Nelson Institute for
Environmental Studies
UNIVERSITY OF WISCONSIN–MADISON

Assessing Land Use Impacts and Promoting Community Engagement in the Waubesa Wetlands Watershed

2018 WATER RESOURCES MANAGEMENT PRACTICUM REPORT

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PREFACE

Water Resources Management (WRM) is a Master of Science degree program housed within the Nelson Institute for Environmental Studies at the University of Wisconsin-Madison. WRM graduate students complete 45 credits of interdisciplinary coursework across categories such as the natural sciences, engineering, social sciences, planning, and water management. Instead of conducting individual research, students participate in a collaborative practicum that extends across their two years in the program. The WRM practicum concentrates on a relevant water management issue facing a local community, and students form partnerships with organizations and institutions to develop project objectives and ultimately deliver management recommendations.

The 2017-18 WRM practicum focused on the watershed of Waubesa Wetlands in Dane County, Wisconsin. This report serves as documentation of the cohort's project: "Assessing Land Use Impacts and Promoting Community Engagement in the Waubesa Wetlands Watershed."

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The 2017-18 WRM cohort. From left to right: Stephanie Herbst, Mitch Buthod, Rachel Johnson, Kyle Pepp, Lianna Johnson, Courtney Botelho, and Némesis Ortiz-Declet.

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ACRONYMS

The following acronyms appear in the report:

ANOVA – Analysis of Variance
AWRA – American Water Resources Association
BMP – Best Management Practice
CARPC – Capital Area Regional Planning Commission
CFS – Cubic Feet per Second
CMIP5 – Coupled Model Intercomparison Project Phase Five
CWA – Clean Water Act
DEM – Digital Elevation Model
DO – Dissolved Oxygen
EPA – Environmental Protection Agency
FQA – Floristic Quality Assessment
GCLAS – Graphical Constituent Loading Analysis System
GIS – Geographic Information Systems
ISCO – Teledyne ISCO portable sampler
LiDAR – Light Detection and Ranging
MEA – Millennium Ecosystem Assessment
MG/L – Milligrams per Liter
NOAA – National Oceanic and Atmospheric Administration
NR – Natural Resources
NRC – National Research Council
NRCS – Natural Resources Conservation Service
NRF – Natural Resources Foundation of Wisconsin
RRC – Rock River Coalition
SNA – State Natural Areas
STEPL – Spreadsheet Tool for Estimating Pollutant Loads
SWIMS – Surface Water Integrated Monitoring System
TAC – Technical Advisory Committee
TKN – Total Kjeldahl Nitrogen
TMDL – Total Maximum Daily Load
TN – Total Nitrogen
TNC – The Nature Conservancy
TP – Total Phosphorus
TSS – Total Suspended Solids
USLE – Universal Soil Loss Equation
USFWS – United States Fish and Wildlife Service
USGS – United States Geological Survey
WDNR – Wisconsin Department of Natural Resources
WICCI – Wisconsin Initiative on Climate Change Impacts
WRAM – Wisconsin Rapid Assessment Methodology
WRM – Water Resources Management
WWI – Wisconsin Wetlands Inventory

EXECUTIVE SUMMARY

Waubesa Wetlands and Their Watershed

Waubesa Wetlands are a 371-acre state natural area in Dane County, Wisconsin. The wetlands are locally and internationally recognized as an ecologically, hydrologically, and culturally unique natural resource. Waubesa Wetlands are fed by groundwater, springs, two tributaries (Swan Creek and Murphy's Creek), and runoff from a 13-square-mile watershed that includes the Town of Dunn and the City of Fitchburg.

Land use in the Waubesa Wetlands watershed is primarily agricultural and natural land. However, the City of Fitchburg has proposed three new residential developments located within the watershed of Waubesa Wetlands. It is possible that these developments could alter stream flows and nutrient loads entering the downstream wetlands and thus change the wetland ecosystems and their abilities to perform critical functions that benefit humans, plants, and wildlife.

Therefore, the 2017-18 WRM cohort, on behalf of the Capital Area Regional Planning Commission (CARPC) and the Wisconsin Department of Natural Resources (WDNR), investigated the possible impacts of upstream development on Waubesa Wetlands. We utilized a variety of methods to provide a better understanding of current watershed conditions as well as potential future conditions. We assessed the ecosystem services provided by upstream wetlands, monitored water quality in the two major tributaries, and modeled runoff and water quality in the watershed. Throughout the project, we engaged with the local community and watershed residents.

Ecosystem Services Assessment

Waubesa Wetlands are connected to a large upstream network of wetlands along Swan and Murphy's creeks. In order to see how these wetlands, and ultimately the downstream Waubesa Wetlands, might be affected by new development, we wanted to understand the current state of the wetlands and the ecosystem services that they provide. Thus, we focused our study on a riparian wetland complex along Swan Creek that spans upstream and downstream of the most immediate development, the Northeast Neighborhood. The riparian complex included four distinct wetland types: southern hardwood swamp, shrub-carr, southern sedge meadow, and emergent marsh. Our ecosystem service assessment considered the presence of eight services: human use values, floristic integrity, wildlife habitat, fish and aquatic habitat, flood and stormwater storage, shoreline protection, groundwater processes, and water quality protection. We found that, overall, upstream wetlands are providing numerous services that may be buffering or protecting the downstream Waubesa Wetlands. Wetlands in the complex each provide different services to different extents, depending on factors such as wetland type and watershed position. Furthermore, synergistic relationships are found between the ecosystem services of shoreline protection, flood and stormwater storage, and water quality protection. This suggests that targeting wetland restoration for shoreline protection could likewise increase other beneficial ecosystem services. With additional time and resources, we also recommend continuing wetland and ecosystem services assessments like the one we conducted along Murphy's Creek to identify additional priority wetlands for restoration and conservation.

Water Quality Monitoring

Water quality in Swan and Murphy's creeks is tied to overall health and ecosystem functioning of wetlands along these tributaries and Waubesa Wetlands. This prompted us to monitor water quality and quantity in Swan and Murphy's creeks and build upon existing efforts of the Rock River Coalition citizen science volunteers. We established three sampling points upstream of Waubesa Wetlands that we sampled monthly between May and October 2018 and analyzed for contaminants including nitrogen, chloride, total suspended solids, and phosphorus. Additionally, we established a continuous monitoring station on Swan Creek at Lalor Road, which allowed us to collect continuous flow data and water quality samples during precipitation events. We found that total phosphorus concentrations for Swan Creek and Murphy's Creek routinely exceeded the 0.075mg/L limit set by the WDNR. We also observed fluctuations in nutrient concentrations at different flow levels and from the upstream site to the downstream site along each creek. Based on these observations, we recommend that future efforts focus on continued monitoring of these sites to establish long-term trends, and that a long-term USGS monitoring station be established on Swan Creek. We also recommend that all of the data from this project, along with previous and future data, be compiled into a comprehensive dataset.

Land Use and Climate Change Modeling

Over the next 45 years, new development and climate change will likely alter stormwater runoff quantity and water quality in the Waubesa Wetlands watershed. To forecast these changes, we used the models HydroCAD (stormwater runoff quantity) and STEPL (water quality). Currently, land use in the 8,434-acre watershed is 41% agriculture, 37% natural, and 22% urban. Our forecast assumes that by 2054, watershed land use will transition to 25% agriculture, 30% natural, and 45% urban. Furthermore, we assume that rainfall intensity will increase by 14% from current conditions by 2062. In light of these changes, our HydroCAD models predicted, on average, a 20% increase in storm event runoff volume and peak flow rate from land use change, and a 39% increase in storm event runoff volume and peak flow rate from climate change by 2062. Our STEPL models predicted a reduction in nutrient loads resulting from the conversion of agricultural land to urban land; however, natural land converted to urban land will increase nutrient runoff. To help mitigate these effects, we recommend restoring wetlands along Swan and Murphy's creeks to moderate and store stormwater runoff. We also recommend revisiting stormwater management design standards to account for a more intense hydrologic climate. Additionally, because a focused groundwater study was beyond our scope, we want to emphasize that a complete management plan for the Waubesa Wetlands watershed requires further examination of local groundwater dynamics.

Community Engagement

Watershed residents and visitors benefit from the many different services that Waubesa Wetlands provide. These services may be threatened by land use changes and urban expansion. We dedicated part of our project to community engagement with the goal of increasing awareness about Waubesa Wetlands, its watershed's resources, and the different ways in which people can become long-term stewards. Through multiple educational events, we interacted with 571 people from in and around the watershed (Appendix L). In order to facilitate education and stakeholder access to information about the wetlands, we compiled existing information about Waubesa Wetlands on a website in partnership with CARPC. Furthermore, we augmented the Friends of Waubesa Wetlands, a citizen-led group that has the mission to "sustain and celebrate the terrestrial and aquatic natural resources of Waubesa Wetlands and the surrounding watershed through environmental education, recreation, and ecological management." The group is currently composed of residents from around Dane County, meets on a monthly basis, and advocates for protecting Waubesa Wetlands. We recommend that the website containing information about Waubesa Wetlands be maintained as part of the CARPC comprehensive Water Quality Plan. We also recommend that the Friends of Waubesa Wetlands continue to be stewards by educating watershed residents about the importance of these high-quality wetlands and engaging with other organizations and groups in order to solidify organizational procedures.

Management Recommendations and Conclusions

Based on the findings from our ecosystem services assessment, water quality monitoring, modeling, and community engagement activities, we provide the following management recommendations to the WDNR, CARPC, the Town of Dunn, the City of Fitchburg, stakeholders, and watershed residents:

1. **Restore wetlands along Swan Creek to enhance ecosystem services provided to Waubesa Wetlands.**
2. **Assess ecosystem services and preserve wetlands along Murphy's Creek.**
3. **Continue surface water monitoring and build a comprehensive watershed dataset.**
4. **Install a USGS long-term monitoring site at Swan Creek.**
5. **Design and build for a changing climate in the Waubesa Wetlands watershed, specifically increased precipitation/flow and more extreme storm events.**
6. **Investigate climate change and land use effects on groundwater.**
7. **Educate new watershed residents about water quality and wetlands.**
8. **Sustain and build the Friends of Waubesa Wetlands.**

Waubesa Wetlands are a natural gem that serve numerous critical ecologic, hydrologic, and cultural functions. As a result of this comprehensive evaluation we, the 2017-18 WRM cohort, hope that conservation, outreach, and monitoring efforts will continue throughout the watershed in order to ensure that future generations of Wisconsinites will be able to enjoy this exceptional place and amazing natural resource.

INTRODUCTION

Waubesa Wetlands are an ecologically, hydrologically, and culturally unique natural resource that have long been treasured by residents of Dunn, Fitchburg, and Madison. The 13-square-mile watershed of Waubesa Wetlands primarily comprises agricultural and natural land use, but this is changing. Madison is currently the fastest growing metropolitan area in Wisconsin (McCann, 2018), and growth will touch the surrounding small towns and agricultural landscapes. The neighboring City of Fitchburg has proposed three new residential developments within the Waubesa Wetlands watershed. Part of one such development, the Northeast Neighborhood, began construction in April 2018. A changing landscape raises concern about potential increased runoff to the wetlands that could pose risks to sensitive ecosystems.

To further consider the possible impacts of development on Waubesa Wetlands, the Capital Area Regional Planning Commission (CARPC), the Wisconsin Department of Natural Resources (WDNR), and a technical advisory committee (TAC) proposed the watershed as a site for an interdisciplinary Water Resources Management (WRM) practicum. The 2017-18 WRM cohort focused on the area with the goal of better understanding baseline watershed conditions prior to future development, in terms of both ecosystem services provision and tributary water quality. The cohort established the following objectives to guide the Waubesa Wetlands practicum:

- **Provide tools and analysis to the City of Fitchburg, Town of Dunn, CARPC, and WDNR regarding potential land use change and climate change scenarios in the Waubesa Wetlands watershed.**
- **Promote community engagement in the protection and appreciation of Waubesa Wetlands.**

The purpose of this document is to share the work conducted by the 2017-18 WRM cohort. The report begins with background information about Waubesa Wetlands and their watershed (Chapter 1), followed by a discussion of past and current conservation and outreach efforts in the watershed (Chapter 2). The next chapters elaborate upon methods used to better understand current and future watershed conditions and the major findings: an assessment of ecosystem services provided by upstream wetlands (Chapter 3), monitoring of water quality on Swan and Murphy's creeks (Chapter 4), and modeling runoff and water quality in response to changes in land use and climate (Chapter 5). We describe our community engagement efforts in the watershed in Chapter 6, and conclude with management recommendations in Chapter 7 regarding how the WDNR, CARPC, the Town of Dunn, the City of Fitchburg, and watershed residents can expand on this project's efforts to assess and protect the functional integrity of Waubesa Wetlands and their watershed.

WAUBESA WETLANDS AND THEIR WATERSHED

Waubesa Wetlands (Figure 2.1) are a 371-acre state natural area, designated in 1974 by the Wisconsin Department of Natural Resources (WDNR) and located on the southwestern toe of Lake Waubesa in the Town of Dunn in Dane County, Wisconsin. The wetlands receive water from a 13-square-mile watershed that includes Bogholt Deep Spring and Swan and Murphy's creeks. Waubesa Wetlands are an ecological gem, and their story is as unique as the wetlands themselves.

Figure 2.1. Waubesa Wetlands, Murphy's Creek, and Lake Waubesa. (Photo by Cal DeWitt.)

2.1 – Wetland Formation

In the simplest sense, wetlands form as a special transition zone between dry land and open water. Waubesa Wetlands formed over a 6,500-year period as vegetation encroached along the toe of Lake Waubesa (Friedman et al., 1979). Water-loving shoreline plants produced biomass faster than could be decomposed in the anoxic, water-logged soil (Zedler, 2018). This allowed peat to form below the flora and provide further habitat for wetland vegetation.

2.2 – Ecological Communities and Wetland Types

Waubesa Wetlands contain 19 ecological communities, of which eight are aquatic and 11 are wetland. The eight aquatic communities are: springs, creeks and streams, peat mound, spring ponds, littoral waters, submersed aquatic vegetation, great floating marsh mat, and mudflats. The 11 rare wetland communities are: southern sedge meadow, calcareous fen, southern tamarack swamp, lake (shallow, hard, drainage), floating-leaved marsh, wet-mesic prairie, emergent marsh, springs and spring runs, streams (slow, hard, warm), shrub-carr, and southern dry-mesic forest (Zedler, 2018). These ecological communities are home to many rare and endangered plant species, including white lady's slipper (Cypripedium candidum), and purple milkweed (Asclepias purpurascens).

2.3 – Ecosystem Services

In addition to displaying biodiversity that is likely unmatched in the area, Waubesa Wetlands provide numerous ecosystem services, or benefits that humans gain from the natural environment and functioning ecosystems. Some of the ecosystem services provided by Waubesa Wetlands include: human use, wildlife habitat, fish habitat, shoreline protection, carbon storage, flood abatement, and water quality protection (Zedler, 2018).

HUMAN USE

As a state natural area, much of Waubesa Wetlands is accessible to the public and can be explored and appreciated in numerous ways. One can walk into the wetlands after parking in a lot owned by the Nature Conservancy on Lalor Road (Rustic Road #19 in the state's registry) and then walk east along a line of open-grown oak trees to reach the wetlands. Visitors can also kayak or canoe (Figure 2.2) from Goodland Park to explore the effigy mounds, vegetation, and rare sites within the wetlands. The wetlands also have educational and scientific value, and have been the focus of numerous studies (Bedford et al., 1974; DeWitt, 1981; Schroeder, 2007; Rojas & Zedler, 2015). Recently, Professor Emeritus Joy Zedler published a book about Waubesa Wetlands to share their stories (Zedler, 2018).

Figure 2.2. Members of the WRM cohort canoed into the wetlands to monitor and sample water quality. (Photo by Courtney Botelho).

WILDLIFE HABITAT

Seventy-five percent of Wisconsin's wildlife depend on wetlands for some stage of their life cycles, as do 32% of Wisconsin's threatened and endangered species. The diverse habitats in Waubesa Wetlands support the presence of many species of birds, mammals, and reptiles (Figure 2.1). Waubesa Wetlands and wetlands along Swan and Murphy's creeks act as nurseries and corridors for wildlife. Large habitat patches in an undisturbed landscape make the wetlands a hotspot for wildlife in the Madison region (Zedler, 2018). Specifically, Waubesa Wetlands support 27 rare species of plants and animals, of which nine are endangered, five are threatened, and 13 are species of concern (Zedler, 2018). Some notable rare species include peregrine falcon (Falco peregrinus), rusty patched bumble bee (Bombus affinis), and Blanding's turtle (Emydoidea blandingii).

FISH AND AQUATIC HABITAT

The cool and clean waters of Waubesa Wetlands sustain fish populations through many stages of their lives. The wetlands are partially fed by groundwater with a constant temperature of 54° F, which has a moderating effect necessary for fish that are heat-sensitive in summer and cold-sensitive in winter. A constant source of groundwater also keeps the wetlands flooded for thermally sensitive fish to spawn. Plus, the submerged and emergent plants throughout the wetlands create a habitat for invertebrates that serve as a food source for fish (Zedler, 2018).

SHORELINE PROTECTION

The rooted and floating vegetation in Waubesa Wetlands helps anchor Lake Waubesa's shoreline. This protects lake water quality and lake ecosystems by reducing sediment delivery further downstream (Zedler, 2018).

CARBON STORAGE

Muck and peat (organic soils found in the various communities of Waubesa Wetlands) are composed of stored carbon from hundreds of years of litter accumulation. The deepest, oldest peat found in Waubesa Wetlands contain approximately 180,000 metric tons of peat biomass; this peat is as deep as 95 feet in some areas of the wetlands (Friedman et al., 1979). This stored carbon is taken from the air by plants through photosynthesis, where it would otherwise contribute to climate change, and is eventually incorporated into soil; thus, Waubesa Wetlands successfully sequester carbon from the atmosphere.

FLOOD AND STORMWATER STORAGE

The dense vegetation of Waubesa Wetlands, such as water-absorbent tussocks (compact tufts of grass or sedge that develop vertical pedestals of organic soil), help to absorb and slow the flow of floodwaters from throughout the watershed (Zedler, 2018). The entrainment of floodwaters in wetlands not only protects downstream lands from the physical destruction of flooding, but also allows sediments in the water to settle in the wetlands, improving downstream water quality.

WATER QUALITY PROTECTION

The dense vegetation and deep organic soils of Waubesa Wetlands also "treat" some of the runoff from the watershed. In addition to slowing floodwaters, tussocks (Figure 2.3) help to settle and remove sediment from floodwater, and the microbial and plant communities of tussocks facilitate the removal of nitrogen through denitrification (Wolf, Ahn, & Noe, 2011). In addition, the organic soils of the wetlands act as a sponge, absorbing runoff and preventing nutrients from reaching downstream areas. It is estimated that every year, Waubesa Wetlands store about 85 kilograms of phosphorus (Friedman, Dewitt, & Kratz, 1979).

Figure 2.3. Sedges (Carex spp.) help to slow runoff and store sediment and nutrients. Their tussocks create lumps in the landscape, which are apparent even in the winter. (Photo by Némesis Ortiz-Declet).

2.4 – Watershed Historic and Future Land Use

South-central Wisconsin's landscape is defined by the most recent glaciation, 10,000 years ago, which filled pre-glacial valleys with many different types of glacial deposits, creating a hummocky landscape of depressions, drumlins, and other new surface features. The glaciers also left behind fertile sediment, which gave way to rich surface-water features and wind-blown deposits of fertile sediments that contributed to the successful establishment of agricultural activities in Dane County in the mid-1800s. Waubesa Wetlands exist predominantly in what is now the Town of Dunn, while their watershed lies mostly within the City of Fitchburg. The Town of Dunn has demonstrated a commitment to environmental conservation and preservation of its rural character. The town's plan contains only limited future development areas in its northeast corner and is intended to maintain non-developed land use near Waubesa Wetlands through conservation easements and agricultural preservation areas (Town of Dunn, 2017). The City of Fitchburg has embraced more urbanized development, capturing opportunities as metropolitan Madison expands. From 2006 to present, roughly 750 acres of agricultural and vacant land has transitioned to commercial and residential land, and the city anticipates a similar transition from present to 2030 (City of Fitchburg, 2017). Fitchburg's designated future development areas are mostly situated along the U.S. 14 corridor. One of the development areas, known as the Northeast Neighborhood, began construction with the Terravessa neighborhood in April 2018.

2.5 – Swan Creek Subwatershed

The Swan Creek subwatershed, which feeds the northern portion of Waubesa Wetlands, covers 56% of the total watershed to the wetlands. Land use in the 4,700-acre watershed is dominated by agriculture (46%), followed by natural land (30%), and developed land (24%). Agricultural land is primarily row crop and the only known animal operation is a 150-head hog farm on the edge of the watershed. Manure from this farm may be spread on fields within the watershed, which could contribute runoff to the creek.

Given that only 30% of this land remains in a natural state, Swan Creek and its tributaries have been considerably modified from their natural flow paths, diminishing the ecological integrity of the watershed. Swan Creek is runoff-dominated, receiving only small inputs from groundwater. This is one of the reasons the WDNR has classified it as a "warmwater forage fishery," comprising a habitat for minnows, suckers, sunfish, and other warmwater aquatic life.

2.6 – Murphy's Creek Subwatershed

The Murphy's Creek subwatershed encompasses most of Waubesa Wetlands and spans 3,735 acres, 44% of the total Waubesa Wetland watershed. Land use in the watershed is primarily natural (44%), followed by agricultural (36%), and developed land (20%). Two small beef farms are sited within the watershed totaling 80 animal units, and agricultural land is primarily row crop. Compared to the Swan Creek subwatershed, the Murphy's Creek subwatershed has more natural land and a higher proportion of wetland-to-watershed area. Upland springs provide most of the baseflow to Murphy's Creek, and the WDNR classifies it as a "warmwater forage fishery."

2.7 – Water Quality Concerns

The water quality of the Yahara chain of lakes—Mendota, Monona, Waubesa, and Kegonsa—has been studied for over 100 years. Since the early 1900s, these four lakes have been eutrophic (overly enriched with nutrients) (Lathrop et al., 1992). When a water body receives excess nutrients such as phosphorus and nitrogen, plants grow in abundance, and when they die and decompose, they deprive the water of oxygen that aquatic animals need to survive (NRC, 1969). Eutrophication and its effects are the most common process of water quality decline. As the Yahara Lakes and their tributaries have become more eutrophic, nuisance algal blooms have developed, leading to beach closings, unpleasant odors, and an overall reduction in the lakes' aesthetic appeal.

As we have seen with the Yahara watershed, our inland aquatic ecosystems are susceptible to eutrophication (Detenbeck, Johnston, & Niemi, 1993). Land use directly affects the water quality of water bodies throughout a watershed. For instance, agricultural production is closely tied with elevated river nitrate concentrations in Midwest river basins (Stets, Kelly, & Crawford, 2015). Urbanization also affects surface water quality as stormwater from urban areas contains pollutants such as sediment, nutrients, road salt, bacteria, pesticides, and metals that can be washed into water bodies (NRC, 2009). Studies have shown that surface water quality declines when as little as 10% of a watershed area is impervious (Center for Watershed Protection, 2003). Other activities like ditching, bank stabilization, and channel straightening also impact water quality by increasing erosion and transporting sediments into downstream water bodies (NRC, 2009).

Because wetlands depend on surface water and groundwater, they are vulnerable to declines in water quality. Swan and Murphy's creeks carry contaminants from their subwatersheds into Waubesa Wetlands, resulting in high concentrations of nutrients and low stream biota in the streams (Zedler, 2018). As land use in the Waubesa Wetlands watershed becomes more urbanized, the threats may continue or change. Several long-term studies conducted in the region hypothesize that Waubesa Wetlands are threatened by upstream development, as has occurred in wetlands and lakes in other watersheds (Woo & Zedler 2002; Drexler & Bedford; 2002, Kercher, Carpenter, & Zedler, 2007; Lathrop, 2007; Lewis, Wurtsbaugh, & Paerl, 2011). Therefore, it is vital to monitor the water quality of tributaries entering Waubesa Wetlands and monitor possible changes to the critical ecosystem functioning of the wetlands.

2.8 – Current Designation

Most of the land encompassing Waubesa Wetlands is protected as a state natural area by the WDNR, along with The Nature Conservancy, Dane County, the National Heritage Land Trust, the Town of Dunn, and some private land owners. Waubesa Wetlands have received recognition from state and international organizations. The Wisconsin Wetlands Association includes them on a list of 100 "Wisconsin Wetland Gems®" because of their ecological and cultural significance. The Society of Wetland Scientists, a world leader in wetland science, designates Waubesa Wetlands as a Wetland of Distinction. Additionally, the wetlands have been nominated as a Wetland of International Importance under the Ramsar Convention, an international treaty for the conservation and sustainable use of wetlands.

2.9 – Current Management Efforts

The Nature Conservancy works closely with the WDNR to organize volunteers in the State Natural Area Volunteer Program, who help restore the wetlands and surrounding woodlands by removing invasive species and conducting controlled burns. The Rock River Coalition (RRC), a local environmental non-profit, is also active in the watershed. RRC leads a team of volunteer citizen-science stream monitors who have collected water quality data at sites along Swan and Murphy's creeks since 2015.

ECOSYSTEM SERVICES ASSESSMENT

3.1 – Introduction

Ecosystem services are the numerous, freely gained benefits that humans get from the natural environment and functioning ecosystems. Evaluating these services can inform decision makers of the consequences of ecosystem degradation and promote policies and decisions that increase long-term ecosystem and infrastructure resilience. Ecosystem services assessments quantify the importance of healthy ecosystems by connecting human benefits to these environmental functions. Additionally, these assessments can be used to optimize multiple services and engage communities, and are risk-assessment tools.

A turning point in the way scientists determine these services was the Millennium Ecosystem Assessment (MEA), which groups ecosystem services into four categories: provisioning, supporting, cultural, and regulating (MEA, 2005). Provisioning services supply products humans can use, like clean drinking water and fish or game for consumption. Supporting services are environmental processes such as nutrient cycling and habitat support for biodiversity and endangered species. Regulating services promote the stability of Earth's systems, including carbon sequestration, shoreline protection, and flood peak reduction. Cultural services are those that provide spiritual, recreational, and aesthetic benefits to humans (MEA, 2005).

High-quality wetlands are some of the most significant producers of ecosystem services, particularly for water-related functions. The dense vegetation and deep, organic soils present in many wetlands help regulate water quantity and quality by acting as both a sponge and a filter. These functions assist in the control of floods, sediment transport, and erosion. Furthermore, wetlands are often very diverse and act as feeding and nesting grounds for migratory species. This high species diversity makes wetlands one of the most productive habitats in the world, which contributes to nutrient recycling and niche specialization. Many of these functions are critical for the health of humans and the environment; these unique ecosystems are often called "working wetlands" (McCartney, Masiyandima, & Houghton-Carr, 2005).

Though many wetlands provide vital ecosystem services, factors such as wetland vegetation type, hydrology, and soil characteristics can influence the types and number of services performed by wetlands. Upstream land use, connectivity to water bodies, and a wetland's location in a watershed, are also important factors for determining service provision. For example, a riparian wetland located upstream of a city serves a critical role in reducing flood peaks and improving water quality and public safety for that city. Thus, the relative position of wetlands in a watershed plays a role in how ecosystem services are distributed among the wetlands (NRC, 2001; Zedler, 2003; Zedler, 2012).

3.2 – Purpose

Waubesa Wetlands connect to a large upstream network of wetlands along Swan and Murphy's creeks. These riparian wetlands are primarily located on private property, are largely unstudied, and are close to the proposed developments. To see how the downstream Waubesa Wetlands might be affected by new development, we identified a need to understand the current state of these upstream wetlands and the ecosystem services that they provide. Thus, we focused our study on a riparian wetland complex along both sides of Swan Creek that extends from US Highway 14 to the Waubesa Wetlands State Natural Area (Figure 3.1). This Swan Creek corridor covers upstream to downstream of the most immediate new development, the Northeast Neighborhood. Our assessment looked at how ecosystem services are distributed throughout the Swan Creek corridor, how these services are related to wetland types, how services are related to wetland location within the complex, and how services occur together in bundles.

This snapshot of current wetland conditions can be used in the future as a baseline reference to evaluate change. Ultimately, future changes in upstream wetlands could translate to potential changes in Waubesa Wetlands. It is our goal that this comprehensive assessment will inform management and restoration decisions throughout the Swan Creek corridor by identifying degraded or vulnerable wetlands, and prioritize the enhancement of 'bundled' services.

3.3 – Methods

WETLAND SELECTION

Before conducting fieldwork, we used the WDNR's Wisconsin Wetlands Inventory (WWI) geodatabase for Dane County to gather spatial data for the Swan Creek corridor (WDNR, 1984). The WWI divides the larger wetland complex into wetland polygons according to vegetation type, hydrology, and soils. Within each polygon, the WWI may identify multiple wetland types. For our analysis, we conducted fieldwork and worked with wetland ecologists (Figure 3.2) to identify the dominant wetland type in each polygon based on vegetation (cover > 50%). In our study area, the four major wetland types include southern sedge meadow, shrub-carr, southern hardwood swamp, and emergent marsh.

Since the wetlands are all located on private property, we reached out to local residents through handwritten letters explaining our project and purpose. We had a great response rate and were allowed to assess wetlands on eight private properties.

ECOSYSTEM SERVICE ASSESSMENT

We evaluated as many wetland polygons in the Swan Creek corridor as we were able; we were constrained by time and access to private property. In each polygon, we conducted a modified level two assessment using the Wetland Rapid Assessment Methodology version two (WRAM) (Appendix A) (WDNR, 2014). Whereas level one monitoring approaches are coarse, broad-scale "landscape assessments," level two approaches are specific wetland site-scale "rapid assessments." With more time and resources, a level three monitoring "intensive assessment" can give more detailed wetland function information (USEPA, n.d.).

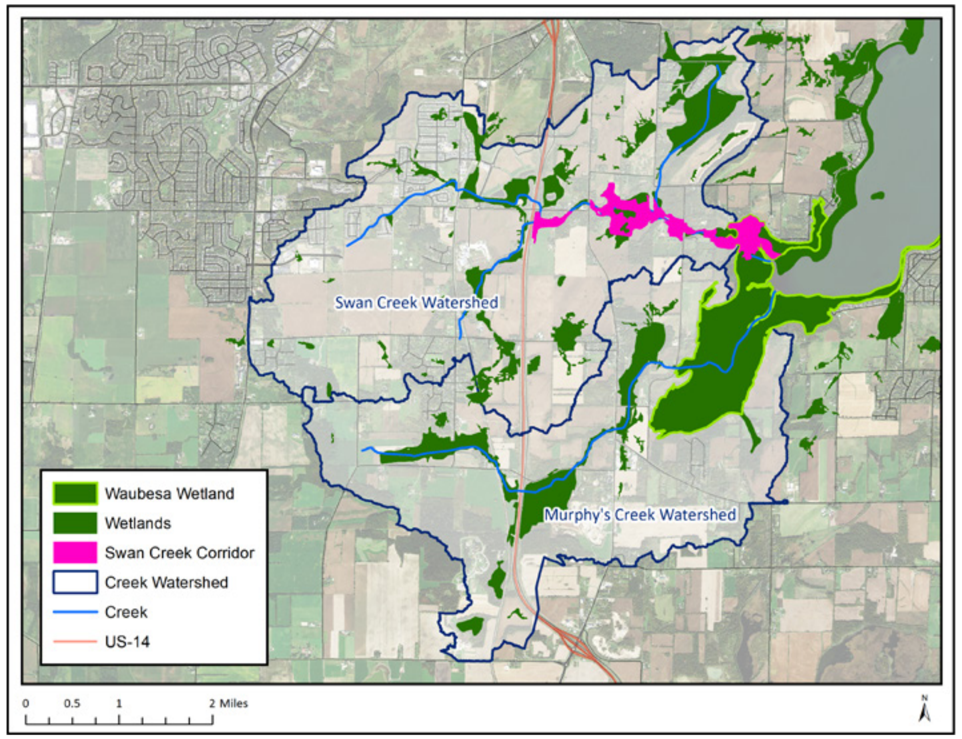


Figure 3.1. Wetlands of the Waubesa Wetlands watershed. Our study area, the Swan Creek corridor wetland complex, is highlighted in pink. The wetland polygons are derived from the Wisconsin Wetland Inventory (WWI) (WDNR, 1984).

The level two WRAM guides the process of translating qualitative, observable characteristics from fieldwork into descriptions of eight ecosystem services. The WRAM uses the term functional values; however, this is interchangeable with ecosystem services. The eight WRAM services are: human use values, floristic integrity, wildlife habitat, fish and aquatic habitat, flood and stormwater storage, shoreline protection, groundwater processes, and water quality protection.

Based on our fieldwork and with input from wetland experts, we developed metrics to translate our WRAM observations into significance scores (Appendix B). Doing this allowed us to compare the capacity of different areas to provide ecosystem services throughout the wetland corridor. We assigned scores of non-applicable, low, medium, high, or exceptional for each wetland and each ecosystem service.

Detailed descriptions of each service and how it was assessed can be found in Table 3.1. The assessment considers the capacity of a given wetland to generate each service and its significance for the watershed and society. An assessor uses best professional judgement to determine this balance between capacity and significance. It is important to note that the capacity to generate a service may differ from the actual services received, since those depend on demand, which is driven by factors like biophysical setting, population size, and management actions (Villamagna, Angermeier, & Bennett, 2013).

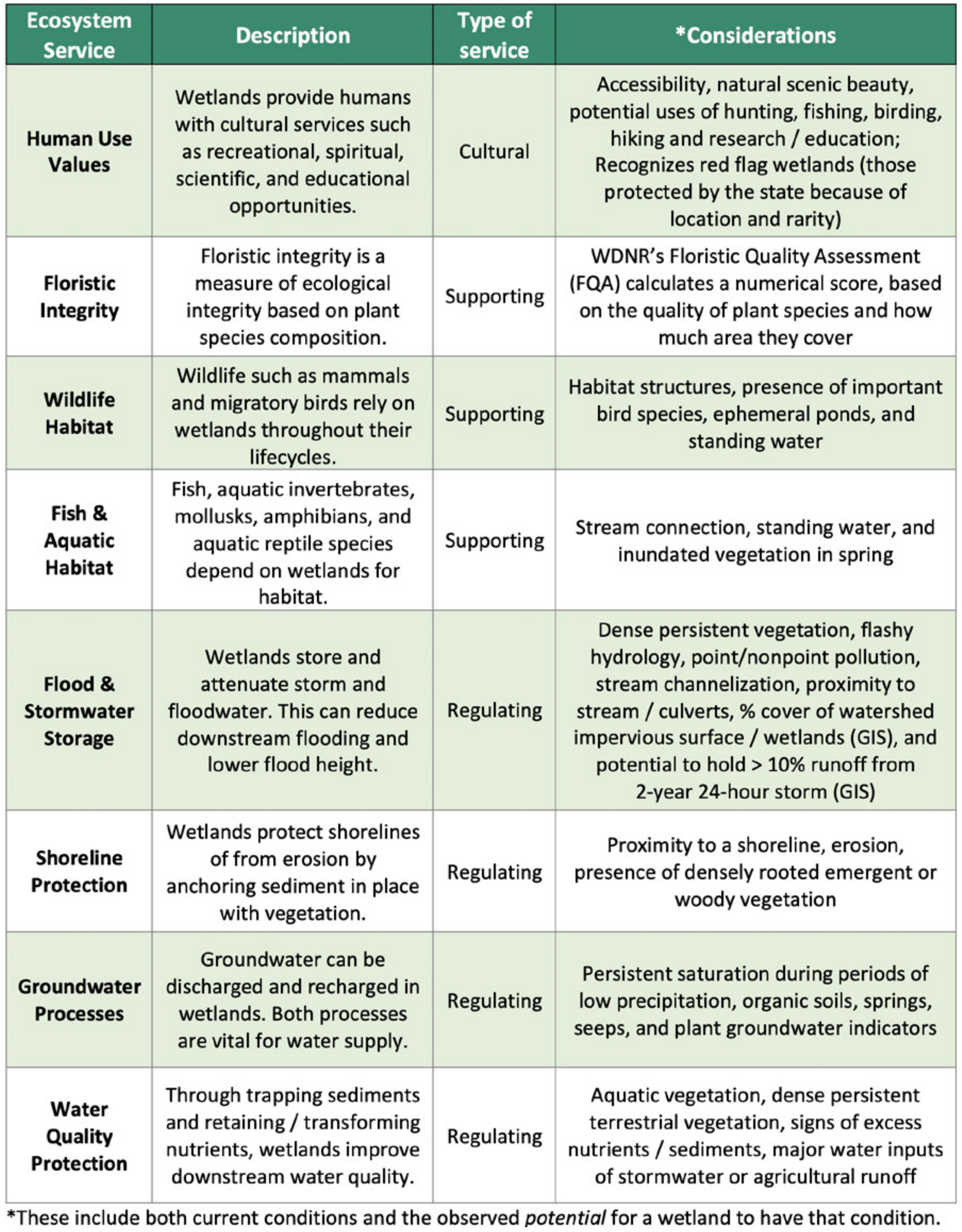
Geospatial analyses using both a geographic information system (GIS) and a field visit are needed to identify the presence or absence of specific characteristics, which indicate the importance of an ecosystem service in each wetland polygon. After field visits, we further split large polygons when we observed substantial differences in ecosystem services within a polygon. This allowed us to have a finer resolution of data. A full list of plants identified in the corridor for the floristic integrity assessment are listed in Appendix C.

STATISTICAL ANALYSIS

We used ANOVA, Tukey HSD tests, two-sample t-tests, and Pearson correlation tests to identify statistically significant relationships between wetland types, locations, and ecosystem services. Please see Appendix E for more details on statistical analysis.

Figure 3.2. Plant identification in a southern sedge meadow with wetland ecologist Tom Bernthal. (Photo by Lianna Johnson).

Table 3.1. Ecosystem services assessed.
*These include both current conditions and the observed potential for a wetland to have that condition.



Ecosystem Service	Description	Type of service	*Considerations
Human Use Values	Wetlands provide humans with cultural services such as recreational, spiritual, scientific, and educational opportunities.	Cultural	Accessibility, natural scenic beauty, potential uses of hunting, fishing, birding, hiking and research / education; Recognizes red flag wetlands (those protected by the state because of location and rarity)
Floristic Integrity	Floristic integrity is a measure of ecological integrity based on plant species composition.	Supporting	WDNR's Floristic Quality Assessment (FQA) calculates a numerical score, based on the quality of plant species and how much area they cover
Wildlife Habitat	Wildlife such as mammals and migratory birds rely on wetlands throughout their lifecycles.	Supporting	Habitat structures, presence of important bird species, ephemeral ponds, and standing water
Fish & Aquatic Habitat	Fish, aquatic invertebrates, mollusks, amphibians, and aquatic reptile species depend on wetlands for habitat.	Supporting	Stream connection, standing water, and inundated vegetation in spring
Flood & Stormwater Storage	Wetlands store and attenuate storm and floodwater. This can reduce downstream flooding and lower flood height.	Regulating	Dense persistent vegetation, flashy hydrology, point/nonpoint pollution, stream channelization, proximity to stream / culverts, % cover of watershed impervious surface / wetlands (GIS), and potential to hold > 10% runoff from 2-year 24-hour storm (GIS)
Shoreline Protection	Wetlands protect shorelines of from erosion by anchoring sediment in place with vegetation.	Regulating	Proximity to a shoreline, erosion, presence of densely rooted emergent or woody vegetation
Groundwater Processes	Groundwater can be discharged and recharged in wetlands. Both processes are vital for water supply.	Regulating	Persistent saturation during periods of low precipitation, organic soils, springs, seeps, and plant groundwater indicators
Water Quality Protection	Through trapping sediments and retaining / transforming nutrients, wetlands improve downstream water quality.	Regulating	Aquatic vegetation, dense persistent terrestrial vegetation, signs of excess nutrients / sediments, major water inputs of stormwater or agricultural runoff

*These include both current conditions and the observed *potential* for a wetland to have that condition.

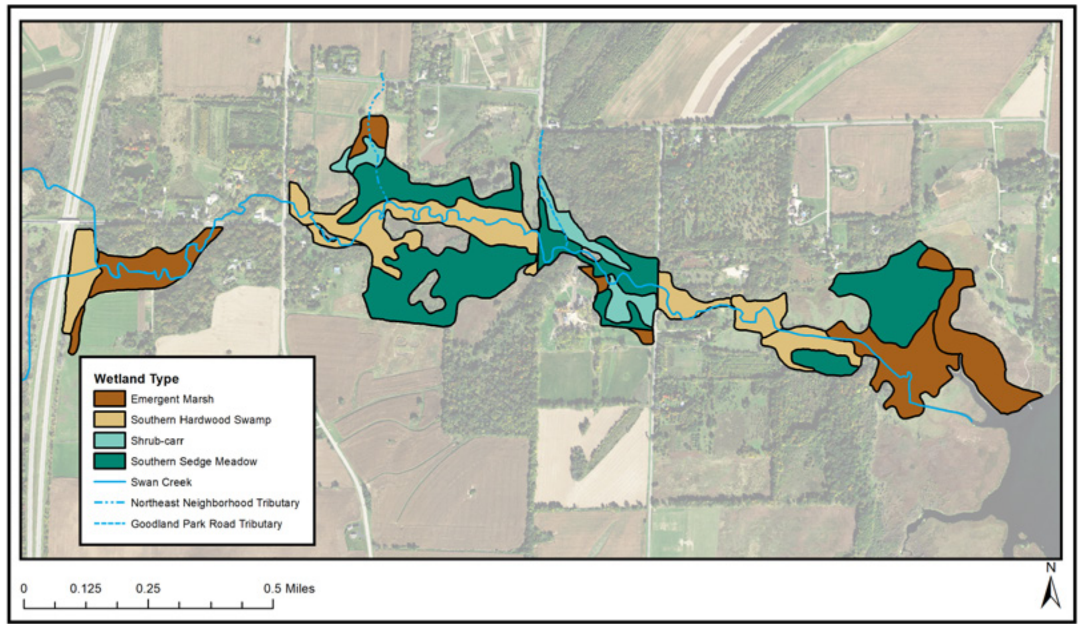


Figure 3.3. Wetland type polygons in the Swan Creek corridor. Each polygon shows the dominant wetland community as identified through the WWI and field observations.

3.4 – Wetland Types in the Swan Creek Corridor

The following descriptions of the dominant wetland types found in the Swan Creek corridor are adapted from the WDNR publication "Ecological Landscapes of Wisconsin" (Epstein, 2017). Wetland types within the corridor are shown in Figure 3.3.

SOUTHERN SEDGE MEADOW

Southern sedge meadows (Figure 3.4) are typically herb-dominated, in particular by the tussock sedge (Carex stricta). This species can be thought of as the keystone species since it greatly influences the physical structure and community composition of this wetland type by providing microsites on which other members of the plant community can establish. Other common plants associated with southern sedge meadows include spotted joe-pye weed (Eupatorium maculatum), boneset (Eupatorium perfoliatum), purple-stem angelica (Angelica atropurpurea), turtlehead (Chelone glabra), and swamp milkweed (Asclepias incarnata).

As minerotrophic wetlands, southern sedge meadows receive the majority of their water inputs from springs and streams. High mineral content from underlying calcareous glacial deposits leads to alkaline soils that support plants that specialize in high pH environments. Groundwater springs and elevated stream levels in the spring months can prevent encroachment of invasive and other woody species because the wetlands are regularly saturated or inundated by water. These hydrological dynamics are an important factor for maintaining the ecological integrity and ecosystem services of southern sedge meadows. Sediment and nutrient delivery to sedge meadows changes these dynamics and also makes them vulnerable to invasions of reed canary grass (Phalaris arundinacea), which can become heavily dominant or a monoculture.

SHRUB-CARR

Shrub-carrs (Figure 3.5) are typically dominated by tall deciduous shrubs like dogwoods (Cornus spp.) and willows (Salix spp.). Shrub stands can be very dense, or interspersed with patches of sedge meadow or emergent marsh. Commonly associated species include blue-joint grass (Calamagrostis canadensis), spotted joe-pye weed (Eupatorium maculatum), and giant goldenrod (Solidago gigantea). With sufficient groundwater inputs, shrub-carrs may support specialists like purple-stem angelica (Angelica atropurpurea), arrowheads (Sagittaria spp.), and bulrushes (Scirpus spp.). Typically, shrub-carr soils are mucks or peats that

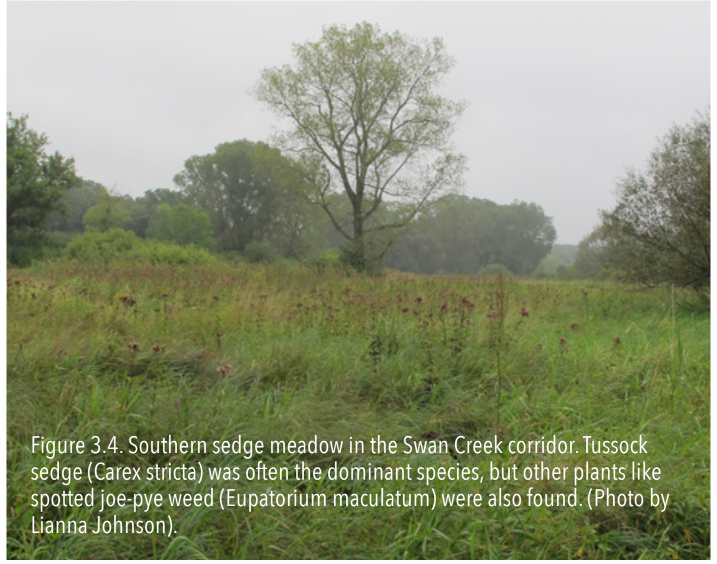


Figure 3.4. Southern sedge meadow in the Swan Creek corridor. Tussock sedge (Carex stricta) was often the dominant species, but other plants like spotted joe-pye weed (Eupatorium maculatum) were also found. (Photo by Lianna Johnson).

Figure 3.5. Shrub-carr in the Swan Creek corridor. Red osier dogwood (Cornus sericea) was a dominant shrub in this wetland. (Photo by Lianna Johnson).

are neutral or slightly calcareous when underlain by glacial deposits. They are minerotrophic wetlands that are hydrologically saturated to seasonally inundated. Wetland drainage, grazing, and fire suppression has allowed shrub-carr wetlands to increase in abundance at the expense of herb-dominated wetlands like sedge meadows.

SOUTHERN HARDWOOD SWAMP

Southern hardwood swamps (Figure 3.6) are dominated by deciduous tree species that are somewhat tolerant of saturated soils, like red maple (Acer rubrum), green ash (Fraxinus pennsylvanica), and American elm (Ulmus americana). Other common tree species include bitternut hickory (Carya cordifomis), silver maple (Acer saccarinum), hackberry (Celtis occidentalis), and American basswood (Tilia americana). Shrub species like dogwood (Cornus spp.) and nannyberry (Viburnum lentago) tend to fill in any canopy openings that result from windfall or major flooding events. Vines can also be common in these communities, with plants like wild cucumber (Echinocystis lobata), poison ivy (Toxicodendron radicans), and river bank grape (Vitis riparia) establishing well in the understory. Other common understory plants include orange jewelweed (Impatiens biflora) and stinging nettle (Urtica dioca). Invasive species are a major threat to this wetland type, including buckthorns (Rhamnus spp.) and box elder (Acer negundo). Reed canary grass (Phalaris arundinacea) is of special concern in southern hardwood swamps because it can dominate any canopy openings and suppress native species, including tree seedlings, especially when there are excessive inputs of sediment from nearby croplands or construction sites.

Figure 3.6. Southern hardwood swamp in the Swan Creek corridor. Eastern black walnut trees (Juglans nigra) were prevalent in this wetland. (Photo by Lianna Johnson).

The soils of southern hardwood swamps are typically mineral soils but can be mucky depending on hydrology and vegetation. The hydrology of this wetland type is distinguished by its seasonal fluctuations in water level. Periodic inundation varies in duration, extent and magnitude and results from snowmelt and spring rains, which can be accompanied by periods of standing water.

EMERGENT MARSH

The dominant species in emergent marshes (Figure 3.7) are typically graminoid (grass-like), and many have the ability to form clones such as cattails (Typha spp.) and bulrushes (Scripus spp.). Other species common in this type of wetland are plants like arrowhead (Sagittaria spp.) and water horsetail (Equisetum fluviatile). It should be noted that it is common for a single species to dominate emergent marshes, barring changes in water depth, clarity, or quality. Emergent marshes can be found in depressional areas with poorly drained soils that typically have some standing water for the majority of the year. They also are common along the shores of lakes and streams that are protected from high winds and waves. The spread of invasive species is a significant problem in emergent marshes, with species like hybrid cattail (T. x glauca) and reed canary grass (Phalaris arundinacea) dominating entire communities.

Figure 3.7. Emergent marsh in the Swan Creek corridor. These wetlands were dominated by cattails (Typha spp.) (Photo by Lianna Johnson).

3.5 – Results and Discussion

DISTRIBUTION OF ECOSYSTEM SERVICES IN THE SWAN CREEK CORRIDOR

We translated our assessment of the current condition and potential of the ecosystem services provided by wetlands throughout the Swan Creek corridor into a significance ranking system for each service (non-applicable, low, medium, high, or exceptional) (Appendix B). This allowed us to compare how the eight services are distributed throughout the Swan Creek corridor.

HUMAN USE VALUE

To obtain an exceptional human use value significance score ranking, a wetland polygon must have shown current or potential recreational, educational and scientific uses, accessibility, natural scenic beauty, and important habitat, and be a red flag area protected by the state. About 14% of the wetland polygons we assessed obtained an exceptional score (Figure 3.8). The lack of one or more of the mentioned criteria resulted in lower scores and therefore lower ranking. Of the rest of the polygons we assessed, 39% ranked high, 43% ranked medium, and four percent ranked low for human use value. These rankings show that many of the wetlands in the Swan Creek corridor are currently providing highly significant cultural resources to human residents and visitors.

FLORISTIC INTEGRITY

Floristic integrity serves as an indicator of the ecological integrity of the Swan Creek corridor. For this supporting ecosystem service, rankings were based on the observed vegetation species composition as directed by the WRAM version two. About nine percent of the wetland polygons ranked exceptional with a weighted mean C estimate range of 3.2 - 4.4 (Figure 3.8). The rest of the wetland polygons ranked high (13%), medium (43%), and low (35%); collectively, their weighted mean C estimate ranged from 1.7-3.1.

WILDLIFE HABITAT

For a wetland polygon to obtain a high wildlife habitat significance score ranking, it must support or potentially support habitat for different kinds of sensitive species through the provision of pockets of standing water and seasonally inundated vegetation, ephemeral ponds, and stream connectivity. Additionally, the wetland polygon must possess diverse habitat structures and at least three vegetation strata, among other criteria. Most of the polygons (74%) ranked high, while other wetland polygons (4%) were attributed bonus points based on landscape and wildlife observations, reaching the exceptional ranking (Figure 3.9). The rest of the wetland polygons ranked medium (17%) and low (4%). This shows how most of the Swan Creek corridor (80%) supports multiple different wildlife species.

FISH AND AQUATIC HABITAT

In order to obtain an exceptional fish and aquatic habitat significance score ranking, a wetland polygon must be connected to a lake or stream, be saturated in response to seasonal precipitation or groundwater inputs, and support or potentially support endangered, threatened, or species of concern. Nine percent of the wetland polygons of the Swan Creek corridor met all criteria resulting in an exceptional ranking (Figure 3.9). About half the wetland polygons (52%) ranked high, 22% ranked medium, and 17% ranked low. Considering both exceptional and high-ranking wetland polygons, it is evident that more than half of the corridor is currently working significantly to support fish and aquatic life.

FLOOD AND STORMWATER STORAGE

The flood and stormwater storage significance score ranking was based on evidence of flashy hydrology, dense persistent vegetation, presence of a constricted outlet, point or nonpoint source pollution inflow, stream presence, stream channelization, and impervious surface cover percent estimates, among other factors. In order to obtain an exceptional score, wetland polygons must have shown evidence of the mentioned criteria and receive bonus points based on landscape observations. About 17% of the assessed wetland polygons ranked exceptional (Figure 3.10). The rest ranked high (43%), medium (35%), and low (4%). In combination, the exceptional and high-ranking wetland polygons make up more than half (60%) the Swan Creek corridor, showing how these wetlands work significantly as a sponge for flood and stormwater mitigation.

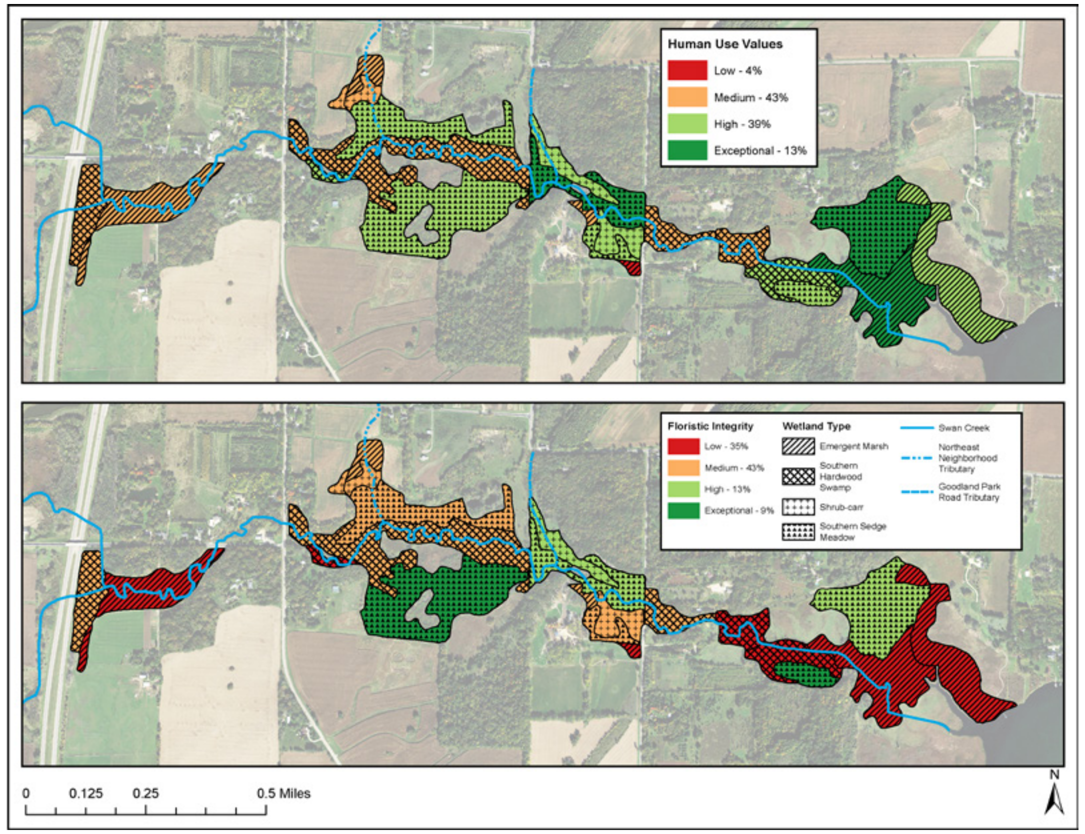


Figure 3.8. Human use values (top) and floristic integrity (bottom) ecosystem services significance scores in the Swan Creek corridor.

SHORELINE PROTECTION

About 35% of the assessed wetland polygons were non-applicable for the shoreline protection ecosystem service because they were not along the shore of a lake or stream (Figure 3.10). The wetland polygons that we assessed obtained a high shoreline protection significance score ranking when about 75% of the area along the shore of a stream or lake was covered in vegetation with minimal erosion observed. About 30% of the wetland polygons ranked high. Similarly, another 30% of the assessed wetland polygons obtained a medium ranking, for which about 50% of the area adjacent to lakes or streams was covered in vegetation and showed moderate erosion or severe erosion. Only four percent of the wetlands that we assessed ranked low, for which about 25% or less of the area along the shore of a stream or lake was covered in vegetation and exhibited severe erosion.

GROUNDWATER PROCESSES

Through our field assessment, we observed numerous groundwater indicators throughout the Swan Creek corridor. This service had the highest number (30%) of exceptional ranking wetland polygons (Figure 3.11). These had to meet the following criteria: be a headwater wetland, remain saturated for an extended period of time without

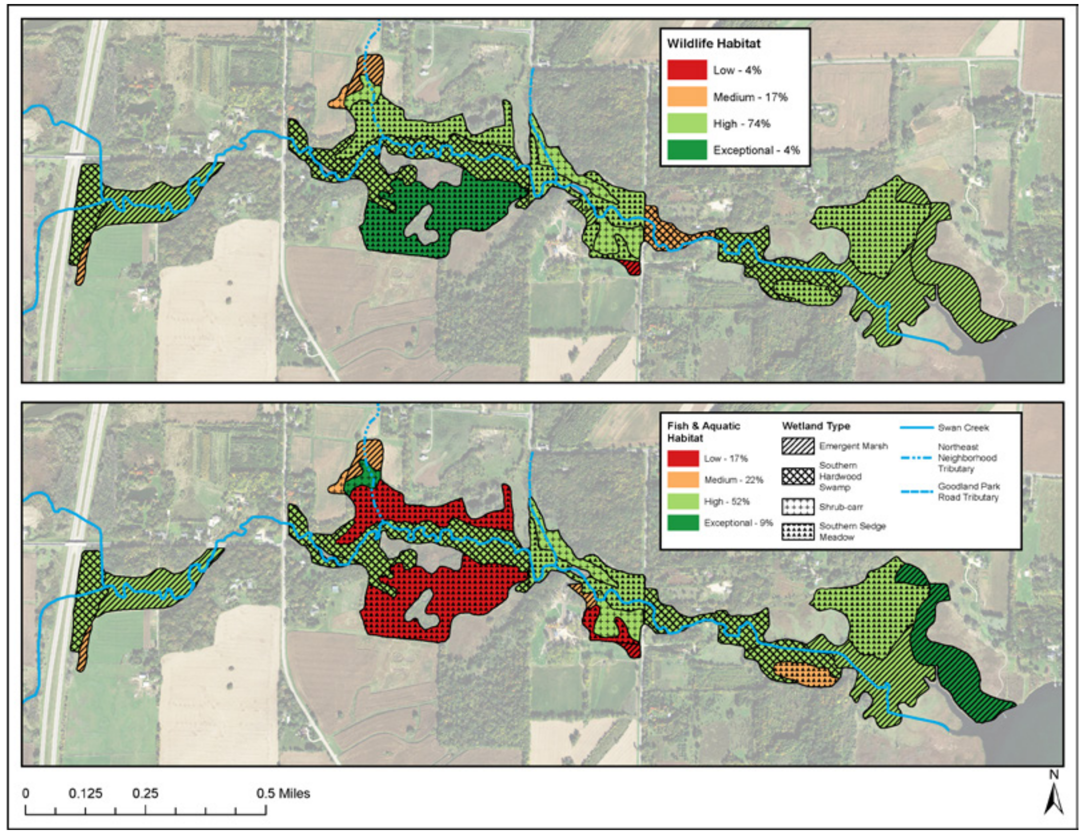


Figure 3.9. Wildlife habitat (top) and fish and aquatic habitat (bottom) ecosystem services significance scores in the Swan Creek corridor.

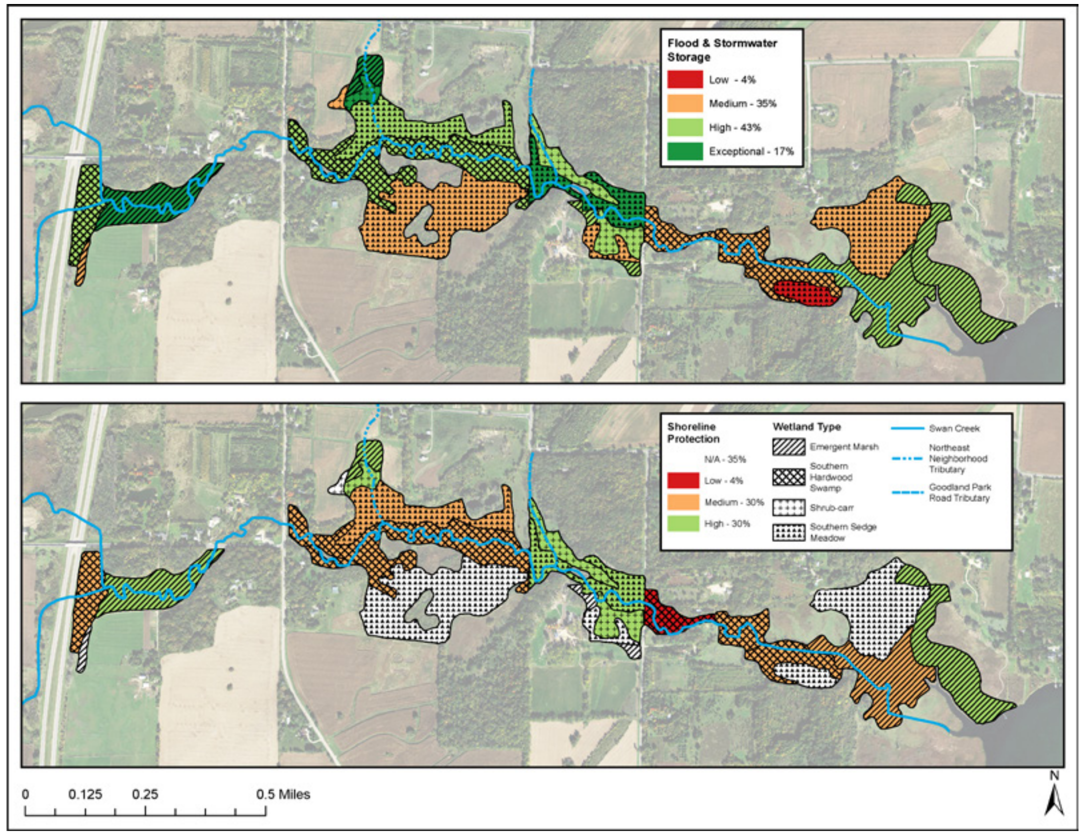


Figure 3.10. Flood and stormwater storage (top) and shoreline protection (bottom) ecosystem services significance scores in the Swan Creek corridor.

significant precipitation input, have organic soils, be within a wellhead protection area, and show the presence of springs or seeps. Wetland polygons that lacked one or more of the criteria would rank lower. However, none of the wetland polygons we assessed ranked lower than medium (35%); the rest ranked high (35%). Taken together, the exceptional and high-ranking wetland polygons make up 65% of the Swan Creek corridor, showing the important connection between wetlands and groundwater processes in this area.

WATER QUALITY PROTECTION

Water quality protection had the second highest number (26%) of exceptional ranking wetland polygons (Figure 3.11). To obtain such ranking, these wetland polygons must have shown evidence of water storage capacity, water flowing through (considering channeling), dense persistent aquatic vegetation, signs of nutrient or sediment retention from stormwater or agricultural runoff, discharge into surface water, and natural land in a 100-meter buffer. We interpreted observations by considering the wetlands' working capacity and the evidence of water quality being protected. Most of the wetland polygons (39%) had a high water quality protection significance score ranking. Others ranked medium (30%) and the minority ranked low (4%). In combination, exceptional and high-ranking wetland polygons make up about 65% of the Swan Creek corridor, showing how more than half of the wetlands are working to protect the quality of water that will eventually reach Waubesa Wetlands.

WETLAND TYPE ECOSYSTEM SERVICES SIGNIFICANCE SCORES

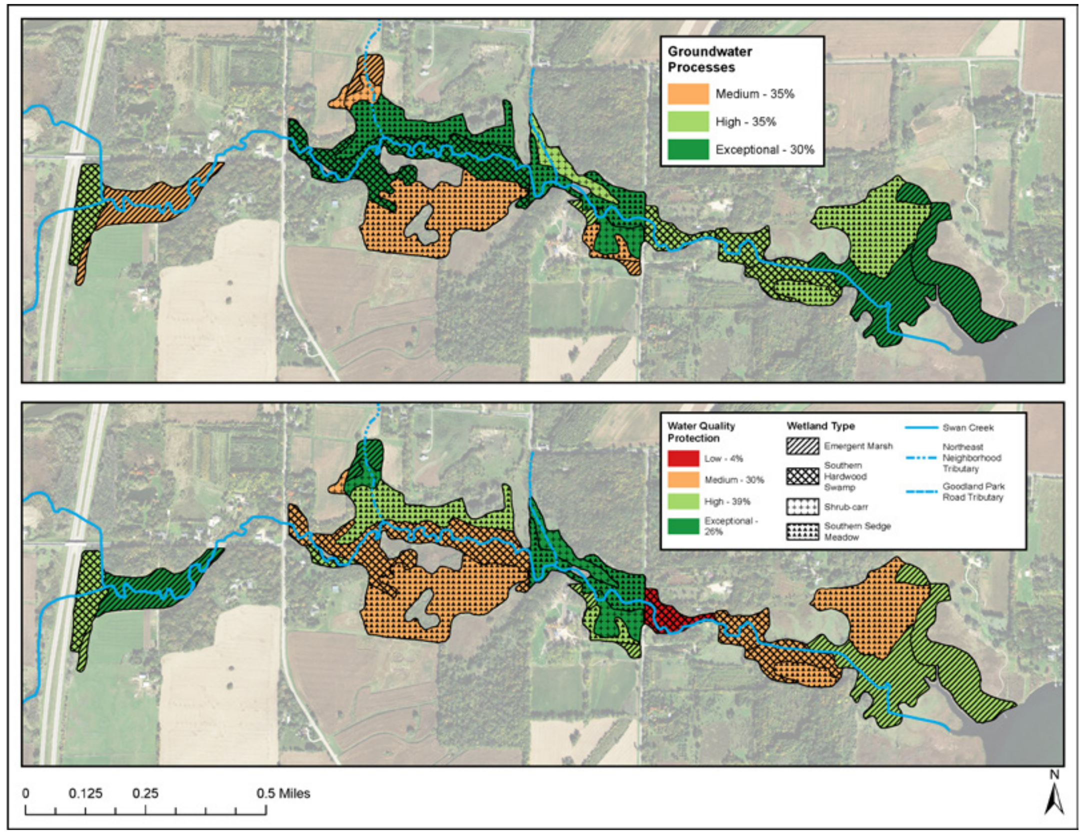


Figure 3.11. Groundwater processes (top) and water quality protection (bottom) ecosystem services significance scores in the Swan Creek corridor.

Wetland type has an impact on the provision of the floristic integrity ecosystem service in the Swan Creek corridor (Figure 3.8). Analysis of our data resulted in a statistically significant difference between the mean floristic integrity of southern sedge meadows and emergent marshes ($p \leq 0.01$) as well as southern sedge meadows and southern hardwood swamps ($p \leq 0.05$). We also found a significant difference between the average shrub-carr, which had the second highest floristic integrity scores by wetland type, and emergent marshes ($p \leq 0.05$). All ecosystem service scores by wetland type can be found in Appendix D.

Our results are not surprising given that the WDNR established separate benchmarks for different wetland plant communities by ecoregion to acknowledge that different communities have naturally different ranges of floristic integrity. In fact, a new benchmark currently in preparation will add new sets of published floristic quality benchmarks for selected wetland plant communities. In our results, southern sedge meadows had the highest floristic integrity scores. Typically, they are dominated by tussock sedge (Carex stricta), which fosters high plant species diversity because it acts like a matrix dominant, meaning it allows many other native plants to co-exist (Palmer et al., 2016). In comparison, research indicates that emergent marshes tend to have a much lower plant species biodiversity than other wetland types (Rojas & Zedler, 2015) because of dominating allelopathic species like cattails (Typha spp.). These species can outcompete native plants by using phytotoxic compounds to prevent germination and growth of other plants (Gallardo et al., 1998). Therefore, the presence of certain plant species typical of a wetland type will, on average, lead to the significant differences in floristic integrity observed in our assessment.

WETLAND LOCATION ECOSYSTEM SERVICES SIGNIFICANCE SCORES

Wetland location in the Swan Creek corridor also has an observable impact on ecosystem services. We considered two different measures of wetland location: inner versus outer riparian wetland, and upstream versus downstream wetland. The location of a wetland significantly impacted significance scores for fish and aquatic habitat, shoreline protection, flood and stormwater storage, human use value and water quality protection ($p \leq 0.05$)(Figure 3.9).

INNER RIPARIAN AND OUTER RIPARIAN WETLANDS

Wetlands considered inner riparian or floodplain wetlands are adjacent to the Swan Creek channel and would be most frequently inundated from overbank flows (Figure 3.12). Outer riparian or fringe wetlands are contiguous to wetlands along Swan Creek but do not touch the stream (Figure 3.12). These location differences in hydrology have implications for most ecosystem services, especially fish and aquatic habitat and shoreline protection.

On average, we found that inner riparian wetlands had significantly higher scores than outer riparian wetlands for fish and aquatic habitat ($p \leq 0.05$). This ecosystem service considers connection to water bodies, frequency of inundation, and the presence of standing water. While outer wetlands can provide habitat for terrestrial flora and fauna, since they are indirectly connected to the stream system, they have less effect on fish and aquatic life. Research indicates that as a whole, riparian wetlands increase species diversity at regional scales because of their high spatial connectivity (Sabo et al., 2005; Clarke, Mac Nally, Bond, & Lake, 2008; Ballinger & Lake, 2006). This underscores the importance of the entire riparian corridor in providing suitable habitat for fish and aquatic life.

Interestingly, shoreline protection was significantly higher in outer riparian wetlands than in inner riparian wetlands ($p \leq 0.05$). We observed that many inner riparian wetlands lacked densely rooted emergent or woody vegetation, the key feature in assessing this service, because of erosion. Riparian vegetation is critical because it can dampen environmental disturbances like streambank erosion (Capon et al., 2013). Management efforts to restore vegetation on inner riparian wetlands could help reduce nutrient and sediment loads entering Swan Creek.

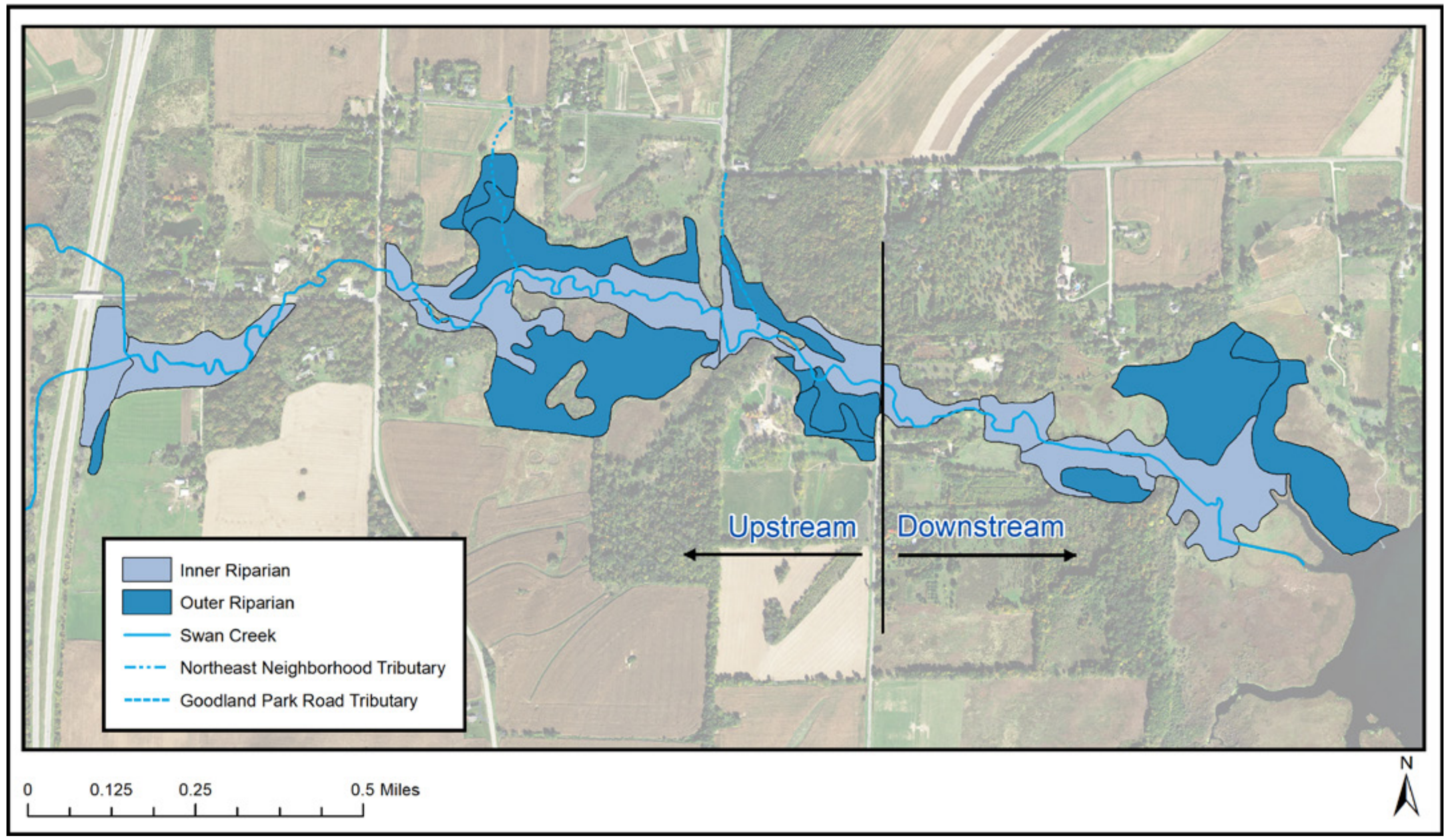


Figure 3.12. Definitions of wetland groupings for statistical analysis. We categorized Swan Creek corridor wetland polygon locations as inner riparian or outer riparian, as well as upstream or downstream.

UPSTREAM AND DOWNSTREAM WETLANDS

Wetlands that are upstream versus those downstream of Lalor Road (Figure 3.12) differ in how they provide ecosystem services, specifically human use value, flood and stormwater storage, and water quality protection. Human use value, on average, was significantly higher in downstream wetlands than upstream wetlands ($p \leq 0.05$). Although upstream wetlands still support many human uses, downstream wetland areas include more accessible public lands, which allow them to support more human uses (Figure 3.8).

The reverse is true for flood and stormwater storage and water quality protection, where we found that upstream wetlands had significantly higher significance scores than downstream wetlands ($p \leq 0.01$). We interpret these results to mean that upstream wetlands in the Swan Creek corridor are working to store floodwater and stormwater, improving the quality of these waters before they flow to the lower reaches of the watershed, including Waubesa Wetlands. Indeed, research indicates that wetlands store water, which attenuates and delays downstream flood peaks (Potter, 2011), reducing the volume of water reaching downstream wetlands. Research also suggests that floodplain wetlands intercept sediments and nutrients, such as phosphorus, that would otherwise move downstream and harm water quality (Noe & Hupp, 2009).

ECOSYSTEM SERVICE BUNDLES AND MANAGEMENT

Ecosystem services can come in bundles, which are sets of services that interact and consistently appear together. Where bundles occur can depend on landscape features, socio-economic conditions, and institutional factors (Saidi & Spray, 2018). A synergy occurs when increasing the supply of one ecosystem service enhances the supply of another, such as flood control and water quality (Bennett et al., 2009). The opposite is true for a trade-off, where increasing the supply of one ecosystem service decreases the supply of another, such as crop production and water quality (Bennett et al., 2009). In planning and making management decisions, it is important to be aware of these synergies and tradeoffs and where they are located.

In the Swan Creek corridor, we found positive correlations that indicate synergies between several of the hydrologic ecosystem services. Shoreline protection has strong associations with flood and stormwater storage (Pearson coefficient, $r \geq 0.5$) and water quality protection ($r \geq 0.5$). Additionally, flood and stormwater storage and water quality protection are highly correlated ($r \geq 0.5$). This indicates that areas with higher scores for shoreline protection also have higher scores for these other services. Since synergies highlight positive connections between multiple ecosystem services, they can help inform ecosystem management that achieves multiple benefits (Saidi & Spray, 2018).

> “ In planning and making management decisions, it is important to be aware of these synergies and tradeoffs and where they are located. ”

These specific synergies suggest that managing for shoreline protection could also enhance flood and stormwater storage and improve water quality (Figure 3.13). Restoration could also lead to future, yet unseen synergies with other services. The provision of regulating services, like shoreline protection, flood and stormwater storage, and water quality protection, have been found to be positively correlated with a greater diversity of ecosystem services (Raudsepp-Hearne, Peterson, & Bennett, 2010).

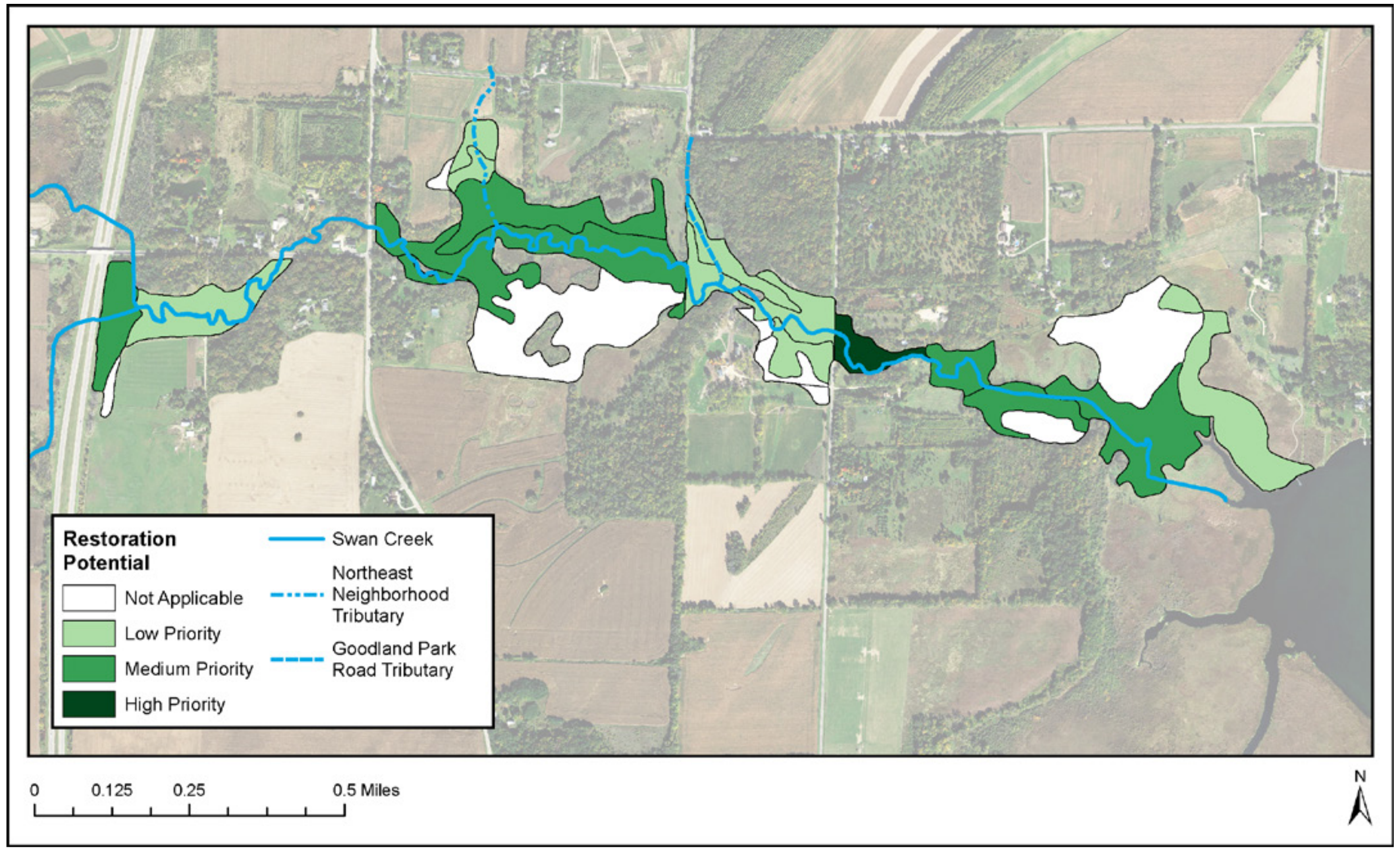


Figure 3.13. Restoration potential for shoreline protection in the Swan Creek corridor. The primary indicator of shoreline protection is the cover of dense, persistent vegetation. These priority areas indicate locations with the greatest potential to restore vegetative cover on eroding streambanks while also enhancing co-benefits of other ecosystem services.

Although we did not find any statistically significant ecosystem service tradeoffs, our field observations suggest that they could exist. One of the most noticeable potential tradeoffs is between floristic integrity and water quality protection. In some wetland polygons, the presence of invasive reed canary grass (Phalaris arundinacea) and cattails (Typha spp.) resulted in low floristic integrity scores. However, these same wetlands also had high scores for flood and stormwater storage and water quality protection because reed canary grass and cattails can provide dense vegetation cover that traps and stores water and nutrients (Lakshman, 1979). Potential tradeoffs like these can develop over time and are important to be aware of if managing for water quality protection is the primary goal.

Synergies and tradeoffs highlight the need to manage wetlands, such as the Swan Creek corridor, at the watershed scale. Research in the larger Yahara watershed found that different areas provide different combinations of ecosystem services (Qiu & Turner, 2013). Looking holistically at both the scale of the Waubesa Wetlands watershed and the larger Yahara watershed is important. This broader approach can help identify combinations of projects and specific locations for restoration that capitalize on positive synergies between multiple ecosystem services (Zedler, 2003).

LIMITATIONS

Our ecosystem services assessment was limited by both methodology and time. The modified WRAM tool is primarily a qualitative, not quantitative, assessment, with the exception of floristic integrity. It is inherently a subjective tool dependent on the expertise of those conducting the observations. Additionally, the tool has some built-in redundancy because some ecosystem service scores rely on the same observable characteristics. When performing statistical analysis, this means that there is not complete independence. WRAM is also a snapshot tool that allows a user to make assessments only on observable characteristics. We visited each site once and thus saw the site only during those specific conditions. Time was also a major factor that constrained our assessment. We were only able to complete these field surveys over a few weeks during one field season in late summer 2018.

With more time and multiple field seasons, the assessment could be more robust. Since the majority of the study area is on private land, additional time would have also allowed us to connect with more land owners. Furthermore, additional wetland complexes along the Goodland Park tributary, upstream of our site on Swan Creek, and in the Murphy Creek watershed could merit an ecosystem service assessment.

3.6 – Conclusions

SWAN CREEK CORRIDOR ECOSYSTEM SERVICES

The previously unstudied wetlands within the Swan Creek corridor play important roles in supporting the downstream Waubesa Wetlands. Each wetland in the corridor provides a different suite of ecosystem services to a different extent. Some of this is related to wetland type and location within the corridor, as well as our metrics for assessment. Many of these wetlands scored high or exceptional in the eight ecosystem services that we assessed, specifically for the services of wildlife habitat, fish and aquatic habitat, flood and stormwater storage, groundwater provision, and water quality protection. Wetlands upstream of Lalor Road appear to be especially important for flood and stormwater storage and water quality protection. As a whole, this wetland complex is providing services that benefit humans and is working to uphold the ecological integrity of Waubesa Wetlands.

RESTORATION PRIORITIES

Our assessment found positive, synergistic relationships between the ecosystem services of shoreline protection, flood and stormwater storage, and water quality protection. We also found lower shoreline protection scores on inner riparian wetland than on outer riparian wetlands. This suggests that targeted streambank restoration on wetlands along Swan Creek could potentially increase flood and stormwater storage and water quality protection in addition to shoreline protection. Streambank restoration could also have co-benefits of enhancing other services such as floristic integrity and habitat if restoration is done in such a way as to introduce native flora and fauna. We recommend working with private landowners on restoration efforts to continue to buffer Waubesa Wetlands from future changes in the watershed.

LAND USE CHANGE EFFECTS AND IMPACTS ON WAUBESA WETLANDS

Urbanization in the Waubesa Wetlands watershed could lead to changes in the ecosystem services provided by the Swan Creek corridor wetlands. A study by Wright et al. (2006), which reviewed more than 100 publications, determined that the effects of urbanization on wetlands include excessive stormwater runoff and increased water level fluctuations. In addition to contributing to flooding and loss of habitat, these hydrologic changes decrease the prevalence of native species and benefit the spread of invasive species.

Some wetland types, including those found in the Swan Creek corridor and Waubesa Wetlands, are very sensitive to hydrologic changes in water quality and quantity. Southern sedge meadows are known to be compromised by stream channelization, decreased groundwater discharge, and poor water quality (Reuter, 1986). As hydrologic regimes change, southern sedge meadows become more susceptible to aggressive invasions of non-native species such as purple loosestrife (Lythrum salicaria), common buckthorn (Rhamnus cathartica), and glossy buckthorn (Rhamnus frangula) (Reuter, 1986). Many of the watershed's emergent marshes have reed canary grass (Phalaris arundinacea), an invasive species that thrives on high nutrients and high water levels (Kercher et al., 2004); further nutrient inputs and elevated water levels from urbanization could enable it to continue to spread. In addition, fens, like the calcareous fens in Waubesa Wetlands, are extremely vulnerable to urbanization because they require a specific range of environmental conditions, including adequate inputs of rain and groundwater and a defined hydroperiod (Wright et al., 2006; Doherty et al., 2014). Thus, it is vital that stormwater management standards for development do not increase stormwater runoff or change wetland hydroperiod through water level fluctuations.

Potential new residents moving into the Waubesa Wetlands watershed will increase the demand for ecosystem services that watershed wetlands provide. This makes it imperative that planning and management efforts focus on the long-term health and resilience of whole-watershed wetland ecosystems. Our ecosystem service assessment provides a snapshot of current conditions of wetlands upstream and downstream of new development in Fitchburg. In the future, it can be used as a baseline reference to evaluate change. Such an assessment would be valuable along Murphy's Creek prior to any future development in that subwatershed. Because of the unpredictable nature of land use changes, active restoration of the Swan Creek corridor wetlands and monitoring of water quality and quantity during and after any development should be a priority.

WATER QUALITY MONITORING

4.1 – Introduction

Wetlands, by definition, depend on local hydrology. Surface and groundwater saturate wetland soils, creating conditions that sustain wetland plant communities. Changes to water quantity and quality can negatively affect wetlands and the ecosystem services that they provide.

EFFECTS OF LAND USE AND CLIMATE CHANGE

Surface water from Swan and Murphy's creeks and groundwater from springs support the hydrology of wetlands in the Waubesa Wetlands watershed. Upstream land use changes affect downstream wetlands by altering surface water quantity and quality (Azous & Horner, 2000; Brabec, Schulte, & Richards, 2002; Lougheed, McIntosh, Parker, & Stevenson, 2008; Dugan et al., 2017). Urbanization can increase surface water quantity when landscapes transition from pervious forests, grassland, and agricultural land to impervious "hardscapes" such as roofs, sidewalks, and streets (NRC, 2009). With fewer areas for water to soak into the ground, the volume of surface water runoff increases during storms. This results in faster, flashier, and more powerful flows (NRC, 2009). Greater flows can carry more nutrients and increase erosion. The extent of this impact depends on the stormwater management standards and best management practices that are required by local governments.

In addition to urbanization, climate change can also contribute to changes in water quality and quantity. Historic patterns in weather in the Midwest from 1950-2006 show that temperatures and precipitation are increasing (Serbin & Kucharik, 2009). Climate change is also expected to bring more extreme weather events, like larger storms and longer droughts (Gallan, Karoly, & Gleason, 2012; Herring, Hoell, Hoerling, Kossin, & Schreck, 2016). In the area encompassing Waubesa Wetlands, it is estimated that annual precipitation will increase by 1.5 inches, and average temperatures will increase by 6.5°F by 2055 (WICCI, 2011). Because of their capacity to carry nutrients and sediment into downstream water bodies, extreme events can cause the greatest impact to wetlands downstream (Reinelt & Taylor, 2000; Griggs et al., 2017).

Given that urbanization and warmer, stormier weather can affect surface water quality and quantity, it is possible that upstream development in Fitchburg and a changing climate will threaten Waubesa Wetlands. Research indicates that elevated phosphorus and nitrogen are damaging to wetland vegetation in the Midwest (Green & Galatowitsch, 2002; Woo & Zedler 2002; Kercher et al., 2007; Boers & Zedler, 2008). Fluctuating water levels can harm specific wetland types that need certain levels to persist (Zedler, 2018). Increases in surface water quantity can also allow invasive species like cattails to dominate, reducing plant diversity (Doherty et al., 2014). With these concerns, monitoring upstream surface water quantity and quality is a way to assess the impacts of land use changes on Waubesa Wetlands.

POLICY REQUIREMENTS AND CURRENT MONITORING

Swan Creek and Murphy's Creek are within the larger Rock River Basin, which has numerous impaired lakes, rivers, and streams because of excessive concentrations of phosphorus and sediment. Under Section 303(d) of the federal Clean Water Act (CWA), states are responsible for establishing total maximum daily loads (TMDLs) for pollutants that do not meet water quality standards in impaired water bodies. In 2011, the WDNR established a TMDL for the Rock River Basin to plan for and address excess total phosphorus (TP) and sediment, or total suspended solids (TSS). The TMDL is essentially the target reduction level for each pollutant. TP and TSS are addressed together because they are closely linked in their sources, transport, and how they are managed.

As of 2018, both Swan and Murphy's creeks have been proposed to be added to the 303(d) list of impaired waters for TP (WDNR, 2018). Citizen science volunteers from the Rock River Coalition (RRC), a nonprofit organization, have been monitoring both streams since 2015. As a basin-wide organization, RRC possesses limited resources to dedicate to the Waubesa Wetlands watershed. We saw an opportunity to build upon and enhance its efforts through continuing long-term monitoring of the watershed. Given current water quality concerns and anticipated changes in watershed land use and climate, sustained monitoring is important to support efforts to maintain the health of the Waubesa Wetlands watershed.

4.2 – Purpose

Waubesa Wetlands and upstream watershed riparian wetlands perform numerous ecosystem services (Chapter 3). These services facilitate human well-being and are indicators of functioning, healthy wetlands. Urbanization throughout the watershed of Waubesa Wetlands could change water quality and quantity, and thus the ability of the wetlands to perform critical ecosystem services. We identified a need to enhance monitoring of surface water quality and quantity within the watershed in order to better understand the watershed's current conditions and inform management decisions that protect the integrity of the wetlands.

We provide a snapshot of water quality and quantity in 2018, as well as identify trends in nutrient concentrations across several years. The monitoring data collected by our cohort and the RRC can be used in conjunction with other available data to assess the effects of land use changes in the watershed in order to infer any potential impacts to Waubesa Wetlands and recommend possible mitigation actions.

4.3 – Water Quality Parameters

The mixed land use of the Waubesa Wetlands watershed contributes nutrients and contaminants that run off the land into Swan and Murphy's creeks and Lake Waubesa. We selected four water quality parameters for analysis based on the current and future land use of the watershed, previous monitoring efforts, and impacts of these nutrients on ecosystem services: nitrogen, phosphorus, total suspended solids, and chloride.

NITROGEN

Nitrogen is vital for plant growth and is a limiting nutrient in water bodies, especially in marine systems. In water bodies, nitrogen occurs in five forms: nitrate/nitrite (NO3/NO2), ammonia (NH3), ammonium (NH4+), and organic nitrogen. When analyzing nitrogen in a water sample, it is common to calculate total nitrogen (TN), which is the sum of all of these forms.

Typically, nitrate and nitrite are formed from the oxidation of ammonia (nitrification), although other sources include nitrate-containing fertilizers, septic tank leaching, and field applications of animal and human waste (Havlin, Beaton, Tisdale, & Nelson, 2005). Nitrate and nitrite become potential threats to human health when they leach into groundwater and surface water at elevated levels; they can cause conditions such as blue baby syndrome (Vitousek et al., 1997). Ammonia is a preferred form of nitrogen in fertilizer because plants easily use it. Typically ammonia accounts for a small amount of the TN in a water body because it is readily converted to nitrite and nitrate through nitrification (Havlin et al., 2005). Ammonium also originates from manure and fertilizer, and under specific temperatures and pH is converted to the more highly toxic ammonia. Organic nitrogen is in the biomass of living and dead organisms and algae.

Total Kjeldahl nitrogen (TKN) is the sum of ammonia, ammonium, and organic nitrogen; nitrate and nitrate plus TKN equals total nitrogen (TN). TKN is a useful parameter when analyzing water quality because it is an indicator of eutrophication. TKN describes how much nitrogen is available for use in primary productivity; for instance, the TKN concentration of a water sample would increase during a big algal bloom. When a majority of TN is TKN, as compared to nitrate and nitrite, it is likely that much of the nitrogen in that water body is organic nitrogen (e.g., biomass) or ammonia (e.g., the byproduct of plant decomposition) (Nahm, 2003).

TOTAL SUSPENDED SOLIDS

Total suspended solids (TSS) are the concentration of inorganic and organic matter that is held in the water column of a river, stream, or lake by turbulence. Suspended solids are commonly considered fine particulate matter with a diameter of 62 micrometers or less (Waters, 1995). While it is typical to find suspended solids throughout the water column as a result of natural erosion or turbulence, levels are often elevated because of any human activity that disrupts soil (McCaleb & McLaughlin, 2008). High concentrations of suspended solids can negatively affect the biota of a water body through changing temperature, light penetration, and sedimentation processes (Bilotta & Brazier, 2008). Sedimentation is an issue because if sediment has high amounts of organic matter during low flow, decomposition in benthic sediments increases, which deprives the water of oxygen and results in fish kills (Bilotta & Brazier, 2008). In addition, the disturbance of benthic sediment can mobilize contaminants such as pesticides, heavy metals, and nitrogen and phosphorus to receiving lakes and streams. The Rock River Basin TMDL (total maximum daily load) has set a limit for TSS at 26 mg/L among all reaches at any point during the year (Cadmus Group Inc., 2011).

PHOSPHORUS

Like nitrogen, phosphorus is an important nutrient for plant growth. Because nitrogen can be produced biologically, phosphorus is more often a limiting nutrient in freshwater systems (Downing & McCauley, 1992). Primary sources of phosphorus in groundwater and surface water include commercial fertilizer, manure, septic tanks, wastewater treatment plants, and runoff from construction sites. Phosphorus mainly enters surface water through soil erosion because it easily binds to soil particles, though inorganic phosphorus can ultimately enter water systems through runoff even if soil erosion is reduced (USEPA, 2007). Like nitrogen, phosphorus contributes to algal blooms, eutrophication of streams and lakes, and ultimately low concentrations of dissolved oxygen (Dodds et al., 2006).

Water quality analysis commonly includes calculation of total phosphorus (TP), which is the sum of dissolved and particulate forms and organic and inorganic forms. In the Yahara Lakes system, TP is a limiting nutrient for much of the year, particularly during the growing season (Lathrop, 2007). Because of its elevated levels, TP is included under the Rock River Basin TMDL, which limits TP concentrations to 0.075 mg/L for small streams (Cadmus Group Inc., 2011).

CHLORIDE

Chloride (Cl-) is an emerging contaminant of concern in freshwater systems and primarily comes from sodium chloride (road salt) application during winter months. Unlike phosphorus and nitrogen, natural processes do not remove chloride ions from the environment (Siegel, 2007). Chloride is also very mobile and entirely soluble and thus easily leaches into soil, groundwater, and surface water, where it may harm plant and animal life. Fish, insects, macroinvertebrates and amphibians typically require chloride to maintain normal physiological functions, but only at specific, steady concentrations to which the animal has adapted. Organisms exposed to elevated or hugely fluctuating chloride concentrations are susceptible to survival, growth, and/or reproduction issues (Siegel, 2007). Furthermore, elevated levels of chloride in soils can cause an osmotic imbalance in plants; this affects the plant's water absorption and can stunt root growth. Similarly, chloride can inhibit nutrient uptake and long-term growth (Siegel, 2007). Chloride is considered an emerging contaminant of concern because Wisconsin lakes have demonstrated increasing concentrations of chloride even in watersheds with less than one percent impervious surfaces, such as roads and rooftops (Dugan et al., 2017).

4.4 – Methods

SITE SELECTION

We selected our five water quality monitoring sites (Figure 4.1; Appendix F) based on factors that included the existing efforts of the RRC, the locations of future development in the watershed, and available funding. RRC volunteers have collected grab samples at set locations along Swan Creek and Murphy's Creek since 2015. We augmented their efforts by continuing to monitor both creeks near the RRC sampling sites at Lalor Road. These Swan@Lalor and Murphy's@Lalor locations are accessible and close enough to Waubesa Wetlands that we assume they are the watershed outlets and represent inputs to the wetland from the creeks.

To investigate how nutrient concentrations might change through the Waubesa Wetlands watershed, we added two lake-edge sites: Swan@Lake and Murphy's@Lake (Figure 4.1). However, we ended up not being able to get good samples at these sites because of a lack of positive flow, and thus we did not analyze them or include the results in this report. In addition, we added a location on Swan Creek upstream of current and future development in the Northeast Neighborhood. This site is on private property at the confluence of two upstream tributaries that converge near Highway 14 and Haight Farm Road. Monitoring of the Swan confluence site can help quantify any changes downstream of development.

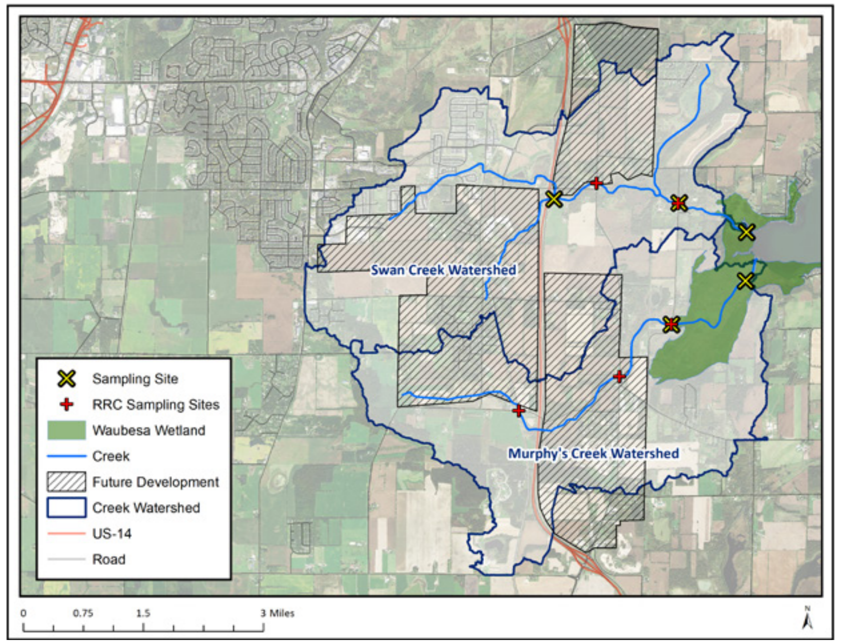


Figure 4.1. Waubesa Wetlands watershed map. RRC sampling sites are shown in red. WRM sampling sites on Swan Creek (yellow) are, from left to right, Swan confluence (WRM), Swan@Lalor (WRM and RRC), and Swan@Lake (WRM). Murphy's Creek WRM sampling sites (yellow) from left to right are Murphy's@Lalor (WRM and RRC) and Murphy's@Lake (WRM). Hashed areas indicate future development sites.

GRAB SAMPLES

We collected grab samples to create monthly snapshots of nutrient concentrations in Swan and Murphy's creeks. Samples were collected on roughly the 22nd of each month from April to October 2018; we sought to collect at times separate from and after RRC's monthly sampling. When sampling multiple locations on the same stream, we collected samples in a downstream-to-upstream direction to avoid contaminating samples with stream disturbance. Because of limitations with accessibility, we only sampled the two lake sites in April and May of 2018. Swan@Lalor, the Swan confluence, and Murphy's@Lalor sites were sampled from April to October 2018. At the lake sample sites, we struggled to collect samples under positive flow conditions. It is important to note that these samples likely contain a mixture of stream and lake water.

To collect samples, we triple-rinsed a 500 mL Nalgene bottle with stream water and submerged it in an area of positive flow to a depth of 0.5 ft. We split the sample for analysis at the State Laboratory of Hygiene and at the UW-Madison Soil Science Department laboratory and stored the capped bottles on ice. After taking each grab sample, we measured surface water temperature, conductivity, dissolved oxygen, and transparency. At the stream sites, we also measured flow.

FLOW RATE MONITORING

Monitoring of stream flow rate, or discharge, is essential in conjunction with water nutrient concentrations to calculate pollutant loads to Waubesa Wetlands. To estimate flow rate, both the stream stage, or depth, and velocity are needed. After selecting our sampling sites, we worked with the USGS to install reference gages at the Swan@Lalor and Murphy's@Lalor sites. These gages are six-foot-long metal rods hammered into the streambed that provide a stationary reference point. Measuring up from the top of the gage to the water's surface gives a functional stream stage based on this fixed reference point. In the absence of a reference point at the Swan confluence site, we measured stage from the deepest point in the stream. To measure velocity at stream sites, we used a portable flowmeter (Flo-Mate 2000, Marsh-McBurney, Inc.) across consistent stream cross-sections (Figure 4.2). We did not measure flow rate at the lake sites.

During monthly grab sampling, we measured flow rate at each stream site. In addition, we installed a portable sampler (6712 Full-Size Portable Sampler, Teledyne ISCO) to continuously measure flow and discharge at the Swan@Lalor site (Figure 4.3). We chose to enhance monitoring there because of its location at the outlet of the developing Swan Creek watershed. The site was also ideal because downstream of the Lalor Road culvert, the stream channel is straight with a stable cross-section and a rock dam that creates a pool that maintains sufficient flow depth. Before we installed the sampler, we developed a stage-discharge curve from depth and velocity measurements taken with the Flo-Mate at the same cross-section on multiple days in April and May under different stream conditions (Appendix G). The portable sampler recorded stream depth with a pressure transducer and utilized the stage-discharge relation to calculate discharge for Swan Creek at one-minute intervals from June to October.

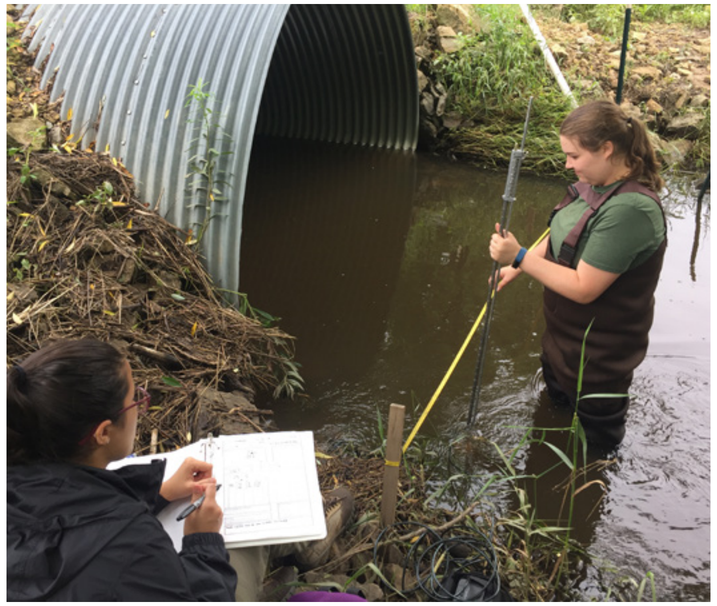


Figure 4.2. Manual flow measurement with a portable flowmeter, recording stream velocity, cross-sectional area, and flow at the Swan@Lalor site. (Photo by Rachel Johnson).

Figure 4.3. Automated sampler monitoring box at the Swan@Lalor site. (Photo by Rachel Johnson).

STORM SAMPLES

We collected samples during storm events at Swan@Lalor to develop information about how nutrient concentrations in Swan Creek change with precipitation and increased flow. The automated sampler allowed us to collect samples during the first flush of a storm, when there is a major release of nutrients, and throughout the rest of the storm. Before anticipated precipitation, we programmed the portable sampler to take flow-based samples spread across the entire hydrograph, based on the amount of rain predicted and initial stream stage. We composited storm samples into rising, peak, and falling limb samples. Throughout the monitoring season, we captured six storm events at different stage heights.

PARAMETER SELECTION

Samples from each site were tested for nutrient concentrations of TP, orthophosphate, nitrite and nitrate (NO2 + NO3), TKN, TSS, and chloride. We chose these parameters because they are indicative of watershed health and build upon previous work conducted by the RRC. Chloride is a new parameter that we selected because it is increasingly a constituent of concern in urban areas (Jackson and Jobbagy, 2005; Novotny, Murphy, & Stefan, 2007).

SAMPLE ANALYSIS

At the UW-Madison Soil Science Department laboratory, we analyzed samples for TSS and chloride following EPA methods (Appendix H). Samples were also sent to the Wisconsin State Laboratory of Hygiene to be analyzed for NO2 + NO3, TKN, orthophosphate, and TP following standard procedures (Appendix H). We report TN as the summation of TKN and NO2 + NO3.

DATA ANALYSIS

In addition to our collected data, we used 2018 precipitation data from a weather station on Syene Road and historical monitoring data from RRC. Precipitation amounts were recorded at 15-minute intervals. We also utilized historical precipitation records from 2015-2017 from the Dane County Regional Airport to determine if RRC samples were collected within 48 hours from the start of precipitation. We evaluated parameters across time by comparing data from our 2018 collected data with RRC data from 2015-2018. We analyzed these data using regression analyses in Excel to identify statistically significant trends (a = 0.05) in nutrient concentrations over time.

4.5 – Results and Discussion

Throughout our monitoring season, we observed how nutrient concentrations changed with variation in factors including discharge, watershed location, prior precipitation, and time. In this section we highlight interesting and representative trends with specific nutrients in the Murphy's Creek and Swan Creek subwatersheds. For context, the relevant U. S. Environmental Protection Agency (USEPA) and Rock River Basin TMDL standards for rivers and streams are presented in Table 4.1. Our full monitoring data set is in Appendix I.

Table 4.1. Standards for selected parameters for streams and rivers (Wisc. Admin. Code NR 102; Wisc. Admin. Code NR 105; Cadmus Group Inc., 2011; USEPA, 1986).

Parameter	Standard	Rationale
Wisconsin Standards (Wisconsin Administrative Code NR 102, NR 105)		
Chloride	395 – 757 mg/L	Protects aquatic life from chronic (395 mg/L) and acute (757 mg/L) toxicity
Ammonia (as N)	2.22 – 19.9 mg/L	Chronic (30-day, 2.22 mg/L) and acute (19.9 mg/L) toxicity for warmwater forage fishery at pH 7.5 and 25 C
pH	6.0 – 9.0	Acceptable range of 6.0 – 9.0, with no change greater than 0.5 units outside the estimated natural seasonal maximum and minimum
Dissolved oxygen	5 mg/L	In surface waters may not be lowered to less than 5 mg/L at any time
Temperature	Warmwater streams: 49 – 81 °F (sub-lethal); 76 – 85 °F (acute)	No greater than 10% of daily maximum values or any weekly average temperature value in a calendar month may exceed acute criteria or sub-lethal criteria, respectively
Wisconsin Rock River Basin TMDL Standards		
TP	0.075 mg/L	For wadeable (i.e., smaller) streams
TSS	26 mg/L	Average TSS concentration target among all reaches and months
EPA Standards		
Nitrate/ nitrite	0.06 – 5 mg/L	0.06 mg/L should be protective of salmonid fishes; 5 mg/L should be protective of most warmwater fishes

MURPHY'S CREEK SUBWATERSHED

All data presented in this analysis for the Murphy's Creek subwatershed is from the watershed outlet to Waubesa Wetlands at the monitoring site Murphy's@Lalor (Figure 4.1).

TOTAL NITROGEN

At the Murphy's Creek watershed outlet, we found total nitrogen (TN) concentrations in 2018 to be generally below the EPA nitrate and nitrite standard of 5 mg/L (Table 4.1). While the EPA has no standard for TN, this is a good indication that TN is also below concentrations that would harm warmwater fishes. With increased discharge from storm events, we observed a general decrease in TN concentration (Figure 4.4). This could be attributed to two different phenomenon. First, it is possible that precipitation with low TN concentrations is diluting surface water that has elevated TN concentrations, and that additional rainfall volume further dilutes the stream. In addition to this, it is possible that with additional precipitation, surface water runoff with lower TN concentrations is diluting the groundwater that feeds that stream and has elevated TN concentrations. Murphy's Creek subwatershed has several springs including one surveyed by WGNHS in 2014 that likely contribute to its baseflow (WGNHS, 2017). Furthermore, nitrate well water concentrations in the Murphy's Creek subwatershed show high levels of between 6 – 14 mg/L (CARPC, 2018).

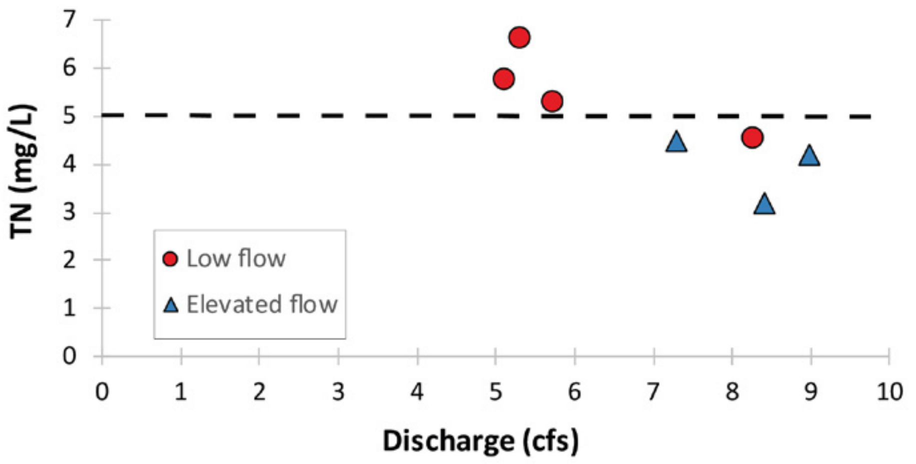


Figure 4.4. TN and discharge at the Murphy's@Lalor site in 2018. Data points are from grab samples collected during low flow conditions (no precipitation within 48 hours) and elevated flow conditions (precipitation within 48 hours). The dotted line indicates the NO2 + NO3 5 mg/L stream health standard.

Average annual TN concentrations under low flow conditions decreased (p<0.05) from 2015 – 2018 at this site (Figure 4.5). This decrease in TN may be related to the presence of wetlands adjacent to Murphy's Creek that have continued to absorb agricultural runoff, or to changes in watershed land use and management. Additional years of monitoring could help identify what is driving this trend. This will be especially important as watershed urbanization increases, since studies identify that urban watersheds can have elevated levels of TN, specifically nitrate (Schoonover et al., 2005; O'Driscoll et al., 2010).

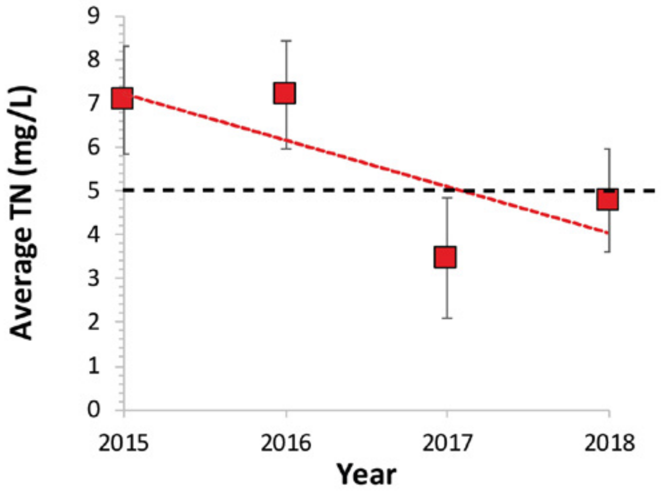


Figure 4.5. Linear regression of average annual low flow TN concentrations at the Murphy's@Lalor site. Bars show one standard deviation. The dotted line indicates the NO2 + NO3 5 mg/L stream health standard. From 2015-2018, TN concentration decreased during low flow conditions ($p<0.05$; $R2=0.57$).

TOTAL SUSPENDED SOLIDS

Total suspended solids (TSS) concentrations in 2018 were mostly below the level established by the WDNR for the Rock River Basin TMDL (26 mg/L) (Table 4.1). We observed generally higher TSS concentrations in samples collected within 48 hours of precipitation (elevated flow) than samples collected during dry conditions (low flow) (Figure 4.6). We interpret these results to indicate that during precipitation events, sediments are mobilized in the Murphy's Creek watershed. Research from other watersheds indicates that TSS tends to increase with discharge (Clinton & Vose, 2006; Lenhart, Brooks, Heneley, & Magner, 2010).

From 2015 to 2018, approximately 40% of samples (13 of 33 total) were at or above the Rock River Basin TMDL (26 mg/L) for TSS concentrations. However, this may be an underestimate as the bulk of monitoring occurring during base or low flow conditions. The samples that exceeded the TMDL were mostly in the months of May, June, and July (Figure 4.6). In particular, the two highest concentrations (from June and July 2017) were collected within 12 hours of the end of a rain event. Studies have shown that TSS increases especially in late spring and early summer (May-June) before vegetation has fully established (Clinton & Vose, 2006; Lenhart, Brooks, Heneley, & Magner, 2010). This indicates that these months are particularly problematic and may be critical periods for management.

These observations regarding temporal variation in TSS concentrations are supported by a previous study in the Rock River Basin, which indicated that precipitation can impact TSS (Mbonimpa, Yuan, Nash, & Mehaffey, 2014). This study also indicated that, overall, other factors such as soil type, land use, terrain slope and anthropogenic activities (e.g., tillage), have a more significant impact on TSS concentrations than precipitation (Mbonimpa et al., 2014).

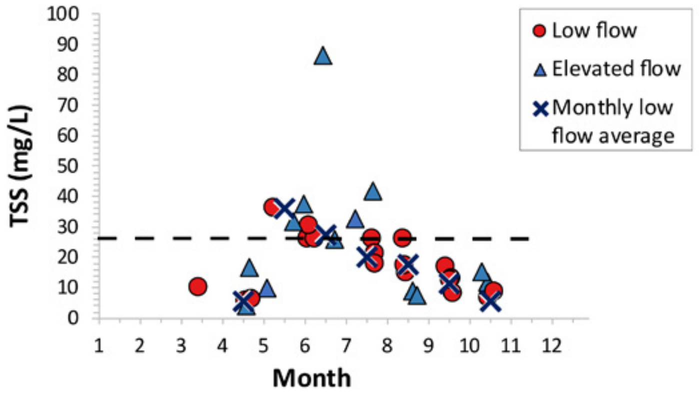


Figure 4.6. TSS grab sample concentrations at the Murphy's@Lalor site. Data from 2015-2017 is from RRC; 2018 data is from RRC and our monitoring work. The dotted line indicates the basin-wide TMDL stream standard of 26 mg/L.

TOTAL PHOSPHORUS

Our monitoring data show that Murphy's Creek had elevated concentrations of total phosphorus (TP) throughout the 2018 monitoring season. This is consistent with data from previous years (Figure 4.7). Of the 34 monthly grab samples collected from 2015-2018, 29 samples (85%) contained TP concentrations above the Rock River Basin TMDL of 0.075 mg/L. TP average monthly concentrations remained below the standard only in March (Figure 4.7). We expect seasonal changes in TP concentrations because different patterns in precipitation and vegetation cover influence rates of runoff and erosion (Mulholland & Hill, 1997).

In determining compliance with TP standards for the Rock River Basin TMDL, the WDNR looks at the median growing-season (May-October) TP concentration for the most recent three years (Cadmus Group, 2011). Analysis of RRC data shows median concentrations above 0.075 mg/L for 2016, 2017, and 2018. These samples were primarily collected under low flow or base flow conditions during which the stream is predominantly fed by shallow groundwater. This indicates that groundwater may be transporting dissolved phosphorus from land sources to Murphy's Creek, or that in-stream sediments may be releasing phosphorus to the water column. With numerous springs in the watershed, groundwater contribution could also be diluting TP concentrations during periods of low flow. This suggests that TP loading may be even higher than monitoring indicates.

During periods of high flow, we found TP concentrations well above those in low flow conditions (Figure 4.7). Storms are known to increase phosphorus loading to streams and can contribute more of the overall P to a watershed than base flow (Sharpley et al., 2008; Heathwaite & Dils, 2000). Surface runoff from storms carries both dissolved phosphorus and phosphorus attached to sediments or organic material. Larger storms produce more runoff and runoff from larger areas of the watershed (Sharpley et al., 2008). During and after rainfall or snowmelt in the Murphy's Creek watershed, TP is likely mobilized from terrestrial, streambank, or in-stream sources. From our observations of watershed land use and management, we hypothesize that agricultural fertilizers and manure applications, runoff from residential areas, and streambank erosion are the most likely sources of TP. Elevated concentrations of TP suggest enhanced management is needed within the watershed to ensure the health of its aquatic ecosystems.

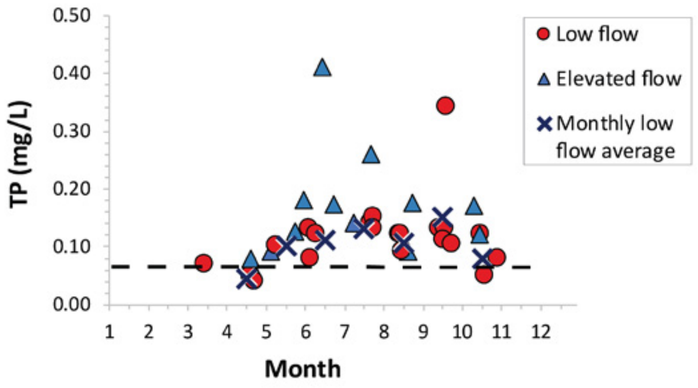


Figure 4.7. TP grab sample concentrations at the Murphy's@Lalor site from 2015-2018. The dotted line indicates the basin-wide TMDL stream standard of 0.075 mg/L; 85% of samples collected exceed the standard. TP concentrations from samples collected within 48 hours after a rain event were up to 5.5 times greater than the TMDL standard.

SWAN CREEK SUBWATERSHED

STREAM DISCHARGE/PRECIPITATION

Stream discharge in Swan Creek in 2018 follows a pattern typical of other temperate streams (Figure 4.8). Although the continuous portable sampler was not installed in the months of April and May, our field observations noted that the creek had high flows. Spring months with snowmelt and rainfall on saturated soils elevate stream flows (Hodgkins & Dudley, 2010). Discharge then recedes in summer months as evapotranspiration increases (Hodgkins & Dudley, 2010). Our lowest flows, near five cubic feet per second (cfs), were in July and August when there had been no precipitation in over seven days. We observed an increase in base flow again in September and October as evapotranspiration decreased. Frequent, low-intensity rainfall during these months likely exceeded the infiltration capacity of the soil, increasing overland flows and raising base flow (Milly & Eagleson, 1988).

Our continuous stream monitoring efforts at the Swan@Lalor site also indicated a hydrologic system that responds quickly to precipitation. After each storm, we saw a sharp increase in discharge (Figure 4.8). This appears to vary with the intensity, duration, and frequency of precipitation. The highest flows we observed in Swan Creek, at 90 cfs, followed a very intense June storm event where one inch of rain fell in a 15-minute period (Figure 4.9). During periods of frequent precipitation in June, August, and October, Swan Creek rose and fell several times before returning to baseflow conditions. This is typical for a small headwater stream (Doyle, 2005). However, urbanization could further increase this hydrologic variability.

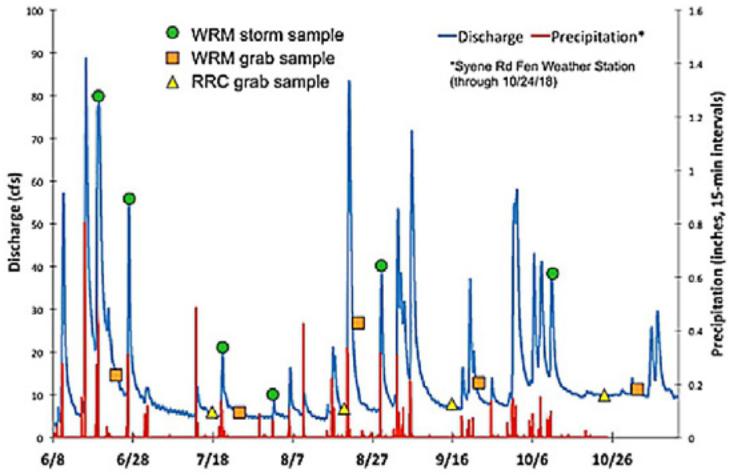


Figure 4.8. Graph of stream discharge, watershed precipitation, and samples collected at the Swan@Lalor site from June to October 2018.

Figure 4.9. Photos of Swan@Lalor Road on June 19, 20, and 22, 2018. It rained about one inch on June 18 and one inch on June 19. (Photos by Rachel Johnson).

TOTAL NITROGEN

At the Swan@Lalor site, we measured nitrate and nitrite (NO2 + NO3) concentrations in 2018 generally below the EPA standard of 5 mg/L (Table 4.1). In the absence of TN standards, this is a good indication that TN is also below concentrations that would be harmful to warmwater fishes. As discharge increases from storm events, we observed a general decrease in TN concentrations (Figure 4.10). Generally, samples collected within 48 hours of precipitation had lower TN concentrations than those collected during dry conditions. As in the Murphy's Creek subwatershed, in Swan Creek this could be attributed to two different processes. Increased precipitation that is low in TN could be diluting runoff entering the creek that is high in TN, or groundwater high in TN may be diluted by runoff with lower TN concentrations. While we did observe decreases in TN concentrations resulting from increased discharge, it does not necessarily mean that TN loads in Swan Creek decrease.

Although TN concentrations are lower, discharge controls the seasonal pattern of TN loads; thus, higher discharge could result in higher loads (Duncan, Welty, Kemper, Groffman, & Band, 2017). It is also important to note that NO2 + NO3 rather than TKN concentrations accounted for the majority of TN. Possible sources of NO2 + NO3 include nitrate-containing fertilizers such as potassium nitrate, calcium nitrate, and ammonium nitrate, and manure field applications (Havlin et al., 2005). With a mix of septic and sewer systems in the Waubesa Wetlands watershed, septic tank leaching may also contribute nitrate to the groundwater (Havlin et al., 2005).

We observed a consistent increase in TN concentrations from the upstream to downstream sites (the Swan confluence and Swan@Lalor sites, respectively) when samples were collected on the same day (Figure 4.11). The magnitude of the TN concentration increase for low flow conditions (April, July, September, and October) is more pronounced than the magnitude of the increase resulting from elevated flow conditions (May, June, and August). This indicates that there may be additional inputs of TN somewhere along the stream between the two sites. Since the majority of the TN was NO2 + NO3, not TKN, much of this nitrogen may be coming from fertilizer or manure applications. While the Swan Creek watershed is primarily agricultural, some residential properties between the Swan confluence and Swan@Lalor sites could be contributing lawn fertilizer to the stream, although studies suggest that nitrogen from lawn runoff is typically not a major contributor to nutrient loading (Garn, 2002). In addition, we observed a statistically significant decrease (p<0.05) in TN concentrations from 2015-2018 at this site (Figure 4.12). As in Murphy's Creek, this decrease may be due to shifts in land use from agricultural to urban in the watershed over time (Yoshikawa, Takahashi, Sasada, & Mochizuki, 2015; Stets et al., 2015). Despite this decrease, it will be important to continue monitoring TN in Swan Creek as the watershed changes from primarily agricultural to residential to ensure that concentrations remain within an acceptable range.

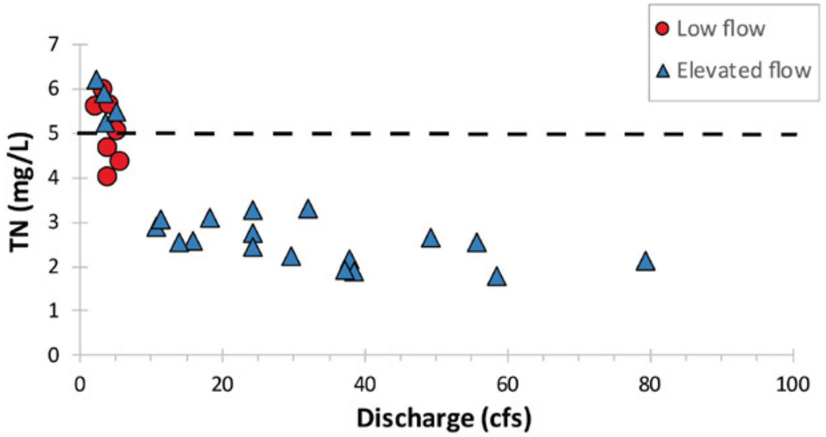


Figure 4.10. TN and discharge at the Swan@Lalor site in 2018. Data points are from both grab samples and samples collected from the automated sampler during rising, peak, and falling storm limbs. Samples were collected during low flow conditions (no precipitation within 48 hours) or elevated flow conditions (precipitation within 48 hours). The dotted line indicates the nitrate + nitrite (NO2 + NO3) 5 mg/L stream health standard.

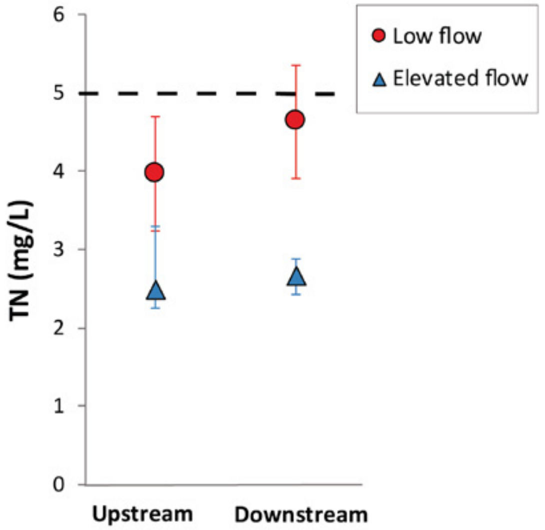


Figure 4.11. Average same-day TN concentrations at upstream (Swan confluence) and downstream (Swan@Lalor) sites. We collected elevated flow samples within 48 hours of precipitation (May, June, and August) and low flow samples during dry conditions (April, July, September, and October). Bars show one standard deviation. The dotted line indicates the NO2 + NO3 5 mg/L stream health standard.

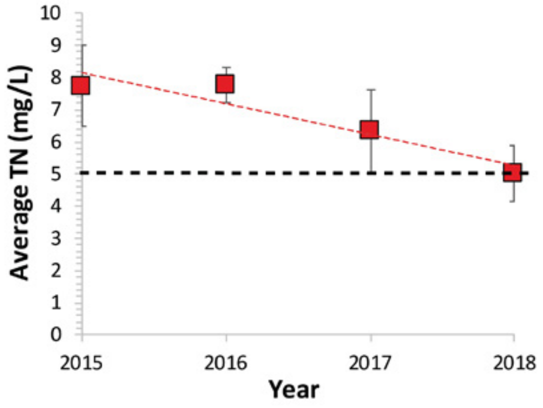


Figure 4.12. Linear regression of average annual low flow TN concentrations at the Swan@Lalor site. Bars show one standard deviation. The dotted line indicates the NO2 + NO3 5 mg/L stream health standard. From 2015-2018, TN concentration decreased during low flow conditions (p<0.05; R2=0.88).

CHLORIDE

At the Swan Creek watershed outlet (Swan@Lalor), we found chloride concentrations to be well below the EPA standard of toxicity for aquatic organisms (395 mg/L) (Table 4.1). According to the EPA guidelines, and the guidelines provided by the WDNR, there is no immediate concern about the chloride concentration in the watershed for aquatic organism health.

With increased discharge from storm events, we observed a general decrease in chloride concentration (Figure 4.13). Generally, during our limited sampling period, samples collected within 48 hours of precipitation had lower chloride concentrations than those collected during dry conditions. We interpret this decrease in chloride concentration to most likely be a result of runoff diluting baseflow (groundwater) chloride concentrations during higher flows. This is consistent with chloride trends discussed in a 2018 road salt report conducted by Public Health Madison & Dane County. Their report showed that chloride levels in local aquifers have been relatively high (approximately 40mg/L in 2017) and increasing (Wenta & Sorsa 2018). However, additional high flow samples would be needed to confirm this trend.

We also observed a decrease in chloride concentrations from the Swan confluence to the Swan@Lalor sites during the field season (Figure 4.14). We attribute this decrease in upstream-to-downstream chloride concentration to dilution of baseflow caused by additional surface water inputs between the two sites.

The USGS recently conducted a survey of chloride trends from 2006-2011 in the Milwaukee River basin. Our findings of lower concentrations at higher flows is contrary to what is reported in the USGS study. It is worth noting that the report looked at long-term data that included monitoring during winter melt events, which contribute significant amounts of chloride. Long-term trends showed increasing baseflow chloride as a key contributor to overall chloride levels within the streams. A continuation of high-resolution chloride data could add to these data by looking at long-term trends to see whether they correspond with other studies, especially as the watershed becomes more urban (Corsi et al., 2015).

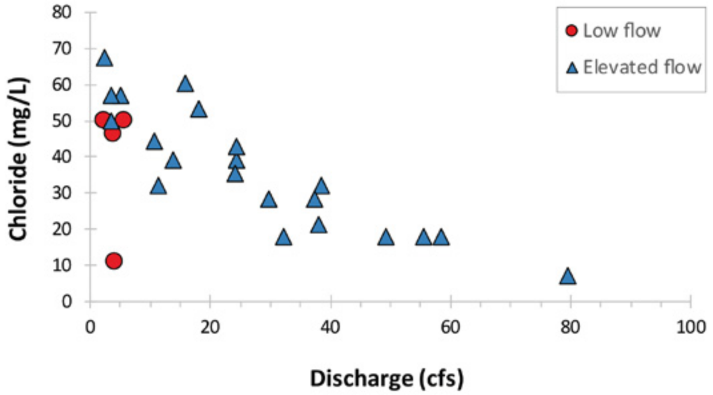


Figure 4.13. Chloride and discharge at the Swan@Lalor site. Data points are from both grab samples and samples collected from the automated sampler during rising, peak, and falling storm limbs. Samples were collected during low flow conditions (no precipitation within 48 hours) or elevated flow conditions (precipitation within 48 hours).

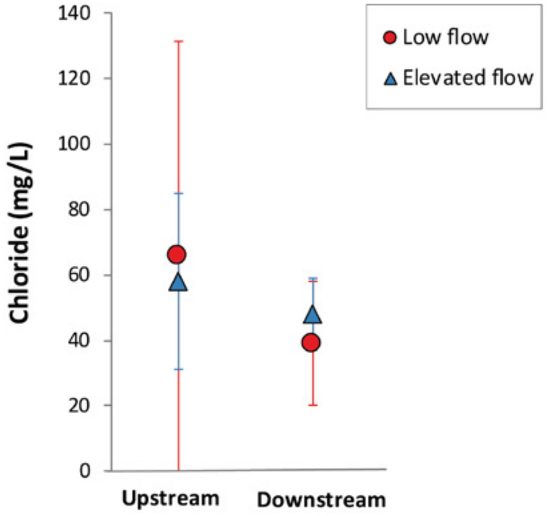


Figure 4.14. Average same-day chloride concentrations at upstream (Swan confluence) and downstream (Swan@Lalor) sites. We collected elevated flow samples within 48 hours of precipitation (May, June, and August) and low flow samples during dry conditions (April, July, September, and October). Bars show one standard deviation.

TOTAL SUSPENDED SOLIDS

Samples collected in 2018 under high flows (within 48 hours of precipitation) at Swan@Lalor generally exceeded the TMDL concentration of 26 mg/L (Table 4.1), whereas low flow samples did not (Figure 4.15). We interpret these results to mean that sediments in the Swan Creek watershed are mobilized during precipitation events caused by streambank erosion along the channel, resuspension of bed sediments, and runoff from upland areas. Roads, highways, and construction sites in the upper reaches of the watershed could be contributing sediment. During our fieldwork, we repeatedly observed severe streambank erosion along Swan Creek (Figure 4.16). Research indicates that urbanization can increase TSS concentrations coming from channel erosion (streambank and streambed) as runoff

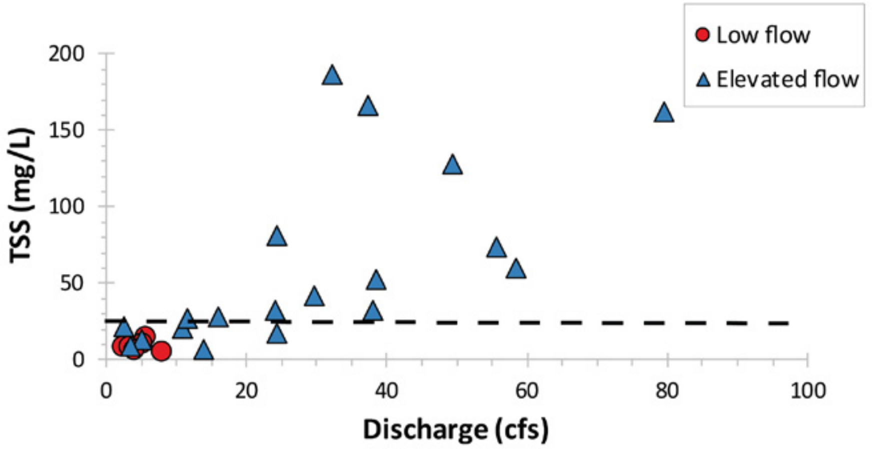


Figure 4.15. TSS concentration and discharge at the Swan@Lalor site in 2018. The dotted line indicates the Rock River Basin TMDL of 26 mg/L.

Figure 4.16. Streambank erosion along Swan Creek. The left photo shows bare streambanks without vegetation in a forested section of the watershed. The right photo shows undercut streambanks that have started to slump into the stream. (Photos by Némesis Ortiz-Declet).

velocity increases from additional impervious surfaces in the watershed (Nelson & Booth, 2002).

TSS concentration increased from upstream to downstream, when sampled on the same day, during base flow conditions (April, July, September, and October) and decreased during elevated flow conditions (May, June, and August; Figure 4.17). The magnitude of the trend of decreasing TSS concentrations resulting from elevated flow is more pronounced than the magnitude of the increasing trend occurring during low flow conditions. We interpret this result to mean that during higher flows, sediments settle out in the slower moving waters of the well-vegetated floodplain between the sites. During lower flow conditions, those sediments seem to remain in the water column for a longer period of time. A previous study from Minnesota found that stream morphology itself (including width, depth, vegetation and presence of back waters) plays a large role in the variability of TSS concentrations from upstream to downstream locations (Lenhart et al., 2010). This may be another factor influencing our results and could warrant further study.

Additionally, from 2015-2018, a statistically significant decrease ($p<0.05$) in TSS concentration was observed at the Swan@Lalor site during base flow conditions (Figure 4.18). However, in monthly samples taken since 2015, approximately 47% (15 of 32 samples) showed TSS concentrations above the Rock River Basin TMDL; all of these elevated levels occurred in the months of June through October (Figure 4.18). In 2015, there were several measurements of TSS concentration that seem to be outliers, especially since these extremely high measurements were collected under base flow conditions (Figure 4.19). It is unknown what caused these outliers, but perhaps a historical account of activities (construction, land modification, etc.) in the watershed corresponding with the sampling dates may provide a reason for these results. Interestingly, 2018 sampling indicated that all TSS concentrations were generally at or below the TMDL which again may be reflective of recent land use changes in the watershed. Once again, the activities contributing to decreasing TSS loads should be investigated.

Furthermore, because long-term monitoring has been limited to grab samples, these trends could be nonrepresentative. The majority of TSS inputs to the watershed could be coming from storm events which have historically not been captured by monitoring efforts. Indeed, previous research indicates that a majority of TSS loading in Wisconsin occurs during late winter and early spring larger precipitation events (>1.5 inches) when summer vegetation is not yet established to reduce erosion impacts (Danz, Corsi, Brooks, & Bannerman, 2013). These types of events have not been captured by the monitoring conducted in this watershed, and they may represent a large and important gap in a comprehensive understanding of the nutrient inputs.

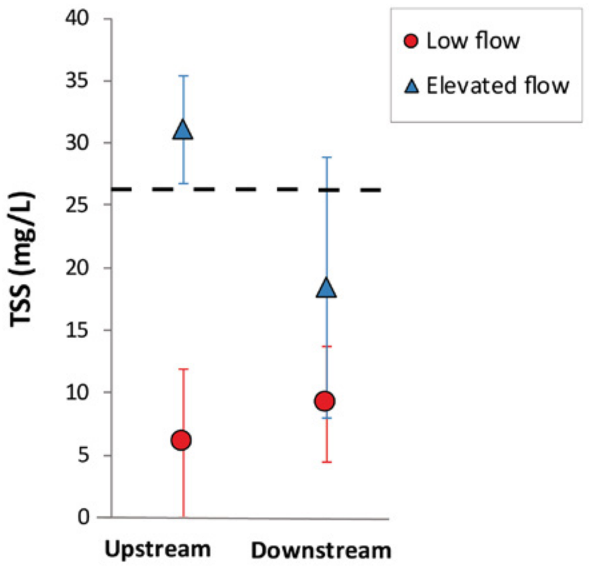


Figure 4.17. Average same-day TSS concentrations at upstream (Swan confluence) and downstream (Swan@Lalor) sites. We collected elevated flow samples within 48 hours of precipitation (May, June, and August) and low flow samples during dry conditions (April, July, September, and October). Bars show one standard deviation. The dotted line is the TMDL of 26 mg/L.

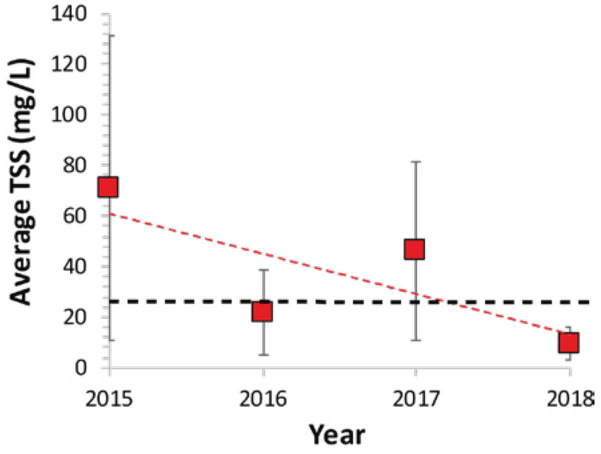


Figure 4.18. Linear regression of average annual low flow TSS concentrations; TSS concentration decreased at the Swan@Lalor site from 2015-2018 during low flow conditions ($p<0.05$; R2=0.33). Bars show one standard deviation. The dotted line indicates the Rock River Basin TMDL of 26 mg/L.

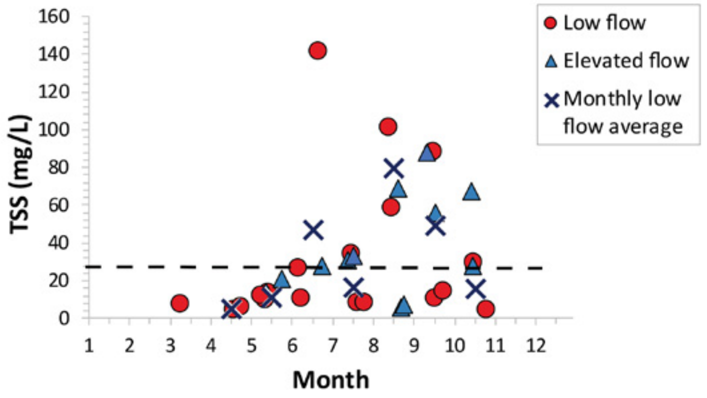


Figure 4.19. TSS grab sample concentrations for low flow and elevated flow conditions at the Swan@Lalor site from 2015-2018. The dotted line indicates the basin-wide TMDL stream standard of 26 mg/L.

TOTAL PHOSPHORUS

Data from 2018 illustrate that TP concentrations in the Swan Creek watershed remain elevated above the Rock River Basin TMDL concentration of 0.075 mg/L (Figure 4.20). In 2018, only low flow samples from April and October fell below this criterion. Monthly low flow averages from 2015 to 2018 meet the standard only in March and April (Figure 4.20). As with Murphy's Creek, early spring and late fall variability in TP is typical because seasonal changes in precipitation and vegetation cover affect rates of runoff and erosion (Mulholland & Hill, 1997). However, 87% of grab samples collected from 2015 to 2018 exceeded the TMDL TP concentration. Although there are is no updated biological data, phosphorus concentrations that are regularly higher than impairment listing criteria for Fish and Aquatic Life use suggest that elevated concentrations may be detrimental to the watershed ecosystem.

TP concentrations are related to precipitation and discharge. Generally, samples collected within 48 hours of precipitation had higher TP concentrations than those collected in dry conditions (Figure 4.22). We know that Swan Creek has flashy hydrology, and that increased precipitation and intensity correspond with increased stream discharge (Figure 4.8). During larger storm events, runoff comes from larger areas of a watershed (Sharpley et al., 2008). As discharge increases in Swan Creek, TP concentrations also increase (Figure 4.21). Whereas the majority of base flow TP concentrations fall between 0.075 – 0.15 mg/L, the majority of elevated flow TP concentrations are above 0.15 mg/L (Figures 4.20 and 4.21). This suggests that much of the phosphorus loading in the watershed may occur during storms. This is consistent with studies of other watersheds where storms, not base flow, have been shown to contribute more of the overall P (Sharpley et al., 2008; Heathwaite & Dils, 2000).

Within the Swan Creek watershed, we also observed that average TP concentrations increased from upstream to downstream (Figure 4.22). This pattern is more pronounced during elevated flow conditions, when there is additional watershed runoff and higher stream velocity.

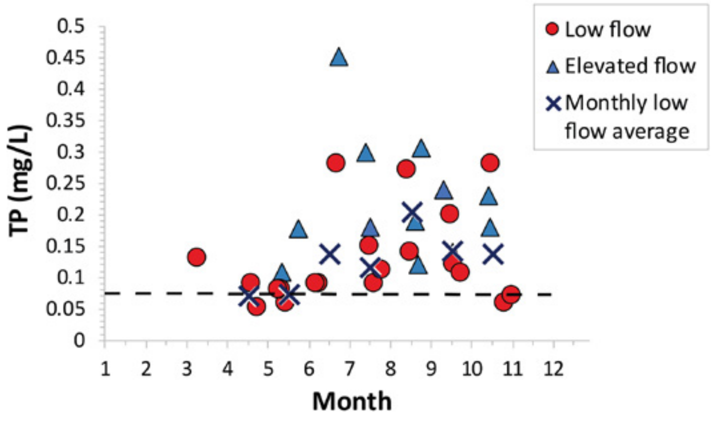


Figure 4.20. TP grab sample concentrations at the Swan@Lalor site from 2015-2018. The dotted line indicates the basin-wide TMDL stream standard of 0.075 mg/L; 87% of samples collected exceed the standard. TP concentrations from samples collected within 48 hours after a rain event were up to six times greater than the TMDL standard.

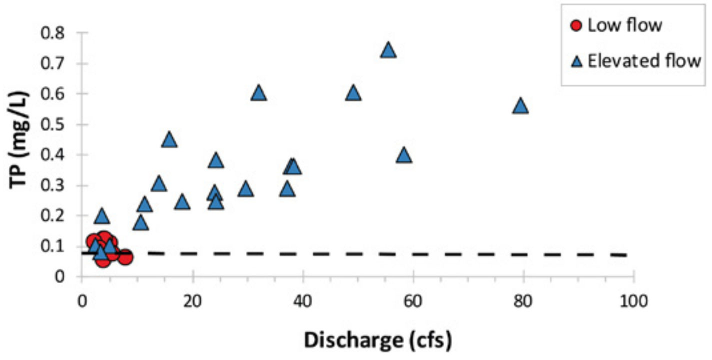


Figure 4.21. TP and discharge at the Swan@Lalor site in 2018. Data points are from both grab samples and samples collected from the automated sampler during rising, peak, and falling storm limbs. The line at 0.075 mg/L indicates the Rock River Basin TMDL for streams.

While average upstream base flow TP concentrations are below the TMDL, the stream exceeds the TMDL at the outlet. This indicates additional loading from upstream to downstream. Since phosphorus binds easily to sediments, erosion can transport high P concentrations to water bodies (Sharpley et al., 1985). However, TP shows the opposite pattern of TSS, which appears to decrease from upstream to downstream during elevated flows (Figure 4.17). This suggests that during elevated flows, dissolved phosphorus is being mobilized, as opposed to particulate phosphorus. During low flow conditions, both TP and TSS increase slightly from upstream to downstream. At these times, finer-grained sediments may be transporting the majority of the phosphorus load. From upstream to downstream, TP may be added to the creek from the Goodland Park Road tributary (Figure 4.1), an ephemeral tributary draining the Northeast Neighborhood, or from streambank erosion. Land management that reduces overland runoff and streambank erosion can help reduce TP concentrations (McDowell, Biggs, Sharpley, & Nguyen, 2003).

Overall, watershed average TP concentrations at the outlet during dry conditions have been decreasing since 2015 (Figure 4.23). This statistically significant decrease ($p < 0.05$) corresponds with a significant decrease in TSS. However, this trend was observed only for low flow conditions. Since the majority of watershed TP inputs are likely from storm events, and two of the highest grab sample concentrations are associated with elevated flow in 2018, this is not indicative of the TP load over time. Efforts to monitor water quality during both dry conditions and during / immediately following precipitation are needed to accurately assess the TP dynamics in Swan Creek and to assess whether land use changes are affecting TP.

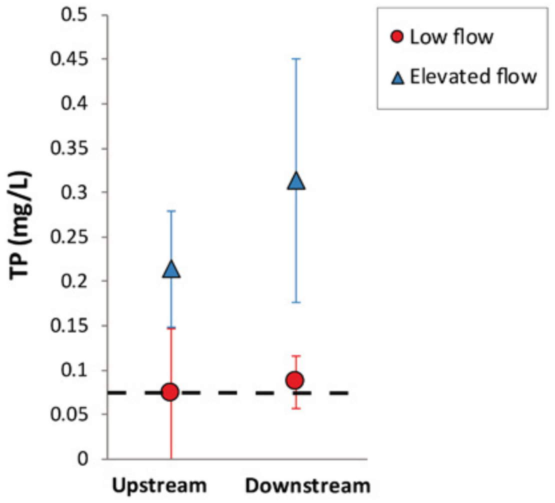


Figure 4.22. Average same-day TP concentrations at upstream (Swan confluence) and downstream (Swan@Lalor) sites. We collected elevated flow samples within 48 hours of precipitation (May, June, and August) and low flow samples during dry conditions (April, July, September, and October). Bars show one standard deviation. The dotted line indicates the Rock River Basin TMDL of 0.075 mg/L for streams.

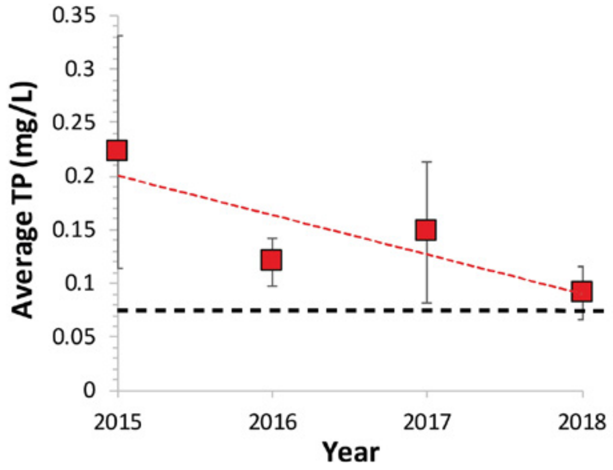


Figure 4.23. Linear regression of average annual low flow TP concentrations; TP concentration decreased at the Swan@Lalor site from 2015-2018 during low flow conditions (p<0.05; R2=0.40). Bars show one standard deviation. The dotted line indicates the Rock River Basin TMDL of 0.075 mg/L for streams.

LIMITATIONS

There are a number of limitations to these results and observations beyond those previously discussed. Some of these limitations are associated with the time constraints of the project. Because of the start date in late April, we did not capture spring snowmelt events. Missing these events means potentially missing a period of heavy nutrient loading for the watershed. Our observations were also limited by the scope of our project. We were only able to set up an ISCO at one site, which limits our understanding of nutrient values and stream flow at multiple locations along Swan and Murphy's creeks.

4.6 – Conclusions

NUTRIENT CONCENTRATION VARIATION UNDER DIFFERENT FLOW CONDITIONS

Differences in water quality were observed between the samples collected after dry periods compared to those collected closer to precipitation events. Currently, the Rock River Coalition (RRC) attempts to collect samples after dry periods, defined as 48 hours or more after the last rainfall. These baseline measurements are important in identifying long-term trends in water quality within the watershed. Yet, our results show that it is also important to collect elevated flow samples, considering how quickly Swan and Murphy's creeks respond to precipitation. This was especially apparent in the variability of chloride and phosphorus concentrations obtained over the course of the summer.

According to a 2007 USGS report from Michigan, the variation in concentration changes with volume as a result of variation in the chemical properties of different nutrients (Weaver & Fuller, 2007). For example, chloride and nitrate ions tend to dilute in larger volumes, while TSS will increase because of overland transport. This highlights the importance of collecting water quality and quantity data and creating a rating curve for each of the sampling locations that can eventually be used to estimate total loading. It should also be noted that in Wisconsin, stormflow contributions to annual loadings are often greater than baseflow contributions, and a few large storms contribute the vast majority of loading annually (Danz et al., 2010). Therefore, any monitoring plan should consider the effects of storm events on the overall quality of water entering wetlands.

LAND USE CHANGE, WATER QUALITY, AND WAUBESA WETLANDS

As the Swan Creek and Murphy's Creek watersheds transition from primarily agricultural to developed residential, the water quality of these tributaries entering Waubesa Wetlands will likely change. Given the current downward trends, we anticipate that TN concentrations in both creeks will continue to decrease over time as the agricultural land in the watershed diminishes (Yoshikawa et al., 2015; Stets et al., 2015). Less nitrate will leach into the groundwater from fertilizers and manure, and therefore less will enter the wetlands and creeks. Similarly, nitrate leaching from septic systems in the watershed will be of reduced concern because future development will be sewered. Even though Waubesa Wetlands have the capacity to remove nitrate from the water through denitrification, elevated levels of N are a threat to key wetland plants that help make denitrification happen (Green & Galatowitsch 2002; Woo & Zedler 2002; Kercher et al., 2007; Boers & Zedler, 2008).

We expect that TSS concentrations in both creeks may increase with urbanization because associated increased water velocities can erode streambanks and streambeds in the channels (Nelson & Booth, 2002). Additionally, with climate change and more frequent severe storm events that mobilize disproportionate amounts of TSS, we expect TSS loads to increase regardless of land use change (WICCI, 2011; Danz et al., 2013). This exemplifies why monitoring water quality is essential during storm events as land use changes in the watershed. This potential increase in TSS loading may have an impact on wetlands in the watershed, including Waubesa Wetlands. Vegetation traps sediments, keeping them out of water bodies, but sediment accumulation can inhibit some or all of the ecosystem services provided by wetlands, including hydrologic functioning and biodiversity (Skagan, Burris, & Granfors, 2016). Without appropriate management, excessive wetland sedimentation resulting from factors described in this report may degrade wetland ecosystems and the services they provide throughout the Waubesa Wetlands watershed.

As with TSS, the dual drivers of urbanization and climate change will likely increase runoff and TP concentrations in the watershed of Waubesa Wetlands. Construction can be a major source of both TSS and TP. While less is known about TP concentrations in construction runoff, TSS export has been found to range from 2000 to 16,000 lbs/acre per year (Line et al, 2011). This suggests that sediment-bound phosphorus can be mobilized in large quantities during construction, especially during intense rain events. Construction will also occur on current agricultural land that presumably has elevated soil P levels (Bennett et al., 1999; Kara et al., 2012). This surplus "legacy phosphorus" is the result of decades of previous land use. Disturbances such as construction can mobilize legacy phosphorus and turn it into available phosphorus, increasing the risk of eutrophication. Monitoring throughout construction is critical. Urbanization will also shift the sources of phosphorus from fertilizer and manure to plant and leaf litter and pet waste. Future management will need to focus on these new sources. With TP concentrations in Swan and Murphy's creeks already consistently above the regional TMDL, any additional inputs could be damaging to wetland ecosystems and Waubesa Wetlands. Continued monitoring and targeted management of phosphorus sources will be of the upmost importance.

EMERGING CONTAMINANTS AND OTHER CONCERNS

With urbanization, chloride, and other currently unmonitored contaminants such as metals, bacteria, and hydrocarbons may increase in concentration (NRC, 2009). These contaminants could damage wetlands throughout the Waubesa Wetlands watershed. Furthermore, characteristics such as stream base flow and temperature could change with development and have a negative impact on aquatic life (Kaushal et al., 2010; Bhasker et al., 2016). For long-term monitoring, it will be important to continue to evaluate the most critical parameters for assessing potential changes in the health of the watershed.

LAND USE AND CLIMATE CHANGE MODELING

5.1 – Introduction

Models are used to understand the current state of a system and project how the system might change over time. In our work, we used models to help us understand baseline water quality and quantity conditions in the Waubesa Wetlands watershed, and how those conditions may vary as climate and land use change.

Scientists have documented a changing climate for several decades. In the upper Midwest from 1950 to 2006 the frequency of heavy precipitation events has increased, snow cover and lake-ice duration has decreased, spring snow melt has trended earlier, peak stream flow and lake levels have gotten higher, and hydrologic flooding occurrences have increased (Motew & Kucharik, 2013; Kucharik, Serbin, Vavrus, Hopkins, & Motew, 2010). Van Vliet et al. (2013) modeled river discharge and water temperature at a global scale and found that both discharge and temperature will increase in Wisconsin. Milly et al. (2008) argued that "stationarity is dead," calling on water engineers and policy makers to discard the assumption that hydrologic systems will behave like they always have, within a margin of historic variability. Waubesa Wetlands are not immune to these changes.

The Waubesa Wetlands watershed, which is mostly situated in the city of Fitchburg, is poised for urban development. Currently, land use in the 8,434 acre watershed is 41% agriculture, 37% natural and 22% urban. Fitchburg's 2017 Comprehensive Plan outlines areas slotted for future development, of which 1,989 acres lie in the watershed (Fitchburg Planning Department, 2017) (Figure 5.1).

Urbanization is associated with a suite of hydrologic impacts, mainly from increased area of impervious surfaces (Chen, Theller, Gitau, Engel, & Harbor, 2016). Impervious surfaces decrease infiltration, creating more runoff (Schueler, Fraley-McNeal, & Cappiella, 2009). Reduced infiltration leads to higher peak flows, even for short duration, low-intensity rainfall, and increases the risk of flooding (Suriya & Mudgal, 2012; Bhaduri, Minner, Tatalovich, Member, & Harbor, 2001). As a result of higher peak flows, erosion potential increases, intensifying sediment and nutrient loads (Bagnold, 1966; Lenhart et al., 2009; Purvis & Fox, 2015). Excess surface water and increased nutrient and sediment loads can allow non-native and invasive species to dominate, crowding out native species and reducing biodiversity (Zedler, 2018). Urban runoff also carries non-point source pollutants like nutrients, oils, metals, pesticides, and pathogens into surface water during rainfall events (USEPA, 1983). The two creeks that drain the Waubesa Wetlands watershed, Swan Creek and Murphy's Creek, will be directly impacted by urbanization. Our modeling helps predict how stream discharge and sediment/nutrient loads to the streams will change as climate and land use change.

5.2 – Purpose

Our project used two models to help understand the hydrologic and water quality impacts associated with climate and land use change: HydroCAD, which predicts surface water runoff rate and quantity, and STEPL, which predicts runoff water quality.

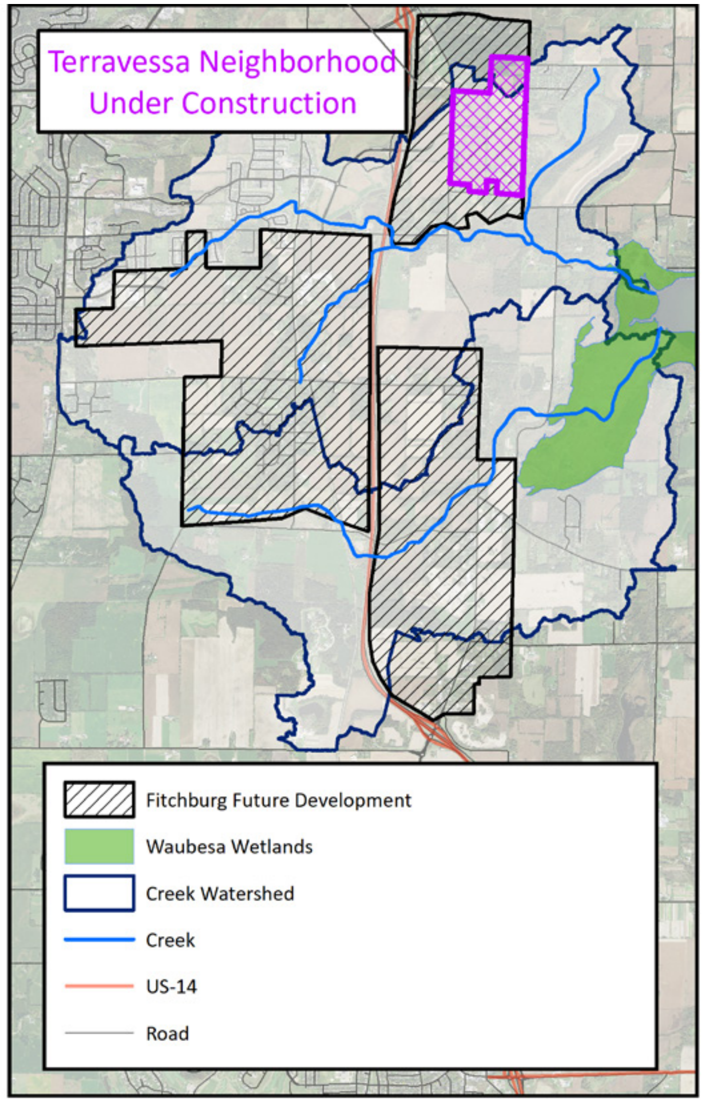


Figure 5.1: Future development areas in the city of Fitchburg.

HydroCAD, which is commonly used for stormwater engineering, incorporates land use, soil type, stream channel characteristics, and hydraulic structures to calculate a watershed's runoff peak flow rate and volume based on synthetic storm events of specified return periods (e.g., one-year, 24 hour events or 100-year, 24-hour events).

STEPL, developed by the U. S. Environmental Protection Agency, stands for Spreadsheet Tool for Estimating Pollutant Loads. It uses simple algorithms to calculate nutrient and sediment loads from different land uses and the load reductions that would result from the implementation of various best management practices (BMPs) (USEPA, 2019). STEPL considers numerous inputs, but is driven mostly by land use, livestock populations, agricultural practices, and soil characteristics. Using HydroCAD and STEPL, we estimated the magnitude of change in surface water quality and quantity that may result from changes to climate and land use from current conditions to the year 2062.

5.3 – Methods

HydroCAD

HydroCAD calculates surface water flows using the U. S. Department of Agriculture's TR-55 method, which uses watershed area, curve number and time of concentration to produce a runoff hydrograph for a given storm event. A curve number is a numerical representation of a watershed's ability to produce runoff based on its land use and soil properties. Time of concentration is the length of time necessary for water from the most remote point in the watershed to reach the watershed's outlet. HydroCAD couples those two properties within a network of stream channels and hydraulic structures (ponds or culverts) to estimate the runoff hydrograph for a given storm. Complete details on HydroCAD's methodology can be found on its website: https://www.hydrocad.net/info.htm.

To begin the HydroCAD modeling process, we constructed base models representative of current conditions for both Swan and Murphy's creeks. Initial subwatersheds were delineated in ArcMap using the stream link tool based on a 2016 LiDAR DEM. Then, using Google street view, WDNR culvert data, and field investigation, subwatersheds were edited based on limiting hydraulic structures (culverts and ponds) and maintained at a reasonable subwatershed resolution.

Ponds at subwatershed outlets were accounted for through one of two methods. Constructed storm ponds with engineering plans were duplicated in HydroCAD with the help of Eric Thompson, a professional engineer at MSA Professional Services. Natural ponds created upstream of culverts were accounted for by extracting contour line data in ArcMap and inputting the geometry into HydroCAD for storage volume calculation.

Using ArcMap, we overlaid subwatersheds with 2015 land use data, provided by CARPC, and NRCS hydrologic soil group data, allowing for the calculation of a curve number for each subwatershed. Table J.1 in Appendix J shows how CARPC land classifications were assigned curve numbers.

By visually inspecting contour, terrain, flow accumulation, and aerial imagery data, three potential flow paths for each subwatershed were digitized. Based on the TR-55 method for time of concentration, travel times for sheet flow, shallow concentrated flow, and open channel flow were calculated for each digitized flow path, and the longest time of the three paths was used in the model.

Manning's equation was used to estimate the relationship between stream stage and discharge. A channel profile was created with the help of ArcMap. On a relatively straight section of the stream, the distance between equivalent elevation contours was measured perpendicularly across the stream channel. Using these distances and elevations, a symmetrical channel profile was created. Slope was identified using contour elevations, and friction coefficients were determined by visual inspection of aerial imagery. Stream channel discharge was then calculated in vertical subsections using Manning's equation.

A base flow of three cubic feet per second (cfs) for Swan Creek and two cfs for Murphy's Creek was used based on our field observations (Chapter 4). With all of the necessary data inputs for HydroCAD assembled, base models for current conditions of Swan and Murphy's creeks were constructed.

LAND USE CHANGE

The methods outlined in this section apply to both HydroCAD and STEPL. To model land use change, Fitchburg's 2017 Comprehensive Plan was used to identify the areas positioned for development, and the rate at which development was to take place. We also met with planners from the City of Fitchburg to confirm and further understand the city's intent. Owing to the nature of real estate development, it is impossible for the city or anyone to accurately predict when and what development will take place. For this reason, we had to make assumptions about what future development will look like and how fast development will occur. A neighborhood currently under construction in the watershed, the Terravessa Neighborhood, was an ideal candidate for our model because it was small and capable of being replicated. Fitchburg's city plan indicated that land is to be developed at an average rate of no more than 75 acres per year. We considered this to be aggressive, and therefore assumed 55 acres would be developed per year, or that a Terravessa-like neighborhood would be constructed every four years. We replicated the Terravessa neighborhood and stormwater plan and substituted it in subwatersheds where development would take place.

As of April 2018, the Terravessa Neighborhood is currently under construction in Fitchburg's northeast corner (Figure 5.1). The development is notable for two reasons: it uses SmartCode, a new zoning ordinance that allows developments more flexibility in relation to form, scale and use; and its stormwater plan is progressively engineered, using distributed bio-retention ponds, engineered soil, and augmented with a natural wetland onsite. Using Terravessa's approved development plan obtained from CARPC, we replicated its HydroCAD stormwater model, confirmed its calculations, and met with its creator, Ryan Stenjem, a professional engineer at Montgomery Associates Resource Solutions, to ensure that the system was properly understood.

While the neighborhood's stormwater plan was successfully replicated, several other issues needed to be addressed. The neighborhood is 250 acres, of which 221 acres drain to an engineered system. Moreover, those 221 acres do not drain to a single outlet. For the watershed development scenarios, we assumed that the 221 acres drained to a single outlet in all cases except in the original Terravessa Neighborhood.

Based on Fitchburg's future development map in its Comprehensive Plan, we digitized the development area using ArcMap. We then overlaid the development area with the subwatersheds from our HydroCAD models. Conveniently, every subwatershed but one contained between 250-350 acres of developable land (agricultural or natural land) in a corresponding development area. Substituting Terravessa-like neighborhoods was then a matter of redistributing land use and adjusting curve numbers. For example, if a 500-acre subwatershed had 200 acres of agricultural land and 100 acres of natural land in an area slotted for development, 147 acres of agricultural land and 74 acres of natural land in that subwatershed were replaced with a 221-acre Terravessa-like system draining directly to that watershed's outlet, and a new curve number was calculated.

This process was carried out six times in the Swan Creek watershed and three times in the Murphy's Creek watershed. Three of Swan Creek's substitutions happened in its largest subwatershed. Overall, land use in the Waubesa Wetlands watershed transitions from the current conditions of 41% agriculture, 37% natural and 22% urban to 25% agriculture, 30% natural and 45% urban by year 2054 (Figure 5.2). In addition to the time component of these substitutions, we assumed that development would originate from the northeast and spread southwest over time, reflecting a sprawl away from downtown Madison. Figure 5.3 shows the development completion year in each subwatershed.

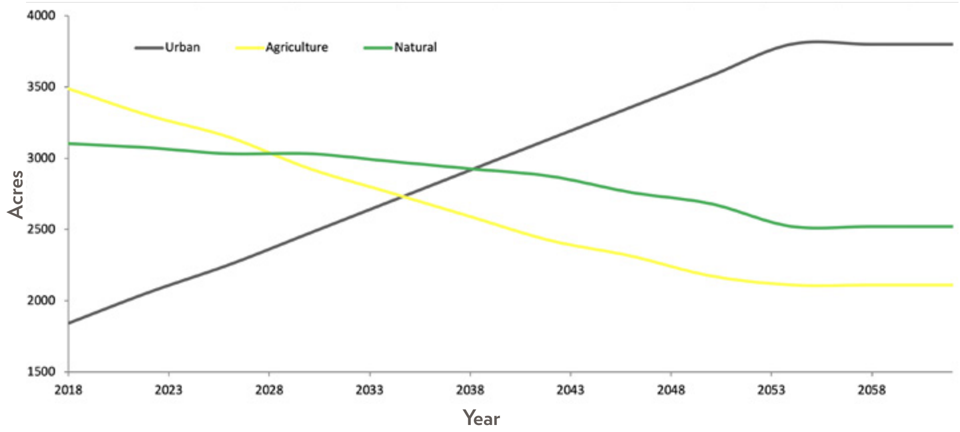


Figure 5.2: Modeled land use change in the Waubesa Wetlands watershed from 2018 to 2062.

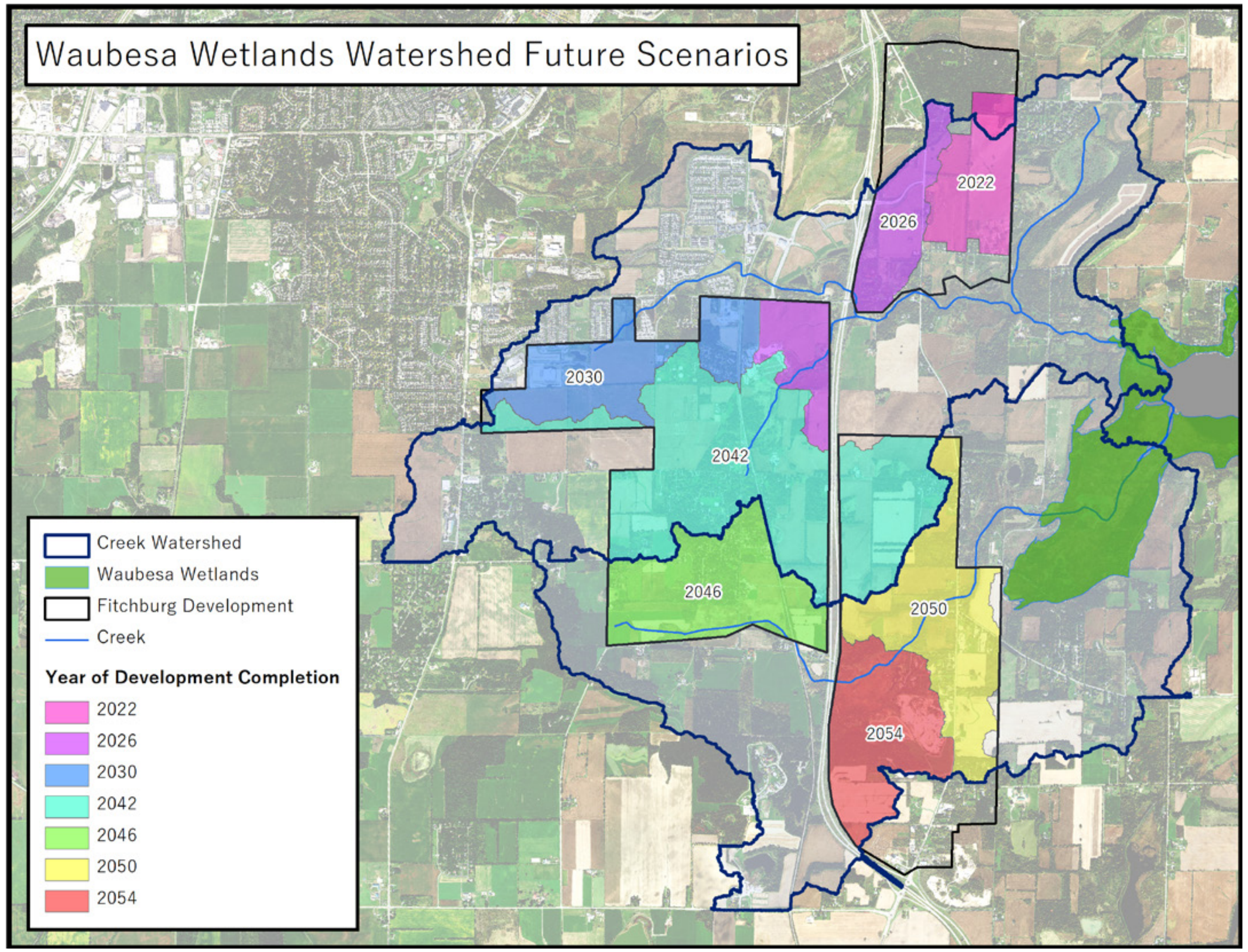


Figure 5.3: Modeled land use change in Swan Creek and Murphy's Creek subwatersheds. Colors represent the development site, and the four-digit number is the anticipated year of completion. Note that in the 2042 subwatershed, three Terravessa-like neighborhoods were substituted, while all other subwatersheds contain only one.

CLIMATE CHANGE

To account for climate change, we met with Dr. David Lorenz and Dr. Steve Vavrus of UW-Madison's Nelson Institute Center for Climactic Research. After consultation, Dr. Lorenz provided 10 model realizations of CMIP5 24-hr daily precipitation depths, downscaled to Madison, Wisconsin, for years 2006 to 2062. CMIP5 stands for Coupled Model Intercomparison Project phase five; it combines outputs from 24 underlying climate models. With 10 realizations of the 24 models, our complete dataset contained 240 simulated time series of daily 24-hour precipitation depths from 2006-2062.

HydroCAD and STEPL rely heavily on precipitation data to perform their calculations; however, each use different representations of that data. STEPL uses total annual rainfall and number of rainfall days to calculate an average rainfall per event. HydroCAD uses simulated storms, most commonly a 24-hour rainfall depth, distributed across a rainfall intensity curve designated for a given region. For Madison, regulations specify MSE4 24-hour rainfall distribution. Given the differences in inputs, separate methods were used to analyze the climate data.

We evaluated the climate data to determine whether STEPL precipitation inputs (total annual rainfall and number of rainfall days) would change from current conditions. To determine if total annual rainfall would change, a pivot table was used to sum annual precipitation each year from 2006 to 2062 for 10 of the 240 model simulations. The sums were then plotted through time, and a linear regression was used to determine a correlation coefficient. Though some regressions had p-values less than 0.05, indicating a significant relationship, the average correlation coefficient for these 10 models was 0.04, indicating that time explained four percent of the variation in the linear model. For this reason and given the scope of our study, we assumed total annual rainfall was constant for the STEPL model.

To determine for STEPL whether number of rainfall days would change, precipitation values were converted to "1" if precipitation occurred, and "0" if no precipitation occurred. Using the same 10 models, we used linear regression to identify how the frequency of rainfall-days changed through time. Like the prior analysis, correlation coefficients for the 10 models were low (.01); therefore, we assumed number of rainfall days did not change through time. For these reasons, we did use climate change as a scenario for our STEPL model.

To prepare our rainfall data for use with HydroCAD, we calculated design storms. Return periods, such as the 25-year event, indicate the likelihood of an event of that magnitude occurring during any given year. For example, a 25-year event has a four percent chance of occurring in any given year (1/25 = 0.04). We chose the one-year, 24-hour storm to represent frequent precipitation events, and the 100-year, 24-hour storm to represent extreme storm events. Historically, these values were calculated based on a time series of actual storms that have taken place. However, with a changing climate, calculating these events becomes more complicated (Milly et al., 2008). While several advanced methods have been used to calculate future recurrence interval storms (Clarke, 2002; Salas, Rajagopalan, Saito, & Brown, 2012; Rashid, Beecham, & Chowdhury, 2013; Mamoon, Rahman, & Qasem, 2015; Degaetano & Castellano, 2018; Maurer, Kayser, Doyle, & Wood, 2018), we used a simpler approach.

To calculate the one-year storm, a pivot table was used to isolate the maximum precipitation depth for each year for all 240 model outputs from 2018 to 2062. Then, for a single year, the 240 depths were sorted from highest to lowest. The depth of the 100th largest event was recorded and used to represent that year. We repeated this for every year, and a linear model of one-year, 24-hour precipitation depth over time was created. The slope of this model was used to project the current NOAA Atlas 14 rainfall depth of 2.49 inches in 2018, to 2.84 inches in 2062, a 14.0% increase in the one-year, 24-hour storm over 44 years.

As with the one-year, 24-hour event, the first step to calculate the 100-year, 24-hour event was to isolate the maximum precipitation depth for each model for each year and then sort from highest to lowest. A Weibull distribution was fit to the 100 largest events for a given year and used to estimate the 100-year, 24-hour event. This was repeated for every year, and a linear model of 100-year, 24-hour precipitation depth over time was created. Again, like the one-year, 24-hour event, the slope of the model was used to project the current NOAA Atlas 14 rainfall depth to 2062. The 100-year, 24-hour event of 6.66 inches in 2018 increased to 7.60 inches by 2062, a 14.1% increase.

Though methods employed in this analysis could be improved, their conclusions were considered reasonable by our climate experts, David Lorenz and Steve Vavrus, in addition to being well inside the ballpark of similar estimates (Kucharik et al., 2010; Motew & Kucharik, 2013; Van Vliet et al., 2013; Maurer et al. 2018).

STEPL

In order to model nutrient loading changes over time, we used STEPL. This model takes into consideration several factors, with an emphasis on land use changes and the effects of best management practices (BMPs). STEPL relies heavily on the universal soil loss equation (USLE), which means that it is sensitive to changes in soil type. STEPL also relies on the curve number method for runoff estimation described previously.

For our STEPL modeling, Dane County annual precipitation was estimated as the mean of reported average annual rainfall from all Dane County weather stations (Based on aggregate data from US EPA BASINS Climate assessment tool in STEPL). Inputs for land use came from our previously described land use change scenarios. Estimates for animal numbers were based on a conversation with Dr. Eric Booth, an assistant scientist in UW-Madison's Agronomy and Civil & Environmental Engineering departments. To determine the inputs for STEPL, we used the watersheds previously delineated in ArcMap to extract data from the Natural Resources Conservation Service Web Soil Survey. STEPL default values were maintained for urban use distribution and septic systems. Dane County Land and Water provided the phosphorus reduction estimates associated with BMPs.

There were several limitations associated with the STEPL analysis. One of these limitations is related to the underlying structure of the model. The EPA developed STEPL to be an easily accessible tool for every state. This means that the underlying assumptions of the model were based on research done across the U.S., which may not directly reflect conditions in Wisconsin. The other major limitation is lack of available agricultural data at the appropriate scale. Estimates for animal numbers were difficult to obtain, information on months of manure spreading was limited, and information regarding best management practices may be missing.

MODEL SCENARIOS

One of the primary advantages of modeling is the ability to investigate potential outcomes under several different conditions. Using our HydroCAD model, we segregated the impacts from climate change, land use change, and stormwater management into four different scenarios: 1) watershed development, 2) climate change, 3) climate change and watershed development, and 4) climate change, watershed development, and no stormwater management. Using our STEPL model, we were able to explore the changes from land use change and best management practices.

For Scenario 1 of our HydroCAD model, watershed development, HydroCAD was run using only current-condition NOAA Atlas 14 simulation storms, but progressed through the land use change models of Terravessa-like neighborhoods. This allowed us to identify the impact of only land use change. For Scenario 2, climate change, we ran only our base HydroCAD model, representative of current watershed conditions, but used our projected storm events. Scenario 3, climate change and watershed development, used our land use change models and climate change storm events to provide a "most likely" scenario, where both factors come into play. Scenario 4, climate change, watershed development, and no stormwater management, was a theoretical scenario where the watershed was developed but no stormwater management was used. The Terravessa stormwater management systems were removed from each model, but the subwatershed curve numbers were adjusted as if 221 acres were urbanized like the Terravessa Neighborhood. Though stormwater management is required by law, this scenario helps us understand the importance of stormwater management and presents a worst-case scenario.

For all STEPL scenarios except the baseline, the projected land use changes were applied. The baseline scenario considered the maximum amount of current potential runoff, ignoring changes in BMPs and development. The changes due to the implementation of BMPs were split into three categories: 1) expiration of BMPS. This represents the baseline BMPs based on our knowledge of currently implemented BMPs (any "soft practices" with short-term contracts were allowed to expire); 2) continuation of current BMPs (no expiration of soft practices); and 3) expanded implementation based on an area-weighted application of the Yahara WINs target implementation goals for each watershed. For the Murphy's Creek watershed, it was assumed that current BMPs would not expire, so scenarios 1 (expiration) and 2 (continuation) were the same.

5.4 – Results

WATER QUANTITY

HydroCAD models runoff and stream discharge, estimating both peak flow rates in cubic feet per second (cfs) and total runoff volume in acre-feet (ac-ft). Therefore, with two creeks (Murphy's and Swan), two storm events (one-year, 24-hour and 100-year, 24-hour storms), and two model outputs (peak discharge and total runoff volume), we have eight initial time series, each representing a respective combination.

Differences in peak flow between Swan Creek and Murphy's Creek result from their development period and the size and composition of their watersheds (Figure 5.4 below, and Figures J.3, J.4, J.5, and J.6 in Appendix J). Development in Swan Creek takes place from 2018 to 2042, while development in Murphy's Creek is from 2042 to 2054. Discharge is larger in Swan Creek because it drains a larger watershed and contains more impervious surface.

Trends in peak discharge versus time for the four scenarios are consistent for both watersheds and design storms; the Swan Creek one-year, 24-hour event is the most illustrative (Figure 5.4). The watershed development scenario (1), shows a subtle increase in peak flow after more than half of the development has taken place, and after complete development, peak flow increases 19% over current conditions. The climate change scenario (2) is the next most significant, causing a 42% increase in peak flow from current conditions. The "most likely" scenario, climate change and watershed development (3), shows a 52% increase in peak flow. Lastly, the climate change, watershed development, and no stormwater management scenario (4), shows the most substantial change, increasing by 70% from current conditions. Figure 5.5 shows the percent increase caused by each scenario, for each creek and storm event.

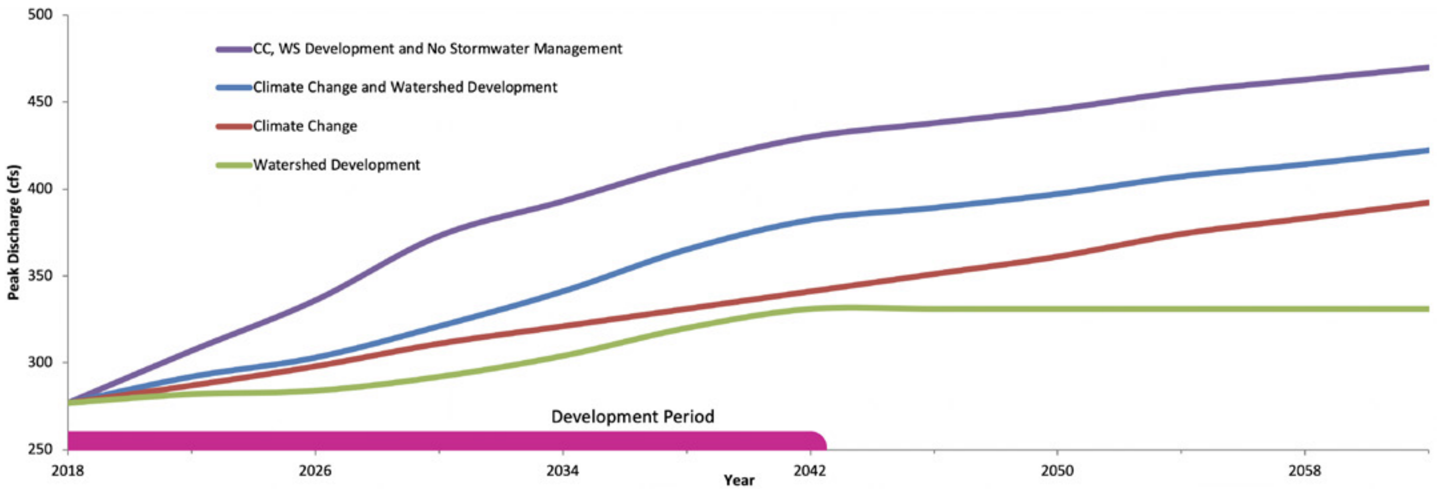


Figure 5.4: Swan Creek peak flow rate for the one-year, 24-hour design storm (MSE4 rainfall distribution).

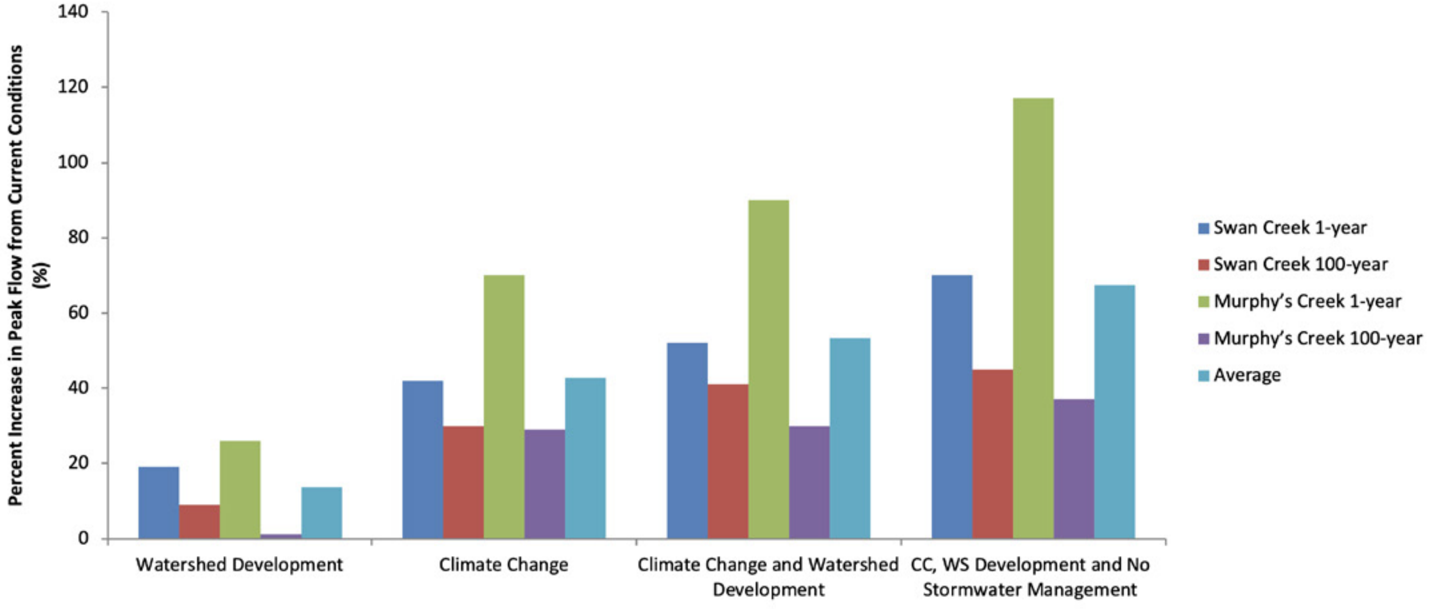


Figure 5.5: Percent increase in peak flow for each of the four scenarios.

Unlike peak flow, trends in flow volume were more variable between creeks and events. Again, Swan Creek's one-year, 24-hour event is used as our example (Figure 5.6). Watershed development and climate change have equal impacts during the timeframe, each responsible for a 39% increase from current conditions. When their impacts are combined, it overshadows every other scenario, with an 82% increase over current conditions. Figure 5.7 summarizes the percent increase in total volume under each scenario for each creek and event.

Increases in flow volume are more dramatic for the one-year, 24-hour events than for the 100-year, 24-hour events. In the climate change and watershed development scenario, flow volume for the one-year, 24-hour events increases by 67%, but only by 25% for the 100-year, 24-hour events.

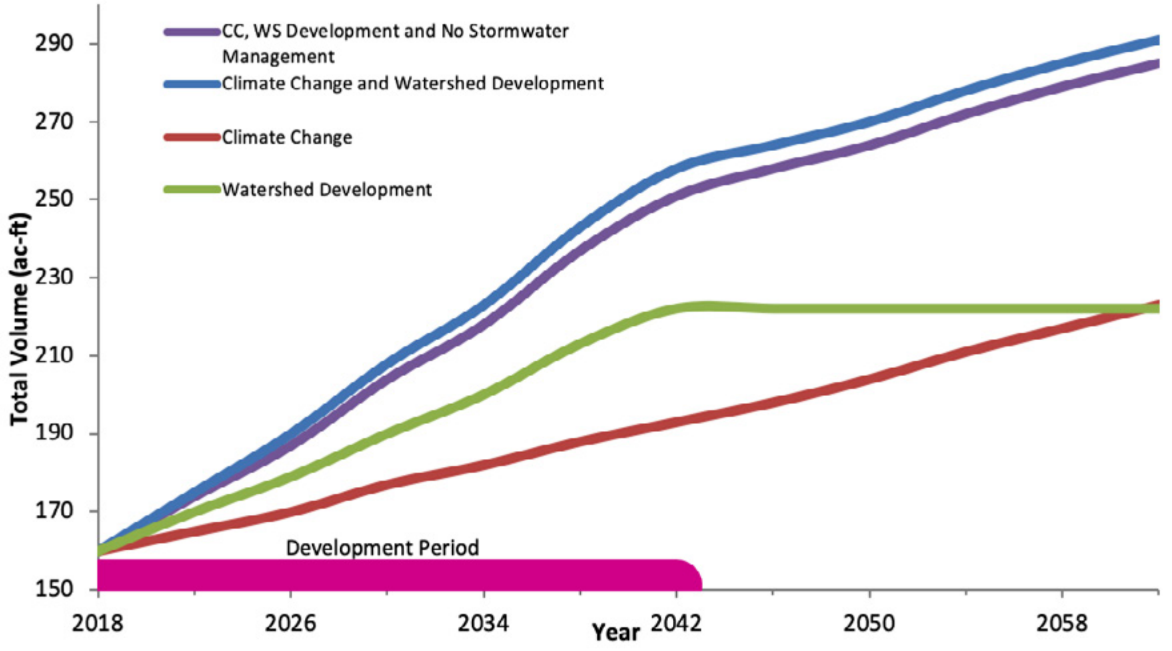


Figure 5.6: Swan Creek flow volume for the one-year, 24-hour design storm (MSE4 rainfall distribution).

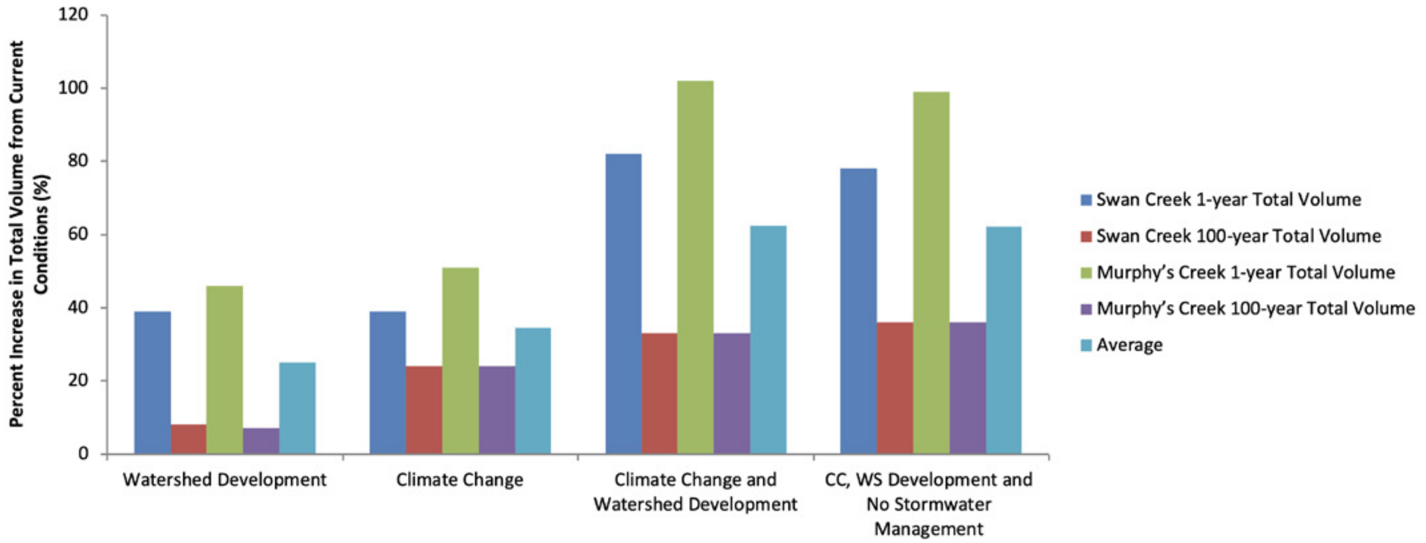


Figure 5.7: Percent increase in total flow volume for Swan and Murphy's creeks each of the four scenarios.

Summarizing the results of our HydroCAD modeling, the most notable observation is the relative impact of climate change, prevailing over development as the leading contributor to increased discharge. This is true for both peak flow and total volume, though this is more evident with peak flow (Figure 5.8).

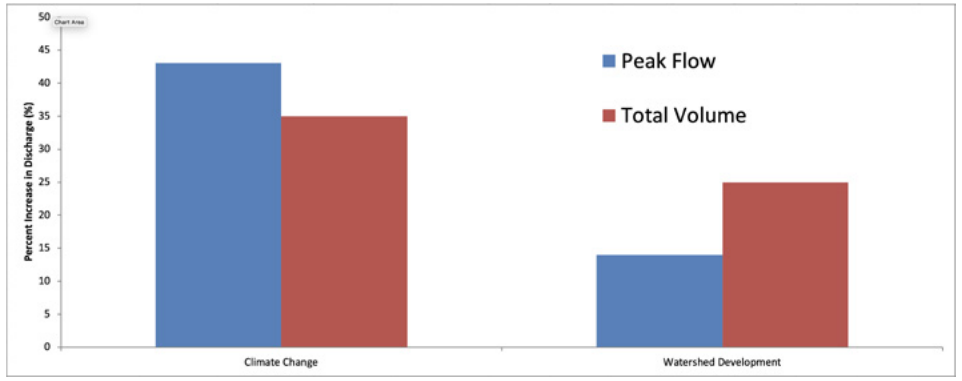


Figure 5.8: Average percent change in discharge for all scenarios and storm events under either climate change or watershed development.

How will these increased surface water volumes and peak flows impact Waubesa Wetlands? One of the defining characteristics of a wetland community is its hydrologic regime. Amon, Thompson, Carpenter, & Miner (2002) characterized temperate fen wetlands, like those within Waubesa Wetlands, as having limited water level fluctuation, limited inundation, high levels of saturation, and high levels of water flow. If water level fluctuation and inundation increase, the fen wetland community may start favoring a marsh wetland community (Amon et al. 2002).

Webb, Wallis, and Stewardson (2012) conducted a comprehensive literature review deciphering how aspects of water regime (waterlogging, inundation, depth, duration, frequency, and timing) affect aspects of wetland flora (establishment, total biomass, belowground biomass, aboveground biomass, shoot length, shoot density, reproductive output, assemblage composition, and diversity). The most notable relationships identified were: 1) that inundation depth and duration affect plant assemblage composition; 2) inundation decreases plant diversity; and 3) water depth is related to eight of the nine wetland plant variables described above. Similar conclusions were made in a controlled experiment by Doherty et al. (2014), finding that differences in hydroperiod caused substantially different plant communities and ecosystem services.

These studies illustrate the dramatic importance of a wetland's flow regime in determining its plant community. However, because our model is runoff-based and does not account for the complex interplay between surface water and groundwater, making inferences about the wetland's response to these surface water changes is tenuous. Moreover, Waubesa Wetlands is unique, largely as a result of its hydrogeology. Our modeling indicates that, on average, combined land use and climate change will increase runoff peak flow by 53%, and runoff volume by 63% by 2062. Given the importance of hydrologic regime, it is likely that these changes will have some effect on Waubesa Wetlands. Beyond the direct increase in surface water quantity, higher peak flows increase erosion potential, which can intensify sediment and nutrient loads (Bagnold, 1966; Lenhart et al., 2009; Purvis & Fox, 2015). Increased sediment and nutrient loads cause non-native and invasive species to dominate, crowding out native species and reducing biodiversity (Zedler, 2018).

WATER QUALITY

In all cases except for the static baseline scenario, phosphorus loading decreased with increased development. As land use changes from agricultural to urban, STEPL predicts a decrease in phosphorus loading. The land use changes are assumed to be the same as those that were used in the HydroCAD scenarios over the timescale shown in the figures below. This is in line with the current distribution of phosphorus sources within the wider Rock River basin. According to the Rock River TMDL, as of 2011, 63.8% of average annual loading basin wide came from agricultural sources compared to 6.8% from urban sources (Cadmus Group Inc., 2011).

It should be noted that one limitation of this STEPL analysis was limited information about manure spreading. Research conducted by Dr. Richard Lathrop of the UW-Madison Center for Limnology discusses the importance of direct manure runoff in phosphorus loading. One particularly interesting finding from his report relates to direct manure runoff during winter months, where "P loadings during January to March were 48% of total loadings measured for 1990-2006 in the Yahara River subwatershed" (Lathrop, 2007). Without detailed information about the specific amount of manure applied in the Waubesa Wetlands watershed, our phosphorus loading estimates may be inadequate.

Figures 5.9 and 5.10 show the estimated phosphorus loads for each model scenario for Swan and Murphy's creeks. Figure 5.9 shows that for Swan Creek, an immediate and substantial decrease in phosphorus load in all scenarios is primarily caused by changes in land use in the watershed. Figure 5.10 shows similar decreases when watershed development begins in Murphy's Creek in 2042.

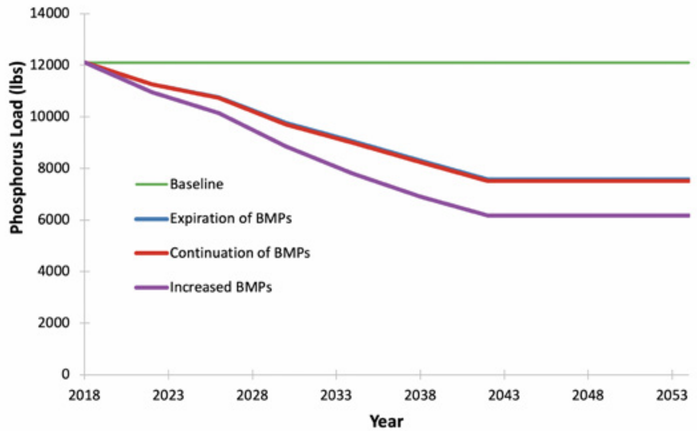


Figure 5.9: Estimated phosphorus loads in the Swan Creek watershed.

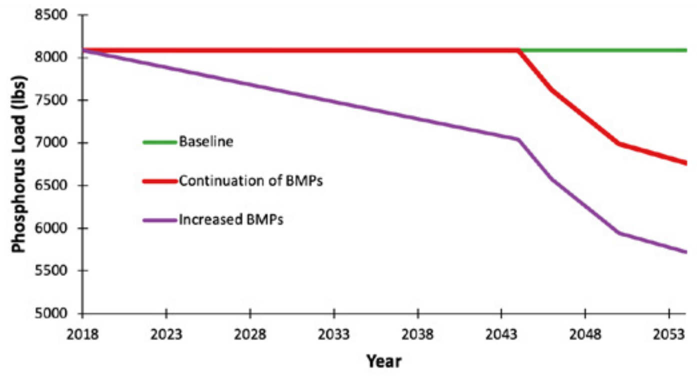


Figure 5.10: Estimated phosphorus loads in the Murphy's Creek watershed. We assumed that current BMPs would not expire and thus there is no expiration scenario.

5.5 – Discussion

Both climate change and watershed development increased measures of discharge in our models, but remarkably, climate change had the dominant impact. On average, watershed development increased measures of discharge by 20%; climate change nearly doubled this, increasing measures of discharge by 39%. While urbanization is a threat to watershed health (Chen et al., 2016), we anticipate that increased precipitation as a result of climate change will have a greater impact on peak flows and water volumes entering Waubesa Wetlands.

Looking closer at the results of our watershed development scenario, our findings demonstrate the importance of understanding a system at the watershed scale. Peak flow rate in Swan Creek remained virtually unaffected by urbanization during the first half of its development phase, and the increase in flow rate during the second half of Swan Creek's development was partially a result of the model's structure. The second half of development in the Swan Creek watershed took place in a single subwatershed. To model this we assumed that each development drained directly to that subwatershed outlet.

Stormwater management systems are designed to meet regulatory standards that require post-development peak flow rates to match pre-development peak flow rates. However, regulations do not require the timing of these peak flow rates to correlate. Development, even with stormwater management, often reduces the time to peak flow. For these reasons, peak flow rates – at the watershed-scale – can be heightened as a result of the decreased time to peak flow caused by several developments within a watershed. This cumulative impact beyond an individual development site can cause negative effects downstream. This is an important consideration for city and regional planners, engineers, and policy makers as a watershed is developed.

While the STEPL model considered management practices designed to reduce phosphorus loads, most of the changes that we observed in phosphorus loading over time are a result of land use change.

> **“ Regulations do not require the timing of these peak flow rates to correlate. Development, even with stormwater management, often reduces the time to peak flow. For these reasons, peak flow rates – at the watershed-scale – can be heightened as a result of the decreased time to peak flow caused by several developments within a watershed. This cumulative impact beyond an individual development site can cause negative effects downstream. ”**

The results of our STEPL model indicate that conversion of agricultural land to urban land will reduce phosphorus loads. This is an intuitive conclusion based on the fact that residential land does not receive a commercial-level application of fertilizer like many agricultural fields. However, STEPL's calculations are not robust because the program was designed to estimate nutrient loads anywhere in EPA Region Five (USEPA, 2019). Furthermore, a local study in the Rock

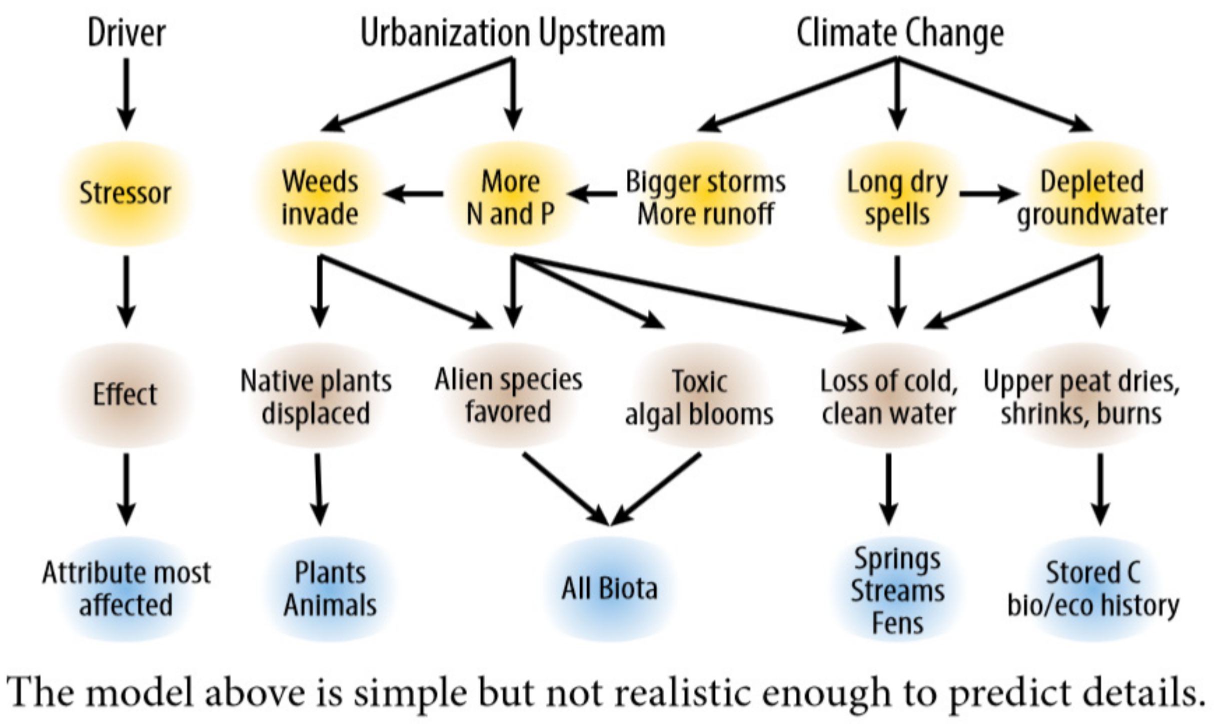


Figure 5.11: A simplified model of how urbanization and climate change modify ecological interactions in Waubesa Wetlands (Zedler, 2018).

River watershed (Mbonimpa et al., 2014) found that urban land use, in addition to agricultural land use, is associated with increased TSS and TP loadings in streams. Our STEPL results therefore paint a limited picture, and emphasis should be given to conclusions from literature (see Chapter 4).

Though a reduction in nutrient loads, as estimated using STEPL, may have some benefit to Waubesa Wetlands, research demonstrates that urbanization impacts wetlands in myriad ways. Wright et al. (2006) reviewed 100 urbanization and wetland impact studies and summarized that "cumulative impacts result in changes to habitat structure and ecosystem properties, which can have a domino effect on many plant and animal species in the wetland." Increases in a watershed's impervious surfaces reduced wetland plant diversity and favored invasive species, impaired the wetland invertebrate community, reduced richness and abundance of reptiles and amphibians, reduced bird species richness if development was within 1,640 feet of a wetland, and altered mammalian behavior (Wright et al., 2006).

In addition to urbanization, climate change poses a threat to the ecological integrity of wetlands. Dr. Joy Zedler addresses how land use change and climate change affect wetland health in chapter six of Waubesa Wetlands: New Look at an Old Gem. Figure 5.11 shows her simplified model. The foundation of the problem lies in the altered hydrologic regime, a result of both climate change and urbanization. The altered hydrologic state negatively effects surface water quantity and quality, and groundwater quality and quantity, altering the wetland's peat, streams, and fens, increasing toxic algal blooms, and favoring alien species, ultimately causing a loss of biodiversity through the displacement of native plants and animals (Zedler, 2018).

5.6 – Conclusions

We used models to help understand baseline water quality and quantity conditions, and how those conditions will vary as climate and land use change. Our HydroCAD model was helpful in determining a magnitude of change in the surface water runoff regime entering Waubesa Wetlands. However, it is not integrated with groundwater, making a complete understanding of the system impossible from this model. Our STEPL model predicted a reduction in nutrient inputs to the wetlands with urbanization, but the model is not robust and does not incorporate all of the impacts associated with urbanization. The HydroCAD model can be improved by updating the development areas with their actual locations, land use, and revised time of concentration. Furthermore, a SWAT (Soil & Water Assessment Tool) model could be developed to provide a more complete and integrated understanding of the Waubesa Wetlands hydrologic system (water quantity and quality).

COMMUNITY ENGAGEMENT

6.1 – Introduction

Waubesa Wetlands have captured the attention of scientists and outdoor enthusiasts for many years and are well recognized for their unique ecological, recreational, and cultural significance. Named a Wetland Gem® by the Wisconsin Wetlands Association, this natural treasure provides people with valuable services as well as recreational and educational opportunities. To promote long-term stewardship of Waubesa Wetlands and the many services they provide, we involved people who most directly impact the future functionality of the wetlands. We increased community awareness of Waubesa Wetlands with the development of a website and through outreach events in which we partnered with several local organizations. Through these outreach events, we augmented Friends of Waubesa Wetlands, a citizen-led group working to sustain and celebrate the terrestrial and aquatic natural resources of Waubesa Wetlands and the surrounding watershed.

Our community engagement activities had three main goals, summarized in Figure 6.1. Our first goal was to synthesize existing information about the Waubesa Wetlands. Second, we sought to increase awareness and engagement with Waubesa Wetlands. Finally, we wanted to support Friends of Waubesa Wetlands, a previously established citizen-led group working to maintain the wetlands.

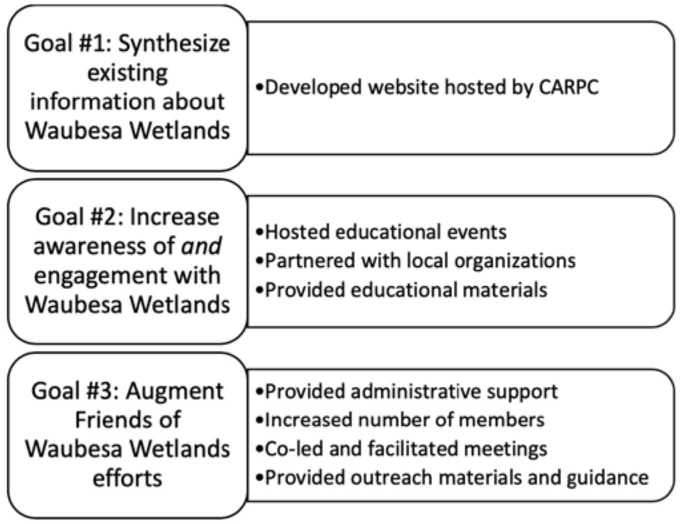


Figure 6.1: Goals of community engagement and the actions we took to meet those goals.

6.2 – Synthesize Existing Information on a Website (Goal #1)

Waubesa Wetlands have been long-studied and are well understood to be an important ecological landscape. Scientists have been studying Waubesa Wetlands for over a century, and studies of Waubesa Wetlands have generated dozens of published research papers and graduate student degrees (Zedler, 2018). UW-Madison Professor Emerita Joy Zedler synthesized much of this information in her 2018 book, Waubesa Wetlands: A New Look at an Old Gem. The book was prompted after Zedler filled out a 50-page form to nominate Waubesa Wetlands for international recognition under the Ramsar Convention. Feeling as though this information needed to be shared with a larger community and not just reviewers at the U.S. Fish and Wildlife Service and the Ramsar Secretariat, Zedler published her book via print and online through the Town of Dunn.

PURPOSE

Zedler's book is an important step in synthesizing the rich history of Waubesa Wetlands, but this information needs to be more accessible to the public through an online platform. Readers are increasingly turning to online sources as preferred media (Liu, 2006), and the accessibility of information online directly correlates to public participation; the more online coverage an issue receives, the more likely people will participate in the policy making process (Gil De Zúñiga, 2009).

Additionally, our project is meant to aid scientists, technical staff, and policy makers in future research and decision making. Thus, we want to ensure that our data is easily accessible and available to a technical audience as well as a general audience.

To address these needs, we synthesized information about Waubesa Wetlands onto a comprehensive online platform and communicated this information to both general and technical audiences.

METHODS

In collaboration with the Capital Area Regional Planning Commission (CARPC), we constructed a website to communicate the importance of the Waubesa Wetlands to a general audience and to house data and results from the ecosystem services assessment, water quality monitoring, and modeling portions of our Water Resources Management (WRM) project. The website, hosted by CARPC and developed using WordPress software, is part of a larger project that will summarize water quality management within all watersheds of Dane County. The website contains links to webpages regarding Waubesa Wetlands and acts as a one-stop shop for information about Waubesa Wetlands.

RESULTS

Although continually evolving, the main page of our website can be found at www.carpcwaterqualityplan.org/waubesa-wetlands/. It contains general information about Waubesa Wetlands and links through which users can retrieve information about how to access Waubesa Wetlands and which organizations are involved in Waubesa Wetlands conservation.

The website also includes several webpages specific to our WRM project. The page at www.carpcwaterqualityplan.org/waubesa-wetlands/waubesawetlands-about-us/ outlines our project and the WRM program. Results from our water quality monitoring, modeling, and ecosystem services assessment will be published here. Our data will be made freely available.

Additionally, the site includes a page about Friends of Waubesa Wetlands and how people can volunteer for this citizen-led organization. Developing a webpage for Friends of Waubesa Wetlands also met Goal #3 of community engagement (augmenting Friends of Waubesa Wetlands efforts); it has been crucial in publicizing the organization through external websites (e.g., River Alliance of Wisconsin) and gaining new membership.

6.3 – Increase Awareness of Waubesa Wetlands (Goal #2)

The common practice in the United States for more than 120 years was to drain wetlands to promote farming and development (Mitsch et al., 2007). Based on aerial photography from 1978, the Wisconsin Wetland Inventory reveals that about 53% of the state's original ten million acres of wetlands has been lost since European settlement (WDNR, 2017). This substantial loss of wetlands is not an uncommon story, and more than half of America's wetlands have been lost since 1780, with wetland losses continuing today (USFWS, 2019). In the 1970s, scientists, ecologists, and conservationists began to articulate the values of wetlands (Fretwell et al., 1996). At a wetland conference in 1973, wetlands were acknowledged to be an important part of the hydrologic cycle (Helfgott et al., 1973). People began to recognize wetland values and attempt to find ways to preserve them, including changing federal laws (Fretwell et al., 1996).

In 1972, Section 404 of the Clean Water Act established a program to regulate the discharge of dredged and fill material into waters, including wetlands. Section 404 states that proposed activities, such as dredging or filling a wetland, are regulated through a permit review process, and individual permits are reviewed by the U.S. Army Corps of Engineers. It is still the primary regulatory program for wetlands (USEPA, n.d.)

However, Section 404 and the no-net-loss wetlands policy endorsed by the first Bush administration are less concerned with wetland protection and more concerned with wetland mitigation. Efforts to compensate fully for damages to wetlands through individually permitted projects often result in a net loss of wetland area (Turner et al., 2001). Furthermore, such policies assume that wetlands fall under federal domain, but this idea has been challenged in recent years by the state of Wisconsin, and Wisconsin has proposed bills that would roll back government regulation of wetlands. Waubesa Wetlands—although well-known as a high-quality wetland system—are subject to the same national-level policies that offer little long-term environmental protection.

PURPOSE

According to Fretwell et al. (1996), "People need to understand what is lost when a wetland is changed into an agricultural field, a parking lot, a dump, or a housing development." In order to protect wetlands, the public first must recognize the value of wetlands. "Understanding the functions of wetlands will make it easier to evaluate wetlands when other uses [of land] are considered" (Fretwell et al., 1996).

Wetlands are important for the services they provide; one of them is flood control. For example, the losses inflicted upon New Orleans by Hurricane Katrina in 2005 added urgency to finding ways to restore wetlands as a natural defense system, and artificial wetlands are commonly constructed as a place to store water (Tibbetts, 2006).

Not all wetlands perform all functions, nor do they perform all functions equally well (Fretwell et al., 1996). Waubesa Wetlands are truly exceptional, in part because they are fed by cold, clean groundwater, which emerges year-round as springs and seepages within a large artesian basin.

> " People need to understand what is lost when a wetland is changed into an agricultural field, a parking lot, a dump, or a housing development. "

Clean groundwater supports a high diversity of plants that in turn support diverse wetland animals. Rare plants and animals are just one measure of a high-quality wetland. For more detail on services specific to Waubesa Wetlands, see Chapter 3.

Despite these values and services, the future of Waubesa Wetlands is uncertain. Most threats to Waubesa Wetlands arise upstream, where land use change is underway and surface water runoff can transport pollutants as it makes its way downslope to Swan Creek and Murphy's Creek. Climate change is also threatening the long-term functionality of Waubesa Wetlands (see Chapter 5).

Community awareness and activism can assist in mitigating or counteracting these threats, and increasing awareness of environmental issues leads to a community more interested in conservation efforts (Stapp, 1969). Yet, the relationship between awareness of environmental issues and conservation action is not a linear one. As stated by Stepath (2000), "awareness is just the initial phase of the process and not an end result." When people are physically involved in the learning process and visit the environmental site, they will be more likely to engage in conservation action (Stepath, 2000; Nyaupane, 2009).

> " Awareness is just the initial phase of the process and not an end result. "

Thus, our Goal #2 has two-parts: to increase awareness of Waubesa Wetlands and to increase community engagement with Waubesa Wetlands.

METHODS

In order to raise awareness of Waubesa Wetlands' high-quality status and help protect them, we communicated the functions of Waubesa Wetlands at several community events. We partnered with eleven different organizations throughout Dane County and engaged with a variety of audiences (Table 6.1).

Interactive education tools not only stimulated participant interest, but such tools also kept participants engaged at our table, with participants spending approximately five-to-ten minutes learning about environmental conservation.

Table 6.1: Summary of community engagement events and list of organizing partners. (For more details on each event, see Appendix L)

	Name of Event	Date of Event	Location of Event	Partner(s)
Meetings	Town of Dunn Annual Hall Meeting	4/17/18	Dunn Town Hall	Town of Dunn
	Resources Conservation Commission Meeting	8/20/18	Fitchburg City Hall	City of Fitchburg
Conferences & Networking Events	2018 Earth Day Conference*	4/26/18	Monona Terrace Community and Convention Center, Madison	Nelson Institute for Environmental Studies
	Rendezvous on the Terrace	9/7/18	Pyle Center, UW-Madison	Nelson Institute for Environmental Studies
	Water@UW Poster Session*	10/16/18	Memorial Union, UW-Madison	UW-Madison
	2018 RRC Confluence	11/10/18	University of Wisconsin - Whitewater	Rock River Coalition (RRC)
	WWA Wetland Science Conference*	2/19/19 - 2/21/19	Madison Marriott West, Madison	Wisconsin Wetlands Association (WWA)
	AWRA Wisconsin Annual Meeting*	2/28/19 - 3/1/19	Delavan, Wisconsin	American Water Resources Association (AWRA)
	2019 Earth Day Conference*	4/22/19	Monona Terrace Community and Convention Center, Madison	Nelson Institute for Environmental Studies
Activities & Festivals	"Your Home in the Waubesa Watershed": A Family Day Event	7/21/18	Goodland County Park Shelter #1	Friends of Waubesa Wetlands, RRC, WDNR, Natural Resources Foundation of WI
	Waubesa Wetlands Paddle Trip	9/7/18	Goodland County Park Boat Launch	Rutabaga Paddlesports
	McFarland Family Festival	9/14/18-9/16/18	McFarland Ice Arena	Village of McFarland
	Harvest Moon Festival	9/28/18	Lussier Family Heritage Center	Friends of Capital Springs
Public Lectures	Yahara Lakes 101: Waubesa Wetlands with Cal DeWitt	8/8/18	The Edgewater, Madison	Clean Lakes Alliance
	Water in Two Parts Public Lecture	3/12/19	City of Fitchburg Library	City of Fitchburg

*Invited to give oral and/or poster presentation

One of our most successful education tools was the EnviroScape® Watershed Model available for rent from the Dane County Natural Resource Education Center. The EnviroScape® models, developed by JT&A, Inc., demonstrate water pollution concepts and their prevention in a hands-on and interactive approach (Figure 6.2). While the EnviroScape® Watershed Model is most appropriate for children aged 4-12 years, we found that it generated interest among adults as well. Furthermore, it provided us with an opportunity to separately communicate with the children's guardians while the children were entertained by the model.

In addition to communicating the importance of Waubesa Wetlands to the community, we also provided opportunities for participants to directly interact with the wetlands and learn more about wetland protection.

On July 21, 2018, we hosted a Family Day Event at Goodland County Park in which community members were invited to test water quality in Lake Waubesa, observe macroinvertebrates under a microscope, and interact with the macroinvertebrates and aquatic plants typically found in Waubesa Wetlands. Such hands-on activities (e.g., water quality monitoring), enhance participant interest, motivation, and ability to think critically (Poudel et al., 2010). Furthermore, we provided informational stations in partnership with representatives of the WDNR, the Natural Resources Foundation of Wisconsin (NRF), and the Rock River Coalition (RRC).

On September 7, 2018, we led a two-hour paddling trip (canoes and kayaks) through Waubesa Wetlands that included 16 participants ranging in age from approximately eight to 60 years old. We partnered with Rutabaga Paddlesports of Monona, which provided exceptional logistical assistance and supplied canoes and kayaks to the 16 paying participants (Figure 6.3). Additionally, NRF advertised the event as a "Pop-Up NRF Field Trip," reaching a wide audience.

Figure 6.2: Rachel Johnson (sitting) and Lianna Johnson (standing) demonstrate water pollution concepts using the EnviroScape® Watershed Model. The EnviroScape® uses colored sprinkles to represent sources of pollution, and a spray water bottle simulates rainfall. (Photo by Némesis Ortiz-Declet).

Figure 6.3: Paddle trip participants enjoy a day on Lake Waubesa and Waubesa Wetlands. (Photo by Kyle Pepp).

At events in which we were not directly interacting with the wetlands, we encouraged citizens to visit the wetlands themselves. We provided paper copies of the Waubesa Wetlands Access Map developed by Dr. Joy Zedler (Appendix K). We also made this map available on our website.

RESULTS

At each event listed in Table 6.1, we estimated the number of people we communicated with about Waubesa Wetlands. In total, we reached 571 people (Appendix L).

Figure 6.4 shows the locations of events and the corresponding estimate of people reached in that area. The size of the bubble corresponds to the number of people reached. Although this map only reflects estimates, it highlights gap areas needed for future community engagement.

As previously mentioned, our goal was to not only communicate the importance of Waubesa Wetlands, but to also increase the number of citizens directly engaging with the wetlands. The Waubesa Wetlands Access Map (Appendix K) was one of the most popular handouts requested by citizens. At several events, we did not have enough hard copies to meet demand; citizens either took a picture of the map or were informed that they could download it through our website.

Although it is difficult to estimate how many people visited the wetlands as a result of our communication efforts, we can assume that at least a portion of people interacted with the wetlands on their own and gained an appreciation for Waubesa Wetlands as a result.

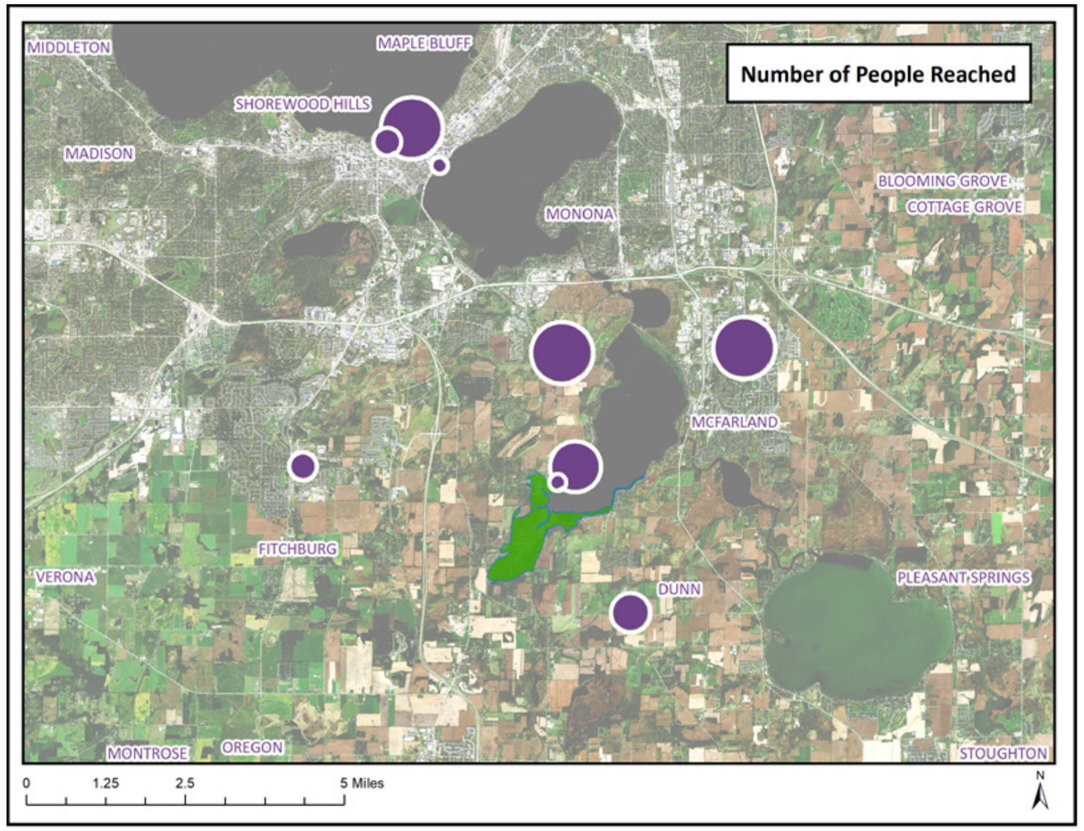


Figure 6.4: Locations of events with estimated number of people reached. The biggest bubbles represent areas in which 75 or more people were reached.

These people may have become inspired to join Friends of Waubesa Wetlands, a group of citizens working to increase community awareness of and engagement with Waubesa Wetlands.

6.4 – Augment Friends of Waubesa Wetlands Efforts (Goal #3)

Friends groups are citizen-led organizations established to benefit a specific park, area, natural resource, or program. More than 70 friends groups have formed in Wisconsin, and members volunteer their time, services, and support in order to enhance Wisconsin's state parks and forests (WDNR, 2012). Friends Groups may choose to register as an official non-profit organization through the state, but registration or non-profit status is not necessary for a group to function.

As highlighted in Zedler (2018), Waubesa Wetlands has many "friends," people and organizations that support their protection and stewardship. The watershed contains dozens of conservation easements, mostly in the Town of Dunn, that protect sensitive lands and agricultural fields from land use change. Also, the local Groundswell Conservancy is purchasing critical upstream land and planning ways to clean the runoff that will come from lands under construction before the water reaches Waubesa Wetlands. Volunteers with the Rock River Coalition (RRC) have been monitoring water quality within the Waubesa Wetlands watershed since 2002.

One very important friend of Waubesa Wetlands is Alex Wenthe. In 2017, Alex Wenthe applied ecological management tools at Waubesa Wetlands for partial completion of his master's degree in Restoration Ecology. Now vice president and ecologist with Quercus Land Stewardship Services in Black Earth, Wisconsin, Wenthe developed a partnership with the WDNR State Natural Areas (SNA) Volunteer Program to lead ecological workdays in Waubesa Wetlands. Under the SNA Volunteer Program, volunteers encourage native plant and animal communities to thrive by cutting brush, pulling invasive species, collecting seeds, and performing other ecological management activities. Workdays are organized by the volunteer program coordinator and publicized on the program website (WDNR, 2019). Participants may also sign up to receive email updates of workdays in their region.

Additionally, in 2017 Wenthe partnered with NRF field trip program and led a four-mile trek through the wetlands. The field trip, advertised by NRF, helped promote conservation efforts to the public, with 22 paying people in attendance (Wenthe, 2017).

Such partnerships are critical for the long-term stewardship of Waubesa Wetlands. In his 2017 report titled "Restoring a Wetland Gem: Applications of Current Tools and Technologies at Waubesa Wetlands State Natural Area," Wenthe expressed the need to collaborate with citizens to continue to protect Waubesa Wetlands. As stated in the conclusion of his report, "Restoration ecology requires expertise from many different fields, and often includes numerous stakeholders, interests, and opinions."

As the number of people in support of Waubesa Wetlands grew, so did the need to organize. In response to the growing interest in Waubesa Wetlands, Wenthe founded the Friends of Waubesa Wetlands later that same year. Wenthe maintained partnerships with WDNR's SNA Volunteer Program and NRF, and he continued to regularly lead ecological workdays. The first Friends of Waubesa Wetlands meeting was held in early 2018 in a volunteer's home with the aim to connect workday volunteers and create community. Additionally, he created the Friends of Waubesa Wetlands Facebook page at www.facebook.com/friendsofwaubesa to promote volunteer events.

The Friends of Waubesa Wetlands is an essential group needed for the long-term stewardship of Waubesa Wetlands, and recognizing its importance, we aimed to support and enhance the Friends of Waubesa Wetlands group during our WRM practicum.

PURPOSE

According to The River Alliance of Wisconsin, which provides watershed groups with tools and training, "strong local groups are essential to water protection in Wisconsin" (River Alliance, 2019). The River Alliance of Wisconsin's local groups program identifies several reasons organized groups are essential to natural resource protection:

- **Organized groups can make a bigger difference than individuals acting alone.**
- **They participate in watershed management decisions and provide a voice for local waters.**
- **Groups apply the lessons of their community's past and provide a vision for the future.**
- **Groups bring together different interests for a common purpose (River Alliance, 2019).**

To highlight the River Alliance's final point, we found the need to bring people together for a common purpose particularly prevalent within the Waubesa Wetlands watershed. After interacting with the community at our events (Table 6.1), it was evident that people were interested in protecting Waubesa Wetlands beyond ecological management. . Several people expressed interest in engaging in recreation in and around the wetlands, volunteering as citizen scientists, and continuing outreach efforts aimed at educating the public. Many agreed that watershed-scale management is necessary to protect against upstream threats to Waubesa Wetlands.

> “Several people expressed interest in engaging in recreation in and around the wetlands, volunteering as citizen scientists, and continuing outreach efforts aimed at educating the public.”

While several organizations are working within the area to protect water quality and encourage ecological services (Zedler, 2018), more supporters of Waubesa Wetlands are needed to sustain the wetland's qualities and value. The waters flowing under Lalor Road into Waubesa Wetlands received "grades of F" based on the Rock River Coalition's stream monitoring data (RRC, 2015), and Waubesa Wetlands are continually threatened by land use change, invasive species, and climate change.

Furthermore, actions to protect wetlands against threats are meaningful and important; these actions provide people with a sense of purpose and a community of like-minded individuals. Not only does the Waubesa Wetlands need friends, but friends need the Waubesa Wetlands (J. Zedler, personal communication, Jan. 24, 2019).

As a new and growing group, Friends of Waubesa Wetlands sought administrative and organizational assistance. Organization within a group is critical to its long-term success. In choosing how to structure an organization, decisions on the issues of incorporation, bylaws, and non-profit status will affect how the organization conducts its business, raises funds, and handles financial reporting (River Alliance, 2019). In short, these decisions affect the long-term functionality of the organization.

The growing and diversifying interest in Waubesa Wetlands from the community led to our Goal #3 of community engagement: to augment the efforts of Friends of Waubesa Wetlands.

METHODS

We augmented Friends of Waubesa Wetlands efforts in several ways. We provided administrative support, increased membership, co-led and facilitated regular meetings, and provided outreach materials and guidance for future efforts.

ADMINISTRATIVE SUPPORT

We created a webpage for Friends of Waubesa Wetlands hosted by CARPC. The webpage at www.carpcwaterqualityplan.org/waubesa-wetlands/friends-of-waubesa-wetlands/ increases community knowledge of the Friends group and provides instruction on how citizens can be added to the Friends of Waubesa Wetlands email list. The Friends of Waubesa Wetlands email list is housed on a Friends of Waubesa Wetlands Google Drive and is accessible only by board members.

We further augmented efforts by organizing the Google Drive and creating a Friends of Waubesa Wetlands email account. The email account, monitored by the Friends of Waubesa Wetlands secretary, is friendsofwaubesawetlands@gmail.com. One of the WRM graduate students, Stephanie Herbst, acted as interim secretary during our project.

Additionally, we advertised events pertinent to Waubesa Wetlands via the Friends of Waubesa Wetlands Facebook page at www.facebook.com/friendsofwaubesa. We posted regularly to the page and publicized upcoming events using the Facebook event pages. We created event pages for each of the Friends of Waubesa Wetlands meetings, the SNA workdays, and partnering events, such as our Waubesa Wetlands paddle trip with Rutabaga Paddlesports.

INCREASED MEMBERSHIP

To increase membership, we promoted the Friends of Waubesa Wetlands at each of our community engagement events (Table 6.1) and encouraged citizens to sign up to become a Friend. We followed up with these individuals via email and added them to the email list housed on the Friends of Waubesa Wetlands Google Drive.

CO-LED AND FACILITATED MEETINGS

We facilitated four Friends of Waubesa Wetlands meetings from October 2018 to February 2019. We met roughly once a month during this period at the Waubesa Beach Community Center on 3rd Street in Madison (with the exception of our November 2018 meeting held at Christy's Landing on Waubesa Avenue).

Prior to each meeting, we reserved the space by corresponding with representatives from the Waubesa Beach Neighborhood Association. They provided us with access to the venue, which includes a full kitchen, bathrooms, tables, and chairs. Additionally, we created meeting agendas and sent them to all Friends on the email list.

At the meetings, we took meeting minutes and facilitated discussion. Following each meeting, these minutes were sent to all Friends on the email list in addition to any other items that were discussed at the meeting.

Under our facilitation, we discussed items such as the Friends of Waubesa Wetlands mission statement, its non-profit status, and its by-laws, which are critical components of any well-organized group.

PROVIDED OUTREACH MATERIAL AND GUIDANCE

Finally, we provided the Friends of Waubesa Wetlands group with outreach material, including an educational brochure (Appendix M) and a coloring book (Appendix N). These can be used for future educational events.

At our November 2018 meeting, we provided the group with options of a Friends of Waubesa Wetlands logo. The group voted on options, and, with input, decided on a Friends of Waubesa Wetlands logo featuring a sandhill crane, one of the iconic bird species present in Waubesa Wetlands (Figure 6.5).

Figure 6.5: Friends of Waubesa Wetlands logo created by Lianna Johnson, 2019.

RESULTS

ADMINISTRATIVE SUPPORT

As of April 2019, the Friends of Waubesa Wetlands email list contains contact details for 93 members. The friends group continues to be housed on the Friends of Waubesa Wetlands Google Drive and is accessed by Friends of Waubesa Wetlands board members.

At our events, we promoted the Friends of Waubesa Wetlands Facebook page, which has seen a substantial increase in followers and likes. Several people heard about the Friends of Waubesa Wetlands meetings via the Facebook page, and social media was an important tool to publicize events. For example, our Waubesa Wetlands paddle trip event Facebook page had 94 people interested and 16 shares.

INCREASED MEMBERSHIP

The Friends of Waubesa Wetlands began with an ecological management focus, with about five regularly attending friends volunteering as part of the WDNR SNA Volunteer Program workdays. Not only did membership grow to 93 Friends of Waubesa Wetlands during our involvement (Appendix L), but the interests of participants expanded beyond ecological management. The group's interests include water quality monitoring, education, recreation, and advocacy. Members represent a wide number of interests and come from throughout Dane County.

CO-LED AND FACILITATED MEETINGS

Prior to our efforts, the Friends of Waubesa Wetlands met sporadically and at members' houses. The Friends of Waubesa Wetlands now meet regularly to discuss group goals and objectives. Roughly 10 members are in attendance every meeting, and they represent a diverse array of perspectives and interests. It is clear from these meetings that members of the community have a strong interest in the long-term protection of Waubesa Wetlands and are willing to volunteer their time to promote stewardship of this wetland gem.

During our involvement, Friends of Waubesa Wetlands developed a mission statement and drafted bylaws and is moving toward non-profit status.

The Friends of Waubesa Wetlands mission grew to include recreation, education, and ecological management components. As of April 2019, its mission statement is "Sustain and celebrate the terrestrial and aquatic natural resources of Waubesa Wetlands and the surrounding watershed through environmental education, recreation, and ecological management."

In February 2019, the group nominated board members and drafted bylaws. The Friends of Waubesa Wetlands is a stand-alone organization moving toward non-profit status with the legal and administrative assistance of Steve Schooler, J.D., a founding board member.

> “Sustain and celebrate the terrestrial and aquatic natural resources of Waubesa Wetlands and the surrounding watershed through environmental education, recreation, and ecological management.”

Becoming a registered non-profit organization will allow the Friends of Waubesa Wetlands to accept donations, which will increase funding transparency, leverage the group, and improve its decision-making power.

PROVIDED OUTREACH MATERIAL AND GUIDANCE

In 2018, the Yahara Chain of Lakes – Lake Levels Task Force was established through Dane County Board Resolution 227 to discuss alternatives to manage lake levels in the Yahara Lakes. The task force held three meetings in February 2019 to discuss adaptation and mitigation alternatives for the Yahara Lakes as outlined in the 2018 Yahara Chain of Lakes Flooding Technical Work Group Report (Yahara Task Force, 2019a).

Our efforts to augment the Friends of Waubesa Wetlands came to fruition when the Friends of Waubesa Wetlands exercised their role as advocates for wetland protection. On March 5, 2019, the Yahara Chain of Lakes – Lake Levels Task Force held a public hearing, and Friends of Waubesa Wetlands were in attendance and well represented. Their expressed interest in wetland protection was noted by the task force and later reflected in the Task Force's final recommendations. Released on March 18, 2019, the Task Force "rejects [pumping] routes that would negatively impact the Waubesa Wetlands, fish habitats, and environmentally and economically significant conservation easements" (Yahara Task Force, 2019b).

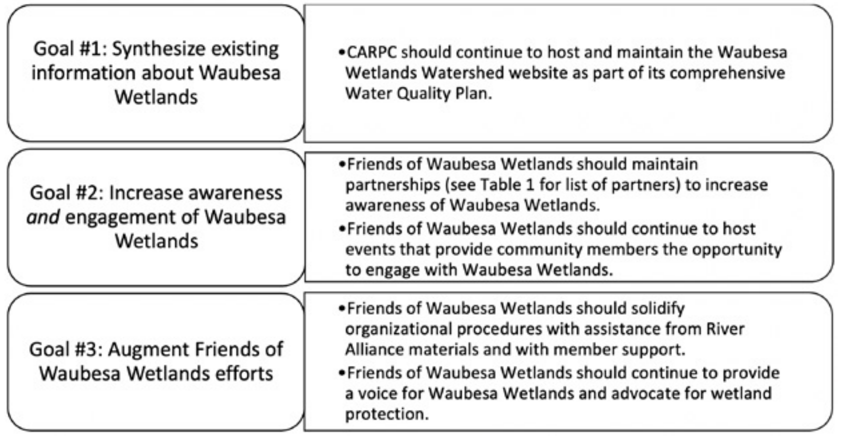
As demonstrated, active and engaged Friends groups provide an advocacy voice at public hearings, and their input is considered in decision-making. A strong Friends group can act as an advocate to help counteract or mitigate threats to a natural resource.

6.5 – Conclusion

To promote the long-term stewardship of Waubesa Wetlands and the many services it provides, we identified three major goals for the community engagement component of our project:

- **Goal #1: Synthesize existing information about Waubesa Wetlands.**
- **Goal #2: Increase awareness of and engagement with Waubesa Wetlands.**
- **Goal #3: Augment Friends of Waubesa Wetlands efforts.**

We recommend that these goals continually be met through the actions summarized in Figure 6.6. Continued coordination by CARPC and increased efforts by the Friends of Waubesa Wetlands are suggested.



Goal #1: Synthesize existing information about Waubesa Wetlands	•CARPC should continue to host and maintain the Waubesa Wetlands Watershed website as part of its comprehensive Water Quality Plan.
Goal #2: Increase awareness *and* engagement of Waubesa Wetlands	•Friends of Waubesa Wetlands should maintain partnerships (see Table 1 for list of partners) to increase awareness of Waubesa Wetlands. •Friends of Waubesa Wetlands should continue to host events that provide community members the opportunity to engage with Waubesa Wetlands.
Goal #3: Augment Friends of Waubesa Wetlands efforts	•Friends of Waubesa Wetlands should solidify organizational procedures with assistance from River Alliance materials and with member support. •Friends of Waubesa Wetlands should continue to provide a voice for Waubesa Wetlands and advocate for wetland protection.

Figure 6.6: Goals of community engagement and the actions that must be continually met to achieve them.

By continuing efforts toward these goals, the unique ecological, recreational, and cultural services of Waubesa Wetlands can be enjoyed by communities to come.

MANAGEMENT RECOMMENDATIONS

In this section, we outline and elaborate upon management recommendations for the Capital Area Regional Planning Commission, the Wisconsin Department of Natural Resources, the Town of Dunn, the City of Fitchburg, watershed residents, and interested individuals and organizations. These recommendations pull upon results from all aspects of our project and seek to integrate social, ecological, and technical considerations. They are part watershed management plan and part directions for future work and study. While some of the recommendations are relatively simple and small in scale, others are more complex and apply to a broader area.

We offer the following recommendations as a result of our study:

RECOMMENDATION 1: RESTORE AND MAINTAIN WETLANDS ALONG SWAN CREEK TO ENHANCE ECOSYSTEM SERVICES PROVIDED TO WAUBESA WETLANDS

Wetlands on private property along Swan Creek represent an opportunity for restoration and maintenance that could benefit the watershed in multiple ways. As discussed in our water quality results (see Chapter 4), eroding streambanks in riparian wetlands along Swan Creek may be contributing to elevated concentrations of TP and TSS. Re-grading and replanting slumping and undercut streambanks would allow elevated water levels to spread out and soak in. This would improve water quality by trapping nutrients and sediments while increasing flood and stormwater storage in upland areas. In addition, adding new vegetation would help stabilize stream shorelines and could increase habitat for wildlife, fish, and aquatic species.

One of the key findings from our modeling effort indicated that the cumulative watershed-scale impact of land use change from individual development sites on surface water quantity is not linear. Restoring wetlands along Swan Creek will help moderate this effect, compensating for these unregulated development impacts. We recommend that the City of Fitchburg and the Town of Dunn coordinate wetland restoration efforts within their respective boundaries with developers, private landowners, CARPC, and the Friends of Waubesa Wetlands.

RECOMMENDATION 2: ASSESS ECOSYSTEM SERVICES AND PRESERVE WETLANDS ALONG MURPHY'S CREEK

Ecosystem service assessments are helpful tools for evaluating the capacity of wetlands to provide specific services. With limited time and resources, we focused our WRAM Level 2 analysis on wetlands along Swan Creek. Given potential future development in the Murphy's Creek watershed, a similar analysis in upstream areas could yield valuable information about where to prioritize land preservation through conservation easements. A survey would also collect baseline information about wetland conditions prior to any future development. Furthermore, this survey data could help identify restoration areas with the purpose of enhancing specific ecosystem services.

- If a Level 2 analysis cannot be conducted, utilize Wetlands by Design or Wetlands and Watersheds Explorer as a Level 1 assessment tool for Murphy's Creek wetlands. In Level 1, landscape-scale assessments are performed using broad-scale datasets in a geographic information system (GIS). This is useful for determining areas for wetland restoration and protection at a watershed scale without conducting fieldwork.
- Prioritize wetland restoration efforts in wetlands where services are "bundled," or occur together, in order to maximize such services and available resources. Some projects that may be employed for wetland restoration include invasive species removal, prescribed burns, and streambank stabilization.

The Friends of Waubesa Wetlands can aid in such efforts in the Waubesa Wetlands State Natural Area; we recommend that these and other restoration volunteer efforts expand to include wetlands throughout the Murphy's Creek watershed.

RECOMMENDATION 3: CONTINUE SURFACE WATER MONITORING AND BUILD A COMPREHENSIVE WATERSHED DATASET

Land use is changing and will continue to change in the Waubesa Wetlands watershed. Sustained monitoring provides metrics to measure the impact of land use change on surface water quality and quantity. Our monitoring data supplement previous monitoring conducted by the Rock River Coalition (RRC) since 2015. Taken together, these data characterize stream conditions during the initial stages of urban development in certain areas of the watershed. Comprehensive surface water monitoring should continue during and after development. Monitoring plans should take into account the information presented in this report as well as planned watershed changes. To build a robust long-term watershed dataset, we specifically recommend investing resources to support RRC in these actions:

- Advance RRC's efforts to collect monthly grab samples under baseflow conditions at watershed outlet sites of Swan and Murphy's creeks on Lalor Road. These data provide an important, comparable baseline to track seasonal and annual changes. Already, we see indications of annual changes in some nutrients, as well as nutrient concentrations that consistently exceed TMDL standards for TSS and TP in both creeks. We suggest starting monitoring in February to capture water quality conditions before spring snowmelt, and monitoring Swan Creek water quality downstream of the Lalor Road culvert. Furthermore, we recommend that when sampling, volunteers measure and record the height from the USGS-installed reference points to the water surface to be able to connect nutrient concentrations with future flow data.
- Coordinate same-day monitoring of paired upstream and downstream sites on Swan Creek. We started this effort to track nutrient changes upstream and downstream of the Terravessa development in the Northeast Neighborhood. Monitoring paired sites on different days does not provide the same data resolution and thus has less value for management efforts. Paired sampling should be considered for Murphy's Creek in the future.
- Expand grab sample collection to include high-flow conditions to capture storm event loads. We observed spikes in nutrient concentrations during and after storms that may represent much of the loading in the watershed for TSS and TP. Without high-flow data, total nutrient loads are grossly underestimated. (See also Recommendation 2).
- Develop a plan to expand monitoring to include emerging contaminants of concern. We observed elevated chloride concentrations and expect levels to increase with urbanization. Wetlands may also be sensitive to thermal pollution, metals, hydrocarbons, and pharmaceuticals, which have not yet been monitored in the watershed.
- Consider adding permanent lake monitoring to track nutrient concentrations in Lake Waubesa and elucidate how they are affected by development. This data may help characterize nutrient dynamics occurring in Waubesa Wetlands as well.
- Ensure that all surface water monitoring efforts for both creeks continue to be aggregated in a central database. Currently, all WRM data and all available RRC data are in the WDNR SWIMS system. We were unable to locate some historical datasets stored outside of this location. An easily accessible, comprehensive database will aid in the creation of future rating curves for both streams and will allow for the identification of long-term trends in water quality.

RECOMMENDATION 4: INSTALL A USGS LONG-TERM MONITORING SITE AT SWAN CREEK

Continuous streamflow data is needed to calculate annual watershed pollutant loading. We began this process by manually collecting stage and flow measurements, creating a rating curve, and then installing an automated sampler on Swan Creek at Lalor Road from June to October 2018. The automated sampler collects stage data and converts it into flow data, resulting in minute-by-minute resolution of stream flow. It can also collect water samples during storm events that can be analyzed for nutrient concentrations. Manually collecting samples during storms is extremely challenging. Our samples collected during storms had different nutrient concentrations than samples collected during base flow. For nutrients like TP and TSS, much of the watershed loading may be from storm events. Thus, it is extremely important to continue to monitor Swan Creek during high flows.

Stream flow and nutrient concentrations can vary year to year because of changes in land use and precipitation. With only one season of data, our rating curve should be considered preliminary. An additional season of manual flow measurements is needed to refine the curve. After that, we recommend installing an automated sampler on Swan Creek at Lalor Road and making it a USGS long-term monitoring site for the watershed. Flow data paired with storm samples and RRC grab samples can be used to calculate watershed loads for pollutants of interest. Any future water quantity/quality models would benefit from being calibrated with high-resolution water quantity data. A monitoring site will enable a robust dataset to be gathered that can be used to evaluate long-term trends connected with watershed land use change.

RECOMMENDATION 5: DESIGN AND BUILD FOR A CHANGING CLIMATE — SPECIFICALLY, INCREASED PRECIPITATION/FLOW AND MORE EXTREME STORM EVENTS

Based on recent trends, climate change will increase the frequency and intensity of precipitation events in Wisconsin, Dane County, and the Waubesa Wetlands watershed. This could be especially detrimental to wetland communities. Because of this, stormwater performance standards for development should be modified to reflect a new reality. Our modeling results indicated that climate change will have a large impact on peak flow rates in the watershed. Coupled with urbanization, the impact is anticipated to be even greater.

Currently, the Wisconsin Department of Natural Resources, Dane County, and the City of Fitchburg require peak flow rates to match for pre- and post-development. To mitigate future sediment and nutrient erosion, we recommend that new development be required to reduce peak flow rates from pre-development conditions, or develop new precipitation frequency estimates for precipitation depth based on a future climate. Utilizing region-specific information from the Wisconsin Initiative on Climate Change Impacts (WICCI) could help future development be built with a greater component of resiliency. This is especially important for wetland ecosystems and their associated services that could deteriorate with increased stormwater runoff and water level fluctuations that change wetland hydroperiods. In addition, we recommend that any new development be built with an emphasis on infiltration by limiting impervious surfaces and maintaining areas of natural vegetation to reduce runoff and support groundwater recharge.

RECOMMENDATION 6: INVESTIGATE CLIMATE CHANGE AND LAND USE EFFECTS ON GROUNDWATER

The hydrogeology of Waubesa Wetlands shapes the wetlands' unique physical environment and plant communities. Our field observations, water quality monitoring, and consultation with a Waubesa Wetlands expert, Professor Emeritus Cal Dewitt, indicate that Waubesa Wetlands are inseparably interconnected with local groundwater. Given our limited scope, we were unable to conduct a focused groundwater study as part of this project. We want to stress, however, that a complete management plan for Waubesa Wetlands requires further examination of groundwater dynamics. Intelligently managing surface water requires fully understanding its relationship with groundwater. Surface water watersheds do not necessarily align with groundwater watersheds. Until those connections are better understood in the Waubesa Wetlands watershed, we strongly recommend that caution be exercised when considering any high-capacity groundwater withdrawal near Waubesa Wetlands or any other wetlands in its watershed.

RECOMMENDATION 7: EDUCATE NEW WATERSHED RESIDENTS ABOUT WATER QUALITY AND WETLANDS

An influx of new residents creates an opportunity to enhance public education about water quality and ways that individuals can support wetland ecosystem health. In and around new developments, we suggest that the City of Fitchburg:

- *Place environmental education signage.* Interpretive information could be located near wetlands and natural features in neighborhoods and address topics such as urban water runoff, low-impact residential landscaping, invasive species control, and wetland ecosystem services. This can help add to sense of place, pride, and stewardship for local natural resources. The city could also consider naming new development street signs after species that live in or near Waubesa Wetlands.

Along roads at boundaries of the Waubesa Wetlands watershed, we advise the City of Fitchburg and Town of Dunn to:

- *Introduce watershed signage.* Visible markers indicating "You are now entering the Waubesa Wetlands watershed" could help increase local awareness of how land is connected to local water bodies and wetlands.

Additionally, we recommend that CARPC:

- *Maintain an updated website for the Waubesa Wetlands watershed.* The website developed through our project serves as a water quality sharing platform and allows watershed residents and interested stakeholders to stay informed. As new water quality data is collected and analyzed, it can be shared in an accessible format. This site, and others such as Wetlands by Design, are resources and tools for residents to increase their knowledge of wetlands in their watershed and the services that these wetlands provide.

RECOMMENDATION 8: SUSTAIN AND EXPAND THE FRIENDS OF WAUBESA WETLANDS

Through our project, we helped increase the membership, capacity, and role of the Friends of Waubesa Wetlands. At outreach and education events, we engaged 416 individuals to increase awareness about Waubesa Wetlands and the Friends group. We coordinated a kickoff meeting and three additional monthly meetings to develop the Friends group's mission statement and structure. Although our cohort will no longer be actively involved with the Friends group, we anticipate that its empowered and motivated members will take the necessary steps to expand and continue to fulfill the goals of the mission statement. We recommend that the Friends of Waubesa Wetlands:

- Continue to coordinate monthly meetings and events. This will help the group finish acquiring non-profit status and thus expand its resources and opportunities. Regular meetings can also increase membership and aid in identifying leaders for education and recreation committees. Augmenting regular wetland restoration and management initiatives with education and recreation could broaden the group's appeal to more people.
- Increase membership diversity. We see opportunities for the Friends group to attract young individuals and members from all areas of the watershed, including both the Town of Dunn and the City of Fitchburg. The Friends group is in a unique position to link upstream and downstream neighbors with stakeholders. We suggest specifically engaging with residents along Swan and Murphy's creeks and with new residents of the Terravessa Neighborhood. Tapping into existing community events has proven effective in reaching wide audiences and potential members.
- Utilize this report to focus future advocacy and ecological management. As the Friends group expands, we hope that this document can guide additional research, protection, and management.

REFERENCES

AMON, J., THOMPSON, C., CARPENTER, Q., & MINER, J. (2002). Temperate zone fens of the glaciated midwestern USA. *Wetlands, 22*(2), 301-317.

AZOUS, A., & HORNER, R. R. (2000). *Wetlands and urbanization: Implications for the future.* Boca Raton, FL: CRC Press.

BAGNOLD, R. (1966). An approach to the sediment transport problem from general physics. Geological Survey Professional Paper 422-I. United States Geological Survey.

BALLINGER, A., & LAKE, P. S. (2006). Energy and nutrient fluxes from rivers and streams into terrestrial food webs. *Marine and Freshwater Research,* 57(1), 15-28.

BEDFORD, B., ZIMMERMAN, L., & ZIMMERMAN, J. (1974). Wetlands of Dane County, Wisconsin. Wisconsin Department of Natural Resources and Dane County Regional Planning Commission, Madison, WI.

BENNETT, E. M., REED-ANDERSEN, T., HOUSER, J. N., GABRIEL, J. R., & CARPENTER, S. R. (1999). A phosphorus budget for the Lake Mendota watershed. *Ecosystems, 2*(1), 69-75.

BENNETT, E. M., PETERSON, G. D., & GORDON, L. J. (2009). Understanding relationships among multiple ecosystem services. *Ecology letters, 12*(12), 1394-1404.

BHADURI, B., MINNER, M., TATALOVICH, S., MEMBER, A., & HARBOR, J. (2001). Long-term hydrologic impact of urbanization: A tale of two models. *Journal of Water Resources Planning and Management, 127*(1).

BHASKAR, A. S., BEESLEY, L., BURNS, M. J., FLETCHER, T. D., HAMEL, P., OLDHAM, C. E., & ROY, A. H. (2016). Will it rise or will it fall? Managing the complex effects of urbanization on base flow. *Freshwater Science, 35*(1), 293-310.

BILOTTA, G. S., & BRAZIER, R. E. (2008). Understanding the influence of suspended solids on water quality and aquatic biota. *Water Research, 42*(12), 2849-2861.

BOERS, A. M., & ZEDLER, J. B. (2008). Stabilized water levels and Typha invasiveness. *Wetlands, 28*(3), 676-685.

BRABEC, E., SCHULTE, S., & RICHARDS, P. L. (2002). Impervious surfaces and water quality: A review of current literature and its implications for watershed planning. *Journal of Planning Literature, 16*(4), 499-514.

CAPITAL AREA REGIONAL PLANNING COMMISSION (CARPC). (2018). Spatial interpolation of nitrate well water concentrations in Dane County for 2010-2014. Retrieved from www.carpc.maps.arcgis.com/apps/webappviewer/index.html?id=9efc83597840415e8a9237c70102279a

CAPITAL AREA REGIONAL PLANNING COMMISSION (CARPC). (2019). *What are the Waubesa Wetlands?* Retrieved from: www.carpcwaterqualityplan.org/waubesa-wetlands/

CAPON, S. J., CHAMBERS, L. E., NALLY, R. M., NAIMAN, R. J., DAVIES, P., MARSHALL, N., PITTOCK, J., REID, M. A., CAPON, T., DOUGLAS, M. M., CATFORD, J. A., BALDWIN, D. S., STEWARDSON, M. J., ROBERTS, J., PARSONS, M. & WILLIAMS, S. E. (2013). Riparian ecosystems in the 21st century: Hotspots for climate change adaptation? *Ecosystems, 16*(3), 359-381.

CENTER FOR WATERSHED PROTECTION. (2003). Impactsof impervious cover on aquatic systems (Watershed Protection Research Monograph Number 1). Ellicott City, Md.: CWP. Available at: www.cwp.org/Resource_Library/Watershed_Management/planning.htm

CHEN, J., THELLER, L., GITAU, M., ENGEL, B., & HARBOR, J. (2016). Urbanization impacts on surface runoff of the contiguous United States. *Journal of Environmental Management,* 470-481.

CITY OF FITCHBURG. (2017). City of Fitchburg comprehensive plan. Fitchburg, WI.

CLARKE, A., MAC NALLY, R., BOND, N., & LAKE, P. S. (2008). Macroinvertebrate diversity in headwater streams: A review. *Freshwater Biology, 53,* 1707-21.

CLARKE, R. (2002). Estimating time trends in Gumbel-distributed data by means of generalized linear models. *Water Resources Research, 38*(7).

CLINTON, B., & VOSE, J. (2006). Variation in stream water quality in an urban headwater stream in the southern Appalachians. *Water, Air, and Soil Pollution, 169*(1-4), 331-353.

CORSI, S. R., CICCO, L. A., LUTZ, M. A., & HIRSCH, R. M. (2015). River chloride trends in snow-affected urban watersheds: Increasing concentrations outpace urban growth rate and are common among all seasons. *Science of The Total Environment, 508,* 488-497.

DANE COUNTY COMMUNITY DEVELOPMENT. (2019). Natural Resources Education Center. Retrieved from: www.fyi.extension.wisc.edu/danecountycommunitydevelopment/natural-resources/water-education-resource-center-werc/

DANZ, M. E., CORSI, S. R., BROOKS, W. R., & BANNERMAN, R. T. (2013). Characterizing response of total suspended solids and total phosphorus loading to weather and watershed characteristics for rainfall and snowmelt events in agricultural watersheds. *Journal of Hydrology, 507,* 249-261.

DEGAETANO, A., & CASTELLANO, C. (2018). Selecting time series length to moderate the impact of nonstationarity in extreme rainfall analyses. *Journal of Applied Meteorology and Climatology, 57,* 2285-2296.

DETENBECK, N., JOHNSTON, C. A., & NIEMI, G. J. (1993). Wetland effects on lakewater quality in the Minneapolis/St. Paul metropolitan area. *Landscape Ecology, 8*(1), 39-61.

DEWITT, C. (1981). Waubesa Wetlands: A case study of wetlands preservation. *Selected Proceedings of the Midwest Conference on Wetland Values and Management.* St. Paul, MN: Minnesota Water Planning Board, 491-501.

DODDS, W. K., SMITH, V. H., & LOHMAN, K. (2006). Nitrogen and phosphorus relationships to benthic algal biomass in temperate stream. *Canadian Journal of Fisheries and Aquatic Sciences, 63*(5), 1190-1191.

DOHERTY, J., MILLER, J., PRELLWITZ, S., THOMPSON, A., LOHEIDE, S., & ZEDLER, J. (2014). Hydrologic regimes revealed bundles and tradeoffs among six wetland services. *Ecosystems, 17*(6), 1026-1039.

DOWNING, J., & MCCAULEY, E. (1992). The nitrogen: phosphorus relationship in lakes. *Limnology and Oceanography, 37*(5), 936-945. www.doi.org/10.4319/lo.1992.37.5.0936

DOYLE, M. W. (2005). Incorporating hydrologic variability into nutrient spiraling. *Journal of Geophysical Research: Biogeosciences, 110*(G1).

DREXLER, J., & BEDFORD, B. (2002). Pathways of nutrient loading and impacts on plant diversity in a New York peatland. *Wetlands, 22,* 263-281.

DUGAN, H. A., SUMMERS, J. C., SKAFF, N. K., KRIVAK-TETLEY, F. E., DOUBEK, J. P., BURKE, S. M., BARTLETT, S. L., ARVOLA, L., JARJANAZI, H., KORPONAI, J., KLEEBERG, A., MONET, G., MONTEITH, D., MOORE, K., ROGORA, M., HANSON, P. C., & WEATHERS, K. C. (2017). Long-term chloride concentrations in North American and European freshwater lakes. *Scientific Data, 4,* 170101.

DUNCAN, J. M., WELTY, C., KEMPER, J. T., GROFFMAN, P. M., & BAND, L. E. (2017). Dynamics of nitrate concentration-discharge patterns in an urban watershed. *Water Resources Research, 53*(8), 7349-7365. www.doi.org/10.1002/2017WR020500

EPSTEIN, E. E. (2017). Natural communities, aquatic features, and selected habitats of Wisconsin. *In The ecological landscapes of Wisconsin: An assessment of ecological resources and a guide to planning sustainable management*. Madison: Wisconsin Department of Natural Resources, PUB-SS-1131H 2017.

FRETWELL, J. D., WILLIAMS, J. S., & REDMAN, P. J. (1996). National water summary on wetland resources. U.S. Geological Survey. Water-Supply Paper 2425.

FRIEDMAN, R., DEWITT, C., & KRATZ, T. (1979). Simulating postglacial wetland formation: A quantitative reconstruction of Waubesa Marsh. IES Report 106, Center for Biotic Systems, Institute for Environmental Studies, University of Wisconsin-Madison.

GALLANT, A. J., KAROLY, D. J., & GLEASON, K. L. (2014). Consistent Trends in a Modified Climate Extremes Index in the United States, Europe, and Australia. *Journal of Climate, 27*(4), 1379-1394. doi:10.1175/jcli-d-12-00783.1

GALLARDO, M. T., MARTIN, B. B., & MARTIN, D. F. (1998). Inhibition of water fern Salvinia minima by cattail (Typha domingensis) extracts and by 2-chlorophenol and salicylaldehyde. *Journal of Chemical Ecology, 24*(9), 1483-1490.

GARN, H. (2002). Effects of lawn fertilizer on nutrient concentration in runoff from lakeshore lawns, Lauderdale Lakes, Wisconsin. U.S. Geological Survey Water-Resources Investigations Report, 2002-4130.

GIL DE ZÚÑIGA, H., PUIG-I-ABRIL, E., & ROJAS, H. (2009). Weblogs, traditional sources online and political participation: An assessment of how the Internet is changing the political environment. *New Media & Society, 11*(4), 553-574.

GREEN, E. K., & GALATOWITSCH, S. M. (2002). Effects of Phalaris arundinacea and nitrate-N addition on the establishment of wetland plant communities. *Journal of Applied Ecology, 39*(1), 134-144.

GRIGGS, G., ÁRVAI J., CAYAN, D., DECONTO, R., FOX, J., FRICKER, H. A. KOPP, R. E., TEBALDI, C., & WHITEMAN, E. A. (2017). Rising Seas in California: An Update on Sea-Level Rise Science. California Ocean Science Trust.

GRIMM, J. W., & LYNCH, J. A. (2005). Improved daily precipitation nitrate and ammonium concentration models for the Chesapeake Bay watershed. *Environmental Pollution, 135*(3 SPEC. ISS.), 445-455.

GROUNDSWELL CONSERVANCY. (2019). Groundswell Conservancy. Retrieved from: www.groundswellwisconsin.org/

HAVLIN, J. L., BEATON, J. D., TISDALE, S. L., & NELSON, W. L. (2005). *Soil fertility and fertilizers: An introduction to nutrient management (7th ed.)*. New Jersey: Pearson.

HEATHWAITE, A., & DILS, R. (2000). Characterising phosphorus loss in surface and subsurface hydrological pathways. *Science of The Total Environment, 251-252*, 523-538.

HELFGOTT, T., LEFOR, M. W., & KENNARD, W. C. (1973). Proceedings: First wetlands conference. Report No. 21. Storrs, Conn.

HERRING, S. C., HOELL, A., HOERLING, M. P., KOSSIN, J. P., SCHRECK III, C. J., & STOTT, P. A. (2016). Explaining extreme events of 2015 from a climate perspective. *Bulletin of the American Meteorological Society, 97*(12), S1–S145.

HODGKINS, G. A., & DUDLEY, R. W. (2011). Historical summer base flow and stormflow trends for New England rivers. *Water Resources Research, 47*(7).

HydroCAD. (n.d.). HydroCAD product information. Retrieved from www.hydrocad.net/info.htm

JACKSON, R. B., & JOBBAGY, E. G. (2005). From icy roads to salty streams. *Proceedings of the National Academy of Sciences, 102*(41), 14487-14488.

KARA, E. L., HEIMERL, C., KILLPACK, T., VAN DE BOGERT, M. C., YOSHIDA, H., & CARPENTER, S. R. (2012). Assessing a decade of phosphorus management in the Lake Mendota, Wisconsin watershed and scenarios for enhanced phosphorus management. *Aquatic sciences, 74*(2), 241-253.

KAUSHAL, S. S., LIKENS, G. E., JAWORSKI, N. A., PACE, M. L., SIDES, A. M., SEEKELL, D., BELT, K. T., SECOR, D. H., & WINGATE, R. L. (2010). Rising stream and river temperatures in the United States. *Frontiers in Ecology and the Environment, 8*(9), 461-466.

KERCHER, S. M., CARPENTER, Q., & ZEDLER, J. B. (2004). Interrelationships of hydrologic disturbances, reed canary grass (Phalaris arundinacea L.), and native plants in Wisconsin wet meadows. *Natural Areas Journal, 24*, 316-325.

KERCHER, S. M., HERR-TUROFF, A., & ZEDLER, J. B. (2007). Understanding invasion as a process: The case of *Phalaris arundinacea* in wet prairies. *Biological Invasions, 9*, 657-665.

KUCHARIK, C., SERBIN, S., VAVRUS, S., HOPKINS, E., & MOTEW, M. (2010). Patterns of climate change across Wisconsin from 1950 to 2006. *Physical Geography, 31*(1), 1-28.

LAKSHMAN, G. (1979). An ecosystem approach to the treatment of waste waters 1. *Journal of Environmental Quality, 8*(3), 353-361.

LATHROP, R. C., NEHLS, S. B., BRYNILDSON, C. L., & PLASS, K. R. (1992). The fishery of the Yahara lakes [Technical Bulletin, 181]. Wisconsin Department of Natural Resources. Madison, WI.

LATHROP, R. (2007). Perspectives on the eutrophication of the Yahara lakes. *Lake and Reservoir Management, 23*, 345-365.

LENHART, C., BROOKS, K., HENELEY, D., & MAGNER, J. (2010). Spatial and temporal variation in suspended sediment, organic matter, and turbidity in a Minnesota prairie river: Implications for TMDLs. *Environmental Monitoring and Assessment, 165*(1-4), 435-447.

LEWIS, W. M., WURTSBAUGH, W. A., & PAERL, H. (2011). Rationale for control of anthropogenic nitrogen and phosphorus to reduce eutrophication of inland waters. *Environmental Science and Technology, 122*(7), 717-730.

LINE, D. E., SHAFFER, M. B., & BLACKWELL, J. D. (2011). Sediment export from a highway construction site in central North Carolina. *Transactions of the ASABE, 54*(1), 105-111.

LIU, Z. (2006). Print vs electronic resources: A study of user perceptions, preferences, and use. *Information Processing and Management, 42*, 583-592.

LOUGHEED, V., MCINTOSH, M. D., PARKER, C. A., & STEVENSON, J. (2008). Wetland degradation leads to homogenization of the biota at local and landscape scales. *Freshwater Biology 53*(12), 2402-2413.

MAMOON, A., RAHMAN, A., & QASEM, H. (2015). Uncertainty estimation in design rainfalls: A modelling framework for Qatar arid region. 21st International Congress on Modelling and Simulation, Gold Coast, Australia.

MAURER, E., KAYSER, G., DOYLE, L., & WOOD, A. (2018). Adjusting flood peak frequency changes to account for climate change impacts in the western United States. *Journal of Water Resources Planning and Management, 144*(3).

MBONIMPA, E., YUAN, Y., NASH, M., & MEHAFFEY, M. (2014). Sediment and total phosphorous contributors in Rock River watershed. *Journal of Environmental Management, 133*(15), 214-221.

MCCALEB, M. M., & MCLAUGHLIN, R. A. (2008). Sediment trapping by five different sediment detention devices on construction sites. *Transactions of the Asabe, 51*(5), 1613-1621.

MCCANN, A. (2018). Fastest-growing cities in America. Retrieved from www.wallethub.com/edu/fastest-growing-cities/7010/

MCCARTNEY, M. P., MASIYANDIMA, M., & HOUGHTON-CARR, H. A. (2005). Working wetlands: Classifying wetland potential for agriculture. Colombo, Sri Lanka: International Water Management Institute (IWMI Research Report 090).

MCDOWELL, R. W., BIGGS, B. J. F., SHARPLEY, A. N., & NGUYEN, L. (2004). Connecting phosphorus loss from agricultural landscapes to surface water quality. *Chemistry and Ecology, 20*(1), 1-40.

MILLENNIUM ECOSYSTEM ASSESSMENT (MEA). (2005). Ecosystems and human well-being: Wetlands and water synthesis. Washington, DC: World Resources Institute.

MILLY, P., & EAGLESON, P. (1988). Effect of storm scale on surface runoff volume. *Water Resources Research, 24*(4), 620-624. www.doi.org/10.1029/WR024i004p00620

MILLY, P., BETANCOURT, J., FALKENMARK, M., HIRSCH, R., KUNDZEWICZ, Z., LETTENMAIER, D., & STOUFFER, R. (2008). Stationarity is dead: whither water management? *Science, 319*(5863), 573-574.

MITSCH, W. J., & GOSSELINK, J. G. (2007). Wetlands (4th ed.). Hoboken, NJ: John Wiley and Sons, Inc.

MOTEW, M., & KUCHARIK, C. (2013). Climate-induced changes in biome distribution, NPP, and hydrology in the Upper Midwest U.S.: A case study for potential vegetation. *Journal of Geophysical Research: Biogeosciences, 118*(1), 248-264.

MULHOLLAND, P. J., & HILL, W. R. (1997). Seasonal patterns in streamwater nutrient and dissolved organic carbon concentrations: Separating catchment flow path and in stream effects. *Water Resources Research, 33*(6), 1297-1306.

NAHM, K. H. (2003). Influences of fermentable carbohydrates on shifting nitrogen excretion and reducing ammonia emission of pigs [Review]. *Critical Reviews in Environmental Science and Technology, 33*(2), 165-186.

NATIONAL RESEARCH COUNCIL (NRC). (2001). *Compensating for wetland losses under the Clean Water Act*. Washington, DC: National Academies Press.

NATIONAL RESEARCH COUNCIL (NRC). (1969). *Eutrophication: causes, consequences, correctives*. Washington, DC: National Academies Press.

NATIONAL RESEARCH COUNCIL (NRC). (2009). Hydrologic, geomorphic, and biological effects of urbanization on watersheds, in *Urban stormwater management in the United States*. Washington, DC: National Academies Press.

NELSON, E. J., & BOOTH, D. B. (2002). Sediment sources in an urbanizing, mixed land-use watershed. *Journal of Hydrology, 264*(1-4), 51-68.

NOE, G., & HUPP, C. (2009). Retention of riverine sediment and nutrient loads by coastal plain floodplains. *Ecosystems, 12*(5), 728-746.

NOVOTNY, E., MURPHY, D., & STEFAN, H. (2007). Road-salt effects on the water quality of lakes in the Twin Cities metropolitan area. St. Anthony Falls Laboratory, St. Paul, MN. (Project Report No. 505).

NYAUPANE, G. P., & TIMOTHY, D. J. (2010). Heritage awareness and appreciation among community residents: perspectives from Arizona, USA. *International Journal of Heritage Studies, 16*(3), 225-239.

O'DRISCOLL, M., CLINTON, S., JEFFERSON, A., MANDA, A., & MCMILLAN, S. (2010). Urbanization effects on watershed hydrology and in-stream processes in the southern United States. *Water (Switzerland), 2*(3), 605-648. www.doi.org/10.3390/w2030605

PALMER, M. A., ZEDLER, J. B., & FALK, D. A. (2016). *Foundations of restoration ecology*. Washington, DC: Island Press.

POTTER, K. W. (1994). Estimating potential reduction flood benefits of restored wetlands. *Water Resources Update, 97*, 34-38.

POUDEL, D. D., VINCENT, L. M., ANZALONE, C., HUNER, J., WOLLARD, D., CLEMENT, T., DERAMUS, A., & BLAKEWOOD, G. (2010). Hands-on activities and challenge tests in agricultural and environmental education. *The Journal of Environmental Education, 36*(4), 10-22.

PURVIS, R., & FOX, G. (2016). Streambank sediment loading rates at the watershed scale and the benefit of riparian protection. *Earth Surface Processes and Landforms, 41*(10).

QIU, J., & TURNER, M. G. (2013). Spatial interactions among ecosystem services in an urbanizing agricultural watershed. *Proceedings of the National Academy of Sciences, 110*(29), 12149-12154.

RASHID, M., BEECHAM, S., & CHOWDHURY, R. (2013). Simulation of extreme rainfall from CMIP5 in the Onkaparinga catchment using a generalized linear model. 20th International Congress on Modelling and Simulation, Adelaide, Australia.

RAUDSEPP-HEARNE, C., PETERSON, G. D., & BENNETT, E. M. (2010). Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. *Proceedings of the National Academy of Sciences, 107*(11), 5242-5247.

REINELT, L., & TAYLOR, B. (2000). Effects of watershed development on hydrology. *Wetlands and Urbanization*, 221-235.

REUTER, D. D. (1986). Sedge meadows of the upper Midwest: A stewardship summary. *Natural Areas Journal 6*(4), 27-34.

RIVER ALLIANCE OF WISCONSIN. (2019). Local groups. www.wisconsinrivers.org/local-groups/

RIVER ALLIANCE OF WISCONSIN (2019). Starting up & running an effective group. Retrieved from: www.wisconsinrivers.org/local-groups/starting-up/

ROCK RIVER COALITION (RRC). (2018). Rock River Coalition. Retrieved from: www.rockrivercoalition.org/

ROCK RIVER COALITION. (2015). Your stream monitoring data. www.rockrivercoalition.org/projects-2/citizen-stream-monitoring/your-stream-monitoring-data/

ROJAS, L., & ZEDLER, J. B. (2015). An invasive exotic grass reduced sedge meadow species richness by half. *Wetland Ecology and Management, 23*, 649-663.

SABO J. L., SPONSELIER, R., DIXON, M., GADE, K., HARMS, T., HEFFERNAN, J., JANI, A., KATZ, G., SOYKAN, C., WATTS, J., & WELTER, J. (2005). Riparian zones increase regional species richness by harboring different, not more species. *Ecology 86*, 56-82.

SAIDI, N., & SPRAY, C. (2018). Ecosystem services bundles: challenges and opportunities for implementation and further research. *Environmental Research Letters, 13*(11), 113001.

SALAS, J., RAJAGOPALAN, B., SAITO, L., & BROWN, C. (2012). Special section on climate change and water resources: Climate nonstationarity and water resources management. *Journal of Water Resources Planning and Management, 138*(5), 385-388.

SCHOONOVER, J., LOCKABY, G., & PAN, S. (2005). Changes in chemical and physical properties of stream water across an urban-rural gradient in western Georgia. *Urban Ecosystems, 8*, 107-124.

SCHUELER, T., FRALEY-MCNEAL, L., & CAPPIELLA, K. (2009). Is impervious cover still important? Review of recent research. *Journal of Hydrologic Engineering, 14*(4).

SCHROEDER, S. (2007). Evidence for Paleoindians in Wisconsin and at the Skare site. *Plains Anthropologist, 52*, 63-91.

SERBIN, S. P., & KUCHARIK, C. J. (2009). Spatiotemporal Mapping of Temperature and Precipitation for the Development of a Multidecadal Climatic Dataset for Wisconsin. *Journal of Applied Meteorology and Climatology, 48*(4), 742-757.

SHARPLEY, A. N. (1985). The selection erosion of plant nutrients in runoff. *Soil Science Society of America Journal, 49*(6), 1527-1534.

SHARPLEY, A. N., KLEINMAN, P. J., HEATHWAITE, A. L., GBUREK, W. J., FOLMAR, G. J., & SCHMIDT, J. P. (2008). Phosphorus loss from an agricultural watershed as a function of storm size. *Journal of Environmen-

tal Quality, 37(2), 362-368.

SIEGEL, L. (2007). Hazard identification for human and ecological effects of sodium chloride road salt. I-93 Chloride TMDL Study: New Hampshire Department of Environmental Services.

SKAGEN, S. K., BURRIS, L. E., & GRANFORS, D. A. (2016). Sediment accumulation in prairie wetlands under a changing climate: The relative roles of landscape and precipitation. *Wetlands, 36*(S2), 383-395.

STAPP, W. B. (1969). The concept of environmental education. *Environmental Education, 1*(1), 30-31.

STEPATH, C. M. (2000). Awareness and community-based monitoring. *Proceedings of the Ninth International Coral Reef Symposium,* Bali, Indonesia, Volume 2, 807-811.

STETS, E. G., KELLY, V. J., & CRAWFORD, C. G. (2015). Regional and temporal differences in nitrate trends discerned from long-term water quality monitoring data. *Journal of the American Water Resources Association, 51*(5), 1394-1407.

SURIYA, S., & MUDGAL, B. (2012). Impact of urbanization on flooding: The Thirusoolam sub watershed - A case study. *Journal of Hydrology,* 412-413.

TIBBETTS, J. (2006). Louisiana's wetlands: A lesson in nature appreciation. Environmental *Health Perspectives, 114*(1), 40-43.

TOWN OF DUNN. (2017). Town of Dunn cmprehensive plan. Town of Dunn, WI.

TURNER, R. E., REDMOND, A. M., & ZEDLER, J. B. (2001). Count it by acre or function: Mitigation adds up to net loss of wetlands. *National Wetlands Newsletter, 23*(6). 5-16.

UNITED STATES DEPARTMENT OF AGRICULTURE (USDA). (1986). Urban hydrology for small watersheds (TR-55). United States Department of Agriculture, Washington, DC.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (USEPA). (n.d.). Overview of Clean Water Act Section 404. www.epa.gov/cwa-404/overview-clean-water-act-section-404

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (USEPA). (1983). Results of the nationwide urban runoff program, volume 1 – Final report. NTIS Accession Number PB84-185552. U.S. EPA Water Planning Division, Washington, DC.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (USEPA). (2019). Spreadsheet tool for estimating pollutant loads (STEPL). Retrieved from www.epa.gov/nps/spreadsheet-tool-estimating-pollutant-loads-stepl

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (USEPA). (n.d.). Wetlands monitoring and assessment. Retrieved from www.epa.gov/wetlands/wetlands-monitoring-and-assessment

UNITED STATES FISH AND WILDLIFE SERVICE (USFWS). (2019). National wetlands inventory. Retrieved from: www.fws.gov/wetlands/

VAN VLIET, M., FRANSSEN, W., YEARSLEY, J., LUDWIG, F., HADDELAND, I., LETTENMAIER, D., & KABAT, P. (2013). Global river discharge and water temperature under climate change. *Global Environmental Change, 23,* 450-464.

VILLAMAGNA, A., ANGERMEIER, P. L., & BENNETT, E. M. (2013). Capacity, pressure, demand, and flow: A conceptual framework for analyzing ecosystem service provision and delivery. *Ecological Complexity, 15,* 114–121.

VITOUSEK, P. M., ABER, J. D., HOWARTH, R. W., LIKENS, G. E., MATSON, P. A., SCHINDLER, D. W., SCHLESINGER, W. H., & TILMAN, G. D. (1997). Human alteration of the global nitrogen cycle: Sources and consequences. *Ecological Applications, 7*(3), 737-750.

WASCHBUSCH, R. J., SELBIG, W. R., & BANNERMAN, R. T. (1999). Sources of phosphorus in stormwater and street dirt from two urban residential basins in Madison, Wisconsin, 1994–95. U.S. Geological Survey Water-Resources Investigations Report 99-4021. www.pubs.er.usgs.gov/publication/wri994021

WATERS, T. F. (1995). Sediment in streams: *Sources, biological effects and control.* Bethesda, MD: American Fisheries Society.

WEAVER, T. L., & FULLER, L. M. (2007). Stream-water quality during storm-runoff events and low-flow periods in the St. Clair River/Lake St. Clair Basin, Michigan. U.S. Geological SurveyOpen-File Report.

WEBB, J., WALLIS, E., & STEWARDSON, M. (2012). A systematic review of published evidence linking wetland plants to water regime components. *Aquatic Botany, 103,* 1-14.

WENTA, R., & SORSA, J. (2018). Road Salt Report for 2017. Public Health Madison & Dane County Open-File Report.

WENTHE, A. (2017). Restoring a wetland gem. Applications of current tools and technologies at Waubesa Wetlands State Natural Area. University of Wisconsin-Madison, Department of Botany. Unpublished report.

WISCONSIN ADMINISTRATIVE CODE Ch. NR 102 (1973).

WISCONSIN ADMINISTRATIVE CODE Ch. NR 105 (1989).

THE CADMUS GROUP INC. (2011) Total Maximum Daily Loads for Total Phosphorus and Total Suspended Solids in the Rock River Basin. Retrieved from: www.dnr.wi.gov/topic/TMDLs/RockRiver/

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (USEPA). (1986). Quality Criteria for Water 1986. Retrieved from: www.epa.gov/wqc/quality-criteria-water-gold-book

WISCONSIN DEPARTMENT OF NATURAL RESOURCES (WDNR). (2012). Friends groups of the Wisconsin state park system. Retrieved from: www.dnr.wi.gov/topic/parks/friends.html

WISCONSIN DEPARTMENT OF NATURAL RESOURCES (WDNR). (2019). State Natural Areas (SNAs) volunteer program. Retrieved from: www.dnr.wi.gov/topic/lands/naturalareas/volunteer.html

WISCONSIN DEPARTMENT OF NATURAL RESOURCES (WDNR) (1984). Wisconsin wetland inventory. Retrieved from www.dnr.wi.gov/topic/wetlands/inventory.html

WISCONSIN DEPARTMENT OF NATURAL RESOURCES (WDNR) (2014). Wetland rapid assessment methodology: User guidance document version 2.0. Retrieved from www.dnr.wi.gov/topic/wetlands/documents/WRAMUserGuide.pdf

WISCONSIN DEPARTMENT OF NATURAL RESOURCES (WDNR). (2017). Wisconsin wetlands: Acreage facts. Retrieved from: www.dnr.wi.gov/topic/wetlands/acreagefacts.html

WISCONSIN DEPARTMENT OF NATURAL RESOURCES (WDNR). (2018). Wisconsin water quality report to congress 2019. Retrieved from: www.dnr.wi.gov/topic/SurfaceWater/IR2018.html

WISCONSIN GEOLOGICAL & NATURAL HISTORY SURVEY. (2017). Springs. Retrieved from www.wgnhs.uwex.edu/water-environment/springs/

WISCONSIN INITIATIVE ON CLIMATE CHANGE IMPACTS (WICCI). (2011). *Wisconsin's changing climate: Impacts and adaptation.* Madison, WI: Nelson Institute for Environmental Studies, University of Wisconsin-Madison and Wisconsin Department of Natural Resources.

WOO, I., & ZEDLER, J. B. (2002). Can nutrients alone shift a sedge meadow toward the invasive Typha × glauca? *Wetlands, 22,* 509-521.

WOLF, K. L., AHN, C., & NOE, G. B. (2011). Microtopography enhances nitrogen cycling and removal in created mitigation wetlands. *Ecological Engineering, 37,* 1398-1406.

WRIGHT, T., TOMLINSON, J., SCHUELER, T., CAPPIELLA, K., KITCHELL, A., & HIRSCHMAN, D. (2006). Direct and indirect impacts of urbanization on wetland quality. Wetlands & Watersheds Article #1. Center for Watershed Protection, Ellicott City, MD.

YAHARA TASK FORCE (2019a). Yahara Chain of Lakes – Lake Levels Task Force. Dane County Land and Water Resources Department. www.lwrd.countyofdane.com/Yahara-Chain-of-Lakes-Lake-Levels-Task-Force

YAHARA TASK FORCE (2019b). 2018 Yahara Chain of Lakes Flooding Technical Work Group Report. Yahara Chain of Lakes – Lake Levels Task Force. Dane County Land and Water Resources Department. www.lwrd.countyofdane.com/documents/pdf/Yahara-Flooding-Technical-Report-Final.pdf

Yoshikawa, S., Takahashi, H., Sasada, Y., & Mochizuki, H. (2015). Impact of land use on nitrogen concentration in groundwater and river water. *Soil Science and Plant Nutrition, 61*(6), 898–909. www.doi.org/10.1080/00380768.2015.1104521

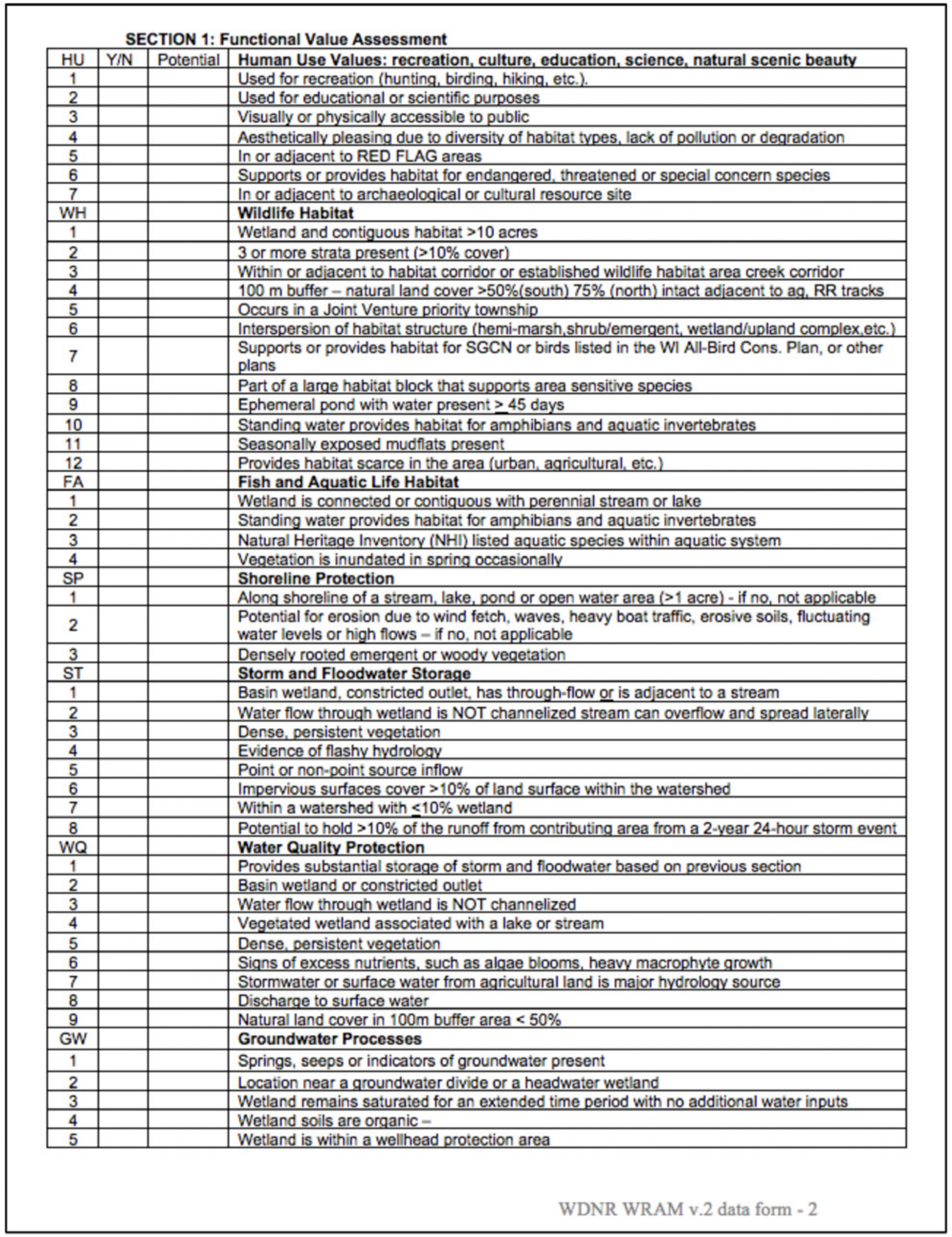
ZEDLER, J. B. (2019). Personal communication with Herbst, S., January 24.

ZEDLER, J. B., DOHERTY, J. M., & MILLER, N. A. (2012). Shifting restoration policy to address landscape change, novel ecosystems, and monitoring. *Ecology and Society, 17*(4), 36.

ZEDLER, J. B. (2018). Waubesa Wetlands: new look at an old gem. Town of Dunn, Dane County, Wisconsin. www.town.dunn.wi.us

ZEDLER, J. B. (2003). Wetlands at your service: Reducing impacts of agriculture at the watershed scale. *Frontiers in Ecology and Environment, 1*(2), 65-72.

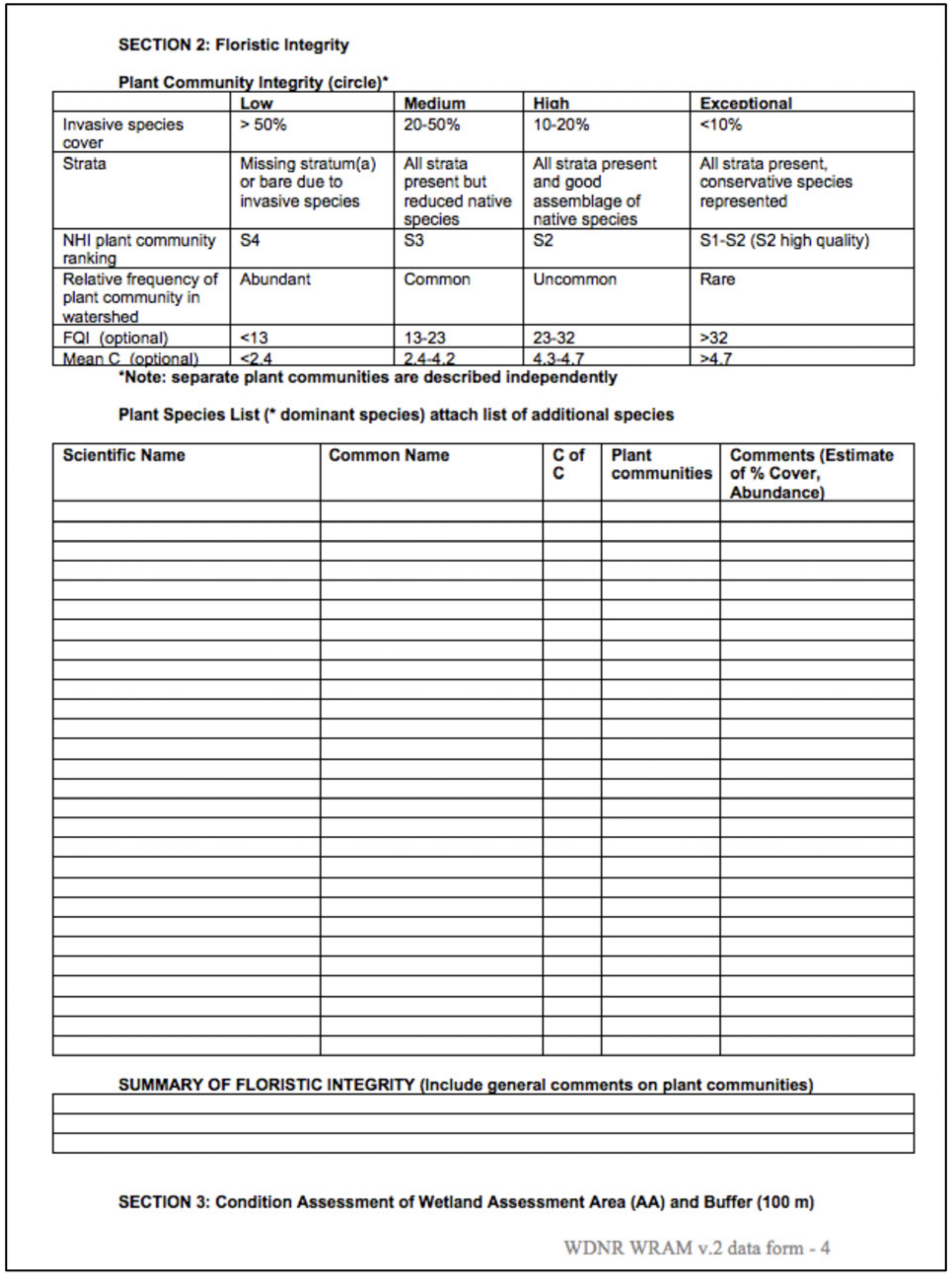
Appendix A – WDNR Rapid Assessment Methodology 2.0



SECTION 1: Functional Value Assessment

HU	Y/N	Potential	**Human Use Values: recreation, culture, education, science, natural scenic beauty**
1			Used for recreation (hunting, birding, hiking, etc.).
2			Used for educational or scientific purposes
3			Visually or physically accessible to public
4			Aesthetically pleasing due to diversity of habitat types, lack of pollution or degradation
5			In or adjacent to RED FLAG areas
6			Supports or provides habitat for endangered, threatened or special concern species
7			In or adjacent to archaeological or cultural resource site
WH			**Wildlife Habitat**
1			Wetland and contiguous habitat >10 acres
2			3 or more strata present (>10% cover)
3			Within or adjacent to habitat corridor or established wildlife habitat area creek corridor
4			100 m buffer – natural land cover >50%(south) 75% (north) intact adjacent to ag, RR tracks
5			Occurs in a Joint Venture priority township
6			Interspersion of habitat structure (hemi-marsh,shrub/emergent, wetland/upland complex,etc.)
7			Supports or provides habitat for SGCN or birds listed in the WI All-Bird Cons. Plan, or other plans
8			Part of a large habitat block that supports area sensitive species
9			Ephemeral pond with water present > 45 days
10			Standing water provides habitat for amphibians and aquatic invertebrates
11			Seasonally exposed mudflats present
12			Provides habitat scarce in the area (urban, agricultural, etc.)
FA			**Fish and Aquatic Life Habitat**
1			Wetland is connected or contiguous with perennial stream or lake
2			Standing water provides habitat for amphibians and aquatic invertebrates
3			Natural Heritage Inventory (NHI) listed aquatic species within aquatic system
4			Vegetation is inundated in spring occasionally
SP			**Shoreline Protection**
1			Along shoreline of a stream, lake, pond or open water area (>1 acre) - if no, not applicable
2			Potential for erosion due to wind fetch, waves, heavy boat traffic, erosive soils, fluctuating water levels or high flows – if no, not applicable
3			Densely rooted emergent or woody vegetation
ST			**Storm and Floodwater Storage**
1			Basin wetland, constricted outlet, has through-flow or is adjacent to a stream
2			Water flow through wetland is NOT channelized stream can overflow and spread laterally
3			Dense, persistent vegetation
4			Evidence of flashy hydrology
5			Point or non-point source inflow
6			Impervious surfaces cover >10% of land surface within the watershed
7			Within a watershed with <10% wetland
8			Potential to hold >10% of the runoff from contributing area from a 2-year 24-hour storm event
WQ			**Water Quality Protection**
1			Provides substantial storage of storm and floodwater based on previous section
2			Basin wetland or constricted outlet
3			Water flow through wetland is NOT channelized
4			Vegetated wetland associated with a lake or stream
5			Dense, persistent vegetation
6			Signs of excess nutrients, such as algae blooms, heavy macrophyte growth
7			Stormwater or surface water from agricultural land is major hydrology source
8			Discharge to surface water
9			Natural land cover in 100m buffer area < 50%
GW			**Groundwater Processes**
1			Springs, seeps or indicators of groundwater present
2			Location near a groundwater divide or a headwater wetland
3			Wetland remains saturated for an extended time period with no additional water inputs
4			Wetland soils are organic –
5			Wetland is within a wellhead protection area

WDNR WRAM v.2 data form - 2



SECTION 2: Floristic Integrity

Plant Community Integrity (circle)*

	Low	**Medium**	**High**	**Exceptional**
Invasive species cover	> 50%	20-50%	10-20%	<10%
Strata	Missing stratum(a) or bare due to invasive species	All strata present but reduced native species	All strata present and good assemblage of native species	All strata present, conservative species represented
NHI plant community ranking	S4	S3	S2	S1-S2 (S2 high quality)
Relative frequency of plant community in watershed	Abundant	Common	Uncommon	Rare
FQI (optional)	<13	13-23	23-32	>32
Mean C (optional)	<2.4	2.4-4.2	4.3-4.7	>4.7

***Note: separate plant communities are described independently**

Plant Species List (* dominant species) attach list of additional species

Scientific Name	**Common Name**	**C of C**	**Plant communities**	**Comments (Estimate of % Cover, Abundance)**

SUMMARY OF FLORISTIC INTEGRITY (Include general comments on plant communities)

SECTION 3: Condition Assessment of Wetland Assessment Area (AA) and Buffer (100 m)

WDNR WRAM v.2 data form - 4

Appendix B – Ecosystem Services Score Significance Rationale

Ecosystem Services	Applicable Categories	Significance Score Rationale	Significance Scores
Human Use Values	Recreation	Fishing, hunting, birding, paddling, or hiking presence / potential. Any = 1 pt.	**Exceptional** = Bonus points **High** = 4.5-6.0 **Medium** = 2.5-4.0 **Low** = 0.5-2.0 **N/A** = 0
	Education & science	Historical or current research & education And / or = 1 pt.	
	Accessibility	Visual = 0.5 pt.; Physical = 0.5 pt. 2 Access ranges total = 1 pt.	
	Natural scenic beauty	Aesthetically pleasing (qualitative). Yes = 1 pt.	
	Red flag areas	Calcareous fen, State Natural Area, unique and significant wetlands, preservation for future generations. Area and/or adjacent = 1 pt.	
	Important habitat	Habitat for threatened, rare, and endangered species. Potential/yes = 1 pt.	
Floristic Integrity	Present vegetation percent cover estimate	Based on plant species list. Calculated weighted mean coefficient of conservationism (C of C). Our data ranged from 0.4 - 4.4.	**Exceptional** = Bonus points **High** = 3.2-4.4 **Medium** = 1.8-3.1 **Low** = 0.4-1.7
Wildlife Habitat	Wetland corridor	Within wetland polygon complex (Dane County maps and Wetlands Inventory). Yes = 1 pt.	**Exceptional** = Bonus points **High** = 7-10 **Medium** = 4-6 **Low** = 1-3 **N/A** = 0
	Environmental corridor	Dane County map evidence. Yes = 1 pt.	
	Habitat that supports area sensitive species	Presence of diverse vegetation, providing habitat. Yes = 1 pt.	
	3 + vegetation strata	Presence of different vegetation levels throughout wetlands. Yes = 1 pt.	
	Diverse habitat structure	Yes = 1 pt.	
	100m land cover buffer	No obstacles for wildlife movement. Yes = 1 pt.	
	Supports/provides habitat for important bird species	Potential / yes = 1 pt.	
	Ephemeral pond potential	Yes = 1 pt.	
	Standing water for amphibians	Yes = 1 pt.	
	Provides habitat scarce in the area	Yes = 1 pt.	
Fish & Aquatic Life Habitat	Connected to lake/stream	Yes = 1 pt.	**Exceptional** = Bonus points **High** = 3 **Medium** = 2 **Low** = 1 **N/A** = 0
	Standing water for amphibians	Yes = 1 pt.	
	Supports endangered, threatened or species of concern	Potential / yes = 1 pt.	
	Spring inundation of vegetation	Yes = 1 pt.	
Shoreline Protection	Along the shore of a stream, lake or pond	Yes = Considered. No = N/A	See column to right.
	Potential for erosion	Yes = Considered. No = N/A	
	Densely rooted emergent or wood vegetation	Qualitative based on vegetation and erosion observed: **Exceptional**: Bonus more than 75% cover in vegetation **High**: 75% covered in vegetation with minimal erosion observed **Medium**: 50% covered in vegetation with moderate erosion; or severe erosion **Low:** 25% or less covered in vegetation with severe erosion	
Flood & Stormwater Storage	Basin wetland, constricted outlet, through-flow, or adjacent to stream	Yes = 1 pt.	**Exceptional** = Bonus points **High** = 5.5 - 7 **Medium** = 3.5 - 5 **Low** = 1 - 3 **N/A** = 0
	Water flow not channelized	If not channeled = 1 pt.	
	Dense persistent vegetation	Yes = 1 point	
	Evidence of flashy hydrology	Matted vegetation, eroded stream banks. Yes = 1 pt.	
	Point / nonpoint source inflow	Presence = 1 pt.	
	Impervious surfaces cover >10% of the watershed	ArcMap analysis. **Yes = 1 pt.**	
	Watershed with >10% wetland cover	ArcMap analysis. No = 0 pts. (all polygons were no)	
	Potential to hold >10% runoff	ArcMap analysis. Wetlands within constricted outlet and along the stream. Yes = 1 pt.	
Water Quality Protection	Storage based on previous section	Captures water when there are floods and high stormwater events. Yes = 1 pt.	**Exceptional** = Bonus points **High** = 6-8 **Medium** = 4-5 **Low** = 1-3 **N/A** = 0
	Basin wetland / constricted outlet	Yes = 1 pt.	
	Water flow through wetland NOT channelized	Channeled = 0 pt. Not channeled = 1 pt. No stream = N/A	
	Vegetated wetland associated with lake / stream	Yes = 1 pt.	
	Dense persistent vegetation	Yes = 1 pt.	
	Signs of excess nutrients	Sediment or duckweed (*Lemna obscura.*) presence. Yes = 1 pt.	
	Ag. land stormwater / surface water major source	Yes = 1 pt.	
	Discharge to surface water	Yes, conducts filtering action = 1 pt.	
	Natural land in 100m buffer <50%	Yes = 1 pt.	
Groundwater Processes	Headwater wetland	Swan Creek is a first order spring. Yes = 1 pt.	**Exceptional** = Bonus points **High** = 4-5 **Medium** = 2-3 **Low** = 1 **N/A** = 0
	Wetlands remain saturated	Springs makes soil remain saturated. Yes = 1 pt.	
	Organic soils	Web Soil Survey maps. Yes = 1 pt.	
	Well Head Protection Area	Wetlands located within City of Fitchburg. Yes = 1 pt.	
	Sprigs / seeps / groundwater indicators	Freshwater pooling, hydrophilic vegetation, saturated soils. Yes = 1 pt.	

Appendix C – Swan Creek Corridor Vegetation

Scientific Name	Common Name(s)
Acer negundo	Ash-Leaved Maple, Box Elder
Acer saccharinum	Silver Maple, Soft Maple
Agalinis purpurea	Purple False Foxglove, Smooth Agalinis
Ageratina altissima	White Snakeroot
Alliaria petiolata	Garlic Mustard
Ambrosia trifida	Giant Ragweed, Great Ragweed, Horse-Cane
Angelica atropurpurea	Common Great Angelica, Great Angelica, Purple-Stem
Asclepias incarnata	Swamp Milkweed
Asclepias syriaca	Common Milkweed, Silkweed
Athyrium filix-femina	Common Lady Fern, Lady Fern
Berula erecta	Cut-Leaved Water-Parsnip, Low Water-Parsnip
Bidens cernua	Nodding Beggar-Ticks, Nodding Bur-Marigold
Bidens frondosa	Common Beggar-Ticks, Devil'S Beggar-Ticks
Bidens trichosperma	Northern Tickseed-Sunflower, Tall Swamp Marigold
Caltha palustris	Cowslip, Marsh-Marigold, Yellow Marsh-Marigold
Campanula aparinoides	Marsh Bellflower
Carex comosa	Bristly Sedge
Carex hystericina	Bottlebrush Sedge, Porcupine Sedge
Carex lacustris	Common Lake Sedge
Carex sprengelii	Long-Beaked Sedge, Sprengel'S Sedge
Carex stipata	Common Fox Sedge, Owl-Fruit Sedge
Carex stricta	Tussock Sedge
Carex vulpinoidea	Brown Fox Sedge, Fox Sedge
Celtis occidentalis	Northern Hackberry
Cichorium intybus	Blue-Sailors, Chicory
Cicuta maculata	Common Water-Hemlock, Spotted Water-Hemlock
Cirsium arvense	Canada Thistle, Creeping Thistle, Field Thistle
Cirsium muticum	Swamp Thistle
Cornus foemina	Gray Dogwood, Northern Swamp Dogwood, Panicled Dogwood
Cornus sericea	Red Osier Dogwood
Crataegus crus-galli	Cockspur Hawthorn
Cuscuta gronovii	Common Dodder, Scald-Weed, Swamp Dodder
Cuscuta pentagona	Field Dodder, Five-Angled Dodder
Daucus carota	Queen Anne'S-Lace, Wild Carrot
Echinacea pallida	Pale Purple Coneflower, Prairie Coneflower
Echinochloa muricata	Barnyard Grass, Cockspur Grass, Rough Barnyard Grass
Echinocystis lobata	Balsam-Apple, Wild-Cucumber
Elaeagnus angustifolia	Oleaster, Russian Olive
Eleocharis erythropoda	Bald Spike-Rush
Epilobium palustre	Marsh Willow-Herb
Equisetum fluviatile	Pipes, River Horsetail, Water Horsetail
Erechtites hieraciifolius	American Burn-Weed, Fireweed
Erigeron philadelphicus	Common Fleabane, Marsh Fleabane, Philadelphia Daisy
Erigeron strigosus	Daisy Fleabane, Prairie Fleabane, Rough Fleabane
Eupatorium altissimum	Upland Boneset, Tall Boneset, Tall Eupatorium
Eutrochium maculatum	Spotted Joe-Pye-Weed
Fraxinus pennsylvanica	Green Ash, Red Ash
Galium aparine	Annual Bedstraw, Cleavers, Goose-Grass
Gentiana andrewsii	Andrews' Gentian, Bottle Gentian, Prairie Closed Gentian
Gleditsia triacanthos	Honey Locust
Glyceria striata	Fowl Manna Grass, Fowl Meadow Grass
Hackelia virginiana	Beggar'S-Lice, Stickseed, Wild Comfrey
Helenium autumnale	Common Sneezeweed
Helianthus giganteus	Giant Sunflower, Swamp Sunflower, Tall Sunflower
Hesperis matronalis	Dame'S Rocket
Impatiens capensis	Orange Jewelweed, Orange Touch-Me-Not
Iris versicolor	Harlequin Blue Flag, Northern Blue Flag
Juglans nigra	Black Walnut
Juniperus virginiana	Eastern Red-Cedar
Leersia oryzoides	Rice Cut Grass
Lemna minor	Common Duckweed, Lesser Duckweed, Small Duckweed
Lobelia cardinalis	Cardinal-Flower
Lobelia siphilitica	Great Blue Lobelia
Lonicera X bella	Bell'S Honeysuckle, Showy Bush Honeysuckle, White-
Lycopus americanus	American Water-Horehound, Common Water-Horehound
Lythrum alatum	Winged Loosestrife, Winged Lythrum
Malus ioensis	Iowa Crab, Prairie Crabapple
Mentha canadensis	Field Mint, Wild Mint
Nasturtium officinale	Watercress
Onoclea sensibilis	Sensitive Fern
Packera aurea	Golden Ragwort, Heart-Leaved Groundsel
Parthenocissus quinquefolia	Virginia Creeper, Woodbine
Pedicularis lanceolata	Fen Betony, Swamp Betony, Swamp-Lousewort
Persicaria arifolia	Halberd-Leaf Tearthumb
Persicaria pensylvanica	Pennsylvania Knotweed, Pennsylvania Smartweed, Pinkweed
Phalaris arundinacea	Reed Canary Grass
Poa palustris	Fowl Meadow Grass, Marsh Bluegrass
Populus deltoides	Eastern Cottonwood
Pycnanthemum tenuifolium	Narrow-Leaved Mountain Mint, Slender Mountain Mint
Quercus alba	White Oak
Quercus macrocarpa	Bur Oak
Quercus rubra	Northern Red Oak
Rhamnus cathartica	Common Buckthorn, European Buckthorn
Rhus glabra	Smooth Sumac
Ribes aureum	Golden Currant
Robinia pseudoacacia	Black Locust
Rubus idaeus	Wild Red Raspberry
Rumex britannica	Greater Water Dock, British Dock
Rumex crispus	Curly Dock, Sour Dock

Rumex obtusifolius	Bitter Dock
Sagittaria latifolia	Broad-Leaved Arrowhead
Salix interior	Sandbar Willow
Salix nigra	Black Willow
Sambucus canadensis	American Elder, Elderberry
Schoenoplectus tabernaemontani	Great Bulrush, Soft-Stem Bulrush
Scirpus atrovirens	Black Bulrush, Dark-Green Bulrush
Solanum dulcamara	Bittersweet Nightshade
Solidago canadensis	Canadian Goldenrod
Solidago gigantea	Giant Goldenrod
Solidago riddellii	Riddell'S Goldenrod
Sonchus oleraceus	Common Sow-Thistle, Field Sow-Thistle
Spartina pectinata	Prairie Cord Grass, Slough Grass
Symphyotrichum novae-angliae	New England Aster
Symphyotrichum puniceum	Swamp Aster
Taraxacum erythrospermum	Red-Seeded Dandelion
Thelypteris palustris	Eastern Marsh Fern, Marsh Fern
Thuja occidentalis	Eastern Arborvitae, Northern White-Cedar
Toxicodendron radicans	Common Eastern Poison-Ivy
Trifolium pratense	Red Clover
Typha angustifolia	Narrow-Leaved Cat-Tail
Ulmus americana	American Elm, White Elm
Ulmus pumila	Siberian Elm
Urtica dioica	Stinging Nettle
Verbascum thapsus	Common Mullein, Flannel Plant, Giant Mullein
Verbena hastata	Blue Vervain, Simpler'S-Joy, Swamp Verbena
Viburnum opulus	Cranberry Viburnum, European Cranberry-Bush, High-Bush Cranberry
Viola cucullata	Blue Marsh Violet, Hooded Violet, Marsh Blue Violet
Vitis riparia	Frost Grape, River Bank Grape
Zizia aurea	Common Golden Alexanders, Golden Alexanders

Appendix D – Significance Score Ranking per Wetland Type

Ecosystem Service	Score Ranking	Number of Wetland Polygons	Number of Wetland Types			
			Southern Sedge Meadow	Shrub-carr	Southern hardwood swamp	Emergent marsh
Human Use Values	Exceptional	3	2	0	0	1
	High	9	4	2	2	1
	Medium	10	0	2	4	4
	Low	1	0	0	0	1
Floristic Integrity	Exceptional	2	2	0	0	0
	High	3	2	1	0	0
	Medium	10	2	3	3	2
	Low	8	0	0	3	5
Wildlife Habitat	Exceptional	1	1	0	0	0
	High	17	5	3	5	4
	Medium	4	0	1	1	2
	Low	1	0	0	0	1
Fish & Aquatic Habitat	Exceptional	2	1	0	1	0
	High	12	2	2	6	2
	Medium	5	1	1	0	3
	Low	5	1	1	0	3
	N/A	4	3	3	0	1
Shoreline Protection	High	7	1	3	0	3
	Medium	7	1	0	5	1
	Low	1	0	0	1	0
	N/A	8	4	1	0	3
Flood & Stormwater Storage	Exceptional	4	1	1	0	2
	High	10	1	2	3	4
	Medium	8	3	1	3	1
	Low	1	1	0	0	0
Water Quality Protection	Exceptional	6	1	3	0	2
	High	9	2	0	2	5
	Medium	7	3	1	3	0
	Low	1	0	0	1	0
Groundwater Processes	Exceptional	7	2	1	2	2
	High	8	2	1	4	1
	Medium	8	2	2	0	4

Appendix E – Ecosystem Services Statistical Analysis

In order to understand the relationship between wetland type and ecosystem services significance score, we conducted an analysis of variance (ANOVA) test to determine if the 4 wetland types performed any ecosystem service at significantly different levels. If the results of the ANOVA indicated a significant difference between how the 4 wetland types performed a given ecosystem service a Tukey HSD post-hoc test was also calculated. The Tukey test allows us to determine if there was a significant difference between any set of 2 wetland types and their scores for a given ecosystem service. Our significance threshold for these analyses was set at 0.05.

To test for differences between wetland polygon location and ecosystem services significance score, we conducted two-sample t-tests assuming equal variances. Upland located wetland polygon ecosystem services significance scores were compared to riparian wetland polygon ecosystem services significance scores. And upstream located wetland polygon ecosystem services significance scores were compared to downstream wetland polygon ecosystem services significance scores. For both analyses we considered the two-tail P(T<=t) value when interpreting statistical significance.

To test for ecosystem service bundles, statistically significant relationships between different ecosystem services. We performed T-tests to calculate Pearson's Coefficient. Values range from 0 to 1, and we consider values greater than 0.5 to be a strong, positive relationship between services.

Appendix F – Water Quality Monitoring Site Descriptions

Site Name	Location Description	GPS Coordinates	Data and Frequency	Parameters
Swan@ Lake	Accessed by boat from Lake Waubesa. Sampled about 100 ft. upstream from where Swan discharges into lake.	Lat: 42.995823 Long: -89.349310	**Monthly grab samples:** April, May, October	**In field:** temperature, conductivity, dissolved oxygen, pH **State Lab of Hygiene analysis:** Total Kjeldahl Nitrogen, NO3+NO2, ortho-phosphate, total phosphorus **UW-Madison Soils lab analysis:** chloride, total suspended solids
Murphy's@ Lake	Accessed by boat from Lake Waubesa. Sampled about 100 ft. upstream from where Murphy's discharges into lake.	Lat: 42.990440 Long: -89.347765	**Monthly grab samples:** April, May, October	
Swan@ Lalor	Downstream of the culvert where Swan Creek crosses under Lalor Road. We collected grab and storm samples from the middle of the stream near the USGS reference gage.	Lat: 42.999497 Long: -89.361303	**Monthly grab samples:** April - October **Storm samples:** June - October **Flow data:** continuous June – October	
Murphy's@ Lalor	Downstream of the culvert where Murphy's Creek crosses under Lalor Rd. We collected samples from the middle of the stream near the USGS reference gage.	Lat: 42.983388 Long: -89.362540	**Monthly grab samples and flow data:** April - October	
Swan Confluence	Located on a private property south of Haight Farm Road and east of Highway 14. We walked through a large wetland area to reach a confluence point where a NW tributary that comes from under Haight Farm Road meets a SW tributary that comes from under Highway 14.	Lat: 43.000130 Long: -89.383510	**Monthly grab samples and flow data:** April – October	

Appendix G – Calculating Pollutant Loads

One goal of our project was to calculate pollutant loads for Swan Creek. With to limited time and resources we were unable to complete all steps. Here we outline our process (1 – 3) and remaining step (4):

1. **Flow rate monitoring. At the Swan Creek outlet, manually measure flow. (Completed).**
2. **Stage-discharge equation. Use collected discharge measurements to install an ISCO continuous flow monitoring device. (Completed).**
3. **Storm event sampling. Collect samples for water quality measurements during high flow conditions. (Completed, could be continued).**
4. **Pollutant load calculation. Correlate water quality measurements with continuous discharge measurements using a rating curve developed with the USGS. (Remaining).**

FLOW RATE MONITORING

We measured flow rate at the Swan Creek outlet downstream of the culvert under Lalor Road. Our site has a relatively straight stretch of channel, is free of flow disturbances, and has a small rock dam that creates a pool. We selected this location through visual assessment and through in the field conversation with USGS monitoring staff. A riffle and quiet section act as a low water control. The site is within the right-of-way for the Town of Dunn.

To measure flow at a location, we took velocity and depth measurements at equal intervals across our cross sections. To do this we first secured a measuring tape across the stream and identified the wetted width of the channel. This number we divided by 24 and rounded to the closest whole number. Starting at the edge of the wetted area, we took velocity and depth measurements at each segment using a Marsh-McBurney Flo-Mate with standard wading rod. Segment width varied with each time we measured as it depends on the total wetted width, which depends on location and flow conditions. We rounded segment widths to the closest whole or half number.

The Marsh-McBurney Flo-Mate 2000 measures velocity with a sensor and relies on Faraday's law of electromagnetic induction. An electromagnetic coil within the open-channel-velocity sensor produces a magnetic field. Water in the stream acts as a conductor and produces a voltage as it flows through the field. The magnitude of this measured voltage is directly proportional to the velocity of the conductor moving through the magnetic field, and yields the velocity of the stream flowing past the sensor.

We measured depth in 0.05-foot increments with a top-setting-wading rod. The open-channel-velocity sensor was adjusted to be at 60% of the stream depth from the surface of the water. We held the sensor at this depth and position for a period of 10 seconds minimum before taking a reading. If the value fluctuated more than 5 ft/s, we waited additional time until the reading settled. With the corresponding depths and velocities, we calculated flow of the open channel flow for the stream cross-sections. Flow is calculated from the continuity equation $Q = U \times A$ where Q is flow, U is mean velocity, and A is cross-sectional area. The velocity that we measured at 60% of the depth is U, the mean velocity. We calculated A for each segment based on the depth measurement and a rectangular channel shape, and then multiplied by U to get flow for each segment. The sum of the flows for the segments is the total flow of the stream cross section.

At the Swan outlet site, we measured flow on different days with varied precipitation. This gave us discharge measurements under a variety of flow conditions.

Figure G.1. Measuring stream flow with the Marsh-McBurney Flo-Mate 2000.

STAGE-DISCHARGE EQUATION AND AUTOMATED SAMPLER

Our 10 flow measurements at the Swan outlet site spanned flow regimes from 1.0 to 2.5 feet of maximum water depth. Since we were unable to measure all discharges, we interpolated and extrapolated additional points with a linear equation (Table G.1., Figure G.1). We then put this equation into the installed Teledyne ISCO 6712 Standard Portable Sampler to calculate instantaneous flow throughout the field season. Flow measurements were collected every minute from June 8th to November 11th, 2018. We did not apply a correction factor. We removed the sampler due to winter and the end of our project budget.

Table G.1. Interpolated and extrapolated flow data based on our field measurements of stage and flow.

Date	Stage (ft)	Flow (cfs)
	1.00	-17.20
	1.20	-6.44
	1.40	4.32
6/11/2017	1.46	8.93
	1.60	15.09
6/7/2017	1.62	17.37
5/30/2017	1.78	23.66
6/15/2017	1.78	22.22
	1.80	25.85
5/12/2017	1.90	36.68
	1.92	32.31
	1.94	33.39
6/4/2017	1.95	31.49
	1.97	35.00
5/21/2017	1.99	34.43
	2.01	37.15
	2.05	39.31
5/26/2017	2.08	43.16
	2.10	42.00
	2.20	47.38
	2.30	52.76
	2.40	58.14
6/29/2017	2.49	58.66
	2.50	63.53
	2.60	68.91
	2.70	74.29
	2.80	79.67
	2.90	85.05
	3.00	90.44
	3.10	95.82
	3.20	101.20
	3.30	106.58
	3.40	111.96
6/23/2017	3.50	119.18
	3.60	122.73
	3.70	128.11
	3.80	133.49
	3.90	138.87

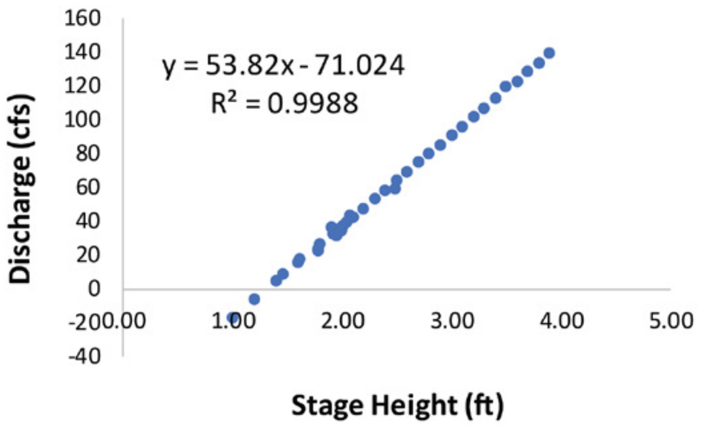


Figure G.1. Interpolated and extrapolated flow data based on our field measurements of stage and flow. The above equation is the one that we programmed into the Isco.

STORM EVENT SAMPLING

We collected storm samples from six storms, spanning June to October and peak discharges from 10 to 80 cubic feet per second (cfs) using the ISCO sampler (See Chapter 4). Our goal was to capture a range of precipitation events. Before each event, we determined the pacing of sample collection based on anticipated precipitation, previous events, and best judgement. In the carousel, we placed ice to keep the samples refrigerated until we could take them to the lab. Within 24 hours of the event, we collected the samples and split and composited them based on their timing in the hydrograph, either "rising", "peak", or "falling" limbs. We calculated mean flow weighted concentrations with our water quality nutrient concentrations.

Future monitoring at this site could build upon our work and measure discharge and nutrient concentrations under more flow conditions, and throughout development. Medium and high flow periods are the most critical times during which to take samples.

POLLUTANT LOAD CALCULATION

A rating curve is a tool that allows conversion of stage data into flow data. It is basically a graph of discharge versus stage and is developed through statistically analyzing flow and stream stage measurements. From this, a flow-weighted mean concentration, or average concentration of a specific pollutant during a monitoring season, can be calculated. This helps calculate the total load (mass) of a pollutant in a watershed. An additional season of flow data and water quality samples are needed for a rating curve to not be considered preliminary. The next step in developing a pollutant load is to work with the USGS and use their in-house Graphical Constituent Loading Analysis System (GCLAS) software to compute daily and annual loadings of watershed pollutants.

Appendix H – Water Quality Laboratory Sample Analysis

Summary of Method for the Determination of Chloride (Argentometric titration of chloride) – Adapted from EPA Method 9253

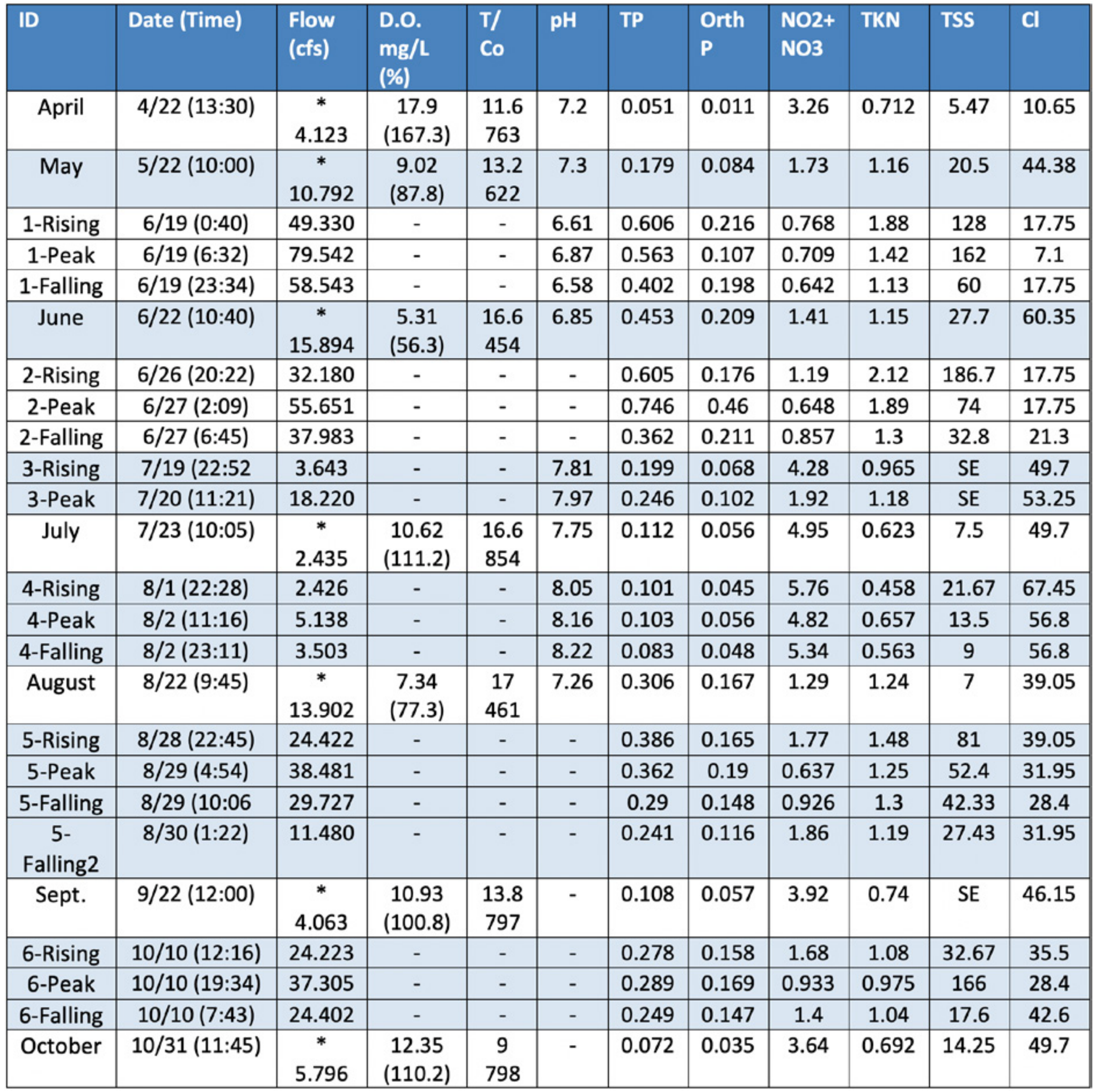
1. Reagents
    - Deionized water for dilutions and preparation of standards
    - 0.025N potassium chromate indicator solution. Note: Reagent is light sensitive
    - 0.025N silver nitrate solution
    - 886 mg/L sodium chloride standard. Prepared by dissolving 0.886 g of dry sodium chloride in chloride-free water in a 1 liter volumetric flask.
2. Laboratory Supplies
    - 100mL glass burette
    - 50mL beaker
    - Stir plate
    - Magnetic stir rod
    - Glass container for storage of standard
    - Balance (for initial preparation of standard)
3. Procedure
    - Measure 50mL of the sample and pour into the 50mL beaker
    - Add 1mL of the potassium chromate indicator
    - Add silver nitrate titrant dropwise until color change is observed
    - Repeat procedure using 1:1 dilution of sample in water (25mL sample to 25mL water)
4. Calculations: Chloride (mg/L) = [(V1 - V2) x N x 71,000] / S
    - V1 = Milliliters of standard AgN03 solution added in titrating the sample
    - V2 = Milliliters of standard AgN03 solution added in titrating the diluted sample
    - N = Normality of standard AgN03 solution.
    - S = Milliliters of original sample in the 50 mL test sample prepared
    - 71,000 = 2 x 35,500 mg Cl /equivalent, since V - 2V
5. Quality Control
    - Blank sample run before any samples are run
    - Control standard prepared by diluting the standard sodium chloride sample (886mg/L standard) by 10x. Repeatability measured as 0.36*x

Summary of Method for the Determination of TSS- Adapted from EPA method 106.2

1. Reagents
    - Deionized water
2. Laboratory Supplies
    - Metal tins
    - Filter paper
    - Vacuum filtration setup (Filter flask, Buchner funnel, Vacuum)
    - Drying oven
    - Balance
    - Forceps/Tweezers
3. Procedure
    - Rinse and dry filter paper in oven if necessitated by filter (may not be necessary based on filter type)
    - Weigh metal tin and filter paper
    - Filter up to 1 L of sample through the filter paper and replace filter into metal tin. For our samples we often used 400mL of sample after which the filter would not process more water
    - Dry in drying oven at 105° C for 1 hour
    - Weigh metal tin and filter paper
4. Calculations
    - TSS = ((A-B)×1000)/C
        i. A = Weight of filter+tin+sample
        ii. B = Weight of filter+tin
        iii. C = mL of sample used
5. Quality Control
    - Blank sample of deionized water run before any samples are run

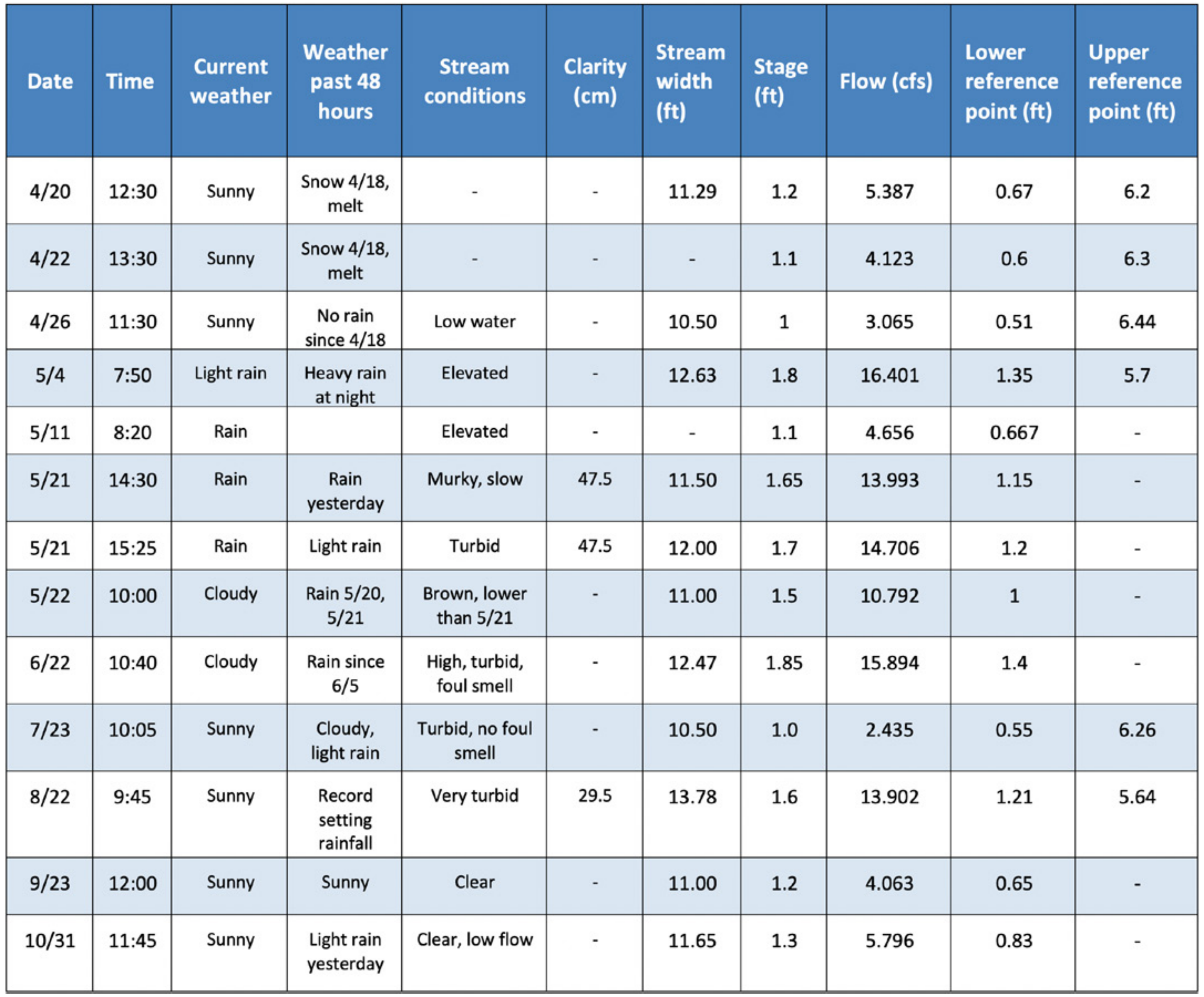
Appendix I – Extended Water Quality Results

Table I.1. Water quality monitoring data for Swan@Lalor for 2018. Discharge/flow is measured from the Marsh Mc-Burney Flo-Mate 2000 if *, otherwise is from the ISCO. All nutrients are in mg/L. T is water temperature (C), Co is conductivity, and Cl is chloride



ID	Date (Time)	Flow (cfs)	D.O. mg/L (%)	T/ Co	pH	TP	Orth P	NO2+ NO3	TKN	TSS	Cl
April	4/22 (13:30)	* 4.123	17.9 (167.3)	11.6 763	7.2	0.051	0.011	3.26	0.712	5.47	10.65
May	5/22 (10:00)	* 10.792	9.02 (87.8)	13.2 622	7.3	0.179	0.084	1.73	1.16	20.5	44.38
1-Rising	6/19 (0:40)	49.330	-	-	6.61	0.606	0.216	0.768	1.88	128	17.75
1-Peak	6/19 (6:32)	79.542	-	-	6.87	0.563	0.107	0.709	1.42	162	7.1
1-Falling	6/19 (23:34)	58.543	-	-	6.58	0.402	0.198	0.642	1.13	60	17.75
June	6/22 (10:40)	* 15.894	5.31 (56.3)	16.6 454	6.85	0.453	0.209	1.41	1.15	27.7	60.35
2-Rising	6/26 (20:22)	32.180	-	-	-	0.605	0.176	1.19	2.12	186.7	17.75
2-Peak	6/27 (2:09)	55.651	-	-	-	0.746	0.46	0.648	1.89	74	17.75
2-Falling	6/27 (6:45)	37.983	-	-	-	0.362	0.211	0.857	1.3	32.8	21.3
3-Rising	7/19 (22:52	3.643	-	-	7.81	0.199	0.068	4.28	0.965	SE	49.7
3-Peak	7/20 (11:21)	18.220	-	-	7.97	0.246	0.102	1.92	1.18	SE	53.25
July	7/23 (10:05)	* 2.435	10.62 (111.2)	16.6 854	7.75	0.112	0.056	4.95	0.623	7.5	49.7
4-Rising	8/1 (22:28)	2.426	-	-	8.05	0.101	0.045	5.76	0.458	21.67	67.45
4-Peak	8/2 (11:16)	5.138	-	-	8.16	0.103	0.056	4.82	0.657	13.5	56.8
4-Falling	8/2 (23:11)	3.503	-	-	8.22	0.083	0.048	5.34	0.563	9	56.8
August	8/22 (9:45)	* 13.902	7.34 (77.3)	17 461	7.26	0.306	0.167	1.29	1.24	7	39.05
5-Rising	8/28 (22:45)	24.422	-	-	-	0.386	0.165	1.77	1.48	81	39.05
5-Peak	8/29 (4:54)	38.481	-	-	-	0.362	0.19	0.637	1.25	52.4	31.95
5-Falling	8/29 (10:06	29.727	-	-	-	0.29	0.148	0.926	1.3	42.33	28.4
5-Falling2	8/30 (1:22)	11.480	-	-	-	0.241	0.116	1.86	1.19	27.43	31.95
Sept.	9/22 (12:00)	* 4.063	10.93 (100.8)	13.8 797	-	0.108	0.057	3.92	0.74	SE	46.15
6-Rising	10/10 (12:16)	24.223	-	-	-	0.278	0.158	1.68	1.08	32.67	35.5
6-Peak	10/10 (19:34)	37.305	-	-	-	0.289	0.169	0.933	0.975	166	28.4
6-Falling	10/10 (7:43)	24.402	-	-	-	0.249	0.147	1.4	1.04	17.6	42.6
October	10/31 (11:45)	* 5.796	12.35 (110.2)	9 798	-	0.072	0.035	3.64	0.692	14.25	49.7

Table I.2. Water quantity monitoring data for Swan@Lalor for flow data in 2018. Discharge/flow is measured from the Marsh Mc-Burney Flo-Mate 2000. Stage is deepest measured depth. Lower reference point is the USGS marker in the streambed. Upper reference point is the notch in the culvert top.



Date	Time	Current weather	Weather past 48 hours	Stream conditions	Clarity (cm)	Stream width (ft)	Stage (ft)	Flow (cfs)	Lower reference point (ft)	Upper reference point (ft)
4/20	12:30	Sunny	Snow 4/18, melt	-	-	11.29	1.2	5.387	0.67	6.2
4/22	13:30	Sunny	Snow 4/18, melt	-	-	-	1.1	4.123	0.6	6.3
4/26	11:30	Sunny	No rain since 4/18	Low water	-	10.50	1	3.065	0.51	6.44
5/4	7:50	Light rain	Heavy rain at night	Elevated	-	12.63	1.8	16.401	1.35	5.7
5/11	8:20	Rain		Elevated	-	-	1.1	4.656	0.667	-
5/21	14:30	Rain	Rain yesterday	Murky, slow	47.5	11.50	1.65	13.993	1.15	-
5/21	15:25	Rain	Light rain	Turbid	47.5	12.00	1.7	14.706	1.2	-
5/22	10:00	Cloudy	Rain 5/20, 5/21	Brown, lower than 5/21	-	11.00	1.5	10.792	1	-
6/22	10:40	Cloudy	Rain since 6/5	High, turbid, foul smell	-	12.47	1.85	15.894	1.4	-
7/23	10:05	Sunny	Cloudy, light rain	Turbid, no foul smell	-	10.50	1.0	2.435	0.55	6.26
8/22	9:45	Sunny	Record setting rainfall	Very turbid	29.5	13.78	1.6	13.902	1.21	5.64
9/23	12:00	Sunny	Sunny	Clear	-	11.00	1.2	4.063	0.65	-
10/31	11:45	Sunny	Light rain yesterday	Clear, low flow	-	11.65	1.3	5.796	0.83	-

Table I.3. Water quantity and quality monitoring data for Swan@Confluence for 2018. Discharge/flow is measured from the Marsh Mc-Burney Flo-Mate 2000. Stage is deepest measured depth. All nutrients are in mg/L. Wid is stream width, St is stage, clar is clarity, con is conductivity and Cl is chloride.

Date/ time	Cond.	Past 48 hours	Stream cond.	Wid (ft)	St (ft)	Flow (cfs)	Clar (cm)	H20 T (C)	D.O. (mg/L) (%)	Con	pH	TP (Ortho P)	NO2 + NO3 (TKN)	TSS	Cl
4/22 14:17	Sunny	Snow 4/18, melt	Deep mucky sed	6.07	1.2	1.94	-	12.1	14.72 (183.3)	880	6.8	0.0418 (0.014)	2.85 (0.308)	3.156	78.1
5/22 11:50	Cloudy	Rain5/20, 5/21	Brown H20, calm, NW branch turbid	7.00	1.6	4.98	52	13.9	9 (89)	666	7.21	0.147 (0.060)	1.42 (0.747)	28.25	88.75
6/22 11:35	Partly sunny	Rain since 6/15	NW branch turbid and murky	8.20	2.1	6.31	-	15.6	8.01 (84.8)	588	7.34	0.277 (0.155)	2.62 (0.905)	36	46.15
7/23 11:00	Sunny	Cloudy, light rain	Very turbid	6.56	1.4	1.46		16	9.12 (92.3)	892	8.09	0.105 (0.049)	4.48 (0.508)	11.43	63.9
8/22 11:48	Sunny	Record setting rainfall	Very turbid, sed plumes	7.71	2.1	6.37	22	17.8	74.6 (82.2)	525	7.16	0.219 (0.096)	1.06 (0.685)	29	39.05
9/23 13:30	Sunny	Sunny	Deep, mucky sedi	6.00	1.7	2.53	120	13.9	9.71 (96.3)	860	-	0.0854 (0.047)	3.08 (0.419)	SE	60.35
10/31 13:00	Partly sunny	Rain 10/30	Low flow	7.71	1.6	2.95	120	9.9	10.36 (94.6)	847	-	0.0603 (0.034)	3.74 (0.515)	3.25	60.35

Table I.4. Water quality monitoring data for Swan@Lake and Murphy@Lake in 2018. All nutrients are in mg/L. Con is conductivity, Cl is chloride

Site	Date/ time	Weather	Past 48 hrs	Stream cond.	Clarity (cm)	H20 temp (c)	D.O. (mg/L) (%)	Con	pH	TP (Ortho P)	NO2 + NO3 (TKN)	TSS	Cl
Swan@ Lake	4/22 11:50	Partly sunny	Snow 4/18, warm since	Low flow, stagnant	-	8.3	17.49 (151.2)	758	6.8	0.0494 (0.0058)	3 (0.657)	3.2	395
Swan@ Lake	5/22 9:20	Cloudy	Rain 5/21, 5/22	Very calm, brown	46	12.7	8.25 (79.7)	608	7.15	0.168 (0.0852)	1.57 (1.02)	13.25	85.2
Murphys @bLake	4/22 11:15	Partly sunny	Snow 4/18, warm since	Low flow, stagnant	-	9.2	15.32 (133.7)	726.5	7.2	0.0349 (0.0026)	3.96 (0.407)	1.67	28.4
Murphys @Lake	5/22 9:45	Cloudy	Rain 5/21, 5/22	Clear, stagnant	60	12.6	9.2 (88.4)	708	7.36	0.0741 (0.0361)	2.63 (0.754)	3.75	24.85

Table I.5. Water quantity monitoring data for Murphy@Lalor for flow data in 2018. Discharge/flow is measured from the Marsh Mc-Burney Flo-Mate 2000. Stage is deepest measured depth. Lower reference point is the USGS marker in the streambed.

Date	Time	Current weather	Weather past 48 hours	Stream conditions	Stream width (ft)	Stage (ft)	Flow (cfs)	Lower reference point (ft)
4/22	11:20	Sunny	Snow 4/18, melt	Normal	9.02	1.3	5.735	-
5/22	11:00	Cloudy	Rain 5/20, 5/21	-	9.33	1.7	7.288	0.7
6/22	10:00	Light rain	Rain since 6/5	High	9.51	1.8	8.380	-
7/23	9:35	Sunny	Cloudy, light rain	Normal	9.19	1.5	5.326	0.47
8/22	10:59	Sunny	Record setting rainfall	Fairly clear	8.86	1.9	8.406	0.85
9/23	12:40	Sunny	Sunny	Lots of sediment	9.00	1.7	5.136	0.6
10/31	12:15	Partly sunny	Light rain yesterday	Clear, low flow	9.45	2.1	8.284	0.38

Table I.6. Monitoring data for Murphy@Lalor Rd for 2018. All nutrients are in mg/L.

Date/time	Clarity (cm)	Temp (C)	D.O. mg/L (%)	Conductivity	pH	TP (Ortho P)	NO2 + NO3 (TKN)	TSS	Chloride
4/22 11:20	-	9.9	15.75 (141)	748	-	0.0418 (0.014)	5 (0.263)	6.19	31.95
5/22 11:00	52	12.6	9.64 (892.9)	741	7.44	0.147 (0.0601)	3.58 (0.912)	31.75	83.43
6/22 10:00	-	15.1	8.9 (91.1)	637	7.28	0.277 (0.155)	3.16 (1.06)	26	39.05
7/23 9:35	-	15	9.9 (100.1)	790	7.95	0.105 (0.0493)	5.97 (0.649)	17.5	39.05
8/22 10:59	53	16	9.07 (10.68)	659	7.43	0.219 (0.0956)	2.39 (0.792)	7.5	35.5
9/23 12:40	75	12.2	10.68 (101.9)	799	-	0.0854 (0.0471)	5.22 (0.534)	SE	53.25
10/31 12:15	111	8.8	11.47 (100.6)	782	-	0.0603 (0.0336)	3.88 (0.642)	3.75	53.25

Appendix J – Modeling Methods and Results

Table J.1: Curve number land classification table.

CARPC Land Use Name	Curve Number	Curve Number Name	Hydrologic Soil Group	Notes
Agriculture	68	n/a	B	Dane County Maximum Curve for Agricultural Land
Woodlands	55	n/a	B	Dane County Maximum Curve for Woodland/Natural Area
Residential	65-80	multiple	B	Based on dominant lot size, measured in ArcMap with 2016 Parcels
Open Space	55-61	Woods-good or Open-good	B	
Transportation	89	Paved; open ditches	B	
Meadow	n/a	n/a	n/a	Insignificant presence
Pasture, Good	n/a	n/a	n/a	Insignificant presence
Open Water	0	n/a	n/a	100% infiltration
Mineral Extraction	79	Open space-poor	B	
Government	75-89	1/4 Acre Lots or Industrial	B	
Vacant	61-69	Open-fair or 1 Acre Lots or Open-good	B	
Commercial	92	Commercial and Business	B	
Recreation	61-69	Open-good or Open-fair	B	
Construction	92	Commercial and Business	B	

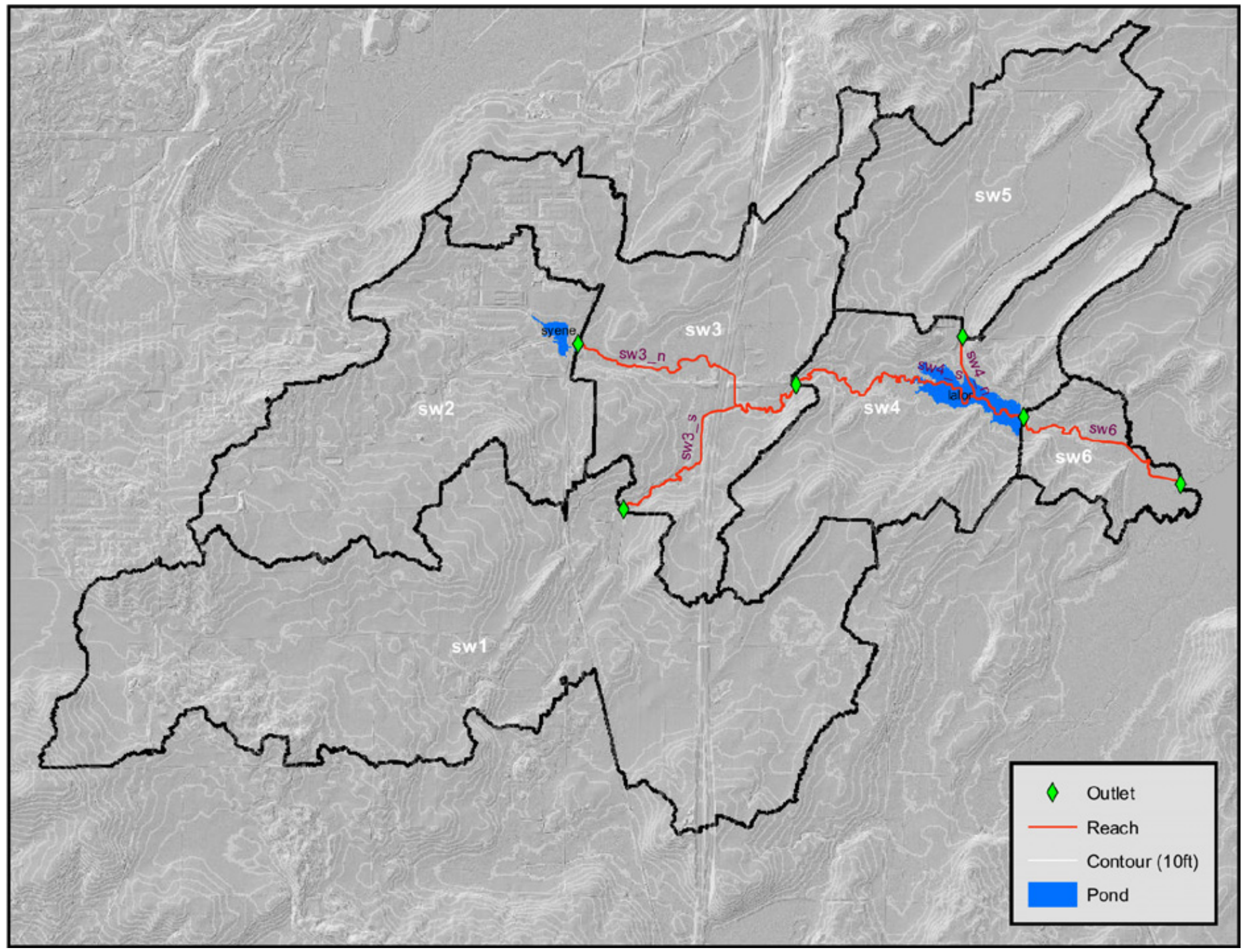


Figure J.1: Swan Creek base model visualization and HydroCAD schematic.

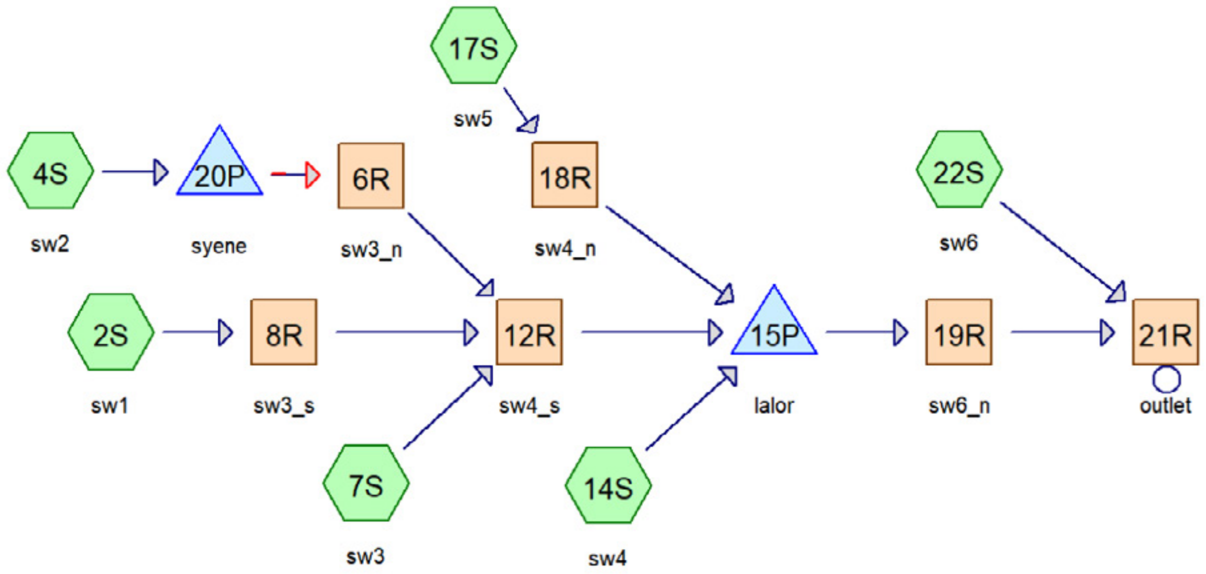


Figure J.2: HydroCAD model outputs for four scenarios from 2018 to 2062 for peak flow and total volume on Swan Creek and Murphy's Creek for one-year, 24-hour and 100-year, 24-hour storm events. Green hexagons represent "subcatchments," blue triangles are "ponds," and brown squares are "reaches."

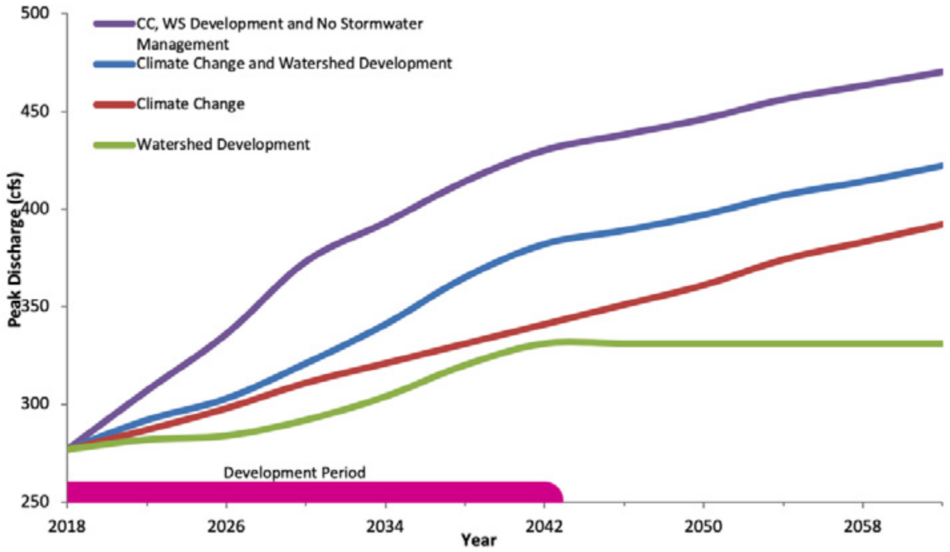


Figure J.3: Swan Creek peak flow for a one-year, 24-hour storm, 2018-2062.

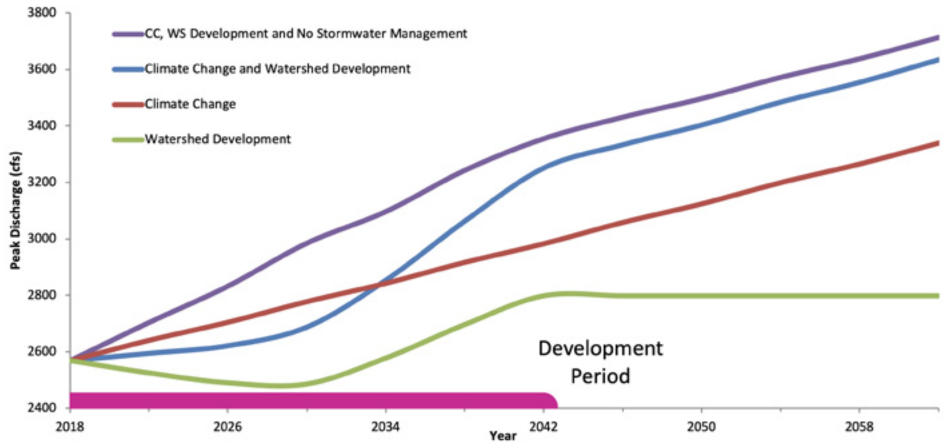


Figure J.4: Swan Creek peak flow for a 100-year, 24-hour storm, 2018-2062.

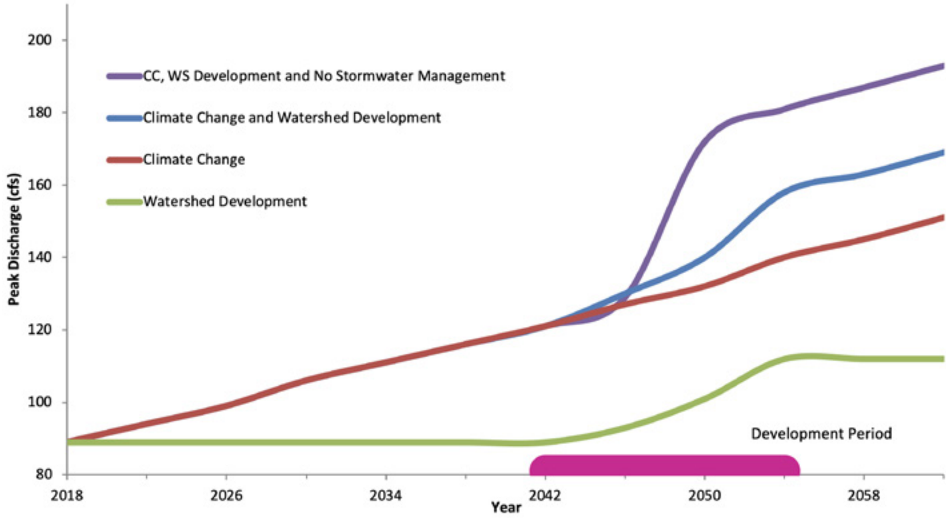


Figure J.5: Murphy's Creek peak flow for a one-year, 24-hour storm, 2018-2062.

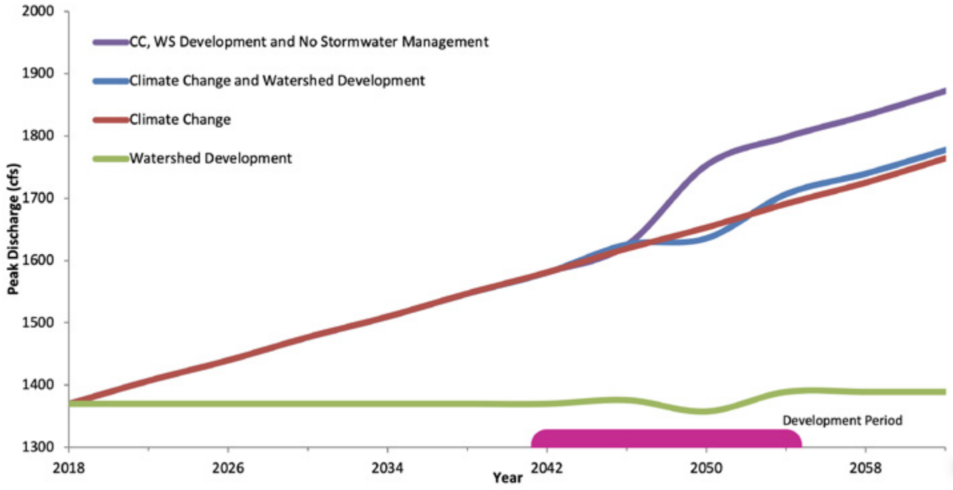


Figure J.6: Murphy's Creek peak flow for a 100-year, 24-hour storm, 2018-2062.

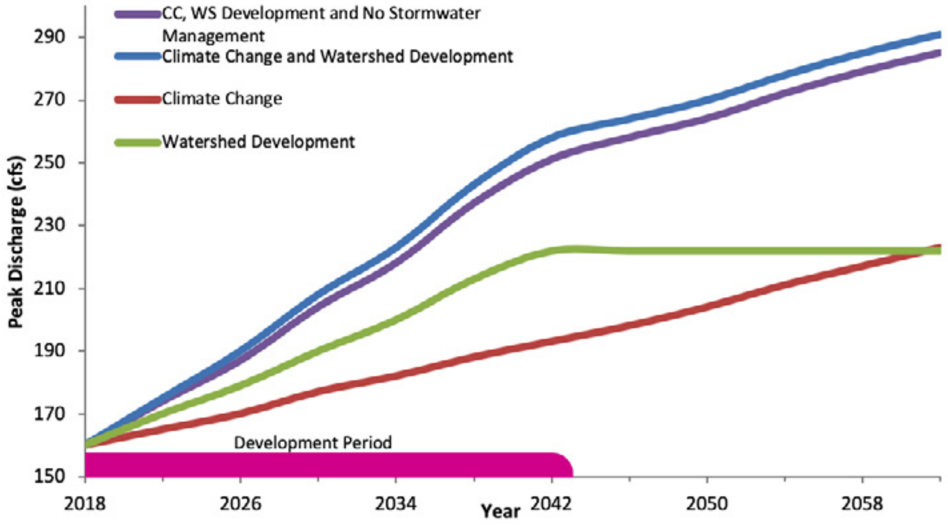


Figure J.7: Swan Creek total volume for a one-year, 24-hour storm, 2018-2062.

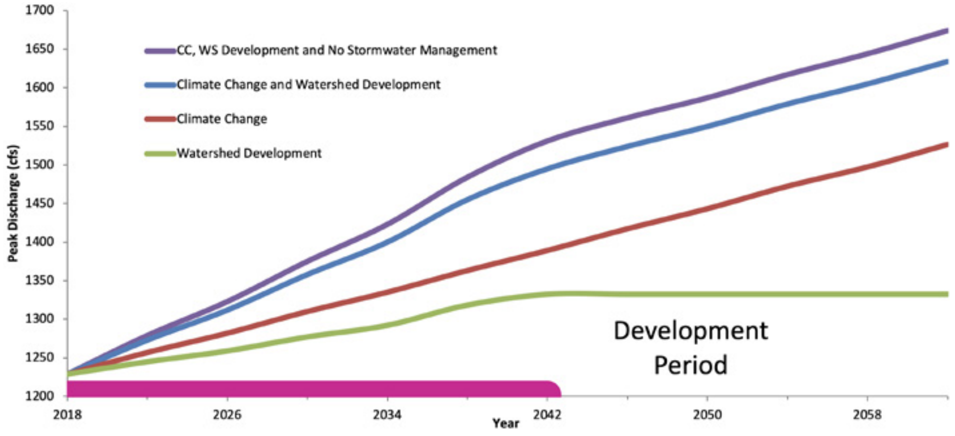


Figure J.8: Swan Creek total volume for a 100-year, 24-hour storm, 2018-2062.

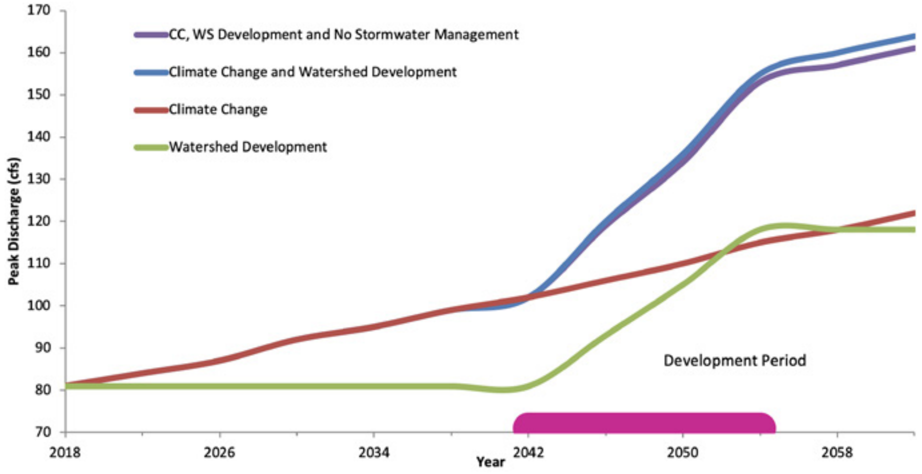


Figure J.9: Murphy's Creek total volume for a one-year, 24-hour storm, 2018-2062.

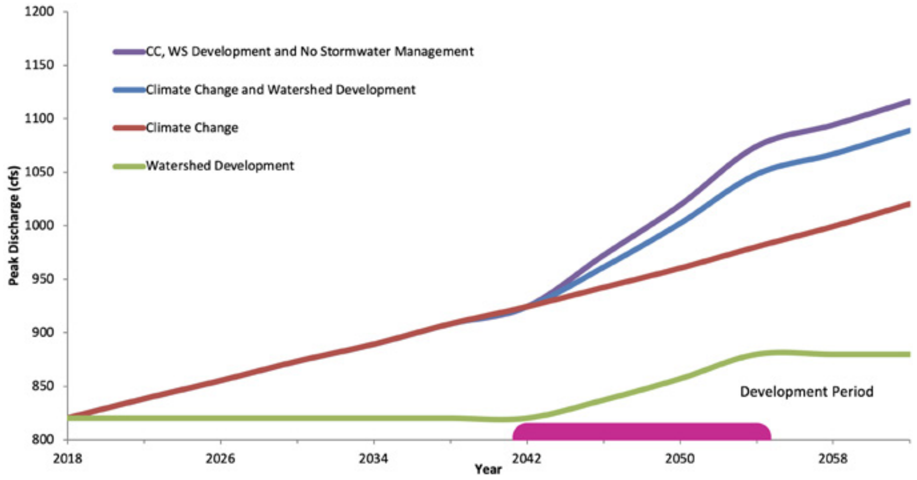
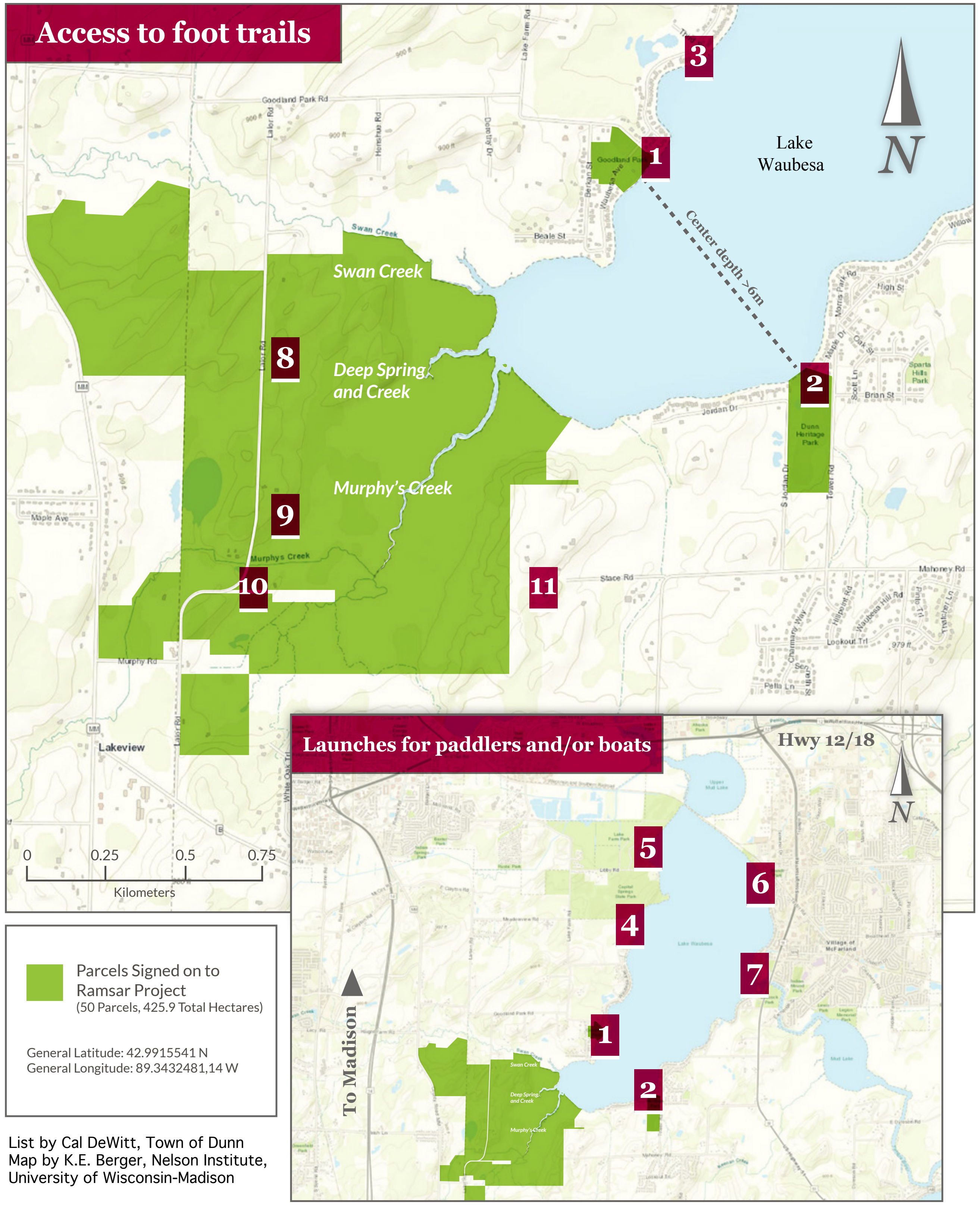


Figure J.10: Murphy's Creek total volume for a 100-year, 24-hour storm, 2018-2062.

Appendix K – Waubesa Wetlands Access Points Map

Created by Joy Zedler in 2018

Waubesa Wetlands Access Points



List by Cal DeWitt, Town of Dunn
Map by K.E. Berger, Nelson Institute,
University of Wisconsin-Madison

Waubesa Wetlands Access Points

11 places to begin your visit (map on reverse side)

1. **Goodland County Park** has restrooms, 2 boat-launch lanes, 87 parking places for cars and 18 places for cars with boat/canoe trailers. Enjoy picnic areas and pavilions, grills, and recreation fields. There is a no-wake zone along the interface of surface water and vegetation of Waubesa Wetlands. Paddlers can enter the three major creeks, Murphy's, Deep Spring, and Swan.

2. **Natural Heritage Park** covers 30 acres, with parking for 10 cars along Tower Road, accessible from County Highway B. It is the Town of Dunn's most visited park with trails through recently restored prairie vegetation and along the lakeshore. Paddlers can launch kayaks and canoes.

3. **Christy's Landing** is where paddlers, boaters, walkers, and auto travelers can enjoy burgers and fish sandwiches, a beer, and sand-lot volley ball.

4. **Town of Dunn McConnell's Landing** has parking for 10 to 15 cars along the street. This small landing is best used for launching canoes and kayaks.

5. **Lake Farm County Park Landing** is a 328-acre park with individual and group camping, 3 shelters, a multi-lane boat launch, a fish-cleaning facility, wildlife pond, observation tower, hiking and cross-country ski trails, the Capital City State Trail, and the Lower Yahara River Trail. Within the park, the Lussier Family Heritage Center supports conferences for up to 180 people.

6. **McDaniel Park** has restrooms, a shelter, and picnic areas and it supports launching of canoes and kayaks. Users can reserve places on the kayak and canoe rack. Nearby is the Green Lantern supper club.

7. **Babcock County Park Boat Launch** has a 4-lane boat launch that is easily accessed from Freeway 90; it has a fishing pier and a fish-cleaning facility. Its 25-unit campground has electricity at all sites, a bathroom and shower, and a sanitary dump station.

8. **The Nature Conservancy Access** has parking for 4 vehicles, with additional space along Lalor Road. The greeting sign shows a route map and aerial photo of Waubesa Wetlands. At trail's end, one can see the Deep Spring and the Great Fen and Woodland Trail. It is the trail most used by walkers.

9. **Wisconsin Department of Natural Resources Access** has parking along the road for about 15 vehicles. The marked trail is used principally by hunters and also hikers.

10. **Research and Educational Access** at the Bend in Lalor Road serves University of Wisconsin faculty and students, nature guides (e.g., from the Aldo Leopold Nature Center), citizens of the region, and visitors from across the U.S. and around the world. A one-lane drive has space for several cars alongside.

11. **Waubesa Wetlands Wildlife Area**—Dane County Access is a 38-acre entrance to land held by the DNR (see front).

Notes: Dane County landings charge an $8.00 daily lake access fee (payable onsite)
Access to private land is by owner's permission.

Appendix L – Number of People Reached and Number of Sign-Ups per Community Engagement Event

	Event Name (and Date)	Location of Event	Estimated Number of People Reached	Friends of Waubesa Wetlands Sign-ups
Meetings	Town of Dunn Annual Hall Meeting (4/17/18)	Dunn Town Hall	25	17
	Resources Conservation Commission Meeting (8/20/18)	Fitchburg City Hall	20	n/a
Conferences & Networking Events	2018 Earth Day Conference* (4/26/18)	Monona Terrace Community and Convention Center, Madison	15	n/a
	Rendezvous on the Terrace (9/7/18)	Pyle Center, UW-Madison	20	3
	Water@UW Poster Session* (10/16/18)	Memorial Union, UW-Madison	30	n/a
	2018 RRC Confluence (11/10/18)	University of Wisconsin - Whitewater	10	2
	WWA Wetland Science Conference* (2/19/19 -2/21/19)	Madison Marriott West, Madison	25	6
	AWRA Wisconsin Annual Meeting* (2/28/19 -3/1/19)	Delavan, Wisconsin	50	n/a
	2019 Earth Day Conference* (4/22/19)	Monona Terrace Community and Convention Center, Madison	25	n/a
Activities & Festivals	"Your Home in the Waubesa Watershed": A Family Day Event (7/21/18)	Goodland County Park Shelter #1	30	9
	Waubesa Wetlands Paddle Trip (9/7/18)	Goodland County Park Boat Launch	16	8
	McFarland Family Festival (9/14/18 - 9/16/18)	McFarland Ice Arena	100	12
	Harvest Moon Festival (9/28/18)	Lussier Family Heritage Center	100	10
Public Lectures	Yahara Lakes 101: Waubesa Wetlands with Cal DeWitt (8/8/18)	The Edgewater, Madison	80	10
	Water in Two Parts Public Lecture (3/12/19)	City of Fitchburg Library	25	n/a
TOTAL			**571**	**77**

Appendix M – Community Engagement Educational Brochure

Water Quality 101

Phosphorus (P)

In Wisconsin, phosphorus is the main culprit in uncontrolled plant & algae growth in water. Excess P makes our lakes unpleasant to use, and harms fish and wildlife. Phosphorus is in leaves, yard waste, pet waste, and some soaps. 1 lb P = 500 lbs algae

Nitrogen (N)

Nitrogen is also tied with plant & algae growth and is found in wastewater, fertilizers, and manure. Groundwater contamination with nitrogen is a human health concern.

Chlorides/salts (Cl)

Found in salt and deicers, chloride is virtually impossible to remove and harms fish and plants when it gets into waterways.

Sediment

Sediment is the most common water pollutant, and often carries others. In lakes and wetlands, it damages habitats and wildlife. Managing erosion is essential to preventing sediment in waterways

The Waubesa Wetlands

Located on the southwest shore of Lake Waubesa, the Waubesa Wetlands are one of the highest quality and most diverse wetlands in southern Wisconsin.

The wetlands are a:
- Nursery for fish like Northern Pike, Walleye, and Muskie
- Refuge for waterfowl and migrating birds
- Home to 27 rare and endangered plants and animals, like the Prairie Vole, the Peregrine Falcon, and the Blanding's Turtle

It is important to protect this incredible ecosystem by caring for its watershed.

Visit the Waubesa Wetlands!

By canoe/kayak: check out the landing at Goodland County Park.

By foot (no dogs): access from the Nature Conservancy parking lot and trails on Lalor Road.

Caring for the Waubesa Watershed

We all live in a watershed.

A watershed is the area of land that drains rain and runoff to a certain lake, river, or wetland. In our case, that may be the Waubesa Wetlands, Lake Waubesa, or one of the other Madison lakes.

Any raindrop that falls in a watershed will eventually make its way to the main waterbody, through the ground, as runoff over the land, or in storm sewers.

The lake begins on your street.

Rain and snow that fall on our lawns, sidewalks, driveways, and streets goes into storm drains, picking up harmful pollutants like fertilizer, oil, chemicals, salt, bacteria, and trash along the way.

This water isn't treated before the storm sewers on our streets carry it directly into our ponds, streams, and lakes.

Keep our watershed healthy

1. Mow long; mulch grass clippings.

Set lawn mowers to cut grass 2 ½ - 3 inches off the ground. This prevents grass from drying and needing more water. Recycle grass clippings in place as mulch. This saves time and keeps nutrients on your lawn. Use a sharp lawnmower blade, and **sweep clippings out of streets and driveways**.

2. Use fertilizer sparingly and read labels.

If you need to use fertilizer, choose **phosphorus-free** and **slow-release nitrogen** products, follow instructions, and **sweep up excess**.

3. Conserve water.

Rain barrels catch water from roofs and downspouts and store it, so it can be used to water plants.

4. Scoop up pet poop.

Animal waste can wash into water carrying bacteria. Clean up at home and on walks.

5. Plant native plants.

Native plants provide valuable habitat for butterflies and birds and also help water quality. Deep roots absorb stormwater.

If you live along a waterbody, consider planting **buffer strips** to protect water quality and habitat.

6. Keep leaves out of streets and storm drains.

Dead leaves are one of the biggest sources of phosphorus and nitrogen in urban areas. **Mulch leaves** with your lawnmower to add these nutrients to your lawn, rather than to nearby waterbodies. If your lawn is covered in more than 50% leaves, consider **bagging or composting leaves** instead.

If you do one thing**, keep leaves out of the street and away from stormdrains**!

Sign up for Dane County fall text alerts before rain storms to remind you it's time to remove street leaves: www.ripple-effects.com/leaf-free-streets/test-rain-text-alert

7. Safely dispose of pollutants.

Bring hazardous waste to Clean Sweep in Dane County.

8. With road salt: shovel, switch, scatter, sweep.

Many salts and deicers contain chloride, a chemical that is toxic to fish and plants when it gets into waterways.

Shovel early and often to prevent ice.

Switch materials depending on temperature. Check the label and thermometer, deicers have different ranges. Switch to sand if you need traction. Sweep up the extra sand; sediment is also a pollutant.

Scatter salt. Aim for 3" between salt granules. A coffee cup is enough for an average sized driveway. Consider buying an inexpensive hand spreader.

Sweep up any excess after the ice is melted, and re-use for the next time

9. Adopt a storm drain.

Find a storm drain near your house and check on it throughout the year. **Keep it clear of leaves, sediment, and trash**.

Contact Dane County UW-Extension to mark your neighborhood storm drains.

Appendix N – Community Engagement Coloring Book

Watershed Word Search

CATTAIL
CONSERVATION
DUNN
ECOSYSTEM
FILTRATION
FISH
FITCHBURG
FLOODPLAIN
FROG
GROUNDWATER
HABITAT
MADISON
NATURE
RAIN
RIVER
STORMDRAIN
STREAM
SUSTAINABILITY
TREE
TURTLES
WATERSHED
WAUBESA
WETLAND

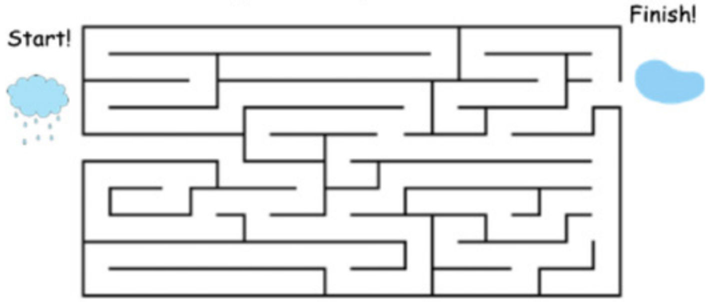
F	R	M	E	T	S	Y	S	O	C	E	H	I	P	D
L	F	I	Y	W	A	T	E	R	S	H	E	D	Y	U
O	G	I	V	M	G	I	X	C	M	N	E	A	S	N
O	R	H	L	E	M	L	A	W	A	R	I	T	Q	N
D	U	A	H	T	R	I	P	S	U	T	O	A	O	A
P	B	B	Y	J	R	B	Q	T	E	R	T	I	R	M
L	H	I	D	H	J	A	A	V	M	B	T	A	A	G
A	C	T	N	S	M	N	T	D	P	A	U	D	I	W
I	T	A	A	D	O	I	R	I	V	I	I	A	A	L
N	I	T	L	A	G	A	Q	R	O	S	C	H	W	I
E	F	Y	T	A	I	T	E	A	O	N	G	O	R	F
E	N	K	E	N	F	S	T	N	S	T	R	E	A	M
R	U	Z	W	I	N	U	S	E	L	T	R	U	T	D
T	G	L	S	O	U	S	P	L	K	P	J	Y	V	S
A	G	H	C	G	R	O	U	N	D	W	A	T	E	R

Everyone lives in a Watershed.

A watershed is an area of land that drains into a certain stream, river, or lake.

It's like a bathtub! All the water flows towards the drain because it's the lowest spot.

Water that falls on the ground moves over the land into streams, rivers, and lakes. Can you find the path it will take?



Trace Murphys Creek in RED
Hint: It looks like this: ═

Draw a fish in Lake Mendota

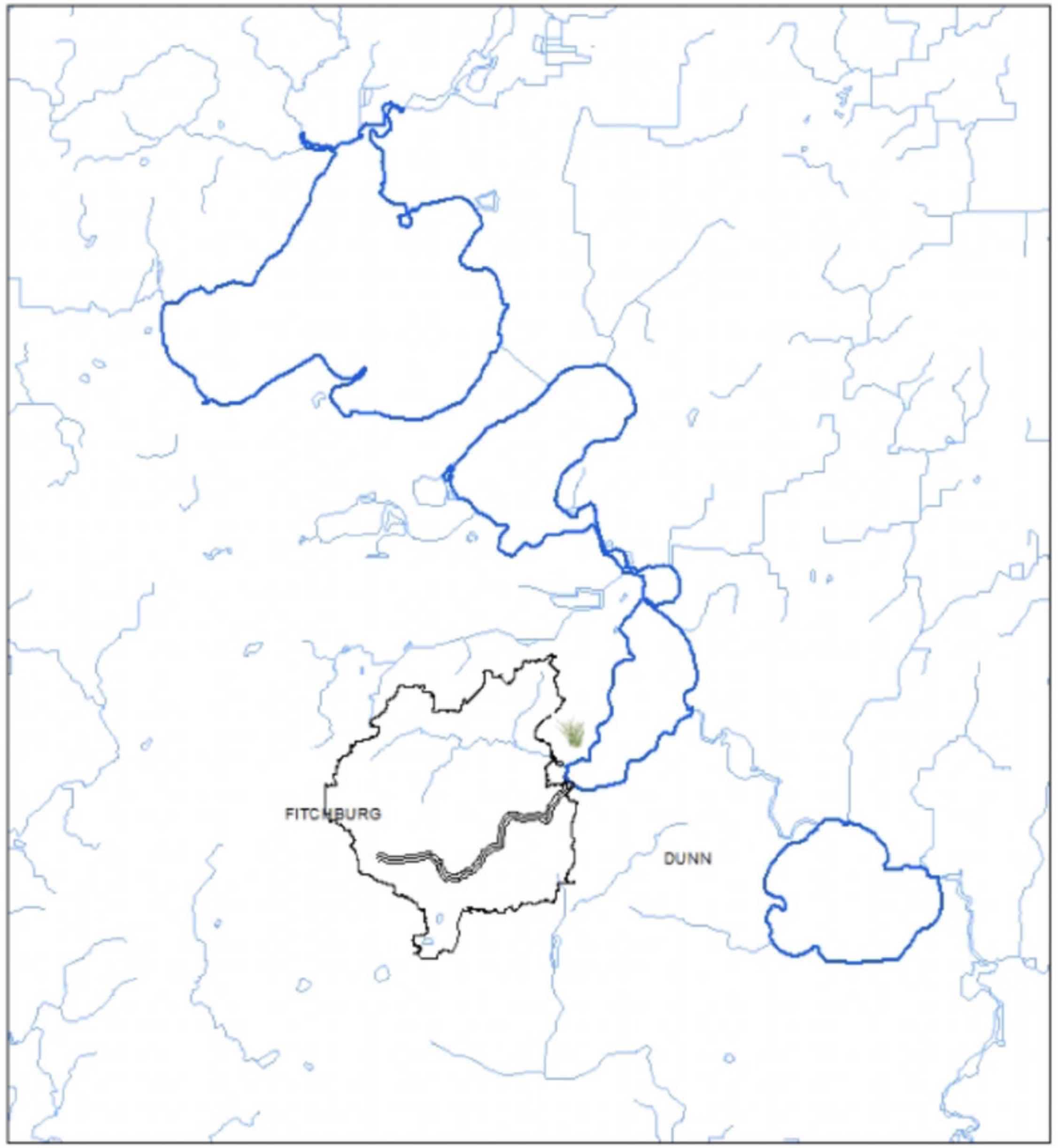
Color in the lakes BLUE
Hint: These are four blue circles

Draw a YELLOW star next to the Town of Dunn
Hint: look for the: DUNN

Circle the Waubesa Wetlands
Hint: Look for this:

Color the land inside the Waubesa Wetlands ORANGE
Hint: It looks like this:

Color all other land GREEN



Nelson Institute for
Environmental Studies
UNIVERSITY OF WISCONSIN–MADISON