Hutchinson
Environmental Sciences Ltd.

Stormwater Assessment, Planning and Implementation of the Cobden Agriculture Area

Planning Phase

Prepared for: Township of Whitewater Region
Job #: J210005

November 19, 2021

DRAFT FOR DISCUSSION

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202-501 Krug Street, Kitchener ON N2B 1L3 | 519-576-1711

November 19, 2021 HESL Job #: J210005

Ivan Burton
Planner/Economic Development Officer
Township of Whitewater Region
44 Main Street, P.O. Box 40
Cobden, ON K0J 1K0

Dear Mr. Burton:

Re: Stormwater Assessment, Planning and Implementation of the Cobden Agriculture Area – Background Review

The goal of this project is to characterize existing stormwater quality and stormwater management in Cobden's agricultural area and recommend and implement mitigation measures to reduce nutrient loading to Provincially Significant Wetland (PSW) and Muskrat Lake. A background review was completed which included preliminary consultation with the agricultural community and environmental partners, characterization of existing stormwater management, identification of source areas of nutrient loss, evaluation of Cobden and Snake River Provincially Significant Wetland functions in relation to stormwater management (SWM), and preliminary identification of priority areas for management.

A multitude of lakes, rivers and wetlands are located in the study area which influence nutrient cycling between the watershed and Muskrat Lake, while agricultural SWM is limited to three tile drains and one municipal drain in the study area. In the Snake River Watershed, large extents of flooding were evident throughout the spring of 2019. Nutrients were similar or slightly higher than other agricultural-dominated watersheds in Ontario. Median total phosphorus and total nitrogen concentrations and loads/ha were all highest at SC-02 which is located at the eastern side of the Snake River PSW. The Cobden and Snake River both support a wide variety of natural heritage features and functions. The Snake River PSW consistently acts as a nutrient sink while the Cobden PSW acts as a nutrient source.

We identified three priority areas for future BMP implementation based on the results of the study: SC-02 catchment, previously flooded areas on the west side of Muskrat Lake, and Muskrat Lake riparian lands. Subsequent phases of the study will focus on a) consultation and education, and b) identification of BMPs and quantification of nutrient load reductions.

Sincerely,
Per. Hutchinson Environmental Sciences Ltd.

Brent Parsons, M.Sc.
Senior Aquatic Scientist

Signatures

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Principal Planning Services, Jp2g Consultants In.

Executive Summary

The goal of this project is to characterize existing stormwater quality and stormwater management in Cobden's agricultural area and local Provincially Significant Wetlands (PSWs), recommend and implement mitigation measures to reduce nutrient loading to PSWs and Muskrat Lake, develop information sharing amongst local and regional groups and residents, and develop lasting partnerships between the agricultural sector and regional organizations to help improve water quality in Muskrat Lake and the PSWs in both the short and long-term. The Muskrat Lake watershed encompasses several different municipalities but the study area and focus for this project has been defined as the Township of Whitewater Region (Figure 1).

The Muskrat Lake watershed has been very well studied in terms of water quality and land use, so a thorough background review was completed to set the stage for subsequent project tasks. The background review is described herein and was completed following five specific tasks:

1. Preliminary consultation with the agricultural community and environmental partners;
2. Characterization of existing stormwater management;
3. Identification of source areas of nutrient loss;
4. Evaluation of Cobden and Snake River Provincially Significant Wetland functions in relation to stormwater management (SWM); and
5. Preliminary identification of priority areas for management.

Preliminary consultation has been initiated through consultation with select groups and will advance after completion of this report through project notification focus group engagement and micro meetings.

A multitude of lakes, rivers and wetlands are located in the study area which influence nutrient cycling between the watershed and Muskrat Lake. These natural heritage features will be considered during future project phases when selecting and implementing of BMPs which aim to improve nutrient retention in these systems. Artificial SWM is limited to three tile drains and one municipal drain in the study area.

In the Snake River Watershed, there are significant floodplains due to the flat surrounding areas between the Snake River PSW and Muskrat Lake. Large extents of flooding were evident throughout the spring of 2019 and designated as either "Class 2 – Open Water" or "Class 3 – Flooded Vegetation".

Nutrients were similar or slightly higher than other agricultural-dominated watersheds in Ontario. Phosphorus concentrations were highest in the summer, TN was highest in the spring and fall, and neither nutrient concentration was statistically significantly related to precipitation. Total suspended solid concentrations were low and significantly related to TP at the three sites located in the Cobden PSW which could be driven by upstream overland runoff.

Median TP and TN concentrations, as well as TP and TN loads/ha were all highest at SC-02. The next most nutrient-enriched sites were MKR-03 and SNR-04.

The Cobden and Snake River both support a wide variety of natural heritage features and functions. The Snake River PSW consistently acts as a nutrient sink while the Cobden PSW acts as a nutrient source. The

assessment of TP retention in the Cobden PSW was limited because the downstream water sampling location was located in the middle of the wetland, thereby limiting the spatial assessment.

We identified the following priority areas for future BMP implementation based on the results of the study:

1. SC-02 Catchment

   Nutrient concentrations and loads/ha were the highest at SC-02 so future project phases should be focused in this area to reduce nutrient loading and nutrient concentrations in the Snake River PSW, Snake River and downstream Muskrat Lake. It should be noted however that the nutrients will be transformed in the PSW through a variety of biogeochemical processes and therefore a reduction in nutrient loads will not equal those that are displaced from Muskrat Lake.

2. Previously Flooded Areas

   Flooding results in significant nutrient loading to downstream receiving waterbodies. Class two and three lands that flooded in the spring of 2019 should be assessed during future project phases in an attempt to lower nutrient loading from these areas and improve agricultural productivity. The majority of these previously flooded areas are located between the Snake River PSW and Muskrat Lake along the western shore of Muskrat Lake.

3. Muskrat Lake Riparian Lands

   The Muskrat Lake watershed includes a number of agricultural lands that drain directly into the western shore of Muskrat Lake and runoff is not afforded phosphorus retention in watercourses, wetlands or other lakes. These lands should be examined as part of future project phases. Many of these agricultural operations appear to have little riparian buffer between cropland and the shoreline of Muskrat Lake.

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1. Introduction

Muskrat Lake is the drinking water source for the Cobden municipal drinking water system, it is nutrient-enriched, and concerns have arisen related to the formation of blue-green algal blooms. Blue-green algal blooms affect recreational opportunities but can also cause significant health effects. AECOM (2009) determined that algal toxins represent a high level of risk to the Cobden drinking water supply. A variety of different physical, chemical and biological factors cause algal bloom formation, but lake and watershed managers often focus on nutrients during management as nutrients are generally the limiting factor for algal growth in freshwater ecosystems.

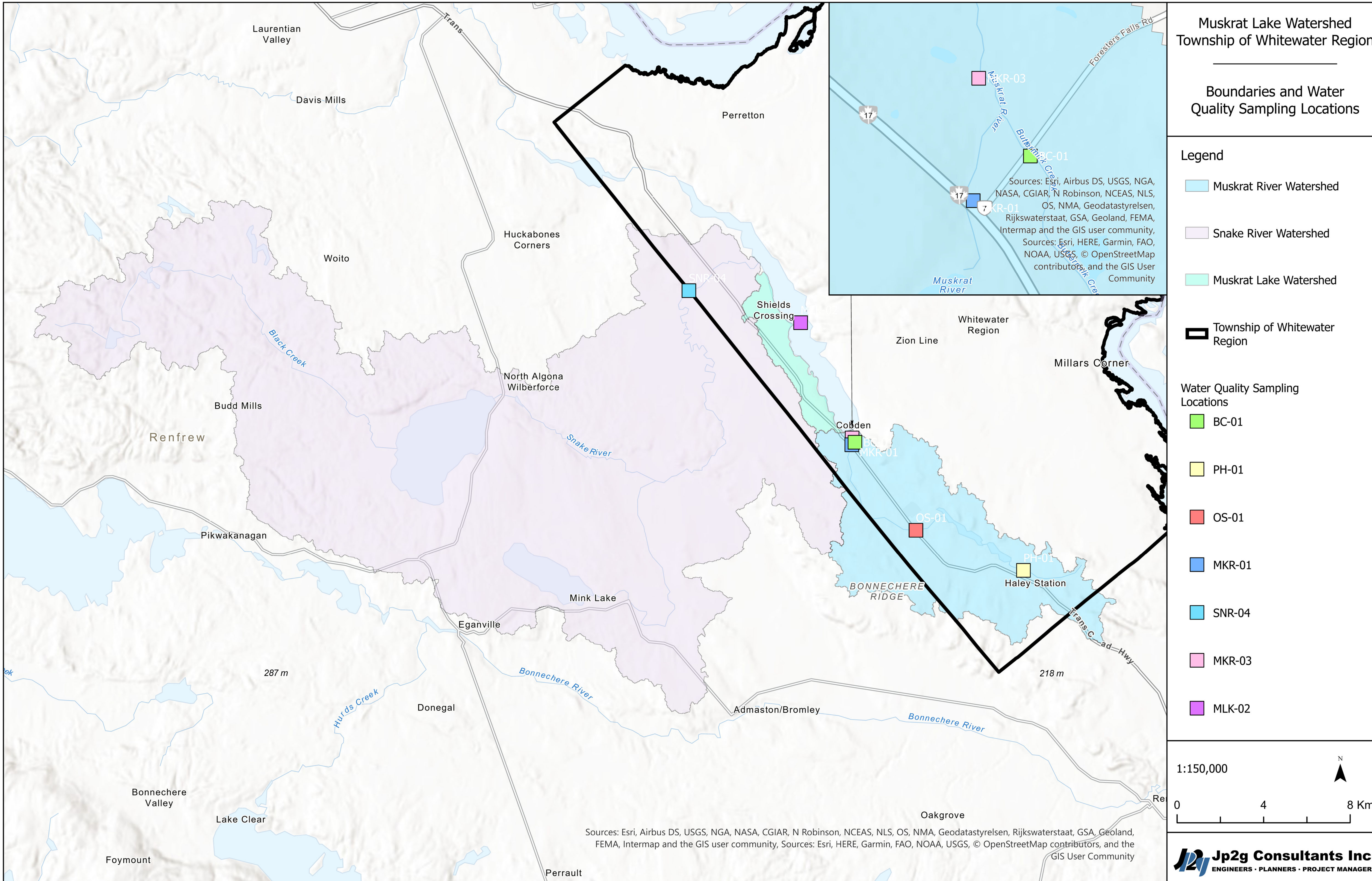
Water quality sampling locations established in the Muskrat Lake watershed have found that nutrient concentrations in inflowing tributaries are high, and in-stream concentrations of nutrients and suspended solids tended to increase with increasing crop land and decrease with increasing natural habitat (Dalton, 2019). Nutrient concentrations were typically elevated in watercourses adjacent to or downstream from agricultural operations due to runoff from fertilizers, decomposed crop residues, and manure. Dalton (2019) therefore recommended that improvements to water quality in Muskrat Lake should focus on reducing nutrient inputs from agricultural lands in the Muskrat Lake watershed.

The goal of this project is to characterize existing stormwater quality and stormwater management in Cobden's agricultural area and local Provincially Significant Wetlands (PSWs), recommend and implement mitigation measures to reduce nutrient loading to PSWs and Muskrat Lake, develop information sharing amongst local and regional groups and residents, and develop lasting partnerships between the agricultural sector and regional organizations to help improve water quality in Muskrat Lake and the PSWs in both the short and long-term. The Muskrat Lake watershed encompasses several different municipalities but the study area and focus for this project has been defined as the Township of Whitewater Region (Figure 1).

The Muskrat Lake watershed has been very well studied in terms of water quality and land use, so a thorough background review was completed to set the stage for subsequent project tasks. The background review is described herein and was completed following five specific tasks:

1. Preliminary consultation with the agricultural community and environmental partners;
2. Characterization of existing stormwater management;
3. Identification of source areas of nutrient loss;
4. Evaluation of Cobden and Snake River Provincially Significant Wetland functions in relation to stormwater management (SWM); and
5. Preliminary identification of priority areas for management.

The next steps in the project will include the Planning, Action and Public Education Phases. The Planning Phase will be focused on identifying BMPs or stewardship activities (such as tile drains, constructed wetlands, manure storage, buffer strips, bank stabilization of cattle exclusion fencing), and quantifying the nutrient load reductions associated with implementation of specific BMPs. The Action and Public Education Phases will be focused on communication, public education and awareness that builds on preliminary consultation activities completed as part of the background review.


Muskrat Lake Watershed
Township of Whitewater Region
Boundaries and Water Quality Sampling Locations
Legend
Muskrat River Watershed
Snake River Watershed
Muskrat Lake Watershed
Township of Whitewater Region
Water Quality Sampling Locations
BC-01
PH-01
OS-01
MKR-01
SNR-04
MKR-03
MLK-02
1:150,000
N
0
4
8 Km
Jp2g Consultants Inc.
ENGINEERS · PLANNERS · PROJECT MANAGERS
Laurentian Valley
Davis Mills
Perretton
Huckabones Corners
Woito
Shields Crossing
Whitewater Region
Zion Line
Millars Corner
North Algona Wilberforce
Budd Mills
Renfrew
Black Creek
Snake River
Cobden
BC-01
MKR-01
OS-01
PH-01
Haley Station
SNR-04
BONNECHERE RIDGE
Pikwakanagan
Mink Lake
Eganville
287 m
218 m
Bonnechere River
Hurds Creek
Donegal
Admaston/Bromley
Trans-Canad Hwy
Bonnechere Valley
Lake Clear
Foymount
Perrault
Oakgrove
Forester Falls Rd
17
MKR-03
Muskrat River
Butternut Creek
Muskrat River
Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community
Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community

2. Methods

2.1 Preliminary Consultation

Jp2g and HESL reached out to agricultural and environmental partners for the purposes of explaining the study program, data collection and establishing contacts to keep agricultural and environmental partners informed throughout the work program. A public and agency contact list was also developed for project notification for future stages of the project.

2.2 Existing Agricultural SWM

Existing SWM for the Cobden and surrounding agricultural area was determined through local knowledge, background material, Google Earth, Ontario Flow Assessment Tool, the Township, and MTO Drainage Management Manual. Jp2g also completed field investigations to document SWM features. National Research Canada flood plan mapping was obtained from the County of Renfrew and reviewed to determine the areas and extent of flooding in the study area.

2.3 Source Areas of Nutrient Loss

Source areas of nutrient loss were identified through field investigations, evaluation of historical water quality data, review of land use and flood plain mapping. Source areas of nutrient loss were identified to focus future phases of the study on priority areas where the implementation of BMPs should be focused to generate the greatest benefit to downstream receiving water systems.

2.3.1 Water Quality

Twenty-two water quality sampling locations were sampled monthly from May to September 2014 – 2019 to characterize stormwater quality and to identify tributaries that are highly impacted by nutrients (Figure 1). The project was led by Algonquin College (Pembroke) and the Muskrat Watershed Council. Water quality parameters were analyzed by Ministry of Environment, Conservation and Parks (MECP) and reports were produced by Rebecca Dalton (Dalton 2015; Dalton 2019).

Water quality data from sampling stations located in the Township of Whitewater were analyzed through comparisons with Provincial Water Quality Objectives (PWQOs) and values reported in literature. Data were assessed spatially between sites and temporally over seasons. Sites included Muskrat River (PH-01), Muskrat River (OS-01), Muskrat River (MKR-01), Buttermilk Creek (BC-01), Cobden Wetland (MKR-03), Unnamed Creek (SC-02), Snake River (SNR-04) and Muskrat Lake (MLK-02; Table 1; Figure 1).

Nutrient loads were calculated to provide another means of identifying nutrient source areas. Loads for each site were calculated by multiplying median concentrations by the mean annual flow. Mean annual flows were estimated using the Ontario Flow Assessment Tool (Ministry of Natural Resources and Forestry, 2020) and the built-in flow Mean Annual Flow Hydrology Model (Ministry of Natural Resources, 2003).

Table 1. Descriptions of Water Quality Sampling Locations (Dalton 2019).

Site	Watercourse	Sub-Watershed	Easting	Northing	Rationale
PH-01	Muskrat River	Muskrat	362174	5047911	Most upstream site on Muskrat River
OS-01	Muskrat River		357146	5049780	This site reflects important land use changes from PH-01 (e.g. increased development and agriculture)
MKR-01	Muskrat River		354178	5053726	Upstream extent of Cobden PSW
BC-01	Buttermilk Creek		354318	5053859	Only site on tributary
MKR-03	Cobden Wetland/Muskrat River		354210	5053897	High phosphorus. This wetland warrants further study to assess the impact of the sewage treatment plant on export of phosphorus to Muskrat Lake.
SC-02	Unnamed Creek	Snake	348236	5058891	Existing highly impacted site. Only site on this tributary.
SNR-04	Snake River		346660	5060866	Existing, highly impacted, most downstream site.
MLK-02	Muskrat Lake	Lake	351810	5059377	Critical site for establishing long-term trends in nutrients within Muskrat Lake.

2.3.2 Land Use Mapping

Land use was determined to help identify source areas of nutrient loss at two different scales. Dalton (2019) characterized land use in a 1000 m x 200 m wide area (100 m on either stream/river bank) using 30 cm resolution satellite imagery data from Agriculture and Agri-food Canada's 2014 Crop Inventory. Percentages of annual crop land, pasture/forage land, natural habitat and developed land were calculated. Those numbers are reproduced here to inform the identification of nutrient source areas.

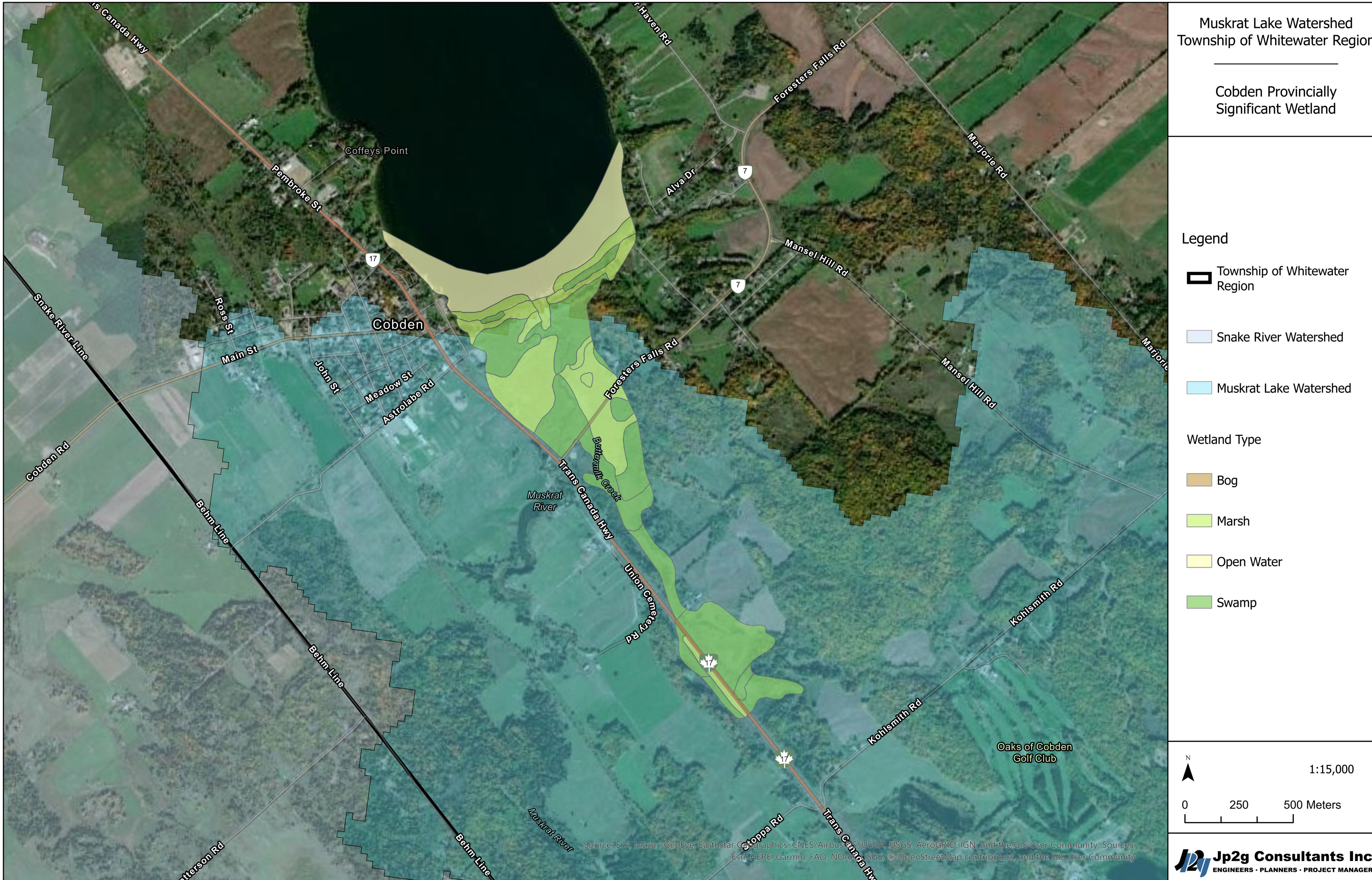
The agricultural area within the catchment for each water quality sampling location was calculated using the Ontario Flow Assessment Tool to provide an indication of land use at a larger scale. Land uses were used to inform the assessment through comparison with water quality data to help determine if there is a linkage between land use and water quality to define future priority areas.

2.4 Cobden and Snake River PSWs

The Cobden and Snake River PSWs are both located in the Muskrat Lake Watershed (Figure 2; Figure 3). The Ministry of Natural Resources and Forestry (MNRF) categorizes wetlands as Provincially Significant based on a science-based ranking system. We characterized the wetland features and functions of the Cobden and Snake River PSWs through review of the:

- Snake River Marsh Conservation Reserve Management Statement (Province of Ontario, 2019)
- Snake River Wetland Data Record (MNRF, undated)
- Cobden Wetland Data Record (MNRF, undated)
- Environmental Impact Study – Cobden Wasterwater Treatment Plant Upgrades (Muncaster Environmental Planning and JP2G Consultants, 2016)

Features and functions of the PSWs were assessed in relation to natural heritage features to define the ecological sensitivities of these wetlands as receiving water systems of agricultural runoff. We also assessed the PSWs in terms of stormwater management through a review of water quality data at upstream and downstream sampling locations to determine when they act as sources or sinks for nutrients.


Muskrat Lake Watershed
Township of Whitewater Region
Cobden Provincially Significant Wetland
Legend
Township of Whitewater Region
Snake River Watershed
Muskrat Lake Watershed
Wetland Type
Bog
Marsh
Open Water
Swamp
1:15,000
0
250
500 Meters
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Cobden
Coffeys Point
Pembroke St
Main St
Ross St
John St
Meadow St
Astrolabe Rd
Cobden Rd
Snake River Line
Behm Line
Patterson Rd
Trans Canada Hwy
Union Cemetery Rd
Muskrat River
Buttermilk Creek
Foresters Falls Rd
Alva Dr
Mansel Hill Rd
Marjorie Rd
Kohlsmith Rd
Stoppa Rd
Oaks of Cobden Golf Club
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community


Township of Whitewater Region
Snake River Provincially Significant Wetlands
Legend
Township of Whitewater Region
Snake River Watershed
Wetland Type
Bog
Marsh
Open Water
Swamp
N
1:25,000
0
0.5
1 Kilometers
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ENGINEERS · PLANNERS · PROJECT MANAGERS
Snake River
Shields Crossing
Lower Stafford
Muskrat Lake
Sturgeon Mountain
Lily Bay
Trans Canada Hwy
Snake River Line
Rollins Rd
Mountain Rd
Eldon Rd
Faught Rd
Stafford 2nd Line
Poff Rd
Stoqua Creek Rd
Egan Line
Waterview Rd
Connaught Rd
Cahill Line
Burwell Rd
Hydro Bay Rd
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community

3. Preliminary Consultation

A project kickoff meeting was completed on February 18, 2021, which included Karen Coulas from the Muskrat Watershed Council, Ivan burton and Lane Cleroux from the Township of Whitewater Region, Jp2g Consultants Inc. and HESL. The meeting included a review of project scope and deliverables, identification of background material, and establishment of lines of communication.

To date, HESL and Jp2g have corresponded with MECP, Rebecca Dalton (author of the Muskrat Lake Watershed – 2017-2019 Water Quality Reports), Julie Sylvestre from Algonquin College, and the County of Renfrew to obtain Natural Resources Canada (NRCAN) mapping information for the 2019 flood.

Jp2g has drafted a public and agency contact list for the purposes of project notification and the identification of individuals and groups interested in participating in the Action and Public Education Stages of the Study process (Appendix A). The draft public and agency contact list includes relevant Provincial agencies, local agricultural organizations, non-government organizations (NGO's), Algonquin College and the general public. A description of the "Purpose of Study" has also been drafted for the project notification purposes.

This public and agency circulation list will be reviewed with the Township and Muskrat Watershed Council prior to project notification. The form of consultation during the Action and Public Education Stages will depend, in part, on the interested expressed by individuals and groups as per the direction of the Township. It is anticipated that public and agency consultation will consist of a combination of macro (broad-based public and agencies) focus group engagement and micro (individual/kitchen-table) level meetings. Options for public notification and participation during the Study process will be developed as per direction from the Township and include, but not be limited to the following:

1. Keeping interested individuals and organizations informed throughout the Study process.
2. General notifications (i.e. local newspapers; Township/MWC web-pages) regarding the Study and opportunities for participation during the Action and Public Education stages of the work plan.
3. Focus group session(s) with one or a combination of interested agricultural; agency, NGO and academic organizations.
4. Identification of individuals from the agricultural community for the purpose of obtaining input and buy-in on effective BMP's.
5. Preparation of information materials that can be circulated to individuals and the public.
6. Public meeting(s) (virtual or in public depending on COVID – 19) to present the study results and Action Plan moving forward.

4. Existing SWM

Existing SWM provided by natural systems and agricultural treatment in the study area was documented through background review and field investigations.

4.1 Natural SWM Features

4.1.1 Watercourses

The Muskrat and Snake Rivers drain into Muskrat Lake. The Muskrat River flows from Renfrew through a chain of small lakes into the Cobden PSW (Figure 4) and Muskrat Lake while the Snake River flows into Lake Dore before emptying into the Snake River PSW and Muskrat Lake.

Nutrient retention in riverine systems occurs through complex biogeochemical and physical processes that remove, delay or transform the nutrients. Factors affecting nutrient retention in watercourses include vegetation, hydrology, morphology, soil properties, water chemistry and groundwater supply. Floodplains, riparian buffers and in-stream processes combine to determine nutrient reduction efficiencies in watercourses, which may vary spatially and temporally in each of these interrelated environments. Lower uptake lengths[1] in first order streams suggests more efficient phosphorus retention driven by the inherent abiotic and biotic characteristics of those watercourse types (HESL, 2017). Higher order and agricultural-influenced watercourses tend retain less nutrients than more pristine or first order watercourses. Phosphorus retention efficiencies from various studies are presented in Table 2 and demonstrate the wide range of phosphorus reduction in watercourses due to site-specific factors.

Table 2. Phosphorus Reduction Efficiencies of Rivers from Various Studies

Total Phosphorus Reduction Efficiency	Primary Influencing Factors Investigated	Reference
28% after restoration	3 stage restoration including streams and wetlands	Richardson et al. 2011
Duffin Creek = 92%, Nottawasaga River = 44%	Seasonality, hydrology	Hill 1982
<10% - >30%	Flow conditions	House 2003
50% of SRP	Biological uptake during spring	
60%	Downstream of sewage treatment plant	Withers and Jarvie 2008

Watercourse BMPs are designed to increase nutrient retention efficiencies within the stream channel and are an important consideration for nutrient management in the Muskrat Lake watershed. Many in-stream and riparian BMPs are available such as shoreline softening, bank stabilization and channel realignment. These BMPs will be considered in future project phases.

[1] *Uptake length is indicative of the phosphorus retention efficiency of a watercourse, lower uptake length suggests higher phosphorus-uptake efficiency and cycling*

Township of Whitewater Region
County of Renfrew

Waterbodies

Legend

Township of Whitewater Region

Watercourse

Muskrat River

Waterbody

1:60,000

N

0 0.5 1 2 Km

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4.1.2 Lakes

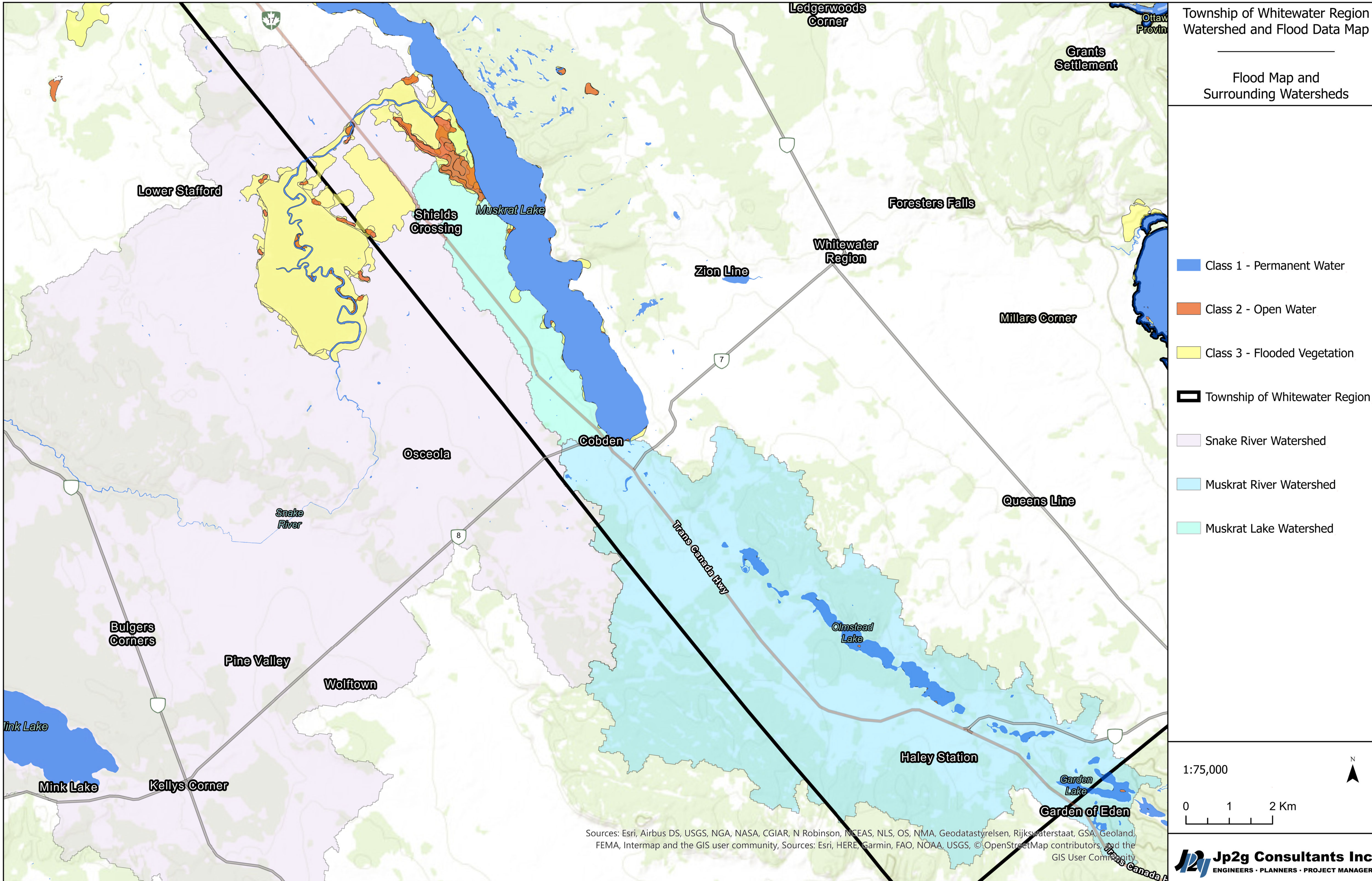
Nutrient retention rates in lakes are affected by a variety of different processes, the most important being water residence time as greater residence time increases settling and nutrient retention. Overland flow passes through a series of lakes in the Muskrat River watershed prior to draining into Muskrat Lake. The lakes include: Garden Lake, Edmunds Lake, Blanchards Lake, Smiths Lake, Galilee Lake, Dump Lake, Eadys Lake, Pumphouse Lake, Jeffreys Lake, Olmstead Lake, Round Lake, and Astrolabe Lake. These lakes all serve as storage and treatment opportunities for sediment prior to reaching Muskrat Lake.

4.1.3 Floodplains

Nutrient processing in floodplains largely dictates nutrient concentrations in adjacent watercourses by transforming nutrient forms and loads from upstream sources and from watercourses through complex biotic and abiotic processes. Hydrology shapes the physical and biological characteristics of floodplains and is therefore the key factor that regulates the transport of nutrients, including phosphorus, between floodplains and watercourses (Hoffmann et al. 2009, Richardson et al. 2011, Newcomer Johnson et al. 2016). Hydrological connectivity and the different flow paths that operate within floodplains determine how, when and where phosphorus interacts with soils and vegetation and are therefore key considerations for assessing the potential for phosphorus retention (Hoffmann et al. 2009.). Sedimentation, which occurs along many flow paths is the main removal process for phosphorus in floodplains.

Flooding can result in the export of nutrient-enriched stormwater from terrestrial lands to adjacent low-lying lands or watercourses. Figure 5 and Figure 6 show the National Research Canada (NRCan) flooding data from 2019. Figure 5 depicts the three classes of flooding: Class 1 represents permanent water bodies, Class 2 represents flood extents that can be directly observed by satellite observation, and Class 3 represents any flood which happens in flooded forest environment. Figure 6 depicts the extent of flooding on five separate days in April and May of 2019. In the Snake River Watershed, there are significant floodplains due to the flat surrounding areas between the Snake River PSW and Muskrat Lake. Large extents of flooding were evident throughout the spring of 2019 and designated as either “Class 2 – Open Water” or “Class 3 – Flooded Vegetation”.

Floodplain reconnection and flood loss reduction are potential BMPs to consider in future project phases. Floodplains have typically become disconnected to improve agricultural potential and for a host of other reasons. Areas that were cut-off by tile drains, or through channel straightening were historically included in the floodplain of a watercourse, greatly improving nutrient retention efficiencies of the riverine system as flows spread out, dissipate and deposited sediment. Flood loss reduction generally refers to improved drainage engineering where flooding is mitigated through improved drainage controls.


Township of Whitewater Region
Watershed and Flood Data Map
Flood Map and
Surrounding Watersheds
Class 1 - Permanent Water
Class 2 - Open Water
Class 3 - Flooded Vegetation
Township of Whitewater Region
Snake River Watershed
Muskrat River Watershed
Muskrat Lake Watershed
1:75,000
N
0 1 2 Km
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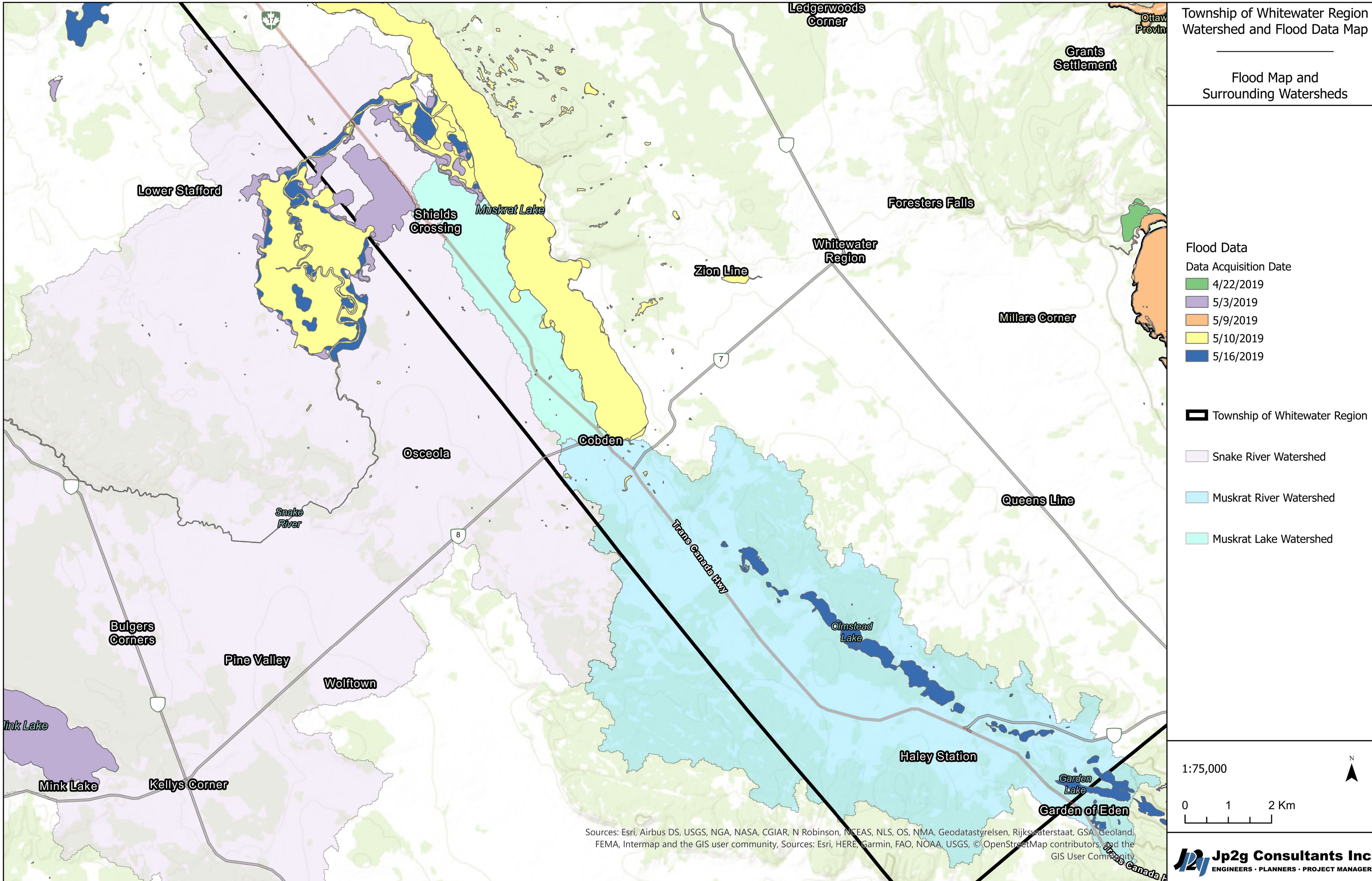
Ledgerwoods Corner
Grants Settlement
Lower Stafford
Shields Crossing
Muskrat Lake
Foresters Falls
Whitewater Region
Zion Line
Millars Corner
Cobden
Osceola
Queens Line
Snake River
Trans Canada Hwy
Olmstead Lake
Bulgers Corners
Pine Valley
Wolftown
Haley Station
Garden Lake
Garden of Eden
Mink Lake
Kellys Corner
17
7
8
Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community



Township of Whitewater Region
Watershed and Flood Data Map
Flood Map and
Surrounding Watersheds
Flood Data
Data Acquisition Date
4/22/2019
5/3/2019
5/9/2019
5/10/2019
5/16/2019
Township of Whitewater Region
Snake River Watershed
Muskrat River Watershed
Muskrat Lake Watershed
1:75,000
N
0
1
2 Km
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Ledgerwoods Corner
Grants Settlement
Lower Stafford
Shields Crossing
Muskrat Lake
Foresters Falls
Whitewater Region
Zion Line
Millars Corner
Cobden
Osceola
Snake River
Queens Line
Trans Canada Hwy
Olmstead Lake
Bulgers Corners
Pine Valley
Wolftown
Haley Station
Garden Lake
Garden of Eden
Mink Lake
Kellys Corner
17
7
8
Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community

4.1.4 Wetlands

The natural heritage features of the Cobden PSW and Snake River PSW and an evaluation of their status as nutrient sinks or sources was assessed in section 6.0.

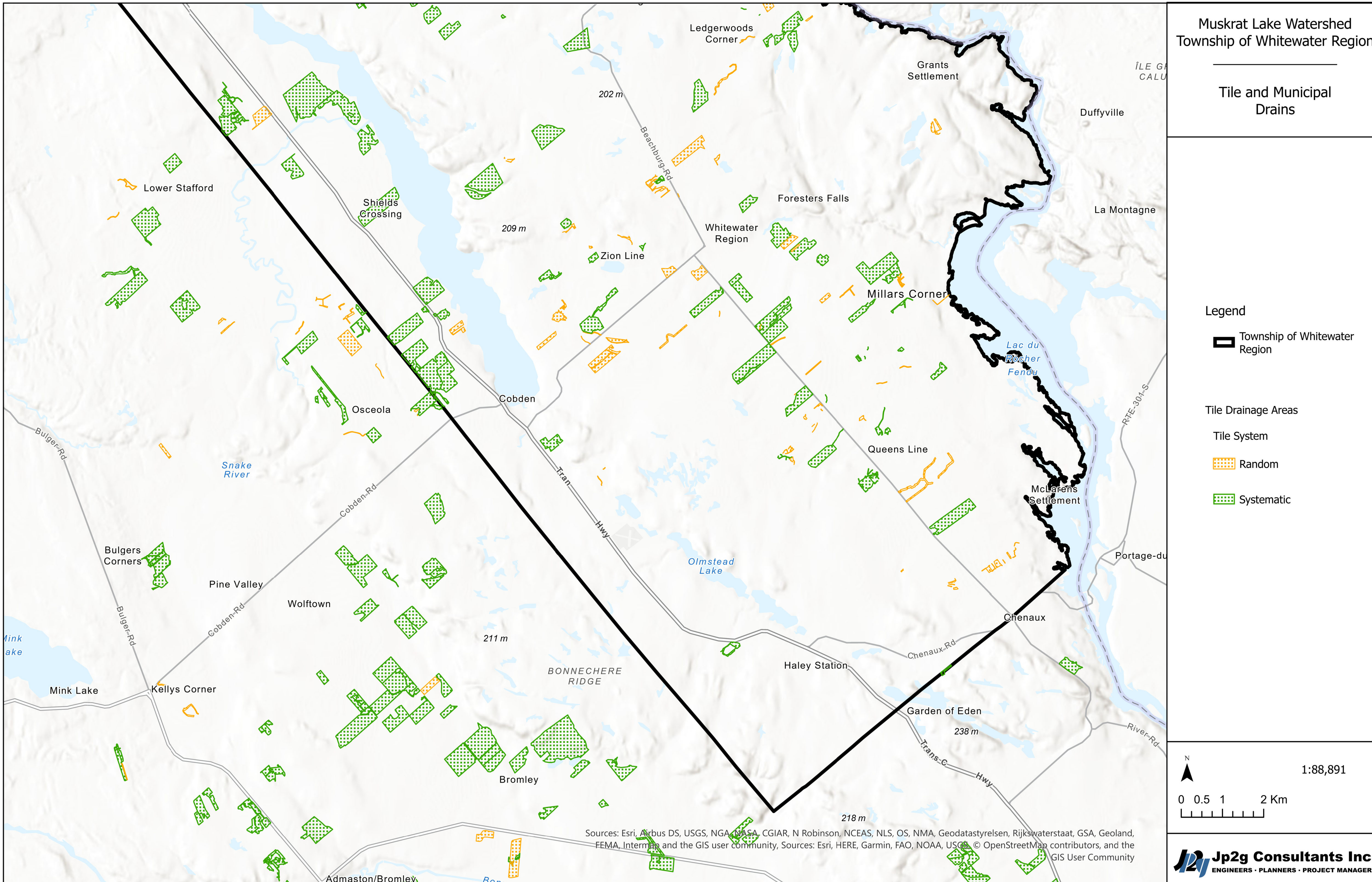
4.2 Artifical SWM Features

The locations of tile drains and municipal drains are provided in Figure 7.

4.2.1 Tile Drainage

Phosphorus is transported from agricultural fields to adjacent watercourses via surface flow and subsurface flow, and much of the subsurface flow is conveyed by tile drains where they exist. Tile drains are designed to remove excess water quickly from below the soil surface to avoid crop damage and decreased yields. Tile drainage impacts hydrology substantially by increasing water output, reducing surface runoff and sedimentation, and eliminating saturated areas.

Dalton (2019) noted that two controlled tile draining structures were implemented and they reduced nitrate by 65% and phosphorus by 63%. There are multiple tile drains in the study area, predominantly in the Snake River Watershed (Figure 7; Photographs 1-5). Tile drains are mapped as either "Systematic" where the drains have been installed in a crosshatched, regular pattern, or "Random" where tile drains have been installed where needed, for example to drain a wet spot in a field.



Muskrat Lake Watershed
Township of Whitewater Region
Tile and Municipal Drains
Legend
Township of Whitewater Region
Tile Drainage Areas
Tile System
Random
Systematic
N
1:88,891
0 0.5 1 2 Km
Jp2g Consultants Inc.
ENGINEERS · PLANNERS · PROJECT MANAGERS
Ledgerwoods Corner
Grants Settlement
Duffyville
Lower Stafford
Shields Crossing
Foresters Falls
Whitewater Region
La Montagne
Zion Line
Millars Corner
Lac du Rocher Fendu
Cobden
Osceola
Queens Line
Snake River
McLarens Settlement
Bulgers Corners
Pine Valley
Wolftown
Olmstead Lake
Portage-du
Chenaux
Haley Station
Mink Lake
Kellys Corner
Garden of Eden
Bromley
Admaston/Bromley
BONNECHERE RIDGE
Beachburg-Rd
Bulger-Rd
Cobden-Rd
Trans-C Hwy
Chenaux-Rd
River-Rd
RTE-301-S
202 m
209 m
211 m
218 m
238 m
Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community

Photograph 1. Tile Drain adjacent to Highway 17 - Snake River Watershed

Photograph 2. Drain Outlet - Snake River Watershed

Photograph 4. Drain Outlet - Snake River Watershed

Photograph 5. Tile Drain Astrolabe Road - Muskrat River Watershed

4.2.2 Municipal Drainage

Municipal drains are often implemented to improve drainage from agricultural lands in a similar manner as tile drains. Based on the Artificial Drainage Mapping from the Ontario Ministry of Agriculture and Food, it was determined that there is one municipal drain in the Muskrat River Watershed, called the Haley Municipal Drain (Photographs 6 and 7). There are multiple municipal drains upstream of Whitewater Region as well which drain to the Snake River.

Photograph 6. Haley Municipal Drain

Photograph 7. Outlet to Haley Municipal Drain

5. Source Areas of Nutrient Loss

Source areas of nutrient loss were identified through multiple lines of evidence. Information on water quality concentrations and loads were combined with information on land use (field investigations and review of mapping) to determine agricultural lands where future phases of the study should be focused. These areas represent source areas of nutrient loss and therefore implementation of BMPs will have the greatest benefit to downstream receiving water systems such as the Cobden PSW, Snake River PSW and Muskrat Lake.

5.1 Water Quality Results

Total phosphorus is generally the limiting nutrient for production of algae and macrophytes in freshwater environments. Various ratios such as Total Nitrogen (TN) to Total Phosphorus (TP) have been developed to define nitrogen-and phosphorus-limited conditions and systems. Guildford and Hecy (2000) found that nitrogen-deficient growth is found where TN:TP<20 and phosphorus-deficient growth is found where TN:TP>50. Schindler et al. (2008) however noted that reducing nitrogen inputs favored nitrogen fixing cyanobacteria and that nitrogen fixation was sufficient to allow for increased biomass in proportion to TP, indicating that lake and watershed management should be focused on TP.

Muskrat Lake data from 2014 – 2018 (MLK-02) were used to calculate the TN:TP molar ratio in Muskrat Lake. The TN:TP molar ratio ranged from 23.3 to 230, with a mean value of 23.3 indicating that Muskrat Lake is generally limited by phosphorus inputs (Table 3). Ratios indicated that the lake was phosphorus-limited on 15 occasions and not limited by either nutrient on three occasions according to ratios presented by Guildford and Hecky (2000).

We have focused on both TN and TP from watershed sampling locations to identify source areas of nutrient loss but nutrient budgets and nutrient removal efficiencies of BMPs will be focused on TP because there is limited information on export coefficient modelling for TN or for TN-related reductions through BMP implementation, reductions in TN will not likely reduce algal biomass in downstream waterbodies because of nitrogen fixing cyanobacteria as noted by Schindler et al. (2008), and algal growth in Muskrat Lake is generally limited by phosphorus. Future BMPs will nonetheless improve TN as well as TP as the nutrients follow similar pathways.

Table 3. Total Phosphorus, Total Nitrogen and Total Nitrogen : Total Phosphorus at MLK-02.

Date	TP mol (mg/L)	TN mol (mg/L)	TN:TP molar ratio
2014-07-09	0.16	37.1	230
2015-06-15	0.45	23.6	52.1
2015-07-14	0.45	27.1	60.0
2015-08-11	0.65	35.7	55.3
2015-09-30	0.68	34.3	50.5
2016-05-24	0.58	33.5	57.7
2016-06-14	0.48	41.4	85.5
2016-07-12	0.58	34.3	58.9
2016-08-17	0.45	34.3	75.8
2016-10-03	0.32	32.1	99.5
2017-06-05	0.55	42.8	78.0
2017-07-10	0.90	32.8	36.3
2017-08-16	0.61	32.1	52.4
2017-09-20	0.58	30.7	52.8
2018-05-15	1.49	44.3	29.8
2018-06-19	0.39	27.8	71.8
2018-07-10	0.36	24.3	68.3
2018-08-13	1.16	27.1	23.3
		Minimum	23.3
		Maximum	230
		Mean	68.8

Total Suspended Solids (TSS) was also examined because nutrients are often elevated under high TSS conditions and TSS is often elevated because of sedimentation which is likely driven by agricultural runoff at the sampling locations.

5.1.1 Total Phosphorus

Median TP concentrations ranged from 0.011 mg/L (PH-01) and 0.012 mg/L (OS-01) to 0.178 mg/L (SC-02; Table 4). Between 2014 and 2019, sites with the greatest TP concentrations included SC-02 (median concentration of 0.178 mg/L), MKR-03 (median concentration of 0.120 mg/L) and SNR-04 (median concentration of 0.042 mg/L).

TP concentrations in the Whitewater Region in general, were highest in July or August (Figure 8). Monthly median TP concentrations were consistently greatest at SC-02 (a tributary that discharges to the Snake River PSW) ranging from 0.056 mg/L in April to 0.469 mg/L in July. Interpretation of monthly data should be viewed with caution due to differences in the number of samples available per site per month (Table 5).

Based on linear regression analysis TP concentrations were not statistically significantly related to total daily precipitation (Table 6).

Total phosphorus concentrations exceeded the PWQO and the threshold for stream impairment developed for Mixedwood Plains Ecozone of Ontario (Chambers et al., 2012) of 0.03 mg/L at all sites on various occasions. Percent exceedances (i.e. the % of samples that exceeded the guideline of 0.03 mg/L) ranged from 7% at PH-01 and OS-01 to 100% at SC-02 (Table 7).

A review of 15 streams in agricultural watersheds in Southwestern Ontario between 2006 and 2009 found a range in TP concentrations between 0.002 to 0.129 mg/L (MOE 2012). The same study with an expanded dataset ranging from 2004 to 2009 found median concentrations ranging between 0.018 and 0.156 mg/L with median concentrations from 9 out of 15 streams exceeding the PWQO (MOE 2012). DeBues et al. (2019) noted mean TP concentrations of 0.01 to 0.044 mg/L in watersheds with 50% agricultural landcover between May and September in Lake Ontario tributaries.

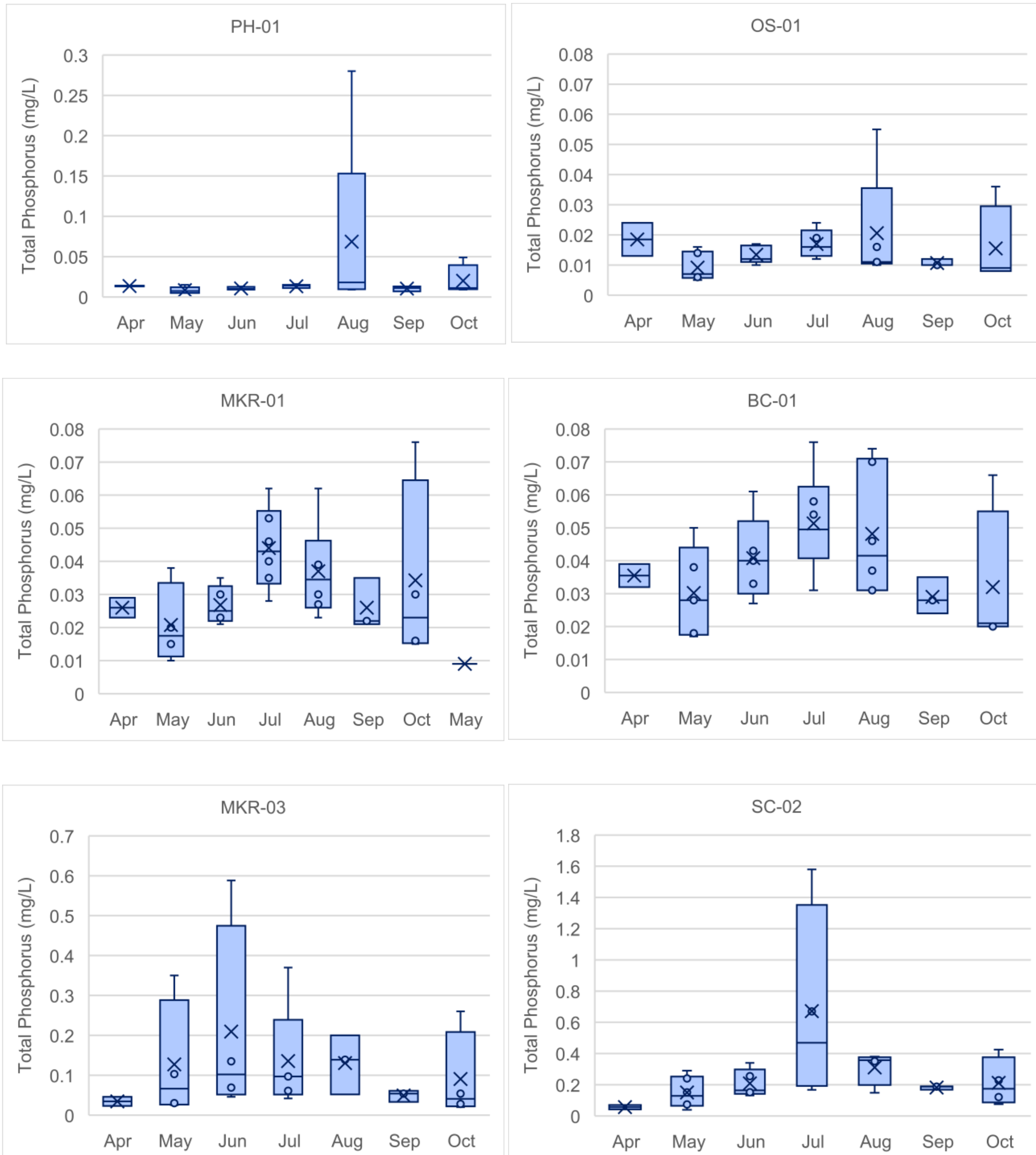
Median TP concentrations measured in the Whitewater Region are similar to those found in Southern Ontario as reported by MOE (2012), while median concentrations at MKR-03 and SC-02 are higher than those presented in DeBues et al. (2019). The MOE (2012) study also found that TP concentrations were close to the annual average between July and September and high in October. This pattern is in contrast to what was observed in the Whitewater Region with low median October TP concentrations and high TP concentrations in July.

Table 4. Total Phosphorus Summary Stats for the Whitewater Region for April to October 2014 to 2019.

Total Phosphorus						
Sites	Mean	Median	Min	Max	Range	Number of Samples
PH-01	0.022	0.011	0.005	0.280	0.275	30
OS-01	0.015	0.012	0.005	0.055	0.050	30
MKR-01	0.032	0.029	0.009	0.076	0.067	31
BC-01	0.040	0.037	0.017	0.076	0.059	31
MKR-03	0.120	0.061	0.020	0.588	0.568	25
SC-02	0.263	0.178	0.039	1.580	1.541	28
SNR-04	0.050	0.042	0.017	0.264	0.247	32
SC-01	0.022	0.085	0.017	0.785	0.768	33

SNR-03	0.015	0.034	0.005	0.054	0.049	32

Figure 8. Monthly Total Phosphorus Concentrations in The Whitewater Region from April to October from 2014 to 2019.



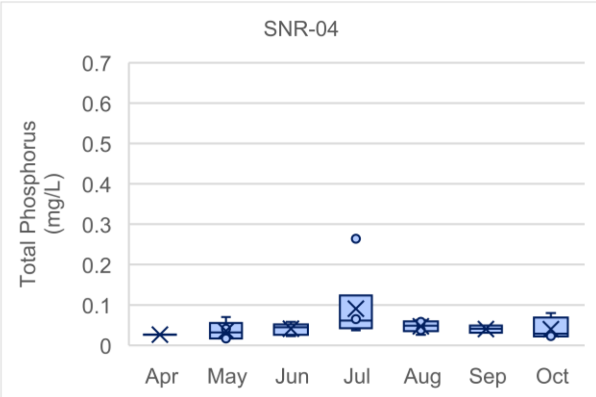


Table 5. Number of Monthly Samples Available per Site.

Site	April	May	June	July	August	September	October	Total
OS-01	2	6	5	5	5	3	4	30
MKR-01	2	5	5	6	6	3	4	31
BC-01	2	5	5	6	6	3	4	31
MKR-03	2	4	4	5	3	3	4	25
PH-01	2	6	5	5	5	3	4	30
SC-02	2	6	5	4	4	3	4	28
SNR-04	2	5	6	6	6	3	4	32

Table 6. Linear Regression Results for Total Phosphorus and Precipitation.

Site	r^2	P
PH-01	0.0048	0.732
OS-01	0.0008	0.890
MKR-01	0.0163	0.517
BC-01	0.0320	0.372
MKR-03	0.0386	0.393
SC-02	0.0001	0.955
SNR-04	0.0083	0.646

Table 7. Exceedance of PWQO and Threshold for Impairment for Phosphorus (0.030 mg/L) in the Whitewater Region.

Sites	Exceedance	Count	Percent Exceedance
PH-01	2	30	7%
OS-01	2	30	7%
MKR-01	12	31	39%
BC-01	22	31	71%

Sites	Exceedance	Count	Percent Exceedance
MKR-03	20	25	80%
SC-02	28	28	100%
SNR-04	23	32	72%
SC-01	31	34	91%
SNR-03	17	32	53%

5.1.2 Total Nitrogen

Median TN concentrations were similar at five of the seven sites and ranged from 0.31 mg/L (OS-01) to 0.48 mg/L (MKR-03), while median concentrations at SNR-04 (0.65 mg/L) and SC-02 (0.92 mg/L) were higher (Table 8). Median monthly TN concentrations at four (PH-01, MKR-01, SC-02, SNR-04) of the seven sites in the Whitewater Region were highest in October, and highest in May at OS-01, BC-01 and MKR-03 (Figure 9). As noted with TP monthly samples varied between sites, interpretation of monthly data should be viewed with caution due to differences in the number of samples available per site per month (Table 9).

TN concentrations were not statistically significantly related with total daily precipitation (Table 8).

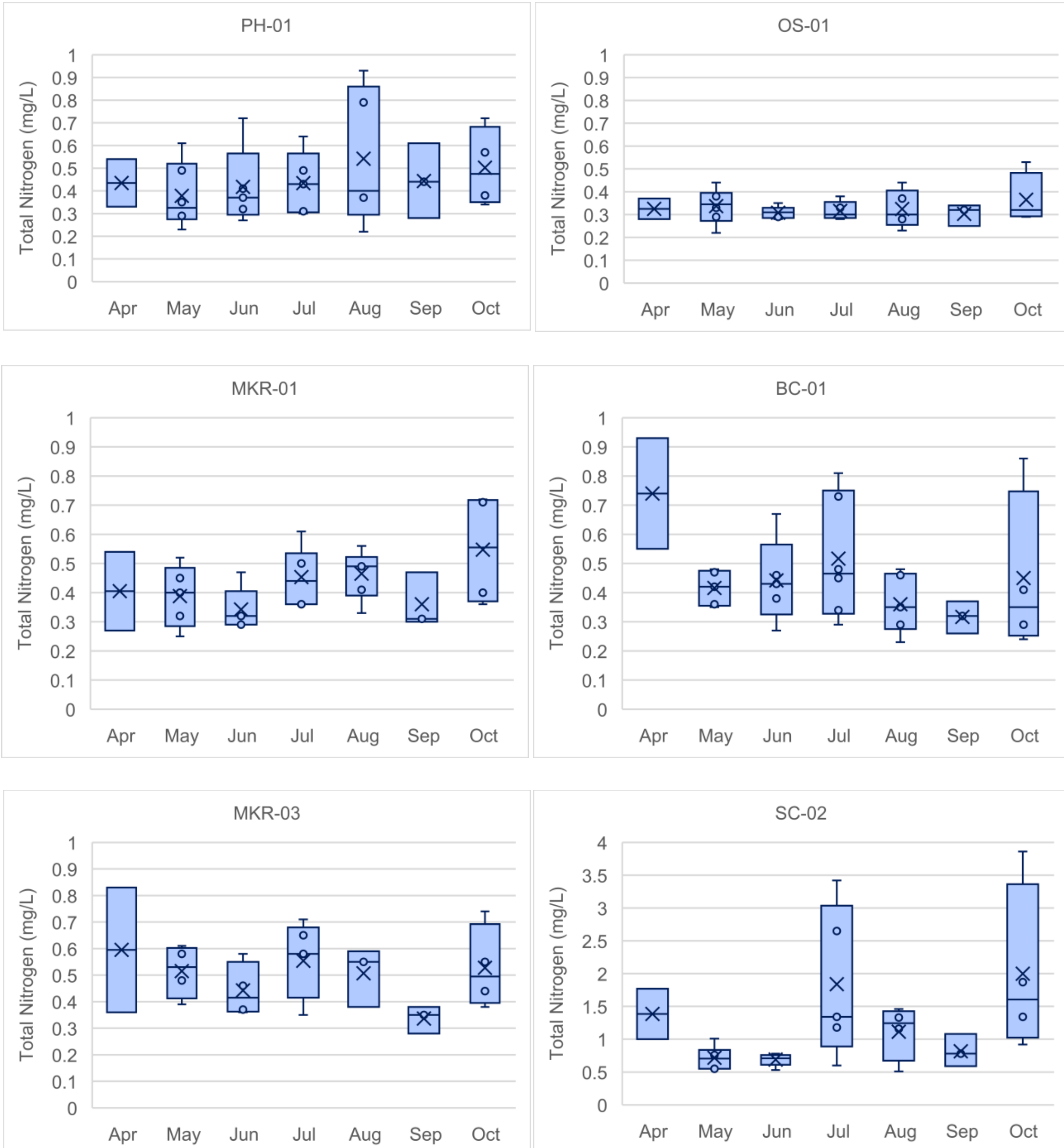
TN concentrations exceeded the threshold for stream impairment (1.10 mg/L) developed for the Mixedwood Plains Ecozone of Ontario (Chambers et al., 2012) at SC-02 (38% of samples) and SNR-04 (10% of samples, Table 11). SC-02, SNR-04 and MKR-03 had high concentrations of both TN and TP.

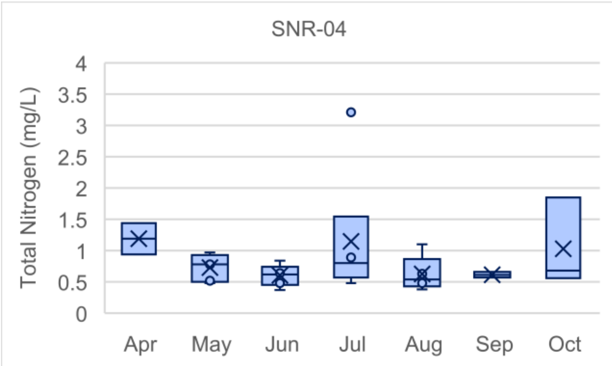
Between 1992-2001 the U.S. EPA (2007) investigated 133 streams in agricultural watersheds across the United States and found that 78% of streams had mean TN concentrations of 2 mg/L or greater during average flow conditions. Only one site in the Whitewater Region had a mean TN concentration greater than 2 mg/L suggesting concentrations in the area are relatively low compared to other agricultural watersheds in North America.

Table 8. Total Nitrogen Concentrations in the Whitewater Region from April to October from 2014 to 2019.

Site	Mean	Median	Min	Max	Range	Count
PH-01	0.45	0.39	0.22	0.93	0.71	30
OS-01	0.33	0.31	0.22	0.53	0.31	30
MKR-01	0.43	0.4	0.25	0.72	0.47	31
BC-01	0.45	0.41	0.23	0.93	0.7	31
MKR-03	0.50	0.48	0.28	0.83	0.55	25
SC-02	1.19	0.92	0.51	3.86	3.35	29
SNR-04	15.4	0.65	0.37	3.21	2.84	30

Figure 9. Monthly Total Nitrogen Concentrations in the Whitewater Region from 2014 to 2019.





Note: The y-axis scale was increased from 1.00 mg/L to 4.00 mg/L for SC-02 and SNR-04 to accommodate the higher monthly concentrations.

Table 9. Number of Monthly Samples Available per Site.

Site	April	May	June	July	August	September	October	Total
OS-01	2	6	5	5	5	3	4	30
MKR-01	2	5	5	6	6	3	4	31
BC-01	2	5	5	6	6	3	4	31
MKR-03	2	4	4	5	3	3	4	25
PH-01	2	6	5	5	5	3	4	30
SC-02	2	6	5	5	4	3	4	29
SNR-04	2	5	6	6	5	3	3	30

Table 10. Linear Regression Results for Total Nitrogen and Precipitation.

Site	r^2	P
PH-01	0.0163	0.525
OS-01	0.0088	0.648
MKR-01	0.0178	0.506
BC-01	0.0842	0.142
MKR-03	0.0201	0.539
SC-02	0.0060	0.713
SNR-04	0.0067	0.685

Table 11. Exceedance of Total Nitrogen Threshold for Stream Impairment (1.10 mg/L) in the Whitewater Region.

Site	Exceedance	Count	Percent Exceedance
PH-01	0	30	0%
OS-01	0	30	0%
MKR-01	0	31	0%

Site	Exceedance	Count	Percent Exceedance
BC-01	0	31	0%
MKR-03	0	25	0%
SC-02	11	29	38%
SNR-04	3	30	10%

5.1.3 Total Suspended Solids

TSS concentrations in the Whitewater Region were variable ranging from 0.5 mg/L (PH-01, OS-01, MKR-03[2], SC-02) to 77.4 mg/L (SC-02, Table 12). Median suspended sediment concentrations were low and ranged from 1.3 mg/L (OS-01) to 5.3 mg/L (BC-01).

There was no month that consistently contained high suspended sediment concentrations in the Whitewater Region (Figure 10). As previously noted, number of monthly samples varied with site (Table 13). Suspended sediment concentrations were not statistically significantly related to total daily precipitation (Table 14).

Suspended solid concentrations had a positive and significant ($p<0.001$) relationship with TP concentrations at MKR-01 (Figure 11), BC-01 (Figure 12) and MKR-03 (Figure 13) while the relationship was close to statistical significance at SC-02 (Figure 14, $p = 0.05$). It should be noted that the significantly positive relationship between TSS and TP occurs at three sites in close proximity to one another suggesting there is a shared driver such as overland runoff. Strong positive relationships between TSS and TP frequently occur in agricultural areas however, pasture land use varies between the three sites and is limited at BC-01 (6.5% of upstream land use) and MKR-03 (4.8% of upstream land use, Section 5.2).

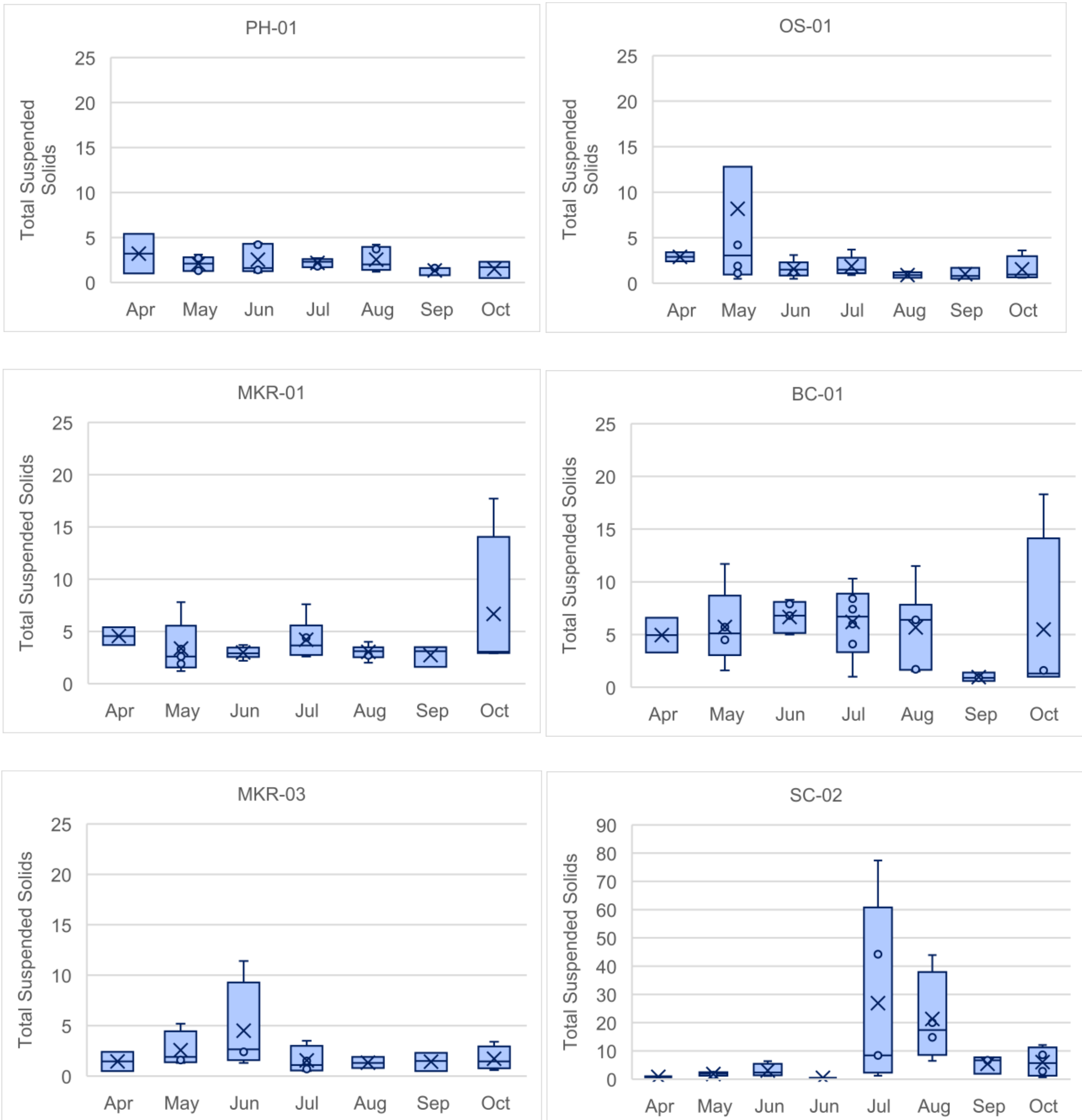
Table 12. Suspended Solids Concentrations in the Whitewater Region from April to October from 2014 to 2019.

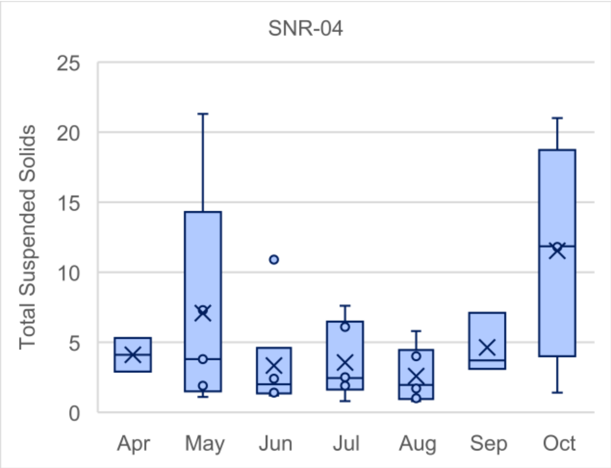
Total Suspended Solids (mg/L)							
Site	Mean	Min	Max	Range	Median	Stdev	Count
PH-01	2.2	0.5	5.4	4.9	1.7	1.2	29
OS-01	2.9	0.5	36.5	36.0	1.3	6.5	30
MKR-01	3.8	1.2	17.7	16.5	3.1	2.9	31
BC-01	5.4	0.6	18.3	17.7	5.3	4.0	31
MKR-03	2.2	0.5	11.4	10.9	1.6	2.3	24
SC-02	9.9	0.5	77.4	76.9	2.6	17.1	29
SNR-04	5.0	0.8	21.3	20.5	2.7	5.3	32

Notes: Range is the maximum minus the minimum. StDev is the standard deviation.

[2] *A TSS value at station MKR-03 collected in July 2015 (33.8 mg/L) was unusually high (greater than the mean plus three times the standard deviation, 23.6 mg/L) and therefore removed from analysis.*

Figure 10. Monthly Suspended Solids Concentrations in the Whitewater Region from 2014 to 2017.





Note: The y-axis scale was increased from 25 mg/L to 90 mg/L for SC-02 to accommodate the higher monthly concentrations.

Table 13. Number of Monthly Samples Available per Site.

Site	April	May	June	July	August	September	October	Total
OS-01	2	6	5	5	5	3	4	30
MKR-01	2	5	5	6	6	3	4	31
BC-01	2	5	5	6	6	3	4	31
MKR-03	2	4	4	4	3	3	4	24
PH-01	2	6	5	5	5	3	4	30
SC-02	2	6	5	5	4	3	4	29
SNR-04	2	5	6	6	6	3	4	32

Table 14. Linear Regression Results for Suspended Sediments and Precipitation.

Site	r^2	P
PH-01	0.0163	0.525
OS-01	0.0088	0.648
MKR-01	0.0178	0.506
BC-01	0.0842	0.142
MKR-03	0.0220	0.524
SC-02	0.0060	0.713
SNR-04	0.0067	0.685

Table 15. Linear Regression Results for Total Phosphorus and Suspended Solids.

Site	r^2	P
PH-01	0.0046	0.722
OS-01	0.0002	0.939
MKR-01	0.5080	<0.001
BC-01	0.5180	<0.001
MKR-03	0.6650	<0.001
SC-02	0.1400	0.05
SNR-04	0.0033	0.756

Figure 11. Total Suspended Solid vs. Total Phosphorus Concentrations at MKR-01.

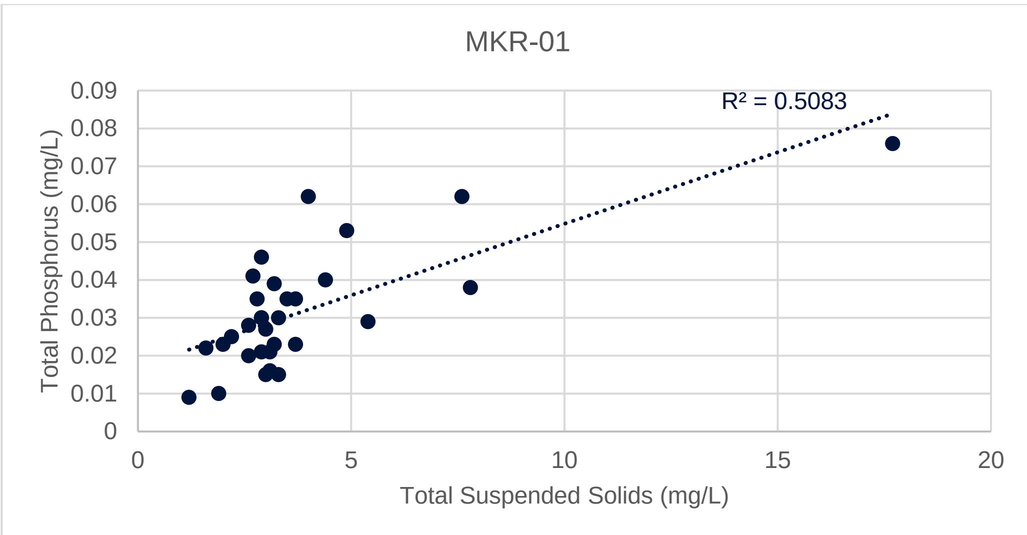


Figure 12. Total Suspended Solid vs. Total Phosphorus Concentrations at BC-01.

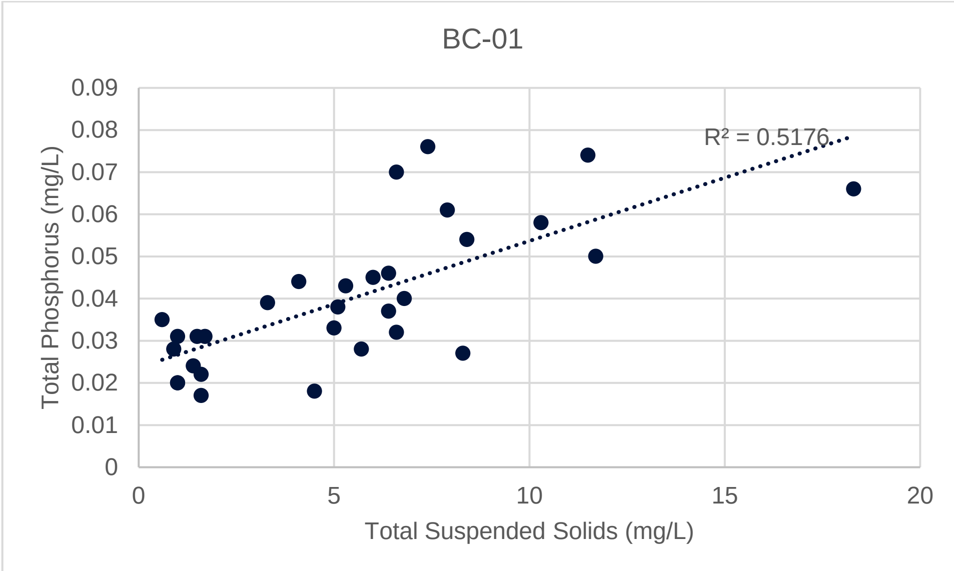


Figure 13. Total Suspended Solid vs. Total Phosphorus Concentrations at MKR-03.

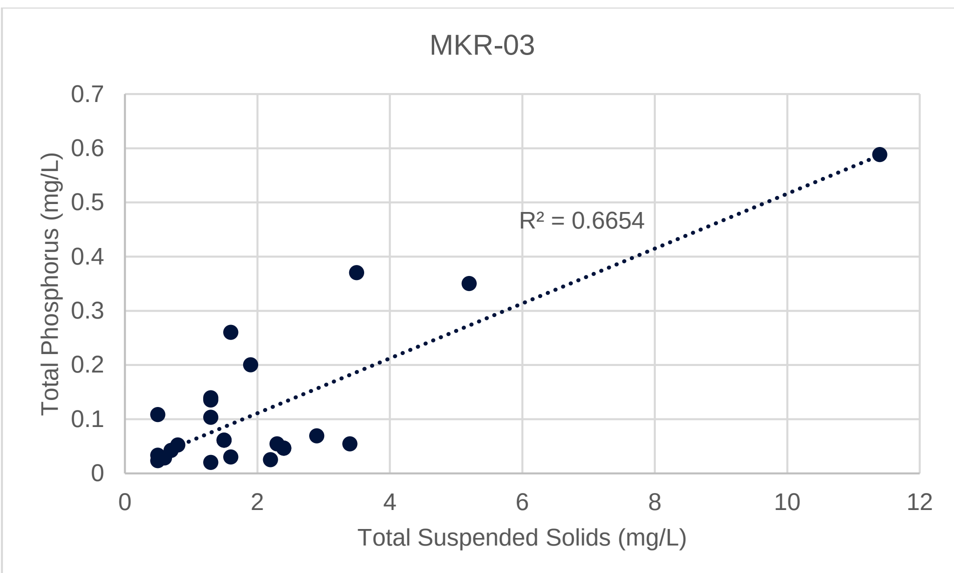
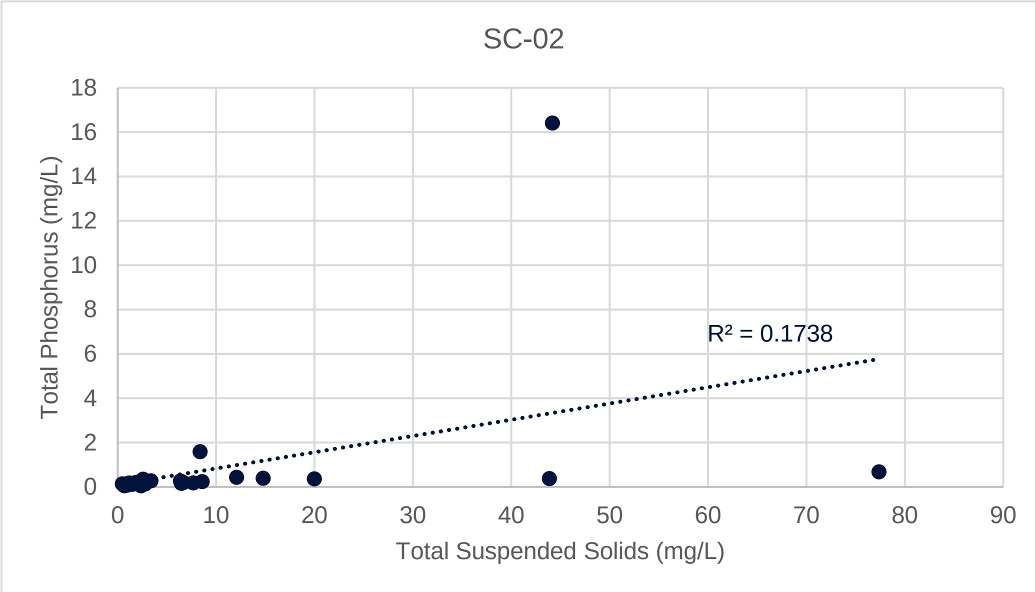


Figure 14. Total Suspended Solid vs. Total Phosphorus Concentrations at SC-02.



5.1.4 Nutrient Loads

5.1.4.1 Flow

The Ontario Flow Assessment Tool (OFAT) was used to calculate mean annual flows for each of the seven Whitewater Region sampling stations (Table 16). Catchment sizes ranged considerably from 1,030 ha (BC-01) to 37,980 ha (SNR-04; Table 16). Flows increased from upstream (e.g., PH-01 with a mean annual flow of 0.15 m^3/s) to downstream in the watershed (e.g., SNR-04 with a mean annual flow of 3.63 m^3/s).

Table 16. OFAT Mean Annual Flow Values at Water Quality Monitoring Sites within Whitewater Region.

Site	Catchment Size (ha)	Mean Annual Flow (m^3/s)
PH-01	1,350	0.15
OS-01	3,810	0.40
MKR-01	5,480	0.56
MKR-03	5,490	0.66
BC-01	1,030	0.10
SC-02	2,130	0.20
SNR-04	37,980	3.63

Annual TP and TN loads were calculated for the seven sites using the mean annual flows calculated using OFAT and site median concentrations.

5.1.4.2 Total Phosphorus Loads

TP loads ranged from 52 kg/year at PH-01 to 4,751 kg/year at SNR-04 while TP loads per ha ranged from 0.04 kg/ha/yr (PH-01 and OS-01) to 0.53 kg/ha/yr (SC-02). SNR-04 (4,751 kg/yr), MKR-03 (1,270 kg/year) and SC-02 (1,123 kg/year) had the largest annual TP loads (Table 17), and the highest median TP concentrations.

Table 17. Mean Annual Total Phosphorus Loads in the Whitewater Region.

Site	kg/year	kg/ha/yr
PH-01	52	0.04
OS-01	151	0.04
MKR-01	512	0.09
BC-01	117	0.11
MKR-03	1,270	0.23
SC-02	1,123	0.53
SNR-04	4,751	0.13

5.1.4.3 Total Nitrogen Loads

Total nitrogen loads ranged from 1,293 kg/year at BC-01 to 76,699 kg/year at SNR-04 and 1.03 kg/ha/yr (OS-01) to 2.72 kg/ha/yr (SC-02). Higher TN concentrations at SNR-04 (median concentration of 0.92 mg/L) in combination with high flows (3.63 m^3/s) resulted in the largest annual TN load calculated in the Whitewater Region (Table 8, Table 16, Table 18)

Table 18. Mean Annual Total Nitrogen Loads for the Whitewater Region.

Site	kg/year	kg/ha/yr
PH-01	1,845	1.37
OS-01	3,910	1.03
MKR-01	7,064	1.29
BC-01	1,293	1.26
MKR-03	9,991	1.82
SC-02	5,803	2.72
SNR-04	76,699	2.02

5.2 Land Use

5.2.1 OFAT Mapping

The amount of agricultural lands within the catchment of each water quality sampling location was calculated using the Ontario Flow Assessment Tool (Table 19). Corresponding figures are provided in Appendix B. The amount of agricultural land ranged from 4.07 km^2 (PH-01) to 126 km^2 (SNR-04). Percent of agricultural land within each catchment was similar for most sites (30.4% to 42%) and highest at SC-02 (67.8%).

Table 19. The Amount and Percentage of Agricultural (and undifferentiated) Land within the Catchment of each Water Sampling Location.

Site	Agriculture and Undifferentiated Rural Land Use (km^2)	
	km^2	%
BC-01	4.33	42.0
MKR-01	21.0	32.2
MKR-03	16.7	30.4
OS-01	12.0	31.5
PH-01	4.07	30.1
SC-02	14.5	67.8
SNR-04	126	33.1

5.2.2 Within 1 km of Water Quality Sampling Locations

Dalton (2019) characterized land use in a 1000 m x 200 m wide area (100 m on either stream/river bank) using satellite imagery data. Percentages of annual crop land (primarily corn and soybean crops), pasture/forage land (pasture land and land that is periodically cultivated with grasses and perennial crops such as alfalfa and clover for hay, pasture and seed), natural habitat and developed land (road, buildings, paved surfaced, urban/suburban areas and associated vegetation) were calculated and are presented in Table 20 and in Appendix C. Annual crop land adjacent to most sites was 0% except for SNR-04 (10.3%) and SC-02 (27.4%). Pasture/forage land ranged from 0% (SNR-04) to 24% (MKR-01).

Table 20. Land Uses Adjacent to Water Sampling Locations

Site	Annual Crop Land (%)	Natural (%)	Pasture/Forage (%)	Developed (%)
BC-01	0.0	90.4	3.2	6.4
OS-01	0.0	91.7	5.7	2.5
MKR-01	0.0	71.2	24.0	4.8
PH-01	0.0	90.9	3.5	5.6
MKR-03	0.0	91.1	0.7	8.3
SNR-04	10.3	87.7	0.0	2.1
SC-02	27.4	66.8	2.4	3.4

6. Cobden and Snake River Provincially Significant Wetlands

Wetlands are among the most productive and diverse habitats which provide a variety of social and economic needs in Ontario such as wildlife habitat, fish habitat, flood control, erosion reduction, groundwater recharge and discharge, climate change mitigation and resilience, recreation and tourism, food source and water quality improvement. Provincially Significant Wetlands have been determined by the Ministry of Natural Resources and Forestry as being the most valuable based on the Ontario Wetland Evaluation System and the standardized approach for evaluating the biological, social, hydrological and species features components of the wetlands.

A complex array of biogeochemical processes within wetlands act to trap and transform incoming nutrients, retaining them in the system for days to years, depending on biotic and abiotic conditions. Nutrient assimilation occurs through biological uptake, sedimentation, adsorption, precipitation and accumulation of organic matter. The functioning of wetlands as nutrient sinks is influenced by a wide variety of factors including vegetation, soil properties, wetland shape and size, hydrologic fluctuations, surrounding land uses, loading rates, hydraulic retention time, and seasonality.

Overall, phosphorus removal efficiencies vary tremendously. Some studies reported a net increase in total phosphorus export or no removal (Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. 2014; Chouinard et al. 2015), while others documented removal efficiencies of over 90% (Reddy et al. 1999; Chouinard et al. 2015. The high variability in phosphorus removal efficiencies is consistent with the wide range of possible biotic and abiotic conditions that influence phosphorus cycling in different wetlands, the dynamic nature of those conditions, and the ability of monitoring programs to capture them (e.g., of sufficient frequency to capture seasonal changes, interannual variability in weather conditions and the full range of flow conditions including floods). TP and TN concentrations and loads upstream and downstream of the Cobden and Snake River PSWs were calculated on a seasonal and annual basis to determine if the two PSWs were sources or sinks of TP and TN.

6.1 Cobden PSW

The Cobden PSW is a combination of swamp (39%) and marsh (61%) occupying 91.5 hectares of land. The site is 70% riverine and 30% lacustrine (Buckland and Beaudette, 1985a). The catchment upgradient of the outflow is 54 km^2 and 50% of the wetland has organic soils (Buckland and Beaudette, 1985a). Blanding's Turtle (threatened) and Spiny Softshell (threatened) have been observed within the PSW and within 100 m of the site (Muncaster Environmental Planning and Jp2g Consultants Inc., 2016). The wetland serves as a breeding or feeding habitat for Black Tern, Northern Harrier, and Marsh Wren and Pintail, Wigeon use the wetland during migration (Buckland and Beaudette, 1985a) and it's a spawning ground for Northern Pike (Muncaster Environmental Planning and Jp2g Consultants Inc., 2016). In 1985 the site was considered moderately disturbed due to roads, drainage, filling and the discharge of treated effluent from the Cobden Waste Water Treatment Plant (WWTP (located on a separate tributary not monitored in this study), Buckland and Beaudette, 1985a).

Total Phosphorus

TP concentrations at MKR-01, a station located on the Muskrat River upstream of the Cobden PSW and the discharge of Buttermilk Creek, and MKR-03, a station within the wetland complex downstream of Buttermilk Creek and MKR-01, were compared to determine if the Cobden PSW was acting as a sink or source of TP and TN. In general, the Cobden PSW acted as a TP source. TP concentrations were higher at the downstream site (MKR-03) compared to the upstream site (MKR-01) on 23 out of 25 occasions (Figure 15).

The differences in event-based TP concentrations were calculated and the median value for each month is presented in Table 21. TP concentrations increased marginally in April and October (0.009 mg/L) with greater changes noted in September (0.026 mg/L), July (0.035 mg/L), May (0.052 mg/L), June (0.077 mg/L) and August (1.00 mg/L). Mean annual TP loads were also greater downstream of the PSW (1,270 kg/year) compared to upstream (512 kg/year).

Figure 15. Total Phosphorus Concentrations Upstream and Downstream of the Cobden PSW between 2014 and 2019.

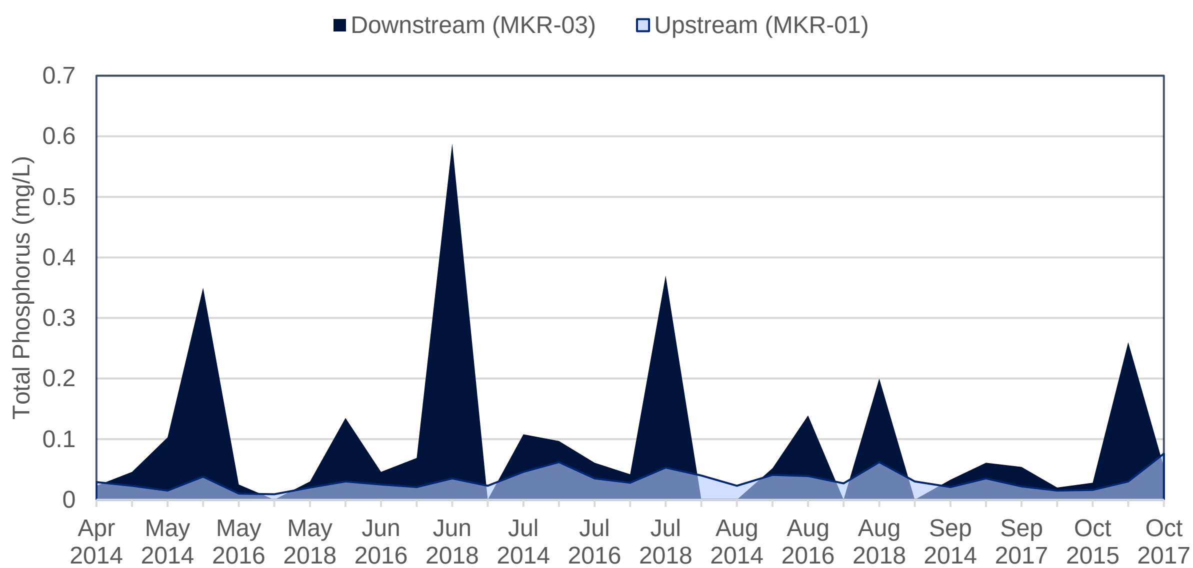


Table 21. Median Monthly Change in Phosphorus Concentrations in the Cobden PSW.

Month	Change in TP (mg/L)
April	+0.009
May	+0.052
June	+0.077
July	+0.035
August	+0.100
September	+0.026
October	+0.009

6.1.1 Total Nitrogen

Concentrations of TN were higher downstream at MKR-03 than MKR-01 on 18 out of 25 sampling occasions (Figure 15) indicating that the Cobden PSW generally acted as a source of TN. TN concentrations increased by 0.06 mg/L (August) to 0.19 mg/L (April), except in September when median concentrations decreased by 0.09 mg/L (Table 22, Figure 16). The mean annual TN load was also greater downstream (1,270 kg/yr) than upstream (512 kg/yr).

Figure 16. Total Nitrogen Concentrations Upstream and Downstream of the Cobden PSW between 2014 and 2019.

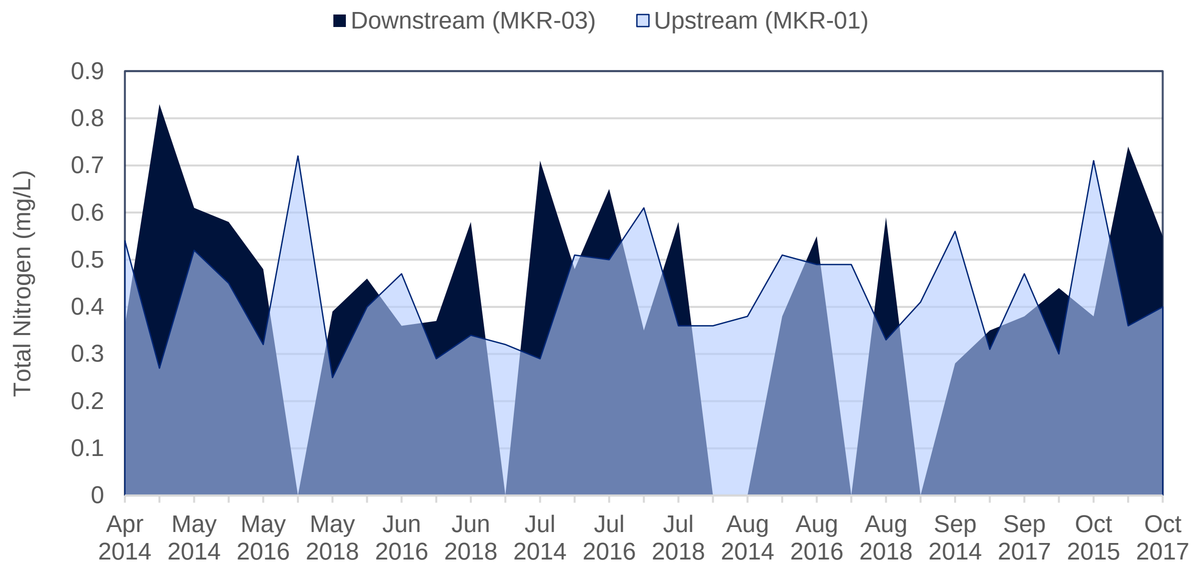


Table 22. Median Monthly Change in Total Nitrogen Concentrations Upstream and Downstream of the Cobden PSW.

Month	Change in TN (mg/L)
April	+0.19
May	+0.14
June	+0.07
July	+0.15
August	+0.06
September	-0.09
October	+0.15

6.2 Snake River PSW

The Snake River PSW is a mixture of deciduous swamp (84%) and marsh (16%) (MOE 2003) making up 879 hectares of land. The catchment basin above the wetland outflow is 302 km^2. The PSW is 95% riverine and 5% lacustrine at the river mouth. Soils in the wetland are a mixture of clays, loams or silts (35%), organic (55%) and undesignated (10%, Buckland and Beaudette, 1985b).

Migratory birds, raptors, marsh wren and black-billed cuckoos frequent the PSW (MOE 2003) and it is a known nesting area for black tern (Buckland and Beaudette, 1985b). The PSW is also known as critical spawning habitat for northern pike (Dillion, 1995). It is susceptible to frequent flooding (MOE 2003) and has been disturbed by roads, drainage and railroad tracks (Buckland and Beaudette, 1985b). MNR (2000) noted that the surrounding agricultural land use has impacted the nutrient status, plant diversity and abundance of the wetland.

6.2.1 Total Phosphorus

Several tributaries flow into the Snake River PSW. Water quality samples have been collected between April and October of 2014 and 2019 for three of these tributaries: SC-01, SC-02 and SNR-03. Water quality samples were also collected from the outlet of the Snake River PSW (SNR-04). Upstream concentrations were compared to downstream concentrations and upstream cumulative loads compared to downstream loads to evaluate if the Snake River PSW was a TP or TN sink between 2014 and 2019.

Average TP concentrations were greater upstream of the Snake River PSW compared to downstream on 31 out of 34 occasions indicating that the Snake River PSW was a sink for TP (Figure 17). The differences in event-based TP concentrations were calculated and the median value for each month is presented in Table 23. TP concentrations declined by 0.015 mg/L in April, 0.045 mg/L in May, 0.07 mg/L in June and between 0.102 mg/L and 0.135 mg/L in the remaining months.

The mean annual TP load downstream of the Snake River PSW (4,751kg/year) was slightly greater than the upstream load (4,589 kg/year). The greater load is due to the higher flow (3.63 m^3/s) downstream of the PSW compared to the three upstream sites (0.13 m^3/s at SC-01 + 0.2 m^3/s at SC-02 + 2.91 m^3/s at SNR-03 = 3.24 m^3/s). It should be noted that not all tributaries discharging to the Snake River PSW were monitored and therefore concentrations and flow entering the PSW were likely higher than those captured by the monitoring program and reported here. The Snake River PSW was a TP sink between 2014 and 2019 based on the decrease in TP concentrations downstream of the wetland.

Figure 17. Total Phosphorus Concentrations Upstream and Downstream of the Snake River PSW between 2014 and 2019.

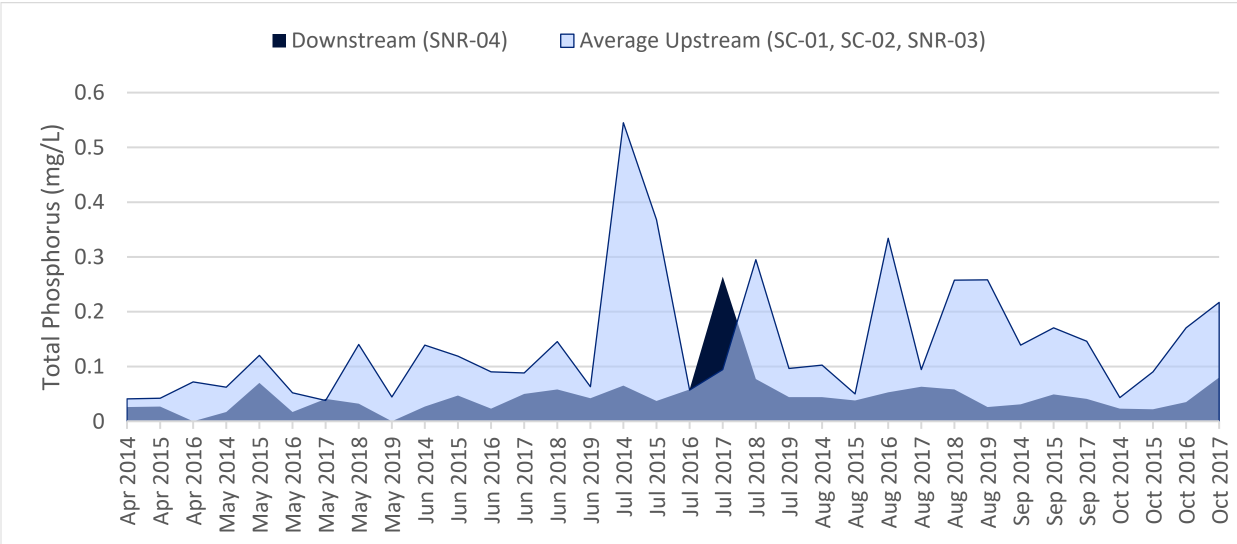


Table 23. Median Monthly Change in Phosphorus Concentrations Upstream and Downstream of the Snake River PSW.

Month	**Change in TP (mg/L)**
April	-0.015
May	-0.045
June	-0.070
July	-0.135
August	-0.129
September	-0.108
October	-0.102

6.2.2 Total Nitrogen

The Snake River PSW acted primarily as a sink for TN as average TN concentrations at the downstream sites were lower than the upstream site on 30 out of 34 sampling occasions (Figure 18). The differences in event-based TN concentrations were calculated and the median value for each month is presented in Table 24. Monthly median decreases in concentration from upstream to downstream ranged from 0.13 mg/L (May) to 0.80 mg/L (August, Table 24). The total upstream load (125,201 kg/yr) was substantially greater than the downstream load (76,699 kg/yr) providing further evidence that the Snake River PSW acted as a TN sink.

Figure 18. Total Nitrogen Concentrations Upstream and Downstream of the Snake River PSW between 2014 and 2019.

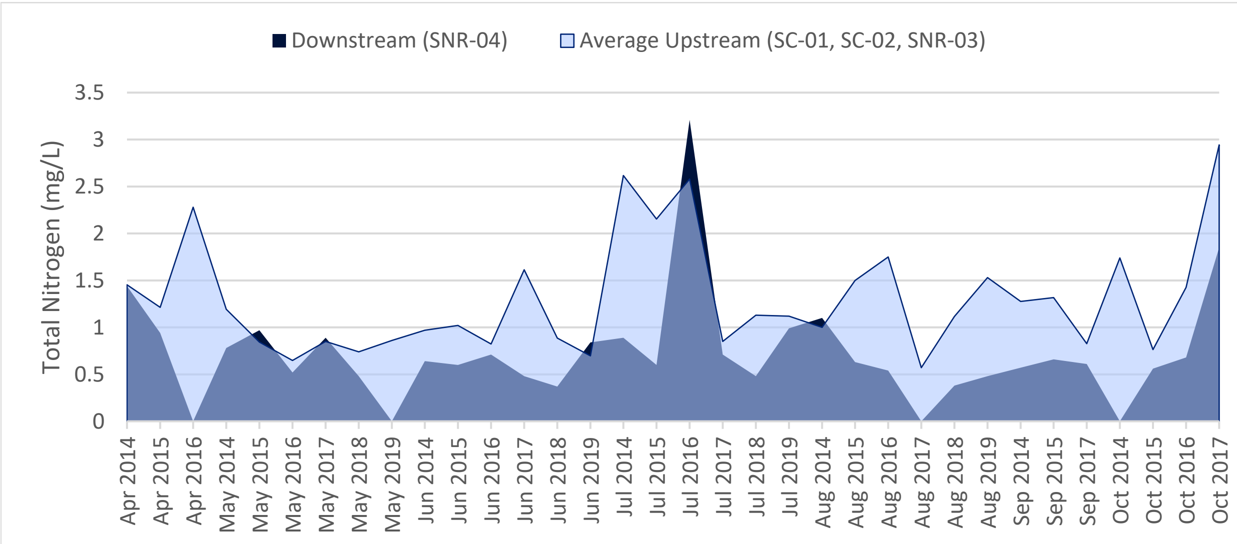


Table 24. Monthly Mean Total Nitrogen Concentrations Upstream and Downstream of the PSWs.

Month	Change in TN (mg/L)
April	+0.14
May	+0.13
June	+0.38
July	+0.40
August	+0.80
September	+0.66
October	+0.75

7. Proposed Treatment BMP's Framework

The intent of the treatment BMP's is to implement one or more options to provide a treatment train, which will capture and control sedimentation from agricultural areas prior to being discharged into the waterways, thereby ultimately reducing nutrient loading to downstream Muskrat Lake. The following treatment options are potentially in place but are not currently known or documented throughout the Muskrat River and Snake River Watersheds and could be implemented to improve water quality in the study area.

7.1 Stormwater Management Treatment Options

Stormwater Best Management Practices (SWM BMPs) can be implemented in three different zones: *At the Source* [where the rain lands], *Conveyance* [across the fields], and *End-of-Pipe* locations [immediately prior to discharge into the nearest waterway].

7.1.1 End-of-Pipe Treatment

7.1.1.1 Wet Pond

According to the *Stormwater Management Planning and Design Manual* (MOE, 2003), wet ponds are the most common end-of-pipe stormwater management facility employed in Ontario. They are less land-intensive than wetland systems and are normally reliable in operation, especially during adverse conditions (e.g., winter/spring). This reliability can be attributed to several factors:

- performance does not depend on soil characteristics;
- the permanent pool minimizes re-suspension;
- the permanent pool minimizes blockage of the outlet;
- biological removal of pollutants occurs; and
- the permanent pool provides extended settling.

Wet ponds can be designed to efficiently provide for water quality, erosion and quantity control, reducing the need for multiple end-of-pipe facilities. Wet ponds can be designed with extensive landscaping, contributing to the character of the agricultural setting.

7.1.1.2 Dry Pond

According to the *Stormwater Management Planning and Design Manual* (MOE, 2003), dry ponds have no permanent pool of water. As such, while they can be effectively used for erosion control and flood control, the removal of stormwater contaminants in these facilities is purely a function of the detention time in the pond. For a 24-hour retention period, this normally means a lower contaminant removal (the inter-event settling time does not exist). While achieving this for smaller drainage areas can be difficult, the use of dry ponds in larger catchments may have greater potential than previously considered. However, there are no documented performance monitoring data for dry ponds with longer detention times and re-suspension of settled material remains a concern. As such, the use of dry ponds (for water quality improvement) remains largely restricted to retrofits, where temperature is an overriding concern, and situations where other more effective SWMP types are infeasible. Dry ponds may be used as part of an overall treatment train approach.

7.1.1.3 Hybrid Wetland

Hybrid wet pond/wetland systems consist simply of a wet pond element and a wetland element, connected in series (MOE, 2003). The system provides for the deep-water component which will be least impacted by winter/spring conditions and the wetland component which provides enhanced biological removal during the summer months. In terms of land requirements, it falls between the amounts needed for wet ponds and wetlands.

Hybrid systems present a more diverse range of opportunities to achieve aesthetic and ecological objectives since they afford greater design flexibility and a diversity of landscape elements.

The design of a hybrid system should be based on the guidance provided for each element (i.e., wet ponds (Section 4.6.2, MOE, 2003) and wetlands (Section 4.6.3, MOE, 2003)), with the following clarifications:

- Volumetric sizing of the permanent pool should be based on the Hybrid Wet Pond/ Wetland SWMP type as presented in Table 25. This assumes that the wet pond comprises 50% of the total permanent pool volume;
- A forebay is required for the wet pond (based on the size of the wet pond, not the entire system) but is not required for the wetland (the wet pond serves this purpose);
- Active storage depth restrictions for wetlands apply to the entire system, unless a terraced, overflow configuration is adopted;
- Detention time for the entire system should be targeted at 24 hours; and
- Length-to-width ratio for the wet pond element may be reduced to 2 to 1, although a higher ratio is encouraged.

Table 25. Water Quality Sizing (MOE, 2003)

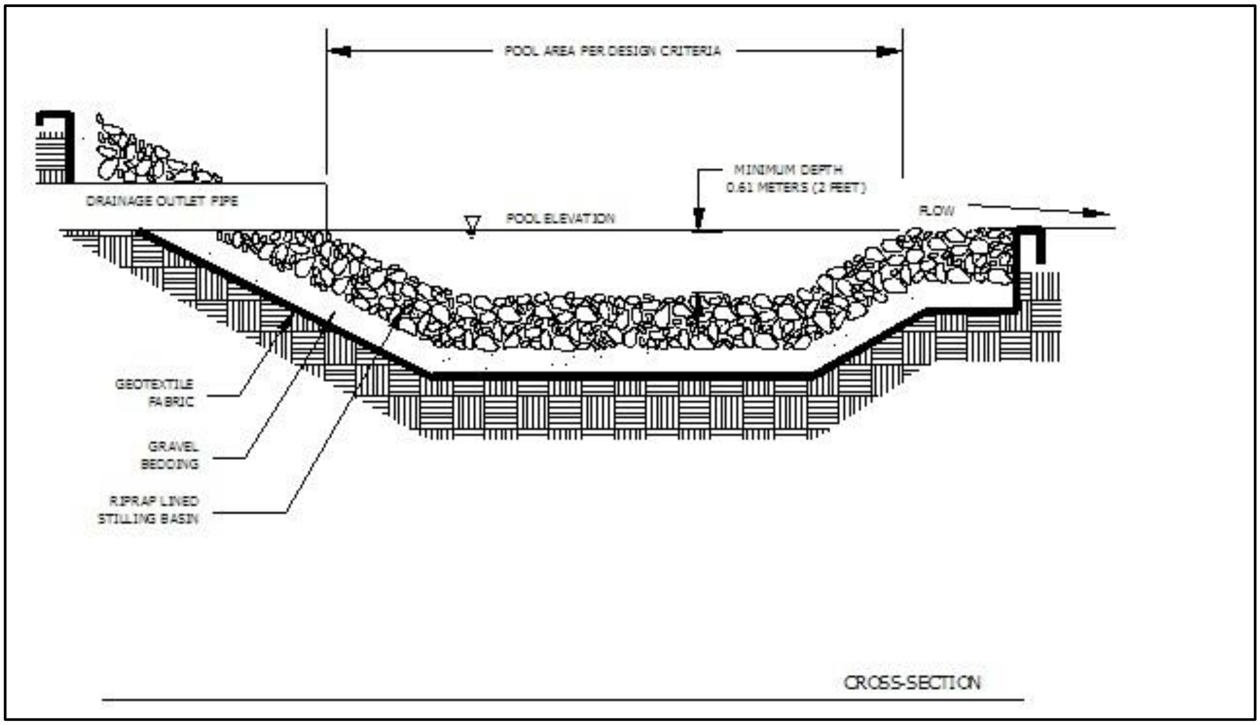
Protection Level	SWMP Type	Storage Volume (m^3/ha) for Imperviousness Level			
		35%	55%	70%	85%
Enhanced 80% long-term suspended solids removal	Infiltration	25	30	35	40
	Wetlands	80	105	120	140
	Hybrid Wet Pond/Wetland	110	150	175	195
	Wet Pond	140	190	225	250

7.1.1.4 Plunge Pool

Plunge pools can be implemented along existing watercourses or drainage outlets to act as storage basins for runoff (Figure 19). A plunge pool functions to dissipate energy and moderate velocities which in turn aid in limiting the re-suspension of accumulated sediments. Plunge pools should be excavated to a greater depth than required and allowed to fill in and reshape to correspond with flow characteristics. Once this evolution of form has taken place, the plunge pool will maintain itself at the required depth. An outlet weir can be used to control the water level in the plunge pool. Plant material interlaced with riverstone to create a weir that is resistant to breaching and will accumulate trash and other floatables, which will allow more efficient removal. Plunge pool energy dissipators are recommended to prevent scour and erosion at the point of discharge.

An outlet sediment trap is a small basin lined with riprap and located at the end of an outlet pipe, or channel outlet. It is designed similar to a plunge pool, to dissipate the energy of the incoming runoff. This device can be used where insufficient space is available.

Figure 19. Plunge Pool (MassHighways, 2004)

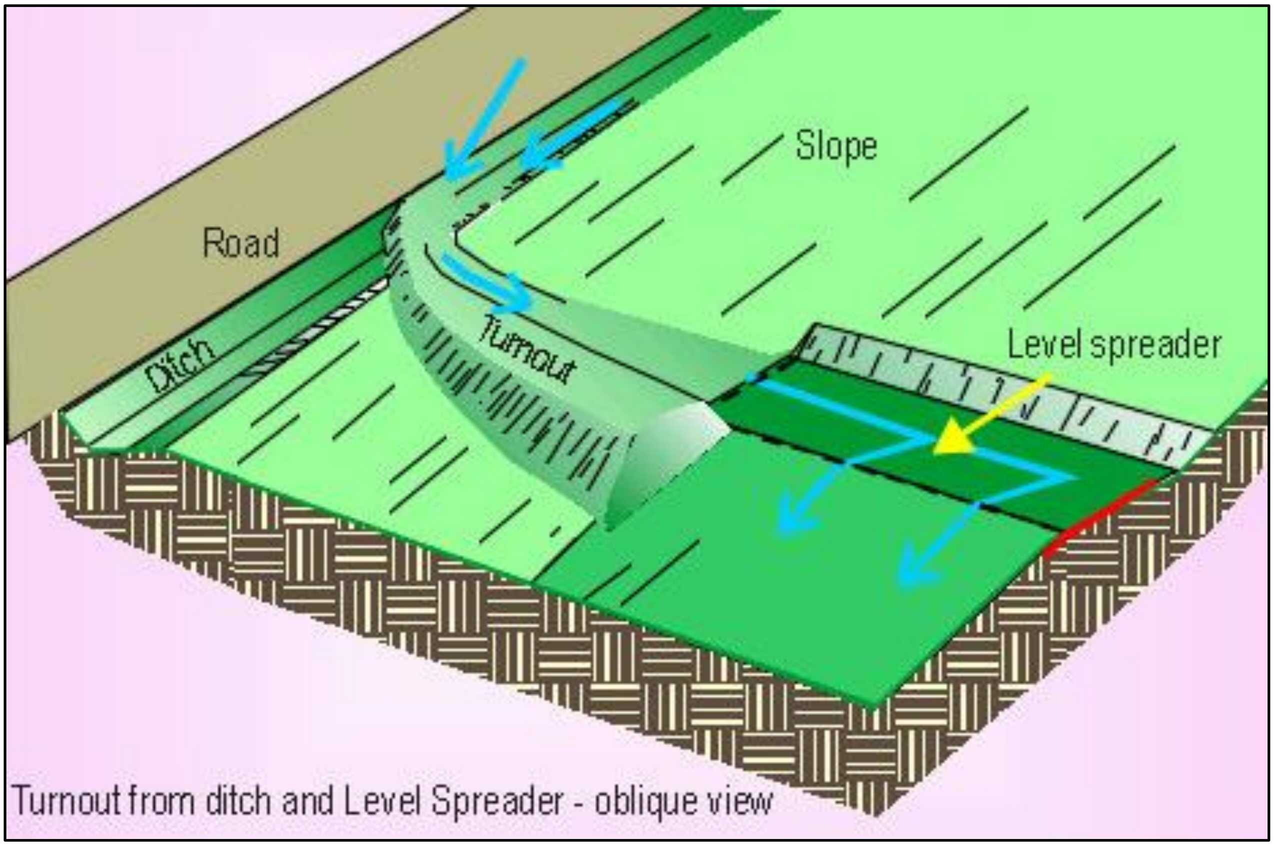


7.1.2 Conveyance Treatment

7.1.2.1 Flow Spreaders

Flow spreaders can reduce the velocity of flows by distributing runoff as sheet flow. This reduces the erosive potential of a concentrated stream. A level spreader consists of a raised weir constructed perpendicular to the direction of flow. Some common types of level spreader devices are pea gravel diaphragms and earthen berms. An example of a flow spreader is shown below in Figure 20.

Figure 20. Level Spreader Example (U.S. Army Corps of Engineers, undated).



7.1.2.2 Vegetated Filter Strips

Vegetated filter strips are engineered stormwater conveyance systems which treat small drainage areas. Generally, a vegetated filter strip consists of a level spreader and planted vegetation. The level spreader ensures uniform flow over the vegetation which filters out pollutants and promotes infiltration of the stormwater.

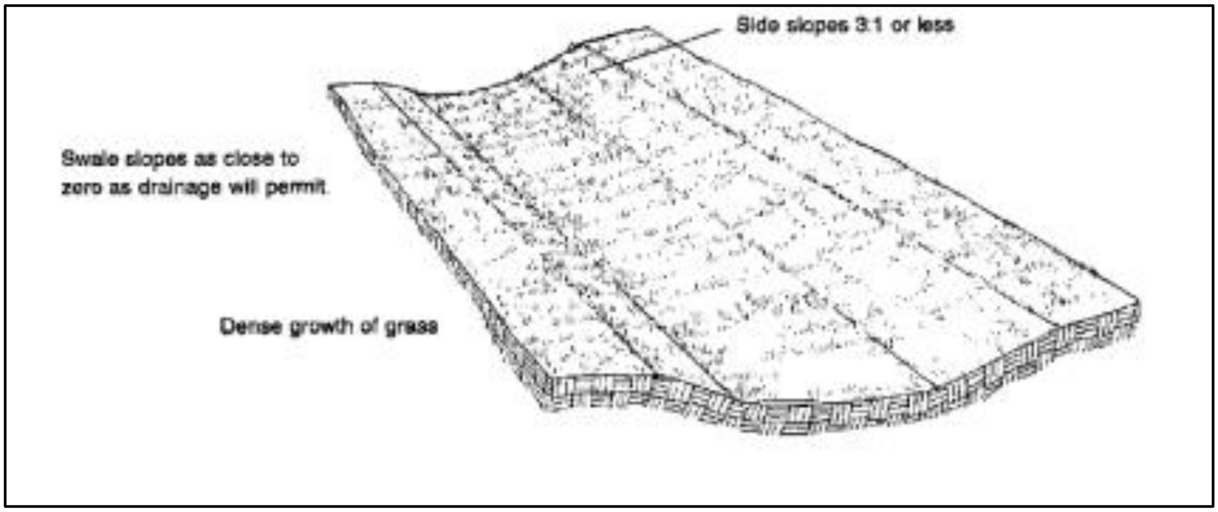
Vegetated filter strips are best utilized adjacent to a buffer strip, watercourse or drainage swale since the discharge will be in the form of sheet flow, making it difficult to convey the stormwater downstream in a normal conveyance system (swale or pipe).

7.1.2.3 Enhanced Grass Swale

Enhanced grass swales are vegetated open channels that convey, treat and attenuate stormwater runoff. Flat bottoms and vegetation in the swale decrease the velocity of the water, allowing for sedimentation, filtration through the root zone and soil, evapotranspiration, and infiltration into the underlying soil (CVC & TRCA, 2010). Check dams can also be added to grass swales to further reduce velocity and enhance infiltration. An enhanced grass swale is illustrated in Figure 21.

Enhanced grass swales are vegetated open channels designed to convey, treat and attenuate stormwater runoff (also referred to as enhanced vegetated swales). Check dams and vegetation in the swale slows the water to allow sedimentation, filtration through the root zone and soil matrix, evapotranspiration, and infiltration into the underlying native soil. Simple grass channels or ditches have long been used for stormwater conveyance, particularly for roadway drainage. Enhanced grass swales incorporate design features such as modified geometry and check dams that improve the contaminant removal and runoff reduction functions of simple grass channel. A dry swale is a design variation that incorporates an engineered soil media bed and optional perforated pipe underdrain system. Enhanced grass swales are not capable of providing the same water balance and water quality benefits as dry swales, as they lack the engineered soil media and storage capacity of that best management practice.

Figure 21. Enhanced Grass Swale (CVC & TRCA, 2010).



7.1.2.4 Field Contouring

Fields within the watersheds can be re-contoured to promote infiltration or re-direct stormwater runoff to another treatment option. Field contouring construction is an extension of the practice of plowing fields at a right angle to the slope. The contour ditches are dug along a hillside in such a way that they follow a contour and run perpendicular to the flow of water. The soil excavated from the ditch is used to form a berm (a narrow shelf) on the downhill edge of the ditch. The berm can be planted with permanent vegetation (native grasses, legumes) to stabilize the soil and for the roots and foliage in order to trap any sediment that would overflow from the trench in heavy rainfall events.

7.1.2.5 Earth Dams/Berms

Dams or berms can be constructed in areas where the stormwater runoff is problematic. The dams or berms can retain the runoff and act as a level spreader. A weir can be constructed at the top of the berm to convey flows.

The California Stormwater Quality Association Stormwater BMP Handbook (2003) considers a check dam to be a small barrier constructed of rock, gravel bags, sandbags, fibre rolls, or reusable products placed across a constructed swale or drainage ditch. Check dams reduce the effective slope of the channel thus reducing the velocity of the surface water runoff, which enhances sedimentation and reduces erosion. It is important to note that check dams will reduce the capacity of the swale. Therefore, extra storage and/or conveyance may be required in order to restore the hydraulic capacity. This can be accomplished by increasing the size – depth and/or width – of the swale.

7.1.2.6 Minor Vegetative Buffers

Buffer strips are simply natural areas between development and the receiving waters. There are two broad resource management objectives associated with buffer strips:

- The protection of the stream and valley corridor system to ensure their continued ecological form and functions; and
- The protection of vegetated riparian buffer areas within the valley system to minimize the impact of development on the stream itself (filter pollutants, provide shade and bank stability, reduce the velocity of overland flow).

Although both types of buffers provide only limited benefits in terms of stormwater management, they are an integral part of overall environmental management for sustainable development. The protection of stream and valley corridors provides significant benefits in terms of sustaining wildlife migration corridors, terrestrial and aquatic species food sources, terrestrial habitat, and linkages between natural areas. Given the larger scale natural system benefits provided by stream and valley corridors, the required width of this type of buffer is best defined at the sub-watershed plan level. Individual conservation authorities and municipalities have developed their own guidelines for buffer areas. The designer should confirm local requirements with the applicable authority.

7.1.2.7 Major Vegetative Buffers

Vegetative buffers can be implemented in areas adjacent to existing watercourses. As mentioned above, there are existing vegetative buffers at some locations throughout the watersheds draining to Muskrat Lake. Multiple vegetative species can be planted along the embankments or adjacent to the watercourse for optimal sediment removal. Vegetative buffers can provide bank stability, filter pollutants, and reduce the velocity of overland flow.

7.1.3 At the Source

7.1.3.1 Tile Drainage

Tile drains are designed to remove excess water quickly from below the soil surface to avoid crop damage and decreased yields. Tile drainage impacts hydrology substantially by increasing water output, reducing surface runoff and sedimentation, and eliminating saturated areas.

7.1.3.2 Soakaways, Infiltration, Trenches

On sites suitable for underground stormwater infiltration practices, there are a variety of facility design options to consider, such as soakaways, infiltration trenches and infiltration chambers.

Soakaways are rectangular or circular excavations lined with geotextile fabric and filled with clean granular stone or other void forming material, that receive runoff from a perforated pipe inlet and allow it to infiltrate into the native soil. They typically service individual lots and receive only roof and walkway runoff (MOE, 2003) but can also be designed to receive overflows from rainwater harvesting systems. Soakaways can also be referred to as infiltration galleries, dry wells, or soakaway pits.

Infiltration trenches are rectangular trenches lined with geotextile fabric and filled with clean granular stone or other void forming material. Like soakaways, they typically service an individual lot and receive only roof and walkway runoff. This design variation on soakaways is well suited to sites where available space for infiltration is limited to narrow strips of land between buildings or properties, or along road rights-of-way. They can also be referred to as infiltration galleries or linear soakaways.

7.1.3.3 Hickenbottom

Hickenbottoms are drain inlets that can be utilized in a variety of agricultural applications. Each hickenbottom inlet is made of high-density polyethylene insuring the longevity and durability of the product. The inlet area is greater than the restricted outlet, eliminating suction and trash plug-ups. A special inlet riser may be installed to maintain ponding at a certain level improving water filtration in semi-arid regions. Hickenbottoms are also known as vertical drains (EMCO Waterworks, undated), primarily serving to collect water retained in low-lying agricultural land. Hickenbottoms allow some soil particles and pollutants to settle out.

Figure 22. A view of a hickenbottom installed in an agricultural setting (Soleno, 2021).

7.2 Agricultural Treatment

7.2.1 Cattle Exclusion Fencing/Livestock Restriction

"*Fencing can be repaired or installed to restrict livestock access to watercourses to reduce the potential for contamination and to reduce stream bank erosion*" (Cole Engineering, 2016). According to the United States Department of Agriculture (USDA), "*A Livestock Exclusion System means a system of permanent fencing (board, barbed, high tensile or electric wire) installed to exclude livestock from streams and critical areas not intended for grazing to improve water quality. Benefits may include reduced soil erosion, sedimentation, pathogen contamination and pollution from dissolved, particulate, and sediment-attached substances*" (North Carolina Department of Agriculture & Consumer Services, undated).

Based on the *Streamside Livestock Exclusion* study, "Even a small separation of livestock and their manure from the stream can significantly reduce the contribution of manure-borne bacteria to the stream." Streamside fencing can reduce negative water quality impacts by excluding livestock from the stream. Streambanks become more stable, and the diversity and abundance of riparian vegetation is improved (Zeckoski et al., 2012).

7.2.2 Milkhouse Wastewater Treatment

"*Milkhouse wastewater refers to wastewater generated from cleaning milking equipment, pipeline, bulk tank, and milk parlour floor which can contain manure, bedding, and feed. The wastewater not only includes phosphorus from milk proteins, fat, bedding, feed, and manure, but also from the detergents and acid rinses used in the cleaning procedures. Milkhouse wastewater can be treated by constructing or expanding a nutrient storage facility for dairy operations. It holds the waste for several days to allow settling. A treatment facility can also be constructed that may included a flocculator to enhance settling, vegetated filter strips, constructed wetlands, lagoons, or ponds.*

The siting or type of milkhouse wastewater treatment structures can be limited by setbacks to surface water, wells, field drains, proximity to nearby neighbouring dwellings, topography, floodplain restrictions, soil type, and depth to water table and bedrock. The structure must comply with the Canadian Farm Building Code, Nutrient Management Act, and Ontario Water Resources Act. It may also require approval under the Environmental Protection Act.

Maintenance of the system can include inspection, addition of chemicals (if using a flocculator system), and removal of sediment and debris. Maintenance costs vary depending on the system in place" (Cole Engineering, 2016).

In New Brunswick, an innovative technology was introduced involving flocculators to remove the majority of phosphates and suspended solids from the milkhouse effluent. The effluent and a proportionate amount of hydrated lime sits undisturbed for two hours to encourage settling and then the clarified liquid is discharged to a tile field while the sludge is sent to the manure storage (Government of New Brunswick, undated).

7.2.3 Manure Storage

"*A manure storage structure is constructed or repaired to provide proper manure storage that will not be carried away during a storm event. A berm, settling basin, and/or buffer strip can also be used for control of manure. These measures are implemented to replace a stacked manure pile.*

These structures are limited by setbacks to surface water, wells, field drains, proximity to nearby neighbouring dwellings, topography, floodplain restrictions, soil type, and depth to water table and bedrock. The structure must comply with the Canadian Farm Building Code and Nutrient Management Act (NMA). Manure storage has a potential benefit of odour reduction and control and can also contain bacteria which would otherwise be transported in runoff. It has a high TP removal capability, The amount of TP removed can be calculated based on the number of farm animals, type of animal, and type of farm (feedlot or dairy). Operations and maintenance costs depend on the type of storage cover and structure" (Cole Engineering, 2016).

Ontario Soil and Crop states that "proper manure storage is an important factor in protecting water resources in close proximity to livestock facilities." The size of the storage facility is very important since it determines how much manure can be stored and how often and how much manure is spread (OMAFRA and MOE, 2005) so that the producer can find the optimum time to apply manure that balances environmental risks with their crop rotation and, equipment and labour availability. These types of BMP projects help reduce the quantity of manure and nutrients potentially entering waterways through potential runoff (Cole Engineering, 2016).

7.2.4 Clean Water Diversion

"*Clean water diversion structures can be installed to direct clean water away from barnyards and other sources of contamination. Structures can include eavestroughs, berms, or ditches. This method is physically constrained primarily by topography and proximity to any permanent nutrient storage facilities. Maintenance activities may include inspection, repairs due to erosion, and cleaning debris*." (Cole Engineering, 2016).

7.3 Treatment BMP's Implementation Strategy

BMP's should be selected and implemented depending on a physical conditions such as soil type, bedrock location, maintenance requirements, field slopes, water table, property limits, and accessibility. Favourable conditions associated with the various BMPs presented in Sections 7.1 and 7.2 are discussed in Table 26. Suitable conditions will be discussed with farmers and used to determine appropriate BMPs for implementation.

Table 26. Agricultural BMPs and Favourable Conditions for Implementation.

BMP	Favourable Conditions
Wet Pond	• Greater than 5 hectares of contributing land • Land contoured towards low area

	• Low infiltration rate of existing soil keeping water within the pond • Pond accessible for routine maintenance • Watercourse nearby to connect pond outlet
Dry Pond	• Greater than 2 hectares of contributing land • Land contoured towards low area • Low to high infiltration rate of existing soil acceptable • Pond accessible for routine maintenance • Watercourse nearby to connect pond outlet
Hybrid Wetland	• Greater than 5 hectares of contributing land • Land contoured towards low area • Low infiltration rate of existing soil acceptable maintaining permanent water • Wetland/watercourse nearby to connect outlet.
Plunge Pool	• Small area outlets (i.e. field ditch or tile drain outlet) • Outside of tilled areas (rocks may get in machinery) • Easy access for maintenance (sediment removals) • Can be in series or in parallel, supporting multiple outlets • Areas that see steady flow, but not flooding.
Flow Spreaders	• Areas with concentrated flow • Along a watercourse, tree line, or vegetive buffer • Outside of tilled areas • Accessible for sediment removals • Generally flat lands to ensure flows don't erode berm and berm can be constructed at straight elevation
Vegetated Filter Strips	• Outside of tilled areas, providing separation between fields, watercourses, or other vegetation • Low slope, promoting sediment trapping/removal and infiltration
Enhanced Grass Swales	• Outside of tilled areas, providing separation between fields, watercourses, or other vegetation • Connection to watercourses • Low slope, promoting sediment trapping/removal and infiltration • Sufficient depth to allow for ponding/flooding • Minimal grass cutting to promote taller growth within the swale
Field Contouring	• Fields with mild to moderate slopes • Within the tilled areas • Moderate to high infiltration rates of existing soils
Earth Dams/Berms	• Similar to the flow spreader, but requires more area available for storage/flooding due to the larger size • Best used along a watercourse to prevent flooding/erosion of a field
Minor Vegetative Buffer	• Along a swale/ditch/watercourse or property limit • Outside of tilled areas • Low slope, promoting sediment trapping/removal and infiltration
Major Vegetative Buffer	• Along a swale/ditch/watercourse or property limit • Outside of tilled areas • Low slope, promoting sediment trapping/removal and infiltration

	• Larger buffer limits
Tile Drainage	• Within the tilled areas • Low slope within the fields • Sufficient depth on the outlet ditch/watercourse for tile outlets • Moderate to high infiltration rates of existing soils • Low groundwater table
Soakaways, Infiltration, Trenches	• Outside of tilled areas and watercourse flooding • Low groundwater table • high infiltration rates of existing soils
Hickenbottom	• Outside of tilled areas and watercourse flooding • Low groundwater table • High infiltration rates of existing soils
Cattle Exclusion Fencing/Livestock Restriction	• Fencing limits free of obstructions (i.e. trees, sharp drop-offs, easements, etc.) • Exterior access not required (or gates installed) • Land mildly sloped at limits of the fence • Treatment BMP's (such as vegetated filter strips or vegetated buffers) located around the exterior perimeter of the fence
Milkhouse Wastewater Treatment	• Available capacity in existing nutrient storage systems • Grade separation sufficient to outlet nutrient storage tank liquids • Available space to install nutrient storage system
Manure Storage	• Available capacity in existing storage system • Available space to install manure storage system • Large separation distances to living spaces • Separation fencing or walls to prevent accidental animal falls into the space
Clean Water Diversion	• Moderate to high infiltration rates of existing soils • Land sloping contoured to separate nutrient area and clean water flows or can be graded to establish separation.

7.3.1 Priority Area #1 – SC-02 Catchment

It is recommended that each farm review the list in Section 7.3.1 and implement two or more BMP's which suite their conditions. At a minimum, we recommend implementation of tile drainage and vegetative buffers.

7.3.2 Priority Area #2 – Previously Flooded Areas

It is recommended that areas receiving frequent flooding should be established into wetlands with a vegetative buffer and flow spreader surrounding the wetland. Other features within Section 7.3.1 should be considered where feasible.

7.3.3 Priority Area #3 – Muskrat Lake Riparian Lands

It is recommended that wet ponds, dry ponds, level spreaders and vegetative buffers be implemented. Other features within Section 7.3.1 should be considered where feasible.

8. Conclusions

8.1 Preliminary Consultation

Preliminary consultation has been initiated through consultation with select groups and will advance after completion of this report through project notification focus group engagement and micro meetings.

8.2 Existing SWM

A multitude of lakes, rivers and wetlands are located in the study area which influence nutrient cycling between the watershed and Muskrat Lake. These natural heritage features will be considered during future project phases when selecting and implementing of BMPs which aim to improve nutrient retention in these systems. Artificial SWM is limited to three tile drains and one municipal drain in the study area.

In the Snake River Watershed, there are significant floodplains due to the flat surrounding areas between the Snake River PSW and Muskrat Lake. Large extents of flooding were evident throughout the spring of 2019 and designated as either “Class 2 – Open Water” or “Class 3 – Flooded Vegetation”.

8.3 Source Areas of Nutrient Loss

Nutrients were similar or slightly higher than other agricultural-dominated watersheds in Ontario. Phosphorus concentrations were highest in the summer, TN was highest in the spring and fall, and neither nutrient concentration was statistically significantly related to precipitation. Total suspended solid concentrations were low and significantly related to TP at the three sites located in the Cobden PSW which could be driven by upstream overland runoff.

Median TP and TN concentrations, as well as TP and TN loads/ha were all highest at SC-02 which was also the catchment with the highest percentage of agricultural lands and annual crop land within 1 km (Table 27). The next most nutrient-enriched sites were MKR-03 and SNR-04.

Table 27. Priority Areas Based on Concentrations and Loads.

Sites	Median TP	TP Load/ha	Median TN	TN Load/ha
PH-01	0.011	0.04	0.39	1.37
OS-01	0.012	0.04	0.31	1.03
MKR-01	0.029	0.09	0.40	0.29
BC-01	0.037	0.11	0.41	1.26
MKR-03	0.061	0.23	0.48	1.82
SC-02	0.178	0.53	0.92	2.72
SNR-04	0.042	0.13	0.65	2.02

Note: *A green, yellow, red, colour scheme is used to designate sites as hot spots based on concentrations and loads. Sites with low concentrations or loads are highlighted in green, intermediate values are highlighted in yellow and the highest values are highlighted in red.*

8.4 Cobden and Snake River PSWs

The Cobden and Snake River both support a wide variety of natural heritage features and functions. The Snake River PSW consistently acts as a nutrient sink with the greatest nutrient retention occurring in the summer and fall. The Cobden PSW acts as a nutrient source but the assessment of TP retention in the Cobden PSW was limited because the downstream water sampling location was located in the middle of the wetland, thereby limiting the spatial assessment.

8.5 Identification of Priority Areas

We identified the following priority areas for future BMP implementation based on the results of the study (Figure 23):

1. SC-02 Catchment

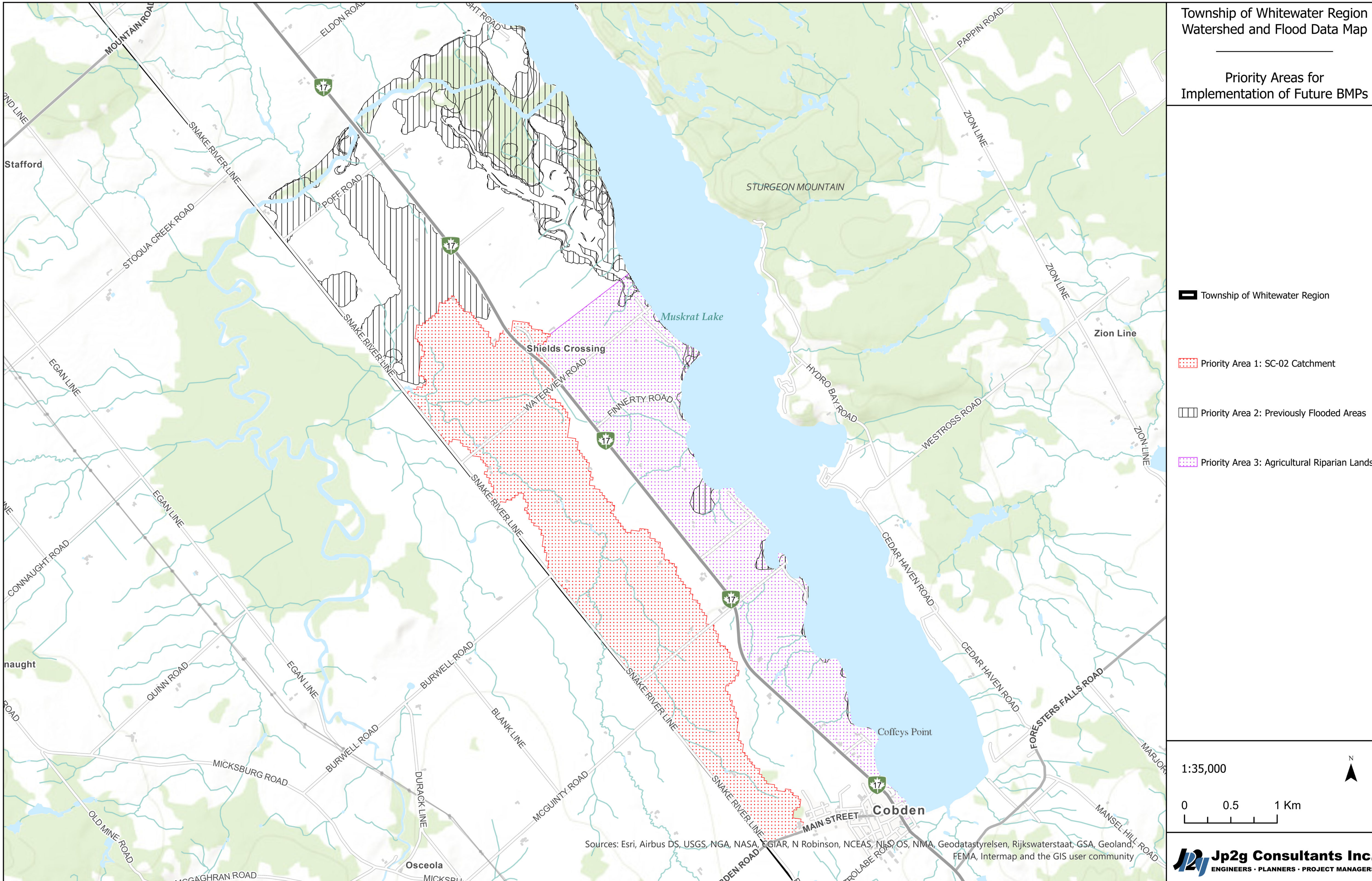
   Nutrient concentrations and loads/ha were the highest at SC-02 so future project phases should be focused in this area to reduce nutrient loading and nutrient concentrations in the Snake River PSW, Snake River and downstream Muskrat Lake. It should be noted however that the nutrients will be transformed in the PSW through a variety of biogeochemical processes and therefore a reduction in nutrient loads will not equal those that are displaced from Muskrat Lake.

2. Previously Flooded Areas

   Flooding results in significant nutrient loading to downstream receiving waterbodies. Class two and three lands that flooded in the spring of 2019 should be assessed during future project phases in an attempt to lower nutrient loading from these areas and improve agricultural productivity. The majority of these previously flooded areas are located between the Snake River PSW and Muskrat Lake along the western shore of Muskrat Lake.

3. Muskrat Lake Riparian Lands

   The Muskrat Lake watershed includes a number of agricultural lands that drain directly into the western shore of Muskrat Lake and runoff is not afforded phosphorus retention in watercourses, wetlands or other lakes. These lands should be examined as part of future project phases. Many of these agricultural operations appear to have little riparian buffer between cropland and the shoreline of Muskrat Lake.


Township of Whitewater Region
Watershed and Flood Data Map
Priority Areas for
Implementation of Future BMPs
Township of Whitewater Region
Priority Area 1: SC-02 Catchment
Priority Area 2: Previously Flooded Areas
Priority Area 3: Agricultural Riparian Lands
1:35,000
N
0 0.5 1 Km
Jp2g Consultants Inc.
ENGINEERS · PLANNERS · PROJECT MANAGERS
Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community
Muskrat Lake
STURGEON MOUNTAIN
Shields Crossing
Cobden
Coffeys Point
Zion Line
Stafford
Osceola
SNAKE RIVER LINE
WATERVIEW ROAD
FINNERTY ROAD
HYDRO BAY ROAD
WESTROSS ROAD
CEDAR HAVEN ROAD
FORESTERS FALLS ROAD
MANSEL HILL ROAD
MAIN STREET
ZION LINE
PAPPIN ROAD
ELDON ROAD
MOUNTAIN ROAD
POFF ROAD
STOQUA CREEK ROAD
EGAN LINE
CONNAUGHT ROAD
QUINN ROAD
BURWELL ROAD
BLANK LINE
MICKSBURG ROAD
DURACK LINE
MCGUNTY ROAD
OLD MINE ROAD
MCGAGHRAN ROAD

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Appendix A. Stormwater Assessment, Planning and Implementation Contact List

Township of Whitewater Region
Stormwater Assessment, Planning and Implementation of Cobden Agricultural Area
Contact List: Public, Agencies, Agricultural Organizations & Other NGO's

Agencies:

1. MECP: Victor Castro Victor.Castro@ontario.ca
2. OMAFRA: Nancy Rutherford nancy.rutherford@ontario.ca
3. MNRF: **Corrie Bourgoin** (Tech/Pembroke Office) Corrie.Bourgoin@ontario.ca and/or Scott Smithers (Kemptville) scott.smithers@ontario.ca; **Kristen Wagner** (Kristen.wagner@ontario.ca), **Lauren Trute** (Lauren.trute@ontario.ca)
4. MTO: Stephen Kapusta, MCIP, RPP Stephen.Kapusta@ontario.ca
5. County of Renfrew:
   - Paul Moreau, CAO Paul Moreau PMoreau@countyofrenfrew.on.ca
   - Craig Kelley, Director of Property and Development; Craig Kelley CKelley@countyofrenfrew.on.ca
   - **Bruce Howarth**, Manager of Planning Services BHowarth@countyofrenfrew.on.ca

Agricultural Organizations:

1. Renfrew County Federation of Agriculture: Filed Letter of Support for Study – Contact on file: Reuben Stone restone84@gmail.com
2. Renfrew County Soil and Crop Improvement Association: Filed Letter of Support for Study– Contact on file: Jennifer Doleman bds@totalcropcare.com/ Craig McLaughlin cmblackhorse@gmail.com
3. Natural Farmers Union - Renfrew County: Marshall Buchanan moonlightcrofters@gmail.com
4. Ontario Federation of Agriculture (Renfrew County): Donna Campbell davdoncampbell@gmail.com
5. Renfrew County Beef: Contact on file: David McGonegal gonegald@nrtco.net
6. Christian Farmers: Contact on file: Gerry Rook diro5@sympatico.ca
7. Renfrew South District Women's Institute: Lillian Collins RenfrewSouthDWI@gmail.com
8. Renfrew County Stewardship Council: Eric Smith ericandlindasmith@sympatico.ca

NGO's

1. Muskrat Watershed Council:
   - Karen and Rene Coulas; coulasdairy@hotmail.com
   - Jim Lawrence and others. jimlawrence@sympatico.ca
2. Muskrat Lake Association:
   - **Kevin Lamorie** klamorie@hotmail.com; 613-558-4364
   - Gary Younghusband muskrats@nrtco.net
   - Hugh Mitchell hughm@aquatactics.com
3. Renfrew County Water Quality Leadership Group
   - **Evelyn St. Amour** (Muskrat Watershed Council) ev_st_amour@hotmail.com
   - Lynn Clelland (Agriculture) Ian Clelland liclelland@nrtco.net
   - Gerry Richards (Agriculture) gerry.richards@yahoo.ca
   - Eric Smith (Agriculture) ericandlindasmith@sympatico.ca

- Jennifer Doleman (Agriculture) bds@totalcropcare.com
- Kathryn Lindsay (Bonnechere Watershed Project) chair@bonnechereriver.ca
- Ole Hendrickson (Ottawa River Institute) ole@nrtco.net

4. Ottawa River Keeper
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5. Ottawa River Institute
   - Ole Hendrickson ole@nrtco.net
6. Bonnechere River Project
   - Kathryn Lindsay chair@bonnechereriver.ca

Colleges and Universities:

1. Algonquin College
   - Sarah Hall halls@algonquincollege.com
   - Julie Sylvestre sylvesj@algonquincollege.com

Other Municipalities in the Muskrat Lake Watershed

1. Township of Admaston Bromley: avereyken@admastonbromley.com
2. Township of North Algona Wilberforce: Andrew Sprunt cao@nalgonawil.com
3. Township of Laurentian Valley: Dean Sauriol dsauriol@lvtownship.ca
4. City of Pembroke: Terry Lapierre tlapierre@pembroke.ca

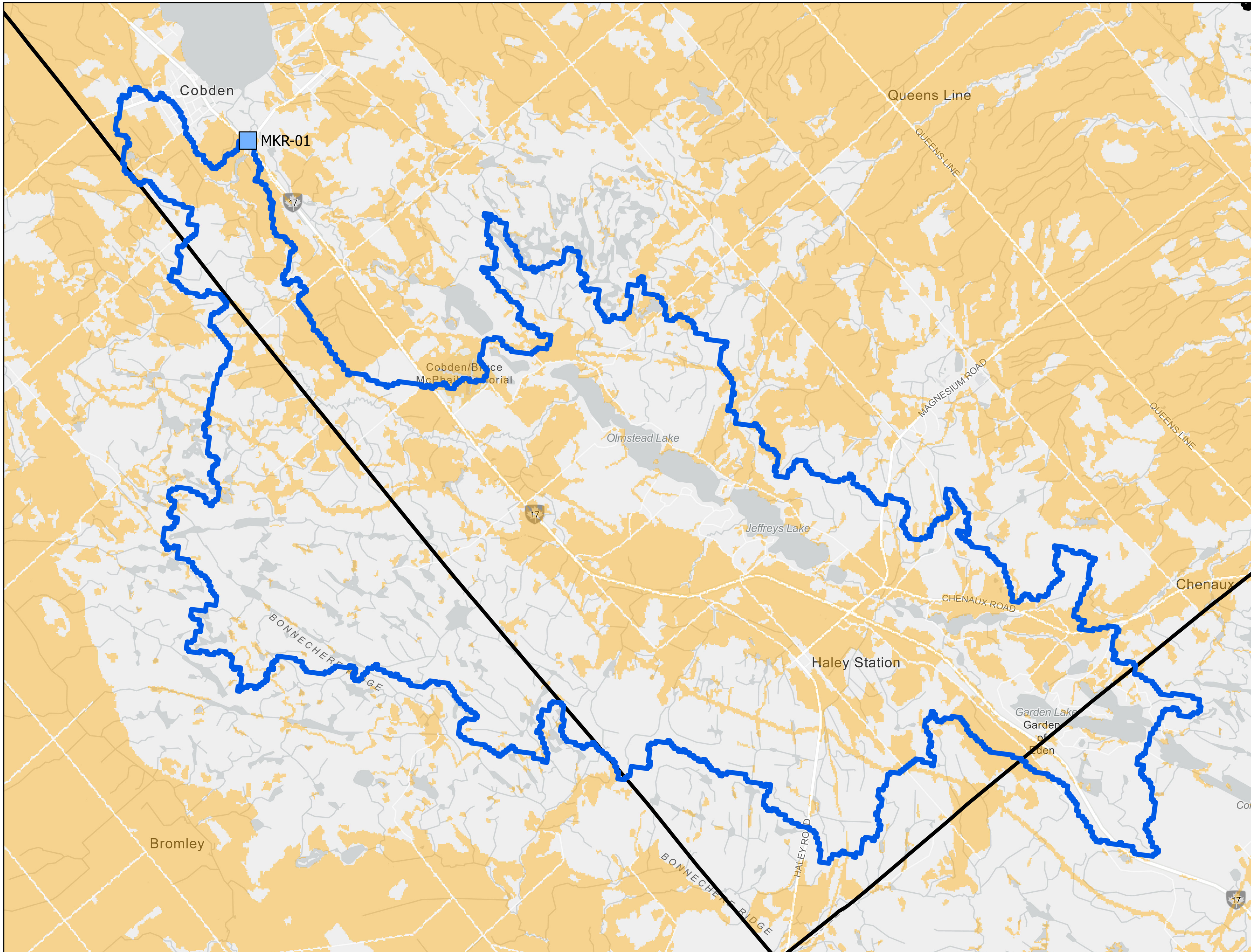
Algonquins of Ontario

1. Kathleen Forward kforward@tanakiwin.com
2. Janet Stvinga jstavinga@tanakiwin.com

Other:

3. Rebecca Dalton becca.dalton@gmail.com

Appendix B. Agricultural Lands within Catchments of Water Quality Sampling Locations



Muskrat Lake Watershed
Township of Whitewater Region

Agricultural Land Use
within the Catchment Areas

Legend

- MKR-01 Catchment Area
- MKR-01
- Township of Whitewater Region
- Agricultural and Undifferentiated Lands

N

1:45,000

0 1 2 Km

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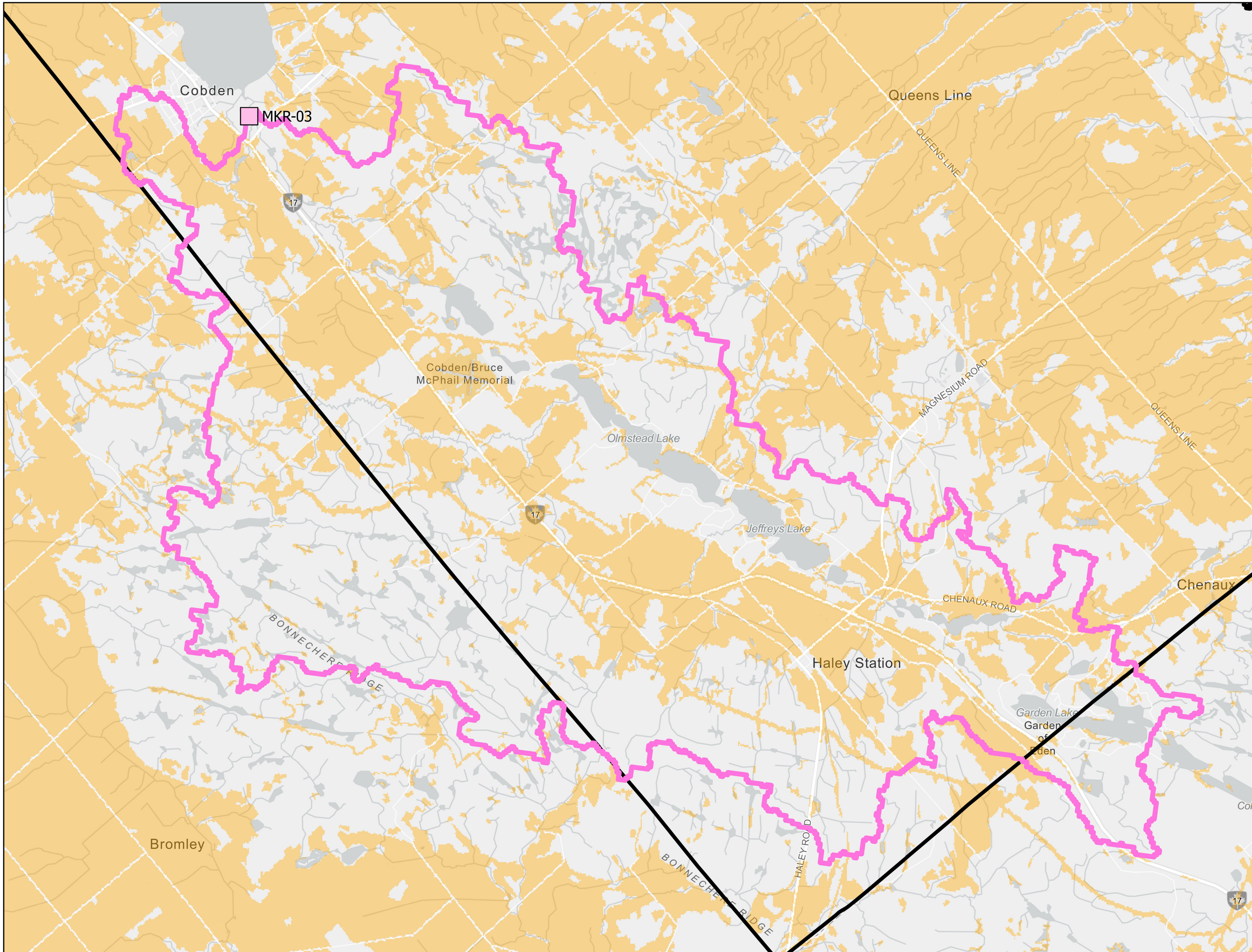

Muskrat Lake Watershed
Township of Whitewater Region

Agricultural Land Use within the Catchment Areas

Legend

- MKR-03 Catchment Area
- MKR-03
- Township of Whitewater Region
- Agricultural and Undifferentiated Lands

N

1:45,000

0 1 2 Km

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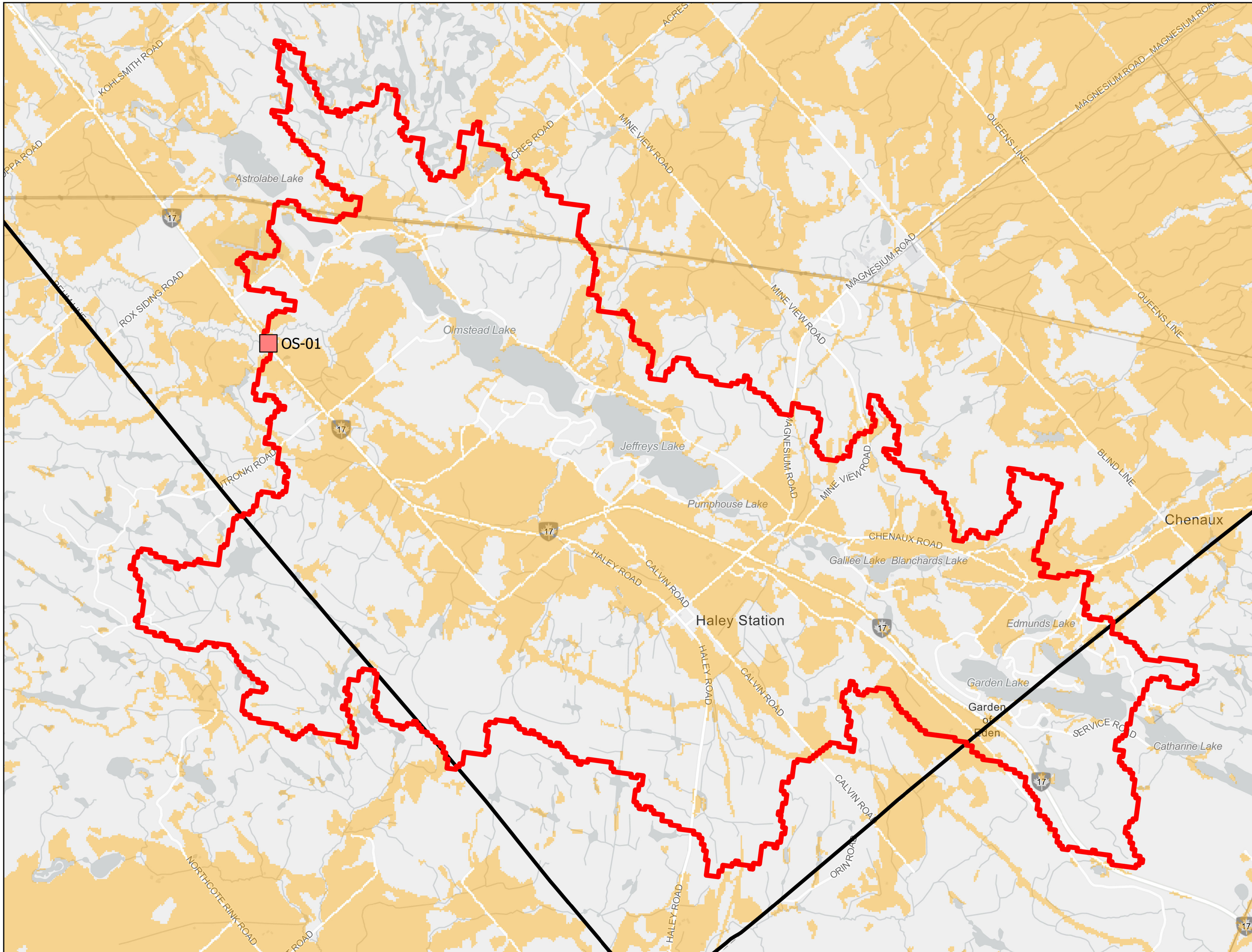
Muskrat Lake Watershed
Township of Whitewater Region

Agricultural Land Use
within the Catchment Areas



Legend

- OS-01 Catchment Area
- OS-01
- Township of Whitewater Region
- Agricultural and Undifferentiated Lands

N

1:35,000

0 0.75 1.5 Km

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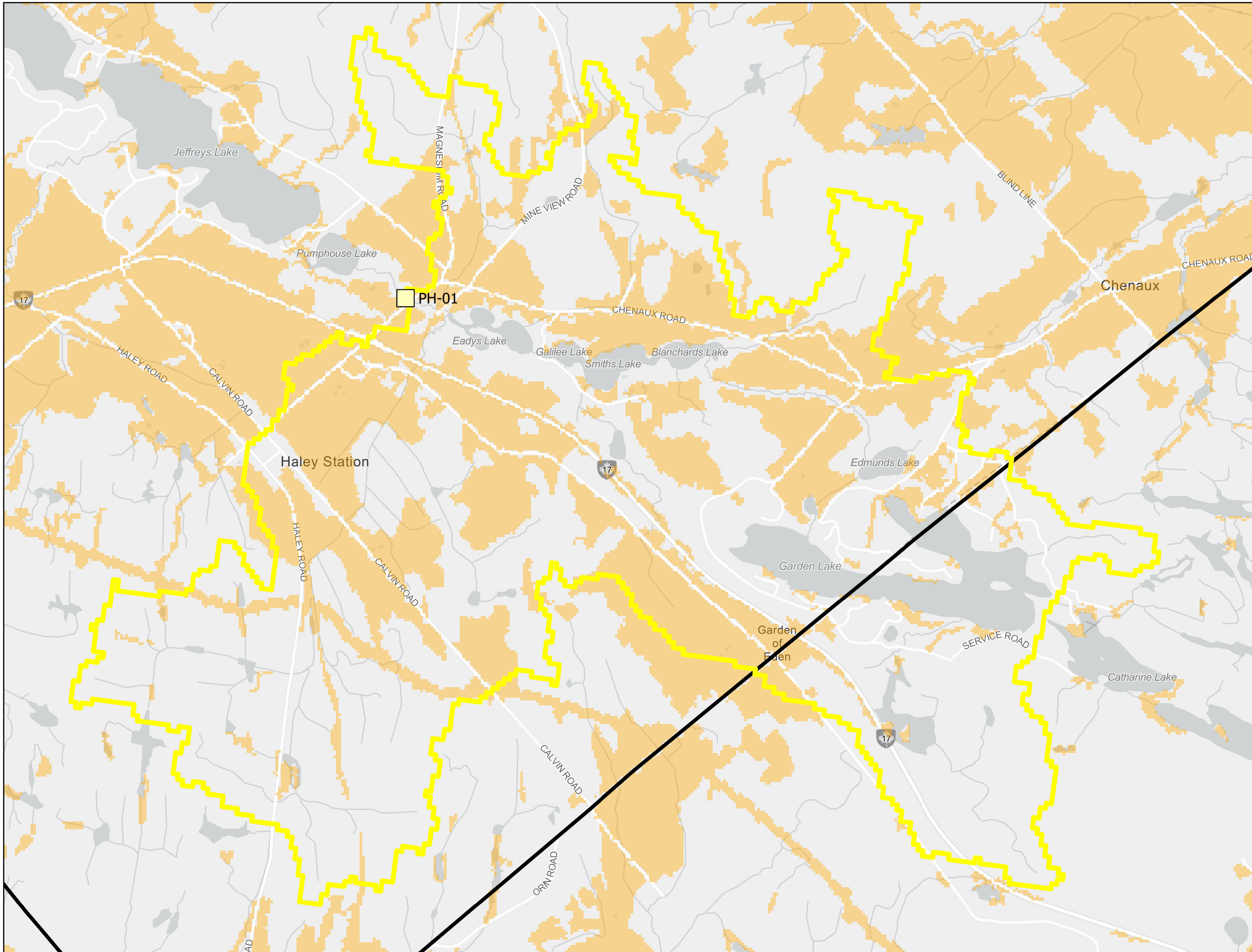
Muskrat Lake Watershed
Township of Whitewater Region

Agricultural Land Use
within the Catchment Areas



Legend

- PH-01 Catchment Area
- PH-01
- Township of Whitewater Region
- Agricultural and Undifferentiated Lands

N

1:20,000

0 0.5 1 Km

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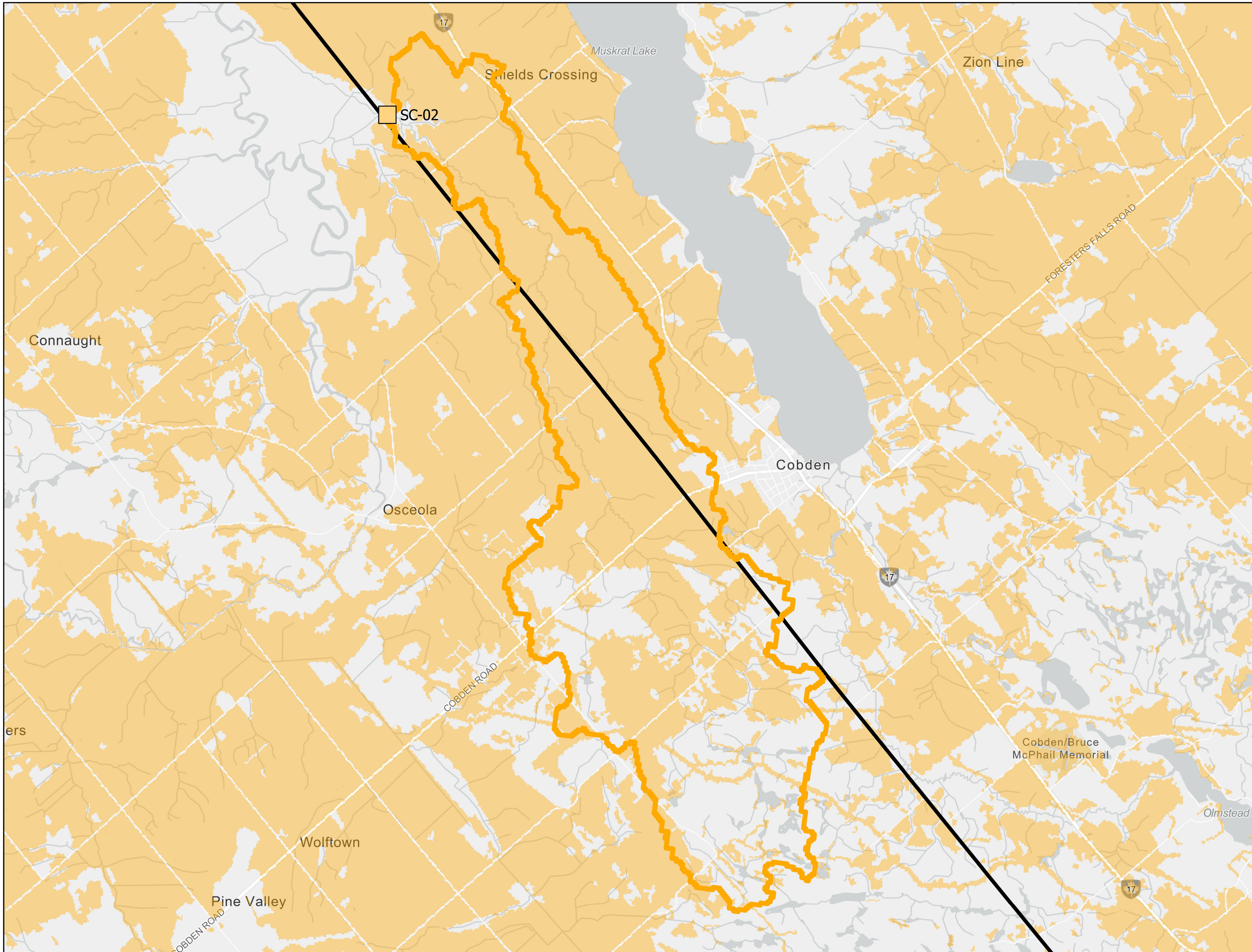

Muskrat Lake Watershed
Township of Whitewater Region

Agricultural Land Use
within the Catchment Areas

Legend

- SC-02 Catchment Area
- SC-02
- Township of Whitewater Region
- Agricultural and Undifferentiated Lands

N

1:45,000

0 1 2 Km

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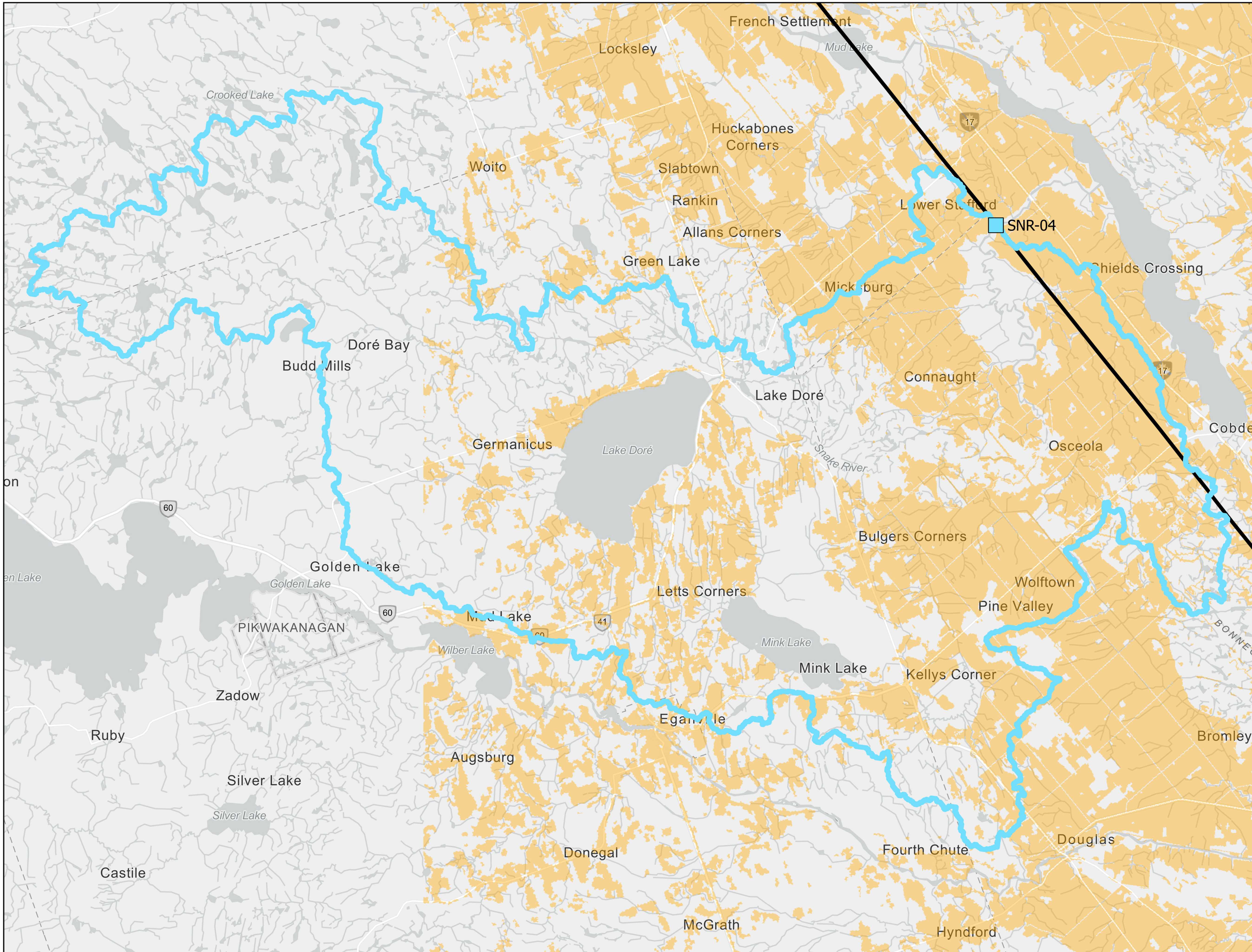

Muskrat Lake Watershed
Township of Whitewater Region

Agricultural Land Use
within the Catchment Areas

Legend

- SNR-04 Catchment Area
- SNR-04
- Township of Whitewater Region
- Agricultural and Undifferentiated Lands

N

1:110,000

0 2.75 5.5 Km

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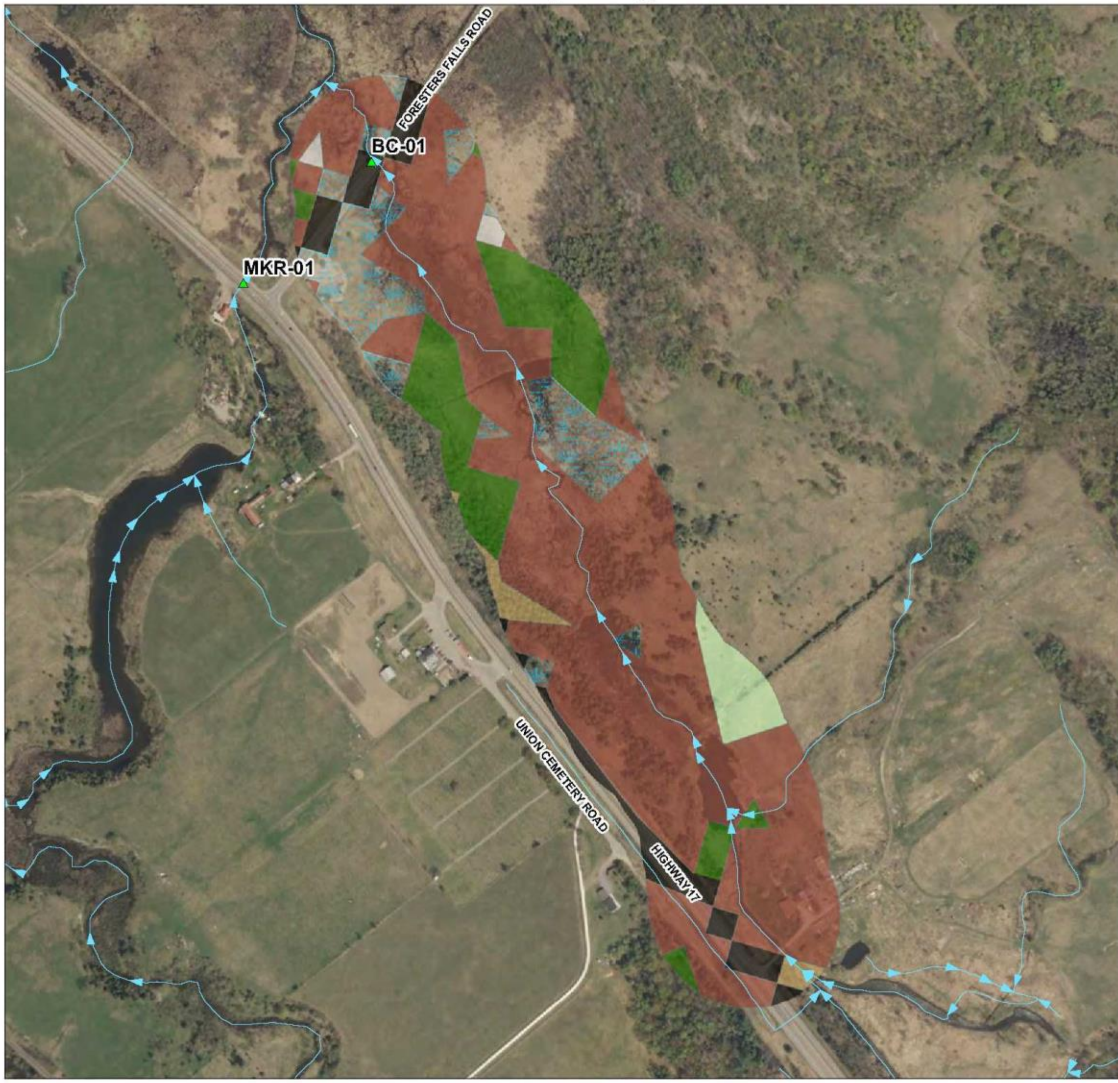
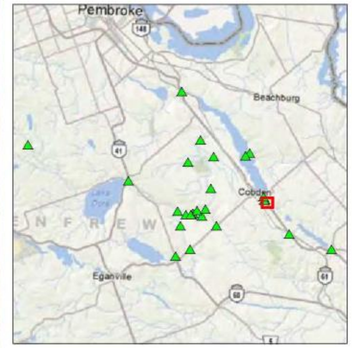
Appendix C. Land Uses within 1 km of Water Quality Sampling Locations (Dalton, 2019)

Ontario

Sampling Location: BC-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

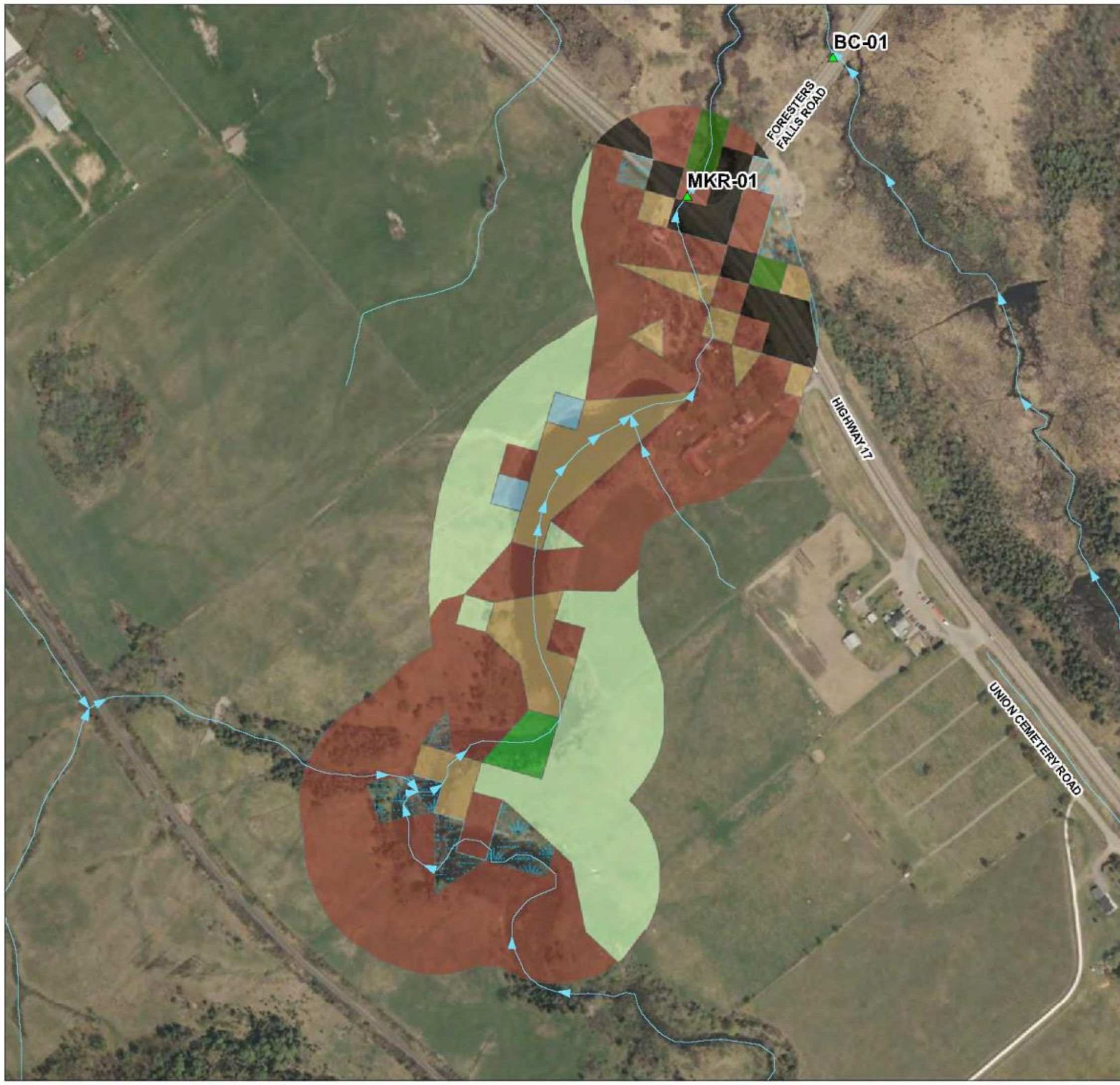
0 25 50 100 150 200 Meters

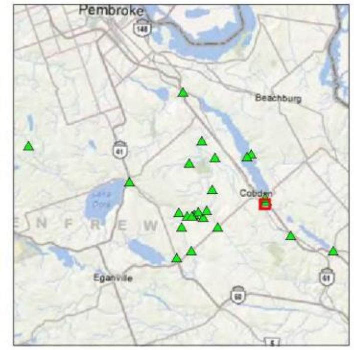
UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
Imagery Provided by Land Information Ontario

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

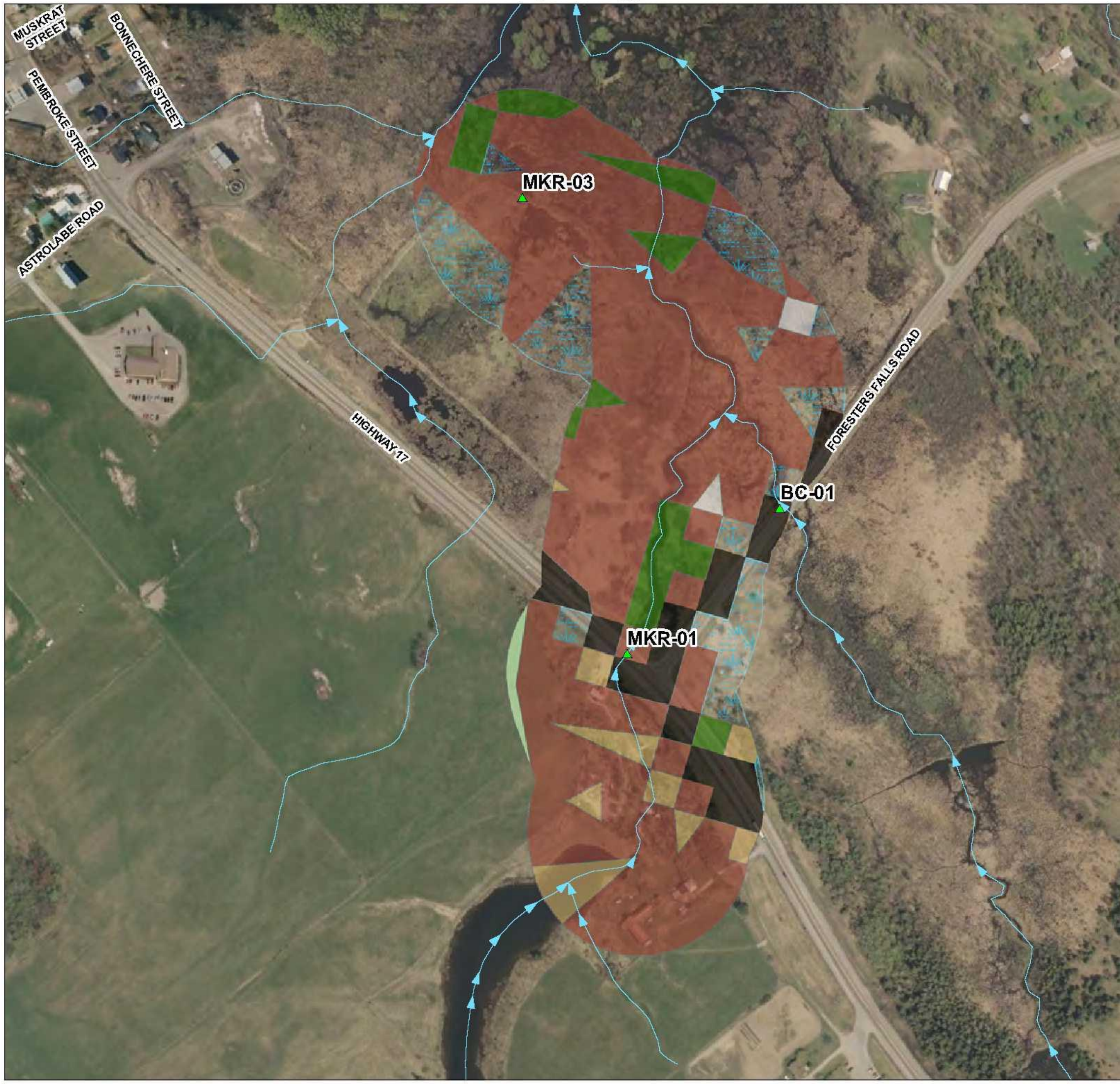
UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
Imagery Provided by Land Information Ontario

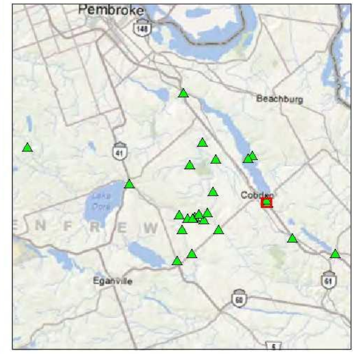
Published 2015

Ontario

Sampling Location: MKR-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 landBarren	Urban/Developed
Grassland	Water
Hemp	Wetland
	Wheat

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

N W E S

0 20 40 80 120 160 Meters

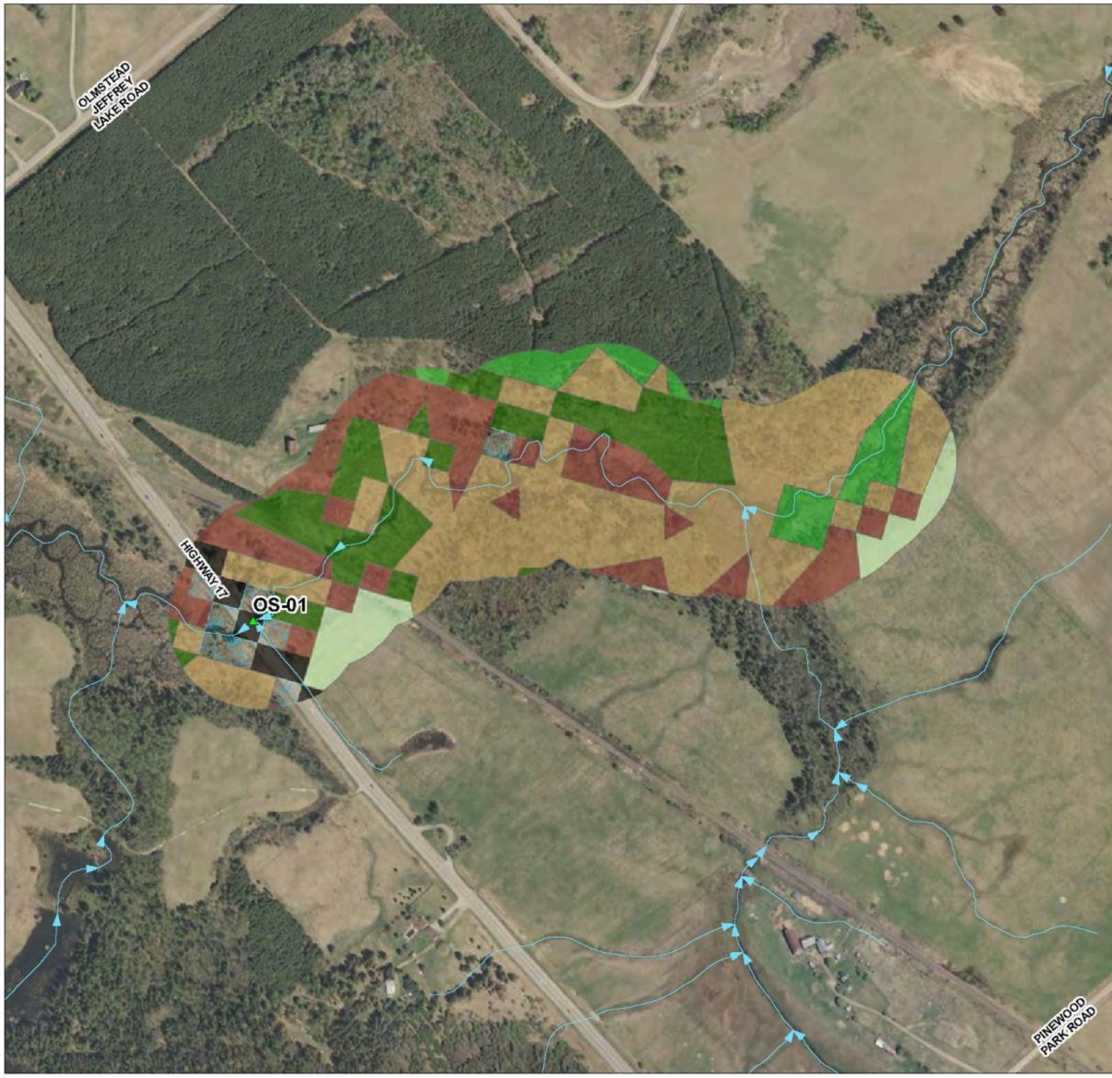
UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
Imagery Provided by Land Information Ontario

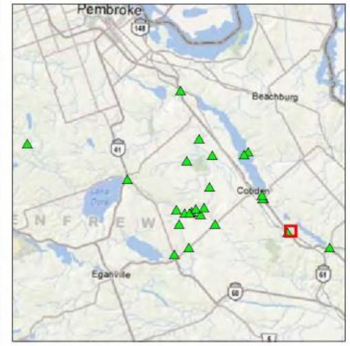
Published 2015

Ontario

Sampling Location: OS-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 land/Barren	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

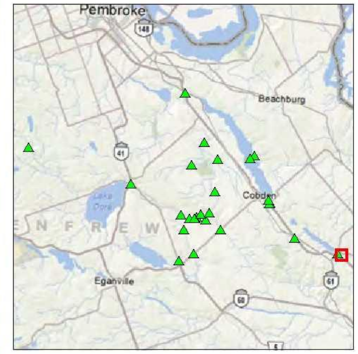
UTM Zone 18 (NAD 1983)
Information Provided by: Ministry of Natural Resources and Forestry, Ministry of the Environment and Climate Change, Ministry of Municipal Affairs and Housing, Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory 2014
Imagery Provided by Land Information Ontario

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

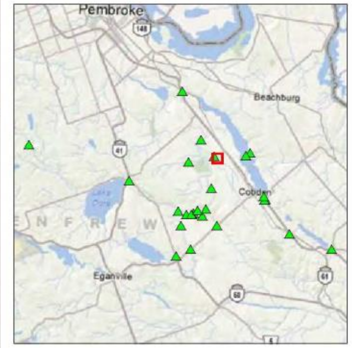
0 25 50 100 150 200 Meters

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

Ontario

Sampling Location: SC-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 land/Barren	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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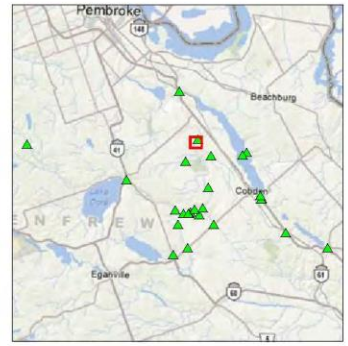
Ontario

Sampling Location: SNR-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)
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