

**Multi-Watershed Nutrient Study Supplemental:  
Summary Overview of Network, Site Conditions, and Data**

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## Document Summary

This document is an overview of the development and operation of the Multi-Watershed Nutrient Study (MWNS), conducted by the Ontario Ministry of the Environment, Conservation and Parks (MECP) between 2014 and 2020, and is intended to provide context to the associated open data sets. It does not provide findings or interpret the data. Data users are strongly encouraged to review this document fully prior to beginning analysis of the datasets.

This document provides background on the reasons for establishing the MWNS, including details of a previous study conducted in the 1970s (Pollution from Land Use Activities Reference Group, PLUARG) as well as project aims. It also gives a fulsome overview of the site selection process, daily operations and equipment used by the MWNS, including details of data telemetry setup, event-based sampling regime and the method by which samples over a hydrograph were selected for analysis across all potential water levels and seasons. A detailed breakdown of instruments used, sampling station and meteorological station setup, and operation are provided. Detailed notes on each site in the network are provided, including feedback from stream gauging experts from Water Survey of Canada, who conducted the flow monitoring for the MWNS. The data management processes for the MWNS stream water quality data, stream sensor monitoring data, and meteorological data are discussed. The outcomes of the blank and replicate sampling are presented along with details of the intensity of sample collection by site and season.

Appendices also include operating procedures, site and equipment details, and analytical method information and detection limits. There is also a list of selected scientific studies published as of October 2025 leveraging MWNS data.

## **1. Introduction**

### **Purpose of this document**

This document is intended to provide an overview of the MWNS's development and methods. Its primary purpose is to provide context to users of the MWNS data regarding the selection of the study sites and watershed characterization information, as well as details on station/equipment configuration, sampling criteria/strategies, operating procedures, laboratory analysis information, and data management and quality assurance and quality control (QAQC). This document is not intended to provide results, findings or interpretations of the data. Data users are strongly encouraged to review the document fully, as sampling methodology can impact data analysis and interpretation. The secondary purpose is to provide a centralized project overview for future researchers, as a point of reference on study design and methods should that be needed for future work.

### **Background**

Following the 1972 Canada-United States Great Lakes Water Quality Agreement (GLWQA), improved water quality was observed in the Laurentian Great Lakes basin due to nutrient management. The GLWQA established water quality objectives and led to the creation of programs aimed primarily at reducing industrial and municipal point-sources of phosphorus (P), including sewage treatment facilities. Nonpoint nutrient sources were investigated, in part, with a bilateral, multi-agency study known as the Pollution from Land Use Activities Reference Group (PLUARG), conducted in the mid-1970s, which examined nutrient loading from several small, agricultural watersheds. Nutrient loadings (the total amount of nutrient delivered by a stream in a given period) from these watersheds were attributed to land use, land management, and physical features of the watersheds. While the effective management of P point sources in the 1970s improved water quality in the Great Lakes, eutrophication re-emerged in the mid-1990's and continues to result in water quality issues today.

From 2014 to 2020, the MECP led the Multi-Watershed Nutrient Study (MWNS). This study aimed to examine how agricultural land use, land management and features of the landscape relate to nutrient losses in agriculturally dominated areas of the Great Lakes basin. A large component of the MWNS was to examine how changes in land-use, land management and climate affect water quality and nutrient loading over time by revisiting some of the same watersheds monitored in the PLUARG study over 40 years ago. The MWNS selected sentinel headwater watersheds in the basins of Lakes Huron, Erie, and Ontario for detailed study. These watersheds represent a range of agricultural conditions in Southern Ontario.

## 2. The MECP Multi-Watershed Nutrient Study (MWNS) Monitoring Network

The MWNS network was comprised of 11 small agricultural head-water streams in southern Ontario (Figure 1). These watersheds are in the Mixed Wood Plains ecozone of southern Ontario (ecoregions 6E and 7E), which are characterized by fertile soils underlain by limestone, sandstone, and shale bedrock (Crins *et al.*, 2009). Additional details on regional physiography and climate are presented in Nelligan *et al.* (2021) and Biagi *et al.* (2022).

Using a combination of new data and modelling approaches, MWNS revisited some of the major goals of the PLUARG studies to generate a comparison of present-day findings to those from approximately 40 years prior. This was done in part by re-examining, using similar (though modernised) approaches, some of the same agricultural watersheds that were studied by PLUARG. Since the representative agricultural regions identified in the original PLUARG study have changed in the intervening period, the MWNS included a regional evaluation of the range in agricultural types and the potential for agricultural landscapes to lose phosphorus to surface water. This evaluation helped to guide site selection to ensure representation of agricultural conditions across the province (See Rosamond *et al.*, 2018).

### The Multi-Watershed Nutrient Study Goals:

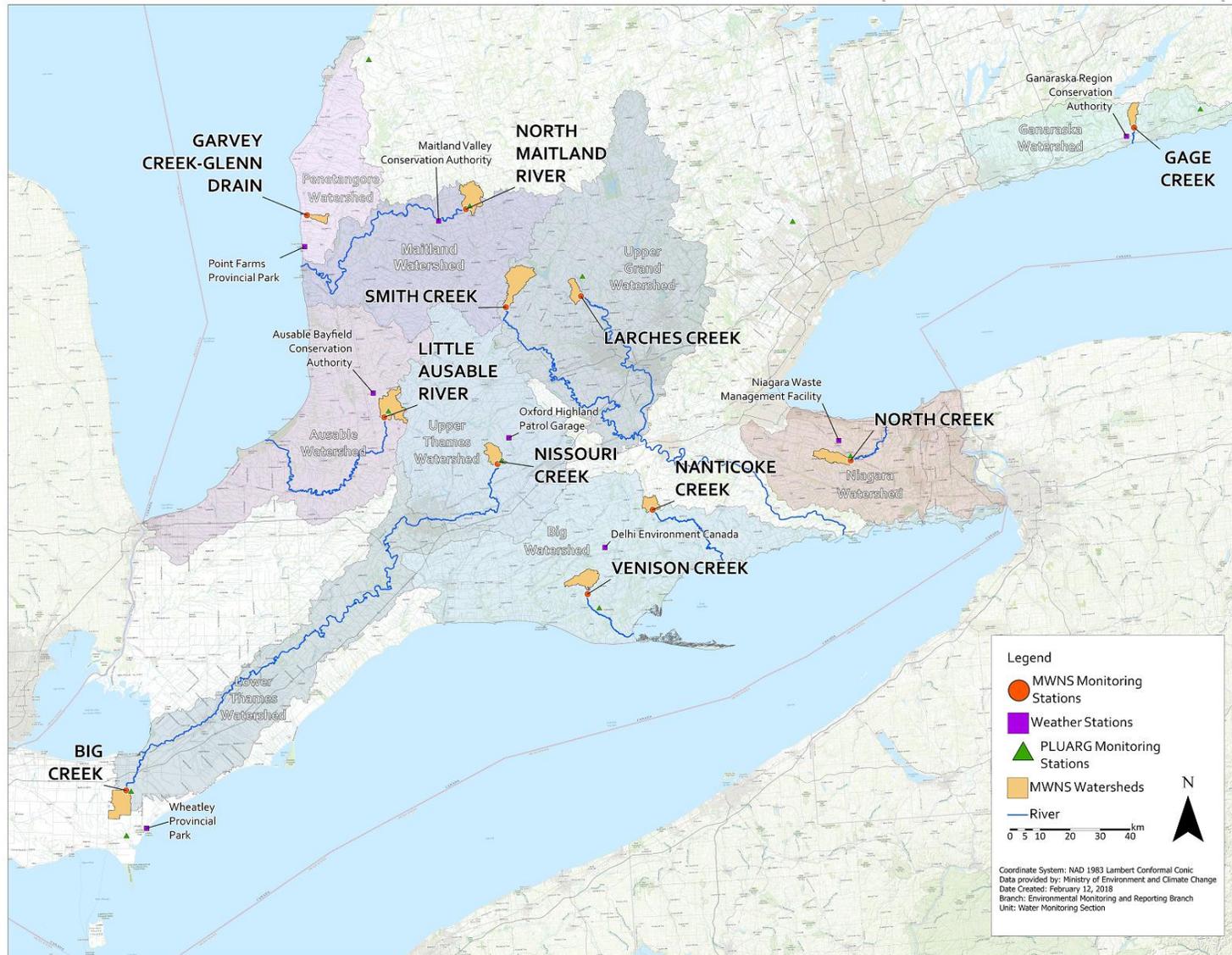
Determine, compared to the 1970s:

- Have loadings of agricultural non-point sources of nutrients changed?
- Has the relationship between land use, land management and the nutrient loads in streams changed?
- Have there been changes in seasonal patterns of nutrient loads?
- Have there been changes in the type of phosphorus entering rivers (particulate form or in dissolved form, which can be used by plants and algae more easily) from agricultural watersheds? What types are found?

### Desired Project Outcomes:

Help decision-makers understand how and when nutrients move in the environment to inform future land management actions.

Produce province-scale datasets that can be used to understand and analyze the relationships between land use, land management, and how nutrients transform while moving through surface waters.



**Figure 1: A map of the Multi-Watershed Nutrient Study (MWNS) Monitoring Network, showing major tributary watersheds in pale colours, MWNS headwater stream watersheds in yellow, and points for station locations for sampling and weather monitoring. The locations of former PLUARG stations are included.**

### 3. MWNS Site Selection and Watershed Characteristics

A novel process, called the Quality Index (QI) approach, was used to evaluate and select a small number of study sites that would represent a broad range of agricultural landscapes across the province of Ontario (Rosamond *et al.*, 2018). This approach was developed in conjunction with MECP, the University of Waterloo, Agriculture and Agri-Food Canada (AAFC), and Ontario Ministry of Agriculture, Food and Agribusiness (OMAFRA). The process was used to select a range of representative agricultural-dominated watersheds in the province with a good coverage of variables representing agricultural phosphorus (P) inputs and P transport mechanisms taken from commonly available geospatial datasets. This process reduces subjectivity in site selection while considering practical constraints when evaluating locations. MWNS sites plotted in relation to QI criteria are found in the Appendix A (Fig. A.1a-d).

To begin, a list of over 400 candidate locations was produced and included existing or historical water quality monitoring sites from a range of programs (e.g., Provincial Water Quality Monitoring Network, Nutrient Monitoring Program, Healthy Lake Huron, PLUARG). In addition, Conservation Authorities (CAs) were contacted to recommend potential subwatersheds using criteria such as small sized agricultural-dominated watersheds (10-100 km<sup>2</sup>), no point sources of nutrients (e.g. wastewater treatment plants, aquaculture, greenhouses) and limited to no urban land use. The 400 locations were narrowed down to 108 candidates for inclusion in the QI process, with priority given to past PLUARG stations. Of the 108 potential locations, a desktop analysis was done using satellite imagery and interviews with participating CAs to assess stream access, proximity to road and hydro, and watershed landuse.

Finally, a short-list of the candidate locations was developed and used by MECP and Water Survey Canada (WSC) technologists to evaluate each potential site in the field. Each location was thoroughly assessed for health and safety attributes, watercourse controls, depths, and stability, access to hydro, cellular service strength (for telemetry), property boundaries, presence of other utilities (e.g. gas line, fiberoptic), and site characteristics documented with photographs and notes.

Six of the MWNS stations overlapped PLUARG locations (Fig. 2: Big, North Maitland, Nissouri, North, Vension, and Little Ausable) and five additional stations were chosen (Smith, Gage, Garvey, Nanticoke, and Larches) to represent the range of agricultural watersheds identified through the QI site selection process. Several historical PLUARG watershed had significant land use changes over the last 40+ years and were therefore excluded from the MWNS. Overlapping PLUARG/MWNS watersheds did not always have the same sample collection location (water quality monitoring station). In several instances, alternate locations were chosen along the watercourse to ensure appropriate stream access, good stream flow, and to avoid point-sources within the watershed (see Table 1 and Table A.1 for further details).

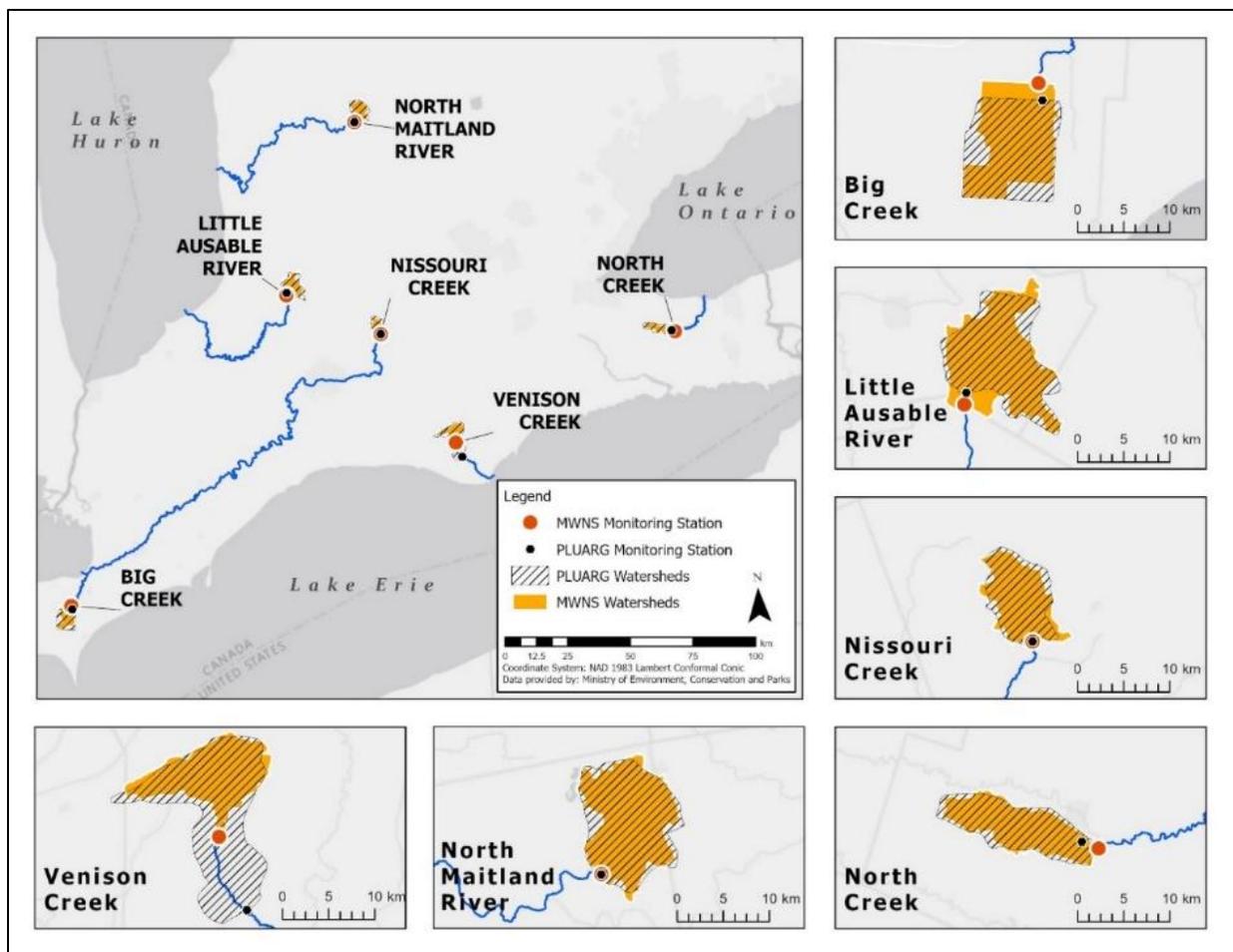


Figure 2. Location of the six overlapping MWNS/PLUARG watersheds depicting past and present watershed boundaries (from Nelligan *et al.*, 2021).

**Table 1. MWNS locations in reference to PLUARG stations.**

PLUARG	MWNS	Selected (Y/N)	Watershed name (PLUARG ID)	Notes on site or watershed changes
✓	✓	Y	Big Creek (AG-1)	Moved site downstream of PLUARG site due to local land use changes
✓	✓	Y	Venison Creek (AG-2)	MWNS site moved upstream to avoid a fish farm discharge
✓	✓	Y	North Creek (AG-10)	Moved upstream by one road as WSC required a better channel for more accurate flow measurements.
✓	✓	Y	Little Ausable River (AG-3)	Moved site downstream of PLUARG site due to local land use changes
✓	✓	Y	Nissouri Creek (AG-5)	Same as PLUARG site location (previously called Holiday Creek)
✓	✓	Y	North Maitland (AG-6)	Same as PLUARG site location
	✓	Y	Gage Creek	This was chosen as an alternate site to PLUARG site, Shelter Valley, with similar land-use and fit similar criteria in QI site selection process.
	✓	Y	Garvey Glen	Long-term monitoring site (Health Lake Huron) with existing infrastructure and CA sampling partner. Filled an important gap for cumulative P Balance coverage in Ontario agricultural landscape during the QI site selection process (Fig. A.1.a).
	✓	Y	Smith Creek	Filled an important gap for cumulative P Balance coverage in Ontario agricultural landscape during the QI site selection process.
	✓	Y	Larches Creek	Filled an important gap for cumulative P Balance coverage in Ontario agricultural landscape during the QI site selection process, as a replacement for former PLUARG site in Canagagigue Creek.
	✓	Y	Nanticoke Creek	Filled an important gap for cumulative P Balance coverage in Ontario Agriculture landscape during the QI site selection process.
✓		N	Salt Creek (AG-11)	Significant land-use change to urban in this watershed since PLUARG.
✓		N	Canagagigue Creek (AG-4)	Well studied watershed with loadings and land-use extensively covered in recent years (replaced by Larches Creek for MWNS). In addition, a fish farm is now established in the watershed.
✓		N	Shelter Valley (AG-7)	Poor stream access, lack of areas for appropriate hydro. Gage Creek was chosen as an alternative based on similar land-use and QI site selection criteria.
✓		N	Hillman Creek (AG-13)	Land-use has changed and includes several greenhouses/nursery/floriculture operations. Big Creek has similar land-use, geology, and QI site selection criteria.
✓		N	Wilmot Creek (AG-14)	Looked for site that gave greater coverage in Ontario Agricultural landscape during the QI site selection process

When previous candidate PLUARG stations could not be selected, substitutions were comparable to the older sites. Further details pertaining to each MWNS watershed soil and land use characteristics are defined in Tables 2 and Table A.1 in Appendix A.

**Table 2. MWNS network land use and watershed characteristics.**

Site	Watershed Area (km <sup>2</sup> )*	Predominant Soil Type	Area Farmed (%)*	Dominant crop types**	Dominant livestock	Manure Additions IROWC (kg P /ha)	Total Animal Units	Area of Tile (%)*	Avg. Slope (%)*	Parent Watershed*	Receiving Water-body
Big	55	Clay	95	Cash crop, soybean	Hog	3.5	978.6	92	0.6	Lower Thames	St. Clair/ Erie
Garvey Glenn	13	Silt Loam/Loam	85	Wheat, corn, soybean	Hog, dairy	27.2	1347.9	90	2.0	Penetanguishene	Huron
Gage	21	Loam/Sandy Loam	72	Pasture, corn, soybean	few	6.3	423.8	51	7.6	Ganaraska	Ontario
Little Ausable	64	Clay loam	91	Corn, soybean, wheat	Beef, dairy**	18.5	5086.5	91	1.5	Ausable	Huron
Larches	23	Loam	86	Pasture, corn, wheat, soybeans	Beef, dairy	88.0	8600.8	79	2.4	Upper Grand	Erie
North Maitland	56	Loam/silt loam	69	Corn, soybean, wheat	Beef, dairy**	18.4	3554.5	54	3.3	Maitland	Huron
Nanticoke	22	Loam/Silt loam	74	Pasture, corn, soybean, rye	few	3.3	269.9	40	2.3	Big	Erie
Nissouri	31	Loam/silt loam	82	Corn, soybean, wheat, hay	Beef, dairy, hog**	56.2	7235.6	91	2.6	Upper Thames	St. Clair/ Erie
North	36	Clay	79	Soybean, wheat, pasture	Beef, poultry**	12.8	1079.8	24	1.5	Niagara	Ontario
Smith	71	Loam/Clay loam	90	Pasture, corn, soybeans, wheat	Beef, dairy, poultry, hog	32.0	10350.6	89	1.5	Upper Grand	Erie
Venison	44	Sand	72	Corn, soybean	few**	0	0	57	1.9	Big	Erie

\* Biagi *et al.*, 2022

\*\* Nelligan *et al.*, 2021

## 4. MWNS Station Design

The MWNS network was developed to provide fully automated monitoring of water quality, water quantity, and meteorological (MET) conditions using industry-standard instrumentation and a custom telemetry system. This design enables remote control of station operations and real-time access to data for project team members. Standard Operating Procedures (SOPs) governed all data collection and regular maintenance activities.

### 4.1 Stream Monitoring Stations

Eleven MWNS sites were chosen for monitoring (see previous section). Each of the stream monitoring stations were configured using a standardized approach (see Fig. 3). A monitoring hut was installed at each location, housing a refrigerated autosampler and a bubbler system. The bubbler line, suction line, and sensor line were extended into the creek to facilitate sampling and measurement. Cellular telemetry was implemented to transmit data at 15-minute intervals to a remote server. The autosamplers were equipped with two-way communication capabilities, enabling remote activation for sample collection.

The Water Survey of Canada (WSC) operated 10 of the 11 sites, performing water level and flow gauging, applying corrections, and developing rating curves. Garvey Glen site was gauged by the Maitland Valley Conservation Authority for the MWNS. MECP staff conducted additional water level monitoring to support operational and decision-making processes and to fill gaps in WSC level data. At the conclusion of MWNS sampling, a survey was distributed to WSC technologists to gather feedback on watercourse conditions for flow metering (see Appendix C).

Precipitation was measured using a 3-season tipping bucket rain gauge located on the top of each hut; however, this measurement was only used for operational purposes and data gap filling for MET stations.

The parameters measured at each stream monitoring station are summarized below (further details in Appendix B):

- Precipitation (three season tipping bucket) – 15-minute intervals
- Gauge height (level) – 15-minute intervals
- Water quality sample – as triggered
- Temperature -15-minute intervals
- Turbidity – 15-minute intervals
- Gauge height (level, WSC) – 5-minute intervals

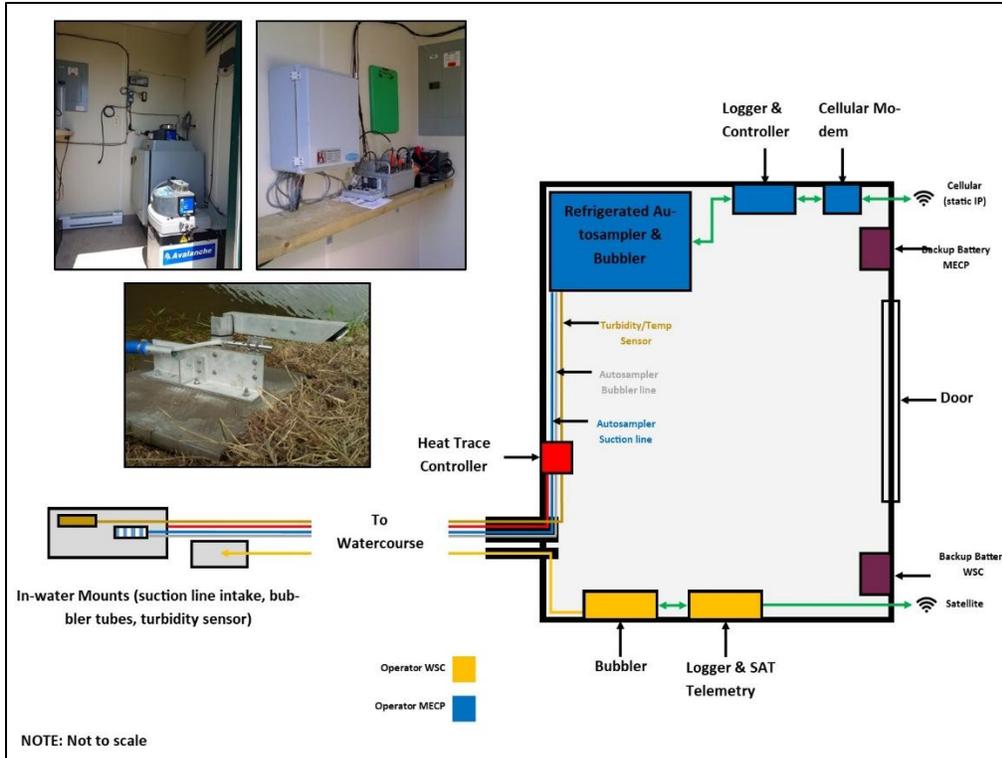


Figure 3: General configuration of an MWNS stream monitoring station.

Real-time custom dashboards were utilized to monitor rainfall intensity, watercourse conditions, timing of sampling, and station status and health (see Fig. 4). Automation and telemetry were essential for managing geographically distributed stations across southern Ontario, enabling coordination with MECP regional offices and partner Conservation Authorities for sample pickup and equipment resets.

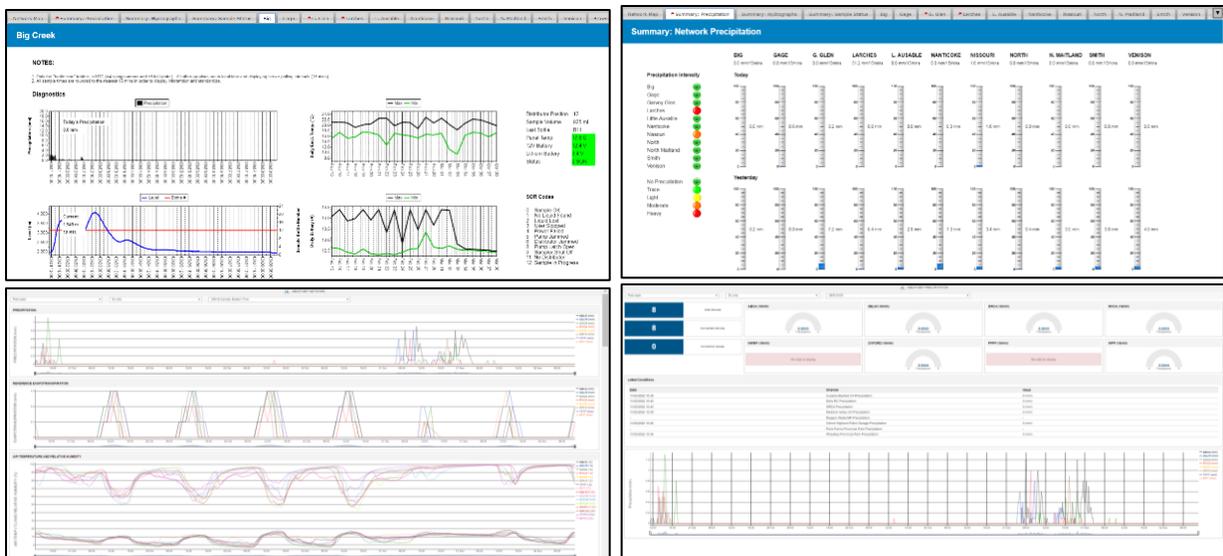


Figure 4: Selected MWNS network dashboards depicting real-time data pertaining to precipitation intensity/volume, water levels, turbidity/water temperature, soil temperature and moisture, equipment status, and other meteorological information.

## 4.2 Meteorological Stations

Each MWNS stream gauge was supported by an off-site meteorological (MET) station to collect soil and climate data. MET stations were located within a 15 km buffer around the watershed to minimize roadside environmental influences (e.g., vehicle spray). Siting adhered to World Meteorological Organization (WMO) criteria. Figure 5 depicts the layout of a MET station. A full summary of instrumentation can be found in Appendix B.

The following parameters were recorded at 15-minute intervals at each MET station:

- Solar radiation, incoming longwave
- Relative humidity
- Air temperature
- Temperature, dew point
- Wind direction
- Wind gust speed
- Wind speed
- Precipitation
- Soil temperature – Depths of 0.05m, 0.1m, 0.25m, 0.5m
- Soil moisture – Depths of 0.1m, 0.25m, 0.5m

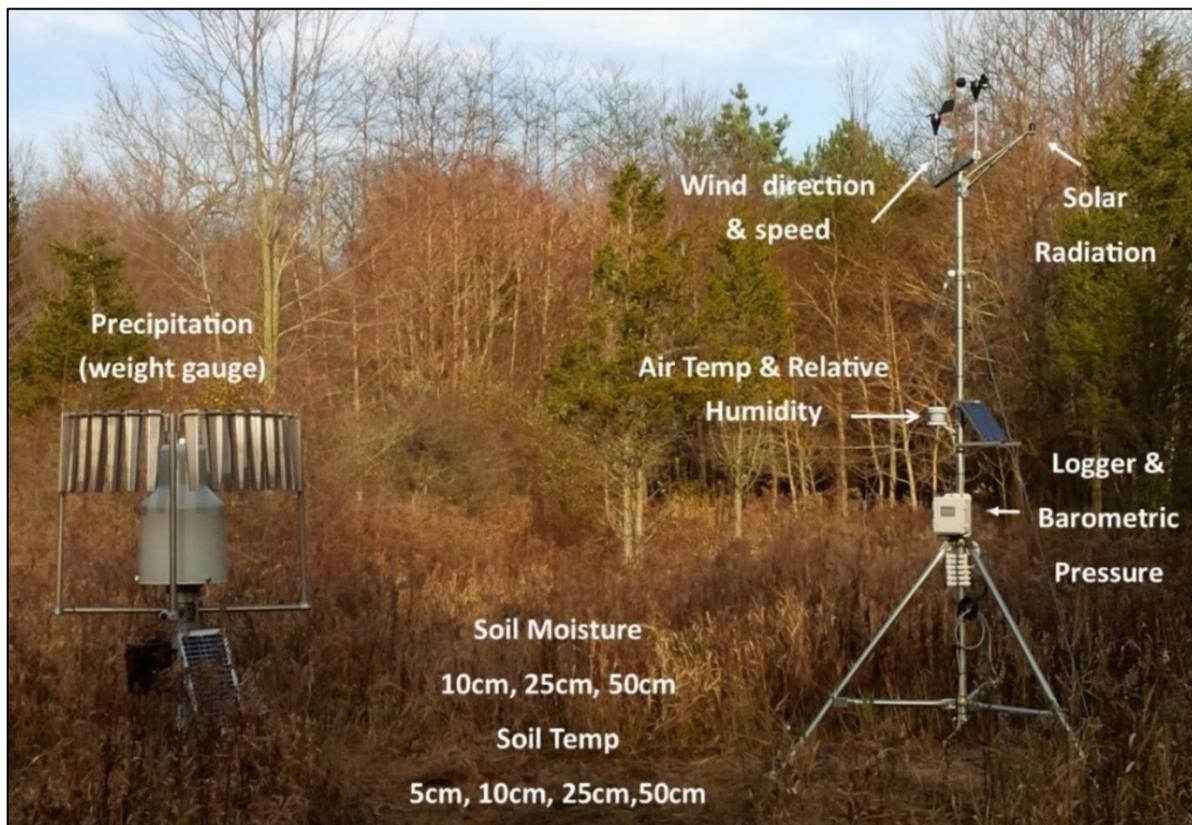


Figure 5: General configuration of an MWNS meteorological station, example Wheatley Provincial Park MET

## 5. MWNS Network Monitoring Stations

This section summarizes each MWNS station in terms of general environmental observations and operating conditions.

### Big Creek

Installed in 2015, the Big Creek stream gauge was located downstream from a previous PLUARG location (Fig. 2). Ground truth assessments were conducted to ensure nearby greenhouses were not discharging into the watershed. The supporting MET station was installed in Wheatley Provincial Park (Fig. 5 & 6). Soon after the installation of the stream gauge in early 2016, the creek channel was cleared of all brush and overgrowth 250m upstream and downstream from the station to improve flow and metering conditions.



**Figure 6. Big Creek Station. Starting upper left and moving clockwise, Big Creek hut 2015-2018, huts in 2018-2020, supporting MET station at Wheatley Provincial Park, upstream, and downstream.**

In 2018, due to safety concerns caused by the station building affecting the line of sight of a driveway exit from a neighbouring property, the building was removed, and two smaller enclosures were installed on the other side of the road. The position of the sensors and intake lines were not changed during this move. However, this did affect the stations performance as hydro was not available and solar power was used. This change in power supply saw the elimination of enclosure heat and plumbing heat tracing. This is essential for 4 season operation (winter, early spring) and as a result, the station did occasionally freeze and sometimes was not able to collect winter samples later in the project. This was compensated for by taking grab samples or visiting the station prior to sampling and clearing suction lines and insulating the enclosure instrumentation.

### Gage Creek

The Gage Creek stream gauge was installed in July 2015 and the first water sample taken was March 2016. The meteorological station was installed at the Ganaraska River Conservation Authority (GRCA) head office only few kilometers away (Fig. 7).



**Figure 7. Gage Creek Station. Starting upper left and moving clockwise, Gage Creek hut, supporting MET station at Ganaraska Conservation Authority head office, upstream, and downstream.**

This site repeatedly experienced naturally high siltation and beaver dam construction. As a result, the in-water sensors and autosampler suction line was relocated several times to avoid being buried. The increased sedimentation was due to natural erosion and beaver dams. The creek was one of the “flashier flowing” watercourses in the MWNS network and due to soil type and higher velocities, bank erosion was commonplace during large storm events. Several beaver dams were constructed in the same location upstream and removed both naturally and manually. In one instance, the first natural dam failure caused major bank and sediment transport which took many months to stabilize.

### **Garvey Glenn Creek (Garvey Creek-Glenn Drain)**

Garvey Glenn is an existing station for the Healthy Lake Huron monitoring program and actively operated by Maitland Valley Conservation Authority (MVCA). Using existing infrastructure, MECP upgraded the site with additional instrumentation including dual autosamplers, in-water sensor, cellular telemetry, weighing precipitation gauge, 12v heat tracing, solar heater, and increased solar power as hydro electricity was not an option. This was the only MWNS station not gauged by Water Survey Canada (WSC) and was instead gauged by MVCA. The first autosampler sample as part of the MWNS project was taken in March 2016 and the closest meteorological station was constructed in Point Farms Provincial Park (Fig. 8).



**Figure 8: Garvey Glen Station. starting upper left and moving clockwise, Garvey Glen hut, supporting MET station at Point Farms Provincial Park, upstream, and downstream.**

This station saw a rare flood in early 2018. Storm volumes were large enough to submerge station equipment, overtop the culvert, and change stream morphology downstream. This ultimately saw the need for MVCA to start developing a new stage/discharge curve for site. While a new rating curve is still under construction, pre and post flood curve points did represent most stream flow regimes during the study.

### **Larches Creek**

Due to siting complications, the Larches Creek station was solar powered. As a result, the station struggled with winter operations due to the lack of enclosure heat and heat tracing. Despite this, the station was outfitted with a solar heater and 12-volt heat tracing to alleviate some of the extreme cold conditions in the winter months. Extra care was taken to subsidize the winter sample collection with grab samples and unfreezing suction lines manually (Fig. 9).



**Figure 9: Larches Creek Station. Starting left to right, Larches Creek hut, upstream, and downstream.**

The station was established in December of 2017 and the first sample was collected in January 2018. Prior to that, grab samples and water level were collected, beginning in April 2016 until the station was constructed. MECP did not install a MET station locally, as the Grand River Conservation Authority had one in proximity to the Larches site at Conestogo Conservation Area. These data can be obtained from CA directly.

## Little Ausable River

The Little Ausable station has been a long-term study watershed. It was a PLUARG watershed (MWNS site just downstream of the PLUARG station location; Fig. 2) and was redeployed for intense water quality monitoring by the MECP in 2004 under the Nutrient Monitoring Program (see Ontario Ministry of the Environment, 2012). The first sample collected for the MWNS was in September 2014 with its supporting MET station installed at the Ausable Bayfield Conservation Authority head office (Fig. 10).



**Figure 10: Little Ausable River Station. Starting upper left and moving clockwise, Little Ausable River hut, supporting MET station at Ausable Bayfield Conservation Authority head office, upstream, and downstream.**

For part of the MWNS study, an older enclosure installed in 2004 was used to house all monitoring equipment, but due to deterioration and positioning in the flood plain, the building was replaced and redesigned in 2018 with all in-water devices staying in the same location. As a result of the construction, the site was offline between May 2018 and June 2018. In addition, the site experienced several periods of sensor/sample downtime prior to the 2018 upgrades due to rodent infestation damaging wiring and tubing.

For the majority of the MWNS, this station was considered a very stable watercourse with a reliable stage discharge curve and chemistry. Unfortunately, the presence of a beaver dam downstream started to influence station measurements despite several successful attempts to remove it. Ultimately, the dam became well established and caused backwater and ponding at the station near the end of the study. This station was regularly affected by algae growth during late summer months.

## Nanticoke Creek

The Nanticoke Creek stream station first water samples was collected in February 2016 and supporting MET station was installed next to Environment Canada's Meteorological Services Delhi climate station #6131983 (Fig. 11).

During the initial setup of the station, it was observed that there may be flow metering challenges due to a shallow slope. The effects of both sedimentation and a stable control required some effort to remediate. With the installation of a natural stone weir at the road culvert, sedimentation on instruments decreased and a stable pool occurred. However, efforts to prevent control leakage was a challenge.



**Figure 11: Nanticoke Creek station. Starting upper left and moving clockwise, Nanticoke Creek hut, supporting MET station at Env Can Delhi MET complex, upstream, and downstream.**

## Nissouri River

This watershed was part of PLUARG and was started again for intense water quality monitoring by the MECP in 2004 under the Nutrient Monitoring Program (see Ontario Ministry of the Environment, 2012). The first autosampler-collected MWNS samples were collected in October 2014. The nearest MET station is Oxford Highland (Fig. 12).



**Figure 12: Nissouri Creek station. Starting upper left and moving clockwise, Nissouri Creek hut, supporting MET station at Oxford Country Municipal Garage, upstream, and downstream.**

During the study, the Nissouri Creek station experienced regular vegetative debris accumulation within the channel due to the woodlands in proximity of creek banks. This was a concern described by WSC as influencing some metering stages. However, the rating curve was complete for all stages during the study due to the site’s long-term operations. In addition, downstream vegetative debris was observed during the final months of the study and its influence was marginal in the longer-term metering records.

## North Creek

North Creek was part of the PLUARG monitoring program. The MWNS station came online in September 2014, and the first autosampler-collected water sample was in March 2015. The closest MET station was sited at the Niagara Waste Management Facility (Fig. 13).



**Figure 13: North Creek station. From left to right North Creek hut, supporting MET station at Niagara Region Waste Management Facility, upstream, and downstream.**

The North Creek station was a particularly challenging location for monitoring flow as it had a poor control and experienced stagnant or no flow during summer months. This is primarily because the creek is predominately fed by surface runoff and has a shallow slope. During the initial setup of the site, a

natural stone weir was installed but frequently experienced infiltration and lowering of the permanent pool under low flow and stagnant conditions.

## North Maitland River

Monitored during PLUARG, the North Maitland MWNS station came online in August 2014 and its first autosampler-collected water sample was in September 2014. The supporting MET station was installed nearby on the property of MVCA's head office (Fig. 14).



**Figure 14: North Maitland River station. Starting upper left and moving clockwise, North Maitland River hut, supporting MET station at Maitland River Conservation Authority head office, upstream, and downstream.**

The North Maitland station was an excellent location for monitoring overall. Being groundwater-fed and non-flashy during event flows, much of the channel was stable, with steady flow throughout the year and minor vegetation growth influence.

## Smith Creek

The MWNS stream station (Fig. 15) came online in February 2016 and the first sample collected in April 2014. Like the Larches Creek station, MECP did not install a MET station locally, as the Grand River Conservation Authority had one in proximity to the station at Conestogo Conservation Area. These data can be obtained from the CA directly.



**Figure 15: Smith Creek station. Starting upper left and moving clockwise, Smith Creek hut, upstream, and downstream.**

While a rating curve was developed for this station, WSC did identify that edge vegetation and unstable/eroding parts of the control affected some gauging points. Algae was also regularly observed during summer months that was more prominent than most MWNS network stations.

## Venison Creek

The MWNS Venison Creek station had to be located upstream from the original PLUARG location to avoid the outfall of a fish farm (see Fig. 2). The MWNS sampling station came online in March 2016, and its first autosampler collected water sample was in May 2016. Due to its proximity to the Nanticoke Creek station, its supporting MET station was also at the Delhi climate station #6131983 (Fig. 16).



**Figure 16: Venison Creek station. From left to right - Venison Creek hut, supporting MET station at Env Can Delhi MET complex, upstream, and downstream.**

This station had virtually no operational issues because of the stable watercourse, non-flashy flow, and very good control. However, early in the study it was observed that channel scour was occurring (sand-based sediments), so a natural stone weir was installed to increase the gauging pool and natural sedimentation made the stone weir somewhat impervious.

## 6. MWNS Sampling

### 6.1 MWNS Sampling Objectives

Sampling was designed to capture a wide range of flow conditions at each MWNS site year-round. Discrete samples, rather than composite samples, were taken. Intensive sampling occurred during storm events or other high-flow periods, including snowmelt, while additional samples were collected under antecedent or base-flow conditions.

Seasons for this study were defined as:

- Spring: Mar/Apr/May
- Summer: June/Jul/Aug
- Fall: Sept/Oct/Nov
- Winter: Dec/Jan/Feb

During the study, the term “event” generally refers to a short-term period of water level rise and recession (due to precipitation or snowmelt). Other data users might define an event differently (e.g. Ross et al. 2022).

### 6.2 Water Quality Sample Collection

The temperature-controlled automated sampler was used to capture a range of flow events at each MWNS site. The automated sampler was equipped with 12 or 24 bottles that were sequentially filled during high-flow events. For each event, sampling frequency depended on the event’s duration. Typically, one discrete bottle was collected every three or four hours. After each event ended and stream levels returned to antecedent conditions, a subset of samples was selected for analysis to represent the hydrograph. For most events, 5-7 discrete bottles were chosen for analysis. Additional grab samples were collected throughout the study period, primarily during antecedent or base-flow conditions. These were either pumped directly from the automated sampler or obtained using a sampling pole, particularly during summer low-flow conditions.

After retrieval from the automatic sampler, each bottle was capped, shaken, and rapidly decanted into sample containers for laboratory submission (Appendix D). Samples were typically collected in batches following each event. A portion of each sample was filtered through a 0.45 µm nylon filter for dissolved parameters. Samples were shipped on ice to the MECP’s Laboratory Services Branch (LaSB; Toronto, ON) and Dorset Environmental Sciences Centre (DESC; Dorset, ON). The full suite of parameters collected by the MWNS are detailed in Appendix E including method descriptions and detection limits.

### 6.3 Sampling Frequency

Over the study, efforts were made to collect a range of flow conditions at each MWNS site. Water level and other sampling conditions were tracked over the project, to adjust event and sample selection to ensure as much as possible that the following were collected annually from each station:

- One base-flow grab sample per month\*
- 1-3 high-intensity\*\* events per season.
- 1-2 medium intensity\*\* events per season.
- 1-2 low intensity events\*\* per season.
- 1 ‘oversampled’ event, for which many more samples (up to 24 bottles) than usual were collected over the hydrograph, during a high-flow event.

\* Base-flow was collected both using grab samples and the autosampler. When a wet weather event was expected, effort was made to collect a base-flow sample using the autosampler, 1-12 hours prior to the event.

\*\* Intensity categories are a relative, qualitative assessment to estimate if the full range of flow has been captured. This was confirmed seasonally to determine if the full range for each stream was successfully captured.

To ensure the entire range of flow condition at each station were captured, a program called the Water Monitoring Multi-Tool (WMMT) was developed to automate the bottle selection process using the real-time hydrograph and collection history at each site to fill in missing data gaps. Starting in late 2018, this application was used to determine which sample bottles would be processed from an event and submitted to the laboratory for analysis (Fig. 17).

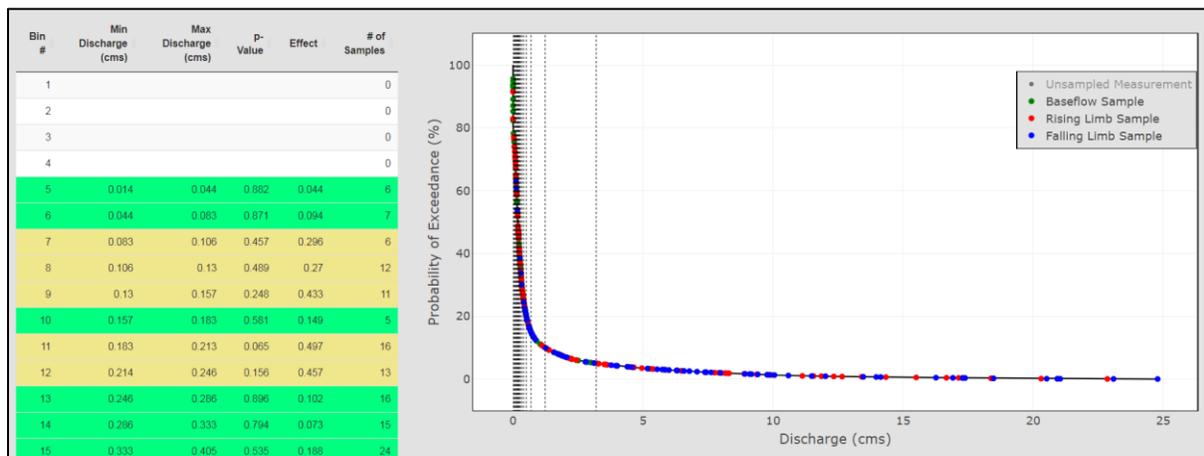


Figure 17. Screen capture of the Water Monitoring Multi-Tool.

A summary of sample frequency by year and season is shown in Table 3, in order to illustrate the relative intensity of sampling efforts over the MWNS.

**Table 3. Sampling frequency of water sample collection by season and year. Each entry represents a sampling instance of either a single grab sample or a multi-sample event. Darker shading represents a higher frequency of collection (events and base-flow) during the MWNS.**

Water Year	Season	Big	Gage	Garvey Glen	Larches	Little Ausable	N. Maitland	Nanticoke	Nissouri	North	Smith	Venison	All stations
2015	Winter					3	3		3	3			12
	Spring					3	2		1				6
	Summer	1				1	1		1	1			5
	Fall					1							1
2016	Winter	1	1	1		1				1			5
	Spring	1	3	3	4	1	3	2	1	2	4	2	26
	Summer	5	3	3	3	2	2	5	4	4	3	4	38
	Fall	6	2	2	3	5	2	5	3	5	5	3	41
2017	Winter	11	12	11	12	8	12	11	12	12	13	12	126
	Spring	7	8	6	8	6	6	7	7	7	10	7	79
	Summer	8	2	2	5	6	1	1	2	7	3	1	38
	Fall	10	4	6	6	8	7	8	7	9	7	4	76
2018	Winter	6	6	5	9	6	6	8	7	8	8	7	76
	Spring	4	8	4	8	3	6	8	5	7	8	8	69
	Summer	6	2	5	3	6	3	3	10	7	2	2	49
	Fall	9	6	9	8	9	5	6	9	7	8	6	82
2019	Winter	4	8	5	5	8	8	8	9	12	8	8	83
	Spring	7	6	8	6	12	7	8	13	14	8	6	95
	Summer	6	6	3	5	6	4	7	10	10	3	6	66
	Fall	4	5	5	10	6	5	6	10	8	7	4	70
2020	Winter	3	4	4	3	4	4	3	8	5	3	3	44
	Fall	1	2	1	1	2	2	2	3	2	1	2	19
All years	Winter	25	31	26	29	30	33	30	39	41	32	30	346
	Spring	19	25	21	26	25	24	25	27	30	30	23	275
	Summer	26	13	13	16	21	11	16	27	29	11	13	196
	Fall	30	19	23	28	31	21	27	32	31	28	19	289
	All seasons	100	88	83	99	107	89	98	125	131	101	85	1106

## 6.4 Quality Assessment and Quality Control

To assess the quality of sample collection and preparation procedures, blank samples and process replicates were conducted during the water quality sampling process. These samples were considered extraneous to the core dataset and therefore have been removed from the MWNS Open Data water quality dataset but can be provided upon request. Discussion of the outcomes of each type of sample is discussed below.

### Blank and sample contamination in MWNS water quality samples

Blank samples were routinely collected during MWNS water quality sampling, comprising approximately 2% of all samples. Blanks were prepared during sample processing using either supplied Reverse Osmosis water in a plastic storage container or commercially available distilled water stored in the sample preparation area and were processed identically to sample waters prior to being sent in for laboratory analysis. Blanks were not prepared at the monitoring site but rather in the laboratory during sample processing.

The detection frequency and upper percentiles of nutrient concentrations were determined in blank samples for comparison to environmental samples collected for water quality analysis (Table 4). While analytes were frequently (46-94%) detected in blank samples, upper limits (95<sup>th</sup>, 99<sup>th</sup> percentiles) of the concentrations remained orders of magnitude lower than the median concentrations of environmental samples.

**Table 4. Summary of blank and environmental sample results for nutrient analytes collected during the MWNS (2014-2020, all sites combined), including sample counts, detection frequencies, upper confidence limits for blank detections and concentrations, and median concentrations for environmental samples.**

	Method Detection Limit (mg/L)	Blanks				Environmental Samples		
		No. Samples	Detection frequency	Percentile of concentration (mg/L)		No. Samples	Detection frequency	Median (mg/L)
				95th	99th			
Ammonium, unfiltered reactive	0.02	123	46%	0.02	0.02	6580	77%	0.047
Total nitrates, unfiltered reactive	0.04	128	45%	0.04	0.04	6581	99%	4.2
Nitrite, unfiltered reactive	0.001	129	51%	0.002	0.002	6584	98%	0.022
Total nitrogen	0.05	108	46%	0.06	0.07	5862	100%	4.86
Total filtered phosphorus	0.0002	99	94%	0.002	0.0024	5050	100%	0.0518
Total unfiltered phosphorus	0.0002	116	86%	0.0062	0.0068	10742	99%	0.123

The high frequency of detections in blank samples shows that there was persistent low-level contamination present for all nutrients. However, except for ammonium, the median concentrations seen in environmental samples generally outstripped the concentrations seen in most blank samples by a factor of ten or more, and thus the low-level contamination is unlikely to materially affect results.

Only total filtered phosphorus and total phosphorus blanks had blank concentrations substantially higher than the method detection limit (95% upper confidence limits at 10x and 30x the MDL, respectively). However, these upper concentrations correspond to the 0.2th percentile of all environmental sample concentrations for total filtered phosphorus, and 0.5th percentile of all environmental sample concentrations for total phosphorus, and are therefore unlikely to impact overall analysis of nutrient samples in MWNS.

Other analytes that were detected in blank samples either had their 95th percentile at least 10x less than the median environmental sample concentrations or had concentration upper confidence limits that fell below the method detection limit. As a result, there are no concerns regarding the remaining analytes reported in the water quality samples for the MWNS.

## Replicates

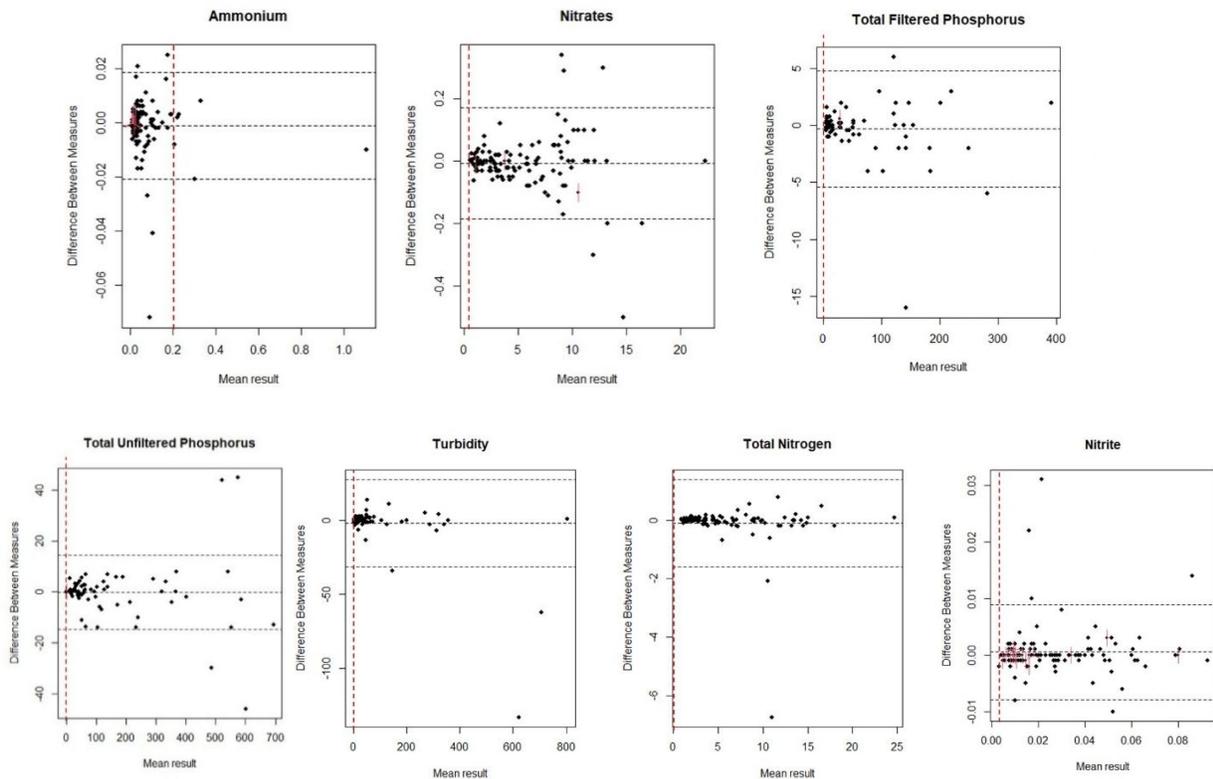
Replicates in the MWNS were made by splitting an individual autosampler bottle into 2 identical submissions, to confirm that sample processing techniques were consistent, and that particulate matter was not getting artificially fractionated between containers sent in for analysis. The autosampler bottle used for replicates was considered an extra bottle and results from replicates were not considered in water quality analysis.

Bland-Altman plots with regression lines were used to assess agreement between replicates. Generally, results were consistent between replicates, with  $r^2$  values greater than 0.95 for replicates across key analytes, although differences between the 2 replicate values typically increased at higher nutrient and turbidity concentrations and had a greater range in unfiltered analytes like total phosphorus and turbidity (Table 5). The major analytes of concern (nutrients, and turbidity as a proxy for other particulate-bound analytes) were assessed using Bland-Altman plots to identify differences between replicate measures (Figure 18).

All the Bland-Altman plots had a mean centered on or very close to 0, with the exception of turbidity, which showed a slight negative bias, likely linked to one instance of an extreme difference between two replicate samples at very high concentration. A mean difference near to 0 indicates no obvious bias towards analytes being fractionated into the first or second replicate during sample processing. Despite analytes linked more closely with particulate in samples (total phosphorus and turbidity) having a broader range of differences between replicates, only 3% of samples fell outside the limits of agreement for these analytes.

**Table 5. Summary of variability between replicates samples of nutrient and turbidity in the MWNS (2014-2020, all sites combined). Limits of agreement are 95%. N represents the number of paired replicate samples.**

	R <sup>2</sup>	Lower Limit of Agreement	Mean Difference	Upper Limit of Agreement	Critical Difference	N	% Outside 95% CI
<b>Nitrite</b>	0.958	-0.008	0.000	0.009	0.008	123	5%
<b>Ammonium</b>	0.992	-0.021	-0.001	0.019	0.020	121	5%
<b>Nitrates</b>	1.000	-0.185	-0.007	0.171	0.178	123	6%
<b>Total Phosphorus</b>	0.997	-14.823	-0.180	14.463	14.643	159	3%
<b>Total Filtered Phosphorus</b>	0.999	-5.429	-0.316	4.796	5.112	67	4%
<b>Turbidity</b>	0.992	-31.483	-1.980	27.522	29.503	103	3%



**Figure 18. Bland Altman plots showing variability between replicates for nutrient and turbidity samples from the MWNS (2014-2020, all sites combined). Dashed red lines indicate the method limit of detection.**

## 7. MWNS Data Management and QAQC

This section reviews the data management process for MWNS datasets, including the use of open-source software and the development of novel QAQC methods for cleaning and editing the data. A full list of parameters collected from stream monitoring stations and meteorological stations can be found in Appendix B and E. Water sample laboratory data will also be discussed in this section.

### 7.1 Cellular Telemetry and Database

MWNS stream monitoring and meteorological stations were equipped with several in-situ sensors. Cellular telemetry transmitted data from the sensors at 15-minute intervals to a remote server. Data were sent via cellular telemetry directly to the MWNS server computer or to third party sensor websites and automatically loaded into the Observations Data Model (ODM) database every 15-minutes.

ODM is an Open-Source data model created by the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (<https://github.com/CUAHSI/HydroServer/wiki/Observations-Data-Model>). The data model is a relational database made for the storage and retrieval of hydrological observations and is intended to store the data in a system designed for optimization of data storage, integration, and sharing. The database is query-able and provides the abilities to trace raw measurements to usable and edited data and information (Horsburgh *et al.*, 2016).

All station data were recorded in Coordinated Universal Time (UTC). When loaded into the ODM database, data were stored in both UTC and Eastern Standard Time (with Daylight Savings applied when applicable). The open MWNS dataset is provided in UTC only.

### 7.2 Quality Assurance and Quality Control

Data quality checks and quality control (QC) were performed site by site and parameter by parameter. A qualifier was recorded to indicate the QC level of each data point. Several parameters are provided in raw format without corrections and are flagged accordingly in the dataset. The following sections review QC procedures for specific parameters and sites.

#### Level Data and Flow Data

Water Survey of Canada (WSC) was contracted to perform water level gauging and rating curve development for MWNS sites, except for Garvey Glenn. The Garvey Glen site's level monitoring and stage-discharge rating curve were developed by the Maitland Valley Conservation Authority and shared with MECP for inclusion in this dataset.

Level data were QCd and corrected by WSC, and flow data were calculated using rating curves at each site. MECP also recorded water levels using sensors for operational purposes and as backup in case of gaps or issues in WSC data. Where WSC data were unavailable, MECP level data were used, and the WSC rating curve was applied to calculate flow.

Data source and QC level are identified in each data file under the QualityControlLevelID field.

## **Turbidity Data**

Turbidity data underwent QC using Turbidity Cleaner, an in-house sensor-data QA software developed by MECP (Yousif *et al.*, 2022). A novel approach was implemented to detect, remove, and replace turbidity anomalies.

The cleaning process involved several stages:

- Automated anomaly detection and removal
- Manual verification to confirm anomalies
- Gap-filling using the Multivariate Imputation by Chained Equations (MICE) package in R

MICE runs a series of imputation models where each variable with missing data is modeled conditionally on other variables. Water level and precipitation data were used as predictors for turbidity.

Program code available here: <https://github.com/mayousif/Turbidity-Cleaner>

## **Precipitation Data**

Precipitation data from the eight MET stations (4-season weighing precipitation gauge) are provided in raw format. Major anomalies were manually removed and flagged in the QualityControlLevelID field.

Precipitation data from MWNS stream monitoring stations (tipping bucket rain gauge located on the top of each hut) were used only as backup to fill gaps in meteorological station data. These gauges were three-season instruments, often covered and inactive during winter months.

## **Soil Moisture Data**

Soil moisture data underwent minimal QC, and anomalies were removed. Readings of zero, indicating sensor errors, were deleted. Data were marked with QualityControlID of 1 to indicate QC.

Some soil moisture readings show negative values. The sensor calculates volumetric water content using dielectric constant. Negative readings typically result from poor sensor-soil contact (air gaps) or applying standard calibration to soils with high organic content or extreme dryness.

## **Water Quality Data**

Water samples collected by the automated samplers, and occasionally as discrete grab samples from the stream, were then sent to MECP laboratories for analysis. This data was stored in the MECP Laboratory Information System, as well as the MECP in-house Stream Data SQL server. Laboratory remarks are provided to indicate laboratory level QAQC, including unreliable results.

Section 5.4 outlines the QAQC processes for water sampling, including the use of blanks and replicates.

Additional quality control was performed on the data to review for transcription errors, for example, incorrect transcription of date and times, as well notes referencing sample filtering or other processing notes.

## **8.0 Summary**

Over the duration of the MWNS, robust data were developed to better understand the dynamics of nutrients in agricultural watersheds, and produce province-scale datasets that can be used to understand and analyze the relationships between land use, land management, and how nutrients transform while moving through surface waters. The work of determining changes in nutrient patterns over time, and informing effective, evidence-based decision making will be supported by the MWNS's nearly 3 million data points of laboratory-analyzed water quality data, and over 28 million records of sensor data over the span the study. The MWNS dataset provides a detailed snapshot of the conditions across stream flow events of all sizes and across all seasons in small agricultural watersheds in the Laurentian Great Lakes area of Ontario between 2014 and 2020. The discrete samples collected across event hydrographs differ from typical ambient water quality monitoring programs, which generally do not target specific hydrologic events across the province. As a result, care should be taken when comparing MWNS data with other available datasets to ensure appropriate context and comparability.

## **9.0 Acknowledgements**

The MWNS would not have been possible without extensive collaboration and support. The MWNS team want to acknowledge the invaluable support of the Laboratory Services Branch and Dorset Environmental Science Centre of the MECP, the critical sampling support of MECP's West Central Region and Southwest Region as well as the Maitland Valley and Ganaraska Region Conservation Authorities. Formal partnerships with Water Survey of Canada and the Ontario Ministry of Natural Resources and Forestry (MNRF) ensured high quality flow data at each site. Informal collaborative arrangements with Ontario Ministry of Agriculture, Food and Agribusiness (OMAFRA), Environment and Climate Change Canada (ECCC), and Agriculture and Agri-Food Canada (AAFC) and several Conservation Authorities were critical to understanding the agricultural landscape in Ontario.

Several university partners were key collaborators on the MWNS throughout the study: University of Waterloo, University of Windsor, and Toronto Metropolitan University. These partners supported MECP in study design, data analysis, and disseminating project information and findings.

## 10.0 References

- Biagi, K. M., Ross, C. A., Oswald, C. J., Sorichetti, R. J., Thomas, J. L., & Wellen, C. C. (2022). Novel predictors related to hysteresis and baseflow improve predictions of watershed nutrient loads: An example from Ontario's lower Great Lakes basin. *Science of The Total Environment*, 826, 154023.
- Crins, W. J., Gray, P. A., Uhlig, P. W., & Wester, M. C. (2009). The ecosystems of Ontario, part 1: ecozones and ecoregions. Ontario Ministry of Natural Resources, Peterborough, Ontario, Inventory, Monitoring, and Assessment, SIB TER IMA TR-01.
- Horsburgh, J. S., Aufdenkampe, A. K., Mayorga, E., Lehnert, K. A., Hsu, L., Song, L., & Whitenack, T. (2016). Observations Data Model 2: A community information model for spatially discrete Earth observations. *Environmental Modelling & Software*, 79, 55-74.
- Nelligan, C., Sorichetti, R. J., Yousif, M., Thomas, J. L., Wellen, C. C., Parsons, C. T., & Mohamed, M. N. (2021). Then and now: Revisiting nutrient export in agricultural watersheds within southern Ontario's lower Great Lakes basin. *Journal of Great Lakes Research*, 47(6), 1689-1701.
- Ontario Ministry of the Environment (2012). Water quality of 15 streams in agricultural watersheds of Southwestern Ontario 2004-2009: Seasonal patterns, regional comparisons, and the influence of land use. <https://www.ontario.ca/document/water-quality-15-streams-agricultural-watersheds-southwestern-ontario-2004-2009>
- Rosamond, M. S., Wellen, C., Yousif, M. A., Kaltenecker, G., Thomas, J. L., Joosse, P. J., Feisthauer, N. C., Taylor, W. D. & Mohamed, M. N. (2018). Representing a large region with few sites: The Quality Index approach for field studies. *Science of the Total Environment*, 633, 600-607.
- Ross, C. A., Moslenko, L. L., Biagi, K. M., Oswald, C. J., Wellen, C. C., Thomas, J. L., Raby, M. & Sorichetti, R. J. (2022). Total and dissolved phosphorus losses from agricultural headwater streams during extreme runoff events. *Science of The Total Environment*, 848, 157736.
- Yousif, M., Burdett, H., Wellen, C., Mandal, S., Arabian, G., Smith, D., & Sorichetti, R. J. (2022). An innovative approach to correct data from in-situ turbidity sensors for surface water monitoring. *Environmental Modelling & Software*, 155, 105461

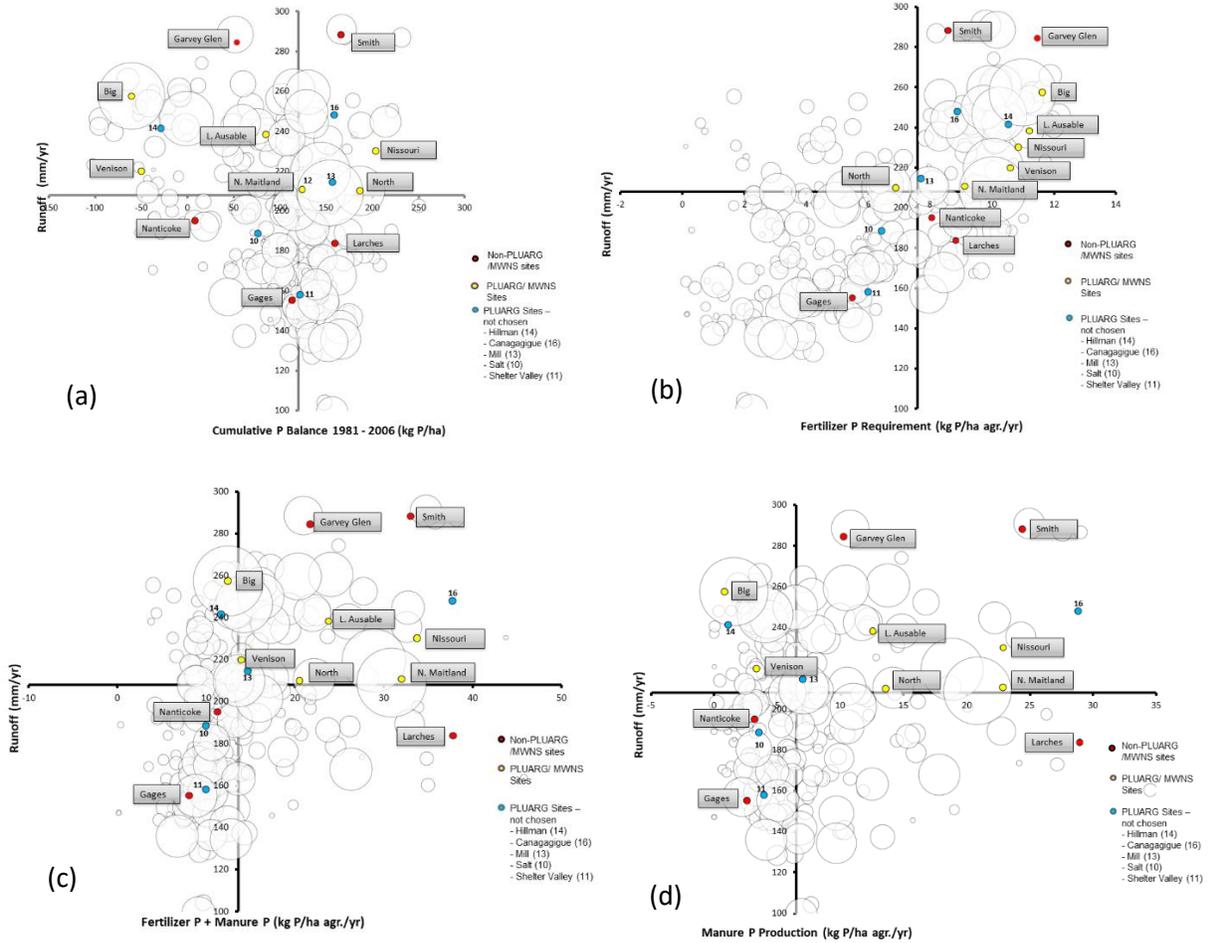
## Appendix A: Details of the site selection Quality Index site characteristics for MWNS stations.

The axes of the bubble plots below show runoff and potential nutrient export of various types, developed as part of the site selection Quality Index (QI) process (Rosamond *et al.*, 2018). The quadrants of each plot represent the ranges of possible conditions in southern Ontario for runoff potential and phosphorus loss potential/sources of phosphorus on the landscape.

Figure A.1 plots each phosphorus input variable against runoff potential. These variables are:

- (a) Cumulative P balance, which is the estimated change in soil P from 1981 to 2006,
- (b) Fertilizer P requirement,
- (c) The sum of fertilizer P requirement and manure P production, and
- (d) Manure P production

Coloured points include both selected MWNS sites and former PLUARG locations that were not selected (as noted in plot legends). Background bubbles without colour represent characteristic conditions in sub-regions of southern Ontario, developed from information in the Soil Landscapes of Canada polygons available from Agriculture and Agrifood Canada. The Quality Index process described in Rosamond *et al.* (2018) describes how sites were selected for the MWNS study to maximize the range of conditions covered by the limited number of sites.



**Figure A.1 MWNS sites (red and yellow circles) plotted in relation to (a) estimated change in soil P from 1981 to 2006 (Cumulative P Balance), (b) fertilizer phosphorus requirement, (c) sum of fertilizer phosphorus requirement and manure production, and (d) phosphorus production from manure, vs. runoff, used as part of the QI for site selection. Open circles show conditions of sub-regions in southern Ontario [Soil Landscape of Canada (SLC) polygons, Rosamond *et al.*, 2018]. PLUARG sites not chosen (blue circles) are plotted for comparison.**

**Table A.1: MWNS network watershed general description and relation to QI.**

Watershed	General Description
Big Creek	Located in the Essex clay plain (Brookston clay), heavily tile drained and has a flat topography. This watershed is dominated by cash crop and has limited livestock farms, with swine farms being the most common in the region (Nelligan <i>et al.</i> , 2021). In context with the QI approach, the Big Creek watershed fell within the higher run-off potential category, lower manure production (Fig A.1d)/higher fertilizer P requirements (Fig A.1b), and higher cumulative P balance (Fig A.1a).
Gage Creek	Chosen as an alternate site to Shelter Valley in the PLUARG study, as both had similar land-use and QI criteria (low run-off potential, moderate cumulative P). The soil formations in the watershed are mainly Bondhead loam and Dundonald Sandy Loam. The Gage Creek watershed fell within the moderate run-off potential category, lower manure production (Fig A.1d)/lower fertilizer P requirements (Fig A.1b), and lower cumulative P balance (Fig A.1a) of the QI.
Garvey Glenn	The QI assessment put Garvey Glenn watershed in the higher run-off potential category, higher manure production (Fig A.1d)/higher fertilizer P requirements (Fig A.1b), and lower cumulative P balance (Fig A.1a). The watershed soils are mainly Perth silt loam, Listowel loam, Perth clay loam and Berrien sandy loam.
Larches Creek	The Larches Creek watershed fell in the lower run-off potential category, higher manure production (Fig A.1d)/higher fertilizer P requirements (Fig A.1b), and higher cumulative P balance (Fig A.1a) in reference to the QI assessment. Watershed soils are mainly Harriston loam and Huron loam.
Little Ausable River	In context with the QI assessment, Little Ausable Creek watershed fell within the higher run-off potential category, higher manure production (Fig A.1d)/higher fertilizer P requirements (Fig A.1b), and lower cumulative P balance (Fig A.1a). Its watershed soils are mainly Huron clay loam and Perth clay loam.
Nanticoke Creek	Nanticoke Creek soils consisted mainly of Scotland and Willsonville well drained sandy loam and loamy sand textures overlying gravelly loam and sandy loam glacial till. The watershed fell within the lower run-off potential category, lower manure production/lower fertilizer P requirements (Fig A.1b,c), and lower cumulative P balance (Fig A.1a) in context of the QI.
Nissouri Creek	The QI assessment put Nissouri Creek watershed within the higher run-off potential category, higher manure production (Fig A.1d)/higher fertilizer P requirements (Fig A.1b), and higher cumulative P balance (Fig A.1a). This is due to watershed soils mainly consisting of Guelph loam and Embro silt loam.
North Creek	North Creek watershed fell within the higher run-off potential category, higher manure production (Fig A.1d)/lower fertilizer P requirements (Fig A.1b), and higher cumulative P balance (Fig A.1a). The watershed soil formations are mainly moderately well-drained Haldimand and Lincoln loamy soil over clayey, glaciolacustrine sediments containing significant proportions of heavy clay textures.
North Maitland River	The North Maitland watershed soil mainly consisted of Teeswater silt loam and Harriston loam and fell within the higher run-off potential category, higher manure production (Fig A.1d)/higher fertilizer P requirements (Fig A.1b), and higher cumulative P balance (Fig A.1a) in accordance with the QI.
Smith Creek	In reference to the QI, Smith Creek watershed had a high run-off potential category, higher manure production (Fig A.1d)/higher fertilizer P requirements (Fig A.1b), and higher cumulative P balance (Fig A.1a) with soils consisting of mainly Perth clay loam and Perth loam.
Venison Creek	In Venison Creek watershed, the QI put the watershed in a higher run-off potential category, lower manure production (Fig A.1d)/higher fertilizer P requirements (Fig A.1b), and lower cumulative P balance (Fig A.1a). The watershed soil formations are mainly Plainfield, Walsingham, and Fox characteristic of rapidly drained, sand plain of Eolian fine sand, and Eolian modified, glaciolacustrine fine sand.

## Appendix B. MWNS monitoring network equipment, dataset variables, and notes.

Monitoring/Station Attribute	Sample Medium	Category	Data Variable Name	Model	Units	Note
<b>Stream Monitoring Station</b>						
Logger	--	--	--	Axiom H2	--	Operated by WSC
Level (primary)	Surface Water	Hydrology	Gauge height (WSC)	Sutron Accubar (bubbler)	m	Operated by WSC
Flow (<= 1m)	Surface Water	Hydrology	Flow (WSC)	Sontek Flow Tracker 2	m/s, m	Operated by WSC
Flow (>1m)	Surface Water	Hydrology	Flow (WSC)	Sontek River Surveyor or Teledyne River Ray	m/s, m	Operated by WSC
Telemetry	--	--	--	GOES transmitter	--	Operated by WSC
Power (WSC)	--	--	--	12VDC	--	Operated by WSC
Autosampler (AC power)	Surface Water	Instrument	Sample Event	ISCO 6712FR refrigerated autosampler (120V)	[categorical]	Used at stations with AC power.
Autosampler (DC power)	Surface Water	Instrument	Sample Event	ISCO Avalanche refrigerated autosampler (12V)	[categorical]	Used at stations with solar power.
Level (secondary)	Surface Water	Hydrology	Gauge height	ISCO 730 bubbler module	m	Backup and for autosampler trigger.
Water temperature	Surface Water	Water Quality	Temperature	FTS DTS-12	°C	--
Turbidity	Surface Water	Water Quality	Turbidity	FTS DTS-12	NTU	Outfitted with sensor wiper for extended deployment.
Tipping bucket	Precipitation	Climate	Precipitation	Hydrological Services LTD TB3LP tipping bucket	mm	3 season tipping buckets used for gap filling and operational decision making to report rainfall intensity.
Logger (primary)	--	--	--	Built in autosampler	--	--
Logger (backup/telemetry)	--	--	--	Campbell Scientific CR800	--	Also used as part of a custom designed telemetry system.
Telemetry	--	--	--	Microhard (IPn3G, IPn4G, Bullet) cellular	--	Custom designed telemetry system used in conjunction with CR800 logger above.
Heat tracing (AC power)	--	--	--	Heatline, Paladin self-regulating heat trace with Johnson Controls A419 thermostat/in pipe temp sensor	--	--
Heat tracing (Solar Power)	--	--	--	Heatline Kompensator low voltage heat trace (12-24V)	--	Timer was used to regulate power use.
Enclosure Heat (AC power)	--	--	--	Radiant electric	--	--

Monitoring/Station Attribute	Sample Medium	Category	Data Variable Name	Model	Units	Note
Enclosure Heat (Solar power)	--	--	--	Solarinfrasystems, exterior radiant solar heater, 24"x36"	--	Positioned outside of enclosure on wall facing most sun.
Power (enclosure)	--	--	--	AC or DC (solar for non-AC stations), All equipment on DC backup	--	Type of power used was determined by the infrastructure available in area.
<b>Meteorological (MET) Station</b>						
MET Sensor Reference	--	--	--	Kestrel 5500 Weather Meter	Various	For selected sensor reference checks using handheld. All except solar, precip, and soil.
MET Sensor Reference	--	--	--	Megger, PVM210 irradiance meter	W/m <sup>2</sup>	For reference check of solar sensor.
Radiation, incoming shortwave	Air	Climate	Radiation, incoming shortwave	Onset Solar Radiation (Silicon Pyranometer S-LIB-M003)	W/m <sup>2</sup>	--
Relative Humidity	Air	Climate	Relative Humidity	Onset Temperature/Relative Humidity (S-THB-M002)	%	--
Air Temperature	Air	Climate	Temperature	Onset Temperature/Relative Humidity (S-THB-M002)	°C	--
Dew Point	Air	Climate	Temperature, dew point	Onset Temperature/Relative Humidity (S-THB-M002)	°C	--
Wind direction	Air	Climate	Wind direction	Onset Wind Direction Smart Sensor (S-WDA-M003)	° (degrees)	--
Wind gust speed	Air	Climate	Wind gust speed	Onset Wind Speed Smart Sensor (S-WSA-M003)	m/s	--
Wind speed	Air	Climate	Wind speed	Onset Wind Speed Smart Sensor (S-WSA-M003)	m/s	--
Precipitation	Precipitation	Climate	Precipitation	OTT Pluvio 2 weighing precipitation gauge with pulse adapter (s-UCx-M00x)	mm	0.1mm
Soil temperature	Soil	Climate	Temperature	Onset 12-bit Temperature Smart Sensor (S-TMB-M006)	°C	Depths 5cm, 10cm, 25cm, 50cm
Water content	Soil Water	Hydrology	Water content	Onset EC5 ECHO Soil Moisture Smart Sensor (S-SMD-M005)	m <sup>3</sup> /m <sup>3</sup>	Depths 10cm, 25cm, 50cm
Evapotranspiration	--	--	--	--	mm	Calculated using station sensors.
Logger	--	--	--	Onset U30-GSM (3G cellular)	--	--
Mounting	--	--	--	3m Tripod	--	--
Power (logger and OTT Pluvio 2)	--	--	--	Solar 12VDC	--	--

## Appendix C: Selected feedback from WSC staff surveys regarding MWNS water stations

	Big Creek	Gage Creek	Larches Creek	Little Ausable River	Nanticoke Creek	Nissouri Creek	North Creek	North Maitland River	Smith Creek	Venison Creek
<b>Benchmark(s) quality</b>	Very Good	Very Good	Good	Very Good	Very Good	Very Good	Good	Excellent (textbook)	Very Good	Very Good
<b>Control quality</b>	Good	Good	Poor	Very Good	Poor	Good	Poor	Good	Poor	Very Good
<b>Bank stability</b>	Very Good	Poor	Good	Very Good	Good	Very Good	Very Good	Good	Good	Very Good
<b>Level stability</b>	Very Good	Good	Good	Very Good	Good	Very Good	Very Good	Very Good	Good	Very Good
<b>Sediment accumulation</b>	Very Good	Poor	Good	Good	Poor	Good	Very Good	Good	Good	Very Good
<b>Vegetation growth</b>	Good	Excellent	Very Good	Good	Poor	Good	Good	Good	Poor	Very Good
<b>Bank under-cutting</b>	N/A	Good	Poor	Good	Good	Very Good	Good	Good	Good	Very Good
<b>Access to metering location</b>	Excellent	Excellent	Very Good	Very Good	Excellent	Very Good	Excellent	Excellent	Very Good	Very Good
<b>Low-flow metering quality</b>	Excellent	Very Good	Good	Very Good	Very Good	Good	Good	Very Good	Good	Excellent
<b>Mid-flow metering quality</b>	Excellent	Very Good	Very Good	Very Good	Excellent	Good	Excellent	Very Good	Good	Excellent
<b>High-flow metering quality</b>	Good	Poor	Good	Very Good	Very Good	Good	Very Good	Very Good	Good	Very Good
<b>Stage/discharge relationship</b>	Very Good	Good	Good	Very Good	Poor	Good	Good	Very Good	Good	Very Good
<b>Overall data quality</b>	Very Good	Poor	Good	Very Good	Poor	Good	Good	Very Good	Good	Very Good

	WSC Comments
<b>Big Creek</b>	The control was surprisingly stable, for placed rocks in a small stream. It remained clear most of the time but did get some algae and debris. The channel has a lot of vegetation growth, which puts the upper end of the curve into some doubt.
<b>Gage Creek</b>	Significant downstream beaver activity causes severe issues with the stage discharge relationship and data quality. High sediment load coupled with a shallow gauge pool results in frequent burial of the pressure sensor orifice and results in unusable water level data.
<b>Larches Creek</b>	Low-medium water control can be improved by excavating and placing large boulders in riverbed.
<b>Little Ausable River</b>	Control was actively dammed by beavers. Constant struggle removing debris/dam material visit to visit.
<b>Nanticoke Creek</b>	Very little slope in this water course. In spring and summer, heavy weed growth backs up flow for a very long distance. Control was built up two or three times, weed-related backwater still managed to submerge the control.
<b>Nissouri Creek</b>	Lots of scatter in low end of curve as is impacted by minor changes to the riffle control. Gravel bed bottom requires numerous deposition shifts applied throughout the year. Ice/slush affect orifice in the winter. Significant debris accumulation (logs, fallen trees, etc.) discovered downstream in 2019 causing backwater in mid-range of curve. It will need to be cleared and maintained and rating curve then needs to be validated. Once debris cleared, will need to monitor if accumulation continues (if it does, this would decrease the ease of maintenance of the site).
<b>North Creek</b>	Very little slope at low to medium water. Control needs to be built up a bit, and small to medium size gravel added to prevent water flowing through/under the control.
<b>North Maitland River</b>	Looking at the data from this station it is of good quality, MP bridge makes for minimal GC's and easy OWL measurements. Benchmarks are stable. Wading section is easy to access, laminar but can get influence by grasses in the summer. Highwater is taken of the regional road bridge at the gauge...the measuring section is good, laminar and ADCP work well. The higher stage section of the curve seems stable over the years the station was run. Ice conditions are light and generally a chip and wade style technique would be used to measure discharge. There is too little winter Q data produced at this site to get a true understanding of the ice conditions. Overall, this station is a good site, produces good data with little technical burden.
<b>Smith Creek</b>	Low-medium water control affected by scour/fill and vegetation growth.
<b>Venison Creek</b>	--

## Appendix D: Sample Bottles

General Water Quality Parameter	Sample Bottles and Notes
<b>Microbial analysis, all</b>	300-mL sterile square PET bottle, pre-charged with sodium thiosulphate 
<b>Total Phosphorous (TP3036A) – filtered and unfiltered</b>	Calibrated 25 x 125 mm borosilicate (Pyrex or Kimax) Tube (P-Tube), polypropylene caps, etched at fill line 
<b>Dissolved Nutrients (DISNUT3364A) and other filtered parameters</b>	100-125-mL clear glass jar/vial 
<b>Unfiltered Nutrients (except TP3036A) and other unfiltered parameters</b>	500-mL clear round PET bottles, wide mouth 63 mm unlined cap 
<b>Metals (unfiltered and filtered) (MET3497)</b>	90 mL sterile specimen polypropylene bottle, acidified with HNO <sub>3</sub> to pH ≤ 2 

## Appendix E: Details of Water Quality Analytical Methods

PARAMETER DESCRIPTION	PARAMETER CODE	ANALYSIS METHOD	METHOD DESCRIPTION	METHOD DETECTION LIMIT	UNITS
ALKALINITY, TOTAL	ALKT	E3218A	THE DETERMINATION OF CONDUCTIVITY, pH AND ALKALINITY IN WATER AND EFFLUENTS BY POTENTIOMETRY		1mg/L
ALUMINIUM, UNFILTERED/FILTERED TOTAL	ALUT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)		2ug/L
AMMONIUM, TOTAL UNFIL.REAC	NNHTUR	E3364A	THE DETERMINATION OF AMMONIA NITROGEN, NITRITE NITROGEN, NITRITE PLUS NITRATE NITROGEN AND REACTIVE ORTHO-PHOSPHATE IN SURFACE WATER, DRINKING WATER AND PRECIPITATION BY COLOURIMETRY		0.02mg/L
BISMUTH, UNFILTERED/FILTERED TOTAL	BIUT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)		5ug/L
BACTERIOIDES BOVINE	BACBOV	E3499	DETECTION OF HUMAN AND BOVINE FECAL SOURCES BY REAL-TIME PCR USING BACTERIOIDES GENETIC MARKERS*		*%
BACTERIOIDES GENERAL	BACGEN	E3499	DETECTION OF HUMAN AND BOVINE FECAL SOURCES BY REAL-TIME PCR USING BACTERIOIDES GENETIC MARKERS*		*cells/100 mL
BACTERIOIDES HUMAN	BACHUM	E3499	DETECTION OF HUMAN AND BOVINE FECAL SOURCES BY REAL-TIME PCR USING BACTERIOIDES GENETIC MARKERS*		*%
CALCIUM, UNFILTERED/FILTERED TOTAL	CAUT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)		0.05mg/L
CARBON, DISSOLVED INORGANIC	DIC	E3370A	THE DETERMINATION OF MOLYBDATE REACTIVE SILICATES AND DISSOLVED CARBON IN WATER, INDUSTRIAL WASTE, SOIL EXTRACTS AND PRECIPITATION BY COLOURIMETRY		0.7mg/L
CARBON, DISSOLVED ORGANIC	DOC	E3370A	THE DETERMINATION OF MOLYBDATE REACTIVE SILICATES AND DISSOLVED CARBON IN WATER, INDUSTRIAL WASTE, SOIL EXTRACTS AND PRECIPITATION BY COLOURIMETRY		0.2mg/L
CHLORIDE, UNFIL.REAC	CLIDUR	E3016A	THE DETERMINATION OF CHLORIDE IN DRINKING WATER, SURFACE WATER, SEWAGE AND INDUSTRIAL WASTE BY COLOURIMETRY		1.5mg/L
CHROMIUM, UNFILTERED/FILTERED TOTAL	CRUT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)		1µg/L
COBALT, UNFILTERED/FILTERED TOTAL	COUT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)		1µg/L
CONDUCTIVITY, 25C	COND25	E3218A	THE DETERMINATION OF CONDUCTIVITY, pH AND ALKALINITY IN WATER AND EFFLUENTS BY POTENTIOMETRY		2µS/cm
CONDUCTIVITY, ESTIMATED	CONDTY	E3196A	LIMS CALCULATIONS-ION BALANCE		3µS/cm
COPPER, UNFILTERED/FILTERED TOTAL	CUUT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)		0.5µg/L
ESCHERICHIA COLI MF	ECMF	E3371A	A MEMBRANE FILTRATION METHOD FOR THE DETECTION AND ENUMERATION OF TOTAL COLIFORM, ESCHERICHIA COLI, PSEUDOMONAS AERUGINOSA AND FECAL STREPTOCOCCI**		<4CFU/100 mL

PARAMETER DESCRIPTION	PARAMETER CODE	ANALYSIS METHOD	METHOD DESCRIPTION	METHOD DETECTION LIMIT	UNITS
FECAL STREPTOCOCCUS MF	FSMF	E3371A	A MEMBRANE FILTRATION METHOD FOR THE DETECTION AND ENUMERATION OF TOTAL COLIFORM, ESCHERICIA COLI, PSEUDOMONAS AERUGINOSA AND FECAL STREPTOCOCCI**	< 4CFU/100 mL	
HARDNESS, TOTAL	HARDT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)	1mg/L	
IRON, UNFILTERED/FILTERED TOTAL	FEUT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)	3µg/L	
LEAD, UNFILTERED/FILTERED TOTAL	PBUT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)	7µg/L	
LITHIUM, UNFILTERED/FILTERED TOTAL	LIUT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)	5µg/L	
MAGNESIUM, UNFILTERED/FILTERED TOTAL	MGUT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)	0.01mg/L	
MANGANESE, UNFILTERED/FILTERED TOTAL	MNUT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)	0.5µg/L	
MOLYBDENUM, UNFILTERED/FILTERED TOTAL	MOUT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)	2µg/L	
NICKEL, UNFILTERED/FILTERED TOTAL	NIUT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)	2µg/L	
NITRATES TOTAL, UNFIL. /FIL. REAC	NNOTUR	E3364A	THE DETERMINATION OF AMMONIA NITROGEN, NITRITE NITROGEN, NITRITE PLUS NITRATE NITROGEN AND REACTIVE ORTHO-PHOSPHATE IN SURFACE WATER, DRINKING WATER AND PRECIPITATION BY COLOURIMETRY	0.001mg/L	
NITRITE, UNFILTERED/FILTERED REACTIVE	NNO2UR	E3364A	THE DETERMINATION OF AMMONIA NITROGEN, NITRITE NITROGEN, NITRITE PLUS NITRATE NITROGEN AND REACTIVE ORTHO-PHOSPHATE IN SURFACE WATER, DRINKING WATER AND PRECIPITATION BY COLOURIMETRY	0.04mg/L	
NITROGEN, TOT, KJELDAHL/UNF.REA	NNTKUR	E3516	COLORIMETRIC DETERMINATION OF TOTAL NITROGEN (TN), TOTAL PHOSPHORUS (TP), NITRITE AND NITRATE (NOT) AND CALCULATED TOTAL KJELDAHL NITROGEN (TKN)	0.05mg/L	
NITROGEN; TOTAL	NTOT	E3567	DETERMINATION OF TOTAL NITROGEN (TN) BY COMBUSTION WITH CHEMILUMINESCENCE DETECTION	0.1mg/L	
NITROGEN; TOTAL	NTOT	E3516	COLORIMETRIC DETERMINATION OF TOTAL NITROGEN (TN), TOTAL PHOSPHORUS (TP), NITRITE AND NITRATE (NOT) AND CALCULATED TOTAL KJELDAHL NITROGEN (TKN)	0.05mg/L	
PH (-LOG H+ CONC)	PH	E3218A	THE DETERMINATION OF CONDUCTIVITY, pH AND ALKALINITY IN WATER AND EFFLUENTS BY POTENTIOMETRY	-	
PHOSPHORUS, UNFILTERED/FILTERED TOTAL	PPUT	E3036A	THE DETERMINATION OF TOTAL PHOSPHORUS IN WATER BY COLOURIMETRY	0.2µg/L	
POTASSIUM, UNFILTERED/FILTERED TOTAL	KKUT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)	0.02mg/L	
RESIDUE, PARTICULATE	RSP	E3188B	THE DETERMINATION OF SOLIDS IN LIQUID MATRICES BY GRAVIMETRY	10mg/L	

PARAMETER DESCRIPTION	PARAMETER CODE	ANALYSIS METHOD	METHOD DESCRIPTION	METHOD DETECTION LIMIT	UNITS
<b>SILICATES, UNFILTERED/FILTERED REACTIVE</b>	SIO3UR	E3370A	THE DETERMINATION OF MOLYBDATE REACTIVE SILICATES AND DISSOLVED CARBON IN WATER, INDUSTRIAL WASTE, SOIL EXTRACTS AND PRECIPITATION BY COLOURIMETRY	0.05mg/L	
<b>SILVER, UNFILTERED/FILTERED TOTAL</b>	AGUT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)	9µg/L	
<b>SODIUM, UNFILTERED/FILTERED TOTAL</b>	NAUT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)	0.02mg/L	
<b>SOLIDS; DISSOLVED ESTIMATED</b>	RSFEST	E3196A	LIMS CALCULATIONS-ION BALANCE	3mg/L	
<b>STRONTIUM, UNFILTERED/FILTERED TOTAL</b>	SRUT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)	0.3µg/L	
<b>SULPHATE, UNFILTERED/FILTERED REACTIVE</b>	SSO4UR	E3172A	THE DETERMINATION OF FLUORIDE AND SULPHATE IN WATER, LEACHATES AND EFFLUENTS BY AUTOMATED ION CHROMATOGRAPHY (IC)	0.1mg/L	
<b>TIN, UNFILTERED/FILTERED TOTAL</b>	SNUT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)	9µg/L	
<b>TITANIUM, UNFILTERED/FILTERED TOTAL</b>	TIUT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)	0.5µg/L	
<b>TURBIDITY</b>	TURB	E3311A	THE DETERMINATION OF TURBIDITY IN WATER BY NEPHELOMETRY UNDER ROBOTIC CONTROL	0.1NTU	
<b>URANIUM, UNFILTERED/FILTERED TOTAL</b>	UUUT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)	3µg/L	
<b>VANADIUM, UNFILTERED/FILTERED TOTAL</b>	VVUT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)	0.5µg/L	
<b>ZIRCONIUM, UNFILTERED/FILTERED TOTAL</b>	ZRUT	E3497	THE DETERMINATION OF METALS IN WATER BY INDUCTIVELY COUPLED PLASMA - OPTICAL EMISSION SPECTROSCOPY (ICP-OES)	1µg/L	

\*method variance holding time was permitted, extended from 48 hr to a 60 hr. See full method in: Lee et al. 2014. <https://doi.org/10.1016/j.watres.2014.01.003>. Host-specific Bacteroides marker (BACHUM or BACBOV) are expressed as a percentage of the total (general) Bacteroides marker (BACGEN) concentration in the same sample. Theoretical sample limit of detection (SLOD) for BACGEN is 15 cells/100 mL and the sample limit of detection (SLOQ) is 75 cells/100 mL.

\*\* method variance holding time was permitted, extended from 48 hr to a 60 hr. See full method in: Lee et al. 2014. <https://doi.org/10.1016/j.watres.2014.01.003>. The detection limit for the method is based on the value of water filtered but was considered < 4 CFU/100mL.

## Appendix F. Multi-Watershed Nutrient Study and Related Publications as of Oct 2025

- Biagi, K.M., Pardy, A., Luymes, M., Mazumder, B., Thomas, J.L., Sorichetti, R.J. & Wellen, C.C. (2025). Phosphorus mass balance of 11 temperate agricultural headwater catchments: accumulating and depleting watersheds exhibit contrasting stream load patterns. *Environmental Research: Water*, 1(1). <https://doi.org/10.1088/3033-4942/adc829>
- Phillips, A.K., Mandal, S., Mohamed, M., Sorichetti, R.J., Ross, C.A., Thomas, J.L., & Wellen, C.C., (2024). Is comprehensive event sampling necessary for constraining process models of water quality? A comparison of high and low frequency phosphorus sampling programs for constraining the HYPE water quality model. *Journal of Hydrology* <https://doi.org/10.1016/j.jhydrol.2024.131502>
- Ross, C. A., Phillips, A. K., Gospodyn, L., Oswald, C. J., Wellen, C. C., & Sorichetti, R. J. (2023). Improving the representation of stream water sources in surrogate nutrient models with water isotope data. *Science of The Total Environment*, 164544. <https://doi.org/10.1016/j.scitotenv.2023.164544>
- Gospodyn, L., Wellen, C., Sorichetti, R. J., & Mundle, S. O. (2023). Using stable water isotopes to evaluate water flow and nonpoint source pollutant contributions in three southern Ontario agricultural headwater streams. *Hydrological Processes*, 37(1), e14802. <https://doi.org/10.1002/hyp.14802>
- Biagi, K.M., Ross, C.A., Oswald, C.J., Sorichetti, R.J., Thomas, J.L., & Wellen, C.C. (2022). Novel predictors related to hysteresis and baseflow improve predictions of watershed nutrient loads: An example from Ontario's lower Great Lakes basin. *Science of The Total Environment*, 826, 154023. <https://doi.org/10.1016/j.scitotenv.2022.154023>
- Kao, N., Mohamed, M., Sorichetti, R. J., Niederkorn, A., Van Cappellen, P., & Parsons, C. T. (2022). Phosphorus retention and transformation in a dammed reservoir of the Thames River, Ontario: Impacts on phosphorus load and speciation. *Journal of Great Lakes Research*, 48(1), 84-96. <https://doi.org/10.1016/j.jglr.2021.11.008>
- Ross, C.A., Moslenko, L.L., Biagi, K.M., Oswald, C.J., Wellen, C.C., Thomas, J.L., Raby, M. & Sorichetti, R.J. (2022). Total and dissolved phosphorus losses from agricultural headwater streams during extreme runoff events. *Science of The Total Environment*, 848, 157736. <https://doi.org/10.1016/j.scitotenv.2022.157736>
- Yousif, M., Burdett, H., Wellen, C., Mandal, S., Arabian, G., Smith, D., & Sorichetti, R. J. (2022). An innovative approach to correct data from in-situ turbidity sensors for surface water monitoring. *Environmental Modelling & Software*, 155, 105461 <https://doi.org/10.1016/j.envsoft.2022.105461>
- Nelligan, C., Sorichetti, R. J., Yousif, M., Thomas, J. L., Wellen, C. C., Parsons, C. T., & Mohamed, M.N. (2021). Then and now: Revisiting nutrient export in agricultural watersheds within southern Ontario's lower Great Lakes basin. *Journal of Great Lakes Research*, 47(6), 1689-1701. <https://doi.org/10.1016/j.jglr.2021.08.010>
- Wellen, C., Van Cappellen, P., Gospodyn, L., Thomas, J. L., & Mohamed, M. N. (2020). An analysis of the sample size requirements for acceptable statistical power in water quality monitoring for improvement detection. *Ecological Indicators*, 118, 106684. <https://doi.org/10.1016/j.ecolind.2020.106684>

Rosamond, M.S., Wellen, C., Yousif, M.A., Kaltenecker, G., Thomas, J.L., Joosse, P. J., Feisthauer, N.C., Taylor, W.D. & Mohamed, M.N. (2018). Representing a large region with few sites: The Quality Index approach for field studies. *Science of the Total Environment*, 633, 600-607.

<https://doi.org/10.1016/j.scitotenv.2018.03.113>