Water Quality Monitoring – Evaluating Agricultural Best Management Practices in a Huron County Watershed

A report prepared for the Ontario Ministry of Agriculture and Food, New Directions in Research Program

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1.0 Introduction

The near-shore area of the Great Lakes provides many residents of Ontario with drinking water and recreational opportunities (*e.g.*, swimming and fishing). However, nutrient, sediment, and bacterial impacts can sometimes limit both the human uses and the ecological integrity of these near-shore waters. Agricultural activities contribute non-point sources of nutrients, sediment, and bacteria to the near-shore waters of the Great Lakes, but these contributions have been difficult to quantify due to the temporal and spatial variability of their sources. Reducing non-point source pollution is an important goal for federal and provincial agencies and local communities.

Agricultural Best Management Practices (BMPs) can help to reduce non-point sources of nutrients, sediment, and bacteria and improve surface water quality. There are many different practices that could be considered BMPs, including:

- nutrient and manure management practices (*e.g.*, following nutrient management guidelines and building adequate manure storage);
- field soil erosion reduction strategies (*e.g.*, conservation tillage and cover crops);
- structural practices (*e.g.*, Water and Sediment Control Basins – WASCoBs);
- fragile land retirement; and
- tile drain management approaches.

Kroger *et al.* (2012) outlined a framework that puts nutrient and sediment management practices into three tiers, with first-tier practices avoiding the introduction of nutrients and sediment into the aquatic system and additional tiers controlling their distribution. The first tier, input management (*i.e.*, nutrient management), avoids the introduction of the pollutant. The second tier controls the movement of the pollutant through field management (*i.e.*, conservation tillage). A third management strategy is to treat or trap the pollutant in primary aquatic systems (*i.e.*, swales, grassed waterways, WASCoBs, and ditch BMPs).

Beginning in 2010, the Watershed Based BMP Evaluation (WBBE), Huron, looked at the effectiveness of Avoid, Control, and Trap/Treat (ACT) BMPs by assessing the BMPs for their environmental effectiveness at the field and watershed scales. (See Simmons *et al.* 2013 for a review of the broader study.) The purpose of this document is to summarize the ongoing water quality monitoring completed to verify the environmental efficacy of agricultural BMPs at the watershed and field scales. The BMPs evaluated included: vegetative cover and WASCoBs. This report in part, helps to meet the deliverable of Objective 1 in the New Directions for Research Project SR9270 Monitoring and Predicting Variable Source Areas in Small Agricultural Watersheds. Furthermore, the water monitoring program described herein addressed the requirements of environmental models that are further described in Golmohammadi *et al.* 2016.

2.0 Watershed Monitoring

2.1 Study Area

The Gully Creek watershed, within the watershed jurisdiction of the Ausable Bayfield Conservation Authority (ABCA), is a representative lakeshore watershed of the Lake Huron Basin (Figure 1).

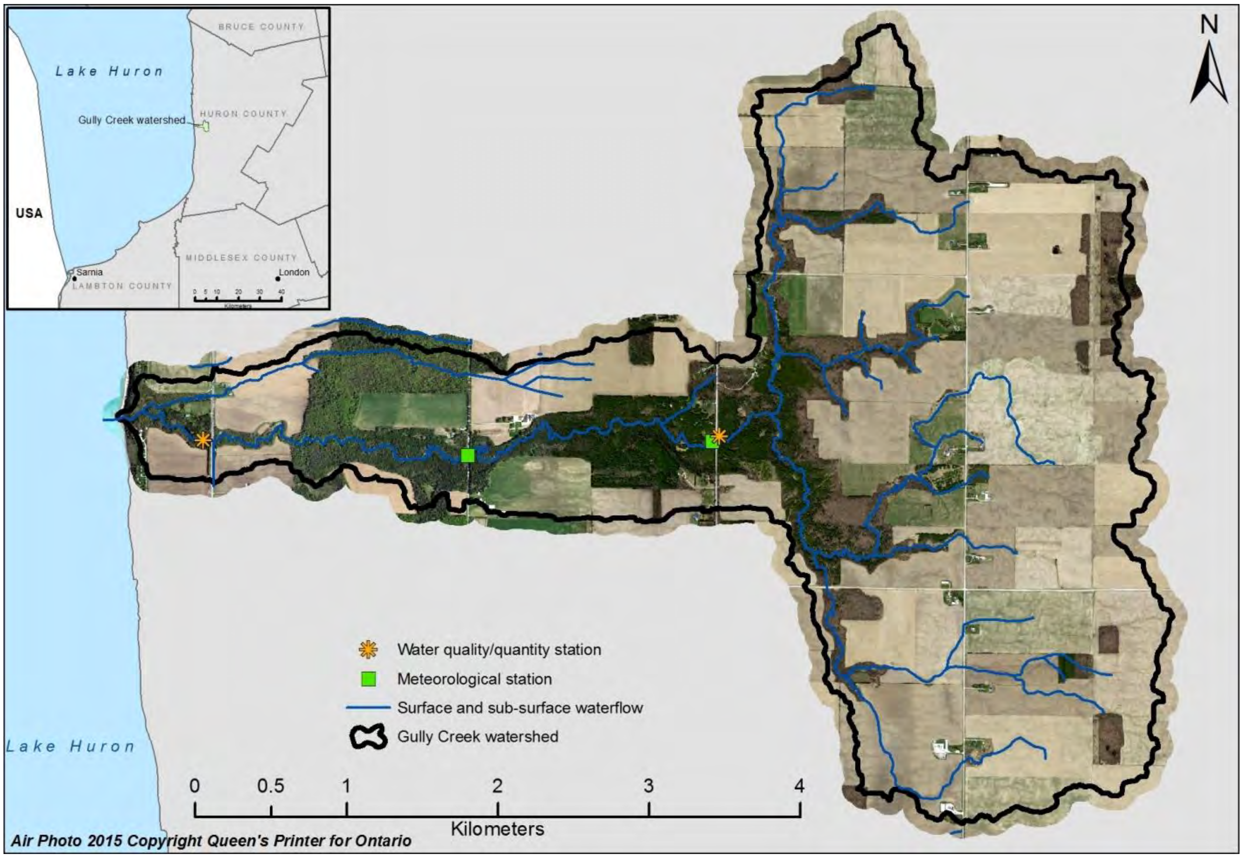


Figure 1: Study area and monitoring locations in Gully Creek watershed.

The Gully Creek watershed is 14 square kilometres; however, the area draining up to the primary gauging station is only 11 square kilometres and mostly agricultural (Table 1).

Table 1: Summary of Gully Creek watershed size and land use (based on 2013 cropping year) upstream of main sampling location.

Watershed	Size (ha)	Corn (%)	Soy (%)[A]	Winter wheat (%)	Other crops (%)[B]	Hay/ pasture (%)	Natural areas/ roughland (%)[C]	Other (%)[D]
Gully Creek, at Porter's Hill Line gauge	1140.4	20.7	31.4	19	0.0	3.7	20.7	4.4

[A] Included soy and edible beans
[B] Included agricultural fields where the crop type was listed as unknown or was another crop including spring cereals, canola, and vegetables
[C] Included riparian corridors, ditches, scrub land, woodlands and wetlands
[D] Included urban, roads, pits, farmsteads, farm access roads, ponds

2.2 Methods

Water quality monitoring stations were selected to be as far downstream as possible in the watershed, but remaining outside of the lake-effect zone. Stations were co-located with reliable flow gauging stations so that water quality results could be combined with stream discharge measurements for the computation of loads (Figure 1). Water level (also referred to as water stage) data were collected every five minutes at all stream gauges except for the Pine River stream gauge, which collected data every fifteen minutes. A WaterLOG H-3553 Compact Combo Bubbler System was used to measure water stage, with a twelve-volt, 100-amp-hour valve-regulated lead acid battery and solar panel providing power, and an FTS Axiom H2 Datalogger logging and transmitting data through a Geostationary Operational Environmental Satellite (GOES) antenna. This continuous record of stage was translated to stream discharge by applying a stage-discharge relationship (also called a rating curve). A stage-discharge relationship was developed for each stream gauge by measuring the flow of the stream with a flow meter (Marsh-McBirney Flo-Mate™ Model 2000). For each measurement of discharge there is a corresponding measurement of stage. High and low stages and flows are particularly important for the development of the rating curve; however, it was unsafe to obtain manual measurements of flow in the streams when they were in peak-flow conditions. Instead, a theoretical equation related to the shape, size, slope, and roughness of the channel at the stream gauge was used to iteratively determine the stage-discharge relationship at higher stages and flows. This relationship differs between stream gauging stations and can also change over time at a specific station. More details on the water quantity monitoring methods can be found in Upsdell Wright *et al.* 2015a.

Many water quality monitoring programs involve a random sampling strategy, whereby samples are collected on pre-determined days of the month. However, rain, rain-on-snow, and snowmelt events (herein referred to as events) are important because high concentrations of some pollutants, particularly sediment and phosphorus, are transported during these events (Upsdell Wright and Veliz 2013). The monitoring and modelling results in the Watershed Based Best Management Practices Evaluation study found that intermittent channels that form across the land contribute to poor water quality during storm events (Simmons *et al.* 2013). Further, practices to address rural water quality nutrient enrichment issues are undertaken to reduce the formation and/or the effects of these intermittent channels on the landscape. To understand the effectiveness of watershed plans and rural best management practices (BMPs) on water quality, it is imperative to collect *event data* prior to and after the establishment of the watershed plans and BMPs. Therefore, water quality monitoring for this study included sample collection when water was running across the landscape in order to improve the accuracy of pollutant load estimates.

For the purposes of this study, water samples were collected year-round under both low-flow and high-flow conditions. Richards (1998) has shown that the 80th percentile of flow is an appropriate division for separating runoff events from low-flow periods for Lake Erie tributaries in Northwest Ohio. This study used the same approach. Continuous flow data from October 2012 to September 2015 were used to establish the low-flow conditions. A threshold was set at the 80th percentile of the continuous flow record for each of the sites to separate low flow from event flow. Low-flow grab samples were collected monthly between October 1, 2012, and September 30, 2015. High-flow events were sampled with an ISCO® 6712 automated sampler at each of the five stations. The ISCO samplers were set to trigger with a rise in water level and to collect samples throughout the hydrograph, attempting to capture samples at the onset of the event, mid-way up the rising limb of the hydrograph, at the peak, mid-way down the falling limb, and at the end of the event.

Water samples were primarily analyzed for nutrients and suspended solids by the Ministry of the Environment and Climate Change (MOECC) laboratory in Etobicoke; however, on occasion, samples were submitted for analysis to ALS Laboratory in Waterloo. There are different analytical approaches to estimating the bioavailable forms of phosphorus. In this study, phosphate-phosphorus was measured.

Approximately 450 tributary water quality samples were collected between October 1, 2012, and September 30, 2015. An additional 245 water quality samples were collected in Gully Creek between October 1, 2010, and September 30, 2012.

In the five-year period (2010 to 2015), Gully Creek had roughly 130 runoff events. Not all events were sampled. Some events were missed due to decisions made *a priori* about the size of the event, equipment malfunctions, and staffing issues (*i.e.,* holidays and other work priorities).

For this report, both the annual flow-weighted mean concentrations and the loads have been summarized. Dickinson (in Upsdell Wright *et al.* 2015b) suggested that, if the focus of the study is on concentration targets or standards, then concentration values are needed. However, if the focus of the study is on land use management or Great Lakes impacts, then load estimates are needed. Past water quality reports completed by the Ausable Bayfield Conservation Authority have reported findings as concentrations (see http://www.abca.on.ca/publications.php for past reports). However, calculating loads is important for comparing the contributions over time and eventually from different watersheds to Lake Huron.

Water quality indicator concentrations (nitrate-nitrogen plus nitrite-nitrogen, phosphate-phosphorus, total phosphorus , and total suspended solids) from the grab and ISCO samples collected during the study period were converted to loads (mass per time), flow-weighted mean concentrations (FWMC) (mass per volume), and export coefficients (mass per watershed area). These computations help to remove the variability associated with event discharge and watershed size.

Loads are the product of stream flow (volume per time) and concentration (mass per volume). A mass load (Equation 1) is a calculation of the total mass of a substance, usually expressed in kilograms, that is transported past a particular point on a stream or river over a given time period, often annually (Cooke 2000). In this study, annual loads were calculated (including events and low-flow periods).

Equation 1

Mass Load (kilograms) $= \sum c_i q_i t_i$

Where,

i = 1 to *n* (number of samples)
c_i = sample concentration (milligrams per litre)
q_i = instantaneous stream flow (litres per second)
t_i = time interval (seconds)

In a flow-proportionate sampling program, an individual water sample does not characterize the event or low-flow period. To estimate the average concentration, each sample must be weighted to represent a particular portion of the hydrograph (Equation 2) (Cooke 2000). Flow-weighted mean concentrations are concentrations that are adjusted for stream flow over a given period – in this study, the length of the water year. This computation allows for comparisons between streams with different flows or the same stream at different times.

Equation 2

Flow-Weighted Mean Concentration (milligrams per litre) =
$$\frac{Mass\ Load\ (kilograms)}{Total\ Stream\ Flow\ Volume\ (litres)} \times 1000$$

The total mass export coefficient or unit-area load (Equation 3) is an estimate of the amount of the constituent that is lost per hectare of watershed for the given time period.

Equation 3

Mass Export (kilograms per hectare) = $\frac{Mass\ Load\ (kilograms)}{Watershed\ Area\ (hectares)}$

Continuous records of both stream flow and concentrations are needed to calculate loads. Since the concentrations of pollutants are not typically monitored continuously, load-estimation methods are used to calculate loads. Generally, there are five types of load-estimation methods: averaging, numeric integration, ratio, regression, and interpolation (Richards 1998). Bittman *et al.* 2016 evaluated the most appropriate approach to calculate loads with the Gully Creek data collected from 2012 to 2015 and found that a linear interpolation method in Water Quality Analyser (WQA), developed by eWater Source in Australia, gave the best estimate of load for this dataset.

2.3 Best Management Practice Adoption

The outreach to landowners in the Gully Creek watershed was initiated in the fall of 2008. Since that time at least 85 agricultural BMPs have been implemented (Table 2), affecting most properties in the watershed (Figure 2).

Table 2: Agricultural Best Management Practice Implementation in the Gully Creek watershed.

BMP Type	Number of Projects	Area Affected (if applicable)
Streamside Restoration	1	50 m
Riparian Tree Planting	1	300 m
Water and Sediment Control Basins (WASCoBs) – includes upgrades	31	
Wetland	1	0.46 ac
Grassed Waterway	2	167 m
Fragile Land Retirement	4	4.1 ac
Fragile Land Retirement – Windbreaks	2	460 m
Fragile Land Retirement – Vegetative Cover	1	5.4 ac
Manure Storage Upgrade	2	
Manure Amendments	4	241 ac
No Till Implemented	5	908 ac
Conservation Tillage Implemented	3	130 ac
Cover Crops Implemented	11	351 ac
Precision Agriculture Implemented[A]	11	670.5 ac
Nutrient Management Implemented	5	89 ac
Residue Management	1	141 ac
Total BMPs	85	

[A] Includes GPS systems, yield monitors, auto-steer equipment and variable rate applicators.

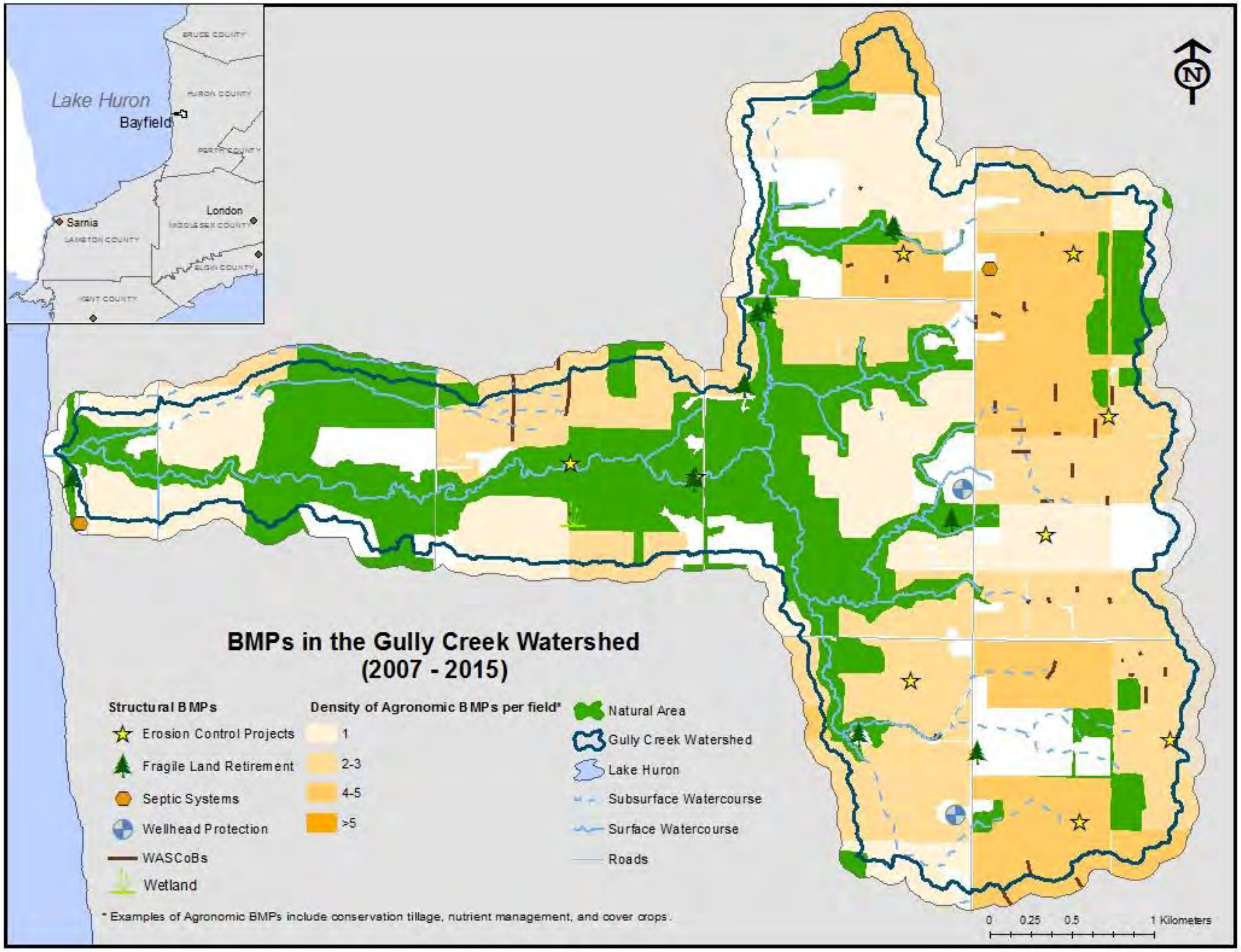


Figure 2: Implementation of agricultural best management practices in Gully Creek watershed (2007 to 2015)

2.4 Results

Annual flow-weighted mean concentrations and mass export coefficients were estimated for Gully Creek over a five-year period. Total phosphorus flow-weighted mean concentrations ranged from 0.14 to 0.67 milligrams per litre during the five-year period, while export coefficients for TP ranged from 0.83 to 4.4 kilograms per hectare (Figure 2). It is important to note that a change of laboratory analysis method for total phosphorus occurred in 2013 at the MOECC. Similar patterns were observed for phosphate-P and TSS (which were not affected by the laboratory method change); however, due to the laboratory methodological changes for determining TP concentrations, the change in TP concentration in Gully Creek over this time period may not be realized.

Although we see a decrease in total phosphorus loads and sediment loads, we cannot attribute the decrease solely to the implementation of BMPs. For instance, the variability in mass export loads could be influenced by total discharge volume in Gully Creek, particularly during the 2013 to 2015 water years. Larger total discharge volumes were a result of increases in total precipitation during this period. However, flow-weighted mean concentrations do not appear to be solely influenced by total discharge volumes, particularly for TP and PO_4-P.

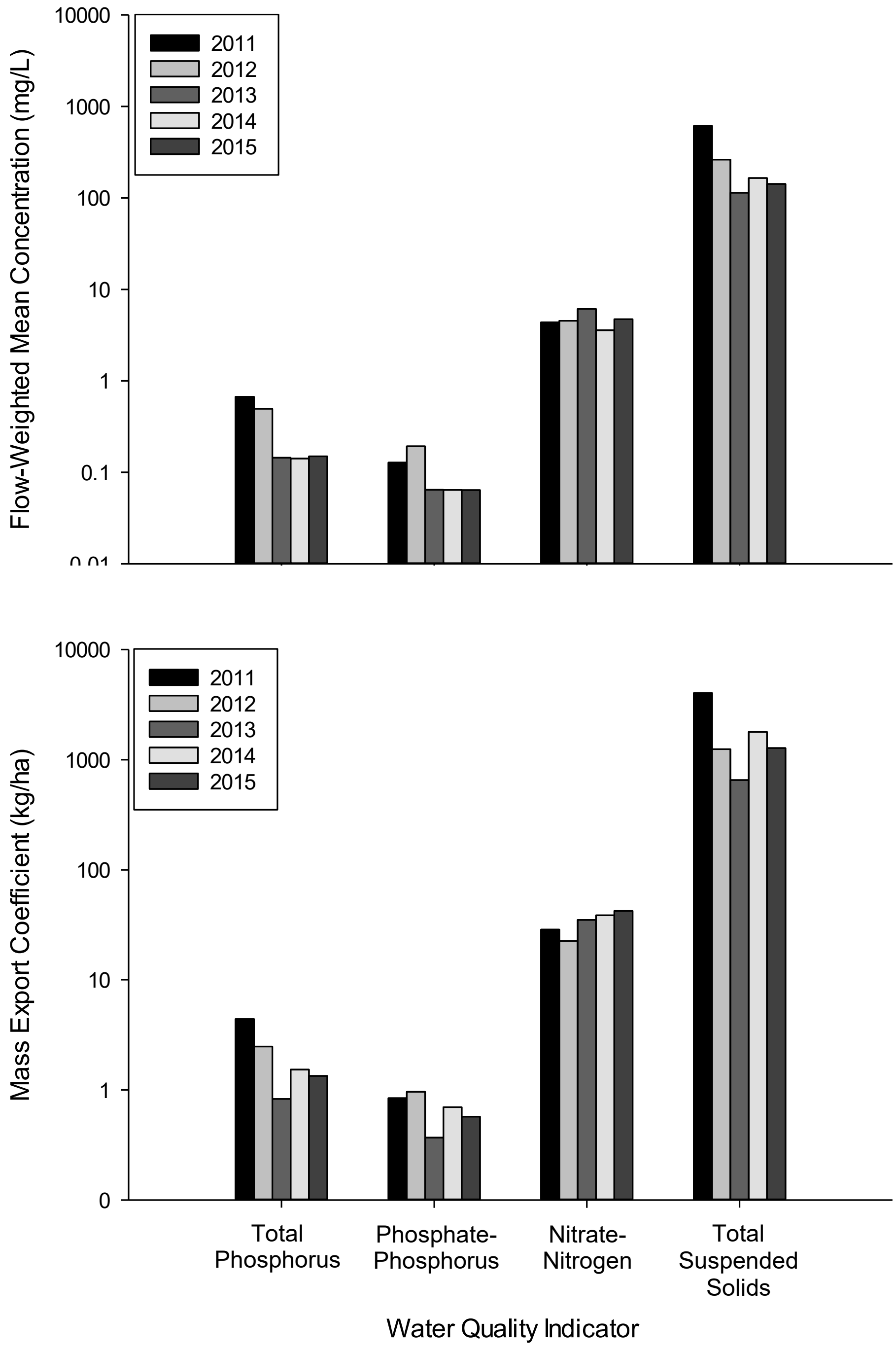


Figure 3: Annual flow-weighted mean concentrations and mass export coefficients in Gully Creek (October 1, 2010 – September 30, 2015). Notes: 1) Station GULGUL5 data were used to estimate mass export coefficients for the 2012-2015 water years. Station GULGUL2 data were used for the 2011 water year. The 2011 water year is October 1, 2010 to September 30, 2011. 2) A change of laboratory analysis method for total phosphorus occurred in 2013 at the Ministry of the Environment and Climate Change.

3.0 Agricultural Best Management Practice Evaluation

Evaluating the effectiveness of agricultural BMPs with water quality samples is confounded by a number of factors, primarily precipitation (frequency and magnitude of events), soil conditions, and topography. However, a most important consideration is that the spatial scale that the field activity can influence is typically much smaller than the size of watershed that generates consistent flow. Thus, samples collected at "downstream" watershed stations will typically reflect a larger watershed area than the area that has had a BMP applied. It is important to remember that a single change in practice in a small area of a large watershed may not provide a large enough reduction in nutrients to produce demonstrable change in downstream nutrient conditions (Makarewicz *et al.* 2009).

The challenge is to collect a sample at the "edge of field" that reflects the effect of the applied BMP. It is also challenging to compare edge-of-field samples collected from fields with and without the BMP under evaluation in practice. The water quality values will reflect not only the employed BMP but also the different slope, soil, and recent land management activities (*e.g.*, manure or fertilizer application, crop rotation). We have attempted to address these confounding issues by evaluating the same edge-of-field location over time to see what effect the land management practices have on the hydrology and water quality.

The following sections detail various BMPs that were evaluated including vegetation cover and Water and Sediment Control Basins. It must be noted that BMP data is being collected at two other study sites but was not included in the assessment as the information is still being processed for future analyses.

3.1 Vegetative Cover

We endeavoured to document the effects of cover from 2012 to 2015 using two approaches. In the first instance, we observed changes in a cropped field to a hay field. In the second approach, we used a Water and Sediment Control Basin (WASCoB) as a longer-term study location to evaluate the role that vegetative cover (*i.e.*, winter wheat, cover crops) has on hydrologic and water quality conditions.

Runoff (also referred to as flow) across agricultural lands is a function of temperature, soils, vegetation type, topography, antecedent moisture conditions, and the intensity, duration, and frequency of rainfall. Precipitation interacts with vegetation by three different methods: interception, stemflow, and throughfall. Interception occurs when precipitation remains on the surface of the plant, preventing water from reaching the soil surface due primarily to canopy storage and evaporation. Water that is not intercepted by the plant (*i.e.*, stemflow or throughfall) may be subsequently converted into runoff.

Interception of rainfall by agricultural crops has largely been overlooked in the soil-hydrologic cycle (Kozak *et al.* 2007). Crop canopy and residue layer interception is a function of crop density, row spacing, areal cover, and the intensity, duration, and frequency of rainfall. Past studies have shown canopy interception of 4 to 58 per cent and residue interception of 4 to 26 per cent (Table 2).

Table 3: Summary of interception results for various crop types.

Canopy type	**Rainfall interception (%) by study**						
	Baver (1938)	**Konstorshichikov and Eremina (1963)**	**Lull (1964)**	**Steiner *et al.* (1983)**	**Mohamoud and Ewing (1990)**	**Leuning *et al.* (1994)**	**Savabi and Stott (1994)**
Corn	22		16	4 - 20			
Soybean	35		15				
Wheat		10 - 25	36			33	
Oat	58	16 - 23	7				
Corn residue					6		7 - 13
Soybean residue					4		14 - 26
Wheat residue							14 - 22

Savabi and Stott (1994) and Kozak *et al.* (2007) found that crop canopy and residue layer interception decreases runoff, or flow potential, during storm events.

3.1.1 Conversion from Cropped Field to Hay Field

Upsdell Wright *et al.* (2013) documented that a five-metre-wide grassed ditch reduced phosphorus and sediment in surface runoff from a three-hectare area of cropland in the Gully Creek watershed. Upon showing these results to the participating landowner, a hay field adjacent to the cropland was extended in 2013 to encompass approximately six hectares (as shown in Figure 3).

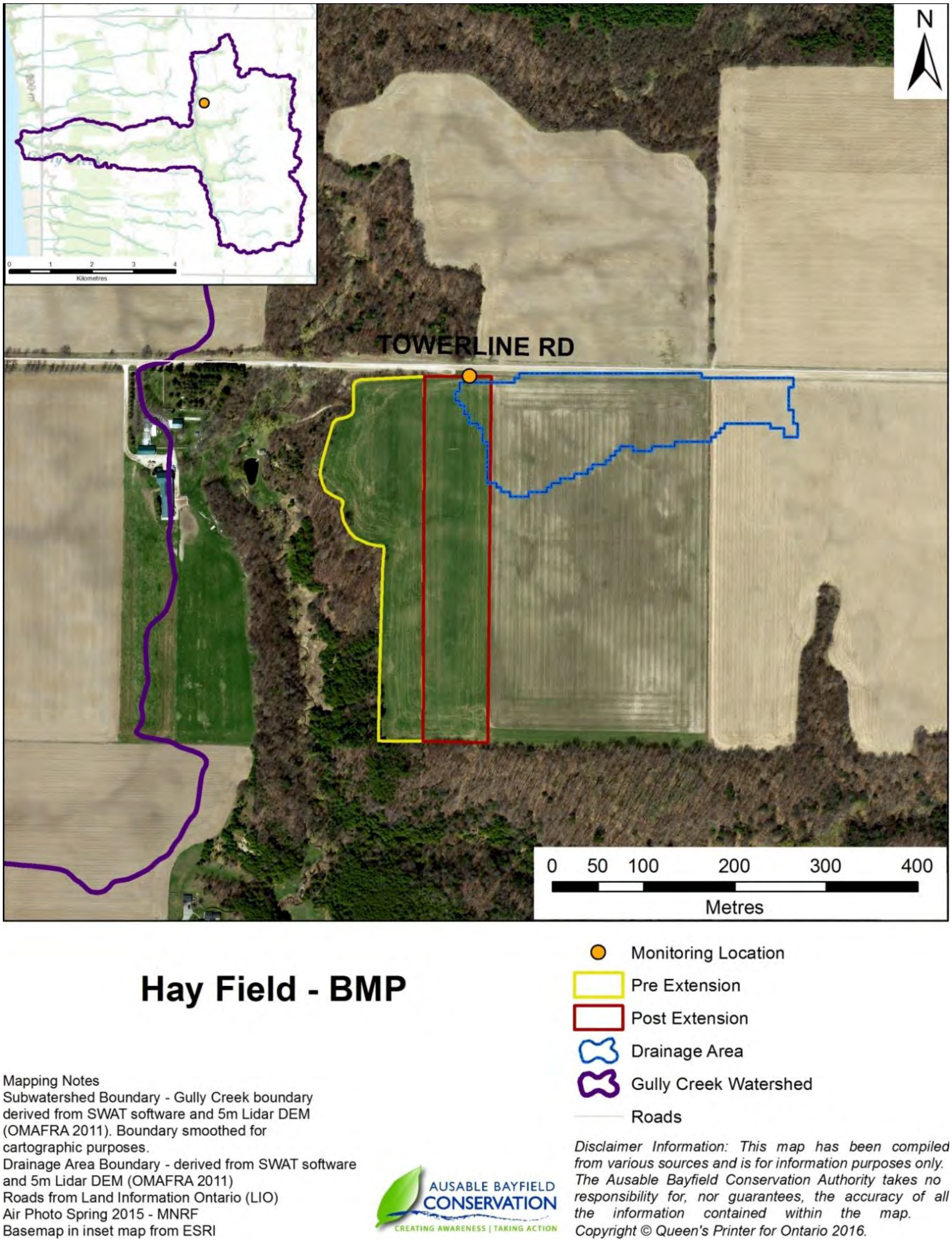


Figure 4: Monitoring site showing pre- and post-extension of a hayfield in the Gully Creek watershed.

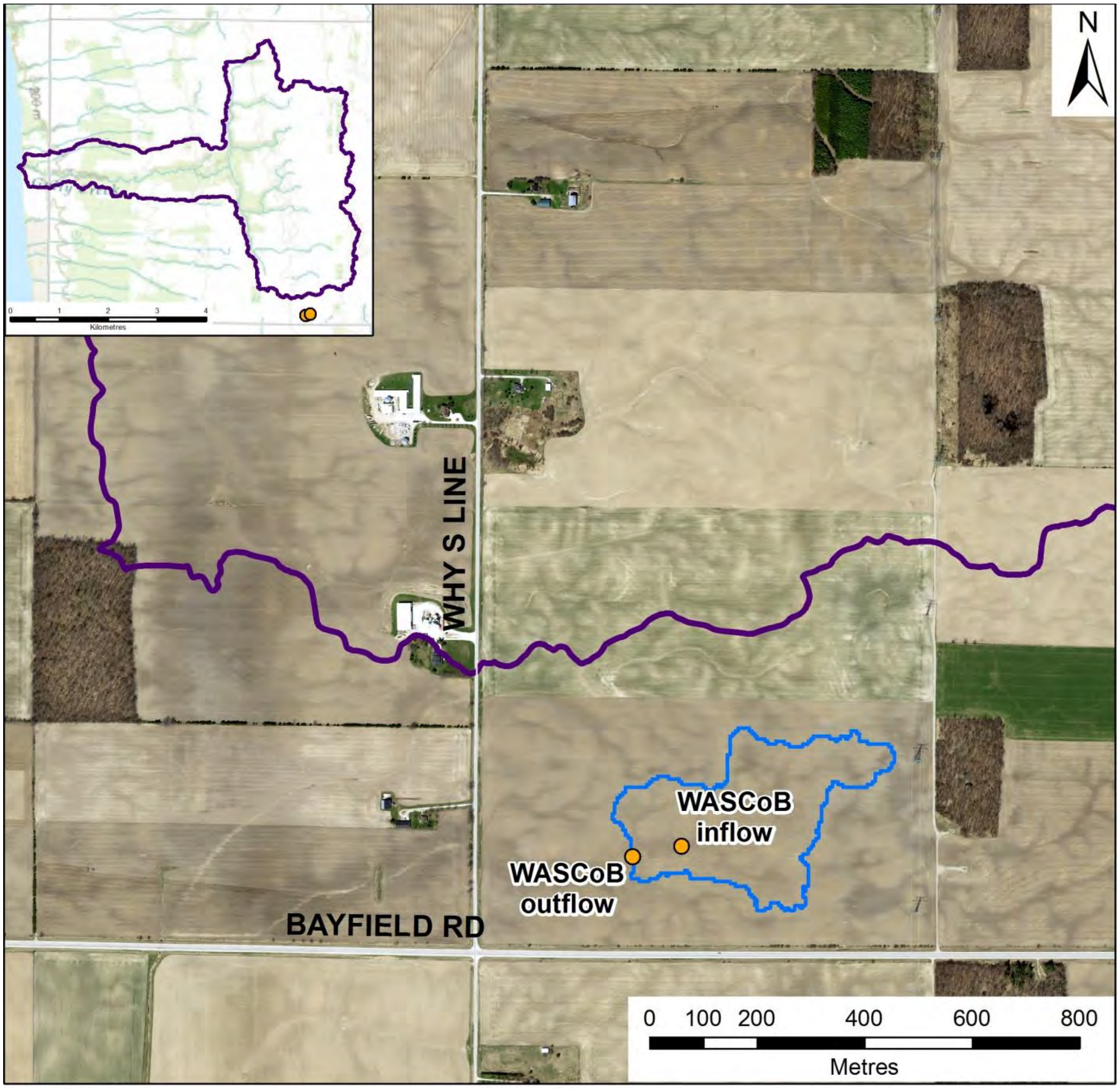
In October 2013, it was observed that the change in land management, from a cropped field to a hay field, resulted in the elimination of a concentrated flow path. The lack of a flow path meant that no water samples could be collected. At this time, decisions had to be made about where to focus monitoring efforts in the Gully Creek watershed and monitoring at this site was discontinued due to the lack of concentrated flow path.

A record of flow versus no-flow observations at this field over time was evaluated to determine whether the hay field resulted in less frequent flow. However, only three observations were made during the timeframe that the hay was established and this was an insufficient number of observations to make any conclusions about the possible benefits of hay over cropland.

3.1.2 Vegetative Cover over Time around a Water and Sediment Control Basin

Approach

We had anticipated that water quantity and water quality from within the WASCoB over the study period would reflect the amount of vegetative or crop residue cover within this small watershed (Figure 4).



Water and Sediment Control Basins - BMP

- Monitoring Location
- Drainage Area
- Roads

Mapping Notes
Subwatershed Boundary - Gully Creek boundary derived from SWAT software and 5m Lidar DEM (OMAFRA 2011). Boundary smoothed for cartographic purposes.
Drainage Area Boundary - Created with ArcHydro toolbox functions using SWOOP 2015 DEM from MNRF
Roads from Land Information Ontario (LIO)
Air Photo Spring 2015 - MNRF
Basemap in inset map from ESRI

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Disclaimer Information: This map has been compiled from various sources and is for information purposes only. The Ausable Bayfield Conservation Authority takes no responsibility for, nor guarantees, the accuracy of all the information contained within the map.

Figure 5: Monitoring stations for evaluating a Water and Sediment Control Basin just south of the Gully Creek watershed.

Different runoff coefficients across the different field crops in various stages of the development within the WASCoB were anticipated. It is important to note that during the study period, March 2012 to September 2015, the crop rotation was corn, soybean, wheat, and corn. Thus, there were potentially twice as much data for corn compared to soybean and wheat, but of course runoff data ultimately depended on how much rain there was.

A first-order, hydrologic response was to compare flow/no-flow conditions in the basin.

3.2 Field Monitoring Methods

A Schlumberger ten-metre mini-Diver level logger (accurate to 0.025 metres) was installed in the ponding area behind the WASCoB on March 6, 2012, to record water depth (stage) at five-minute intervals. Data included in this report extend to the end of the 2014/2015 water year, September 30, 2015. During this time, the Diver malfunctioned due to cold weather from October 27, 2014, to June 1, 2015. For the period of record from March 6, 2012, to October 27, 2014, and June 1, 2015, to September 30, 2015, there were 61 events recorded. The stage (in metres) was converted to outflow (in cubic metres per second) following the methods documented by Wilson (2016).

Two meteorological stations were installed in close proximity to the study area to provide unfrozen precipitation data. The stations were leveled to allow for correct operation. A Davis Instruments Vantage Pro2 tipping bucket rain gauge (0.2 millimetres per tip) collected hourly rainfall data. The Davis unit was located approximately five kilometres from the WASCoB and collected precipitation data for the period March 6, 2012, to January 10, 2013. An FTS RG-T Precision Tipping Bucket Rain Gauge was also used to collect unfrozen precipitation data on five-minute intervals. The FTS logger was located approximately three and a half kilometres from the WASCoB and collected precipitation data for the period January 11, 2013, to September 30, 2015.

Water samples were collected from the hickenbottom outlet in the ponding area with an ISCO sampler and were analyzed for nutrient and sediment concentrations. Water quality data were captured for 19 of the 61 events that had a measurable stage response. Some events were missed because equipment had to be removed to accommodate farm field work. At other times, there were equipment malfunctions, especially during the winter months.

3.3 Data Analysis Methods

In order to help explain the impact that vegetative cover has on flow, we used data from the WASCoB to determine runoff coefficients and compare flow and no-flow conditions under different crop types. Predictive models were developed to estimate the occurrence of flow in the WASCoB during a precipitation event. Additionally, loads were examined under different land management activities, vegetative cover, precipitation, and runoff conditions to better understand differences in the loads between events.

3.3.1 Runoff Coefficients

Runoff coefficients were determined for events with a stage response at the Diver located at the hickenbottom outlet. A runoff coefficient is a dimensionless coefficient equal to the ratio of runoff volume to precipitation volume (Equation 4). Runoff coefficients vary depending on the type of soil, percentage of impervious land cover, and frequency of rainfall. Coefficients range between 0 (for permeable areas, such as forests) and 1 (for impervious areas with low infiltration, such as pavement).

Equation 4

$$Runoff\ Coefficient, k\ (dimensionless) = \frac{Total\ Runoff\ Volume\ (m^3)}{Total\ Precipitation\ Volume\ (m^3)}$$

The total volume of water leaving the ponding area behind the WASCoB through the hickenbottom outlet (in cubic metres) was calculated by multiplying the outflow (in cubic metres per second) by the duration of the precipitation event (in seconds). Total precipitation volume (in cubic metres) was calculated by converting the depth of precipitation to metres and multiplying it by the drainage area of the WASCoB (in square metres).

Runoff coefficients were evaluated by dividing them between the growing season (May 1 to September 30) and the non-growing season (October 1 to April 30), and graphing the relative frequency of runoff coefficients of different intervals (*e.g.*, 0, >0 – 0.1, >0.1 – 0.2). Within each interval, runoff coefficients were categorized by the amount of rainfall that occurred during the event (*i.e.*, less than 20 millimetres, between 20 and 40 millimetres, and greater than 40 millimetres). Runoff coefficients were also related to various crop conditions, including corn, soybean, winter wheat, oat cover crop, corn residue, soybean residue, winter wheat stubble, and no cover (*i.e.*, bare soil).

3.3.2 Flow versus No-flow

Stage data from the WASCoB was used to evaluate the effect of crop type on runoff during the growing and non-growing season. For simplicity, the response from precipitation events was divided into binary conditions: flow or no-flow. Events that generated flow were defined as having a water level greater than 0.025 metres; otherwise, an event was considered a no-flow event. No-flow events were characterized as those precipitation events that produced greater than 10 millimetres of rainfall, or had rainfall intensity greater than one millimetre per hour.

Flow/no-flow conditions were recognized to be highly constrained by the time of the year with different evapotranspiration rates and crop conditions. For simplicity, the year was divided into the growing season (May 1 to September 30) and non-growing season (October 1 to April 30).

A total of 129 precipitation events were observed for the period March 2012 to September 2015 (Table 3), 61 of which generated flow (or runoff) and 68 of which did not generate flow (*i.e.*, runoff was not observed).

Not surprisingly, flow occurred more often under non-growing season conditions (44 instances) compared to when flow was generated (17 instances) in the growing season.

Table 4: Summary of runoff conditions during precipitation events at a Water and Sediment Control Basin under different growing conditions (March 2012 to September 2015).

Runoff Condition	Number of Events		
	Total	Growing Season[a]	Non-growing Season[b]
Flow	61	17	44
No-flow	68	51	17

[a] Growing season is defined as May 1 to September 30.
[b] Non-growing season is defined as October 1 to April 30.

In an attempt to relate crop conditions to flow and no-flow conditions (recognizing that growing season conditions were also relevant and potentially a confounding variable, so for instance wheat is growing in seasons that are typically wetter than corn or soybean), the crop type was divided into eight (8) categories: corn, soybean, winter wheat, oat cover crop, corn residue, soybean residue, winter wheat stubble, and no cover (*i.e.*, bare soil).

A Fisher's exact test of independence was performed to evaluate the association between crop type and flow/no-flow conditions. A two-tailed Fisher's exact test is used to see whether the proportions of two or more categorical variables are statistically different from one another. The test is appropriate for contingency table analyses involving small sample sizes of less than 1,000 (McDonald 2014) as is the case in this study.

Two further tests, the odds ratio (OR) and one-tailed Fisher's exact test, were performed to evaluate the magnitude and directionality of association between crop types and flow/no-flow conditions. In this case, the OR explains how much more likely it is that flow will occur depending on crop type compared to when flow is not observed under similar conditions. The odds of an event occurring is the probability that the event will happen divided by the probability that the event will not happen. For instance, if the probability of flow occurring under corn residue is 75 percent and the probability that flow did not occur was 25 percent then the ratio would be 3:1 (*i.e.,* flow occurs three times more often than when flow is not generated). A *p*-value of less than 0.05 indicates that the association between crop type and flow condition is statistically significant. Conversely, a *p*-value greater than 0.05 suggests that there is not enough evidence to infer an association between crop type and flow condition (*i.e.,* flow is equally likely to occur as when flow is not generated).

3.3.3 Predicting Flow Occurrence

An added benefit of collecting flow/no-flow information, as well as meteorological data, is the ability to construct predictive models; however, it is not possible to conduct ordinary linear regression when the response variable is binary and not continuous. A different approach is therefore necessary to accommodate this type of data. The purpose of this section is to present models for estimating the occurrence of flow in a WASCoB during a precipitation event under a variety of crop types. The following methods are adapted from Levin and Zarriello (2013) who developed models to predict irrigation water use in the eastern United States.

Logistic regression is a method for modelling the dependence of a binary response variable (denoted by either 1 or 0) on one or more explanatory variables, which can be a mix of continuous and categorical variables. Logistic regression equations were developed for each of the eight crop types to predict flow/no-flow conditions using data from the WASCoB. Meteorological and hydrological data was used to investigate how flow (1) and no-flow (0) can be predicted by the amount of precipitation (0 to ∞) during the growing season (1) and non-growing season (0) in which antecedent moisture conditions were either wet (1) or dry (0). Antecedent moisture conditions were considered wet if the accumulated precipitation was greater than 2.5 millimetres within 72 hours of a precipitation event.

The model coefficients were determined using a bias-reducing logistic regression approach developed by Firth (1993). Firth's approach is appropriate to address the small sample sizes and bias of the parameter estimates in this study.

A general logistic regression equation for predicting the occurrence of flow in a WASCoB during a precipitation event is presented below in Equation 5.

Equation 5

$$P = \frac{1}{1 + e^{-(B_0 + B_1 \times PRCP + B_2 \times SESN + B_3 \times ANT\_CD)}}$$

Where,

P = probability of flow condition (ranges from 0 to 1)

e = base of the natural logarithm, equal to approximately 2.7183

B_0 = logistic regression intercept coefficient (log units)

B_1, B_2, B_3 = logistic regression independent variable coefficients (log units)

PRCP = total event precipitation (mm)

SESN = seasonal condition (1 = growing season, 0 = non-growing season)

ANT_CD = antecedent moisture conditions (1 = wet, 0 = dry)

In the event an independent variable is not appropriate for use in the model (e.g., seasonal condition) the term can be removed from the equation.

A variety of metrics were used to determine the fit and predictive accuracy of each logistic regression model. The model coefficients were tested for significance using Wald's test (*p*-values < 0.05 indicate that the explanatory variable is a good predictor of the response variable). A likelihood ratio chi-square test was used to determine the overall fit of the model compared to a simplified model without predictor variables (*p*-values < 0.05 indicate that the overall fit of the model is statistically significant). The strength of the model was evaluated using a pseudo R-square developed by McFadden (1974). McFadden's pseudo R-square is typically lower than traditional R-squared values. For instance, a value less than 0.2 indicates a weak relationship; 0.2 to 0.4 indicates a moderate relationship; and greater than 0.4 indicates a strong relationship.

A probability cut-off (in this case the threshold for predicting the occurrence of flow) was determined for each model by plotting type I error (sensitivity) against type II error (specificity). Type I error occurs when an effect is detected that is not present, while type II error is failing to detect an effect that is present. The optimal cut-off value is found where the lines of sensitivity and specificity intersect (Figure 5). Computed probabilities equal to or greater than the cut-off represent events that generated flow and those less than the cut-off predict events that failed to generate flow. Overall accuracy of equations was determined by comparing the predictions of flow/no-flow occurrence and determining the percentage of correct predictions.

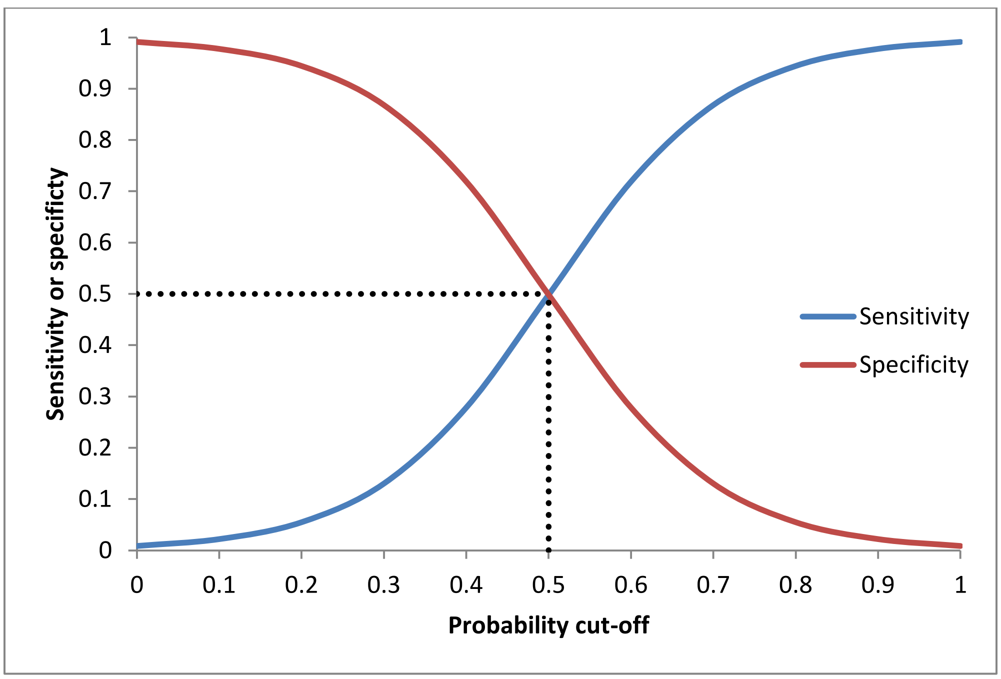

Figure 6: Sensitivity-specificity graph.

3.3.4 Load Estimation

Loads were calculated for the 19 events with water quality data using the linear interpolation method in Water Quality Analyser. The events were categorized as well-sampled (*i.e.*, samples were collected on the rising limb, peak, and falling limb of the outflow hydrograph), fairly-sampled (*i.e.*, samples were missing from either the rising or falling limb), or poorly-sampled (*i.e.*, no more than two samples were collected during the event or most of the hydrograph was not sampled). Land management activities, vegetative cover, precipitation, and runoff information were examined to better understand differences in the loads between events.

3.4 Results

3.4.1 Runoff Coefficients

Of the 61 events recorded from March 2012 to September 2015, there were five events for which runoff coefficients exceeded 1.0. These events typically corresponded to snowmelt events; however, on one occasion (March 15, 2012) the high runoff coefficient could not be explained. A large portion of the remaining 56 events (19) were small events with runoff coefficients of less than 0.1 (Figure 6).

Dividing the runoff coefficients between the growing season and the non-growing season showed that higher runoff coefficients occurred more frequently during the non-growing season. Runoff coefficients of zero (*i.e.*, rainfall did not produce runoff) were more frequent during the growing season. In the growing season, even events with more than 40 millimetres of rainfall produced runoff coefficients of 0.3 or less. By contrast, in the non-growing season, events with less than 20 millimetres of rainfall could produce runoff coefficients greater than 0.6.

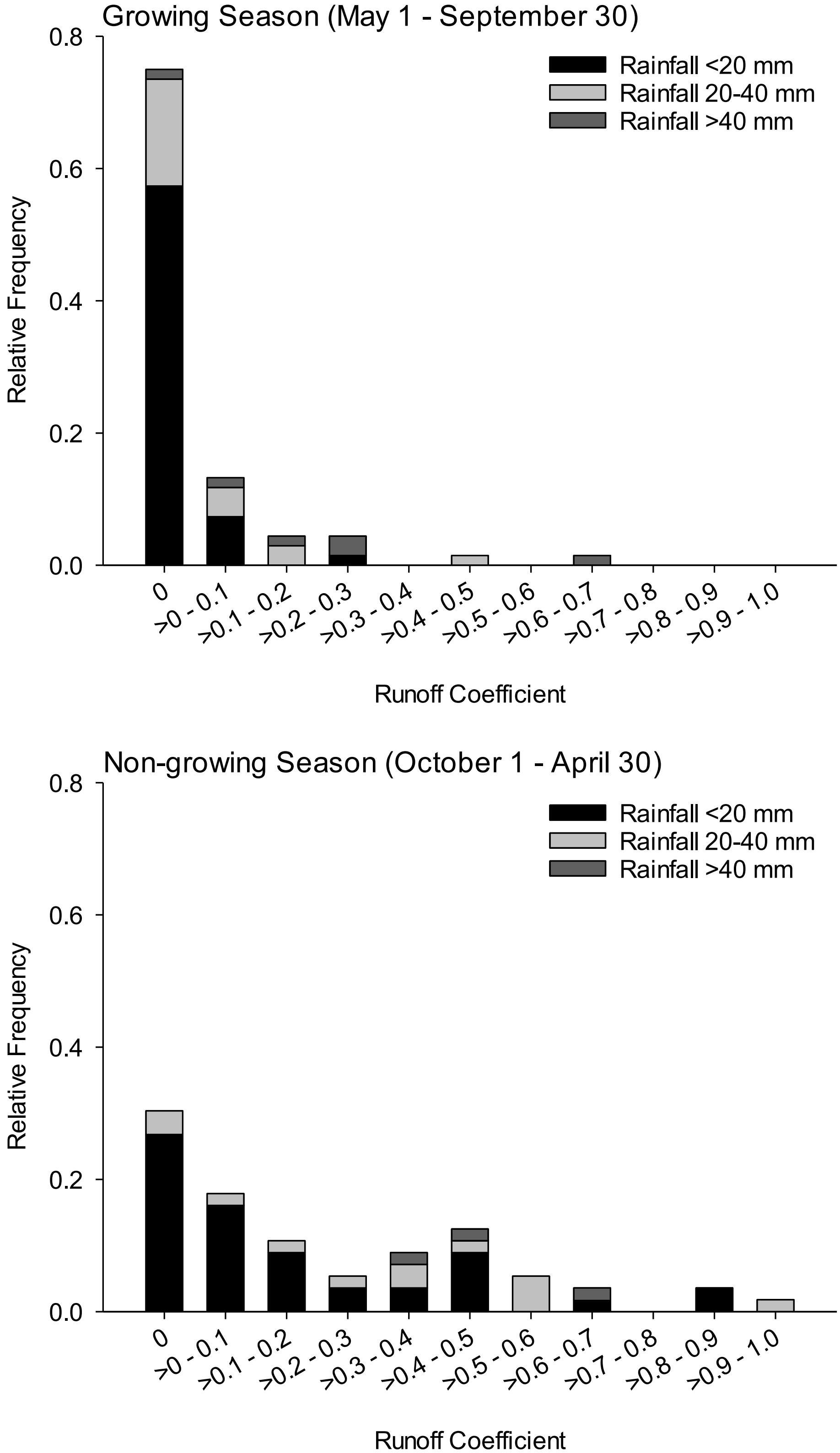

Figure 7: Relative frequencies of runoff coefficients at a Water and Sediment Control Basin outflow during the growing season versus non-growing season, and following different rainfall amounts, between March 2012 and September 2015.

In addition to detecting differences in runoff coefficients by season, a great deal of variability in runoff coefficients was observed under different crop conditions. Precipitation events under corn residue and soybean residue produced the largest runoff coefficients on average, while soybean and oat cover crop produced the smallest runoff coefficients (Table 4).

Table 5: Summary of mean runoff coefficients for various crop types (March 2012 to September 2015).

Crop type	**Growing season**				**Non-growing season**			
	Mean seasonal runoff		**Mean event runoff**		**Mean seasonal runoff**		**Mean event runoff**	
	n	***k***	***n***	***k***	***n***	***k***	***n***	***k***
Corn	28	0.03	6	0.15	3	0	0	-
Soybean	9	0.008	2	0.04	0	-	0	-
Winter wheat	15	0.11	5	0.33	0	-	0	-
Oat cover crop	5	0.003	1	0.02	5	0	0	-
Corn residue	8	0.007	3	0.018	22	0.28	19	0.32
Soybean residue	0	-	0	-	25	0.26	19	0.34
Winter wheat stubble	3	0	0	-	0	-	0	-
No cover	0	-	0	-	1	0.02	1	0.02

Notes: Runoff coefficients greater than 1 were excluded from the table (including two corn residue, two soybean residue, and one no cover). Mean event runoff coefficients included only runoff events, while mean seasonal runoff coefficients included both runoff events and non-runoff events.
n = number of precipitation events
k = runoff coefficient

3.4.2 Flow versus No-flow

Average precipitation per event was 14.9 mm (range = 4 mm to 57.4 mm) during the growing season and 19.2 mm (range = 0.2 mm to 63.4 mm) during the non-growing season.

The two-tailed Fisher's exact test indicated that there was a strong association between crop type and the presence or absence of flow during precipitation events in the WASCoB through the growing season (p = 0.003) and non-growing season (p = 0.003). Not surprisingly, flow was less likely to occur during the growing season when canopy density and areal extent is greatest and more likely to occur during the non-growing season when canopy density and areal extent is lowest (Figure 7).

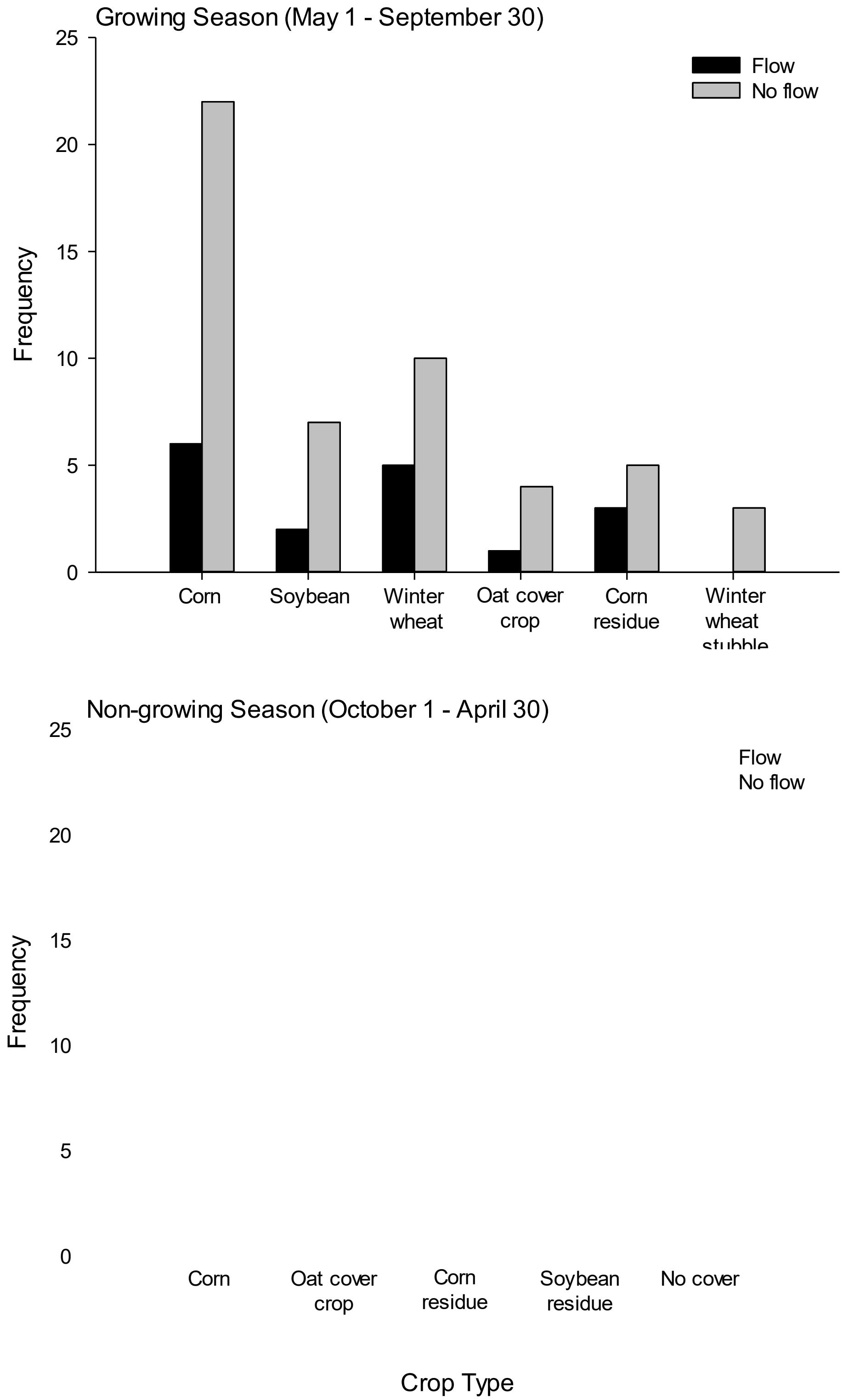

Figure 8: Frequency of flow/no-flow occurrences by crop type during the growing season versus the non-growing season at a Water and Sediment Control Basin (March 2012 to September 2015).

Some crop canopies were found to reduce flow potential. For instance, during the growing season precipitation events were about four times more likely to result in no-flow under corn (p = 0.002) compared to when flow was generated (Table 5). Additionally, precipitation events during the non-growing season were about six times more likely to result in no-flow under oat cover crop (p = 0.038) compared to when flow did occur.

A significant and negative relationship between flow occurrence and crop residue was evident. For instance, during the non-growing season precipitation events were about five times more likely to generate flow under soybean residue (p < 0.001) and 11 times more likely to occur under corn residue (p < 0.001) compared to when flow was not observed.

Table 6: Likelihood of flow by crop type during the growing and non-growing seasons at a Water and Sediment Control Basin (March 2012 to September 2015).

Growing conditions	Crop type	Ratio of flow to no-flow			One-tailed *p*-value	Implication
		Flow		No-flow		
Growing[a]	Corn	1	:	4	p = 0.002*	Less likely to generate flow
	Soybean	1	:	3	p = 0.111	Equally likely to generate flow
	Winter wheat	1	:	2	p = 0.191	Equally likely to generate flow
	Oat cover crop	1	:	4	p = 0.218	Equally likely to generate flow
	Corn residue	1	:	2	p = 0.421	Equally likely to generate flow
	Winter wheat stubble	1	:	4	p = 0.143	Equally likely to generate flow
Non-Growing[b]	Corn	1	:	4	p = 0.143	Equally likely to generate flow
	Oat cover crop	1	:	6	p = 0.038*	Less likely to generate flow
	Corn residue	11	:	1	p < 0.001*	More likely to generate flow
	Soybean residue	5	:	1	p < 0.001*	More likely to generate flow
	No cover	3	:	1	p = 0.228	Equally likely to generate flow

[a] Growing season is defined as May 1 to September 30
[b] Non-growing season is defined as October 1 to April 30
* Statistically significant result

3.4.3 Predicting Flow Occurrence

The logistic regression equations for corn, soybean, winter wheat, oat cover crop, corn residue, and soybean residue were determined as follows:

Equation 6

$$P_{Corn} = \frac{1}{1 + e^{-(-5.811 + 0.095 \times PRCP + 0.986 \times SESN + 3.228 \times ANT\_CD)}}$$

Equation 7

$$P_{Soybean} = \frac{1}{1 + e^{-(-1.538+0.053\times PRCP-1.216\times ANT\_CD)}}$$

Equation 8

$$P_{Winter\ wheat} = \frac{1}{1 + e^{-(-6.276+0.191\times PRCP+3.107\times ANT\_CD)}}$$

Equation 9

$$P_{Oat\ cover\ crop} = \frac{1}{1 + e^{-(-2.299+0.091\times PRCP+0.036\times SESN-1.906\times ANT\_CD)}}$$

Equation 10

$$P_{Corn\ residue} = \frac{1}{1 + e^{-(0.458+0.008\times PRCP-2.866\times SESN+3.831\times ANT\_CD)}}$$

Equation 11

$$P_{Soybean\ residue} = \frac{1}{1 + e^{-(-0.342+0.035\times PRCP+2.014\times ANT\_CD)}}$$

Goodness-of-fit statistics and predictive power were statistically significant for corn, winter wheat, and corn residue, and nearly significant for soybean residue (Tables 6 and 7). Fit and predictive power was not appropriate for soybean and oat cover crop likely due to small sample size. Additionally, predictive models could not be made for winter wheat stubble and no cover conditions due to insufficient data.

In general, the logistic regression equations predicted the occurrence of flow/no-flow reasonably well. When precipitation, soil moisture conditions, and season were known, regression equation accuracies were 87 percent for corn, 87 percent for winter wheat, 84 percent for corn residue, and 81 percent for soybean residue. Refer to Tables A-2 and A-3 for additional model metrics.

In the future we intend to evaluate the models by comparing the probability of flow occurrence between different crop types under similar precipitation, soil moisture, and seasonal conditions. For instance, we could determine the likelihood that flow will occur for corn residue versus for soybean residue if 20 millimetres of rain falls in the non-growing season when antecedent moisture conditions are wet. To aid in this analysis, data from a nearby WASCoB monitoring site can be used for comparison and to help improve the current models.

Table 7: Summary statistics for logistic regression equations developed to predict flow/no-flow for two ***canopy types*** at a Water and Sediment Control Basin (March 2012 to September 2015).

	Corn				Winter wheat		
	Intercept	**PRCP**	**SESN**	**ANT_CD**	**Intercept**	**PRCP**	**ANT_CD**
Model variables, coefficient values, and statistical significance							
Model coefficients (log units)	-5.811	0.095	0.986	3.228	-6.276	0.191	3.107
Standard error	2.57	0.04	1.95	1.53	3.32	0.10	2.17
Wald's test *p*-value	0.024	0.029	0.613	0.035	0.059	0.059	0.153
Goodness-of-fit metrics of the model							
Likelihood ratio test *p*-value	0.01				0.011		
McFadden's pseudo R-square	0.38				0.47		
Predictive accuracy of the model							
Sample size	31				15		
Optimal probability cut-off	0.32				0.43		
Percent of correct predictions	87				87		

PRCP = precipitation
SESN = seasonal condition
ANT_CD = antecedent moisture conditions

Table 8: Summary statistics for logistic regression equations developed to predict flow/no-flow for two ***residue types*** at a Water and Sediment Control Basin (March 2012 to September 2015).

	Corn residue				**Soybean residue**		
	Intercept	**PRCP**	**SESN**	**ANT_CD**	**Intercept**	**PRCP**	**ANT_CD**
Model variables, coefficient values, and statistical significance							
Model coefficients (log units)	0.458	0.008	-2.866	3.831	-0.342	0.035	2.014
Standard error	1.09	0.08	1.47	1.71	0.98	0.05	1.06
Wald's test *p*-value	0.674	0.924	0.051	0.025	0.728	0.448	0.058
Goodness-of-fit metrics of the model							
Likelihood ratio test *p*-value	<0.001				0.059		
McFadden's pseudo R-square	0.61				0.20		
Predictive accuracy of the model							
Sample size	32				27		
Optimal probability cut-off	0.63				0.63		
Percent of correct predictions	84				81		

PRCP = precipitation
SESN = seasonal condition
ANT_CD = antecedent moisture conditions

3.4.4 Load Estimation

Of the 61 events that produced runoff at this field edge loads could be calculated for 19 events, nine events were well-sampled, three events were fairly-sampled, and 7 events were poorly-sampled (Figure 10). It is important to note that because this is a working agricultural field, we often have to remove water sampling equipment to accommodate planting, harvesting and other field crop activities. Nitrate-nitrogen loads generally ranged from 1 to 52 kilograms, but loads up to 551 kilograms were measured during May or June following a broadcast nitrogen fertilizer application (Table 8).

Phosphate-phosphorus (phosphate-P) loads mostly ranged between 0.05 and 2 kilograms, with two exceptions (Figure 10). An event on July 4, 2012, had a phosphate-P load of 11.5 kilograms while the field was planted in corn (Table 8). The runoff coefficient for this event (0.24) was higher than is typical for July. Other July events had lower runoff coefficients by one to two orders in magnitude. Another event, on November 17-18, 2013, had a phosphate-P load of 3.9 kilograms while the field was planted in winter wheat. The land management, rainfall, and runoff information did not shed any light on the reason for the elevated load during this event.

Total phosphorus (TP) loads tended to vary from 0.16 to 14 kilograms (Figure 10). The smallest loads occurred during snowmelt events (Table 8). An exceptionally large TP load of 45 kilograms occurred during an event on June 18-19, 2015. Rainfall during this event was very intense, with 19 millimetres falling in just two hours. This was also the third rainfall event that month, so the soil may have been saturated from the previous events, enhancing runoff. This set of conditions is not predictable; however, collecting more data at the same site as well as comparable data at different locations over time may help to predict patterns.

Suspended solids loads generally ranged from about 60 to 13,000 kilograms; however, the intense rainfall of the June 18-19, 2015 event also resulted in an exceptionally large suspended solids load of about 60,000 kilograms (Figure 8, Table 8).

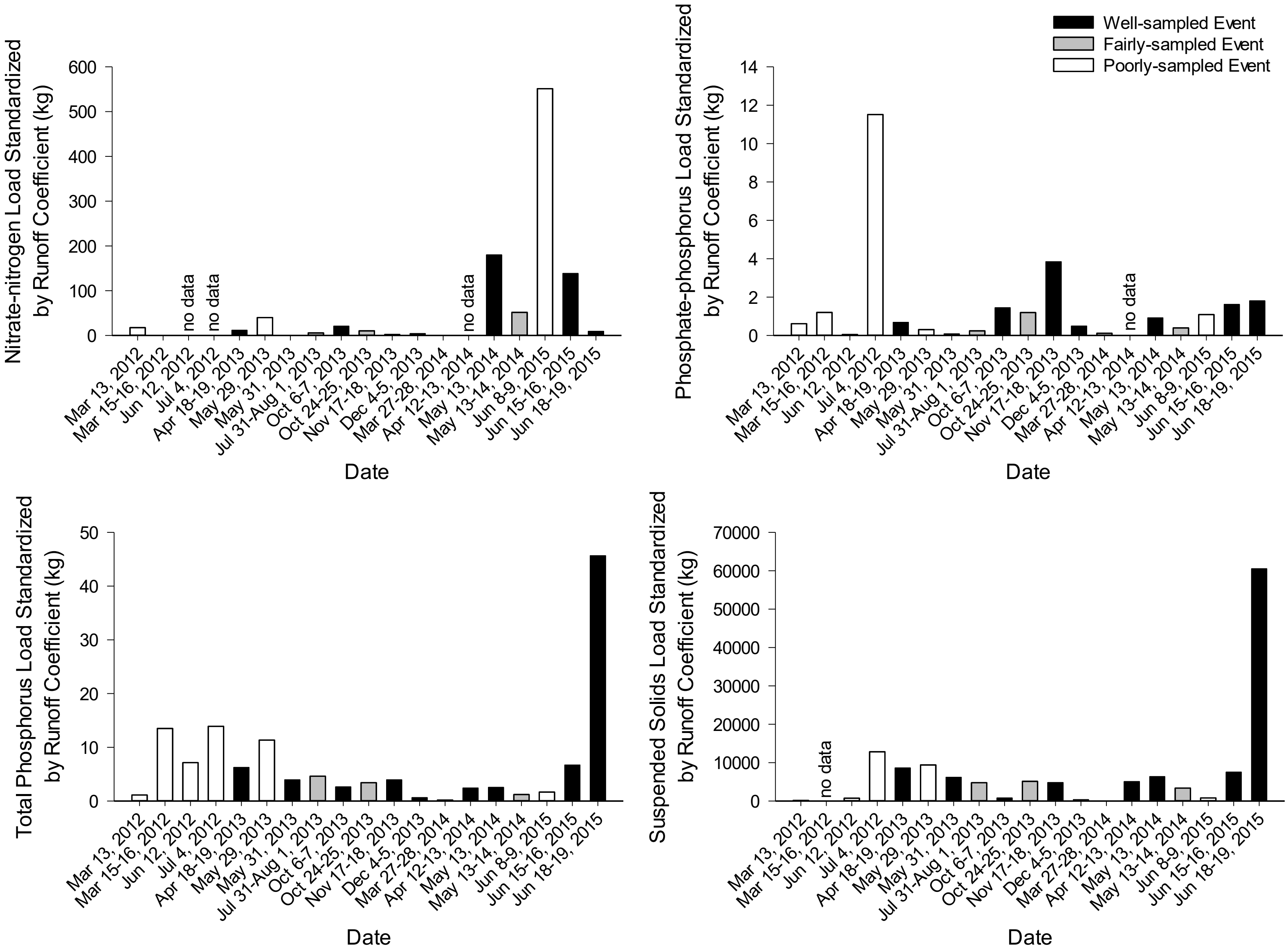

Figure 9: Nutrient and suspended solids loads, standardized by the runoff coefficient, for 19 events at a Water and Sediment Control Basin outflow between March 2012 and September 2015.

Table 9: Land management activities, vegetative cover, rainfall, and runoff information for 19 events with nutrient and suspended solids loads at a Water and Sediment Control Basin outflow between March 2012 and September 2015.

Date	Land Activity or Cover	Rainfall Depth (mm)	Rainfall Duration (h)	Event Rainfall Rate (mm/h)	Runoff Depth (mm)	Runoff Coefficient
Fall 2011	manure application, conventional tillage					
Mar 13, 2012	bare soil	16	14	1.2	0.3	0.02
Mar 15-16, 2012	bare soil	4	11	0.4	13	3.09
Spring 2012	starter broadcast nitrogen application					
Jun 12, 2012	corn less than 1 foot in height	13	4	3.2	0.5	0.04
Jul 4, 2012	corn	46	21	2.2	11	0.24
Fall 2012	conservation tillage					
Apr 18-19, 2013	60% corn residue	43	40	1.1	15	0.35
Spring 2013	conservation tillage					
May 29, 2013	60% corn residue, soybeans planted	35	34	1.0	1	0.04
May 31, 2013	60% corn residue, soybeans planted	5	6	0.9	0.1	0.01
Jul 31-Aug 1, 2013	soybeans	63	15	4.2	1	0.02
Fall 2013	no till					
Oct 6-7, 2013	30% soybean residue, winter wheat planted	23	38	0.6	7	0.30
Oct 24-25, 2013	30% soybean residue, winter wheat planted	38	19	2.0	22	0.55
Nov 17-18, 2013	winter wheat	20	24	0.8	6	0.32
Dec 4-5, 2013	winter wheat	23	23	1.0	12	0.57*
Mar 27-28, 2014	winter wheat	12	27	0.4	29	2.44*
Apr 12-13, 2014	winter wheat	29	7	4.1	5	0.19
Spring 2014	broadcast nitrogen application					
May 13, 2014	winter wheat	43	11	3.9	9	0.21
May 13-14, 2014	winter wheat	15	4	3.8	7	0.46
Fall 2014	conventional tillage					
Spring 2015	starter broadcast nitrogen application					
Jun 8-9, 2015	corn less than 1 foot in height	57	23	2.5	7	0.13
Jun 15-16, 2015	corn less than 1 foot in height	33	7	4.7	4	0.11
Jun 18-19, 2015	corn less than 1 foot in height	19	2	9.7	5	0.27

* This was a snowmelt event and the runoff coefficient does not account for the snow portion of the precipitation that contributed to the runoff.

4.0 Water and Sediment Control Basin Evaluation

Water and Sediment Control Basins (WASCoBs) hold back surface water runoff in headwater areas. This has been demonstrated to reduce sediment and nutrient loading into watercourses (Harmel *et al.*, 2008, Makarewicz *et al.*, 2009, Stuart *et al.*, 2010). Water quantity and quality was monitored at a WASCoB location near the Gully Creek watershed to determine its influence on the magnitude of peak flows during runoff events and nutrient and sediment loads within the study area.

4.1 Field Monitoring Methods

In addition to obtaining an outflow and nutrient and sediment concentration datasets from the hickenbottom outlet in the ponding area of the WASCoB (see methods in section 3.1.2), water samples were collected from one of the rill paths into the basin (inflow) for the analysis of nutrient and sediment concentrations. The inflow (in cubic metres per second) was calculated from the outflow and the change in basin water storage following the methods documented by Wilson (2016). The outlet tile was 200 millimetres in diameter with a slope of approximately 2.5 percent. As a result, the outflow rate was limited to a maximum drainage capacity of 37 litres per second. Bottles were installed at different heights above the ground surface (0, 5, 10, 15, and 20 centimetres) to attempt to capture water moving through the inflow rill path at different times during the event (Plate 1).

Plate 1: Pipe organ sampler designed to capture runoff waters at different heights above the ground surface (from left to right: 0, 5, 10, 15, and 20 centimetres).

4.2 Data Analysis Methods

4.2.1 Peak Flow Analysis

Peak flow characteristics were evaluated for monitored runoff events in the WASCoB. Reductions in peak flow between inflow and outflow were calculated by finding the difference in the peak inflow rate and the peak outflow rate of each runoff event. Inflow and outflow rates were determined by following the methods described by Wilson (2016). A total of 61 events were captured at the WASCoB for the period March, 2012 to September, 2015. Differences between inflow and outflow rates were also tested with a Wilcoxon Signed Rank Test (the non-parametric equivalent of a paired t-test).

4.2.2 Load Estimation

Of the 19 events for which outflow loads could be calculated, nutrient and sediment concentration data were also captured at the inflow for 14 events, making a comparison of inflow and outflow loads possible. Similar to the outflow loads, the inflow loads were calculated with the linear interpolation method in Water Quality Analyser. It should be noted that the inflow loads are very much approximations, as they are based on concentrations from a single rill path into the basin when there are in fact multiple rill paths and sheet flow contributing runoff to the basin. Also, the inflow load was estimated from a limited number of water samples (between one and three) that were collected from the rill path during each event.

Differences between the inflow and outflow loads were evaluated by calculating the percentage change from inflow to outflow. The events were categorized as well-sampled, fairly-sampled, or poorly-sampled at the outflow. Inflow and outflow loads were also compared with a Wilcoxon Signed Rank Test (the non-parametric equivalent of a paired t-test).

4.3 Results

4.3.1 Peak Flow Analysis

Reductions in the peak flow rate into and out of the basin occurred on 59 of 61 occasions, with a mean of 31 percent and ranging between 1 and 97 per cent (Figure 9). The peak outflow rate is largely driven by the size of the outlet tile. As a result, the median inflow rate was significantly higher than the median outflow rate ($p < 0.001$). By holding back surface water runoff we would expect to see a decrease in erosion potential and removal of suspended solids and nutrients from the runoff waters. Evidence of decreases in sediment loads and some nutrients loads likely due to peak flow reductions in the WASCoB are presented in the Loads results section (refer to F

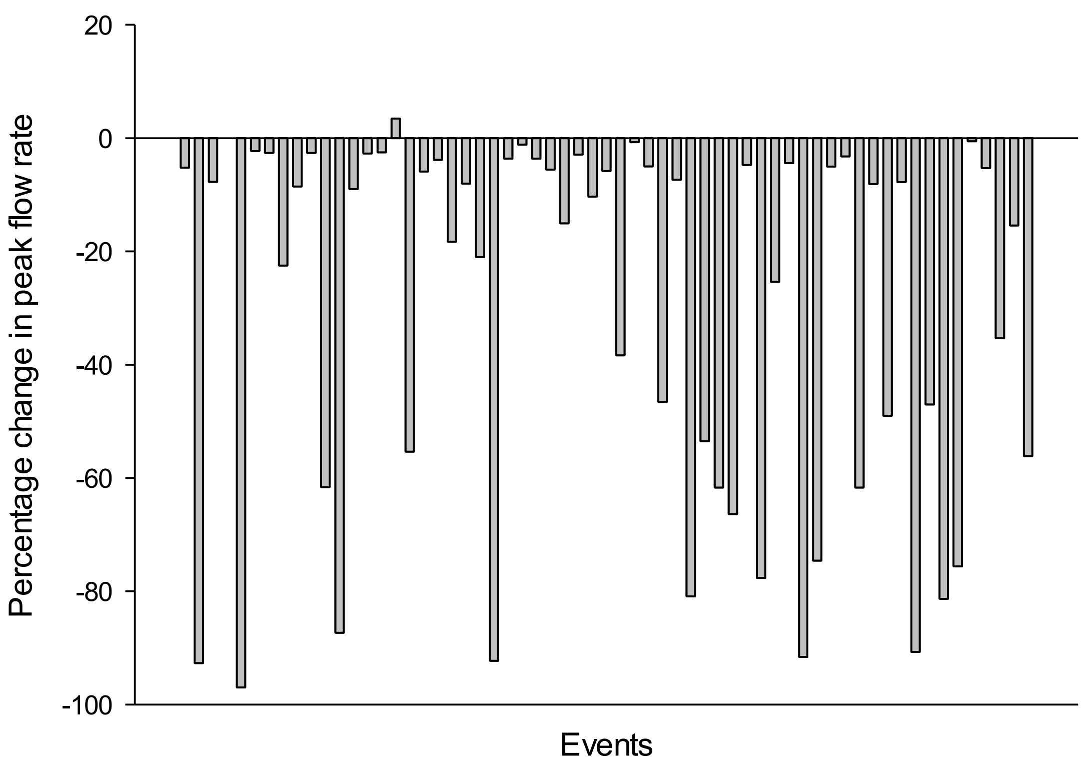

Figure 10: Percentage change in peak flow rates between inflow and outflow runoff from a Water and Sediment Control Basin (March 2012 to September 2015).

Reductions in peak flow appear to also be related to the amount of runoff generated during an event. Minor reductions in peak flow (*e.g.*, less than 20 per cent) tended to coincide with small runoff volumes and increased rapidly while approaching a threshold runoff volume of approximately 1,000 cubic metres (Figure 10). Refer to Table A-1 for a summary of meteorological and hydrological data for the WASCoB.

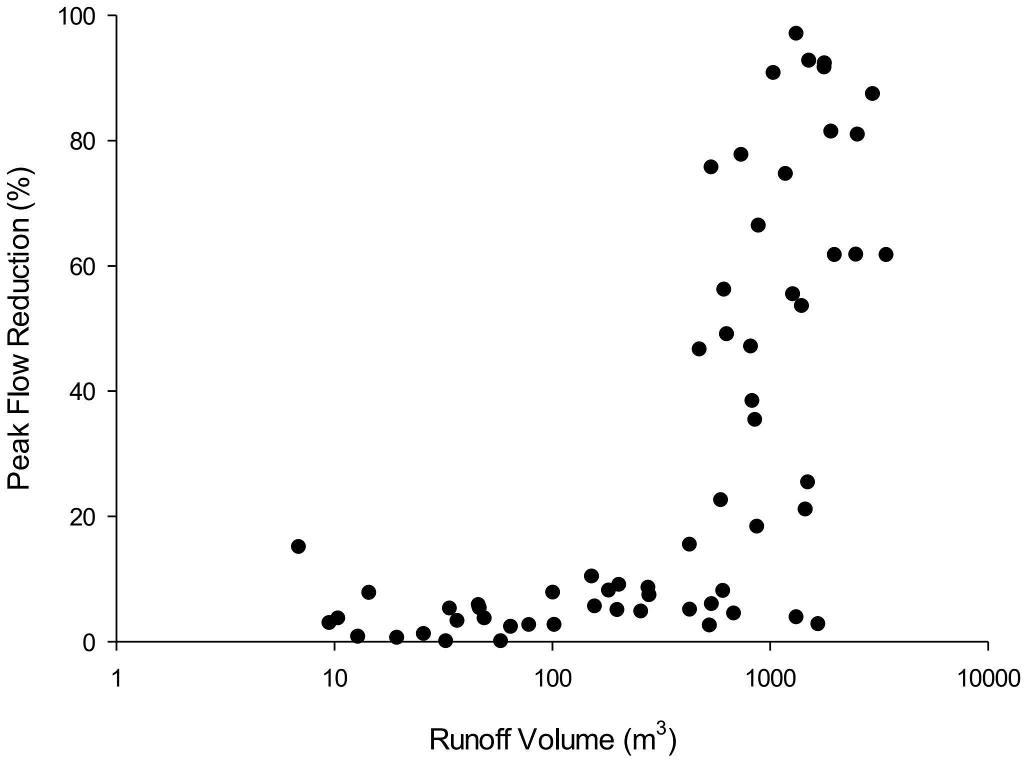

Figure 11: Peak flow reduction versus runoff volume at a Water and Sediment Control Basin (March 2012 to September 2015).

4.3.2 Load Estimation

Phosphate-P, TP, and suspended solids loads declined between the WASCoB inflow and outflow during most of the 14 events monitored (Figure 11). The differences between the inflow and outflow were statistically significant for these water quality indicators, with *p*-values of 0.023 for phosphate-P and 0.003 for each of TP and suspended solids. By contrast, nitrate-N loads more often increased between the inflow and outflow, although the differences for nitrate-N were not statistically significant (p = 0.347). These results suggest that a WASCoB may reduce phosphorus and suspended solids loads in surface runoff before it leaves the field through a hickenbottom outlet in the basin.

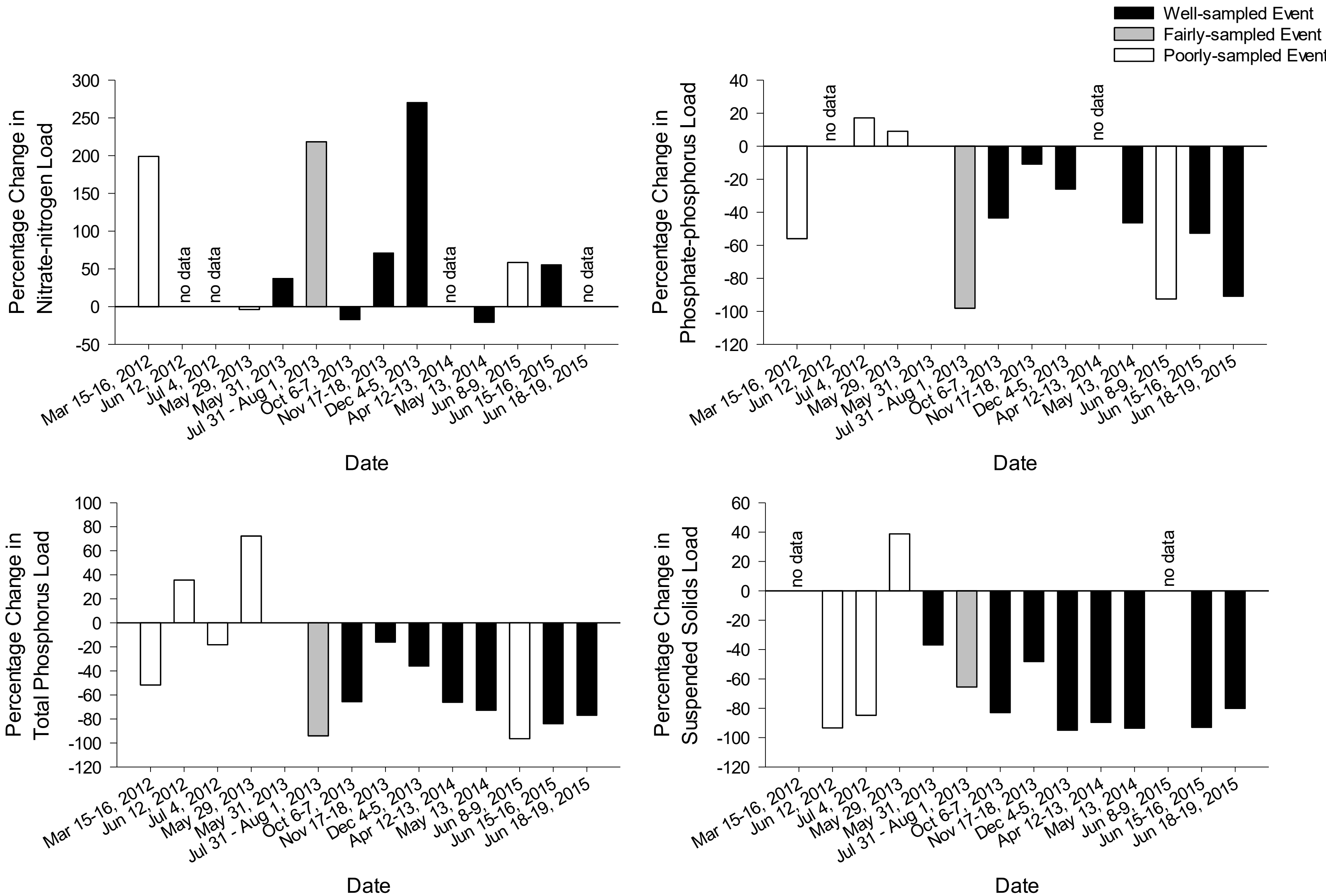

Figure 12: Percentage change in nutrient and suspended solids loads between the inflow runoff and outflow from a Water and Sediment Control Basin (March 2012 to September 2015).

5.0 Conclusions

Overall, watershed-scale monitoring showed that it is difficult to link changes in stream water quality to the implementation of BMPs. Long-term monitoring of high-flow water quality – with concurrent collection of climate, slope, soil, and land use and management information – will be necessary to evaluate the range of BMP effectiveness. However, it may be that the effectiveness of the different BMPs are overwhelmed by precipitation events and that other landscape factors (e.g., soil antecedent conditions, land management activities in other areas of the watershed) may overwhelm the improvements at the watershed scale.

A helpful framework for thinking about the role of the agronomic BMPs was proposed by Tomer *et al*. 2013. Implementing a hierarchy of BMPs has been the suggested approach to reduce sediment and nutrient loss. Practices that cover the soil and build soil health are a most important first step to reduce sediment and nutrient loss. Through our continued watershed and field scale evaluations, we continue to be confounded by not having equipment in place to measure before and after agronomic BMP implementation. For example in the case of converting the cropped field to a hay field, the site was not instrumented with a diver and we were unable to quantify the observation that the hay field generated less runoff than the cropped field.
The implications of the change in land management, in this case from a cropped field to a hay field extend to the downstream channel. Without the excess water, there is potential for there to be reduced downstream channel erosion. Changes in water flow over multiple fields throughout a watershed are difficult to capture with traditional monitoring techniques.

We continue to find it difficult to measure the effectiveness of the management practices such as cover crops, nutrient management, and conservation tillage at the field-edge. Although, we have made some understanding about the type of response we might be able to expect at the field edge. We think that the collection of flow/ no-flow information over different precipitation regimes with different crops and management practices should help to explain some background variability that should make the effectiveness of the BMPs more understandable. We have found that large runoff volumes and/or pollutant loads tend to occur during extreme events that result from a combination of contributing factors (*i.e.*, precipitation, soil moisture conditions, and recent land management practices). However, the particular combinations of conditions that result in extreme events are not predictable. We need more data from our WASCoB monitoring location over time (with rotating crop conditions) and comparable data from other locations over time. Building a more comprehensive dataset may help to identify patterns in the conditions that generate higher runoff volumes and practices that ameliorate the flow generating conditions.

Measuring the effectiveness of the structural BMPs, particularly WASCoBs has been more easily accomplished. In this current study, we have documented decreases in peak flows in the basins. There has also been some suggestion of reduced loads of phosphorus and sediments within the basin.

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7.0 Appendix

Table A-1: Summary of meteorological and hydrological data at a Water and Sediment Control Basin (March 2012 to September 2015).

Event date	Total precipitation (mm)	Peak inflow rate (L/s)	Peak outflow rate (L/s)	Runoff coefficient
Mar 13 2012	16.2	1.7	1.6	0.018
Mar 15-16 2012	4.2	506.8	37.0	3.090
Jun 4 2012	1.4	4.8	4.4	0.088
Jun 12 2012	12.8	13.6	13.6	0.039
Jul 4 2012	46.4	1236.4	37.0	0.244
Oct 23 2012	13.6	7.3	7.2	0.041
Oct 31 2012	13.2	9.2	9.0	0.066
Dec 2 2012	13.2	41.3	32.0	0.387
Dec 4 2012	10.8	24.9	22.8	0.220
Dec 20-21 2012	9.6	9.2	9.0	0.070
Jan 11-12 2013	17.6	96.5	37.0	0.965
Jan 29-30 2013	39.6	292.7	37.0	0.641
Feb 19 2013	15.6	9.9	9.0	0.112
Feb 22-25 2013	4.6	9.2	9.0	3.101
Feb 26-27 2013	12.4	13.9	13.6	0.366
Feb 28 2013	4.6	5.1	5.3	0.061
Mar 10-11 2013	0.2	82.9	37.0	54.587
Mar 11-12 2013	7.2	24.2	22.8	0.643
Apr 9-10 2013	32.8	18.7	18.0	0.345
Apr 10 2013	15.0	39.2	32.0	0.499
Apr 11 2013	12.8	29.4	27.0	0.408
Apr 11-12 2013	14.0	46.8	37.0	0.890
Apr 18-19 2013	43.4	480.1	37.0	0.352
Apr 24 2013	13.4	5.5	5.3	0.031
Apr 25 2013	7.8	7.2	7.2	0.028
Apr 25 2013	1.4	5.5	5.3	0.064
May 29 2013	35.0	14.4	13.6	0.039
May 31 2013	5.4	1.9	1.6	0.011
Jun 12 2013	17.8	3.6	3.5	0.005
Jul 31 - Aug 1 2013	63.4	20.1	18.0	0.021
Sep 7 2013	7.6	5.6	5.3	0.052
Oct 6-7 2013	23.4	60.0	37.0	0.293
Oct 8 2013	1.6	3.5	3.5	0.069
Oct 19 2013	12.8	14.3	13.6	0.129
Oct 21 2013	9.0	69.3	37.0	0.436
Oct 23 2013	11.6	14.7	13.6	0.199
Oct 24-25 2013	38.0	193.8	37.0	0.549
Oct 26-27 2013	20.0	79.6	37.0	0.579
Oct 31 - Nov 1 2013	43.8	96.7	37.0	0.469
Nov 1-2 2013	17.6	110.0	37.0	0.431
Nov 6 2013	15.6	28.3	27.0	0.141
Nov 17-18 2013	20.0	165.6	37.0	0.316
Dec 4-5 2013	22.6	49.6	37.0	0.566

Dec 22-23 2013	12.0	14.2	13.6	0.488
Jan 11-12 2014	37.6	440.5	37.0	0.405
Mar 19-20 2014	5.8	145.7	37.0	1.743
Mar 21-22 2014	4.2	14.3	13.6	0.876
Mar 22 2014	4.6	11.7	11.3	0.068
Mar 27-28 2014	12.0	96.6	37.0	2.442
Apr 4 2014	6.4	19.6	18.0	0.244
Apr 12-13 2014	28.6	72.6	37.0	0.190
Apr 30 2014	27.6	9.8	9.0	0.031
May 13 2014	42.8	399.1	37.0	0.208
May 13-14 2014	15.2	69.9	37.0	0.461
May 15 2014	25.8	198.3	37.0	0.635
May 21-22 2014	23.6	151.9	37.0	0.196
Jul 6-7 2014	37.4	7.2	7.2	0.004
Sep 10 2014	23.2	9.5	9.0	0.017
Jun 8-9 2015	56.6	49.5	32.0	0.129
Jun 15-16 2015	33.0	37.8	32.0	0.111
Jun 18-19 2015	19.4	84.4	37.0	0.272

Table A-2: Summary statistics for logistic regression equations developed to predict flow/no-flow for two ***canopy types*** at a Water and Sediment Control Basin (March 2012 to September 2015).

	Soybean			Oat cover crop			
	Intercept	**PRCP**	**ANT_CD**	**Intercept**	**PRCP**	**SESN**	**ANT_CD**
Model variables, coefficient values, and statistical significance							
Model coefficients (log units)	-1.538	0.053	-1.216	-2.299	0.091	0.036	-1.906
Standard error	1.31	0.05	1.97	2.11	0.11	2.03	2.45
Wald's test *p*-value	0.241	0.319	0.536	0.276	0.409	0.986	0.437
Goodness-of-fit metrics of the model							
Likelihood ratio test *p*-value	0.337			0.689			
McFadden's pseudo R-square	0.23			0.23			
Predictive accuracy of the model							
Sample size	9			10			
Optimal probability cut-off	0.25			0.46			
Percent of correct predictions	67			100			

PRCP = precipitation
SESN = seasonal condition
ANT_CD = antecedent moisture conditions

Table A-3: Summary statistics for logistic regression equations developed to predict flow/no-flow for two ***residue types*** at a Water and Sediment Control Basin (March 2012 to September 2015).

	Winter wheat stubble			No cover		
	Intercept	**PRCP**	**ANT_CD**	**Intercept**	**PRCP**	**ANT_CD**
Model variables, coefficient values, and statistical significance						
Model coefficients (log units)	Insufficient data			Insufficient data		
Standard error						
Wald's test *p*-value						
Goodness-of-fit metrics of the model						
Likelihood ratio test *p*-value	Insufficient data			Insufficient data		
McFadden's pseudo R-square						
Predictive accuracy of the model						
Sample size	3			2		
Optimal probability cut-off	Insufficient data			Insufficient data		
Percent of correct predictions						

PRCP = precipitation
ANT_CD = antecedent moisture conditions