FINAL REPORT

University of Wisconsin – Green Bay *Sub-Award Report*

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Primary Project Title: Silver Creek Sediment & Nutrient Reduction & Habitat Restoration
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Managed Grazing - Paired Field Monitoring: Evaluation of the Water Quality Impacts of Managed Grazing with a Paired Study Design in N.E. Wisconsin.

October 2021

University of Wisconsin – Green Bay

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Foreword

A combination of issues including a wet fall in 2018, deeply rutted fields due to a late corn silage harvest in fall 2018, record-setting rainfall in 2019, a change in farm operators, and drier than normal conditions in 2020 and 2021 prevented the achievement of our primary objective of this study, which was to estimate the impact of switching from a typical corn silage dairy crop to managed cattle grazing on yields of runoff, TSS and dissolved and total phosphorus. This problem is discussed in detail in the report.

The University of Wisconsin – Green Bay was solely responsible for conducting the monitoring study, including the construction, operation and maintenance of all monitoring equipment.

Acknowledgements: This project involved the Oneida Nation, Northeast Wisconsin Technical College (NWTC) Sustainable Agricultural program (grazing program), NRCS, Glacierland Resource Conservation and Development (RC and D), and the GrassWorks, a Wisconsin state-wide grazing non-profit group that focuses on educating farmers. As part of the larger Silver Creek watershed pilot project they transitioned the acres to continuous cover, and put in required infrastructure prior to the change in farm operation from the former land operator to the Oneida Nation in 2019, which also owns the land. The Oneida Nation transition to managed cattle grazing was undertaken by the Oneida Nation Tsyunhehkw^ culturally based community agriculture program. The contribution of these organizations to this study is greatly appreciated. Without the assistance of these people and organizations, this study would not have been possible.

Problem Definition/Background

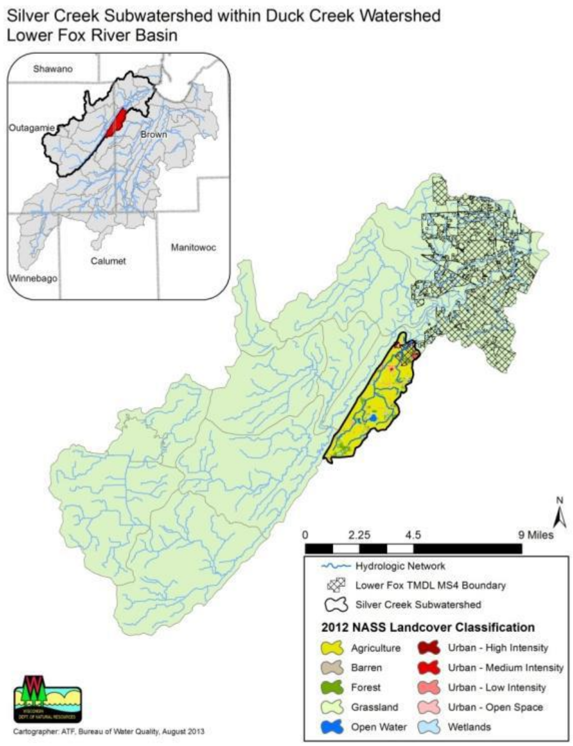

Figure 1. Location of Silver Creek sub-watershed within the Duck Creek watershed and Lower Fox.

Approximately one-third of the total sediment and phosphorus loading to the Lake Michigan basin comes from Green Bay, most of which is from the Fox River at the southern end of the bay. About 45% of the phosphorus loading to lower Green Bay is from the 1,620 km^2 Lower Fox River sub-basin (WDNR 2012). Silver Creek is a 19.4 km^2 sub-watershed located in the Duck Creek watershed of the Lower Fox River sub-basin (Figure 1). The study described in this report is part of the overall GLRI Silver Creek project entitled "Silver Creek Sediment & Nutrient Reduction & Habitat Restoration", GLRI Grant Number GL00E01450). The overall goal of the Silver Creek project is to reduce agricultural nonpoint runoff by installing permanent conservation measures to achieve sediment and nutrient goals consistent with state water quality standards of 0.075 mg/l of total phosphorus (for tributary streams) and 18 mg/l of total suspended solids (TSS) to restore the biological habitat of the stream.

Dairy farms have a large impact within the Lower Fox sub-basin, including the Silver Creek project area. Due to the large number of cattle in the area, crop rotations have changed to include a greater amount of corn silage, leaving little residue to hold soil in place during runoff events. The increased cattle numbers also lead to increased manure and the need for producers to apply manure to cropland in both fall and spring. This manure is required to be incorporated, which means additional tillage passes and even less residue on the surface to protect and hold soil in place.

The monitoring project goal was to investigate Managed Grazing as an alternative to the standard dairy crop rotation which relies heavily on corn silage production. This practice establishes year-round vegetative soil cover, thereby greatly reducing soil loss during major storm events and during the critical time periods when fields are typically left uncovered.

The approach of our study was to employ a paired watershed study design to evaluate the water quality impacts of Managed Grazing. <u>The primary objective of this study was to estimate the effect of switching from a typical corn silage dairy crop to cattle grazing on yields of runoff, TSS and dissolved and total phosphorus from one of two paired agricultural field catchments in the Silver Creek sub-watershed</u>. We wished to answer the following question: How effective is managed grazing in reducing soil loss and phosphorus runoff relative to a conventionally farmed corn silage dairy field? We expect that soil loss would be greatly reduced; however, the manure from grazed cattle is on the soil surface, so the concentration and yield (mass/area) of phosphorus in runoff from this surface-applied manure is the primary unknown quantity.

The study area serves as a demonstration site by other parties in the overall Silver Creek GLRI project. The location of our study catchments was on the 104.6 acre planned grazing field illustrated in Figure 2 (Section 9 & 16 – T23N – R19E), which is located within the Silver Creek Watershed, Oneida Reservation and Outagamie County, Wisconsin. This land is owned by the Oneida Nation, but it was leased and operated by a private farm operator as a conventional dairy farm transitioning to managed grazing, until the lease was discontinued at the end of 2018, when the Oneida Nation then took over operation. Most of the land transitioned to managed grazing during the project study period. The specific location of the paired monitoring stations is approximately 44.475338 latitude and -88.19662 longitude.

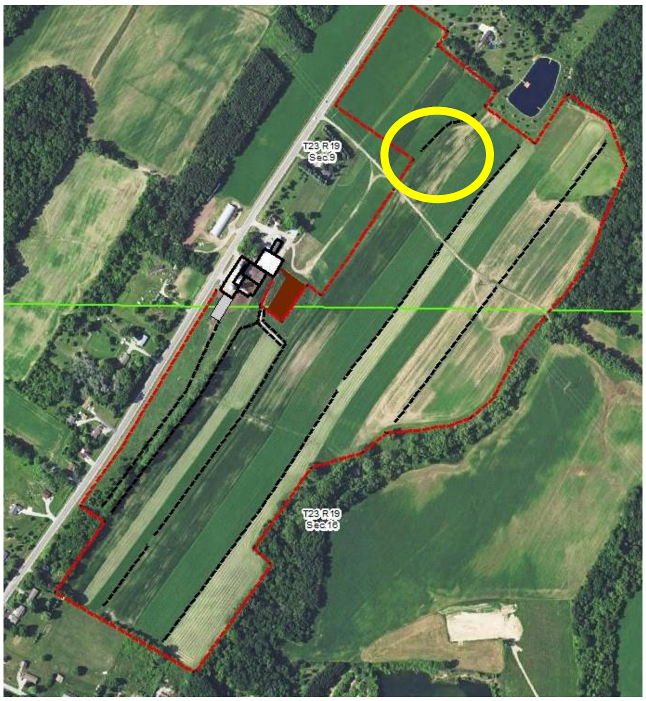

Figure 2. Managed Grazing farm field boundaries (red), with water monitoring study area circled.

The project involved the Oneida Nation, Northeast Wisconsin Technical College (NWTC) Sustainable Agricultural program (grazing program), NRCS, Glacierland Resource Conservation and Development (RC and D), and the GrassWorks, a Wisconsin state-wide grazing non-profit group focuses on educating farmers. As part of the larger pilot project they transitioned the acres to continuous cover, and put in required infrastructure prior to the change in farm operation to the Oneida Nation in 2019. Excluding the study plots, the entire area transitioned to seasonal grazing during the growing season by 2019 under the Oneida Nation Tsyunhehkw^ culturally based community agriculture program (Tsyunhehkw^: "life sustenance" in Oneida, pronounced Joon-heh-kwa).

Monitoring Design Overview: The study site is in an agricultural field located in the Silver Creek watershed, which is within the Lower Fox subbasin, in NE Wisconsin (Figures 1 to 3). Our study utilized a paired edge-of-field (EOF) water quality monitoring design (Spooner and Clausen 1993) to estimate the effect of switching from a conventional dairy corn silage crop to managed grazing on yields of runoff, TSS and phosphorus. In this paired watershed design, both the control north catchment and transition (treatment) south catchment were monitored for the first portion of the study under the existing conventional dairy row crop rotation during the calibration period (corn silage with fall chisel plow tillage after harvest and manure application). In this way, a relationship is established between the response of the control and the treatment catchments to precipitation events, prior to any changes. After a sufficient number of samples were collected during the calibration period, we then proceeded with the treatment phase whereby only the south treatment catchment was converted to Managed Grazing for the remainder of the monitoring period. The pre- and post-treatment relationships between the control and treated catchments can then be compared. Statistically significant changes in the relationships can then be attributed to the treatment effect, and quantified.

The null hypothesis is that the constituent event-mean concentrations or event yields from the catchment with managed grazing is greater than or equal to the conventional corn silage field without this targeted practice. If there is a statistically significant difference ($p < 0.05$) between the pre- and post- treatment relationships, the null hypothesis will be rejected in favor of the alternative hypothesis that there is a decline in these constituents that is likely due the managed grazing practice.

Primary constituents of concern that will be evaluated are runoff volume, TSS, total phosphorus and dissolved phosphorus, with special emphasis on the latter two constituents.

The study design consisted of three phases: pre-treatment, transitional and post treatment. The pre-treatment phase ended when statistical analysis of the events determined that there were enough events to detect a change. The transition phase consisted of planting and establishing the grazing pasture mix in the south treatment catchment. The post-treatment phase began after this vegetation treatment was judged to be sufficiently established that it would reduce excessive soil erosion relative to the corn silage field. The paired study design greatly reduces the influence of climate differences between the pre- and post-treatment phases. The adjacent paired plots were managed the same by the farm operator during the entire pre-treatment phase of the study (continuous corn silage crop and intensive tillage).

Our edge-of-field (EOF) monitoring design followed similar protocols to those used for Wisconsin USGS EOF monitoring (Stuntebeck et al. 2008, 2011). Monitoring stations installed at the outlet of each catchment were configured to collect continuous discharge data and automated event samples. Flow from each of the paired field catchments was directed to H-flumes at each of the respective outlets. Flume stage and sampling information were monitored continuously and recorded by a data logger. Discrete samples were collected during each runoff event by an automated sampler. Flow-weighted composite samples were created by taking sub-samples from each of the collected event samples in proportion to the flow runoff volume that occurred within each sample interval. A flow-weighted composited sample was used to represent the event-mean concentration (EMC) for each storm event. The cumulative flow and EMC were multiplied to calculate the total constituent load for each runoff event. Paired relationships between the north and south catchments were established for flow, TSS, TP (total phosphorus) and DP (dissolved phosphorus) during the pre-treatment phase. When a sufficient number of paired pre-treatment samples are obtained, these relationships can be compared to relationships during the post-treatment phase to determine if there were any changes. Detected changes that are statistically significant ($p < 0.05$) can likely be attributed to the managed grazing treatment practice. A detailed description of study methods is provided in the methods section.

Site Description: The study site was within a farm field under continuous corn silage rotation, with intensive tillage, including chisel plow incorporation of surface-applied manure after fall harvest. The GIS-estimated drainage areas of the north and south catchment monitoring sites shown in Figure 3 are about 0.57 acres. These areas were based on visual estimation of catchment boundaries using the 1 foot elevation contour shapefile (based on 2018 LIDAR) and a 2021 aerial ortho-photo provided by the

Outagamie County Land Information Office. The slope was too planar to estimate with a watershed delineation tool such as the Soil and Water Assessment Tool model (SWAT, Arnold 1997). The field contours are nearly parallel to one another, so the catchments generally don't concentrate runoff that well. Therefore, the primary mechanisms for concentrating runoff toward the monitoring flumes were plywood wingwalls and soil berms.

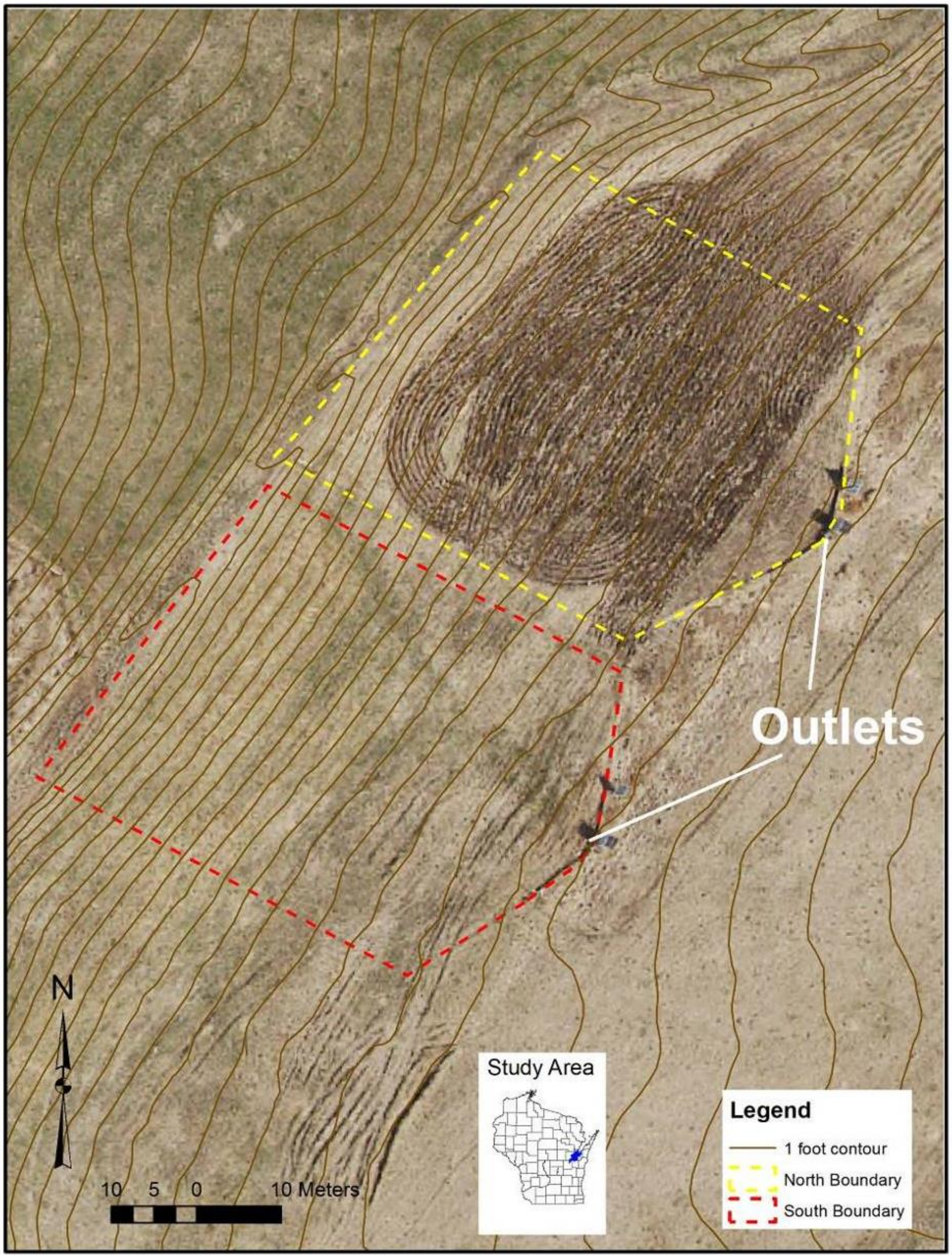

Figure 3. Study site with paired north and south catchment boundaries, and 1 foot contours. Monitoring station houses, wingwalls and solar panels can be seen in April 2021 aerial ortho-photo. The tillage pattern from the fall 2020 chisel plow operation can be seen in the north catchment. One foot elevation contours (2018 LIDAR) and background 2021 aerial ortho-photo are from the Outagamie County Land Information Office.

GIS analysis was conducted with ESRI ArcMap 10.5 to obtain watershed characteristics and to create related images displayed in this report. The mean, maximum and standard deviation of overland slope in the north catchment is 9.3%, 27.0% and 4.2%, respectively. The mean, maximum and standard deviation of overland slope in the south catchment is 10.1%, 29.5% and 4.9%, respectively. These values, along with the contour pattern shown in Figure 3 indicate that the topographic landscapes of both catchments are nearly the same.

Soils within both paired catchments are primarily Hortonville loam and hydrologic group B (HrD2, Kalk 2018), which indicates a moderate infiltration rate. Three soil samples were collected by UWGB in 2017 from each catchment and analyzed at the University of Wisconsin-Extension Soil and Forage Analysis lab for Soil Test Phosphorus (STP). Each of these samples were based on compositing five nearby soil samples using standard methods. Mean STP was 52 and 39 mg/g Bray-P1 from the south and north sites, respectively. Three additional soil samples were collected in 2021, and Mean STP was 72 and 55 mg/g Bray-P1 from the south and north sites, respectively. It is likely that STP concentrations in these catchments pose a moderate risk of contributing to high concentrations of DP in runoff because they are above the optimum range for growing crops that are typically grown in this region, including corn, soybean, winter wheat and alfalfa (Laboski and Peters 2012).

Monitoring Methods and Field Management

Water quality monitoring stations were installed at the outlets of two flow paths that drain north (0.57 acres) and south (0.57 acre) catchments, located in a farm field within the Silver Creek watershed. (Figures 2 and 3). The monitored catchments are directly adjacent to each other.

As previously stated, the monitoring design followed similar protocols to those used by the Wisconsin USGS for edge of field monitoring (Stuntebeck et al. 2008, 2011). However, our study was not intended to cover all seasons. Therefore, winter runoff events when substantial ice was present were generally not captured. The two monitoring stations were configured to collect continuous discharge data and automated event samples from their respective catchments. The EOF monitoring stations became operational in early June 2016. A Rubbermaid 5’ wide x 6’ high, and 4’ deep vinyl station house with a dual doors was used to house the sampler, logger and related equipment at the outlet of each field plot (Figure 4). The station house was mounted on a wood base that was elevated above ground level approximately 1.5’ using steel struts and stakes driven into the ground below frost depth. All electronic equipment was powered by four large capacity 12 volt DC deep recharge glass-mat batteries. These batteries were charged by 390 watt and 240 watt solar panel arrays at the north and south stations, respectively. No power failures occurred during our study. Campbell Scientific CR-1000 data loggers provided systems control over all monitoring equipment. The USGS had previously provided a Campbell Scientific CR-Basic program for a stream monitoring project on the UWGB campus. We modified this program slightly to suit site-specific conditions for this study (e.g., variable sample times, etc). Remote access via cell phone modems enabled real-time monitoring including setting sampling stage thresholds and intervals, triggering sample events, and downloading data as needed.

Figure 4. Station housing and monitoring equipment at outlet of south catchment (left, 5/5/18) and north catchment (right). Turbidity probe is mounted below flume in half-pipe.

Surface water run-off was directed toward an H-flume by installing small dirt berms and treated plywood wing-walls to direct runoff from the catchment to a single inlet where a 1.0 foot H-Flume served as the control structure. A two foot high 2x3 inch welded wire mesh fence was installed just upslope of the flume to ensure that trash/debris from the field did not enter and clog the narrow outlet of the flume (Figure 5). A nitrogen tank and Conoflow sight feed regulator assembly provided a steady supply of gas to a bubbler orifice line that was inserted near the H-flume stage height location and affixed at the bottom of the flume. A Sutron Accubar pressure transducer system measured how much pressure was in the line due to water depth, which was converted to feet and recorded by the datalogger. The higher the stage in the flume, the greater the pressure in the line. A 16 minute data recording interval was used during non-event conditions and 2 to 8 minute intervals during storm events, depending on event duration.

The data logger program triggered the logger and sampler equipment to enter event monitoring mode at a user defined water level of 0.085 feet. Runoff-event samples were collected with refrigerated Teledyne ISCO 3700 automated samplers that were triggered to collect a discrete sample (~ 900 mL) in response to the initialization of event sampling mode, and stage changes during runoff events, via user-defined stage rise and fall thresholds. Samples were drawn through 3/8" i.d. polyethylene tube that was anchored 0.25 inches above the flume bottom, and 4 inches above the flume outlet. Heat tape was placed along the sampler line, with appropriate foam insulation, and into the flume to extend the monitoring period as much as possible. Samples were collected in 1000 mL semi-clear wedge-shaped polyethylene sample bottles. A total of 6 to 18 discrete samples were typically collected from each EOF site during a runoff event (e.g., Figure 5), except for when a single sample collected during the peak flow was used to represent a snowmelt runoff event on 2/18/17. Flume stage measurements recorded by the Accubar pressure transducer system and datalogger were converted to a record of runoff rate based on a standard 1.0 foot H-flume stage-flow table within an Excel spreadsheet. This spreadsheet was used to create a sample collection field log and sample processing log. Flow-weighted composite samples were created by taking sub-samples from each of the discrete samples collected during an event, in proportion to the runoff volume that occurred within each sample interval, as calculated in the spreadsheet. The flow-weighted composite sample was used to represent the event-mean concentration (EMC) for each runoff event. Cumulative flow volume and EMC were multiplied to calculate the total constituent load for each runoff event.

Figure 5. Photo view looking downslope toward north station plywood berms and 1' H-flume, with trash fence just upslope of flume to prevent clogging of narrow flume outlet by debris (left, 10/22/16). Image on right of south and north station automated sampler bottles collected from 4/20/17 event and awaiting compositing and processing.

Sample Retrieval and Processing: Samplers were typically serviced by UWGB field personnel within 24-hours of the end of a storm event. The caps of the 1000 mL ISCO-3700 sample bottles were marked with a unique sample ID that was sequentially tracked by the data logger; for example, OF-N-1001 and OF-S-7001 represented the first ISCO samples from the north and south sampling stations, respectively. Sample bottles were then placed in coolers and processed in the UWGB water lab where they were composited based on flow volume. Flow composited samples therefore represented the mean concentration for each event and site. Flow composited samples were split with a Decca 10-port splitter to divide the sample prior to subsample preservation and analyses. Subsamples included four separate smaller polyethylene bottles that were labeled for TSS (~400 mL), TP (~100 mL), and DP (~100 mL) analysis; plus an extra bottle (~400 mL) was kept for later retesting or confirmation if issues came up with a missing, or unexpected result from the lab. The DP subsample was filtered with a 0.45-micrometer pore size filter prior to preservation. All water sample bottles except the TSS and reserved samples were preserved with H_2SO_4. A unique sequentially numbered sample ID label was placed on each of the composited bottle samples, based on event order (e.g, OF-N-101 and OF-S-101 represented the first event composites from the north and south stations). A Chain-of-Custody (COC) form was filled out with the sample date, time, sample ID, and parameters to be analyzed. Samples were then transported 4.5 miles to the New Water Laboratory for analysis. The NEW Water lab is USGS accredited and approved by the USGS Branch of Water Quality Systems, and it is certified by the State of Wisconsin under Ch. NR 149, Wis. Adm. Code by the Wisconsin DNR Bureau of Science Services Laboratory Certification and Registration Program.

Lab results in Adobe Acrobat format were usually received about 10 days after sample drop-off via email. These results were checked for potential errors based on comparisons between the paired samples, and the three constituents. Retests were requested if there were any issues. An Excel spreadsheet of all NEW Water analytical data that UWGB requested was occasionally received and these data were used to confirm or correct the originally transcribed lab results. Resulting constituent concentrations from the composited samples and the discharge record from each event were used to calculate EMC's and loads from each of the catchments. The paired data were to be used to assess the effectiveness of the managed grazing plot compared to the standard corn silage crop.

Flume Maintenance and Levels: Debris and dirt buildup were removed from flumes during sample collection: both were relatively minimal during all events, and did not affect sample water quality, stage height or flow velocity. Flume levels were measured when event samples were collected at both stations to ensure accurate flow volume measurements which require that the H-flumes be level in both directions (side to side, and inlet to outlet). In addition, flume levels were checked periodically, including late winter and early spring prior to expected spring runoff, because flume height and level are often displaced by frost heave. Corrections were made when the flumes were not level. Nearly all corrections were minor, except when ground frost melted, and these changes typically took place prior to a major spring runoff event. A major correction was required in 2019 because frost heave caused about a 50-60 mm increase in elevation above the soil surface at the flume inlet at both stations. This issue did not affect the flume level, because the flume outlet level was adjusted accordingly, as needed. However, this problem could have reduced runoff volume because of increased ponding, and potentially increased suspended sediment deposition above the flume. Therefore, it was deemed enough of an issue by spring 2019, that it was remedied August 2019 by digging down below the bottom of the plywood and lowering the plywood to its original location where the flume entrance was at soil surface level. Additional corrections were made to account for frost heave in mid-spring 2020 and 2021 by cutting a portion of the plywood that holds the flume and lowering and leveling the flume to the original installation state, near the soil surface level.

Direct stage as measured inside the flume, and stage as measured by the pressure transducer system were compared and recorded when there was sufficient water in the flume to perform this check during site visits. An offset was used to correct the recorded stage based on these measurements. In general, this offset amounted to subtracting about 0.028 feet and 0.036 feet (on average) from the recorded stages at the south and north stations, respectively.

Precipitation: Calibrated eight-inch diameter Rain Wise and Texas Instrument tipping bucket rain gauges were employed to measure non-frozen precipitation (0.01 inch increments) near each of the station houses, and this data was recorded by the data logger. Precipitation intensity and volume data were utilized to characterize those periods responsible for runoff and erosion, but these parameters were not critical to success of the study.

Turbidity: A second means of potentially computing event-mean constituent TSS and TP concentrations and loads by using turbidity as a surrogate was employed by combining continuous discharge data with continuous turbidity data from a Campbell Scientific OBS-501 turbidity probe that measures both backscatter and sidescatter turbidity units (up to 4000 BTU and 1000 STU, respectively). This probe has a retractable head to protect the optics from fouling and it greatly decreases clogging normally associated with standard wiper mechanisms. The probes were mounted vertically at each station such that the sensor end was placed in a half-pipe below the flume outlets, with a “weir” plate to maintain sufficient water depth.

Only three discrete samples were collected from each of the two stations, and analyzed for TSS, TP and DP. Concurrent turbidity measurements were also recorded. Sample numbers were small because it was difficult to collect enough water volume for separate chemical analysis beyond the amount of water needed to create the composite for the event, and to have the sample coincide with a turbidity measurement that was sufficiently stable. Therefore, the data were too sparce to establish regression-derived relationships between discrete concentration and concurrent in-situ turbidity measurements. However, relationships between the composited event-mean concentrations and “composited” turbidity measurements were established.

Quality Control: Field blank results and a discussion of stage quality checks are included in Appendix B. Copies of event sample processing and field collection logs, lab analysis chain of custody forms and field station logs are included in Appendix C, D and E, respectively, as attachments to this report.

Field Management and Transition to Managed Grazing

Crops, Tillage and Nutrients: Both field catchments were managed the same by the initial farm operator through the first part of the study. Crop practices in these catchments consisted of corn silage in 2015, 2016, 2017 and 2018. Commercial fertilizer and manure were applied to the study site. Fertilizer was incorporated at planting. Manure was incorporated with fall tillage or injection after harvest. Typical tillage included fall chisel plow after harvest and a field cultivator prior to spring planting. A transition to a new farm operator, the Oneida Nation which owns the land, and record-setting rainfall in 2019 prevented planting a corn crop in 2019. This problem is discussed in detail later in this section. Typical pre-treatment seasonal site conditions can be seen in Figure 6 and Figure 9 (left).

Figure 6. Seasonal images at study site: wet conditions during sample collection on 4/4/18 (upper left), corn crop well underway by 6/28/16 (upper right), after corn silage harvest (lower left, 9/21/16), and during 12/28/16 winter melt conditions (lower right). The winter site visit conditions confirmed our expectations that snow melt sampling would not be likely given the large volume of frozen runoff water that was held up by the berms and flume setup.

Treatment Phase Initiation: Statistical analysis was conducted with the SAS 9.4 statistical analysis program in mid-2018, which indicated that data quality and quantity were sufficient to proceed with transitioning to the treatment phase (see results section for more detail). While more runoff events would have been desired prior to transitioning, it become clear that due to the nature of this site (more permeable soils, and smaller catchment size), only about 50 to 70% of the measurable runoff events could be expected compared to a larger site with heavier clay soils (e.g., our GLRI funded paired EOF catchment study in Plum Creek, which is also in the Lower Fox River basin).

Based on the reasonably good relationships between the two catchments, and the time frame of our funding, we intended to transition to the Managed Grazing treatment phase of the study by directly planting a grazing pasture mixture into the south catchment after corn silage was harvested in early September 2018 (i.e., no-till planter). Our observations, and typical corn silage harvest dates indicated that the corn silage crop appeared to be well ahead of schedule and should have been harvested by that time. After the pasture was established, cattle grazing was expected to start in the south treatment plot by summer 2019. Potential treatment phase runoff events could've been sampled as soon as the pasture mix provided reasonable cover (early winter 2018 to spring 2019), because the conventional north catchment would have been chisel plowed and much more prone to soil erosion compared to the south catchment --- therefore a typical representative comparison between the two very different management systems.

<u>Unfortunately, a number of factors disrupted our planned schedule</u>: (a) the farm operator had a major spillage issue with their manure storage system in summer 2018 which diverted focus from our collaborative study; (b) unusually high rainfall from August 28, 2018 through October 2018 created wet field conditions; (c) farm operator substantially delayed harvesting corn silage crop until very late October or early November 2018, by which time crop moisture was actually too dry for a good silage crop; (d) corn crop was finally harvested as silage prior to a November 5, 2018 runoff event, but it was too late and wet to plant the grazing mixture; (e) field was deeply rutted by the harvesting equipment during initial harvest, and some standing crop was left unharvested because that portion of the remaining field was too wet (Figure 7); (f) operator finished harvesting the remaining silage crop, but left even more and deeper ruts (Figure 8), so potential samples from a runoff event in December were not collected since it was unreasonable to expect that the samples from both plots would be representative, or could be expected to still have a good relationship between them. Many of the ruts left by the harvesting equipment in fall 2018 were over 12 inches deep, as seen in Figures 7 and 8.

Therefore, the planned no-till pasture mix seeding could not take place in fall 2018. Importantly, the deep ruts held-back and/or diverted runoff from the field in an unpredictable fashion. The ruts seemed worse in the north catchment, so the impact of the ruts was not likely to be the same in both catchments. Furthermore, the slopes of the study plots are nearly planar in nature, so they don't strongly focus runoff along a concentrated pathway; thereby, exaggerating the impact of the ruts on runoff variability during runoff events (variability in direction of runoff, and volume). So, runoff could go between the plots, or outside the plot areas depending on variables like wind direction/speed or any slight alteration due to corn stalks, etc. In addition, the ruts served as runoff detention areas and likely would have served as areas where suspended soil particles settled during runoff events, greatly disrupting the viability of representative runoff samples. Unfortunately, the ruts remained in the field from fall 2018 until the north control catchment and a small portion of the south treatment catchment were rotary tilled in May 2020. Only then could paired water sampling resume.

Figure 7. Photos of field ruts caused by harvesting under wet conditions, and standing corn crop yet to be harvested as of 11/23/18 (date of photos). The deep ruts greatly disrupted runoff flow paths and created settling areas for TSS and phosphorus, so representative water samples could no longer be counted on. It seemed unscientific to eyeball the samples collected during each ensuing runoff event to see if they looked representative or not (i.e., to toss or keep). Heavy rains in 2019 and some grazing of cattle did little to level the ruts. Therefore, water monitoring was discontinued until tillage removed the ruts in May 2020.

2019 delays: By late spring 2019, we were informed that the initial farm operator was no longer renting and operating the farm because the lease was discontinued in late 2018. Instead, the owner, the Oneida Nation would take over operations, including grazing the entire farm, as well as direct field operation of the grazing study plots. This changeover created a potential delay in the expected field cultivation, including planting of both the planned corn silage crop in the control plot, and the grass mixture in the grazing plot. However, record-setting rain in 2019 delayed planting in N.E. Wisconsin, which greatly delayed and even prevented tillage and planting of crops in our study area. So, the changeover of farm operators may not have contributed as much to our delayed progress as the wet field conditions. Many farmers in the area did not plant their crops due to wet field conditions and signed up for the U.S.D.A. Prevent Plant government program. The annual precipitation record of 48.63 inches in 2019 exceeded the previous record which was set in 2018 by 9.42 inches, or 24% (nearby NWS Green Bay station; records 1887 to present). As a result of the transition to a new operator and the extremely wet field conditions, the control plot was not tilled or planted in 2019, and a fair amount of grass was growing in the fallow soil (instead of the planned corn silage). Because the exceedingly wet soil conditions continued through the fall and winter of 2019, the planned conventional fall tillage operation was not possible in the control catchment.

Figure 8. Photos taken 4/19/19 of deep ruts looking toward north catchment (upper left), upslope of north catchment (upper right), just upslope of south catchment outlet (lower left), and looking downslope toward both monitoring stations (lower right). These ruts greatly disrupted the flow path of runoff until spring tillage in 2020.

The Oneida Tribal Nation began grazing their own cattle on the study farm in summer 2019, and these cattle were first grazed in the south treatment catchment by late summer 2019. However, the conventional corn silage crop and tillage were not in place in 2019 to compare to the grazed catchment. Overall, the fencing and grazing management improved compared to the previous operator.

Treatment Period - Conventional corn crop: As previously stated, it was too wet to plant a corn crop in 2019 due to record-breaking precipitation. The extreme ruts from the previous fall harvest in 2018 only made the situation worse. Conventional tillage via a rotary tiller was conducted in spring 2020 in the north control catchment by the new operators, the Oneida Nation which owns the land and started farm operations in 2019. Tillage removed the ruts and killed volunteer grasses that otherwise prevented a good comparison to the grazed treatment plot. Corn was planted May 5, 2020 to closely parallel the corn silage that was grown under the previous farm operator. The grazed area was reseeded with a pasture mix in the treatment catchment in spring 2020: mostly with no-till, but part of the grazing plot required tilling to remove ruts. Electric fencing was added to the control catchment and around the monitoring equipment using project funds, shortly before grazing in that area resumed in summer 2020. Fencing was maintained by UWGB until monitoring equipment was removed at project end. Corn in the north control catchment was harvested and chisel plowed November 12, 2020. UWGB removed as much of the remaining vegetation by hand 12/3/20 in the area above the outlet flumes that was "enclosed" by the berms, but was not plowed in the control plot. The early spring 2021 study site conditions can be seen in Figure 9, where new growth is just starting in the pasture mix south treatment catchment, in contrast to the north control catchment where the fall chisel plowed soil is bare and prone to erosion.

Figure 9. Aerial orthophotos of grazing study monitoring stations and catchments: April 2017 (left) during pre-treatment phase, prior to spring tillage and planting, and May 2020 (right) at beginning of treatment phase, after spring tillage and corn planting in north control plot. Additional grazing pasture mix was planted in the south treatment plot shortly after May 2020 to fill in the areas that were tilled to remove deep ruts from 2018 late corn silage harvest. Note grazing area surrounding north control plot, including most of the south treatment plot in the May 2020 image. Monitoring station houses, solar arrays, wood wingwalls and runoff collecting berms can be seen in these images.

Treatment Period Sampling: No runoff event samples were collected in 2020 or 2021 because the runoff events were too small, or rainfall intensity did not exceed the soil infiltration capacity sufficiently enough to collect representative samples (flume height < 0.08 foot, and fairly dry summer), or there were other issues. Precipitation and runoff were well below normal since summer 2020, so no runoff event samples were captured during the treatment phase of the study. A runoff event occurred in October 2020; however, it was apparently just below the threshold for collecting viable water samples with the automated sampler. Runoff events were also low throughout the USGS/UWGB Lower Fox River monitoring network. As previously stated, the Oneida Nation continued to keep the non-treatment north catchment in conventional farming by harvesting the corn crop, and chisel plowing the field by mid-November 2020.

Due to delays, and the lack of runoff samples during the treatment phase of this GLRI study, we had anticipated continuing the managed grazing project after this GLRI grant concluded by applying to other RFP's for the minimal financial assistance needed to finish the treatment phase of our monitoring study.

However, while cooperation with the new farm operators (Oneida Nation) was good, they did not plan on farming any portion of the farm field encompassing our study area in a conventional dairy crop manner. Therefore, they did not till, plant or harvest a corn silage crop in 2021 because the entire acreage there was intended for organic cattle grazing operations through the Oneida Nation Tsyunhehkw^ culturally based community program, and continuing to manage the conventional plot was probably too difficult, particularly given the resource stresses caused by COVID-19. The small area of the conventionally-farmed plot contributed to this difficulty.

Therefore, after discussions with NEW Water (Main grant awardee), it was decided that we should not expect to continue to utilize the Oneida Nation for conventional farming of the control plot. Furthermore, it was also unlikely that we could get another operator that could consistently manage about 0.75 acres as a typical corn silage field (convention dairy), so the project was <u>reluctantly</u> discontinued and all of the monitoring equipment was removed in September 2021.

Results And Discussion

Pre-Treatment Period: Event runoff volume, precipitation, and TSS, TP and DP event-mean concentrations (EMC's) are listed by event in Table 1 for the pre-treatment (control) period (6/9/16 to 11/6/18). Precipitation listed in Table 1 is based on either the north or south station gauge, depending on which one was determined to provide the most accurate result, because there were times when wind affected the precipitation amount, or one of the gauges was plugged, etc. Runoff volume in mm is based on the total event runoff (flow) volume divided by the estimated drainage area of each catchment. An expanded table that includes these parameters, plus flow in liters, and loads and yields from the control period is included in the Appendix A.

Area-weighted runoff volume during the pre-treatment/control period events ranged as high as 20.2 mm, with a mean of 4.8 mm and a median of 2.3 mm at the south catchment. Runoff volume was somewhat less at the north catchment, with a maximum of 14.6 mm, a mean of 3.9 mm and a median of 2.6 mm.

During the pre-treatment phase, the median TSS EMC from the south catchment was much lower than the north catchment: 165 and 273 mg/L, respectively (Table 1). However, the median TP EMC from south catchment was similar to the north catchment: 1.01 and 1.09 mg/L, respectively. The median DP EMC from the south catchment was also similar to the north catchment: 0.35 and 0.30 mg/L, respectively.

The TSS EMC's ranged as high as 1,450 mg/L at the south catchment (4/15/17), with a mean of 378 mg/L. The TSS EMC's were generally higher at the north catchment, with a maximum of 3,010 mg/L (4/16/17) and a mean of 641 mg/L. The TP EMC's ranged as high as 4.39 mg/L at the south catchment (4/15/17), with a mean of 1.44 mg/L. The TP EMC's were generally higher at the north catchment, with a maximum of 7.57 mg/L (4/16/17) and a mean of 1.92 mg/L.

The DP EMC's ranged as high as 0.85 mg/L at the south catchment (10/10/18), with a mean of 0.43 mg/L. The DP EMC's were somewhat lower at the north catchment, a maximum of 0.73 mg/L (11/6/18), and a mean of 0.36 mg/L. All EMC phosphorus concentrations listed in Table 1, including the lowest DP EMC of 0.18 mg/L, are much higher than the Silver Creek TMDL standard of 0.075 mg/L total phosphorus (May to October median).

The dissolved phosphorus fraction varied from over 90% during the smallest events, to 10% or lower during the largest events when the particulate phosphorus dominated. The average dissolved phosphorus fraction was 45.6% and 39.6% from the south and north catchments, respectively. The median dissolved phosphorus fraction was 41.7% and 32.2% from the south and north catchments, respectively. These relatively high DP fractions indicate that standard best management practices would not likely be effective in greatly reducing TP during many events. The ratio between TP and TSS was also calculated (not shown). Interestingly, with one exception, the ratio was the same or higher for the south catchment events. This observation could be related to the soil test phosphorus results, where the south catchment was 40% higher than the north catchment, despite the catchments being directly adjacent to each other in the same farm field, and along the same slope (i.e., not up or down slope).

Table 1. Event-mean constituent concentration (mg/L) and runoff volume (mm) at North and South Paired Field Catchments: pre-treatment period.

			Runoff		**TSS**		**Total Phosphorus**		**Dissolved Phosphorus**	
	Mean		4.8	3.9	378	641	1.44	1.92	0.43	0.36
	Median		2.3	2.6	165	273	1.01	1.09	0.35	0.30
	maximum		20.2	14.6	1,450	3,010	4.39	7.57	0.85	0.73
Event	**#**	**Rain**	**South**	**North**	**South**	**North**	**South**	**North**	**South**	**North**
2/18/17	1	47.5	1.9	1.9	24	47	0.87	0.77	0.75	0.62
3/7/17	2	6.9	1.7	3.4	842	830	2.42	2.43	0.47	0.41
3/24/17	3	15.0	0.9	1.6	48	79	0.48	0.62	0.34	0.36
3/26/17	4	13.0	2.1	2.7	143	217	0.65	0.79	0.33	0.29
3/30/17	5	7.1	0.7	1.4	21	30	0.40	0.37	0.27	0.22
4/3/17	6	7.6	0.7	0.8	132	156	0.76	0.81	0.29	0.28
4/4/17	7	6.4	1.0	1.0	20	38	0.41	0.39	0.25	0.25
4/15/17	8	17.5	2.4	2.4	1,450	2,630	4.39	6.51	0.41	0.33
4/16/17	9	11.4	4.2	4.4	1,220	3,010	3.51	7.57	0.36	0.30
4/20/17	10	21.8	6.7	6.3	1,020	1,320	3.14	3.55	0.45	0.29
4/21/17	10a	4.1	0.9	1.0	Inadequate runoff to sample in both plots					
4/27/17	11	34.3	3.0	3.4	200	328	1.07	1.17	0.27	0.23
5/1/17	12	22.4	2.6	3.0	508	875	1.83	2.59	0.27	0.22
4/21/18	13	101.6	20.2	14.6	19	46	0.32	0.24	0.29	0.24
5/2/18	13a	30.7	1.1	0.3	inadequate runoff in north plot to sample					
5/3/18	14	35.6	9.2	8.4	187	411	0.69	1.01	0.18	0.19
6/18/18	15	66.9	1.2	2.2	224	704	1.02	1.71	0.45	0.37
10/9/18	16	23.4	18.3	11.6	520	600	1.96	2.05	0.77	0.63
10/10/18	17	12.4	10.9	4.3	125	68	1.06	0.65	0.85	0.58
11/6/18	18	23.9	5.7	2.6	110	156	1.00	1.25	0.72	0.73

Area-weighted runoff volume, and TSS and TP EMC's for north and south catchments are compared and plotted serially by event in Figure 10, during the pre-treatment period. A total of 20 events were captured during the pre-treatment phase. Event runoff volumes and TSS and TP EMC's varied greatly in the pre-treatment phase, which was useful for establishing paired relationships for a wide range of conditions and seasons. Despite this variability, the TSS and TP EMC's of the two catchments generally tracked closely together, with the exception of the April 15 and 16, 2017 events, when there was much more soil erosion in the north catchment, which was also reflected in the TP concentrations (i.e., mostly from particulate phosphorus). The April 15, 16 and 20, 2017 events had the highest TSS and TP EMC's.

Runoff between the two catchments tracked closely together, with the exception of the April 23, 2017, October 9 and 10, and November 6, 2017 events, when runoff was higher from the south catchment. It appears that the south catchment captured a greater area during large runoff events, which was most likely from the area adjacent to the south side of the plot. The drainage area of the south catchment likely increases during some runoff events because the field slope is planar and generally doesn't concentrate flow that well. Therefore, high runoff from the adjacent area to the south can spill over to the south catchment, or windy conditions can change the drainage areas of each catchment somewhat.

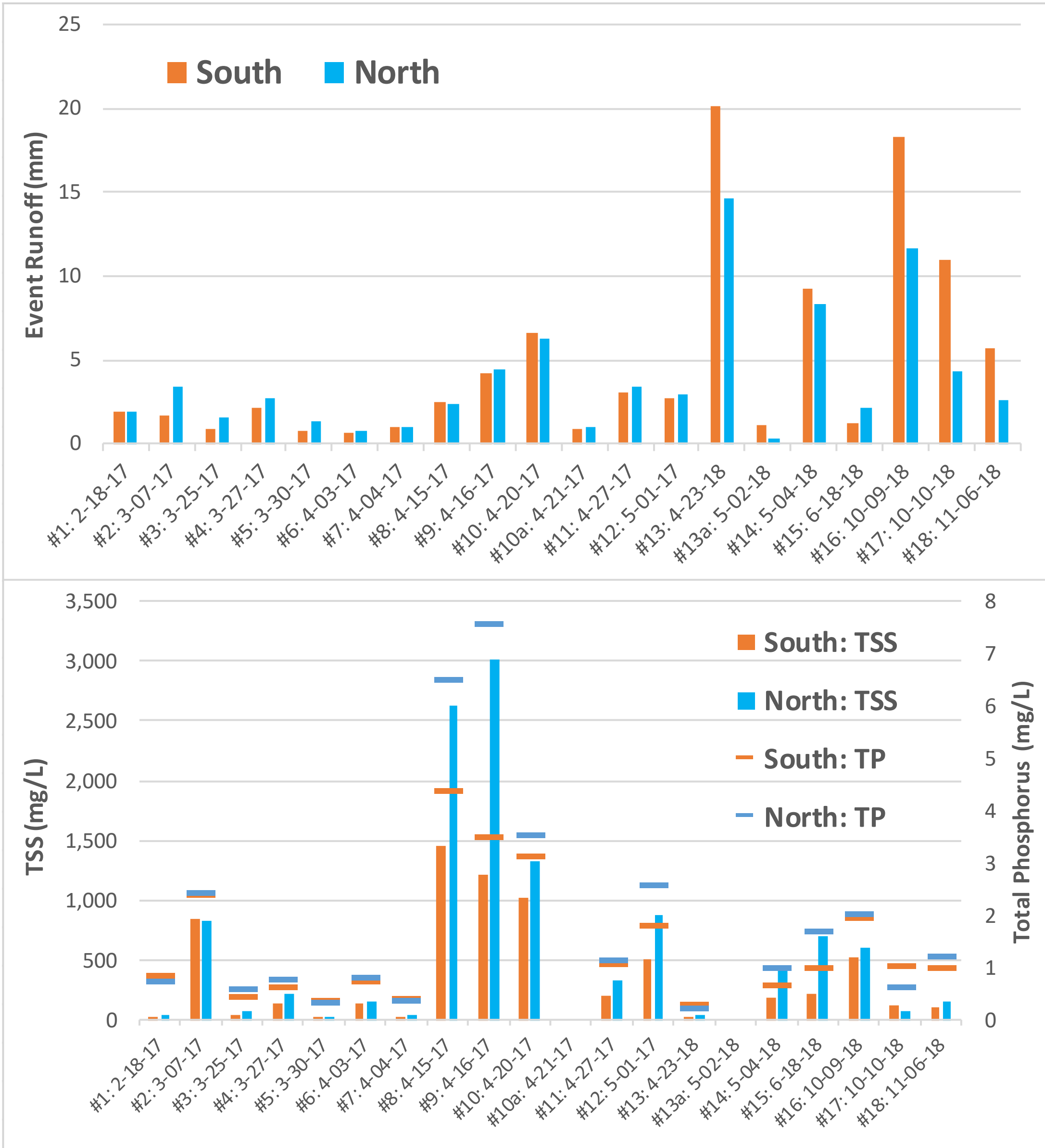

Figure 10. Area-weighted runoff volume (upper, in mm), and event-mean concentrations of TSS and total phosphorus (lower, in mg/L) by event for south and north paired catchments during pre-treatment period.

The plotted relationships between the north and south plots for runoff volume (mm), and event-mean concentrations of TSS, TP and DP are shown in Figure 11 for the pre-treatment period. These same relationships are plotted in natural log space in Figure 12. These plots include only the pre-treatment period, for which the associated best-fit trend regression lines and R^2 statistics are shown. The relatively high R^2 statistics lend credence to the validity of the relationships between the north and south catchments, for runoff volume and concentrations of TSS, TP and DP. Both normal and log-space regressions indicate that it is likely we would have been able to detect whether there was a change in the relationships between the north and south catchments (pre- vs post-treatment) if an adequate number of events were captured during the treatment period --- and to then calculate the change.

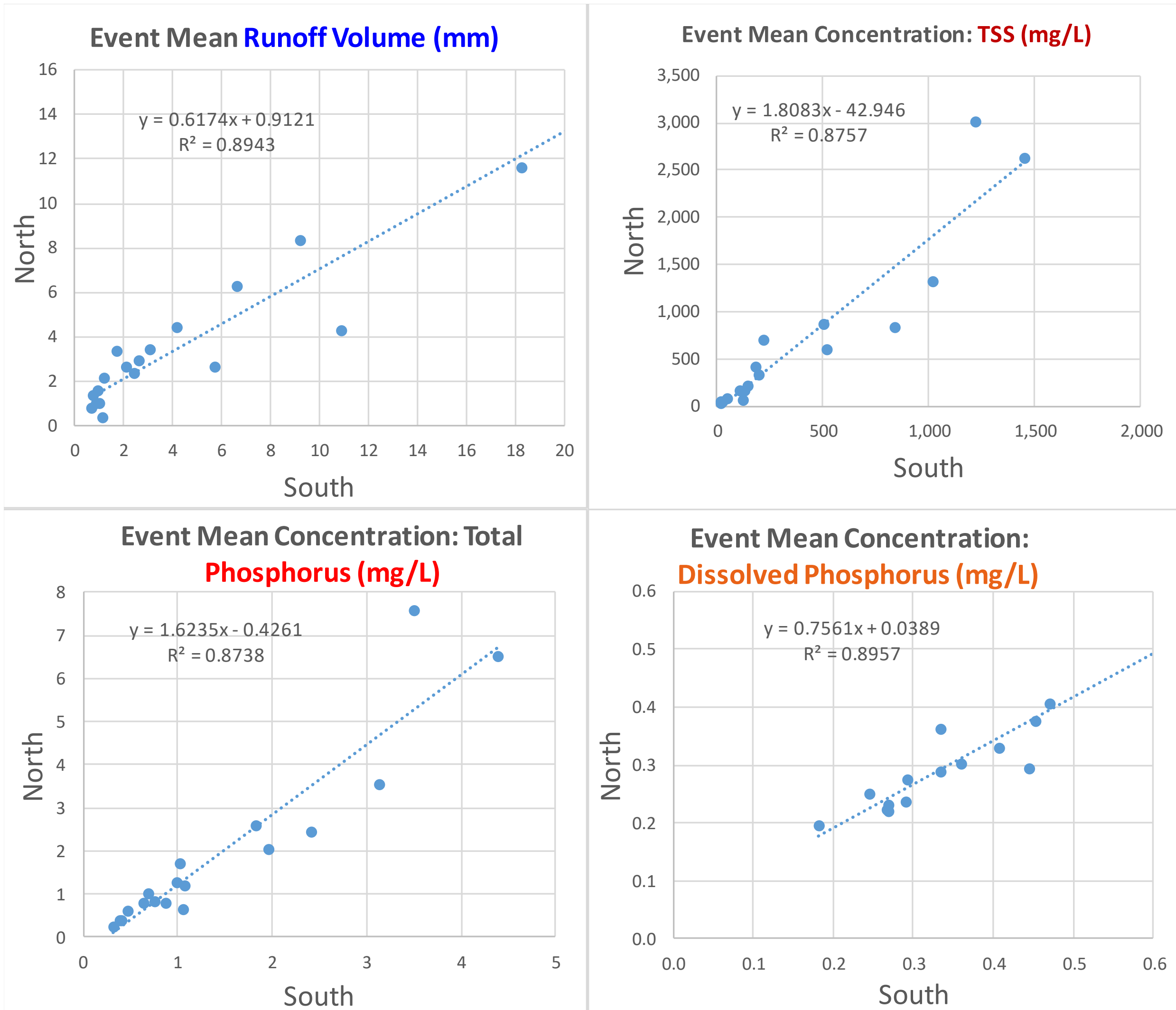

Figure 11. Regression plots of South and North paired EOF catchments for runoff volume (n=20), and event-mean concentrations of TSS (n=18), TP (n=18) and DP (n=18) during 20 calibration (pre-treatment) period events.

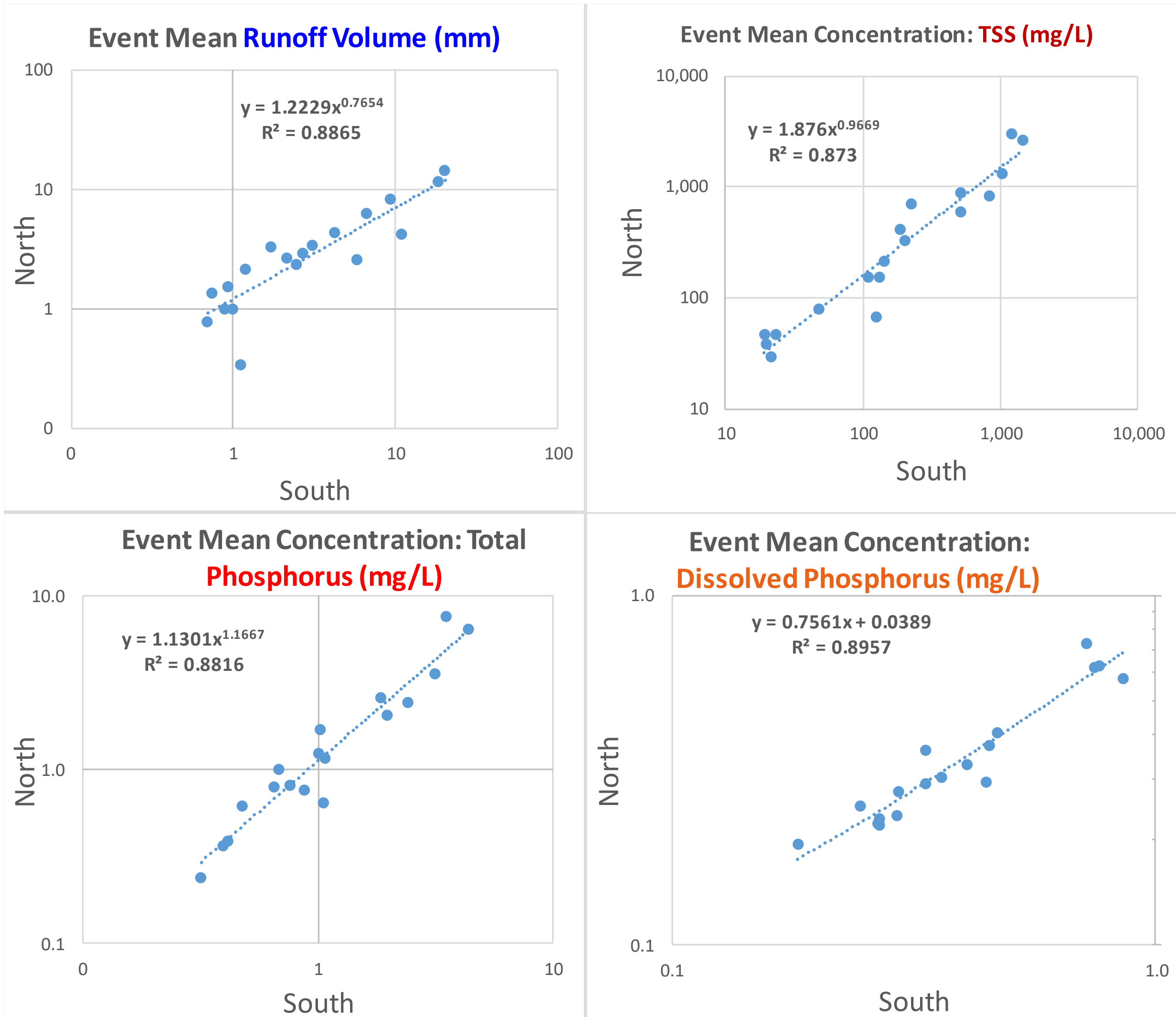

Figure 12. Log-space regression plots of South and North paired EOF catchments for runoff volume (n=20), and event-mean concentrations of TSS (n=18), TP (n=18) and DP (n=18) during 20 calibration (pre-treatment) period events.

Treatment period: Precipitation and peak stage are listed by event in Table 2 for the transition and treatment periods. Precipitation amounts listed in Table 2 are based on either the north or south station gauge, depending on which one was determined to provide the most accurate result. Runoff stage in feet represents the maximum stage recorded for the event.

As previously stated, the field catchments were judged to be too rutted to collect valid representative samples from December 2019 until May 5, 2020. As shown by the peak runoff stages listed in Table 2, many sampling events could have otherwise been captured during this period. As many as 21 of these events had peak stages at both sites that seemed high enough to sample. In addition, the ruts likely served to hold back runoff from the fields at times, thereby lowering the duration, stage, and frequency of the measured runoff.

Table 2. Treatment period (transitional and managed grazing treatment). Underlined peak runoff stages were negligible, and blue were less than could be sampled.

			Peak	**Stage**		
	Precip.	**(inches)**	**Runoff**	**(feet)**	**notes, sample ids**	**notes, sample ids**
Event	**South**	**North**	**South**	**North**	**South**	**North**
12/2/18	0.54	0.95	0.014	0.041	rain & snow	
12/27/18	0.66	0.66	0.208	0.194		
1/6/19	1.01	1.26	0.452	0.433	rain & melt	
3/12/19	1.30	1.38	0.341	0.465	rain & melt	
4/7/19	0.53	0.39	0.100	0.197		
4/12/19	0.53	0.65	0.100	0.154		ON#1232-1233
4/17/19	0.77	0.79	0.221	0.281		
4/22/19	0.87	0.89	0.278	0.035	OS#7216-7222	
5/1/19	0.47	0.53	0.159	0.040		
5/8/19	1.55	1.55	0.334	0.062	OS#7223-7229	
5/19/19	1.20	1.25	0.255	0.069		
5/27/19	1.54	1.64	0.390	0.058		
6/18/19	0.70	0.70	0.435	0.010	south brief	
6/24/19	0.94	0.97	0.212	0.025	south brief	
7/7/19	0.55	plugged	0.010	0.305		
7/20/19	2.29	plugged	**0.560**	**0.535**		
8/5/19	2.32	plugged	0.410	0.323	GBay NWS = 2.32"	
9/3/19	2.00	1.95	0.142	0.268		
9/10/19	1.60	1.67	0.159	0.291		
9/10/19b	1.25	1.30	**0.826**	**0.866**		
9/11/19	1.47	1.47	**0.552**	**0.631**	1st of 2 events on	same day
9/12/19	1.48	1.45	**0.740**	**0.849**		
9/19/19	0.91	0.91	0.174	0.444	south brief	
9/22/19	0.64	0.64	0.039	0.137		
9/27/19	1.03	1.06	0.450	0.577	south brief	
10/1/19	0.66	0.66	0.141	0.270		
10/1/19b	1.06	1.11	0.301	0.377		
10/2/19	0.30	0.33	0.010	0.128		
10/5/19	0.35	0.34	0.010	0.138		
10/11/19	0.82	0.86	0.125	0.222		
10/21/19	0.61	0.67	0.010	0.131		
11/22/19	0.80	0.83	0.010	0.122	no fall tillage, too	wet
11/27/19	1.28	1.31	0.067	0.212		
12/29/19	0.46	0.47	0.168	0.255		
12/30/19	1.65	1.61	0.206	0.200		
3/9/20					possible runoff	event
3/12/20	0.75		0.578		stage uncertain &	possible ice/melt
3/13/20	0.78	0.75	0.473	0.173	stage uncertain &	possible ice/melt
3/29/20					possible runoff	event
5/5/20	*tilled & corn planted in control plot*				*treatment phase*	*with control OK too*
5/18/20	2.96	3.42	0.148	0.073		
5/28/20	1.81	1.78	0.131	0.059	OS#7231-7235	
10/12/20	0.45	0.46	0.054	0.157		
10/22/20	**3.71**	**3.77**	0.055	0.311	OS#7238-7241	ON#1234-1255
11/12/20	*chisel plowed in control plot*					
4/8/21		0.45		0.163	not enough to	sample
5/4/21	0.85	0.87	0.047	0.128		
8/8/21	**4.27**	plugged	0.089	0.084	OS#7245-7247	ON#1264-1266
7/21/21	stage testing, OK		sampler tests		OS#7242-7244	ON#1261-1263
9/13/21	stage testing, OK		sampler tests		OS#7248-7252	ON#1267-1271

Volunteer grasses and other vegetation took hold during this un-tilled period, which also likely contributed to lower runoff amounts than would have otherwise occurred if the control catchment had continued to be managed as the conventional corn silage dairy row crop, because tillage and bare fields contribute to relatively high potential for runoff. Had these undesirable conditions not been present, an estimated 30 or more sampling events may have been captured during this period.

If the pasture mixture had been no-till planted in late summer or early fall 2018 as planned (and the control plot tilled), runoff events reflecting both the managed grazing treatment and control could have been captured starting as soon as April or May 2019, when the pasture crop would have been established enough to provide reasonable cover compared to the control plot. A total of up to 25 runoff events could have been collected for comparing the treatment and control plots from May 8, 2019 to December 2019 (Table 2). This estimate assumes that a concentration could have been substituted for runoff events for which there were representative samples from the control catchment, but inadequate runoff from the treatment catchment (and recognizing that field ruts would no longer disrupt runoff from either catchment). This estimate of potential runoff events may seem high for such a short period of time; however, a record amount of precipitation occurred in 2019 at the nearby Green Bay NWS station; plus, the UWGB collected 26 runoff events in 2019 from our other paired edge-of-field watershed monitoring project in the Plum Creek watershed (GLRI Grant GL00E01451), where precipitation was somewhat lower than at the Oneida study site.

On May 5, 2020 the north control field was tilled and planted, so both the control and treatment areas were finally fully functional from a representative treatment vs control perspective. Unfortunately for our study, relatively dry weather conditions were present in 2020 and 2021, when we estimate that there were only about 7 runoff events at most that came close to having adequate samples for treatment period comparisons (Table 2). However, no sample water was collected when sampling was triggered during this period, even during what appeared to be a moderate event on 10/22/20 when 22 bottles from the north station were supposed to have had runoff samples. It is suspected that stage may have been overstated at such times, perhaps caused by worms slightly plugging the stage bubbler tube, despite a potential remedy that had been installed (see Appendix B). Another possible explanation was that stage and samplers were not functioning correctly. However, the stage and samplers were functioning correctly during prior event sampling; plus, sampler function was also tested during prior annual quality control checks. Stage and sampler function were also confirmed when tests were conducted on 7/21/21 and 9/13/21.

Therefore, no runoff samples were collected during the treatment period which could otherwise have been used to compare to the pre-treatment results. Therefore, we were unable to fulfill the primary objective of our study, which was to estimate the impact of switching from a typical corn silage dairy crop to managed cattle grazing on yields of runoff, TSS and dissolved and total phosphorus.

If we had been able to obtain sufficient runoff samples during the treatment phase of our study, we would have employed a weight-of-evidence approach to judge treatment effectiveness to ensure that a finding of statistical significance alone would not be mis-interpreted. This is the approach that UWGB employed in the ephemeral gully grass strip treatment study in Plum Creek (UWGB 2021, GLRI Grant

GL00E01451). For example, other lines of evidence and evaluation could have been included besides the primary Analysis of Covariance (ANCOVA) test recommended by Clausen and Spooner (1993) for a paired watershed study design, including: a) sequential event plots showing before and after treatment periods; b) plots of ranked differences before/after treatment; c) before/after treatment boxplots; d) scatter plots of north versus south catchments before/after treatment; e) simple regression plots to visualize before/after treatment differences; and f) non-parametric Wilcoxon Ranked sum difference test. Statistical analysis would have primarily been conducted with the SAS program. Finally, to estimate the potential reductions in runoff, TSS, TP and DP, we would have applied the log-space regression relationships between the north and south catchments, which were derived during the calibration period (Figure 12), to each of the north event EMC's during the treatment period to predict what the south values would have been without the managed grazing treatment (Clausen and Spooner 1993; e.g., based on the difference between the mean predicted and observed values).

As previously stated, due to the lack of treatment period samples, it was not possible to conduct statistical analyses with ANCOVA to test for significant differences between pre- and post-treatment periods for TSS, TP, DP and runoff volume. However, Figure 13 is an example of what we would have liked to have shown.

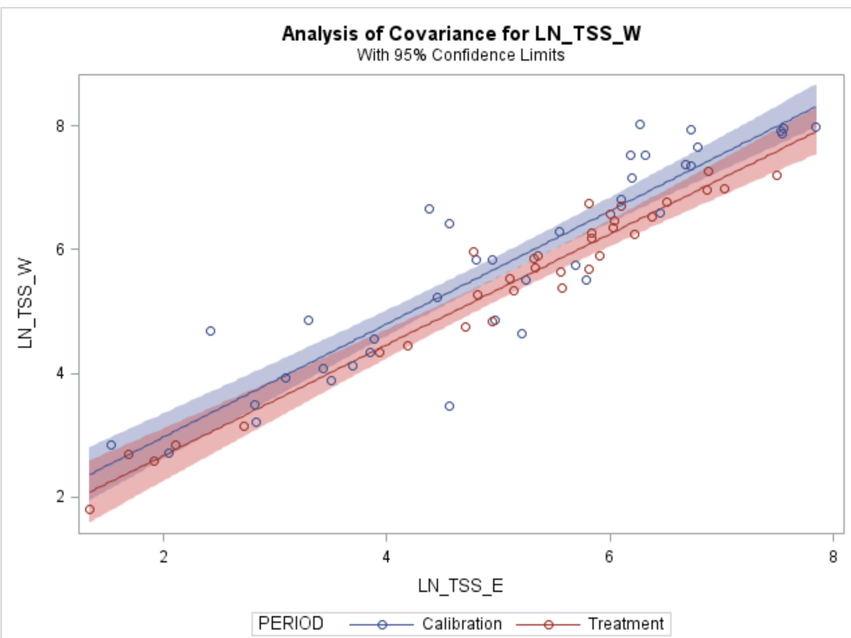

Figure 13. EXAMPLE ONLY: ANCOVA plot of the natural log of event-mean TSS concentrations (mg/L) during the calibration and treatment periods: east catchment (LN_TSS_E) versus west treatment catchment (LN_TSS_W), with 95% confidence limits. This figure is an excerpt of a similar paired edge-of-field catchment study conducted by UWGB in the Plum Creek watershed to estimate the impact of installing a grass strip in the concentrated flow channel to reduce ephemeral gully erosion (UWGB 2021, Figure 17; significant treatment effect was found, p<0.05).

In-Situ Turbidity compared to TSS and TP Results: Campbell Scientific OBS-501 turbidity probes were installed at both stations in a half-pipe below the H-flumes to measure continuous in-situ turbidity during runoff events. Turbidity measurements were collected and logged every two to four minutes during events. Turbidity units were summed on a flow-weighted basis during each event to create an event-mean turbidity "concentration", similar to the flow volume proportional method used to create the composited sample that represented each event, and associated event-mean concentration (EMC).

The relationships between backscatter and sidescatter turbidity and EMC of TSS at the north and south stations are illustrated in Figures 14, on an event basis. The relationships between backscatter and sidescatter turbidity and EMC of TP at the north and south stations are illustrated in Figure 15, on an event basis. Some events were excluded from the plots and statistics: 2//18/17 and 3/7/17 (turbidity and TSS too low); 3/24/16 and 3/26/17 (only backscatter excluded at south station, possible debris issue); 4/15/17 and 4/16/18 (only sidescatter excluded at north station because turbidity range exceeded).

R^2 statistics were calculated for the relationships between turbidity and both TSS and TP EMC's, as well as on a mass basis (i.e., total TSS and TP mass, versus summed turbidity units for each event). These statistics are summarized in Table 3.

The relationships and R^2 statistics displayed in Figures 14 and 15 and summarized in Table 3 look reasonably good, except for the mass comparisons. However, much of the data required extensive smoothing and removal of extraneous data caused by small debris. This problem was primarily caused by low runoff flow rates exiting the flumes, which was due to the small drainage areas of the catchments (0.57 acres), and moderately permeable soils (Hydrologic Group B). Therefore, we would not generally recommend deploying this type of probe in a similar low flow edge-of-field situation where even small amounts of debris can disturb the optical path (without a means to keep nearly all debris out of optical path). Note that the 1 foot H-flume had an opening of only 0.875 inches at the narrowest point, so there is not much water volume when stage is less than 0.25 feet. In addition, the backscatter turbidity device requires a large obstruction-free optical zone of about 100 mm during low turbidity conditions.

The turbidity probes were removed in 2019 due to these issues, coupled with concerns about possible damage to the relatively expensive turbidity probes if grazed cattle got through the fence. Grazed cattle caused some minor damage November 7, 2016 to the station houses by removing doors, etc., so it could happen again. After the probes were removed, the UWGB put one of the probes to immediate use by installing it at the GLRI-funded USGS Plum CTH D monitoring station (#04084911), and it was operating at least through November 2021 (via Fox-Wolf Watershed Alliance administered GRLI grant GL00E01451).

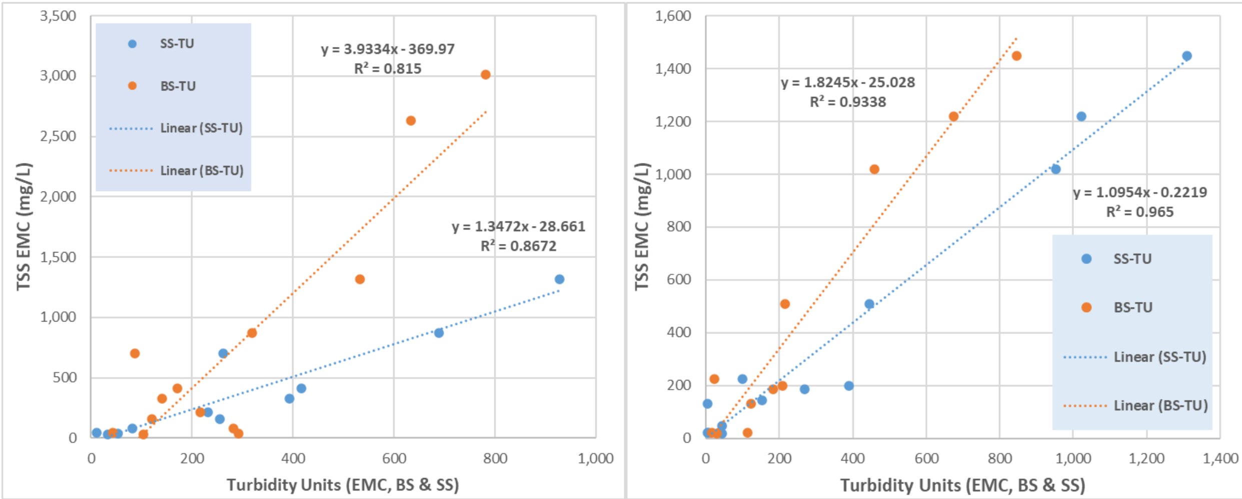

Figure 14. Backscatter (BS-TU) and sidescatter (SS-TU) turbidity units compared to TSS concentrations, on an event-mean basis. North station (left) and south station (right) at Oneida grazing study site.

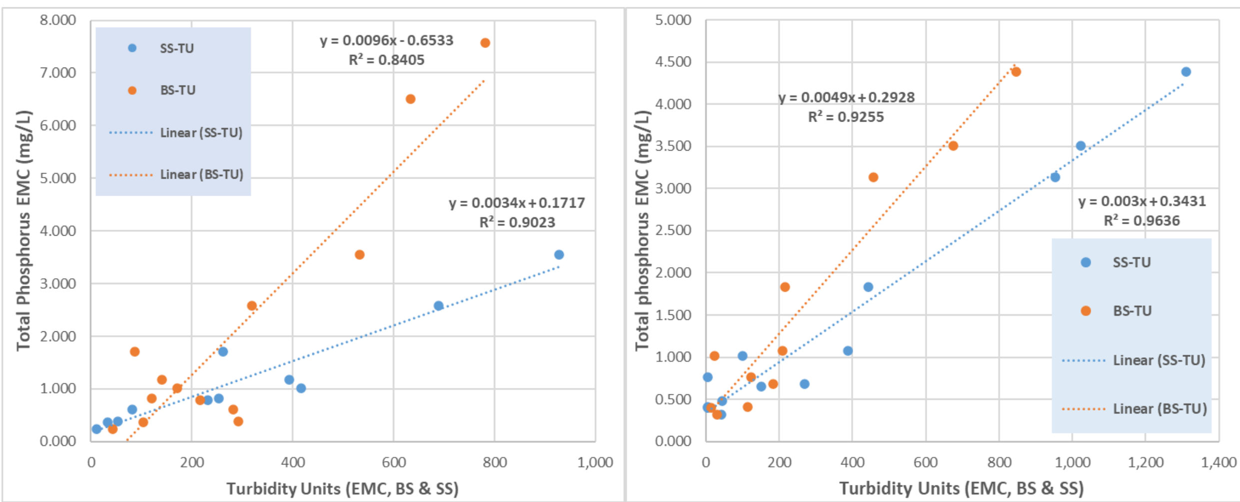

Figure 15. Backscatter (BS-TU and sidescatter (SS-TU) turbidity units compared to total phosphorus concentrations, on an event-mean basis. North station (left) and south station (right) at Oneida grazing study site.

Table 3. R-squared statistics for relationships between event-mean concentrations and event-mean turbidity units, and between event mass and event turbidity quasi-mass units at the Oneida north and south monitoring stations. BS-TU and SS-TU are backscatter and sidescatter turbidity units, respectively.

		TSS		Total phosphorus	
		BS-TU	SS-TU	BS-TU	SS-TU
Concentration (mg/L)	North	0.82	0.87	0.84	0.90
	South	0.93	0.97	0.93	0.96
Mass (kg)	North	0.90	*0.35*	0.59	0.53
	South	*0.06*	0.53	*0.002*	*0.24*

UWGB APEX Field Modeling Project: In his graduate thesis for the University of Wisconsin-Green Bay, Kalk (2018) conducted an evaluation of the Agricultural Policy/Environmental eXtender (APEX) model (Steglich et al. 2019) to simulate runoff, sediment, and phosphorus loss from agricultural fields in northeast Wisconsin, which included delineating and modeling the two catchments in this grazing study (Figure 16). As an extension of the project work, initial modeling using data from the paired grazing study EOF catchments was performed by Kalk. The same USDA APEX model framework and parameter set used to calibrate other EOF sites in the Lower Fox River watershed was used to simulate runoff, TSS and phosphorus losses from the north and south catchments. These sites had the smallest observed runoff per unit area of all sites tested in Kalk's study. An example of his work to simulate event runoff at the two project sites is shown in Figure 16, where the general response to the events was good.

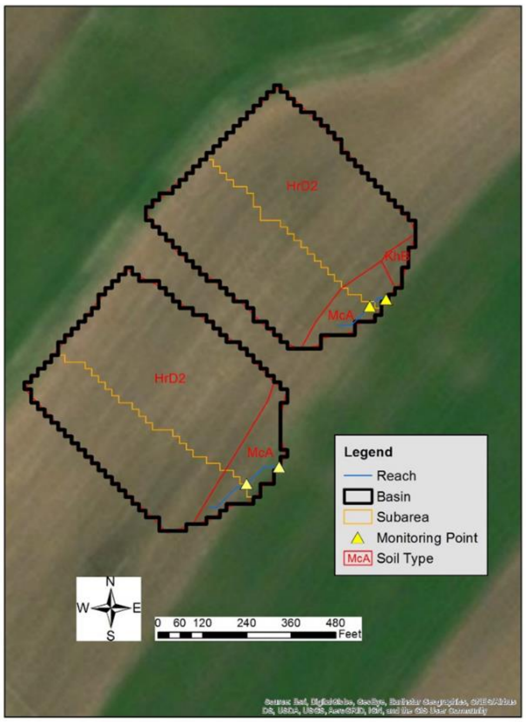

Figure 16. Watershed boundaries, subareas, water reaches, soils, and outlet points for Oneida North and South paired watersheds as modeled by Kalk (2018). Soil type map units are from the USDA SSURGO database.

In general, both catchments responded similarly to precipitation. Inspection of the individual runoff events (Figure 16) shows that most of the events were simulated reasonably well at the north and south sites, despite less than ideal evaluation statistics. The largest under prediction was for the 16 April event that immediately followed the 15 April event. The following coefficient of determination statistics (R^2) between observed and APEX-modeled results were determined for runoff volume (0.36, 0.31), TSS (0.06, 0.03), TP (0.05, 0.60) and DP (0.16, 0.86), for the north and south catchments respectively (Tables 3.2, 3.3 and 3.4, Kalk 2018).

Although these model evaluation statistics are not ideal, it should be noted that these APEX model results were obtained without altering the calibration parameters which were established with entirely different EOF sites. In addition, and field to field variation in runoff, TSS and phosphorus can be much greater than at the typical watershed scale where differences between fields and various sources are diminished through aggregation and integration of their runoff and constituent load contributions. Seemingly small changes in farm management can make a large difference at the field scale.

This work is an example of the value of edge of field data to advancing models used in conservation planning and management practice assessment. We intended to run the SNAP-Plus model to test how well the model did at predicting TSS and phosphorus yields from the managed grazing treatment catchment. Unfortunately, no water quality runoff data were captured during the treatment period, so there were no observed yields to compare to the modeled values, thereby negating the rationale for running the SNAP-Plus model.

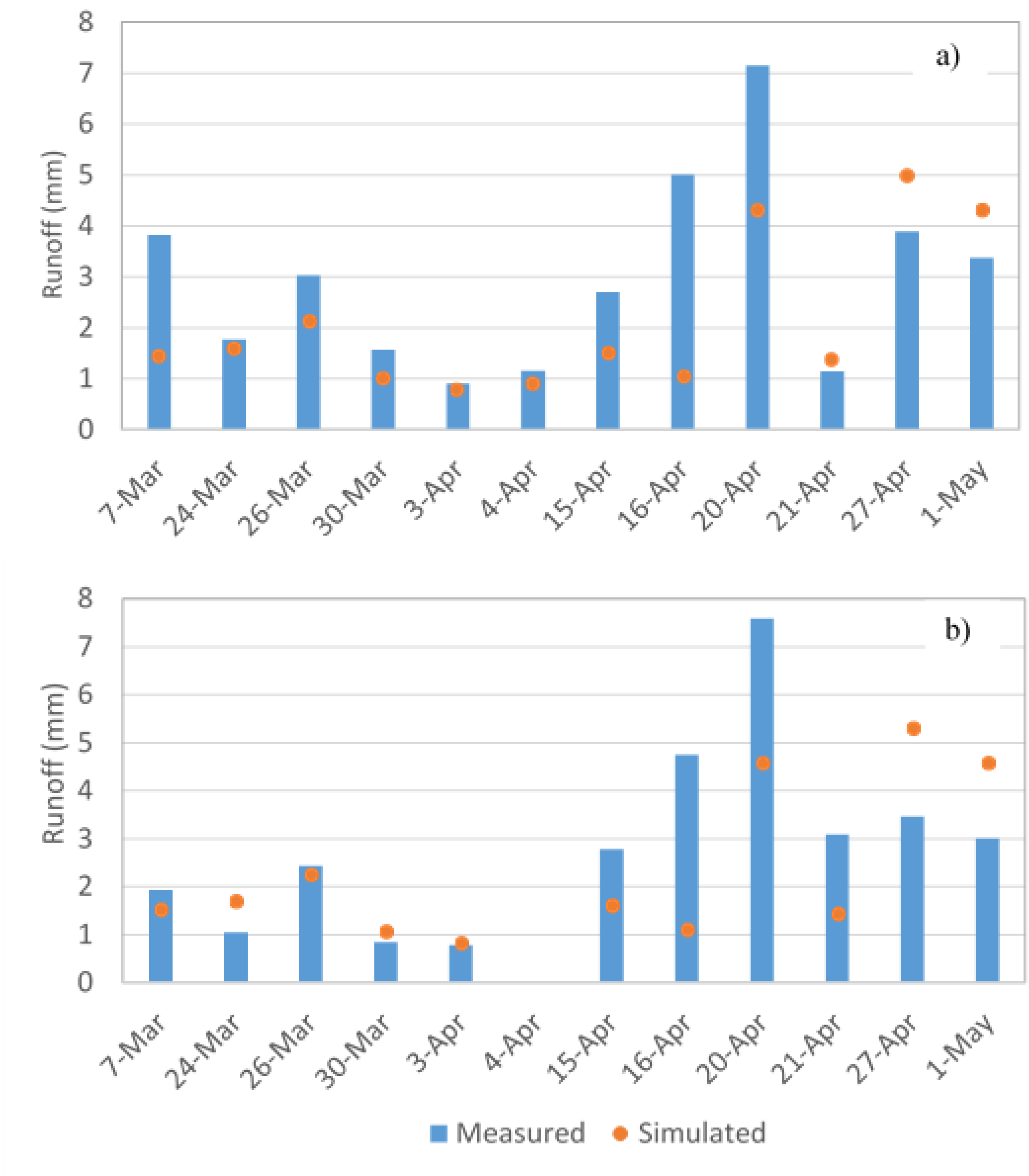

Figure 17.. Preliminary APEX simulated and observed event-based runoff comparisons at Oneida North (a) and South (b) catchments for 2017 (Kalk 2018). All events occurred during the same rainfall/snowmelt periods, excluding the April 4th event at Oneida S, because data was not collected for this period.

Conclusions

A total of 20 runoff events were collected from the north and south catchments during the pre-treatment phase of our study. Statistical analysis was conducted with the SAS 9.4 statistical analysis program in mid-2018, which indicated that data quality and quantity were sufficient to proceed with transitioning to the treatment phase. Based on the reasonably good relationships between the two catchments, and the time frame of our funding, we intended to transition to the Managed Grazing treatment phase of the study by directly planting a grazing pasture mixture into the south catchment after corn silage was harvested in early September 2018 (i.e., no-till planter).

Unfortunately, a variety of major issues including a wet fall in 2018, deeply rutted fields due to a late corn silage harvest in fall 2018, record-setting rainfall in 2019, a change in farm operators, and drier than normal conditions which produced no treatment phase event samples in 2020 and 2021, all combined to prevent the achievement of our primary objective of this study --- which was to estimate the impact of switching from a typical corn silage dairy crop to managed cattle grazing on yields of runoff, TSS and dissolved and total phosphorus.

In-Situ Turbidity probes were installed below the flume outlets at each of the stations. Real-time Turbidity measurements were successfully collected and logged during the pre-treatment period every 2 to 4 minutes during runoff events. Turbidity units were summed on a flow-weighted basis during each event to create an event-mean turbidity "concentration", similar to the flow volume proportional method used to create the composited sample that represented each event, and associated event-mean concentration (EMC). R^2 statistics were calculated for the relationships between turbidity and both TSS and TP EMC's, as well as on a mass basis (i.e., total TSS and TP mass, versus summed turbidity units for each event). The relationships and R^2 statistics were reasonably good, except for the mass comparisons. However, much of the data required extensive smoothing and removal of extraneous data caused by small debris. This problem was primarily caused by low runoff flow rates exiting the flumes, which was due to the small drainage areas of the catchments, and moderately permeable soils. Therefore, we would not generally recommend deploying this type of probe in a similar low flow edge-of-field situation where even small amounts of debris can disturb the optical path.

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APPENDIX A. Full Event Data Summary

		Oneida South Edge-of-Field					area =	0.23	ha				Oneida North Edge-of-Field					area =	0.23	ha			
	rain	Runoff		Sediment			Total Phosphorus			Dissolved P			Runoff		Sediment			Total Phosphorus			Dissolved P		
EVENT	mm	Liters	mm	mg/L	kg	kg/ha	mg/L	kg	kg/ha	mg/L	kg	kg/ha	Liters	mm	mg/L	kg	kg/ha	mg/L	kg	kg/ha	mg/L	kg	kg/ha
#1: 2-18-17	**47.5**	4,279	1.86	24	0.1	0.4	0.873	0.004	0.016	0.748	0.003	0.014	4,279	1.86	47	0.2	0.9	0.773	0.003	0.014	0.624	0.003	0.012
#2: 3-07-17	**6.9**	3,919	1.70	842	3.3	14.3	2.416	0.009	0.041	0.471	0.002	0.008	7,742	3.36	830	6.4	27.9	2.434	0.019	0.082	0.406	0.003	0.014
#3: 3-25-17	**15.0**	2,131	0.92	48	0.1	0.4	0.476	0.001	0.004	0.335	0.001	0.003	3,601	1.56	79	0.3	1.2	0.615	0.002	0.010	0.362	0.001	0.006
#4: 3-27-17	**13.0**	4,923	2.13	143	0.7	3.1	0.648	0.003	0.014	0.334	0.002	0.007	6,140	2.66	217	1.3	5.8	0.793	0.005	0.021	0.288	0.002	0.008
#5: 3-30-17	**7.1**	1,720	0.75	21	0.0	0.2	0.397	0.001	0.003	0.267	0.000	0.002	3,169	1.37	30	0.1	0.4	0.368	0.001	0.005	0.222	0.001	0.003
#6: 4-03-17	**7.6**	1,593	0.69	132	0.2	0.9	0.763	0.001	0.005	0.294	0.000	0.002	1,830	0.79	156	0.3	1.2	0.814	0.001	0.006	0.275	0.001	0.002
#7: 4-04-17	**6.4**	2,281	0.99	20	0.0	0.2	0.41	0.001	0.004	0.246	0.001	0.002	2,330	1.01	38	0.1	0.4	0.391	0.001	0.004	0.250	0.001	0.003
#8: 4-15-17	**17.5**	5,646	2.45	1,450	8.2	35.5	4.385	0.025	0.107	0.407	0.002	0.010	5,451	2.36	2,630	14.3	62.1	6.507	0.035	0.154	0.328	0.002	0.008
#9: 4-16-17	**11.4**	9,621	4.17	1,220	11.7	50.9	3.509	0.034	0.146	0.361	0.003	0.015	10,142	4.40	3,010	30.5	132.3	7.572	0.077	0.333	0.302	0.003	0.013
#10: 4-20-17	**21.8**	15,354	6.66	1,020	15.7	67.9	3.137	0.048	0.209	0.445	0.007	0.030	14,473	6.27	1,320	19.1	82.8	3.547	0.051	0.223	0.292	0.004	0.018
#10a: 4-21-17	**4.1**	2,046	0.89										2,299	1.00									
#11: 4-27-17	**34.3**	6,999	3.03	200	1.4	6.1	1.073	0.008	0.033	0.269	0.002	0.008	7,864	3.41	328	2.6	11.2	1.170	0.009	0.040	0.230	0.002	0.008
#12: 5-01-17	**22.4**	6,079	2.64	508	3.1	13.5	1.833	0.011	0.049	0.269	0.002	0.007	6,831	2.96	875	6.0	25.9	2.585	0.018	0.077	0.220	0.002	0.007
#13: 4-23-18	**101.6**	46,520	20.17	19	0.9	3.8	0.317	0.015	0.064	0.291	0.014	0.059	33,774	14.64	46	1.6	6.8	0.241	0.008	0.035	0.235	0.008	0.034
#13a: 5-02-18	**30.7**	2,561	1.11	78	0.2	0.9	0.58	0.001	0.006	0.203	0.001	0.002	781	0.34									
#14: 5-04-18	**35.6**	21,246	9.21	187	4.0	17.2	0.685	0.015	0.063	0.182	0.004	0.017	19,296	8.37	411	7.9	34.4	1.010	0.019	0.084	0.194	0.004	0.016
#15: 6-18-18	**66.9**	2,748	1.19	224	0.6	2.7	1.02	0.003	0.012	0.453	0.001	0.005	4,975	2.16	704	3.5	15.2	1.710	0.009	0.037	0.374	0.002	0.008
#16: 10-09-18	**23.4**	42,226	18.31	520	22.0	95.2	1.96	0.083	0.359	0.766	0.032	0.140	26,824	11.63	600	16.1	69.8	2.050	0.055	0.238	0.626	0.017	0.073
#17: 10-10-18	**12.4**	25,224	10.93	125	3.2	13.7	1.06	0.027	0.116	0.854	0.022	0.093	9,842	4.27	68	0.7	2.9	0.650	0.006	0.028	0.577	0.006	0.025
#18: 11-06-18	**23.9**	13,164	5.71	110	1.4	6.3	1	0.013	0.057	0.720	0.009	0.041	6,013	2.61	156	0.9	4.1	1.250	0.008	0.033	0.727	0.004	0.019

APPENDIX B. Quality Control

Field blanks were collected through the ISCO sampling system chain by connecting one end of a silicone tube to the sample inlet in the flume, placing the other end into a four liter container of UWGB derived di-ionized or ultra-pure water, and then forcing a manual ISCO sample to be pumped into a standard 1 liter ISCO sampler wedge-shaped polyethylene bottle. This bottle was processed at the UWGB lab using the same techniques as done with the composite samples (i.e., cone-splitter, preservation for phosphorus, and filter for DP), before being delivered to the NEW Water lab for analysis. The collection dates and lab analysis results are summarized in Table B1. Field blanks were collected October 16, 2016; June 29, 2017; September 18, 2018; June 26, 2019; July 20, 2020; July 21, 2021; and analyzed for TSS, TP and DP. Results were reported as below the LOD, or nearly so. Trip blanks were not performed because the field blanks were run through the same processing method at the UWGB lab that would have been performed for the trip blanks.

Table B. Field blank analytical results in mg/L (di-ionized or ultra-pure water pumped from flume sample inlet through ISCO sampler system to field bottle in sampler).

Sample ID	Date-Time	TSS	Phosphorus	Dissolved phosphorus
OF-N-QC-1	10/16/16 15:00	< 2.27	< 0.03	< 0.03
OF-N-QC-2	6/29/17 17:15	< 2.22	< 0.028	0.043
OF-N-QC-2018	9/18/18 15:45	< 2.2	0.063	0.058
OF-N-QC-2019	6/26/19 11:00	< 2.0	< 0.023	< 0.023
OF-N-QC-2020	7/20/20 14:55	< 2.41	< 0.023	< 0.023
OF-N-QC-2021	7/21/21 15:45	< 2.13	0.034	< 0.023
OF-S-QC-1	10/16/16 15:15	2.8	< 0.03	< 0.03
OF-S-QC-2	6/29/17 17:00	< 2.5	< 0.028	< 0.028
OF-S-QC-2018	9/18/18 15:55	< 2.27	0.038	0.039
OF-S-QC-2019	6/26/19 11:15	< 2.0	< 0.023	< 0.023
OF-S-QC-2020	7/20/20 14:40	< 2.02	< 0.023	< 0.023
OF-S-QC-2021	7/21/21 16:30	< 2.35	< 0.023	< 0.023

Stage measurements taken from the gage on the inner sidewall of the flume were compared during runoff conditions to values measured by the pressure transducer to ensure accurate stage readings, and to calculate offsets for the final stage readings. Due to the small catchment size, runoff was usually short in duration, so these reading were primarily made during early spring runoff and snow melt, when flow was more persistent.

There were situations in late 2020 and early 2021 when recorded stage levels indicated that runoff was high enough to collect samples, so sampling was triggered. However, the sample bottles were empty. At other times in 2020 and 2021, it seemed that stage might have been higher than recorded because rainfall was excessive. Additional testing was conducted to ensure that there wasn't a problem with the system. Therefore, stage measurements were also tested July 21, 2021 during field blank collection to determine whether stage was being recorded. This testing confirmed that logged stage rose as depth of water above the nitrogen bubbler tube increased at both stations, and sample collection was triggered accordingly. Plus, the sampler pumps pulled in water for the quality control samples, as they did in previous years. Stage measurements checks were also conducted September 13, 2021 prior to station removal, tests confirmed that the stage was being logged correctly, and samples collection was triggered accordingly. It is possible that stage was incorrectly recorded as higher than it really was. It could be that worms were clogging the nitrogen bubbler tube as they appeared to do earlier in the study when stage was unstable (only during late spring to early fall periods when worms were active, and usually during lower stage reading periods when stage readings may have been more prone to worm activity near the bubbler tube). In such cases, stage corrections were made by assuming that high readings during unstable periods of an event were not valid (and accounting for concurrent rain fall readings), and the remaining stage data was used to smooth the stage. After this problem was observed, a wire screen was placed over, and about 8 mm apart from where the bubbler tube is inserted in the flume to prevent worms from getting into the tube. The worm population at the sites appeared to be unusually high, and worms were observed in high densities many times during sample collections shortly after runoff ended.

In the case of high rainfall but low recorded stage and flow, it is likely that the soil infiltration rate was high enough to accommodate the high rainfall amounts because rainfall intensity did not exceed the infiltration capacity of the Hortonville Hydrologic Group B soils present at the study site. The 10/22/20 event fits both of these scenarios, as 3.80 inches of rain fell, stage rose, but never that high due to only moderate rainfall intensity and high soil infiltration capacity, and stage seemed to be erratic (possibly caused by worms).