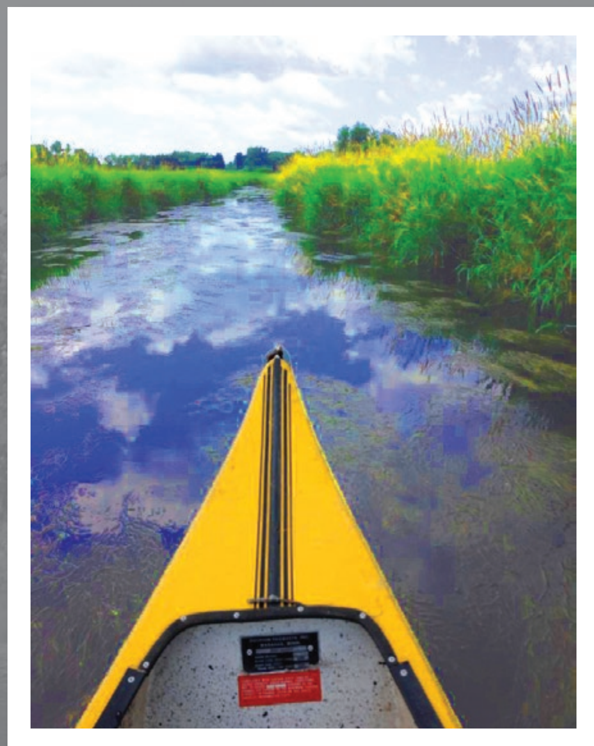
2014 WATER RESOURCES MANAGEMENT PRACTICUM REPORT



REVITALIZING A LEGACY

A Restoration Proposal for the Nine Springs E-Way

UNIVERSITY OF WISCONSIN-MADISON

The Water Resources Management Practicum is a regular part of the curriculum of the Water Resources Management Graduate Program in the Nelson Institute at the University of Wisconsin-Madison. The practicum involves an interdisciplinary team of faculty members and graduate students in the analysis of a contemporary water resource problem.

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WATER RESOURCES MANAGEMENT PROGRAM

The central component of the Water Resources Management program has always been the practicum. Graduate students enroll in the program as a cohort and work together on a single, unifying project examining a real-world problem. The advising faculty works with the local community to find opportunities that are beneficial to both the students and the community. Our advisor, Dr. Ken Potter, was approached by Rick Eilertson of the City of Fitchburg with the idea of looking at potential improvements to Dunn's Marsh. As we learned of its role within the larger Nine Springs E-way, we expanded our scope to include the creek and the wetlands and developed a plan to improve the entire system.

The Water Resources Management program is meant to produce people capable of working on a wide variety of problems, including those that are scientific and community-focused. Our practicum served as a perfect laboratory for that training. Dunn's Marsh offered us a stormwater pond with little community access and a lot of interested community members, while Nine Springs Creek inversely proved to be an engineered stormwater-removal channel that proved deleterious to the function of the surrounding wetland.

In the process of developing our plans, we were able to work with a range of engaged stakeholders, as recognized in the acknowledgements. They represent an informed effort to find a plan that benefits everyone with an interest in the Nine Springs E-way. For a WRM practicum cohort, the best possible result is that the interested parties actually implement our recommendations.

2014 WRM practicum participants, from left to right: Luke Wynn, Anna Brown, Justin Chenevert, Hangjian Zhao, Daniel Aragon, Korin Franklin, Ken Potter, Cynthia Novak-Krebs, Caitlin Soley, Andrew Mangham, Christian Dewey, Aaron Lamb and Andrew Stevens.

TABLE OF CONTENTS

INTRODUCTION

The Nine Springs E-Way is a seven-mile-long, 1,300-acre stretch of land, nestled between Madison, Wisconsin, to the north and Fitchburg, Wisconsin, to the south. Established in 1969, the E-Way is an example of a concept developed by UW-Madison professor Phillip Lewis that serves to "show how a community can identify and capitalize on existing natural and manmade resources in an effort to elevate environmental, ecological, and esthetic planning decisions to a higher priority within the community development decision-making process." This report presents recommendations for three major features of the Nine Springs E-Way, with the intended benefit of enhancing the functionality of the E-way. These three features are Nine Springs Creek, associated wetlands, and Dunn's Marsh.

Nine Springs Creek is a spring-fed waterway that runs through the center of the E-way. The creek is listed as an impaired waterway by the Wisconsin Department of Natural Resources (WDNR) and the U.S. Environmental Protection Agency due to impacts from agricultural and urban development. The lower half of Nine Springs Creek was ditched early in the 20th century to support unsuccessful agricultural production. The resulting lowering of the water table led to severe deterioration of the quality of the extensive wetland bordering the ditched portion of the creek. Dunn's Marsh is at the headwaters of Nine Springs Creek. Diversion of stormwater from a densely developed area outside the watershed has converted the marsh to a permanent pond with poor water quality. We have three main recommendations for these three features of the Nine Springs E-Way.

Our first recommendation is to restore the lower ditched portion of Nine Springs Creek by reconstructing a shallower, meandering channel. The new channel would be designed to frequently flood the channel, enhancing both the wetland and stream water quality.

The second recommendation is to enrich the ecosystem of the E-way by establishing spawning habitat for northern pike within the existing channel. This could be done with minor alterations to the channel, and would result in the significant increase of an important game fish.

Our final recommendation focuses on Dunn's Marsh, and is based on the recognition that it is not feasible to correct the altered hydrology of the marsh. We support the implementation of prior recommendations for the active maintenance of native vegetation around the pond, and recommend efforts that increase access and educational resources.

Details and support for these three recommendations are presented in the following chapters. We believe that the adoption of these recommendations would significantly increase the value of the Nine Springs E-way to the surrounding community.

This project is dedicated to **Phil Lewis**, landscape architect, author and longtime professor at the University of Wisconsin-Madison. Through his work for Governor Gaylord Nelson, taking inventory of the natural and cultural resources of Wisconsin's 72 counties, he created the concept the E-corridor or E-way. Professor Lewis called these usable green spaces "life support systems," with the "E" representing education, environment, esthetics, ecology and exercise. Eventually he came to develop the Nine Springs E-Way.

"If we look at what we've already done that's good and correct, and continue to support ways of protecting and enhancing [what we have], I think there's still hope, [and it's] essential that we do it."

— Phil Lewis

RESTORING NINE SPRINGS CREEK

Nine Springs Creek background

Nine Springs Creek begins at Dunn's Marsh, just east of Seminole Highway, and runs for seven miles, ultimately ending at Upper Mud Lake (Figure 1.1). Dunn's Marsh receives stormwater runoff from a densely developed area outside of the natural watershed, and gradually releases it to the stream. The stream then flows through residential neighborhoods, where it gradually increases in size as it is fed by stormwater runoff and flow from several springs. Between Fish Hatchery Road and the stream's terminus at Upper Mud Lake, the creek runs through broad, low-lying wetlands owned by state and municipal authorities as well as private landowners. Both the creek and the surrounding wetlands are two of the defining natural features of the Nine Springs E-Way, enjoyed by cyclists on the Capital City Trail and visitors to the Capital Springs State Recreation Area. However, both of these features have been damaged and degraded by agricultural and urban development.

The Environmental Protection Agency designated Nine Springs Creek as an impaired waterway due to high levels of total suspended solids (TSS), nitrate, and both dissolved and particulate phosphorus (WDNR, 2014). Virtually all of this impairment can be attributed to urban and suburban development. Our cohort performed a modest assessment of water quality, based on measurements of temperature, dissolved oxygen levels and anion concentrations. We also evaluated an index of biological integrity (IBI) based on assemblage of benthic macroinvertebrates found in

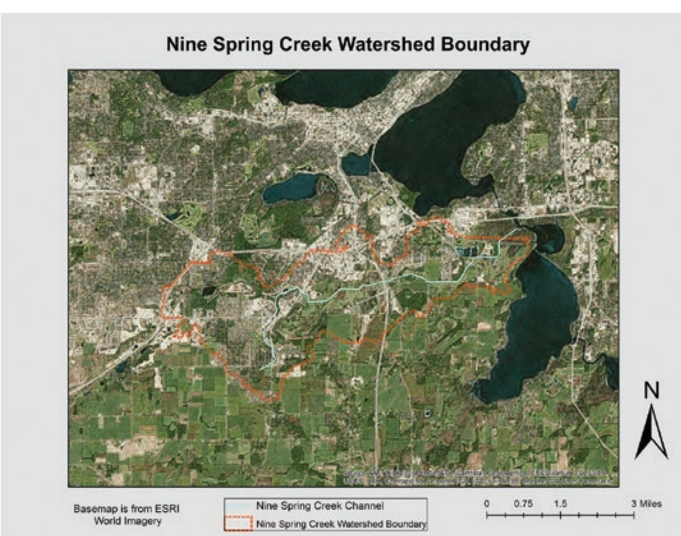

Figure 1.1: The Nine Springs Creek watershed boundary is outlined in orange.

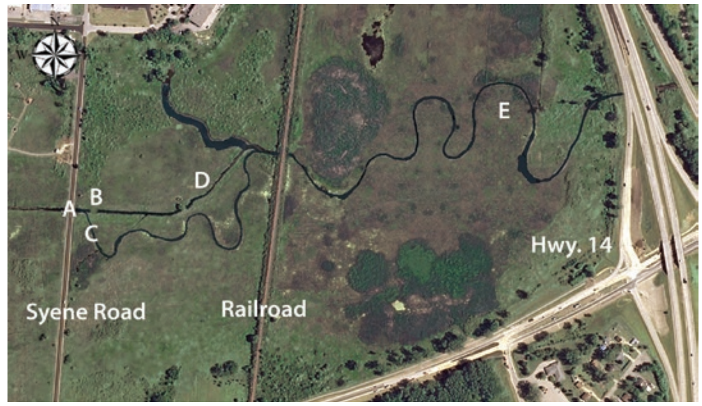

Figure 1.2: Proposed channel between Syene Road and Highway 14.

the creek (Appendix A). Although not comprehensive, our findings support the EPA's designation of impaired water quality (Appendix B).

The Nine Springs wetlands are also degraded as a result of past agricultural activity and subsequently by urban development. The ditching of the channel below Fish Hatchery Road permanently lowered the water table, resulting in wetland desiccation. The combination of agricultural activity and subsequent urbanization has suppressed native vegetation, resulting in a wetland dominated by invasive cattail and reed canary grass (Appendix C).

In this chapter, we present recommendations to improve hydrological and ecological function for the first two components of the Nine Springs E-Way: Nine Springs Creek and the adjacent wetlands. These recommendations would restore vitality to the wetlands and improve water quality in the creek. While these recommendations are currently restricted to the area between Syene Road and Highway 14 (Figure 1.2), they can serve as a template for the complete restoration of the lower Nine Springs channel and associated wetlands. We present the results of hydraulic and hydrologic models that provide estimates of the hydrologic and water quality benefits of our recommended strategies.

Design for Nine Springs Creek

We recommend the naturalization of the channel from Syene Road to Upper Mud Lake. Figure 1.3 shows an aerial photograph of the site taken in 1937. That photo shows evidence of a natural channel for Nine Springs Creek, which we have highlighted in Figure 1.3. Naturalization of the channel would involve relocating the channel to that original flow path. This new channel would not only follow the previous natural meanders, but would also be shallower and narrower to encourage frequent overbank flooding during storm events. The proposed re-meandering would increase the length of that section of Nine Springs Creek by 57%, and therefore also increase the connection between the stream and the local vegetation and facilitate plant restoration in the wetland.

Reducing the channel volume and raising the elevation of the channel bed would increase the frequency of overbank flooding and wetland inundation and raise the water table of the adjacent wetland. Wetland streams are atypical of most streams, as their water levels are commonly near the top of the stream bank during baseflow (slowly varying low flows, primarily from groundwater discharge). As a result, such streams commonly overflow their banks much more often than typical non-wetland streams (Boyington, 2010). Indeed, such streams overflow their banks approximately 12-18 times a year. Water is exchanged so readily between the wetland and the stream that the two ecosystems can be described as tightly connected. Such a connection is a defining characteristic of a healthy wetland ecosystem.

Figure 1.3: Aerial photograph of the study site section of Nine Springs Creek taken in 1937. The white line follows the path of the historic, natural channel. PHOTO: WISCONSIN STATE CARTOGRAPHER

We did not produce a detailed design of a restored channel. However, we did conduct hydrologic and hydraulic modeling to develop a typical cross section and to evaluate the approximate impact of such a channel on inundation frequency and sediment trapping. The models used included HEC-RAS, a hydraulic model developed by the U.S. Army Corps of Engineers, and a reservoir routing/sedimentation model that we developed.

Hydraulic model

HEC-RAS is an open source, one-dimensional hydraulic model that can be used to calculate water surface elevations in a channel for any chosen flow rate. We used HEC-RAS to model the reach of Nine Springs Creek that runs between Fish Hatchery Road and Upper Mud Lake based on field measurements of the channel and existing hydraulic structures, as well as on publicly available elevation data on the surrounding wetlands. We developed two models — one for present conditions and one for restored conditions. The modeling details are presented in Appendix D. As mentioned previously, our goal was to design a channel that raised the water table and overflowed its banks 12 to 18 times per year. We estimated that our channel needed to be at bank-full conditions with 20 cubic feet per second (cfs) of flow to achieve the desired effect. The analyses that led to that value are also discussed in Appendix D. Figure 1.4 shows two cross sections used in our models. The upper cross section represents the existing channel and was developed from survey results conducted in the field. The lower cross section represents our proposed channel. Our proposed channel geometry is a 3.5-foot wide and 2.5-foot deep rectangular channel representative of channel shapes commonly found in wetlands (Boyington, 2010). The elevation of the proposed channel bed is approximately 1.5 feet higher than the elevation of the existing channel bed. The proposed channel represents an 85% volumetric reduction from the existing conditions and is designed so that 20 cfs of flow represents bankfull discharge.

Our HEC-RAS model for the existing channel was calibrated against a FEMA Flood Insurance Study that produces

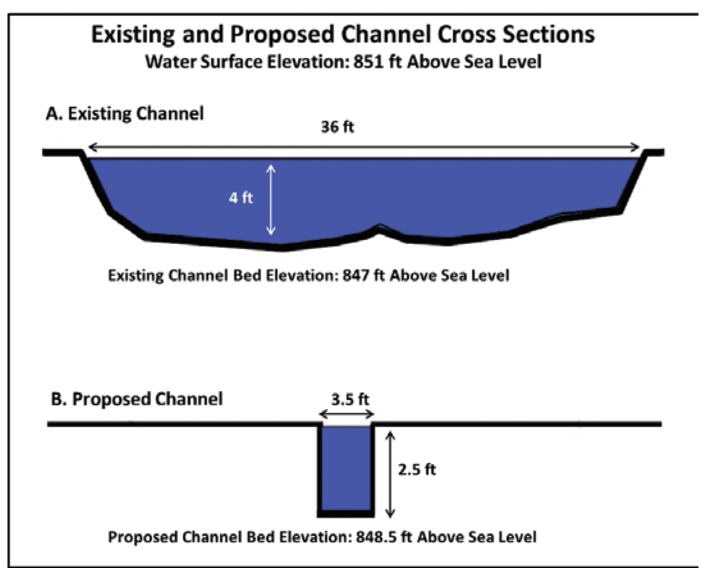

Figure 1.4: Comparison between existing and proposed channel geometry.

estimates of the water levels resulting from the 10-year and 100-year flows. The resulting modeled water surface elevations matched the FEMA results. We then developed a second hydraulic model that incorporated our proposed flowpath and channel geometry.

While frequent overbank flooding is our goal, it is critical that the proposed channel geometry does not create a flooding hazard. Our principal concerns were Syene Road and the Nevin Fish Hatchery. Syene Road is heavily used and runs along the western edge of our proposed restoration area. The critical issue there would be road flooding. The Nevin Fish Hatchery is located about 1.2 miles upstream of Syene Road. The critical issue there would be preventing facilitation of the movement of invasive species into the hatchery. The hydraulic model of the proposed channel was run using the calibration flows (10-year and 100-year FEMA Flood Insurance Study flows). The predicted water surface elevations based on the new channel were only about two inches higher than those predicted for the current channel. This minor increase strongly suggests that the channel restoration would not adversely affect either Syene Road or the fish hatchery.

Reservoir routing and sedimentation modeling

Nine Springs Creek is designated as an impaired waterway due to elevated total suspended solids. Particulate phosphorus is commonly bound to suspended sediment particles and provides a source for increased dissolved phosphorus in the water. Increasing the frequency and extent of wetland flooding events would decrease the transport of sediment and phosphorus to Upper Mud Lake and enhance water quality in downstream Lake Waubesa and Lake Kegonsa. Showing that our proposed design can result in these benefits could be a motivator for future implementation.

To demonstrate these benefits, we designed a model that allowed us to examine the effects of our design channel on the extent and frequency of wetland flooding and to estimate the amount of sediment that could be trapped in the wetlands during flooding events. A traditional reservoir routing model served to show the differences in flooding between the existing and proposed conditions. To examine the effects on sediment trapping, we combined that model with a version of the DETPOND code developed by Professor Kenneth Potter. DETPOND estimates the sediment trapping efficiency of a flooded region based on average sediment particle size and flow velocity of the floodwaters. Both of these models are discussed further in Appendix D, but we have included an overview of the approach and results below.

Our modeling approach treats the section of Nine Springs Creek running between Fish Hatchery Road and Highway 14 as a chain of three linked reservoirs, representing the channel wetland system between Fish Hatchery Road and Syene Road, Syene Road and the railroad, and the railroad and Highway 14. The outflow for each basin serves as the inflow for the next. The stage storage relationships for each reservoir were developed by running a series of peak flow values through our HEC-RAS models. The input for the model is an NRCS Type II stormflow hydrograph. We ran the same series of these hydrographs through both the existing and proposed condition models. Each storm had a duration of 72 hours; peak flows ranged from 5 cfs to 700 cfs. These values came out of the rainfall-runoff and gauge-transfer analyses we used to determine the design channel geometry and are discussed in more detail in Appendix D. The reservoir routing model provided a value for the maximum area of flooding that would be observed for each peak flow volume. These results are shown in Figure 1.6 and clearly demonstrate that our proposed design would increase the frequency and extent of flooding, compared to the existing drainage channel.

Our model shows that the current channel begins to overtop its banks at flows of 90 cfs. By contrast, our model shows that the design channel would start flooding at flows above 20 cfs, consistent with our intended design. Each of the peak flow values used for our stormflow hydrographs has a probability associated with it. For example, there is approximately a 65% chance that in any given year, you could expect to see a peak flow of 20 cfs or less. These probabilities are also directly associated with the values for the maximum area of flooding that result from each storm. Based on the results of our model and the probabilities associated with each peak flow value, we can estimate the average area of flooding one could expect to see in any given year. Our model predicts that the proposed channel would show an average of 9.3 acres of flooded wetland per year, more than double the value of 4.2 acres predicted by the model of the existing conditions. Furthermore, our comparisons show that the proposed channel would also increase the amount of time the wetland was flooded. Our models predict that the proposed channel would result in the wetlands experiencing at least some flooding for an average of 51 days per year, while the existing channel only results in flooding for an average of 12 days per year. Clearly, the proposed channel would improve the natural connection between the stream and the wetland.

The DETPOND component of our model estimates the efficiency with which a flooded area can trap, or remove, sediment from floodwaters. Trapping efficiency is associ-

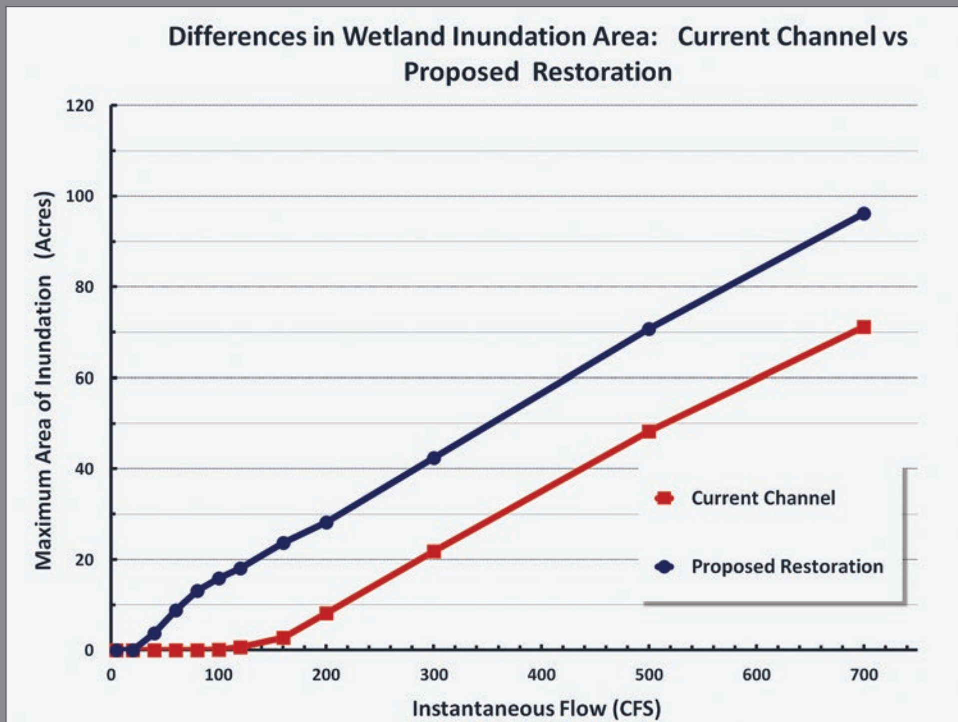

Figure 1.5: Maximum area of flooding as a function of peak flow volume from storms for the models of the existing and proposed channels.

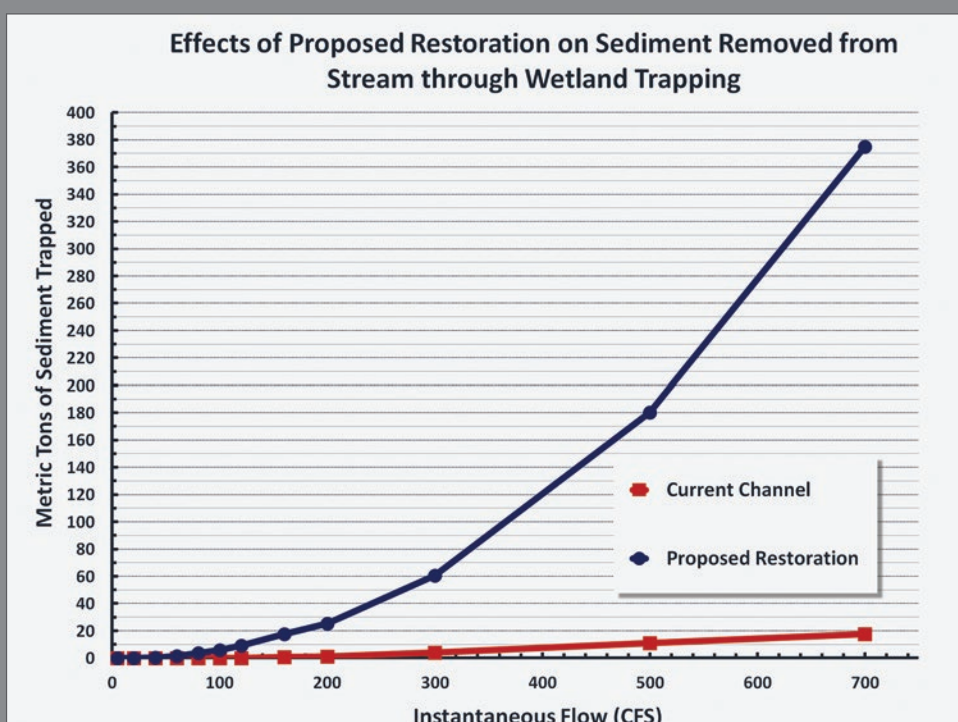

Figure 1.6: Graph showing the amount of sediment trapped versus peak daily flows for the existing and proposed conditions.

Figure 1.7: Soil sample acquired through a Russian peat borer during the Nine Springs Creek soil analysis.

Figure 1.8: Adult northern pike sunning itself in a shallow river.
PHOTO: DR. SOLOMON DAVID

ated with the velocity of the floodwaters and the average size of the sediment particles suspended in those waters. In our model we used an average particle size of 10 micrometers (μm), consistent with very fine silt. This was done to provide the most conservative estimates for the amount of sediment removed, as trapping efficiency decreases with particle size. To estimate the actual amount of sediment removed, the model requires values for the concentration of suspended sediment and the area of flooding. Our concentration values were taken from the Spring Harbor storm sewer gauge. This was the same gauge used to develop our range of peak flow values. Once these relationships were set, our sedimentation model functioned as part of our reservoir routing model. Just as each design storm we ran through the model estimated maximum area of flooding, it also estimated the amount of sediment that could be removed. Figure 1.6 shows the amount of sediment trapped that both of our models predict with each of our design storms. Just as with our estimates of the average area of flooding, the probabilities associated with each of our design storms allows us to estimate an average amount of sediment that would be removed by the wetlands per year. Our model predicts that with the proposed design, the wetlands would trap an average of 16,787 kilograms (kg) of sediment per year, compared with the 899 kg predicted by the model of the current conditions.

Along with total suspended solids, Nine Springs Creek is impaired for total phosphorus content, and our model allows us to estimate the amount of phosphorus removed per year under both conditions. Phosphorus content was not determined from the Spring Harbor data, but rather from measurements made in the mid-1990s of phosphorus and total suspended solids from samples of runoff taken at a site near the northern end of Syene Road in our study area. An average ratio of total phosphorus to total suspended solids was used to calculate the mass of phosphorus trapped in the wetlands as a result of trapped sediment. In this way, our estimate of the expected mass of phosphorus that would be trapped by our designed conditions is simply a result of multiplying the estimate of total expected mass of trapped sediment by that ratio. Our models predict that the proposed design would remove 32.7 kg of phosphorus per year, while the current conditions remove 1.8 kg per year.

Along with the phosphorus associated with sediment, soils also have the potential to remove dissolved phosphorus from the water. This depends on the chemical composition of the soils, specifically on their pH and the presence of several important metals such as calcium, aluminum and iron (Richardson, 1985). While we did not perform a comprehensive analysis of our site, we did take 18 samples at varying depths along three north-south transects of the proposed meander (Appendix E; Figure E.1) using a Russian peat borer (Figure 1.7). These samples were analyzed by the UW-Madison Soil and Plant Analysis Laboratory. The analyses measured very consistent quantities of calcium, aluminum and iron in all of the samples. These measurements were consistent with soils capable of removing dissolved phosphorus from water. While we have no estimates of the magnitude of that contribution, the combination of that effect with the results from the sedimentation model supports our claim that the new design will improve water quality.

Repurposing an existing channel as northern pike spawning habitat

Northern pike (Esox lucius) have been spotted swimming up Nine Springs Creek in the springtime in search of spawning grounds (Welke, 2013). However, due to the current impaired state of the waterway, pike are not finding suitable spawning habitat in the creek. Re-meandering the proposed portion of Nine Springs Creek would provide an opportunity for additional stream modifications that would both attract spawning pike and harbor potential egg and fry development.

The northern pike is an impressive predator. It is much sought after by anglers, especially ice fishermen. In Wisconsin, the annual economic impact of recreational fishing is valued at $1.4 billion dollars. The estimated economic benefit of esocids (musky, pike and pickerel) to Wisconsin is estimated at $397 million per year (U.S. Fish & Wildlife Service, 2011). Further estimation based on creel survey results from northern Wisconsin and total angler effort yield an economic benefit of $119 million dollars per year from northern pike alone (Sorenson, 2015). In addition to these economic benefits, northern pike play a critical role in the health of freshwater ecosystems. A robust pike population can contribute to cascading trophic interactions, which affect lake productivity and ultimately improve water quality (Carpenter, Kitchell, & Hodgson, 1985).

Although progressive management in both Wisconsin and Minnesota has supported local northern pike communities, pike habitat is still compromised by anthropogenic pressures, such as lakeshore development, water-level impoundments, and the invasion of exotic plants (Timm & Pierce, 2014). The life history of northern pike spans from the wetlands and tributaries that serve as spawning habitat to the lakes and slow-moving rivers where the species spends the majority of its adult life. Northern pike need each type of habitat to thrive.

Currently, the pike fishery in the Yahara Lakes is stable and consists of a low-density population with better-than-average growth rates and size structure compared to statewide averages. Maintenance of northern pike populations depends on the production of juvenile fish in their spawning habitat (Forney, 1968). Improving that habitat in the Yahara Lakes has the potential to strengthen ensuing northern pike year-classes, thus enhancing the overall fishery.

NORTHERN PIKE SPAWNING

Northern pike begin seeking spawning grounds early in the spring. This activity has been observed in mid-March in southern Minnesota and early May in northern Minnesota (Pierce, 2012). Thermal gradients play a factor. Pike can sense warmer water sources connecting to a lake and immediately will seek shallow, warmer water as the ice recedes. Immigration to spawning grounds in Gilbert Lake, Wisconsin, has been observed to occur when water temperatures were 38°F to 51°F and coincided with ice breakup in the spawning area. The actual spawning occurred when surface water temperatures reached 50°F to 64°F (Priegel & Krohn, 1975). Pike tend to migrate up tributaries to flooded marshes, wetlands or shallow pools. It has been suggested that in a given location, pike will use the same spawning ground every year (Bregazzi & Kennedy, 1980; Frost & Kipling, 1959; Raat, 1988). The males arrive first, followed by the females. The number of eggs carried by each female is proportional to its body size. A 15-inch fish produces about 7,500 eggs, whereas a 35-inch fish produces 97,000 eggs (Franklin & Smith, 1963). These eggs are then distributed sporadically depending on habitat suitability.

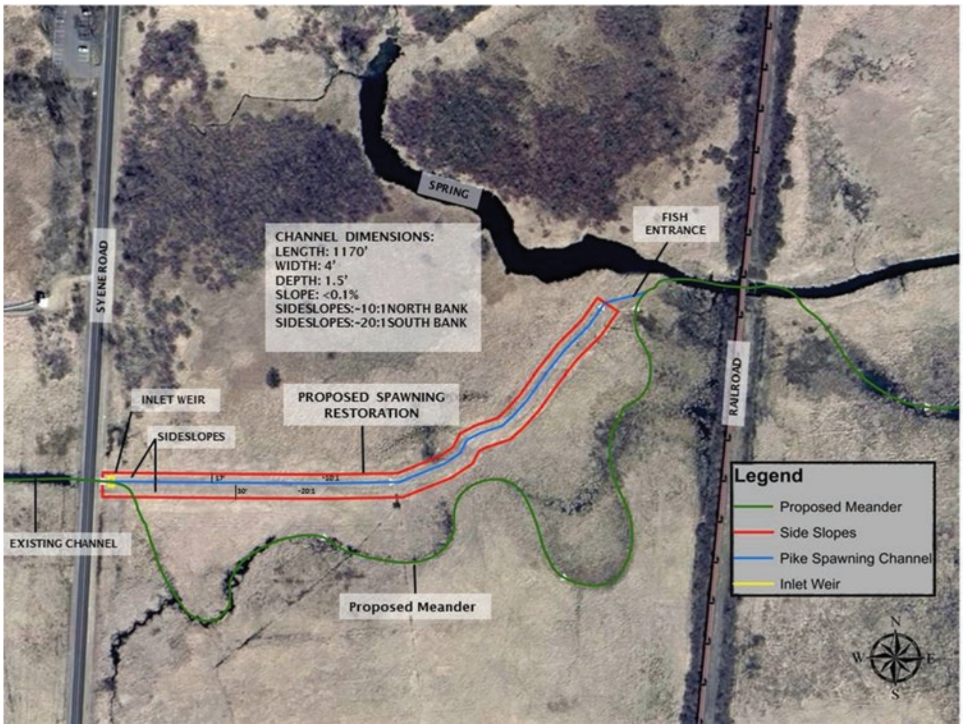

Figure 1.9: Map of proposed pike spawning habitat specifications along Nine Springs Creek re-meander.

We propose altering the lower portion Nine Springs Creek to improve spawning habitat for northern pike. This would involve re-grading the bed of the channel to achieve faster warming through maximizing solar gain, constructing a weir to protect eggs and juveniles from high flows, and providing adequate spawning substrate.

Design of pike channel

Our design of habitat improvement features is based on habitat suitability studies for northern pike and existing pike spawning habitat restoration projects in Wisconsin. A number of key spawning habitat characteristics increase the survival of northern pike fry, which ultimately determines the strength of that year-class and contributes to the overall population. In the early spring, adult pike sense subtle changes in water temperature and begin to seek out warmer habitats in which to spawn. Temperature also largely regulates the timing and success of development from the embryo stage. At 42°F, an egg takes 30 days to hatch, compared to only five days at 68°F. Suitable spawning grounds should be able to warm faster than the connecting channels.

Another critical component of effective pike habitat is the presence of live or decaying aquatic vegetation, which act as substrate for females to lay eggs and protection for fry from predators and environmental stressors. Grasses, sedges or rushes with fine leaves appear to make the best substrate for egg deposition (Franklin & Smith, 1963). However, research suggests that the species of vegetation may not be as important as the overall physical quality of the vegetation available for feeding or hiding from prey (Pierce, 2012). In addition, fry are able to swim upward and attach vertically to aquatic vegetation via an adhesive structure, which allows them to develop above the anoxic sediment in which they would perish (Franklin & Smith, Jr., 1963; Hassler, 1970). Northern pike can often be seen spawning with their backs sticking out in less than nine inches of water, indicating a preference for shallow water areas (Clarke, 1950). However, providing a sufficient area of shallow water habitat (approximately six inches in depth) for multiple weeks can be difficult in flashy systems like Nine Springs Creek. It should be noted that optimal nursery habitat for the juvenile fry differs from optimal spawning habitat in small, but important, ways. A study following the movement of northern pike fry in a flooded wetland found that the juveniles preferentially selected the deeper areas of inundation through an 18-day period of growth. This study suggested that six inches of inundation was the lower threshold of suitable habitat for juveniles, and they were more commonly located in areas of 6”-14” of inundation (Cucherousset, Paillisson, Cuzol, & Roussel, 2009). This may relate to the instinctual need of juveniles to emigrate from the spawning grounds to nursery habitat when the spawning grounds dry out. Connectivity from shallower spawning habitat to relatively deeper nursery habitat is critical and must be maintained for fry emigration.

The physical design of our proposed habitat improvements is based on projects completed by the Brown County Land Conservation Department that incorporated the requirements discussed above. A photo of a recently constructed channel is seen in Figure 1.10. Once the water is routed through the proposed re-meander, the present channel becomes a prime candidate for re-grading into a feature similar to the Brown County projects. The existing channelized section of Nine Springs Creek that runs through the study area has minimal hydraulic connection to wetland vegetation due to steep banks and a channel bed artificially lowered by historic wetland drainage projects. Additionally, the spawning grounds must connect to the main channel of Nine Springs Creek so that emigrating fry have an egress from the side channel. Our side channel is designed to maintain a depth of 1.15 feet at baseflow conditions.

Public outreach opportunities for pike spawning habitat

The addition of this new core feature to the Nine Springs E-Way presents a unique opportunity to offer learning experiences for the community. The Nine Springs E-Way is frequently utilized by bikers, kayakers and birders and provides a variety of natural hiking trails. A learning kiosk like the one shown in Figure 1.11 would provide information about the benefits of wetland restoration.

Figure 1.10: Photograph of a completed pike river restoration project in Brown County, Wisconsin.

PHOTO: BROWN COUNTY LAND AND WATER CONSERVATION DISTRICT

Chapter summary

In this chapter, we have proposed a set of transformative recommendations for two of the central natural features of the Nine Springs E-Way. At the heart of our proposal is a restoration of the currently channelized Nine Springs Creek. We propose to re-meander the creek along a previous natural pathway, which will increase the ecotone of the Nine Springs E-Way by increasing the length of the boundary between two ecosystems (Figure 1.2). We also propose to reduce the volume of the channel to encourage more frequent overbank flooding events. This will restore the connection between the wetland and the creek and improve water quality. Finally, we propose adding an entirely new feature to the Nine Springs E-Way, a spawning habitat for northern pike that uses the current channel to provide a feature that yields ecological, educational and economic benefits. Enacting these proposals will enrich the environment and the community and bring the Nine Springs E-Way closer to the ideals upon which it was founded.

Figure 1.11: Signage near Green Bay, Wisconsin, showing information about northern pike.

PHOTO DR. SOLOMON DAVID

ENHANCING DUNN'S MARSH

Dunn's Marsh background

Dunn's Marsh is the third component of the Nine Springs E-Way. Dunn's Marsh serves as the headwaters of the Nine Springs Creek watershed and is located on the western edge of the Nine Springs E-Way along Seminole Highway, south of the Beltline Highway between Madison and Fitchburg. Though previously flanked by agricultural lands, the marsh is now largely bordered by single- and multi-family residential developments. Approximately 30 acres in size, Dunn's Marsh is a former prairie pothole wetland. It has been converted into a permanent pond as a result of the diversion of large quantities of stormwater from an increasingly urbanized area to the north and west. Over time, the stormwater has caused extreme, irreversible changes to the ecosystem. According to a study conducted by Stantec, an engineering firm, the plant communities in and around the marsh have undergone significant changes due to the influx of stormwater. Non-native species such as reed canary grass and narrow-leaf cattail are becoming more dominant, thereby decreasing plant species diversity. Despite best management practices by the cities of Fitchburg and Madison to improve the quality of incoming water, the quantity of water has made restoration impossible.

The purpose of this portion of the project is to evaluate the marsh as a community asset and identify opportunities for, and hindrances to, enhancement of the marsh as a recreational resource. As a natural resource, the marsh has a strange duality of use and neglect. On the one hand, Dunn's Marsh functions as a stormwater retention pond, receiving inputs from a heavily developed and expanding watershed that has greatly altered the flow regime of the marsh. On the other hand, the marsh serves as a popular location for birding and other outdoor recreation. In fact, the benefactor of the land had a particular interest in the bird population in and around the marsh. Naturalists who frequent the area for the chance to view the many bird species that call it home often refer to it as a "hidden gem" within Madison's city limits. It is a main component of Fitchburg's plan to increase bike-ability; it recently became the site of a new bike hub. These factors influenced our decision to focus on bird habitat with an emphasis on public access.

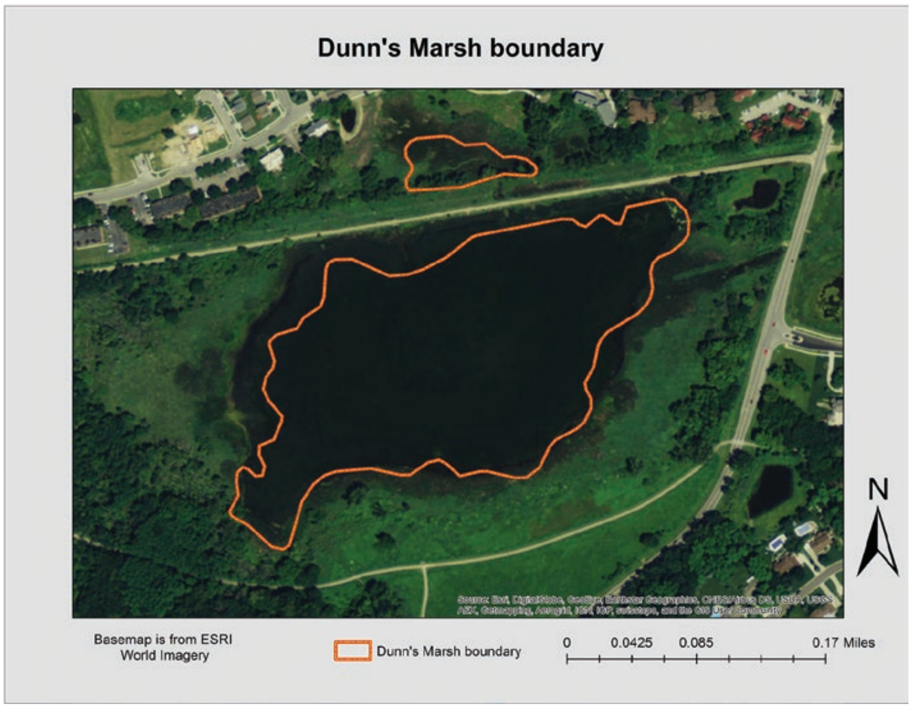

Figure 2.1: Georeferenced photo showing the Dunn's Marsh boundary outlined in orange.

To begin our study, we evaluated a variety of features, including water quality, ecological diversity, and connectedness of the marsh to the surrounding community (Appendix F; Appendix G). Our evaluations were based on results from our fieldwork and conclusions from previous studies (Appendix G). We then determined whether those features, based on input from a neighborhood survey and our evaluations, were beneficial for or a hindrance to Dunn's Marsh being utilized as a recreational resource (Appendix H). The beneficial aspects identified are: the presence of greenspace and nesting sites and habitat for various bird species; the close proximity of the marsh to several residential communities; and the presence of both citywide and nearby neighborhood interest in the marsh. The concerns we identified are: the existence of obstacles to direct physical access to the marsh; water quantity and quality issues; low biological diversity and poor ecological health of the marsh; and reduced awareness of the marsh outside of neighborhood organizations.

From the concerns we identified, we developed recommendations that would help to enhance the marsh for use as a recreational and educational resource. Our recommendations will improve access to the marsh, allow for better viewing of the marsh, and provide educational and community engagement opportunities. Together, our recommendations would enhance Dunn's Marsh as a natural recreational resource in an otherwise developed area and add to the recreational opportunities of the Nine Springs E-Way. We recognize that the marsh will not be returned to its natural, pre-urbanized state, but we believe that through maintenance of the marsh edge, habitat may improve. The following sections describe our assessment of Dunn's Marsh, provide supporting results, and describe our recommendations in more detail.

Dunn's Marsh assessment

We evaluated several features of the marsh through a variety of ecological, physical, and community assessment tools. Our assessment of the plant communities of Dunn's Marsh consisted of an aquatic plant inventory and a review of previous scientific studies to understand the terrestrial plant community (Appendix G). We conducted an aquatic vegetation survey in order to assess the diversity of the plants in the water. The results showed low diversity in aquatic vegetation. Previous studies showed low diversity among terrestrial vegetation and labeled Dunn's Marsh as a degraded wetland. Based on these results, we concluded that the plant communities in and around the marsh are heavily impaired. In order to effectively improve the plant communities, the studies we reviewed stressed the need for stormwater management strategies and significant off-site remediation to add lasting diversity to the system.

Repeated visits to the Dunn's Marsh site during the study period showed an amazing explosion of plant life over the summer months, including many species that impeded physical access to the marsh. Wildlife trails that were available in the spring were found overgrown by the onset of summer, with many plants that not only impeded progress, but often enough accosted our teams with thorns and prickles. Our conclusion is that for individuals to gain access to the marsh, engineered trails such as boardwalks or gravel paths will need to be established.

We evaluated the quality of birding at the site through site visits and conversations with birding organizations. Considering the low diversity of the plant communities both in and around the marsh, it shows a surprising diversity of birds and seems to serve as important bird habitat in the Nine Springs E-Way. We concluded that it would be beneficial to incorporate enhancement of recreational

APACHE POND

The changes to hydrology and degraded water quality in Dunn's Marsh have been largely driven by single-family home development in the catchment dating back to a 1950s building boom. Over a 20 year period from 1950 to 1970, nearly all the farmland was converted to housing. Beginning in 1970 with the preservation of the marsh, area residents became interested in preserving the remaining open space and pushed back against several proposed developments. In 1975, the Dunn's Marsh Neighborhood Association successfully prevented the development of two lots north of Dunn's Marsh, where Apache Pond was subsequently built.

Apache Pond intercepts approximately 132 acres prior to discharging into Dunn's Marsh through a culvert under the railroad, 50 acres of which are in the city of Madison. The pond is one of several that have been constructed around Dunn's Marsh that have generated a substantial improvement in water volume, rate and quality. However, several stormwater outfalls still flow directly into the marsh. As part of the Nine Springs Master Plan, several options are being explored to enhance the performance of the outlet north of the marsh where Apache Pond sits, including building a second pond and enhancing an existing rain garden (Renaissance) with a stormwater treatment structure or converting it to a wet pond.

opportunities for the community related to bird watching and education.

Our physical assessment of Dunn's Marsh consisted of chemical analyses of water samples taken from Dunn's Marsh over the spring and summer months, as well as continuous monitoring of dissolved oxygen, water temperature, and water level (Figure 2.2). We concluded that due to the chemical make-up of the water samples, Dunn's Marsh is primarily fed by surface water runoff from storm events. Although the water is nutrient-rich, the overall water quality is good. The water monitoring concluded that Dunn's Marsh is prone to daily temperature and oxygen spikes during the summer months, making the marsh ideal for vegetation and macroinvertebrate communities, but unlikely to support fish species.

Our community assessment was based on a survey of residents in the neighborhoods near Dunn's Marsh and interviews with stakeholders (Appendix H; Figure2.3). The survey focused on the demographics of the surrounding neighborhoods of Dunn's Marsh and their awareness of Dunn's Marsh as a community resource. We found that the Dunn's Marsh neighborhood is highly diverse, both racially and economically. While this presents a challenge for outreach efforts, requiring a multipronged approach, it also provides an opportunity for environmental projects to reach populations that may be traditionally underserved. The top three recreational activities preferred by survey respondents are: scenic beauty enjoyment, biking and winter activities, and family picnicking near water. Our results concluded that survey respondents had little awareness of Dunn's Marsh, its location, and its availability as a public green space and community resource.

Figure 2.2: Korin Franklin and Aaron Lamb collecting water samples and preparing water monitoring equipment.

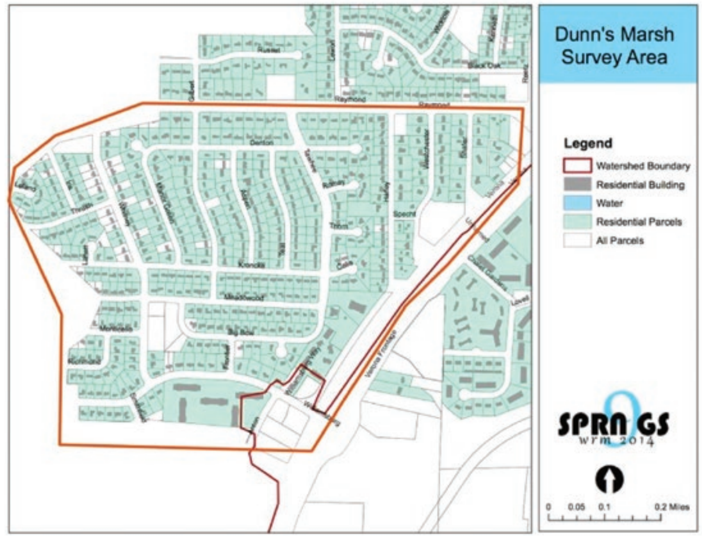

Figure 2.3: Survey distribution area outlined in orange.

These assessments led us to conclude that rehabilitating entire plant communities in Dunn's Marsh would be infeasible without also addressing stormwater inputs. Because of this, our recommendations focus on the improvement of the marsh as a community recreational resource. The marsh itself is functioning as a wetland, but community awareness of the resource is low, and as a result the marsh is underutilized as a recreational and educational resource.

Dunn's Marsh recommendations

From the concerns we identified, we developed four recommendations to enhance the marsh as a recreational and educational resource. Our first recommendation is to improve direct access to the marsh by adding a boardwalk to connect two existing trails (Figure 2.4). The marsh is flanked by the Cannonball Path to the north and the Capital City Trail to the south. As the marsh currently exists, a hiker or cyclist interested in walking or biking around the marsh to access the other side would have to exit the trail and walk or bike along Seminole Highway, a heavily traveled roadway without a cycling lane or foot path. With this in mind, we recommend a boardwalk that extends across the marsh, thereby completing the circle and improving public safety. This will also allow user access to the water.

Our second recommendation is to improve viewing of the marsh by installing viewing platforms that would extend from the existing Apache Pond Boardwalk. This will provide a place to install educational signage to inform users about the history of the marsh and the importance of pro-

Figure 2.4: Stylized graphic showing a proposed boardwalk connecting Apache Pond and Dunn's Marsh, with a view of the marsh.

tecting places on the landscape, like the marsh, that serve as important habitat for birds. This will also provide a space to install stationary binoculars (Tower Viewer) that encourage users to look for the birds they learned about on adjacent signage. It is also important to highlight recent efforts by the Cities of Madison and Fitchburg and the Dunn's Marsh Neighborhood Association to expand recreational facilities in and around the marsh over the previous two years. Viewsheds or priority areas should be developed that take into account the location of these facilities and the likely viewpoints into the marsh.

Our third recommendation is to enhance the edge vegetation and incorporate edge maintenance of the marsh. Vegetation removal and subsequent planting could be done through volunteer efforts and used as an educational tool for youth in the area.

Lastly, we recommend that the cities of Madison and Fitchburg partner with area stakeholders for the purpose of engaging interest groups and the public and to educate potential users about the enhancements and benefits from the use of the marsh as a natural resource. Dunn's Marsh provides numerous opportunities for public engagement and education, such as the addition of interpretive signage; youth birding activities co-organized by the Audubon Society and City of Fitchburg; a partnership between the City of Madison and the local Boys & Girls Club or scouting groups to build wood duck boxes; and the use of Dunn's Marsh as an outdoor classroom for science education in area schools (Figure 2.5).

Community benefits

The existence of quality natural amenities in urban areas is important to human health and well-being. Green spaces such as the Nine Springs E-Way and Dunn's Marsh contribute to healthy, livable communities. Dunn's Marsh and the Nine Springs corridor are beneficial for recreation such as birding, walking, cycling and running. In addition to enhancing the bordering neighborhoods of Dunn's Marsh, these resources are available to the larger community by adjacent trails. The community is fortunate to have these natural amenities to use, but in order to be of value, more awareness and accessibility are needed, as evidenced by the results of a community survey. The added benefit of educational components such as youth birding and building duck boxes, volunteer work days, and other activities, can lead to the long-term commitment and interest of the community.

Cost estimation and funding opportunities

Based on work already completed at Apache Pond just to the north of the marsh, we expect interpretive signs to cost approximately $2,000 per sign. This cost includes graphic design, printing, and aluminum frame materials. Cost of a boardwalk, based on the walk that extends from Apache Pond to Cannonball Path, is estimated to be approximately $100,000. Potential sources of funding include the Madison Stormwater Utility; the Wisconsin DNR Urban Non-Point Source and Stormwater Grant Program; City of Madison

Figure 2.5: Signage detailing Dunn's Marsh ecology and history.

general funds; and Dane County's Partners for Recreation and Conservation (PARC) grant program.

Chapter summary

Our recommendations for Dunn's Marsh revolve around maintaining the current site with potential for improvement of the flora and fauna along with structural improvements that will provide connectivity around the marsh. We recognize that the marsh will not be returned to its natural, pre-urbanized state, but we believe that through maintenance of the marsh edge, habitat — especially that of birds — may improve. The marsh is an important area for many community members for education and recreation. Many community members are not aware of the area and what is needed to minimize further degradation. Our key recommendations include edge maintenance and enhancement along the marsh. We envision this removal and subsequent planting being done through volunteer efforts and used as an educational tool for youth in the area. Birding is a popular activity in the marsh, and since Fitchburg is recognized as a Bird City, this seems a natural extension of that distinction. Extending the boardwalk from Apache Pond to either reach across the marsh or connect for circulation around the marsh is also recommended. Alternatively, the boardwalk could end with a lookout and viewfinder binoculars.

Lastly, we recommend that the cities of Fitchburg and Madison partner with other area stakeholders they can identify as champions of the marsh. The Dunn's Marsh Neighborhood Association seems a natural partner to continue efforts in educating the community on best practices for stormwater management, and other improvement efforts. Our recommendations will benefit the community by providing a natural space for educational opportunities and recreation for years to come.

Conclusion

In this report we have presented a set of recommendations for Nine Springs Creek and Dunn's Marsh. When evaluating these recommendations, we must consider the two sites as features within the larger context of the Nine Springs E-Way. When Phil Lewis presented the concept of an E-way, he challenged all of us to move beyond thinking of urban and natural environments as mutually exclusive. The E-way is an interactive environment that strings together natural and cultural resources into a corridor with ecological and educational value that exists within the heart of a community. Dane County took up this challenge and set aside 1,300 acres of land to form a continuous corridor running from Dunn's Marsh to Lake Waubesa. The very existence of the Nine Springs E-Way is a credit to the county's dedication to Phil Lewis' idea.

However, in studying the E-way, we learned an important lesson: It is not enough to set land aside. It is not even enough to enhance access to the land with cycling and walking paths. We have to consider the health and functionality of the land within the corridor. The major features of the Nine Springs E-Way are vibrant and beautiful pieces of land, but they are also impaired. Nine Springs Creek has been channelized and used to drain its surrounding wetlands. Dunn's Marsh has been transformed into a stormwater retention pond. If we truly want the E-way to live up to its goals, we have to address these problems.

For Nine Springs Creek, we recommend running the creek through a much smaller channel that follows a historic meander through the surrounding wetlands. Raising the bed of the channel and reducing its volume will reconnect the creek to the wetlands through more frequent, small-scale flooding. Along with restoring a natural relationship between the creek and the wetlands, increased flooding will trap sediment and phosphorus within the wetlands, improving water quality. Our models show that our design clearly has the potential to achieve all of these benefits.

At Dunn's Marsh, we found that the transition to a stormwater retention pond is permanent. Without major changes

Figure 2.6: Winter in the wetlands.

to the heavily urbanized area draining to the marsh, certain wildlife will be excluded, and boating and fishing on Dunn's Marsh will be impossible. Nonetheless, we found that Dunn's Marsh was still highly valued by the people who lived nearby. Our analysis suggested that educational opportunities and increased access will reinvigorate the connection between the community and the E-way, while managing the vegetation in and around the marsh will improve habitat. These recommendations are not restorative, but adaptive. We cannot undo the changes brought about by development, but we can learn from them. Dunn's Marsh can warn of the impacts of development while at the same time temper that warning by demonstrating that even an impaired environment can have ecological value.

Adding the pike spawning bed as a new feature within the E-way is another example of an adaptive recommendation. Repurposing the old channel into a feature that enhances the ecological and economic health of the E-way sends an important message: that when we restore an area, we don't have to discard all of the features that were introduced during development. These can be recycled to serve an entirely new purpose that benefits the entire system.

Our recommendations are practical but ambitious, achievable but transformative. They are the result of working hard, thinking carefully, and listening closely. While each recommendation is very different in approach and expected outcome, they each build on efforts of Dane County. If implemented, these recommendations will contribute to the needs of the community and the health of the environment, and help the Nine Springs E-Way take a profound step toward realizing Philip Lewis' vision.

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AQUATIC BENTHIC MACROINVERTEBRATES AS INDICATORS OF STREAM QUALITY

Introduction

Benthic macroinvertebrates are a diverse group of organisms inhabiting stream-bottom sediment and clinging to submerged rocks and vegetation. Benthic macroinvertebrates are an important component of the food web and are needed to support a variety of fish species (Horne & Goldman, 1994). These organisms display a wide range of pollution tolerance levels, and there are strong correlations between the richness and abundance of certain species and water quality. In contrast to chemical parameters, which only indicate conditions at the time of sampling, the results of a macroinvertebrate survey integrate water quality conditions over a longer time scale (the life span of the organisms). An index of biological integrity (IBI) is a numeric score of the overall health of a waterway, determined by comparing the quantities of given species against their tolerance levels. By assessing the biological integrity of Nine Springs Creek in this way, we hoped to provide an updated baseline that may be referred to in future studies and add to our overall interpretation of the study site.

Site selection and sample collection

We conducted a family-level index of biological integrity (IBI) to assess stream health along a portion of Nine Springs Creek (Barbour, Gerritsen, & Stribling, 1999; Hilsenhoff, 1988). To supplement this, and to comment on overall benefit of these types of analyses, we used the same macroinvertebrate samples to compare the results of our IBI, which in theory is more accurate and detailed, to the results of the UW Extension's Citizens Monitoring Biotic Index.

We conducted two sampling events, during April and June, at six sites along Nine Springs Creek from the Nevin Fish Hatchery to Highway 14 (Figure A.1). These sites were chosen to represent the diversity of habitats in the creek, with varying widths, flows, substrate types, and canopy cover. Sampling methods were adapted from the State of Wisconsin Guidelines for Collecting Macroinvertebrate Samples in Wadeable Streams (WDNR, 2000). At each sampling site, bottom sediment was suspended while a standard D-frame net was swept back and forth in the sediment plume until a softball-sized lump of substrate, vegetation, and benthic invertebrates was collected. The habitat and substrate were classified and water temperature and dissolved oxygen (DO) were recorded in conjunction with the sampling.

Figure A.1: Sites sampled for index of biological integrity (IBI) and Citizen Monitoring Biotic Index (CMBI) in April and June 2014 on Nine Springs Creek.

Samples were stored in jars containing 95% ethanol to preserve the macroinvertebrates.

Laboratory methodology

Lab procedures for sorting and identifying organisms were adopted from the standard operating procedure (SOP) written by Kurt Schmude of the University of Wisconsin-Superior titled "Standard Operating Procedure Picking Benthic Invertebrates from Qualitative Samples (Using Cation Trays)." These procedures are congruent with EPA's SOP for "Wadeable Streams Assessment" (U.S. EPA, 2004).

A 25 ml sample was randomly measured from which all debris and organisms were removed and transferred to a petri dish. Using a dissecting microscope, macroinvertebrates were removed from the sample and placed into ice-cube trays, each holding an order or common family.

Once 100 macroinvertebrates were counted among observers, collection from the main sample tray was stopped, remaining sub-samples were processed completely, and the macroinvertebrates were identified to the family level and counted (Bouchard, Ferrington & Karius, 2004).

The IBI score was calculated by multiplying the number in each family by the tolerance value for that family. The products were them summed and divided by 100 or by the total number of macroinvertebrates observed (Hilsenhoff, 1988).

Table A.1: Biotic Indices		
Hilsenhoff FBI	Water Quality	Degree of Organic Pollution
0-3.75	Excellent	Pollution Unlikely
3.76-4.25	Very Good	Possible Slight Pollution
4.26-5.00	Good	Some Pollution Probable
5.01-5.75	Fair	Fairly Substantial Pollution Likely
5.76-6.50	Fairly Poor	Substantial Pollution Likely
6.51-7.25	Poor	Very Substantial Pollution Likely
7.26-10.00	Very Poor	Severe Organic Pollution Likely
CMBI	Water Quality	
3.6+	Excellent	
3.5-2.6	Good	
2.5-2.1	Fair	
2.0-1.0	Poor	

Table A.1: Hilsenhoff's (1987) range of IBI scores and water quality criteria (top), and CMBI scores (bottom).

Table A.2 IBI Results		
Site (Month)	CMBI	FBI
1 (April)	N/A	N/A
1 (June)	1.6	7.9-8.0
2 (April)	1.6	7.6-7.9
2(June)	1.6	7.7
3(April)	1.7	7.9-8.1
3(June)	1.5	7.9-8.1
4(April)	1.6	7.8
4(June)	1.3	7.8
5(April)	1.9	7.7
5(June)	1.5	7.9-8.0
6(April)	1.7	7.5-7.9
6(June)	N/A	N/A

Table A.2: Sampling sites and associated tolerance scores for each month sampled.

The Citizen Monitoring Biotic Index (CMBI) was also calculated following the same methods as the IBI above, but macroinvertebrates were identified to the order level instead.

Results

Table A.1 shows ranges for both IBI and CMBI scores and their associated water quality. Table A.2 shows sampling sites for each month with their associated tolerance scores. In Table A.2, N/A represents sites that were sampled incorrectly and did not contain enough macroinvertebrates for analysis. The varying ranges for the IBI were for organisms designated either as red midges (left value) or non-red midges (right values). One drawback of the application of the rose bengal solution is that every organism is tinted red, so the differentiation between red and non-red midges was lost.

Discussion and conclusions

Both the Citizen Monitoring Biotic Index and the more specific Family Biotic Index found every sample taken from Nine Springs Creek to be indicative of poor water quality and severe organic pollution (Table A.1). Every sample was dominated by pollution-tolerant oligochaetes (worms) with an assortment of isopods, leeches, chironomid midge larvae, crustaceans, and gastropods. Relatively pollution-intolerant dragonfly, mayfly, and stonefly larvae were absent from samples except for a single baetid mayfly. Pollution-tolerant organisms are often classified as such because of their ability to survive in streams with low dissolved oxygen (DO), which is removed from the stream as organic matter decomposes. While our field measurements found high DO levels in the water column, levels just below the sediment surface can drop dramatically.

Several limitations are associated with our approach. We sampled exclusively benthic habitats consisting mostly of stream-bottom sediment; focusing on those habitats likely skewed our results. The methodology we used was designed for riffles rich in sand and gravel rather than fine sediment. While we did adapt this methodology by tailoring our sampling technique, we would have benefited from sampling bankside habitats as well. Sampling conducted by Wisconsin DNR biologists in the fall of 2014 on the eastern reaches of Nine Springs Creek included sampling from bankside overhanging vegetation and revealed more diversity with a greater representation of pollution-intolerant mayflies (Sorge, 2014).

Additionally, the optimal time of year for sampling defined by Hilsenhoff is before June 1 and between September 1 and October 15 (Hilsenhoff, 1987). Sampling outside of these recommended dates risks missing invertebrates that have matured and left the water, or juveniles that are too immature to be accurately identified. Biotic index scores calculated by Hilsenhoff's methods are normally inflated in summer relative to the rest of the year. Due to the limitations of our available sampling time, we sampled in April and June and were not able to collect samples in the fall.

Our analysis of macroinvertebrates in Nine Springs Creek is consistent with previous work suggesting that Nine Springs suffers from organic and nutrient pollution. Two previous indices of biological integrity (using Hilsenhoff's biotic index) were calculated by WDNR staff. In 1989, the reach of Nine Springs Creek near Mooreland Road scored 6.1, and in 2011, the reach near Brendan Avenue scored 8.9. These samplings included a higher proportion of sensitive mayflies, caddisflies, and stoneflies than our efforts, probably due to field technique.

Improving the diversity of macroinvertebrates in Nine Springs Creek will require reducing organic matter inputs at a watershed level. However, re-meandering the stream between Syene Road and Highway 14 would likely improve water quality in downstream reaches and make low DO events less likely. With less organic matter undergoing decomposition, more oxygen would be available for macroinvertebrates, increasing the number of species that would find the stream habitable. A more diverse macroinvertebrate assemblage would also provide a greater array of prey organisms for fish, amphibians, and some mammals.

NINE SPRINGS CREEK WATER QUALITY ANALYSIS

The term "quality" describes the impact of chemical and physical parameters, in both soil and water, on a healthy ecosystem. We built our assessment of quality from three main components: water quality, soil chemistry and an index of biological integrity (IBI). Our choice of parameters was driven not only by our examination of land usage, but also by specific events associated with common water quality issues in Wisconsin. Before discussing our assessment, it is important to review these events to provide context for some of the choices we made.

Discussions on water quality in Wisconsin are often focused on nutrient load and eutrophication. Eutrophication of a waterway leads to a series of negative impacts, including blooms of toxic algae, decreased oxygen levels, and death of aquatic organisms. In Wisconsin, phosphorus loading is the primary cause of eutrophication. It is most frequently introduced into wetlands and waterways by runoff that contains phosphates, a broad range of chemicals found in fertilizers, detergents, and wastewater. We assess phosphorus pollution by measuring the combination of soluble and insoluble phosphates as a total phosphorus (TP) concentration. However, phosphates are so frequently a component of sediment that high measurements of total suspended solids (TSS) often indicate high measurements of phosphorus, and so regulations meant to combat eutrophication usually address levels of both TP and TSS.

In order to meet the requirements of the Clean Water Act, the Wisconsin Department of Natural Resources (WDNR) submitted a list of impaired waters to the U.S. Environmental Protection Agency. In 2011, the EPA subsequently approved total maximum daily loads (TMDL) for total phosphorus (TP) and total suspended solids (TSS) to address degraded aquatic habitat in the Rock River Basin. A TMDL determines the maximum amount of a pollutant that a water body is able to incorporate while meeting water quality standards (U.S. EPA, 1991). Nine Springs Creek has been added to the list of impaired waterways because water samples exceeded limits for both total phosphorus and total suspended solids.

This informed both our site assessments and our site recommendations. While we measured many water quality parameters that are important to habitat, we did not thoroughly measure TP or TSS. Given the importance of TP and TSS to our design, this may seem like an oversight, but in fact it was a conscious choice. The fact that Nine Springs Creek is an impaired waterway meant that any recommendations we would make would have to include steps to reduce phosphorus and sediment loads. Therefore, phosphorus and sediment load became design parameters, and we felt it best to rely on larger bodies of existing data rather than basing our designs on a limited set of measurements we might take. One such source of data came from the Madison Metropolitan Sewerage District (MMSD). Water quality testing undertaken by MMSD from 2002 to 2012 showed about half of samples exceeded Wisconsin's state criteria for total phosphorus.

Water chemistry

This section includes the discussion of several chemical and physical parameters that we measured in Nine Springs Creek. These parameters include pH, specific conductivity, major anions, dissolved oxygen and temperature.

We gathered data on dissolved oxygen concentration and

Figure B.1: Daniel Aragon performing cleaning and maintenance on a miniDOT sonde.

Table B1: Major Anion Concentrations in Nine Springs Creek (mg/L)

Site	Date	Chloride	Nitrate	Sulfate
Jenni-Kyle	19-May	59.9	17	19
East Syene		62.5	16.7	19.6
East Railroad		72.7	15.6	20
Jenni-Kyle	6-Jun	60.3	18.4	18
East Syene		59.2	16.4	16.2
East Railroad		67	15.4	16.7
Jenni-Kyle	7-Jul	65	11.8	16.1
East Syene		56.5	8.7	14.4
East Railroad		55.7	7.8	12.7
East Syene	28-Jul	21.7	18.4	15.1
East Railroad		26.9	16.6	13.3

Table B.1: Table of water quality parameters from three sites during May and June, 2014.

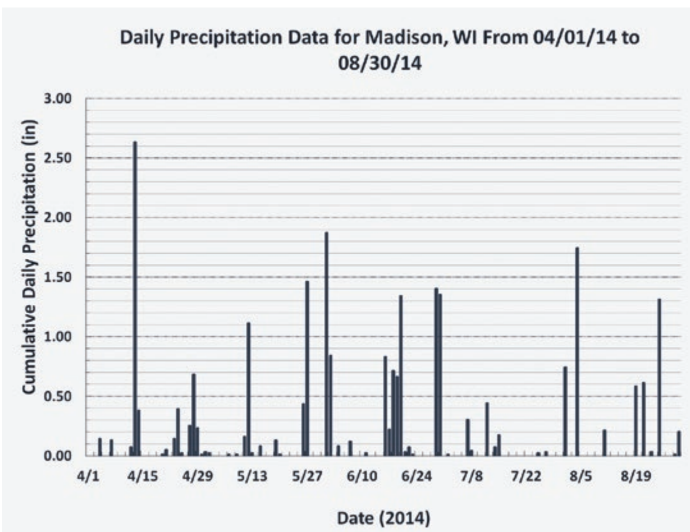

Figure B.2: Graph of precipitation time series for Madison, Wisconsin, April 1, 2014, through August 30, 2014 (Source: NOAA).

water temperature by deploying two miniDOT sensors that took readings every ten minutes from approximately May 15 through August 31, 2014. The first sensor was placed immediately west of the railroad bridge; the second sensor was placed to the west of Jenni-Kyle Preserve.

A summary of our analyses of water quality parameters appears in Table B.1. We will go through these parameters separately to discuss the significance of our findings and the impact that each had on our design goals.

pH

The pH scale, which measures acidity, runs from 1 to 14, with a measurement of 7 considered neutral, a measurement below 7 indicating acidity, and a measurement above 7 indicating alkalinity. Because differences exist in tolerances among fish, we measured various pH levels in order to help determine what species we could design habitat for.

Changes in pH can affect the composition and properties of other chemicals. Sudden shifts in pH along a waterway can be a telling indicator of a point-source for pollution; hence our decision to collect samples at several points along our site.

All of our measurements showed slightly alkaline pH, with the lowest measurement at 7.8 and the highest at 8.7. We observed no appreciable spatial variation in pH. On May 19, the pH was 8.5 at the East Railroad sampling site and 8.7 at the Jenni-Kyle Preserve sampling site. On June 6, both sites were measured at 7.8.

The pH values measured on May 19 are consistent with pH measurements of groundwater from nearby wells supporting the idea that, along this reach, Nine Springs Creek is predominately spring-fed rather than fed by surface water. The lower pH observed on June 6 would seem to call this into question but can be explained by a dilution of groundwater by more acidic rainfall that occurred on June 3, as shown in Figure B.2. The spatial consistency of both sets of measurements further supports the idea that there is no surface water point-source within our reach. While this is a limited data set that should be augmented, it suggests that we do not need to accommodate a major point-source of surface water into any restoration designs that are limited to our study site.

Specific conductivity

The conductivity of water is affected by the quantity and compositions of ions within the water. Conductivity in inland waters is typically measured in micro-Siemens (μS/cm) (Kalff, 2002). The source of ions in water can vary, with one source being sediment-rich runoff. High measurements of conductivity are often correlated with high levels of total suspended solids. Sudden variations in conductivity can indicate a point-source of pollutants. To provide a good benchmark, streams that support a healthy fishery will have a range of conductivity between 150 and 500 μS/cm (U.S. EPA, 2012).

We measured specific conductivity at all three sites on Nine Springs Creek. Measured values ranged from 656.9 μS/cm at Jenni-Kyle on May 19th to 715.5 μS/cm at the East Railroad site on June 6th, with the average value being 669 μS/cm. Compared against streams of similar size and from similar ecological regions in the state (Figure B.3), Nine Springs Creek is in the 77th percentile for high conductivity.

Dissolved oxygen and temperature

Dissolved oxygen (DO) is essential in aquatic environments for plants and animals to survive. If the concentration of DO

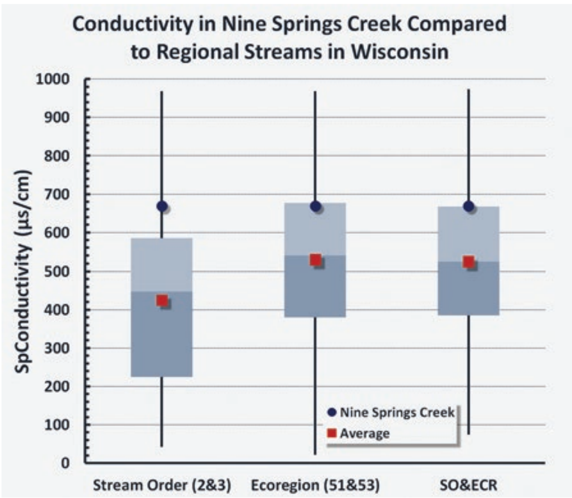

Figure B.3: Comparison of specific conductivity in Nine Springs Creek to similar streams in Wisconsin.

falls below 5 ppm, many species of fish begin to die, followed by invertebrates and even aerobic bacteria if it continues decreasing. Because Nine Springs Creek is fed by a series of natural springs, it could be expected to have low dissolved oxygen due to an anaerobic process that removes oxygen from groundwater. However, the springs here are fed by local percolating waters that have low underground residence time; therefore the springs retain much of this dissolved oxygen.

In aquatic systems, temperature is responsible primarily for establishing thermal stratification and regulating chemical reactions and biological processes (Kalff, 2002). While thermal stratification is not an issue in Nine Springs Creek due to its shallow depths, water temperature is critical to biota that are present. Fish have a specific thermal optimum at which they thrive. If this thermal optimum is exceeded, temperature can be lethal to fish as well as other biota present (Fry, Black & Black, 1947). Usually, shallow, slow-flowing water bodies like Nine Springs Creek respond rapidly to increases in solar radiation. Due to the creek being fed largely from cool groundwater inputs, it resists rapid temperature fluctuations.

We measured dissolved oxygen and temperature in Nine Springs Creek throughout the summer. We deployed two sensors that measured and recorded DO and temperature at ten-minute intervals (Figure B.4; Figure B.5). Overall, our data suggest that in its current state, the study reach is fairly inhospitable during the summer months. DO fluctuates diurnally, reaching maximum concentrations well above saturation during the day, when photosynthesis yields oxygen, and dropping to extreme lows at night, when cellular respiration occurs without photosynthesis. These large diurnal fluctuations suggest that sensitive organisms would struggle to survive in the study reach under current conditions.

Chloride, nitrate and sulfate

We analyzed samples for chloride, nitrate and sulfate (Table B.2; Table B.3). Samples were collected and analyzed approximately once per month from May through August. We converted our measured nitrate concentrations to NO_3-N concentrations for the purpose of comparison to other groundwater data (Figure B.6). We found that the absolute values of these measurements supported the idea that Nine Springs Creek is primarily fed by groundwater, and spatial consistency of all measurements again supports the conclusion that there is no point-source of surface water flowing into our reach.

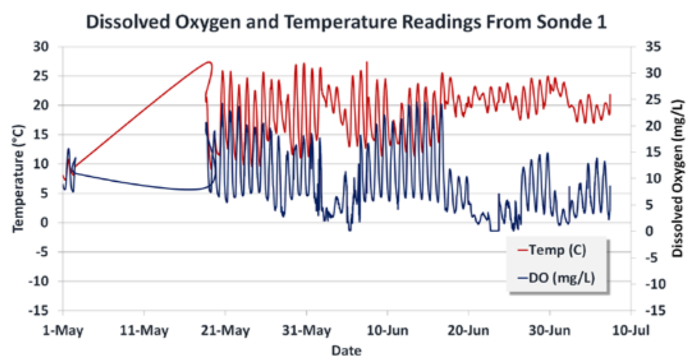

Figure B.4: Time series of DO and temperature from sonde 1.

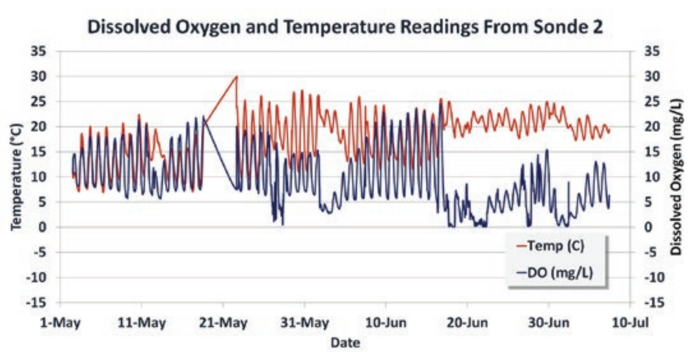

Figure B.5: Time series of DO and temperature from sonde 2.

Table B2: Nine Springs Creek Water Quality Parameters

Site	Date	T (°C)	pH	Cond (µS/cm)	Chlorophyl l (µg/L)	fDOM (RFU)
Jenni-Kyle	19-May	7.8	8.7	656.9	25.3	8.6
	6-Jun	7.8	7.8	696.7	8.6	7.4
East Syene	19-May	8	8.6	666.2	30.6	12.2
	6-Jun	8.9	7.8	693.2	1.7	15.3
East Railroad	19-May	10.6	8.5	686.6	57.8	10
	6-Jun	8.4	7.8	715.5	1.5	16.8

Table B.2: Major anions from water samples taken from three sites on Nine Springs Creek throughout the summer of 2014.

Table B3: Nitrate as nitrogen in NSC.

Site	Date	NO_3-N (mg/L)
Jenni-Kyle East Syene East Railroad	19-May	3.8 3.8 3.5
Jenni-Kyle East Syene East Railroad	6-Jun	4.1 3.7 3.5
Jenni-Kyle East Syene East Railroad	7-Jul	2.7 1.9 1.8
East Syene East Railroad	28-Jul	4.1 3.7

Table B.3: NO3-N concentrations in water samples taken from three sites on Nine Springs Creek throughout the summer of 2014.

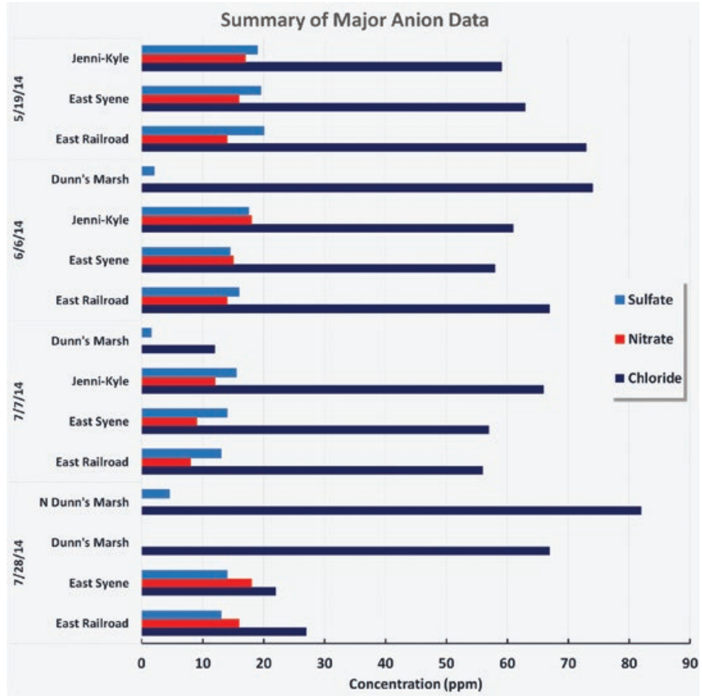

Figure B.6: Summary of water quality parameters from samples taken from four sites in the Nine Springs E-Way during the summer of 2014.

Discussion and conclusions

There are two important points that we took away from our chemical analyses of water quality in Nine Springs Creek. The first pertains to the uniformity of the channel input. Our analyses upstream and downstream of Syene Road showed both consistency in the absolute values of various parameters as well as the response of those parameters to rainfall events. These observations suggest that there is no single point-source of pollution that we needed to be concerned with along our reach. The water that dominates the channel appears to be mostly groundwater, with no major inputs of surface water within our study site. The second point concerns oxygen levels in the stream. We observed very low concentrations of oxygen during the summer months, with large diurnal fluctuations of both dissolved oxygen and temperature. It is our opinion that the low DO levels result from nutrient-fed blooms of vegetation during the summer months. The temperature swings are likely a result of the fact that Nine Springs Creek is a broad, shallow, slow-moving channel with very little shade provided by overhanging vegetation.

Our proposal to re-meander the stream through a smaller channel might mitigate these factors by removing nutrients from the water and increasing flow velocity in the channel itself. However, those outcomes are not guaranteed. Certain fish species such as trout rely on high DO levels and cold temperatures over sustained periods. Our analyses suggest that even with modification, this channel could only serve such species in the early spring and would not be able to sustain hospitable conditions throughout the summer.

NINE SPRINGS CREEK ECOLOGICAL HEALTH AND DIVERSITY

Introduction

The Nine Springs Creek ecosystem is largely defined by the hydrologic regime and the vegetative makeup of the marsh. As the former is addressed in other sections, our discussion of ecological health focuses on the latter. Vegetation plays a crucial role in the ecology of wetlands by providing structure, sustenance and habitat. We were unable to conduct a vegetation survey of the Nine Springs study site, but were able to draw upon literature and previous fieldwork to inform our recommendations and consider the implications of our recommendations for the organisms inhabiting our study site. Our assessment of ecological health in the channel has already been discussed in our water quality section. The focus below is on the surrounding wetland.

The ecological state of wetlands around Nine Springs Creek

Vegetation conditions in the wetland around Nine Springs Creek have likely been driven by channelization and nutrient input. In a healthy wetland, we would expect to see a range of emergent wet-meadow species such as sedges (*Carex sp.*), bluejoint grass (*Calmagrostis canadensis*), and hardstem bulrush (*Scirpus acutus*). Channelization decreased the frequency and length of flooding thereby drying out the wetland and opening the door to invasive species. Some areas were overtaken by woody shrubs, including buckthorn (*Rhamnus cathartica*) (Bedford, Zimmerman & Zimmerman, 1974). In other areas, increased nutrient input and active planting efforts helped establish two other invasive species that are notorious in the Midwest: reed canary grass (*Philaris arundinacea*) and hybrid cattail (*Typha x glauca*) (Woo & Zedler, 2002; Zedler & Kercher, 2004). The extent of the reed canary grass invasion in our study area is visible at many points. While woody shrubs persist adjacent to the trail and the ponds of the preserve, reed canary grass is the only visible plant across broad swaths of the wetland, occasionally broken by large monocultures of invasive narrow-leaf cattail.

Previous accounts of vegetation from a 1974 wetland survey and the 1996 WRM practicum show that the transition from native wet meadow to reed canary grass/cattail monocultures has taken place over decades. In 1974, the south bank of the stream in what today is the Capital Springs State Recreation Area was still identified as sedge meadow, but by 1994 much of that area had been encroached upon and was labeled "transitional." Today this area harbors only small pockets of non-invasive vegetation. East of Highway 14, areas labeled "transitional" in 1974 had become fully invaded by 1996. The 1996 practicum report noted that some areas of native vegetation persisted near springs where frequent inundation still occurs.

Changes in habitat and food sources lead directly to changes in the population of consumers, especially arthropods. The presence of reed canary grass has a negative impact on plant-feeding arthropods, birds, amphibians, and small mammals. The changes in vegetative structure associated with a reed canary grass invasion are important for animals that use wetland plants for cover, nesting, or as hunting grounds.

Conclusions

The ecological health of the surrounding wetland is clearly compromised by colonization of invasive species and a resulting loss in diversity. As the success of these species is aided by channelization and drainage of the wetland, it is important for us to consider what possible impacts stream restoration would have on the health of the surrounding wetland.

The stream restoration we propose will increase the length of the channel and decrease its volume, making the Nine Springs Creek wetland a more dynamic habitat. Lengthening the channel increases the boundary area along the channel, and decreasing the channel volume leads to more frequent inundation. The new Nine Springs Creek wetland would be a mosaic of stream habitat, pools and side channels. Complex and dynamic habitats, with varying degrees of connectedness and edge lengths, are crucial for a healthy floodplain ecosystem (Naiman, Decamps, Pastor & Johnston, 1988; Ward, Tockner & Schiemer, 1999). However, our proposal is not designed to directly combat the reed canary grass invasion. In places where the grass has grown for many years, the native seed bank is likely depleted, and concentrated restoration efforts will be needed. Reed canary grass is able to grow in a variety of hydrologic regimes, including areas with constant flooding (Zedler & Kercher, 2004). Nevertheless, our proposed re-meander would result in overbank flooding an estimated 10 to 12 times per year, which, if not less suitable for reed canary grass, is more suitable for native wet meadow species, leading to better results if a restoration effort was attempted.

DESIGN OF THE HYDRAULIC, HYDROLOGIC ROUTING AND SEDIMENT TRAPPING MODELS

We propose a restoration of Nine Springs Creek that consists of routing the existing channelized stream through a smaller, shallower, and longer meandering channel. These changes to the dimensions and bed elevation of the channel are intended to promote frequent overbank flooding events, which will reestablish a hydrologic connection between the creek and the surrounding wetlands. Restoring the connection will raise the water table and more frequently inundate the wetlands, soaking the desiccated soils and restoring a regime that is more favorable to native emergent wetland vegetation. In addition to the reconnection of the creek and wetland, the proposed restoration will likely promote improvements to the water quality of the creek. Currently, the creek is considered an impaired waterway because of high levels of total suspended solids (TSS). A key pollutant associated with TSS is particulate phosphorus from urban and agricultural fertilizers that is bound to these sediment particles. Therefore, this restoration of the channel will not only address suspended solids, but also phosphorus that is a key driver of the chronic eutrophication and algae blooms that plague our lake system.

During storm events, two sources are mainly responsible for the sediment pollution in Nine Springs Creek. The first source is overland runoff, which picks up exposed and eroded soil from the local landscape and eventually carries it into Nine Springs Creek. The second source is urban storm sewers that rapidly deliver runoff from impervious surfaces to Nine Springs Creek. Both of these sources contribute to high concentrations of sediment and associated pollutants entering the creek. The impact of the high concentrations of sediment and associated pollutants is augmented by the fact that the existing channel is relatively large and straight, which conveys water too rapidly for the suspended solids to settle out. Therefore, the creek currently acts as a conduit for delivering pollutants into the rest of the Rock River watershed.

By increasing the frequency of overbank flooding, we can spread surges of runoff water over the wetland. When the runoff water is allowed to spread into the wetland, the flow velocity slows down and offers sediment an opportunity to settle out. Additionally, the wetland can act as a structural filter to remove sediment from the floodwater before it flows back into the creek as the storm surge passes. By these two mechanisms, we aim to remove total suspended solids before they enter the rest of the watershed.

To verify the hypothesized benefits outlined above, we constructed and calibrated a hydraulic model of the existing conditions within our study area. The stage-storage relationships of this model were used to construct a hydrologic routing and sediment trapping model of the existing channel conditions. We then used a rainfall runoff model, coupled with statistical analysis of a nearby watershed of similar size and land cover, to determine the maximum flow that would result in an average of 15 overbank flooding events per year. Our analyses showed that having a proposed channel that ran at bankfull conditions at 20 cfs would give us the desired flooding results. This allowed us to build a second set of hydraulic and routing/sedimentation models for our proposed design. By comparing the response of these two models to a series of design storms, we are able to quantitatively answer the following questions:

- How will the proposed restoration affect the frequency of overbank flooding?
- How will the proposed restoration affect the area that is inundated during flooding?
- How will the proposed restoration affect the amount of time that the wetland will be inundated?
- How will the proposed restoration affect the amount of sediment trapped by the surrounding wetland?

The answers to these questions are directly tied to our design goals. If our models show that the proposed restoration increases the frequency, area, and duration of inundation as compared to the existing channel, then we can conclude that our design will achieve the goal of reconnecting the wetland to the creek. If our model shows that the proposed restoration increases the amount of sediment and phosphorus trapped in the wetland, then we can conclude that our design will achieve the goal of improving water quality in the creek and, by extension, the overall watershed.

In the remainder of this appendix, we will go through the construction of the model and discuss how we obtained the necessary inputs to allow the model to answer our design questions.

Hydraulic model construction of existing and proposed conditions

We used HEC-RAS to model the reach of Nine Springs Creek that runs between Fish Hatchery Road and Upper Mud Lake based on field measurements of the channel and existing hydraulic structures, as well as publicly available elevation data on the surrounding wetlands. An early FEMA study gave water elevations and flow rates for a series of return storms. We calibrated our hydraulic model of the existing conditions against those numbers by running the flow rate associated with the return storms and checking the water surface elevations predicted by our model at several points throughout our study area. We found that our model gave a 99% match in water surface elevation to the FEMA report.

Based on our reading of the study by Boyington et al., we determined that to mimic natural conditions, we wanted a design channel that would overflow approximately 15 times per year. To design a channel capable of doing that, we first had to understand the probability associated with various flow rates produced by storms. We approached this problem in two ways. The first was to use the TR-55 method to build a rainfall-runoff model of our existing conditions, using the 1983 precipitation data for our area of Wisconsin. The data from this year is considered by state and federal agencies to be suitable for use as the average precipitation conditions in our region of Wisconsin. Running the precipitation data through our rainfall runoff model gave us a series of stormflow hydrographs with associated peak flow values. The 16^{th} largest flow volume observed from the 1983 data was approximately 20 cfs. Approximately 65% of the peak flows observed were at or below 20 cfs. From these values, we determined that approximately 20 cfs would be the maximum discharge we would want our design channel to hold in order to average 15 overbank flooding events per year.

Our second approach involved adapting gauge-transfer techniques, using flow data from another watershed to generate flood hydrographs. Where gauges exist, flood hydrographs and frequency characteristics are easy to obtain from recorded data. However, Nine Springs Creek has no such dataset, so estimation was necessary. Much work has been done in developing techniques to estimate runoff flow in ungauged watersheds based on physical characteristics. These techniques are imperfect, mostly applied to large rural watersheds, and they vary in both approach and efficacy. Exactly reproducing these techniques in a small, urbanized watershed such as that of Nine Springs Creek is completely unrealistic. However, the concepts behind this approach are not unreasonable. The Spring Harbor storm sewer gauge is located approximately 10 miles from our study area. The gauge records the flow data for a 3.2 square mile watershed with very similar urbanization characteristics, which experiences the same rainfall patterns in an average year as Nine Springs Creek. By scaling the flows from this gauge up to the area of the Nine Springs Creek watershed, we arrive at a reasonable estimate of the flows we can expect.

Analyzing the frequency characteristics of the peak flow data allows us to arrive at a reasonable estimate of the probability of observing our scaled flows. We estimated frequency by analyzing peak flows from 15 years of flow data taken at 15-minute intervals, selecting the peak flows for a given day. Some of these peak flows are artificially high as a result of a malfunction in the gauge. To account for this, we compared the peak flow to an average of the measurements taken before and after the peak flow to check for unreasonably high jumps in flow rate. We calculated an average ratio of peak flow to these bracketing flows and then discarded peak flows that were below the second quantile or above the third quantile of the range of ratios we calculated. By doing so, we were reasonably confident in the peak flow measurements used for frequency analysis. These measurements were separated into 12 flow bins, and an empirical measurement of probability was developed by looking at the number of observations of flows falling within each bin. Our analysis agreed with the results of our rainfall-runoff model, showing that approximately 65% of the flows observed in any given year would be at or below 20 cfs.

This number led us to our proposed channel design. Our channel geometry was a rectangular box approximately 3.5 feet wide and 2.5 feet deep. We chose this shape because natural streams running through wetlands often show a rectangular or square geometry (Boyington, 2010) and because that volume resulted in bankfull discharge at 20 cfs of flow.

Hydrologic routing model construction and inputs

Our study area is the reach of Nine Springs Creek that runs between Fish Hatchery Road in the east to Highway 14 in the west. In that reach, Nine Springs Creek runs through wetlands that slope upward as you move north or south of the creek, forming a broad shallow basin. In a prior flood insurance study, FEMA showed that this basin is capable of containing floods as strong as the 500-year event. Our HEC-RAS hydraulic model was calibrated against the water surface elevations presented in that study and supports that finding.

The basin formed by the wetlands in our study area is broken up into three pieces by two barriers: Syene Road and the railway. The raised bed of supporting these constructs runs north/south through the wetland and effectively creates three sub-basins connected by the culverts under Syene Road and an arch under the railway. All of the water coming in from the upper watershed enters into the western basin.

At the eastern end, all of that water, plus any additional runoff accumulated in the watershed between Fish Hatchery Road and Highway 14, flows out of the basin through the box culverts under Highway 14.

Therefore, our hydrologic model is conceived as reservoir routing models consisting of three basins connected at eastern and western points. The western basin is the first reservoir and consists of the wetland between Fish Hatchery Road and Syene Road. Outflow from the western basin serves as inflow for the central basin (the area of the wetlands between Syene Road and the railway). Outflow through the arch of railway serves as inflow for the eastern basin, which consists of the wetland between the railway and Highway 14.

The reservoir routing model consisting of three connected basins is the first part of our model and addresses the questions previously posed regarding the reconnection of the creek to the wetland. The only inputs required for this model to work are:

- Stage storage tables for each basin;
- Outflow rating curves for the culverts at Syene Road and Highway 14 and the arch under the railway; and
- Stormflow hydrographs that serve as the initial input and increase each hour over a set period of time to a predetermined peak flow.

The stage storage tables and the outflow rating curves were constructed using our HEC-RAS hydraulic model — which in turn was built from survey measurements of our culverts and the arch and digital elevation maps — which allows us to represent the actual topography of the wetlands. Calibration of the water surface elevations associated with particular flow rates against the FEMA flood insurance study gives us confidence that the stage storage tables are reasonable representations of the storage characteristics of the study area. We simulated a series of flow rates and recorded the predicted storage volume and outflow from each of the connection points to use for these inputs. Flows from 5 cfs to 1,000 cfs were considered, representing baseline to a reasonable extreme maximum based on the FEMA flood insurance study, respectively, rather than trying to work with rainfall data and a rainfall runoff model to produce a flood hydrography.

Analyzing the duration of increases and decreases associated with peak flows in the Spring Harbor storm sewer gives us a reasonable estimate of the overall duration of the entire hydrograph. Transferring that duration to Nine Springs Creek is more of an open question. In terms of strict measurements of area for the Spring Harbor watershed to the Nine Springs Creek watershed, scaling the flows essentially means doubling the flows, but duration of a flood event doesn't depend on area in quite the same way. To keep things simple and conservative, we used the average duration of flooding events from Spring Harbor, which is 72 hours. We can expect that the duration for Nine Springs Creek would be somewhat longer, though the absolute size of the Nine Springs Creek watershed is so small that it would likely be a minor change. Regardless of that, any change in the flooding duration or area that resulted from the proposed restoration would scale with that duration and remain consistent, so this approach retains its utility in developing a comparative model. Finally, the shape of our storm flow hydrograph was determined using a Type II storm equation, which is the favored approach for this region of the United States.

Hydrologic routing model function

The hydrologic routing model functions by using the flood hydrographs as the initial input at the eastern end of the basin. Flow is transferred to the subsequent basins using the outflow characteristics generated from the HEC-RAS model. The stage storage tables for each basin allow us to estimate the volume of water held during overbank flooding, which occurs when the volume of water being stored exceeds the volume of the channel. The detailed topographic information used to build those tables allows us to calculate differences between the water surface elevation and the average land surface elevation to arrive at a reasonable estimate of the area of inundation for each flow rate examined.

The proposed restoration has a much smaller channel volume than the existing Nine Springs Creek and therefore overtops the banks at much lower peak flows. Estimating the impact of our proposed restoration on the frequency of overbank flooding therefore relies on determining the minimum peak flow that can be contained by the restored creek and estimating the expected frequency of floods that exceed that flow. By tracking the area of wetland flooded over the 72-hour hydrograph, we can estimate changes in the area and duration of flooding for a given peak flow for both the existing and proposed conditions. Taking all of that information together allows us to estimate the relative efficacy of our proposed restoration in reconnecting the creek to wetlands, as measured by increases in frequency, area and duration of flooding.

Sediment trapping model construction and inputs

An important motivator for our proposed restoration of Nine Springs Creek is to improve water quality by trapping phosphorus-laden sediment in the surrounding wetlands during overbank flooding events. As stated in the main body of our report, we estimate that the proposed site design will be able to remove roughly 16,787 kg of sediment in any given year, compared to 899 kg of sediment removed by the channel under current conditions. This section of the appendix explains how we arrived at that estimate.

As explained earlier, the reduced volume and raised elevation of our proposed channel encourages frequent overbank flooding events. Using our reservoir routing model, we can estimate the area and depth of floodwaters in our study area during a given storm event. To estimate the amount of sediment that could be trapped during these flooding events, we used a version of DETPOND developed by Professor Ken Potter in Excel. This model estimates trapping efficiency as a percentage of the total sediment particles that could be trapped under the flow conditions present. That trapping efficiency is based on Stokes' Law and takes into account particle size and flow velocity. Particle size is not constant but follows a distribution around a central mean determined from previous studies on suspended sediment characteristics. Flow velocity is determined by the slope characteristics of the wetlands, and for a given velocity, trapping efficiency increases as mean particle size increases. This is logically sound; faster water is capable of moving larger particles than slower water. If we had chosen a mean particle size consistent with sand or even gravel, then trapping efficiencies would have been 100%, even at relatively rapid flow. These wetlands are very flat, so even on a smooth surface the flow velocity of floodwaters would be expected to be very slow. By adding the structural filtering capacity of the vegetation, the velocity is slowed even more. To be conservative in our estimates of trapping efficiency, we estimated a mean particle size consistent with silt particles, 10 μm. This presented the most challenging realistic size distribution for our suspended solids and gave us the most conservative estimate of trapping efficiency.

To effectively estimate an expected mass of sediment trapped by the wetlands in any given year, our model required two main inputs. The first is an estimate of the concentration of total suspended solids in our channel. We had no data on the concentration of total suspended solids for Nine Springs Creek and did not have the time or resources to get that data. We approached this problem by using data from the Spring Harbor storm sewer as a proxy. We analyzed 15 years of instantaneous data for suspended sediment (g/ml) and used linear regression to develop an estimated relationship between flow rate and concentration of suspended sediment. We used our stormflow hydrograph with this relationship to calculate the amount of sediment being delivered in a given hour into the system. The adapted version of DETPOND we used gave us a trapping efficiency, and we used that number to calculate the mass of sediment that could be removed during a storm of a given duration and peak flow.

With a model in place to route storms, measure the volume and duration of flooding, and a relationship between flow and suspended sediment concentration, all that was required was an estimate of expected flows. As discussed earlier, we used daily peak flow data from the Spring Harbor storm sewer, scaled to area, as a proxy for the flow data in Nine Springs Creek. Using an empirical analysis, we developed estimates for the probability of observing flow within a given range on any given day in any given year. We divided the flows into 12 bins and used the average peak flow for each bin as the peak flow for a model storm run through our reservoir routing and sedimentation model. For each of the 12 representative storms, our model gave a predicted mass of sediment that we would expect to be trapped in the wetlands, given the suspended solid concentrations we expect during that storm. These estimates of total mass were multiplied by the probability associated with observing a storm of that peak flow in any given year, and those probability-scaled estimates of sediment mass were then summed together for all 12 events, yielding our expected estimate of 16,787 kg. Again, that number is based on a mean particle size of 10 μm and is the most conservative predicted estimate based on our model and input conditions. The estimate of 899 kg of sediment trapped by the wetlands in their current conditions was developed in exactly the same way, using the same mean particle size, storm inputs, probabilities and sediment trapping model. The only difference was in the stage storage characteristics of our flow routing model.

Phosphorus content was not determined from the Spring Harbor data, but rather from measurements made in the mid-1990s of phosphorus and total suspended solids from samples of runoff taken at a site near the northern end of Syene Road in our study area. An average ratio of total phosphorus to total suspended solids was used to calculate the mass of phosphorus trapped in the wetlands as a result of trapped sediment. In this way, our estimate of the expected mass of phosphorus that would be trapped by our designed conditions is simply a result of multiplying the estimate of total expected mass of trapped sediment by that ratio.

Conclusion

We developed a combined hydrologic routing and sediment trapping model to compare the overbank flooding frequency, area and duration characteristics as well as the mass of sediment and phosphorus that could be removed for both the existing conditions in Nine Springs Creek and for our proposed restoration. Inputs were estimated using data from the Spring Harbor storm sewer gauge.

As discussed in the main body of our report, our model predicts significant increases in the area and duration of inundation and in the amount of sediment that could be trapped. Our model is strictly comparative, meant to examine the differences in performance between the existing and proposed conditions. For more accurate predictions of absolute performance, more data must be collected from Nine Springs Creek. However, we are confident that the nature of the differences between the two conditions predicted by our model would be consistent if an accurate data set was used for the inputs. We are therefore satisfied that our proposed restoration of Nine Springs Creek will have positive effects on reconnecting the wetland to the creek and improving the water quality of the creek. Therefore, we strongly recommend implementing this restoration to affect transformative improvements in the ecological health of Nine Springs Creek and its surrounding wetlands.

NINE SPRINGS CREEK WETLAND SOIL SAMPLING AND ANALYSIS

Background

Increased nutrient loads in surface water runoff from agricultural and urban sources have led to increased frequency of eutrophication in our lakes and rivers. This degradation of our freshwater systems is exacerbated by the effects of climate change, which is predicted to get worse. Phosphorus is of particular concern in Wisconsin because it is often the limiting nutrient in our aquatic ecosystems. Wetlands are generally thought of as filters for freshwater contaminants, capturing excess nutrients from upstream sources leading to improved surface water quality in downstream lakes and rivers. This ecosystem service, when utilized correctly, can be extremely beneficial, especially in areas with stringent regulations. However, it's important to note that when it comes to phosphorus (P), wetlands have the potential to act as both a sink (by filtering water from upstream) and a source of nutrients to downstream water bodies.

Phosphorus enters the wetland either as dissolved P or as inorganic P bound to particles suspended in the water. During optimal conditions, wetlands serve as sinks for excess nutrients by capturing phosphorus from surface water in the wetland's organic soils and vegetation. However, these sinks have limits to the amount of nutrients that can be stored. When the retention capacity is exceeded, wetlands can become a source of nutrients to surface waters. Primary mechanisms that enable wetlands to capture excess phosphorus include adsorption, sediment accumulation and plant uptake. The phosphorus storage capacity of a wetland depends on the soil's ability to incorporate organic phosphorus into the peat through sedimentation and the removal of dissolved inorganic P from the water through soil adsorption as well as plant and microbial uptake.

Proposed Soil Sampling Locations

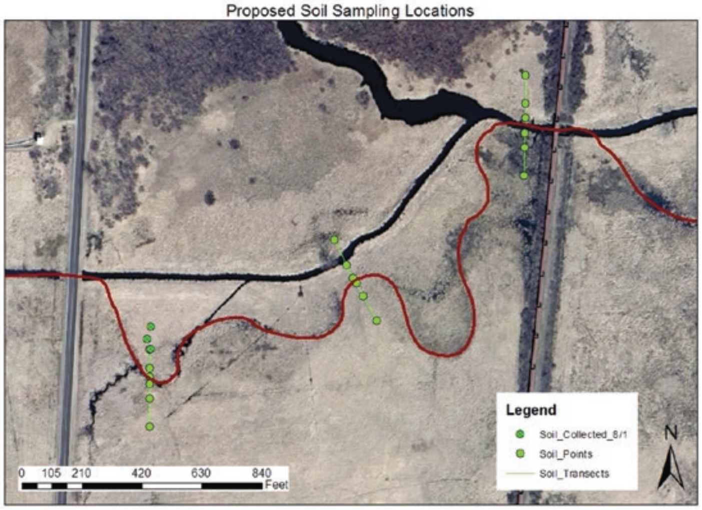

Figure E.1: Soil sampling locations near Nine Springs Creek.

Phosphorus is of particular concern in the surface waters of our study area. Nine Springs Creek was added to the EPA's impaired water list because it tested high for both TP and TSS pollutants, and had low dissolved oxygen and elevated water temperatures. These impairments of Nine Springs Creek are caused by rural and urban nonpoint source pollution, municipal stormwater systems, and streambank modifications and destabilization (WDNR, 2014).

Our design for Nine Springs Creek would reconnect the stream channel to the surrounding wetland floodplain. This would increase the number of yearly over-bank flow events and, in turn, increase opportunities for the surrounding wetland to capture excess nutrients. Upon entering the wetland, water would be slowed. This would allow phosphorus attached to sediment suspended in the water to drop out and settle in the wetland. Most of the phosphorus contributed to streams in runoff from nonpoint sources is bound to sediment. Therefore, reducing sediment load often results in simultaneous phosphorus reduction. The Wisconsin DNR sediment reduction targets were developed in consideration of this well-established link between TSS and phosphorus. Although our study design focuses mainly on capturing phosphorus through sedimentation, it's important to point out that in addition to sedimentation, dissolved nutrients in the slowed water would be absorbed by microorganisms and plant roots or adsorbed to the wetland soils (U.S. EPA, 2001).

Ideally, the wetland in our target area would function as a phosphorus sink, collecting more P than it releases. However, when developing our restoration design plan, it was important that we consider the possibility for our wetland to act as a source. In an attempt to determine the capacity of the wetland in our area of interest to store phosphorus, we sampled and analyzed the wetland soils.

Site selection

According to the Natural Resources Conservation Service Web Soil Survey, the soils in the wetland surrounding Nine Springs Creek in our target project area are relatively homogenous. High-resolution aerial photographs were used to pre-select soil sample locations based upon proximity to the historic meander, accessibility, and elevation within the anticipated floodplain design. In order to maximize the coverage area of our samples, locations were placed along three north-south transects across the historical meander of Nine Springs Creek (Figure E.1).

Table E1a: Soil Analysis Results

Sample	Depth	P	K	Ca	Mg	S	OM	Zn	B	Mn	Fe	Cu	Al	Na
ID	(Inches)	(%)						(ppm)						
T1N1-A	0-6	0.1	0.29	5.1	0.7	0.5		150.1	25.6	419.7	16332	28.22	29778	327.4
T1N1-B	6-12	0.11	0.28	5.13	0.62	0.59		135.8	21.49	681.2	19464	27.34	30417	276.6
T1N3-A	0-6	0.11	0.3	0.85	0.5	0.32		140.6	13.88	149.6	20559	23.18	29870	231.5
T1N3-B	6-12	0.12	0.14	1.44	0.35	0.6		63.47	16.89	214.1	16365	11.87	14324	188.3
T1N4-A	0-6	0.17	0.16	1.9	0.44	0.34		79.3	14.14	301.6	13904	14.87	18050	171.8
T1N4-B	6-12	0.15	0.1	2.42	0.44	0.56		47.18	14.73	77.59	6644	11.44	11901	95.8
T1S1-A	0-6	0.17	0.07	2.79	0.42	0.71		30.3	26.17	178.4	8480	11.84	8558	326.2
T1S1-B	6-12	0.15	0.04	2.95	0.39	0.75		12.6	25.17	131.1	6036	8.51	5361	309
T1S1-G	36-42	0.12	0.05	2.91	0.44	0.88		16.7	13.77	110.1	6807	6.59	6027	356.2
T1S2-A	0-6	0.26	0.1	3.32	0.52	0.54		55.5	31.3	444.7	10734	14.84	12213	306.9
T1S2-B	6-12	0.29	0.05	3.61	0.45	0.58		14.2	34.97	331.3	8076	11.83	7386	276.3
T1S3-A	0-6	0.26	0.11	3.44	0.51	0.48	38.8	52.9	41.67	291.1	11783	16.1	12453	369.2
T1S3-B	6-12	0.23	0.06	3.82	0.39	0.44		24	32.64	244.8	11420	10.64	9603	286.5
T2N1-A	0-6	0.16	0.24	3.03	0.92	0.18		148.8	14.37	692.4	16182	30.83	21775	288
T2N1-B	6-12	0.16	0.25	3.09	1.03	0.18		133.5	16.71	571.9	15441	28.65	21879	253.6
T2N2-A	0-6	0.17	0.21	3.28	0.97	0.15		129.1	18.11	734.3	17131	27.99	20519	295.4
T2N2-B	6-12	0.2	0.25	3.71	1.1	0.2		148.7	25.95	718.5	17477	31.28	22832	319.6
T2N3-A	0-6	0.18	0.32	0.72	0.54	0.13		141.7	16.55	229.9	25292	31.33	35260	298.3
T2N3-B	6-12	0.17	0.23	0.72	0.42	0.11		109.9	12.94	277.7	19348	25.38	24283	195.1
T2S1-A	0-6	0.14	0.23	1.46	0.44	0.35		84.8	18.69	262.5	16474	21.7	25307	260.8
T2S1-B	6-12	0.12	0.19	1.57	0.38	0.35		78.5	11.48	295.8	13999	20.57	21269	205.1
pH Measurements Conducted on Two Samples:									T1N3-A2		6.009	T1N4-A2		6.553
Results reported on a 'dry weight' basis.														

Table E.1a: Soil sample results for the Nine Springs Creek wetland.

Table E1b: Soil Analysis Results

Sample	Depth	P	K	Ca	Mg	S	OM	Zn	B	Mn	Fe	Cu	Al	Na
ID	(Inches)	(%)						(ppm)						
T2S2-A	0-6	0.14	0.21	1.76	0.44	0.37		92.7	22.13	114	14431	21.55	25771	340.5
T2S2-B	6-12	0.13	0.09	2.35	0.38	0.55		39.9	15.11	102.6	8276	14.45	12595	293.5
T2S3-A	0-6	0.22	0.16	2.49	0.44	0.4		76.9	18.87	350.2	18229	19.67	21084	439.4
T2S3-B	6-12	0.21	0.08	3.11	0.36	0.46		25.7	24.03	192.3	10940	15.03	12863	378
T3N1-A	0-6	0.26	0.27	1.95	0.65	0.16		104.3	21.48	228.6	18440	81.88	32650	439.6
T3N1-B	6-12	0.16	0.13	2.67	0.46	0.7		42.5	23.92	178.9	9463	44.3	16402	271
T3N2-A	0-6	0.29	0.12	2.69	0.43	0.62		46	28.7	134.6	11981	21.5	20570	269.9
T3N2-B	6-12	0.08	0.03	3.12	0.25	0.93		10.8	27.26	109.4	5490	5.61	5256	185.8
T3N3-A	0-6	0.16	0.07	3.34	0.4	0.55	38.7	50.7	22	79.51	4556	14.73	9637	147.6
T3N3-B	6-12	0.13	0.06	3.69	0.41	0.61		20.8	23.61	61.91	4826	12.47	9896	147.9
T3S1-A	0-6	0.15	0.37	1.59	0.84	0.16		143.7	21.22	327.1	24748	32.54	35458	319.7
T3S1-B	6-12	0.1	0.34	1.68	0.65	0.38		171.2	35.72	315.4	19880	35.35	33512	323.9
T3S2-A	0-6	0.09	0.31	1.79	0.83	0.23		122.5	19.99	210.3	20012	34.42	31239	372.6
T3S2-B	6-12	0.08	0.33	0.92	0.65	0.17		121	19.91	188.7	19395	33.08	35184	278.3
V1A	0-3	0.12	0.12	1.34	0.26	0.21		51.56	3.57	331.2	12062	8.87	11302	211.2
V1B	3-6	0.13	0.15	1.83	0.37	0.28		58.23	4.28	300	15244	11.21	16469	229.6
V1C	6-9	0.12	0.1	1.9	0.33	0.3		40.77	<2	179.3	11427	9.9	13368	182.9
V1D	9-12	0.13	0.11	2.11	0.35	0.33		28.57	8.48	132.8	8640	9.82	13536	174
V1E	12-15	0.12	0.07	2.22	0.34	0.39		20.68	5.87	116.3	6424	8.61	10429	155.9
V1F	15-18	0.08	0.04	2.17	0.27	0.56		11.98	4.25	97.29	4487	7.99	5543	128.8
Results reported on a 'dry weight' basis.														

Table E.1b: Soil sample results for the Nine Springs Creek wetland.

Sample collection

For the purpose of our study, discrete shallow soil samples were collected using a Russian peat borer (RPB) along three transects from predetermined locations. If a thick, matted root zone was present at or near the surface, it was removed before the sample was collected. The depth measurement for the sample began at the top of the soil horizon, immediately following any removed materials.

We collected 41 discrete shallow soil samples from 18 locations using a Russian peat borer (RPB) (Figure 1.7 on page 11). Sample collection methods were adapted from the EPA (U.S. EPA, 1999). Of those samples, 35 were divided into six-inch discrete depth intervals, and six were divided into three-inch intervals. Each interval was measured and portioned in the field and stored in plastic bags. Samples were kept on ice until processed. Each discrete sample was analyzed separately to examine shallow vertical variability in soil properties or mineral content. Samples were sent to the UW-Madison Soil and Plant Analysis Laboratory for analysis (Soil & Plant Analysis Laboratory, University of Wisconsin-Madison, 2005).

Results and discussion

The wetland that surrounds Nine Springs Creek in our project area is an emergent/wet meadow with highly organic soils (NRCS, n.d.). Wetland soils in our study are predominately Houghton Muck with little spatial variability, both vertically and horizontally in the profile. Soil organic matter (SOM) of the wetland soil was 38.8%, supporting previous findings that the soils were highly organic. Soil pH was between 6 and 6.5, based on two discrete samples. Aluminum, iron, and calcium, among other minerals, were present in all of the soil samples as shown in Table E.1.

The presence of aluminum, calcium, and iron in the Nine Springs Creek wetland soils, as shown in Table E.1, indicates that the wetland surrounding the creek has some capacity to adsorb phosphorus and the potential to serve as a long-term phosphorus sink. While further analysis is necessary to develop a quantitative estimation of capacity, our findings support our proposal to reconnect the stream to the wetland as a viable strategy for phosphorus retention.

DUNN'S MARSH WATER QUALITY ANALYSIS

To gain a better understanding of water quality in Dunn's Marsh, we measured major ions, temperature, and dissolved oxygen. Data were then compared to results from samples collected in Nine Springs Creek.

Major anions

We collected water samples from a single location on the north shore of Dunn's Marsh to test for major ions. The location of the sample was not recorded; it was assumed that the pond was well mixed. This site was chosen both because it was accessible and because it was located away from major outfalls. We analyzed samples for chloride, nitrate and sulfate (Table F.1). Samples were collected and analyzed approximately once per month from May through August. We converted our measured nitrate concentrations to NO_3-N concentrations for the purpose of comparison to other groundwater data.

Table F1: Major Anion Concentrations in Dunn's Marsh (mg/L)				
Date	Chloride	Nitrate	Sulfate	Nitrate as N
6-Jun	74.3	<1	2.4	<1
7-Jul	12	<1	1.6	<1
28-Jul	65	11.8	16.1	16.1
	65	11.8	16.1	16.1

Table F.1: Water quality data from Dunn's Marsh samples collected during summer 2014.

Water temperature and dissolved oxygen

We deployed a miniDOT sonde to measure temperature and dissolved oxygen. The sensor was anchored approximately 100 meters from the north shore. The sensor recorded data every 10 minutes from April 5 to August 23, 2014. Data were collected from the sonde approximately once a week (Figure F.1).

Other water quality parameters

We measured water quality parameters for Dunn's Marsh from a sample collected on June 6, 2014. The results of our analysis of water quality parameters appear in Table F.2. Note that the temperature reported is the temperature of the sample at the time of analysis (samples were refrigerated between collection and analysis).

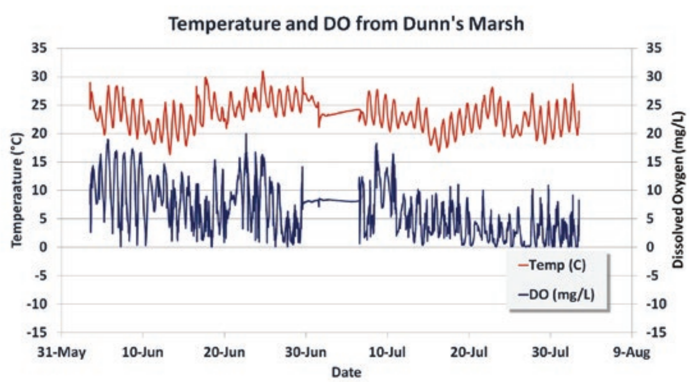

Figure F.1: Temperature and dissolved oxygen concentrations as monitored every 10 minutes for four consecutive months.

Discussion

Overall, our data suggest that in its current state, Dunn's Marsh is fairly inhospitable during the summer months. Dissolved oxygen fluctuates diurnally, reaching maximum concentrations well above saturation during the day, when photosynthesis yields oxygen, and dropping to extreme lows at night, when cellular respiration occurs without photosynthesis. These large diurnal fluctuations suggest that sensitive organisms would struggle to survive in the marsh under current conditions.

Major anion data support the conclusion that Dunn's Marsh receives a higher proportion of surface water than Nine Springs Creek. Nitrate and sulfate levels in Dunn's Marsh are well below levels in Nine Springs Creek, suggesting that a much smaller fraction of the water in Dunn's Marsh passed through the shallow aquifers before discharging into the marsh. Chloride levels are roughly equivalent to those measured in Nine Springs Creek; however, the chloride in Dunn's Marsh is likely the consequence of road salt in runoff that directly flows into the marsh, whereas chloride in Nine Springs Creek, while also likely the result of road salt, probably infiltrated into the shallow, local aquifer system that feeds the creek before being discharged.

Comparing the water quality parameter data against similar values for Nine Springs Creek measured on the same day led to some important conclusions. Notably, the specific conductivity of the Dunn's Marsh sample is much lower than the specific conductivity of the Nine Springs Creek samples. The minimum specific conductivity measured in Nine Springs Creek was 693.2 μS/cm, whereas the value measured in Dunn's Marsh was 178.7 μS/cm. The measured pH in Dunn's

Table F2: Dunn's Marsh Water Quality Parameters					
Date	T (°C)	pH	Cond (µS /cm)	Chlorophyl l (µg /L)	fDOM (RFU)
6-Jun	8.5	7.2	178.7	3.7	13.5

Table F.2: Water quality parameters for Dunn's Marsh, sampled on June 6, 2014.

Marsh of 7.2 was also lower than the lowest pH measured in Nine Springs Creek of 7.8. These differences are likely the result of dilution by surface runoff. Several outfalls were observed at the Dunn's Marsh site. This initial survey of water quality parameters seems to suggest that surface water constitutes a more significant water source for Dunn's Marsh than it does for Nine Springs Creek. This is further supported by the fact that Nine Springs Creek is fed by several springs.

APPENDIX G

STANTEC MANAGEMENT RECOMMENDATIONS FOR DUNN'S MARSH

- Continue to provide and/or improve upstream volume, peak flow, and sediment control for stormwater runoff inputs.
- Control sediment inputs into the marsh from the channel through the west woodland using check dams, sediment traps, vegetated filter strips, diversion swales, or similar.
- Reduce the population of narrow-leaved cattail using herbicides designed for use in aquatic settings. Alternatively, cut or crush the cattail stems at ground level or below the estimated maximum flood levels.
- Remove the dead biomass. Standing dead biomass may be removed using prescribed burns.
- After adequate control is achieved, seed treated areas with a cover crop (*Bidens spp. and Polygonum spp.*) and other native wet meadow species.
- Continue to manage native vegetation establishment through follow-up spot herbicide treatments and burning.
- Reduce the population of reed canary grass using herbicide treatments. Use mowing and/or burning to reduce the biomass and vigor of the reed canary grass.
- Consider using drawdowns to rebuild emergent vegetation areas in the open water zone.
- Consider using floating wetlands for nutrient removal, plant species diversity, avian habitat, and increased structural diversity.

DUNN'S MARSH COMMUNITY SURVEY

Demographic analyses

All demographic data are from the 2010 U.S. Census (U.S. Census Bureau, 2010). Data have been collected down to the block-group scale, a subset of the census tract. Only block groups where a majority of the properties are within the drainage shed were included, so there is an area in the southwest corner of the drainage shed that is omitted from the demographic results.

The neighborhoods in the Dunn's Marsh drainage shed are diverse relative to both the cities of Madison and Fitchburg. The racial composition is 58% white, 18% black, and 24% other, including Asian, Native American, and one or more races. The city of Fitchburg is 72% white and 10% black, and the city of Madison is 79% white and 7% black. The actual composition varies quite significantly by block group, however. The block group with the largest white population is 90%, while the group with the smallest is 33%. Similar patterns emerge in the Hispanic and non-Hispanic composition. Those neighborhoods with very large white populations have very high populations of non-Hispanic residents. The block group with the highest percentage of Hispanic residents is 60% Hispanic and is only 44% white. (It is important to note that the census handles race and ethnicity in separate and nonexclusive categories.)

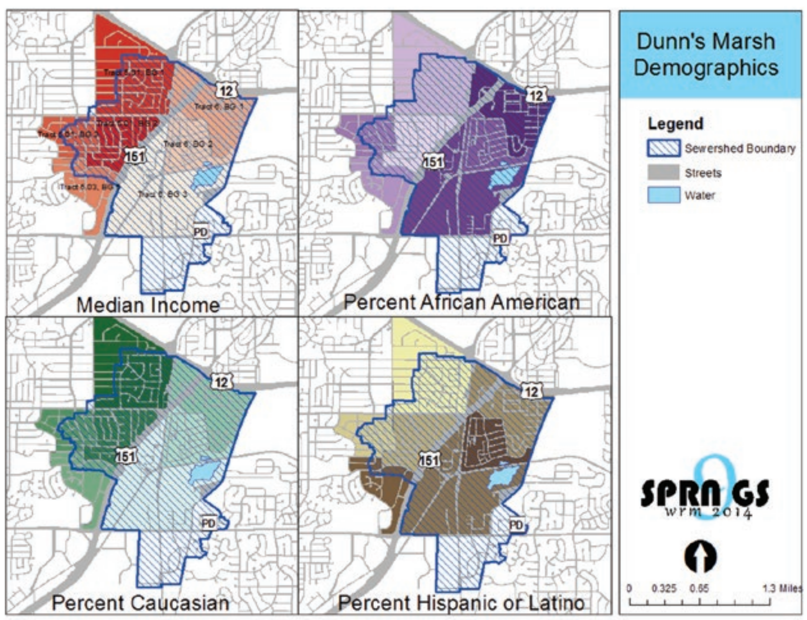

Figure H.1: Distribution of socioeconomic factors across the Dunn's Marsh drainage shed.

The median income also ranges significantly, from approximately $31,000 to $71,000. Controlling for population distribution, this makes the overall median income $45,790. This is significantly lower than the overall median income in Fitchburg of $61,482 and $53,464 in Madison. Figure H.1 shows the distribution of these factors across the Dunn's Marsh drainage shed. The map illustrates results only on a relative scale, using a color ramp from low (light colors) to high (saturated colors).

Community survey

The community survey was developed using the Social Indicator Planning & Evaluation System (SIPES) for non-point source management under the guidance of Professor Ken Genskow. Figure 2.3 in the main text shows the survey area that was chosen based on the drainage shed boundary in which water from the sewer system drains to Dunn's Marsh. In total, 1,025 surveys were distributed to households inside the survey area, and 139 surveys were retrieved from an online system or through the mail.

The survey respondents generally agree that quality of life and the stability of the economy are linked with good water quality, and they also agree that personal actions, like yard care, influence local water quality, with a recognition of personal responsibilities in water resources protection. The majority of the respondents strongly disagree that water quality can be sacrificed for economic development. Compared with all responses among all statements, a large portion of "neither agree or disagree" in the cost-related option indicates that the public may lack information about costs associated with actions to protect water resources (Figure H.2).

Among all the potential concerns, most of the respondents indicated that "excessive aquatic plants or algae" can be a severe problem, while fewer responded that "lower property values" and "contaminated drinking water" are community concerns. However, many people chose "don't know" as an option in every potential concern (Figure H.3).

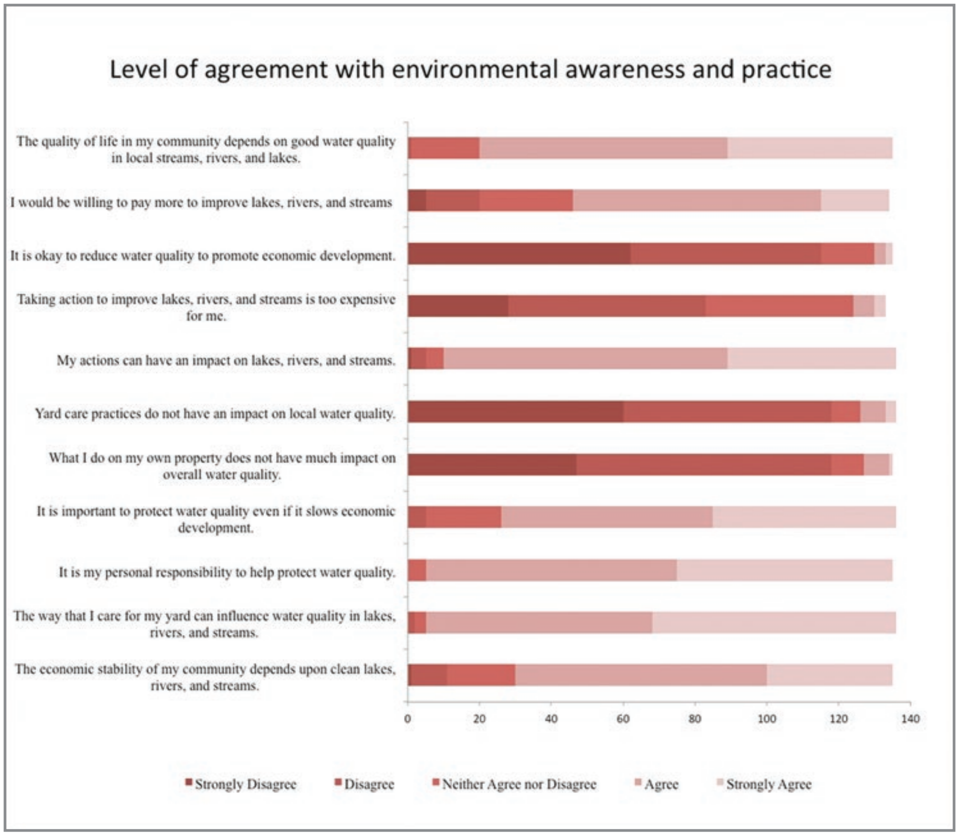

Figure H.2: Level of agreement with survey statements regarding environmental awareness and practice.

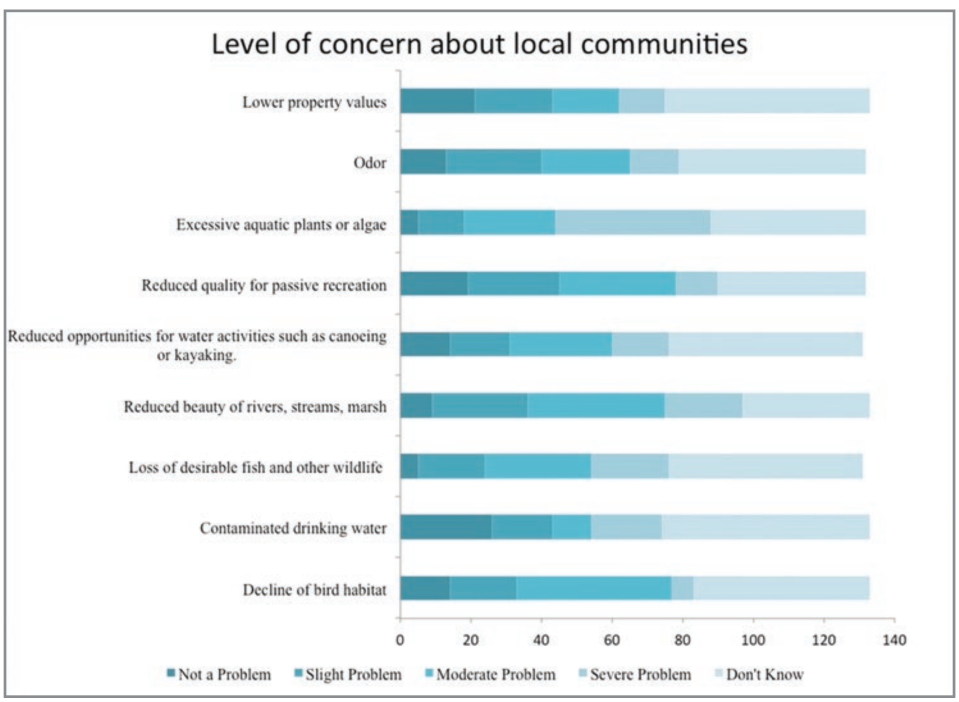

Figure H.3: Level of concern about local issues.

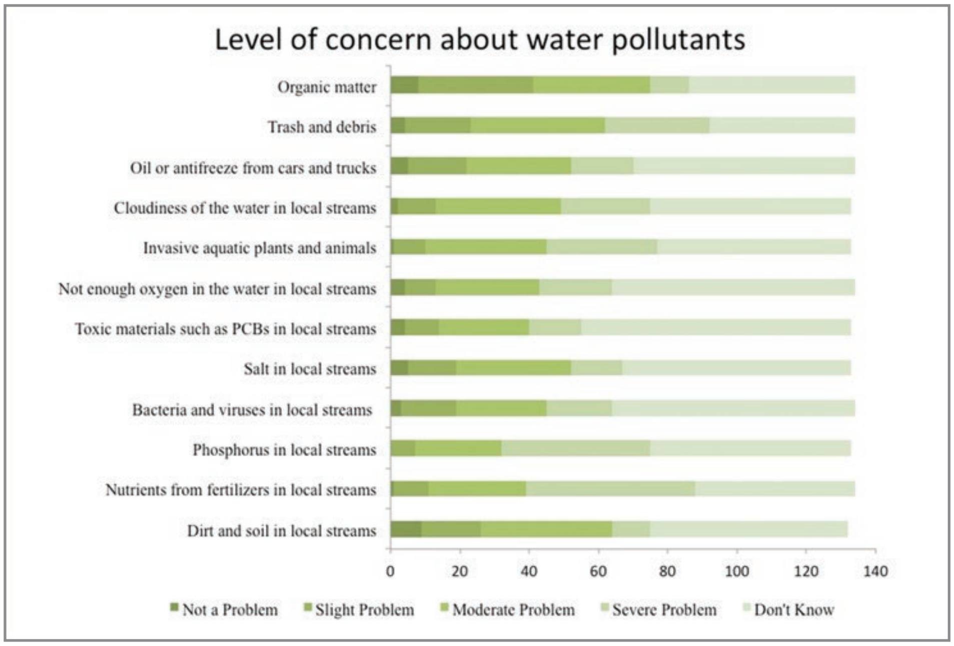

Figure H.4: Level of concern about water pollutants.

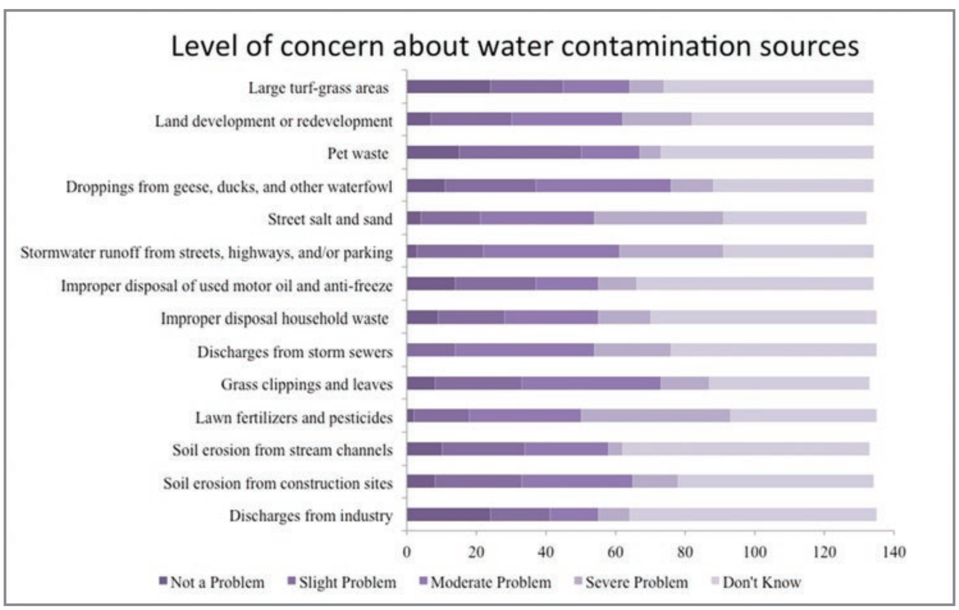

Figure H.5: Level of concern about water contamination sources.

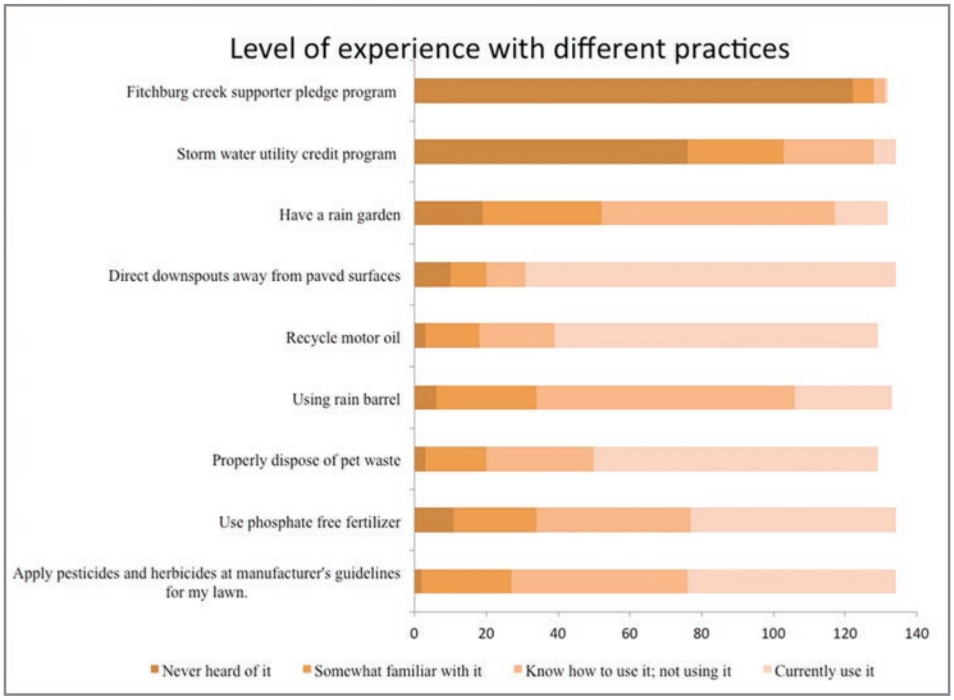

Figure H.6: Level of experience with different practices.

With regard to the water pollutants and contamination sources, "nutrients from fertilizer" was seen to be a big problem in this area (Figure H.4). "Lawn fertilizers and pesticides" and "street salt and sand" were believed to be serious water contamination sources. However, more people did not think that "large turf-grass area" and "discharge from industry" are significant problems (Figure H.5).

The respondents' level of awareness of related environmental protection programs and practices shows that potential barriers still exist in the program development and implementation process. A majority of the respondents were not familiar with the "Fitchburg creek supporter pledge program" and the "stormwater utility credit program." However, people indicated more experience with household-related practices such as "direct downspouts away from paved surface," "recycle motor oil," and "properly dispose of pet waste." Respondents were familiar with "rain gardens" and "rain barrels," but are not currently using them (Figure H.6).

Given the limitations in changing household and lawn-care practices based on the available options, cost and differing perspectives in effective lawn care and yard maintenance can be barriers to changing environmental behavior (Figure H.7).

The Wisconsin State Journal and a neighborhood association newsletter are two main sources of information about water quality and local environmental issues, but a significant portion of the survey respondents indicated that they are not using those information sources (Figure H.8).

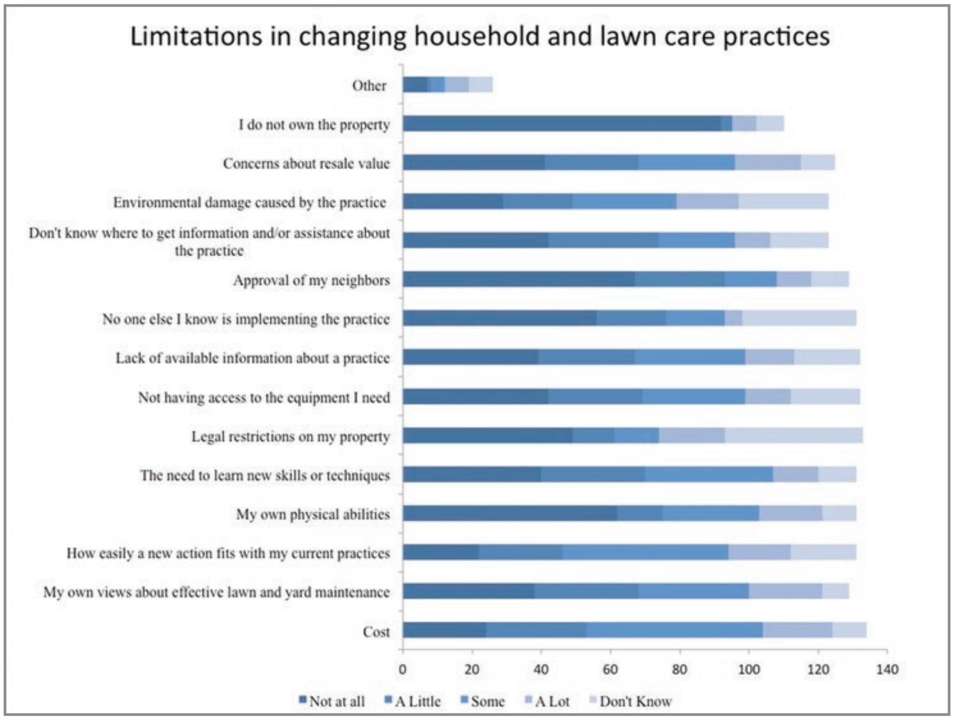

Figure H.7: Limitations in changing household and lawn-care practices.

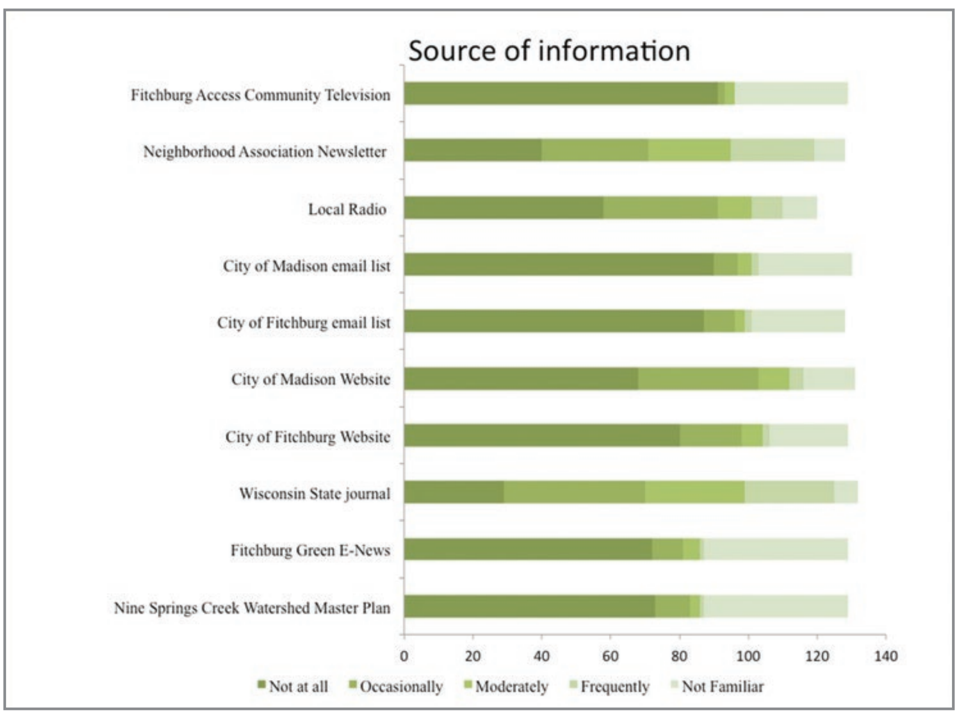

Figure H.8: Sources of information about water quality.

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