Beaver Dam Lake

Dodge County, Wisconsin

Management Plan Phase II

May 13, 2019

Prepared by: Beaver Dam Lake Improvement Association

University of Wisconsin

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Water Resource Management

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Funded by: Beaver Dam Lake Improvement Association

Wisconsin Department of Natural Resources

(LPL 161717)

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1.0 Introduction

Beaver Dam Lake (BDL), Dodge County, is a 6,840 Acre impoundment of the Beaver Dam River with a maximum depth of 9.0 ft. and a mean depth of 5.6 ft. BDL is listed on the EPA Clean Water Act 303 (d) impaired water listing due to total phosphorus and chlorophyll-*a* concentrations. Nutrients enter BDL through surface water run-off, from the common carp population and legacy sediment resuspension. The September 2015 Lake Management Plan (LPL 1555-14) provided initial base line data while identifying a number of Management Action initiatives. We will present here this phase II of the ongoing Plan presenting significant data from tributaries, in Lake, Community and the Fishery which will be core to habitat improvement, promote Healthy Land and Healthy Water practices.

The Beaver Dam Lake Improvement Association (BDLIA) was fortunate to have secured the interest of the Nelson Institute for Environmental Studies, University of Wisconsin Madison, Water Resource Management (UW WRM) Practicum for 2017. Through their efforts valuable technical research and analysis was performed at Beaver Creek and other tributaries which provide significant inflow into BDL. Beaver Creek represents 21 % of the watershed area and is on the EPA 303 (d) impaired water list due to total phosphorus and impaired habitat. The UW WRM Practicum collected upland soil data, sediment samples, in stream assessment, and engaged valuable Community outreach. A UW WRM sub-Group also performed in lake sampling which extended our ongoing water quality testing with two continuous years of significant sampling data. The combination of these efforts added fact based data and reduced modeling bias to these important segments of the Beaver Dam Watershed. The UW WRM Report (Enclosure 1) has been used as the core document for identification of objectives and further analysis.

The general summary for each of the attached Reports will identify the framework for the various segments of the watershed analysis and will defer to the individual Report for detailed data and analysis.

Beaver Dam Lake Basic Data

BDL Surface Area	(Acres)	6,840
Maximum Depth	(Ft)	9.0
Mean Depth	(Ft)	5.6
Watershed	(Acres)	98,186
Shoreline	(Mile)	50.6 miles
		43 % Natural

There are three HUC segments in the Beaver Dam Lake Sub watershed;

Beaver Creek, Rakes Bay, Beaver Dam Lake

(21,813 A) (9,280 A) (22,398 A)

Tropic State	Hypereutrophic
Residential Family Units on BDL	850

2.0 Objectives

The 2015 Lake Management Plan provided a baseline for future evaluation and management decisions for BDL. A majority of the Management Objectives identified within that plan have been completed with the balance of those actions requiring additional data collection followed by evaluation in order to provide a framework for implementation of the remaining Objectives. With the availability of 15 graduate students from the UW WRM Practicum for 2017 we were able to identify areas of concentrated evaluation to further expand data and locations for habitat recovery. As part of this study various sub watershed segments were reviewed for their impact on the habitat as well as water quality. The Beaver Creek segment of the sub-watershed was selected as the primary objective for the program due to its designation on the EPA 303 (d) Impaired Waterway Listing as impaired for total phosphorus and habitat.

Three of the UW WRM Teams were dedicated to the analysis of Beaver Creek with the scope of study for the sub watershed detailed to include; Community Outreach, Upland EVAAL modeling, In Creek water screening, sediment analysis and fishery data collection. Investigation of historic records found that Beaver Creek had not previously been a focus of a comprehensive study with only periodic sampling performed over the previous years. In an effort to offer a better understand of Beaver Creek, preliminary research identified the sampling protocols with WI wadable stream assessment methods utilized. Laboratory analysis protocol and quality was insured with water samples analyzed by the Wi State Hygiene Lab in Madison and sediment by the UW Soils and Forage Lab at Marshfield. This invaluable data and field surveys have provided a solid baseline for current recommendations, as well as, future watershed management decisions.

A fourth UW WRM Team focused on nutrient loading to BDL considering the effect of primary tributaries and evaluation of the most significant wind fetch wave action on shoreline erosion. The WRM report provided excellent base line data which would be utilized for implementation of objectives and water quality confirmation. Further detailed assessment was provided by Montgomery Assoc. in 2018 to complete the data collection initiated by the WRM. The combination of three years of robust data (2014, 2017, and 2018) presents a statistically meaningful picture for a better understanding for BDLs nutrient dynamic profile. This analysis has led to an internal and external mass loading as identified in (encl. 1) with nutrient loads quantified from external watershed land, internal rough fish and sediment resuspension. The external potential sources for the TP mass load was identified by means of the WRM EVAAL EVI ranking. This analysis method provides an excellent guideline for field observation confirmation, at a number of watershed sites, which present opportunities to reverse the impact from these negative environmental factors. Twenty eight areas with high EVI values were confirmed with LIDAR imagery from the Wisconsin View Data Portal to identify target sites which should be considered as near term objectives.

The wealth of meaningful data gathered over the past two years has identified areas of primary concern which have been utilized to prepare Implementation Objectives. We have incorporated the input of a very diverse group of Stakeholders to insure the broadest participation by the Community. Fish and Wildlife habitat restoration has been the primary focus of this work with the understanding that habitat and water quality are interrelated. Poor water quality causes impairment to the habitat, with a higher rate of eutrophication and undesirable algae growth. Actions identified in Section 8 of this report would have an immediate positive impact on habitat and water quality. This summary of the Plan-Phase II will present a high level review of the work performed and proposed implementation with the supporting data presented as Enclosures.

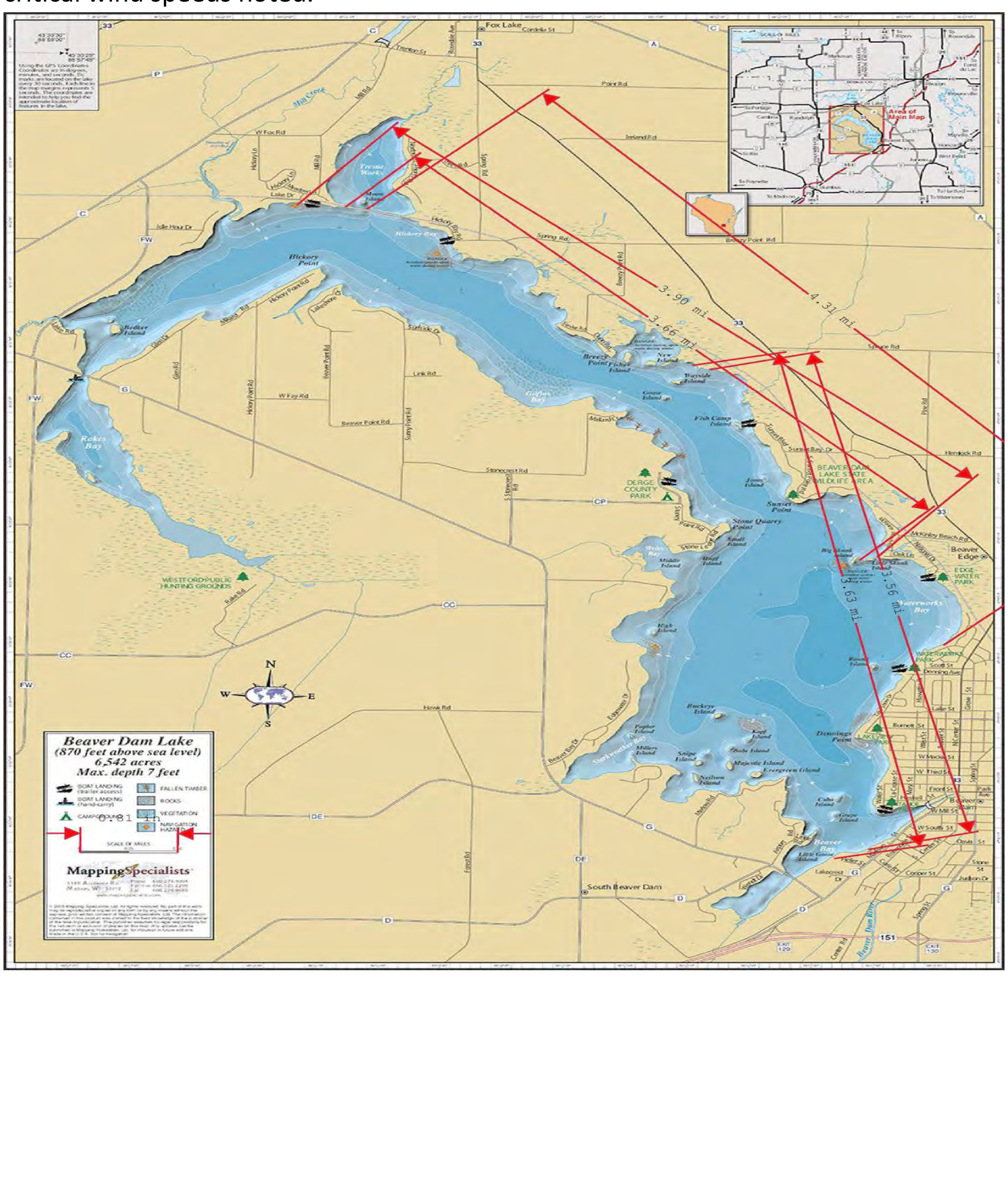
The UW WRM Practicum evaluated nutrient and sediment delivery which adversely impacts the length of the Beaver Creek Tributary from State Hwy 146 to BDL. Water quality sampling and Legacy sediment deposition sumps were inventoried with samples forwarded to the State of Wis. Hygiene Laboratory or UW Soils and Forage Laboratory for analysis. These findings combined with macro-invertebrate, creek bank assessment and fishery data will provide a multi-tier view for all aspects for this sub-watershed. (Encl. 1 Fig 12)

The UW WRM Teams worked closely with the WDNR along with the Dodge and Columbia County Conservation Departments for the collection of data which identified parameters for the analysis of land and creek conditions. The Upland Team collected soil nutrient data, LIDAR topography imagery and historic crop rotations which allowed the preparation of an EVAAL assessment which identified highly erodible areas. Those areas with high values were ranked through the Erosion Vulnerability Index (EVI) method in table 6 which was used as a guide for additional field investigation. Upland and In-Creek Teams worked together to identify and prioritize impact areas with the potential for habitat recovery and reduced sedimentation along with the corresponding excess nutrient gain. Follow up investigation found that there were a number of opportunities present for habitat improvement, land management, creek bank buffering and bank stabilization. The difficult task of implementing these targeted area will now begin with the support of Stakeholders and the deployment of Best Management Practices to improve watershed habitat and water quality.

Our project timing was fortuitous with the UW Civil Engineering Department offering CE 618, Lake & River Restoration, during the summer of the 2017 semester. A number of the UW WRM members participated in this class, presented by Dr. Chin Wu, with one of the study teams preparing the Fetch Analysis for BDL. Wind-wave fetch erosion is an important consideration for BDL with degraded wetlands negatively impacting the water and critical near shore habitat quality. Significant areas of shoreline erosion were noted during follow up investigation.

BD Lake has a total shoreline length of 50.6 miles with 43 % in a natural undeveloped condition. (LPL 1555-14, Map 4) It is understood that ninety percent of the watershed wildlife is dependent on this important transition band of land and if lost would severely impact spawning and nesting areas around BDL. Much of the 22 miles of natural shore abuts wetlands which provide critical habitat for fish and water fowl. A diverse biological environment is dependent on preserving this narrow band where the land meets the water.

The BDL fetch analysis was conducted with methodology published by the USGS and Professor Chin Wu's wind-wave resuspension model. The significant wave height and peak wave period were calculated utilizing the mean lake depth, maximum fetch length, critical wave period and wind speed. (Encl. 2 appendix C) Wind induced resuspension of sediment and nutrients were calculated with appendix A, graphically identifying segments with high fetch lengths. These levels of high energy erosion were found to occur on at least 43 days of the year at the critical wind speeds noted.



5.0 Nutrient Mass Analysis 2018 Montgomery Associates (MARS) Encl. 3

Upon completion of the UW WRM phase of work the program transitioned to Montgomery Assoc. who then was tasked to resolve watershed specific gaps with flow rate and water quality sampling. The MARS 2018 sampling captured spring and fall rain events which complemented the WRM report with additional essential peak data events that were not reflected during the 2017 season. With multiple significant rain events occurring in 2018, the ISCO field samplers provided collection of runoff effluent and volumes throughout this growing season. The timing was such that both spring and fall events occurred which depicted nutrient runoff loss comparisons for covered and bare field conditions.

Complementing this effort was water quality sampling within BDL by our BDL Citizen Sampler and discharge to the Beaver Dam River by the Beaver Dam Water Utility. The combination of this data allowed MARS to establish a nutrient profile and quantify a nutrient mass balance calculation for the watershed. During this phase of the program BDLIA and MARS utilized results presented in the UW WRM report to collect information for the development of site specific actionable elements. With the addition of these sub watershed physical parameters, MARS was able to prepare preliminary plans with engineered cost estimates which will allow planning for future project development. Detailed data outlines were prepared for presentation to Stakeholders with results oriented initiatives outlined to engage their support for implementation. These projects will address objectives previously recommended in comprehensive plans LMP 1555 and/or LPL 581. The subject work product from these efforts will be detailed in the Implementation Section 8 of this report.

6.0 Tributary Inventory Encl. 4

The nutrient mass analysis outlined within Encl. 1 identifies the impact of internal and external sources on the BDL watershed. Upon review of the watershed map it is readily found that the three primary tributaries, Beaver Creek, Mill Creek and Rakes Bay, define 73 % of the surface area with the associated sediment and nutrient loading from these segments. In order to better understand the remaining surface inputs and identify the remaining potential mass loads a compilation of culverts and unnamed streams was initiated with those sources inventoried. The larger unnamed creeks were identified with locally known descriptions (AKA) which will be used as an aid for future reference. It is difficult to quantify the input from the various nonpoint sources, therefore, this inventory will be used for ongoing work to better define sub segments of the watershed. This survey will be an active document with updates made as new information is collected with those segments referred to the appropriate Stakeholder for follow up action.

While performing this survey the unnamed creek which passes through Derge Park was identified as an outflow from the west shore of BDL. This outflow presents an opportunity to manage adjacent field runoff in order to reduce nutrient deposits and soil loss. Runoff from approximately 300 Acres flows through the storm water ditch way conveying sediment, phosphorus and nitrogen into BDL. Field investigation and topographic review of this flowage identified that a sediment basin could be an effective practice to slow the water velocity and allow nutrient settling prior to discharge.

As a separate parallel project the Dodge County Parks Dept. was contacted to determine the potential for implementation of BMPs at this site. We were pleased to find that the Parks Master Plan included drawing for the future addition of a sediment basin/lagoon. Preliminary meeting with the Dodge Co Parks Dept. identified that drawings were available, with recommended elevations for bank heights, which would allow for temporary detention and flow management during rain fall events. Estimates for excavation cost and construction drawings have been obtained which will permit a quick start to achieve this objective.

7.0 Community Outreach

Communications with the Community is essential to present educational material, as well as, provide a format to receive valuable feedback. Many of the Environmental practices and concepts are not well understood with alternative facts distorting the factual based conditions found in the watershed. In order to bridge this gap significant measures were taken to inform and educate the Community pertaining to water quality, shoreline impact and conservation practices. The participation of the Community is essential to provide planners with critical input regarding changing conditions while identifying the relative importance of local lake aspects to our Stakeholders.

The UW WRM Report (Encl. 1) identifies their outreach efforts with Town Hall meetings, group presentations and other initiatives to engage and inform the Community.

Shoreline Restoration and Native Planting Training

On May 22, 2017 BDLIA provided instruction with hands on training to a group 43 homeowners. Lisa Rees presented methods and practices for the implementation of Native Plantings, Rain Gardens and shoreline Rip-Rap which would reduce run off and nutrient loading. The afternoon session included hands on training for practices that would improve plant yield with follow up maintenance methods. BDLIA followed up this presentation with a BDL Guide to identify local shore line zoning, participating contractors with a practical do-it-yourself example. This information is available on the BDLIA web site. (bdliainc.org)

WBEV Community Comment Radio Broadcast

May 30, 2017, Members from each of the UW WRM Teams presented a summary of the field work which was underway and the background science that was employed. Basic limnology concepts were explained with an explanation of how field sampling is utilized to analyze the Lake and Watershed. The impact of the Community on our local environment and how they may be active stewards was emphasized. This form of media guaranteed maximum dissemination of information and presented an opportunity for feedback.

Public Meeting 2017 Joint presentation UW WRM & BDLIA

On August 26, 2017 for 69 people were in attendance to learn from the UW WRM Practicum the approach to Beaver Creek and BDL data collection and analysis. Environmental factors and the interrelation of habitat and water quality were presented with pertinent aspects unique to BDL. Through the dissemination of limnology basics the Community will be able to make informed decisions. Extensive Q & A time was provided with good Community input.

Town Hall Meeting conducted by UW WRM at Watermark

On September 12, 2017, 23 people were in attendance to learn of the program status and direction which was followed by break-out sessions for small group discussion. Six person break out groups were formed to discuss the areas of the study which were important to them and provided feedback for ongoing analysis.

Public Meeting 2018 Joint presentation MARS & BDLIA

On August 25, 2018 72 people were in attendance to learn of the progress of the ongoing data collections and results as of that date. This presentation utilized various hands on examples regarding how residents could improve nutrient management. Visual displays were presented for mass analysis, native plant root depths, runoff from different soil types and Wi State Soils Lab residential analysis of soils. Followed by Q & A which provided important Community feedback.

Individual Community Organization Presentations

Other community service organizations were presented fact based information to offer a better understanding of BDL and the BD Watershed; Lions Club, Dodge Co. Rotary, Kiwanis AM & PM This periodic review of the UW WRM Practicum allowed for Community to be education regarding the scientific practices which are being employed while soliciting valuable feedback. As leading Organizations in the Community their participation and support for environmental practices were highlighted as essential to future progress.

Producer Outreach & BDL Tour

On August 31, 2017 BDLIA, working with Dodge Co. Healthy Soil & Water Alliance, provided 108 Producers an on lake tour of BDL. This innovative approach brought diverse Stakeholders together to discuss the interaction of healthy land practices on surface and ground water quality. To demonstrate the watershed runoff cycle, pontoon rides, on the north end of BDL were offered to Producers. Located in this area of BDL are the inlets from Beaver Creek and Mill Creek tributaries to Beaver Dam Lake which have a significant impact from upland farming practices. The connection of Nonpoint sources conveyed through creek tributaries was well demonstrated with the presence of sediment banks and algae caused by nutrient loading. We were fortunate to have had a nesting pair of Eagles offer us fly overs for many of the tour participants to observe. These majestic birds rather effectively demonstrated the interconnection of Land and Water on our resulting Habitat.

Dodge County Farmers for Healthy Soil and Water & Dodge County Lakes Alliance

An exceptional parallel program which is underway in Dodge County has been the Healthy Soils – Healthy Water Program which joins Producers and the Lake Community with a common cause. Through these joint efforts the environmental reaction which our watershed has on soil health, surface and groundwater quality continue to be explained. The Producers whom attended the BDL lake tour experience in 2017 had an exceptional introduction to this lake and better understanding for habitat pollinators, fowl and game fish. Data and literature developed through this Phase II Plan has been presented to the Producers for their consideration. This initiative continues with ongoing dialogue in a rational but respectful manner with common goals and objectives. Mission statement;

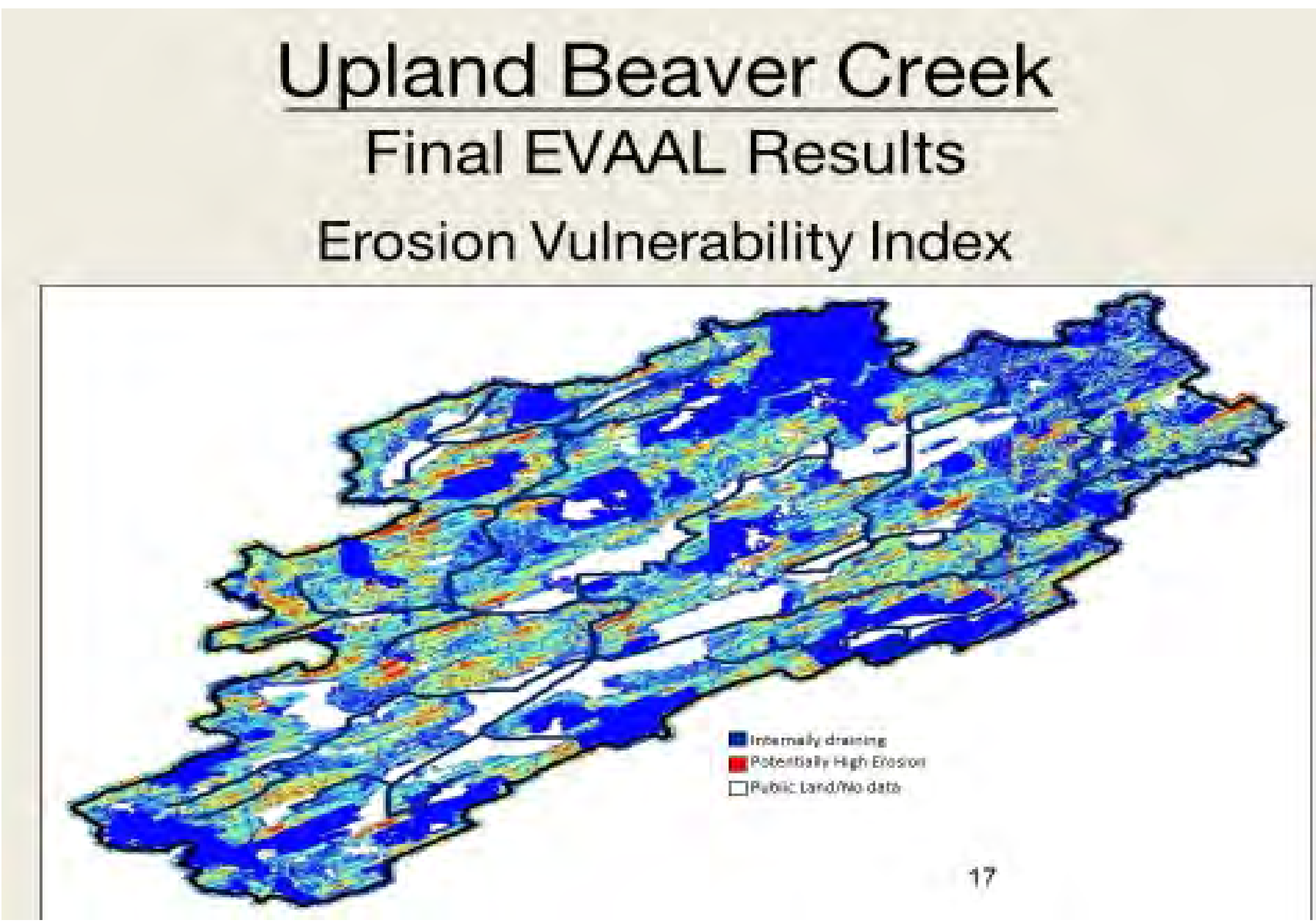
Producers: ‘Improving our Community’s Soil and Water through Conservation Practices & Education’

Lake Alliance: ‘To build a Community dedicated to Soil and Water Health’

8.0 Implementation Phase

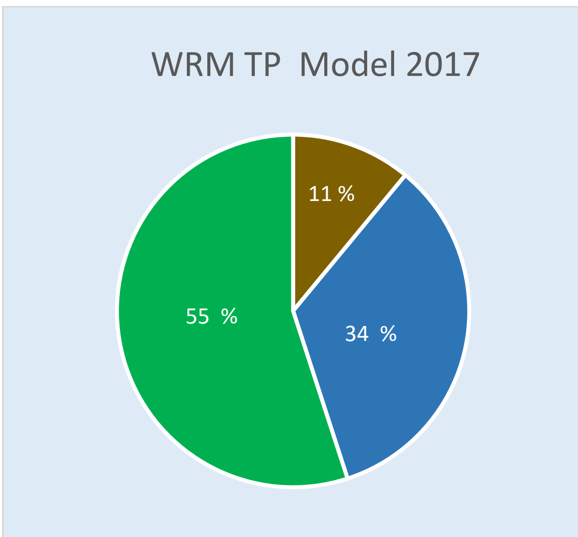
This WRM Program presented field data and modeling which then progressed to further on-site work to address the objectives detailed within our stated Deliverables. While collecting upland and water samples, a number of beneficial observations were identified which would complement our efforts to achieve our objectives. Examples of these synergies were the placement of CWH on natural shorelines and reconfirmation of endanger species; Forester Tern and Egret while this phase of the project continued to be developed. The UW WRM Practicum, MARS, BDLIA and other Community volunteers should all be rightfully proud of the quality and breadth of their work product.

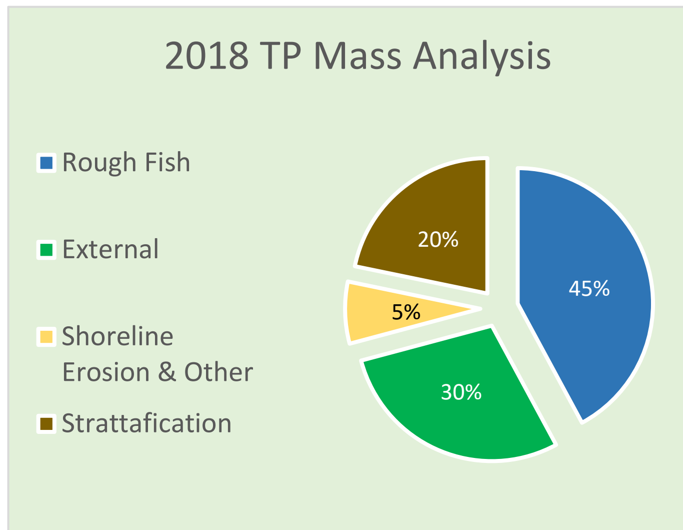
Our primary focus has been habitat assessment with upland inputs and water quality forming critical elements of this program. Following the progression of environmental factors from the creek, through the buffer area and into the upland these interactions were quantified with EVAAL Modeling targets. This analysis was only possible, at this time, due to a number of new tools which were not available to previous studies and researchers. The EVAAL and LIDAR tools, for example, permitted focused field work which ultimately resulted in the preparation of priority implementation areas for the application of Best Management Practices. This process has substantiated prior recommended management actions which were recommended for further investigation in previous management plans, such as those outlined in LPL 581.



Encl. 1 Fig. 47

It is well understood that improved habitat will result in better water quality with better water quality benefiting the habitat. This symbiotic relationship became very apparent as sample analysis and field surveys were blended to prepare a better understanding of watershed sub-segments. Key to this understanding and prioritization of future efforts is the identification of nutrient source concentrations. This was accomplished with the BDL watershed model being enhanced with field based data, as well as, a better understanding regarding the extent of the nutrient contribution from the primary and secondary tributaries. The source of nutrient inputs will fluctuate from year to year with a range of phosphorus loads dependent on human activity and the changing weather patterns. The UW WRM analysis for 2017 presented modeling with the advantage of further upland sampling to refine the nutrient loads and other physical parameters. This extensive work was followed up by enhanced sampling during the 2018 season which presented tributary results that further clarified the dynamic nutrient flow within the watershed. The WRM model and the refined Mass Analysis proportions are shown here:





Encl. (1) Fig 46

It is readily observed that legacy phosphorous will be an important consideration for the management of the watershed and future corrective action. The eutrophication of BDL is not the result of a significant event rather the impact of human activity over an extended period of time which has hampered the restorative process of the environment through natural absorption and infiltration. It is not suggested that we turn back the clock but as we enjoy this great asset our Stakeholders will use proven practices to reverse or restore segments of the watershed. Fully 80 % of the TP loading is within the management purview of Stakeholders with reductions in rough fish populations, the volume of runoff and stabilization of the shoreline all impacting the tipping point where by the TP inflow and outflow will be balanced or negative.

Over the course of the program it has been found that there is no silver bullet which will result in immediate change but rather the positive impact of incremental improvements. Our implementation objectives are presented with this mindset to maximize positive practices in order to allow the habitat to recover and secondarily promote healthy water quality.

8.0 Implementation Plan

a. Natural Shoreline Habitat Restoration Puckagee Springs Encl. 5

The BDL Management Plan map 4 identifies that there is 50.6 miles of shoreline with 43% in a natural condition. This near shore transition area is essential to the water quality and the strength of the habitat for the watershed. Ducks, geese, shorebirds, turtles and frogs are born in these wetlands but without this habitat they will not survive. Our objective is to restore this critical area where 90% of the animal life resides along with filtering of rainwater run off with flow velocity management within this near shore area.

While assessing the shore line it was observed that Puckagee Springs/Creek was a critical habitat for BDL containing important spawning and nesting features essential to maintaining a strong fishery and waterfowl reproduction. This approximately 1080 acres segment of the watershed flows from north to south through agricultural and rural residential properties. Prior to entering BDL the storm water run-off experiences rough sediment filtering from upland fields and natural near shore wetland.

Further investigation found that the near shore habitat has experienced severe shoreline erosion exposing the wetland to wind wave fetch energy. Shore line breaching was noted at a number of locations with a 175 LFT of barrier washed away at the outflow of Puckagee Creek. Creek bed sampling in this area further confirmed a relatively high wet extractible phosphorus content of 28 ppm in that sediment. The resulting damage from this ongoing erosion will be demonstrated with lost wetland and habitat while impacting water quality through the transfer of phosphorus rich nutrients to BDL.

Upon review of Dodge County GIS aerial views for 2017 and 2012 it was confirmed that this severe damage has occurred over this six year period. Some erosion was noted from the 2006 ortho view but not to the same extent and progression as the most recent 2017 aerial view. Realizing the importance of this segment of the watershed to the overall health of BDL, additional more detailed surveys were performed to assess the lake bed and shoreline condition. With this data Montgomery Eng. Prepared a scope of work and engineering drawing for restorative work.

b. Shoreline Coarse Woody Habitat

While performing the shoreline evaluation three segments were identified that would benefit from the placement of Coarse Woody Habitat (CWH). Littoral zone tree drops have been shown to provide fish with refuge and spawning habitat, bird nesting and turtle cover while reducing shoreline erosion. These specific near-shore areas were selected due to their natural condition and the potential to complement existing woody clusters. The placements of ‘fish sticks’ filled in exposed shore segments that would now present a continuous habitat layer while forming a barrier to low energy wind wave action. The WDNR Fisheries CWH Guide was used as the source for technical information to plan and implementation of these tree clusters.

BDLIA prepared an Implementation plan and secured matching funds through a Dodge Co. County Conservation Aid Grant for the management of these natural shorelines. BDLIA took advantage of favorable ice conditions which allowed for this project to be completed in parallel with this Planning Project during the winter of 2017 as permit GP-SC-2017-14-00311. Additional CWH sites will be evaluated for future placement as funding, Stakeholder participation and manpower becomes available.

c. Beaver Creek Habitat Columbia County Encl. 1

The data gathered by the UW WRM Upland Team formed the basis for interpretation of the topography, soils and crops to prepare an EVAAL model for Beaver Creek (BC). This analysis was strengthened by the In-Stream Team with TP and TSS results plotted to identify the relative load at various segment of BC over the 2017 season. The WRM Teams then utilized the EVI ranking to perform field surveys and soil sampling to identify sites which should be considered for the implementation of Best Management Practices (BMP). Subsequent analysis using Columbia Co. GIS records and field photography has further focused on priority EVI sites which would have the most immediate impact on BC and BDL. Each of the sites identified within the EVAAL analysis deserve further investigation with the sites identified in this summary considered high value opportunities.

The body of information gathered for BC presents a compelling case for the need to initiate habitat and watershed improvement. With this objective as a goal the priority sites with the most immediate potential have been reviewed with the Columbia County Conservation Dept. and preliminary field assessments have been performed. The initial series of sites were selected from the EVAAL VRI ranking to assess how BMP s could best be implemented.

Site 7-8, Fields 3 & 4:

Currently in production for row crops with a corn soybean rotation. The topography for this site has elevation change of 50 ft. with a slope from north to south 8 - 12 %. The upland section presents evidence of sheet erosion along with multiple areas of severe rill erosion adjacent at BC. (Field check spring 2019 has identified the rill erosion segments have worsened to gulley erosion) Visual inspection of the soil indicates a high concentration of Clay resulting in significant run off during rain events (field 5). BMPs would be selected to promote greater infiltration and reduce runoff while improving soil retention. Potential practices should be selected which will benefit the Producer while having a positive impact on the watershed, such as;

- Contour plowing upper land area
- Water flow management to reduce velocity, grass waterways, etc.
- Stone splash area at invert of culverts
- Convert low yield acreage to potential CRP program for wetland recovery and pollinator habitat

Site 24:

For this length of BC the topographic map identifies a high slope gradient which would promote soil loss along with the included contribution to the nutrient load. The land tangent to BC has an elevation change of 40 ft. in a segment which has minimal creek bank protection. Upland practices will strongly influence the rate of soil loss and immobilize sediment which will ultimately reduce the mass load to BC. Measures identified for site 7-8 above should be considered along with stream bank stabilization.

Site 23:

The Lidar aerial photographs for this site indicates stream bank erosion extending 100 ft. downstream of the culvert under County Rd. DG. The UW WRM field survey confirmed extensive creek bed legacy sediment build up at this site with a lateral recession rate in the very severe category. This condition must be assessed with consideration of the upstream marsh conditions which impact this area of BC.

Approximately 900 ft. downstream of County Rd. DG the near stream bank transition area on the south bank has a 52 ft. drop to BC with a slope of 11%. This area would benefit from habitat improvement through stream bank protection with rip-rap, deflectors and vegetative buffers. These measures should be engineered to provide cover for waterfowl which will present contiguous habitat to promote brood rearing.

Site 13 – 14 - 15:

These sites are adjacent to 146 and BC with the EVAAL EVI ranking indicating a high potential for erosion. The EVAAL EVI ranking identifies these sites as priority 12 (83A.) and 6 (59A. w/ 5 % slope) respectively prior to considering the potential farmstead nutrient rich runoff. Upon Lidar examination and further field evaluation, the potential for manure runoff was present with paddock areas adjacent to an open ditch-way with direct discharge into BC. The ditches run parallel and bisect BC with direct in line high ground velocity flow. The barnyard and feed lots have the potential for direct transfer of high levels of manure into BC. Working with the Producer, improved barnyard and pasture practices should be investigated and implemented to improve runoff management and permit solids removal.

Upland flow diversion would initially reduce runoff velocity with contour farming and the addition of filter strips. Multiple BMPs would then improve the nutrient runoff potential with runoff management diverting solids to a solid separation basin. Finally, the existing stream bank filter strips would be enhanced to allow for P uptake. A phosphorus target of .075 mg/L should be established at the WI Hwy 146 bridge underpass outflow to Beaver Creek.

Site 2: Paradise Marsh

Paradise marsh is an exceptional asset for the watershed with 1588 acres under management by the WDNR. The current Marsh management plan expands the usage and habitat acres with the potential to improve down-stream water quality. Current runoff flow conditions are unrestricted through the marsh with upland runoff transiting directly to Beaver Creek. Stakeholder coordination in cooperation with the property manager and the Columbia County Conservation Dept. should be initiated to identify practices that would beneficially impact the BC sub watershed and BDL habitat. The objective would be to reduce the runoff rate which will promote infiltration, provide water storage thereby downstream season flooding. E.g.:

- Storm water retention to mitigate storm flows, one acre of wetland with a depth if one ft. will hold 330,000 gal. recharging the groundwater.
- Potential for ditch plugs and low head dikes
- Seasonal water management for vegetative growth
- One 30 Acre impoundment is present, are there other locations where the topography will permit impoundment or ox bow features
- Spawning pools
- Educational potential

d. Rakes Bay Habitat Encl. 6

Rakes Bay (RB) represents 9280 acres or 9 % of the BD watershed with the land usage is a mixture of row crops, dairy and wetlands. During storm events observed in 2018 the pulse flow resulted in an inflow of 2 ft. /sec with an outflow of 6 ft. /sec. The pulse rate frequency is irregular with frequent reversals occurring within a 24 hour period. The suction motion creates by these pulses draw a high TP nutrient concentration into BDL in both dry and high precipitation conditions.

It would be desirable to reduce the run off flow velocity through upland management thereby retaining nutrients in upland areas. These efforts would target improved retention to permit infiltration. With the reduced flow rate a corresponding reduction of sediment transfer of resuspension would occur to help stabilize the vegetation at the waters' edge. With improved establishment of native grass the habitat will present expanded waterfowl nesting potential.

The headwaters of RB originates at a Glacial Recovery Area with an extensive array of legacy open ditch way feeder culverts. Over the years the hydrology of the marsh area has been altered limiting the more gradual sheet flow. This altered run off the watershed has contributed to high levels of sediment and nutrient loading. It is suggested that this area would receive a field assessment for potential restoration, to a more natural condition, that would permit infiltration during storm water events and reduce of discharge velocity. Potential practices;

- Storm water detention ponds
- Use of flow control structures
- Alter ditch ways to reflect more natural flow characteristics
- Waters' edge vegetative improvements
- Rough fish management Carp Barrier
- In bay flow velocity restriction should be investigated,

e. In-Lake Habitat Fishery

BDL continues to be a good warm water fishery with walleye and perch commonly caught. This resource is in a delicate balance with strong competition from rough fish. Stocking efforts by WDNR and BDLIA have maintained a healthy population, however, strong natural reproduction is essential.

Over population/concentrations of rough fish put stress on the fishery resulting in game fish loss and lake bed destruction. (Lathrop 2003, US Fish & Wildlife 2010) The large population of rough fish stirs up the bottom sediment with an increase of nutrient resuspension and water turbidity. Management of the carp and buffalo population is essential for shallow water lakes. (Cunningham, 2017) A combination of practices are required to control the rough fish population throughout their life cycle. BDLIA continues to stock predator fish (walleye, blue gill, and perch) to consume carp spawn in order to increase early life cycle mortality. Commercial fishing then harvests carp and buffalo to reduce the mature population with recent history resulting in large catches on BDL with an average volume of 750,000 lbs./yr.

Stone Reef Maintenance

Natural reproduction of game fish is essential in order to maintain a good balance of game fish species and year populations. To further this goal in 2001 the WDNR placed stone reefs at various location of the lake to provide rocky habitat necessary to protect and incubate walleye eggs. We propose to inspect these reefs for condition and sediment build up which would be followed up by dressing with additional stone.

As part of the assessment at Puckagee Spring the adjacent bay was identified as a potential protected fishery habitat. In an effort to verify the characteristics of this bay the bottom depth contour was verified and sediment samples analyzed. The conditions found will meet basic requirements for the addition of fish reefs and promote spawning for walleye and perch species. (WDNR Habitat Structure, Fish Management

Handbook) It is proposed that six additional 20 ft. x 50 ft. beds be placed parallel to the north shoreline approximately 100 Lft. from the stone barrier.

Carp Management

US Fish & Wildlife has identified that carp concentrations in excess of 268 lbs. /acre will cause excessive vegetative and lake bed damage. (US FG 2010) Rough fish cause this damage through their foraging methods which remove beneficial plant and root up the lake bed. The carp then process food matter with high phosphorus nutrient discharged into the lake. Carp management studies (LaMarra 1975) have confirmed that their excretion will discharge phosphorus at a rate of .011 lbs. for each pound of rough fish biomass over a typical lake growing season. In 2014 BDL biomass study confirmed that 330 lbs./acre or carp and buffalo fish are resident in the lake. With this known large concentration of rough fish and the 6480 acre lake footprint this internal load is a significant portion of the BDL phosphorus mass loading.

Multiple management practices must be pursued to reduce the mature fish through commercial capture essential to check additional population growth while pursuing practices that will reduce the habitat quality for rough fish. There are three large shallow bays on BDL which provide high quality breading areas for rough fish. Degrading of those areas or restricting access would have a beneficial effect with the goal to restrict spawning area which would reduce reproduction. The addition of a barrier at Rakes Bay would restrict a 450 A. preferred spawning ground and push rough fish into more exposed areas of BDL. MARS has measured seasonal water flow velocities and prepared preliminary drawings and cost estimates for further project development. These parameters have been shared with local contractors which will allow development of barrier design options and budget estimate.

One of the past management efforts was initiated by BDLIA in 2017 with the repair of the carp barrier at Trestle Bay which encompass 250 acre at a shallow depth of 3 ft.. Repairs were effected to the existing bar grate barrier to restrict rough fish access to a high quality spawning area. Follow up commercial fishing was conducted during the 2017 season which resulted in the capture 40,000 lbs. of rough fish. Further analysis by the WDNR Fishery Biologist will identify what near term BMP s would be advisable to efficiently manage this segment of the watershed.

Multiple studies have confirmed that rough fish are drawn to shallow soft bottom bays along the natural and developed shores of BDL. Two such backwater wetland area were found adjacent to McKinley Beach Blvd with the local Community reporting that high levels of spawning activity occur on a frequent basis. There are two access point for this undesirable activity with access through the 6 ft. culvert at S. McKinley Beach Blvd and 5 ft. culvert under the Wisconsin Southern RR tracks west of the Beaver Dam CC. Both wetland segments have shallow-much bottoms which provide a preferred spawning habitat for carp and buffalo fish. BDLIA will gather additional site specific information, while working with the local Stakeholders, to determine the potential and effectiveness of fixed barriers at both culverts. Preliminary estimates indicate that cost effective barriers could be installed which would restrict seasonal access and force spawning into less protected open water.

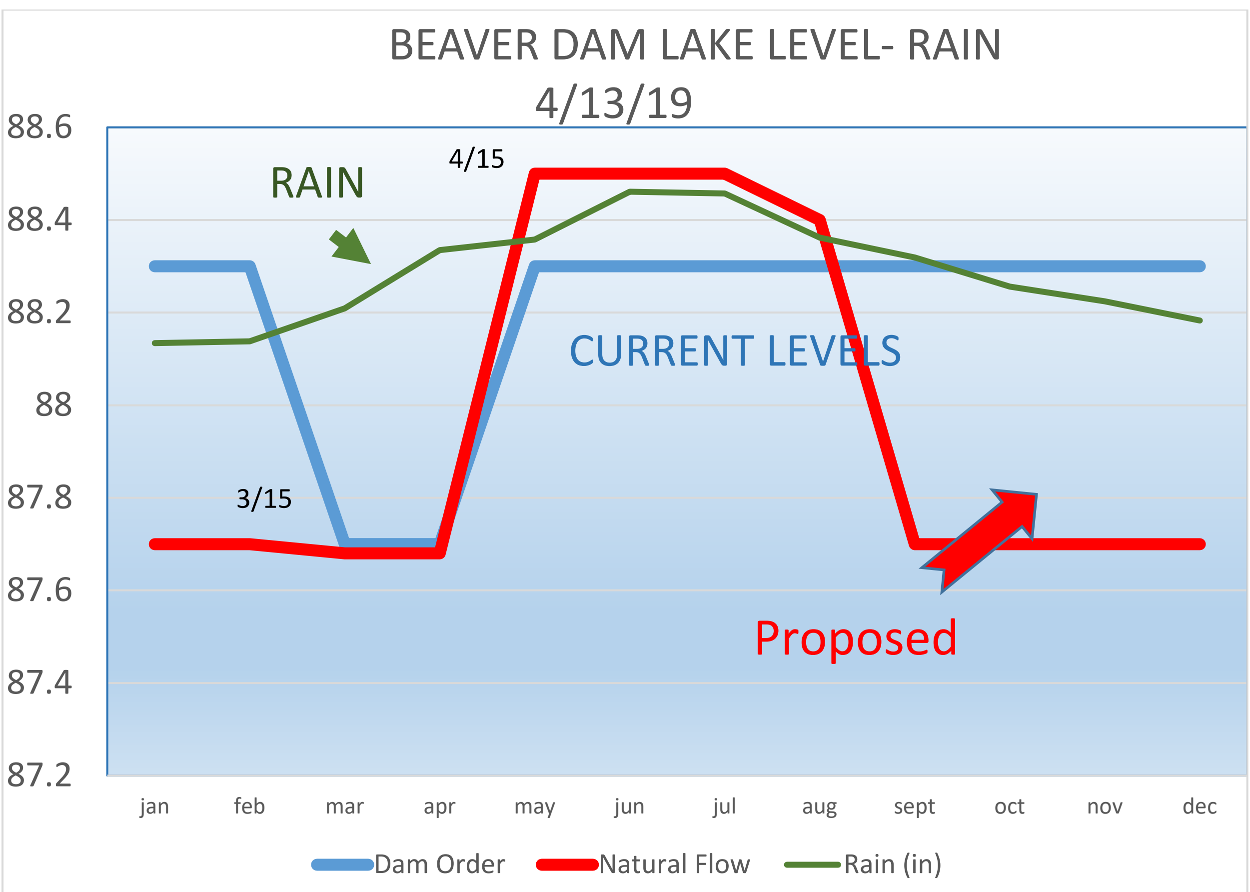
The biomass study performed in 2014 will be used as our reference value for the rough fish population baseline. This measure will be compared against the US Fish and Wildlife assessment for fish per acre which determine potential damage caused by foraging rough fish. We will assess progress through the performance of a follow up biomass study in 2022.

f. Water Level Management Encl. 7

LMP 155-14 recommended an Action Objective to review the Lake Order which is currently in place. While conducting data collection for this analysis and receiving feedback from the Community the existing Lake Order was identified as a potential contributor to shoreline erosion and negatively impacted habitat.

1. Extreme environmental forces which occur in the late fall present conditions which would cause high energy wind fetch. Exposed natural shorelines, with reduced vegetative cover, will experience wave action resulting in erosion.
2. Winter freeze presents ice heave conditions with high water levels which in the early spring could result in shoreline pull back as the ice shelf dissipates.
3. The current Dam Order maintains the lake levels at the normal height of 88.3 ft. which is then reduced to 87.7 ft. in March for a duration of four weeks, followed by spring run-off back to 88.3 ft.. This limited seasonal reduction has the potential of exposing hibernating reptile population to freezing conditions with ensuing mortality. The proposed change would 'lower the water level to 87.7 ft., October 9th to be completed October 15th of each year'.

The proposed modification to the Dam Order would use natural rainfall averages (inch per month) as a guide for lake level targets for the proposed lake elevation targets (feet at dam).



g. Sediment Trap

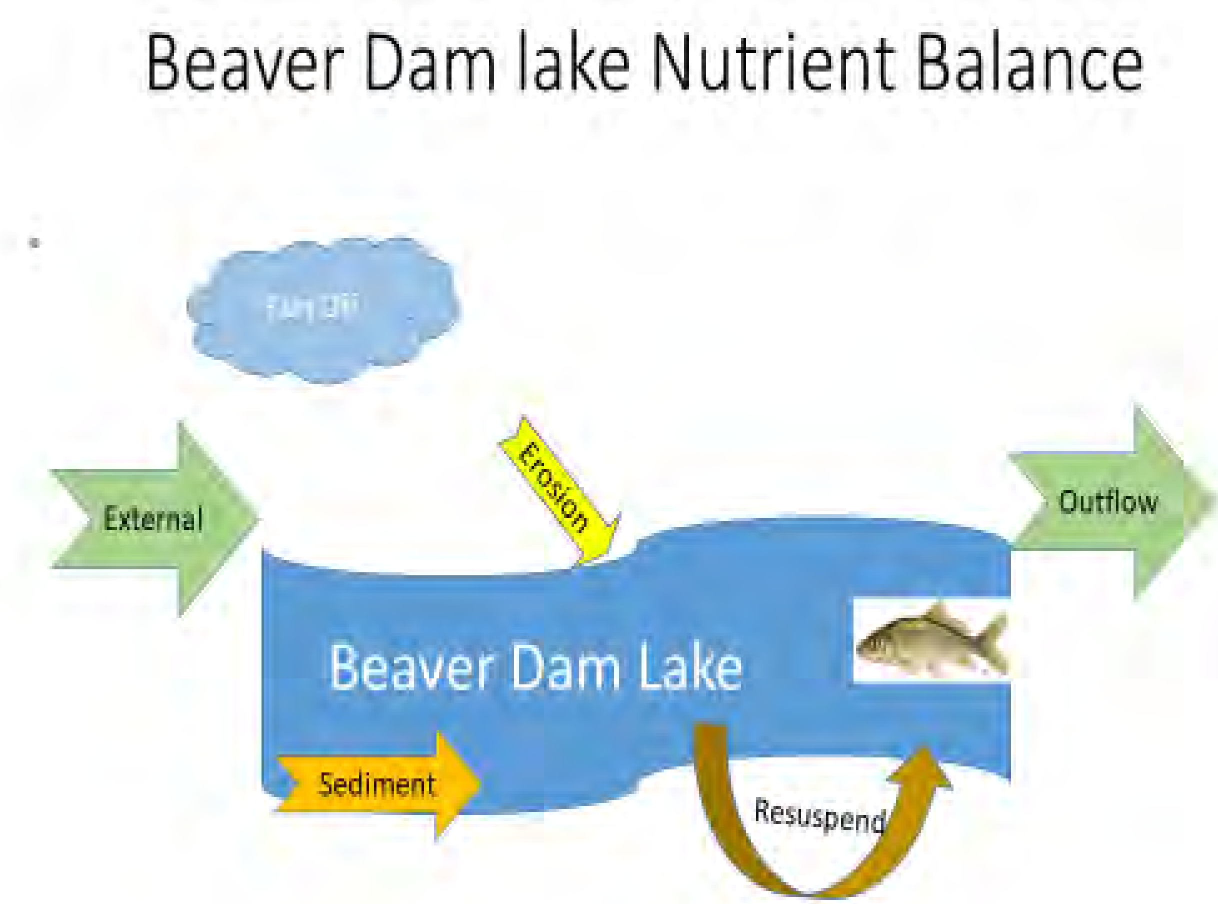
While performing the shoreline evaluation an inventory of inlets to BDL was compiled which identified the numerous unnamed creeks and culverts that would have the potential to transport non-point runoff to BDL. During this survey the small creek at Derge Park, on the west shore of BDL, was identified as a potential location for a sediment basin which would present an opportunity for reduced nutrient loading to BDL. The topography of this section of the watershed indicates that this basin could be installed rather easily and not disturb the overall function of this Park. A preliminary meeting with the Dodge County Parks identified that the master plan for this site outlined the future placement of a lagoon at outflow of this creek. Utilizing the drawing from the County Master Plan a preliminary scope of work was prepared and installation estimates determined.

Implementation of the Derge Park lagoon/sediment trap would provide immediate nutrient capture benefits while serving as a demonstration structure for other locations on BDL. Development of this project will continue with the Dodge County Parks Dept.

9.0 Next Phase for Watershed Implementation, Study & Monitoring

a. Nutrient Mass Balance

The nutrient mass balance for BDL is in flux with weather conditions, land practices and rough fish management. This is not an unusual scenario for a shallow lakes with 43% natural shoreline, high agricultural production and a large number of residential properties. The data has confirmed that the contributed external phosphorus (TP) load very nearly matches the outflow through the Beaver Dam River with the addition of 12 tons of phosphorus per year to BDL. We can infer from this mass balance equation that the remaining TP in solution of BDL has been provided by internal sources. This also implies that any reduction of external load, through Best Management Practices, will allow the watershed to shed remaining TP downstream. With this progression, over a number of years, the TP mean load will reduce with the resulting improvement to water quality. Lowered TP will proportionally reduce algae growth (green & blue-green), increase recreational days, improve natural spawning of game fish and advance near shoreline habitat. The total Eco-System has been considered in this study and proposed implementation.



b. Communications with our Community

It goes without saying that our Stakeholders must be involved in the future maintenance of the health and stewardship of BDL. The key to these and future communications will be a series of diverse initiatives which inform and engage the Community. The current BDLIA newsletter, seminars and annual meeting will be augmented with additional methods for public media outreach. Two recently initiated outreach approaches will offer enhanced messaging with the second offering environmental education. In an effort to improve our electronic media presentation professional on line support has been engaged and the use of a standard descriptive message format will be utilized. Educational programs are essential to provide clear messaging regarding the impact to our watershed and local environment. In an effort to continue the understanding offered by this study we have initiated the joint development of an Advanced Placement Program with the Beaver Dam Unified School District. These initiatives will be supported by a core Communications Team which will offer essential information to the Community regarding our environment and the human contribution to Beaver Dam Lake and Watershed.

So what did we learn? Diversity is key to a robust program with outreach to as many segments of the Community as possible. Many Stakeholders whom initially did not consider that their efforts impacted their neighbors, as a whole, acknowledged we have common challenges with joint objective. Be it the Dodge Co. Producer Healthy Soils & Water Program, Dodge Co. Lakes Alliance, Community service groups, Municipal government, County government and of course individual participation once we had an opportunity to communicate the conservation message, and interact with Q & A, the previously relied upon alternative facts could be debunked. An accurate baseline of information is essential for a common understanding in order to achieve progress for our Watershed and Community. This has been achieved.

c. Stakeholders

A strong list of objectives has been delineated with preliminary parameter identified which will now require preparation of additional engineered details and scope of work to permit implementation. It will be essential to engage Stakeholders for meaningful change whom will provide a positive impact to the BDL watershed habitat. The objectives identified within the Plan are achievable and will provide significant benefits for the Community and wildlife. The participation of multiple Stakeholders is critical to foster positive change in order to improve the watershed habitat, recreational use and enhance our quality of life.

Support from Stakeholder has been well documented through the Community Outreach performed during this Program. The diverse group of participants which took part in this analysis touch on all functional organizations, recreational users and littoral land neighbors. Their feedback provided essential information regarding the perception of the watershed and the expectations of the Community.

The work performed over the past two years has confirmed that the Community Stewardship practices identified will have a positive impact on our Watershed and Beaver Dam Lake with the resulting improvement to the habitat and Community enjoyment.

Enclosures:

1 Nelson Institute for Environmental Studies

Water Resource Management 2017 Practicum Report

2 UW Civil Engineering course 618 Fetch Analysis BDL May 2017

3 Mass Analysis 2018 Montgomery Engineering, December 2018

3.1 BDL Watershed Map

3.2 BDL Sub-watershed Map

4 Tributary Inventory Beaver Dam watershed December 2018

5 Puckagee Spring Shoreline Restoration

5.1 Puckagee Springs Site Location

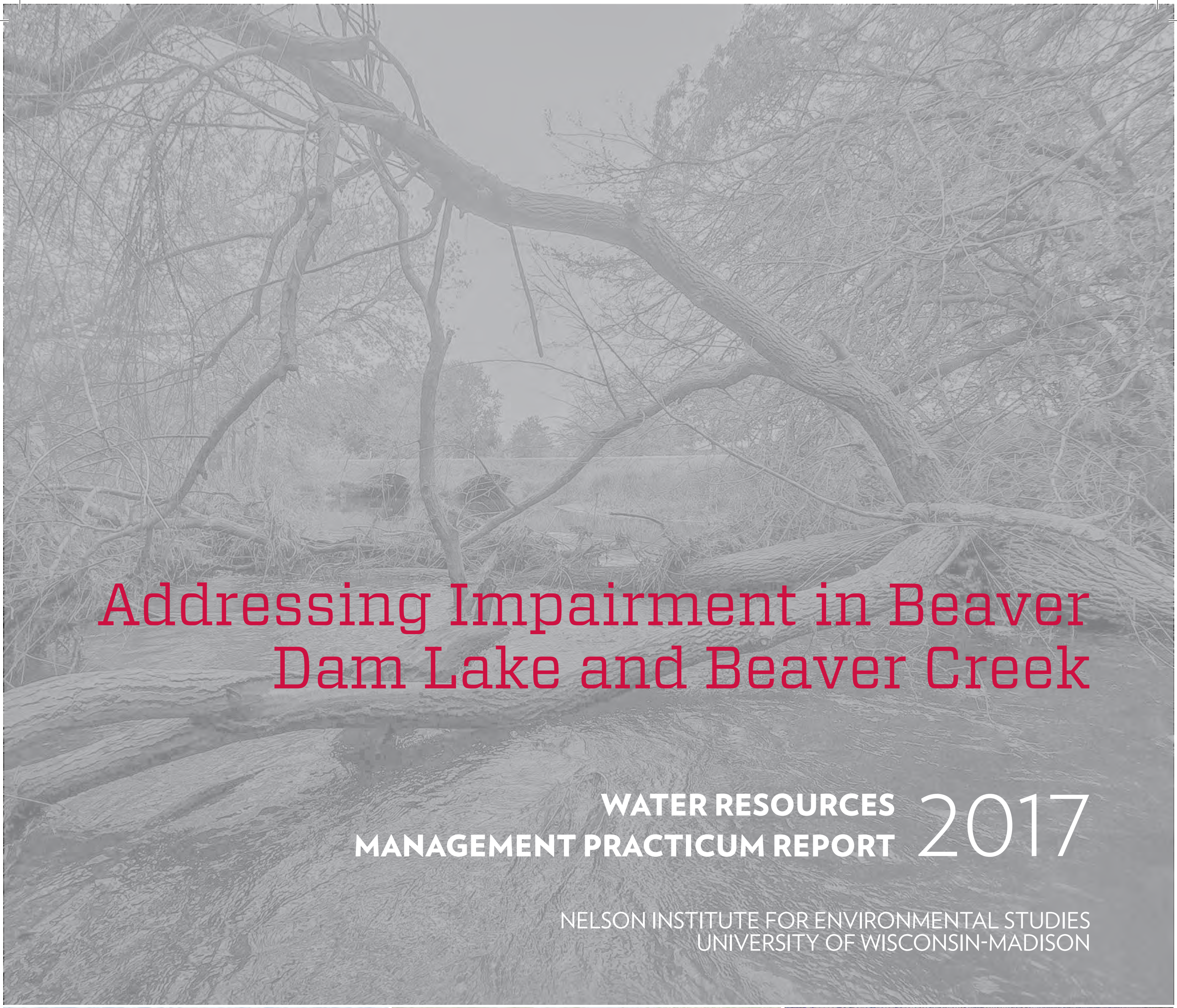
5.2 Puckagee Springs Project Estimate

6 Rakes Bay Analysis

6.1 Rakes Bay Site Location

6.2 Rakes Bay Details

7 Dam Order Review Natural flow July 2018



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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ACKNOWLEDGMENTS

We would like to extend our sincere thanks to the individuals who helped make our work possible. We would like to thank our sponsor, the Beaver Dam Lake Improvement Association. Additionally, we would like to thank the Wisconsin Department of Natural Resources and the agricultural producers and landowners of the area. Finally, we would like to thank our advisor, Dr. Anita Thompson, professor of biological systems engineering at the University of Wisconsin-Madison, for her guidance on this project. We appreciate their generous donations of time and resources.

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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.

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).

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.

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).

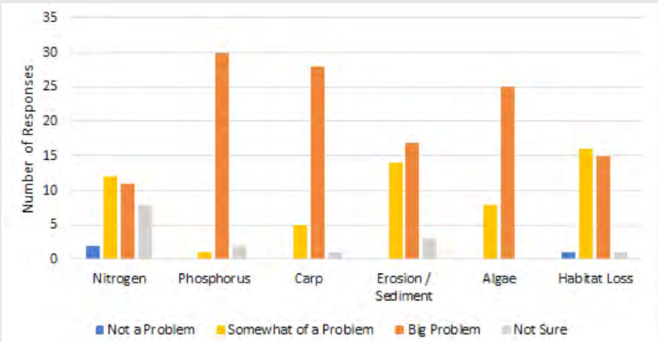


Figure 2: Community survey ratings of various lake water quality issues.

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).

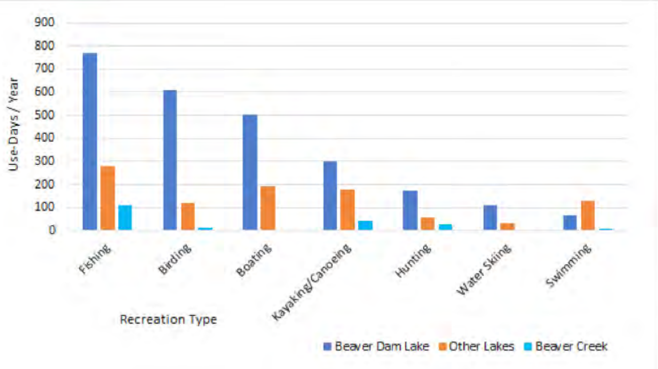


Figure 3: Community survey results for frequency of various forms of recreation in use-days/year.

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).

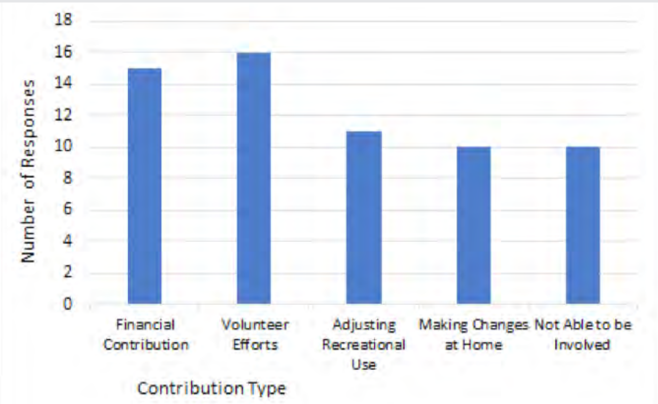


Figure 4: Number of survey respondents (out of 37 total) willing to contribute to various water quality improvement efforts in the watershed.

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).

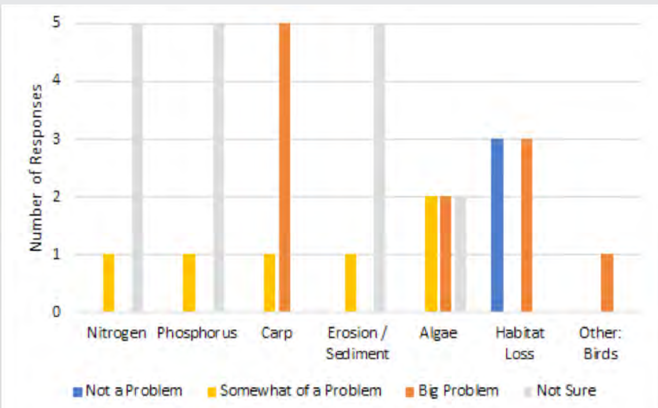


Figure 5: Lake water quality issues rated in producer interviews.

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).

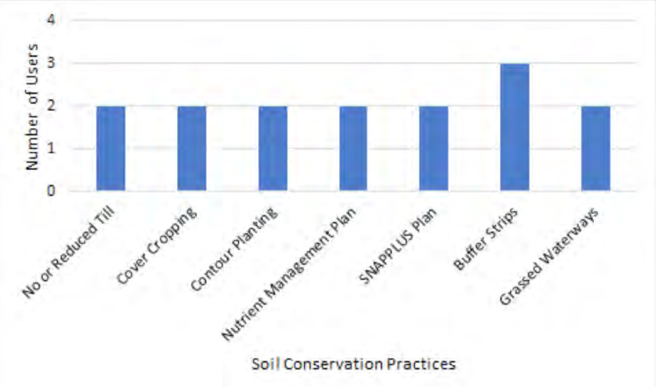


Figure 6: Number of interviewed producers (out of six total) in the Beaver Creek subwatershed using various soil conservation practices.

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.

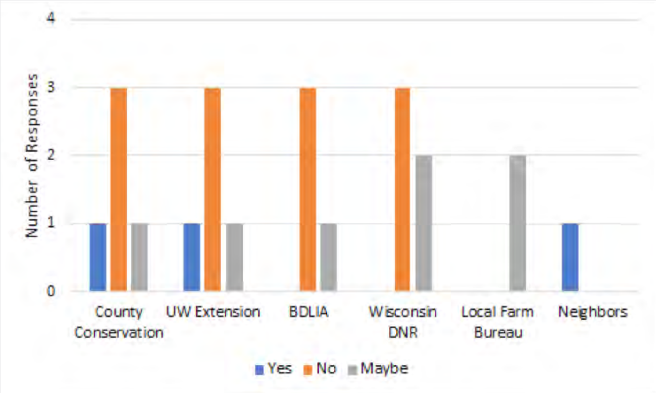


Figure 7: Producer trust in organizations providing land management information.

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.

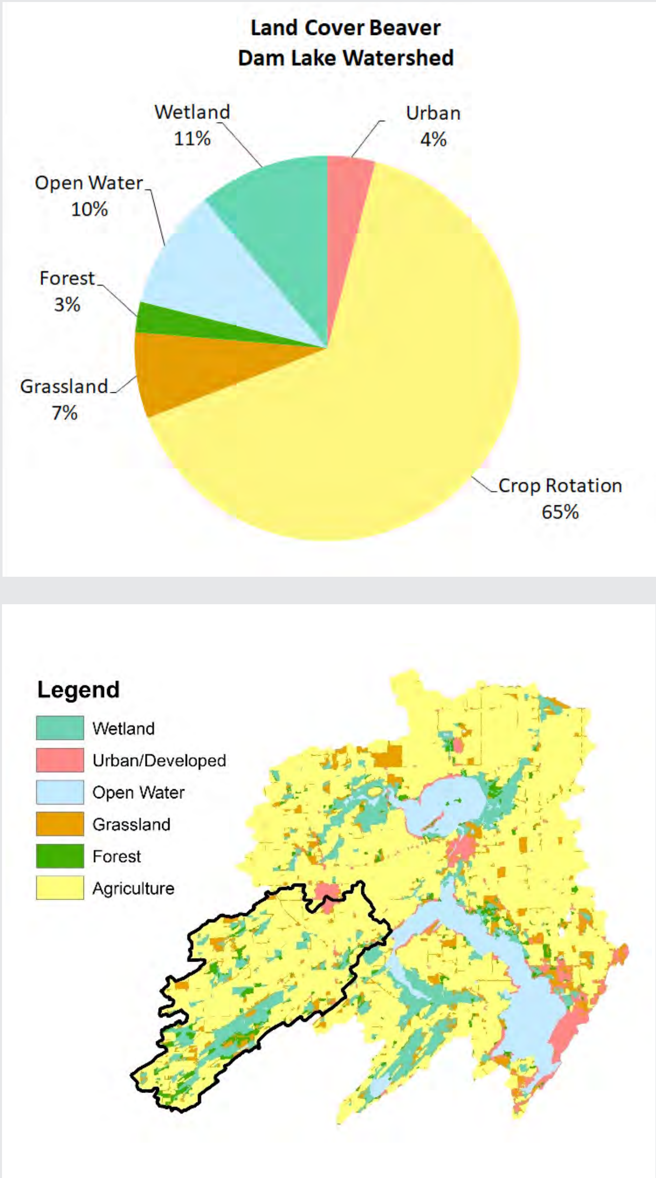


Figure 8: Land cover throughout the Beaver Dam Lake watershed. The Beaver Creek subwatershed is outlined in black.

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.

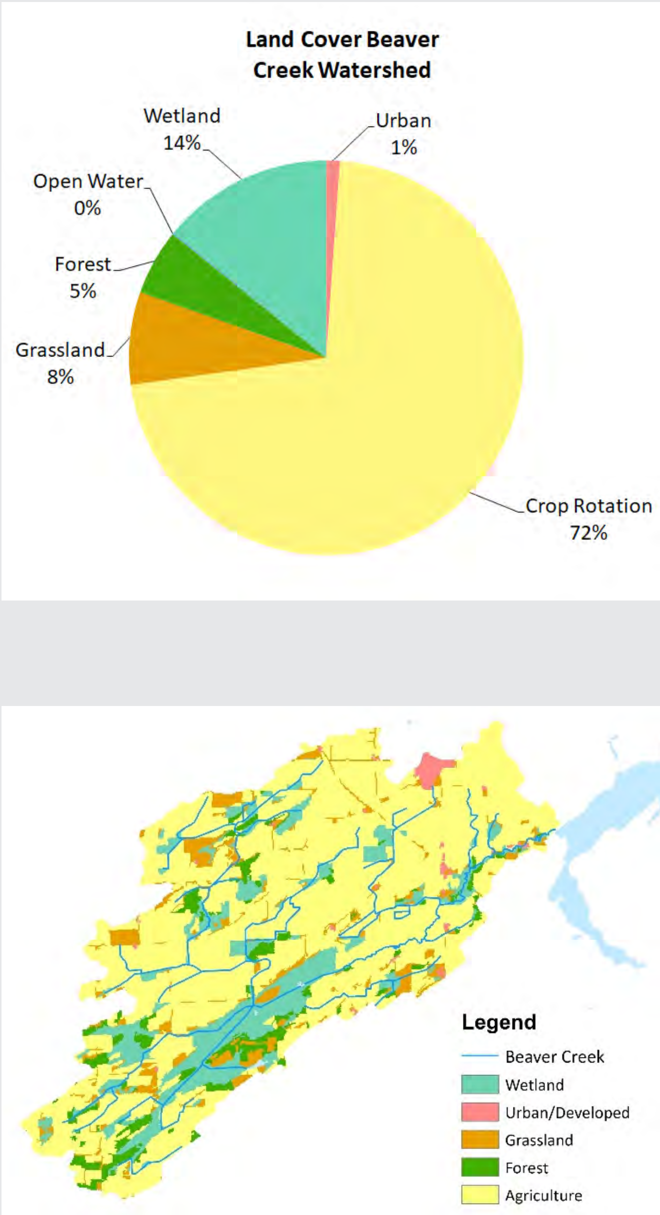


Figure 9: Land cover within the Beaver Creek subwatershed.

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.

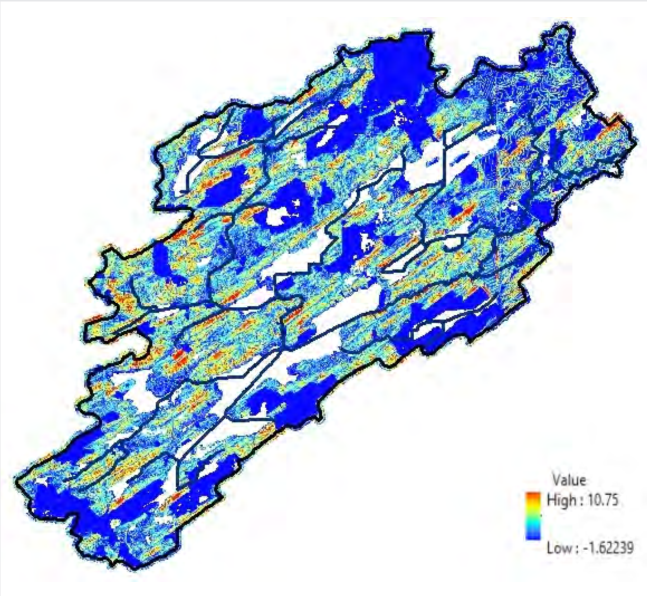


Figure 10: Final EVAAL results: erosion vulnerability index (EVI) throughout the Beaver Creek subwatershed.

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.

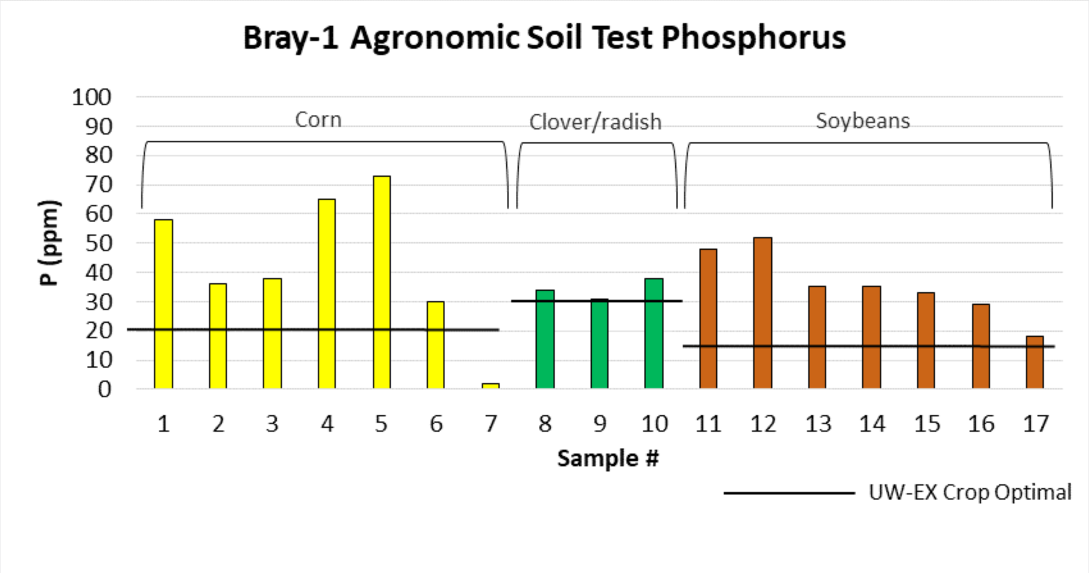


Figure 11: Bray-1 P in soil samples.

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.

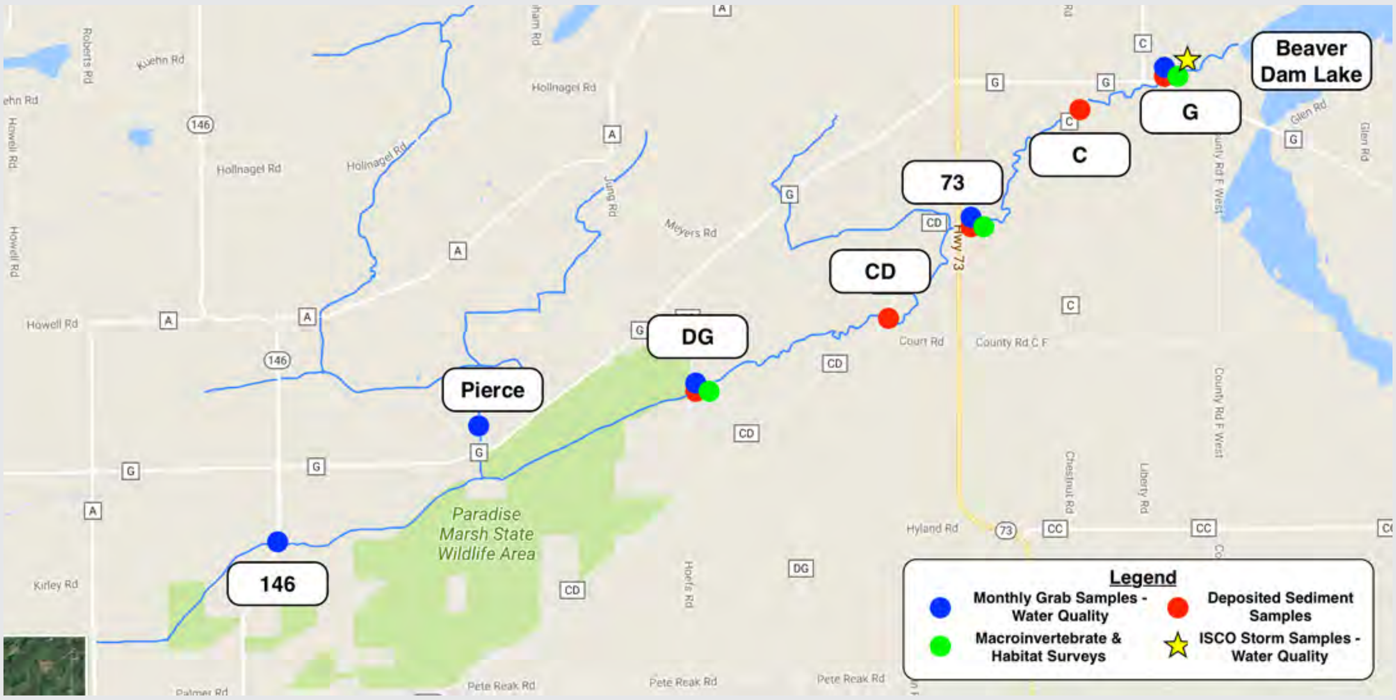


Figure 12: Sample locations along Beaver Creek.

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.

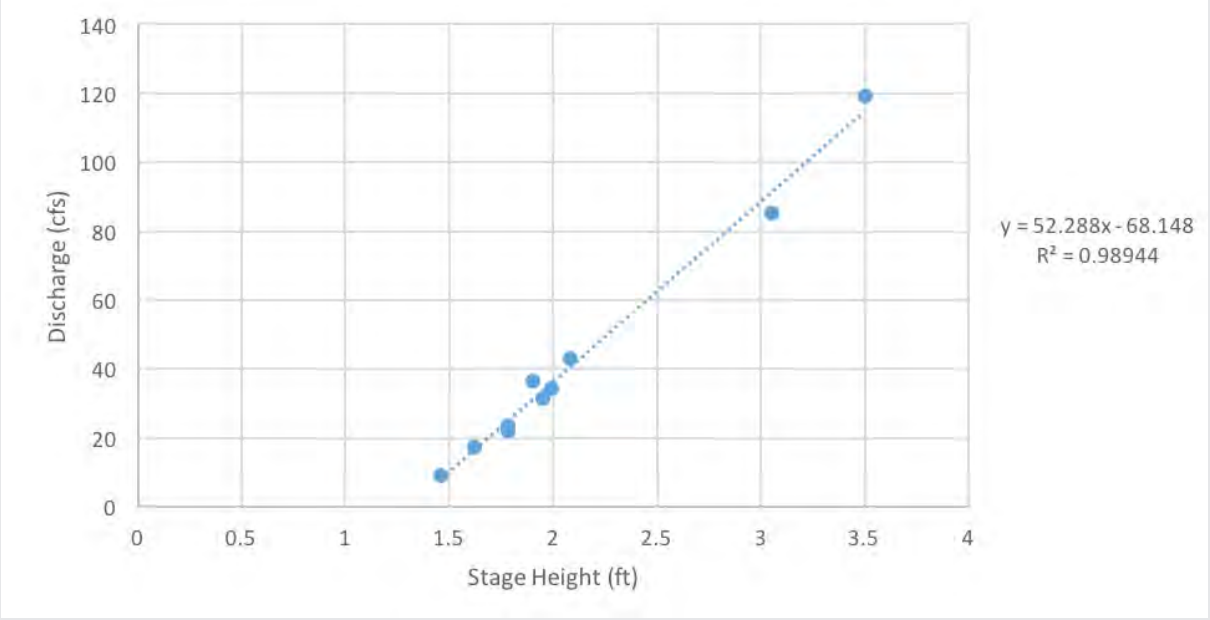


Figure 13: Stage-discharge curve from 12 observed measurements for Beaver Creek at the County Road G sampling location.

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).

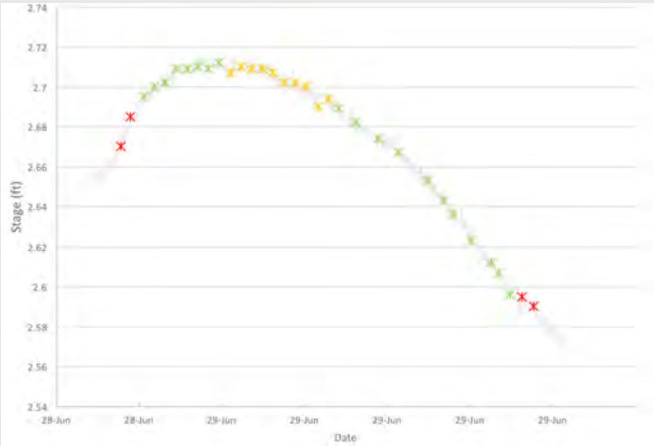


Figure 14: Storm 1 hydrograph with the composite water samples color-coded to show the different stages captured.

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.

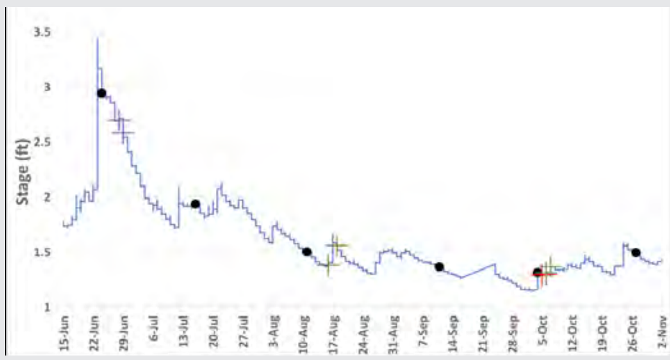


Figure 15: Stage height of Beaver Creek recorded by ISCO at County G from June 15 to November 2. Black dots correspond to monthly grab samples, while colored marks indicate the beginning and end of sampled storm events.

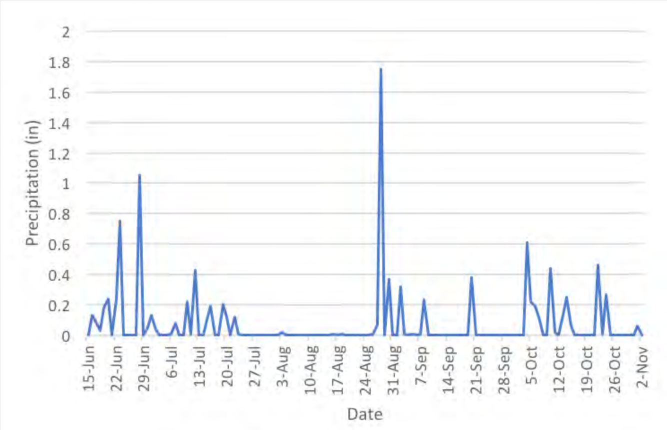


Figure 16: Daily precipitation for Juneau, Wisconsin.

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.

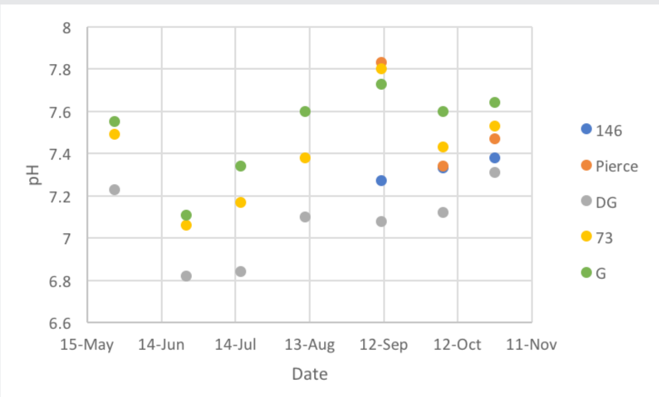


Figure 17: pH of monthly grab samples at five locations in Beaver Creek.

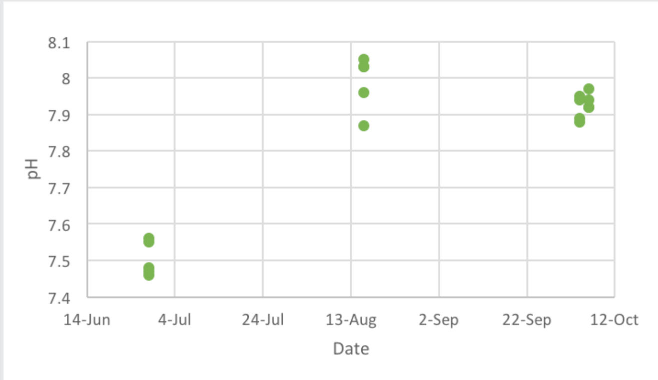


Figure 18: pH of storm-event samples at County Road G from Beaver Creek.

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.

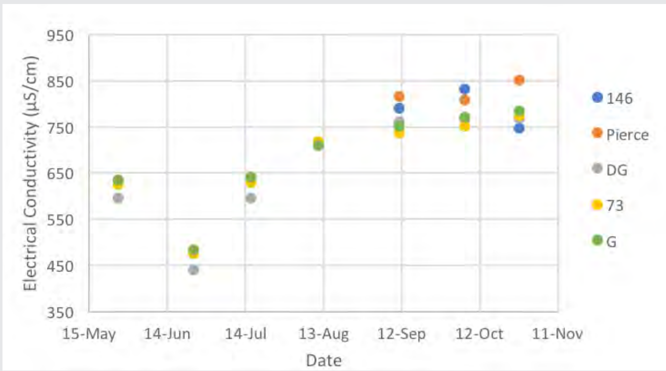


Figure 19: Electrical conductivity of monthly grab samples from Beaver Creek.

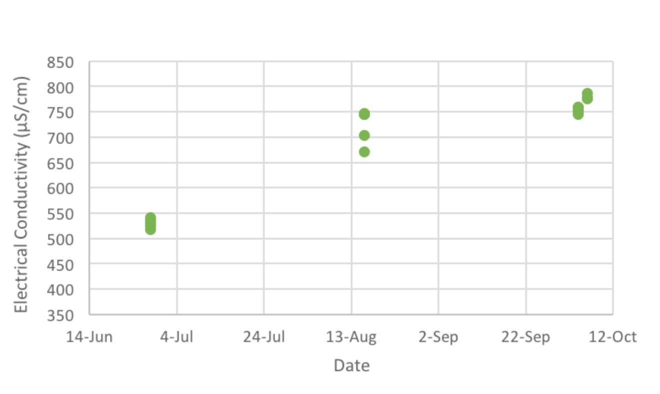


Figure 20: Electrical conductivity of storm-event samples at County Road G from Beaver Creek.

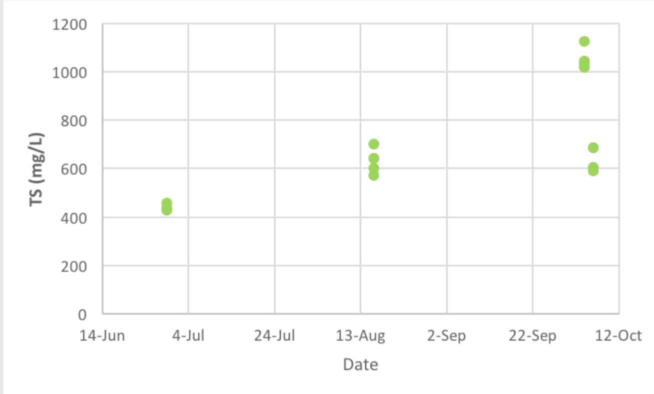


Figure 22: TS of storm samples from Beaver Creek.

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.

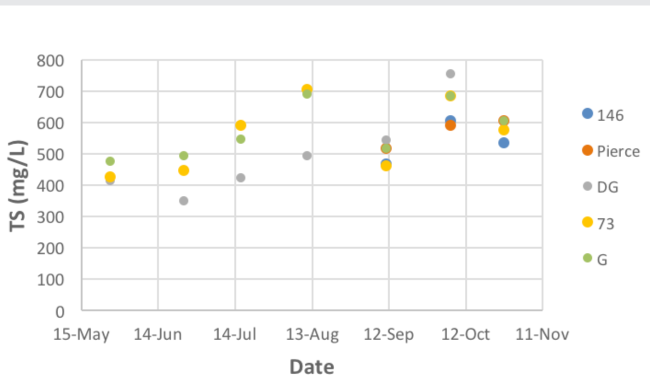


Figure 21: TS of monthly grab samples from Beaver Creek.

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.

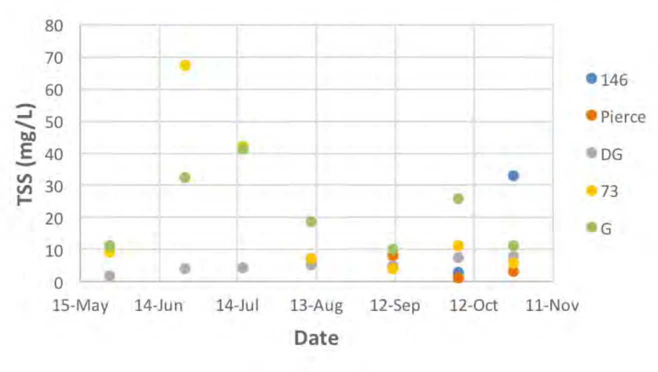


Figure 23: TSS of monthly grab samples from Beaver Creek.

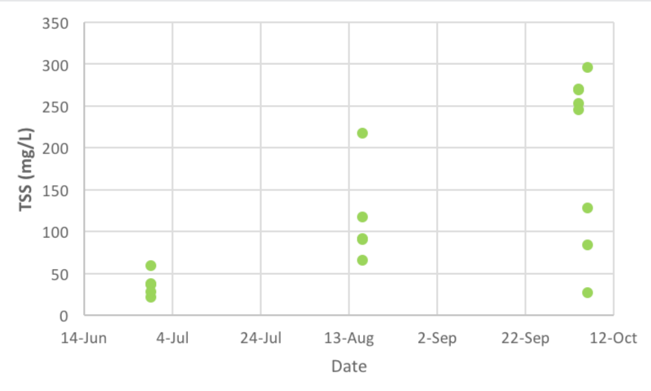


Figure 24: TSS of storm samples from Beaver Creek.

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.

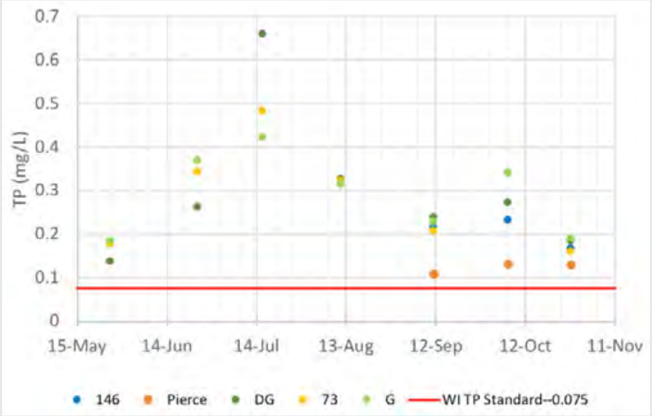


Figure 25: TP grab sample concentrations.

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).

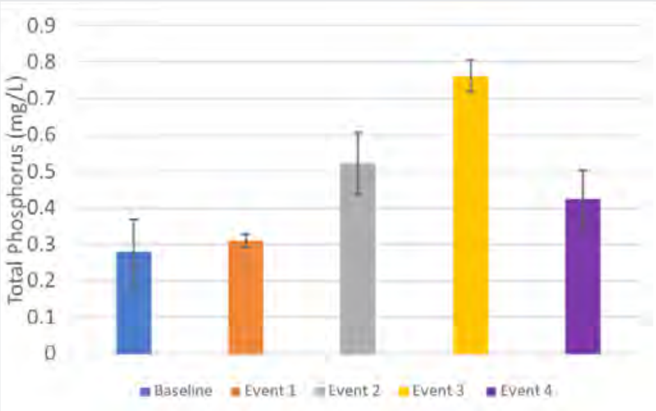


Figure 26: Average TP concentrations during baseline streamflow (grab samples) and the four captured storm events. Error bars represent the standard deviation.

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).

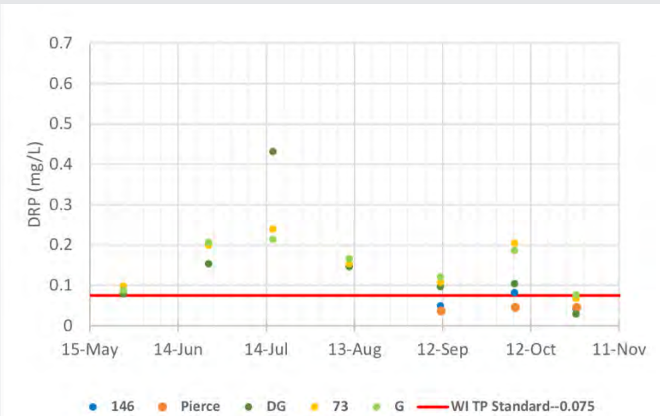


Figure 27: DRP grab sample concentrations.

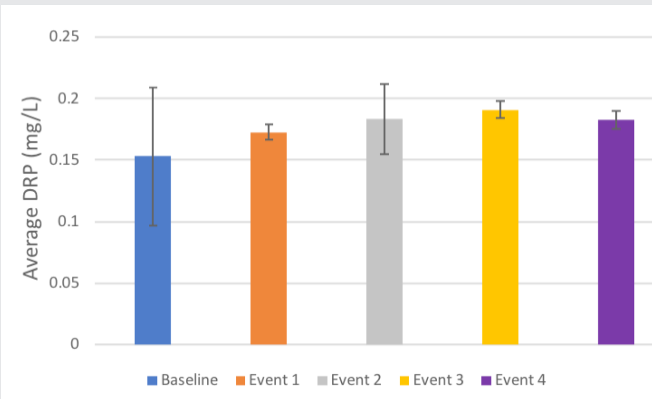


Figure 28: DRP levels during baseline streamflow and the four captured storm events.

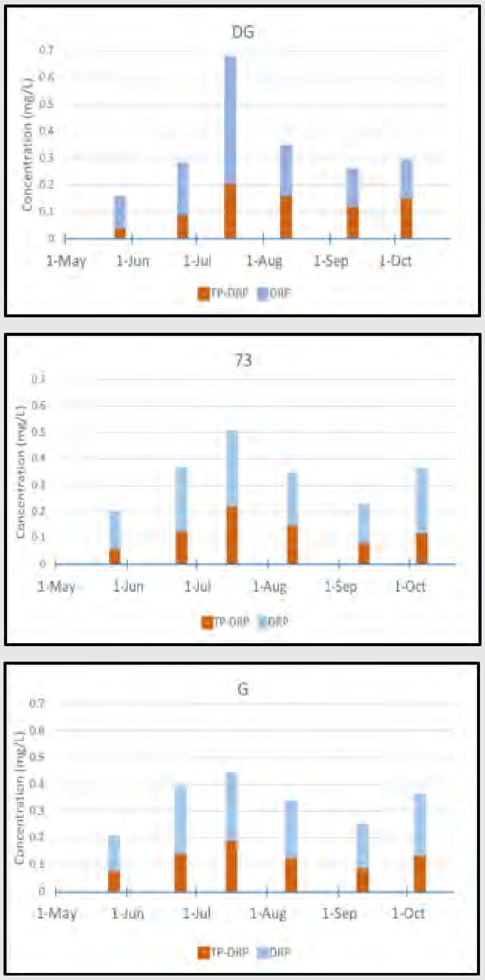


Figure 29: DRP as a proportion of TP for sites DG, 73, and G.

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).

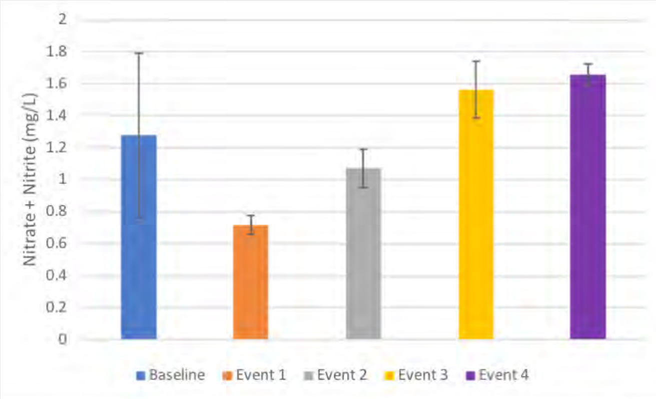


Figure 30: Nitrate + nitrite concentrations during baseline streamflow and the four captured storm events.

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.

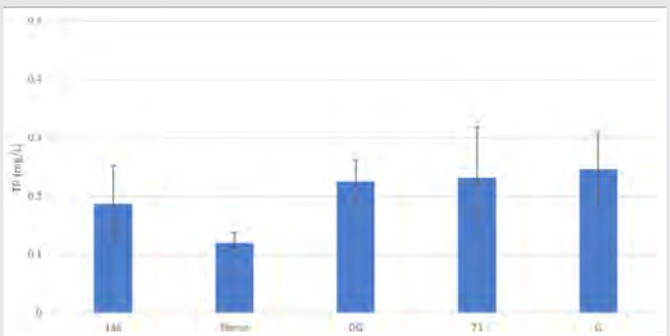


Figure 31: Average TP across sites for the last three sample dates.

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.

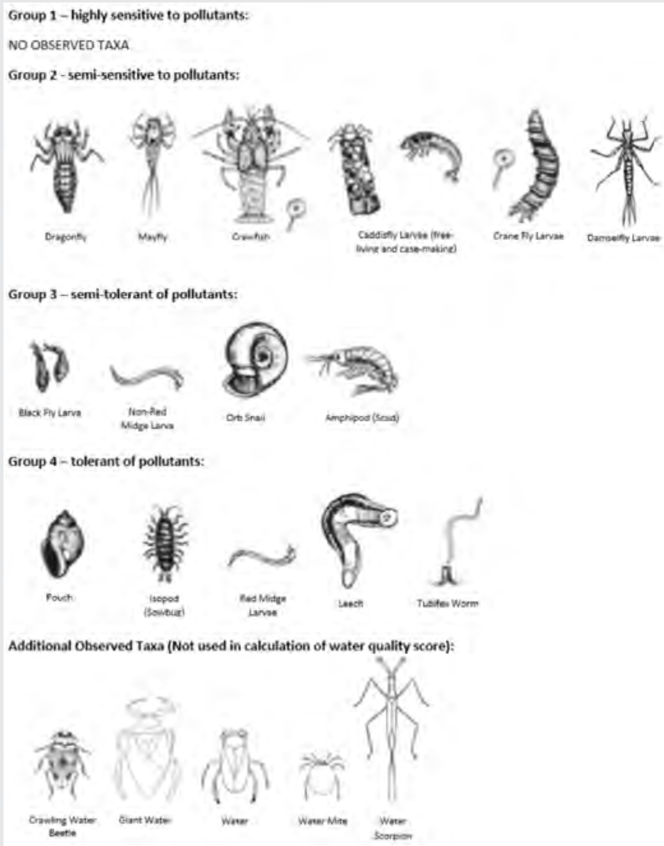


Figure 32: Observed taxa at three Beaver Creek sites grouped by sensitivity to water quality.

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).

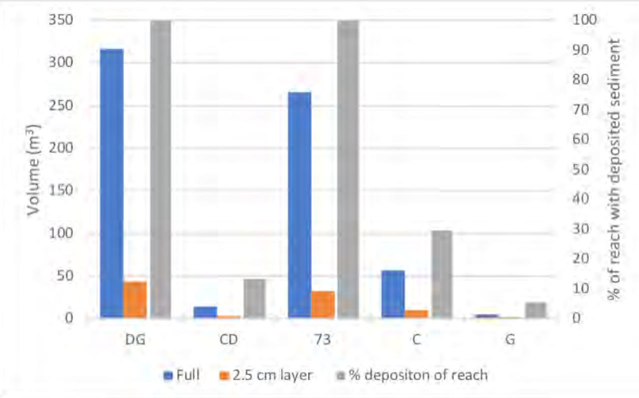


Figure 33: Full and top 2.5-cm layer sediment volumes for the 80-m reach at each site. Grey bar is the percentage of the reach with deposited sediment.

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).

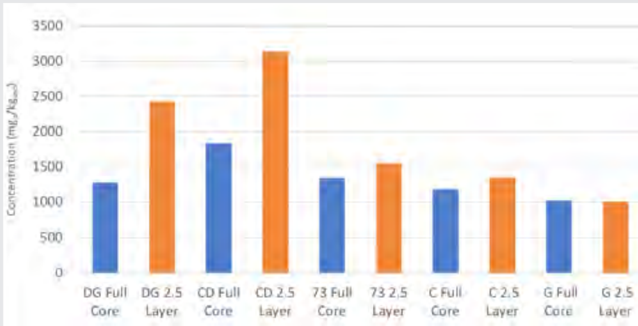


Figure 34: Sediment P concentrations for full and top 2.5-cm layer cores.

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.

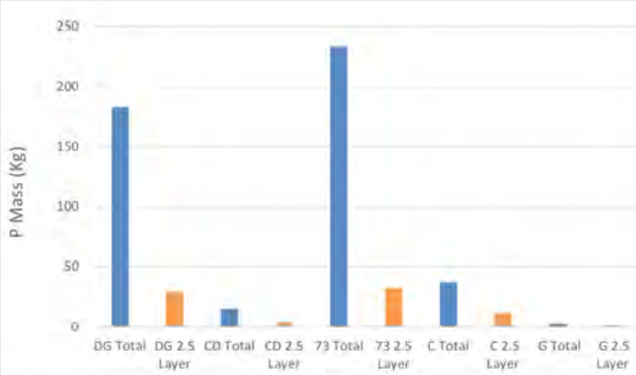


Figure 35: P mass in deposited sediment for the entire site and the top 2.5-cm layer.

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

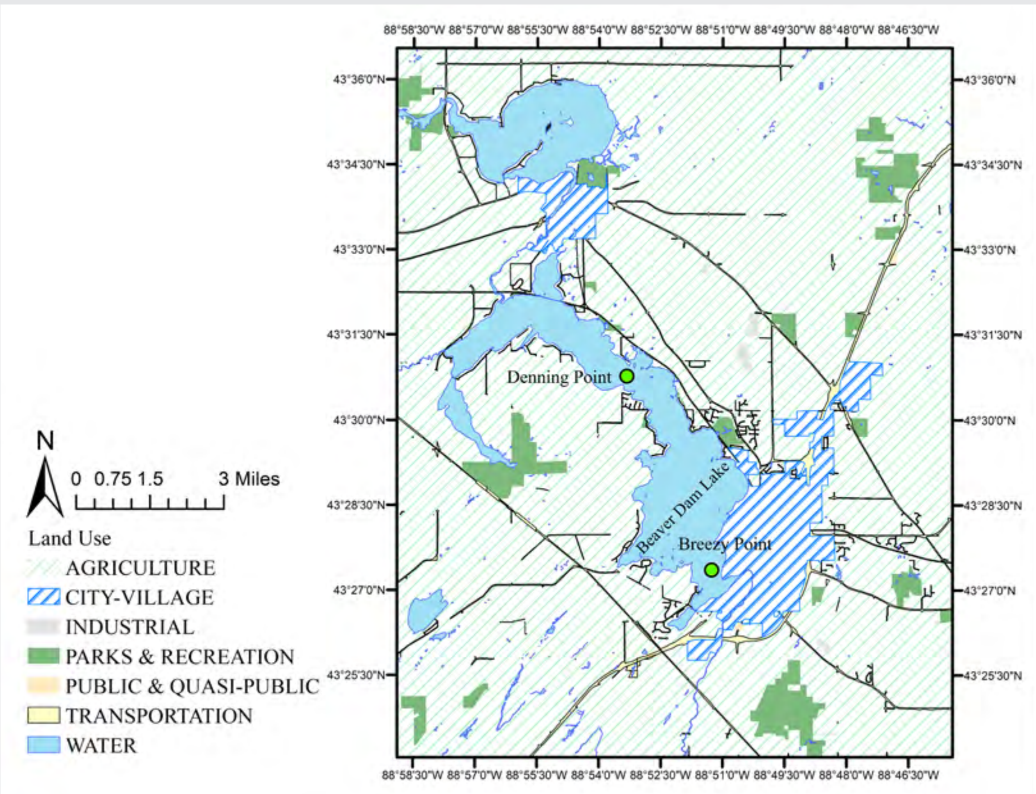


Figure 36: Denny Point and Breezy Point are locations of historical sampling efforts (1973 to 2016). The land use data are from the 2014 Dodge County Land Use Geodatabase.

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.

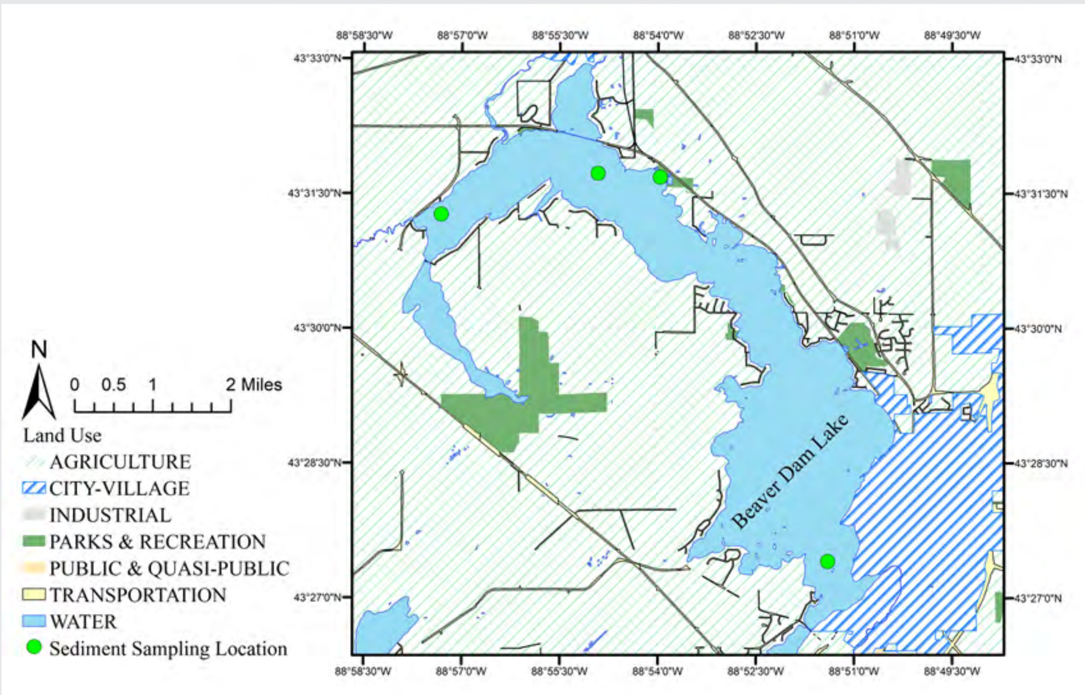


Figure 37: The locations of the 2017 sediment sampling. The land use data are from the 2014 Dodge County Land Use Geodatabase.

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.

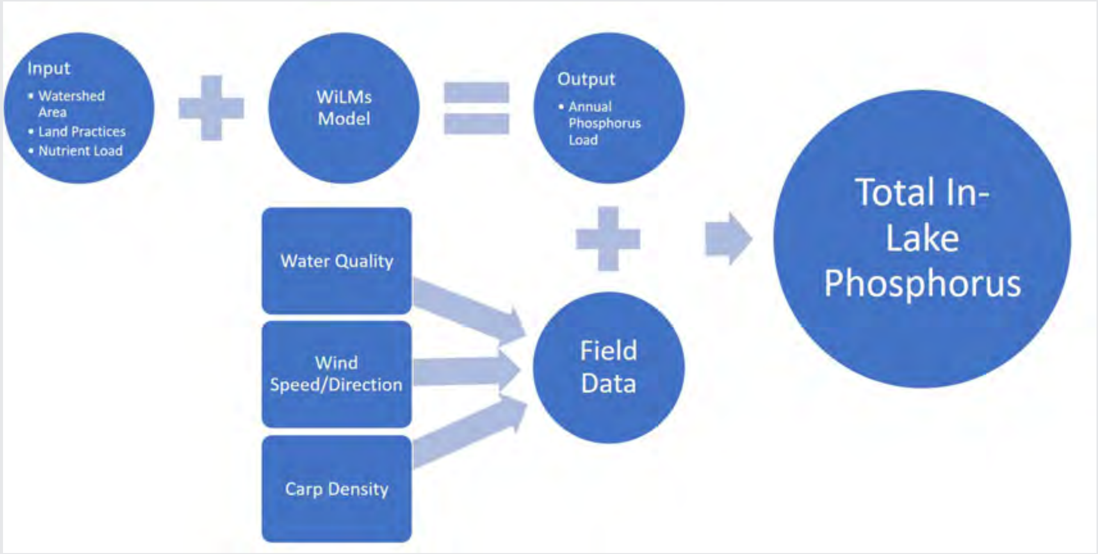
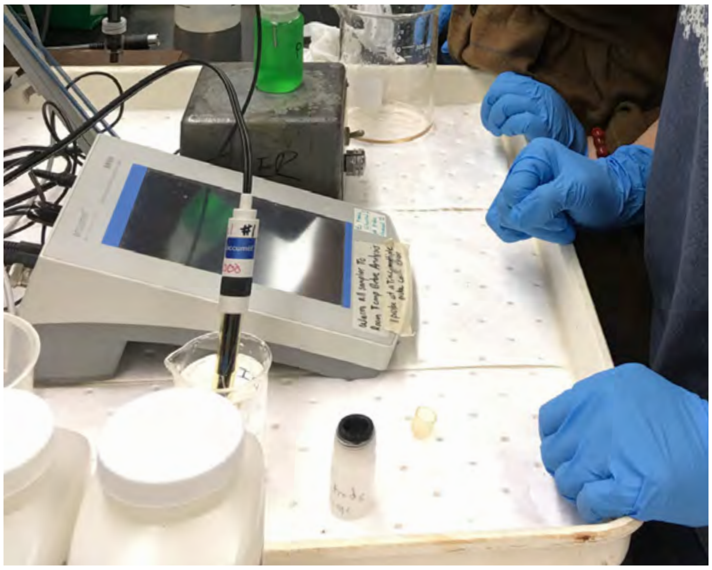


Figure 38: Flow chart of the WiLMs model and total in-lake phosphorus sources analysis.



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.

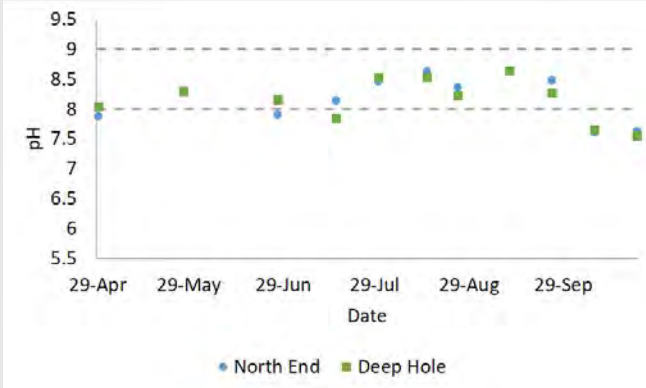


Figure 39: Plot of 2017 pH data for Beaver Dam Lake. The range of the 2014 pH data is represented by the dashed lines.

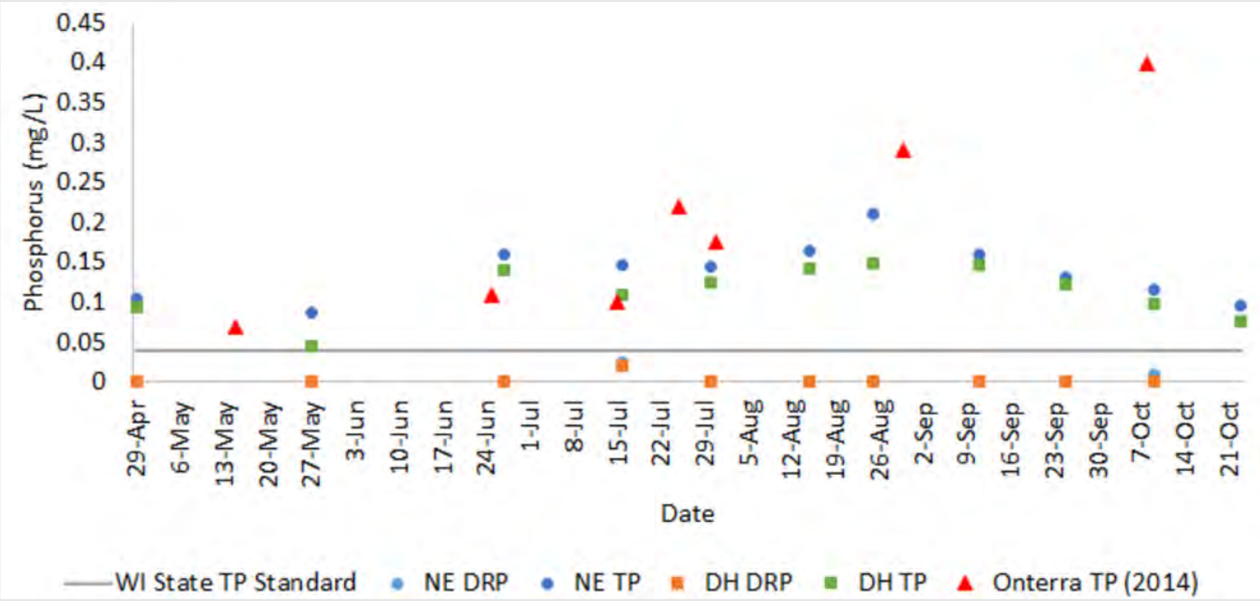


Figure 40: Comparison of TP and DRP (mg/L) at North End (NE) and Deep Hole (DH), with Onterra data and the Wisconsin state standard.

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.

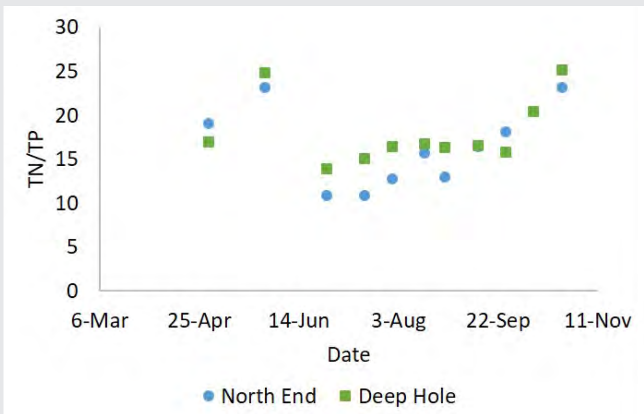


Figure 41: The TN/PP ratio of 2017 samples.

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).

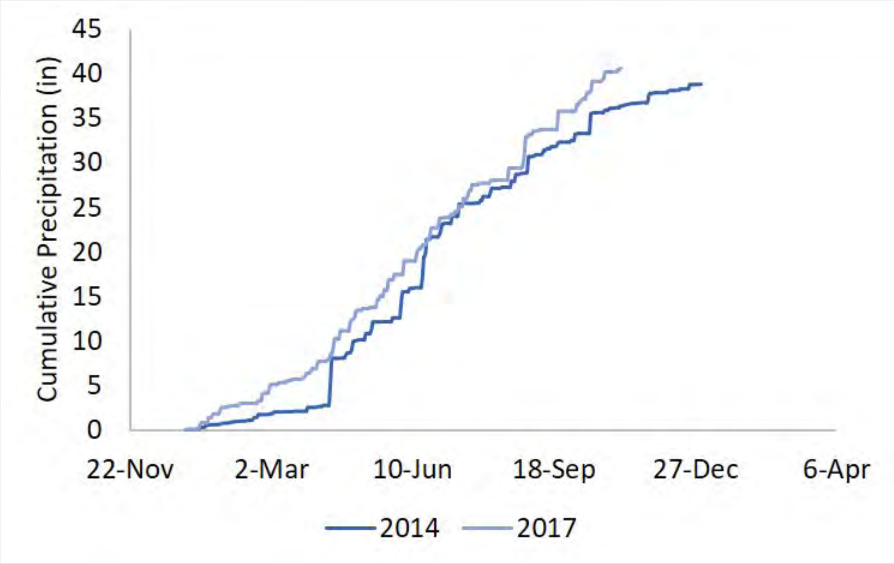


Figure 42: Total precipitation in 2014 and 2017.

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.

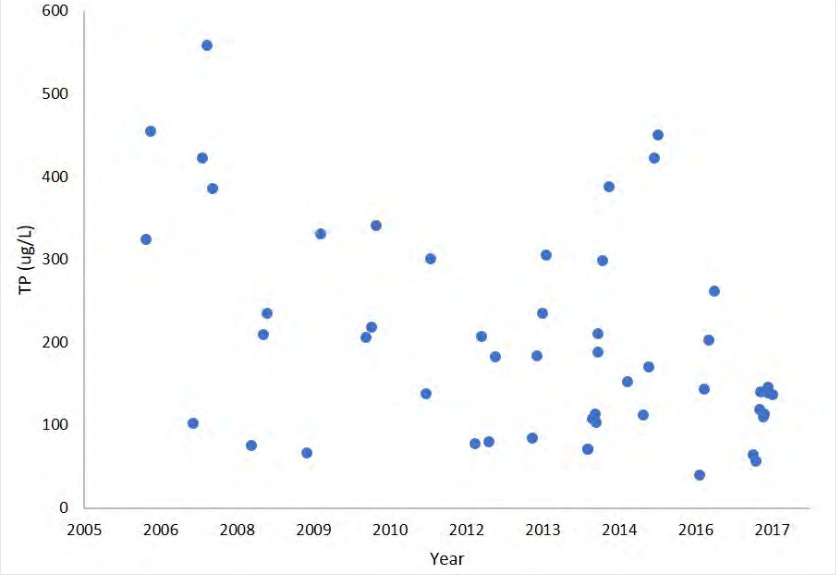


Figure 43: Historical TP data for Beaver Dam Lake at Deep Hole. Data retrieved from Wisconsin DNR website, Onterra Report and 2017 field sampling data.

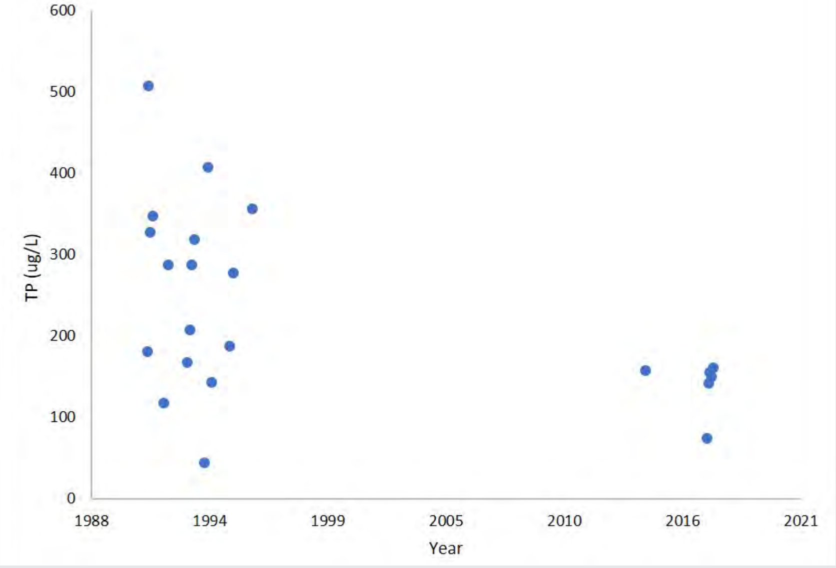


Figure 44: Historical TP data for Beaver Dam Lake at North End. Data retrieved from Wisconsin DNR website, Onterra Report and 2017 field sampling data.

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.

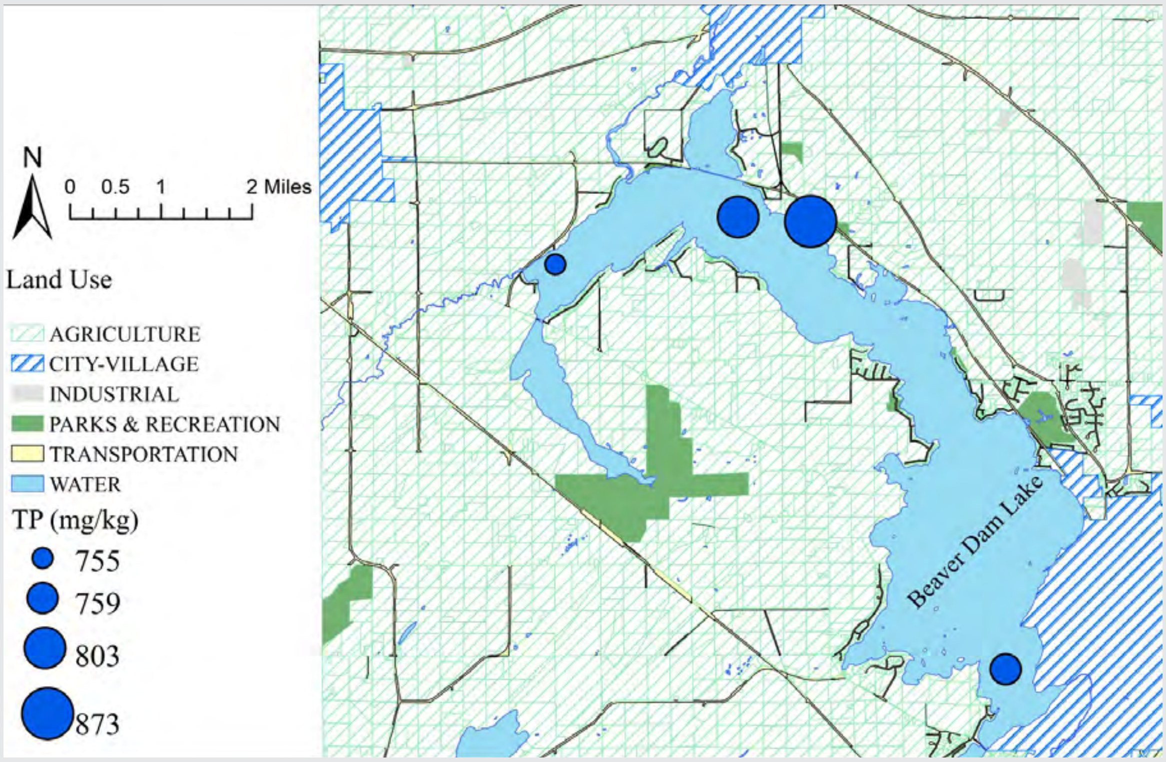


Figure 45: Total phosphorus concentrations (TP) in lake sediments (mg P/kg sediment). This map shows the TP in the top layer of sediment (0-2.5cm). The other layers and the distribution of water extractable phosphorus are shown in Appendix E.

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 non-point 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).

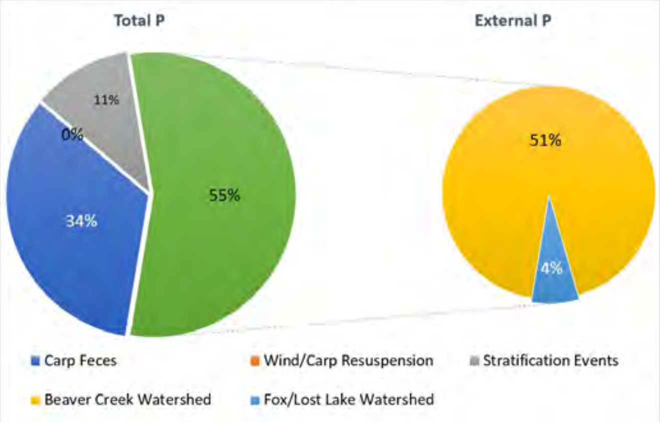


Figure 46: Plausible breakdown of phosphorus sources in the Beaver Dam Lake (using 4% body weight for loading for carp feces, 3 kg/ha external loading for watershed contribution).

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.)

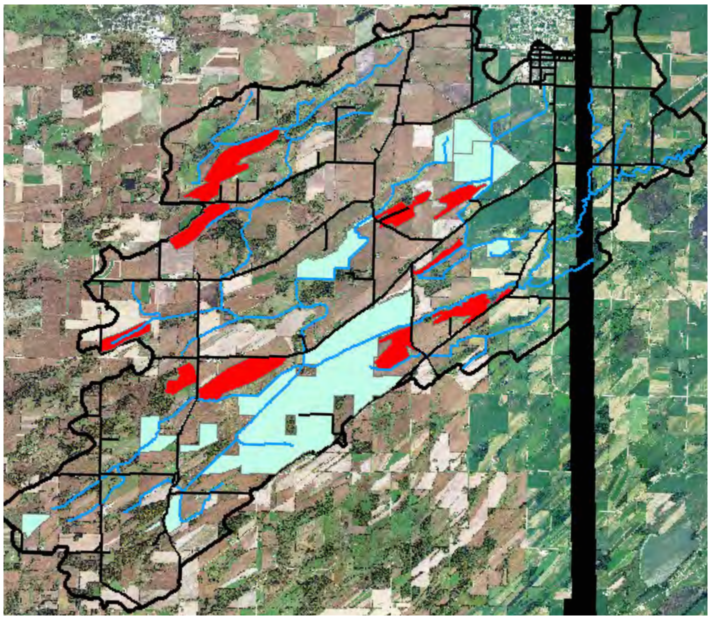


Figure 47: The ten highest-priority vulnerability sites (highlighted in red).

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.

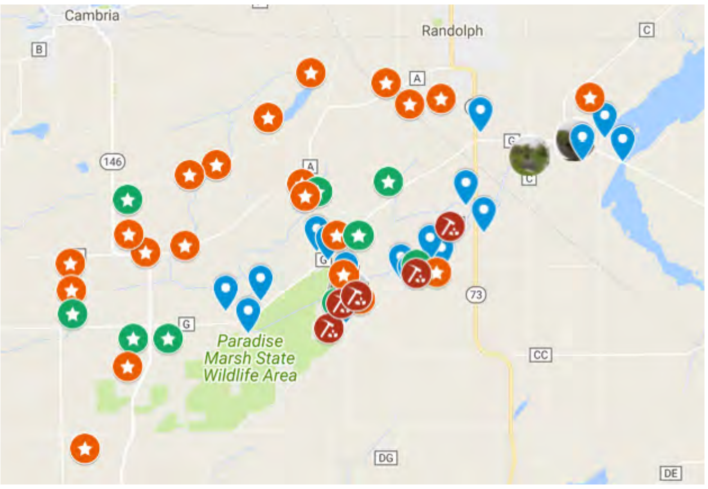


Figure 48: Map of windshield survey, macroinvertebrate sampling, and soil sampling sites.

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).

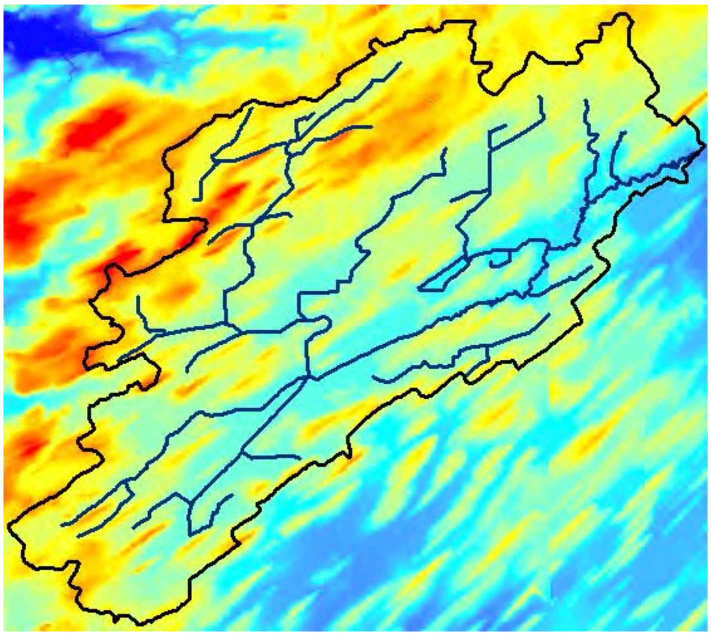


Figure 49: LiDAR and DEM imagery.

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.

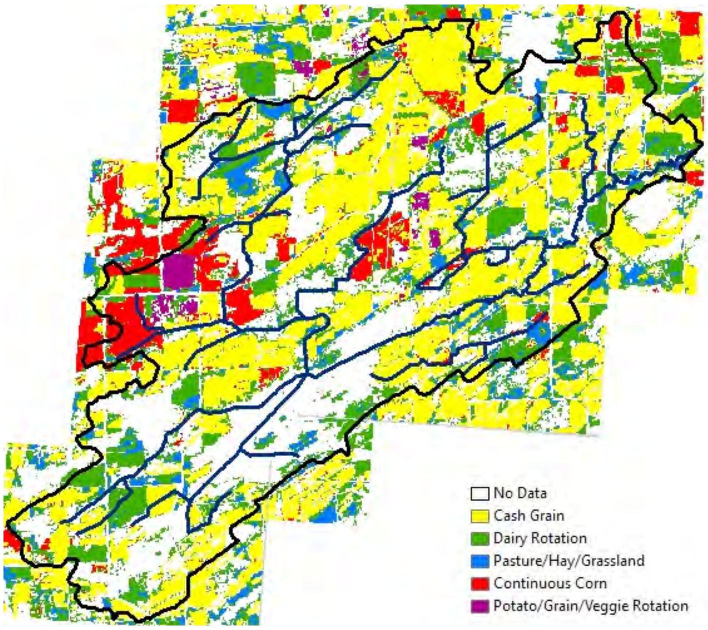


Figure 50: Crop rotations from 2012-2016.

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.

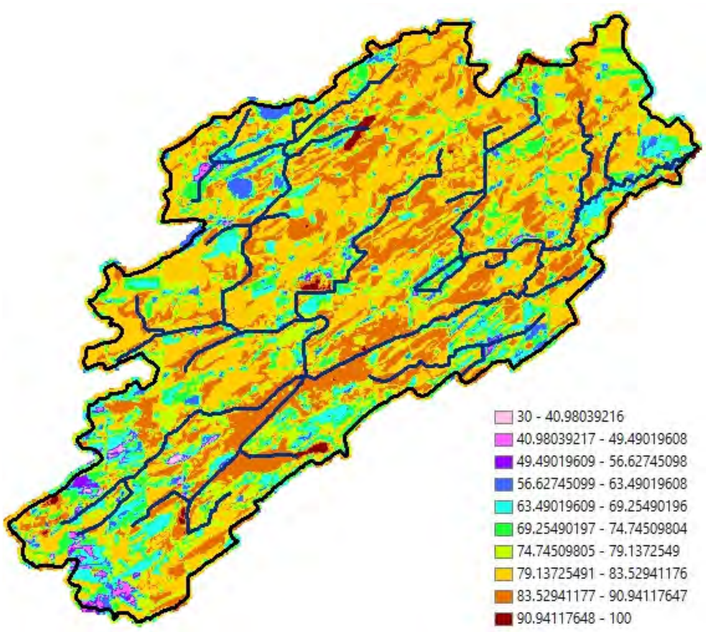


Figure 51: Curve number values.

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.

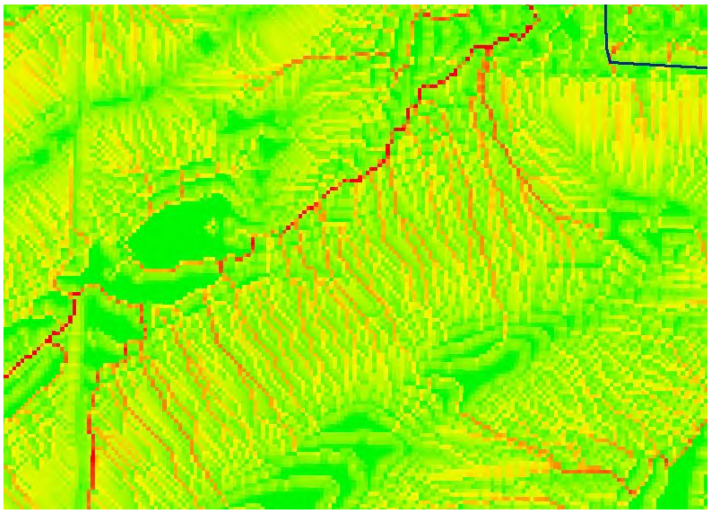


Figure 52: Stream power index.

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).

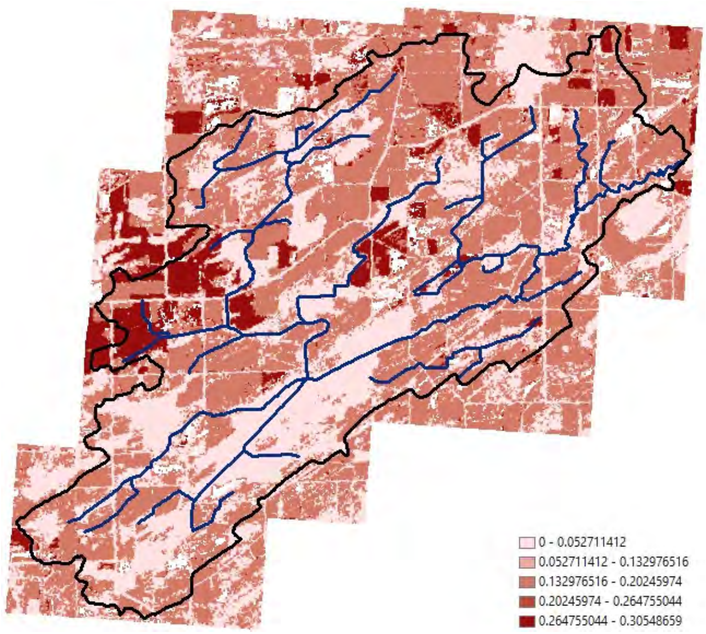


Figure 53: C-factor values.

APPENDIX E – ADDITIONAL IN-LAKE RESULTS

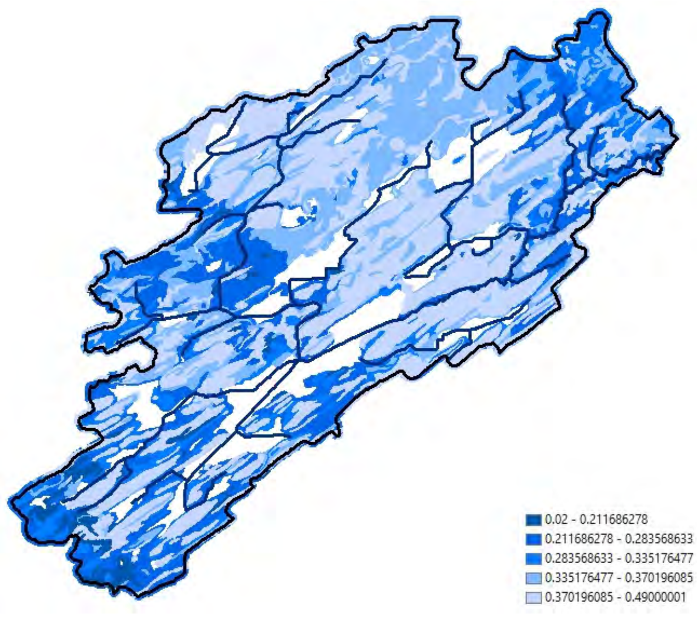


Figure 54: K-factor values.

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.

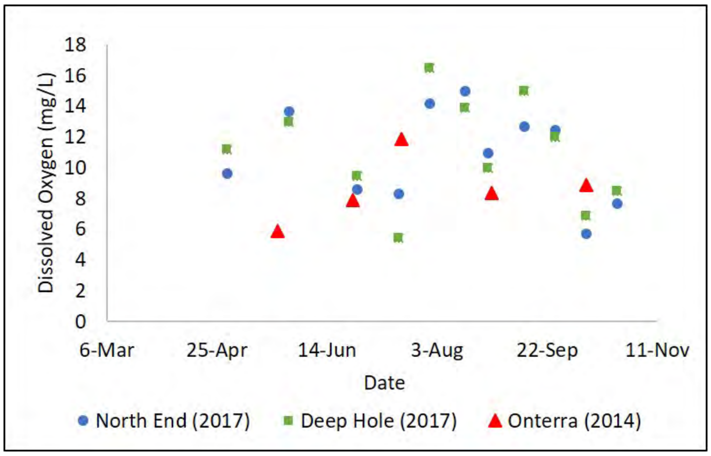


Figure 55: Dissolved oxygen over the growing season as measured by WRM and Onterra.

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).

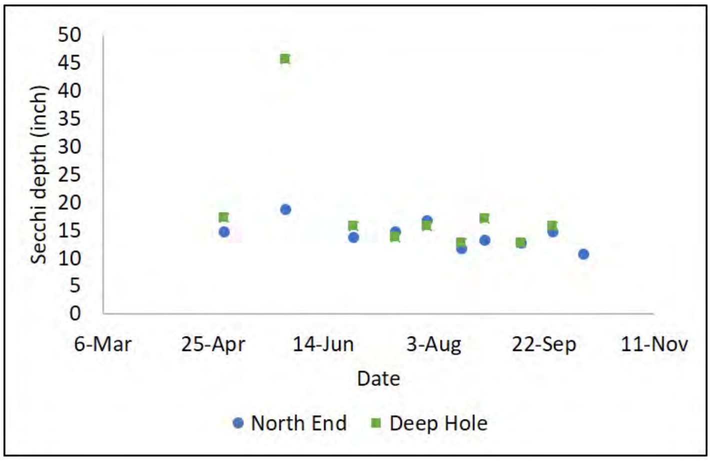


Figure 56: Secchi depth over the growing season as measured by WRM.

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).

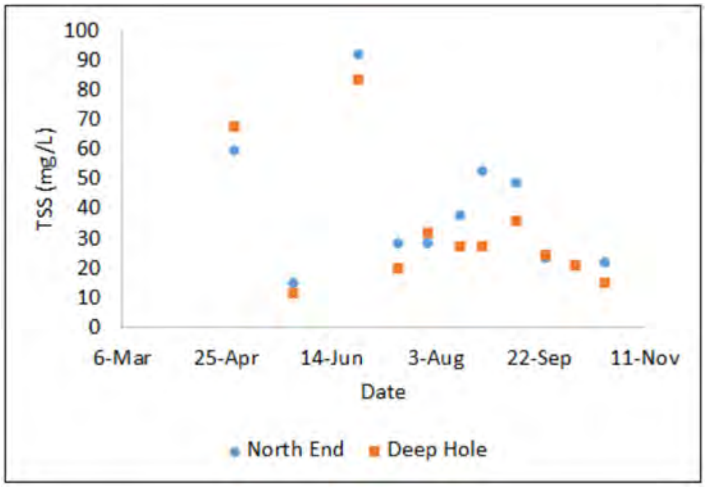


Figure 57: Total suspended solids (mg/L) over 2017 as measured by WRM.

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

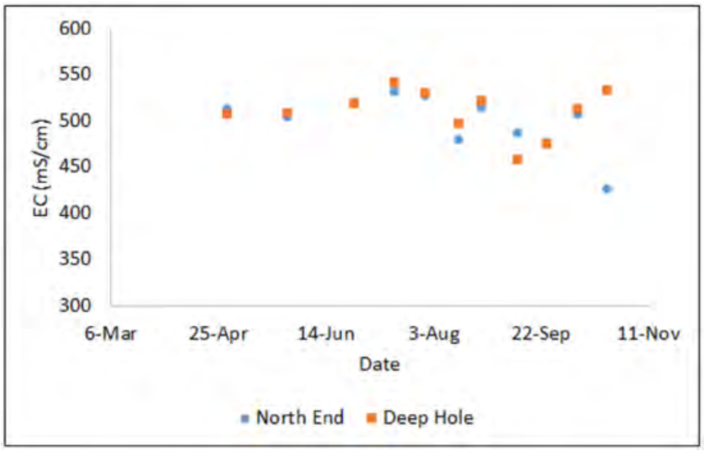


Figure 58: Electrical conductivity (mS/cm) over 2017 as measured by WRM.

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

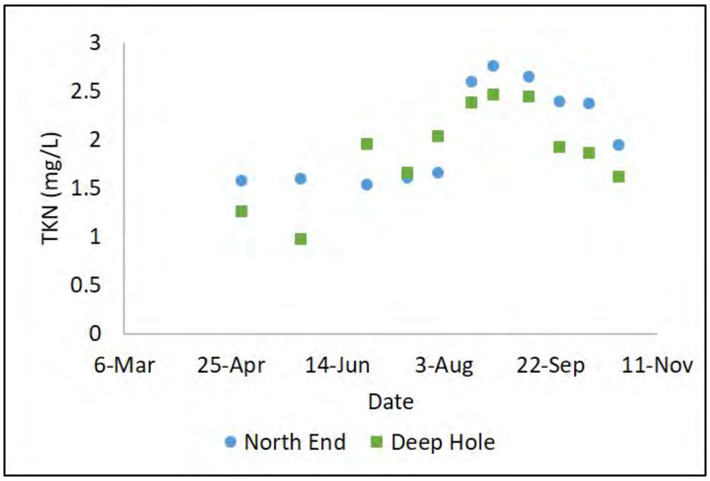


Figure 59: Total Kjeldahl nitrogen (mg/L) over 2017 as measured by WRM.

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).

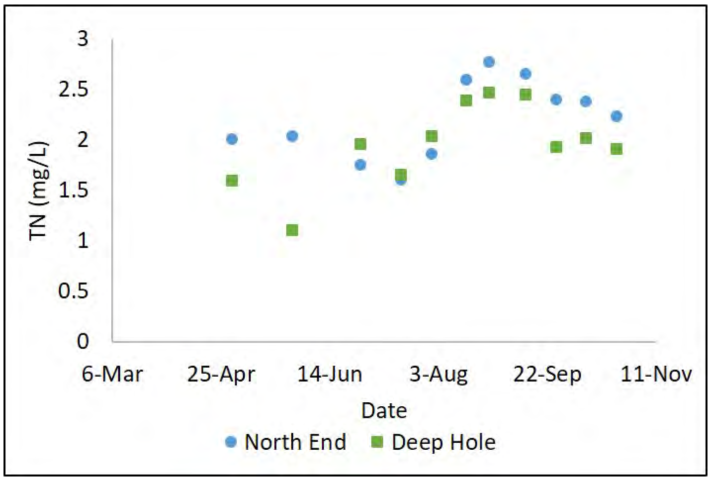


Figure 60: Total nitrogen (mg/L) over 2017 as measured by WRM.

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.

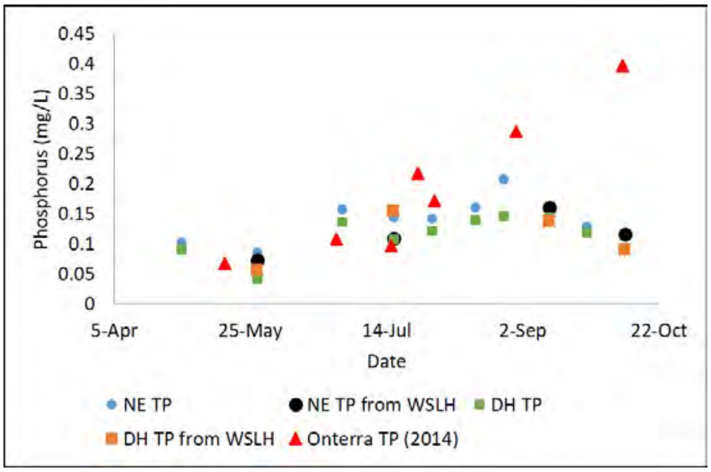


Figure 61: Comparison of total phosphorus (mg/L) data from Onterra (2014), WSLH and the UW-Madison BSE Lab.

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.

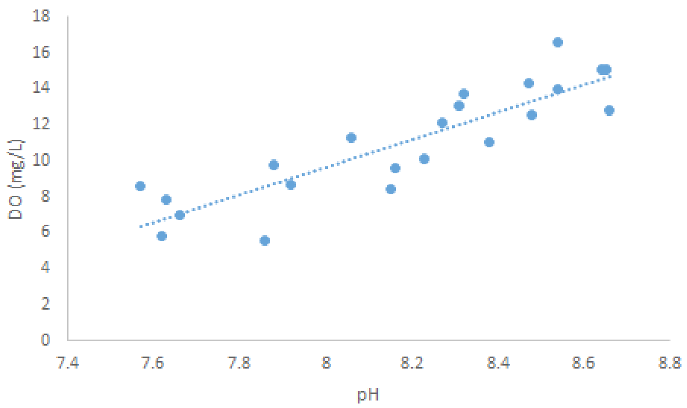


Figure 62: Relationship between DO and pH. The trendline equation is y = 7.693x - 51.898.

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

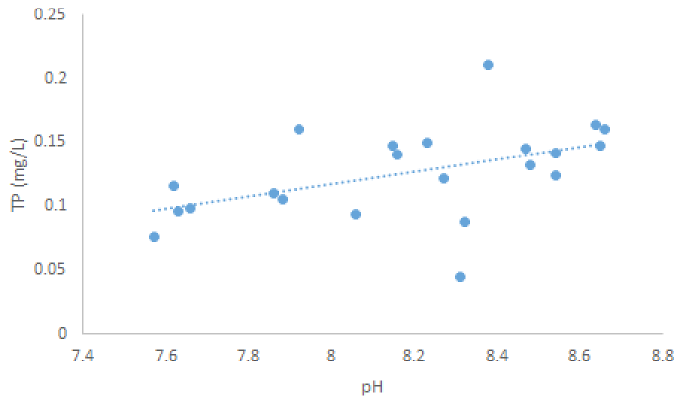


Figure 63: Relationship between TP and pH. The trendline equation is y = 0.0479x - 0.2658 and R² = 0.2287.

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.

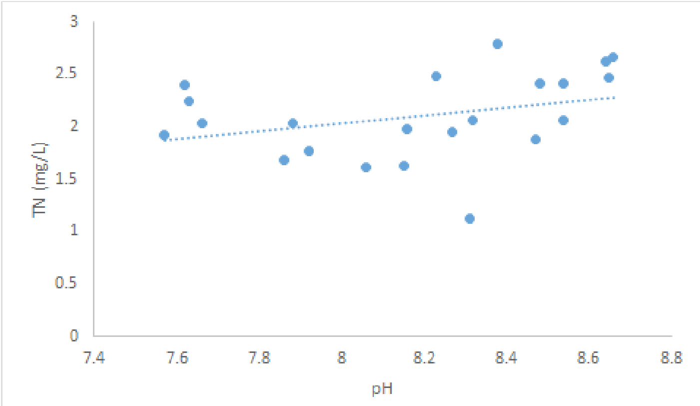


Figure 64: Relationship between TN and pH. The trendline equation is y = 0.3783x - 0.9913 and R² = 0.1119.

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 (ºC)	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 (ºC)	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.

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.

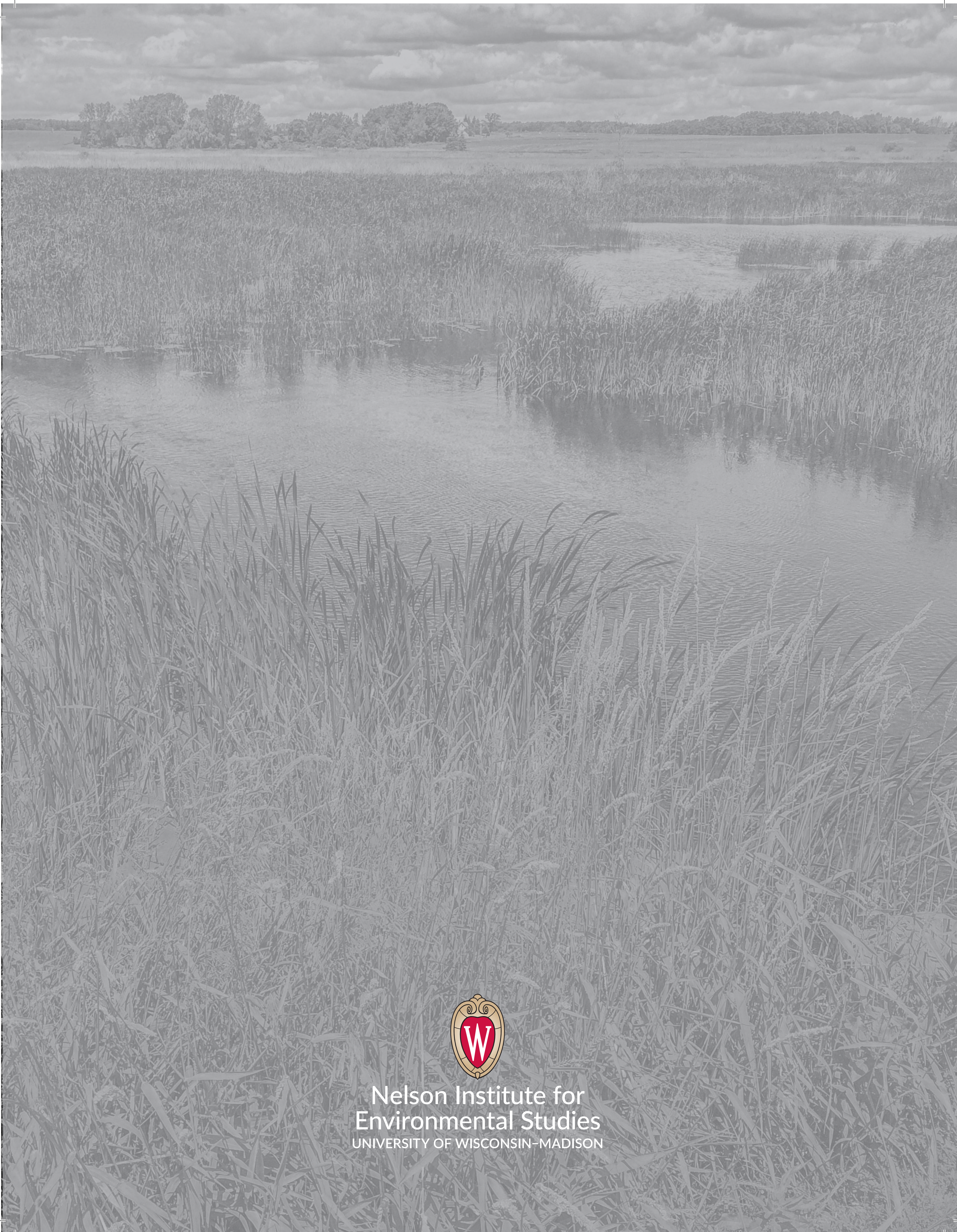
	Date	146	Pierce	DG	73	G
pH	05/26/17			7.23	7.49	7.55
	06/24/17			6.82	7.06	7.11
	07/16/17			6.84	7.17	7.34
	08/11/17			7.10	7.38	7.6
	09/11/17	7.27	7.83	7.08	7.8	7.73
	10/06/17	7.33	7.34	7.12	7.43	7.60
	10/27/17	7.38	7.47	7.31	7.53	7.64
EC (µS/cm)	05/26/17			595	625	636
	06/24/17			440	475	483
	07/16/17			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	


Nelson Institute for
Environmental Studies
UNIVERSITY OF WISCONSIN–MADISON

Beaver Dam Lake Internal Phosphorus Loading Assessment

FETCH ANALYSIS AND AGRICULTURAL LOADING ASSESSMENT

Ben Bradford, Marty Dillenberg, Falon French, and Dan Graf
Prepared for the Beaver Dam Lake Improvement District
CEE 618, Professors Wu, Montgomery, Possin, and Reimer
May 10, 2017

Acknowledgements

We would like to thank the instructors who led this class and provided guidance and advice throughout the course of the semester: Professor Chin Wu; Professor of Practice Rob Montgomery, with Montgomery Associates; Mary Possin, Hydrologist; and John Reimer, Water Resources Engineer.

Several experts contributed to this analysis. Brenton Butterfield, a consultant with Onterra, LLC, provided background information on the existing Beaver Dam Lake Management Plan, and helped us understand some of the assumptions and data that went into the initial WiLMS analysis. Paul McGinley, the creator of the WiLMS Lake Eutrophication model, graciously provided time to walk us through the modeling suite and underlying assumptions.

Finally, we would also like to thank the Beaver Dam Lake Improvement District for supporting this analysis as well as the larger assessment and management plan being undertaken by the Water Resources Management 2017-2018 cohort.

Table of Contents

Executive Summary

Based on the results and recommendations in the existing Beaver Dam Lake Management Plan, we chose to address two key questions related to the nutrient loading in Beaver Dam Lake: The external loading from the primarily agricultural watershed; and the potential for wind-wave sediment resuspension based on the fetch and wind speed. We mapped the fetch of the lake, which we found had been overestimated in previous reports.

We drew on methodology published by the United State Geological Survey as well as resources provided by Professor Chin Wu to conduct a wind wave resuspension analysis. After calculating the shear stress on the bottom of the lake and the wind speeds, we found that resuspension of sediment occurs frequently in this shallow lake.

After recreating the initial analysis of external phosphorus loading, we found that the per-acre loading could have been substantially underestimated. We estimate a range of 80,000-120,000 pounds per year, which represents between 20 and 25 percent of the total phosphorus in the lake based on the mean growing season concentration.

We also investigated some of the other potential causes of internal loading, to better account for the phosphorus levels reported in the lake. We find that carp contribute substantially to the lake phosphorus levels, and that the alkalinity of the lake could be contributing to eutrophication.

Introduction

BEAVER DAM LAKE OVERVIEW

Beaver Dam Lake, located in Dodge County, Wisconsin, is a shallow dammed lake suffering from excess sediment and nutrient loading. The 6841-acre lake is long and narrow, shallow, and classified as hypereutrophic. Nuisance blooms of blue-green algae have become common, with nitrogen and phosphorus both contributing as the limiting nutrient at various times of the year.

The lake is highly utilized for recreation, and has been the focus of research in the past. The most recent analysis published, produced by Onterra, LLC, highlighted several potential problems and opportunities for further research. In particular, the management plan recommended a fetch analysis to determine phosphorus contributions from wind-wave sediment resuspension. The initial lake analysis suggested that nearly 90 percent of all phosphorus contributions to the lake were coming from internal rather than external sources, a surprising finding for a lake with such a large agricultural watershed.

RESEARCH QUESTIONS

In order to address the question of internal versus external loading of the lake, which suggests that phosphorus contributions from the watershed may be underestimated, we chose to confront two main research questions:

1. What is the fetch of the lake, and how does it contribute to wind-wave resuspension?
2. Are the phosphorus contributions originally modeled by Onterra realistic, or could they be underestimating phosphorus loading from the watershed?

Literature Review

FETCH ANALYSIS

In order to conduct an effective and thorough fetch analysis to approximate the significance of wind-induced resuspension on Beaver Dam Lake, previous literature was sought out for background on the necessary calculations. The Upper Klamath Basin Nutrient-Loading Study (Laenen & LeTourneau, 1996) revealed a lake that has many similar characteristics to Beaver Dam Lake. This study sought to quantify the amount of wind-induced resuspension in Upper Klamath Basin, which demonstrated how to determine resuspension in Beaver Dam Lake.

In terms of shared characteristics between the two lakes, both lakes are hypereutrophic and have similar mean depths between five and six feet. Although Upper Klamath Basin is approximately six times the size of Beaver Dam Lake in acreage, the average wind speed is nearly the same at both lakes around 10 miles per hour annually. Overall, the study was crucial to the fetch analysis as it outlined, step by step, the calculations necessary to approximate the amount of wind-induced resuspension of sediments during average wind speeds along the direction of the longest fetch in Beaver Dam Lake.

WILMS ANALYSIS

Because the majority of the watershed is zoned for agriculture, and because practices implemented on farms have a heavy impact on soil loss and phosphorus runoff, we focused on identifying likely phosphorus contributions from agriculture. The Yahara WINS (MMSD, 2016) adaptive management pilot project included an extensive inventory of agricultural fields. Researchers found that phosphorus runoff varied widely, with a mean loading of 3.3 pounds per acre and the highest loads approaching 16 pounds per acre. This loading is slightly higher than loads reported in an edge-of-field analysis of Discovery and Pioneer farms (Stuntebeck et al., 2011), which ranged from 0.3 to 7 pounds per acre. The mean loads reported were approximately 2 pounds per acre.

Madison et al. (2014) tested phosphorus loading differences between surface runoff and the contributions from tile drainage. Tile drainage yielded total phosphorus loads ranging from 0.24 to 2.73 kg/ha, while surface runoff carried significantly more phosphorus. Surface run-off ranged from 0.6 to 9.73 kg/ha.

CASE STUDY: GRAND LAKE ST. MARYS

Grand Lake St. Mary's is a 13,500 acre, shallow, and hypereutrophic lake in northwestern Ohio. It is an American state park, with primary uses consisting of boating, swimming, and fishing. Grand Lake St. Mary's experiences a significant amount of agricultural runoff, increasing levels of phosphorous and nitrogen in the lake resulting in the growth of blue-green algae. Lack of community sewage treatment facilities around Grand Lake have lead to increased drainage pollution.

There are many similarities between Grand Lake and Beaver Dam Lake, although Beaver Dam Lake is approximately half size. The 112 square mile watershed for Grand Lake in a primarily agricultural region of Ohio contributes the extremely high phosphorous levels, promoting the growth of harmful algal blooms in the lake. The use of Alum seasonally to combat the high phosphorous and nitrogen levels in the lake and surrounding watershed has proven to be reasonably successful, something that could be considered for Beaver Dam Lake if the Beaver Dam Lake Improvement Association deems it necessary.

Methodology

FETCH ANALYSIS

The preliminary step in quantifying the concentration of suspended sediments was using Professor Chin Wu's Wind Wave Model to determine the significant wave height and peak wave period. Using the Upper Klamath Basin Nutrient-Loading Study, the remaining calculations needed to achieve the goal of the fetch analysis were computed.

A similar methodology was used to calculate the theoretical annual frequency that wind-induced sediment resuspension occurs. Using the U.S. Army Corps of Engineers Shore Protection Manual, empirical relationships for determination of the critical wind speed for sediment resuspension were obtained. The lake mean depth was used to determine the critical wave period. Then, using the maximum lake fetch, the critical wind speed could be easily calculated. This critical wind speed was then compared with the 2016 daily average wind speed data, displayed in Figure 1.

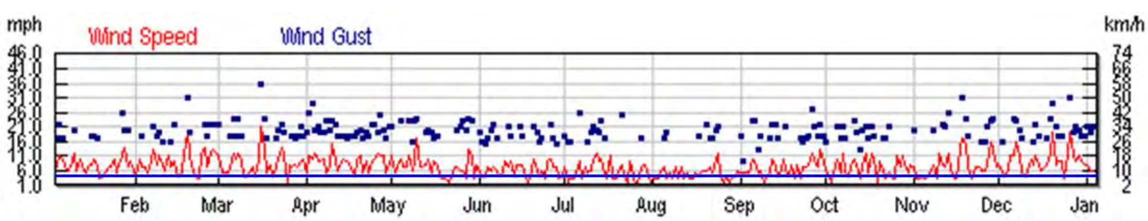


Figure 1: 2016 Wind speed data for Beaver Dam Lake. Note the blue horizontal line, which represents the calculated critical wind speed.

From this comparison, the number of days in which the critical wind speed is exceeded could be determined. Using wind rose data from the Beave Dam Juneau weather station, available in Appendix B, the relative frequency that wind blows in the direction of the maximum was determined. This frequency could then be applied to the days in which critical wind speed is exceeded to estimate the rate of wind-induced sediment resuspension.

WILMS ANALYSIS

Phosphorus loading from agricultural land uses can vary widely based on the soil type, topography, crop rotations and conservation practices implemented on the field. The Wisconsin Lakes Management Suite (WiLMS) predicts phosphorus loads from agricultural land uses ranging from 0.5 kg/ha-year to 3 kg/ha-year, with a median probably loading of 1.0 kg/ha-year.

Using WiLMS, we first recreated Onterra's original findings, then altered the phosphorus loading from agriculture to reflect recent published studies, displayed in Appendix E. We then drew from a review of regional studies on phosphorus loading, to determine whether this range and expected phosphorus load are realistic for the watershed. The results are summarized in Table 2, in Appendix E.

RESULTS

FETCH ANALYSIS

Using Professor Wu's Wind-Wave model, and inputting the mean Beaver Dam Lake depth of 1.74 meters, a maximum measured fetch of 6936 meters, and a historical wind speed of 5.36 meters per second resulting in a calculated significant wave height of 0.19 meters and a peak wave period of 1.9 seconds. These results are reasonable given the moderate annual wind speed and size of Beaver Dam Lake.

The wavelength of the waves produced from the wind, which we found to be in 0.167 meters, is consistent with the significant wave height previously determined. From the wavelength calculation, the maximum bottom velocity of the lake can be determined which turned out to be 0.22 meters per second. While this number seems fairly insignificant, it should be noted that this number is on the higher side due to the low depth of the lake.

Using a recommended Reynolds's number of 15, the shear stress was calculated to be 0.75 dynes per square centimeter. The shear stress as a result of the wind is important because it is the primary mechanism of the resuspension in Beaver Dam Lake and determines the resuspension rate of sediments, which was 3.3 x 10-7 grams per square centimeter seconds. Converting this resuspension rate to a concentration value using the volume of Beaver Dam Lake and a two-hour period of wind blowing along the fetch direction, an approximate suspended sediment concentration value of 24.1 milligrams per liter was determined. Table 1 in Appendix C of this report outline the above calculations.

Using the empirical relationships from the U.S. Army Corps of Engineering Shore Protection Manual and previously determined values for mean lake depth and maximum fetch length, the critical wave period and wind speed for resuspension were determined to be 1.40 s and 1.78 m/s or 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. Wind rose data from the Beaver Dam Juneau weather station provided a value of 13.7% relative frequency that wind blows along the direction of maximum fetch. Applying this relative frequency to the value of 315 days yielded a theoretical value of 43 days per year that critical wind speed is exceeded along the direction of maximum fetch.

WiLMS Analysis

We initially assume that the mean growing season phosphorus levels reported in the lake are accurate, and use a 10-year average of 256 ug/L, which translates to a yearly phosphorus loading total of 531,000 pounds. We also assume that the phosphorus inputs from the Fox Lake and Lost Lake sub-watersheds are accurate, since monitors installed at the inlet from each of these sub-watersheds have nutrient data. Alternate scenarios were considered, and are presented in Appendix D.

When we adjusted the phosphorus loading from the WiLMS default of 1 kg/ha, we found a dramatic increase in the total watershed contributions, displayed in Appendix E. This analysis indicates that phosphorus contributions from agricultural sections of the watershed could be significantly underestimated. Using only the mean reported phosphorus loading, we find that the total contribution of phosphorus from the watershed could be two or three times higher than initially predicted. It is worth noting that, while we modeled the watershed contributions using the highest levels of phosphorus loading reported in the studies cited, we consider these levels to be unrealistic for much of the watershed. Our results are presented in Appendix E.

Discussion

We found a wide range of potential phosphorus contributions from the watershed. Given the data available, we cannot determine the exact loads from the watershed. Our results would be far more certain with field-level data. In the absence of such data, we assume that the average phosphorus contributions from all agricultural areas will fall within the ranges established above. However, conservation practices and existing soil phosphorus levels could vary widely across the watershed. We recommend that future analyses focus on collecting field-level data, so that the watershed phosphorus contributions can be calculated more accurately.

Based on our literature review, it appears that tile drainage could reduce phosphorus contributions. 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 percent of agricultural lands in Columbia County, and 10-20 percent 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 drainage permits or plans published, it is difficult to identify where such drainage is installed. Further, because tile drainage is not routinely inspected, it would be impossible to know whether the drainage pipes had moved or become clogged, reducing their effectiveness.

It is well known that the common carp (Cyprinus carpio) may resuspend silts, sediments, and bound nutrients through benthivorous feeding habits, but they also directly add phosphorus (P) to the system through defecation at the rate of 0.11 pounds of phosphorus per pound of carp per year, which can be quite significant. A carp density of 330 lbs/acre leads to a yearly phosphorus contribution of 36.3 pounds of phosphorus per acre, or 256,000 lbs/year in Beaver Dam Lake.

Strong evidence for wind-induced wave resuspension of sediments and bound nutrients have been discussed, but the true phosphorus contribution due to wind waves is not completely known. Combined with resuspension due to carp, these factors account for a differing percentage of phosphorus contributions depending on the true phosphorus contributions from external loading.

Conclusions

From the fetch analysis and determination of suspended sediment concentration, a few conclusions about the significance of wind-induced resuspension on Beaver Dam Lake can be reached. While the concentration value was slightly higher than the measured value in Onterra's report, it is consistent with a rather large amount of suspended sediments in Beaver Dam Lake as a result of the wind. What should be noted is that the calculations in this report do not cover resuspension due to wind coming from other directions other than along the maximum measured fetch, so the value of 43 days per year represents a theoretical minimum. Wind-induced resuspension is significant in Beaver Dam Lake and contributes to the internal loading of the lake.

We found that the phosphorus contributions from agriculture could be significantly underestimated. Given the average phosphorus loads reported in published studies, we would estimate total watershed phosphorus contributions of 80,000-120,000 pounds per year, more than twice the external loading predicted in the Beaver Dam Lake Management Plan. Without field-level data, we cannot determine a more precise level of contributions. We also find that other watershed characteristics could contribute more substantially to internal loading. Data collection, including soil and sediment phosphorus samples and a review of conservation practices, could yield more accurate results.

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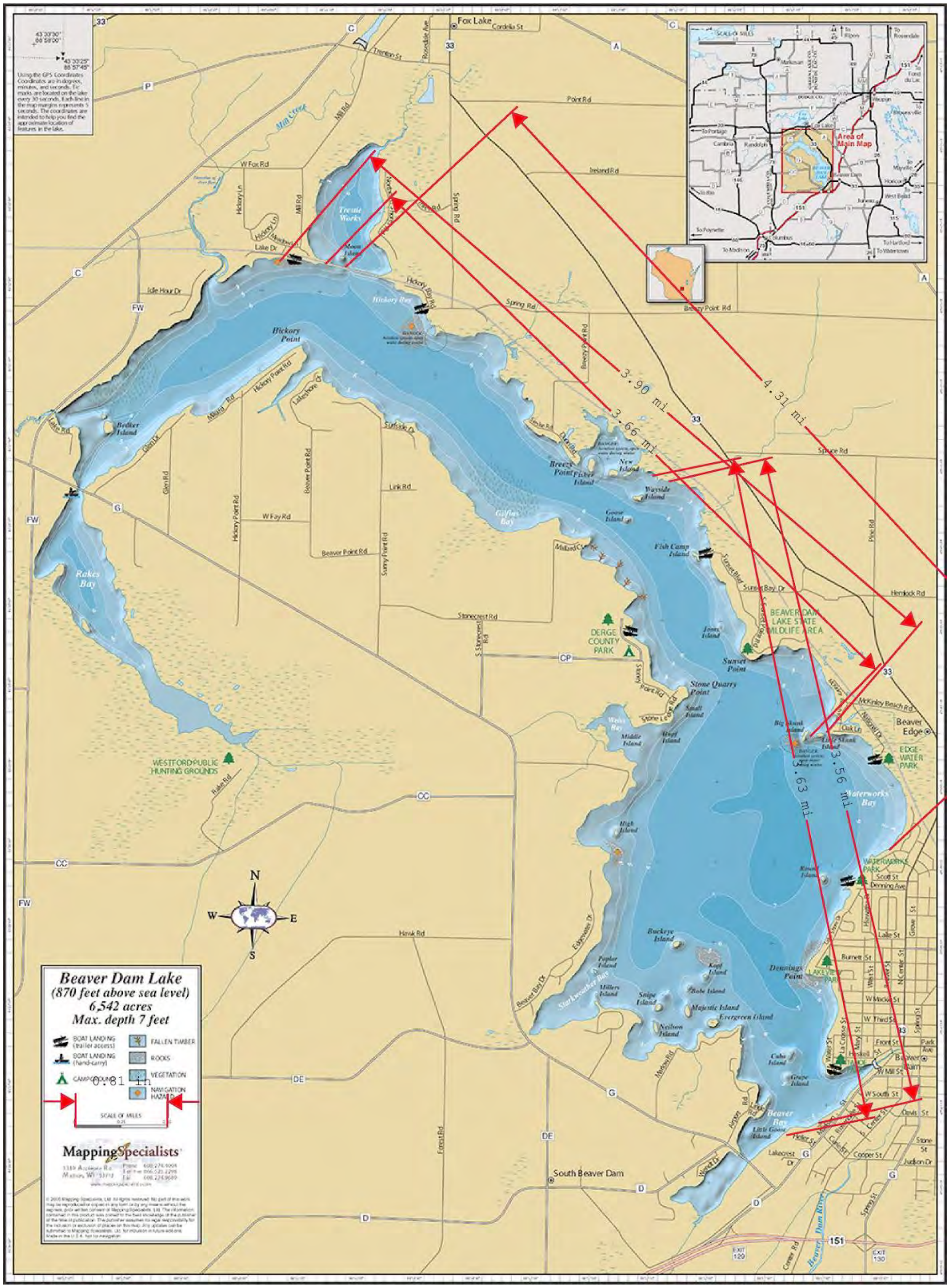
Appendices

APPENDIX A: BEAVER DAM LAKE FETCH ANALYSIS



APPENDIX B: WIND ROSE ANALYSIS

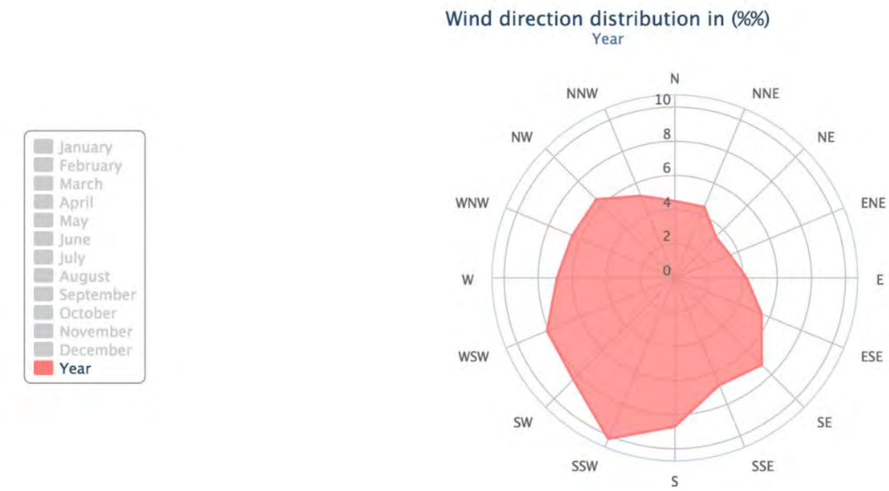


Figure 2: Wind rose data for Beaver Dam Lake from Juneau weather station

APPENDIX C: WIND WAVE ANALYSIS FINAL RESULTS

Wind Wave Model ~ Significant Wave Height and Peak Wave Period							
			Chin H. Wu, University of Wisconsin, Madison, November 2015				
Input Data				Metric System		SI Unit System	
					Unit		**Unit**
Lake Mean Water Depth d =				1.73736	m	5.6	ft
Lake fetch x =				6936.273	m	4.311	mile
Historical Wind Speed U10 =				5.36448	m/s	17.6008589	ft/sec
Process Parameter							
non-dimensional fetch gx/(U10)^2 =				2364.5033		2363.9669	
non-dimensional water depth gd/(U10)^2 =				0.5922		0.5816	
non-dimensional epilson g^2 E/(U10)^4 =				2.5324E-04		2.5131E-04	
wave energy/(lenghth weight) E =				0.0022	m^2	0.0233	ft^2
non-dimensional mu fp*U10/g =				2.8657E-01		2.8719E-01	
Output Results							
Hs (significant Wave Height) =				0.19	**m**	0.61	**ft**
Tp (peak period) =				1.9	**seconds**	1.9	**seconds**
	Value	Value	Units				
Wave Length	0.16712	0.16712	m				
Max Bottom Boundary Velocity	0.223833976	0.223833976	m/s				
Reynolds Number	15	30					
Bottom Shear Stress	0.751524734	1.503049468	dynes/cm^2				
Resuspension Rate	3.34528E-07	1.33406E-06	g/s*cm^2				
Suspended-Sediment Concetration (2 hr period)	**24.1**	**55.3**	mg/L				

Table 1: Wind Wave Model

APPENDIX D: MEAN GROWING SEASON PHOSPHORUS CONCENTRATIONS

The original nutrient assessment was based on a mean P concentration of 256 ug/L, which translates to a yearly phosphorus loading total of 531,000 pounds. However, considering the most recent four years and excluding two previous years of higher than average P levels, the mean P concentration and yearly total drop to 200 ug/L and 414,000 lbs/year, respectively. This increases P contribution ratios from carp feces, high pH levels during the summer, and external loading while decreasing the amount of unaccounted P contributions.

More importantly, Figures 3 and 4 illustrate more realistic ranges of P contributions based on more accurate external loading and mean P levels. Further knowledge of external P loading would serve to reduce uncertainty on exact contribution values from wind and carp induced P resuspension. Figure 3 illustrates the decreasing amount of P due to wind and carp resuspension as external loading values for P are increased. At 6.25 lb/acre, only 2% of the lakes total P is unaccounted for.

As discussed above, there is great reason to believe that wind and carp P resuspension is occurring, leading us to believe that external loading factors are currently undervalued. Figure 4 further illustrates this point, showing P contributions as a percentage of 414,000 total lbs of P, based on the most recent four years of data. Even if external P loading was simply doubled on row crops only to 1.78 lb/acre, only 43,000 lbs of the total P would be due to wind and carp, or the previously "unknown internal" P loading. Increasing external P loading to a still-realistic value of 2.68 lb/acre (3 kg/ha) further reduces the amount of wind and carp induced P resuspension to 16,500 lbs/year. This value seems extremely plausible, working out to 0.000672 lbs P/acre/day.

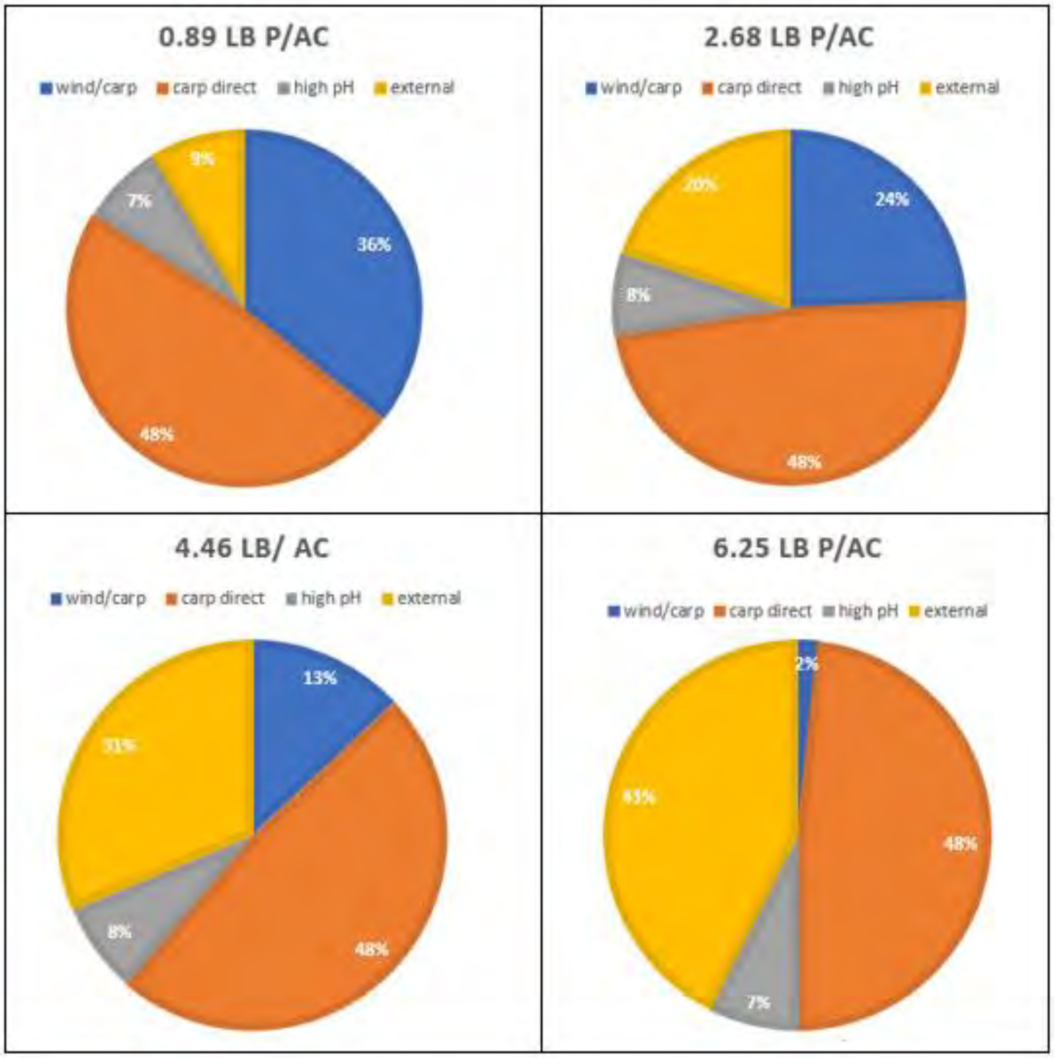


Figure 3: *Total P loading 531,000 lb, external loadings of 0.89, 2.68, 4.46, and 6.25 lbs/acre*
(1, 3, 5, 7 kg/ha, respectively)

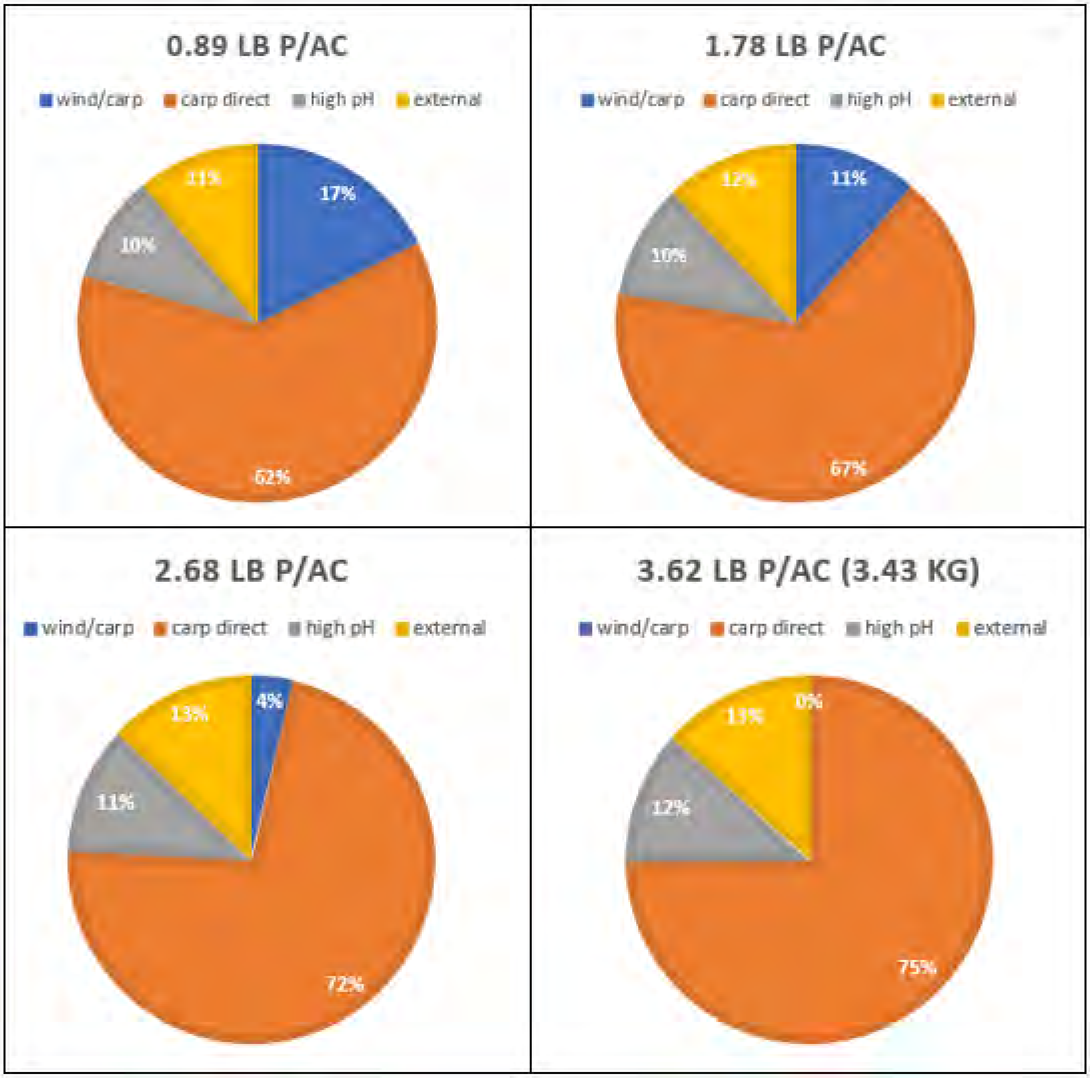


Figure 4: *Total P loading 414,000 lb, external loadings of 0.89, 1.78, 2.68, and 3.62 lbs/acre*
(1, 2, 3, 3.43 kg/ha, respectively)

APPENDIX E: WATERSHED PHOSPHORUS CONTRIBUTIONS

Table 2. Range of Possible Watershed Phosphorus Contributions to Beaver Dam Lake		
Source	Average P Loading (lbs/acre)	Estimated Watershed P (lbs/year)
WiLMS Default Assumption	0.89	45, 858.6
Tile P Run-off (Madison et al., 2014)	1.04	50,835.0
Edge-of-Field (Stuntebeck et al., 2011)	2.0	83,149.8
Surface P Run-off (Madison et al., 2014)	2.85	111,749.7
Yahara WINS (MMSD, 2016)	3.3	126,910.0

Figure 5: Reported Agricultural Phosphorus Loads

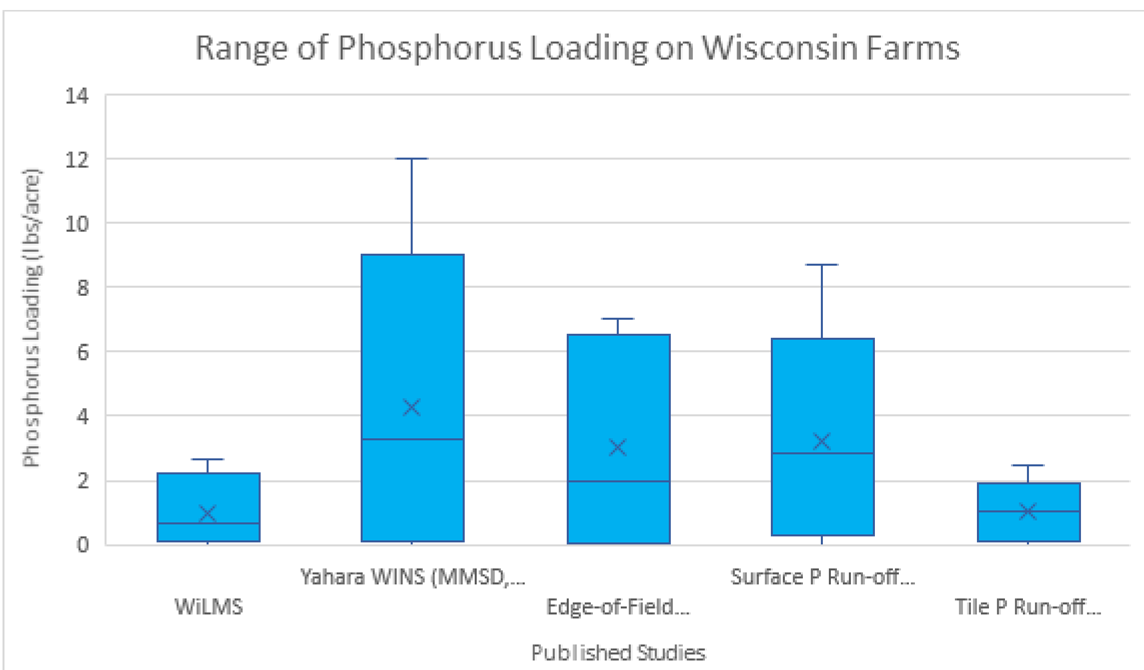
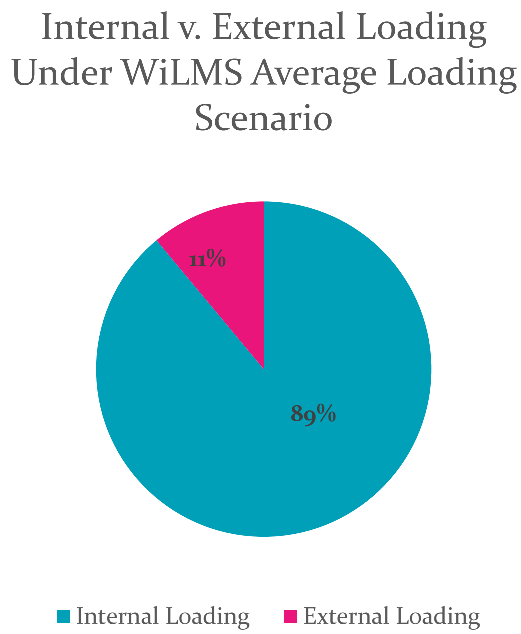
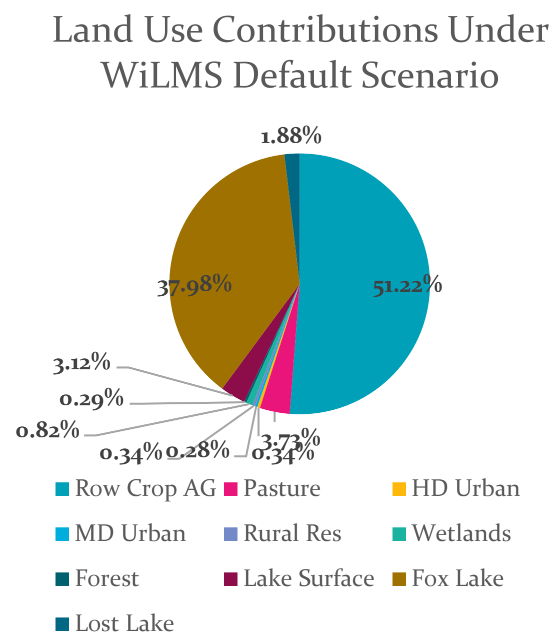
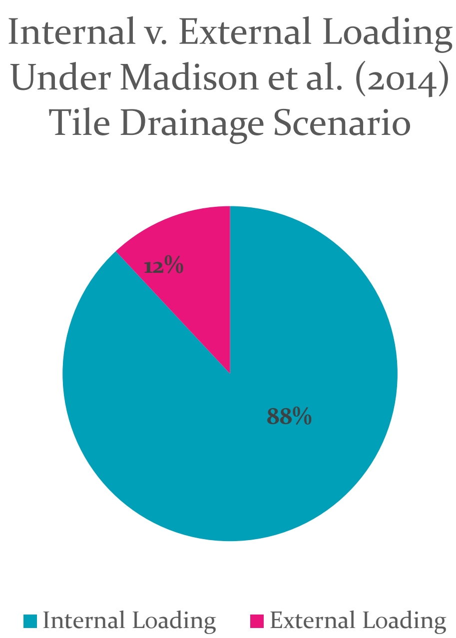
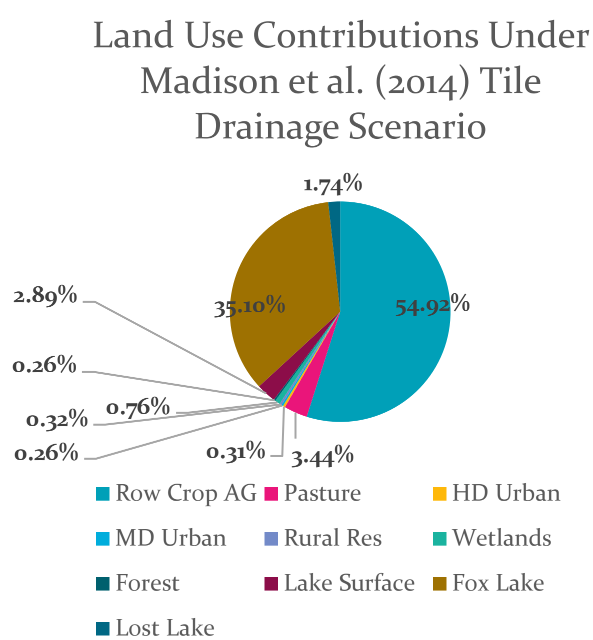


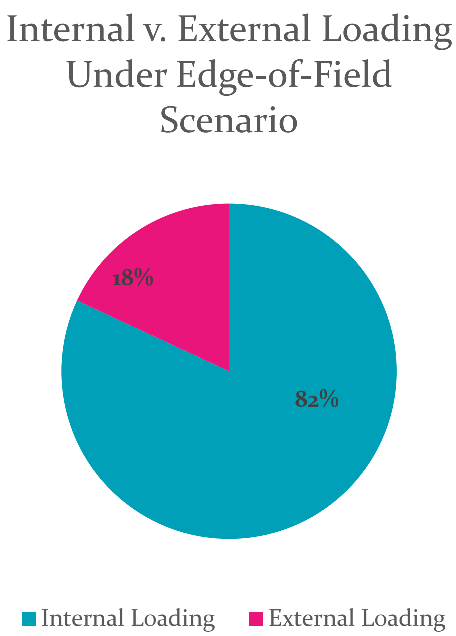
Figure 6: Internal V. External Loading and Land Use Contributions

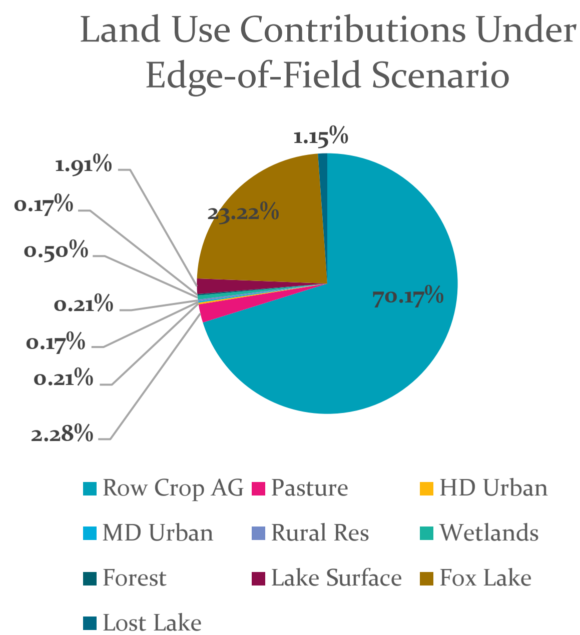


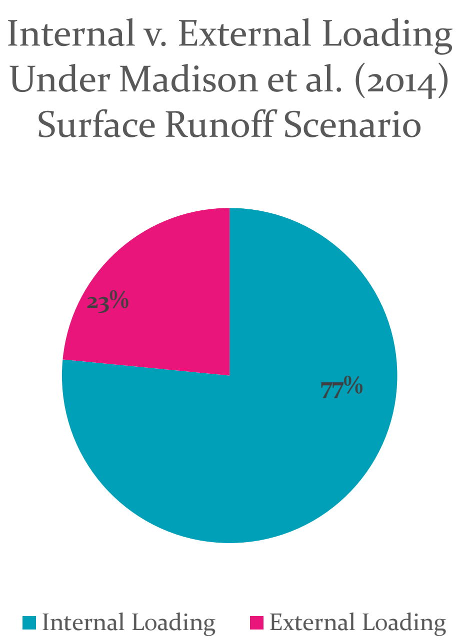


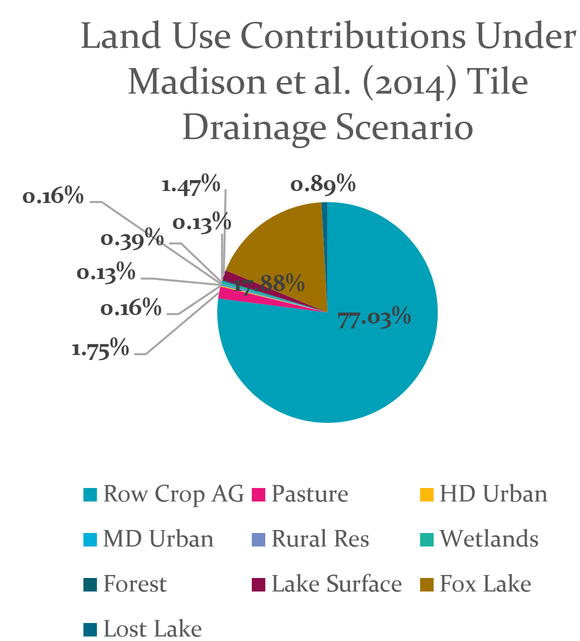


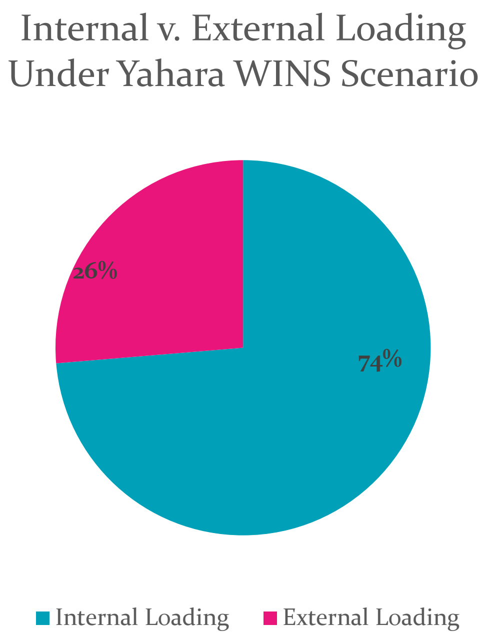


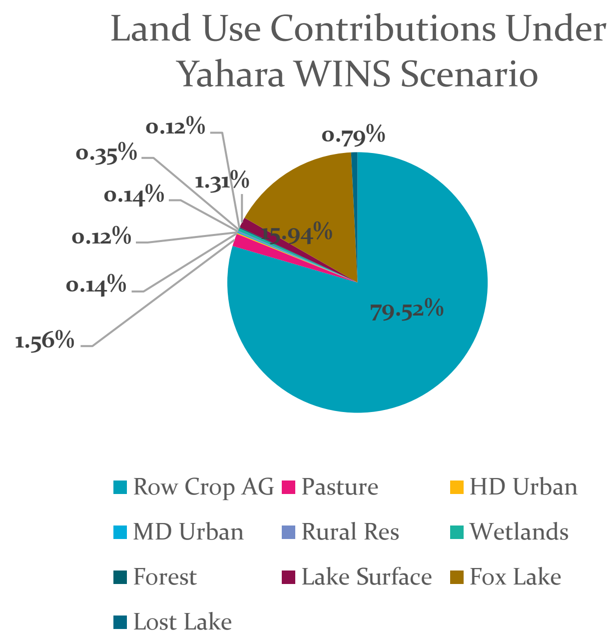

Internal v. External Loading Under Edge-of-Field Scenario
18%
82%
Internal Loading
External Loading


Land Use Contributions Under Edge-of-Field Scenario
1.15%
1.91%
0.17%
23.22%
0.50%
0.21%
70.17%
0.17%
0.21%
2.28%
Row Crop AG
Pasture
HD Urban
MD Urban
Rural Res
Wetlands
Forest
Lake Surface
Fox Lake
Lost Lake


Internal v. External Loading Under Madison et al. (2014) Surface Runoff Scenario
23%
77%
Internal Loading
External Loading


Land Use Contributions Under Madison et al. (2014) Tile Drainage Scenario
0.16%
1.47%
0.89%
0.39%
0.13%
0.13%
17.88%
0.16%
77.03%
1.75%
Row Crop AG
Pasture
HD Urban
MD Urban
Rural Res
Wetlands
Forest
Lake Surface
Fox Lake
Lost Lake


Internal v. External Loading Under Yahara WINS Scenario
26%
74%
Internal Loading
External Loading


Land Use Contributions Under Yahara WINS Scenario
0.12%
0.35%
0.14%
0.12%
0.14%
1.56%
1.31%
0.79%
79.52%
Row Crop AG
Pasture
HD Urban
MD Urban
Rural Res
Wetlands
Forest
Lake Surface
Fox Lake
Lost Lake

Montgomery Associates Resource Solutions, LLC

MEMORANDUM

To: Bill Foley, Beaver Dam Lake Improvement Association

From: Rob Montgomery, Gabe Montgomery

Date: December 31, 2018

Re: Results of 2018 water quality monitoring at Beaver Dam Lake

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INTRODUCTION AND OBJECTIVE

This memo presents the results of water quality monitoring conducted during 2018 on tributaries to Beaver Dam Lake. This work was done as part of the Beaver Dam Lake Management Plan Phase II, prepared by the Beaver Dam Lake Improvement Association (BDLIA), funded by Wisconsin DNR Lake Protection Grant 161717. The objective of the water quality monitoring was to provide additional data on total suspended solids (TSS) and total phosphorus (TP) loading to Beaver Dam Lake. Activities included:

1. Obtain data on TSS and TP loading to the lake over most of the growing season, and especially the early-season rainfall/runoff events that were likely to produce heavy loads to Beaver Dam Lake;

2. Utilize water quality data collected by BDLIA and the Beaver Dam on the Beaver Dam River downstream of the lake to evaluate TP movement into, through and out of Beaver Dam Lake;

The results of the water quality monitoring will supplement recent evaluations of the nutrient balance of Beaver Dam Lake, including the WILMS modeling and Lake water quality evaluation described in the Beaver Dam Lake Comprehensive Plan by Onterra funded by the Wisconsin DNR and conducted for BDLIA in 2015, and also the water quality sampling, analysis and WILMS model evaluation described in the University of Wisconsin-Madison Water Resource Management Practicum project report issued in 2018.

Data collection was conducted primarily by Montgomery Associates: Resource Solutions LLC (MARS) supported by personnel from the Beaver Dam Lake Improvement Association (BDLIA) and personnel from the Beaver Dam water/wastewater utility (Beaver Dam). This water quality monitoring effort was part of the activities funded by a Wisconsin DNR Lake planning grant awarded to BDLIA.

MONITORING LOCATIONS AND ACTIVITIES

Data collection locations used in this analysis are shown on the attached map and are described below:

LOCATION	PARAMETERS	EQUIPMENT	DATES OF DATA COLLECTION (2018)
Beaver Creek at CTH G	Continuous discharge, flow proportional TP and TSS	MARS Isco 2150 flow module paired with Isco 3600 sampler	April 27 through October 25
Mill Creek at Westfox Rd.	Continuous discharge, flow proportional TP and TSS	MARS Isco 2150 flow module paired with Isco 3600 sampler	May 11 through October 25
B Unnamed tributary at Spring Rd.	Grab sample for TP and TSS	NA	May 4 and 11
C Unnamed tributary at STH 33	Grab sample for TP and TSS	NA	May 4 and 11
D Unnamed tributary at CTH F	Grab sample for TP and TSS	NA	May 4 and 11
E Unnamed tributary at CTH CC	Grab sample for TP and TSS	NA	May 4 and 11
Beaver Dam River at City WWTP	Grab sample for TP and TSS	NA	Weekly, May 7 through October 11
Rakes Bay at CTH G	Water depth and velocity	(2) MARS Isco 2150 flow modules mounted in waterway beneath bridge	April 27 through September 26
	Grab sample for TP and TSS or TK	NA	May 4, May 11, May 18, Jun. 21, Jul. 20, Aug. 28, and Oct. 25.
Beaver Dam River at Cooper St.	Continuous Discharge	USGS Gage 05425912 – water stage recorder with rating curve	March 1985 to present
Beaver Dam Lake	Grab sample for TP and TSS at 2 locations	Volunteer Lake Monitoring by BDLIA, data maintained by DNR	May 18, Jun. 21, Jul. 28, and Aug. 28
Beaver Dam Lake	Lake Stage	Water level recorder maintained by Beaver Dam	Daily data
Beaver Dam	Precipitation	USGS Gage 05425912 – Precipitation Gage	March 1985 to present

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Water quality data collection and analysis procedures are summarized below:

LOCATION	PARAMETERS	COLLECTION	ANALYSIS
Beaver Creek at CTH G	TP and TSS	MARS staff through Jun. 14, Beaver Dam WWTP staff through Sep. 13	Wisconsin state hygiene laboratory (WSLH) before Jun 14, Beaver Dam Waste Water Treatment Plant (WWTP) laboratory Jun. 14 through Sep. 13
Mill Creek at Westfox Rd.	TP and TSS	MARS staff through Jun. 14, Beaver Dam WWTP staff through Sep. 13	WSLH before Jun. 14, Beaver Dam WWTP laboratory Jun. 14 through Sep. 13
Rakes Bay tributary at CTH G	TP and TSS	MARS staff May 4, May 11, and Oct. 25. Beaver Dam WWTP staff May 18 through Aug. 28.	WSLH May 5, May 11, and Oct. 25. Beaver Dam WWTP laboratory May 18 through Aug. 28
B Unnamed tributary at Spring Rd.	TP and TSS	MARS staff	WSLH
C Unnamed tributary at STH 33	TP and TSS	MARS staff	WSLH
D Unnamed tributary at CTH F	TP and TSS	MARS staff	WSLH
E Unnamed tributary at CTH CC	TP and TSS	MARS staff	WSLH
Unnamed tributary to Mill Creek at Westfox Rd.	TP	Beaver Dam WWTP staff	Beaver Dam WWTP laboratory
Beaver Dam River at City WWTP	TP and TSS	Beaver Dam WWTP staff	Beaver Dam WWTP laboratory
Beaver Dam Lake	TP and TSS	BDLIA volunteer monitor	WSLH

The discharge monitoring and water quality sampling stations at Beaver Creek and Mill Creek were installed by MARS with support from BDLIA. The flow sensors and sampler intake screens were installed on precast concrete blocks placed 4 inches to 5 inches above creek bottom. Stage/discharge rating curves were established using several measurements using a pygmy current meter. Discharge was evaluated using both the flow velocity/depth sensor and the rating curve, compared (at Beaver Creek) with the results of the Water Resource Management Practicum study conducted in 2017. Water quality sampling was conducted using several grab samples as well as both time- and flow-proportional sampling by the Isco sampler. Power to the samplers and flowmeters was supplied using lead-acid batteries with a supplemental trickle charge provided by solar panel. In general, data collection was reliable but several gaps in the flow and sample record occurred to malfunctions.

Grab sampling was conducted on May 4 and 11 at 4 watersheds that are directly tributary to Beaver Dam Lake, as shown on the attached figure. The purpose of this sampling was to provide data on TSS and TP to assist in estimating loads to Beaver Dam Lake.

Daily rainfall depth and Grab sampling for TSS and TP analysis was conducted weekly on the Beaver Dam River adjacent to the Beaver Dam WWTP by water utility personnel in cooperation with this study. Sample analysis was conducted by the Wisconsin state hygiene lab and, later, by the laboratory at the Beaver Dam WWTP.

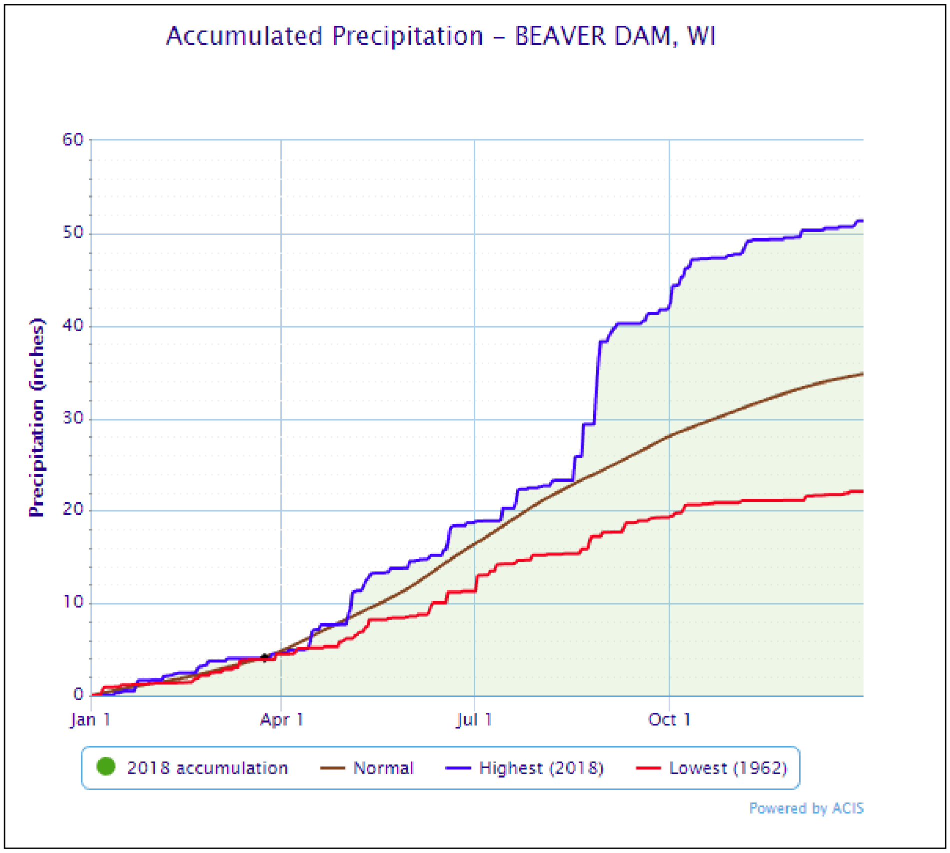
Water quality sample analysis results are presented in the tables and figures attached to this memorandum.

WEATHER AND RUNOFF IN 2018

2018 was a year of heavy rainfall and very substantial flooding. The cumulative precipitation at Beaver dam in comparison to long-term averages and the lowest precipitation amounts are shown in the figure below. More than 50 inches of rain fell at the Beaver Dam precipitation reporting station, making 2018 the record high year for precipitation depth. However, as illustrated in the figure, apart from the extraordinarily high rainfall that was received in late August and early September 2018 was an approximately “normal” year in terms of the accumulation of precipitation through the year.

Relevant to the potential for TSS and TP loading to Beaver Dam Lake, heavy rainfall occurred in late April and early May, in a heavy snow/heavy rain weather system that produced substantial local runoff. Visual observations and collected data indicate that the April/May runoff was very turbid compared to typical conditions. Additional significant rainfall occurred in June and July. The record-high rainfall events struck the area in late August and early September, with more than 16 inches of rainfall occurring.

Therefore, because of the heavy precipitation received, the 2018 water quality data collection program would be expected to result in TSS and TP loadings higher than long-term average rates. However, because the very high precipitation in August and September fell on cropland that was covered with mature vegetation, it is possible that the loading rates may not be as extreme as the annual precipitation depth would suggest.



Heavy flow and muddy water at the Beaver Creek monitoring site, May 4, 2018

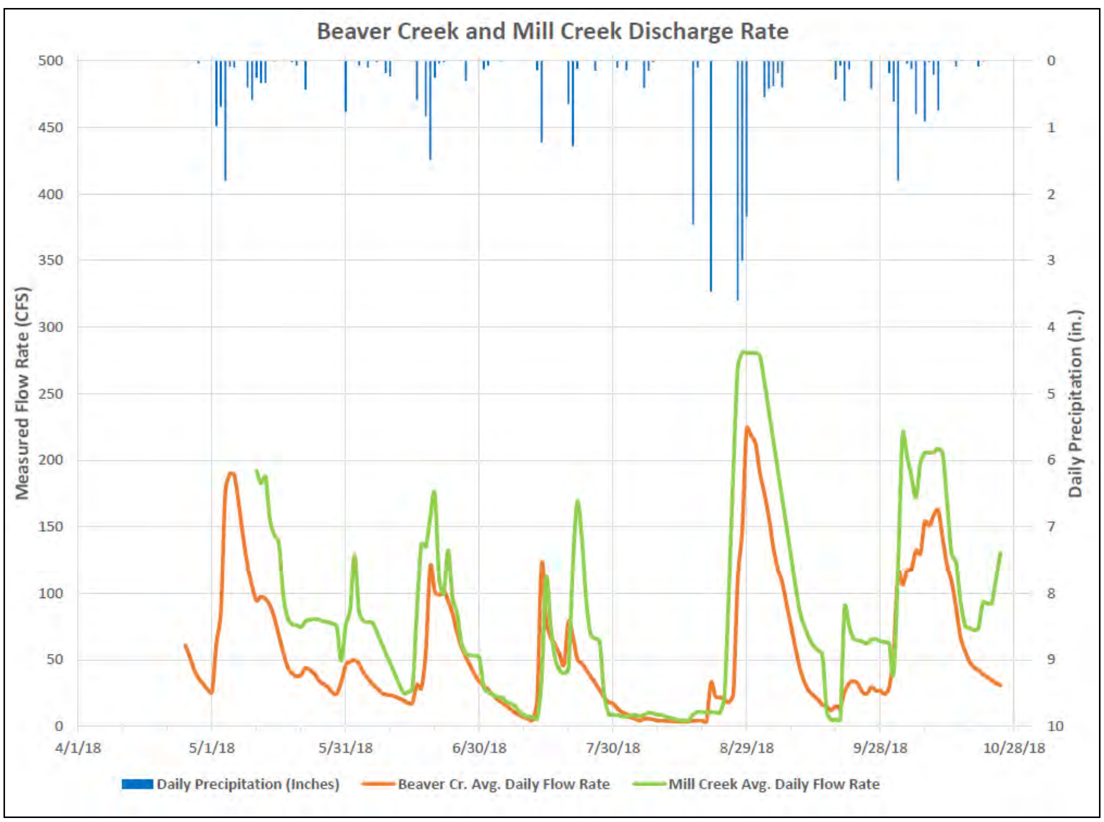
TSS AND TP LOAD CALCULATIONS FOR BEAVER AND MILL CREEKS

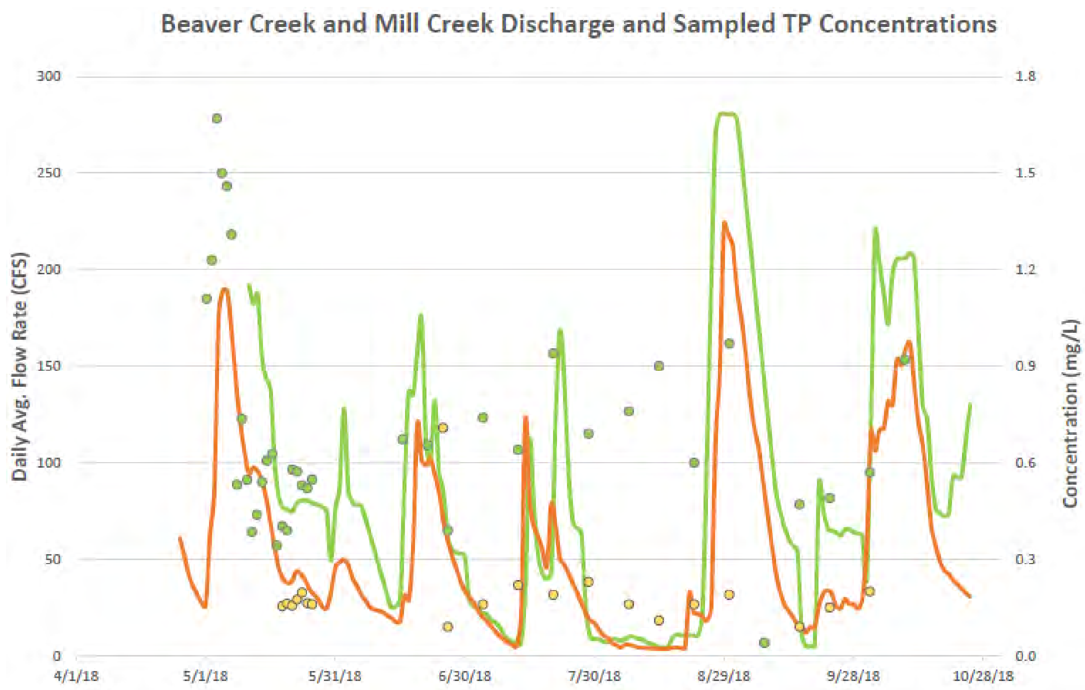
Calculation of TSS and TP loads at Beaver Creek and Mill Creek was completed using the following procedure:

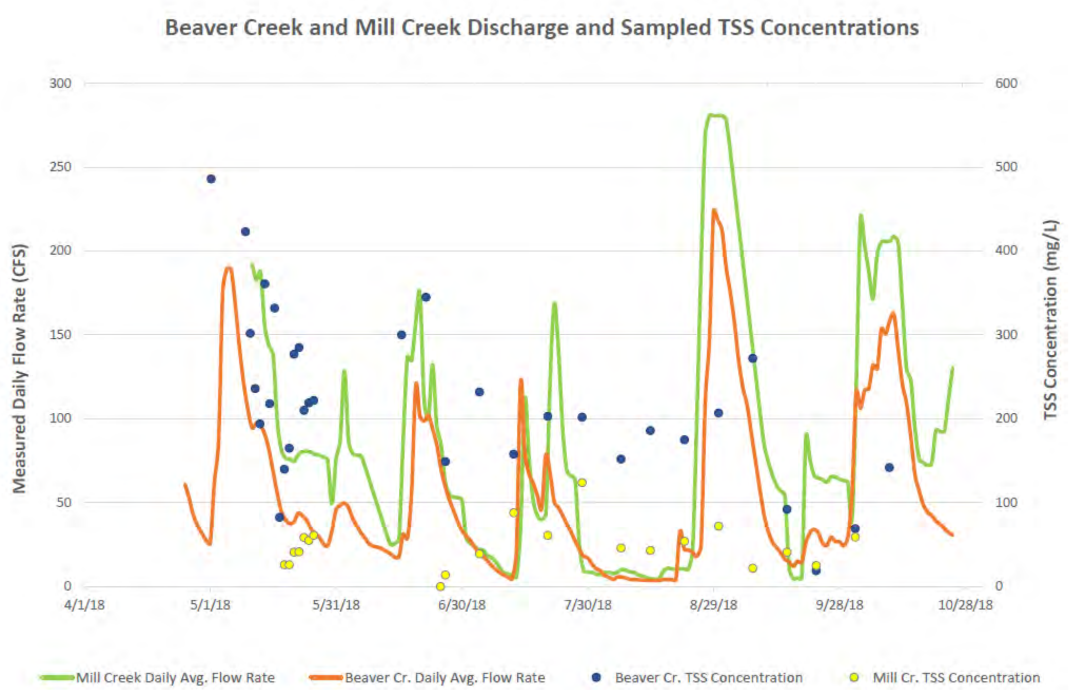
1. Download and assembly of depth and velocity data from the Isco flow module, correlation to determine discharge using rating curve with checks using flow module calculations, data plotting and visual correlation checks with measured precipitation, and calculation of flow volumes.

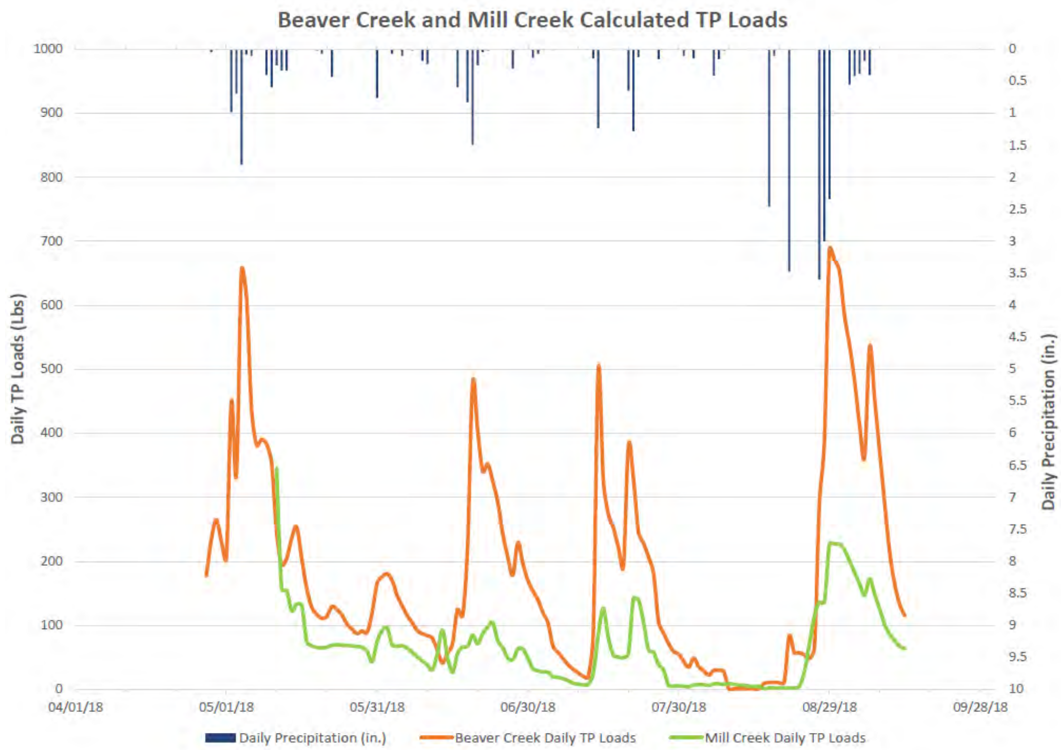
2. Assembly of grab, time-proportional and flow-proportional water quality sample analysis results, assignment of applicable periods of discharge to the sample dates, followed by calculation of loads for sample periods.

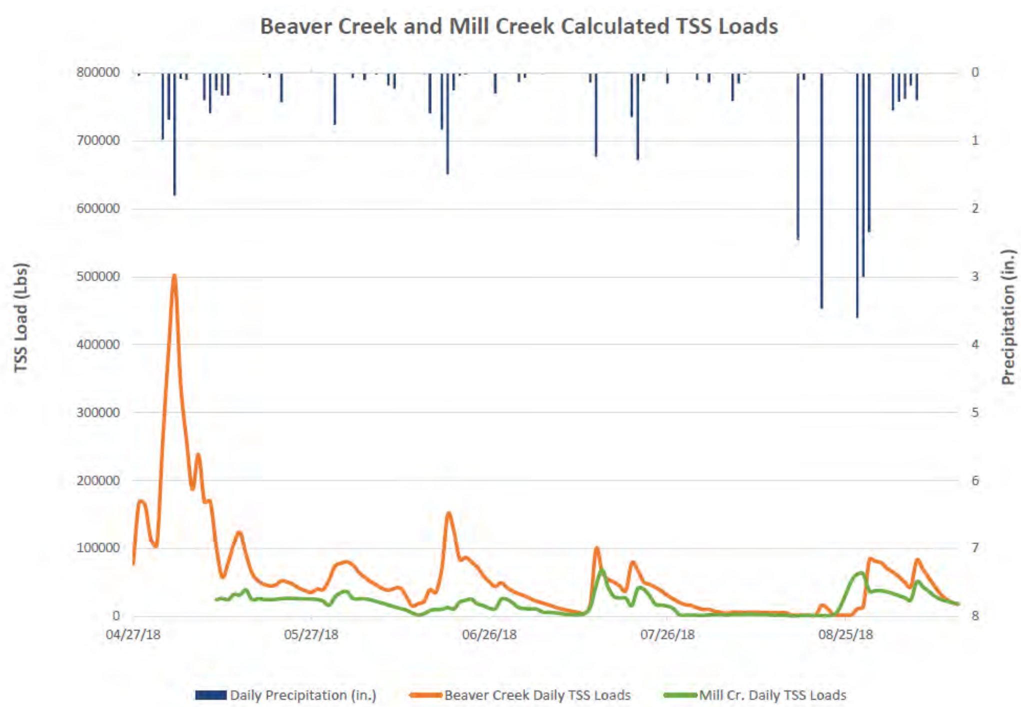
The sequence of this load calculation procedure is illustrated in the following figures for Beaver and Mill Creeks:




Beaver Creek and Mill Creek Discharge and Sampled TP Concentrations
Daily Avg. Flow Rate (CFS)
Concentration (mg/L)
300
250
200
150
100
50
0
1.8
1.5
1.2
0.9
0.6
0.3
0.0
4/1/18
5/1/18
5/31/18
6/30/18
7/30/18
8/29/18
9/28/18
10/28/18


Beaver Creek and Mill Creek Discharge and Sampled TSS Concentrations
Measured Daily Flow Rate (CFS)
TSS Concentration (mg/L)
300
250
200
150
100
50
0
600
500
400
300
200
100
0
4/1/18
5/1/18
5/31/18
6/30/18
7/30/18
8/29/18
9/28/18
10/28/18
Mill Creek Daily Avg. Flow Rate
Beaver Cr. Daily Avg. Flow Rate
Beaver Cr. TSS Concentration
Mill Cr. TSS Concentration


Beaver Creek and Mill Creek Calculated TP Loads
Daily TP Loads (Lbs)
Daily Precipitation (in.)
04/01/18
05/01/18
05/31/18
06/30/18
07/30/18
08/29/18
09/28/18
Daily Precipitation (in.)
Beaver Creek Daily TP Loads
Mill Creek Daily TP Loads


Beaver Creek and Mill Creek Calculated TSS Loads
TSS Load (Lbs)
Precipitation (in.)
04/27/18
05/27/18
06/26/18
07/26/18
08/25/18
Daily Precipitation (in.)
Beaver Creek Daily TSS Loads
Mill Cr. Daily TSS Loads

A summary of the calculated TSS and TP loads is provided in the following table:

	Beaver Creek Watershed		Mill Creek Watershed	
Month	TP Load (Lbs)	TSS Load (Lbs)	TP Load (Lbs)	TSS Load (Lbs)
Apr	900	523,600		
May	7,300	3,916,200	2,000	553,800
Jun	5,500	1,733,900	1,900	530,600
Jul	4,700	1,019,200	1,300	531,700
Aug	3,400	413,800	1,300	381,000
Sep	4,700	639,000	1,800	400,300
Totals	26,500	8,245,700	8,300	2,397,400

Observations from the collected data include:

1. The TSS and TP loads are expected to be much higher than long-term average values due to the extremely heavy precipitation that occurred in 2018.

2. Beaver Creek is a free-flowing stream, whereas Mill Creek discharge is strongly related to gate operation and spillway overflow at the structure controlling Fox Lake.

3. Heavy snow occurred in April followed by heavy rains producing substantial flooding throughout the watershed. Conditions at Beaver Creek and Mill Creek included large channel discharge including out of bank flooding, and extremely turbid water.

4. TP concentrations in Beaver Creek were very high in April and early May (TP typically 1.2 to 1.5 mg/L) but are consistently lower, with TP in the range of 0.3 to 0.9 mg/L from May through September. TP concentrations in Mill Creek are much lower, typically approximately 0.2 mg/L.

5. The TP concentrations at Beaver Creek collected by grab samples and the flow/sampler equipment used in this analysis were consistently higher than the grab sample results for sampling by BDLIA volunteer staff and uploaded to the SWIMS database. This difference could be due to sampling location or technique.

6. Due to the differences in sample concentrations, calculated TSS and TP loads are much higher from Beaver Creek than they are for Mill Creek, even though the Mill Creek

watershed has a larger area. This is likely to be due to trapping of TSS and associated TP in Fox Lake and may also be due to lower loading rates in the Mill Creek watershed.

CALCULATION OF TOTAL TSS AND TP LOAD TO BEAVER DAM LAKE

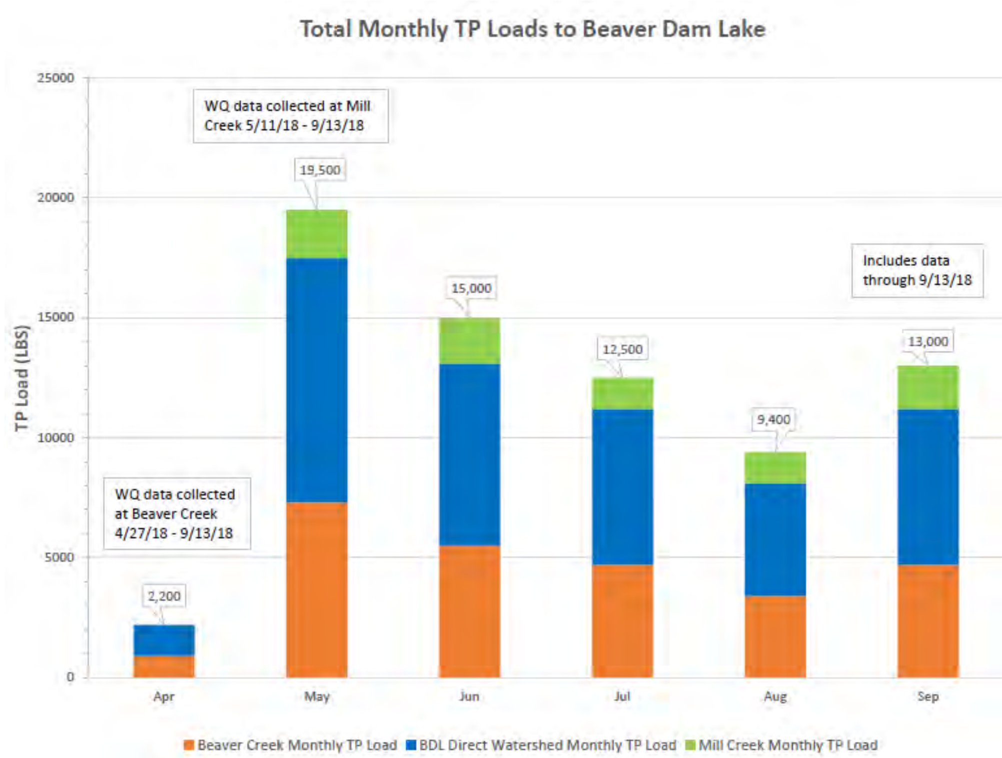
Total TSS and TP loads to Beaver Dam Lake were calculated using the measured loads at Beaver and Mill Creeks, and an estimate of the load from the watershed contributing directly to Beaver Dam Lake (see watershed location figure). Calculated TSS and TP loads for Beaver Creek were as an estimate of loading from the watershed directly tributary to the lake because Beaver Creek is a free-flowing stream and had generally similar land use as the directly tributary watershed (see figure).

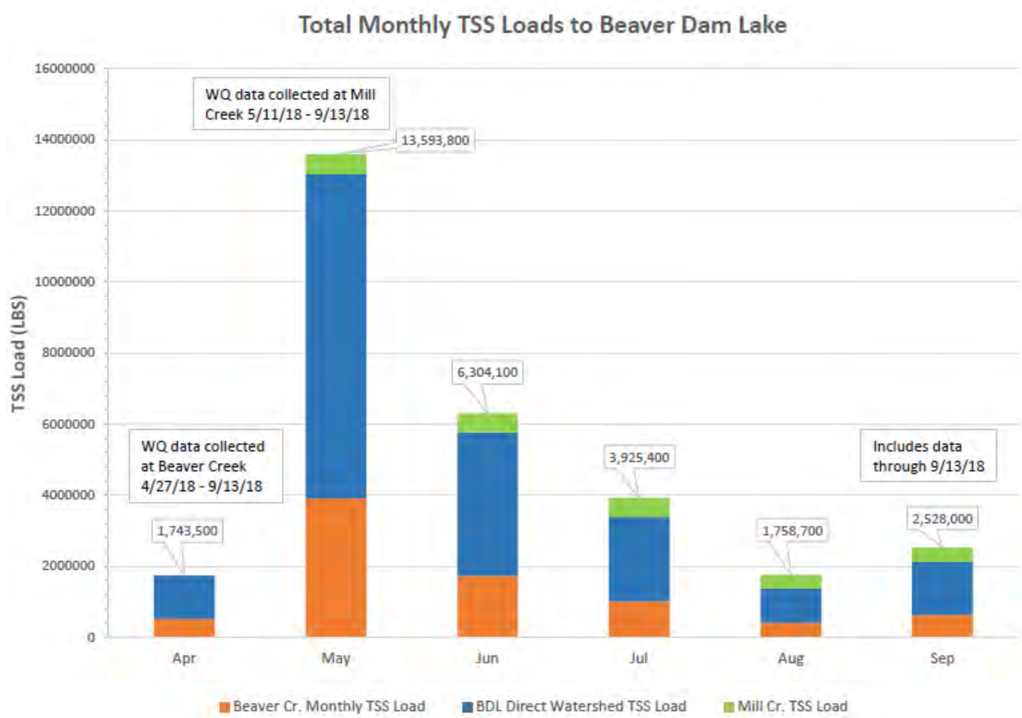
Beaver Dam Lake (BDL) Sub-watershed Areas	USGS Hydrologic Unit Code (HUC-12) Area (acres)
Beaver Creek	**21,328**
Mill Creek	**41,579** >Fox Lake = 32,651 >Alto Creek = 8,928
Beaver Dam Lake Direct	37,012
BDL Surface Area	6,718
BDL Direct - BDL Surface Area =	**30,294**
Watershed Area Ratio	30,294/21,328 = **1.42**

Grab sample results collected at four subwatersheds of the directly tributary watershed (see figure) on May 5 and 11 were compared to grab sample results at Beaver Creek. The resulting average ratio of TSS and TP concentration shown in the table below was used together with the ratio of watershed areas to estimate loading from the directly tributary watershed.

	Sample Location TP Concentration Ratios				Sample Location TSS Concentration Ratios			
Grab Sample Site Location	Sample TP Concentration 5/4/2018	Ratio (Site Sample Conc.)/(BC Sample Conc.)	Sample TP Concentration 5/11/2018	Ratio (Site Sample Conc.)/(BC Sample Conc.)	Sample TSS Concentration 5/4/2018	Ratio (Site Sample Conc.)/(BC Sample Conc.)	Sample TSS Concentration 5/11/2018	Ratio (Site Sample Conc.)/(BC Sample Conc.)
Beaver Creek (BC)	0.483		0.294		78		11.7	
B	0.392	0.81	0.118	0.40	57	0.73	13.3	1.14
C	0.842	1.74	0.282	0.96	180	2.31	42	3.59
D	0.194	0.40	0.128	0.44	11	0.14	4	0.34
E	0.204	0.42	0.786	2.67	33.5	0.43	52	4.44
	avg1	0.84	**avg2**	1.12	**avg1**	0.90	**avg2**	2.38
			avg(avg1, avg2) =	**0.98**			**avg(avg1,avg2) =**	**1.64**

The calculated loads for Beaver Creek, Mill Creek and the directly tributary watershed were combined to provide an estimate of total TSS and TP loading to Beaver Dam Lake over the monitoring period, as shown in the figures below:


Total Monthly TP Loads to Beaver Dam Lake
TP Load (LBS)
25000
20000
15000
10000
5000
0
WQ data collected at Mill Creek 5/11/18 - 9/13/18
WQ data collected at Beaver Creek 4/27/18 - 9/13/18
Includes data through 9/13/18
2,200
19,500
15,000
12,500
9,400
13,000
Apr
May
Jun
Jul
Aug
Sep
Beaver Creek Monthly TP Load
BDL Direct Watershed Monthly TP Load
Mill Creek Monthly TP Load



A summary of the calculated TP and TSS total loads to Beaver Dam Lake is provided in the following table:

	Beaver Creek Watershed		Mill Creek Watershed		BDL Direct Watershed			
Month	TP Load (Lbs)	TSS Load (Lbs)	TP Load (Lbs)	TSS Load (Lbs)	TP Load (Lbs)	TSS Load (Lbs)	Total Monthly TP Loads (Lbs)	Total Monthly TSS Loads (Lbs)
Apr	900	523,600			1,300	1,219,900	2,200	1,743,500
May	7,300	3,916,200	2,000	553,800	10,200	9,123,800	19,500	13,593,800
Jun	5,500	1,733,900	1,900	530,600	7,600	4,039,600	15,000	6,304,100
Jul	4,700	1,019,200	1,300	531,700	6,500	2,374,500	12,500	3,925,400
Aug	3,400	413,800	1,300	381,000	4,700	963,900	9,400	1,758,700
Sep	4,700	639,000	1,800	400,300	6,500	1,488,700	13,000	2,528,000
Totals	26,500	8,245,700	8,300	2,397,400	36,800	19,210,400	71,600	29,853,500

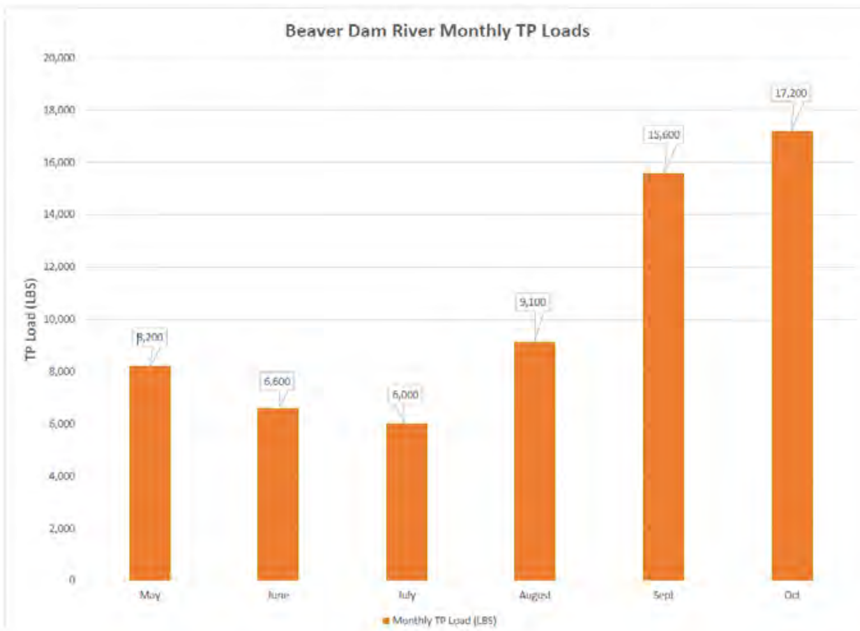
Observations from the above table of calculated loading rates include:

1. The direct watershed TP and TSS loadings are substantial in comparison to the Beaver Creek and Mill Creek watershed loadings.

2. Because the direct watershed loadings are based on Ray showing a relatively small number of data, the total monthly loading rates calculated should be considered to have higher uncertainty than those for either Beaver Creek or Mill Creek

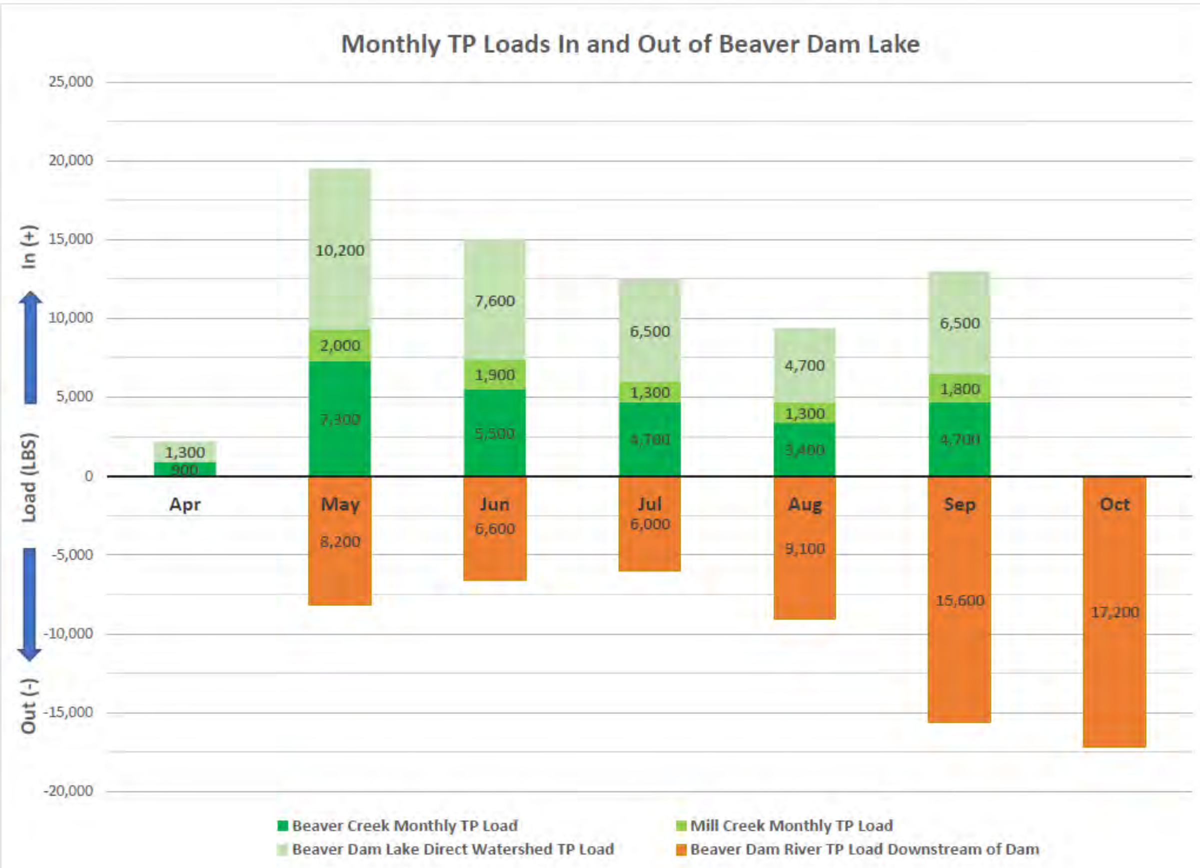
MEASURED TP AND TSS LOADS OUT OF BEAVER DAM LAKE FOR BEAVER DAM RIVER

TSS and TP loads out of Beaver Dam Lake were calculated using dam discharge rates from the USGS gage and grab sample concentrations from analysis of samples collected approximately weekly by the City of Beaver Dam, shown in the figures below:



EVALUATION OF TP LOADING INTO AND OUT OF BEAVER DAM LAKE

Beaver Dam Lake monthly TP inflow and outflow calculated as described above are shown the figure below.



Observations from this comparison include:

- Monthly TP inflow and outflow show months of net absorption of TP (May through July) and periods of pass-through or TP release (August and September).
- The total TP inflow from May until September was 69,400 pounds, and the outflow was 45,100 pounds.

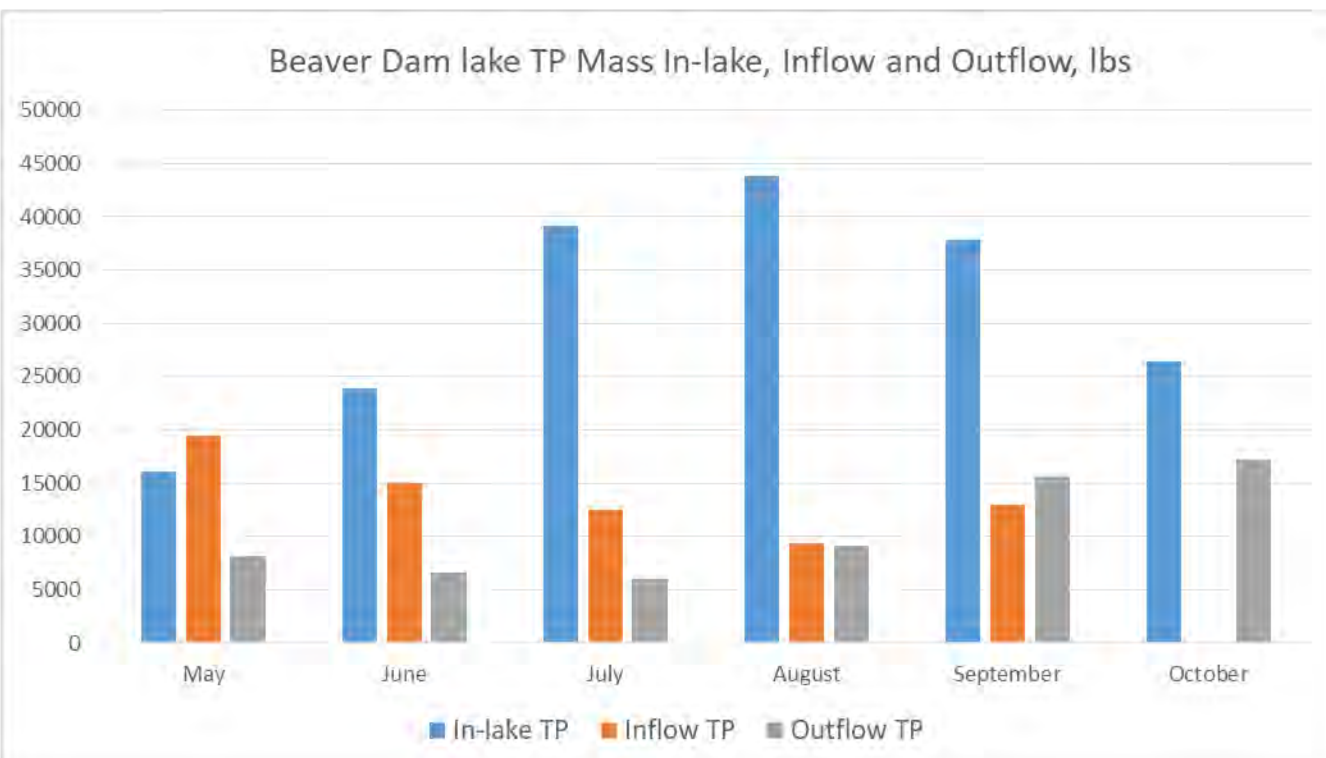
The monthly loading analysis data suggests that Beaver Dam Lake absorbed approximately 24,000 pounds of inflow TP for May through September.

BDL IN-LAKE TP MASS COMPARED TO INFLOW AND OUTFLOW

The mass of phosphorus in the lake was calculated using concentration data collected by MARS and BDLIA personnel, and Lake level and volume data from DNR record sources. The table below summarizes observational data on water column phosphorus concentrations:

	Rakes Bay		Dennening Point		Breezy Point		AVG
Date	TP Conc. (mg/L)	TP Conc.(lb/cf)	TP(mg/l)	TP(lb/cf)	TP(mg/l)	TP(lb/cf)	(TP (Lbs/cf)
5/4/2018	0.248	0.00001548					0.00001548
5/11/2018	0.244	0.00001523					0.00001523
5/18/2018	0.31	0.00001935	0.0457	0.00000285	0.0963	0.00000601	0.00000941
6/21/2018	0.59	0.00003683	0.196	0.00001224	0.135	0.00000843	0.00001917
7/28/2018	0.95	0.00005931	0.335	0.00002091	0.357	0.00002229	0.00003417
8/28/2018	0.65	0.00004058	0.334	0.00002085	0.549	0.00003427	0.00003190
10/25/2018	0.317	0.00001979					0.00001979

The In-lake TP mass data was categorized by month for comparison with the calculated TP inflow and outflow data, and graphed below for comparison.



The monthly TP mass data plot indicates the following:

1. The mass of phosphorus in the lake was generally similar to the inflow mass in May and June, and possibly October.

2. However, in July August and September, the mass of phosphorus in the lake grew substantially, and cannot be explained by calculated TP inflow minus outflow. In-Lake generation of TP in the water column could be produced by bioturbation, possibly by carp, and by algal growth.

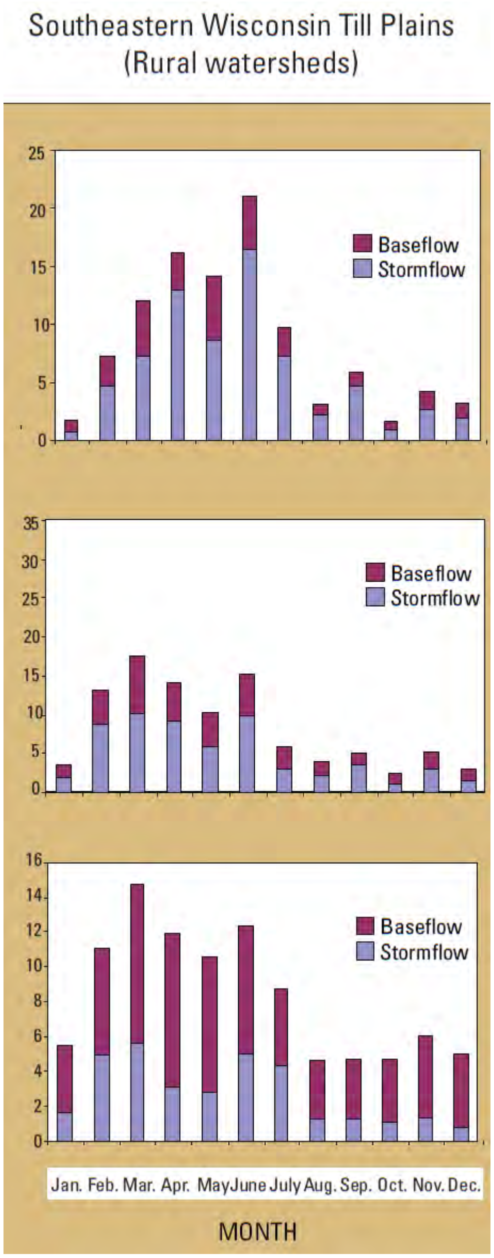
3. Although complete data for the year is not available, the trends in spring and fall suggest that that the annual inflows and outflow mass of TP may be roughly similar to the average mass of TP in Beaver Dam Lake.

ESTIMATED WHOLE-YEAR TP INFLOW MASS AND VARIABILITY

The streamflow data collection program provides TSS and TP inflow data for only the months of May through September 2018. It would be useful to estimate the associated annual loadings to the lake and put these loadings into some context of annual variability, especially considering the extremely high rainfall that the watershed experienced in 2018. The estimates presented in this section should be considered draft, because we have not comprehensively evaluated all of the data that could be considered.

Several watershed monitoring programs have been in place for a number of years in similar agricultural landscapes to Beaver Dam Lake, which can provide an understanding of potential whole-year loadings, given the 5 months of data available. An example is presented below, taken from the US Geological Survey Publication "Characterization of Suspended Solids in Total Phosphorus Loadings from Small Watersheds in Wisconsin", Scientific Investigations Report 2010-5039, published in 2010. This study investigated TSS and TP loading from a variety of watersheds throughout the state. Beaver Dam Lake is located in the area identified as "Southeastern Wisconsin till Plains". A portion of Figure 3 from this report is presented below. This figure indicates that based on the average analysis of multiple stream gages and multiple years of data, the percent of TP delivered for the months of May, June, July, August, and September is approximately 40% of the average annual total. The bulk of the additional TP load typically occurs in February March and April, corresponding with times of snowmelt and the springtime rainfall events that fall on predominantly bear ground in agricultural watersheds.

As tabulated in the table above, the total 2018 TP load to Beaver Dam Lake for May through September was approximately 70,000 pounds. Based on the USGS publication discussed above, and initial approximation of the whole year load for 2018 could be 70,000 / 0.4, or approximately 170,000 pounds.



Percent of average annual solids load

Percent of average annual total phosphorus load

Percent of average annual streamflow

From: Figure 3 Percentage Of Average Annual Solids In Total Phosphorus Loads An Average Annual Streamflow Contributed By Base Flow And Storm Flow For Selected Watersheds In Wisconsin, by month.

The approximated 140,000 pounds TP load for 2018 is clearly on the high (or highest) end of the range for annual average TP load, because 2018 had such extraordinarily high precipitation. The graph presented below is a tabulation of USGS Gage monitoring data for the Yahara River at Windsor for water years 1991 through 2017. All of the years of high TP load (the orange trace) occurred during periods of very high rainfall. Provisional data from USGS loading analyses for Lake

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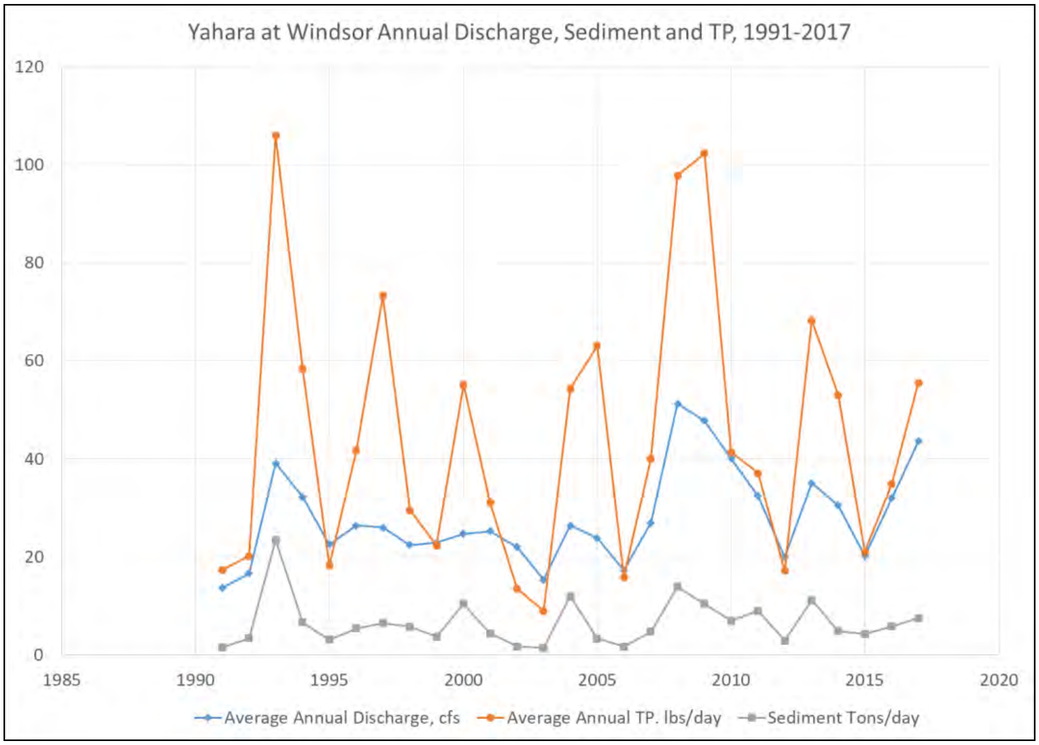
Mendota indicate a total TP load of slightly more than 100,000 pounds, and the 2018 load was the highest for detailed monitoring conducted beginning in 2013.



Based on this brief review, we anticipate that the TP load to Beaver Dam Lake is probably the highest that has occurred over the past several decades. The USGS gauge on the Yahara River at Windsor has the longest TP load record available in southern Wisconsin. This record indicates that loadings range over a factor of 5. The average loading rate is in the range of 40% to 50% of the maximums.

Using this interpretation, and the estimated 2018 load to Beaver Dam Lake of approximately 140,000 pounds, we would anticipate that the long-term TP load to Beaver Dam Lake would be expected to be approximately in the range of 40,000 to 60,000 pounds per year. Given the variability and anticipated accuracy of the data used in developing this projection, our estimate of average loading rates should probably be considered to be from 30,000 pounds to 70,000 pounds per year. We caution that this is an approximate estimate.

Discussion

This report presents a large amount of data that needs to be carefully reviewed in the context of previous studies and other data available in the region. However, some initial observations are:

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1. The approximate long-term TP loading estimate of 30,000 to 70,000 pounds per year is consistent with the WiLMS estimate of 46,000 pounds per year, presented in the 2015 Beaver Dam Lake comprehensive management plan report.

2. Referencing the inflow outflow and water quality TP figure above, the estimated in Lake water column TP mass is approximately 4 times the mass of the monthly load. Although full year data is not available, the TP mass on an annual basis would likely be significantly less than 4 times the inflow load. Thus, the collected data suggests that the external watershed TP load to Beaver Dam Lake is a significant fraction of the total TP load to the lake.

We suggest that data collection continue, because it will be important to collect data in a more "normal" precipitation year. However, the data also suggest that intensive efforts to manage and reduce watershed TP loading to Beaver Dam Lake will be relatively more valuable than previous Lake nutrient model analyses have suggested.

Raw data from this project is available on your request.

We appreciate the opportunity to be involved with this project.

Attachments: Watershed figure showing watershed extent and monitoring points.

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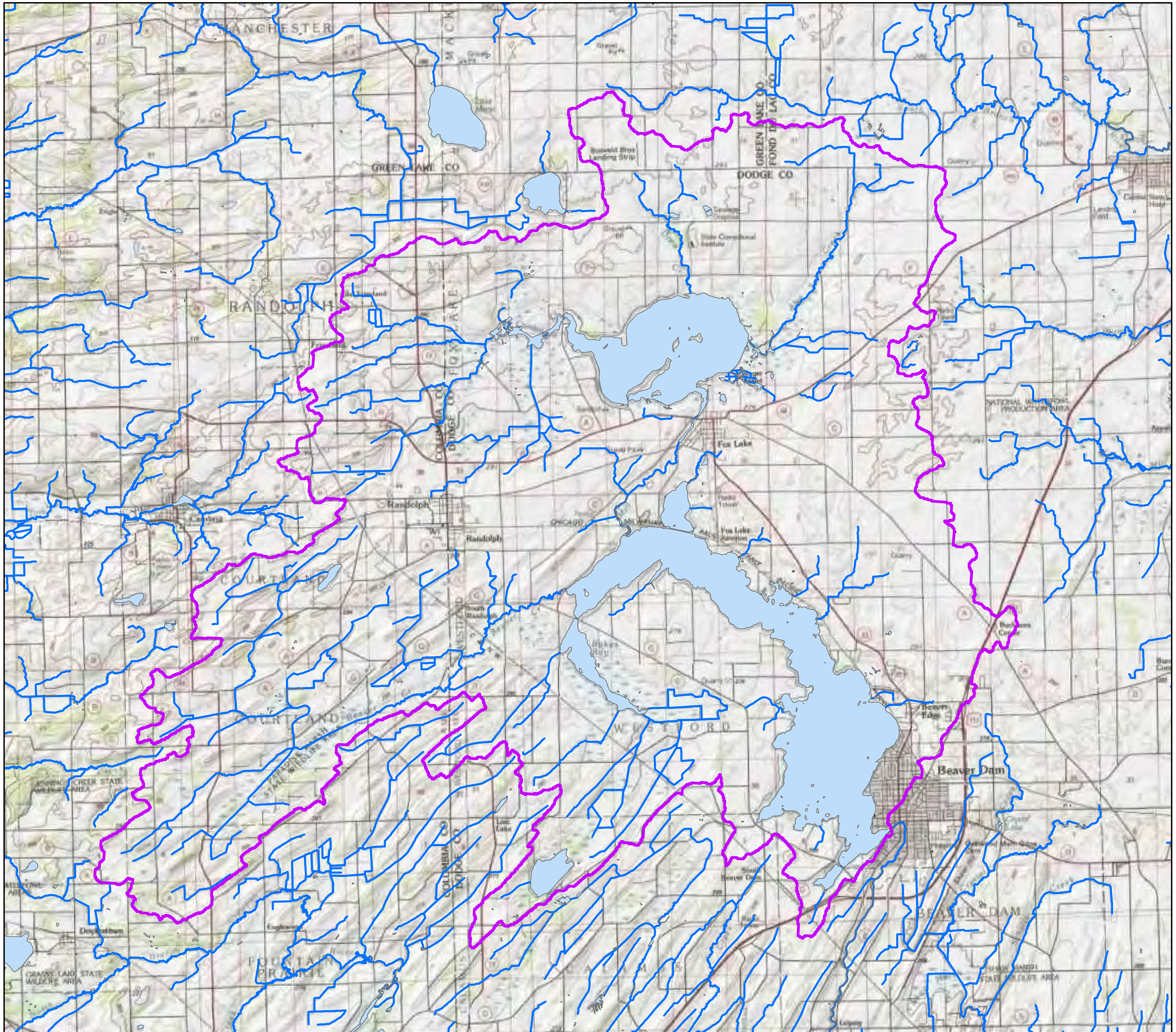

Project Details

- Watershed Area
- WDNR Waterbody
- WDNR Waterway

Locator Maps Not to Scale

Main Map Projection:
NAD 83 Wisconsin State Plane South

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GJM	RJM

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Beaver Dam Lake Watershed Area

Beaver Dam Lake
City of Beaver Dam and Towns of Westford,
Fox Lake, Trenton, and Beaver Dam
Dodge County and Columbia County, WI

Beaver Dam Lake Improvement Association

N
W E
S

0 5,000 10,000 Feet

SCALE
1 inch = 10,000 feet

PROJECT NO.	DATE
1708	11/7/2018

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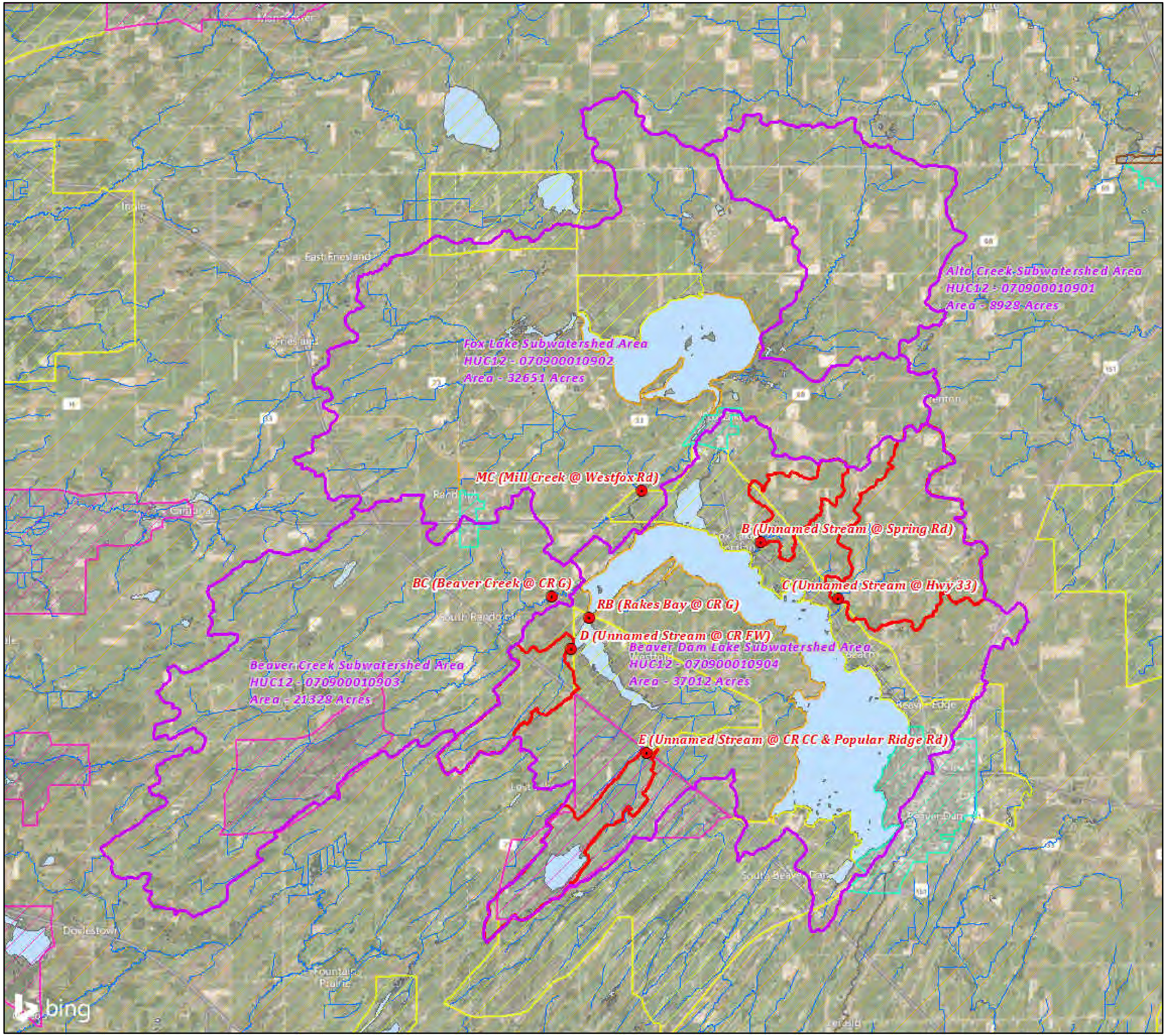
1 of 1



Legend

- Water Quality Sample Locations
- USGS Hydrologic Unit Code Areas (HUC-12)
- Sample Location Subwatershed Areas
- WDNR Waterbody
- WDNR Waterway

USDA NASS Cropland Data Layer

- > 75% Cultivated
- 51 - 75% Cultivated
- 15 - 50% Cultivated
- Agri-Urban > 100 Homes per Sq. Mi.
- Commercial > 100 Homes per Sq. Mi.

Locator Maps Not to Scale

Main Map Projection:
NAD 83 Wisconsin State Plane South

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Beaver Dam Lake Watershed Areas and Sample Locations

Beaver Dam Lake Management Plan Phase II
2018 Water Quality Monitoring

Beaver Dam Lake Improvement Association

N S E W

0 5,000 10,000 Feet

SCALE: 1 inch = 10,000 feet

PROJECT NO. 1708 | DATE 12/31/2019

SHEET NO. 1 of 1

TRIBUTARY & SHORELINE INVENTORY

31-Dec-18

	Location	Type	Inflow		Condition	Action Steps
	(% of watershed, BDL 6%)					
1	City of Beaver Dam	LD Res	Various		BD under stormawater runoff permit	
					shoreline zoning ordinance 1-2015	BDLIA review with Building Inspector
1.1	Lakeshore Hospital	HD Res		plot	Renovation in 2019	BDLIA review shoreline restoration
						Potential Healthy Lakes Program
2	Edgewater	Rip Rap & Nat				Healthy Lakes 2017, native
					No significant culvert along 33 from B to Fox Lake	
2.1	Edgewater DR	LD Res		photo	Severe shoreline erosion	property transfer in 2016,
				plot		construction 2018
2.2	Culvert fm Industrial Park	Culvert	< 48 in			
2.3	Park Spilway & drainage	Culvert	< (2) 24 in	ph	Carp concentration point	BDLIA to harvest 2018
3	McKinley	Rural Res	8 ft w/	plot	Carp concentration point	BDLIA to harvest in 2019
			48 in clear	photo	Potential for bar grate east side	2017 & 2018 spawning verified
4	BD Golf Course	Culvert	5 ft	plot	Invert exit restricts rough fish	2018 report of heavy carp spawning
				photo	Install grate cover east side	
5	Sunset Beach	Rural Res			mostly rip rap	
6	Fish Camp	Natural	creek		erosion of wetlands	invetigate in winter
6.1	Fish Camp Dam				E of Fisher Isl	check in winter
6.2	Guetchell Spring/Creek	culvert @ RR	4246 A.		N.E to Hwy 33, 1500 ft N of Fish Camp	
					43.511488 -88.867712	
6.3		cuvert @ RR			43.517727 -88.877251	

7	Dunn Rd	Rural Res				
8	Puckagee Springs/ Creek	Natural	creek	ph	Extreme shoreline erosion	BDLIA survey 2018
		1080 A.	RR Bridge	plot	cold water inlet <10 F> 15 cfs	MARS to prepare plan & drawing
					43.528783 -88.896643	
9	Trestle Bay 2%		RR Bridge	ph	Carp barrier in poor repair	BDLIA repaired bar grates 2016
					bridge detail, 2k A	Commercial harvest 2016, 41,000 lbs
						DNR Biologist to assess BMPs
10	Mill Rd Ramp	Rip rap		photo	shoreline runoff and ramp damage	WDNR & BDLIA grub out & grass
						2017 stone barrier at ril line
					Natural creek west of parking	
11	Mill Creek 40%	Natural			Fox Lake watershed 40k A, 40%	
11.1	Cty Rd C	culvert			At Creek midway	
11.2	Cty Rd C	culvert			South of Cty Rd P	
11.3	Wis Souther RR Trestle	bridge				
11.4	West Fox Rd	bridge				
12	Cty Rd FW	Rural Res				Note: 1600 lft of improved shore
						buffer strip, rip rap, cut back slope
12.1	N9196 Cty Rd FW			ph	severe shoreline erosion	Note: 1600lft of improved shore
12.2	Cty Rd FW	culvert				plan repair 2018
12.3	Cty Rd FW	culvert			South of Cty Rd C	
13	Beaver Creek 20%	Mixed	Bridge	photo	See WRM Program & bridge detail	See WRM survey locations
				plot	BC watershed, 20k A	
14	Rakes Bay 9%	Natural		photo	Storm event with high TP	BDLIA prelimianry survey
		9200 A.	Bridge	plot	9k A, pulse flow	MARS to prepare drawings
					aquatic vegitation + 50% 2018	CH 30 permit 2018
	W. Bay inlet Cty Rd FW	1607 A.				ENCLOSURE 4
	Lost Lake	1923 A.				

						BDLDC w/ partial funding of barrier
14.1	Cty Rd G	culvert			N of Bridge	2100 lft from wetland
						drains 200 A. natural wetland
15	Hickory Point	Rural Res				
16	Sunny Point 2%	Rural Res		plot	2k A	
		Culvert	< 36 in	ph	Heavy Ag runoff with P & > T	
17	Gilfins Bay	Natural				Investigate shore in winter
18	Cty Rd. CP	Rural Res				
18.1	Derge Park	Culvert	24 in	plot	inflow approx 300 A	Potential for Sediment Trap
18.2	North of Derge Park	Culvert				
18.3	Derge Park	Shoreline			Primarily rip rap	water lillies in bay
18.4	Stone Ledge RD	culvert			43.498669 -88.880711	drains 175 ft to pond
19	Weiss Bay	Natural	creek			CWH installation 2017 -18
						Extensive upland wetland
19.1	Cty Rd G	box culvert			creek / wetland N of CC	
19.2	Cty Rd G	culvert			S of CC	
20	Beaver Bay	Rural Res		plot	Rip rap shoreline	
20.1	Cty Rd G	Culvert		plot	fixed carp barrier east of G	low priority
					43.457304 -88.884103	drains 50 A west of G
20.2	Edgewater	Culvert			drains 80 + A	good potential for T reduction
21	Millers Woods	Rural Res		plot	Rip rap shoreline	
21.1	Rose Circle	culvert	12 in			low priority

22	Conservation Bay	Natural;		photo	Shoreline erosion	BDLIA to monitor
				plot	Heavy Ag runoff & > T, two creeks	Converted to CREP in 2016
22.1	Cty Rd G	culvert			entry via wetland and woods	low priority
					43.450152 -88.879215	
22.2	Cty Rd G	culvert			entry via conservation CREP	low priority
22.3	Town of BD Mathias	natural shore		photo	shoreline eroison see ortho 2006	potential for native planting &
				plot		1:4 slope correction
23	Town of BD	Natural	creek			
23.1	Cty Rd G	culvert			entry via creek and wetlands	invesigate in winter
23.2	Cty Rd G	culvert			at Airport Rd through Marina grasses	high flow at rain events
23.3	Airport Rd	Natural	creek		rural residential	
24	Bayside 1%		Bridge		approx 1k A	
	Note:: Road culverts that cross from ditch to ditch without meaningful impact are not included					

MEMORANDUM

To: Bill Foley, Beaver Dam Lake Improvement Association

From: Rob Montgomery, Gabe Montgomery

Date: December 30, 2018

Re: Evaluation of shoreline protection at the Puckagee Springs area

---

This memo presents a plan for shoreline protection at the Puckagee Springs area. The objective of this shoreline protection proposal is to prevent further destructive erosion of the wetland shoreline in this area and the destruction of the protected open water adjacent to Puckagee Springs Creek. This area has been steadily eroding for decades. Previously-installed partial riprap shoreline protection has become displaced and is absent in many areas. The creek and open water body adjacent have become silted in at many locations. Our evaluation was based on the following:

- We used LIDAR topographic and GIS-based parcel boundary data available from Dodge County together with bathymetric and lake bottom characteristic data collected by BDLIA to produce the base map for the project area.

- The open water fetch across Beaver Dam Lake from many directions exceeds 1 mile and observed wave action in storms is significant and has produced ongoing significant erosion. In addition, access to the site is relatively difficult due to the wetland areas adjacent, making maintenance of any protection system problematic. Therefore, a "hard" armoring approach, with a long expected service life, is appropriate at this location.

- The proposed protection system was based on typical riprap berm design, similar to that installed at many locations on Lake Poygan by Winnebago County.

The proposed protection system layout is shown on Sheets 1 and 2, attached and a cross-section of the proposed stone berm protection breakwater is shown on Sheet 3. The design incorporates the following features:

1. The stone berm will be constructed of quarry stone rock. The gradation of the rock will be in the range of 8-inch to 30-inch diameter.

2. The arrangement of the stone berms protecting the shoreline will include several gaps (refer to sheets 1 and 2) to allow for navigation (shallow draft fishing boats are anticipated) behind the berms so as not to impede public access in the navigable water.

3. The berm protection will include additional protection at the entrance of the shallow protected water body on the east side of the creek.

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Resource Solutions, LLC

4. We anticipate that the berms will be placed using a winter construction approach where the stone be placed on Lake ice (with a geotextile below), so that when the ice melts, the berm section will settle to the lakebed. Because this construction approach will inevitably result in some variation in the section after ice melt, the stone placed will include an overage allowance to make sure the minimum section is achieved.

We have developed a planning level projection of installation cost for this shoreline protection system. The total probable construction cost is estimated at $168,000.

These drawings in description should be sufficient to begin discussions with DNR on implementation of this shoreline protection plan. As your conversations continue, don't hesitate to call us with any questions.

Attachments: Statement of probable construction cost.
Drawing sheets 1, 2, 3

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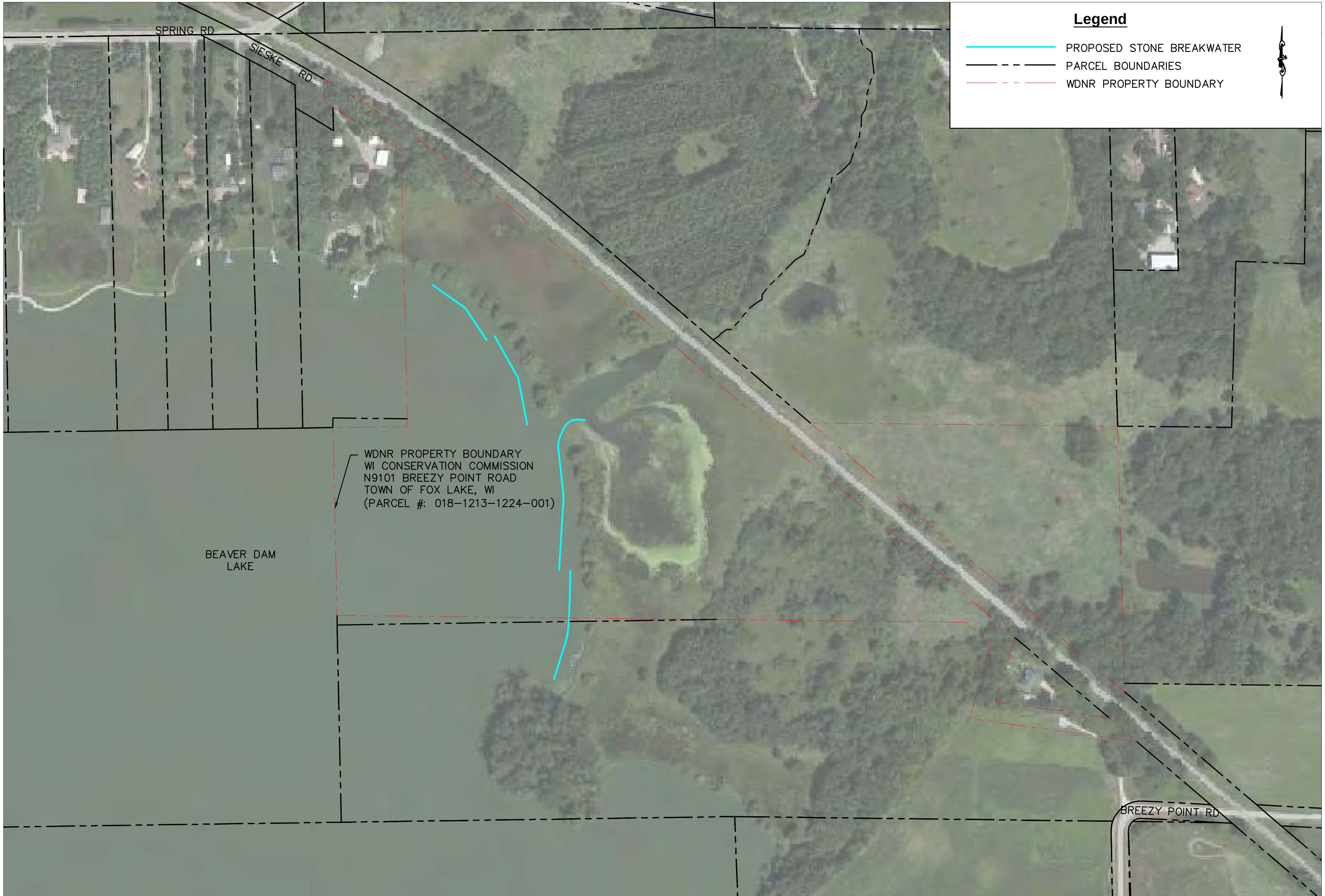

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SITE LOCATION MAP

PUCKAGEE SPRINGS-BDL
N9101 Breezy Point Road
Town of Fox Lake, WI 53933
Beaver Dam Lake Improvement Association

IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE
0 ½ 1

SCALE
1 IN = 300 FT

PROJECT NO. 1708
DATE 12/20/18

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1/3

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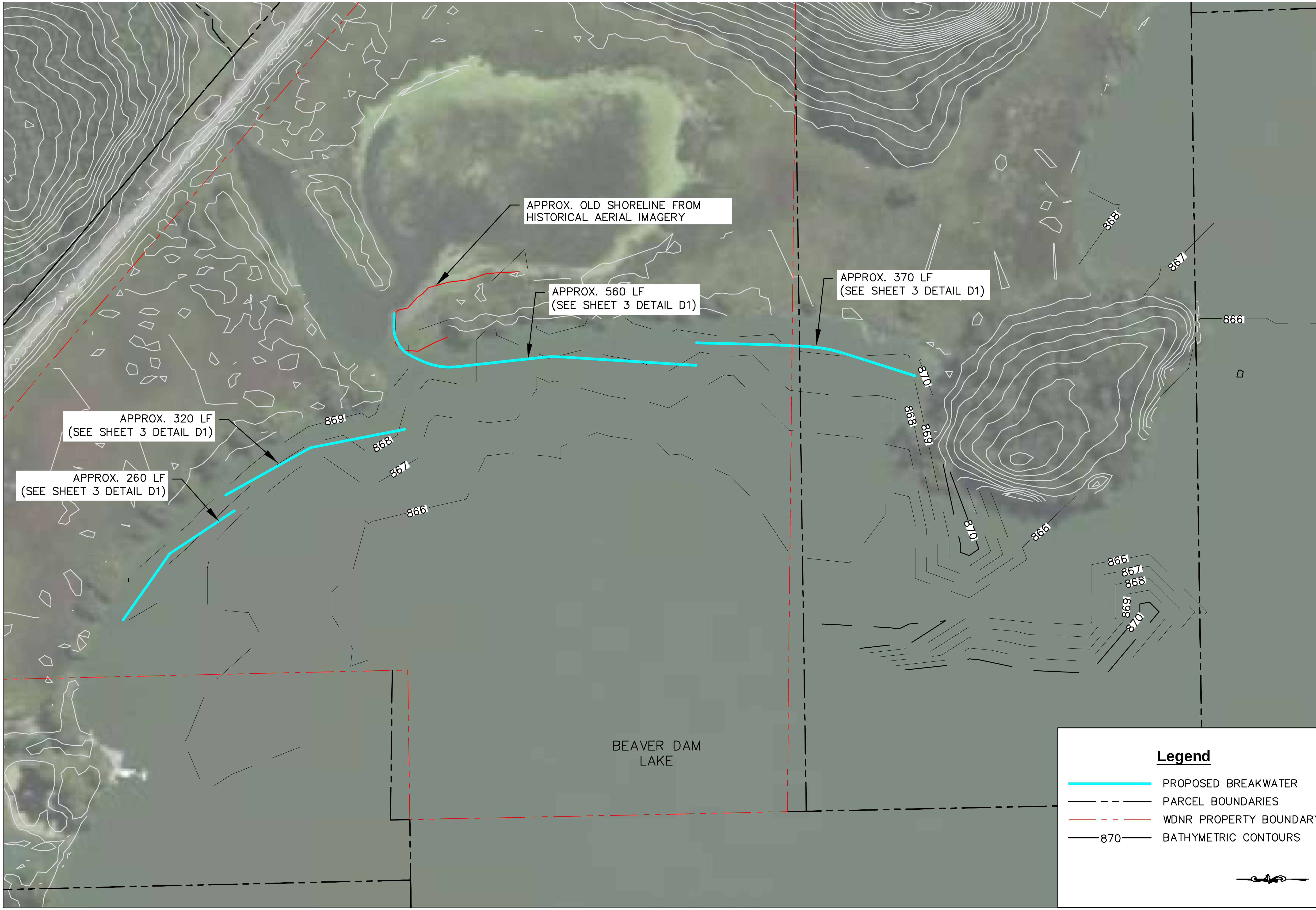

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PRELIMINARY SHORELINE PROTECTION PLAN

PUCKAGEE SPRINGS–BDL
N9101 Breezy Point Road
Town of Fox Lake, WI 53933
Beaver Dam Lake Improvement Association

IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE
0 ½ 1

SCALE
1 IN = 150 FT

PROJECT NO.	DATE
1708	12/20/18

SHEET NO.
2/3

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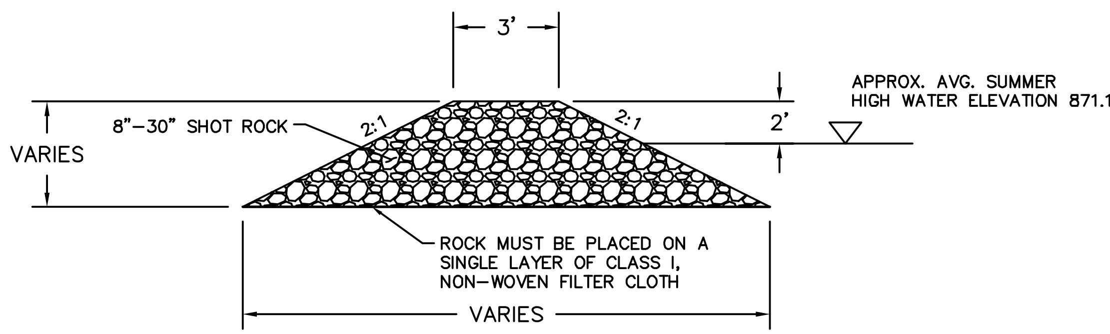

NOTES:
1. ALLOW APPROXIMATELY 30 FEET OF SPACE BETWEEN ADJACENT BREAKWATERS AT THE AVERAGE SUMMER HIGH WATER ELEVATION.
2. BREAKWATERS TO BE CONSTRUCTED ON ICE AND SINK INTO PLACE WHEN ICE THAWS.
3. OVERLAP UNDERLYING CLASS I NON-WOVEN FILTER FABRIC A MINIMUM OF 3 FEET.

D-1 / 3 LAKE BREAKWATER STRUCTURE – TYPICAL CROSS SECTION

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SHORELINE PROTECTION DETAIL DRAWINGS

PUCKAGEE SPRINGS-BDL
N9101 Breezy Point Road
Town of Fox Lake, WI 53933
Beaver Dam Lake Improvement Association

IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE
0 ½ 1

SCALE
N.T.S

PROJECT NO.	DATE
1708	12/20/18

SHEET NO.
3/3

Statement of Probable Construction Cost

Project: Beaver Dam Lake - Puckagee Springs Shoreline Restoration

Project Element	Quantity	Unit	Unit Rate	Cost
Construction Elements				
Mobilization	1	ls	10,000	$10,000
Clear and grub	0	cy		
General fill	0	cy		
8-30" Riprap Breakwater- 4 ft high - 1600 lf	3,837	tons	30.50	$117,000
Non-woven geotextile Class 1-Type R	3,380	cy	3.55	$12,000
Subtotal, Construction Elements				$139,000
Site investigation and survey	3%			$4,000
Permitting	3%			$4,000
Engineering design services	10%			$14,000
Construction time services	5%			$7,000
Subtotal, engineering services				$29,000
Estimating Contingency	15%			$25,000
TOTAL PROBABLE CONSTRUCTION COSTS				$168,000

MEMORANDUM

To: Bill Foley, Beaver Dam Lake Improvement Association

From: Rob Montgomery, Gabe Montgomery

Date: December 30, 2018

Re: 2018 monitoring at Rakes Bay entrance and schematic description of carp gate

---

WATER LEVEL AND VELOCITY MONITORING AT THE ENTRANCE TO RAKES BAY

As part of the DNR Lake Planning Grant work for 2018, we installed velocity and water level sensors at the CTH G bridge at the entrance to Rakes Bay. BDLIA had obtained permission from the County highway department to install this equipment.

We installed 2 ISCO 2150 velocity/depth sensors and data logging modules, housed in a waterproof cabinet attached to the southeast abutment retaining wall of the bridge. One velocity/depth sensor was mounted on the east abutment retaining wall underneath the bridge, and the other sensor was mounted in approximately mid-channel. Duplicate sensors were installed to provide redundancy in collected data. Data was collected beginning on April 27, 2018 and data collection ended on September 26, 2018. Data was downloaded periodically from the data logging modules. Several time periods of lost data due to data logger cable problems were encountered, but data was collected during most of the boating season, including times of high and average water levels. The collected water level data at rakes Bay correlated well with the Beaver Dam Lake water level data collected by the City of Beaver Dam. A summary of the elevation and velocity data collected for the most reliable sensor, that mounted on the abutment side wall, as shown in the figure below.

Velocity elevation sensor mounting on the CTH G southeast abutment wall. The data loggers were installed in the locking cabinet. The flexible piping contains the cables for the sensors located beneath the bridge.

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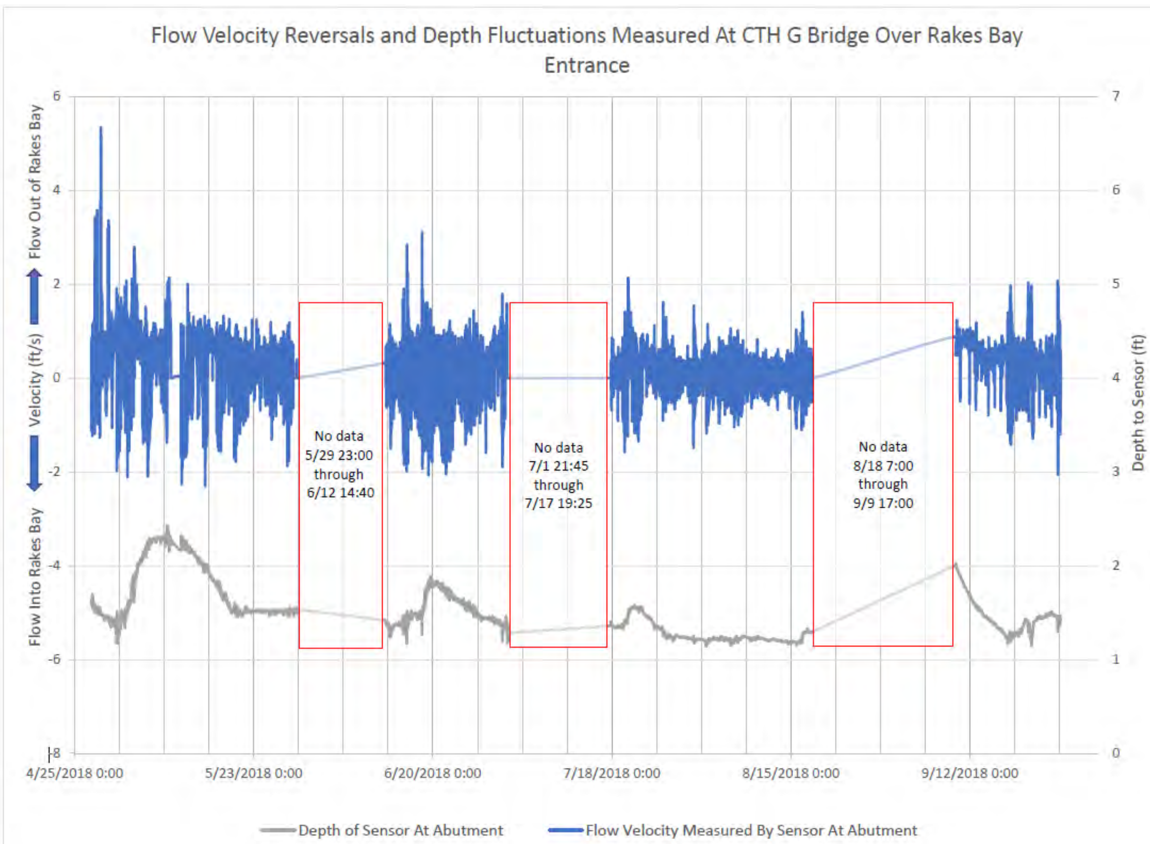
The velocity data indicated frequent and substantial fluctuation of velocities into and out of Rakes Bay, confirming visual observations. The observed maximum flow into the bay was slightly greater than 2 ft./s. In contrast the maximum velocity of flow out of Rakes Bay approached 6 ft./s. The variation of velocities was rapid (many times per day, typically) and was not correlated with the presence of generally high or generally low water levels on Beaver Dam Lake which occurred typically over days. Rather, the velocities appear to be driven by much more frequent (hourly) variations in water levels in Beaver Dam Lake adjacent to the rakes Bay entrance.



The correlation between lake water level and the velocity of flow into and out of Rakes Bay is illustrated in the several figures below, which show fluctuations over approximately one-day timeframe. Observations are:

- Velocities reverse and change magnitude over an interval of minutes, in most cases related to small fluctuations (less than 0.1 feet) in Beaver Dam Lake. When water levels increase, flow enters rakes Bay, and when it drops, water leaves the bay.

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- During times of substantial net flow into Rakes Bay, the flow and velocity fluctuations illustrated are superimposed on net outflow from the bay – as shown on the upper figure on the next page.

- During times of no inflow, the velocity fluctuations often result in reversals, where flow periodically enters the bay and later discharges from the bay, often fluctuating in this way many times per day.

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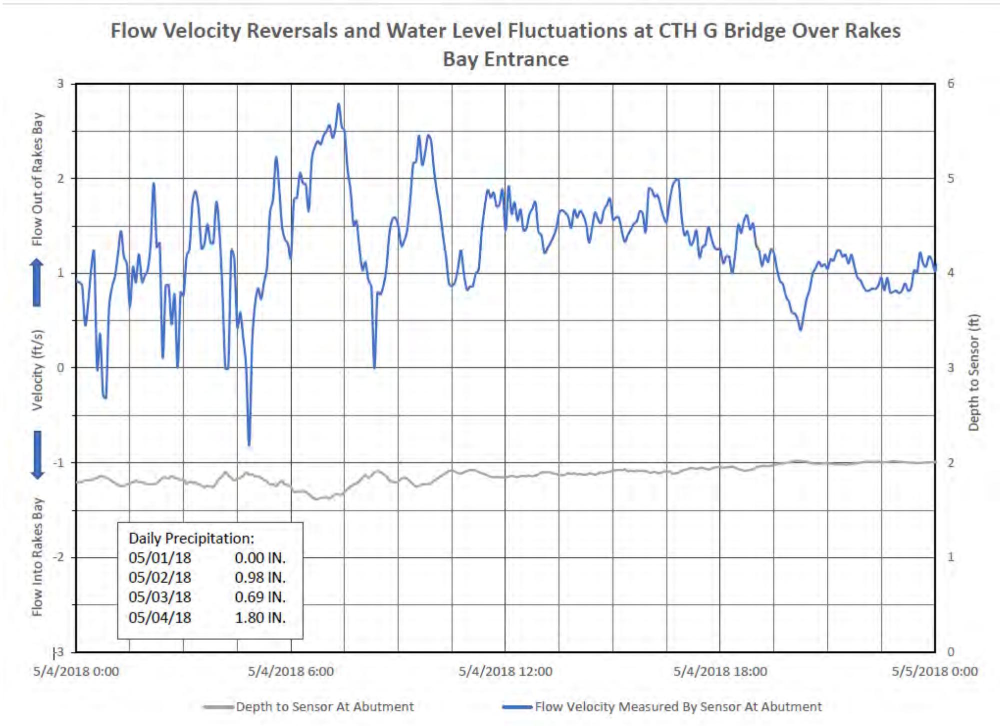
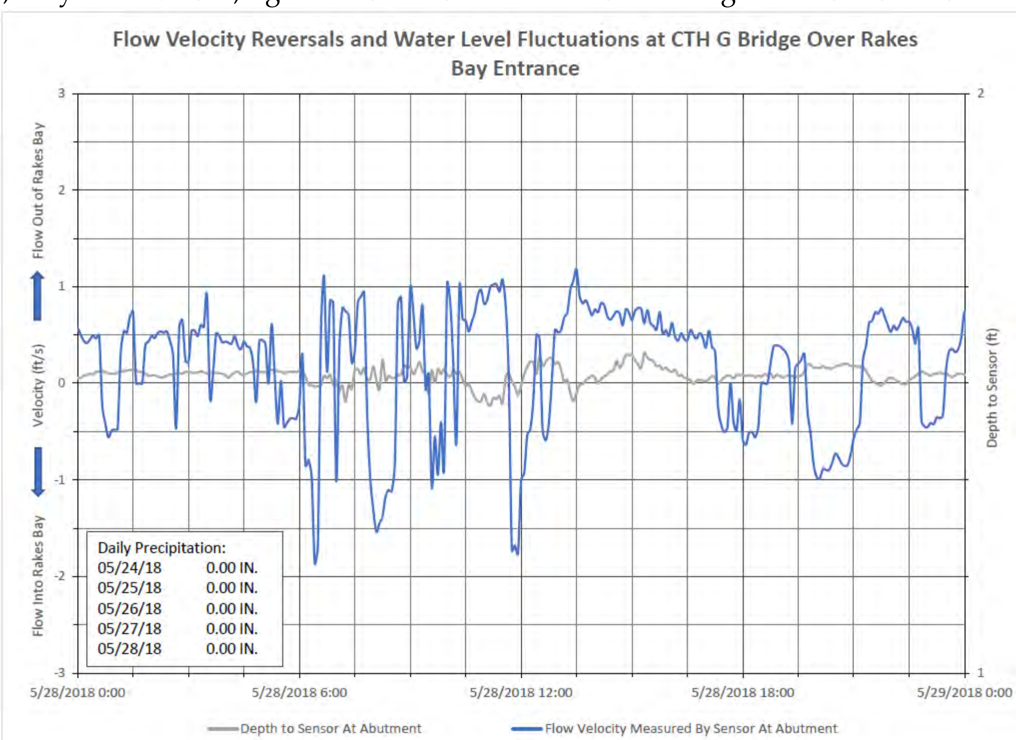


Figure above shows velocities and water level fluctuations for a time of substantial runoff into rakes Bay, May 4 and 5 2018; figure below shows fluctuations during a time of no runoff inflow.



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IMPLICATIONS FOR DESIGN OF THE CARP BARRIER AT THE RAKES BAY ENTRANCE

The purpose of a carp barrier at the Rakes Bay entrance would be to provide isolation of the shallow waters of the bay from disturbance and uprooting by carp, to allow increased propagation of rooted aquatic vegetation. More dense aquatic vegetation is projected to be beneficial to gain fish propagation and may also produce localized areas of increased water clarity.

It is anticipated that the carp barrier installation would be in 2 phases. The first barrier to be installed would be mechanical, consisting of a physical barrier with bars or a grate to limit large carp access to the bay (particularly in springtime). The physical barrier would need to extend across the entrance channel and would include a gated section to allow for boat access over the barrier. Following several years of successful isolation of Rakes Bay with improving aquatic vegetation conditions, a non-physical "bubble barrier" could be installed. The bubble barrier would consist of several sets of air diffusers on the lakebed, which would produce a dense curtain of bubbles that would tend to discourage carp movement across the curtain. The advantage of the bubble barrier would be that in-water mechanical system maintenance would be minimized, and the bubble barrier would provide effectively no limitation to boat passage through the Rakes Bay entrance. Bubble barriers for limiting carp movement into shallow bays have been successfully implemented on Green Lake.

Design considerations for the mechanical carp barrier to be initially installed at Rakes Bay entrance include:

- Ability to withstand substantial inflow and outflow velocities – we suggest that the barrier be designed to be stable for flow velocities up to 10 ft./s, based on the velocity data collection described above.

- Firm anchorage system to provide continuous direct contact with the lake bottom. At the entrance, large stone is present in places which would need to be removed and potentially reinstalled adjacent to the mechanical barrier to make sure that gaps are not present at the base of the barrier.

- Given water level fluctuations observed, we suggest that the barrier extend to at least elevation 873, which is more than 2 feet above the target water level but less than 1 foot above water surface elevations observed during the extreme conditions of 2018.

The attached drawing sheets show a schematic design for a mechanical carp barrier system. The drawings are based on the structure drawings for the CTH G bridge, obtained from Wisconsin DOT.

The details of the design have not been developed for this study. Given the dimensions of the projected barrier and depth considerations, we suggest that a planning level budget of $25,000 be allocated for implementation of this carp barrier. It is also important to recognize that the installed barrier will require frequent observation, maintenance and potentially repair, and must be described

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in a broad public relations/education program to educate fishermen and other lake users of the objective of the barrier installation. The costs of these operation, maintenance and education programs would be additional to the planning level implementation cost presented above.

Please contact us any questions.

Attachment: Drawing sheets 1 and 2 illustrating Rakes Bay fish barrier

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SITE LOCATION – PROPOSED RAKES BAY FISH BARRIER

RAKES BAY–BDL CTH G FISH BARRIER
11146–11192 County Highway G
Town of Westford, Dodge County WI 53916
Beaver Dam Lake Improvement Association

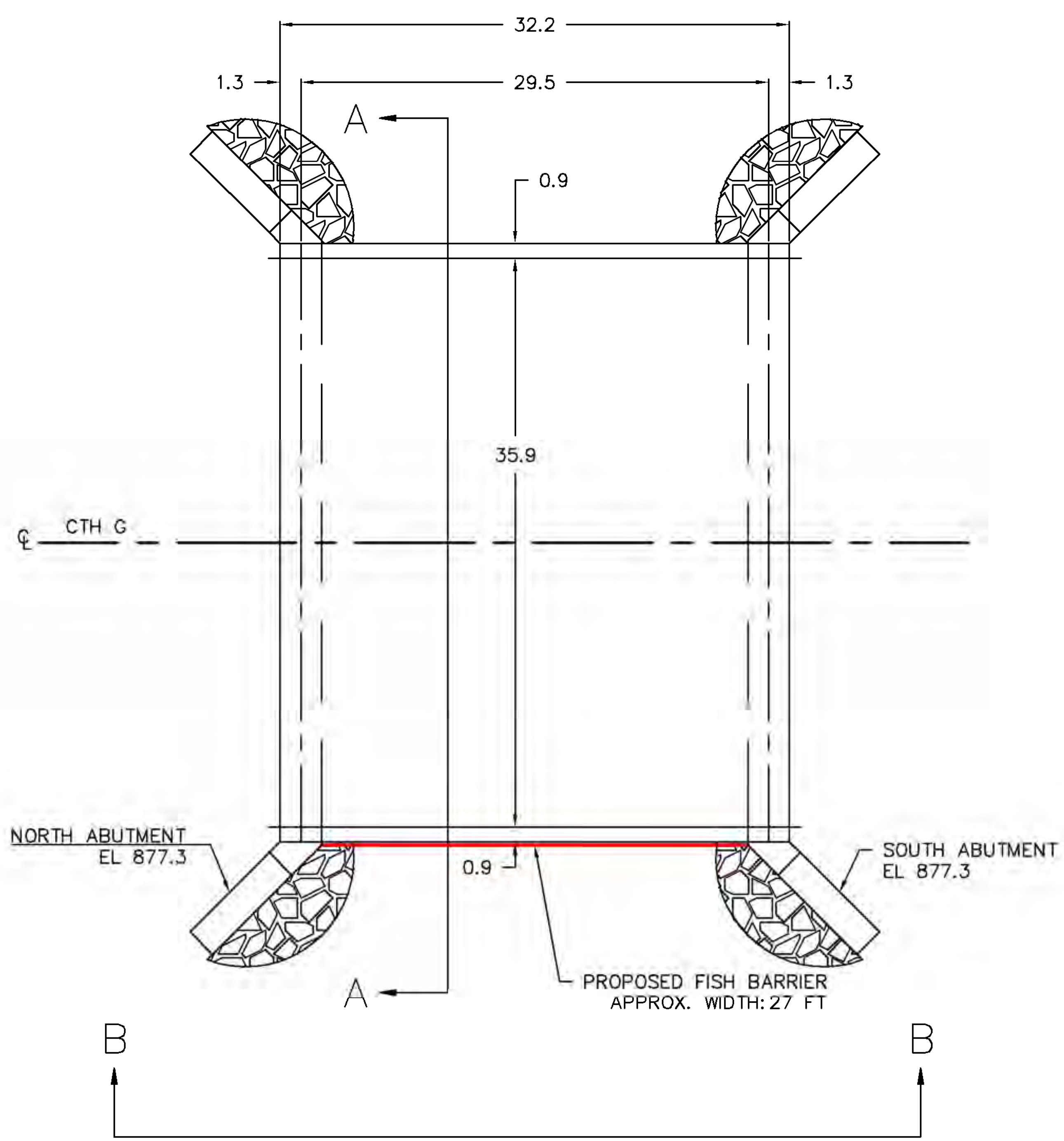
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE
0 ½ 1

SCALE: 1 IN = 100 FT

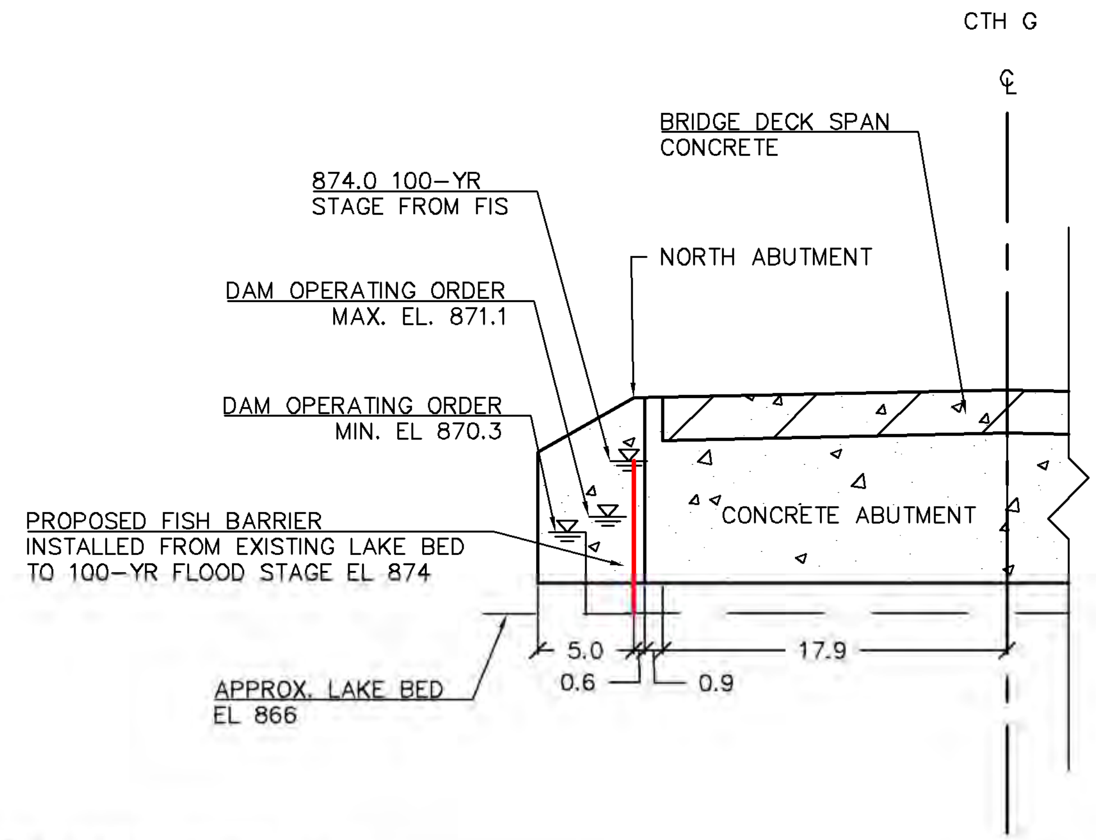
PROJECT NO. 1708 | DATE 1/23/18

SHEET NO. 1/2

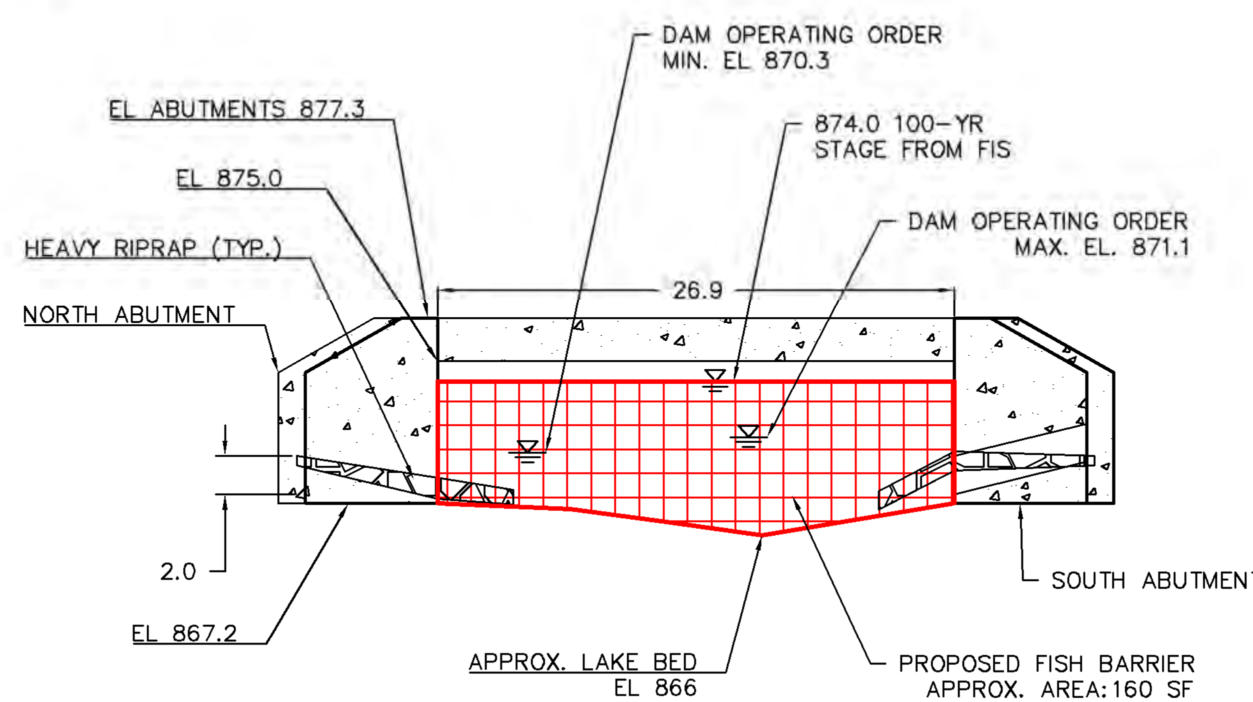
P:\1708 – Beaver Dam Lake Improvement Association – DNR Grant app\Drawings\RAKES BAY_CTH G_BRIDGE&FISHBARRIER.dwg



D-1 / 2 LAYOUT OF CTH G BRIDGE AND FISH BARRIER



D-2 / 2 CROSS-SECTION AA



D-3 / 2 CROSS-SECTION BB

DRAWN BY GJM | CHECKED BY RJM

DATE | REVISION / ISSUE | NO.

MONTGOMERY ASSOCIATES: RESOURCE SOLUTIONS, LLC
119 SOUTH MAIN ST
COTTAGE GROVE, WI 53527
www.ma-rs.org

DETAILS – PROPOSED
RAKES BAY FISH BARRIER
RAKES BAY-BDL CTH G FISH BARRIER
11146-11192 County Highway G
Town of Westford, Dodge County WI 53916
Beaver Dam Lake Improvement Association

IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE
0 ½ 1

SCALE
1 IN = 10 FT

PROJECT NO. 1708
DATE 1/23/18

SHEET NO.
2/2

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Beaver Dam lake dam control order January 30, 2018

The Beaver Dam Lake (BDL) watershed is composed of various streams and creeks with Fox Lake discharging into BDL through Mill Creek from the North. The current dam control order was established March 4, 2004 with targets and guidelines for flow management. The USGS station 05425912 monitors discharge, precipitation and water level at the City of Beaver Dam. In 2013 the City of Beaver Dam rebuilt this dam with improved gate control which provides more efficient operations.

BDLIA sponsored the 2015 Lake Management Plan which recommended; Management Goal 2 Management Action: 'Reevaluate Beaver Dam Lake's Dam Order'.

Additional in depth data has been collected by BDLIA during 2016 and in 2017 with the assistance of the UW Water Resource Management Program. As part of this investigation water and sediment samples were gathered with analysis performed by the Wi Hygiene Laboratory. A more detailed assessment of fetch, shoreline and streambank conditions were performed with habitat and the impact of erosion identified as concerns. Preliminary findings were then documented and presented at a number of public meetings with attendee feedback requested.

In consideration of the data collected and the response from the Community a proposed dam management plan has been prepared which more closely follows the natural rainfall conditions experienced in this watershed. The objectives are to improve habitat for fish and fowl, reduce the loss of shoreline and wetlands, and maintain the watershed as a recreational resource for the Community.

The proposed dam flow plan relies on the current order with seasonal revisions identified as targets more closely paralleling natural conditions. The proposal and supporting logic is as follows;

- Spring Fill would initiate as per current order beginning April 1st with completion by April 15th. (no change)
- Spring – Summer lake level management
  a) The WDNR Fish Biologist has indicated that the minimum discharge of 3 cfs. Is considered insufficient to enhance the fishery on the Beaver Dam River. It is desirable to increase this flow and not impact other recreational activities on BDL.
  b) The current lake level of 88.3 is considered the minimum required to permit safe navigation on BDL and even at this level boat damage frequently occurs.
     i) The Spring Fill would proceed to a level of approximately *88.5* which would provide additional water volume to permit flow in excess of 3 cfs. (currently at 88.3)
     ii) The dam operator will monitor lake level and rainfall run off to maintain lake level through the fall at 88.3 (Attn. 1: Lake Level Graph)

- Fall water level reduction:
  a) The current fall -winter target of 88.3 has contributed to severe ice damage to shoreline protection and personal structures. Numerous property owners were required to repair these structures at

significant personal expense in 2016 - 2017. A lower lake level will reduce the detrimental impact of ice heave on shorelines. (Attn. 2: Shoreline photo)

b) Utilizing Dr. Chin Wu's fetch model, a maximum fetch on BDL is indicated 43 days per year with critical wind experienced on 315 days per year. The fall season presents significant wind energy on open water with resulting damage to shorelines.
(Attn. 3 Wind fetch impact map, Attn. 4: Ave. wind speed)

c) Shoreline physical surveys and aerial photos for 2010 and 2017 have verified sever erosion and loss of wetland areas which adversely impact habitat and water quality. Wetland has been lost with the resulting phosphorus rich sediment entering Beaver Dam Lake. (Attn. 5: typical aerial view)

d) A reduction of water levels in the fall will expose low lying fine sediment areas and permit beneficial oxygenation contact with those soils resulting in long term seasonal habitat improvement.

e) BDL receives water from Fox Lake via Mill Creek from the north with a level reduction period from Oct 15 through Nov 10th. The proposed BDL revision will permit managed flow of the discharge from Fox Lake.

f) The lake level reduction is essential to manage snow melt and rainfall with 69% of normal runoff occurring in the March to June timeframe. (Attn. 6: Ave Rainfall Attn:7 Critical Runoff Periods)

i) It is proposed that the dam owner begin lowering the water level by October 5 *through October 20th* to *87.5* and maintain that level until the spring fill 1) April 1st or 2) until the lake is ice free. (Currently lower level date March 1st through March 15th to 87.7)

The proposed lake management measures address a number of current concerns with the Community and beneficially impacts shoreline habitat. These levels more closely follow average rainfall rates with a more natural environmental profile. The proposed revision will improve Beaver Dam Lake as a Resource and the Beaver Dam Watershed wildlife habitat while enhancing the Community recreational usage.

Schedule of Attachments:

1. Lake Level Graph – Current, Proposed, Rainfall Ave.

2. Shoreline photographs – erosion and barrier damage

3. UW WRM Wind fetch impact map

4. Dodge Co. KUNU: Ave wind speed

5. Typical aerial view of shoreline damage

6. Dodge Co. KUNU: Ave. rainfall

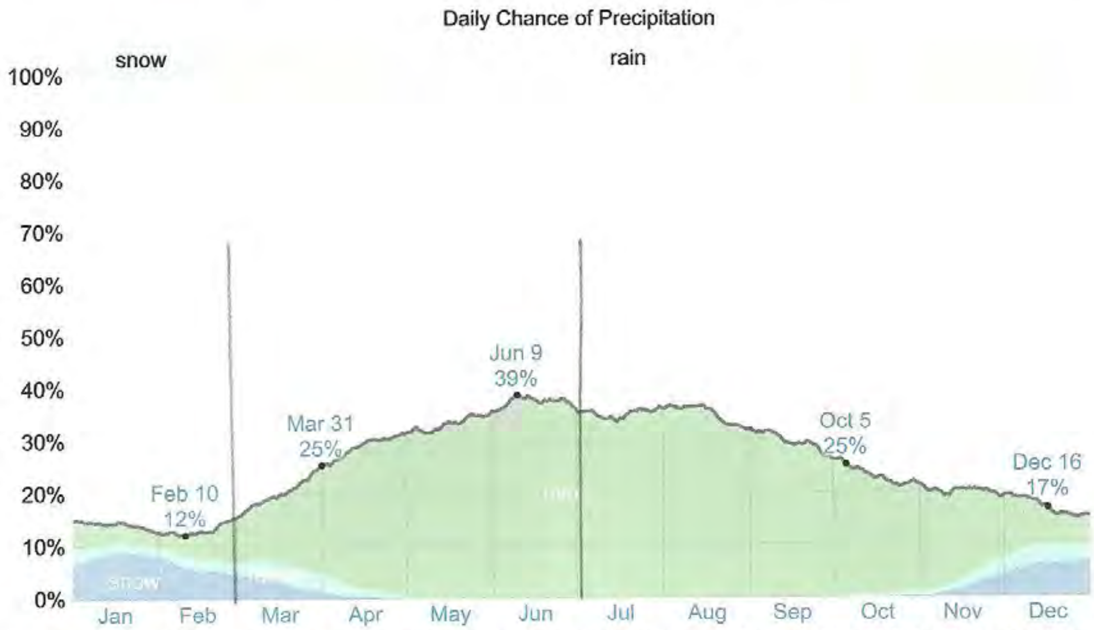
7. USGS: Critical runoff periods

The drier season lasts 5.8 months, from October 5 to March 31. The smallest chance of a wet day is 12% on February 10.

Among wet days, we distinguish between those that experience rain alone, snow alone, or a mixture of the two. Based on this categorization, the most common form of precipitation in Juneau changes throughout the year.

Rain alone is the most common for 9.8 months, from February 20 to December 16. The highest chance of a day with rain alone is 39% on June 9.

Snow alone is the most common for 2.2 months, from December 16 to February 20. The highest chance of a day with snow alone is 9% on January 19.



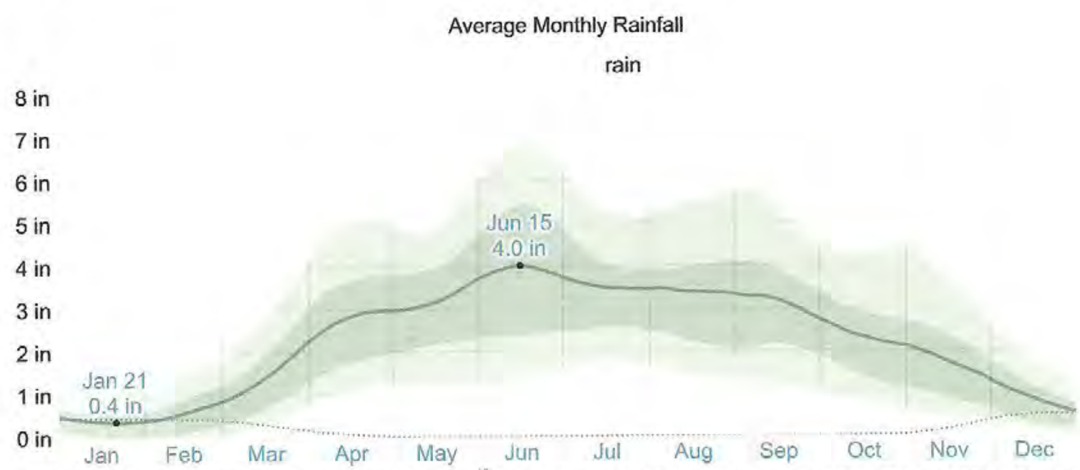
The percentage of days in which various types of precipitation are observed, excluding trace quantities: rain alone, snow alone, and mixed (both rain and snow fell in the same day).

Rainfall

To show variation within the months and not just the monthly totals, we show the rainfall accumulated over a sliding 31-day period centered around each day of the year. Juneau experiences significant seasonal variation in monthly rainfall.

The rainy period of the year lasts for 11 months, from February 10 to January 1, with a sliding 31-day rainfall of at least 0.5 inches. The most rain falls during the 31 days centered around June 15, with an average total accumulation of 4.0 inches.

The rainless period of the year lasts for 1.3 months, from January 1 to February 10. The least rain falls around January 21, with an average total accumulation of 0.4 inches.



The average rainfall (solid line) accumulated over the course of a sliding 31-day period centered on the day in question, with 25th to 75th and 10th to 90th percentile bands. The thin dotted line is the corresponding average liquid-equivalent snowfall.

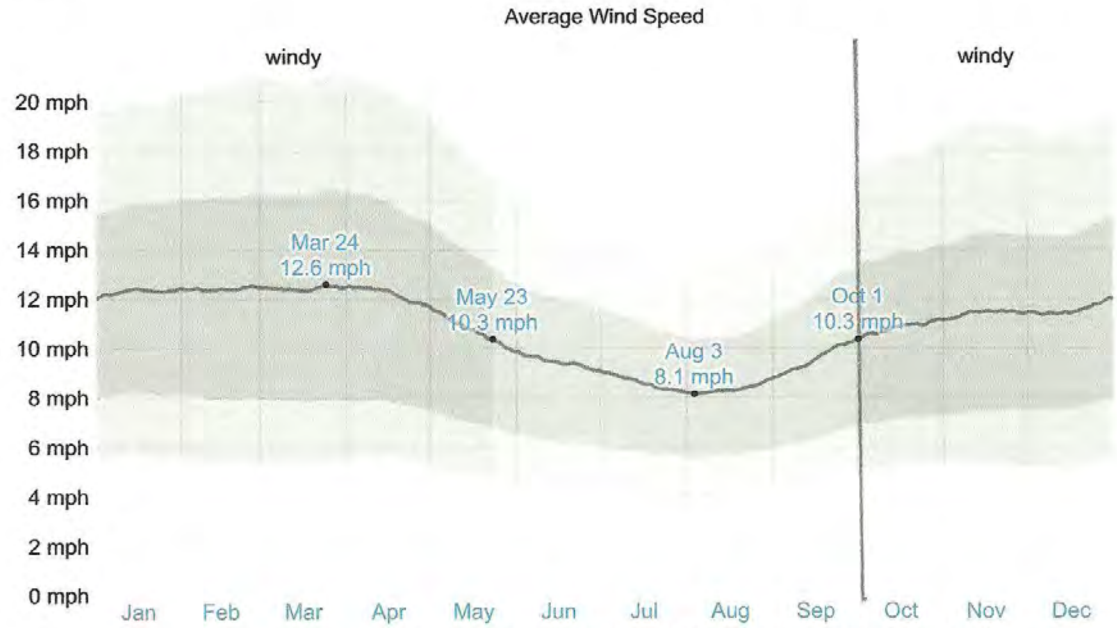
ATTN : 6

This section discusses the wide-area hourly average wind vector (speed and direction) at 10 meters above the ground. The wind experienced at any given location is highly dependent on local topography and other factors, and instantaneous wind speed and direction vary more widely than hourly averages.

The average hourly wind speed in Juneau experiences significant seasonal variation over the course of the year.

The windier part of the year lasts for 7.7 months, from October 1 to May 23, with average wind speeds of more than 10.3 miles per hour. The windiest day of the year is March 24, with an average hourly wind speed of 12.6 miles per hour.

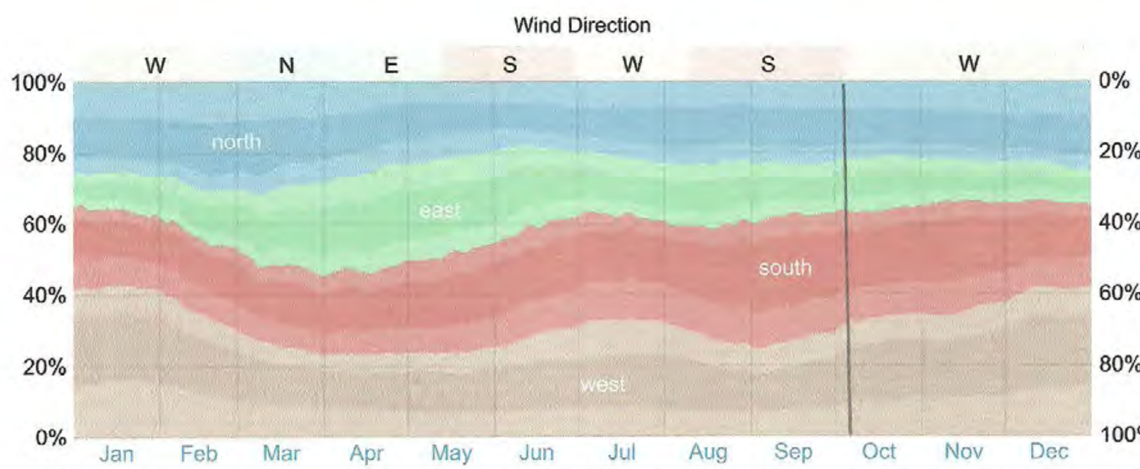
The calmer time of year lasts for 4.3 months, from May 23 to October 1. The calmest day of the year is August 3, with an average hourly wind speed of 8.1 miles per hour.



The average of mean hourly wind speeds (dark gray line), with 25th to 75th and 10th to 90th percentile bands.

The predominant average hourly wind direction in Juneau varies throughout the year.

The wind is most often from the east for 1.3 months, from April 5 to May 14, with a peak percentage of 29% on April 26. The wind is most often from the south for 1.5 months, from May 14 to June 29 and for 1.8 months, from August 10 to October 4, with a peak percentage of 36% on September 6. The wind is most often from the west for 1.4 months, from June 29 to August 10 and for 4.9 months, from October 4 to February 28, with a peak percentage of 33% on July 19.



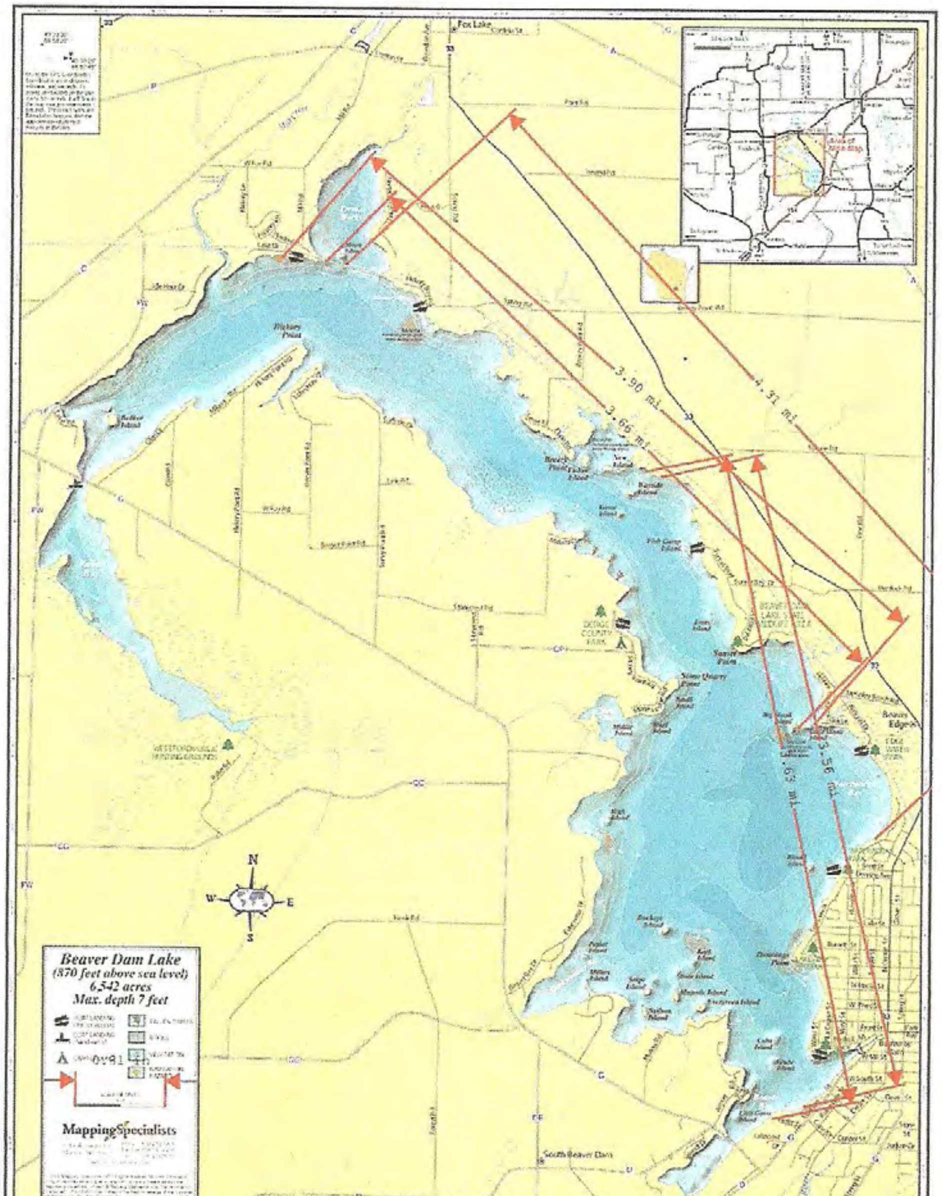
The percentage of hours in which the mean wind direction is from each of the four cardinal wind directions (north, east, south, and west), excluding hours in which the mean wind speed is less than 1 mph. The lightly tinted areas at the boundaries are the percentage of hours spent in the implied intermediate directions (northeast, southeast, southwest, and northwest).

ATTN: 4

Appendices

ATTN 3

APPENDIX A: BEAVER DAM LAKE FETCH ANALYSIS



Critical runoff periods

- 6 years of data (2003 -2008) from 23 sites on 6 farms
- No-till, tillage, and grazing operations
- Periods which are "best" for producers to apply manure coincide with the periods which are higher risk for runoff!

January 4%	February 16%	March 34%
April 4%	May 12%	June 19%
July 3%	August 3%	September <1%
October 3%	November <1%	December 1%

Average percent of annual runoff

University of Wisconsin–Extension DISCOVERY FARMS University of Wisconsin–Madison

USGS science for a changing world

ATTN : 7