Addressing Impairment in Beaver Dam Lake and Beaver Creek

WATER RESOURCES MANAGEMENT PRACTICUM REPORT 2017

NELSON INSTITUTE FOR ENVIRONMENTAL STUDIES
UNIVERSITY OF WISCONSIN-MADISON






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ACRONYMS

BDLIA – BEAVER DAM LAKE IMPROVEMENT ASSOCIATION

BMP – BEST MANAGEMENT PRACTICE

CAFO – CONCENTRATED ANIMAL FEEDING OPERATION

CN – CURVE NUMBER

DO – DISSOLVED OXYGEN

DRP – DISSOLVED REACTIVE PHOSPHORUS

EC – ELECTRICAL CONDUCTIVITY

EPA – ENVIRONMENTAL PROTECTION AGENCY

EVI – EROSION VULNERABILITY INDEX

EVAAL – EROSION VULNERABILITY ASSESSMENT FOR AGRICULTURAL LANDS

GIS – GEOGRAPHIC INFORMATION SYSTEMS

N - NITROGEN

P – PHOSPHORUS

SIPES – SOCIAL INDICATOR PLANNING AND EVALUATION SYSTEM FOR NONPOINT SOURCE MANAGEMENT

SPI – STREAM POWER INDEX

SSURGO – SOIL SURVEY GEOGRAPHIC DATABASE

TN – TOTAL NITROGEN

TKN – TOTAL KJELDAHL NITROGEN

TP – TOTAL PHOSPHORUS

TS – TOTAL SOLIDS

TSS – TOTAL SUSPENDED SOLIDS

USDA-NRCS – UNITED STATES DEPARTMENT OF AGRICULTURE – NATURAL RESOURCES CONSERVATION SERVICE

USLE – UNIVERSAL SOIL LOSS EQUATION

UWEX – UNIVERSITY OF WISCONSIN EXTENSION

WDNR – WISCONSIN DEPARTMENT OF NATURAL RESOURCES

WSLH – WISCONSIN STATE LABORATORY OF HYGIENE

WILMS – WISCONSIN LAKES MODELING SUITE

WPDES – WISCONSIN POLLUTANT DISCHARGE ELIMINATION SYSTEM

WRM – WATER RESOURCES MANAGEMENT PROGRAM

PREFACE

The University of Wisconsin-Madison Water Resources Management (WRM) master's degree program in the Nelson Institute for Environmental Studies is an interdisciplinary program designed to prepare students for careers as water resource management professionals. Since 1965, the WRM program has successfully prepared students to work, lead and thrive in the field of environmental management. Each WRM cohort is required to conduct a practicum focused on a contemporary problem in water resources, giving students practical, hands-on experience.

The purpose of the 2017 WRM Practicum is to support the Beaver Dam Lake Improvement Association (BDLIA) with further land and water data analysis of the Beaver Creek subwatershed and Beaver Dam Lake. The findings of this study will assist with addressing concerns of nutrient loading to the lake and creek and provide management recommendations to the BDLIA and its stakeholders.

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EXECUTIVE SUMMARY

Beaver Dam Lake and Beaver Creek

Beaver Dam Lake in Dodge County, Wisconsin, is listed as an impaired water under Section 303(d) of the Clean Water Act due to total phosphorus (TP) and chlorophyll a. Beaver Creek is the largest and one of three main tributaries to the lake and is on the impaired waters list for TP and degraded biological community impact. Land use within the Beaver Creek subwatershed (33.3 square miles) is dominated by agriculture, and the Beaver Dam Lake watershed is within the greater Rock River watershed in south-central Wisconsin. With close sponsorship from the Beaver Dam Lake Improvement Association, the 2017 Water Resources Management workshop focused on evaluating and making recommendations to improve water quality within Beaver Creek and Beaver Dam Lake.

Assessment of Upland Land Use

To address potential sources of sediment, phosphorus (P) and nitrogen (N) loading, it was important to evaluate which land uses in the Beaver Creek subwatershed might have the greatest impact on overall water quality. Our assessment focused on agricultural practices by conducting windshield observation surveys and modeling potentially high-erosion areas with the Erosion Vulnerability Assessment of Agricultural Lands (EVAAL) tool, developed by the Wisconsin Department of Natural Resources. These modeling results can be used to help prioritize where farmland conservation practices should be implemented.

Assessment of Habitat and Water Quality in Beaver Creek

To better understand how Beaver Creek contributes to the quality of Beaver Dam Lake and how the creek can be improved, we assessed stream biotic integrity, habitat, sediment P, and water quality in Beaver Creek. We characterized the habitat composition and quality in and along the stream to provide a preliminary assessment for the future analysis of baseline conditions. We analyzed the composition of the macroinvertebrate community in the stream. Together this information provides insight into the overall integrity of the stream's biological community. Sampling results within the creek indicate that some locations have significant P within the sediment. This represents the P that could be leached out or transported via sediment into the lake. Moreover, P concentrations in the water column are far above the recommended levels for beneficial uses of the creek.

Assessment of Water Quality in Beaver Dam Lake

Due to its shallow nature and the various contaminants it receives, Beaver Dam Lake often suffers from impaired water quality. Wind and carp-induced resuspension of sediments decrease water clarity, while excess phosphorus from agriculture in the lake's watershed, carp feces, and anoxia-induced sediment P release often cause large algal blooms, which also deplete oxygen from the water during decay. Sampling results from Beaver Dam Lake indicate high P levels in lake water and lake-bottom sediments. Using the Wisconsin Lake Modeling Suite (WiLMS) model, we evaluated various internal and external sources of P to the lake. Modeling results suggest that even with higher P loads from agricultural land uses, the vast majority of P is attributed to internal loading rather than external sources. This could indicate high rates of wind-induced sediment resuspension, additional P sources from carp, or other sources of P (internal or external) that are not captured in the model.

Stakeholder Engagement

To engage stakeholders, we focused on learning about producer practices in the Beaver Creek subwatershed. We created a semi-structured interview survey to use with targeted landowners east of Paradise Marsh. We interviewed six landowners on three different farms with questions about stormwater runoff, soil management practices, and conceptions of lake and creek use and issues. We also brought awareness to the Beaver Dam Lake community with an exhibit at large summer events. Finally, we held a community discussion workshop centered on increasing knowledge of lake issues and collecting ideas for and willingness to participate in water quality improvements. We recommended outreach activities that build relationships with a variety of stakeholders, especially farmland owners.

Key Recommendations

FOR STAKEHOLDER ENGAGEMENT:

1. Build partnerships with local schools
2. Organize workshops and volunteer events
3. Establish a farmer-led council in Columbia County
4. Bring producers onto the BLDIA board

FOR BEAVER DAM LAKE WATER QUALITY:

1. Develop an active carp management plan
2. Conduct a carp exclosure study
3. Conduct a shoreline erosion assessment
4. Establish regular lake-condition monitoring

FOR BEAVER CREEK WATER QUALITY:

1. Update the watershed plan
2. Implement best management practices for improving soil retention and habitat for overall stream health
3. Encourage CREP, land easements, in-line nutrient mitigation, and dredging to assist with improving stream health
4. Plan future watershed studies: more detailed sediment phosphorus load analysis throughout Beaver Creek; a field study on efficacy and locations of current BMPs in subwatershed; and a Paradise Marsh nutrient study

INTRODUCTION

1.1 – Issue

Beaver Dam Lake is an impoundment lake located in Dodge County in east-central Wisconsin (Figure 1). It is listed as an impaired water under Section 303(d) of the Clean Water Act due to total phosphorus (TP) and chlorophyll a. Beaver Creek, one of three main tributaries to the lake, is also on the impaired waters list for TP and degraded biological community impact.

Phosphorus (P), the main nutrient of concern, is a vital plant nutrient and a key ingredient in most fertilizers. However, too much of this nutrient leads to unsightly and potentially toxic algal blooms. The creek acts as a conduit for excessive nutrients transported to the lake. Additionally, common carp were introduced to the lake in 1877 as a source of inexpensive fish meal to improve the fishery for human food access. Managers involved in this decision were not aware how detrimental the soon-to-be invasive species would be to the water quality of the area. Carp contribute to internal loading, exacerbating eutrophication by disturbing substrate sediment and releasing bioavailable P into the water.

Beaver Dam Lake is a popular water body for a variety of recreational pursuits, from fishing for largemouth bass, northern pike, and walleye, to canoeing and kayaking, birdwatching, and seasonal swimming. The lake has a total surface area of 6,841 acres and a contributing drainage area of 98,000 acres (154 square miles), mainly comprised of cash-crop agriculture and several small urbanized areas, including the cities of Fox Lake and Beaver Dam.

Beaver Creek is a tributary that discharges into the northwestern corner of Beaver Dam Lake (Figure 1). The creek contributes approximately 20% of the lake's total annual volume (Butterfield, Hoyman, Cibulca, & Heath, 2015). The contributing drainage area to the creek is 21,300 acres (33.3 square miles) with the primary land use categorized as agriculture (76%), followed by wetland (12%). According to the Wisconsin Department of Natural Resources (WDNR) Pollutant Load Ratio Estimation Tool (PRESTO), the average annual nonpoint P load into Beaver Creek from 2010-12 was 5,513 pounds (2501 kilograms), while the average annual point source P load to Beaver Creek from 2010-12 was 2,064 pounds (936 kilograms).

Characterizing P loading in Beaver Creek is important to understand its contributions to Beaver Dam Lake. Additionally, improving the water quality of Beaver Creek may allow it to be removed from the 303(d) impaired list.

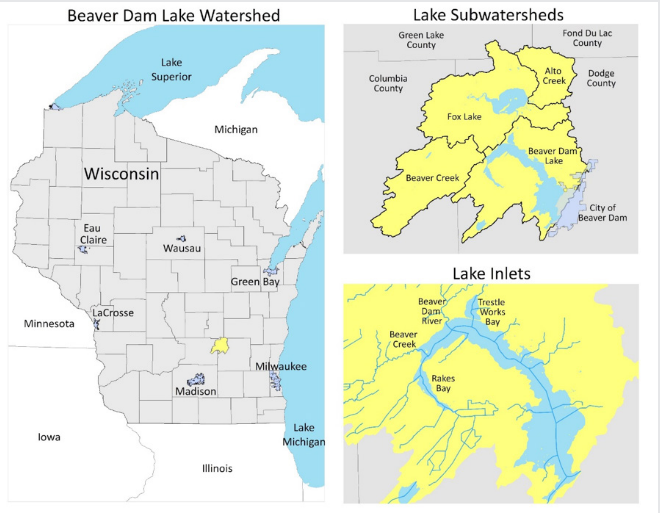


Figure 1: Location of Beaver Dam Lake in Wisconsin (left); map of the Beaver Dam Lake subwatersheds (upper right); inlets to Beaver Dam Lake (lower right).

1.2 – Previous Efforts

In 1996, the Beaver Dam Lake Property Owners Association became the Beaver Dam Lake Improvement Association (BDLIA). Shortly after becoming active, the group initiated a large-scale carp removal effort. Twenty years later, carp removal continues to be a major focus for BDLIA. This organization works to manage desirable fish populations, educate and provide events for the community, and secure funding for lake improvement projects. The BDLIA has worked with the WDNR's Healthy Lakes Program to provide grants to shoreline residents who undertake projects to limit erosion from their property, such as planting native vegetation and installing rain gardens and stone infiltration. The BDLIA has also routinely collected water quality data at the lake since 1996. Intermittent water quality data exists for Beaver Dam Lake dating back to 1973.

In 2014, the BDLIA contracted Onterra, LLC, a lake management planning company, to conduct a study of water quality and aquatic conditions in the Beaver Dam Lake and to develop a comprehensive management plan for the lake (Butterfield, Hoyman, Cibulca, & Heath, 2015). This group focused on Secchi disk depth, TP, and chlorophyll a as its primary metrics of water quality. Based on modeling results from the Wisconsin Lake Modeling Suite (WiLMS), Onterra found that nearly 90 percent of the TP in Beaver Dam Lake was the result of internal loading. This number seemed extremely high, indicating that external phosphorus sources could be underestimated. For this reason, the WiLMS analysis was redone as part of a collaborative project in a UW-Madison Civil and Environmental Engineering class (CEE 618; two of the WRM workshop students worked on this class project). The WiLMS model was initially constructed to recreate Onterra's results, then expanded to account for varying levels of P found in agricultural fields in the region. This analysis found that, even accounting for greater levels of P in soils, the majority of TP in the lake was still attributed to internal loading.

Onterra concluded that while summer concentrations of P in the lake have declined since 2007, concentrations at both of their sampling sites were nearly ten times greater than the average for other Wisconsin lowland drainage lakes. This may be attributed to internal loading — primarily due to carp stirring up bottom sediments — exacerbating the impaired water quality of the lake. The BDLIA has been working with private harvesters for carp control and the WDNR on a fish study of Beaver Creek.

Additionally, the BDLIA received a report from the CEE 618 faculty advisor detailing the WiLMS modeling data for Beaver Dam Lake watershed P inputs. This report includes information on regional agricultural soil P levels as well as a fetch analysis and the WiLMS expansion from the UW-Madison Department of Civil and Environmental Engineering. This model was expanded upon as part of this WRM workshop.

1.3 – Gaps

This study continues data collection on Beaver Dam Lake and provides baseline data for Beaver Creek. Beaver Creek is relatively unstudied despite its volumetric input to the lake, which is one of the motives behind its priority in this study. It is also on WDNR's 303(d) impaired list for exceeding the standard of 0.075 milligram per liter (mg/L) for TP in wadable streams. Given its unstudied nature, there was a range of issues to study to determine its relative health and its contribution to lake eutrophication. This included assessing water quality under normal and elevated flow, biotic health through habitat and macroinvertebrate surveys, and soil nutrients to determine current and legacy impacts from deposited sediments. Gathering information on these topics served to advise better management of both the creek and the lake.

Land use within the Beaver Creek watershed has a direct effect on the levels of sediment and P within the creek. Therefore, characterizing land use patterns, crop management practices, and erosion and sediment transport within the watershed is also essential to understanding nutrient loading from Beaver Creek.

Water quality data for Beaver Dam Lake has been collected relatively consistently for the past couple decades at several locations; however, most locations lack some or all water quality data for periods of several years. Inflow volumes and nutrient loads to the lake are estimated but not known exactly, although somewhat consistent flow data exists for some tributaries to the lake. Carp densities are based on the most recent data from 2014, and exact population densities in 2017 during the time of the study were unknown. In addition, consistent phosphorus data for waters both entering and exiting Beaver Dam Lake are lacking.

1.4 – Addressing the Gaps

Through the sponsorship and support of the BDLIA, the 2017 Water Resource Management graduate student cohort in the Nelson Institute for Environmental Studies at the University of Wisconsin-Madison conducted monitoring, modeling, and data analysis on Beaver Creek, the Beaver Creek subwatershed, and Beaver Dam Lake during the 2017 growing season. The cohort split into four groups, each with a specific focus: stakeholder, in-lake, in-stream, and upland. This allowed gaps to be identified and addressed.

The cohort collected water quality, discharge, and sediment cores in Beaver Creek to provide insight into P loading levels. In addition, water quality and lake sediment cores were collected in Beaver Dam Lake throughout the summer. Additionally, the cohort analyzed soil nutrients and soil erosion potential in the upland region of the Beaver Creek subwatershed.

Taken together, this WRM study and the Onterra study provided a greater understanding of nutrient inputs from Beaver Creek to Beaver Dam Lake and allowed the WRM cohort to make recommendations to the BDLIA for next steps and management strategies to improve the health of Beaver Creek and Beaver Dam Lake.

BACKGROUND ON LAKE PHOSPHORUS SOURCES

2.1 – Lake Characteristics

Beaver Dam Lake is an impoundment lake, artificially created by the damming of Beaver Dam River in 1842. Impoundments are as common as natural lakes in Wisconsin, and vary greatly in characteristics based on the stream and topographical features (WDNR, 2017). The health of a lake can be influenced by physical features such as depth and temperature as well as chemical features like pH, dissolved oxygen, and presence of nutrients such as phosphorus and nitrogen.

2.2 – Physical Features

Most large, deep lakes found in temperate climates will mix from top to bottom, or "turn over," twice a year. These lakes are called "dimictic"; the overturning happens in the spring and fall, when the lake water temperature is nearly equal between deep and shallow water. Beaver Dam Lake is not deep enough to lead to this pattern of seasonal stratification and mixing. At an average depth of 5.6 feet (1.7 meters), and with a long "fetch" allowing for wind-induced mixing, Beaver Dam Lake is polymictic, meaning its water can mix from top to bottom throughout the ice-free period. Any stratification that does occur is short-lived and difficult to record.

Because it is relatively shallow, it is likely that Beaver Dam Lake warms up more quickly in spring and may reach higher temperatures through the full water column than deeper lakes. High lake temperatures can be problematic for a few different reasons. All lake organisms, including microorganisms and insects, have different preferred temperature ranges at which they thrive. In addition, water at higher temperatures cannot hold as much dissolved oxygen, which can be detrimental to more sensitive aquatic species. Furthermore, warm temperatures are highly conducive to the growth of blue-green algae.

Eutrophic lakes are defined as having high nutrient concentrations that support high biological productivity. Due to excessive nutrients, especially nitrogen and phosphorus, these water bodies typically support an abundance of aquatic plants or algae. Beaver Dam Lake is considered hypereutrophic, meaning it is excessively loaded with nutrients to the point of creating conditions in which algae and other macrophytes dominate the habitat. If algal blooms are large enough, their subsequent die-offs have the potential to consume most or all of the available oxygen in the lake, leading to hypoxic conditions that can result in die-off events for fish and other aquatic species.

These features contribute heavily to the water quality problems in Beaver Dam Lake. However, the greatest area of concern is excessive phosphorus (P) in the water, which expedites the growth of harmful algae. Excess phosphorus can enter a lake through outside sources in the watershed (external loading) or through processes occurring within the lake (internal loading).

2.3 – External Sources of Phosphorus

Phosphorus from external sources can enter lakes in several ways: through streams that discharge into the lake, erosion of phosphorus-laden shoreline sediments, and runoff from the surrounding landscape, particularly during and immediately following storm events.

In Beaver Dam Lake, WiLMS analysis revealed that the majority of external P loading is attributed to the cash-grain agriculture that dominates much of the watershed (Bradford et al., 2017; Onterra, 2014). Erosion of agricultural land carries sediment from nearby fields to waterways and eventually to the lake. This sediment often carries nutrients from commercial fertilizers and manure application, as well as other contaminants such as pesticides. Urban runoff from lawns and construction sites can also contribute to external loading into the lake. While the original WiLMS analysis (Onterra, 2014) considered only the default P loading to the lake from agricultural land uses, a range of soil P values taken from regional studies (e.g., Madison et al., 2014; MMSD, 2016; Stuntebeck et al., 2011) demonstrated that the P loading from row crop agriculture could be greater than originally modeled (Bradford et al., 2017).

2.4 – Internal Sources of Phosphorus

Internal P loading occurs when legacy P bound in the lake sediment is released into the water column. As dissolved oxygen concentrations decrease, P that is bound to sediments is released in pulses. P that is bound to iron is the quickest to be released, but as dissolved oxygen continues to decrease, compounds of magnesium and other elements also release their P (Doig et al., 2017). These pulses of P-laden water are then swept up by wind-induced currents and spread throughout the lake. Wind driven waves, particularly breaking waves, can excavate sediment from the lake bottom and distribute it through the water column.

In addition, pH is related to internal P loading. In high-pH environments, when concentrations of hydroxide (OH-) are high, hydroxide molecules can substitute for bound phosphates in compounds within lake sediments. This results in P release similar to that caused by low dissolved oxygen (Penn et al., 2000). pH can increase in a lake due to a variety of factors, such as photosynthesis by aquatic plants that strips hydrogen from water molecules and leaves hydroxide.

Plant and animal life within and around the lake also play a role in internal P loading. For example, the common carp (Cyrprinius carpio), introduced to the waterways of the Midwest in the 1880s as a game fish, has become a highly damaging problem throughout the country. As bottom-feeders, carp routinely disturb the sediment as they forage, muddying the water and uprooting plant life. Carp reproduce in large numbers and in habitats where their eggs are not readily eaten. Carp can quickly dominate a lake ecosystem. The carp concentration in Beaver Dam Lake is estimated to be 330 pounds per acre (370 kilograms per hectare) (Butterfield et al., 2015). Carp removal that does not disrupt other fish species is very challenging (Thompson, 2016).

STAKEHOLDER ENGAGEMENT

3.1 – Purpose

This chapter describes the efforts and activities used to increase community engagement regarding the water quality issues in Beaver Dam Lake, and how the stakeholder group acted as a liaison between WRM and the community.

New plans for lake improvement will need to include wide community ownership. Agricultural producers, residential homeowners, commercial and industrial businesses, and recreational users all have an impact on water quality and an interest in lake health. As plans are developed for managing the lake and its watershed, it is vital that efforts are supported by a variety of stakeholders.

The recommendations suggested here are presented for consideration for action by BDLIA, the Dodge County and Columbia County Land and Water Conservation Departments, and the Beaver Dam Lake watershed community.

3.2 – Methods

Our work involved three focus areas. We shared information about our overall project progress with media outlets and local groups at events and meetings. We surveyed community members regarding their recreational use, values, and willingness to act for lake improvements. Finally, we interviewed producers in the Beaver Creek subwatershed to learn about their land management practices, resource values, and willingness to act for lake improvements.

3.2.1 – COMMUNICATIONS

Throughout our project timeline (January 2017 to January 2018), we provided reports on our progress and findings to the media. Updates were published on the BDLIA website at the beginning of data collection and at the halfway point in our timeline. We were interviewed by local radio station WBVA in May and the Beaver Dam Daily Citizen online newspaper in June. We wrote a report on our project for the Rock River Coalition's September newsletter.

We reported preliminary results (30-minute presentations) in the fall of 2017, near the end of data collection, during the BDLIA annual meeting in August; at our WRM town hall meeting and a Kiwanis luncheon in September; and at a Kiwanis breakfast meeting in December.

Our group also exhibited a project poster at community events to engage the public. We staffed a table at the BDLIA Fish n' Fun (June) and Great Beaver Paddle Festival (July) events, and at the city of Beaver Dam's Lake Days (July) event. At these lake celebrations, we discussed our project with passersby to learn about people's lake use, values, and understanding of the watershed and to build awareness for lake issues and our project goals.

3.2.2 – COMMUNITY SURVEYS

A 2012 survey commissioned by BDLIA and conducted by Environmental Horizons, Inc., was distributed to all Beaver Dam Lake lakeshore property owners and focused on recreational use and knowledge of lake issues. The survey had a response rate of 25% (394/1595). Important results included that 86% of respondents rated the water quality of Beaver Dam Lake as "poor," recognizing that water quality and algae are significant problems. In addition, 62% of respondents indicated that they were willing to pay more for lake management. Finally, they reported a wide variety of recreational uses, including birdwatching, walking/jogging, fishing, and powerboating.

We used these findings to create a shorter questionnaire to continue data collection on lake use, values, and issue knowledge. Our questionnaire was produced using modified questions from Social Indicator Planning and Evaluation System for Nonpoint Source Management (SIPES), 3rd edition (Genskow, 2011). The survey had 10 questions (Appendix A) that focused on location of property ownership, lake issue ratings, water quality in Beaver Creek, recreational use on Beaver Dam Lake and Beaver Creek, and willingness to contribute to lake health actions, including financial or time contributions or changing behaviors.

Questionnaires were distributed and collected at our September 2017 town hall meeting in Beaver Dam and at the October meeting of the Kiwanis Club of Beaver Dam. We collected 37 surveys. Questionnaire results were compiled and scored in a data table. Written answers to qualitative, free-response questions were coded for key themes. For quantitative questions, mean scores were calculated for each.

3.2.3 – WRM TOWN HALL MEETING

To report on our project and listen to the perspectives of the public in the Beaver Dam Lake watershed, we hosted a town hall meeting in the city of Beaver Dam. Attendees were invited via emails sent to various community groups. At the meeting, we presented background information on water quality issues in Beaver Creek and Beaver Dam Lake and an overview of our project. We then distributed and collected questionnaires. Additionally, we fostered dialogue by splitting meeting attendees into small groups, where participants discussed their present understanding of the lake and lake issues, and why they valued it as a community resource.

3.2.4 – LANDOWNER INTERVIEWS

At the suggestion of the BDLIA, we focused on interviewing producers in the Beaver Creek subwatershed about their soil management practices, knowledge of lake issues, and recreational use of Beaver Creek and Beaver Dam Lake. We targeted 15 landowning producers working on lands east of Paradise Marsh along a seven-mile stretch of Beaver Creek. Letters with invitations to a conversation at their homes or in a public setting were sent to the 15 addresses in early June. Reminder letters were sent in late July. Six producers from three different farm properties were interviewed.

Interviews were designed to last approximately 60 minutes and consisted of questions about current land management practices, understanding of land management practices, barriers to adopting other practices, trust in government and non-government agencies, and perceptions and uses of Beaver Creek and Beaver Dam Lake. Interview prompts were modified from the SIPES 3rd edition (Genskow, 2011). Audio recordings were made at each interview and then transcribed for coding purposes.

Interview transcriptions were coded first for responses to interview prompts. Answers were tallied and quantified for further analysis. Additionally, transcriptions were coded to identify other key concerns or ideas not specifically prompted by interview questions.

We were contacted by two lakeshore homeowners who had interest in discussing our project. We met with each at their homes and shared our project progress while listening to their concerns about the lake. These discussions did not include the targeted questions from our other interviews, and no data were collected.

3.3 – Results and Discussion

The results from our stakeholder engagement research suggest that an abundance of knowledge and energy for soil conservation and water health improvement exists in the community. Despite the limited sample sizes for our community surveys and producer interviews, the people who did agree to speak with us and attend our events are willing to work with the BDLIA on efforts to improve water quality.

3.3.1 – COMMUNITY SURVEYS

We collected 37 surveys from community members. Respondents either attended our WRM town hall meeting or were members of the Kiwanis Club of Beaver Dam and therefore responses may be more indicative of those already committed to working on lake improvement efforts. For this survey, we were able to distinguish responses from Beaver Dam Lake property owners (14), Beaver Creek property owners (3), and non-water property owners (20). Not all questions were answered on each survey.

For the question about lake and creek water quality issues, out of 33 responses, P was rated as a “big problem” 30 times, as “somewhat of a problem” one time, and “not sure” twice. Out of 34 responses, carp was rated as a “big problem” 28 times, as “somewhat of a problem” five times and “not sure” one time. Of 32 responses, algae was rated as a “big problem” 25 times and as “somewhat of a problem” seven times (Figure 2).

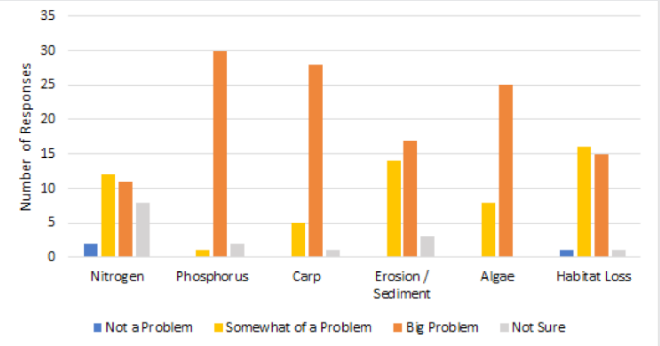


Figure 2: Community survey ratings of various lake water quality issues.

Recreational uses and frequency were categorized for Beaver Dam Lake, other area lakes, and Beaver Creek. Fishing, birding, and boating were the most frequent uses on Beaver Dam Lake, while canoeing and kayaking was also a frequent mention for other area lakes. On Beaver Creek, the most frequent recreational uses mentioned were fishing, kayaking and canoeing, and hunting (Figure 3).

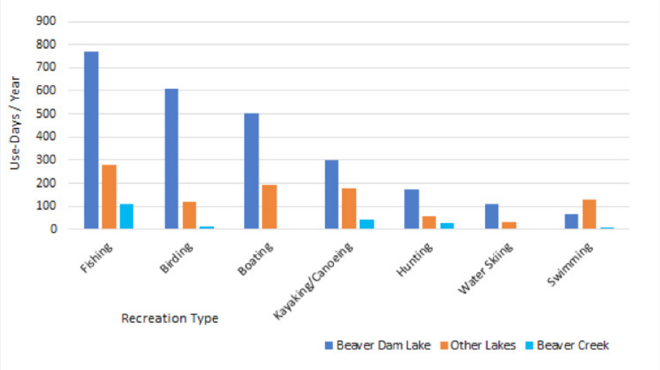


Figure 3: Community survey results for frequency of various forms of recreation in use-days/year.

Overall, of the 37 respondents, 25 (68%) would increase recreational use of the lake or creek if water quality was improved, and 28 (76%) respondents believe that Beaver Dam Lake provides economic benefits to the community. Finally, when asked if they were willing to contribute to water quality improvement efforts in the watershed, 15 (41%) agreed to financial contributions, 16 (43%) were willing to volunteer their time, 11 (30%) were willing to adjust recreational use, and 10 (27%) were willing to make changes at home. Ten of the 37 (27%) respondents said they could not be involved (Figure 4).

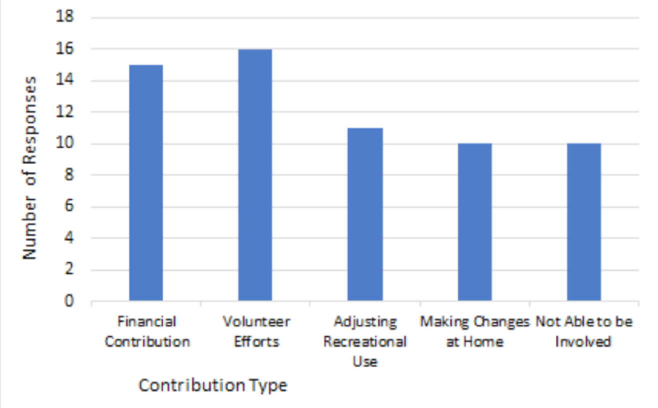


Figure 4: Number of survey respondents (out of 37 total) willing to contribute to various water quality improvement efforts in the watershed.

Our community questionnaires indicate general awareness of water quality issues in Beaver Dam Lake. The majority of the community is willing to offer time and resources, and change behaviors at home to improve water quality. The community is also invested in recreational opportunities on the lake and understand the lake's value to the city of Beaver Dam economy. These data reflect a potential base of support for increased lake management efforts. The BDLIA should use this diversity of community awareness and interests to build support for future planning and management.

3.3.2 – WRM TOWN HALL MEETING

Small group discussions at our September town hall meeting were open-ended. Groups were instructed to discuss their values and interests in Beaver Dam Lake, recreational uses, and questions about lake issues. Discussion ranged from shoreline erosion and wetland revegetation to boating, swimming, and fishing concerns.

After these dialogues, participants were invited to share with the larger group as a final exercise. One or two people from each group presented a summary of their discussion while others asked questions. Participants demonstrated a range of knowledge about specific lake issues (P, carp, algae, sediment, erosion, wetlands). Participants were interested in contributing to lake management as a means to protect property values and the area's tourist economy.

3.3.3 – PRODUCER INTERVIEWS

The six producers that agreed to interviews control three properties (out of 15 properties targeted for interviews) that comprise less than 5% of the farmland in the Beaver Creek subwatershed. Therefore, both by numbers of respondents and percentage of land area controlled, the sample size for the producer interview process is small. Caution should be used in interpreting these results as representative of the opinions of producers in the Beaver Creek watershed.

From our semi-structured interviews with six producers representing three farm properties, we discovered a mix of lake-issue understanding; awareness and moderate use of soil conservation strategies; infrequent recreational use of Beaver Dam Lake and Beaver Creek; and a lack of trust in information from key land resource agencies.

In their rating of water quality issues for Beaver Dam Lake, five producers rated carp as a "big problem" and one rated it as "somewhat of a problem." Only one thought that P was "somewhat of a problem," while five were "not sure." Split responses were given for algae and habitat loss, while one interviewee mentioned birds as a "big problem" (Figure 5).

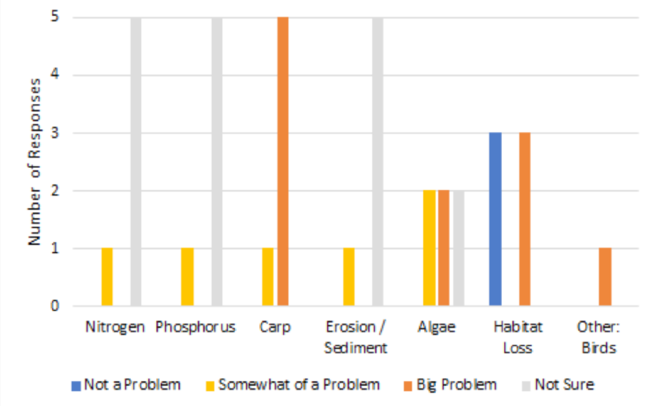


Figure 5: Lake water quality issues rated in producer interviews.

When asked about soil conservation strategies, two producers responded that they use cover cropping, two reported using reduced or no-tillage planting, two used contour planting on steep slopes, two used nutrient management plans, three used buffer strips, and two used grass waterways (Figure 6).

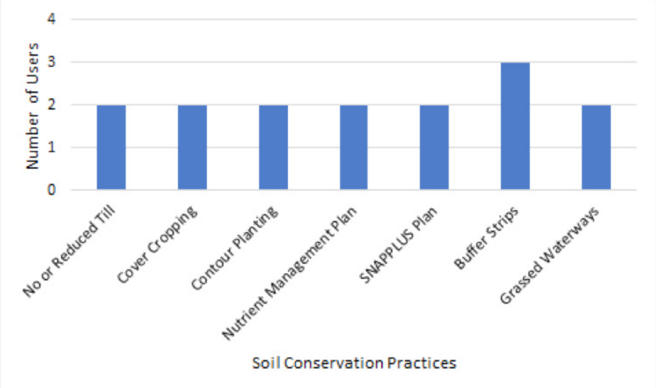


Figure 6: Number of interviewed producers (out of six total) in the Beaver Creek subwatershed using various soil conservation practices.

Producers reported fishing and boating on Beaver Dam Lake very infrequently, citing the preference to do these activities at other regional lakes that have better fisheries. Some reported fishing and hunting on Beaver Creek, though only on a few days per year.

Finally, producers were asked about their trust in information from several organizations (Figure 7). Results show that only one producer trusted the Columbia County Land and Water Conservation Department, one trusted UW-Extension resources, and one trusted agricultural neighbors. Trust was very low for the BDLIA and WDNR. This indicates a lack of trust by the producers interviewed in the BDLIA and its lake management efforts.

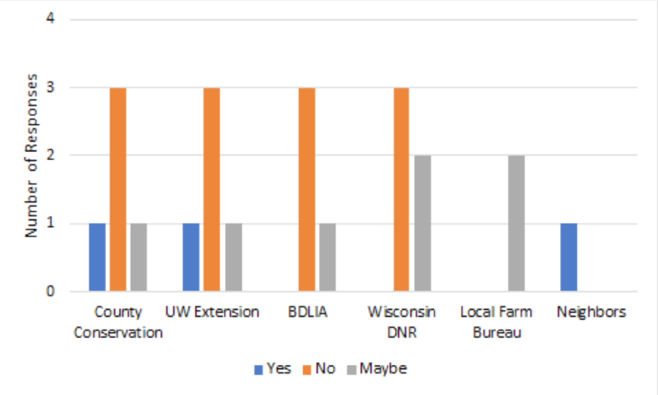


Figure 7: Producer trust in organizations providing land management information.

Our limited producer interviews revealed a lack of understanding of lake water quality issues but an awareness of and interest in soil management practices. Producers were unsure about phosphorus as a significant issue for water quality, but did believe that carp are a big issue.

Farmers in the Beaver Creek subwatershed use a variety of soil retention techniques, including reduced tillage, nutrient management plans, and vegetative cover in waterway drainages and riparian areas of Beaver Creek. However, producers are using these practices in a limited area of their total planted acreage, and cost of implementation is a driving factor in their decision not to use these practices at a larger scale. Most importantly, we learned that producers do not currently trust information from agencies and organizations, including the BDLIA.

The recommendations presented in Chapter 7 highlight producer awareness and make suggestions for efforts to create a larger culture of soil management among producers in Columbia County.

UPLAND

4.1 – Purpose

Land uses and management practices throughout the Beaver Creek subwatershed have an impact on the water quality of Beaver Creek and Beaver Dam Lake. By identifying areas within the subwatershed with high potential for soil loss, more effective land management recommendations can be made to improve the area's water quality.

To characterize land uses, we conducted windshield surveys, collected land use data, and used a model to estimate erosion potential throughout the watershed. Areas with high potential for soil erosion and nutrient loss were determined with the Erosion Vulnerability Assessment for Agricultural Lands (EVAAL) model (Version 1.0.1; WDNR, 2015). Soils in select high-priority areas identified via EVAAL were sampled and agronomic soil tests performed. This additional evaluation allowed us to estimate soil P levels in a small area near Beaver Creek.

4.2 – Methods

4.2.1 – LAND USE AND LAND COVER DATA

Land cover data were taken from the Wiscland2 dataset from the Wisconsin Department of Natural Resources GIS Open Data Portal (WDNR, 2016). The Level 2 land cover raster file (30-meter resolution) was analyzed within the Beaver Dam Lake watershed and the Beaver Creek subwatershed. Watershed shapefiles from the hydrologic units/12-digit subwatersheds dataset (HUC12) were also acquired from the WDNR Open Data Portal. The Beaver Creek waterway line file was obtained from the WDNR Hydrography Geodatabase (24K flowlines dataset) (WDNR, n.d.). Crop data were obtained from USDA CropScape (USDA, 2012-2016).

4.2.2 – OBSERVATIONS OF LAND USE AND LAND MANAGEMENT PRACTICES

To better understand land use and management in the subwatershed, we conducted two "windshield surveys," during which we visited the watershed, gathered visual observations of land management practices along Beaver Creek, and noted areas of high erosion potential. For the first windshield survey (May 20, 2017), we traveled north from Paradise Marsh State Wildlife Area to the northeastern edge of the Beaver Creek subwatershed, near Randolph, Wisconsin, essentially following Beaver Creek, to identify crops, signs of manure spreading, and evidence of soil disturbance. We also observed and documented tillage and other best management practices already in place. During the second survey (June 24, 2017), we evaluated areas identified with EVAAL as having a high erosion vulnerability index. This "ground-truthing" helped us assess current land management practices and identify potential sites for soil sampling (access roads, ownership, etc.) in these high-priority areas.

4.2.3 – EVAAL MODELING

The EVAAL model was used to determine areas with high erosion potential in the Beaver Creek subwatershed. The model, developed by the Wisconsin Department of Natural Resources (WDNR), runs through ArcGIS software using Python scripting language. EVAAL accounts for topography, slope, soil type, precipitation, and crop rotation over the past five years to estimate erosion potential within a subwatershed. EVAAL utilizes the Universal Soil Loss Equation (USLE) and the Stream Power Index (SPI) to estimate where soil erosion is most likely to occur. The HUC12 (file 070900010904; WDNR GIS Open Data Portal) subwatershed boundary was subdivided into smaller HUC16 subwatersheds. EVAAL was run separately for each HUC 16 because the computer processor was not able to handle the large amount of data necessary to run the model for the HUC12.

Topography and slope data were obtained from LiDAR data (five-meter resolution) for Columbia County and from digital elevation model (DEM) data (10-meter resolution) for Dodge County; both data sets are publicly available (WisconsinView, n.d.). The two datasets were merged and the model delineated depressions in the landscape within the subwatershed based on elevation. Culverts were drawn under roads, in the direction of hydrologic flow, throughout the subwatershed. The input of culverts was needed for EVAAL to accurately identify drainage flow paths and model sheet and rill erosion, since the LiDAR and DEM data shows only the total elevation rather than elevation of the land itself. For this reason, the use of roads and bridges can make it appear that water does not have an outlet, leading to inaccurate conclusions without this additional data. Drawing the culverts involved using Google Maps to virtually move along the roads and determine where culverts were located so internally draining areas could be mapped in later EVAAL steps.

Crop data from the previous five years (2012-16; USDA CropScape) were incorporated into EVAAL to characterize crop rotations (cash grain, dairy rotation, pasture/hay/grassland, continuous corn, or potato/grain/vegetable) throughout the subwatershed. Soil data from USDA NRCS were also incorporated through the Gridded Soil Survey Geographic (gSSURGO) Database (USDA, 2017b). The data has a 10-meter resolution and includes soil erodibility based on soil types. The 10-year, 24-hour rainfall intensity data were downloaded through the National Oceanographic and Atmospheric Association's (NOAA) National Weather Service and used in EVAAL to account for differences in precipitation throughout the subwatershed. Combining the crop rotations, soil data, and precipitation data allowed for a layer assigning spatially distributed estimates for curve number (CN) across the subwatershed as created through the EVAAL modeling process. The model separately assesses the risk for sheet and rill erosion (using the Universal Soil Loss Equation and data described above) and gully erosion (using the Stream Power Index) while deprioritizing areas that are not hydrologically connected to surface waters (also known as internally drained or non-contributing areas). The model uses these inputs to estimate the final EVAAL result, an erosion vulnerability index (EVI). This is a relative index, which means that the values are not directly comparable to those from a separate model. The index is only intended to prioritize or rank areas, not estimate the actual magnitude of sediment or nutrient runoff. The EVI is a numeric value that ranged from -1.62 to +10.75 and varied across this watershed (Figure 10), indicating the likelihood of erosion occurring and impacting surface water bodies. Again, the model does not estimate EVI for depressions or internally drained areas because it is assumed that soil in these areas would not be transported to surface water bodies. Areas with high EVI correspond to high erosion potential, meaning that soil and excess nutrients (e.g., phosphorus) in these areas are likely to move in runoff and reach surface water bodies if proper land management practices are not implemented. The model does not account for important aspects of land management such as tillage, manure application, tile drainage, or best management practices (BMPs) within the subwatershed.

4.2.4 – SOIL SAMPLING

Prioritizing Areas

We incorporated the EVI values from EVAAL, which identify an area's susceptibility to soil loss and likelihood of exporting nutrients like P, into a ranking system that we developed to determine our highest-priority vulnerability sites. Our system equally weighted an area's: 1) EVI number, 2) area of high erosion vulnerability (acres), and 3) distance to nearest surface water body. Large areas with high EVI that are close to surface waters ranked high on the priority scale. We developed this ranking system with the assumption that a higher degree of effectiveness in improving water quality would be realized if best management practices are implemented in these top-priority areas (see Appendix B). We collected soil samples in some of these areas. Due to time constraints and our need to obtain property access agreements from landowners, we were only able to sample a small portion (approximately 85 acres) of the watershed.

Soil Testing

Seventeen soil samples among six fields were collected following the UW-Extension protocol defined in Form A2100 (Peters & Laboski, 2013). Using this protocol, we collected several composite samples for each field we visited. These composite samples were made of 10 soil cores per five-acre segment representing the areas of potential high erosion vulnerability within the field. When gathering the soil cores to make a composite sample, we walked in a W-shaped pattern (following the contours of the field) across the five-acre area. Each soil core contained the top 15 centimeters (six inches) of the field. The cores were then placed into a bucket and thoroughly mixed before placing about two cups into a sample bag.

Soil samples were sent to University of Wisconsin Soil Testing Lab in Marshfield for the standard agronomic soil test. This analysis provided data on several soil chemical factors, such as pH, organic matter, and nutrient recommendations, in addition to our primary interest, Bray-1 P. For comparison, we also sampled areas of the subwatershed with lower erosion vulnerability as well as a field planted with cover crops.

4.3 – Results and Discussion

4.3.1 – LAND USE AND LAND COVER

The dominant land cover throughout the Beaver Dam Lake watershed is agriculture, specifically cash crops (Figure 8). The urban land cover is in the cities of Randolph, Fox Lake, and Beaver Dam.

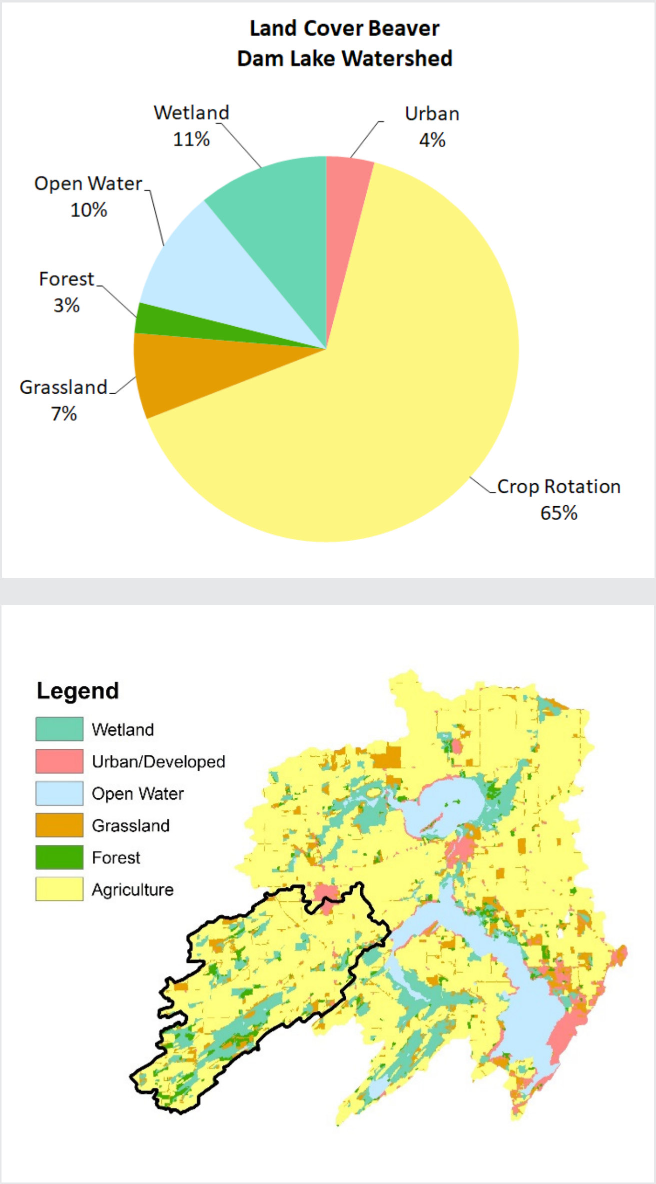


Figure 8: Land cover throughout the Beaver Dam Lake watershed. The Beaver Creek subwatershed is outlined in black.

Similar to the overall Beaver Dam Lake watershed, the primary land cover within the Beaver Creek subwatershed is agriculture and the majority is cash crops (Figure 9). Paradise Marsh is a large wetland complex in the headwaters of Beaver Creek. The southern half of the city of Randolph is within the Beaver Creek subwatershed.

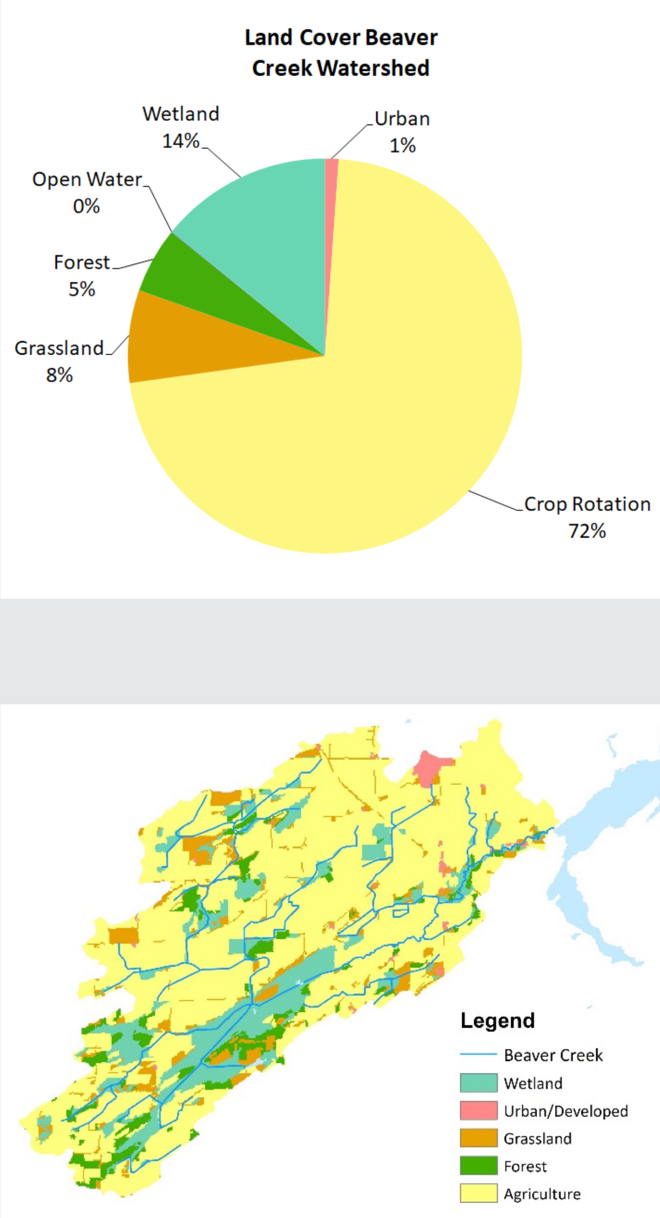


Figure 9: Land cover within the Beaver Creek subwatershed.

4.3.2 – OBSERVATIONAL DATA

At the time of the first windshield survey (May 20, 2017, described in section 4.2.2), many of the fields were freshly planted. We observed some equipment in use in the northern section of the subwatershed, which was kicking up a good deal of dust. This could be a common problem for some farmers in the watershed, so methods to reduce wind erosion and soil loss could be beneficial to local farm managers.

Most of the fields bordering Beaver Creek incorporated vegetated buffers between the farm fields and the waterway. Several other fields incorporated more robust practices, including grassed waterways and contouring. Some fields left steep slopes covered in either grass or a cover crop rather than row crops.

During our second windshield survey (June 24, 2017), we observed water ponding on the surfaces of several fields. A conversation with the farmer who owned one of the fields revealed that the tile drains, which had been installed every 20 feet, were not sufficient to drain water from the field. Though several fields held a healthy corn crop, the farmer indicated that corn was not doing well due to the intense rain and storms in 2017, and estimated that his yield would be reduced by approximately one-third compared to what was typical.

We identified several other fields with water ponding on the surface, likely due to recent heavy rainfall and internally draining land. Many fields had healthy corn crops; on a few fields, the crops appeared stunted, possibly due to flooding. Several fields had incorporated erosion prevention and sediment control practices, such as grassed waterways and grass plantings on steep slopes. Only a few fields encountered were left fallow. By far, corn was the most commonly planted crop.

Additional documentation of observations were taken with photos and then placed within a custom Google Map, found in Appendix B.

4.3.3 – EVAAL MODELING

The EVAAL model created several GIS layers that contained information, such as stream power and soil erodibility factor (USLE K-factor). These additional layer outputs can be found in Appendix D.

The result of the EVAAL model is the EVI, which indicates areas of potentially high soil loss (Figure 10). The solid blue areas are internally draining, so it is assumed that if soil erosion occurs in those areas, it will not actually reach a surface water body. The areas in red have the highest erosion potential in the subwatershed. These are priority areas where BMPs should be evaluated and targeted to reduce erosion. One important thing to consider is that current land management practices are not accounted for in the model, and areas with high erosion potential could already have best management practices in place. Therefore, the results should be used to prioritize areas of high erosion potential and to determine where BMPs should be targeted to reduce the risk of erosion and nutrient loading to Beaver Creek (and ultimately Beaver Dam Lake). However, these results need to be verified with field observations in order to determine where best management practices, such as grassed waterways, buffer strips, and cover cropping, should be implemented. Based on visual observations, some of these BMPs are already being used on farms throughout the subwatershed. Further research should account for practices already in use by incorporating results from models like SnapPlus (Soil Nutrient Application Planner), which provide more data on a field-by-field basis and incorporate current management practices.

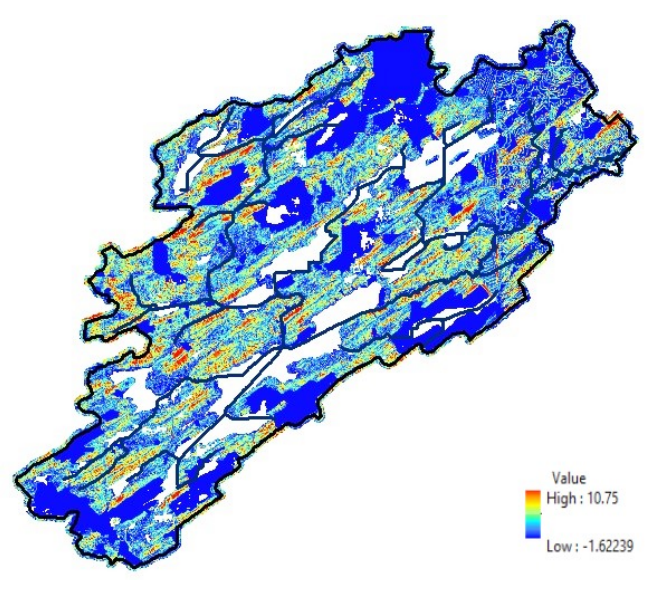


Figure 10: Final EVAAL results: erosion vulnerability index (EVI) throughout the Beaver Creek subwatershed.

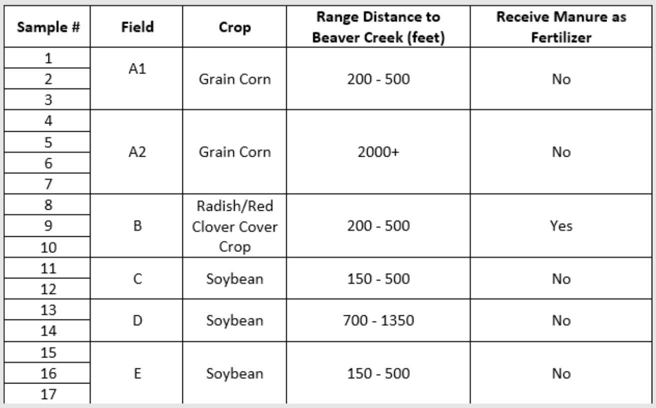
Land use decisions made throughout this subwatershed to reduce sediment and nutrient pollution have the potential to improve water quality in Beaver Creek and Beaver Dam Lake. Given the large watershed, modeling data is useful for targeting and implementing land conservation and management practices. The EVAAL modeling results provide important information on soil erosion vulnerability that can be used to target management practices in places where they are needed most within the subwatershed. However, the modeling results should be field verified. For example, our visual observations supported the maps derived from the model; we could see clear visual evidence of the erosion once the crop had been harvested. However, we did not have data on past efforts to prevent erosion. This information was only obtained through conversations with a member of BDLIA. Therefore, we consider it essential that the EVAAL results be combined with other resources for both county and private agronomists and to ensure that BMPs are effectively and efficiently designed and sited.

It is our understanding that many farmers already use SnapPlus directly or employ consultants who use this model to develop nutrient management plans. While this data is proprietary, compiling the results of existing field-scale modeling (with appropriate permission of the landowners) could be valuable in revealing practices already in place and allowing future research to identify the efficacy of these BMPs. Working in collaboration with local farmers to learn the history of the land and the perception of BMPs will be essential going forward. The EVAAL results and soil samples we have provided can be used as a starting point to open discussions with farmers on their own challenges, either confirming intuitions the farmers already held or providing them with the data needed to recognize what is happening on their fields.

4.3.4 – SOIL SAMPLES

Table 1 shows the sample number, field label, crop type, average distance to Beaver Creek, and whether the field has received manure as fertilizer. The cornfields (A) have not had manure spread in three-plus years. The soybean fields (C, D and E) also have not received manure fertilizer in recent years, to the best of our knowledge. The cover crop field (B) recently had manure applied. Also, soybean field D drains to soybean field E via a culvert.

Table 1: Soil samples information



Sample #	Field	Crop	Range Distance to Beaver Creek (feet)	Receive Manure as Fertilizer
1	A1	Grain Corn	200 - 500	No
2				
3				
4	A2	Grain Corn	2000+	No
5				
6				
7				
8	B	Radish/Red Clover Cover Crop	200 - 500	Yes
9				
10				
11	C	Soybean	150 - 500	No
12				
13	D	Soybean	700 - 1350	No
14				
15	E	Soybean	150 - 500	No
16				
17				

Figure 11 shows the soil test P levels (ppm) from each of the samples. Lines across the bars show the crop-optimal P (ppm) as identified by UW-Extension (Laboski and Peters, 2012). With the exception of sample #7, soils at all locations had Bray-1 P levels above or far above crop-optimal levels, meaning that soil P levels are in excess of nutrient recommendations. Note that only sample 7 was lower than optimal. Samples 4 – 7 were from the same area of the field, indicating variability in nutrient levels within the same field. The number of soil samples did not allow for statistical comparisons and are not representative of the entire subwatershed.

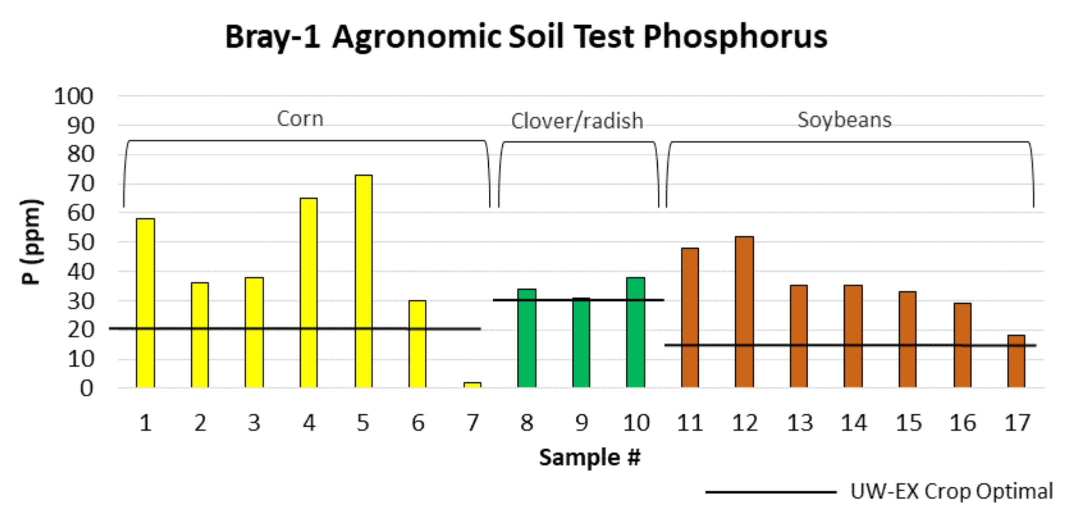


Figure 11: Bray-1 P in soil samples.

The soil sampling we conducted provides some insight into the agronomic needs and current condition of the soil in a small portion of the watershed. The above crop-optimal levels may be a result of historic agricultural practices including long-term manure application. Further soil sampling and data analysis can help quantify the potential for nutrient pollution from the land. Models (e.g., Pote et al., 1995; Vadas et al., 2004) could be used to estimate the amount of dissolved P that would be present in runoff based on soil Bray-1 P. More detailed watershed scale modeling, for example with the Soil and Water Assessment Tool (SWAT), can build on our results and help identify sediment and nutrient delivery to Beaver Creek. Soil sampling results can also be used with further field-scale modeling, such as SnapPlus, to assist producers with nutrient management planning on their fields. SnapPlus is a viable option that supports protecting water quality while allowing the producer to plan for optimal crop yields.

The Upland goals were threefold: to identify areas of high erosion vulnerability; to ground our model in field-level observations, and to establish a preliminary understanding of soil P. We modeled erosion potential with EVAAL and verified a few highly vulnerable areas through visual observations. We gained access to several sites and collected soil samples, which provided a snapshot of soil nutrient levels in fields planted with corn, soybeans, and cover crops.

The recommendations presented in Chapter 7 highlight the need for county agronomists and officials to share our EVAAL results, and use them to target best management practices. We also recommend ongoing and expanded soil sampling, as well as future modeling to predict sediment and P delivery to Beaver Creek and to help farmers reduce erosion on their fields and better manage their soil and nutrient levels to minimize P run-off.

IN-STREAM

5.1 – Purpose

Beaver Creek, an impaired water body, discharges directly into Beaver Dam Lake; therefore, it is important to determine the impact the creek may have on the lake. We assessed stream biotic integrity, habitat, sediment P load, and water quality in the creek to understand how Beaver Creek contributes to the quality of Beaver Dam Lake, and how the creek can be improved.

Current biological data for the Beaver Creek ecosystem is limited. We characterized the habitat composition and quality in and along the stream to provide a preliminary assessment for the future analysis of baseline conditions. We analyzed the composition of the macroinvertebrate community in the stream, which can serve as a proxy for long-term trends in water quality, as certain species are sensitive to certain pollutants (Miller et al., 2014). This information provides insight into the overall integrity of the stream's biological community.

Historic sediment P deposition within Beaver Creek, hereafter referred to as legacy P, was assessed by sampling sediment and estimating the total sediment P deposited on the stream bottom. This represents the P that could be leached out or transported via sediment into the water. Understanding the P within the sediment is important because it will move over time to the lake, further amplifying eutrophication.

5.2 – Methods

5.2.1 – SAMPLING SITES

Sampling sites were established at locations along Beaver Creek (Figure 12) based primarily on sufficient access to the creek (e.g., upstream or downstream of roadways and bridges). These sites were distributed relatively evenly along the length of the creek.

For water quality samples, three main sites were selected downstream of Paradise Marsh: crossings at County Road DG (farthest upstream), State Highway 73, and County Road G (farthest downstream) (Figure 12). Water quality grab samples were collected monthly at the three main sites from May until October. Two sites (Highway 146 and Pierce Road) were added in September 2017 to bring the number of sites to five for September through November. These two additional sites were added to more fully assess potential nutrient sources from upstream of Paradise Marsh.

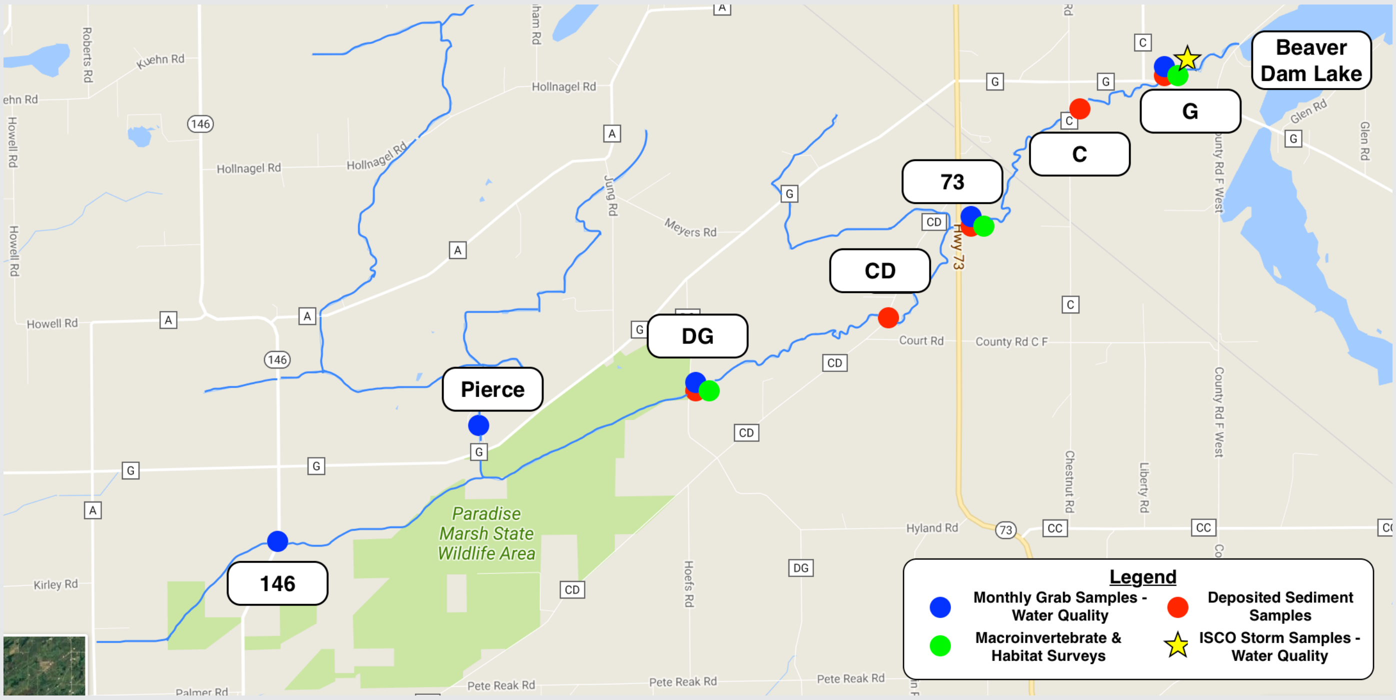


Figure 12: Sample locations along Beaver Creek.

All samples were collected within 24-hour periods. Sampling periods corresponded closely to when samples were collected in Beaver Dam Lake, typically within 48 hours of each other. In addition to monthly grab samples, three storm events were sampled using a Teledyne ISCO 6712 Standard Portable Sampler (ISCO), which was positioned at the County Road G site. This site drained most of the watershed and is assumed to represent inputs to Beaver Dam Lake from Beaver Creek.

5.2.2 – WATER QUALITY

Sample bottles where triple-rinsed with stream water, submerged to a depth approximately 15 centimeters below the surface in a location with good flow, and capped under water. Samples were stored on ice, transported to the Water Quality Laboratory in the UW Biological Systems Engineering Department and refrigerated prior to analysis. All grab and storm samples were analyzed for pH, EC, TS, TSS, TP, DRP, TN, and TKN using an AQ2 Discrete Autoanalyzer and according to appropriate EPA procedures (Appendix F).

Measurements were tested for statistical analysis by using a t-test to reveal any significant difference among averages. This method was chosen due the relatively small sample size and unknown variance (SPSS Tutorials, n.d.). Significance was defined as a p-value less than 0.05. T-tests were performed between sites, times of year, and grab samples versus storm samples.

Storm Events

Monitoring storms required more preparation than obtaining monthly grab samples. County Road G was selected because the stream reach was relatively uniform, with a straight channel and sufficient flow depth. A stage-discharge curve was developed from depth and velocity measurements taken at the same cross section on several different days from May through mid-June. These measurements (12 observed stages total; see Appendix F — Additional In-Stream Methods and Results) captured different flow regimes from 1.4 – 3.5 feet (approximately .43 – 1.1 meters) depth within the stream channel and allowed estimation of the associated discharge-versus-depth relationship (Figure 13). A linear equation was used to interpolate/extrapolate discharges not measured.

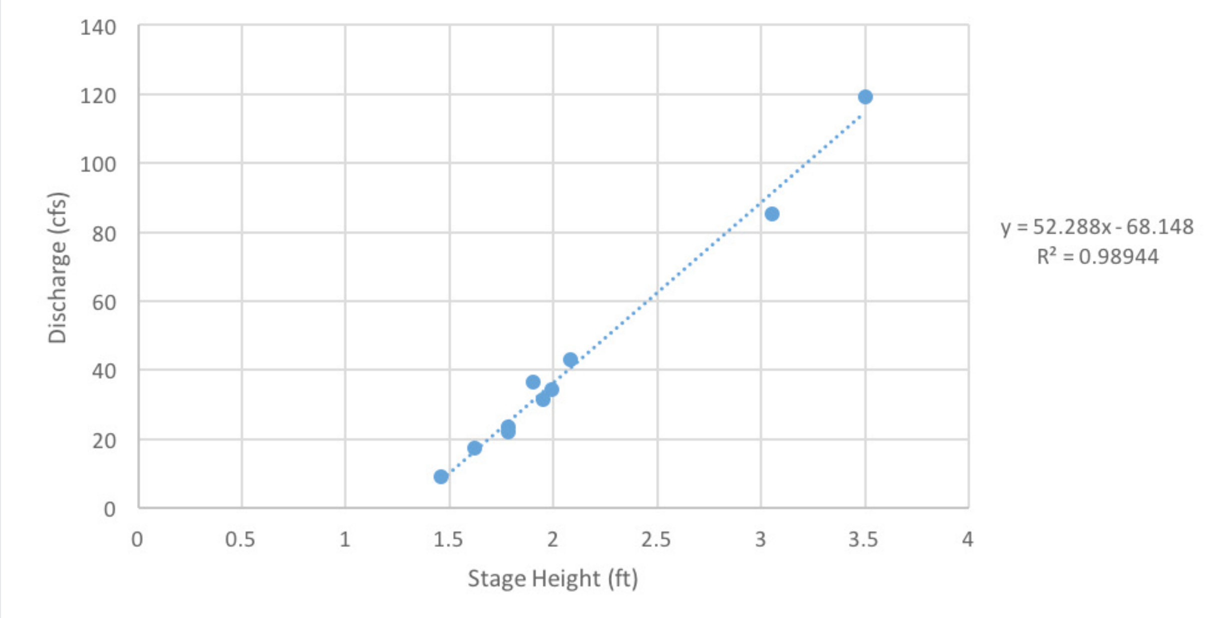


Figure 13: Stage-discharge curve from 12 observed measurements for Beaver Creek at the County Road G sampling location.

The ISCO sampler was programmed to record flow depth and calculated flow volume every two minutes. Flow during a preliminary storm was measured to guide programming of the ISCO so that volume based samples were spread over the entire hydrograph. Volume intervals were changed for each storm based on the amount of rain predicted and the pre-storm stage height of the stream. Samples were composited for analysis. Generally, five composites were created to represent the start, the rising limb, the peak, the falling limb, and the end of the hydrograph (Figure 14).

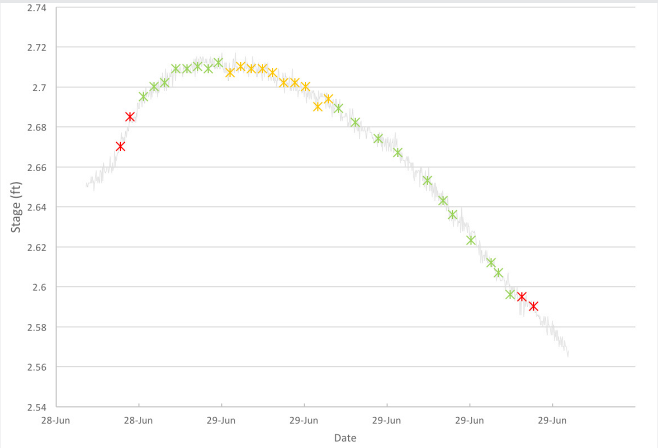


Figure 14: Storm 1 hydrograph with the composite water samples color-coded to show the different stages captured.

5.2.3 – BIOTIC HEALTH

Sites

The biological surveys, which included macroinvertebrate surveys and riparian and habitat assessments, were conducted at the three main sites (County Road DG, State Highway 73, and County Road G) to represent upstream, midstream, and downstream conditions of the stream (Figure 12). One 80-meter reach per site was surveyed, with length based on the ability to comprehensively sample the site while maintaining an adequate number of riffles, pools, runs, and deposition sites (Shelton & Capel, 1994).

Methods

Water samples were collected monthly and during storm events to determine baseline and storm-event water chemistry. Specifically, pH, electrical conductivity (EC), total solids (TS), total suspended solids (TSS), total phosphorus (TP), dissolved reactive phosphorus (DRP), total nitrogen (TN), and total Kjeldahl nitrogen (TKN) were measured and analyzed using EPA assessment techniques (Appendix F). TS and TSS are important as measures of sediment within the water column. DRP is organic P in the form of orthophosphates; it is directly available for plant uptake and is a fraction of TP. TN is a measure of all species of nitrogen (N), while TKN is a measure of organic N, ammonium (NH4), and ammonia gas (NH3). These data were used to help formulate management recommendations aimed at improving stream water quality and removing Beaver Creek from the impaired waters list.

Biological assessments utilized indices created by UW-Extension because they are available to citizen monitoring groups. Macroinvertebrates were sampled on May 12 and September 9, 2017. Two collectors used 2-mm dip nets continuously for 15 minutes to catch species dislodged from rocks, leaf packs, undercut banks, and under other suitable surfaces. Collections were sorted on the streambank for no more than 30 minutes. The UW-Extension Recording Form for the Citizen Monitoring Biotic Index was used to calculate the biotic index, which was used to indicate the relative health of the macroinvertebrate community. This index organizes the identified taxa into four groups based on their sensitivity to water quality from most (group 1) to least sensitive (group 4). The number of taxa from each group was used to calculate a total water quality score ranging from 1.0 (poor) to 3.5 (good), by assigning more weight to more sensitive groups. Riparian and habitat health was assessed on September 9. Unfortunately, little rain fell for a few weeks before the assessment, causing the stream water level to drop and exposing the banks. The WDNR Wadable Stream Qualitative Fish Habitat Rating for Streams ≤ 10 m Wide was used for this portion of the assessment. This index assesses habitat quality based on several parameters, including quality of riparian buffer vegetation, presence of in-stream habitats, and presence of fine sediments (see Table 3 in the results section). Each parameter was qualitatively assessed and assigned a corresponding score. The scores for each individual parameter were then totaled, yielding an overall score ranging from 20 (poor) to 80 (excellent).

5.2.4 – SEDIMENT

Sites

Sediment was sampled at five sites: County DG, County CD, State Hwy 73, County C, and County G. Site lengths for sediment sampling also consisted of one 80-meter (262.5-foot) reach per site to allow comprehensive sampling along an adequate number of riffles, pools, runs, and deposition sites (Shelton & Capel, 1994).

Methods

Streambed sampling procedures were based on those described in Shelton and Capel (1994) and EPA (2001). Samples were obtained either upstream or downstream of the crossing depending largely on landowner permission to access the land adjacent to the stream. County Road DG, Highway 73, and County Road G were sampled downstream of the crossing, while County Roads CD and C were sampled upstream. Sampling was done near the road crossings because of the relative ease of collection. We understand that the chosen side of the road crossing—upstream versus downstream—as well as sampling near the crossing, could affect the results.

Sediment analysis was performed to characterize the in-place (deposited) sediment within the creek. Preliminary testing of the streambed sediment at each site was conducted to determine if enough fine-grained (<0.06 mm) silts and clays were present (Ohio EPA, 2001) for nutrient adsorption. A sediment depth of at least 8 cm was determined to be adequate to be sampled with the coring device; this minimal depth was a constraint of the coring device to capture sediment, but provided sufficient sediment to determine a "deposition zone." Cores were taken at crossings DG, CD, 73, C, and G (Figure 12) using a Wildco sediment coring device. The number of cores within each zone was determined by the size and shape of the zone compared to the reach. At each location, a full core and a surface (2.5-cm) core were collected. The full core sample was the total depth of deposited material or the maximum depth of material that could be collected using the corer (32 cm). The 2.5-cm core represents the top layer of deposited sediment that is more likely to be mobilized with increased flow.

Within each deposition zone, the deposited sediment depths, widths and lengths were measured at several locations. The average length, width and depth were multiplied to estimate deposition zone volume. All deposition zone volumes within the 80-m reach were added together to estimate the total sediment deposited within the reach.

Within each reach, all cores from the same depth (total or 2.5 cm) were composited and dried thoroughly at 60°C. Dried samples were crushed to a fine powder with a mortar and pestle and put through a two-millimeter sieve. Sediment was analyzed for TP by the WSLH, and for water extractable phosphorus (WEP) and soil texture by the University of Wisconsin Soil and Forage Laboratory.

Total mass of P in deposited sediment was calculated for each reach. Bulk density (kg/m3) was calculated by dividing the dry sediment weight of the core by the volume of the core. Total sediment (kg/reach) was calculated by multiplying the total volume of sediment (m3/reach) by the bulk density (kg/m3). Finally, the total mass of P in the deposited sediment was calculated by multiplying the concentration of P (mg/kg) by the total sediment (kg/reach).

5.3 – Results and Discussion

Water quality monitoring results indicate high levels of nutrients in the Beaver Creek water column as well as in the sediment deposited on the creek bed. Specifically, TP concentrations in the water were far above WDNR criterion of 0.075 mg/L. Although not regulated in Wisconsin streams, N levels were also very high and could be problematic downstream and to groundwater-sourced drinking water. Substantial P-laden sediment accumulations were measured at DG and 73, while relatively low accumulations were measured at County Roads CD, C, and G.

5.3.1 – DISCHARGE

The stream stage height at County G varied from June 15 – November 2: water levels started high with spring rains and decreased throughout the summer (Figure 15; Figure 16). The maximum stage height of approximately 3.5 feet (1.07 meters) was measured on June 22, and the minimum of approximately 1.3 feet (0.4 meters) on October 1.

In 2017, stage height was highest throughout the spring and early summer. For example, the storm event on June 22, 2017, was quite large compared to the rest of the year. Such storm events could significantly affect the movement of sediment and nutrients. The stream response will change based on yearly and event precipitation; however, it is likely that spring will continue to be the wettest season, with snowmelt and rain events.

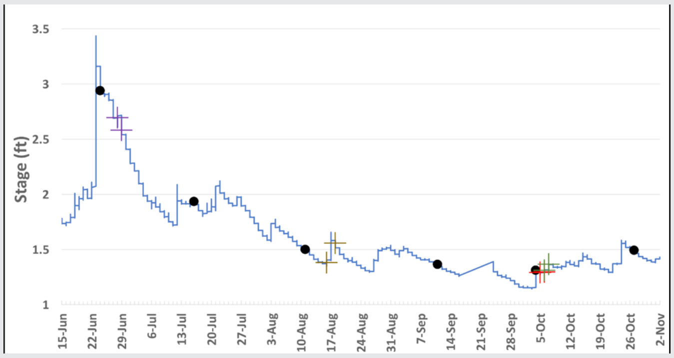


Figure 15: Stage height of Beaver Creek recorded by ISCO at County G from June 15 to November 2. Black dots correspond to monthly grab samples, while colored marks indicate the beginning and end of sampled storm events.

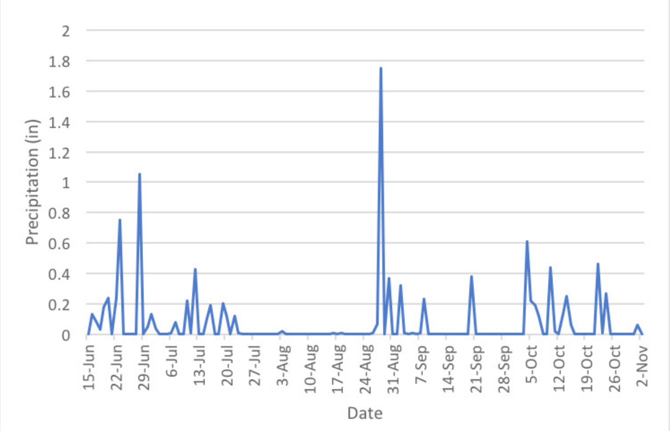


Figure 16: Daily precipitation for Juneau, Wisconsin.

5.3.2 – WATER QUALITY

pH

Stream pH ranged from 6.8 to 7.9 for grab samples collected between May 26 and October 27, with an average just above 7, or neutral (Figure 17). During storm events, pH was slightly more basic, ranging between 7.4 and 8.1 (Figure 18). The higher pH of storms significantly differed from that of monthly grab samples ($p < 0.05$, t-test).

Because pH impacts living organisms, Beaver Creek's neutral pH is encouraging for supporting a healthy ecosystem. However, a higher pH during storm events could indicate future problems. The higher pH during storm events could be caused by surface runoff from farm fields containing high levels of nutrients. For example, fertilizers containing ammonia or lime increase the pH of water. Also, certain minerals that naturally occur in the soil can alter the pH of runoff to the creek. Monthly grab samples are more likely to be influenced by the pH of groundwater (which ranges from 6.0 to 9.0 throughout Wisconsin; Masarik et al., 2007), which dominates baseflow and is reflected in Figure 17.

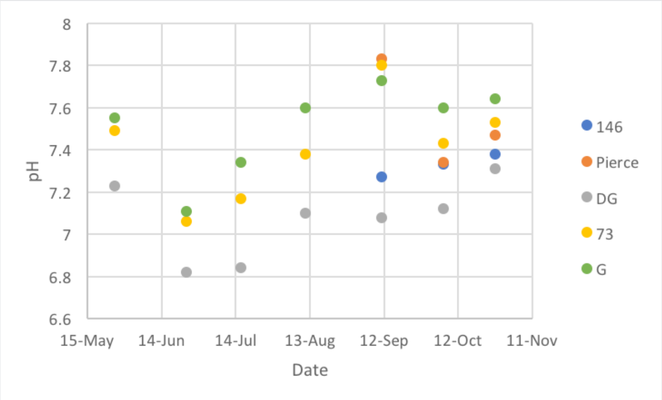


Figure 17: pH of monthly grab samples at five locations in Beaver Creek.

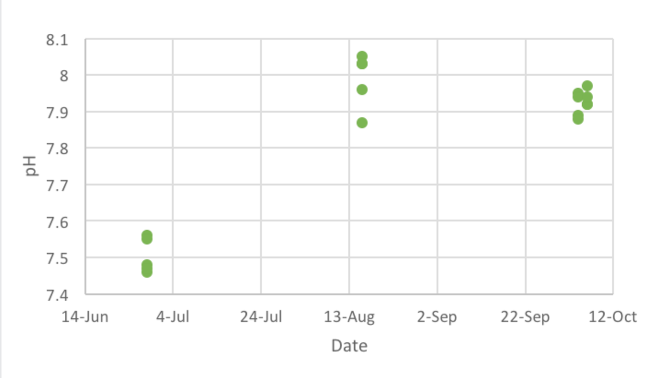


Figure 18: pH of storm-event samples at County Road G from Beaver Creek.

Electrical Conductivity

Electrical conductivity generally increased from May through November, and from upstream to downstream sites (Figure 19, Figure 20). The spatial trend was not significant ($p = 0.95$); however, the increasing trend across time was significant ($p < 0.05$, one-way ANOVA).

Electrical conductivity tends to increase with increased sediments (Walton, 1989). This may explain the increase in EC from upstream to downstream as more sediments, and thus ions, entered the water. However, this trend for TS also was not significant ($p = 0.55$). EC did increase significantly over time ($p < 0.05$), which may be due to sediment becoming more concentrated over the summer as stream flow decreased. However, as electrical conductivity tends to vary, these results indicate only a modest difference over time.

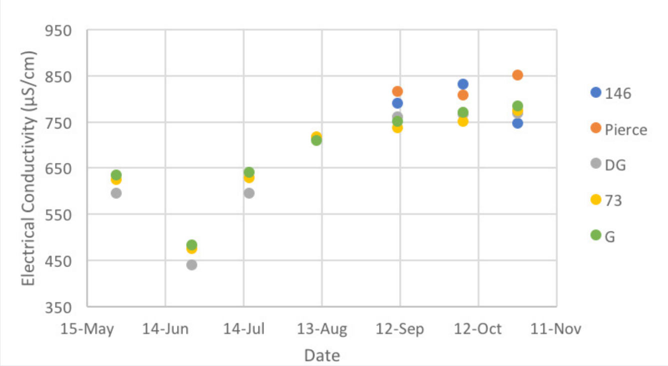


Figure 19: Electrical conductivity of monthly grab samples from Beaver Creek.

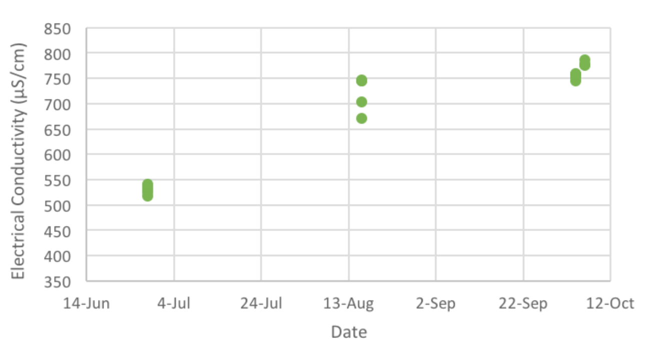


Figure 20: Electrical conductivity of storm-event samples at County Road G from Beaver Creek.

Total Solids (TS)

Total solids (TS) concentrations increased from approximately 450 mg/L in May to 750 mg/L in November (Figure 21). Similar to pH and EC, TS generally increased from upstream to downstream sites (trend not significant: p value = 0.55), and significantly from May to November (p value < 0.05). The increasing trend over time is significant, as TS varied over a fairly large range. TS of storm samples showed no significant trend (p value = 0.13) (Figure 22).

While there is no standard for total solids, TS are associated with issues such as decreasing visibility for predatory fish, smothering larvae, warming water temperature, etc. (Miller et al., 2014; WDNR, 2006). The relatively high levels of sediment suspended in the water column suggest that erosion from the watershed and creek banks may be contributors. The increase in TS throughout the year could be due to the increasing amount of agricultural activity disturbing the soil in the spring. Also, as with EC, TS could have become more concentrated with decreased flow to remain high for the summer.

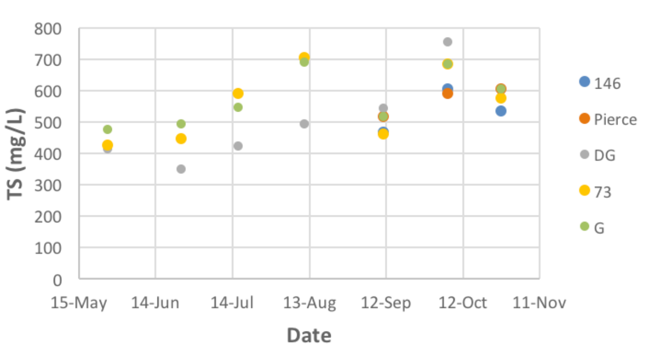


Figure 21: TS of monthly grab samples from Beaver Creek.

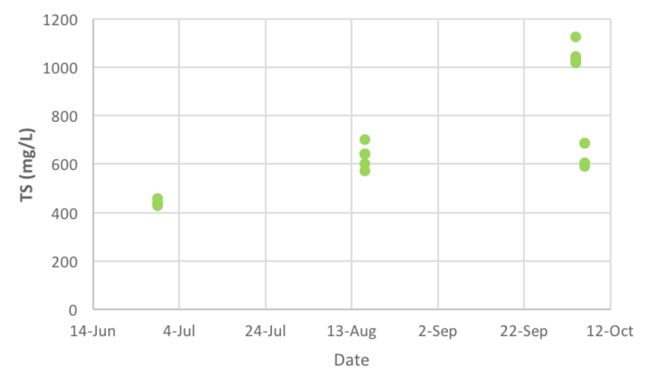


Figure 22: TS of storm samples from Beaver Creek.

Total Suspended Solids

Total suspended solids (TSS) concentrations for monthly grab samples ranged from approximately 1 mg/L on May 26 to 70 mg/L on June 24 (Figure 23). TSS was relatively constant over time (p value = 0.21), but tended to increase from upstream to downstream (p value = 0.11). Storm samples ranged from 21 to 300 mg/L. The average TSS concentration of County Road G storm samples was greater than the average of County Road G monthly grab samples (p value < 0.05).

Suspended solids carry nutrients, particularly phosphorus, which is why TSS is important to this study. While most of the concentrations are relatively low, the few large values on June 24 and July 14 at State Highway 73 and County Road G are noteworthy as these are two to four times the average

TSS concentration of southeastern Wisconsin, which is ~15 mg/L (WDNR, 2006). These high values could be due to specific applications of fertilizer followed by rain events coming through drainage tiles. A fair amount of rain fell shortly before these two samples were taken, with 0.75 inches on June 23, and 0.43 inches on July 12. Storm samples carried more TSS than monthly samples due to increased flow suspending more small particles (Figure 24). This statistically significant finding supports the hypothesis that storm events are the main transport mechanisms for nutrients through the stream into the lake. However, the amount of sediment in the water column does not necessarily equal what enters the lake; it can be deposited beforehand and take time to be carried into the lake.

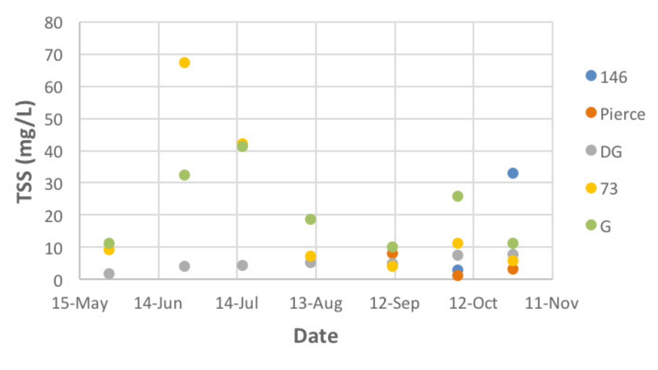


Figure 23: TSS of monthly grab samples from Beaver Creek.

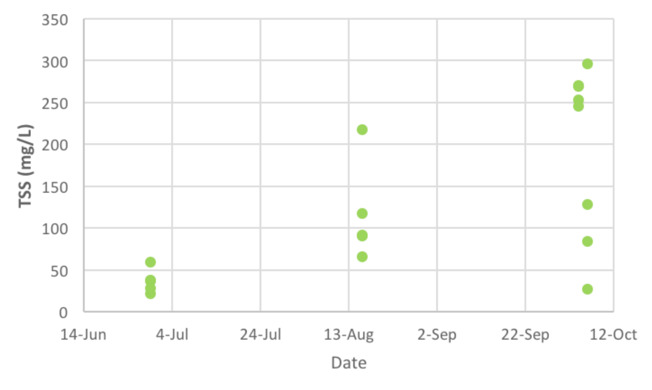


Figure 24: TSS of storm samples from Beaver Creek.

Total Phosphorus

Grab sample total phosphorus (TP) concentrations from May to November were all above water quality standards for Wisconsin surface waters (NR 102, 2010.) at every site. Furthermore, the grab samples collected on July 16 had concentrations that were eight, six, and five times the standard at DG, 73, and G respectively (Figure 25). This indicates long-term, excess phosphorus throughout the watershed that needs to be addressed.

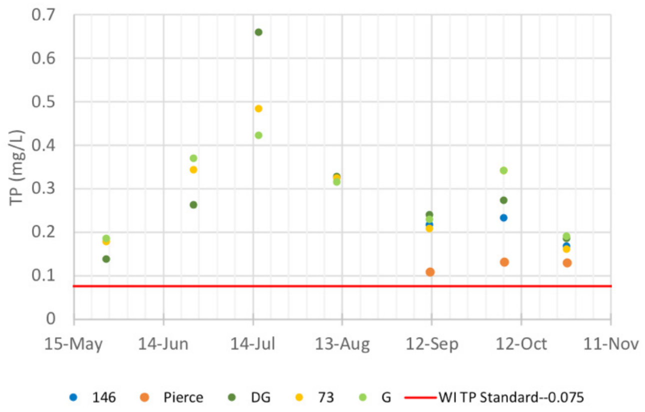


Figure 25: TP grab sample concentrations.

Average TP was lower for the baseline than the storm events. TP had an increasing trend from storm event 1 to event 3, and then decreased between events 3 and 4 (Figure 31). The average TP concentrations from composite samples during storm events 2 and 3 significantly differ from the average baseline TP concentration ($p < 0.05$), while storm events 1 and 4 are not significantly different from the baseline level of TP in Beaver Creek (Figure 23). The average TP values for the baseline as well as during the storm events are substantially higher than state instream water quality standards (0.075 mg/L) (Figure 26).

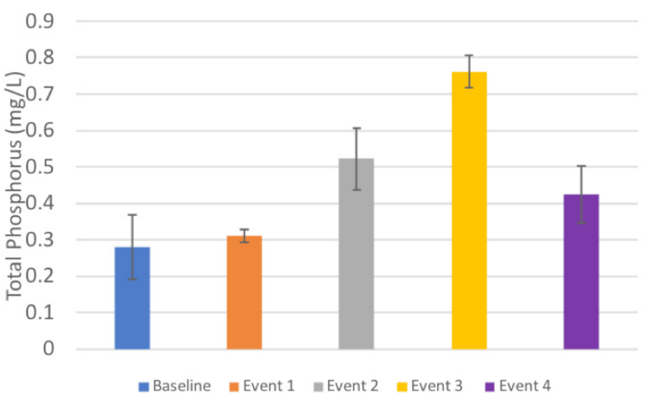


Figure 26: Average TP concentrations during baseline streamflow (grab samples) and the four captured storm events. Error bars represent the standard deviation.

Total TP delivered during storm events varied (Table 2). These estimates are conservative; composite samples do not account for all the time, and therefore, the volume of water throughout the storm. Event 2 carried an order of magnitude more TP than the other storm events due to higher sustained flow rates than the other storms.

Table 2: Estimated total phosphorus during storm events.

Storm	Total TP (lb)
Event 1 (06/28-06/29/17)	4.4
Event 2 (08/16-08/18/17)	56
Event 3 (10/04-10/06/17)	7.2
Event 4 (10/06-10/07/17)	3.0

Dissolved Reactive Phosphorus

Dissolved reactive phosphorus (DRP) is a proportion of TP and is not specifically regulated like TP. However, DRP concentrations in the majority of grab samples were above the Wisconsin TP standard of 0.075 mg/L (NR 102, 2010) (Figure 27). DRP concentrations during all storm events were not significantly different from the baseline DRP concentrations (Figure 27). DRP for all sites ranged from 21-65% of TP with an average of 44% and median of 45%. Grab sample TP and DRP concentrations increased from late May to a peak on July 16 and then decreased over the remainder of the season. The sample on July 16 at the DG location was especially high in both TP and DRP (Figure 29).

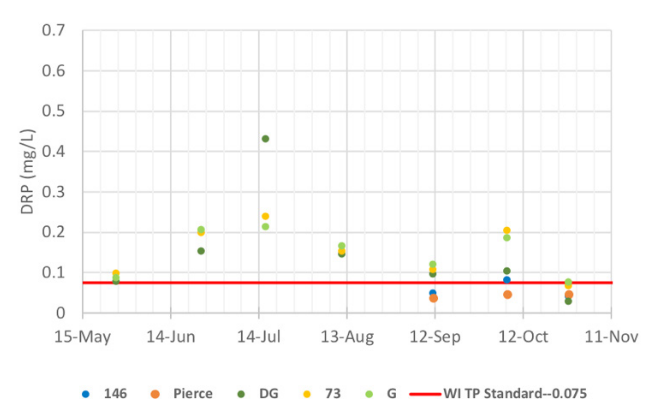


Figure 27: DRP grab sample concentrations.

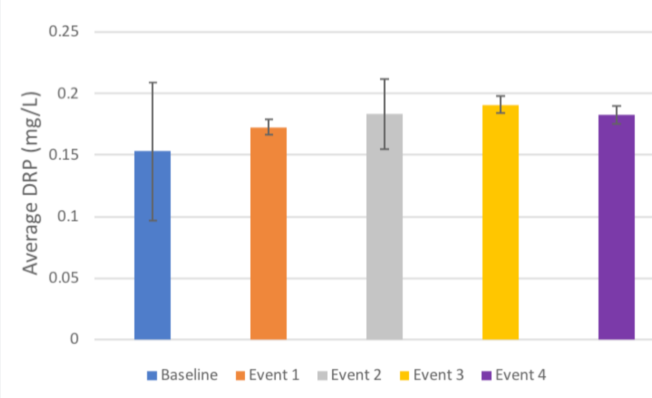


Figure 28: DRP levels during baseline streamflow and the four captured storm events.

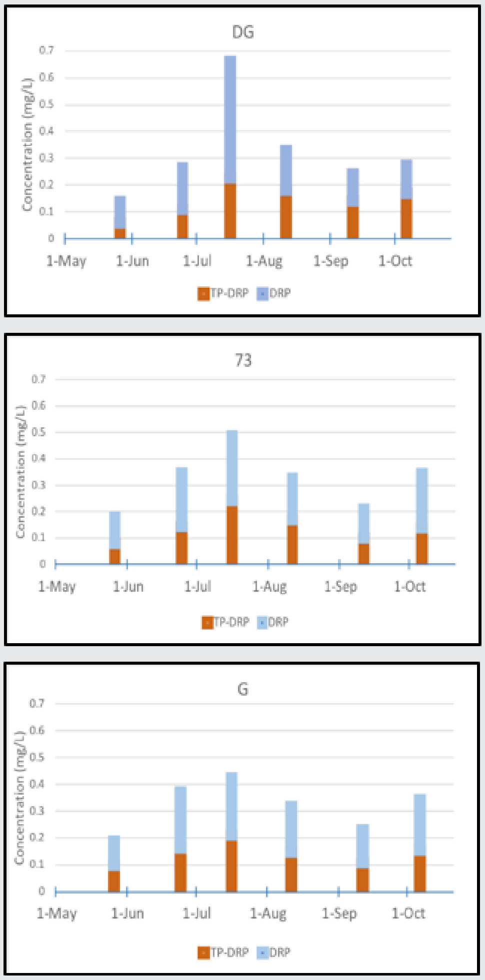


Figure 29: DRP as a proportion of TP for sites DG, 73, and G.

The increase in TP and DRP concentrations from May 26 to July 16 (Figure 25, Figure 27) could be attributed to heavy discharges associated with spring rain as well as minimal vegetation on the land to prevent sediment and nutrient runoff. In contrast, lower concentrations for the last three months correspond to lower stream discharges and increased vegetation.

Site DG is directly downstream of Paradise Marsh. A duration of high stream discharge occurred between June 17 and July 11 (Figure 15) and DRP spiked on July 16 (Figure 27). This delayed increase in DRP may indicate a groundwater origin after filtering through the marsh. This groundwater origin, together with a release of the legacy DRP accumulation in the marsh, may have contributed to the relatively large proportion of DRP in this sample.

Nitrates

Storm event 1 was the only storm event to have a significantly different level of nitrates compared to the baseline nitrate level ($p < 0.05$). All other storm events do not significantly differ from the baseline level of nitrates in Beaver Creek (Figure 30).

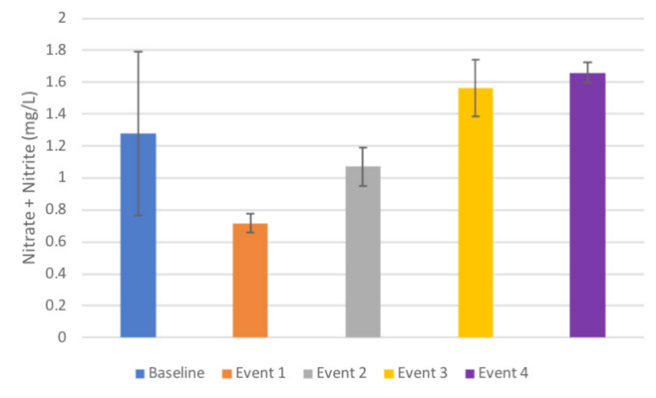


Figure 30: Nitrate + nitrite concentrations during baseline streamflow and the four captured storm events.

When comparing nitrate levels during baseline stream flow to nitrate levels during captured storm events, only the first storm event showed a significantly lower nitrate level (Figure 30). The other storm events did not have significantly different nitrate levels from the baseline flow. This suggests that storm events, and by extension agricultural runoff, do not significantly affect the nitrate levels in Beaver Creek. However, USGS (2017) suggests that surface water can be a predominant source of nitrates, particularly when carrying fertilizers and animal waste.

Site Nutrient Comparisons

The average TP concentration for the last three sampling dates (samples were collected at Pierce Road and Highway 146 only on these three dates) was lowest at the Pierce Road site compared to the other four sites (Figure 32). However, the only significantly different TP values were between Pierce Road and Highway DG.

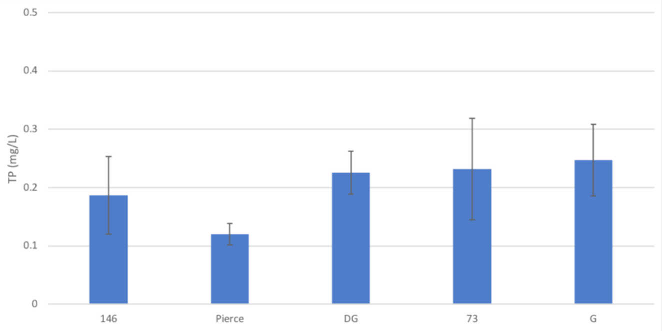
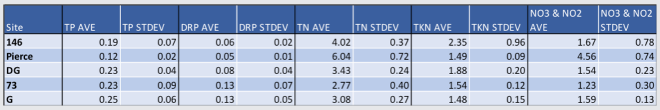


Figure 31: Average TP across sites for the last three sample dates.

Table 3: Average nutrient values across sites for last three sampling dates. Units are mg/L.



Site	TP AVE	TP STDEV	DRP AVE	DRP STDEV	TN AVE	TN STDEV	TKN AVE	TKN STDEV	NO3 & NO2 AVE	NO3 & NO2 STDEV
146	0.19	0.07	0.06	0.02	4.02	0.37	2.35	0.96	1.67	0.78
Pierce	0.12	0.02	0.05	0.01	6.04	0.72	1.49	0.09	4.56	0.74
DG	0.23	0.04	0.08	0.04	3.43	0.24	1.88	0.20	1.54	0.23
73	0.23	0.09	0.13	0.07	2.77	0.40	1.54	0.12	1.23	0.30
G	0.25	0.06	0.13	0.05	3.08	0.27	1.48	0.15	1.59	0.13

5.3.3 – BIOTIC HEALTH

Benthic Macroinvertebrate Sampling

Table 4 shows macroinvertebrate water quality scores for the three sample sites. Water quality scores ranged from 1.73 (poor) to 2.3 (fair), and most scores fell on the border between the poor and fair water quality categories (around 2.0) for both spring and fall 2017. The lowest scores were observed at site DG in both spring and fall, and in general, fall scores were lower than spring scores.

Table 4: Macroinvertebrate water quality scores for fall and spring 2017. Scores of 1.0-2.0 indicate poor water quality, 2.1-2.5 indicate fair water quality, and 2.6-3.5 indicate good water quality.

Site	Spring Water Quality Score	Fall Water Quality Score
DG	1.73	2
73	2.3	2
G	2.3	2.1

Possible reasons for poor to fair water quality scores in the stream include the presence of a lot of fine sediment causing reduction in visibility and an increase in temperature, or lack of suitable cover for organisms to hide (Miller et al., 2014). Figure 32 shows all taxa found at the three sites for both spring and fall samples, grouped by sensitivity to pollutants. No group 1 (highly sensitive) taxa were observed at any site for either sampling period. Observed taxa were largely similar between fall and spring samples with no new types being observed in the fall that were not previously seen in the spring.

It is also important to note that indices such as the UW-Extension citizen monitoring index are biased toward cold-water trout streams, meaning a warm agricultural stream such as Beaver Creek would be unlikely to receive a “good” rating, even if water quality in the region was adequate. This likely explains the lack of group 1 taxa across all sites, as these organisms tend to prefer cold, well-oxygenated waters that simply do not occur in streams like Beaver Creek. Overall, the taxa observed indicate a diverse warm-water macroinvertebrate community with substantial populations of more sensitive taxa such as mayfly and damselfly. This is further corroborated by the presence of some of the additional taxa, such as the water scorpion and giant water bug, which are not included in the water quality score but whose presence is often indicative of suitable habitat and water quality in warm-water invertebrate communities. Future surveys could use an index more tailored to warm-water communities to obtain a more accurate rating; however, the UWEX index is easily repeatable and has a large database for comparison to other streams similar to Beaver Creek.

Generally, spring water quality scores were higher than fall scores. This is likely a result of having fewer mature insect larvae in fall compared to spring rather than a product of decreasing water quality; many larvae advance to their terrestrial adult life stages during the summer. The immature larvae that remain in the fall are smaller and more difficult for the samplers to find and identify, making slightly lower fall scores common during benthic macroinvertebrate surveys. As a result, lower fall scores are likely not a cause for concern regarding stability of the macroinvertebrate community or water quality in Beaver Creek.

Water quality scores increased slightly from upstream (site DG) to downstream (site G). However, site DG received the lowest scores in both spring and fall (1.73 and 2.0, respectively). There is little observable evidence at the site or in the habitat and water quality data that indicate this site should be any less suitable for macroinvertebrates than the other sites. One possibility for the lower scores is that this site is immediately downstream of Paradise Marsh. The invertebrate community in the marsh likely resembles that of a lentic body of water, which transitions to a lotic community in the downstream portion of the creek. Site DG could represent a "transition zone" not entirely suitable for either lentic or lotic invertebrate communities, resulting in the lower scores, but again not representing any concerns for water quality at this site.

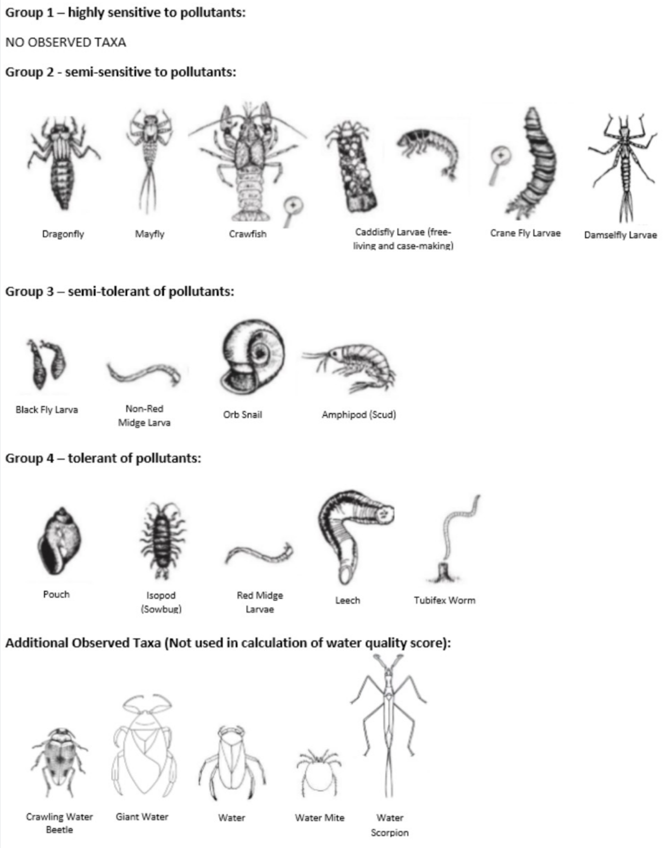
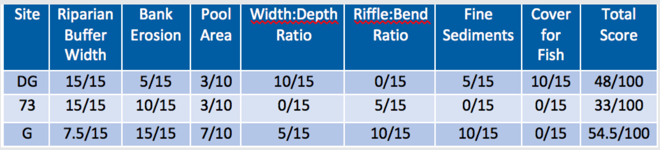


Figure 32: Observed taxa at three Beaver Creek sites grouped by sensitivity to water quality.

Qualitative Habitat Surveys

Table 5 shows the habitat quality scores for all three sample sites. Habitat quality scores ranged from 33 to 54.5, meaning all scores fall within the “fair” range. The site at crossing G received the highest overall score of 54.5, while the site at Highway 73 received the lowest at 33. Riparian buffers generally received very high scores across all sites. Fine sediments and fish cover received generally low scores across all sites. Stream morphology parameters such as width:depth and riffle:bend ratios were highly variable across the three sites.

Table 5: Qualitative habitat assessment scores for all Beaver Creek sites. Total scores below 20 indicate poor habitat, 20-60 indicate fair habitat, 60-80 indicate good habitat, above 80 indicate excellent habitat.



Site	Riparian Buffer Width	Bank Erosion	Pool Area	Width:Depth Ratio	Riffle:Bend Ratio	Fine Sediments	Cover for Fish	Total Score
DG	15/15	5/15	3/10	10/15	0/15	5/15	10/15	48/100
73	15/15	10/15	3/10	0/15	5/15	0/15	0/15	33/100
G	7.5/15	15/15	7/10	5/15	10/15	10/15	0/15	54.5/100

Fish cover scores all fell within the “fair” range, which corroborates the results of the macroinvertebrate sampling. Overall, the observed sites demonstrate relatively undisturbed, natural environments, which are good for providing habitat for fish and benthic macroinvertebrates. However, several parameters of the habitat assessment received consistently low scores across the three sites, leading to lower habitat ratings (Table 5).

Riparian buffer scores at all sites were very high, with the sites at DG and 73 receiving a perfect 15/15 rating. Vegetative buffers are important to maintaining water quality, as they stabilize the streambank and uptake nutrients and pollutants that would otherwise reach the stream, in addition to providing habitat. The buffers at these sites extended more than 10 meters back from the streambank and included a variety of vegetation, both herbaceous and woody. Both of these sites are immediately adjacent to agricultural fields, demonstrating that several landowners in the Beaver Creek watershed choose not to develop the area immediately adjacent to the stream, a practice that will lead to better habitat and water quality in the creek. The site at crossing G received a 7.5/15 for its buffer because, while the west bank had an extensive buffer similar to the other sites, the east bank was mowed directly to the edge of the stream, resulting in an inadequate turf grass buffer. The east bank was a residential property rather than agricultural, indicating that while producers tend not to develop the stream bank area, homeowners may be more likely to mow the area around the stream, resulting in decreased habitat and water quality.

One parameter that received low scores across all sites was fine sediments, the presence of which can result in reduced visibility, increased temperatures, and reduced dissolved oxygen for stream organisms. Because riparian buffers are adequate and bank erosion scores at the sites were generally high, the excess sediment is likely sediment yield from the watershed. Fine sediments not only threaten habitat quality, but also form likely bonding sites for P, which leads to algal blooms in Beaver Dam Lake. Site G received the highest sediment scores and had greater water clarity and fewer deposition zones compared to the other two sites. This could be the result of higher flow rates at this site flushing sediment, or the site’s position downstream of a large bend in the stream, which represents a significant deposition zone. Given the ubiquity of fine sediment in the stream, targeting its sources to Beaver Creek may be the most important parameter for simultaneously increasing habitat scores and decreasing phosphorus loading into Beaver Dam Lake.

Fish-cover scores across all sites were generally low, representing a lack of things like submerged logs, vegetation, or rocks, which provide shelter for stream organisms. This may be an easy parameter to target to increase habitat scores, as there are many options available for introducing fish cover into streams at low cost.

Stream morphology parameters such as the width:depth and riffle:bend ratios were highly variable among sites. While they did contribute to the lower scores seen at some sites (site 73 in particular), they are mostly a function of topography and stream behavior at the site and may be difficult to increase without significant alteration of the landscape. In particular, riffles seem to be a very rare natural feature of Beaver Creek and thus increasing them may not be feasible. As a result, it may make more sense to prioritize sedimentation and fish cover to increase future habitat quality scores over stream morphology parameters.

5.3.4 – SEDIMENT

Sediment volume

Total deposited sediment volume within the five reaches varied from 5.6 to 316 m3 (198 – 11,159 ft3). The largest volumes of 316 m3 and 265 m3 (9,358 ft3) were at DG and 73, respectively; the deposition zones within these reaches covered 100% of the 80-meter (262.5 ft) reach. The least amount of sediment, 14 m3 (494 ft3) and 5 m3 (177 ft3), was observed at Crossings CD and G, respectively; the proportion of these reaches considered deposition zones was 13% for CD and 5% for G (Figure 33).

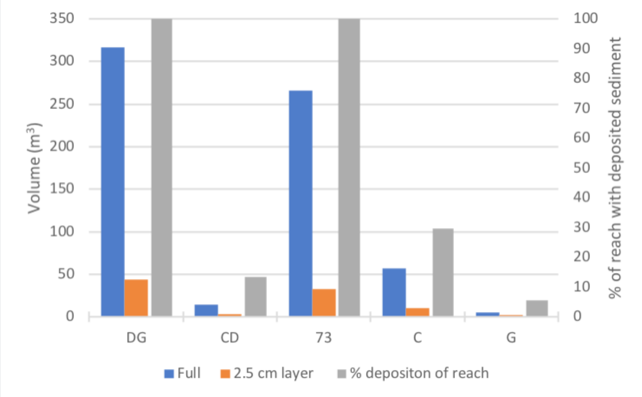


Figure 33: Full and top 2.5-cm layer sediment volumes for the 80-m reach at each site. Grey bar is the percentage of the reach with deposited sediment.

Sediment accumulations at DG and 73 could be a result of many factors. Historically, there has been dredging within Paradise Marsh and large portions of Beaver Creek (Paradise Marsh Wildlife Area, 2017). Channeling in the marsh and stream, combined with a lower elevation gradient at DG and 73 compared to downstream of site 73, could allow sediments to be flushed out of some areas only to be deposited in lower-flow areas nearby. Rogers et al. (2009) found that the amount of sediment leaving their study wetland during two storm events was close to double the amount of sediment that entered the wetland during their entire study. They concluded that sediment that had accumulated in the low-gradient channel, which trapped sediment during the wetland-filling stage, was transported out of the low-gradient area and deposited downstream.

Based on our results, sampling upstream of the crossings did not indicate that the site would have more sediment deposition; the sites with the most deposition were DG and 73 (both samples downstream of the crossing). DG is directly downstream of the marsh and as a result likely has some of the same characteristics as the marsh (e.g., low gradient and low flows) that promote sediment settling and accumulation.

Creek sinuosity seems to be the highest between 73 and C. Over the entire Beaver Creek study reach, crossings are relatively channelized compared to stream segments that are farther away. As a result, the largest deposition zones may be located away from the crossings in more sinuous stretches where we were not able to sample. A comparison of the sediment deposition on both sides of the crossings, assessing culvert sizing throughout the creek, and assessing locations farther from the crossings, could all help in understanding the stream's sediment dynamics.

Finally, any of our sampling locations can be affected by adjacent land practices that reduce or increase erosion on the land and change the amount of sediment transported through runoff to the stream. For example, cover crops planted before winter can prevent erosion; buffer strips between farm fields and the creek, as well as infiltration/detention ponds, can trap sediment; and residue left on the field can reduce soil detachment caused by raindrops. Contributions from the land should be further considered to better understand the spatial distribution of creek sediment.

Sediment phosphorus concentrations

Sediment P concentrations in the top 2.5 cm and full core were greatest at site CD. The top 2.5-cm layer at CD and DG had higher TP concentrations than the downstream sites (73, CD, and G). At all sites except G, P concentrations were greater in the top 2.5 cm compared to the full core (Figure 34).

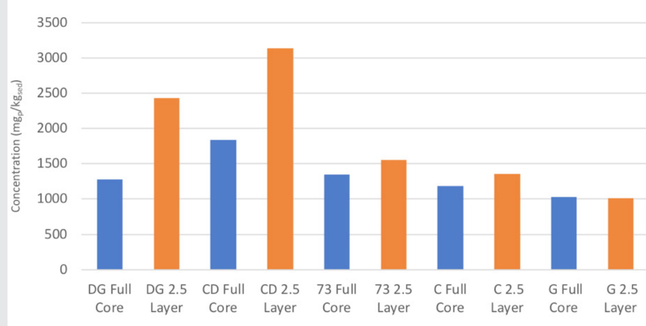


Figure 34: Sediment P concentrations for full and top 2.5-cm layer cores.

P concentration ranged from a low of 1010 milligrams of phosphorus per kilogram of sediment (mgp/kgsed) to a high of 3140 mgp/kgsed. Previous studies in the Upper Dorn Creek Wetland in Dane County found sediment concentrations ranging from 700–3000 mgp/kgsed , considered to be a "substantial cache" (Madison Metropolitan Sewerage District, 2016).

Concentration of P was higher within the top 2.5-cm layer of sediment than in the full core for all sites except G (concentration of 1010 mgp/kgsed for the 2.5-cm layer compared to 1030 mgp/kgsed for the full core). Sediment on the uppermost layer is more recently deposited compared to sediment deeper down. Therefore, the more recent deposition had higher concentrations of P, indicating that the concentration at DG has recently increased. DG has essentially no other inputs other than the marsh, so its sediment is most likely coming from that source. DG and CD are the first and second sites downstream of the marsh, respectively. CD had the highest concentrations in both the full and top 2.5-cm layer cores (Figure 34), which may be due to a nearby P source or soil characteristics that allow for increased P adsorption. Further research into the land practices nearby as well as the sediment composition could help identify the high P origin.

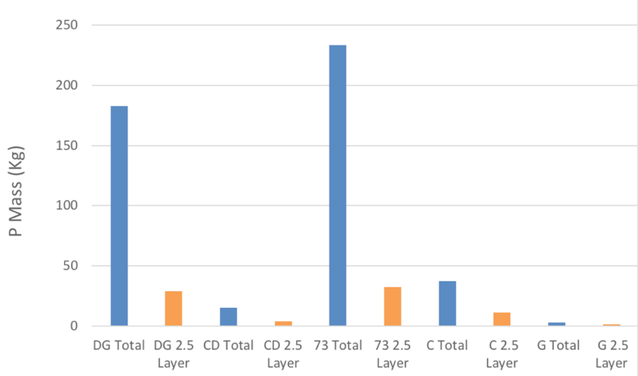


Figure 35: P mass in deposited sediment for the entire site and the top 2.5-cm layer.

Mass of P in deposited sediment

Mass of P in deposited sediment was greatest for site DG and 73. TP mass in the top 2.5-cm layer was higher at DG than the entire TP mass at CD, C, and G (Figure 35). The average P mass for the five 80-m sites is 93.9 kg (207 pounds). The distance from Paradise Marsh to the lake is roughly 9,977 meters (6.2 miles). Given that our sampling reaches covered only 4% of this distance, we did not think it appropriate to extrapolate our results to the entire stream length.

At site CD, where the highest concentrations were observed, total mass was relatively small. This is a result of the low amount of sediment at this site. DG is highly affected by the marsh characteristics. The site's high P concentration in the 2.5-cm layer, combined with the large volume of sediment, results in a large top-layer P load (Figure 30). Highway 73 also had a very high volume of sediment, the second highest full-core P concentration, and third-highest top-layer P concentration, resulting in high sediment P loads. The crossing at G had the lowest load due to its low volume of sediment combined with the lowest concentration of P.

In conclusion, Beaver Creek, while healthy in some aspects, suffers largely from an overabundance of P, which is why it is on the 303(d) impaired waters list. High early-season precipitation, coupled with nutrient-rich soils and bare or minimally covered soils, is likely the cause of high P in the creek-water samples. Increasing the uptake of P with continual vegetation during the growing season, leaving cover crops and/or harvested stubble in the fields, reducing P applications, and decreasing tilling, when used separately or combined, could reduce the P being transported to the creek. Addressing soil loss from the upland through best management practices is the first priority in reducing sedimentation to the creek. Pinpointing the highest P-mass locations within the creek will help determine the extent of the sedimentation. However, this study did not determine the quantity of sediment being transported, and at this point we can only infer the amount of sediment that may be moved during a flood event. Lastly, sediment removal within the creek, if deemed economically viable, could be performed to enhance Beaver Creek health as well as mitigate P contributions to Beaver Dam Lake.

The recommendations detailed in Chapter 7 highlight the need for continuing studies, easements on riparian areas, and improved soil retention through reduced tillage in order to begin reducing P entering Beaver Creek and achieving the goal of having it removed from the impaired waters list.

IN-LAKE

6.1 – Purpose

Nutrient levels are a key factor in determining the overall health of a lake. In the case of Beaver Dam Lake, excess phosphorus (P) has seasonally created hyper-eutrophic conditions, which often induce harmful algal blooms. By understanding sources of excess P in the water column, we can attempt to provide lake management recommendations for water quality improvement.

Phosphorus can come from either external or internal sources, meaning that it is either introduced from outside of the lake or comes from within the water body itself. Potential external sources of P include inflows from the Beaver Creek and Fox Lake subwatersheds, from other less-significant upstream tributaries, and from shoreline erosion. Internal sources may include carp feces, resuspension of sediment due to carp and wind, high-pH-induced sediment P release, and anoxia-induced sediment P release resulting from intermittent lake stratification. All of these sources may contribute to eutrophication, so we attempted to roughly deduce what portion of the P can be attributed to each of source. The largest contributors should be prioritized for lake management consideration.

6.2 – Methods

6.2.1 – WATER QUALITY SAMPLING

The Wisconsin Department of Natural Resources and the BDLIA have measured total phosphorus (TP), Secchi disk depth, and chlorophyll a in Beaver Dam Lake over the past several years. The measurements were taken discontinuously at Breezy Point between 2006 and 2014, and Denning Point (Figure 36) from 1973 to 2016. Data from the Denning Point location is missing for the periods of 1981-1990, 1997-1998, and 2000-2005. Plots for the historical TP data for both Breezy Point and Denning Point can be found in the Appendix. Six open-water sampling sites, including four new locations in addition to the Breezy Point and Denning Point sites, were sampled by Onterra, LLC, in 2014.

We chose two sampling sites, Denning Point and Breezy Point (renamed North End and Deep Hole, respectively) to conduct sampling in 2017 to compare our results to the historic measurements (Figure 36). Furthermore, these sites were of interest because of their locations within the lake. North End is located toward the northern end of the lake near the main lake inlets of Fox River and Beaver Creek. Deep Hole is in the southern end of the lake relatively close

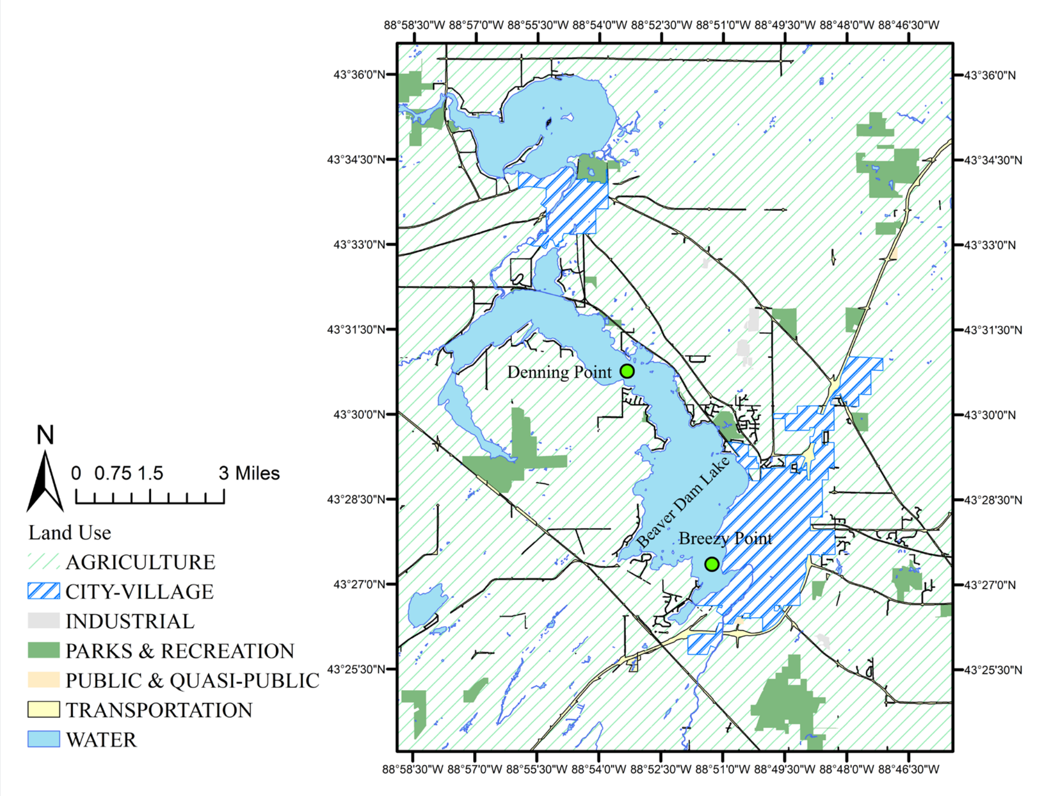


Figure 36: Denny Point and Breezy Point are locations of historical sampling efforts (1973 to 2016). The land use data are from the 2014 Dodge County Land Use Geodatabase.

to the lake outlet into the Rock River. As the name "Deep Hole" indicates, it is also the deepest point in the lake. This spatial difference may help determine the effect of external water inputs and the contaminants they may contain and shed light on lake-mixing mechanisms.

Water quality samples were collected biweekly from April 2017 through October 2017 (totaling 11 sampling events) from the two locations (Figure 36). Samples were collected from a depth of 30 centimeters (12 inches) below the lake surface using a bottle attached to a pole. Upon reaching the desired depth, a rubber stopper was released from the bottle to collect the sample. Samples were then either filtered, sterilized with sulfuric acid or left untreated, depending on the analysis to be performed. Samples from both locations and all dates were analyzed in the Water Quality Laboratory of the Biological Systems Engineering Department within 48 hours of collection (BSE Lab). The method used for TP analysis was EPA 135 A Rev. 5, which was measured by total Kjeldahl P digestion, with the rationale that Kjeldahl digests (Cu catalyst) are reacted with acidic molybdate/antimony with ascorbic acid reduction.

DRP analysis followed the guidelines established by EPA 118 A Rev.5, under which reduction is achieved with acidic molybdate-antimony and ascorbic acid (phosphomolybdenum blue). The pH and EC were measured using an Accumet AB 30 conductivity meter. TS and TSS were measured to an accuracy of 0.0001g using methods described in the Standard Methods for the Examination of Water and Wastewater (pages 2-54, 2540B, and pages 2-56, 2540D). In addition, the water samples collected on May 27, July 16, September 11, October 9 and October 23, 2017, were sent to the WSLH for TP analysis. The method used by WSLH followed EPA 365.1, which determines P by semi-automated colorimetry.

We expanded the data collection categories conducted in the 2014 Onterra study by also measuring wind speed (Holdpeak HP-866B), dissolved oxygen (DO) and water temperature (YSI Pro-2030 sensor). In this way, we can get a better understanding of the physical and chemical conditions of the lake and provide more information for the overall lake management considerations.

6.2.2 – SEDIMENT SAMPLING

Sediment sampling was conducted at four sites: North End, Deep Hole, Beaver Creek Outlet and Lurch Bay (also called Puckagee Springs) (Figure 37). These four locations represent several different environments within the lake. The North End and Deep Hole sites were chosen to maintain consistency with our water quality data. The Beaver Creek Outlet was chosen to provide insight into TP contributions from this tributary to the lake. Lurch Bay was identified as a region of severe soil erosion by local residents.

A sediment sampler was used to collect 10-cm cores, and each core was divided into three layers: 0-2.5 cm, 2.5-5 cm, and 5-10 cm. The effects of wind and carp are most prominent at the surface layer. At each location, four cores were taken, and samples from each layer were composited for analysis. The sediment samples were sent to the WSLH for TP analysis (method SW846 6010B, which is inductively coupled plasma-atomic emission spectrometry). These samples were also sent to the Soil and Forage Analysis Laboratory in Marshfield for water extractable phosphorus (WEP) analysis.

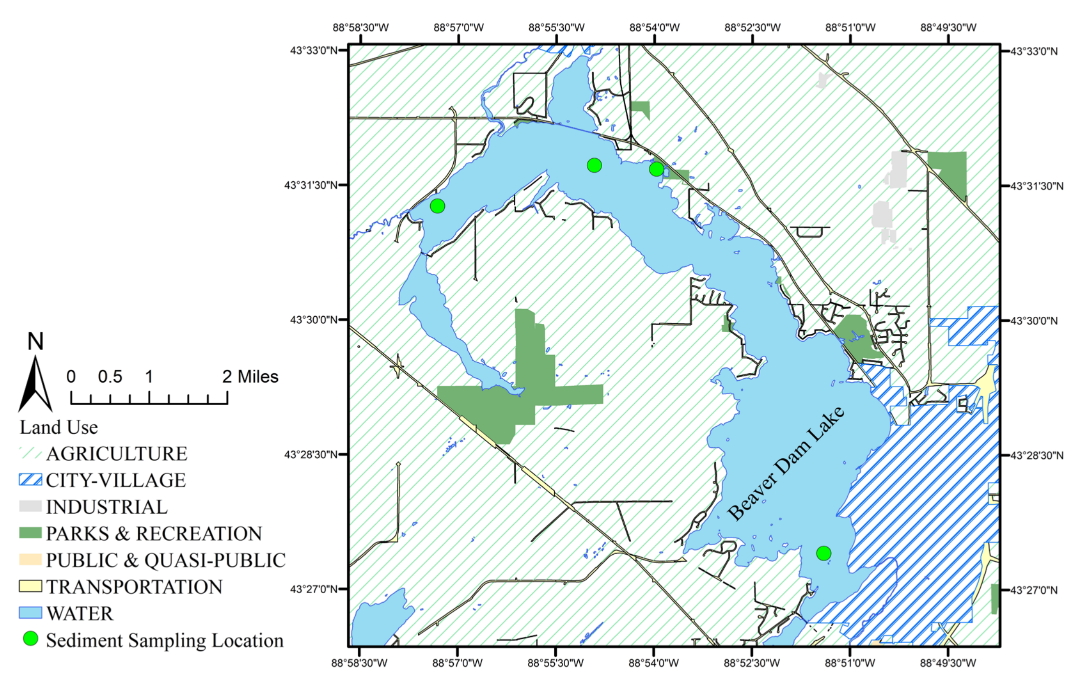


Figure 37: The locations of the 2017 sediment sampling. The land use data are from the 2014 Dodge County Land Use Geodatabase.

6.2.3 – WIND-INDUCED SEDIMENT RESUSPENSION MODELING

Sediment resuspension caused by wind was determined using a numerical model created by Dr. Chin Wu at the University of Wisconsin-Madison that relates wind speed to lake-bottom disturbance. Using this model and inputting the mean Beaver Dam Lake depth of 1.74 meters, a maximum measured fetch of 6,936 meters, and a wind speed of 12 mph from historical Beaver Dam wind data, results in an estimated significant wave height of 0.19 meters and a peak wave period of 1.9 seconds (Bradford et al., 2017). The impact of wind resuspension on lake P loading will be discussed in a later section.

6.2.4 – IN-LAKE P BUDGET MODELING

The Wisconsin Lake Modeling Suite (WiLMS) model is a computer program that aids in planning for lake water quality. Using inputs based on a lake's watershed characteristics such as area, land use practices, precipitation, soil types, and topography, the model estimates the amount of externally loaded phosphorus that would enter a body of water each year from the landscape as external loading. This external loading quantity can be added to internal phosphorus sources or other external sources to calculate an annual phosphorus load.

Figure 38 illustrates the sequence of data collection and analysis used in determining lake phosphorus budgets. We combined a WiLMS model output of external phosphorus loads with in-lake data, collected by ourselves and others, that included carp, wind, and stratification. We also incorporated rough estimates of total in-lake phosphorus quantities based on past data collection, allowing us to create a possible breakdown of the lake's annual phosphorus budget.

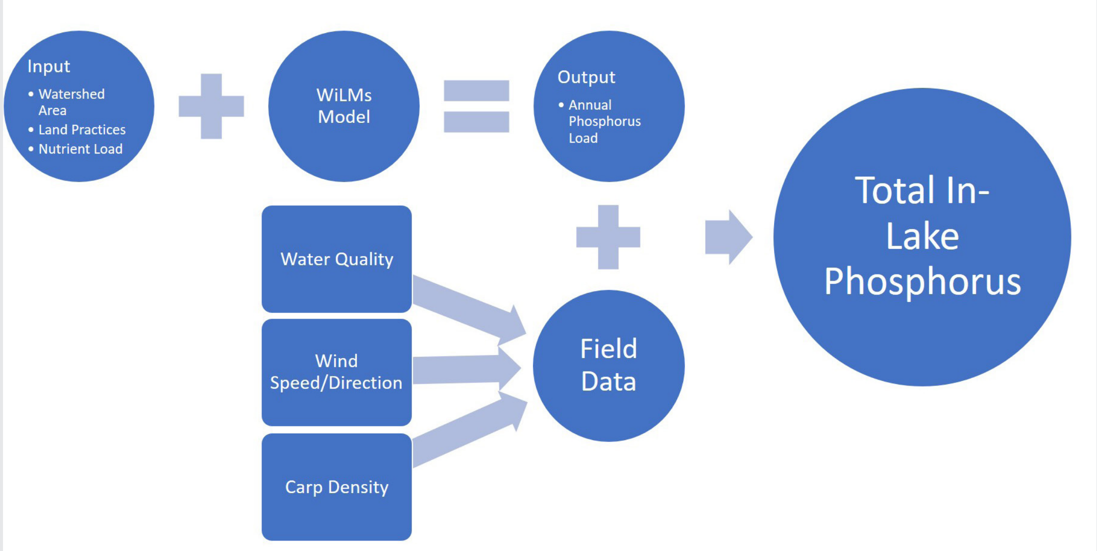
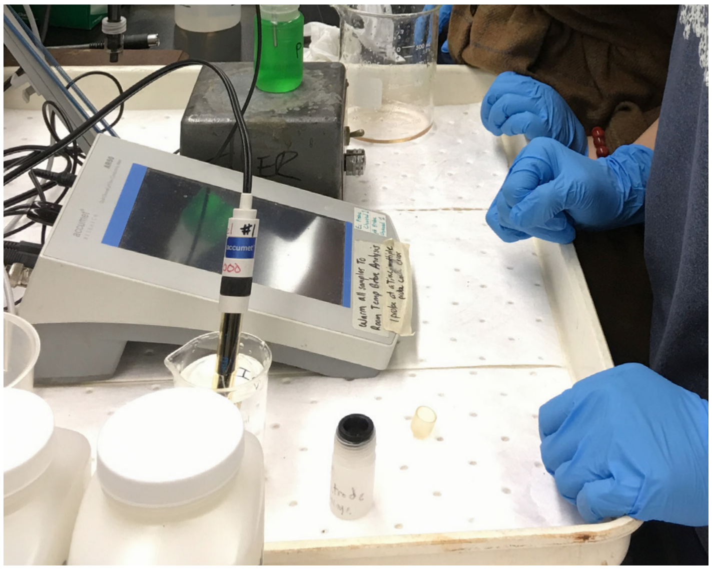


Figure 38: Flow chart of the WiLMs model and total in-lake phosphorus sources analysis.



6.3 – Results and Discussion

6.3.1 – WATER QUALITY DATA ANALYSIS

pH

Our 2017 sampling data show that the pH for Beaver Dam Lake varied from 7.5 to 8.7 between the end of April through October and was similar between the two sampling locations, North End and Deep Hole (Figure 39). In 2014, the pH of the water in Beaver Dam Lake ranged from 8 to 9, based on the Onterra report. According to a eutrophic lake study by Solim and Wanganeo (2009), measurable P release in a shallow lake setting may occur at pH levels around 7.5, but significant release can only occur at pH levels over 9. Based on the 2014 and 2017 pH data, P release due to pH levels in 2017 was not likely significant but may have been possible from late July to mid-September 2017 and in the summer of 2014.

TP & DRP

The Wisconsin water quality criteria regarding TP for a non-stratified drainage lake like Beaver Dam Lake is 40 µg TP/L. When compared with this Wisconsin state standard, Beaver Dam Lake's TP concentrations were far higher in 2017, even though they were lower than in 2014 (Figure 41). Water column TP concentration values measured by Onterra in 2014 ranged from 0.07 to 0.40 mg TP/L (or 70 to 200 µg TP/L), while our 2017 TP values range from 0.04 to 0.18 mg TP/L (or 40 to 180 µg TP/L), which at maximum is more than four times greater than the Wisconsin standard.

Dissolved reactive phosphorus (DRP), as an indicator of directly absorbable P by algae, was only found at detectable levels one time over the course of the summer 2017, in early July (Figure 40). This does not correlate with any significant trends in TP.

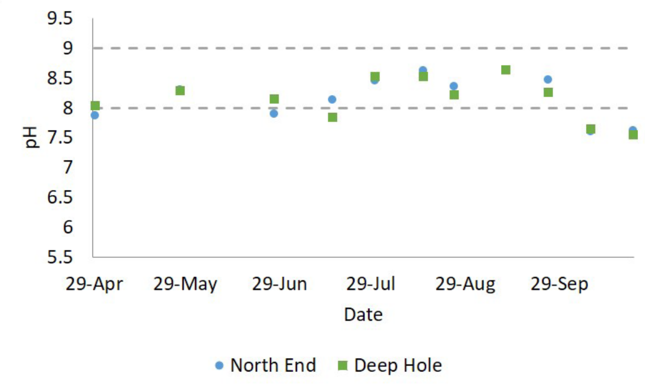


Figure 39: Plot of 2017 pH data for Beaver Dam Lake. The range of the 2014 pH data is represented by the dashed lines.

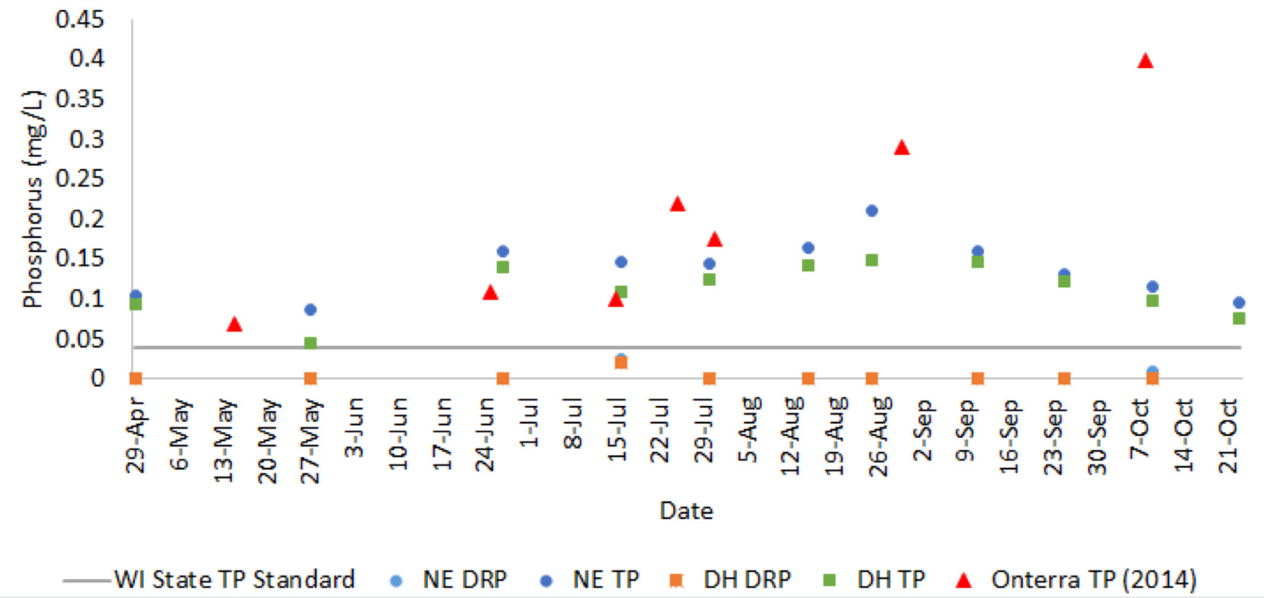


Figure 40: Comparison of TP and DRP (mg/L) at North End (NE) and Deep Hole (DH), with Onterra data and the Wisconsin state standard.

TN:TP Ratio

In the beginning of spring 2017, the TN:TP ratio has a higher value compared to average summer ratios, which seems related to the higher runoff in spring with snow melting (Figure 41). The ratio decreased in mid-June and then increased through November. A TN:TP ratio higher than 16:1 indicates P limitation in the lake (Redfield, 1958); this occurred from June through October.

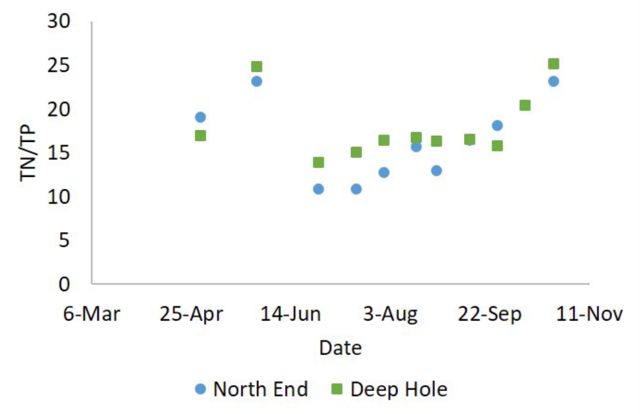


Figure 41: The TN/PP ratio of 2017 samples.

6.3.2 – SHORT-TERM TP DATA COMPARISON

The most notable difference between our 2017 findings and the 2014 Onterra study is that the lake water TP level decreased noticeably from mid-July to the end of summer, and overall when compared to 2014-2016 TP data averages. While Onterra observed a steady increase of P from April to October, we found that in 2017, P peaked in August and moderately decreased in the months that followed (Figure 35). This significant decrease in P between 2014 and 2017 may be due to several reasons, including different data management methods, differences in frequency, intensity, and total volume of precipitation, variation in annual carp harvest rates of hundreds of thousands of pounds, and potential pH-induced P release from sediments.

Data Management Methods

While determining total phosphorus loads into Beaver Dam Lake, previous estimates have been based on water quality data that are not necessarily recent. Estimates done by Onterra in 2014 used all available historical data to calculate an average phosphorus concentration during the growing season of 256 micrograms per liter (µg/L), which requires a yearly P load of 241,000 kilograms (531,000 pounds) to reach those levels (Onterra, 2014). When considering only the most recent year with data available (2014), the average P concentration during the growing season is approximately 20% lower at 195 µg/L. To reach this growing-season average, an annual phosphorus load of 184,000 kilograms (405,000 pounds) to Beaver Dam Lake would be required. Additionally, it was determined that phosphorus concentrations from October should not be used when considering growing-season average concentrations. Removing October values from the 2014 growing-season average results in an even lower value of 160.8 µg/L. To reach this growing-season average, an annual phosphorus load of 151,000 kilograms (333,600 pounds) to Beaver Dam Lake would be required. This value is roughly 24% greater than the annual phosphorus load in 2017 of 121,701 kilograms (267,742 pounds; growing season average P concentration of 135 µg/L).

Precipitation

As seen above, Onterra's TP values were comparable to ours for most of the year until late summer, when our P measurements remained somewhat consistent and the Onterra values increased. While precipitation levels were similar between years, several very large storms occurred in the spring of 2017 that may account for several large influxes of phosphorus to Beaver Dam Lake.

The explanation for this discrepancy may be improved agricultural practices within the watershed, carp removal efforts before 2017, or different precipitation patterns between 2014 and 2017.

Figure 42 shows that the total precipitation in 2014 and 2017 was comparable; however, 2014 was characterized by early-season storm events during a critical time in which fertilizer was being applied. In 2017, the storm events occurred later in the season, when fertilizer was no longer being applied; therefore, the potential for P runoff was lower. As a result, more P input in the early portion of the growing season in 2014 from storm-induced sediment runoff might have led to greater P resident in the lake at a later time of the year compared with 2017 (Figure 42).

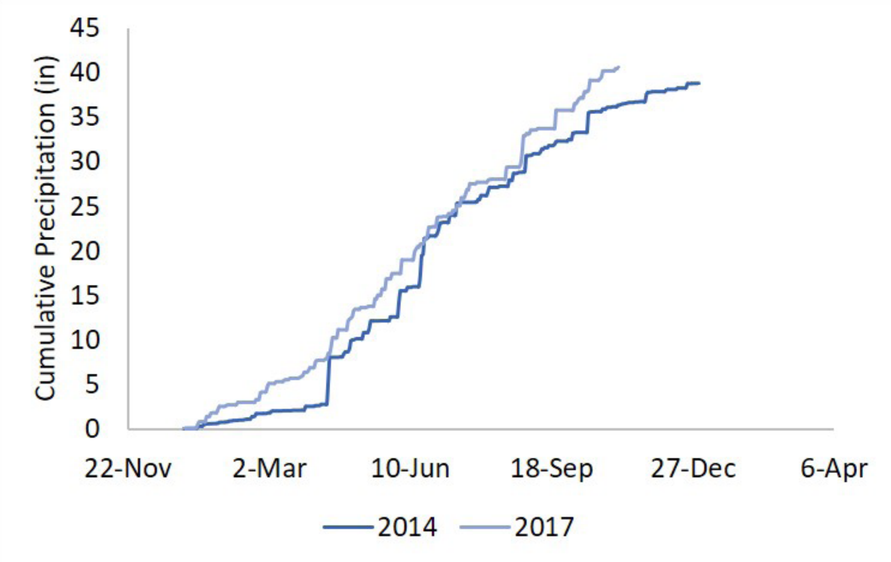


Figure 42: Total precipitation in 2014 and 2017.

Commercial Carp Harvesting

Wisconsin DNR has been hiring commercial fishers to harvest carp in the lake every year since 2014; 635,000 kilograms (1.4 million pounds) of carp were taken out of the lake in 2014 and 353,000 kilograms (780,000 pounds) in 2017. As a result, commercial carp harvesting efforts might have contributed to the decreased P loading from 2014 to 2017.

pH

Data collected throughout 2017 indicated that pH levels in Beaver Dam Lake were lower than pH levels measured in 2014 and were not at a level that would cause significant phosphorus release (based on a study by Penn et al., 2000; also refer to section 2.4 for a description of the pH release mechanism). P loading was estimated to be about 18,000 kilograms (40,000 pounds) lower in 2017 compared to 2014 due to the differences in pH.

6.3.3 – HISTORICAL TP DATA COMPARISON

Decreasing TP levels were observed at Deep Hole, based on WDNR historical data (Figure 43). No valid conclusion can be reached solely from considering the North End data due to a large sampling gap (Figure 44). The long-term trend over the last decade toward lower TP concentrations at Deep Hole may be due to consistent, concerted efforts to implement best management practices in the agriculture-dominated watershed.

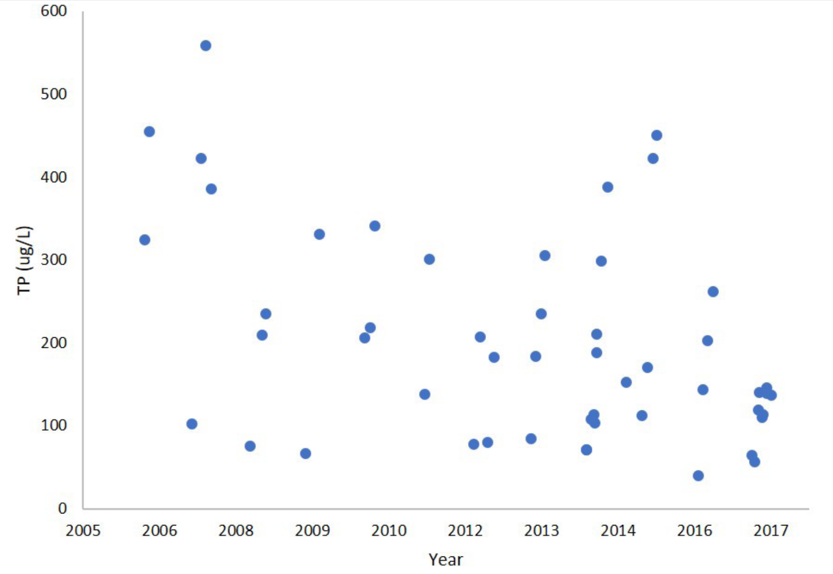


Figure 43: Historical TP data for Beaver Dam Lake at Deep Hole. Data retrieved from Wisconsin DNR website, Onterra Report and 2017 field sampling data.

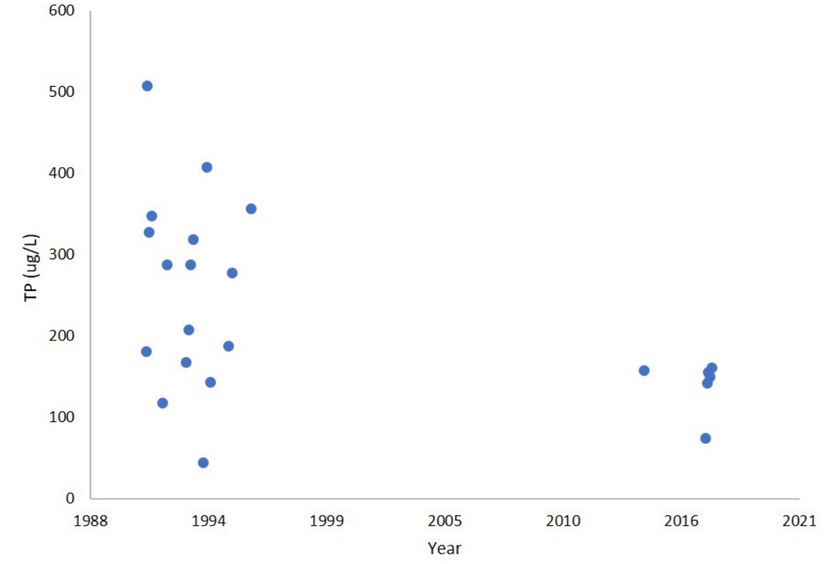


Figure 44: Historical TP data for Beaver Dam Lake at North End. Data retrieved from Wisconsin DNR website, Onterra Report and 2017 field sampling data.

6.3.4 – SEDIMENT P ANALYSIS

The measured sediment phosphorus (P) concentrations were relatively higher at North End and Lurch Bay than at Beaver Creek Outlet and Deep Hole (Figure 45). This observation has several possible explanations. The wind over the lake blows the water and P-laden sediment from southwest to northeast. The inflows from Fox Lake or the Beaver Creek watershed might also enhance the total P level in the northeastern part of the lake. Furthermore, there is a known location of high erosion potential over the northeastern bank of the lake; this shoreline erosion probably contributes P to the lake sediments.

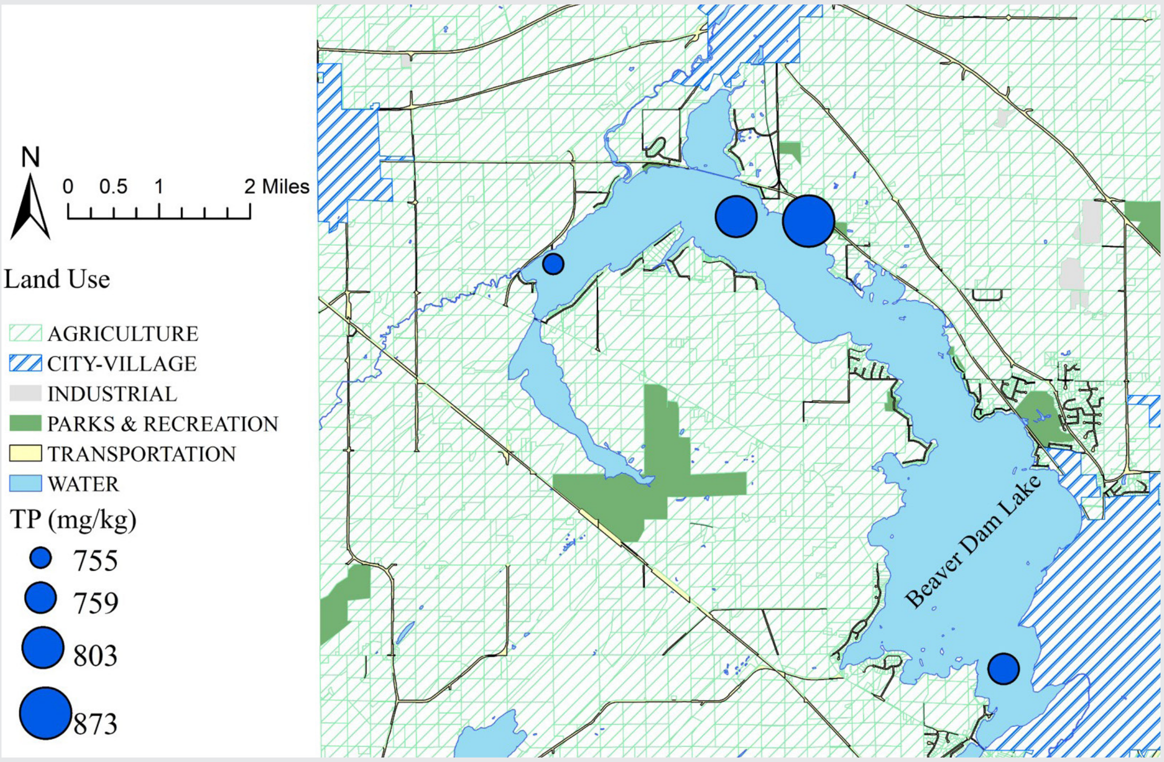


Figure 45: Total phosphorus concentrations (TP) in lake sediments (mg P/kg sediment). This map shows the TP in the top layer of sediment (0-2.5cm). The other layers and the distribution of water extractable phosphorus are shown in Appendix E.

6.3.5 – IN-LAKE P BUDGET ANALYSIS

The phosphorus in the lake comes from both external and internal sources. By combining the phosphorus data collected throughout the 2017 growing season and the extrapolation method used by Onterra in their 2014 study of Beaver Dam Lake, we determined that 121,701 kilograms (267,742 pounds of P from various internal and external sources would have to be introduced to the water column annually to reach the observed lake P values.

EXTERNAL LOADS

Discharges from Beaver Creek

Increasing phosphorus loading from the landscape in the WiLMS model, from a default of 1 kg/ha to 2-3 kg/ha, resulted in 39,000 – 62,600 kilograms (86,000 – 138,000 pounds) of phosphorus entering Beaver Dam Lake each year through Beaver Creek. Based on the results presented in regional P loading studies (e.g. Madison et al., 2014; MMSD, 2016; Stuntebeck et al., 2011), depending on the sediment delivery ratio, this range may still underestimate actual external phosphorus loads. This makes up the majority of external phosphorus loading to Beaver Dam Lake. There is uncertainty around the exact phosphorus loading rate from the watershed due to inherent difficulties in measuring nonpoint pollutants. A study for eastern Wisconsin reports annual phosphorus loading rates ranging from 0.6 to 9.73 kg/ha for agricultural land in southeastern Wisconsin (Madison et al., 2014), leading us to believe that prior estimates of external nutrient loading were low.

Inputs from Fox Lake and Lost Lake subwatersheds

Roughly 4,580 kilograms (10,100 pounds) of phosphorus enter Beaver Dam Lake from the Fox Lake and Lost Lake subwatersheds each year, based on flow rate and P-concentration data collected from the Fox River, which drains into the north end of Beaver Dam Lake (data provided by BDLIA).

We found a wide range of potential P contributions from the lake's watershed. Given the available data, we cannot determine the exact loads from the watershed. Our results would be more certain with field-level data to support past studies. Conservation practices and existing soil P levels vary widely across the watershed, and this adds uncertainty to the exact amounts of phosphorus expected from external loading. Additionally, climate and rainfall/runoff varies from year to year. We recommend that future analyses focus on collecting field-level data, so that the watershed P contributions can be better estimated.

The Yahara WINS (MMSD, 2016) adaptive management pilot project included an extensive inventory of agricultural fields. Researchers found that agricultural soil phosphorus varied widely, with a mean value of 3.3 pounds per acre (3.7 kg/ha) and the highest loads approaching 16 pounds per acre (18 kg/ha). These estimates are slightly higher than edge-of-field loads reported for the Discovery and Pioneer Farms (Stuntebeck et al., 2011), which ranged from 0.3 to seven pounds per acre (mean loads were approximately two pounds per acre). Madison et al. (2014) reports total phosphorus loads in tile drainage ranging from 0.24 to 2.73 kg/ha and in surface runoff ranging from 0.6 to 9.73 kg/ha.

When the external phosphorus loading rate for agricultural land used in the WiLMS model by Onterra is increased from the WiLMS default of 1 kg/ha to values of 2-3 kg/ha that may be more representative of Beaver Dam Lake's watershed, the expected external loading rate subsequently increased from 21,000 kg/year (46,000 lbs/year) to 39,000 – 62,600 kg/year (86,000-138,000 lbs/year). Using the average P concentration data we collected in 2017, we found that the total contribution of P from the watershed could be two or three times higher than initially predicted, some of which may be attributed to tile drainage. It is worth noting, however, that even when the WiLMS model accounts for the highest level of loading from agricultural lands, this still represents only about half of the total P in lake.

Without field-level data, it is unclear how prevalent tile drainage may be within the watershed boundaries. The United States Census of Agriculture (1992) reported tile drainage on only 0-5% of agricultural lands in Columbia County, and 10-20% tile drainage on agricultural lands in Dodge County. Anecdotal evidence from farmers in the watershed indicates that tile drainage has become more prevalent, but without published drainage permits or plans, it is difficult to identify where such drainage is installed.

INTERNAL LOADS

Carp feces

Due to the dynamic nature of a lake's ecosystem, it is difficult to capture an accurate breakdown of internal nutrient sources. We can be fairly certain that the largest internal source of phosphorus is carp, but this load depends on a number of variables. The biggest factor in P contributions from carp is population density. Our analysis uses the most recent data, collected in 2014. Due to annual carp harvesting that varies greatly in quantity, high reproduction rates, and uncertainty that comes during data collection studies, there is substantial uncertainty regarding the carp population at any time, and therefore also uncertainty about total P contributions from carp.

Common carp (Cyprinus carpio) may increase sediment-bound phosphorus release through bioturbation as they feed (Weber and Brown, 2009), but they also directly add P to the system through defecation. Depending on carp densities, this contribution can be significant (LaMarra, 1975; Andersson, Graneli, & Stenson, 1988; Qin & Threlkeld, 1990).

Studies report phosphorus loading rates from carp to be approximately two-to-four percent of body weight each year (Andersson et al, 1988; LaMarra, 1975). Using a loading rate of three percent (assumed to account for lower winter temperatures that decrease a carp's metabolism and fecal output) and an estimated carp density of 370 kg/ha (330 lbs/acre) per a 2014 carp-density study conducted by the WDNR, yearly phosphorus contributions to the lake were estimated to be approximately 31,000 kilograms (67,725 pounds) (Butterfield, Hoyman, Cibulca, & Heath, 2015). A lower yearly phosphorus loading rate of two percent of body weight decreases the contribution to 20,400 kilograms (45,150 pounds) per year. There is some uncertainty associated with both the contribution from each carp due to varying size, and with the overall carp density, as the most recent carp population data available is from a 2014 mark-recapture study.

These values differ from previous estimates. For example, one estimate for yearly phosphorus additions to Beaver Dam Lake used a loading rate of 0.11 lbs P/lb carp, or 11% of the carp's body weight. Using the most recent carp density data from 2014 (370 kg/ha or 330 lbs/acre) this led to a previous estimate of 116,000 kilograms (256,000 pounds) of phosphorus added to the lake each year through carp feces. This differs significantly from our calculated values of 31,000 kg/yr (67,725 lbs/year) and 20,400 kg/year (45,150 lbs/year) of P contributions based on loading rates of three percent of body weight and two percent of body weight, respectively.

Also directly affected by carp density is bioturbation caused by foraging, which also has associated uncertainty. It is difficult to quantify due to variations in sediment-bound phosphorus concentrations across the lake and differences in foraging behaviors of different age-class fish. (Zambrano, Scheffer, & Martinez-Ramos, 2001; Driver, Closs, & Koen, 2005). Foraging habits are also influenced by food availability, which determines how much time must be spent looking for food, directly impacting suspended sediment concentrations (Abrams, 1984; Werner & Anholt, 1993)

Stratification

As previously discussed, temporary stratification may occur throughout Beaver Dam Lake during calm periods, causing phosphorus to reenter the water column (Nurnberg, 2009). Using wind data from 2017, it was determined that there were approximately 50 periods of calm that year. Using data from previous studies and assuming 1) this stratification occurred only in areas six feet deep or greater, and 2) each calm period lasted 12 hours, results in an estimated yearly P contribution to Beaver Dam Lake of approximately 13,600 kilograms (30,000 pounds) (Penn et al., 2000). Wind speed was typically different at different locations around Beaver Dam Lake, and winds would often start and stop quickly. Due to dissolved oxygen levels in water being limited by temperature, both temporal and spatial variation to stratification add to uncertainty in determining the associated phosphorus contribution.

Previous estimates of phosphorus loading due to lake stratification were over 18,000 kilograms (40,000 pounds) contributed per year. Using wind data from 2017, we determined a P-loading contribution of 13,600 kilograms (30,000 pounds), or roughly a 25% decrease, which is quite significant when determining the lake's phosphorus budget.

Wind-induced and carp-induced sediment resuspension

Using phosphorus concentrations in lake sediment collected during the summer of 2017, a contribution of 10.6 kilograms (23.3 pounds) of phosphorus each year was estimated due to wind and carp-induced sediment disturbance and resuspension. Using wind data along with a sediment resuspension model, it was estimated that 7.8 kilograms (17.2 pounds) of phosphorus were added to the lake each year due to wind resuspension of lake sediments (Bradford et al., 2017). This leaves 2.8 kilograms (6.1 pounds) of phosphorus added to the lake each year due to carp-induced sediment resuspension.

As previously noted, sediment resuspension caused by wind was determined using a numerical model created by Dr. Chin Wu at the University of Wisconsin-Madison that relates wind speed to lake bottom disturbance. Using this model and inputting the mean Beaver Dam Lake depth of 1.74 meters, a maximum measured fetch of 6,936 meters, and a wind speed of 12 mph from historical Beaver Dam wind data, results in a calculated significant wave height of 0.19 meters and a peak wave period of 1.9 seconds.

Using these values, along with empirical relationships from the U.S. Army Corps of Engineers Shore Protection Manual, the critical wind speed for resuspension were determined to be 3.97 mph, respectively. Comparison of this value with 2016 average daily wind speed data for Beaver Dam Lake yielded a value of 315 days per year, or 86%, in which critical wind speed is exceeded and sediment resuspension occurs.

While sediment resuspension regularly occurs, the amount of sediment suspended in the water column does not constitute significant mass per volume of water, even though the water appeared relatively turbid. More importantly, the amount of phosphorus in the sediment does not represent a large percentage. The overall amount of suspended solids in the lake and the small amount of adsorbed phosphorus do contribute thousands of pounds of the nutrient to the lake, but compared to external sources and carp, it is not a major source.

When considering these internal and external sources, along with our determined yearly phosphorus load of 121,701 kilograms (267,742 pounds, we can create a possible scenario of phosphorus loading contributions, seen below in Figure 46. This annual P budget assumes annual contributions from the following: carp feces at four percent of body weight (Andersson et al, 1988) that produces a 40,960-kilogram (90,301-pound) load; a watershed phosphorus loading rate of three kilograms per hectare that produces an annual external load of 67,130 kilograms (148,000 pounds); 50 periods of stratification that produce a 13,600-kilogram (30,000-pound) load; and 10.6 kilograms (23.3 pounds) of phosphorus due to wind and carp-induced sediment resuspension (an amount too small to appear in Figure 46).

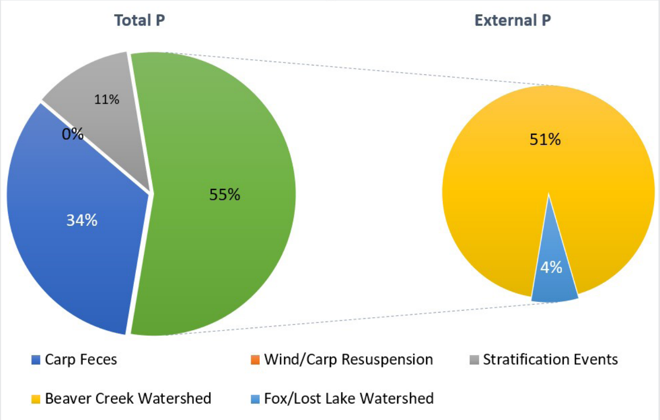


Figure 46: Plausible breakdown of phosphorus sources in the Beaver Dam Lake (using 4% body weight for loading for carp feces, 3 kg/ha external loading for watershed contribution).

Based on our combined analyses, we believe that carp removal should be the priority for in-lake restoration efforts. The next chapter proposes recommendations for in-lake treatment. Our proposed recommendations include adopting an active carp management plan to effectively eliminate the carp population; conducting a carp enclosure experiment to examine the effectiveness of carp removal regarding P reduction; and implementing a long-term water quality monitoring program for future research and citizen engagement efforts. Conducting a shoreline assessment is also recommended.

RECOMMENDATIONS

Our recommendations are divided into three categories: improving stakeholder engagement, Beaver Creek water quality, and Beaver Dam Lake water quality.

7.1 – Stakeholder Engagement

7.1.1 – LOCAL SCHOOL PARTNERSHIPS AND WATER STUDIES

To continue collecting water quality, vegetation, and physical data in Beaver Dam Lake and Beaver Creek, the BDLIA could begin partnering with local school districts to create field trip and science study opportunities for students. Classes could visit the lake and/or creek to collect a series of data similar to the data our Beaver Creek group collected. This data could then be analyzed over years to show trends. Students and their families would get involved in lake issues and be exposed to BDLIA and community efforts toward water quality improvements.

Local schools that could potentially serve as partners include Beaver Dam High School, Randolph High School, and Wayland Academy. Biology, chemistry, or environmental science classes could take field trips once per semester or year to Beaver Dam Lake or Beaver Creek. These classes could be split up to collect data on water chemistry, clarity, and physical characteristics, as well as macroinvertebrates, habitat, and vegetation. Depending on the time of year, students could also survey bird species or people who are taking part in various recreational activities as well.

If several classes collect data over several years, this citizen science effort could produce a strong baseline of water quality data while giving high school students (and possibly their parents) exposure to these important water bodies and their pressing health issues. BDLIA could spearhead this effort and supply equipment if the schools are in need and teach data collection methods to the students.

7.1.2 – WORKSHOPS AND VOLUNTEER EVENTS

To build more awareness of and interest in positive lake efforts, the BDLIA can structure an ongoing series of events and workshops. These could be tailored to a variety of interests and commitment levels in the public and take place in a variety of places. If the BDLIA can only support a few activities in the first year, it should work toward an eventual series of monthly events during the summer season (April – October).

Workshops could include a "Lake Issues 101" boat tour of Beaver Dam Lake to provide general audiences with background information on lake studies and how the connected issues of high phosphorus, carp, and algae affect the lake ecosystem. It should also offer management strategies and teach the audience about the time, human resources, and finances needed to implement each. Such a class should also make time for the participants to state their interests in the lake and share ideas for how to improve lake health. This will reveal the talents and potential connections of the group to the BDLIA.

Another workshop idea is to arrange for a private homeowner to teach a group (preferably lakeshore property owners) about native plantings for protection from shoreline erosion and general landscaping for polluted-water runoff reduction. Beaver Dam Lake residents need to realize that they are responsible for some portion (albeit a small one) of the water quality issues in the lake and that they can make changes at home to prevent pollution and sediments from entering the lake. Also, lake property owners can protect shoreline susceptible to erosion by strategically planting trees, restoring wetland plants, and reducing lawn cover along the shore. This workshop should cover these points and teach participants about the costs and ongoing management necessary to make landscape changes effective over the long-term.

In addition, the BDLIA could arrange volunteer efforts aimed at citizen science, clean ups, and invasive species removal and vegetation plantings. The need for lake and tributary data collection will be ongoing. Groups of citizens could fill this need during a series of meetups over the summer season with BDLIA's technical assistance. To reduce shoreline erosion and retain sediment from waters while maintaining or even improving biological health, work parties could be assembled in spring, summer, or fall to remove invasive plants and plant or maintain native vegetation on public land or private property, if landowners are willing to establish a cooperative partnership.

7.1.3 – FARMER-LED COUNCIL IN COLUMBIA COUNTY

Recently, Dodge County established the Farmers for Healthy Soil & Healthy Water Council, a volunteer-led group of producers that shares strategies and information about cover cropping, nutrient management, and reduced tillage. This group hosted a two-day indoor workshop about these and other practices in February 2017. They also organized a cover-cropping field day in October 2017 with stops at three different farms. Participants learned about the resources needed and on-the-ground examples from farmers on the council.

BDLIA should work with Dodge County Land and Water Conservation staff to develop a similar farmer-led council in Columbia County. This effort will require building relationships with farmers in Columbia County and organizing time and space for them to share soil management practices. From our producer interviews and in our cohort's communication with staff from both counties, it appears that groups of farmers already meet to share information. BDLIA should work to find these voluntary groups and expand their influence through a farmer-led council that works for Columbia County.

7.1.4 – BRING PRODUCERS ONTO THE BDLIA BOARD

Finally, BDLIA should work to get more producers involved with lake improvement efforts by recruiting a producing landowner to the association's board. This needs to be a person willing to dedicate energy to BDLIA efforts as well as someone respected and listened to by other producers in the watershed. The greatest benefit of having a producer in this position is to expose other producers to BDLIA's efforts and work to create positive relationships between agriculture and Beaver Dam Lake interests in the watershed.

7.2 – Beaver Dam Lake Water Quality

7.2.1 – ACTIVE CARP MANAGEMENT PLAN

Based on our combined analyses, we believe that carp removal should be the priority for Beaver Dam Lake restoration efforts. The Wisconsin Department of Natural Resources has been hiring commercial fishers to harvest carp in the lake every year since 2014. According to the BDLIA, 1.4 million pounds (635,000 kilograms) of carp were harvested from Beaver Dam Lake in 2014 alone. Decreasing carp density is such a high priority because these fish reproduce quickly and can carry up to 2,000,000 eggs each year (Swee & McCrimmon, 1966). As a result, even after aggressive commercial efforts, populations have the capacity to rebound quickly to high densities (Harris and Gehrke, 1997; Barton, Kelton and Eedy, 2000).

Effect of Carp Removal

Maintaining a lower carp density will be essential in maintaining a clearer lake and reducing carp-induced phosphorus. Studies have shown that decreasing carp densities to less than 100 kilograms per hectare (kg/ha), or 89.3 pounds per acre (lbs/acre), allows aquatic vegetation to exist with relatively little damage (Mehner et al., 2004; Bajer, Sullivan and Sorensen, 2009). Similarly, numerous other studies have suggested a population reduction of 70% is necessary to see biotic improvements, which would equate to a post-harvest carp density of 99 lbs/acre (111 kg/ha) in Beaver Dam Lake (Meijer et al., 1999; Schrage & Downing, 2004).

Adequate harvest rates and population densities must be maintained because carp have high fecundity rates, and studies have suggested that they respond to harvest in a density-dependent, or compensatory, nature (Weber et al., 2016). That is, without maintaining a low enough carp density, populations may increase at a faster rate than prior to the harvest. A study performed at a lake similar to Beaver Dam Lake in Iowa estimated a doubling of carp biomass in 2.7 years if continued removal was not performed (Colvin et al., 2012). However, if harvest occurs prior to seasonal periods of increased natural mortality, such as winter, it is more likely to be compensatory and increase population growth, while harvest taking place after or during periods of increased natural mortality is more likely to be additive in nature and decrease the compensatory effect (Hudson et al., 1997; Boyce et al., 1999; Ratikainen et al., 2008).

Water clarity may dramatically increase with appropriate removal rates due to processes directly and indirectly related to carp removal. Reducing carp density decreases the impact of their foraging. Especially in a shallow water body such as Beaver Dam Lake, carp foraging can significantly decrease water clarity as the fish root through the sediment and expel non-food items through their gills as they search for invertebrates (Breukelaar et al., 1994; Zambrano et al., 2001). A large carp may root as deep as 30 centimeters (12 inches) into sediments while foraging for food (Panek, 1987). Decreased foraging reduces levels of sediment-bound phosphorus that become available to organisms when resuspended, thereby decreasing nutrients available to phytoplankton populations. A large reduction in phosphorus from carp feces also occurs as the population is reduced, which further decreases available nutrients for phytoplankton and adds to clarity (Lougheed et al., 2004; Morgan & Hicks, 2013).

A reduction in the carp population also enables an increase in the zooplankton community, which leads to greater water clarity. Zooplankton feed on phytoplankton, but large zooplankton are the primary food source for carp under 100 centimeters in length (larger carp feed on benthic invertebrates) (Britton et al., 2007; Weber & Brown, 2009). As the carp population is reduced, the zooplankton population grows and acts to control phytoplankton levels (Gliwicz, 2002). A key part of this mechanism is the shift from smaller zooplankton species to larger zooplankton such as Daphnia. Larger zooplankton are more efficient at eating phytoplankton, but they are also easier prey for carp (Shapiro & Wright, 1984; Carpenter et al., 1985). Maintaining lower carp levels also helps large zooplankton feed more efficiently as water clarity increases due to a reduction in carp-induced sediment disturbance (Hart, 1988; Kirk, 1991).

With the expected increase in water clarity, macrophyte communities should improve in both diversity and abundance (Schrage & Downing, 2004). As suspended solid levels caused by foraging carp are reduced, light can penetrate farther into the water column, allowing submerged vegetation to grow in a much greater area than currently possible in the lake (Lougheed et al., 1998; Skubinna et al., 1995; Hootsmans et al., 1996). Light penetration would also increase with the expected decrease in phytoplankton, which can shade out submerged vegetation (Crowder & Painter, 1991). Along with increased light, an appropriately reduced carp population will be necessary to allow submerged vegetation to reestablish itself, as regrowth is difficult when water is turbid or the plants are disturbed by foraging fish (Painter et al., 1988). Once aquatic vegetation is reestablished, it will be important to maintain decreased carp populations to prevent the fish from rooting up the submerged vegetation.

A reduction in carp density may cause aquatic plants to proliferate for several years due to phosphorus loads both trapped in the sediment of Beaver Dam Lake and entering the lake each year from the watershed (Morgan & Hicks, 2013). While improved water quality and submerged vegetation are preferred to high carp densities and turbid waters, it should be noted that the amount of submerged vegetation present after carp removal may be great enough to impede lake uses such as boat travel, swimming, and fishing. While costly, raking or harvesting some submerged vegetation would remove phosphorus from the system, as opposed to letting the vegetation die, decompose, and become a source of phosphorus. Submerged macrophytes also provide a number of benefits. These plants aid in increasing water clarity as they decrease phytoplankton biomass through nutrient competition, and they help maintain lower suspended sediment levels (James & Barko, 1990; Van Donk et al., 1993; Perrow et al., 1997). Submerged macrophyte restoration has been shown to aid in recruitment of other fish species as well (Scheffer et al., 1993).

As water clarity increases, desired fish populations should increase as the reduction in turbidity enables more efficient foraging (De Robertis et al., 2003, Miner & Stein, 1996). Additional stocking of predators of carp eggs, such as bluegills, would further suppress young carp, which cannot be removed by netting or other methods targeted at adult fish.

Three-Step Carp Control Plan

To ensure effective carp population control, we propose an active carp management plan comprised of three major steps.

The first step is to reassess the carp population by capturing fish around the lake and recording data such as age, weight and length, using methodology similar to that used by DNR in 2014 (Welke & Derks, 2015). These data can be used to build a reproduction model to simulate future population changes.

The second step is to better understand the spatial distribution of carp and determine where they aggregate in winter and where they spawn in the spring. Carp tend to aggregate densely during winter, so by identifying where they aggregate, commercial fishers can efficiently focus on that area (Bajer, Chizinski & Sorensen, 2011).

The third step is to physically remove carp and restore predators. Commercial fishing and other removal methods can reduce the number of mature carp. Stocking predators such as bluegills in the carp's spawning area can effectively control juvenile fishes, which will help keep the population from rebounding (WSB & Associates, Inc., 2017).

7.2.2 – CARP EXCLOSURE SITE

Our second recommendation is to conduct a carp exclosure study. A carp exclosure study site involves removing all the carp within a small, physically isolated section of the lake. Such a study would remove the impact of carp to enable a better understanding of how other factors, such as wind and stratification, affect water quality. A carp exclosure experimental site is also a good demonstration to the public on the effectiveness of carp removal on lake quality (National Science Foundation, n.d.). As a reference, Lake Wingra in Madison, Wisconsin, also a shallow eutrophic lake, was the site of a successful experimental carp exclosure site (National Science Foundation, n. d.).

In addition, non-native macrophytes can rapidly proliferate following carp removal efforts (Knopik, 2014). A carp exclosure experimental site can demonstrate both positive and negative effects of successful removal of carp in Beaver Dam Lake.

7.2.3 – SHORELINE EROSION ASSESSMENT

Shoreline erosion has been observed along the northeastern portion of the lake, particularly in Rake's Bay. The extent to which this shoreline erosion contributes to total P in-lake, either in the water or sediment, and the magnitude of that contribution is unclear. Our third recommendation is to complete a shoreline erosion assessment to better understand this potential source of phosphorus to the lake. The goal would be to quantify the shoreline erosion, identify erosion hotspots, and test the level of total P and extractable P within those sediments. Erosion hotspots can be identified by surveying shoreline properties, after which soil samples could be taken to determine levels of TP and extractable P.

7.2.4 – REGULAR LAKE CONDITION MONITORING

A continuous program of lake monitoring is recommended to create a robust dataset and to track changes in lake quality over time. Implemented solutions can then be evaluated for their success over time. This also provides an opportunity for increased engagement with the community as students and interested citizens could partake in such efforts. While BDLIA has been organizing lake sampling volunteer events once each summer, increasing sampling frequency and adding sampling metrics would be beneficial to the management of the whole watershed. Recommended parameters include DO, pH, wind speed, TS, TSS, TP, DRP, sediment TP and extractable P, and TN.

7.3 – Beaver Creek Water Quality

7.3.1 – UPDATE WATERSHED PLAN

The Beaver Dam River watershed plan was developed in 1994 and expires in 2019. We recommend developing a watershed-scale plan to focus efforts on restoring Beaver Creek, an impaired waterway, and increase funding opportunities. The EPA has identified nine key planning elements that are critical for protecting and improving water quality (WDNR, 2017). Much of the information-gathering for the nine elements has already been completed for this area through recent studies, including this study, and local management of total maximum daily load (TMDL) of pollutants, required under the U.S. Clean Water Act for restoring impaired waters. Each of the nine key elements and their status relating to this project are listed below.

Element 1. Identify the causes and sources that need to be controlled to achieve P-load reductions within the Beaver Creek watershed.
Status: Review the Onterra 2015 and WRM (this study) reports.
Element 2. Estimate the pollutant load reductions expected from selected management measures.
Status: Review DNR PRESTO, Onterra, and WRM reports, and possibly Rock River TMDL reports.

Element 3. Describe the management measures that need to be implemented to achieve P-load reductions. Map priority areas for implementing practices.
Status: The management measures need to be defined. Use WRM EVAAL modeling results for mapping priority areas.

Element 4. Estimate the amounts of technical and financial assistance needed, associated costs, and/or the sources and authorities that will be relied upon to implement the plan.
Status: The counties will need to determine the costs.

Element 5. Develop an information and education component to encourage participation and plan implementation.
Status: Use WRM stakeholder recommendations and BDLIA as a resource. Develop a citizen monitoring program.

Element 6. Develop an implementation schedule for the management measures identified above.
Status: Utilize the citizen monitoring program and continue collecting monthly water quality samples along the creek. Perform biannual macroinvertebrate and habitat surveys.

Element 7. Describe interim, measurable milestones to assess while the plan is being implemented.
Status: Improved water quality would be defined as decreased TP, EC, TS, TSS, and DRP.

Element 8. Identify a set of criteria to evaluate plan objectives.
Status: Utilize water quality metrics.

Element 9. Develop a monitoring component to evaluate the effectiveness over time.
Status: Elements 6-9 are all related. The schedule would be determined at the county level. A citizen monitoring effort can assist with elements 5 and 9.

7.3.2 – IMPROVE SOIL RETENTION AND STREAM HABITAT THROUGH BEST MANAGEMENT PRACTICES

While it is important to address current water quality and stream health issues in Beaver Creek, it is also possible to prevent the movement of nutrient-laden soils by improving soil retention plans within the Beaver Creek watershed.

Since erosion from farm fields is the largest contributing factor of P entering surface waters (A. Craig, personal communication, September 8, 2017), we recommend using the current EVAAL results to identify and work with producers in priority zones to implement best soil retention practices. These practices can include:

- Implementing reduced tillage systems to minimize erosion and runoff. Leaving crop residue from harvest on the soil surface reduces runoff and soil erosion, conserves soil moisture, helps keep nutrients and pesticides on the field, and improves soil health and water and air quality (EPA, 2018).

- Using cover crops to protect soil surface from erosion. This practice works well with reduced tillage systems. Cover crops protect the soil surface from raindrop impact, trap eroding particles, and improve infiltration (USDA, 2017).

- Managing riparian zones along Beaver Creek to trap eroded sediment and P and manage runoff. Buffer widths of 30-60 feet are most effective, preventing 95% of sediment in runoff from reaching the stream (UW-Extension). Minimally, a buffer width of 10 feet can effectively decrease TP and TN. Buffers can also increase wildlife diversity and aquatic habitat (USDA, 2017).

- Installing grass waterways can prevent erosion and slow runoff (USDA, 2017).

Each of these best management practices and its efficiency will be site-specific. On-the-ground evaluation, starting with the EVAAL modeling results, and further field-scale modeling such as SnapPlus, will help determine what will be most effective. This recommendation can be tied into Element 3 of the watershed management plan update described above. Requiring a combination of these practices in a land-lease agreement will act as a preventative step that helps keep soil-bound nutrients out of Beaver Creek and, ultimately, out of Beaver Dam Lake.

7.3.3 – ENCOURAGE CREP, LAND EASEMENTS, IN-LINE NUTRIENT MITIGATION AND DREDGING

This next set of recommendations is designed to address current stream health issues identified during this study.

First, participation in the Conservation Reserve Enhancement Program (CREP) and land easements can improve habitat along Beaver Creek and provide buffer zones to manage surface runoff. Farmers and landowners can be incentivized through state and federal funding opportunities to participate in these programs.

Second, tile drains can be an important source of P and nutrients into the creek (King et al., 2015; Smith et al., 2015). Identifying and mapping tile drains can be an important first step for managing this input of P through in-line nutrient mitigation practices such as retention ponds and step-pools.

Finally, dredging a creek channel removes sediment high in P. Since this is a costly and labor-intensive process, it is important to use sediment data, such as that collected in this study, to identify areas that are high in legacy P, such as the sites located along County Road DG and Highway 73.

These management practices can also be included as part of Element 3 of the watershed management plan update described above.

7.3.2 – FUTURE WATERSHED STUDIES

Since one purpose of this study was to establish baseline stream health conditions for Beaver Creek, our first recommendation is to continue studying Beaver Creek's subwatershed, as well as other subwatersheds, to evaluate their interactions with Beaver Dam Lake. Doing so will help identify specific management needs not addressed in the scope of our study.

First, we suggest determining the P contribution of tributaries that flow into Beaver Dam Lake to refine P-load estimates into the lake. It would also be beneficial to evaluate erosion potential within these tributary subwatersheds using EVAAL. Areas to consider include Trestle Works Bay and the unnamed creek on the eastern side of Beaver Dam Lake.

It would also be beneficial to continue monitoring Beaver Creek to evaluate the efficacy of management measures. The biotic surveys done in our study could also be expanded. We suggest incorporating fish surveys to better understand the biological community within Beaver Creek. We also suggest utilizing more comprehensive habitat surveys that take channel diversity, streambed composition, algae cover, macrophyte diversity, and riparian land use into consideration.

Further, we recommend a more in-depth analysis of Paradise Marsh to evaluate whether it behaves as a source and/or sink of P. Then an assessment can be performed to determine the impacts of P flux from the marsh on aquatic life both in and downstream of the marsh.

Finally, county conservationists can lead the development of a watershed-scale plan that evaluates agricultural producer practices within the Beaver Creek subwatershed. Effective nutrient management plans, including manure and fertilizer management, are essential to controlling producer costs as well as improving creek water quality.

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APPENDIX A – STAKEHOLDER SURVEYS

Producer Questionnaire

1. TELL ME ABOUT YOUR FARM.

a. How long has your family been farming here?
b. How many acres do you own?
c. What types of things do you grow and raise?
d. What has changed over the years?

2. WHERE DOES THE RAINWATER GO THAT LANDS ON YOUR FARM?

☐ Drainage ditch
☐ Tile drains
☐ Roadway ditch
☐ Creek
☐ Other
☐ Not sure

3. WE ARE GOING TO ASK YOU ABOUT SEVERAL SOIL-MANAGEMENT PRACTICES, TO LEARN WHICH ONES YOU USE. FOR EACH ONE OF THESE, WE ASK:

a. Do you use it?
b. How much of your land do you use it on?
c. How long have you been using it?
d. What made you decide to try it?
e. If not, what are the barriers to using it?

SOIL MANAGEMENT PRACTICES:

☐ No-till planting
☐ Vertical-till planting
☐ Cover cropping
☐ Contour farming on steep slopes
☐ Working with a nutrient management plan
☐ Using SnapPlus to track nutrient applications
☐ Buffer strips
☐ Grass waterways
☐ Other practices we did not mention that you use

4. TO WHAT EXTENT DO YOU TRUST THESE AGENCIES FOR INFORMATION ABOUT FARMING AND SOIL MANAGEMENT?

☐ County Conservation staff
☐ UW-Extension
☐ Beaver Dam Lake Improvement Association
☐ Department of Natural Resources
☐ Local Farm Bureau
☐ Neighbors
☐ Other sources

5. WE ARE GOING TO ASK YOU ABOUT A FEW DIFFERENT THINGS THAT MAY IMPACT WATER QUALITY IN WISCONSIN LAKES AND STREAMS. IN YOUR OPINION, HOW MUCH OF A PROBLEM IS EACH OF THE FOLLOWING IN BEAVER CREEK AND BEAVER DAM LAKE? (USE THE SCALE BELOW).

☐ Nitrogen
☐ Phosphorus
☐ Carp
☐ Erosion and sediment build-up
☐ Algae
☐ Aquatic and riparian habitat loss
☐ Human recreational use of Beaver Dam Lake
☐ DNR management of Beaver Dam Lake
1 – Not a problem
2 – Somewhat of a problem
3 – Significant problem
4 – Very significant problem

6. OVERALL, HOW WOULD YOU RATE THE QUALITY OF WATER IN BEAVER CREEK?

7. DO YOU USE BEAVER CREEK OR BEAVER DAM LAKE RECREATIONALLY?

a. What activities do you do?
b. How many days per year?
c. If no, what prevents you from using Beaver Creek or Beaver Dam Lake recreationally?

8. WOULD YOU BE MORE LIKELY TO USE BEAVER CREEK OR BEAVER DAM LAKE RECREATIONALLY IF WATER QUALITY IMPROVED?

9. ARE YOU INTERESTED IN JOINING EFFORTS TO IMPROVE THE QUALITY OF BEAVER CREEK OR BEAVER DAM LAKE?
HOW ARE YOU INTERESTED IN BEING INVOLVED?

a. Financially
b. Volunteering time at events or cleanups
c. Adjusting recreational use to improve the lake
d. Make changes on your land

10. DO YOU BELIEVE THERE IS AN ECONOMIC BENEFIT TO THE SURROUNDING COMMUNITIES RESULTING FROM IMPROVING THE WATER QUALITY OF BEAVER DAM CREEK AND BEAVER DAM LAKE?

11. ARE YOU PLANNING ON ANY CHANGES IN YOUR FARM IN THE NEAR FUTURE? WHAT IS YOUR MOTIVATION BEHIND THESE CHANGES?

Town Hall and Community Survey

1. DO YOU OWN PROPERTY ON THE SHORE OF BEAVER DAM LAKE OR ALONG BEAVER CREEK?

2. WHEN IT RAINS AT YOUR HOME, WHERE DOES THE RAINWATER GO? CIRCLE ALL THAT APPLY

☐ Drainage ditch
☐ Storm sewer
☐ Creek
☐ Lake
☐ Other
☐ Not sure

3. VARIOUS CONDITIONS AND POLLUTANTS PRESENT IN WISCONSIN LAKES CAN BECOME A PROBLEM WHEN PRESENT IN EXCESSIVE AMOUNTS. IN YOUR OPINION, HOW MUCH OF A PROBLEM ARE THE FOLLOWING IN BEAVER CREEK AND BEAVER DAM LAKE? CHECK ONE IN EACH ROW.

	Big Problem	Somewhat of a Problem	Not a problem	Not Sure
Nitrogen				
Phosphorus				
Carp				
Erosion and Sediment Build-up				
Algae				
Habitat Loss				
Other: ____________				

4. OVERALL, HOW WOULD YOU RATE THE QUALITY OF WATER IN BEAVER CREEK? CIRCLE ONE.

1. Poor
2. Fair
3. Good
4. Excellent
5. Not Sure

5. WHICH OF THE FOLLOWING RECREATIONAL ACTIVITIES DO YOU DO ON BEAVER DAM LAKE AND FOR HOW MANY DAYS PER YEAR?

Activity	Days per year
Fishing	
Boating	
Water Skiing	
Swimming	
Birding	
Hunting	
Kayaking or Canoeing	
Other (please specify)	

IF NO, WHAT PREVENTS YOU FROM USING BEAVER CREEK OR BEAVER DAM LAKE RECREATIONALLY?

7.WHICH OF THE FOLLOWING RECREATIONAL ACTIVITIES DO YOU DO ON LAKES OTHER THAN BEAVER DAM LAKE AND FOR HOW MANY DAYS PER YEAR?

Activity	Days per year
Fishing	
Boating	
Water Skiing	
Swimming	
Birding	
Hunting	
Kayaking or Canoeing	
Other (please specify)	

8. WHICH OF THE FOLLOWING RECREATIONAL ACTIVITIES DO YOU DO ON BEAVER CREEK AND FOR HOW MANY DAYS PER YEAR?

Activity	Days per year
Fishing	
Swimming	
Birding	
Hunting	
Kayaking or Canoeing	
Other (please specify):	

9. WOULD YOU BE MORE LIKELY TO USE BEAVER CREEK OR BEAVER DAM LAKE RECREATIONALLY IF WATER QUALITY IMPROVED?

10. DO YOU BELIEVE THERE IS AN ECONOMIC BENEFIT TO THE SURROUNDING COMMUNITIES RESULTING FROM IMPROVING THE WATER QUALITY OF BEAVER DAM CREEK AND BEAVER DAM LAKE?

11. WOULD YOU BE WILLING TO BE INVOLVED IN ANY OF THE FOLLOWING EFFORTS TO IMPROVE THE QUALITY OF BEAVER CREEK OR BEAVER DAM LAKE? CIRCLE ALL THAT APPLY.

a. Monetary (Including taxes or direct contributions)
b. Volunteering time
c. Adjusting recreational use
d. Making changes on your property
e. Not able to be involved

APPENDIX B - PRIORITIZING EVAAL-IDENTIFIED AREAS

Table 6 lists the sites we identified with EVAAL as appearing to have large areas with high EVI values. Since more than 25 sites were identified, we wanted to come up with a ranking system to determine the ten highest-priority vulnerability sites. Our system equally weighted an area's: 1) EVI number, 2) area of high erosion vulnerability (acres), and 3) distance to nearest surface water body. We developed this ranking system with the assumption that a higher degree of effectiveness in improving water quality will be realized if best management practices are implemented in these top-priority areas. All sites that we observed during the windshield survey and included in our ranking below can be identified via our custom Google map and the labels identified on June 24, 2017 (Appendix C). Below is a map that highlights the top ten priority areas (Figure 47). (Please note some site names do not follow appropriate numerical order; we identified additional sites while out in the field that had not been identified during the computer model review.)

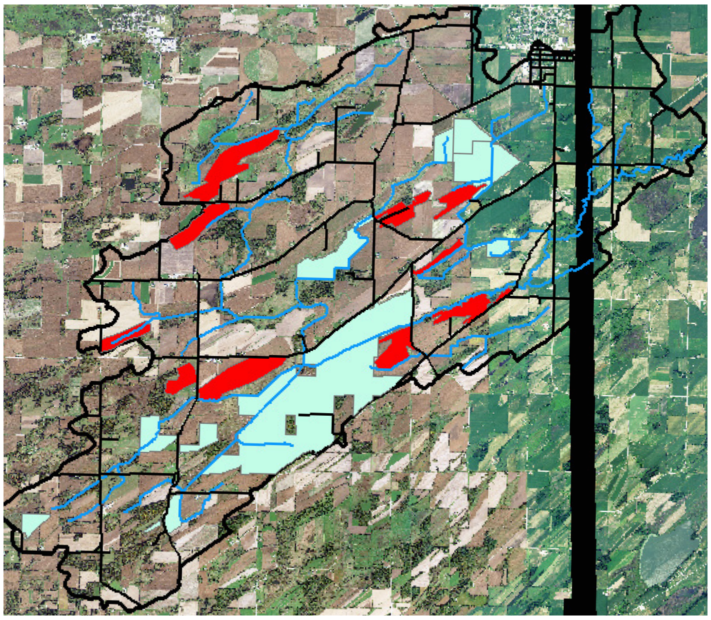


Figure 47: The ten highest-priority vulnerability sites (highlighted in red).

Table 6: Areas with high erosion potential identified via EVAAL. These sites were also evaluated via other parameters to establish the ten highest-priority sites.

Overall Rank	Site #	Proximity to Water Body (m)	Rank	Acres	Rank	EVI	Rank	Overall Rank Calculation
1	**6.5**	0	1	77.30	5	8.5	4	3.3
2	**24**	10	2	79.49	3	8	9	4.7
3	**15**	86	13	192.96	1	9	3	5.7
4	**19**	100	16	71.79	6	8.4	5	9.0
5	**22**	46	3	55.46	10	7.5	15	9.3
6	**14**	190	20	58.97	8	9.4	1	9.7
7	**Field 2**	84	12	57.19	9	7.9	10	10.3
8	**8**	76	9	78.63	4	6.6	20	11.0
9	**11**	68	7	50.07	12	7.5	14	11.0
10	**20**	95	14	46.97	13	8.1	8	11.7
11	**23**	76	10	25.76	20	8.2	7	12.3
12	**13**	112	17	83.51	2	6.5	21	13.3
13	**18**	198	21	35.12	17	9.2	2	13.3
14	**5**	50	4	37.17	16	6.2	22	14.0
15	**16**	500	26	59.13	7	7.7	12	15.0
16	**6**	63	6	42.05	15	6	24	15.0
17	**7**	58	5	17.35	21	6.7	19	15.0
18	**21**	432	24	51.51	11	7.8	11	15.3
19	**Area 1**	97	15	42.24	14	6.8	18	15.7
20	**25**	488	25	17.34	22	8.3	6	17.7
21	**17**	75	8	1.96	28	6.8	17	17.7
22	**2**	82	11	34.74	18	4.8	28	19.0
23	**1**	630	27	29.31	19	7.5	13	19.7
24	**3**	143	19	11.85	25	6.1	23	22.3
25	**9**	138	18	15.96	23	5.7	27	22.7
26	**Field 1**	internally drained	28	2.29	27	7.2	16	23.7
27	**4**	296	22	14.76	24	5.8	26	24.0
28	**10**	368	23	8.49	26	5.9	25	24.7

APPENDIX C – WINDSHIELD SURVEY GOOGLE MAP

The “My Maps” function under Google Maps allows customization and the ability to add photos to any location (Figure 48). We documented our observations with photos and notes and placed them within a custom Windshield Survey Google Map, available at this link: https://www.google.com/maps/d/edit?mid=1fVSrKB9LuKUB8RBCPKJ5-BFBiWA&ll=43.49215227498841%2C-89.0361428&z=12. Users can click on marked locations to review additional observational notes and photos.

Sites viewed on May 20, 2017, are marked by the blue points. Sites viewed on June 24, 2017, include the green stars, which are our top 10 priority sites, and the orange stars, which are the sites we observed after identifying large EVI areas in EVAAL modeling (these are also the sites included in our rankings in Appendix B). The red hammers mark the approximate locations where we collected soil samples.

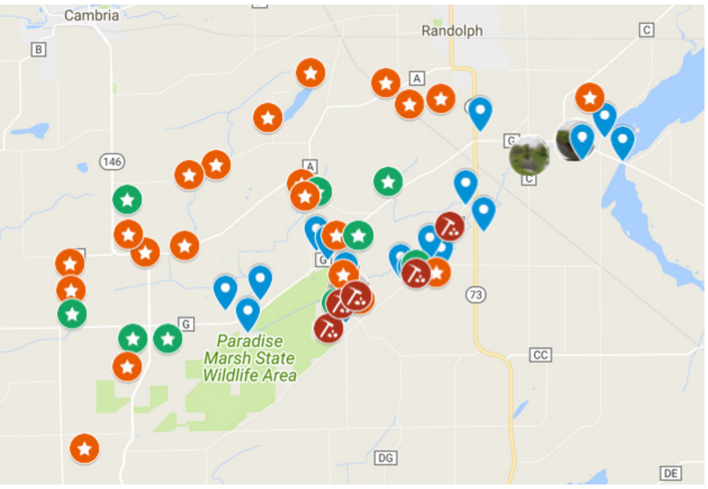


Figure 48: Map of windshield survey, macroinvertebrate sampling, and soil sampling sites.

APPENDIX D – ADDITIONAL EVAAL RESULTS

LiDAR imagery was taken from the WisconsinView Data Portal for Columbia County. The Dodge County data comes from Wisconsin Department of Natural Resources open data. The data was merged along the county line between Dodge County and Columbia County because LiDAR, which has higher resolution, was not available for both counties (Figure 49).

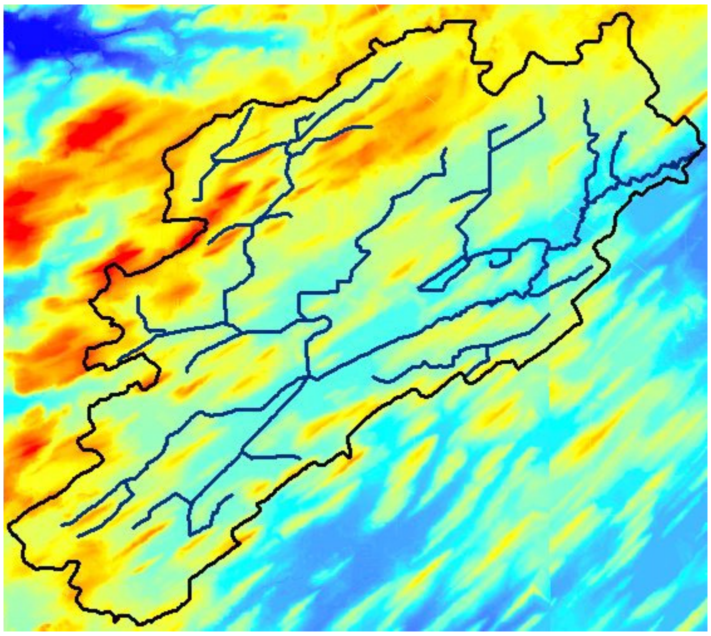


Figure 49: LiDAR and DEM imagery.

Figure 50 shows the crop rotations over the past five years taken from CropScape. Most of the subwatershed has cash-grain rotations, represented in yellow on the image. CropScape data is satellite-derived, so any areas with no data most likely come from errors in determining land use from that process.

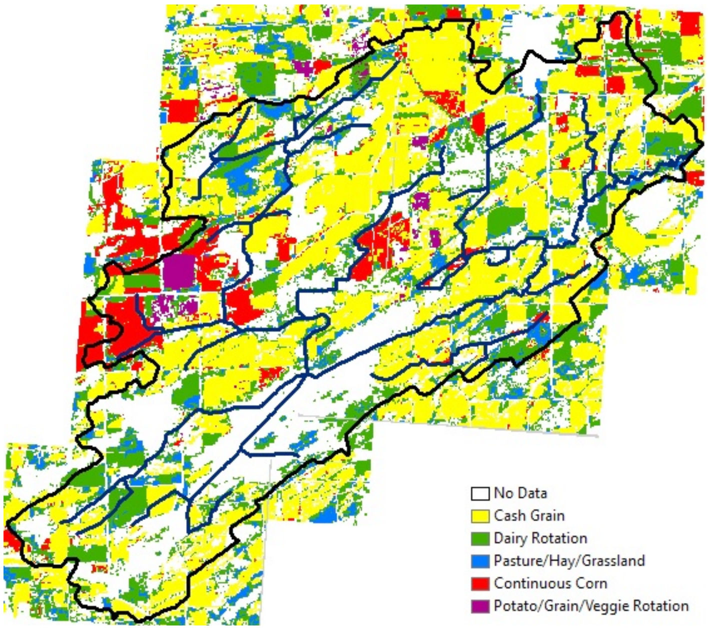


Figure 50: Crop rotations from 2012-2016.

The curve number values throughout the watershed are on the relatively high end, meaning an increase in erosion potential on the land (Figure 51). This image was created by EVAAL and incorporated NRCS soils data as well as NOAA precipitation data.

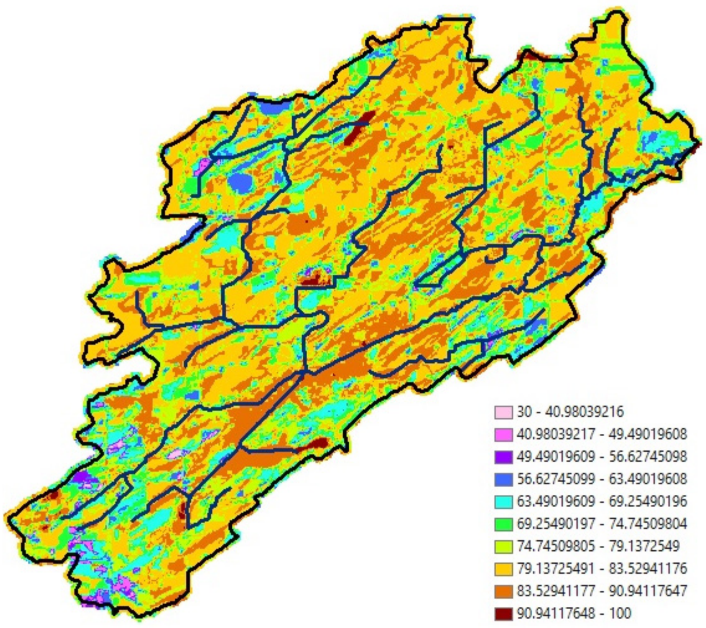


Figure 51: Curve number values.

The Stream Power Index results (Figure 52) show the formation of rills and gullies across the landscape and can help determine areas where best management practices, such as grassed waterways, could possibly be used. This information matched well in comparison to ground-truthing the model results and showed areas of high-erosion potential on the landscape.

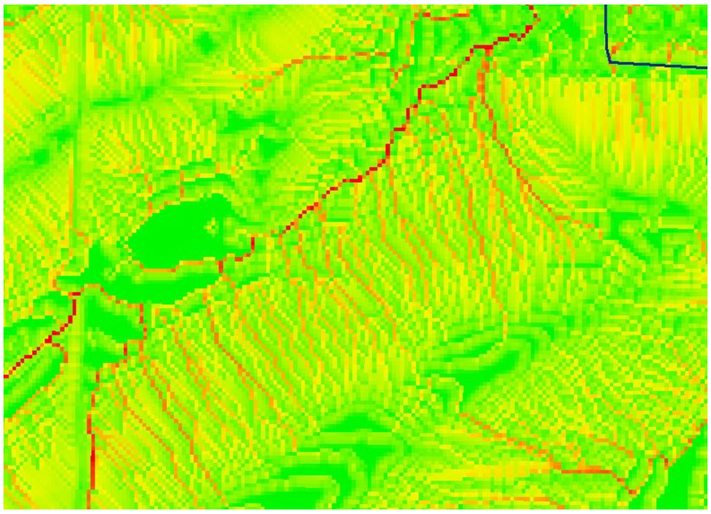


Figure 52: Stream power index.

C-factor values represent the cover management factor of the RUSLE equation, accounting for surface cover on the land and its effect on soil erosion. High values mean less continuous cover leading to higher rates of soil erosion (Figure 53).

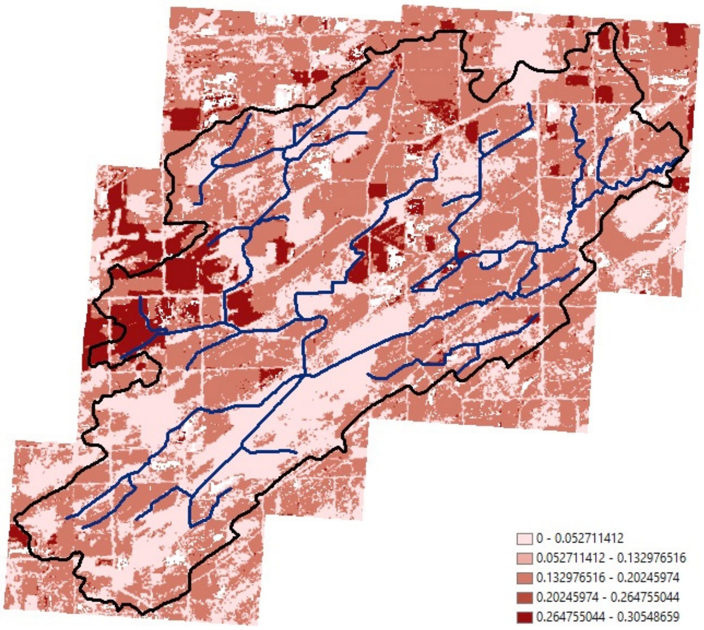


Figure 53: C-factor values.

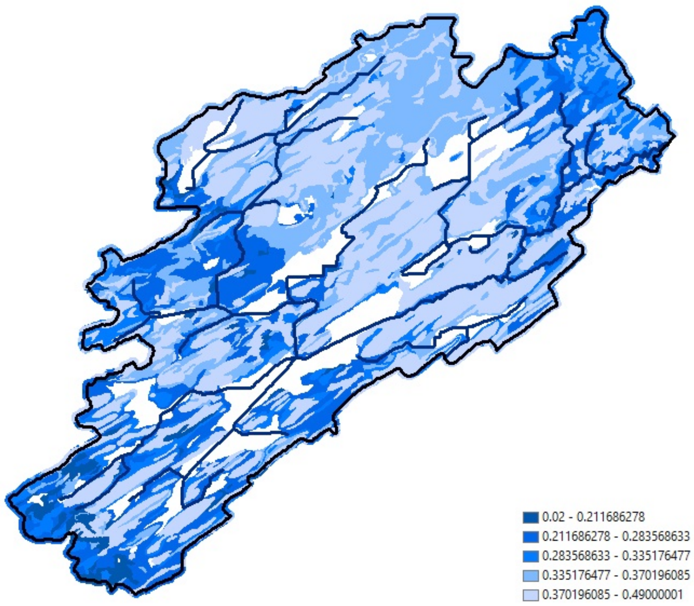


Figure 54: K-factor values.

APPENDIX E – ADDITIONAL IN-LAKE RESULTS

Our dissolved oxygen (DO) results were compared with those found by Onterra, LLC, three years ago, and we found that for a majority of the summer, DO was significantly higher at both Deep Hole and North End compared to this previous study (Figure 55). Because DO can be considered a measure of lake health, this is a positive finding that may relate to improved agricultural practices in the watershed.

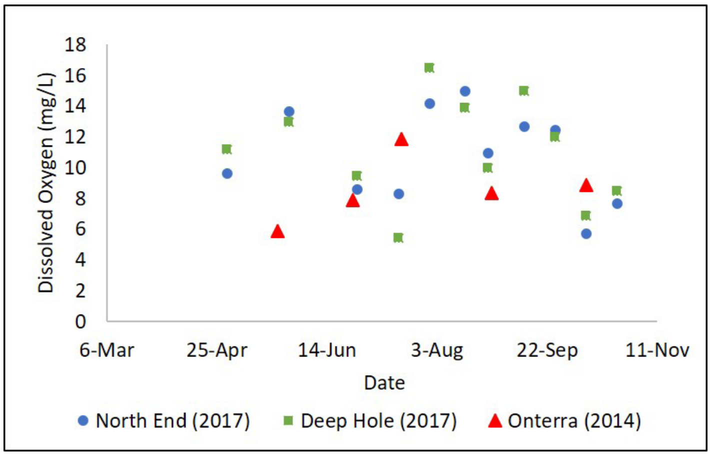


Figure 55: Dissolved oxygen over the growing season as measured by WRM and Onterra.

Our Secchi-disk depths were relatively consistent throughout the summer, both temporally and between both locations, with the exception of one outlying data point that we believe can be attributed to error in measurement (Figure 56).

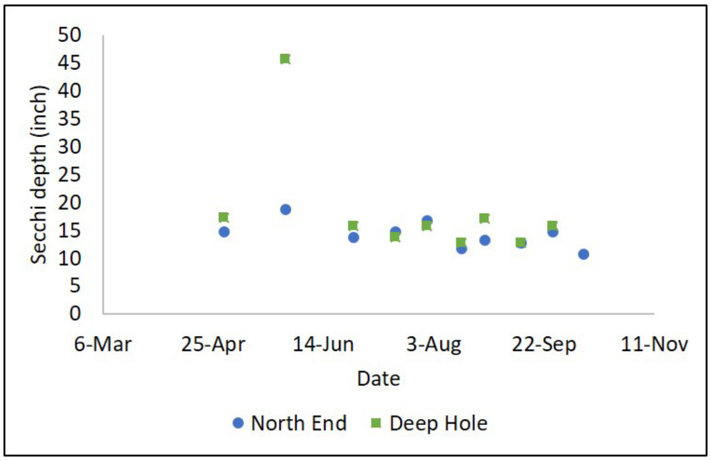


Figure 56: Secchi depth over the growing season as measured by WRM.

Total suspended solids (TSS) correlates closely between both sampling locations. The most significant finding was the sudden spike in early July to between 80-90 mg/L (Figure 57).

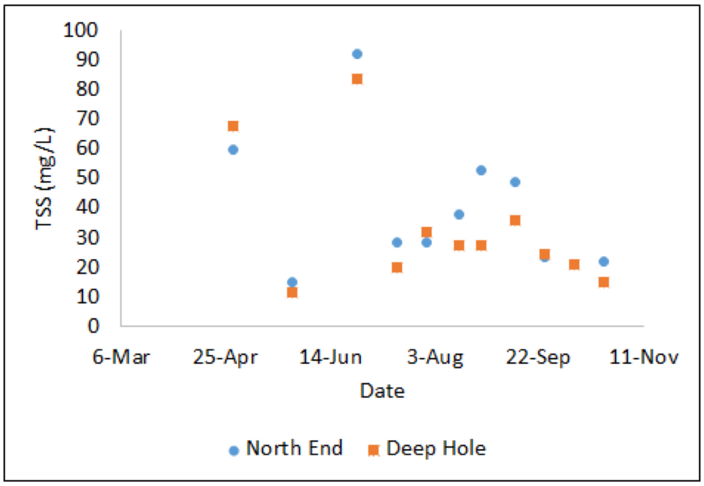


Figure 57: Total suspended solids (mg/L) over 2017 as measured by WRM.

Electrical conductivity correlates closely between both sampling locations except for the last sampling point (Figure 57).

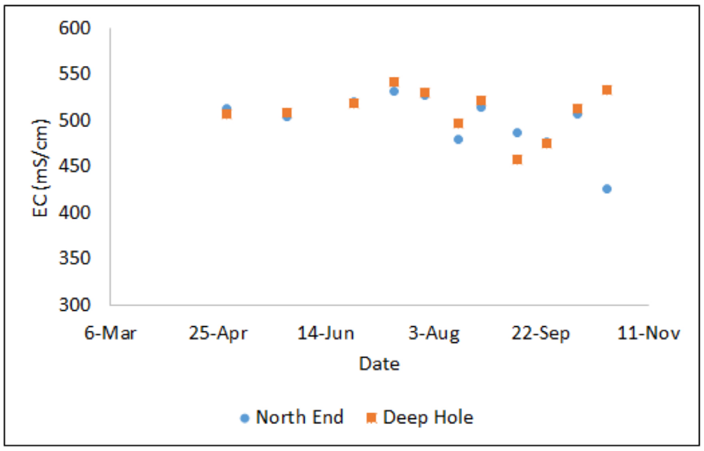


Figure 58: Electrical conductivity (mS/cm) over 2017 as measured by WRM.

Total Kjeldahl nitrogen correlates closely between both sampling locations (Figure 59).

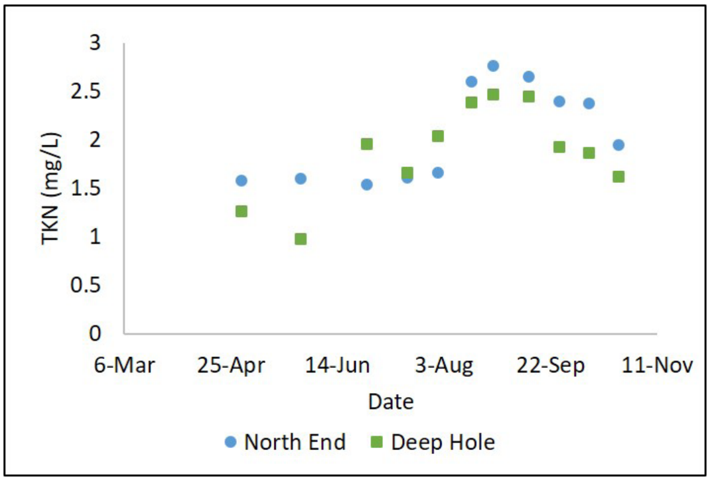


Figure 59: Total Kjeldahl nitrogen (mg/L) over 2017 as measured by WRM.

Total nitrogen at the two sampling locations followed the same trend as total Kjeldahl nitrogen. The nitrogen concentration reached its peak by the end of summer at both sampling locations (Figure 60).

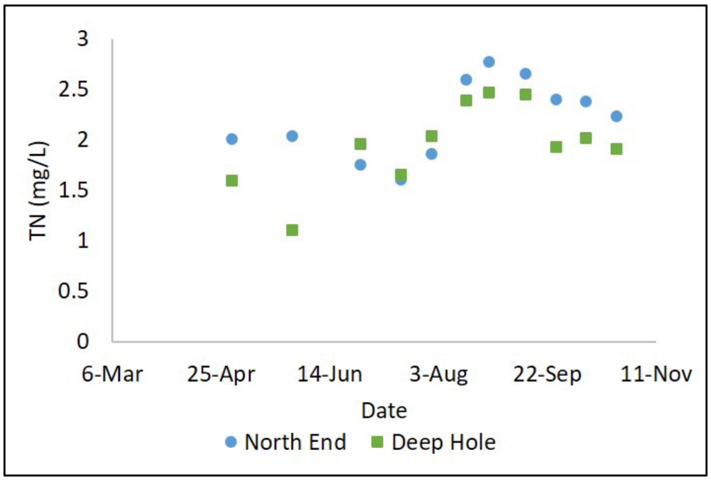


Figure 60: Total nitrogen (mg/L) over 2017 as measured by WRM.

The TP results from WSLH and the UW-Madison BSE Lab were similar throughout the study (Figure 61). Differences between trends seen in 2014 and 2017 are discussed in Chapter 6.

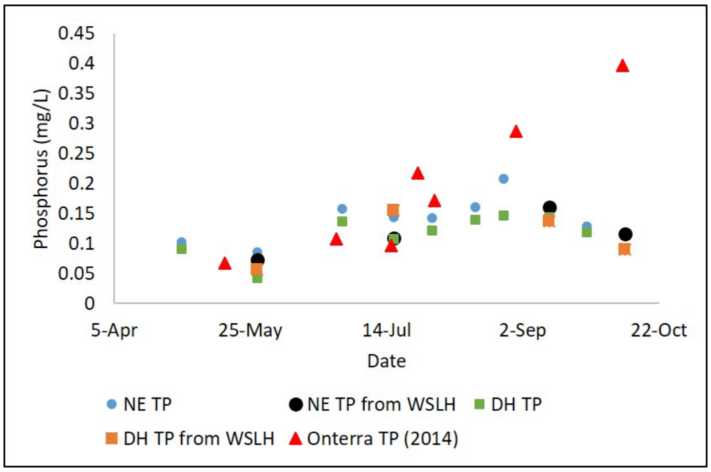


Figure 61: Comparison of total phosphorus (mg/L) data from Onterra (2014), WSLH and the UW-Madison BSE Lab.

This correlation coefficient comparison table (Table 7) shows the overall Pearson Correlation coefficients between water quality variables. The closer the absolute value of a correlation coefficient is to 1, the stronger the correlation. Positive values represent an increasing trend, and negative values refer to a declining trend. The corresponding coefficient values of dissolved reactive phosphorus (DRP) are relatively high because the DRP only contains four detected values. All measures of lake water quality depend upon one another in complex relationships. A few of these are explored below.

Table 7: Pearson Correlation Coefficients

	pH	DO (mg/L)	DO %	TS (mg/L)	TSS (mg/L)	DRP (mg/L)	Secchi (m)	Water Temp (°C)	Ec (mS/cm)	TDS (mg/L)	Wind Speed	TP (mg/L)	TKN (mg/L)	TN (mg/L)	N/P
pH	1.000	0.878	0.387	0.238	0.047	0.964	0.105	0.563	-0.173	0.054	0.070	0.478	0.418	0.335	-0.370
DO (mg/L)	0.878	1.000	0.459	0.135	-0.037	0.680	0.204	0.355	-0.227	-0.048	-0.030	0.185	0.206	0.205	-0.075
DO %	0.387	0.459	1.000	0.104	-0.195	-0.695	0.117	0.288	-0.272	0.100	0.141	0.050	0.352	0.229	0.092
TS (mg/L)	0.238	0.135	0.104	1.000	-0.165	-0.952	-0.293	0.266	0.051	0.730	0.493	0.409	0.557	0.558	-0.119
TSS (mg/L)	0.047	-0.037	-0.195	-0.165	1.000	0.676	-0.228	-0.225	0.119	-0.338	0.053	0.440	-0.006	0.025	-0.562
DRP (mg/L)	0.964	0.680	-0.695	-0.952	0.676	1.000	0.998	0.980	0.812	-0.995	-0.999	0.631	-0.968	-0.968	-0.990
Secchi (m)	0.105	0.204	0.117	-0.293	-0.228	0.998	1.000	-0.080	0.133	-0.071	-0.237	-0.555	-0.572	-0.626	0.391
Water Temp (°C)	0.563	0.355	0.288	0.266	-0.225	0.980	-0.080	1.000	0.163	0.275	0.165	0.461	0.318	0.119	-0.547
Ec (mS/cm)	-0.173	-0.227	-0.272	0.051	0.119	0.812	0.133	0.163	1.000	0.087	0.089	-0.012	-0.346	-0.408	-0.264
TDS (mg/L)	0.054	-0.048	0.100	0.730	-0.338	-0.995	-0.071	0.275	0.087	1.000	0.331	0.110	0.391	0.338	0.109
Wind Speed	0.070	-0.030	0.141	0.493	0.053	-0.999	-0.237	0.165	0.089	0.331	1.000	0.179	0.345	0.260	-0.141
TP (mg/L)	0.478	0.185	0.050	0.409	0.440	0.631	-0.555	0.461	-0.012	0.110	0.179	1.000	0.723	0.656	-0.796
TKN (mg/L)	0.418	0.206	0.352	0.557	-0.006	-0.968	-0.572	0.318	-0.346	0.391	0.345	0.723	1.000	0.955	-0.250
TN (mg/L)	0.335	0.205	0.229	0.558	0.025	-0.968	-0.626	0.119	-0.408	0.338	0.260	0.656	0.955	1.000	-0.121
N/P	-0.370	-0.075	0.092	-0.119	-0.562	-0.990	0.391	-0.547	-0.264	0.109	-0.141	-0.796	-0.250	-0.121	1.000

The dissolved oxygen (DO) level increases with an increase in pH (Figure 62). This might relate to the conversion of carbonate in chemical reactions.

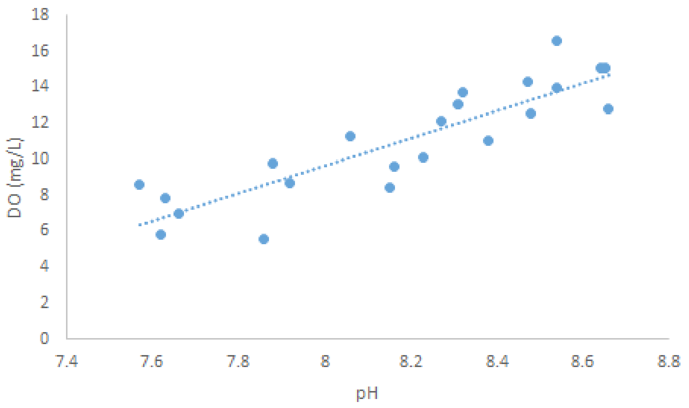


Figure 62: Relationship between DO and pH. The trendline equation is y = 7.693x - 51.898.

The relationship between increasing pH and total phosphorus was not found to be significant (Figure 63).

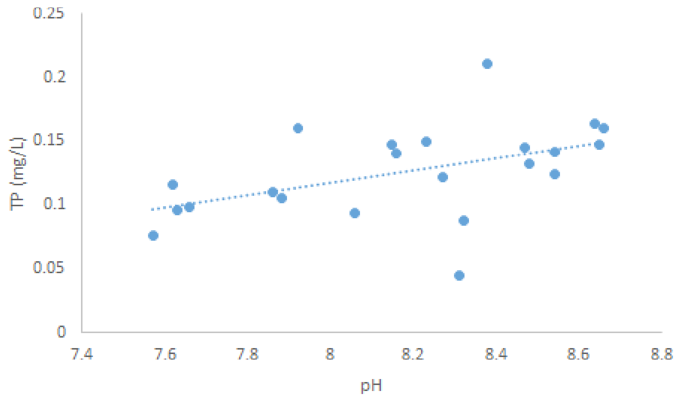


Figure 63: Relationship between TP and pH. The trendline equation is y = 0.0479x - 0.2658 and $R^2 = 0.2287$.

Increasing pH corresponds to an increase in TN, but the R-square value is comparatively low (Figure 64) and the relationship could be better explored in a larger dataset.

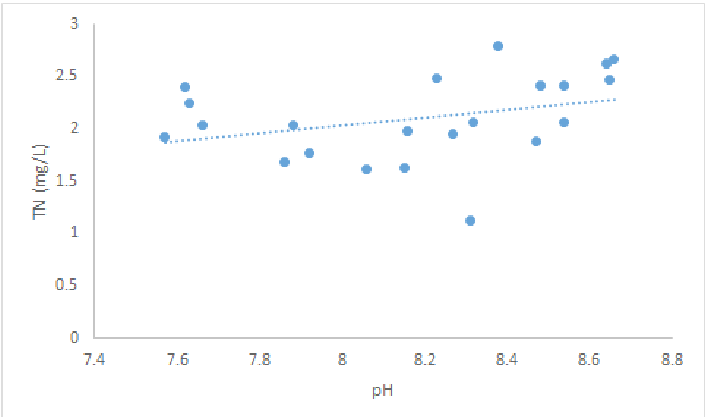
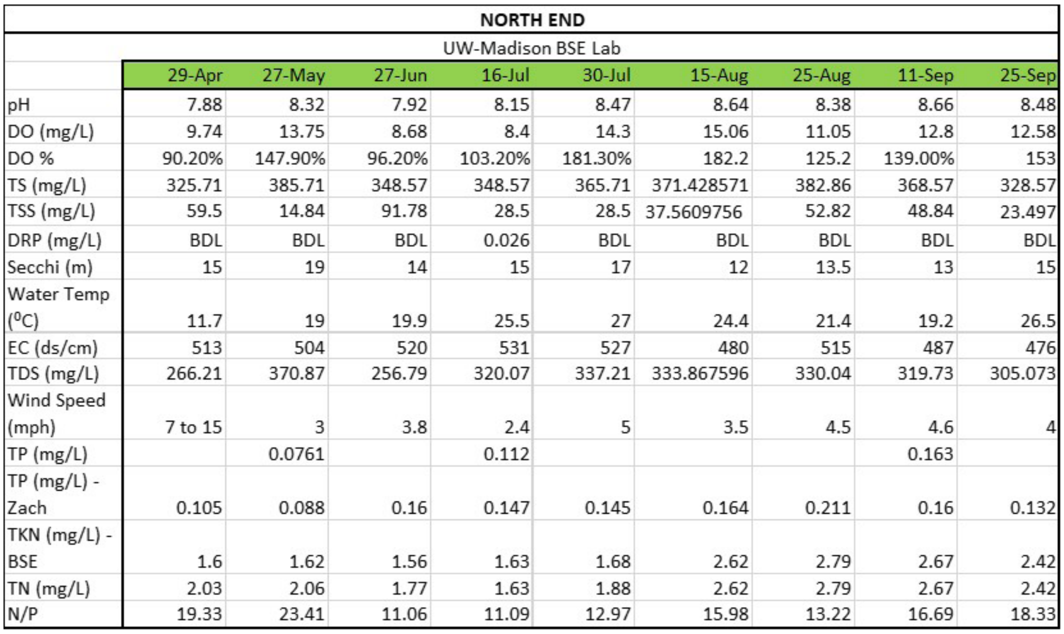
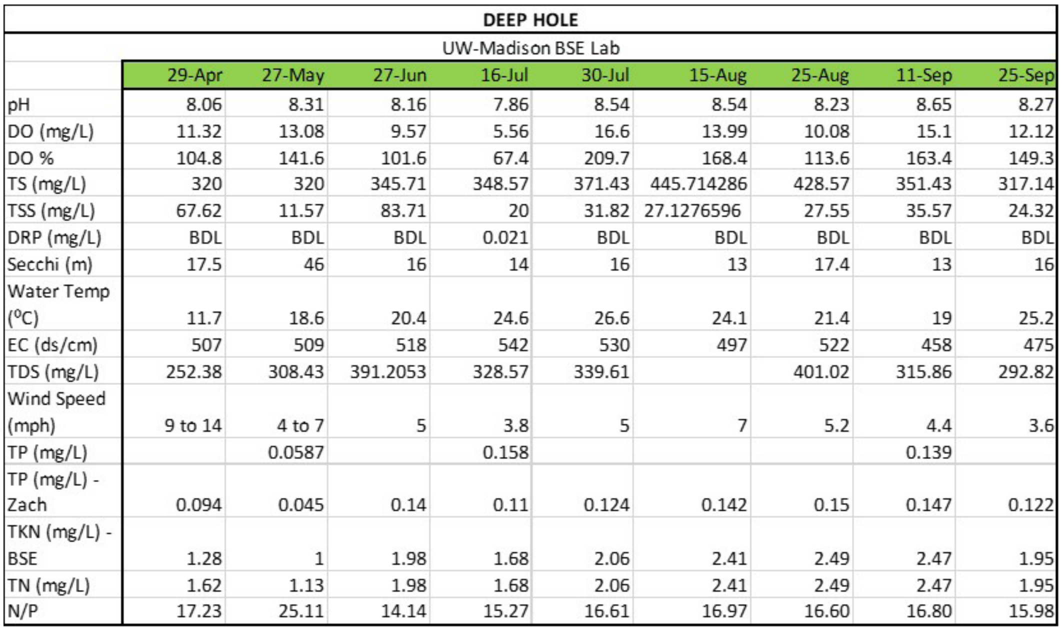


Figure 64: Relationship between TN and pH. The trendline equation is y = 0.3783x - 0.9913 and $R^2 = 0.1119$.

Table 8: Raw sampling data conducted by in-lake group at North End and Deep Hole at the UW-Madison BSE Lab.

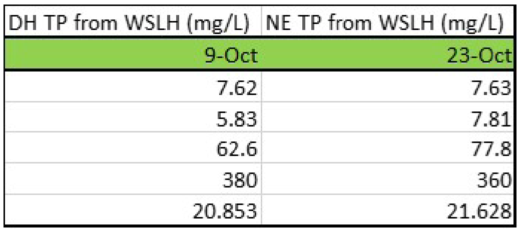


NORTH END									
UW-Madison BSE Lab									
	29-Apr	27-May	27-Jun	16-Jul	30-Jul	15-Aug	25-Aug	11-Sep	25-Sep
pH	7.88	8.32	7.92	8.15	8.47	8.64	8.38	8.66	8.48
DO (mg/L)	9.74	13.75	8.68	8.4	14.3	15.06	11.05	12.8	12.58
DO %	90.20%	147.90%	96.20%	103.20%	181.30%	182.2	125.2	139.00%	153
TS (mg/L)	325.71	385.71	348.57	348.57	365.71	371.428571	382.86	368.57	328.57
TSS (mg/L)	59.5	14.84	91.78	28.5	28.5	37.5609756	52.82	48.84	23.497
DRP (mg/L)	BDL	BDL	BDL	0.026	BDL	BDL	BDL	BDL	BDL
Secchi (m)	15	19	14	15	17	12	13.5	13	15
Water Temp (^{0}C)	11.7	19	19.9	25.5	27	24.4	21.4	19.2	26.5
EC (ds/cm)	513	504	520	531	527	480	515	487	476
TDS (mg/L)	266.21	370.87	256.79	320.07	337.21	333.867596	330.04	319.73	305.073
Wind Speed (mph)	7 to 15	3	3.8	2.4	5	3.5	4.5	4.6	4
TP (mg/L)		0.0761		0.112				0.163	
TP (mg/L) - Zach	0.105	0.088	0.16	0.147	0.145	0.164	0.211	0.16	0.132
TKN (mg/L) - BSE	1.6	1.62	1.56	1.63	1.68	2.62	2.79	2.67	2.42
TN (mg/L)	2.03	2.06	1.77	1.63	1.88	2.62	2.79	2.67	2.42
N/P	19.33	23.41	11.06	11.09	12.97	15.98	13.22	16.69	18.33



DEEP HOLE									
UW-Madison BSE Lab									
	29-Apr	27-May	27-Jun	16-Jul	30-Jul	15-Aug	25-Aug	11-Sep	25-Sep
pH	8.06	8.31	8.16	7.86	8.54	8.54	8.23	8.65	8.27
DO (mg/L)	11.32	13.08	9.57	5.56	16.6	13.99	10.08	15.1	12.12
DO %	104.8	141.6	101.6	67.4	209.7	168.4	113.6	163.4	149.3
TS (mg/L)	320	320	345.71	348.57	371.43	445.714286	428.57	351.43	317.14
TSS (mg/L)	67.62	11.57	83.71	20	31.82	27.1276596	27.55	35.57	24.32
DRP (mg/L)	BDL	BDL	BDL	0.021	BDL	BDL	BDL	BDL	BDL
Secchi (m)	17.5	46	16	14	16	13	17.4	13	16
Water Temp (^{0}C)	11.7	18.6	20.4	24.6	26.6	24.1	21.4	19	25.2
EC (ds/cm)	507	509	518	542	530	497	522	458	475
TDS (mg/L)	252.38	308.43	391.2053	328.57	339.61		401.02	315.86	292.82
Wind Speed (mph)	9 to 14	4 to 7	5	3.8	5	7	5.2	4.4	3.6
TP (mg/L)		0.0587		0.158				0.139	
TP (mg/L) - Zach	0.094	0.045	0.14	0.11	0.124	0.142	0.15	0.147	0.122
TKN (mg/L) - BSE	1.28	1	1.98	1.68	2.06	2.41	2.49	2.47	1.95
TN (mg/L)	1.62	1.13	1.98	1.68	2.06	2.41	2.49	2.47	1.95
N/P	17.23	25.11	14.14	15.27	16.61	16.97	16.60	16.80	15.98

Table 9: Raw data (mg/L) from the WSLH Lab for Deep Hole and North End.



DH TP from WSLH (mg/L)	NE TP from WSLH (mg/L)
9-Oct	23-Oct
7.62	7.63
5.83	7.81
62.6	77.8
380	360
20.853	21.628

APPENDIX F — ADDITIONAL IN-STREAM METHODS AND RESULTS

Methods

PH

pH was evaluated in the lab on the day of collection or within a 24-hour period of collection. Samples were analyzed at room temperature using a combined pH/EC probe that was calibrated for each use. After calibration, the clean pH probe was rinsed and the sample placed on a magnetic stir plate with a magnet spinning to move the water without creating a vortex. The probe was then inserted into the sample, and measurements recorded after the machine had stabilized. The probe was rinsed with deionized water and dried gently with a Kimwipe before the next sample was analyzed.

ELECTRICAL CONDUCTIVITY

Electrical conductivity (EC) was also analyzed with the pH/EC measuring device. After the EC probe was rehydrated for 10 minutes, the calibration was checked using the standard before analyzing the samples. Like the pH procedures, the probe and temperature sensor were cleaned between each sample and prepped with the new sample prior to measurement.

TOTAL SOLIDS

Total solids (TS) is a measure of all the solids contained within the water sample. Ceramic crucibles were cleaned at 100°C and washed prior to use. An extra crucible was used as a blank to evaluate error between weighings. The water sample was placed on a stir plate and set to create a small vortex to ensure a well-mixed sample. A 35-mL sample was pipetted using a vacuum pipette into each crucible and allowed to evaporate completely at 100°C. Crucibles were weighed again after the samples had evaporated. The difference between the initial weight and the dried weight of the crucible, minus the error accounted for by the blank, divided by the volume of water is the TS in mg/L of the sample.

TOTAL SUSPENDED SOLIDS

Total suspended solids (TSS) are the solids trapped by a 0.7-µm filter. Filters were prepared by placing the patterned side face up on an Erlenmeyer flask hooked up to a vacuum system and passing 60-mL of DI water through it. The clean filters were then placed on small aluminum tins and dried in the oven at 100°C. A blank was used to assess error. The tin and filter's dry combined weight were recorded before a defined volume of the site's water sample was pulled through the filter using a vacuum apparatus. Sample water was added until a definitive discoloration was visually observed on the filter. The total sample volume was recorded. DI water was then used to rinse any particles from the sides of the graduated cylinder used to measure the sample volumes and from the beaker. The filter was then returned to its tin, dried at 100°C and reweighed. The difference between the dry and wet weights of the tins divided by the volume of water equals the TSS.

PHOSPHORUS

Two labs were used to analyze phosphorus (P): the Biological Systems Engineering (BSE) Water Quality Laboratory at UW-Madison and the Wisconsin State Laboratory of Hygiene (WSLH). We used two labs to comply with the project grant, which specified that representative samples were to be analyzed by WSLH; testing the samples twice also allowed for potential errors to be found. TP samples were acidified upon collection. Samples analyzed in the BSE lab were acidified using 1:2 sulfuric acid, while those analyzed by WSLH were acidified using 1:3 sulfuric acid. Samples were dropped off to WSLH within one business day of collection. DRP was analyzed from an approximately 40-mL filtered sample. A few mL of stream water was passed through a 0.45-µm Whatman filter in preparation for sampling, followed by collection into a clean 60-ml bottle. These samples were analyzed within a week of collection.

NITROGEN

TN and TKN were also analyzed at the BSE lab from the acidified samples with 1:2 sulfuric acid. Likewise, 1:3 acidified samples were also analyzed by WSLH using EPA-approved methods.

RESULTS

Table 10: Raw data for stream discharge curve for ISCO.

Date	Stage Height (ft)	Discharge (cfs)
05/12/17	1.90	36.7
05/21/17	1.99	34.4
05/26/17	2.08	43.2
05/30/17	1.78	23.7
06/04/17	1.95	31.5
06/07/17	1.62	17.4
06/11/17	1.46	8.9
06/15/17	1.78	22.2
06/23/17	3.50	119.2
06/24/17	3.05	85.2

Table 11: Raw monthly water quality data for Beaver Creek. Blanks indicate no data. "BDL" means below detectable level.

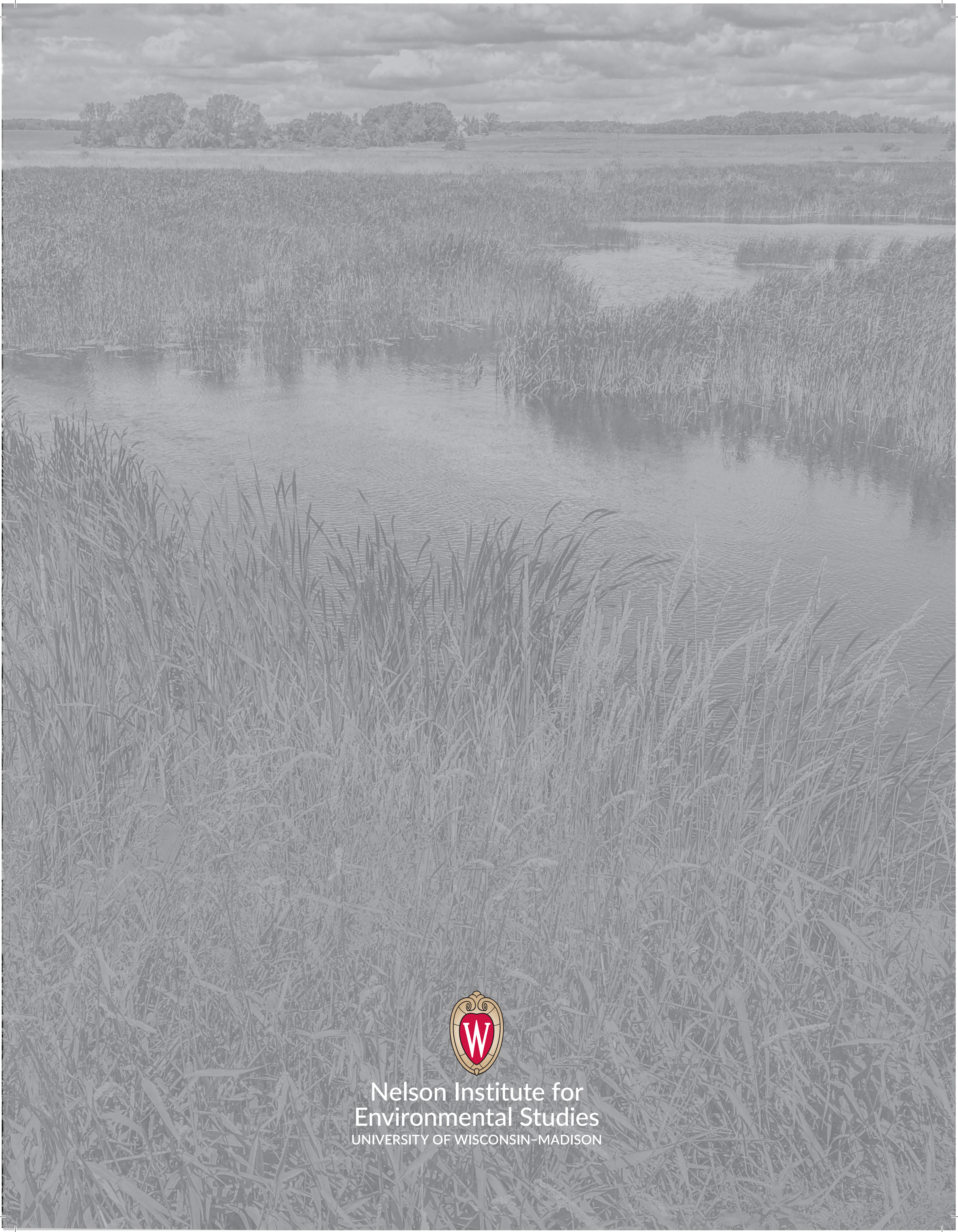
	Date	146	Pierce	DG	73	G
pH	05/26/17			7.23	7.49	7.55
	06/24/17			6.82	7.06	7.11
	07/16/17			6.84	7.17	7.34
	08/11/17			7.10	7.38	7.6
	09/11/17	7.27	7.83	7.08	7.8	7.73
	10/06/17	7.33	7.34	7.12	7.43	7.60
	10/27/17	7.38	7.47	7.31	7.53	7.64
EC (µS/cm)	05/26/17			595	625	636
	06/24/17			440	475	483
	07/16/17			595	630	641
	08/11/17			715	718	709
	09/11/17	791	816	762	737	751
	10/06/17	833	809	768	751	770
	10/27/17	747	852	769	774	785
TS (mg/L)	05/26/17			414.3	425.7	477.1
	06/24/17			351.4	445.7	494.3
	07/16/17			422.9	591.4	545.7
	08/11/17			494.3	705.7	691.4
	09/11/17	468.6	517.1	542.9	462.9	517.1
	10/06/17	605.7	591.4	757.1	685.7	685.7
	10/27/17	534.3	605.7	580	577.1	605.7
TSS (mg/L)	05/26/17			1.7	9.2	11.3
	06/24/17			4.0	67.4	32.6
	07/16/17			4.3	42.2	41.4
	08/11/17			5.4	7.2	18.7
	09/11/17	4.7	8.0	5.1	4.2	10.2
	10/06/17	2.9	1.2	7.4	11.3	26.0
	10/27/17	33.0	3.2	7.7	5.9	11.4
TP (mg/L)	05/26/17			0.14	0.18	0.19
	06/24/17			0.27	0.35	0.37
	07/16/17			0.66	0.49	0.43
	08/11/17			0.33	0.33	0.32
	09/11/17	0.22	0.11	0.24	0.21	0.23
	10/06/17	0.24	0.14	0.28	0.34	0.34
	10/27/17	0.17	0.13	0.19	0.16	0.19

Continued , Table 11: Raw monthly water quality data for Beaver Creek. Blanks indicate no data. "BDL" means below detectable level.

DRP (mg/L)	05/26/17			0.08	0.10	0.09
	06/24/17			0.16	0.20	0.21
	07/16/17			0.43	0.24	0.22
	08/11/17			0.15	0.16	0.17
	09/11/17	0.05	0.04	0.10	0.11	0.12
	10/06/17	0.08	0.05	0.11	0.21	0.19
	10/27/17	0.04	0.05	0.03	0.07	0.08
TN (mg/L)	05/26/17			1.6	2.4	2.5
	06/24/17			2.4	3.1	3.4
	07/16/17			1.4	1.9	2.0
	08/11/17			2.1	1.7	2.0
	09/11/17	3.6	6.4	3.2	2.4	2.8
	10/06/17	4.3	5.2	3.5	2.8	3.1
	10/27/17	4.1	6.5	3.6	3.2	3.4
TKN (mg/L)	05/26/17			1.0	1.2	1.3
	06/24/17			1.2	1.7	1.7
	07/16/17			1.4	1.6	1.5
	08/11/17			1.6	1.5	1.3
	09/11/17	1.4	1.4	1.7	1.4	1.3
	10/06/17	2.4	1.5	2.1	1.6	1.5
	10/27/17	3.3	1.6	1.8	1.6	1.6
NO2 & NO3 (mg/L)	05/26/17			0.6	1.2	1.2
	06/24/17			1.2	1.4	1.8
	07/16/17			BDL	0.3	0.5
	08/11/17			0.5	0.2	0.7
	09/11/17	2.2	5.0	1.5	1.0	1.5
	10/06/17	2.0	3.7	1.4	1.2	1.5
	10/27/17	0.8	5.0	1.8	1.5	1.7

Table 12. Raw storm water quality data for Beaver Creek at County Road G. Blanks indicate no data.

	Date	Composite 1	Composite 2	Composite 3	Composite 4	Composite 5
pH	06/28/17	7.56	7.55	7.46	7.48	7.47
	08/16/17	8.05	7.96	8.03	7.87	8.03
	10/04/17	7.95	7.94	7.89	7.88	
	10/06/17	7.97	7.92	7.92	7.94	
EC (µS/cm)	06/28/17	517	525	530	535	541
	08/16/17	745	671	704	745	746
	10/04/17	753	745	758	759	
	10/06/17	775	778	786	778	
TS (mg/L)	06/28/17	434.3	434.3	437.1	428.6	457.1
	08/16/17	702.9	600	571.4	642.9	642.9
	10/04/17	1125.7	1045.7	1020	1031.4	
	10/06/17	608.6	580	545.7	837.1	
TSS (mg/L)	06/28/17	59.9	37.5	37.2	21.3	28.1
	08/16/17	218.1	90.5	66.0	117.3	91.4
	10/04/17	270.2	253.3	245.8	268.8	
	10/06/17	128.3	84.1	27.1	296.6	
TP (mg/L)	06/28/17	0.32	0.32	0.33	0.29	0.29
	08/16/17	0.62	0.47	0.44	0.57	0.52
	10/04/17		0.63	0.72	0.70	
	10/06/17	0.47	0.40	0.32	0.83	
DRP (mg/L)	06/28/17	0.17	0.18	0.18	0.17	0.17
	08/16/17	0.16	0.20	0.19	0.15	0.22
	10/04/17	0.18	0.20	0.20	0.19	
	10/06/17	0.17	0.19	0.19	0.18	
TN (mg/L)	06/28/17	2.1	2.1	2.1	2.2	2.2
	08/16/17	3.6	2.9	2.8		2.7
	10/04/17	5.1	4.2	4.3	4.8	
	10/06/17	3.7	3.6	3.2	5.1	
TKN (mg/L)	06/28/17	1.5	1.4	1.4	1.4	1.4
	08/16/17	2.4	1.8	1.7		1.8
	10/04/17	3.3	3.6	2.9	3.3	
	10/06/17	2.0	1.9	1.6	3.7	
NO2 & NO3 (mg/L)	06/28/17	0.6	0.7	0.7	0.8	0.8
	08/16/17	1.2	1.1	1.1		0.9
	10/04/17	1.8	1.6	1.4	1.5	
	10/06/17	1.7	1.7	1.6	1.4	



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