ONFARM

Water Quality Technical Report

March 31, 2023

Acknowledgements

The On-Farm Applied Research and Monitoring (ONFARM) program was a four-year, applied research initiative delivered by the Ontario Soil and Crop Improvement Association (OSCIA) on behalf of the Ontario Ministry of Agriculture Food and Rural Affairs (OMAFRA) to support soil health and water quality research across farms in Ontario. This program is funded by the Canadian Agricultural Partnership, a five-year federal-provincial-territorial initiative. OSCIA would like to acknowledge the support of several organizations and members of the agricultural community for their contributions to the program:

- Soil health data was collected, compiled, and analyzed by The Soil Resource Group (SRG) located in Guelph, Ontario. SRG played an instrumental role working directly with ONFARM cooperators to organize and execute the soil health trials, and collect soil health data for the edge-of-field sites.
- Five partnering Conservation Authorities (CAs) implemented the Priority Subwatershed Project (PSP) component of ONFARM. They worked in six PSPs to collect key water quality, water quantity, and land-use data to achieve the program objectives. CAs also provided technical advice and worked directly with cooperators to carry out ONFARM outreach activities. Partnering CAs include: Ausable Bayfield Conservation Authority (ABCA), Essex Region Conservation Authority (ERCA), Maitland Valley Conservation Authority (MVCA), Lower Thames Valley Conservation Authority (LTVCA), and Upper Thames River Conservation Authority (UTRCA).
- The Watershed Evaluation Group at the University of Guelph delivered the modelling component of the program using the water quality, soil health, and economic data gathered as part of ONFARM to create a representative watershed model for each of the priority sub-watersheds using the Integrated Modelling for Watershed Evaluation of BMPs (IMWEBs) model and Ecosystem Services Assessment Tool (ESAT).
- Representatives from Agriculture and Agri-Food Canada (AAFC), Environment and Climate Change Canada (ECCC), and OMAFRA who sit on the ONFARM Technical Working Group and provide valuable input on several technical aspects of the program, such as data management and collection.
- OSCIA would like to highlight the critical role of the participating ONFARM Cooperators in accommodating the research program’s objectives on their respective farms. ONFARM is an applied research program that is being implemented on working farms across the province. ONFARM would not be possible without the dedication of cooperating farmers and the agricultural community.

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1.0 Introduction

1.1 Technical Report Overview

The ONFARM Water Quality Technical Report was released at the end of the On-Farm Applied Research and Monitoring (ONFARM) Program. The objective of this Technical Report was to summarize the water quality monitoring done through ONFARM research program, examine the best management practices (BMPs) being monitored, and present program findings.

1.2 ONFARM Program Description

ONFARM was a four-year initiative funded by the Canadian Agricultural Partnership. It was announced on December 5, 2019, by the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA). ONFARM was delivered by the Ontario Soil and Crop Improvement Association (OSCIA) with the support from various organizations, including OMAFRA, Agriculture and Agri-Food Canada (AAFC), five Conservation Authorities (CAs), The Soil Resource Group (SRG), and the Watershed Evaluation Group from the University of Guelph. ONFARM is also supported by a network of cooperating farmers who are essential to the success of the program.

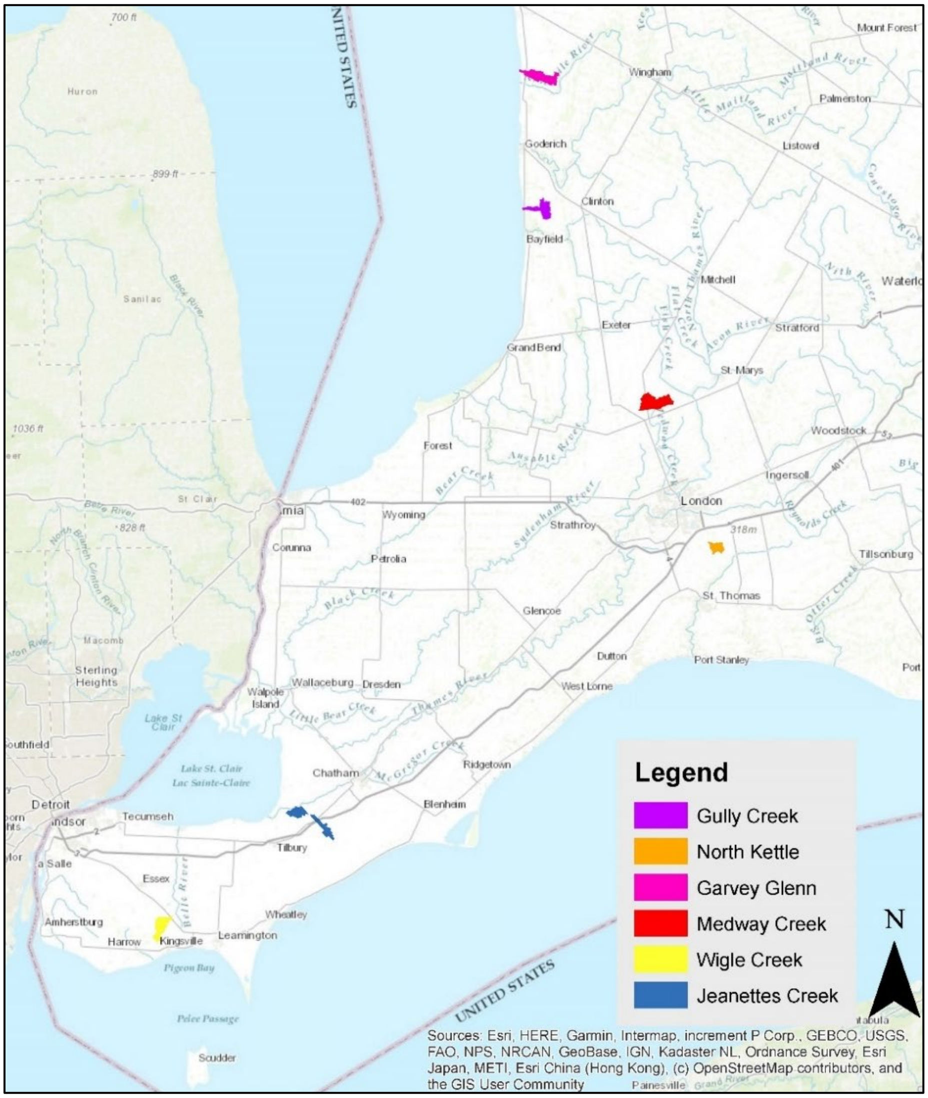
ONFARM's water quality component built on work completed under the Great Lakes Agricultural Stewardship Initiative's (GLASI) Priority Subwatershed Project (PSP). The soil health BMPs side-by-side field trials supported Ontario's Soil Health and Conservation Strategy. Both of these ONFARM initiatives were undertaken with the intent of helping the industry meet commitments under the Great Lakes Water Quality Agreement. The three pillars of ONFARM designed to support Ontario's agricultural industry are:

- Continuation of the monitoring and modelling in the PSPs established under the preceding GLASI program to assess the effectiveness of select agricultural BMPs in improving water quality leaving the field edge and at the subwatershed scale;
- Establishment of on-farm plot-scale trials, in cooperation with farmers, to identify key soil health indicators and test the effectiveness of select best management practices in improving soil health;
- Enhanced engagement opportunities with stakeholders and farmers to foster a network of demonstration farms.

1.3 Water Quality Program Goals

Previous work through the GLASI program enabled the establishment of water quality monitoring equipment and procedures in six sub-watersheds: Garvey-Glenn, Gully Creek, Wigle Creek, Jeanettes Creek, Upper Medway Creek, and North Kettle Creek, which are shown in Figure 1. These PSPs were originally targeted with a cost-share incentive program for farmers to adopt agricultural best management practices (BMPs). With the addition of extensive new BMPs, a modeling component of the GLASI program was established to model the effectiveness of implemented BMPs in improving water quality at the field edge as well as at a subwatershed scale.

As a continuation of the water quality monitoring started in the GLASI program, monitoring through ONFARM was intended to enhance the previous modeling by developing a longer, continuous dataset for each PSP. The goals of the ONFARM PSP component were to better understand the dynamics of phosphorus and other water quality parameters in the agricultural landscape, and to model the impact and efficacy of select agricultural BMPs on water quality at a subwatershed scale. A description of the water quality modeling work and its outcomes are detailed in a separate, standalone ONFARM Modeling Technical Report.



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Figure 1. Locations of ONFARM Priority Subwatersheds (PSP).

2.0 Water Quality Monitoring

2.1 Priority Sub-Watershed and Site Descriptions

Water monitoring in ONFARM took place at two scales: the field scale as monitored at the edge-of-field (EOF) and at a watershed scale, undertaken in-stream, through a network of monitoring stations established at various subwatershed locations. Eight EOF monitoring stations were established on working farms. Each of these EOF locations evaluated unique sets of BMPs, as described in Table 1. The site numbering in Table 1 follows what is also shown in the ONFARM Interactive Map, which includes further site details and photographs from the field.

Table 1. Edge of Field site characteristics

Site Number	Watershed	Conservation Authority	Acreage	Best Management Practices
1	Wigle Creek	Essex Region Conservation Authority	48	No-till, cover crops
2	Jeanettes Creek	Lower Thames Valley Conservation Authority	20	No-till, continuous cover
3	Jeanettes Creek	Lower Thames Valley Conservation Authority	20	Conservation tillage
4	Kettle Creek	Upper Thames River Conservation Authority	19	Cover crops
5	Upper Medway Creek	Upper Thames River Conservation Authority	34	Controlled tile drainage
6	Gully Creek	Ausable Bayfield Conservation Authority	16.2	WASCoB, cover crops
7	Bayfield River (outside of PSPs)	Ausable Bayfield Conservation Authority	30.2	Contour and controlled tile drainage, wetland
8	Garvey-Glenn	Maitland Valley Conservation Authority	31.9	Manure management, cover crops

Soil samples were collected at each EOF site in accordance with the suite of indicators assessed at the soil health BMP trial sites (detailed separately in the ONFARM Soil Health Technical Report). Values from this monitoring for each EOF site are included in Appendix A.

2.2 Hydrology Monitoring and Water Quality Sampling

Collection of data at both the subwatershed and EOF scale began at different times between PSPs – some watershed monitoring locations were established much earlier by the conservation authorities through other programs and have collected up to a decade of water quality data, whereas other EOF sites were established in either 2016 through GLASI or in 2019 directly through ONFARM. Each EOF site and monitoring locations within the PSPs collects a large variety of monitoring parameters which are detailed in Table 2.

Water was also monitored at established EOF sites embedded in the PSPs. The monitoring included surface runoff flow and quality, and where possible, subsurface (tile drainage) flow and quality at most sites (Site 1 did not have tile monitoring established). This monitoring is visualized in the conceptual diagram shown in Figure 2. Overland flow patterns were assessed at site establishment to ensure all flow leaving a sub-watershed within the field area was directed through flumes or water control basins. Monitoring the rate of flow and the depth of water allowed for the calculation of discharge at any given time. Similar sensors in the tile drain captured subsurface flow rates. ISCO water samplers were used to collect samples for water quality analysis at regular intervals when triggered by the flow sensors. Figure 3 shows the inside of one of the water quality monitoring stations with this equipment in place.

Table 2. Examples of data collected at each EOF location and within PSPs.

Data Collected	Examples
Weather	Rainfall, snowfall, snowpack, temperature
Hydrologic layers	Stream/water body layer, municipal drainage layer (open and closed), tile surface inlet locations, subsurface tile drainage layer
Land use layers	Non-agricultural land use boundaries, land-based BMP layer (WASCoB, buffer, etc.), field boundaries, agricultural land use by field
Field/soil characteristics	Soil phosphorus (P) and potassium (K) test, potentially mineralizable nitrogen (N), soil organic matter, soil aggregate stability, bulk density, infiltration
Field activities information	Fertilizer application, manure application, tillage, surface residue cover, planting, point discharges
Water quantity	Stream flow
Stream water quality	Total suspended solids, total P, dissolved reactive P, total organic P, total N, nitrate-N, ammonia-N, organic-N

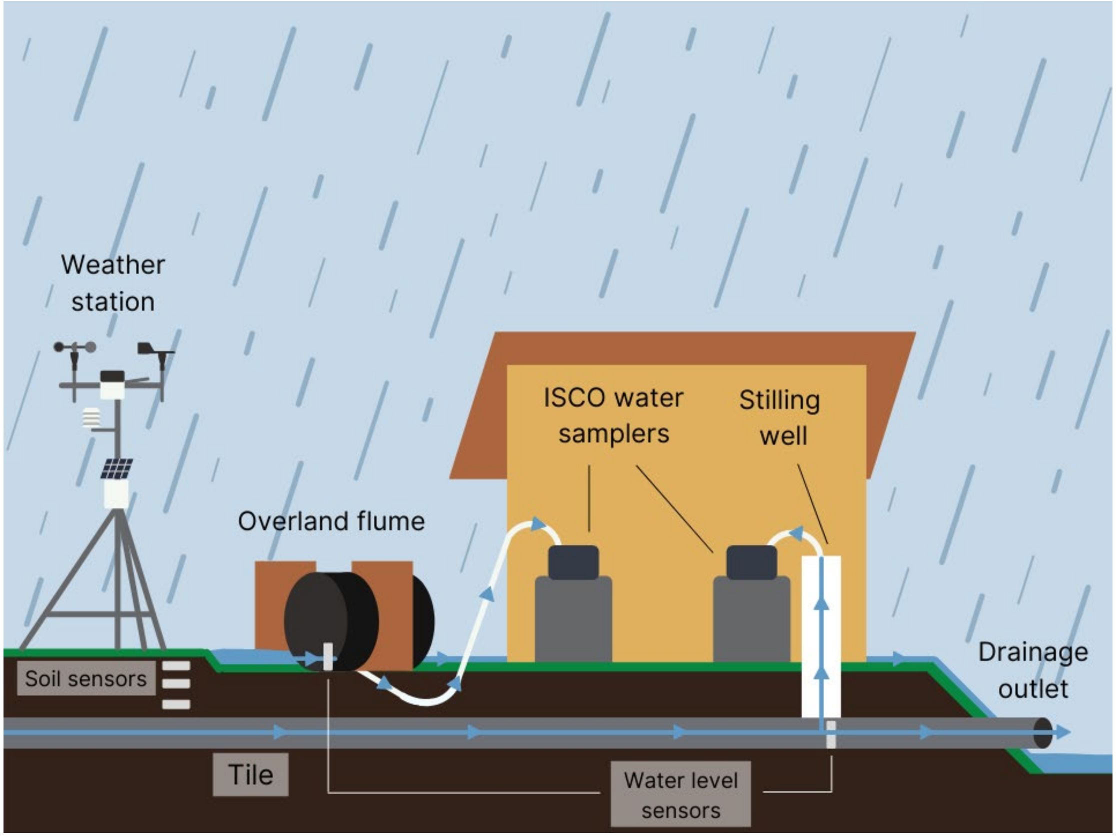


Figure 2. Conceptual diagram of an Edge of Field (EOF) monitoring station in the Garvey-Glenn PSP (MVCA). Sensors capture weather, soil, and water level data, and water movement triggers automatic collection of water samples from overland flow or tile drains.

Figure 32. The inside of a water monitoring station established by UTRCA (left) and a watershed monitoring station during a period of high-flow.

Water monitoring collection can be separated into two distinct classifications: baseflow and event-flow. Baseflow conditions are monitored on a regular, scheduled basis, where water level was measured consistently to calculate discharge, and water quality samples were taken on a weekly or bi-weekly basis. At EOF sites, baseflow conditions may have only occurred at certain times of year, such as the non-growing season (NGS) where tile flow may be triggered regularly by slow snow melt on more saturated soils, but during the growing season (GS), consistent baseflow in tiles was not often observed.

Unlike the scheduled nature of baseflow monitoring, event-flow is monitored during and after precipitation or snowmelt events generating runoff. Figure 4 shows an example of an event in November 2020 captured by MVCA, which shows a hydrograph tracking the flow of water overlain with phosphorus measurements from automated ISCO sampling. The hydrograph demonstrates the limited amount of water that moves offsite during baseflow conditions (seen at the beginning and end of the event), and how a rain event quickly drives the flow level to its peak, which gradually reduces back to base flow over the course of a day. In most cases, multiple water quality samples are collected throughout the event to capture the rising limb, peak flow, and the falling limb as concentrations can vary greatly with the fluctuation in discharge. To accurately monitor discharge, sites are instrumented with data loggers that measure water level at 15 minute intervals, and instantaneous discharge is measured by field staff at different water depths. These two sets of data are used to create a rating curve, a stage / discharge relationship, which is applied to the continuous record of water level to generate the hydrograph. A rating curve is unique to each site and must be maintained or adjusted when there are changes to the watercourse, such as drain maintenance.

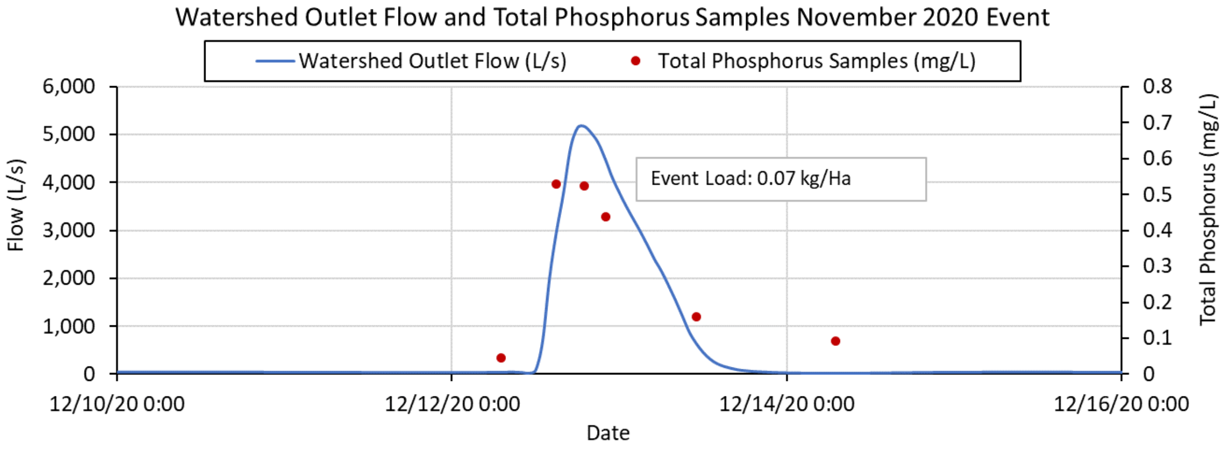


Figure 4. Watershed outlet flow from the Garvey-Glenn Watershed and total phosphorus concentrations resulting from a rain event in November 2020 (MVCA).

Following the ONFARM Data Management Plan, conservation authority staff input data collected into the Kisters Water Information System (WISKI) database for long-term storage and analysis. The WISKI database is well suited for time-series data, such as the water discharge, and using WISKI has enhanced the management and reporting of ONFARM data.

2.3 Context for Concentrations and Calculating Nutrient Loads

In the following sections of this report, water quality parameters, such as total phosphorus or nitrate-N, are reported on in two distinct ways: as concentrations or as loads. Both measurements provide value to researchers, and the use of one or the other can depend on the context or goal for a comparison.

Concentrations measure the amount of a parameter in the water at a given time and are typically shown as mg/L. When samples are measured in a laboratory for any of these water quality parameters, results are reported as concentrations. Concentration values are useful for comparing sample values collected at subwatershed monitoring stations because thresholds for water quality concerns are also set and evaluated using concentration data. For example, Ontario's interim Provincial Water Objective standard for Total Phosphorus suggests excessive plant growth in surface waters should be eliminated at concentrations below 30 µg/L, or 0.03 mg/L. Monitoring in-stream concentrations during both baseflow conditions and events can help researchers understand if this threshold is being exceeded on a chronic basis, or if there are only certain periods which exceed the threshold. Concentration measurements are more challenging to compare between sites in EOF monitoring because every site receives a different amount of precipitation onto different field areas, and therefore, these comparisons are typically shown using loads instead of concentrations.

Nutrient loads are calculated as a product of stream flow and nutrient concentrations. By multiplying a concentration (as mass / volume) by flow (as volume / time), the total mass of nutrient lost in a given time-period is determined. Dividing this value by the contributing area results in a load, typically shown as kg/ha, which can be used to easily compare loadings between watersheds of different sizes. Loads may be evaluated at different time-scales based on the needs of the analysis, from a single-event load, to larger periods like a NGS load, to loads for an entire water year (measured as October 1 – September 30).

Determining the absolute value of nutrients lost from a field can contribute to our understanding of whether BMPs are working effectively.

While the basic calculation to determine nutrient loads is not mathematically difficult, the estimation of accurate loads requires several years of data collected over a range of meteorological conditions, and is often challenged by gaps in the dataset that can result from equipment failure in the field. The requirement for continuous discharge data means that data gaps must be interpolated, for which there are various methods, or depending on the severity of the gap, left unfilled to avoid inaccurate interpolations and poor interpretations of the dataset (an example of this type of gap is shown in the 2019 data in Figure 5). As a result of the time requirements to process load data, much of the ONFARM data discussed below only continues to the end of the 2020-2021, despite water quality monitoring continuing until at least September 30, 2022 at these sites.

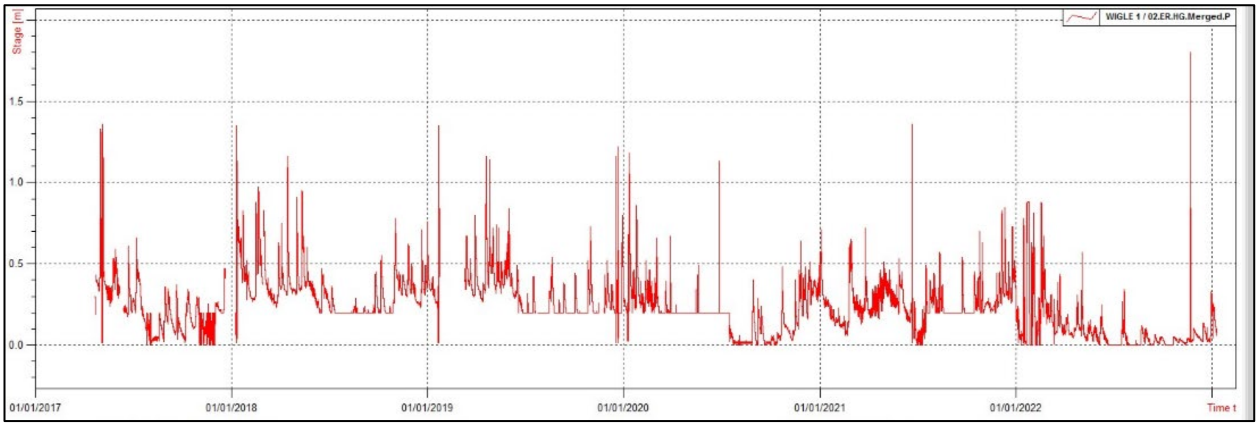


Figure 5. Entire water level record for Wigle 1 from GLASI and ONFARM monitoring. A gap in early 2019 was intentionally left unfilled to avoid an inaccurate interpolation.

3.0 Results from ONFARM Study Period

3.1 Variability in Water Quality Parameters

Concentration values for all TP and DRP samples collected throughout the ONFARM program from each of the subwatershed outlet monitoring stations are shown in Figure 6. This figure is presented to show the wide range in concentrations that naturally occurs in each of these subwatersheds captured during the ONFARM sampling program. The data used to create this figure include both baseflow and event samples. It should be noted that each sample only captures a single moment in time and because phosphorus levels fluctuate greatly during events, many more samples were collected during each period of event-flow compared to baseflow monitoring to improve event estimates. Therefore, the distribution of concentrations has been skewed more to representing event levels which have higher concentrations. For example, Figure 7 shows differences between median TP concentrations sampled in Wigle creek during events and from routine baseflow samples, demonstrating the potential increase in concentrations during event flow that was observed at all ONFARM sites.

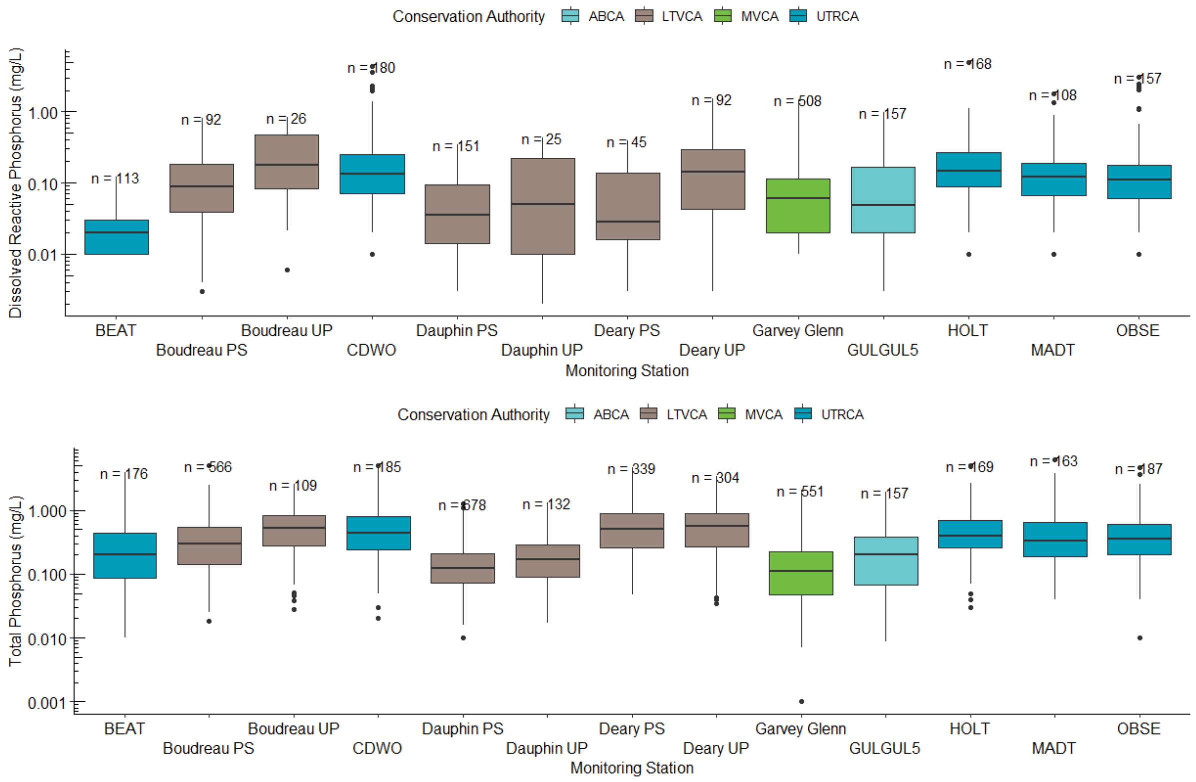


Figure 6. All dissolved reactive phosphorus (DRP; top) and total phosphorus (TP; bottom) concentrations from samples taken at subwatershed outlet monitoring stations throughout the ONFARM program. Note that LTVCA and UTRCA both monitored positions within their respective subwatersheds, with all of LTVCA's stations monitoring pump scheme sub-basins draining into Jeanettes Creek, whereas BEAT, CDWO, and OBSE monitor the Medway Creek and HOLT and MADT monitor Kettle Creek.

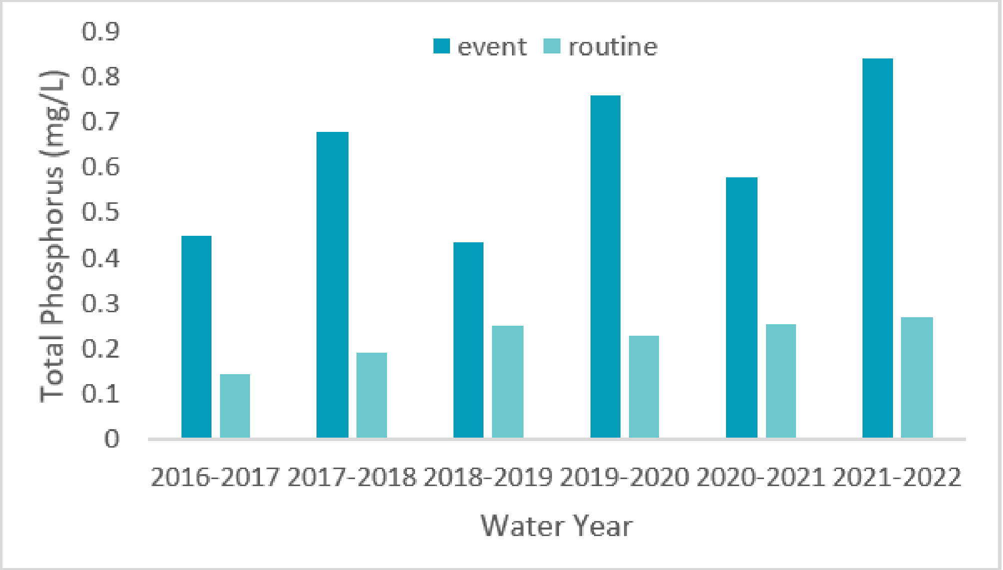


Figure 7. Median event and routine TP concentration data from Wigle 1 compared between water years.

However, when the concentrations shown in Figure 6 are compared to Ontario's threshold target for phosphorus set at 0.03 mg/L, it is clear many of these sites have often exceeded the threshold, at the very least during event-flow, and are still at great risk for contributing to nuisance algal blooms.

Figure 6 highlights the variability that can occur on a regional basis, and the need for regionally specific water quality analysis. The geographic location of some sites being closer together did not necessarily result in consistent observations between those sites. For example, while DRP concentrations measured by MVCA and ABCA were quite similar in separate but nearby watersheds, the six sites monitored by LTVCA had very different results depending on the subwatershed location, and the characteristics of the drainage system that the samples were taken from (this effect is discussed in further detail in Section 3.4). The high degree of variability affirms a key conclusion from the previous GLASI program, in that more monitoring time would be needed to capture inter-year variability in weather, and weather's impact on nutrient dynamics.

Results from routine sampling shown in Figure 8 from the Wigle 1 monitoring station in Wigle Creek demonstrate that even baseflow concentrations can vary depending on the weather conditions in a given year, and that trends were not consistent between different water quality parameters.

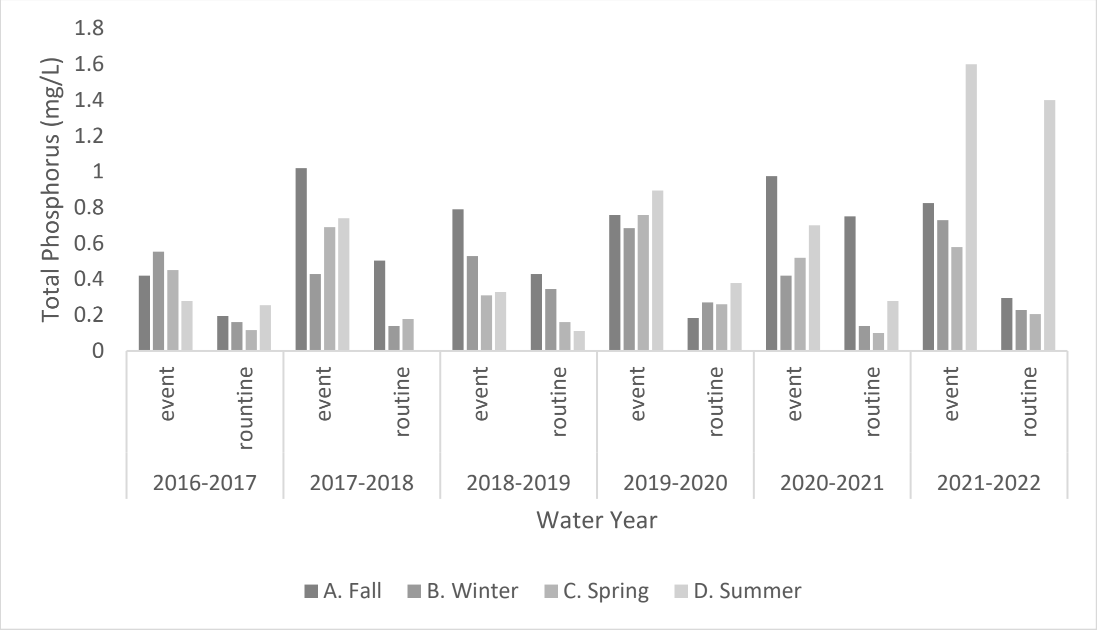


Figure 8. Median Seasonal TP concentrations across multiple years using pooled data from Wigle 1.

3.2 Seasonal Effects on Water Quality Loads

To understand how agricultural BMPs may be impacting water quality observations, it is important to consider what conditions and timings led to increased nutrient loads. Figure 9 shows the average loads from all ONFARM sites grouped together for DRP and TP based on the time of year, i.e. split between the NGS and the GS. The NGS is typically considered to run from October 1 to April 30, and the GS from May 1 to September 30. These timeframes are set based on the regional context for crop planting and harvest, and when crops are impacting the water cycling with substantial amounts of evapotranspiration. For example, while a corn crop may not be harvested until November or December, its rate of growth and water uptake has likely declined, and those months are therefore considered to be non-growing. Notably, data from ERCA uses a different range with the NGS beginning at November 1 instead, based on the longer GS and warmer conditions found at the southern most region of Ontario.

Approximately 70% of all phosphorus loss from the PSPs was found to occur during the NGS. This was consistent with previous findings, and not unexpected. Without consistent crop cover and increased numbers of freeze-thaw cycles during the NGS, soils are more prone to erosion. Additionally, the combination of rain and snow melt can result in large runoff events.

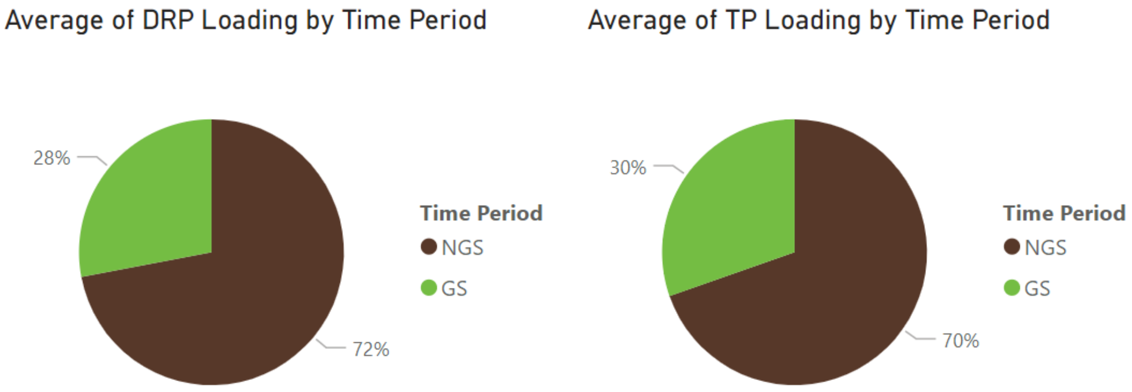


Figure 9. Average of all dissolved reactive phosphorus (DRP; left) and total phosphorus (TP; right) loads from all ONFARM watershed outlet sites.

A hydrograph from the monitoring station GULGUL5 in Gully Creek, shown in Figure 10, visualizes the interaction between precipitation (on the top) as a driver of flow through the monitoring station (on the bottom) across an entire water year. Despite the GS receiving several large precipitation events, this only led to two large runoff events as growing crops and warm temperatures resulted in drier soils which prevented runoff. The NGS shows more flow events occurring frequently, with higher base flow and the capacity for the greatest flow conditions.

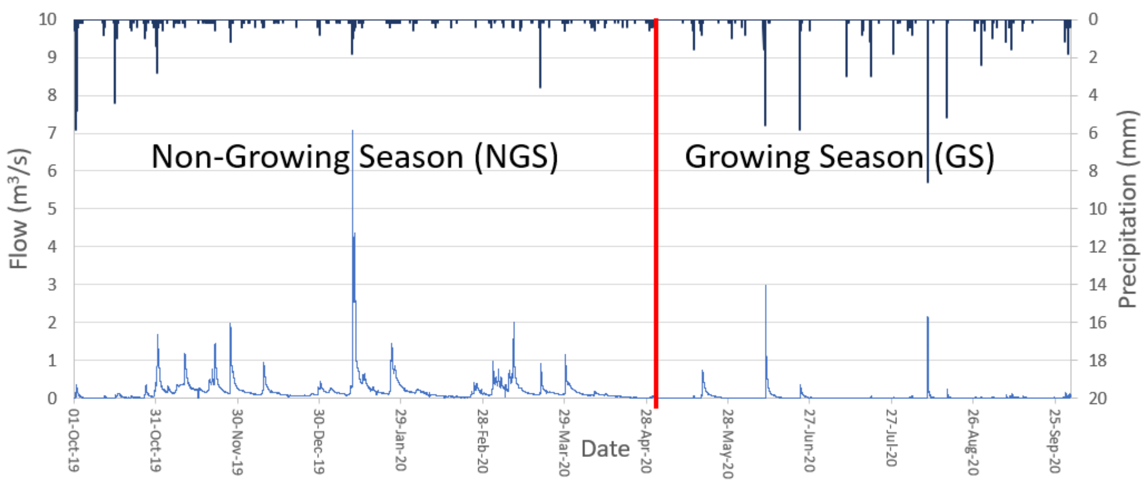


Figure 10. Hydrograph from the 2019-2020 water year at the GULGUL5 monitoring station in Gully Creek (ABCA). Precipitation is shown on the right axis with data along the top in bars and flow is shown on the left axis with data along the bottom in a continuous line. A vertical red line indicates the separation between growing season and non-growing season days.

These large scale flow-events were found to be the dominant time when nutrient loading occurred. Figure 11 shows two water years of hydrographs from 2019-2021 taken from the Garvey-Glenn monitoring station. A substantial flow event occurred in September 2021 from approximately the 22nd to the 27th. For most PSPs, this was the largest event that occurred in any GS (notably, this flow event did not occur at sites monitored by LTVCA and ERCA, both located further south-west compared to other monitoring stations). Results from this event and a separate event that occurred January 10th to 18th in the NGS show how much impact one event can have on a seasonal load, discussed in section 3.3.

Just as high levels of discharge result in more nutrient loading during wet years, the opposite effect is equally possible. Figure 12 shows the impact of drought conditions on TP loads from Wigle Creek (note that these values show the actual mass of TP exported, and are not shown per acre), which were nearly zero during the 2021-2022 GS. Without the flow to move nutrients over several months, nutrient loading was substantially reduced during that time. Years with low nutrient loads, therefore, cannot necessarily be attributed to BMP efficacy without also evaluating the context of weather and hydrology in the same system.

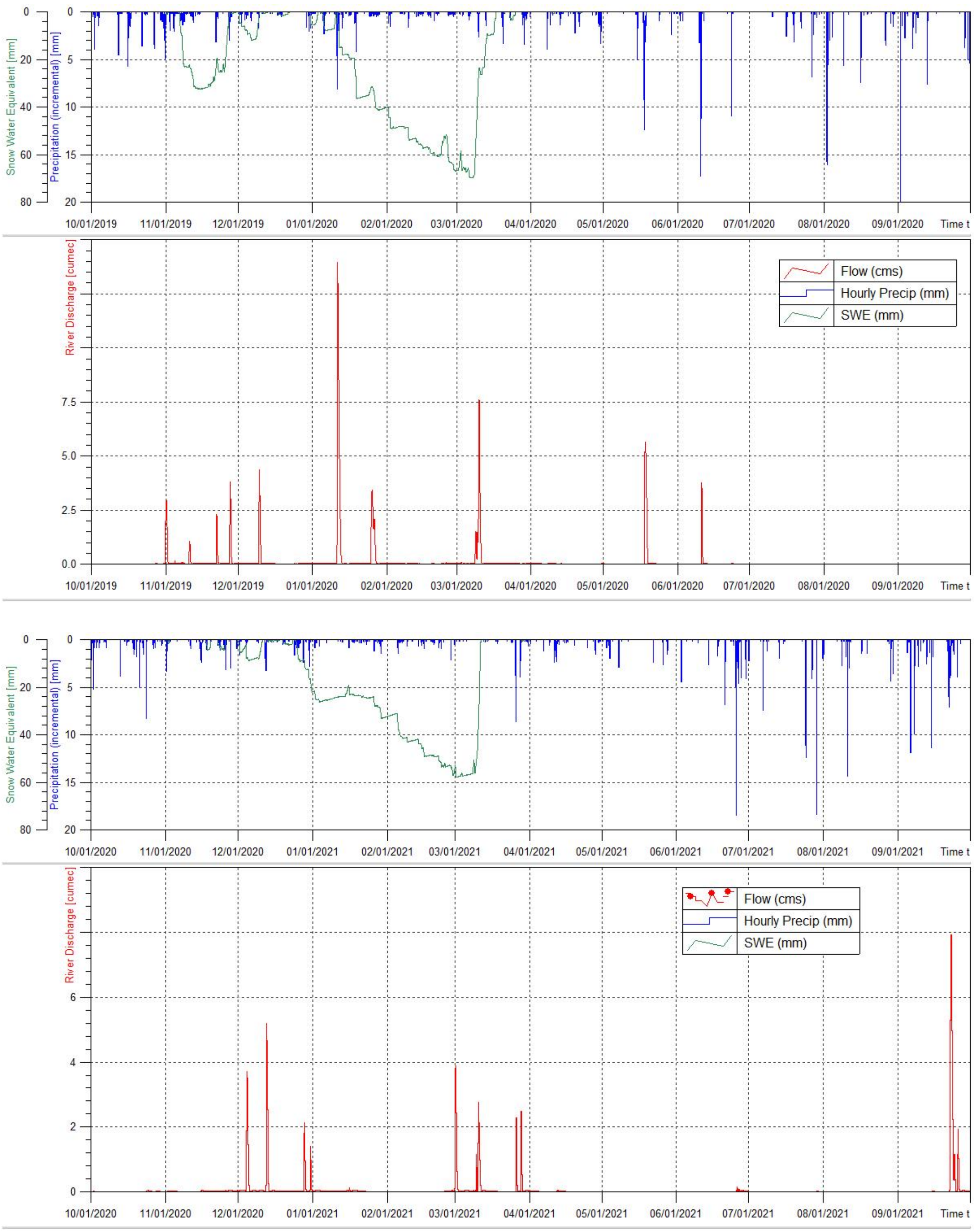


Figure 11. Hydrographs from the 2019-2020 (top) and 2020-2021 (bottom)water year at the Garvey-Glenn monitoring station (MVCA). Precipitation is shown in blue bars paired with snow water equivalent (SWE) in a continuous green line and flow in a continuous red line.

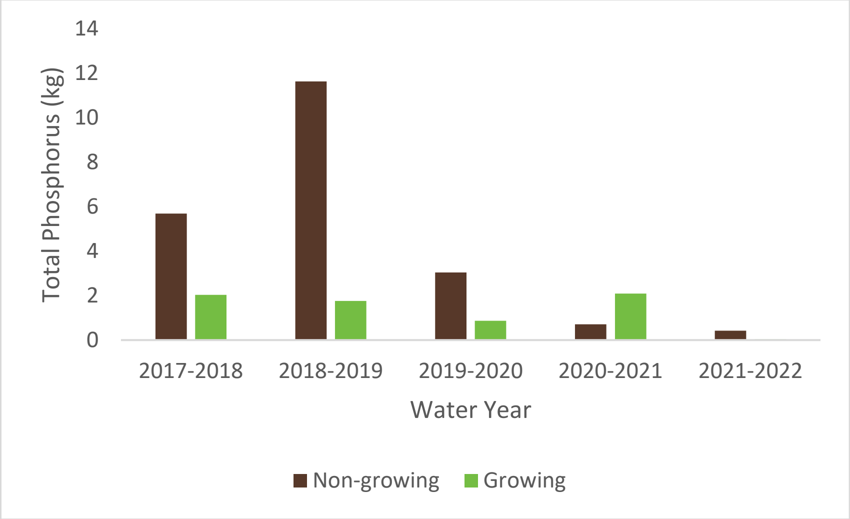


Figure 12. Median daily TP load in the GS and NGS over five water years from Wigle Creek. Note that the 2021-2022 GS load is near-zero, and reflects stream conditions during that period.

3.3 Impact of Runoff Events on Seasonal Loads

For the 2019-2020 water year at the Garvey-Glenn outlet monitoring site, the NGS DRP load was 0.13 kg/ha and the event-load from the peak flow event resulted in 0.02 kg/ha of DRP loss. This NGS saw many smaller events as well that consistently led to runoff, and that event was only one of many that contributed to a larger load of DRP. In 2021, the DRP load for the GS was 0.05 kg/ha, of which 0.04 kg/ha, or 80% of the season's load were driven by one flow event. This event appeared to be driven by a good amount of preceding rainfall in the weeks before, leading to high antecedent moisture conditions. Takeaways from these events show that, while phosphorus loss does predominantly occur in the NGS, a late spring or early fall events can still contribute a substantial amount of nutrient loss. The use of BMPs should be targeted to maintain soil cover as much as possible during these times of peak phosphorus loss, and field management practices should be timed based on both the weather forecast as well as current field conditions – the potential for BMPs to impact water quality is discussed further in section 5.0.

Similar findings were observed at the streamflow monitoring stations established in the Upper Medway (at the subwatershed monitoring station OBSE) and Kettle Creek (at the subwatershed monitoring station HOLT) for these two events. Figures 13 and 14 show event hydrographs from these two sites. Discharge observed at both watershed monitoring stations occurred differently, with OBSE showing a much more sudden increase compared to the more gradual increase, with multiple peaks in flow captured at the HOLT station. The rapid increase at OBSE may have led to much higher TP concentrations observed at the beginning of the event, compared to the slower, and generally lower increase in TP concentrations captured at HOLT. Differences between the structure (i.e. timing of flow and the resulting phosphorus concentration peaks) of these events demonstrate the need to monitor at multiple stations even within a region to best understand water quality dynamics.

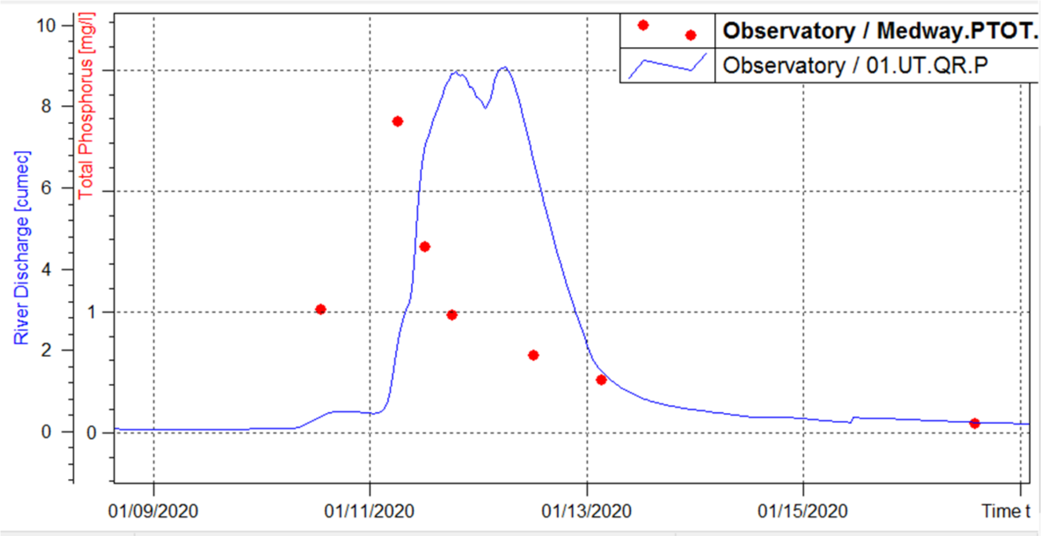


Figure 13. OBSE discharge (blue line) and TP grab sample concentrations (red points) during a January 2020 flow event.

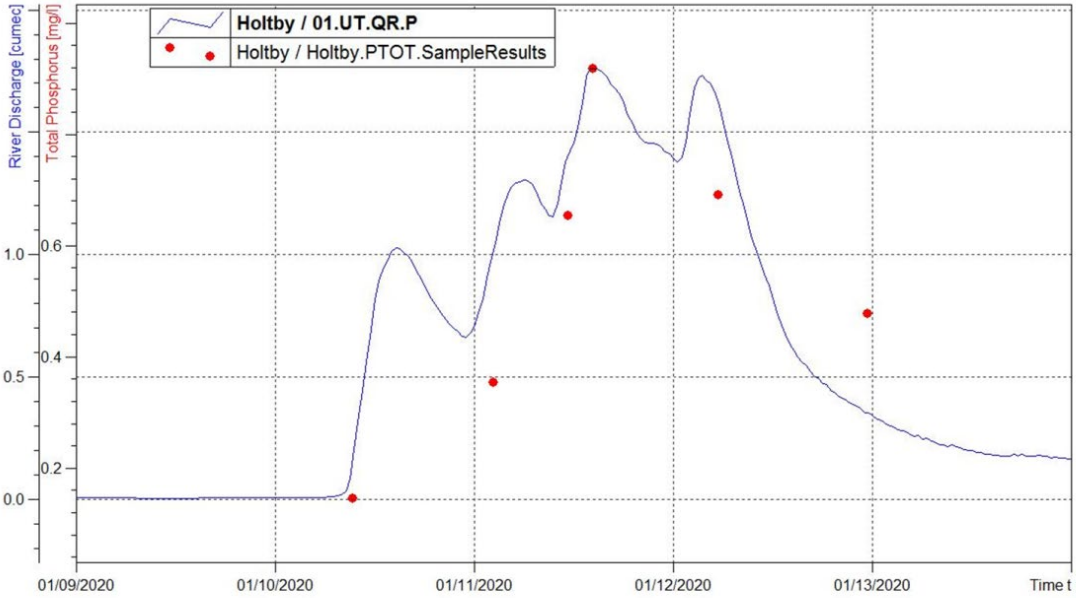


Figure 14. HOLT discharge (blue line) and TP grab sample concentrations (red points) during a January 2020 flow event.

These single events contributed 42.5% of TP, 35.4% of DRP, and 22.9% of total nitrogen (TN) losses in the 2020 water year from OBSE, and 33.7% of TP and 13.7% of TN from HOLT. The Medway Creek received slightly more precipitation, 76.1 mm compared to 63.2 mm during this event, which may have led to slightly greater numbers at OBSE.

For the September 2021 event, 105.6 and 93.4 mm of precipitation were measured at OBSE and HOLT, which led to the greatest discharge value observed at both sites for the entire project and resulted in nearly half of the year's TP load at both sites. Average loading estimates for all monitoring sites in the Upper Medway and Kettle Creek split by NGS and GS are shown in Table 3. These estimates demonstrate how much potential loss can vary within a region. These rain events demonstrate the need to assess BMP efficacy against the largest potential storms, and their need to accommodate for a changing climate in which more sporadic and more intense rain events become the norm.

Table 3. Seasonal nutrient loading estimates by monitoring station from the Upper Medway Creek and Kettle Creek. Medway sites highlighted in blue; Kettle sites are white.

		Loading Estimates (kg/ha)		
Monitoring Station	Season	TP	TN	DRP
BEAT	NGS	1.70	79.10	0.143
	GS	0.26	8.96	0.030
CDWO	NGS	2.34	46.89	0.000
	GS	1.76	25.00	0.001
OBSE	NGS	2.21	31.72	0.501
	GS	0.65	2.57	0.192
HOLT	NGS	3.38	19.12	0.002
	GS	1.14	3.35	0.000
MADT	NGS	7.10	23.18	0.003
	GS	1.70	5.75	0.001

3.4 Comparing nutrient load differences between sites in a hydrologically unique subwatershed

The Jeannettes Creek subwatershed has been monitored by the LTVCA since 2016. Unlike other PSPs, the water level of the creek and the Thames River which it feeds into is at some points above the level of crop land. With the landscape having very little topography, a system of municipal drainage ditches, dykes, and mechanical pumps are used to control water levels and prevent flooding. LTVCA monitors three pump stations, Boudreau, Deary, and Dauphin, to assess water quality moving into Jeannettes Creek.

The Boudreau pump station has a drainage area of 131 ha. The subwatershed consists primarily of agricultural fields. Water flows from the fields to the municipal drains via subsurface tile drainage systems. There is a pump station at the outlet of the Boudreau municipal drain that is used to discharge water into the adjacent Jeannettes Creek. The electric pump is float triggered and turns on when the water level in the drain exceeds a set level. With a lower capacity pump and a drainage reservoir to store water, the duration of pumping events is often longer.

The Deary Pump Station has a drainage area of 715 ha. During the study period, the station was equipped with a single diesel pump that is manually operated during rain and runoff events. When water levels in the drain rise, the pump is turned on, and remains on until the water level has dropped to appropriate levels. A new higher capacity pump consisting of a 205 hp diesel-powered axial-flow propeller pump was added to the site and began operation in 2023.

The Dauphin Pump Station has a drainage area of 911 ha. The station is equipped with two diesel powered pumps that are manually operated by a local landowner. When water levels are high, a single pump is turned on and in heavy rain scenarios the secondary pump is also turned on. As a result of the higher capacity pumps, annual pumping hours can be lower than the Deary and Boudreau pump stations. The agricultural land within the subwatershed is below the elevation of the surface water in Jeannettes Creek and the Thames River. The predominant soils within the subwatershed are the lacustrine Rivard and Clyde clays. Soil sample results shared by farmers show that the soils have high levels of organic matter, which range from 4%-10%. The soil phosphorus levels in the region ranges from 7-20 ppm (bicarbonate test).

Soils in the Deary and Boudreau subwatersheds consist primarily of Brookston Clay soils. In contrast to the soils of the Dauphin subwatershed, these soils have lower levels of organic matter, however there is little difference in the observed levels of soil test P. Soil sample results provided by subwatershed farmers indicate organic matter ranges from 3.0% - 4.5%. The soil test P (Bicarb) ranges from 7-22 ppm. More work and sampling is required to further define the soil characteristics in each subwatershed to evaluate how these differences may be affecting water quality.

The majority of the fields within all three subwatersheds are systematically tiled. Very little surface water runoff was observed in the Dauphin and Boudreau subwatersheds; surface runoff is rare in the Deary subwatershed, but does occurs during periods of higher antecedent moisture, when rain falls on frozen soils, or during high intensity rain events. These soils also have a tendency to crack during dry periods and can form preferential flow paths from the surface to tile drains, shown in Figure 15.

Figure 15. Photograph of a sizeable crack forming in Brookston Clay soil from the Deary Pump Station subwatershed.

Rainfall in the Jeannettes Creek study area averaged 800 mm/yr over the five-year period. This is slightly less than the 30 year average for the area of 882 mm. The study period includes wet years in 2018 and 2019 as well as dry years in 2017 and 2022. Seasonally, more precipitation occurred in winter and spring. The amount of water moved by each pump varied over the study period, shown in Figure 16 with the annual precipitation data. However, in wetter years a larger percentage of rainfall resulted in pump flow (50-75%) while drier years saw < 50% of total rainfall result in flow. The largest pump scheme Dauphin consistently produced the largest flow volumes.

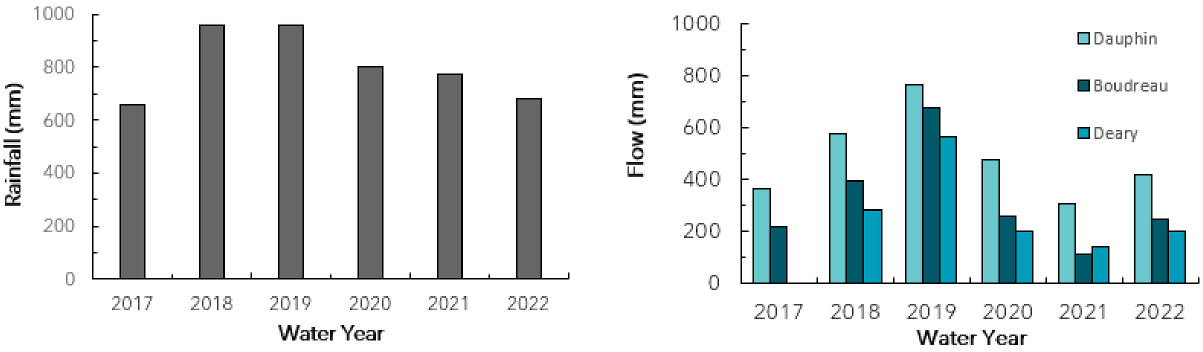


Figure 16. Annual rainfall (left) and flow through pumping stations (right) in Jeannettes Creek. Note that no flow data was available for Deary in 2017.

Annual loading results for water quality parameters are shown in Figure 17. Consistently higher loads of TP were observed from the Deary pump scheme with Boudreau in second and the largest pump Dauphin showing the lowest relative loads. The wettest years 2018 and 2019 also produced the largest TP loads. However, dry years like 2022 also produced high loads, due to timing and intensity of rainfall events. Differences between soil type and characteristics, i.e. the Brookston clay found in Boudreau and Deary compared to the Rivard and Clyde soils found in Dauphin, may be contributing to the differences in annual TP loads. However, it is possible that variances in crop management practices could also be a factor—further monitoring and analysis would be required to better understand these interactions. These differences in loads were most strongly reflect in TP and TSS. To contextualize the loss of soil as TSS, in 2019 when TSS losses peaked in the Deary subwatershed, the Deary basin lost 92 tonnes, which is the equivalent of seven dump truck loads of sediment. While managing phosphorus loss is often the primary target for reducing the severity of harmful algal blooms in the Lake Erie watershed, it is important for future research and management programs strive to manage all water quality parameters, as this level of TSS can have its own impacts on aquatic ecosystems. The co-benefits of protecting water quality and soil health must also be considered here – protecting soil from future loss helps ensure these systems can be sustainably cropped far into the future. However, these results also demonstrate that the capacity for a BMP to affect change in a region may always be limited somewhat by the natural or inherent characteristics, whether that is topography or soil types which influence the movement of water through a field.

As the largest pump in terms of volume discharged, Dauphin, consistently showed the highest nitrate volumes and annual discharge (Figure 16). Boudreau had a particularly high load, similar to Dauphin, during 2019 which coincided with the increase in discharge measured at the pump station during that year. Further analysis is required to better understand the efficacy of BMPs for managing nitrate loss, and how they interact with the unique soil and drainage characteristics of the watershed.

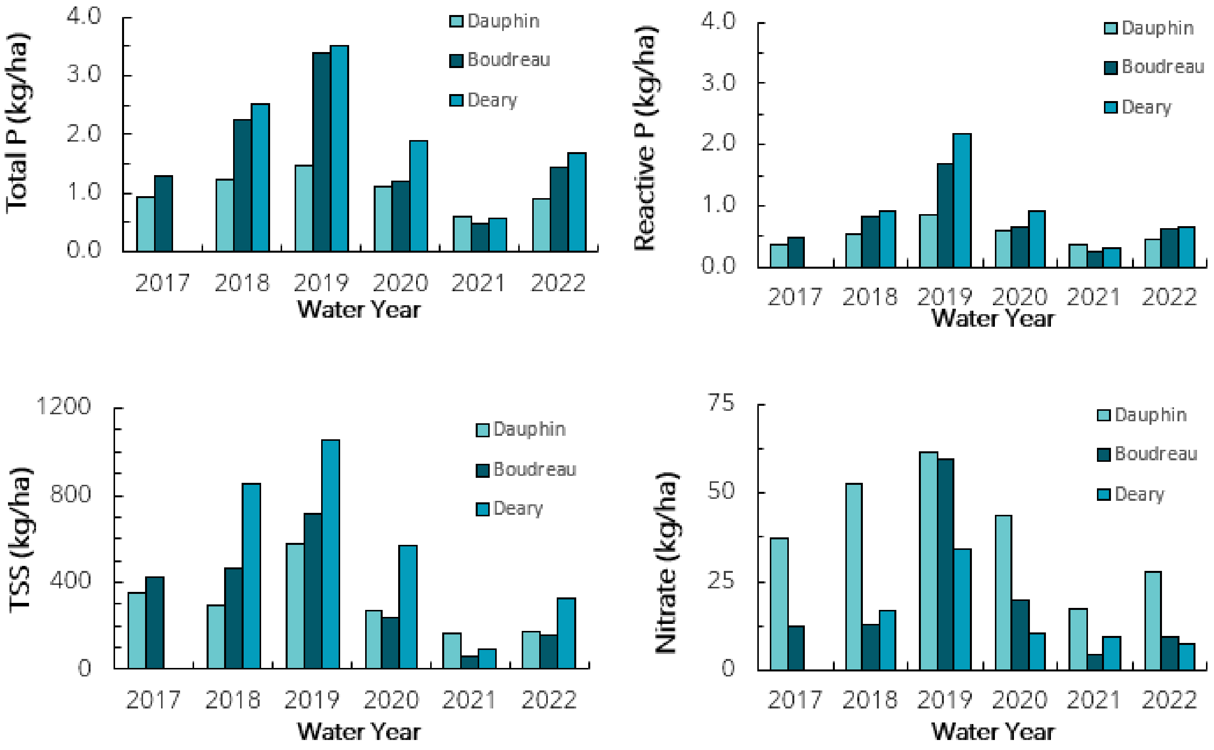


Figure 17. Annual loads for water quality parameters from three pumping stations in Jeanettes Creek. Note that scale on the vertical axis differs between parameters, and that monitoring data was not established at Deary in 2017.

4.0 Management Impacts on Water Quality

The impacts of applying several agricultural management practices: cover crops, water, and sediment control basins (WASCoBs), reduced tillage, and the timing of nutrient application, are shown through three case studies from ONFARM's EOF monitoring sites, from Site 6, DFTILE in the Gully Creek watershed, Site 8, the Garvey-Glenn EOF, and Site 7, the Huronview Demonstration Farm. These studies demonstrate how the understanding of hydrology in these systems and working around the main drivers of nutrient loss can help to mitigate phosphorus loading, and how the impacts of nutrient management at the EOF scale transfer to the watershed scale.

4.1 Managing infiltration and runoff with systemic management and cover crops

Site 6 (DFTILE), the EOF site in Gully Creek, has been monitored for water quality since 2010 by ABCA. As part of the preceding GLASI program, water quality monitoring on the farm has been in place at three of six WASCoBs and a tile flow monitoring outlet at the EOF, covering an 18 ha subwatershed within the farm. Previous work through GLASI examined how the morphology of the sub-basins feeding the WASCoBs with runoff water impacted nutrient loads, how WASCoBs consistently worked to reduce peak flow, and how using different materials to filter the runoff water entering the surface water inlets (i.e. hickenbottoms) had potential to reduce TSS and phosphorus loss at least in the short term. In the GLASI program, the DFTILE farm (Site 6) was used to research the impact of vegetative cover on runoff water quality. An extreme event just after a crop of corn had been planted on vertical tilled ground had loads that were many times greater than other events, including times when there was no vegetation.

When examining the runoff coefficient (ratio of runoff volume to precipitation volume) and the presence or absence of flow (flow vs. no-flow data), it was found that surface runoff was more likely to occur during the non-growing season. From the preliminary GLASI dataset, the effect of crop type was considered in the NGS—corn residue and soybean residue produced higher runoff coefficients and were more likely to generate flow (runoff) when compared to a cover crop. In contrast, in the same season, oat cover crop produced the smallest runoff coefficient and flow was less likely to occur under oat cover than under other crop types. A goal for the site during the ONFARM program was to continue monitoring the site with the same methodology as was used in GLASI, and to evaluate the effect of crop type on runoff during several more years of the rotation.

To assess no flow conditions, event responses were divided into binary conditions: flow or no-flow. Events that generated flow were defined as having generated a water level greater than 0.025 m, as measured at the WASCoB's riser inlet. Otherwise, an event was considered a no-flow event. No-flow events were characterized as those precipitation events that produced greater than 10 mm of rainfall within a 24-hour period, or had rainfall intensity greater than two mm per hour, but did not generate sufficient runoff to exceed a level of 0.025 m at the WASCoB's riser inlet. Events were divided between NGS and GS time periods, and the crop type was used as the basis for separating events into another eight categories: corn, soybean, winter wheat, oat cover crop, corn residue, soybean residue, winter wheat stubble, and no cover (i.e., bare soil).

A total of 277 precipitation events were observed between June 2013 and September 2021 (with GLASI and ONFARM datasets combined). The number of events that generated flow and those that did not are detailed in Table 4. Mean precipitation per event from 2013 to 2021 was 23.7 mm (range = 7.0 mm to 86.4 mm) during the growing season and 19.1 mm (range = 5.2 mm to 78.4 mm) during the non-growing season. Runoff flow occurred more often under non-growing season conditions (93 instances) compared to when flow was generated in the growing season (40 instances).

Table 4. Summary of runoff conditions during precipitation events at three Water and Sediment Control Basin monitoring locations under different growing and land cover conditions (June 2013 to September 2021)

Runoff Condition	Number of Events		
	Total	Growing Season	Non-Growing Season
Flow	133	40	93
No-Flow	144	93	51

There was a strong association between crop type and the presence or absence of flow during precipitation events as observed at the WASCoBs during the growing season and non-growing season. Runoff was less likely to occur during the growing season when canopy cover is greatest, shown in Figure 18, and more likely to occur during the non-growing season when canopy cover is lowest, shown in Figure 19.

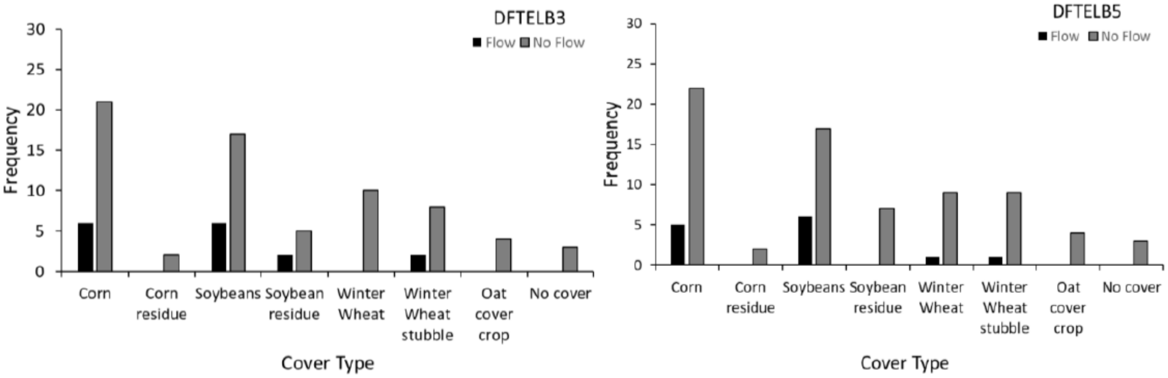


Figure 18. Flow/No Flow frequency during the growing season in the two WASCoBs monitoring sub-basins DFTELB3 (left) and DFTELB5 (right) at Site 6 from 2016-2021

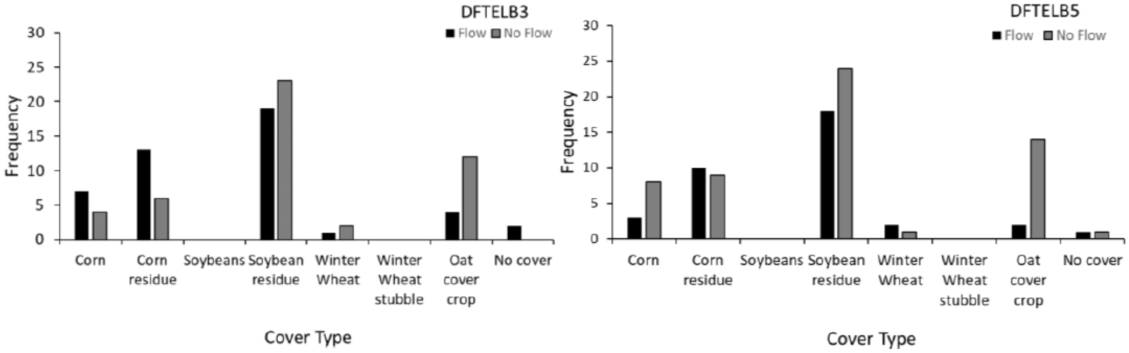


Figure 19. Flow vs No-Flow frequency during the non-growing season in the two WASCoBs monitoring sub-basins DFTELB3 (left) and DFTELB5 (right) at Site 6 from 2016-2021

In addition to monitoring flow conditions within these basins under varying crops, the Site 6 farm was also used for a side-by-side demonstration comparing harvested and unharvested cover crop conditions during the NGS of 2020 to 2021. Following wheat harvest in July 2020, 4,000 gallons/acre of liquid dairy manure was applied and lightly incorporated. A pea and oat cover crop mix was drilled in during August 2020 at a forage rate of 80 to 90 lbs per acre. Around October 20th 2020, the cover crop was cut at approximately the 10 cm level and removed as baleage from most of the field, including DFTELB3. The area draining into DFTELB5, however, was not harvested (the treatment areas are highlighted in Figure 20). DFTELB3 and DFTELB5 are two sub-basins of the field which are monitored at WASCoBs.

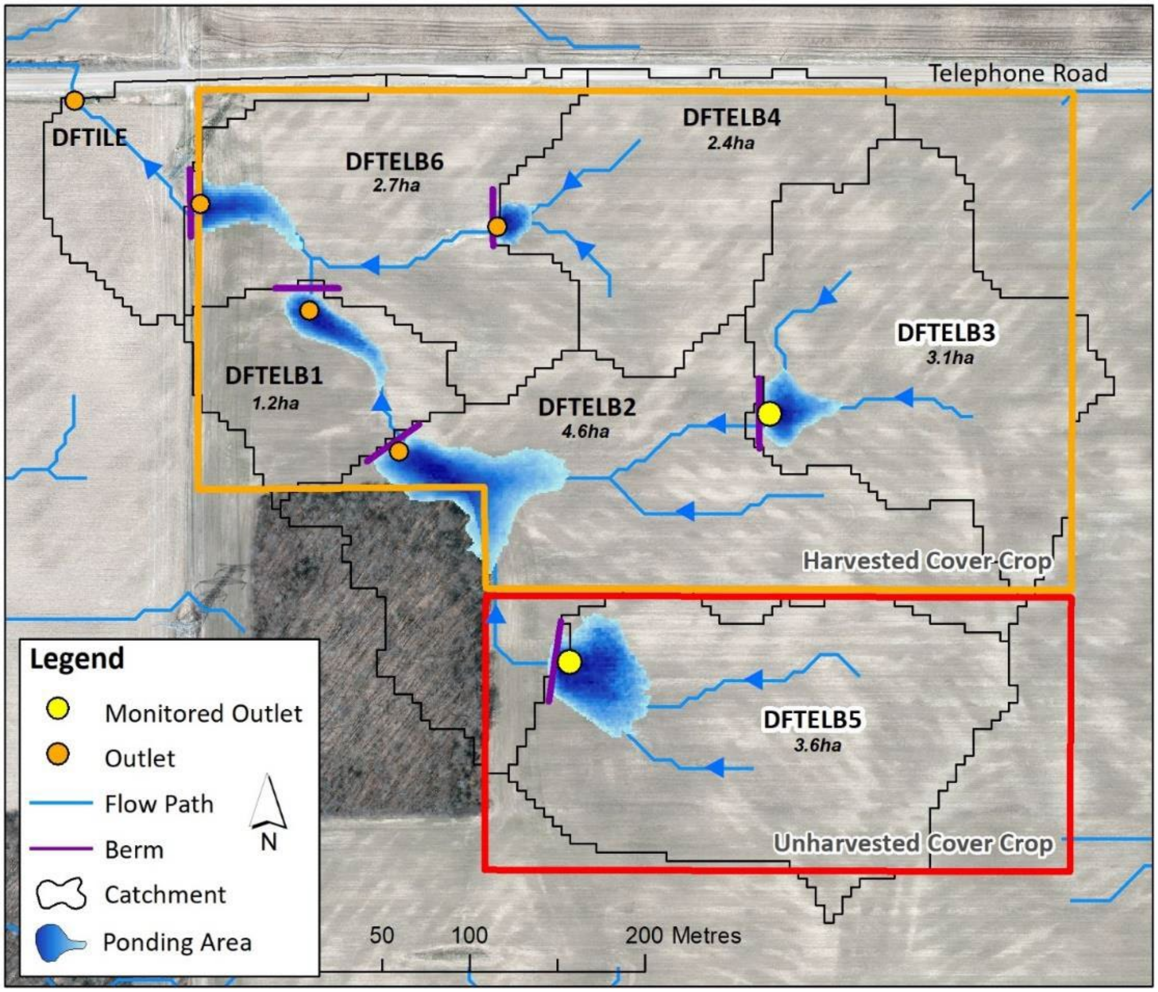


Figure 20. Map of Site 6, the DFTILE EOF site in the Gully Creek watershed. WASCoBs 2, 3, 5, were monitored for water quality from sub-basins within the field, and the tile outlet (top left) was monitored for water leaving the entire field. Flow direction is indicated by blue arrows.

Following wheat harvest and the planting and harvesting of the cover crop from most of the field, between October 2020 and April 2021, there were 13 rain events. Four of these rain events generated overland flow in DFTELB3 (the harvested basin), as well as three flow events presumably resulting from snowmelt. The largest rain event in the NGS of 2020 and 2021 occurred on March 25-26th, 2021, with 41.2 mm of rain. There was runoff observed in basin DFTELB3 and no runoff in DFTELB5 (the unharvested basin). There was also a smaller event on October 23rd, 2020, that triggered runoff in DFTELB3 and no runoff in DFTELB5.

A rain event on December 12th, 2020 was the only event in which flow was generated in both sub-basins and samples were collected by the ISCO – event-loads are shown in Table 5 for comparison between sub-basins. DFTELB5 (the unharvested basin) showed lower loads for nearly all parameters, except for DRP (measured in laboratory analysis as Phosphate-P at this site). While DRP loads were similar between the two basins, TP, TSS, and nitrate loads were greatly reduced with the presence of the cover crop. Therefore, in addition to numerous other rain events not driving runoff and resulting in nutrient loss from the basin, the cover cropped basin showed lower losses when flow did still occur. A slightly higher loading of DRP observed in the basin with unharvested cover crop, DFTELB5, is possibly a consequence of the presence of the unharvested cover crop leaching DRP. It is also notable that this farm received a manure application earlier in 2020 – nutrient loss from this application appears to be minimal, which may be the result of quick incorporation and the use of the cover crop, when compared to finding discussed in Section 4.2 below.

Table 5. Total phosphorus, dissolved reactive phosphorus, total suspended solids and nitrate-N load (kg/ha) results from the December 12, 2020 rain event at the DFTILE EOF site.

Monitoring location	Total Phosphorus (kg/ha)	Dissolved Reactive Phosphorus (kg/ha)	Total Suspended Solids (kg/ha)	Nitrate-N (kg/ha)
DFTELB3 (harvested cover crop)	0.072	0.017	12.602	0.024
DFTELB5 (unharvested cover crop)	0.033	0.020	6.076	0.003

Findings from the trial in this field indicated that land management and structural BMPs improve water quality by reducing runoff and preventing excess nutrients and sediment from entering waterways. More specifically, there was less runoff from a field with an overwintering cover crop compared to a harvested cover crop. Structural BMPs such as WASCoBs improved water quality at a field scale and increased water storage, which should reduce overall sediment and nutrient loss from watersheds.

4.2 Managing manure application timing

At the Garvey-Glenn EOF site, average annual runoff from tile and overland combined was 402 mm and ranged between 218 mm and 589 mm. Between 2016 and 2022, tiles accounted for 95% of total runoff, and overland accounted for 5% of total runoff, shown in Figure 21.

Figure 21. Total Phosphorus (TP) loads by water year from tile and overland flow at the Garvey-Glenn EOF site. Data are combined from GLASI and ONFARM monitoring.

Despite contributing such a low proportion of the total runoff, overland flow contributed an average of 28% of TP loss, depending on the year. As shown in Figure 22, overland flow was found to be an equal or dominant source of TP loss in any particular year. Losses measured in 2017-2018 were distinctly higher than other years. Table 6 provides a summary of monitoring data and land management context to compare the findings from 2017-2018 against other similar years, for example, 2020-2021, which had the same rotation, and 2021-2022 which had similarly high levels of runoff.

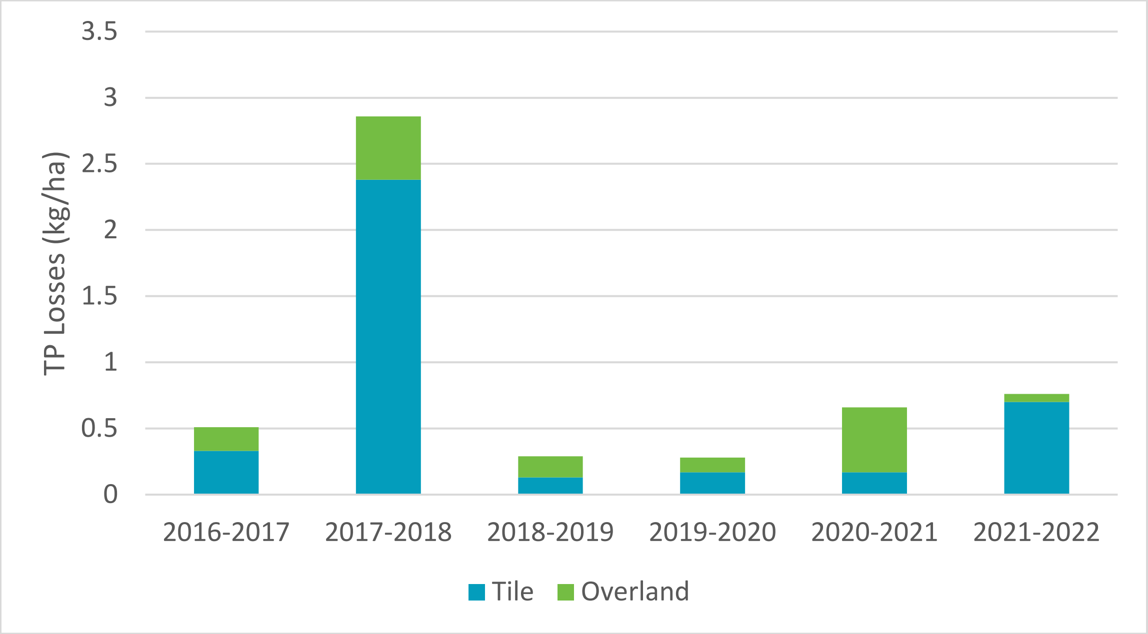


Figure 22. Total Phosphorus (TP) loads by water year from tile and overland flow at the Garvey-Glenn EOF site. Data are combined from GLASI and ONFARM monitoring years.

Table 6. Summary of runoff, phosphorus losses, and management practices at the Garvey-Glenn EOF site.

	2017-2018	**2020-2021**	**2021-2022**
Runoff (mm)	589	296	498
Total Phosphorus Losses (kg/ha)	2.86	0.66	0.76
Fall Crop Harvested	Wheat	Wheat	Corn
Fall Crop	Cover Crop	Cover Crop	Corn Stalks
Fall Nutrient Application	Manure October – Surface Applied	Manure August – Surface Applied	None
Fall Tillage	Chisel Plow November	Chisel Plow November	None
Soil Residue Cover - Non-Growing Season	Tilled - No residue	Tilled - 50% Residue (cover crop)	100% Residue cover (corn stalks)

Both 2017-2018 and 2021-2022 were clearly the highest years in terms of runoff, and both were also similar in terms of the timing of runoff. The two years both had relatively wet falls, followed by significant mid-winter melts. Still, the losses observed in 2017-2018 were considerably higher than those in 2021-2022 despite that consistency in the hydrology which was expected to drive nutrient loading.

Moving further from the EOF scale to the watershed outlet, Figure 23 shows how similar these years were for TP loads on the larger scale. Indeed, the 2021-2022 water year which had the second highest amount of runoff on the EOF site had the largest watershed wide TP load. While the load in 2021-2022 may have been driven more by weather and hydrology, the key difference in 2017-2018 was the interaction of land management with the timing and amount of precipitation. In 2017, a wet fall led to consistent runoff events throughout September and October. When liquid manure was applied on October 26, the combination of antecedent moisture and rainfall the next day resulted in a tile flow event.

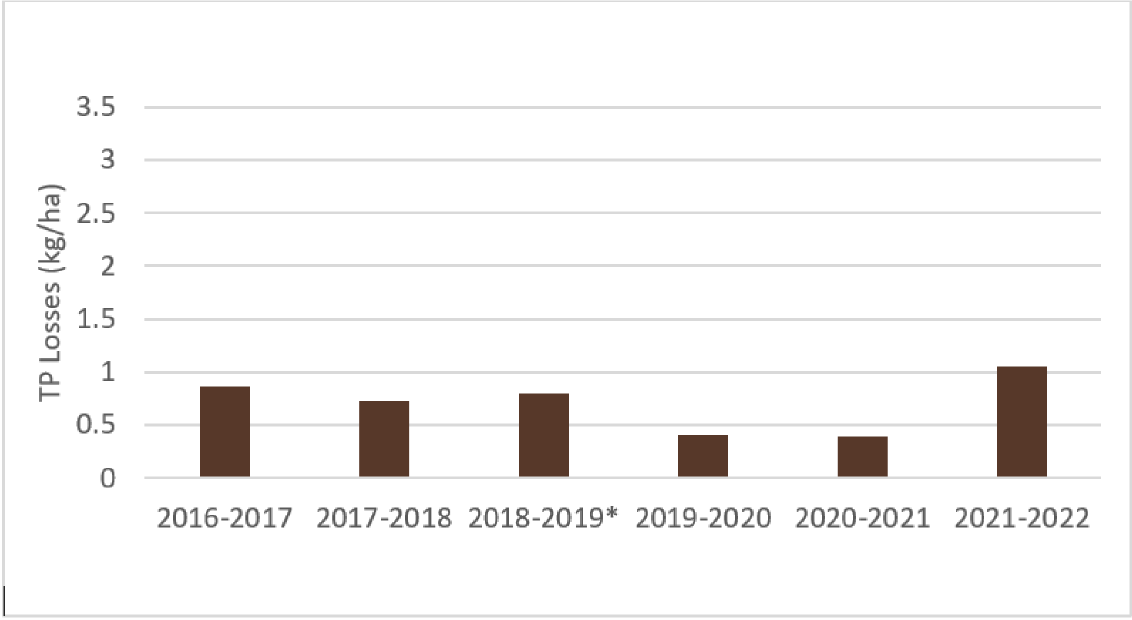


Figure 23. TP loads by water year from tile and overland flow at the Garvey-Glenn subwatershed outlet. Data are combined from GLASI and ONFARM monitoring years.

Samples collected at the Garvey Glen EOF site for the Oct 2017 event are shown in Figure 24. Total phosphorus concentrations were up to 12 times higher in the earliest samples compared to the overall average for the site (TP concentration values from throughout the monitoring program are shown in Figure 25 for comparison). Despite good efforts to manage the field with a cover crop grown between winter wheat harvest and manure application, the manure was incorporated leaving little residue cover. A normal amount of rain and snowmelt events continued through the 2017-2018 NGS and continued to contribute higher than normal TP loads through tile and overland flow between November and February.

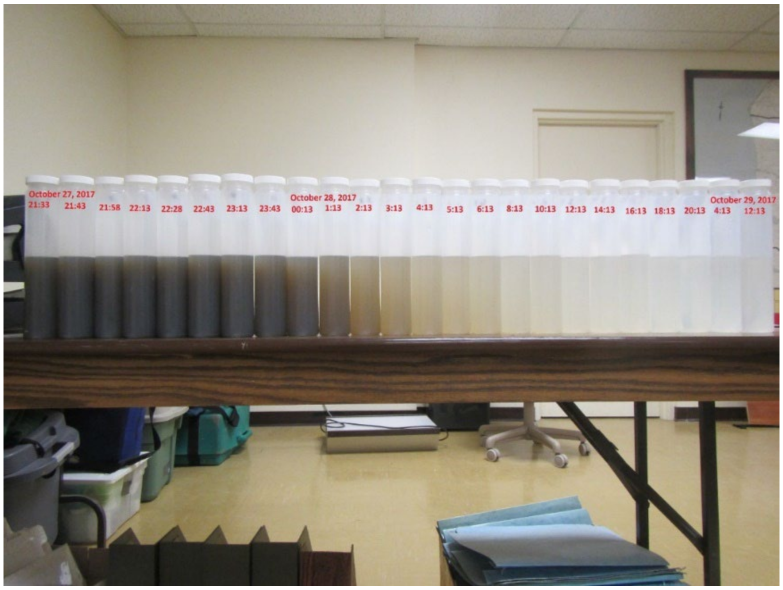


Figure 24. Photograph of tile water samples collected from the Garvey Glenn EOF site during the Oct 27th event.

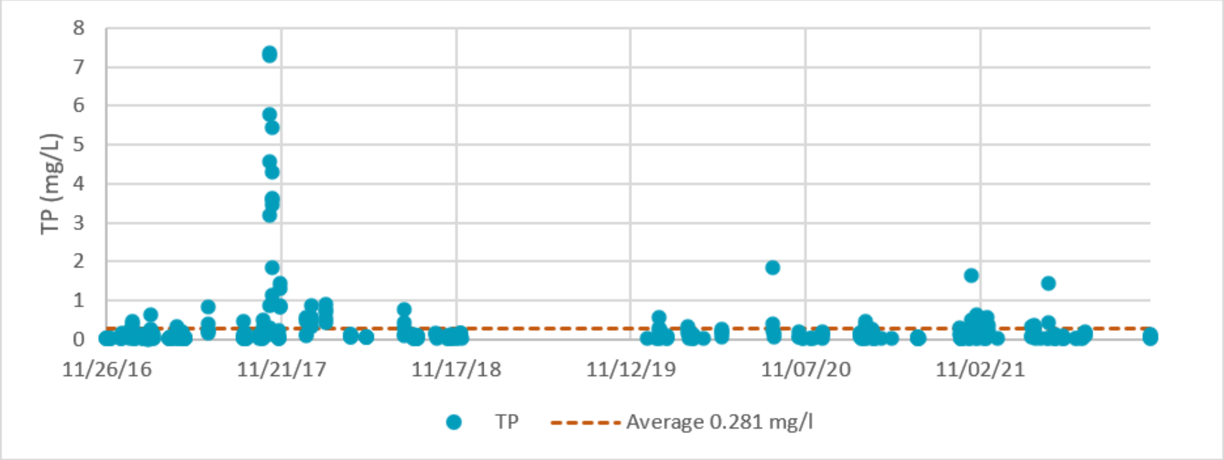


Figure 25. TP concentrations taken from tile water at the Garvey Glenn EOF site from 2016-2022.

Compared to 2017-2018, changes made in 2020-2021 to the tillage and manure spreading approaches had a big impact on residue cover going into the NGS and water quality observations during the NGS, even though these practices occurred at the same stage of time within the field's crop rotation. These effects can be visualized in Figure 26. In 2020-2021, manure was applied onto a living cover crop in early August instead of October. The field was later chisel-plowed Nov. 20th, 2020, but more residue was left on the surface than in 2017-2018. In 2021-2022, no nutrients were fall applied, and the corn stubble was left untouched to maintain good residue cover, and neither year showed the same level of phosphorus loss as 2017-2018. The application of organic amendments is a BMP with benefits to crops and soil health. While these findings demonstrate the benefit or need for managed application timing, the ONFARM soil health trials have shown strong benefits for soil health resulting from organic amendment applications. Generally, while applying in the fall after winter wheat harvest is an ideal timeframe, aiming to apply nutrients while fields are drier and avoiding applications before heavy rainfall are recommended BMPs to keep nutrients in the field and preserve water quality. Alternatively, immediate incorporation, as was done at Site 6 (in Gully Creek), after spreading has more potential to reduce phosphorus loss, but comes with tradeoffs from soil disturbance. It should also be noted that spreading manure earlier in the summer or fall in warm conditions has more potential for nitrogen loss through volatilization, especially when nutrients are surface applied without incorporation, which should be balance in setting management decisions.

Figure 26. Photographs of the Garvey Glenn EOF site during November 2017 (left), 2020 (middle), and 2021 (right)

4.3 Nutrient loss from rain directly following a fertilizer application

The Huronview Demonstration Farm, Site 7, is actively farmed by the Huron County Soil and Crop Improvement Association to demonstrate agricultural BMPs (particularly to inform management of tile drainage and its impact on water quality). The site has two permanent subsurface water quality monitoring stations located in Field A and Field B (Figure 27). As with the event described in Section 4.2 from the Site 8, a rainfall event was captured by following a nutrient application. After soybean harvest in October 2022, 116 lbs/ac of monoammonium phosphate (MAP) was applied to Fields A and B. The site received 100 mm of precipitation from October 17-20 which resulted in subsurface flow.

During the event, concentrations of TP ranged from 0.04-0.2 mg/L in Field A and 0.1-0.9 mg/L in Field B, which were approximately ten times greater than typical for the site. TP loads for the event were 0.06 lbs/ac from Field A and 0.13 lbs/ac from Field B. The majority of phosphorus lost in both fields was DRP; due to the timing of the nutrient application, phosphorus loss for this event was less driven by erosion and loss of particulate phosphorus from soils and more from the fertilizer application.

Considering the MAP which was applied at 116 lbs/ac, the soil had received an addition of 60.3 lbs/ac of phosphorus as P_2O_5, or 26.4 lbs/ac of elemental phosphorus. Therefore, the TP loss from this rain event was approximately 0.2% and 0.5% of the phosphorus fertilizer applied on Fields A and B, respectively. Agronomically, this reduction in fertilizer would have a negligible impact on the following crop's growth potential, but from a water quality perspective, this load was incredibly high for Site 7. Compared to the annual TP load of 0.09 lbs/ac for the previous two years from Field A, approximately 66% of the typical TP load was lost during one event. What could still be considered an efficient phosphorus application from an agronomic perspective with an acceptable amount of fertilizer loss demonstrates how, what seem to be insignificant amounts of phosphorus lost from many locations can, over time, contribute to larger downstream issues. Contextualizing different perspectives on sustainability in this way, and at multiple scales, are important considerations for balancing a strong and sustainable agricultural industry with goals for improving water quality.

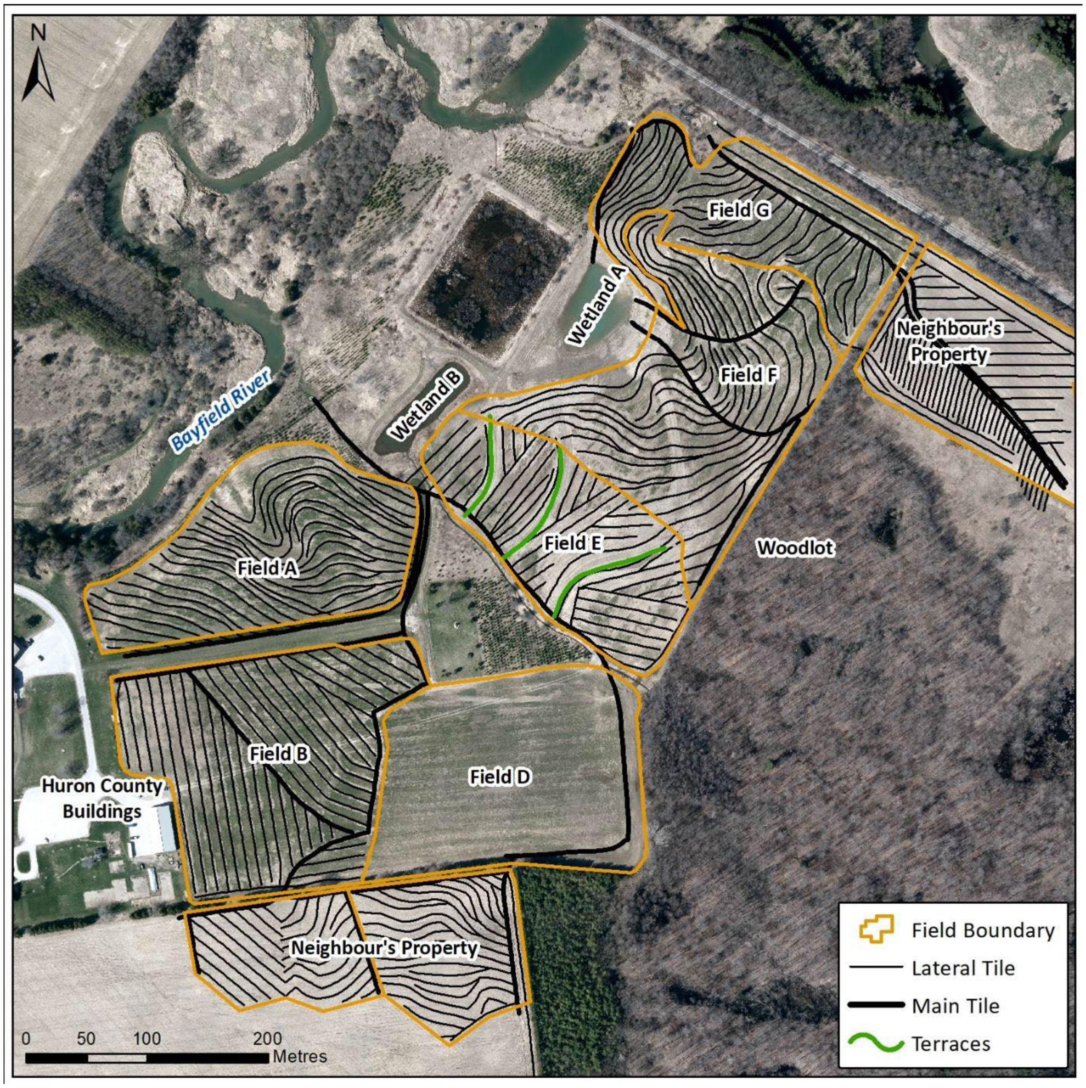


Figure 26. Site 7, the Huronview Demonstration Farm, shown by field and drainage sub-basins with the various tile drain setups.

5.0 Conclusions

Work completed under the ONFARM monitoring program has successfully developed long-term water quality monitoring datasets started under GLASI. With these additional years of data, ONFARM has captured much more variability in weather, both wet and dry years, to show how greatly weather patterns impact the hydrology and nutrient loading in these subwatersheds. It was important to capture not only variability in weather patterns but also in cropping, as rotations take place over several years and management practices for different crops impact nutrient dynamics as well.

Results have shown that nutrient losses are highest during precipitation events during the NGS, which was typical for all PSPs. This results in the highest concentrations and loads, particularly for TP, where an average of 70% of TP loading occurred during the NGS. This demonstrates the need to consider which time period BMPs are targeting to be most effective. For example, timing a conservation tillage pass to happen in spring rather than late fall can contribute to more of the soil surface being covered over the critical NGS period when overland runoff typically occurs.

Examining two of the largest flow events that occurred during the ONFARM monitoring has shown that large precipitation or snowmelt events can contribute a substantial portion of total seasonal loads (in some cases contributing 50-80% of all TP lost during a GS or NGS). Future efforts must consider how BMP recommendations hold up against these large storm and rapid melt events, as more irregular and higher intensity precipitation is anticipated to become common with climate change.

Different water quality parameters have been shown to respond with varying levels of impact from BMPs. For example, cover crops have reduced TP and TSS loss, but did not show the same impact on DRP. For example, it was evident that reducing the number of rain events resulting in overland flow with cover crops may be the most direct way to address TP and TSS, but BMPs targeted to conserve DRP or nitrate may need to focus on other factors to reduce the overall discharge from the field. For each water quality parameter, we need to consider what the dominant factors or pathways are driving loading, and target BMPs to influence them, and ensure risks for each parameter are considered before recommendations are made.

ONFARM studies have demonstrated that a farmer’s management choices can make a real impact on what leaves their farm. The use of BMPs that improved soil cover (e.g. leaving a cover crop in place over winter) reduced both the overall amount of runoff and the amount of nutrients within that runoff. Timing manure application to occur on drier soils, and maintaining more surface residue coverage were shown to have lower nutrient loads that had otherwise occurred throughout the NGS after spreading.

Through ONFARM’s combination of monitoring at the plot scale in soil, the field scale for runoff, and the larger scale with multiple subwatersheds, the research has shown linkages in how BMPs directed at farmers for improving soil health have co-benefits with improving water quality. While there are often assumptions made that these BMPs improve water quality, understanding these relationships and potential tradeoffs must continue to be refined. For example, ONFARM has shown a cover crop may reduce TP and TSS loss, but not necessarily DRP. Developing suites of BMPs and recommendations that account for these balances will continue to take time and further research. Likewise, ONFARM provides perspective on the timeframe it will take for BMP implementation at the farm level to influence water quality downstream. In some cases, such as the case-study of high TP loss captured in one fall runoff event at the Garvey-Glenn EOF (Site 8), the impact of this TP load did not translate through to the subwatershed TP concentrations because of differences in scale and dilution. Conversely, incremental improvements at the farm-scale will take time to build up positive changes in our water quality, and continued implementation across more farms is critical to result in province-wide improvements.

To learn more about ONFARM, and discover more results and program findings from the Soil Health BMP trials and the Water Quality Modeling, please visit the ONFARM website. Please visit our news page or follow OSCIA’s twitter to stay up to date on project information and future activities.

Appendix A – Edge of Field site soil health indicator averages from 2020 and 2022

		SOM (%)		Active Carbon (ppm)		Solvita CO_2 (ppm)		SLAN (ppm)		PMN (ppm)		Aggregate Stability (%)		Bulk Density (g/cm^3)	
Site	Treatment	2020	2022	2020	2022	2020	2022	2020	2022	2020	2022	2020	2022	2020	2022
1	1	5.5	4.0	246	407	48	65	81	179	6	24	61	66	1.38	1.39
	2	5.4	3.2	228	480	55	67	47	146	9	25	52	70	1.41	1.60
	3	5.1	3.4	171	335	50	54	71	119	7	15	57	60	1.39	1.33
2	1	3.7	3.7	470	407	56	66	69	148	9	34	66	73	1.34	1.33
3	1	3.5	3.2	289	512	58	69	75	175	9	44	61	63	1.27	1.16
	2	3.8	3.2	270	508	58	71	83	163	12	41	72	69	1.27	1.00
4	1	3.8	3.5	505	510	65	66	51	102	4	9	66	70	1.40	1.36
	2	3.7	4.1	487	563	62	63	93	162	3	8	66	72	1.39	1.40
5	1	6.0	6.9	717	821	65	69	172	251	8	22	63	67	1.09	1.27
	2	5.4	6.0	747	708	61	68	153	218	5	20	69	65	1.25	1.20
6	1	4.4	4.5	440	529	60	65	56	113	5	31	63	72	1.45	1.41
	2	3.8	3.5	463	450	65	69	54	137	7	42	68	69	1.43	1.46
7	1	5.4	4.9	523	536	66	76	75	203	3	37	67	77	1.33	1.39
	2	4.5	4.2	492	473	65	68	48	145	4	34	61	63	1.33	1.40
	3	5.4	4.5	527	546	68	73	93	131	4	26	66	68	1.22	1.43
8	1	6.1	5.3	672	630	60	72	110	149	4	19	67	66	1.29	1.36