sampling.

2.0 Methods

2.1. Field sites

A total of 27 field sites located throughout the Muskrat Lake watershed were sampled in 2014 (Appendix A Table A1). The monitoring network included 10 existing sites established by the MOECC/ Ontario Ministry of Natural Resources and 17 new sites established by the Muskrat Watershed Council and Algonquin College. Field sites were located in the Muskrat River (7 sites) and Snake River watersheds (20 sites) and were surrounded by a range of land uses. Sites included several locations along the Muskrat and Snake Rivers as well as their main tributaries. A reference site, Black Creek (BLC-01), was included to estimate background nutrient concentrations.

2.2 Water quality sampling

The 2014 water sampling campaign was coordinated by Algonquin College. Grab samples were taken monthly from April to October at each field site. Samples were analyzed by the MOECC Laboratory Services Branch following established analytical methods. In total, 43 parameters were measured including measures of general water chemistry (8 parameters), major fractions of nitrogen and phosphorus (7 parameters) and metals (28 parameters) (Appendix B Table B1). This report focused on the major fractions of nitrogen, phosphorus and solids (Table 1). In particular, the report focused on total nitrogen, total phosphorus, nitrate, reactive phosphorus and total suspended solids.

2.3 Data Analysis

Nutrient and total suspended solid data were summarized and average (± standard deviation) concentrations and their ranges were calculated. Nitrate and reactive phosphorus concentrations were compared to estimated background concentrations calculated from a comprehensive survey of streams in the United States (Dubrovsky et al., 2010). Total nitrogen and total phosphorus were compared to thresholds for stream impairment that were developed for the Mixedwood Plains Ecozone of Ontario (Chambers et al., 2012). Total suspended solids were compared to an ideal performance standard developed for the Mixedwood Plains of Ontario as part of Canada's National Agri-Environmental Standards Initiative (Culp et al., 2009). The ratio between total nitrogen and total phosphorus (TN: TP) was calculated.

Statistical differences between nutrient and total suspended solid concentrations across field sites and over time were assessed with several two-way analyses of variance (ANOVA). The dependent variables were total nitrogen, total phosphorus, nitrate, reactive phosphorus and total suspended solids and the independent variables were site and time of sampling (month). No interaction term was included because the samples were not replicated. The model assumption of normality of residuals was evaluated with a Shapiro-Wilk's test and data transformed (log10) to improve normality. Sidak post-hoc tests were conducted to assess which sites and sampling months differed. However, due to the nature of the data (e.g. no replication, non-normal) and the large number of comparisons between months and sites, these tests sometimes gave conflicting results. It was concluded that the *statistical* results of the post-hoc tests were not useful in interpreting *biologically relevant* differences in nutrient concentrations and these results were not reported.

The effects of land use on nutrients and total suspended solids were assessed by examining land use immediately upstream of each site. Upstream land use was calculated in a 1000 m long and 200 m wide area (100 m on either stream/river bank) using 30 m resolution satellite imagery data from Agriculture and Agri-food Canada's 2014 Crop Inventory. The percentages of annual crop land, pasture/ forage land, natural habitat and developed land were calculated. Annual crop land was composed primarily of corn and soybean crops but also included minor crops of barley and oats. Pasture and forage crop land included pasture land and land that is periodically cultivated with grasses and perennial crops such as alfalfa and clover for hay, pasture or seed. Natural habitat included broadleaf, coniferous and mixedwood forests, shrubland, wetlands, water and exposed land. Exposed land was predominately non-vegetated and non-developed (e.g. rocks, sediments). Developed land included roads, buildings, paved surfaces, urban/suburban areas and associated vegetation. Simple linear regressions were used to assess the effects of land use (independent variables) on the concentrations of nutrients and total suspended solids (dependent variables) at the 27 field sites. Average concentrations (April to October 2014) were used. Model assumptions of normality of residuals were evaluated with Shapiro-Wilk's tests and data transformed (log10 or inverse) to improve normality. Statistical analyses were conducted with SPSS V22 (IBM Corp., Armonk, USA).

3.0 Results from 2014

3.1 Nitrogen

From April to October 2014, overall concentrations of both nitrate and total nitrogen were high throughout the Muskrat Lake watershed (Table 2). Concentrations of nitrate often exceeded the estimated background concentration of nitrate due to natural processes (240 μg/L) and these elevated concentrations represented contamination due to agricultural and urban activities (Dubrovsky et al., 2010). Concentrations of total nitrogen often exceeded the threshold for stream impairment (1100 μg/L) developed for the Mixedwood Plains Ecozone of Ontario (Chambers et al., 2012).

Overall significant differences were observed between sampling months for nitrate ($F=5.968$; $df=6, 152$; $p<0.001$; $R^2=0.807$) and total nitrogen ($F=4.703$; $df=6, 152$; $p<0.001$; $R^2=0.794$). Seasonal trends were similar to those observed in other North American streams (Dubrovsky et al., 2010), with nitrogen concentrations tending to be higher in the spring compared to late summer and early fall. Discharge data were not available for individual field sites. However, discharge data for the Muskrat River near

Pembroke, Ontario illustrated that discharge for this portion of the Muskrat River was elevated from March to July, with peak discharge occurring from mid to late April (Fig. 2). The observed trends for nitrogen suggest that peak concentrations occurred during periods of high discharge. High concentrations of nitrogen occurred following the spring freshet (thaw of snow and ice) with possible sources including excess soil nitrogen from the previous year's fertilizer application and tilling practices as well as winter application of manure. High nitrogen concentrations also followed the spring application of fertilizers (typically occurring in May and early June). It was notable that overall average concentrations exceeded threshold values every sampling month for nitrate and every month except August for total nitrogen (Table 2).

Nitrogen concentrations ranged between sub-watersheds, tributaries and within tributaries (Table 3). Sites differed significantly in both nitrate ($F=23.283$; $df=26, 152$; $p<0.001$; $R^2=0.807$) and total nitrogen ($F=21.498$; $df=26, 152$; $p<0.001$; $R^2=0.794$) concentrations. Concentrations averaged over all sampling dates ranged from 38-5377 µg/L nitrate and 377-6099 µg/L total nitrogen. Sites within the Muskrat River watershed tended to be less nitrogen enriched compared to sites within the Snake River watershed. Of particular concern were a number of small tributaries that were highly nitrogen enriched, including the Upper Harris Drain, North Tributary and O'Gorman Agnew Drain (Table 3). Along a given tributary, nitrogen tended to be higher at downstream sites compared to those located upstream due to the movement of nutrients and sediments downstream and the larger area of land drained. For example, nitrogen increased along Mink Creek and the Snake River (Table 3). Nitrogen was lower in the most downstream site of the Snake River (SNR-04) after passing through the Snake River Marsh (Fig. 1) (a portion of which is a provincial conservation reserve) where nitrogen was likely taken up by plants and converted to nitrogen gas by denitrifying bacteria.

3.2 Phosphorus

Overall concentrations of both reactive and total phosphorus were high throughout the Muskrat Lake watershed (Table 2). Concentrations often exceeded the estimated background concentration of reactive phosphorus due to natural processes (10 μg/L) and elevated concentrations represented contamination due to agricultural and urban activities (Dubrovsky et al., 2010). Concentrations of total phosphorus also often exceeded the threshold for stream impairment (30 μg/L) developed for the Mixedwood Plains Ecozone of Ontario (Chambers et al., 2012).

Overall significant differences were observed between sampling months for reactive phosphorus ($F=16.751$; $df=6, 152$; $p<0.001$; $R^2=0.749$) and total phosphorus ($F=8.398$; $df=6, 152$; $p<0.001$; $R^2=0.678$). Temporal and spatial trends in phosphorus were more complex than those of nitrogen. Dubrovsky et al. (2010) found that in some regions of the United States, phosphorus concentrations were highest in the summer and fall when discharge was low and less dilution of point sources occurred. In other regions, phosphorus was highest in the spring when discharge was high and sediment-bound phosphorus was transported by erosion and runoff from agricultural lands. While considerable variation occurred between field sites, reactive phosphorus and total phosphorus concentrations in the Muskrat Lake watershed tended to be highest during the summer months (Table 2). Overall average concentrations exceeded threshold values every sampling month for reactive phosphorus and every month except May and October for total phosphorus (Table 2).

As with nitrogen, phosphorus concentrations ranged between sub-watersheds, tributaries and within tributaries (Table 3). Sites differed significantly in both reactive phosphorus ($F=14.004$; $df=26, 152$; $p<0.001$; $R^2=0.749$) and total phosphorus concentrations ($F=10.526$; $df=26, 152$; $p<0.001$; $R^2=0.678$). Concentrations averaged over all sampling dates ranged from 3-143 μg/L reactive phosphorus and 8-393 μg/L total phosphorus. Of particular concern were a number of small tributaries that were highly phosphorus enriched, including the Unnamed Creek (SC-02), Stoqua Creek, Upper Harris Drain and O'Gorman Agnew Drain (Table 3). In addition, the Cobden Wetland is a considerable source of phosphorus. The Muskrat Lake watershed was generally enriched with nitrogen relative to phosphorus with high ratios of total nitrogen to total phosphorus (Table 3, Table 4). Ratios >16: 1 indicate phosphorus limitation (Redfield, 1958) but nutrient limitation is also a function of absolute concentrations of nitrogen and phosphorus, both of which were high in the Muskrat Lake watershed.

3.3 Total suspended solids

Total suspended solids were moderately high across the Muskrat Lake watershed. Concentrations of total suspended solids were similar between sampling months (F=0.761; df=6, 152; p=0.601; R^2=0.556) but differed between field sites (F=7.140; df=26, 152; p<0.001; R^2=0.556). In all sampling months, total suspended solids exceeded the ideal performance standard (4.1 mg/L) developed for the Mixedwood Plains of Ontario (Culp et al., 2009). Total suspended sediments were typically low in the Muskrat River watershed. Total suspended sediments were high in two tributaries that were also nutrient enriched, the Upper Harris Drain and North Tributary. Along the Snake River, total suspended sediments increased from upstream to downstream sites. Total suspended sediments peaked in concentration at SNR-03 which is located upstream of the Snake River Marsh. The Snake River Marsh appeared to be a considerable sink for total suspended sediments. Average total suspended sediment concentrations were ~ 4 × lower in SNR-04 compared to SNR-03 after passing through the wetland.

3.4 Effects of land use

Average land use upstream of the 27 field sites in the Muskrat Lake watershed was predominately natural habitat (average 57.8 ± 37.9 %), followed by areas of annual crop land (27.7% ± 31.6 %) and pasture/forage land (11.7 ± 14.9 %). Developed land represented a small portion of total land use (2.8 ± 2.5 %, ranging from 0 to 9.3%). Across the field sites, land use varied from 0 to 98.3% natural habitat, 0 to 92.8% annual crop land and 0 to 68.2% pasture/forage land.

In-stream concentrations of both nitrate and total nitrogen increased as the percentage of upstream land in annual crops increased (Fig. 3). Annual crops, particularly the cultivation of corn crops, are associated with the application of nitrogen-based synthetic fertilizers as well as manure. Nitrate and total nitrogen also increased significantly as the percentage of pasture and forage land increased (Fig. 3). However, this trend was not as strong as the trend observed for annual crops (as determined by the lower F-statistics and lower percentages of variation in nitrogen explained). Nutrient inputs to pasture and forage land were likely lower and more variable than annual crops and may include manure from grazing livestock and the application of nutrients, particularly manure to forage crops. Nitrate and total nitrogen concentrations decreased as the percentage of natural habitat increased (Fig. 3).

Both reactive phosphorus and total phosphorus increased as the percentage of annual crop land and percentage of pasture/ forage land increased (Fig. 4). In contrast, phosphorus concentrations decreased as natural habitat increased. Trends were not as strong as those observed for nitrogen because nitrogen-based synthetic fertilizers are more closely associated with annual crops such as corn. Also, as in most surface waters, phosphorus was present at lower concentrations compared to nitrogen. Grab sampling may miss peaks in concentrations and phosphorus may be rapidly incorporated into organic tissue. Phosphorus enrichment likely occurred as a result of non-point source pollution (e.g. surface runoff from agricultural fields) but also from point sources (e.g. wastewater treatment plant).

Total suspended sediments also increased with increasing annual crop land and decreased with increasing natural habitat (Fig. 5). This suggested that total suspended sediments were exported from annual crop land through surface runoff and tile drainage and that they were retained when natural habitat was present. No relationship was found between total suspended solids and pasture/ forage land. This type of land use may be variable. For example, pasture land is likely to have high total suspended solids if cattle have access to water bodies but may not contribute to total suspended solids if cattle access is restricted. Forage crops planted close to the water's edge may contribute to erosion and total suspended solids but fields well-buffered by natural vegetation may export few total suspended solids.

4.0 Conclusions and Recommendations

4.1 Conclusions from 2014 water quality monitoring

The Muskrat Lake watershed was characterized by high concentrations of nitrogen and phosphorus and by moderate concentrations of total suspended sediments. High nutrient concentrations were not just transient, but were persistent over several months. Nutrient enrichment was directly and positively related to annual crop land. Pasture and forage crop land also contributed significantly to nutrient enrichment, but to a lesser extent. Nutrients were lowest in areas with high percentages of natural habitats, highlighting the importance of conserving natural habitat. The strong positive relationship between nitrate and annual crop land provided evidence that annual crop land was a significant contributor of non-point source nitrogen pollution from runoff and tile drainage. Annual crop land was also a contributor of non-point source phosphorus pollution. However, the relationship was less clear and there was also evidence of point sources of phosphorus pollution, characterized by sites with moderate nitrogen and high phosphorus concentrations. Several tributaries were identified as being highly impacted by nutrients:

- Cobden Wetland- high phosphorus
- Upper Harris Drain- high nitrogen and phosphorus
- North Tributary- high nitrogen and phosphorus
- O'Gorman Agnew Drain- high nitrogen and moderately high phosphorus
- Stoqua Creek- moderately high nitrogen and high phosphorus
- Unnamed Creek (SC-02)- high phosphorus

Portions of Mink Creek and Snake River were also nutrient enriched, whereas the Muskrat River generally did not exceed threshold values for impairment. Nutrient enrichment in tributaries of the Muskrat Lake watershed is contributing to eutrophication in Muskrat Lake. Reducing nutrient loading from tributaries draining into Muskrat Lake is an essential step in improving its water quality.

4.2 Recommendations for the monitoring network

Following an assessment of data collected in 2014 and feedback from the Muskrat Watershed Council, recommendations were made for future monitoring, including the 2015 monitoring campaign. It was concluded that the 2014 monitoring network was fairly comprehensive and clearly identified several tributaries of concern. Significant differences in nutrient concentrations may occur between years due to factors such as changes in land use practices (e.g. planting corn versus soy) and differences in precipitation. In order to make comparisons between years, it is better to keep the same sites over time rather than move them in an effort to find the "perfect" sampling locations. In order to optimize resources, several changes were made to the monitoring network for 2015.

Rationale for recommendations:

- Existing MOECC/OMNR sites should be kept where possible. If available, historical data will be useful.
- Keep sites where there is only a single site on a given tributary and where there is a rationale for including that tributary in the network.
- Where there are multiple sites along a tributary, keep the most upstream and downstream sites. The upstream site can be used as a reference for that tributary and the downstream site likely represents the most impacted site as nutrients and sediments move along the tributary.

Recommendations:

1. MKL-01 (Muskrat Lake deep water site) should be sampled monthly. This will establish a consistent record of water quality within Muskrat Lake.

2. In order to optimize resources, it was recommended that the following four sites be dropped in 2015:

- HT-01 (Harlow Trail Creek). This site has low discharge and is only moderately impacted by nutrients.
- HC-02 (Upper Harris Drain at Barr Line). There are sites located both upstream and downstream of this site on the Upper Harris Drain.
- SNR-05 (Snake River above Mink Creek). There are sites located both upstream and downstream of this site on the Snake River. This site is only moderately impacted and it is difficult to access.
- SNR-07 (Snake River above Upper Harris Drain). There are sites located both upstream and downstream of this site on the Snake River, including existing MOECC/OMNR sites.

3. It was recommended that the locations of the remaining sites remain the same. The total number of sites sampled in 2015 will be 24, including MKL-01. Site level recommendations and their rationale are provided in Table 4.

4.3 Recommendations for future sampling and data analysis

Sampling frequency

Data were collected from a single year and from grab samples. Changes in land use (e.g. crop rotation) may results in changes in nutrient and total suspended sediment concentrations at the site level. Grab samples are point-in-time estimates that provide a snapshot of concentrations of nutrients and sediments. Peaks in concentrations are expected to occur in pulses following rain events and therefore may be variable even within a short time scale. Samples were collected monthly from April to October. Discharge data for the Muskrat River near Pembroke, Ontario illustrated that peak discharge occurred from mid to late April. It would be ideal to have samples collected year round or at least in the period before discharge begins to peak. However, this is generally not practical and sampling during the winter and early spring months is challenging and monitoring programs commonly use the period from April to October.

Recommendations:

- Sites should be sampled monthly within a short timeframe so that they are comparable (as was done in 2014).
- Given the seasonal and temporal variation in nutrient concentrations, sampling should continue to occur monthly from April to October.
- Additional years of sampling will provide additional confidence in the reported results. However, 2014 trends were consistent within sites (e.g. a number of sites had high nitrogen and high phosphorus during multiple months). Action to reduce nutrient loads in these tributaries should not wait for multiple years of monitoring data.

Data gaps and quality control

Data were missing for one month at several field sites (e.g. MKR-03- August, MC-02- September, MKR-02- August and SC-02- August), likely because there was no moving water during these time periods. With only one year of sampling, missing data may skew average concentrations. Overall, data appeared to be of good quality. However, there were a few issues with the data. For example, total nitrogen for SNR-04 in October was 226 000 µg/L. This concentration was calculated from a diluted sample and was two orders of magnitude higher than the next highest concentration. Another example of a potential data issue was the July total nitrogen concentration for BLC-01 which seemed uncharacteristically high for the site (2900 µg/L compared to an average of 506 µg/L). There were several instances where reactive phosphorus was substantially higher than total phosphorus, particularly during August when water levels were likely lowest. For example, August reactive phosphorus concentrations were 50 and 130 µg/L and total phosphorus concentrations were 20 and 62 µg/L at MC-01 and HC-01 respectively.

Recommendations:

- Document sample collection protocols with particular emphasis on reducing possible sources of contamination.
- Document conditions when samples were collected. For example, several sites may have little or no flowing water during late summer. This may result in data gaps or somewhat misleading data. Nutrient and sediments may become highly concentrated during periods of low flow but during these periods, movement of these compounds to Muskrat Lake is also low.
- Verify if there were any differences in sample preparation for the analytical methods. For example, were any of the samples filtered or diluted?
- It was recommended that duplicate samples be collected for at least 10% of all samples. Although this was not possible, it was feasible to collect one duplicate sample per month. Recommendations were made to either: 1) Collect duplicate samples from 7 different impacted sites (e.g. MKR-02, HC-03, MC-04, NT-01, OAD-01, SC-01, SNR-04, SC-02). These sites represent the major tributaries and those that were most highly impacted or 2) Alternate duplicate samples on the most downstream sites of the Snake (SNR-04) and Muskrat (MKR-02) Rivers (e.g. 4 duplicates on the Snake and 3 on the Muskrat). These sites are important because they reflect the discharge of nutrients into Muskrat Lake from its major tributaries.

Complementary data

In addition to nutrient and total suspended sediment data, several other types of data would be useful in characterizing field sites. They would provide context for the existing data and be useful in assessing the fate of nutrients in the Muskrat Lake watershed. Generally, most of these data are already collected but need to be organized and analyzed. Additional data may be particularly useful for sites/tributaries that are of particular concern or where further study is required. For example, wetlands can be considerable nutrient sinks but can also be sources in some instances. Further data would be helpful in understanding nutrient dynamics in the Cobden Wetland.

Recommendations:

- Basic water chemistry parameters would be useful to characterize field sites and assess seasonal changes. This would include temperature, pH, dissolved oxygen and conductivity. MOECC data include pH measured in the laboratory. However, changes in pH may occur during sampling storage.
- Physical parameters also provide important information. Ideally discharge would be measured so that nutrient loads could be calculated. Even if this is not possible, variables such as depth, stream width, bank slope and surface velocity can be important in characterizing sites.
- Primary production, including aquatic plants, benthic algae and planktonic algae, can be indictors of nutrient enrichment and are also important in the uptake of nutrients. Even a simple visual assessment of aquatic plant cover or the presence of benthic algae mats could be useful. A record of primary production would be particularly useful in Muskrat Lake itself (e.g. planktonic chlorophyll *a*) as well as details of any algal blooms.
- Land use data are key in linking nutrients to their sources and to eventually implementing beneficial management practices. The AAFC Annual Crop Inventory provides useful data, especially at the watershed scale. At the site level, aerial images would be useful to identify specific land use in more detail. Landowner surveys and reconnaissance may also be needed to assess patterns in crop rotation, tilling practices and the presence of tile drains.
- Metals were analyzed in 2014 along with other parameters (Appendix B) and will be analyzed again in 2015. These data should be assessed to determine if they are needed in subsequent years.

Data management, analysis and synthesis

A considerable amount of data were collected in the 2014 monitoring program and more will be collected in 2015. Careful consideration is needed to manage, analyze and synthesize the data.

Recommendations:

- An assessment is needed of the data existing to date, including any historical data. What data are available and what data will be useful in efforts to improve water quality in the Muskrat Lake watershed?
- Raw data and data analysis should be stored in a central location (e.g. FTP site).
- A strategy for reporting results is needed. What information is needed to make decisions on future efforts to improve water quality? For example, a comparison of nutrient concentrations with threshold values such as those reported here might suffice on an annual basis. A more in-depth technical report may only be needed on a longer timeframe (e.g. every 5 years).

4.4 Considerations for improving water quality in the Muskrat Lake watershed

Phosphorus is considered to be the nutrient limiting primary production in freshwater ecosystems and most efforts to reduce eutrophication focus on controlling phosphorus. Nitrogen is generally not considered to be a limiting nutrient and therefore reducing nitrogen loads are often not considered in efforts to reduce eutrophication. However, recent research has shown that nitrogen limitation can occur in streams (reviewed in Keck and Lepori, 2012) and lakes (reviewed in Moss et al., 2013) suggesting that there is value in reducing both phosphorus and nitrogen loads. In addition, nitrogen enrichment has been shown to have negative effects on aquatic plant communities which are important to fish and ecosystem function (Moss et al., 2013), including those in an eastern Ontario watershed (Dalton, et al., 2015). Point sources of nutrients should be identified and addressed where possible. For example, phosphorus is very high in the Cobden Wetland near the sewage treatment plant and in the Unnamed Creek (SC-02). Several beneficial management practices (BMP) have potential to reduce non-point source nutrient loading from agricultural activities.

The Watershed Evaluation of Beneficial Management Practices (WEBs) program (2004-2013) was a comprehensive initiative by the Government of Canada to determine the economic and water quality impacts of several BMPs in nine watershed sites across Canada. A key finding from work in the South Nation River watershed, Ontario was that controlled tile drainage (CTD) structures dramatically reduced the loss of nutrients from fields to surface waters and reduced the export of nitrate by 65% and phosphorus by 63% (Agriculture and Agri-Food Canada. 2010). These structures allow free drainage early in the growing season and retain water later in the growing season. The cost of installing CTD structures is approximately \$208/ ha and the structures have a lifespan of 25 years. Average crop yields increased with CTDs by approximately 3% for corn and 4% for soybeans making this BMP an attractive economic and environmental investment (Agriculture and Agri-Food Canada. 2010).

Other BMPs have potential to improve water quality and reduce the export of nutrients to Muskrat Lake. However, their benefits were less clear than those of CTDs and several resulted in either trade-offs or had mixed results. For example, conservation tillage reduced exports of sediment and total nitrogen compared to conventional tillage in the South Tobacco Creek watershed, Manitoba. However, export of total phosphorus actually increased as a result of the release of dissolved phosphorus from crop residues during freeze-thaw events and an accumulation of phosphorus near the soil surface (Agriculture and Agri-Food Canada. 2011). Similarly, vegetated buffer strips can be effective in reducing stream nutrient concentrations, particularly nitrogen, but also have the potential to release phosphorus seasonally (Osborne and Kovacic, 1993). In the Salmon River watershed, British Columbia, cattle exclusion fencing reduced sediment in nearby waterbodies but did not result in clear improvements in other measures of water quality (Agriculture and Agri-Food Canada. 2011).

Recommendations:

- An assessment is needed of various BMPs, their feasibility and their likelihood of improving water quality in Muskrat Lake watershed. This should include details of current farming practices at the watershed, tributary and site level.
- Findings from the WEBs initiative suggest that controlled tile drainage structures are a promising option. This BMP appears to have the clearest success in reducing nutrient exports in a watershed similar to the Muskrat Lake watershed.

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Table 1. Major fractions of nutrients and solids

	Fraction	Abbreviation	Description
Phosphorus (P)	Reactive phosphorus	RP	Includes orthophosphate and other types of reactive phosphorus. These are the most available types of P for algae and plants.
	Total phosphorus	TP	All forms of P including organic, inorganic, particulate and dissolved.
Nitrogen (N)	Ammonia + Ammonium	$NH_3 + NH_4^+$	Sources include nitrogen fixation, decomposition and fertilizers/manure. Converted to nitrate.
	Nitrite	NO_2^-	Intermediate form in the conversion of ammonium to nitrate. Generally found at low concentrations. Unstable and converted to NO_3^-.
	Nitrate + Nitrite	NO_3^-	Main form of inorganic N in surface waters. Elevated concentrations indicate nutrient pollution.
	Total Kjeldahl Nitrogen	TKN	Laboratory measurement of organic N, $NH_3 + NH_4^+$.
	Total Nitrogen	TN	Sum of nitrogen forms (TKN + NO_2^- + NO_3^-).
Solids	Dissolved Solids	DS	Includes calcium, chlorides, nitrate, phosphorus, iron, sulfur and other ion particles smaller than 2 µm.
	Total Suspended Solids	TSS	Includes silt and clay particles, algae, fine organic debris and other particulate matter.
	Total Solids	TS	Sum of dissolved and suspended solids.

Table 2. Major fractions of nutrients and solids over time (2014) in the Muskrat Lake watershed, Canada. Concentrations averaged from 27 sites (± standard deviation) are shown with the range in brackets.

Time	Nitrate (µg/L)	Total nitrogen (µg/L)	Reactive phosphorus (µg/L)	Total phosphorus (µg/L)	TN:TP	Suspended solids (mg/L)
Overall	**795± 1307** (20−**7860**)	**1406± 1545** (230−**8220**)	**25± 40** (1−**282**)	**43± 121** (5−**1580**)	61± 75 (N) (2−720)	**7.4± 10.6** (0.5−**104.0**)
April	**1267± 1724** (20−**6710**)	**1800± 2008** (270−**7700**)	**13± 11** (2−**56**)	**31± 17** (11−**93**)	60± 67 (N) (13−280)	**8.1± 8.4** (0.5−**26.2**)
May	**790± 1399** (38−**6790**)	**1351± 1590** (320−**7770**)	**12± 28** (1−**121**)	23± **32** (5−**151**)	92± 83 (N) (5−310)	**4.4**± 3.6 (1.0−**14.5**)
June	**889± 1644** (20−**7860**)	**1290± 1674** (230−**8190**)	**22± 43** (1−**209**)	**36± 66** (5−**340**)	62± 49 (N) (2−195)	**7.0± 7.0** (0.5−**27.8**)
July	**684± 1331** (21−**6930**)	**1643± 1565** (380−**8220**)	**31± 57** (1−**282**)	**100± 299** (5−**1580**)	82± 139 (N) (2−720)	**8.1± 12.0** (0.5−**62.6**)
August	**362± 440** (20−**1510**)	945± 450 (440−**1980**)	**45± 50** (4−**160**)	**44± 46** (11−**176**)	34± 22 (N) (4−99)	**6.3± 4.9** (0.9−**19.2**)
September	**680± 858** (30−**3060**	**1151± 1003** (250−**3390**)	**35± 49** (1−**203**)	**46± 51** (8−**216**)	33± 21 (N) (5−101)	**8.5± 9.2** (0.5−**40.2**)
October	**837± 1168** (20−**5410**)	**1346± 1306** (280−**5990**)	**19± 17** (5−**80**)	22± 15 (9−**75**)	62± 49 (N) (13−202)	**9.7± 19.9** (0.7−**104.0**)

Blue bold values exceed stream background concentrations for nitrate (240 µg/L) and reactive phosphorus (10 µg/L) (Dubrovsky et al., 2010).
Red bold values exceed thresholds for impairment of streams for total nitrogen (1100 µg/L) and total phosphorus (30 µg/L) for the Mixedwood Plains of Ontario (Chambers et al., 2012). The Ontario Provincial Water Quality Objective for total phosphorus in lakes is 20 µg/L (Ontario Ministry of the Environment and Climate Change, 1994).
Total nitrogen: Total phosphorus (TN: TP) averages followed by (N) are nitrogen enriched and those followed by (P) are phosphorus enriched
Purple bold values exceed the ideal performance standard (4.1 mg/L) for the Mixedwood Plains of Ontario (Culp et al., 2009).

Table 3. Major fractions of nutrients and solids at 27 sites in the Muskrat Lake watershed, Canada. Concentrations averaged from samples collected monthly from April to October 2014 (± standard deviation) are shown with the range in brackets and are followed by the percentage of samples exceeding guideline concentrations[a].

Sub-watershed	Tributary	Site[b]	Nitrate (µg/L)	Total nitrogen (µg/L)	Reactive phosphorus (µg/L)	Total phosphorus (µg/L)	TN:TP	Suspended solids (mg/L)
Muskrat	Buttermilk Creek	BC-01	141± 135 (35−**438**) 14 %	559± 218 (370−930) 0 %	**23± 10** (**15−42**) 100 %	**34± 9** (20−**45**) 71 %	17± 4 (12−24) N	3.6± 2.4 (1.0−**6.8**) 43 %
	Cobden Wetland	MKR-03	51± 18 (31−70) 0 %	477± 159 (280−710) 0 %	**62± 46** (9−**109**) 83 %	**70± 51** (20−**135**) 67 %	10± 7 (3−22) **P**	0.9± 0.4 (0.5−1.3) 0 %
	Harlow Trail Creek	HT-01	169± 199 (20−**610**) 14 %	476± 224 (250−940) 0 %	10± 4 (4−**15**) 71 %	24± 9 (14−**40**) 14 %	20± 7 (10−31) N	**27.6± 35.7** (**4.6−104.0**) 100 %
	Muskrat River	PH-01	109± 63 (44−231) 0 %	616± 116 (440−790) 0 %	3± 2 (1−7) 0 %	13± 3 (9−18) 0 %	49± 10 (40−68) N	2.2± 1.3 (1.0−**4.4**) 14 %
	Muskrat River	OS-01	38± 17 (20−61) 0 %	380± 44 (340−440) 0 %	3± 2 (1−6) 0 %	13± 6 (6−24) 0 %	36± 19 (15−73) N	1.2± 0.7 (0.5−2.4) 0 %
	Muskrat River	MKR-01	83± 83 (33−**242**) 14 %	510± 117 (310−710) 0 %	**15± 6** (5−**25**) 86 %	26± 11 (15−**46**) 14 %	23± 13 (11−47) N	3.2± 1.0 (2.0−**5.4**) 14 %
	Muskrat River	MKR-02	214± 197 (83−**598**) 33 %	675± 197 (490−1010) 0 %	7± 7 (2−**18**) 33 %	15± 6 (10−**26**) 0 %	47± 9 (37−59) N	3.3± **4.5** (0.9−**12.5**) 17 %

Sub-watershed	Tributary	Site[b]	Nitrate (µg/L)	Total nitrogen (µg/L)	Reactive phosphorus (µg/L)	Total phosphorus (µg/L)	TN:TP	Suspended solids (mg/L)
	Black Creek	BLC-01	50± 30 (20−102) 0 %	849± 910 (410−**2900**) 14 %	3± 2 (1−6) 0 %	14± 5 (7−20) 0 %	58± 40 (29−145) N	2.9± 2.4 (0.9−**7.8**) 29 %
	Upper Harris Drain	HC-01	**2373± 1365** **(1040−5000)** 100 %	**3019± 1615** (**1520−6350**) 100 %	**45± 42** (3−**130**) 86 %	**44**± 28 (10−**93**) 57 %	105± 99 (25−310) N	**10.3± 9.2** (1.5−**26.0**) 71 %
	Upper Harris Drain	HC-02	**1053± 1073** (34−**3050**) 57 %	**2001± 1001** (1020−**3940**) 71 %	**37± 53** (3−**152**) 57 %	**51± 36** (17−**116**) 57 %	72± 64 (14−164) N	**5.9± 9.8** (1.3−**27.9**) 29 %
	Upper Harris Drain	HC-03	**2086± 1187** (102−**3840**) 86 %	**2993± 1282** (950−**4930**) 86 %	**35± 31** (4−**89**) 86 %	**70± 58** (14−**180**) 86 %	91± 90 (9−264) N	**7.6± 7.4** (1.8−**23.3**) 43 %
Snake	Mink Creek	MC-03	62± 33 (20−118) 0 %	671± 409 (420−**1530**) 14 %	6± 8 (1−**22**) 14 %	8± 3 (5−12) 0 %	89± 48 (N) (41−172) N	2.9± 2.3 (1.7−**8.0**) 14 %
	Mink Creek	MC-02	**509± 440** (84−**1220**) 67 %	870± 467 (530−**1800**) 17 %	**13± 18** (1−**47**) 33 %	16± 11 (8−**37**) 17 %	65± 29 (30−101) N	**5.6**± 3.8 (3.1−**13.2**) 50 %
	Mink Creek	MC-01	**1156± 417** (**680−1760**) 100 %	**1790± 527** (**1230−2750**) 100 %	**16± 18** (1−**50**) 43 %	20± 15 (7−**52**) 14 %	116± 59 (53−234) N	**8.2± 6.9** (3.4−**21.7**) 71 %
	Mink Creek	MC-04	**1236± 363** (**862−1870**) 100 %	**1826± 481** (**1380−2710**) 100 %	**15± 13** (4−**36**) 57 %	24± 17 (11−**54**) 29 %	103± 55 (40−202) N	**7.6± 3.1** (**5.2−14.4**) 100 %

Sub-watershed	Tributary	Site[b]	Nitrate (µg/L)	Total nitrogen (µg/L)	Reactive phosphorus (µg/L)	Total phosphorus (µg/L)	TN:TP	Suspended solids (mg/L)
Snake	North Tributary	NT-01	**2002± 1173** (163−**4040**) 86 %	**3069± 1280** (960−**5320**) 86 %	10± 5 (4−**17**) 43 %	**40± 44** (18−**140**) 29 %	130± 91 (19−280) N	**14.7± 21.8** (0.5−**62.6**) 71 %
	O'Gorman Agnew Drain	OAD-01	**5374± 2520** (**861−7860**) 100 %	**6099± 2689** (**1430−8220**) 100 %	**69± 55** (**21−160**) 100 %	**74± 57** (27−**176**) 86 %	145± 104 (8−288) N	**6.2**± 3.6 (1.3−**11.8**) 71 %
	Stoqua Creek	SC-01	**940± 561** (20−**1900**) 86 %	**1544± 539** (740−**2500**) 86 %	**75± 71** (7−**203**) 86 %	**82± 78** (17−**216**) 71 %	37± 26 (4−75) N	**6.0± 8.9** (1.0−**25.5**) 29 %
	Snake River	SNR-01	42± 24 (20−76) 0 %	377± 172 (230−690) 0 %	4± 3 (1−9) 0 %	14± 6 (6−25) 0 %	28± 8 (18−38) N	2.0± 0.7 (0.9−3.3) 0 %
	Snake River	SNR-02	136± 93 (20−**306**) 14 %	469± 232 (300−930) 0 %	10± 10 (3−**31**) 29 %	13± 4 (9−19) 0 %	39± 29 (23−103) N	**4.6**± 2.1 (2.8−**7.8**) 43 %
	Snake River	SNR-05	91± 73 (20−**248**) 14 %	419± 152 (250−680) 0 %	10± 6 (4−**21**) 43 %	19± 7 (11−29) 0 %	22± 5 (13−28) N	**10.2± 5.8** (**5.0−19.6**) 100 %
	Snake River	SNR-06	**551± 216** (**305−796**) 100 %	959± 302 (640−**1350**) 43 %	**11± 4** (4−**18**) 57 %	21± 7 (9−28) 0 %	49± 13 (29−71) N	**10.5± 5.0** (**6.3−20.3**) 100 %
	Snake River	SKR-07	**607± 200** (**355−857**) 100 %	1019± 283 (700−**1380**) 43 %	**13± 6** (4−**25**) 71 %	23± 10 (10−**34**) 29 %	50± 14 (28−70) N	**13.5± 6.0** (**8.1−24.8**) 100 %

Sub-watershed	Tributary	Site[b]	Nitrate (μg/L)	Total nitrogen (μg/L)	Reactive phosphorus (μg/L)	Total phosphorus (μg/L)	TN:TP	Suspended solids (mg/L)
Snake	Snake River	SNR-08	**646± 169** (**421−876**) 100 %	**1103± 213** (790−**1410**) 57 %	**15± 8** (3−**27**) 71 %	29± 12 (12−**49**) 29 %	45± 21 (23−85) N	**14.7± 5.5** (**8.9−26.2**) 100 %
	Snake River	SNR-03	**683± 171** (**444−892**) 100 %	**1496± 966** (800−**3600**) 57 %	**15± 7** (6−**26**) 71 %	26± 15 (5−**51**) 43 %	142± 256 (20−720) N	**15.7± 7.0** (**7.2−27.8**) 100 %
	Snake River	SNR-04	**322± 278** (110−**934**) 43 %	903± 323 (570−**1440**) 29 %	**24± 21** (6−**69**) 71 %	**33± 16** (17−**65**) 43 %	30± 17 (14−55) N	4.0± 4.0 (0.8−**11.9**) 29 %
	Unnamed Creek	SC-02	**449± 613** (40−**1250**) 33 %	**1438± 783** (780−**2650**) 50 %	**143± 91** (**29−282**) 100 %	**393± 591** (**42−1580**) 100 %	13± 17 (2−42) **P**	3.6± 3.5 (0.7−**8.4**) 33 %

[a]**Blue bold** values exceed stream background concentrations for nitrate (240 μg/L) and reactive phosphorus (10 μg/L) (Dubrovsky et al., 2010).
Red bold values exceed thresholds for impairment of streams for total nitrogen (1100 μg/L) and total phosphorus (30 μg/L) for the Mixedwood Plains of Ontario (Chambers et al., 2012). The Ontario Provincial Water Quality Objective for total phosphorus in lakes is 20 μg/L (Ontario Ministry of the Environment and Climate Change, 1994).
Total nitrogen: Total phosphorus (TN: TP) averages followed by (N) are nitrogen enriched and those followed by (P) are phosphorus enriched
Purple bold values exceed the ideal performance standard (4.1 mg/L) for the Mixedwood Plains of Ontario (Culp et al., 2009).
[b]Multiple sites located along the same tributary are ordered from upstream to downstream.

Table 4. Summary of field sites, their status, level of nutrient enrichment and importance to sampling in 2015

Watershed	Tributary	Site	Status (new for 2014 or existing)	Level of Impact	Importance to sampling	Recommendation	Rationale
Muskrat	Buttermilk Creek	BC-01	New	Moderate	Moderate	Keep	Only site on this trib.
	Cobden Wetland	MKR-03	New	High Phosphorus	High	Keep	High phosphorus, likely from a point source. This wetland warrants further study to assess the impact of the sewage treatment plant on export of phosphorus to Muskrat Lake.
	Harlow Trail Creek	HT-01	New	Moderate	Moderate	Discard	This site has low discharge and is only moderately impacted by nutrients.
	Muskrat River	PH-01	New	Low	High	Keep	Most upstream site.
	Muskrat River	OS-01	New	Low	Low	Keep	This site reflects important land use changes from PH-01 (e.g. increased development and agriculture)
	Muskrat River	MKR-01	Existing	Moderate	High	Keep	Existing site.
	Muskrat River	MKR-02	New	Moderate	High	Keep	Most downstream site.
Snake	Black Creek	BLC-01	New	Low	High	Keep	Reference site.

Watershed	**Tributary**	**Site**	**Status (new for 2014 or existing)**	**Level of Impact**	**Importance to sampling**	**Recommendation**	**Rationale**
Snake	Upper Harris Drain	HC-01	New	High	High	Keep	Highly impacted, most upstream site.
	Upper Harris Drain	HC-02	New	High	Low	Discard	There are sites located both upstream and downstream of this site.
	Upper Harris Drain	HC-03	New	High	High	Keep	Highly impacted, most downstream site.
	Mink Creek	MC-03	Existing	Moderate	High	Keep	Existing site, most upstream site.
	Mink Creek	MC-02	Existing	Moderate	High	Keep	Existing site.
	Mink Creek	MC-01	Existing	High	High	Keep	Existing site.
	Mink Creek	MC-04	New	High	High	Keep	Most downstream site.
	North Tributary	NT-01	New	High	High	Keep	Highly impacted, only site on this trib.
	O'Gorman Agnew Drain	OAD-01	New	High	High	Keep	Highly impacted, only site on this trib.
	Stoqua Creek	SC-01	Existing	High	High	Keep	Existing, highly impacted, only site on this trib.

Watershed	**Tributary**	**Site**	**Status (new for 2014 or existing)**	**Level of Impact**	**Importance to sampling**	**Recommendation**	**Rationale**
Snake	Snake River	SNR-01	Existing	Low	High	Keep	Existing, most upstream site.
	Snake River	SNR-02	Existing	Moderate	High	Keep	Existing site.
	Snake River	SNR-05	New	Moderate	Low	Discard	There are sites both upstream and downstream of this site. Only moderately impacted. Access is difficult.
	Snake River	SNR-06	New	High	Low	Keep	This site reflects upstream to downstream changes along the Snake River.
	Snake River	SNR-07	New	High	Low	Discard	There are sites upstream and downstream of this one.
	Snake River	SNR-08	New	High	Low	Keep	This site reflects upstream to downstream changes along the Snake River.
	Snake River	SNR-03	Existing	High	High	Keep	Existing, highly impacted site.
	Snake River	SNR-04	Existing	High	High	Keep	Existing, highly impacted, most downstream site.
	Unnamed Creek	SC-02	Existing	High	High	Keep	Existing, highly impacted, only site on this trib.

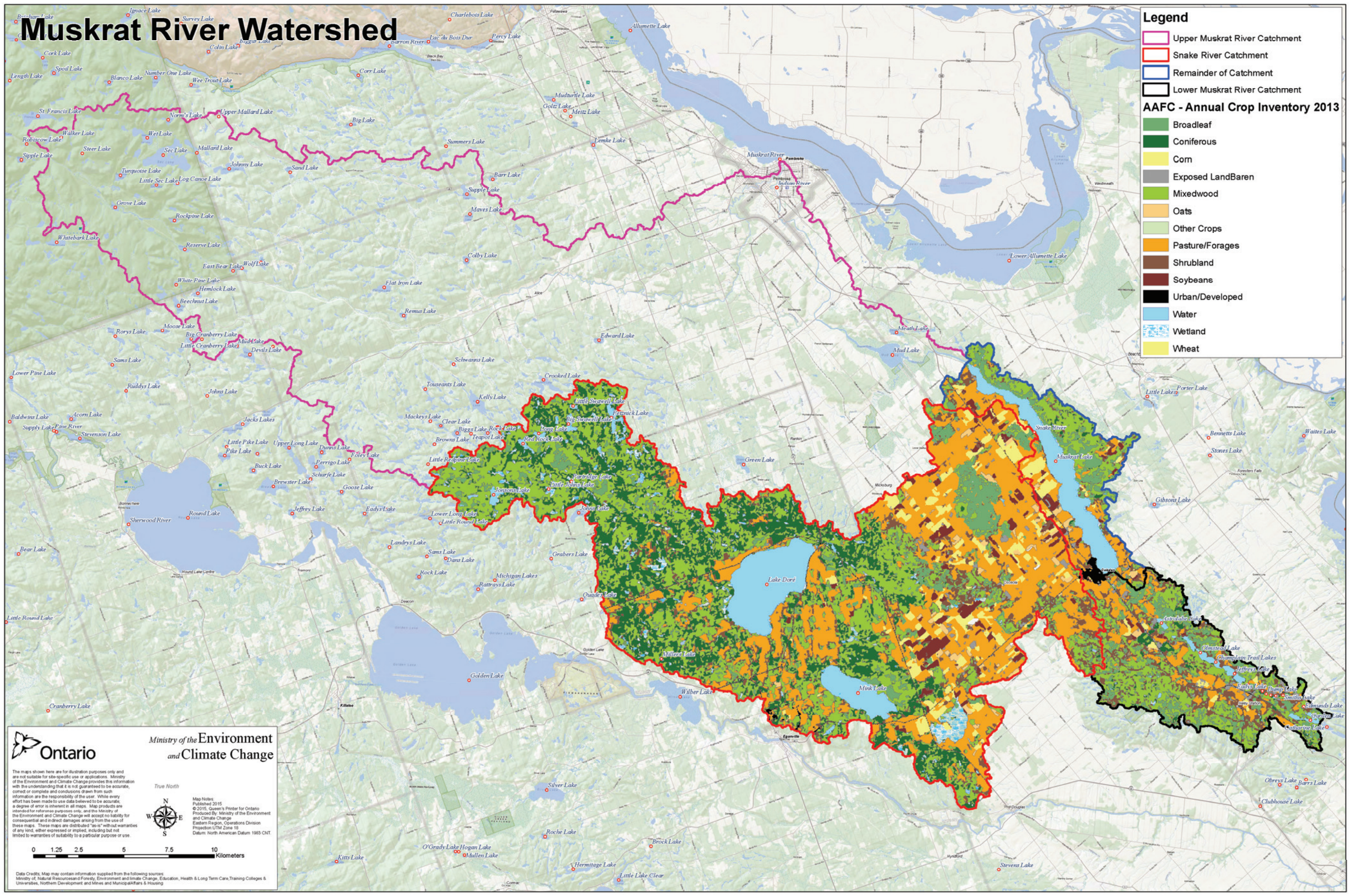


Fig. 1 Map of the Muskrat Lake watershed, within the Muskrat River watershed (Ontario Ministry of the Environment and Climate Change, 2015)

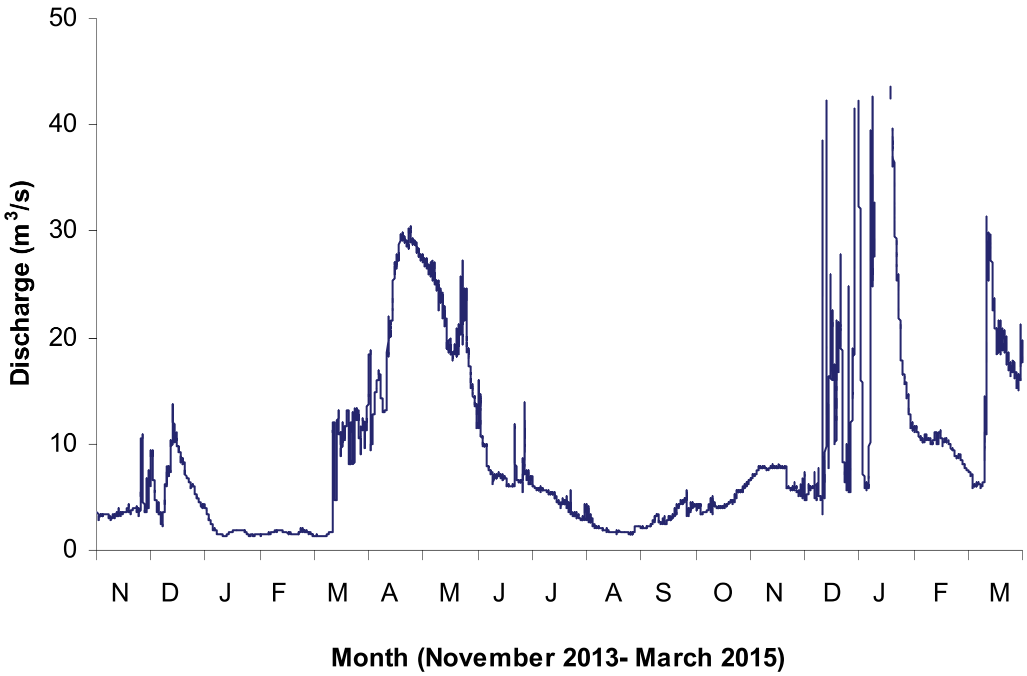


Fig. 2 Daily discharge in Muskrat River near Pembroke (Station 02KC015) from November 2013- March 2015 (Environment Canada, 2015).

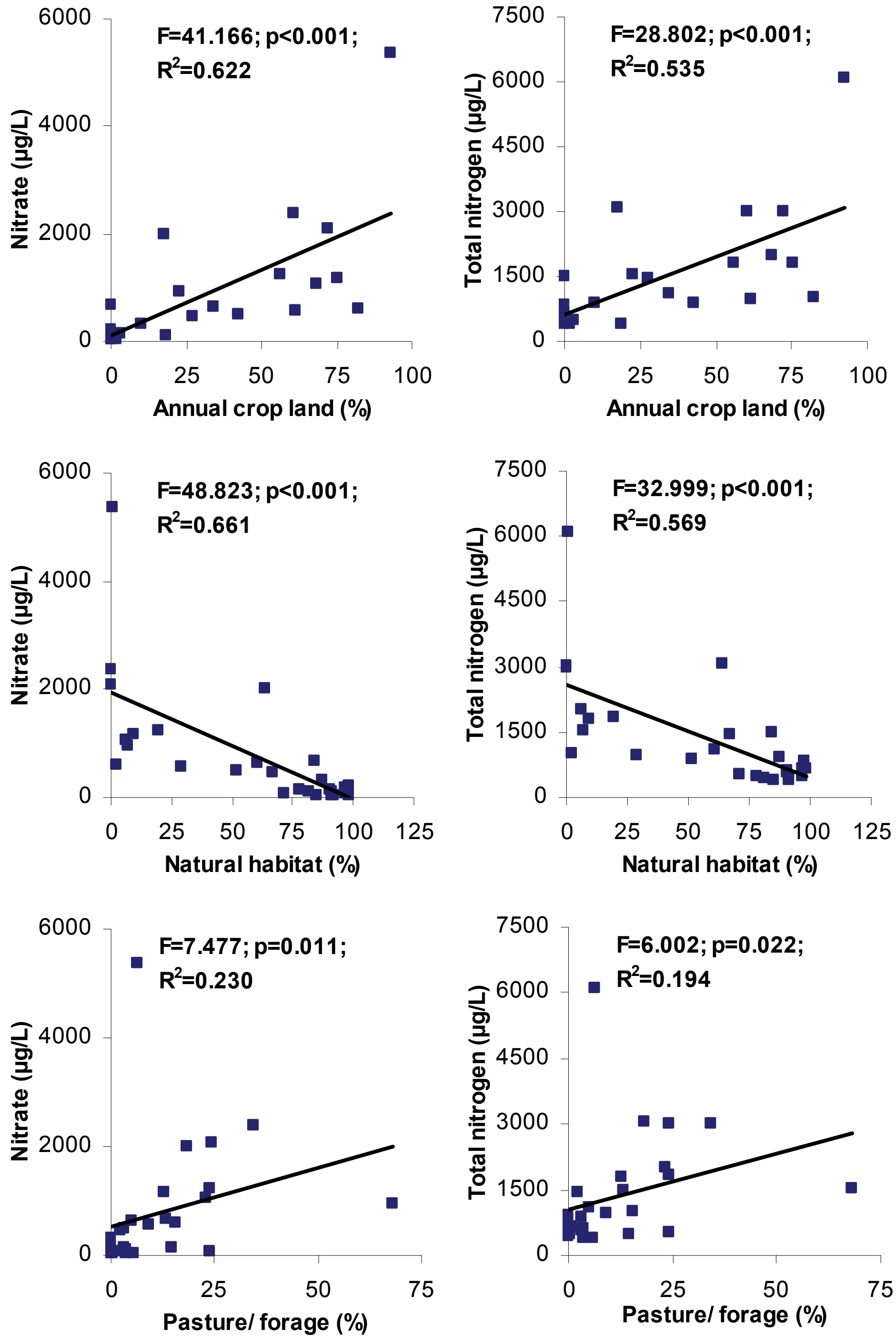


Fig. 3 Relationship between nitrate and total nitrogen concentrations and the dominant land uses 1 km upstream of 27 sites located in the Muskrat Lake watershed, Canada. Significant ($p \leq 0.05$; solid lines) linear regressions are shown.

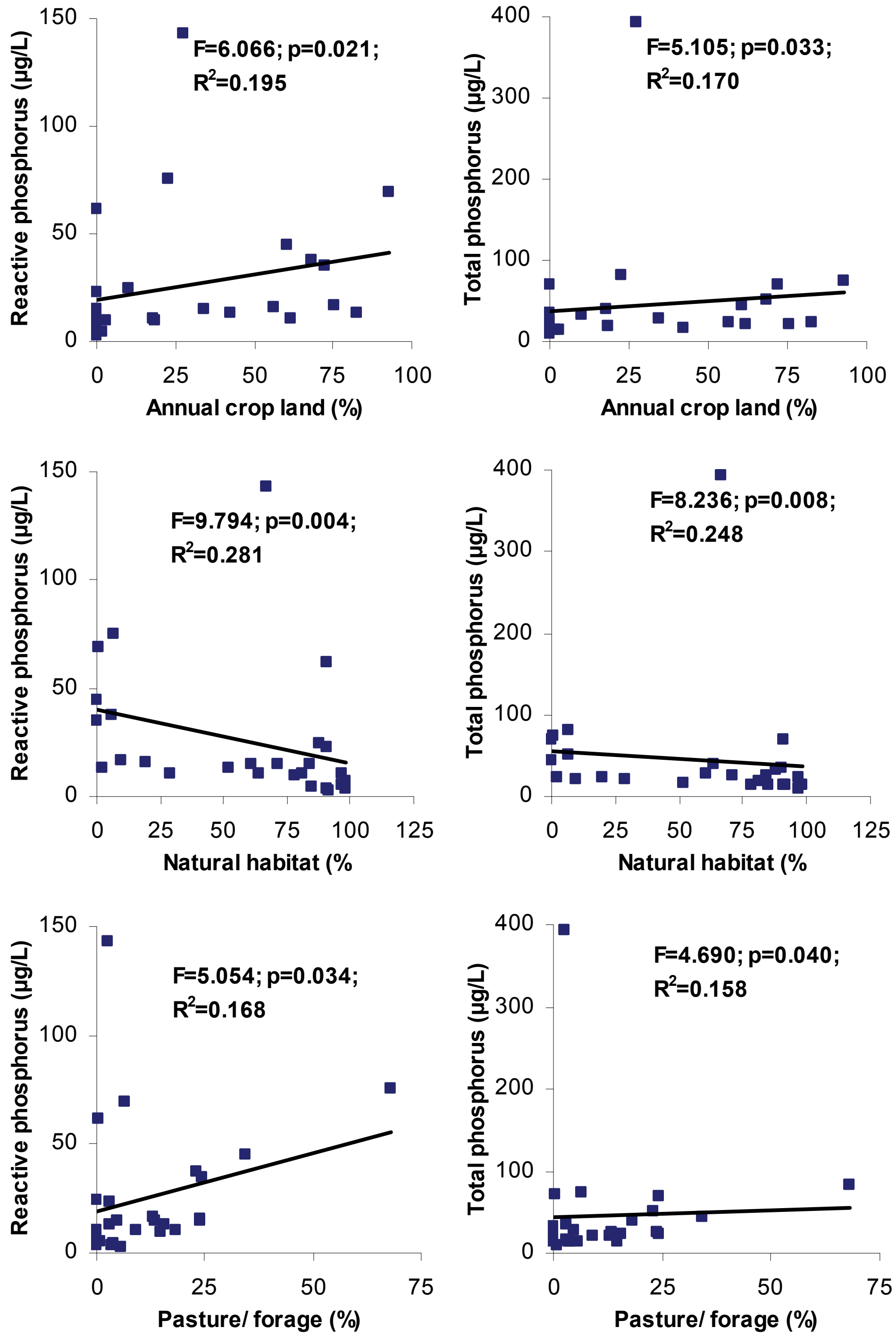


Fig. 4 Relationship between reactive phosphorus and total phosphorus concentrations and the dominant land uses 1 km upstream of 27 sites located in the Muskrat Lake watershed, Canada. Significant ($p \leq 0.05$; solid lines) linear regressions are shown.

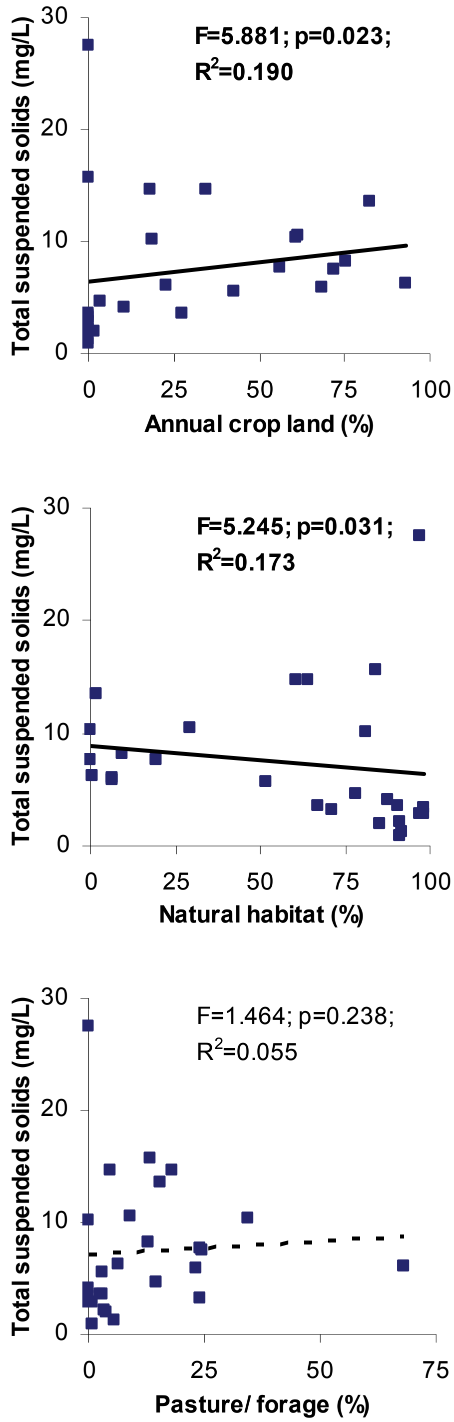


Fig. 5 Relationship between total suspended sediment concentrations and the dominant land uses 1 km upstream of 27 sites located in the Muskrat Lake watershed, Canada. Significant ($p \leq 0.05$; solid lines) and insignificant ($p > 0.05$; dashed line) linear regressions are shown.

Appendix A

Table A1. 2014 Muskrat Lake watershed monitoring network field sites

Watershed	Tributary	Site code	Status (new for 2014 or existing)	Easting	Northing
Muskrat	Buttermilk Creek	BC-01	New	354318	5053859
	Cobden Wetland	MKR-03	New	354082	5054143
	Harlow Trail Creek	HT-01	New	352460	5059310
	Muskrat River	PH-01	New	362174	5047911
	Muskrat River	OS-01	New	357146	5049780
	Muskrat River	MKR-01	Existing	354178	5053726
	Muskrat River	MKR-02	New	344384	5066594
Snake	Black Creek	BLC-01	New	326225	5060307
	Upper Harris Drain	HC-01	New	348562	5050762
	Upper Harris Drain	HC-02	New	346825	5051849
	Upper Harris Drain	HC-03	New	346272	5052530
	Mink Creek	MC-03	Existing	343662	5047089
	Mink Creek	MC-02	Existing	345399	5047908
	Mink Creek	MC-01	Existing	344283	5050769
	Mink Creek	MC-04	New	344915	5052044
	North Tributary	NT-01	New	345750	5052142
	O'Gorman Agnew Drain	OAD-01	New	345540	5051983
	Stoqua Creek	SC-01	Existing	345174	5058263
	Snake River	SNR-01	Existing	338075	5056042
	Snake River	SNR-02	Existing	343937	5052457
	Snake River	SNR-05	New	344923	5052079
	Snake River	SNR-06	New	345506	5052002

Watershed	Tributary	Site code	Status (new for 2014 or existing)	Easting	Northing
Snake	Snake River	SNR-07	New	346223	5052512
	Snake River	SNR-08	New	347207	5052680
	Snake River	SNR-03	Existing	347843	5055143
	Snake River	SNR-04	Existing	346660	5060866
	Unnamed Creek	SC-02	Existing	348236	5058893

Appendix B

Table B1. List of parameters measured in 2014 water samples

Category	Parameter	MOECC method	Method detection limit (MDL)
Category	Alkalinity	PHALCO3218	2.5 mg/L CaCO3
	Carbon; dissolved inorganic	DCSI3370	1 mg/L
	Carbon; dissolved organic	DCSI3370	0.5 mg/L
	Conductivity	PHALCO3218	5 µS/cm
	pH	PHALCO3218	none listed
	Solids; dissolved	TSD3188	50 mg/L
	Solids; suspended	TSD3188	2.5 mg/L
	Solids; total	TSD3188	50 mg/L
Major Nutrient Fractions	Nitrogen; ammonia + ammonium	DISNUT3364	0.01 mg/L
	Nitrogen; nitrate + nitrite	DISNUT3364	0.025 mg/L
	Nitrogen; nitrite	DISNUT3364	0.005 mg/L
	Nitrogen; total	TOTNUT3516	0.05 mg/L
	Nitrogen; total Kjeldahl	TOTNUT3516	0.05 mg/L
	Phosphorus; phosphorus	DISNUT3364	0.0025 mg/L
	Phosphorus; total	TOTNUT3516	0.005 mg/L
Metals	Aluminum	MET3497	2 µg/L
	Barium	MET3497	0.1 µg/L
	Beryllium	MET3497	0.1 µg/L
	Bismuth	MET3497	5 µg/L
	Cadmium	MET3497	0.8 µg/L
	Calcium	MET3497	0.05 mg/L
	Chromium	MET3497	1 µg/L
	Cobalt	MET3497	1 µg/L
	Copper	MET3497	0.5 µg/L
	Hardness	MET3497	1 mg/L
	Iron	MET3497	3 µg/L
	Lead	MET3497	7 µg/L
	Lithium	MET3497	5 µg/L
	Magnesium	MET3497	0.01 mg/L

Category	Parameter	MOECC method	Method detection limit (MDL)
Metals	Manganese	MET3497	0.5 µg/L
	Molybdenum	MET3497	2 µg/L
	Nickel	MET3497	2 µg/L
	Potassium	MET3497	0.02 mg/L
	Silicon; reactive silicate	DCSI3370	0.1 mg/L
	Silver	MET3497	9 µg/L
	Sodium	MET3497	0.02 mg/L
	Strontium	MET3497	0.3 µg/L
	Tin	MET3497	9 µg/L
	Titanium	MET3497	0.5 µg/L
	Uranium	MET3497	3 µg/L
	Vanadium	MET3497	0.5 µg/L
	Zinc	MET3497	2 µg/L
	Zirconium	MET3497	1 µg/L

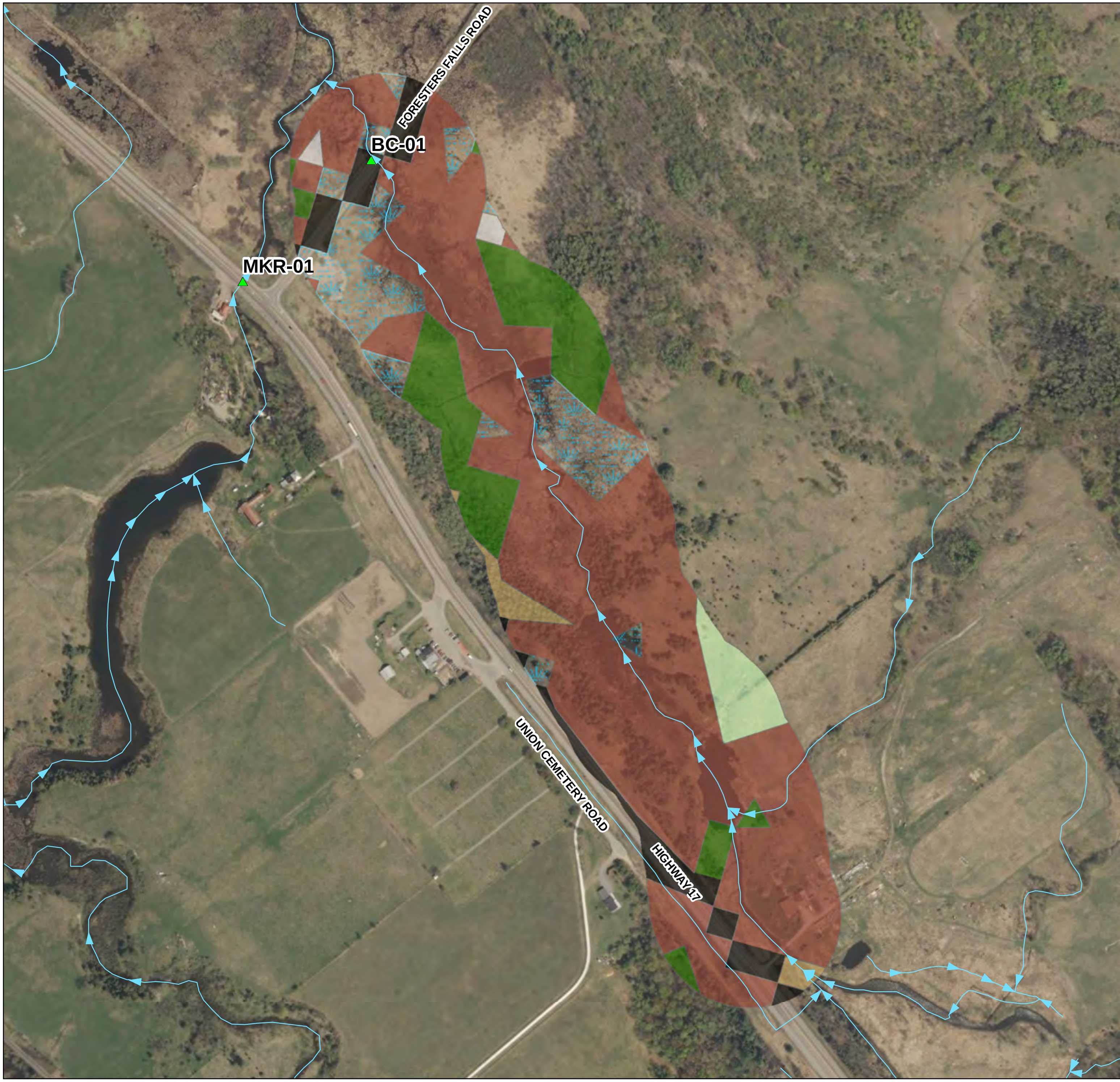
Appendix C

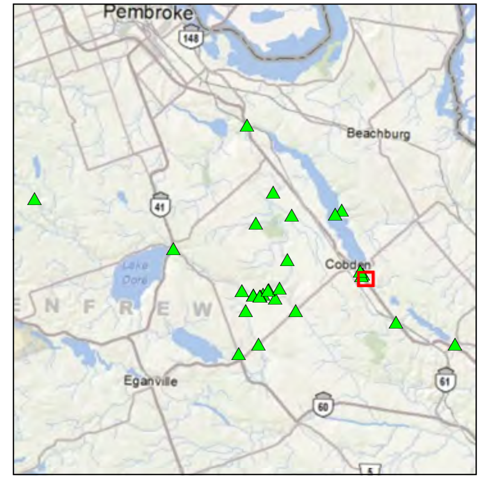
Land use 1 km upstream of 27 sites within the Muskrat Lake watershed, Canada

Ontario

Sampling Location: BC-01

Ministry of the Environment and Climate Change





Legend

SampleSites — Flow Direction

AAFC Data Categories

Label

- N/A
- Barley
- Berries
- Broadleaf
- Canola/Rapeseed
- Coniferous
- Corn
- Exposed landBaren
- Grassland
- Hemp
- Mixedwood
- Nursery
- Oats
- Other Grains
- Pasture/Forages
- Shrubland
- Soybeans
- Urban/Developed
- Water
- Wetland
- Wheat

**Note: not all AAFC classes are present at each sampling site

N W E S

0 25 50 100 150 200 Meters

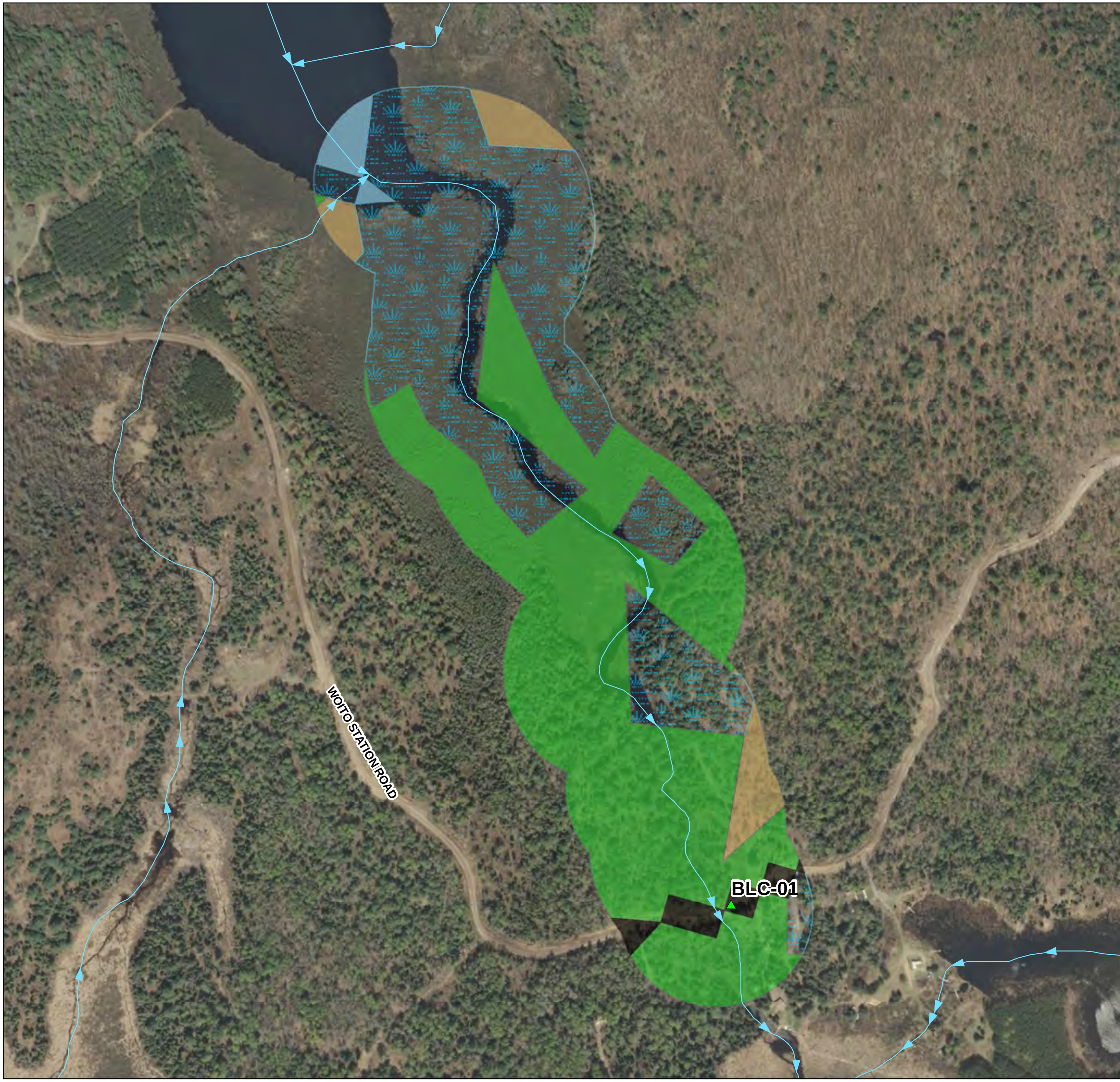
UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
Imagery Provided by Land Information Ontario

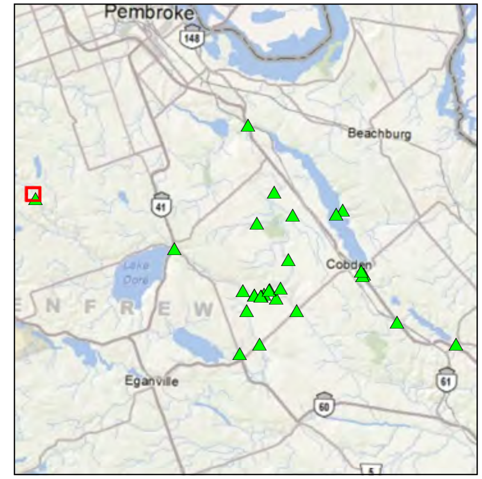
Published 2015

Ontario

Sampling Location: BLC-01

Ministry of the Environment and Climate Change





Legend

SampleSites
Flow Direction

AAFC Data Categories

Label

N/A	Mixedwood
Barley	Nursery
Berries	Oats
Broadleaf	Other Grains
Canola/Rapeseed	Pasture/Forages
Coniferous	Shrubland
Corn	Soybeans
Exposed landBaren	Urban/Developed
Grassland	Water
Hemp	Wetland
	Wheat

**Note: not all AAFC classes are present at each sampling site

N
W E
S

0 25 50 100 150 200 Meters

UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
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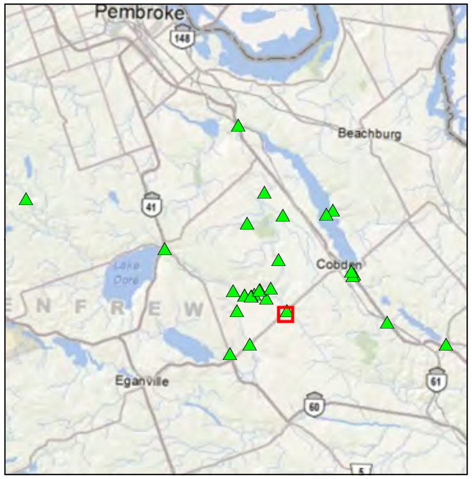
Ontario

Sampling Location: HC-01

Ministry of the Environment and Climate Change



Legend

SampleSites
Flow Direction

AAFC Data Categories

Label

- N/A
- Barley
- Berries
- Broadleaf
- Canola/Rapeseed
- Coniferous
- Corn
- Exposed landBaren
- Grassland
- Hemp
- Mixedwood
- Nursery
- Oats
- Other Grains
- Pasture/Forages
- Shrubland
- Soybeans
- Urban/Developed
- Water
- Wetland
- Wheat

**Note: not all AAFC classes are present at each sampling site

N
W E
S

0 25 50 100 150 200 Meters

UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
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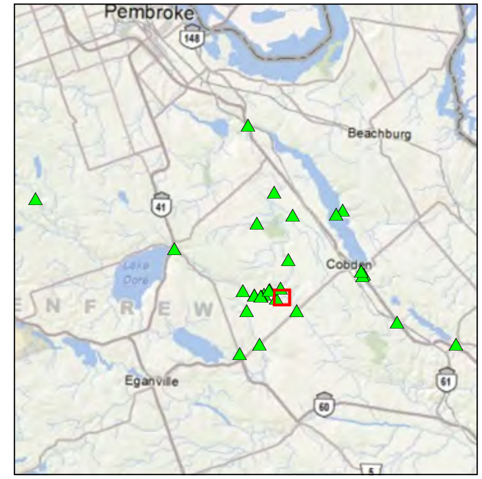
Published 2015

Sampling Location: HC-02



Legend

SampleSites
Flow Direction

AAFC Data Categories

Label

- N/A
- Barley
- Berries
- Broadleaf
- Canola/Rapeseed
- Coniferous
- Corn
- Exposed landBaren
- Grassland
- Hemp
- Mixedwood
- Nursery
- Oats
- Other Grains
- Pasture/Forages
- Shrubland
- Soybeans
- Urban/Developed
- Water
- Wetland
- Wheat

**Note: not all AAFC classes are present at each sampling site

N
W E
S

0 25 50 100 150 200 Meters

UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
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Ontario

Sampling Location: HC-03

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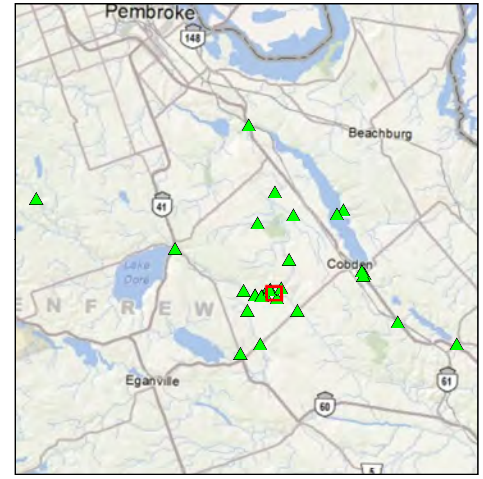
and Climate Change



Legend

- SampleSites
- Flow Direction

AAFC Data Categories

Label

N/A	Mixedwood
Barley	Nursery
Berries	Oats
Broadleaf	Other Grains
Canola/Rapeseed	Pasture/Forages
Coniferous	Shrubland
Corn	Soybeans
Exposed landBaren	Urban/Developed
Grassland	Water
Hemp	Wetland
	Wheat

**Note: not all AAFC classes are present at each sampling site

N
W E
S

0 25 50 100 150 200 Meters

UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
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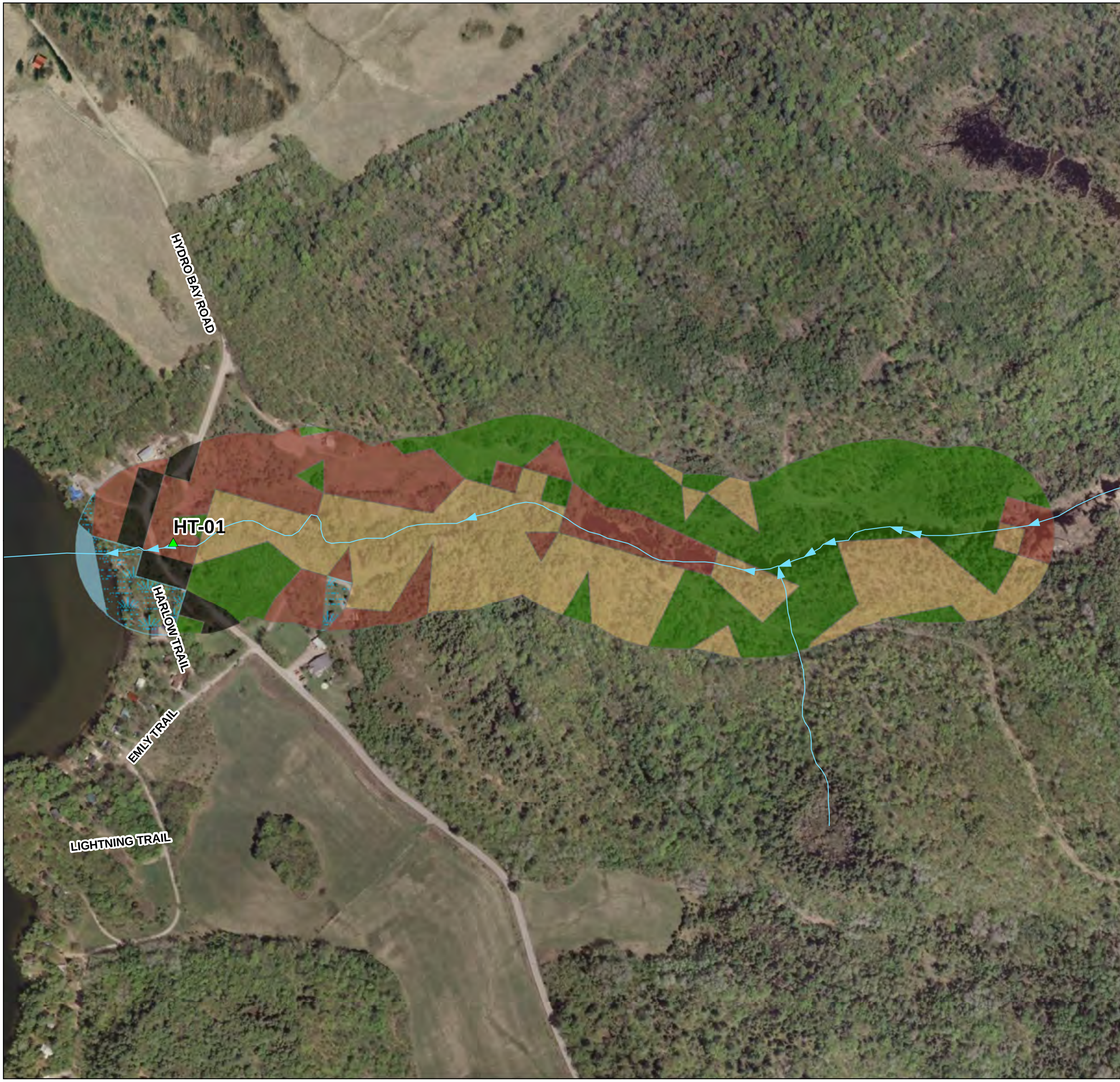
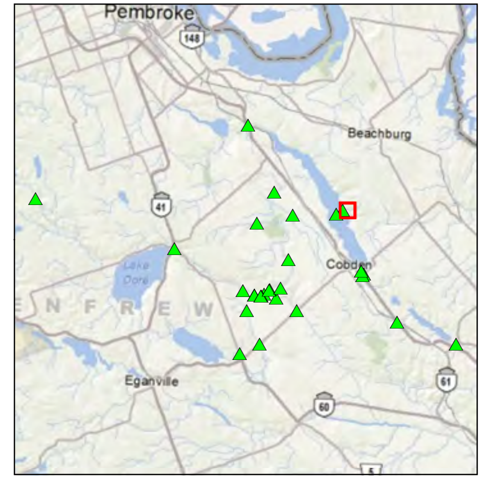
Ontario

Sampling Location: HT-01

Ministry of the Environment and Climate Change





Legend

SampleSites — Flow Direction

AAFC Data Categories

Label

N/A	Mixedwood
Barley	Nursery
Berries	Oats
Broadleaf	Other Grains
Canola/Rapeseed	Pasture/Forages
Coniferous	Shrubland
Corn	Soybeans
Exposed landBaren	Urban/Developed
Grassland	Water
Hemp	Wetland
	Wheat

**Note: not all AAFC classes are present at each sampling site

N W E S

0 25 50 100 150 200 Meters

UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
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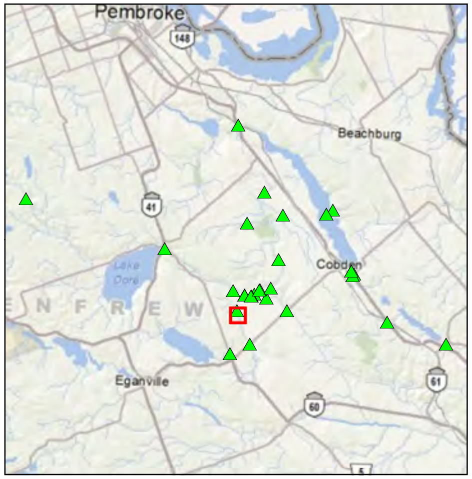
Ontario

Sampling Location: MC-01

Ministry of the Environment and Climate Change



Legend

SampleSites
Flow Direction

AAFC Data Categories

Label

N/A	Mixedwood
Barley	Nursery
Berries	Oats
Broadleaf	Other Grains
Canola/Rapeseed	Pasture/Forages
Coniferous	Shrubland
Corn	Soybeans
Exposed landBaren	Urban/Developed
Grassland	Water
Hemp	Wetland
	Wheat

**Note: not all AAFC classes are present at each sampling site

N W E S

0 25 50 100 150 200 Meters

UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
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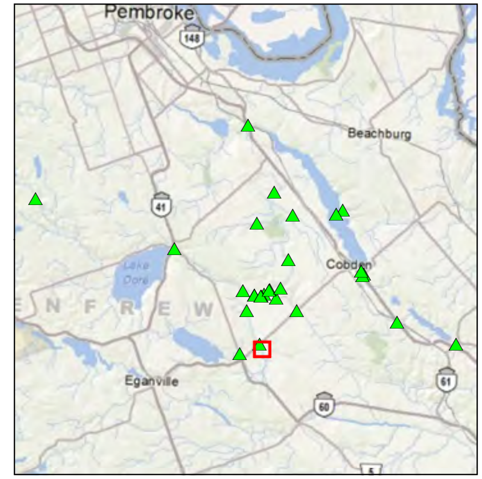
Ontario

Sampling Location: MC-02

Ministry of the Environment and Climate Change



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SampleSites
Flow Direction

AAFC Data Categories

Label

N/A	Mixedwood
Barley	Nursery
Berries	Oats
Broadleaf	Other Grains
Canola/Rapeseed	Pasture/Forages
Coniferous	Shrubland
Corn	Soybeans
Exposed landBaren	Urban/Developed
Grassland	Water
Hemp	Wetland
	Wheat

**Note: not all AAFC classes are present at each sampling site

N W E S

0 30 60 120 180 240 Meters

UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
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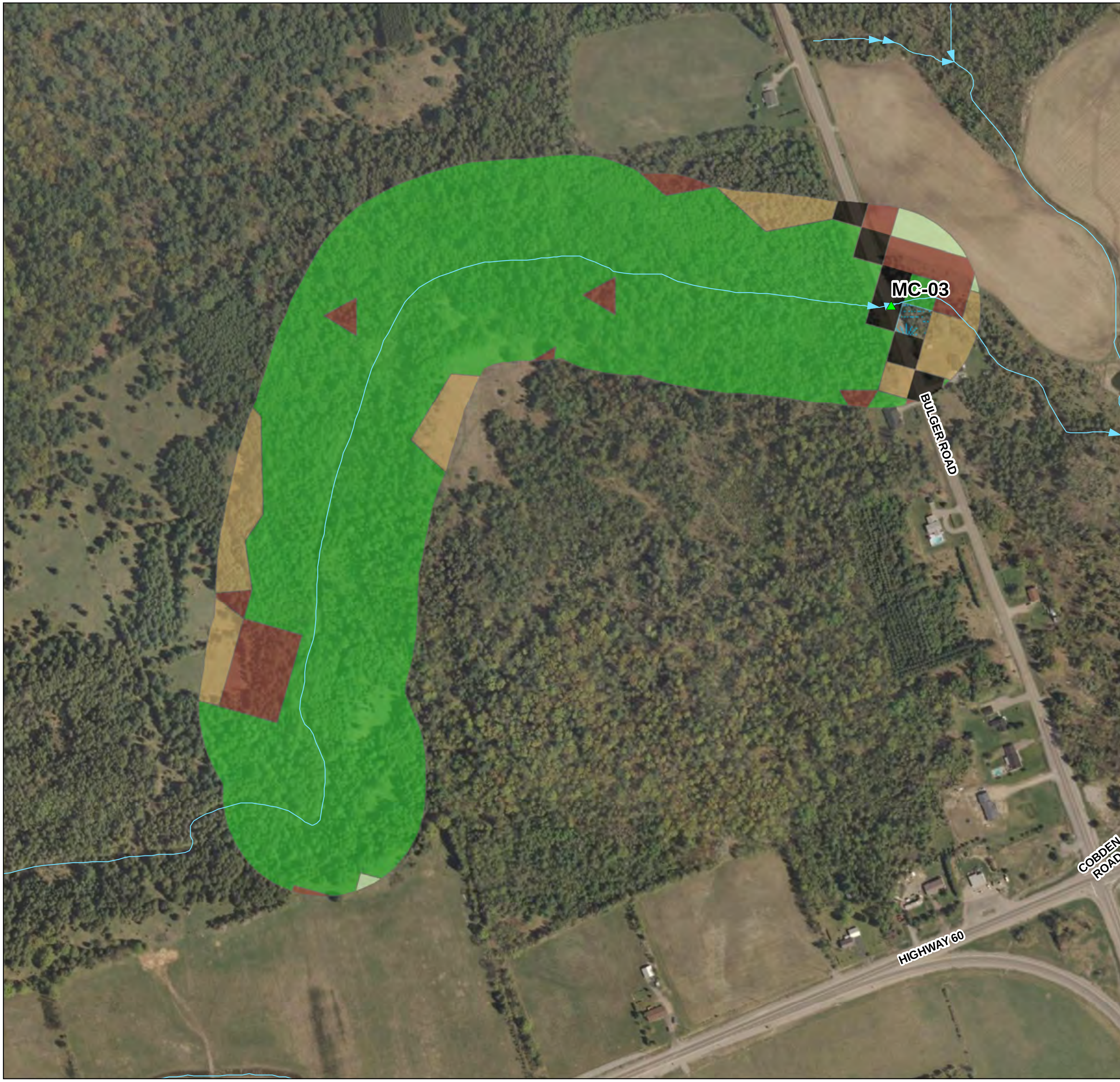
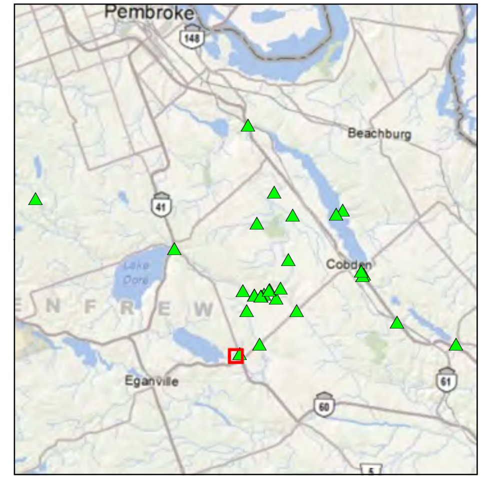
Sampling Location: MC-03

Ministry of the Environment and Climate Change





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SampleSites
Flow Direction

AAFC Data Categories

Label

N/A	Mixedwood
Barley	Nursery
Berries	Oats
Broadleaf	Other Grains
Canola/Rapeseed	Pasture/Forages
Coniferous	Shrubland
Corn	Soybeans
Exposed landBaren	Urban/Developed
Grassland	Water
Hemp	Wetland
	Wheat

**Note: not all AAFC classes are present at each sampling site

N
W E
S

0 25 50 100 150 200 Meters

UTM Zone 18 (NAD 1983)
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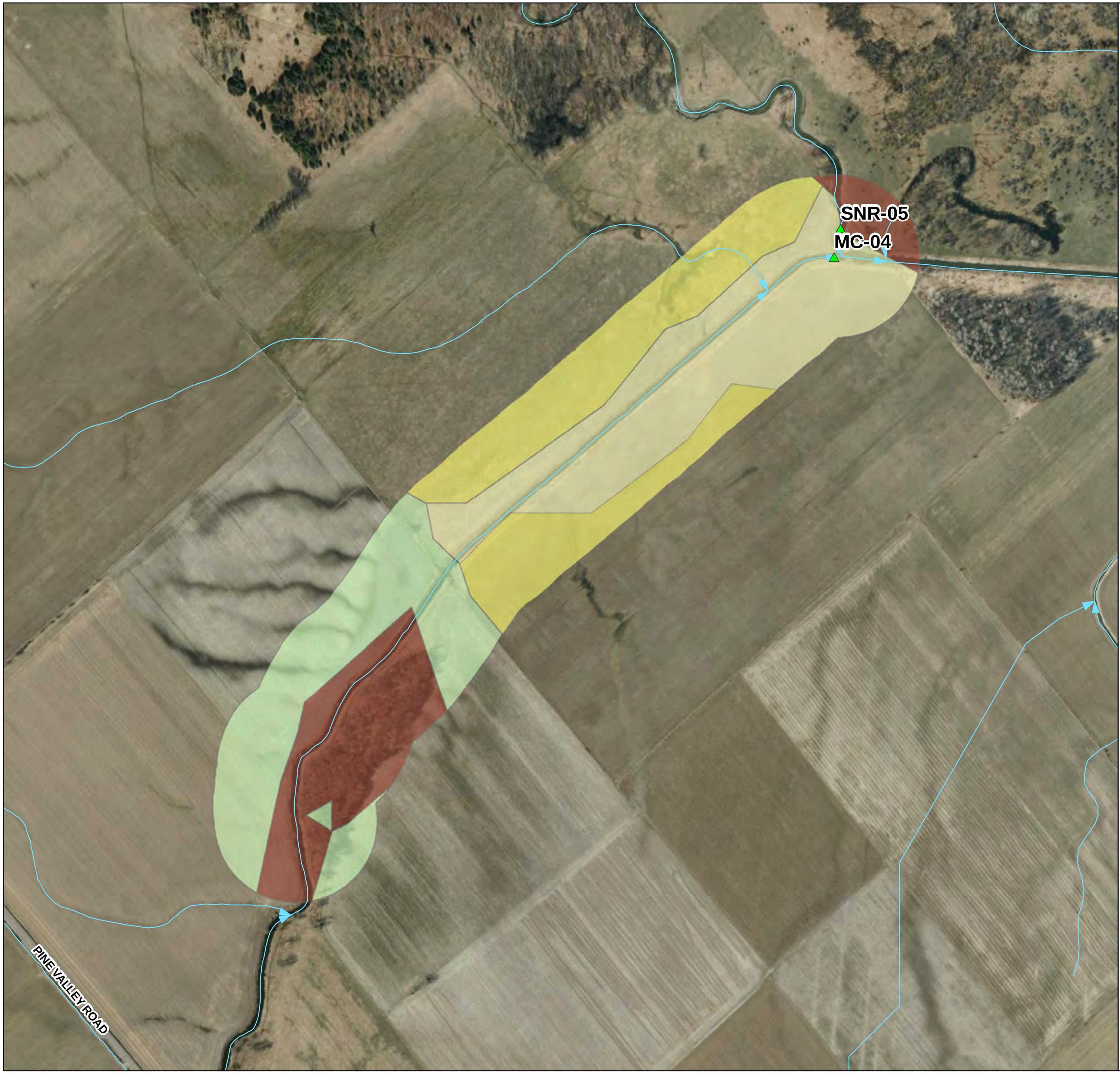
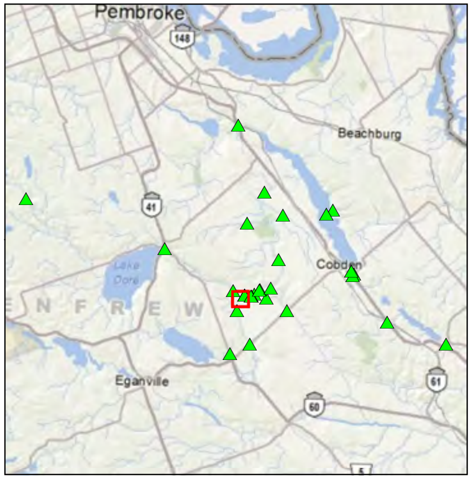
Ontario

Sampling Location: MC-04

Ministry of the Environment and Climate Change





Legend

SampleSites
Flow Direction

AAFC Data Categories

Label

N/A	Mixedwood
Barley	Nursery
Berries	Oats
Broadleaf	Other Grains
Canola/Rapeseed	Pasture/Forages
Coniferous	Shrubland
Corn	Soybeans
Exposed landBaren	Urban/Developed
Grassland	Water
Hemp	Wetland
	Wheat

**Note: not all AAFC classes are present at each sampling site

N
W E
S

0 30 60 120 180 240 Meters

UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
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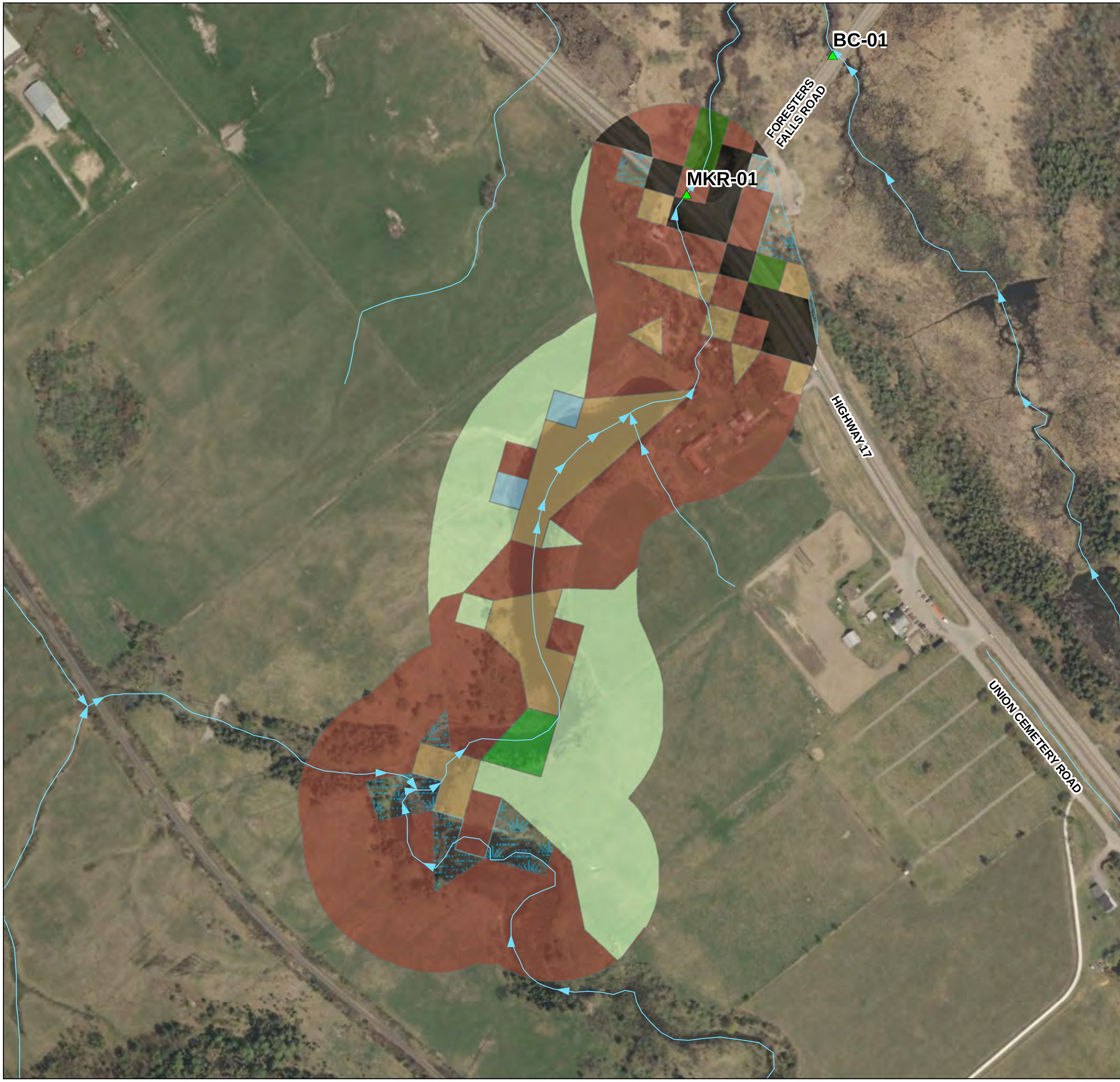
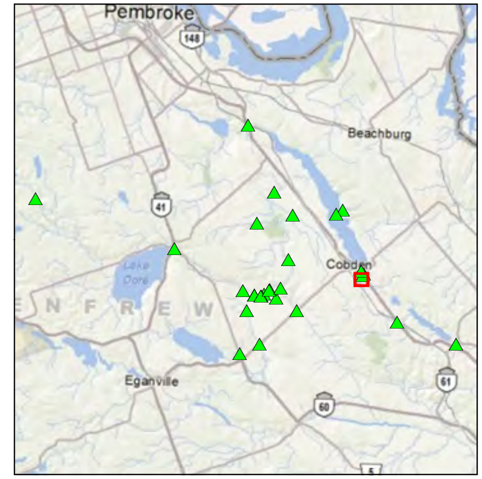
Ontario

Sampling Location: MKR-01

Ministry of the Environment and Climate Change





Legend

SampleSites
Flow Direction

AAFC Data Categories

Label

N/A	Mixedwood
Barley	Nursery
Berries	Oats
Broadleaf	Other Grains
Canola/Rapeseed	Pasture/Forages
Coniferous	Shrubland
Corn	Soybeans
Exposed landBaren	Urban/Developed
Grassland	Water
Hemp	Wetland
	Wheat

**Note: not all AAFC classes are present at each sampling site

N
W E
S

0 25 50 100 150 200 Meters

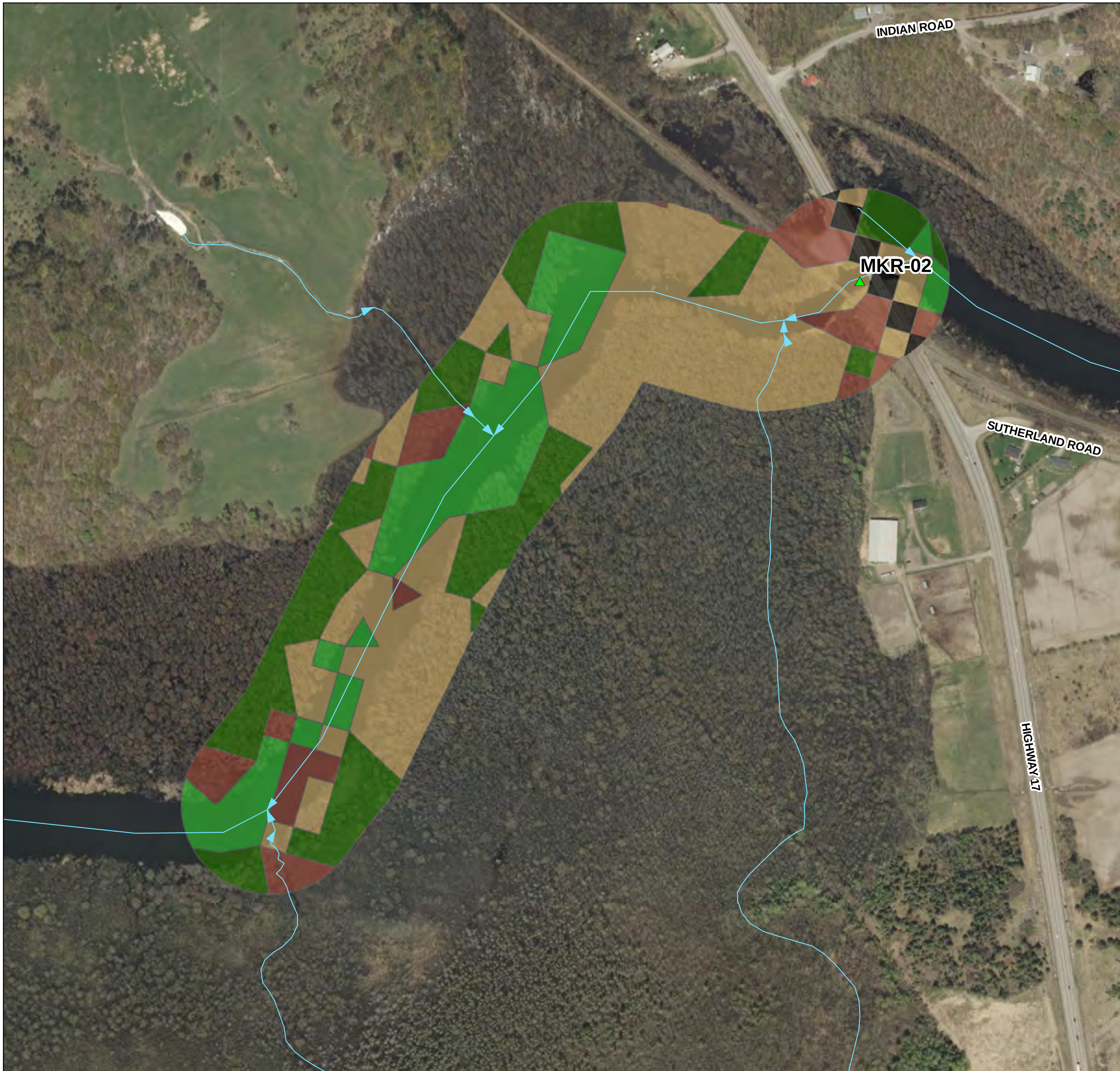
UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
Imagery Provided by Land Information Ontario

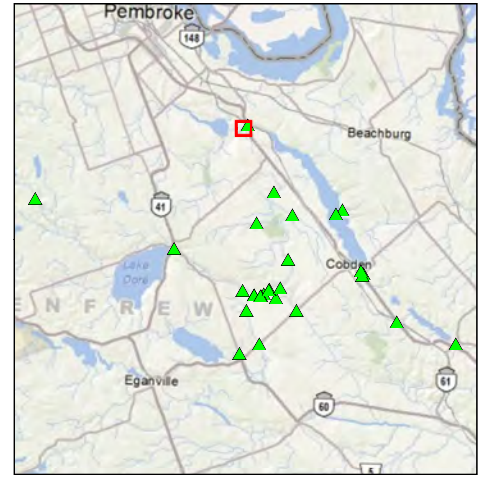
Published 2015

Ontario

Sampling Location: MKR-02

Ministry of the Environment and Climate Change





Legend

▲ SampleSites → Flow Direction

AAFC Data Categories

Label

N/A	Mixedwood
Barley	Nursery
Berries	Oats
Broadleaf	Other Grains
Canola/Rapeseed	Pasture/Forages
Coniferous	Shrubland
Corn	Soybeans
Exposed landBaren	Urban/Developed
Grassland	Water
Hemp	Wetland
	Wheat

**Note: not all AAFC classes are present at each sampling site

N W E S

0 30 60 120 180 240 Meters

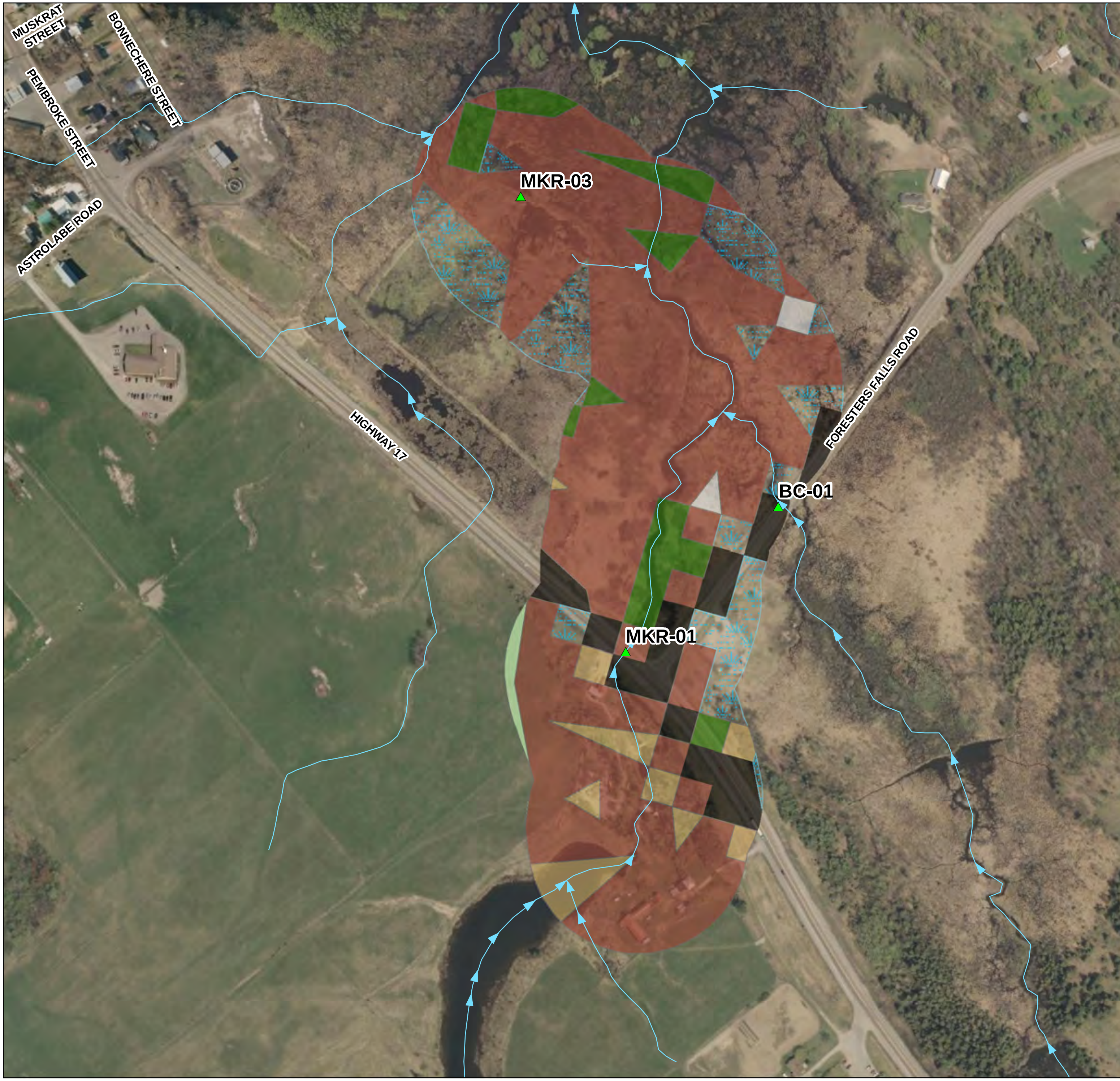
UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
Imagery Provided by Land Information Ontario

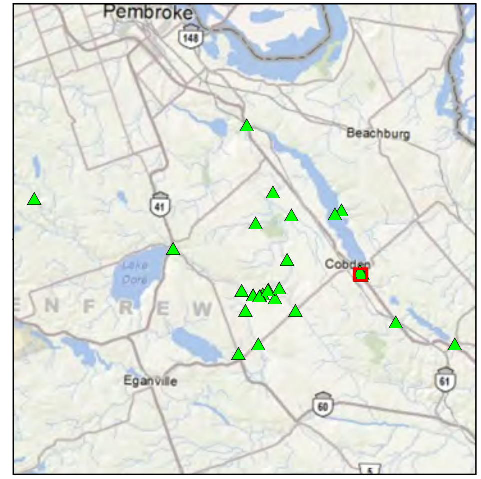
Published 2015

Ontario

Sampling Location: MKR-03

Ministry of the Environment and Climate Change





Legend

SampleSites
Flow Direction

AAFC Data Categories

Label

- N/A
- Barley
- Berries
- Broadleaf
- Canola/Rapeseed
- Coniferous
- Corn
- Exposed landBaren
- Grassland
- Hemp
- Mixedwood
- Nursery
- Oats
- Other Grains
- Pasture/Forages
- Shrubland
- Soybeans
- Urban/Developed
- Water
- Wetland
- Wheat

**Note: not all AAFC classes are present at each sampling site

N W E S

0 20 40 80 120 160 Meters

UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
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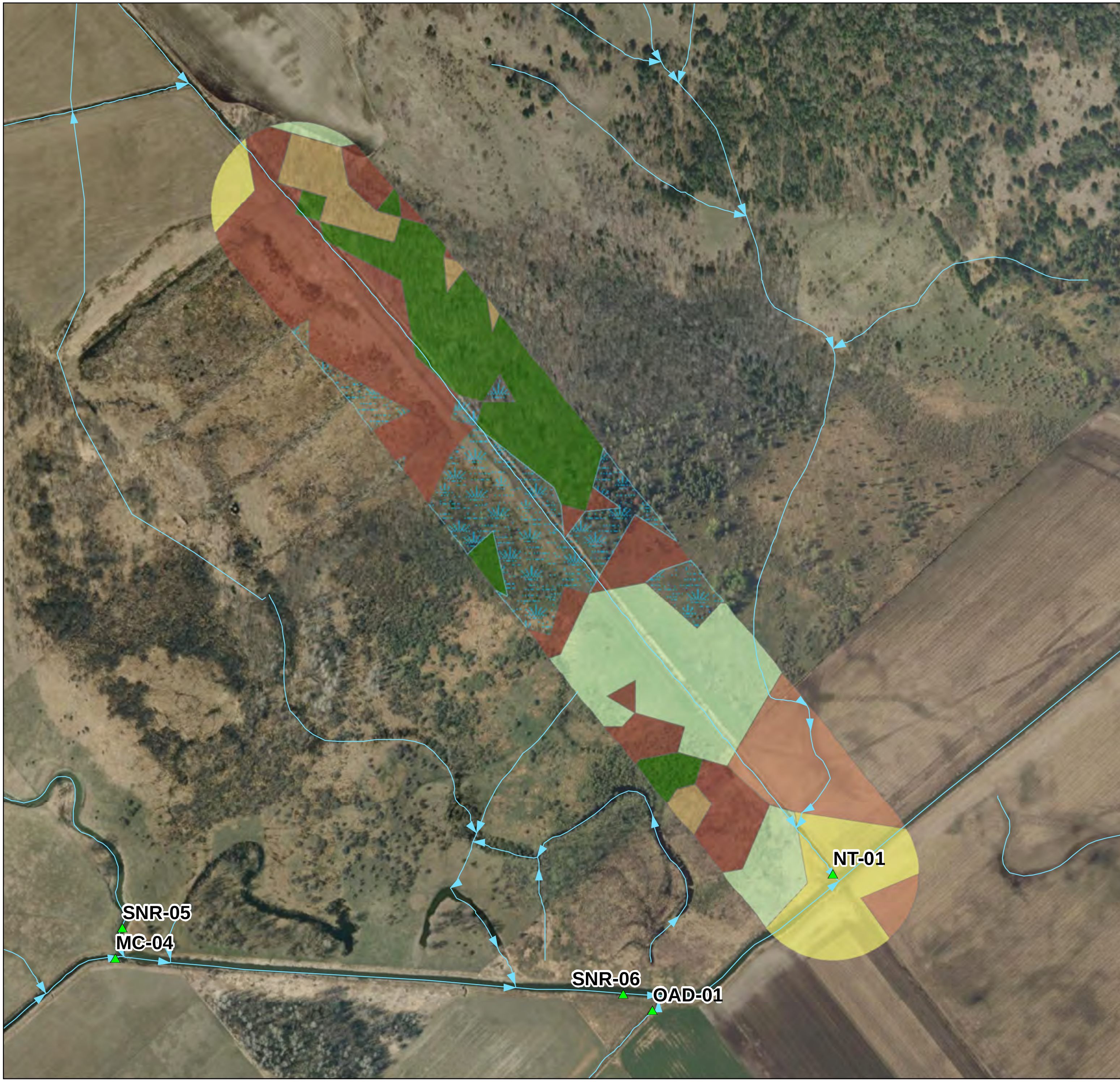
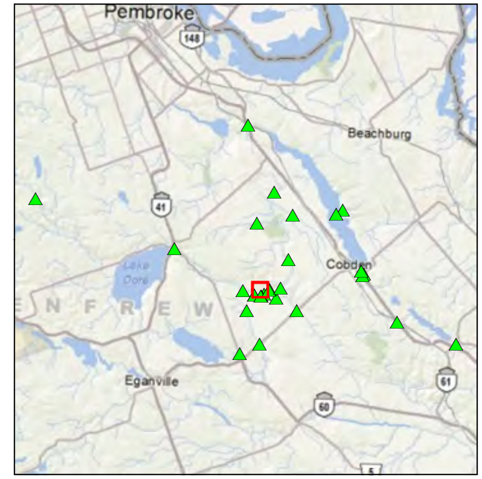
Published 2015

Printed in Ontario, Canada

Sampling Location: NT-01

Ministry of the Environment and Climate Change





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SampleSites
Flow Direction

AAFC Data Categories

Label

- N/A
- Barley
- Berries
- Broadleaf
- Canola/Rapeseed
- Coniferous
- Corn
- Exposed landBaren
- Grassland
- Hemp
- Mixedwood
- Nursery
- Oats
- Other Grains
- Pasture/Forages
- Shrubland
- Soybeans
- Urban/Developed
- Water
- Wetland
- Wheat

**Note: not all AAFC classes are present at each sampling site

N
W E
S

0 30 60 120 180 240 Meters

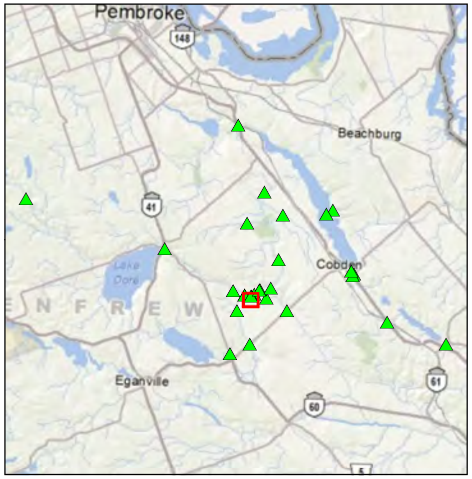
UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
Imagery Provided by Land Information Ontario

Published 2015

Ontario

Sampling Location: OAD-01

Ministry of the Environment and Climate Change



Legend

SampleSites   Flow Direction

AAFC Data Categories

Label

N/A	Mixedwood
Barley	Nursery
Berries	Oats
Broadleaf	Other Grains
Canola/Rapeseed	Pasture/Forages
Coniferous	Shrubland
Corn	Soybeans
Exposed landBaren	Urban/Developed
Grassland	Water
Hemp	Wetland
	Wheat

**Note: not all AAFC classes are present at each sampling site

N
W E
S

0 25 50 100 150 200 Meters

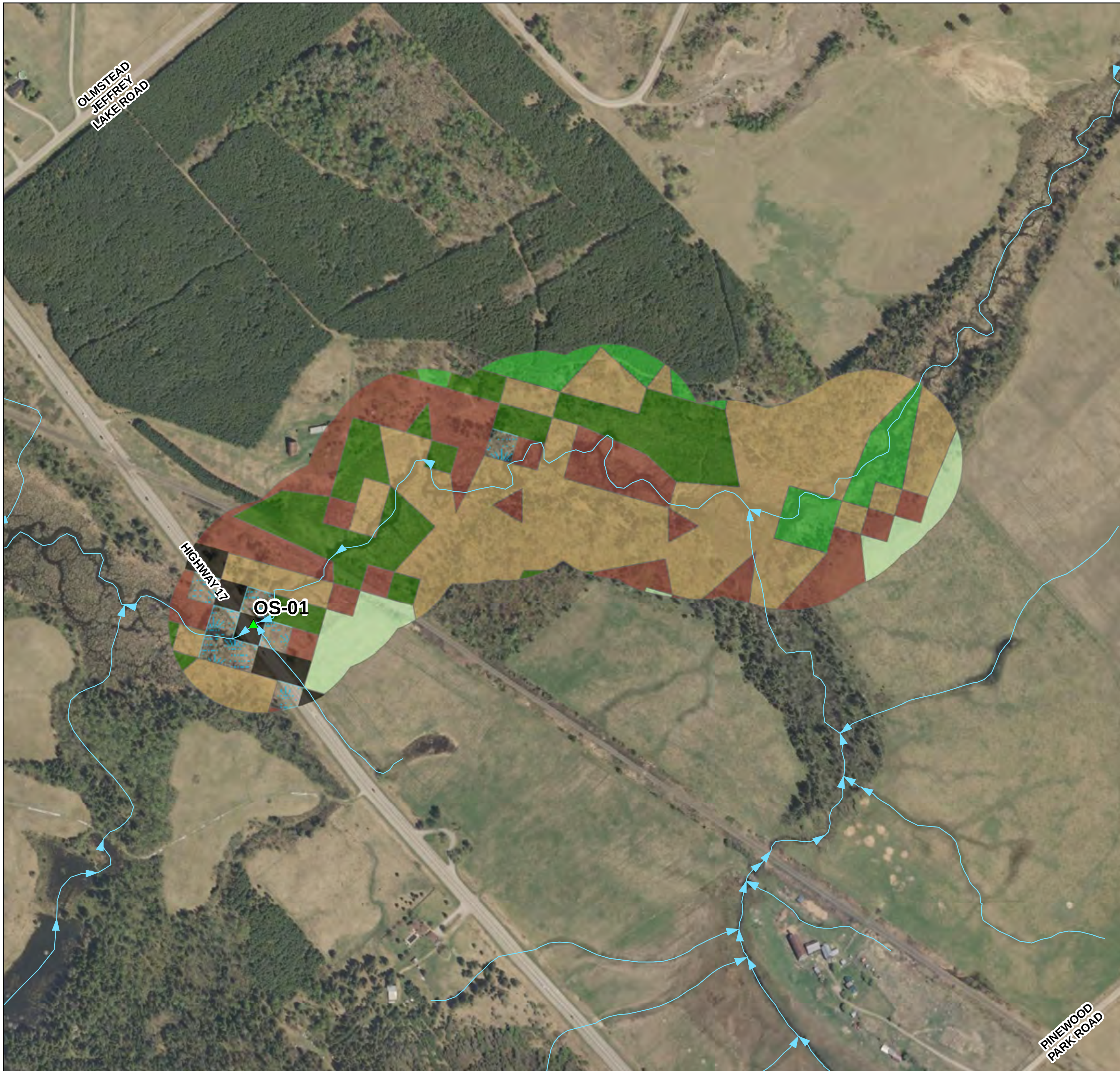
UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
Imagery Provided by Land Information Ontario

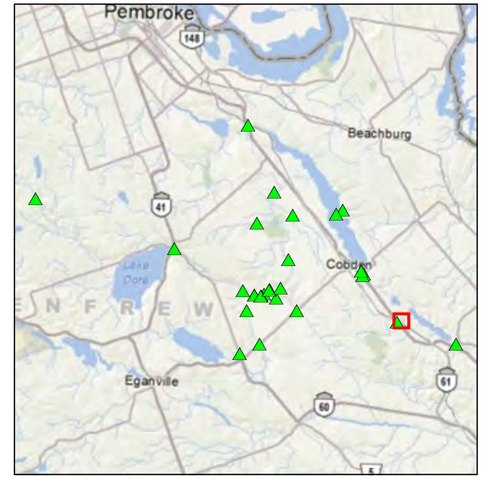
Published 2015

Printed in Ontario, Canada

Ministry of the Environment and Climate Change

Sampling Location: OS-01





Legend

- SampleSites
- Flow Direction

AAFC Data Categories

Label

N/A	Mixedwood
Barley	Nursery
Berries	Oats
Broadleaf	Other Grains
Canola/Rapeseed	Pasture/Forages
Coniferous	Shrubland
Corn	Soybeans
Exposed landBaren	Urban/Developed
Grassland	Water
Hemp	Wetland
	Wheat

**Note: not all AAFC classes are present at each sampling site

N
W E
S

0 25 50 100 150 200 Meters

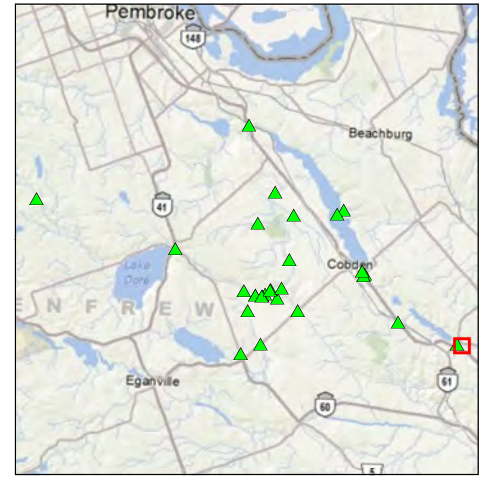
UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
Imagery Provided by Land Information Ontario

Published 2015

Ontario

Sampling Location: PH-01

Ministry of the Environment and Climate Change



Legend

SampleSites
Flow Direction

AAFC Data Categories

Label	
N/A	Mixedwood
Barley	Nursery
Berries	Oats
Broadleaf	Other Grains
Canola/Rapeseed	Pasture/Forages
Coniferous	Shrubland
Corn	Soybeans
Exposed landBaren	Urban/Developed
Grassland	Water
Hemp	Wetland
	Wheat

**Note: not all AAFC classes are present at each sampling site

N
W E
S

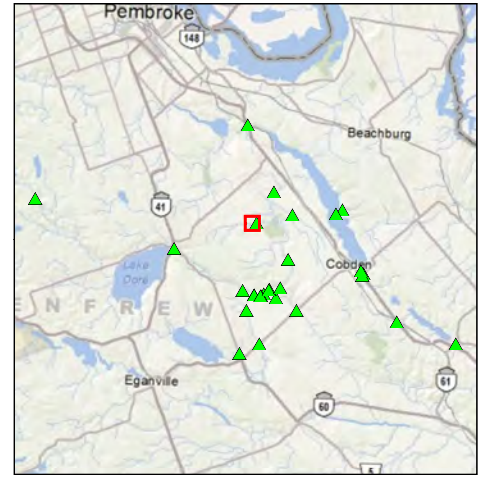
0 25 50 100 150 200 Meters

UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
Imagery Provided by Land Information Ontario

Published 2015

Ministry of the Environment and Climate Change

Sampling Location: SC-01



Legend

SampleSites
Flow Direction

AAFC Data Categories

Label

N/A	Mixedwood
Barley	Nursery
Berries	Oats
Broadleaf	Other Grains
Canola/Rapeseed	Pasture/Forages
Coniferous	Shrubland
Corn	Soybeans
Exposed landBaren	Urban/Developed
Grassland	Water
Hemp	Wetland
	Wheat

**Note: not all AAFC classes are present at each sampling site

N
W E
S

0 25 50 100 150 200
Meters

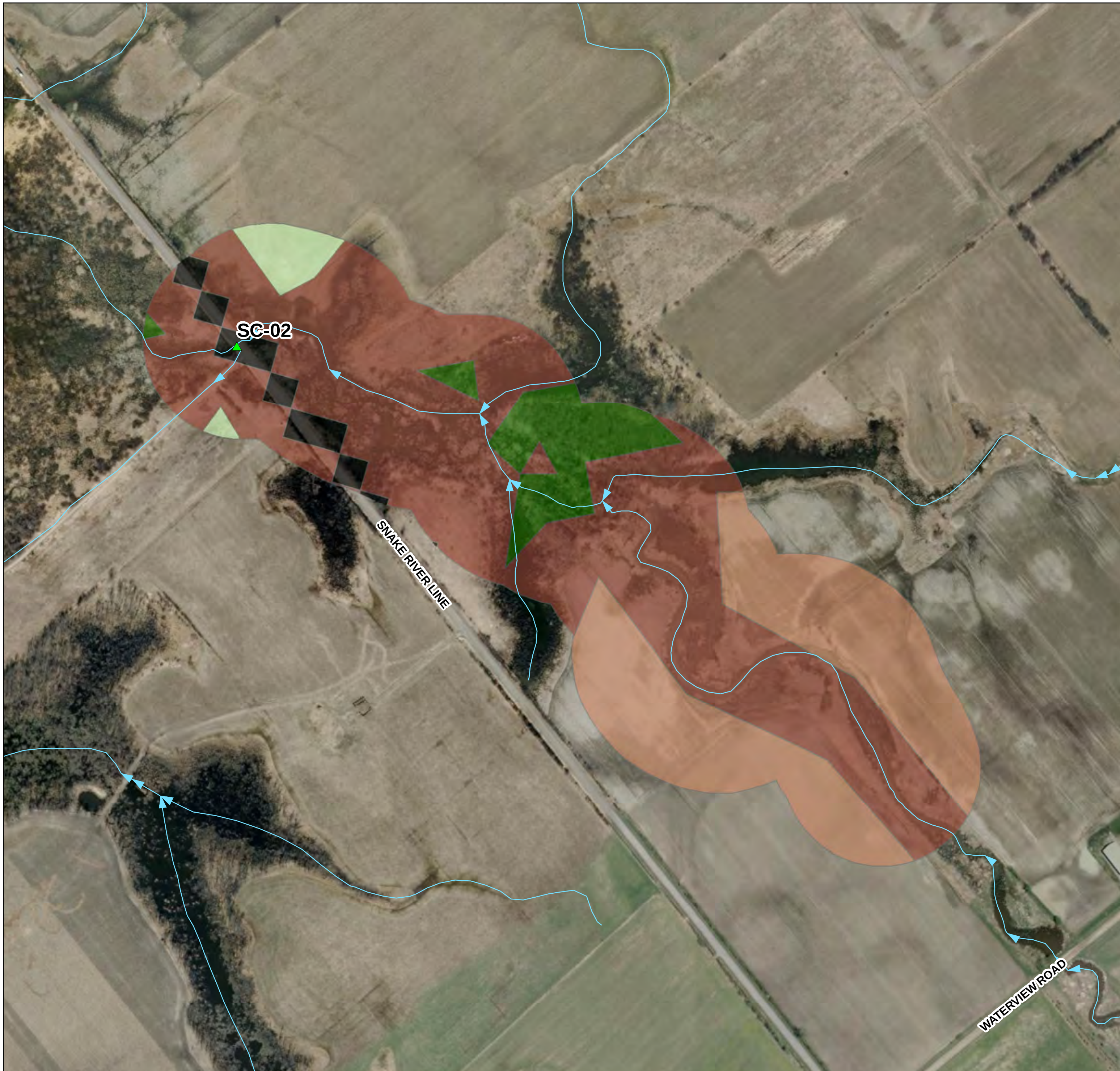
UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
Imagery Provided by Land Information Ontario

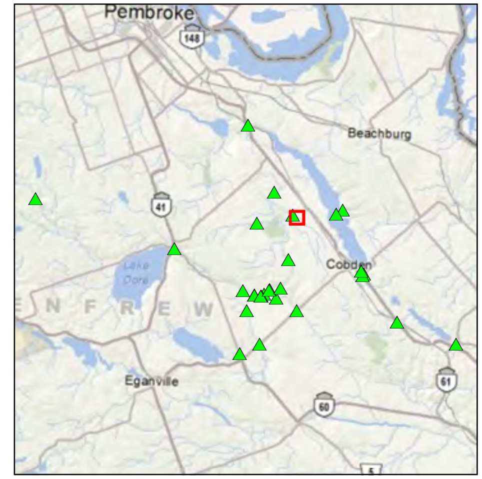
Published 2015

Ontario

Sampling Location: SC-02

Ministry of the Environment and Climate Change





Legend

SampleSites
Flow Direction

AAFC Data Categories

Label

- N/A
- Barley
- Berries
- Broadleaf
- Canola/Rapeseed
- Coniferous
- Corn
- Exposed landBaren
- Grassland
- Hemp
- Mixedwood
- Nursery
- Oats
- Other Grains
- Pasture/Forages
- Shrubland
- Soybeans
- Urban/Developed
- Water
- Wetland
- Wheat

**Note: not all AAFC classes are present at each sampling site

N W E S

0 25 50 100 150 200 Meters

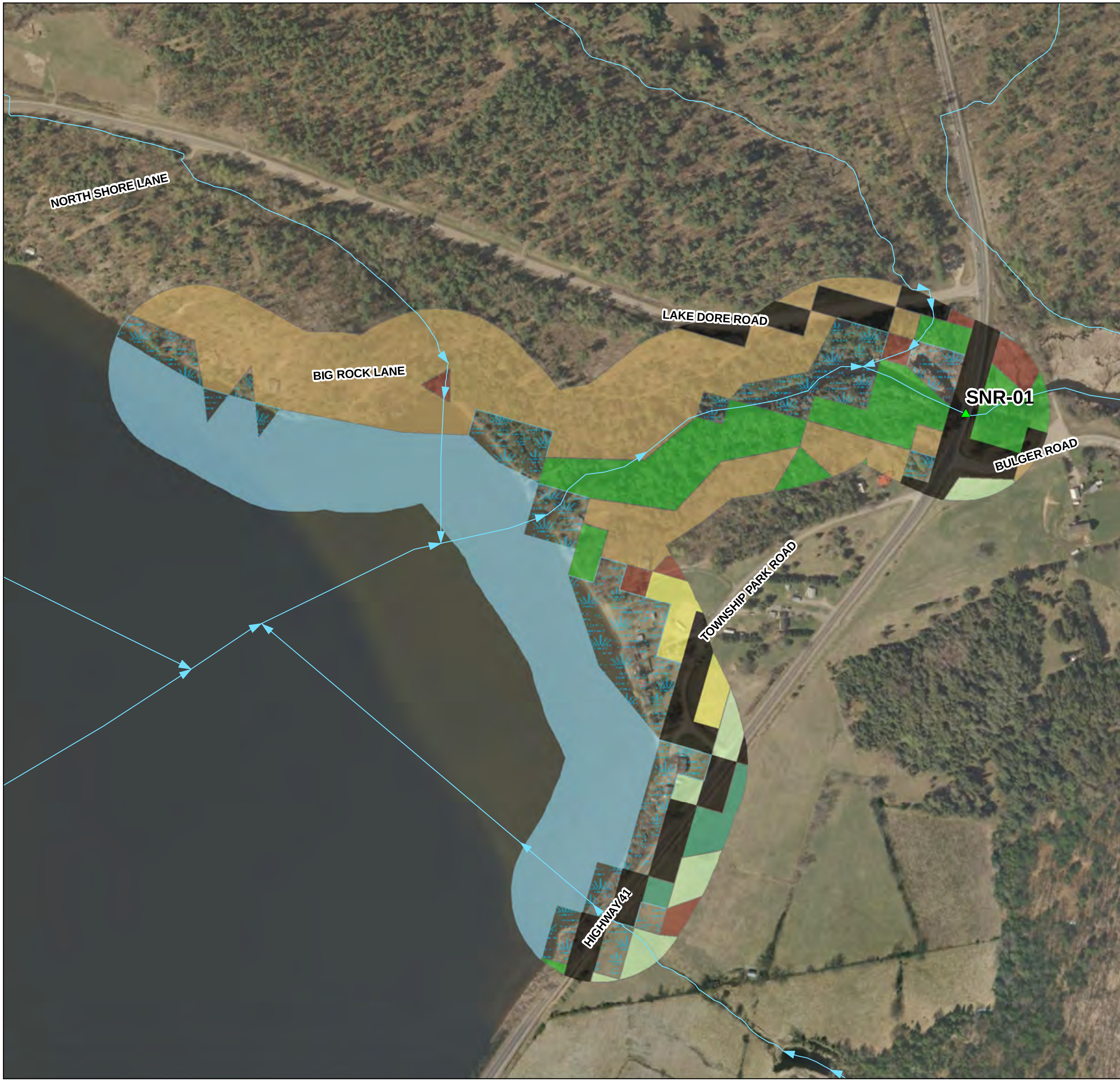
UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
Imagery Provided by Land Information Ontario

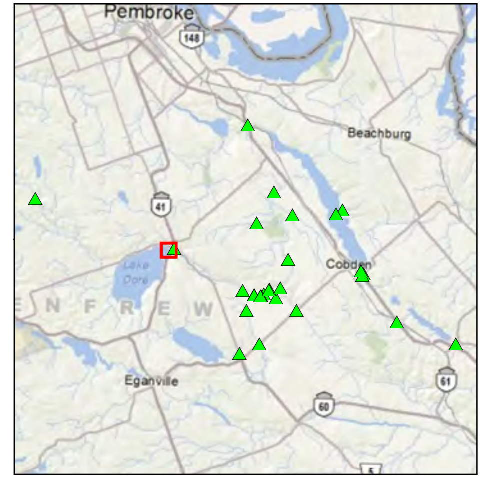
Published 2015

Ontario

Sampling Location: SNR-01

Ministry of the Environment and Climate Change





Legend

SampleSites
Flow Direction

AAFC Data Categories

Label

N/A	Mixedwood
Barley	Nursery
Berries	Oats
Broadleaf	Other Grains
Canola/Rapeseed	Pasture/Forages
Coniferous	Shrubland
Corn	Soybeans
Exposed landBaren	Urban/Developed
Grassland	Water
Hemp	Wetland
	Wheat

**Note: not all AAFC classes are present at each sampling site

N W E S

0 25 50 100 150 200 Meters

UTM Zone 18 (NAD 1983)
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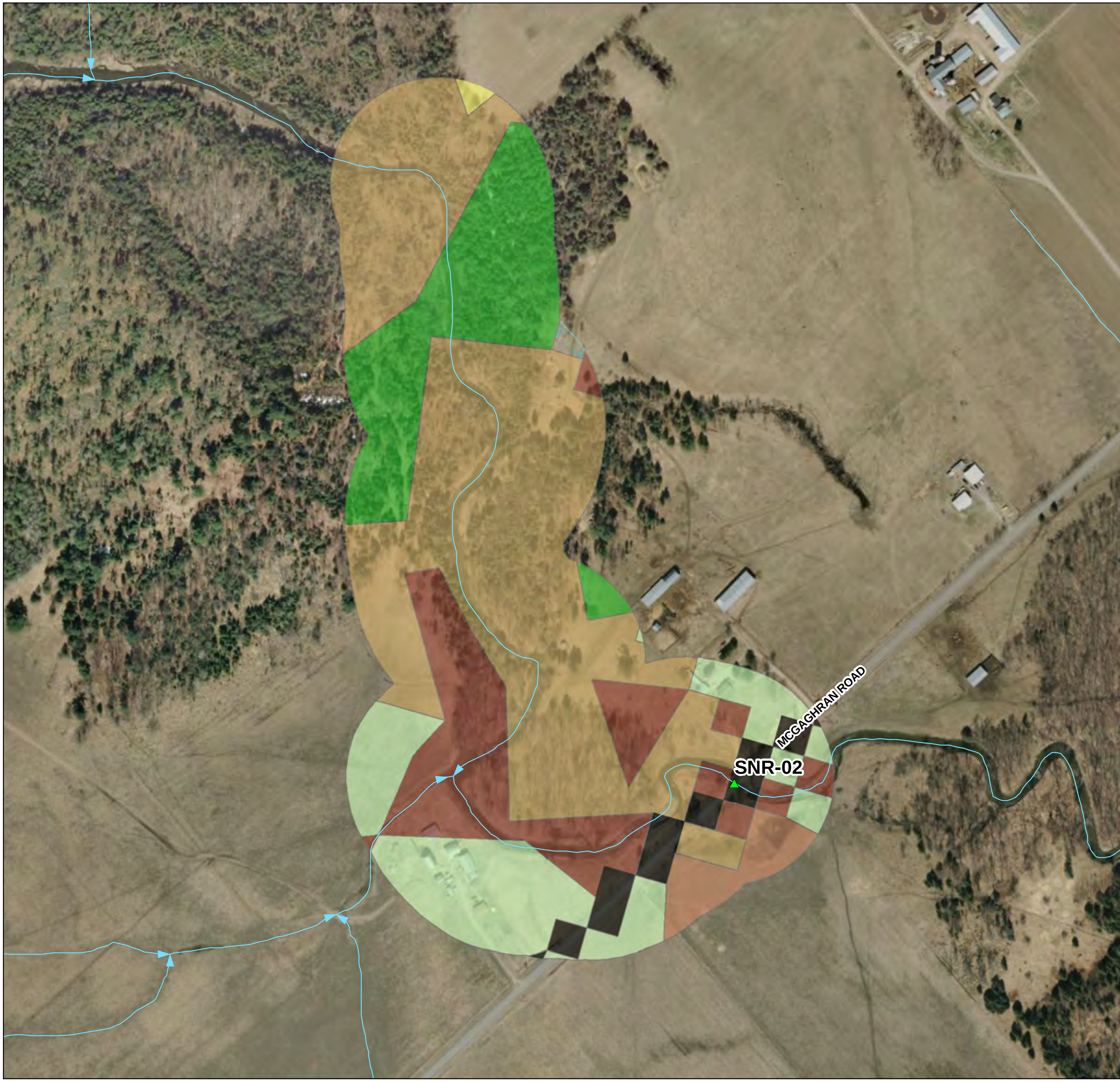
Imagery Provided by Land Information Ontario

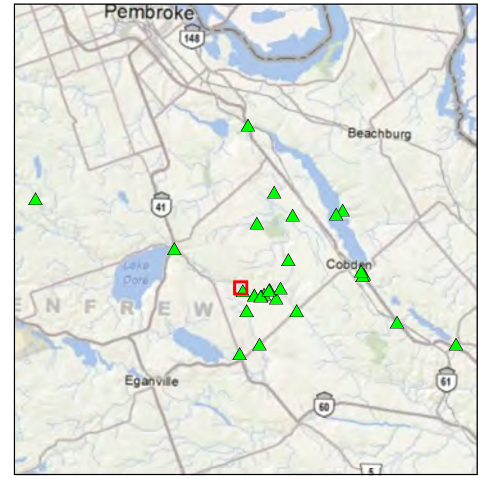
Published 2015

Ontario

Sampling Location: SNR-02

Ministry of the Environment and Climate Change





Legend

SampleSites
Flow Direction

AAFC Data Categories

Label

N/A	Mixedwood
Barley	Nursery
Berries	Oats
Broadleaf	Other Grains
Canola/Rapeseed	Pasture/Forages
Coniferous	Shrubland
Corn	Soybeans
Exposed landBaren	Urban/Developed
Grassland	Water
Hemp	Wetland
	Wheat

**Note: not all AAFC classes are present at each sampling site

N
W E
S

0 25 50 100 150 200 Meters

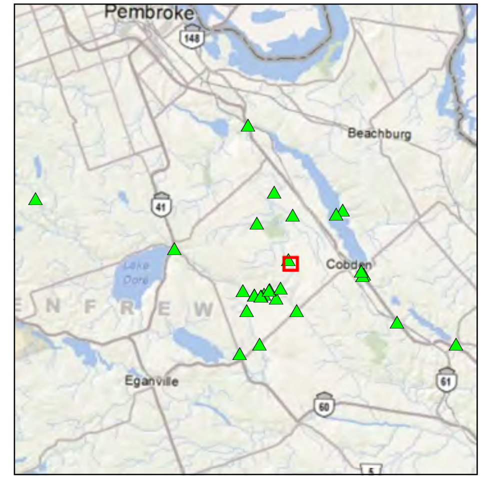
UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
Imagery Provided by Land Information Ontario

Published 2015

Ontario

Sampling Location: SNR-03

Ministry of the Environment and Climate Change



Legend

SampleSites — Flow Direction

AAFC Data Categories

Label

N/A	Mixedwood
Barley	Nursery
Berries	Oats
Broadleaf	Other Grains
Canola/Rapeseed	Pasture/Forages
Coniferous	Shrubland
Corn	Soybeans
Exposed landBaren	Urban/Developed
Grassland	Water
Hemp	Wetland
	Wheat

**Note: not all AAFC classes are present at each sampling site

N W E S

0 25 50 100 150 200 Meters

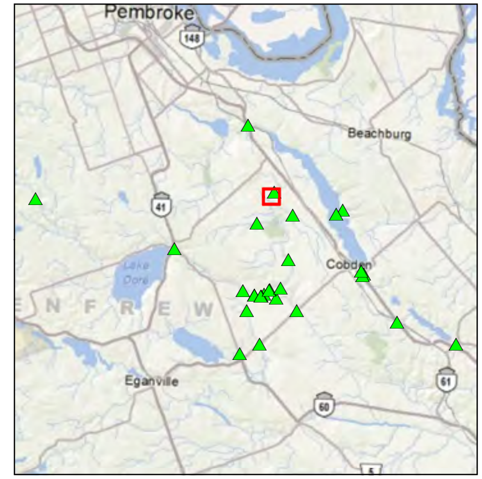
UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
Imagery Provided by Land Information Ontario

Published 2015

Ontario

Sampling Location: SNR-04

Ministry of the Environment and Climate Change



Legend

SampleSites
Flow Direction

AAFC Data Categories

Label

- N/A
- Barley
- Berries
- Broadleaf
- Canola/Rapeseed
- Coniferous
- Corn
- Exposed landBaren
- Grassland
- Hemp
- Mixedwood
- Nursery
- Oats
- Other Grains
- Pasture/Forages
- Shrubland
- Soybeans
- Urban/Developed
- Water
- Wetland
- Wheat

**Note: not all AAFC classes are present at each sampling site

N
W E
S

0 30 60 120 180 240
Meters

UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
Imagery Provided by Land Information Ontario

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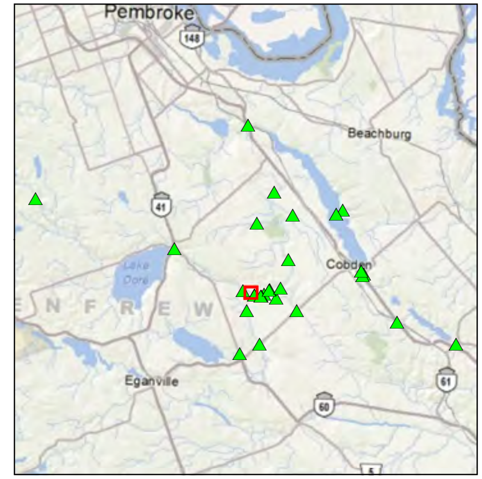
Ontario

Sampling Location: SNR-05

Ministry of the Environment and Climate Change



Legend

SampleSites
Flow Direction

AAFC Data Categories

Label

N/A	Mixedwood
Barley	Nursery
Berries	Oats
Broadleaf	Other Grains
Canola/Rapeseed	Pasture/Forages
Coniferous	Shrubland
Corn	Soybeans
Exposed landBaren	Urban/Developed
Grassland	Water
Hemp	Wetland
	Wheat

**Note: not all AAFC classes are present at each sampling site

N
W E
S

0 25 50 100 150 200 Meters

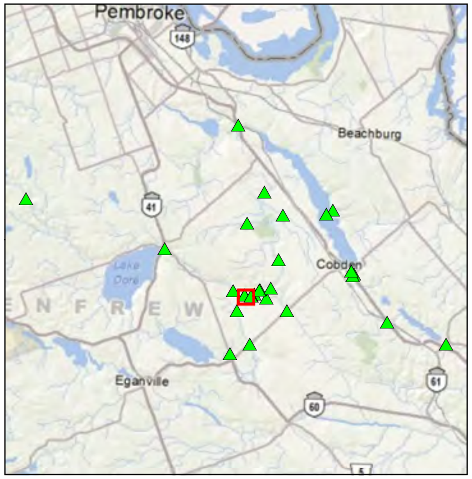
UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
Imagery Provided by Land Information Ontario

Published 2015

Ontario

Sampling Location: SNR-06

Ministry of the Environment and Climate Change



Legend

▲ SampleSites → Flow Direction

AAFC Data Categories

Label	
N/A	Mixedwood
Barley	Nursery
Berries	Oats
Broadleaf	Other Grains
Canola/Rapeseed	Pasture/Forages
Coniferous	Shrubland
Corn	Soybeans
Exposed landBaren	Urban/Developed
Grassland	Water
Hemp	Wetland
	Wheat

**Note: not all AAFC classes are present at each sampling site

N W E S

0 30 60 120 180 240 Meters

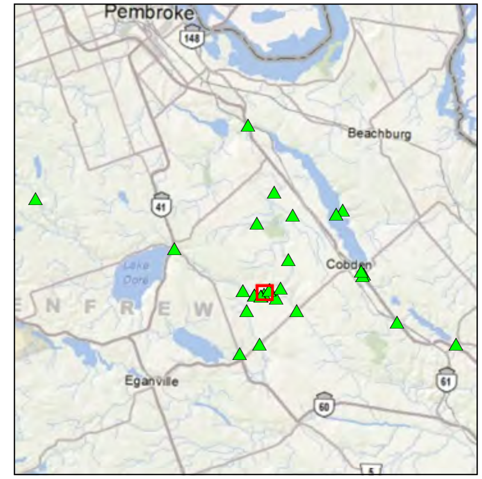
UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
Imagery Provided by Land Information Ontario

Published 2015

Ontario

Sampling Location: SNR-07

Ministry of the Environment and Climate Change



Legend

SampleSites
Flow Direction

AAFC Data Categories

Label

N/A	Mixedwood
Barley	Nursery
Berries	Oats
Broadleaf	Other Grains
Canola/Rapeseed	Pasture/Forages
Coniferous	Shrubland
Corn	Soybeans
Exposed landBaren	Urban/Developed
Grassland	Water
Hemp	Wetland
	Wheat

**Note: not all AAFC classes are present at each sampling site

N W E S

0 25 50 100 150 200 Meters

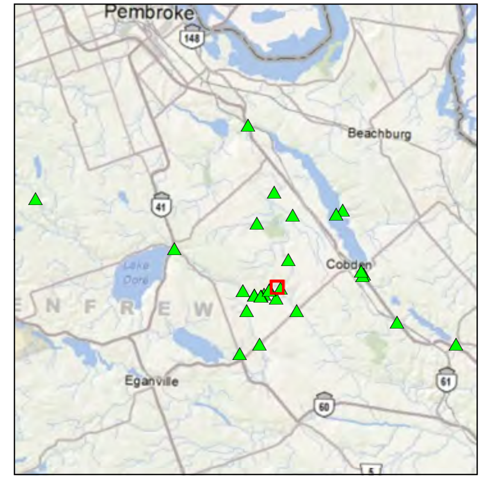
UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
Imagery Provided by Land Information Ontario

Published 2015

Ontario

Sampling Location: SNR-08

Ministry of the Environment and Climate Change



Legend

▲ SampleSites → Flow Direction

AAFC Data Categories

Label

N/A	Mixedwood
Barley	Nursery
Berries	Oats
Broadleaf	Other Grains
Canola/Rapeseed	Pasture/Forages
Coniferous	Shrubland
Corn	Soybeans
Exposed landBaren	Urban/Developed
Grassland	Water
Hemp	Wetland
	Wheat

**Note: not all AAFC classes are present at each sampling site

N W E S

0 25 50 100 150 200 Meters

UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
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