ASSESSMENT OF TRANSIENT SEDIMENT IN THE SIX-MILE CREEK WATERSHED

University of Wisconsin-Madison
Nelson Institute for Environmental Studies
Water Resources Management Practicum

2013

ASSESSMENT OF TRANSIENT SEDIMENT IN THE SIX-MILE CREEK WATERSHED

2013 WATER RESOURCES MANAGEMENT PRACTICUM

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2013 Water Resources Management Practicum
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The Water Resources Management Practicum is a regular part of the curriculum of the Water Resources Management Graduate Program 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 resources problem.

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Table of Contents

List of Figures

List of Tables

Preface

The Water Resources Management (WRM) Master's degree program in the Gaylord Nelson Institute for Environmental Studies at the University of Wisconsin – Madison is an interdisciplinary program designed to prepare students for employment as water resources management professionals. Since the 1970s the cornerstone of the WRM program has been a seminar focusing on current issues in Wisconsin water resources management. This seminar has developed into a year-long applied learning opportunity known as the WRM Practicum that is the central requirement of the program's Master of Science Degree.

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Group photo of WRM Students at Dorn Creek and Meffert Road, Left to Right: Karen Bednar, Jeremy Jones, Nicholas Funk, Uyenlan Vu, Susan Montgomery, Samuel T. Christel, Christina Anderson, Courtney Kruger, and Anke Keuser.

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Rex's Innkeeper

Executive Summary

The 2013 University of Wisconsin-Madison Water Resources Management Program Practicum investigated the feasibility of watershed management practices that could be used to remove sediment and associated phosphorus from strategic locations in the drainage network of Six-Mile Creek, a tributary of Lake Mendota. The practicum was sponsored by the Madison Metropolitan Sewerage District as part of an adaptive management pilot project of the Yahara Watershed Improvement Network, known as Yahara WINs. The goal of Yahara WINs is to reduce nutrient transport to Lake Mendota in order to improve water quality in the Yahara chain of lakes.

This practicum studied the area of Dorn Creek, a tributary of Six-Mile Creek. Previous research (Rogers et al., 2009) demonstrated that large quantities of sediment and associated phosphorus are intermittently stored in the segment of Dorn Creek that passes through a small wetland in the area of Meffert Road. This wetland, referred to as the Upper Dorn Creek Wetland, was the primary focus of this project. The practicum also investigated opportunities for removing sediment from agricultural ditches and stream segments at bridge crossings in the Six-Mile Creek watershed, as well as from Mary Lake, a constructed pond on Six-Mile Creek. The first part of the practicum focused on the quantification of the amount of sediment and phosphorus stored in low gradient reaches of the Six-Mile Creek watershed, with particular focus on stream reaches and agricultural ditches in the Upper Dorn Creek Wetland. In the latter locations, we estimated that there were 792.8 cubic meters of sediment and 1,940 pounds of phosphorus, with average phosphorus concentrations ranging from 1,054 to 1,900 milligrams of phosphorus per kilogram. Based on the use of sliding rebar monitors we were able to demonstrate that there was active erosion and deposition of streambed sediment during storms.

The second part of the practicum was the conceptual design and modeling of a floodplain wetland restoration project in the Upper Dorn Creek Wetland. Research by Rozumalski (2007) and Boyington (2010) demonstrated that wetlands at study locations in Dane County, Black Earth Creek, and the upper Yahara River overflow their banks 5 to 15 times per year. However, the research of Rogers et al. (2009) indicated that in the Dorn Creek wetland the stream overflowed its bank only about once per year. This reduction in overflow is likely due to excessive soil erosion from upstream agricultural areas that is subsequently deposited in the wetland. Removal of some or all of this sediment would restore the natural relationship between the stream and the wetland and trap sediment and phosphorus.

To estimate the potential water quality benefits of a wetland restoration project, we conducted hydrologic and sedimentation modeling. For demonstration purposes, we evaluated a 5-acre restoration located immediately upstream of Meffert Road. The hydrologic modeling was conducted using the Soil and Water Assessment Tool (SWAT), building on previous modeling conducted by Montgomery and Associates (MARS, 2011) for the Yahara Lakes watershed. The sedimentation modeling used WinDETPOND. Although this model is commonly used in Wisconsin to design sedimentation basins, considerable additional modeling and analysis was required to use WinDETPOND in this application. The results indicate that a 5-acre restoration would annually trap about 187,000 pounds of sediment and 281 pounds of phosphorus annually. The costs of this restoration project are estimated at $28,876 annually, over a 25-year lifespan.

Based on our results we recommend serious consideration be given to constructing a wetland restoration project in the Upper Dorn Creek Wetland. More detailed analysis will be required to determine the appropriate scale of such a restoration, as well as to obtain accurate estimates of the effectiveness and cost.

Mary Lake also presents an opportunity for substantial nutrient removal projects but further study will be required. Overall, the recommendations within this report demonstrate opportunities for the Yahara WINs to reduce nutrient and sediment loads in the Yahara chain of lakes.

1 Introduction

With leadership from the Madison Metropolitan Sewerage District (MMSD), the Yahara Watershed Improvement Network (Yahara WINs) is conducting an adaptive management pilot project for phosphorus reduction in the Six-Mile Creek watershed, a sub-watershed of the Yahara Lakes and larger Rock River Basin in southeastern Wisconsin. Historically, regulatory approaches for addressing nutrient pollution in the Yahara watershed have focused on point sources, such as wastewater treatment plants. Adaptive management is a new regulatory option in Wisconsin where generators of both point and non-point sources collaborate to implement cost effective nutrient management practices. Yahara WINs is testing the feasibility of adaptive management in a pilot project within the larger Yahara watershed (Figure 1.1).

As part of this pilot project, MMSD partnered with the University of Wisconsin-Madison Water Resources Management (WRM) Program to investigate the potential for implementation of practices aimed at capturing sediment and associated phosphorus across the pilot project area. Phosphorus is a key ecosystem nutrient, the amount of which is dramatically increased by human sources, and is found in discharge from wastewater treatment plants and runoff from agriculture fields, construction sites, streets, and parking lots. In the case of runoff from agriculture fields, most of the phosphorus is typically attached to soil particles that have been eroded during significant rain or snowmelt events. Excess phosphorus in natural waters promotes excessive growth of algae and aquatic vegetation, often leading to episodes of low dissolved oxygen. Some algae are also toxic to humans and wildlife. Agricultural phosphorus management has historically been conducted at source areas, such as agricultural fields. However, recent research suggests that effective management can also be conducted on the ditches and streams that convey runoff from agricultural fields.

The WRM study sites within the pilot project area were selected based on previous research that demonstrated they act as short-term sediment sinks (Figure 1.1). These study sites include a small agricultural wetland on Upper Dorn Creek and bridge crossings on Dorn Creek and Six-Mile Creek. Dorn Creek is a small sub-watershed of Six-Mile Creek that flows into the Yahara Lakes watershed and eventually into the larger Rock River watershed. The dominant land use practice in the Six-Mile Creek watershed is agriculture with rapidly increasing suburban land use. As both an agriculture and suburban center, the Dorn Creek and Six-Mile Creek watersheds are an ideal location to study the potential of adaptive management. Prior research in these study sites have shown that wetlands and flat, low gradient stream segments accumulate sediment during small to moderate runoff events and that this sediment is subsequently flushed out during large runoff events (Rogers et al., 2009). Based on this research and the land use, these study sites present an opportunity to investigate how the transport of transient phosphorus-laden sediment can be reduced through the use of unique management strategies.

The main goal of the WRM study is to provide MMSD with information on the quantity and distribution of transient sediment and associated phosphorus in the Yahara WINs pilot project area, as well as the potential effectiveness of novel management practices. Through field sampling we have found areas of significant sediment deposition and have used modeling to generate management options for the control of this sediment. The first management option is a wetland restoration project in the Upper Dorn Creek Wetland with the goal of reconnecting the wetland to stream channel flows, thus sequestering more transient sediment. The second management option is the selective dredging of stream channels at bridge crossings and culverts. Cost, feasibility, and the needs for each of these management options are outlined within this report. Recommendations for larger-scale applications of this study are also included.

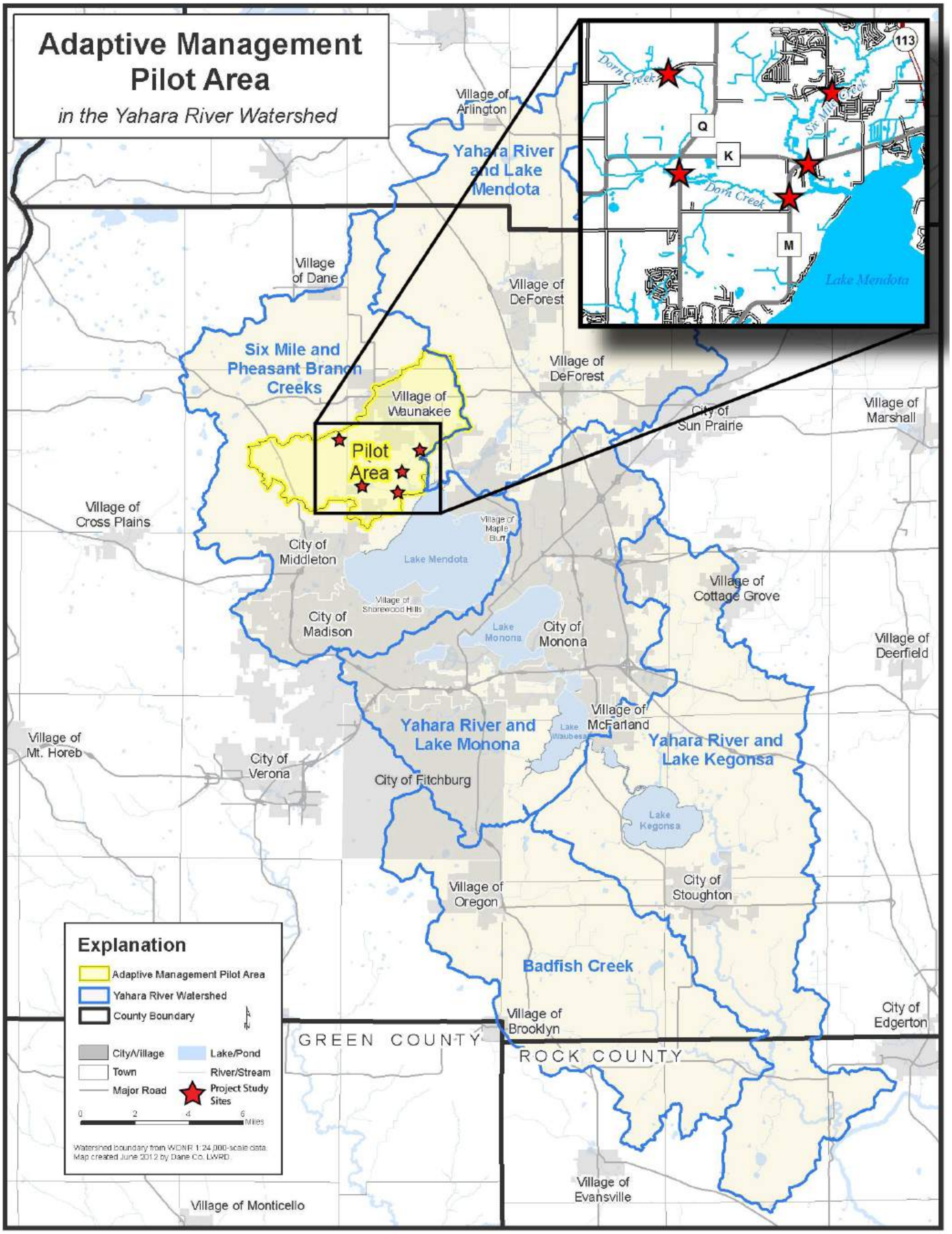


Figure 1.1 Adaptive Management Pilot Project Area.
Map courtesy of Madison Metropolitan Sewerage District.

2 Practicum Site Selection

2.1 Introduction

The Yahara WINs pilot project area is located in the Rock River Basin, a 3,700 square mile drainage basin in south central Wisconsin that feeds into the Mississippi River south of the Wisconsin-Illinois border (Johnson, 2002) (Figure 2.1). The Yahara Lakes watershed, a sub-watershed of the Rock River Basin, drains lakes Mendota, Monona, Waubesa, Kegonsa and Wingra via the Yahara River. The Six-Mile Creek watershed (43 square miles), located in the northwest portion of the Yahara Lakes watershed in Dane County, is a sub-watershed of Lake Mendota. The watershed is situated west of the Yahara River and drains into Lake Mendota, the upper lake of the Yahara Lakes watershed. The Dorn (Spring) Creek watershed (12.7 square miles) is a small sub-basin within the Six-Mile Creek watershed. Dorn Creek originates west of Six-Mile Creek and travels east through the Town of Springfield and south across the City of Middleton before joining Six-Mile Creek.

Historically, the land cover in the Six-Mile Creek watershed consisted of a mix of oak savanna, forest, prairie and wetland vegetation, though less than 10% of the original land cover remains today (Wisconsin Department of Natural Resources [WDNR], 2011). Currently, the dominant land use in the Six-Mile Creek watershed is agriculture (56%), with significant open space coverage (19%), and rapidly increasing suburban/urban land uses (15%) (Figure 2.2).

The Dorn Creek watershed contains several previously identified and distinct wetland areas along the stream corridor (Rogers et al., 2009) (Figure 2.3). The two primary wetlands along Dorn Creek are the Upper Dorn Creek Wetland, located south of the Village of Waunakee, and the Dorn Creek Wetland, located northwest of Governor Nelson State Park. The Upper Dorn Creek Wetland is approximately 111 acres in size and is the main focus of this study. The land in this area is predominately used for agriculture and is planted with corn or soy. There are also several small dairy herds. The majority of land in this area is in private ownership.

In addition to the Upper Dorn Creek Wetland, this study focuses on the lower reaches of the Six-Mile Creek system near the outlet to Lake Mendota (Figure 2.4). Field data were collected at sites upstream of bridges that cross the stream at Highway M and South Woodland Drive in the Town of Westport. The site on Six-Mile Creek just east of South Woodland Drive is also known as Mary Lake, a small constructed pond set in a residential community.

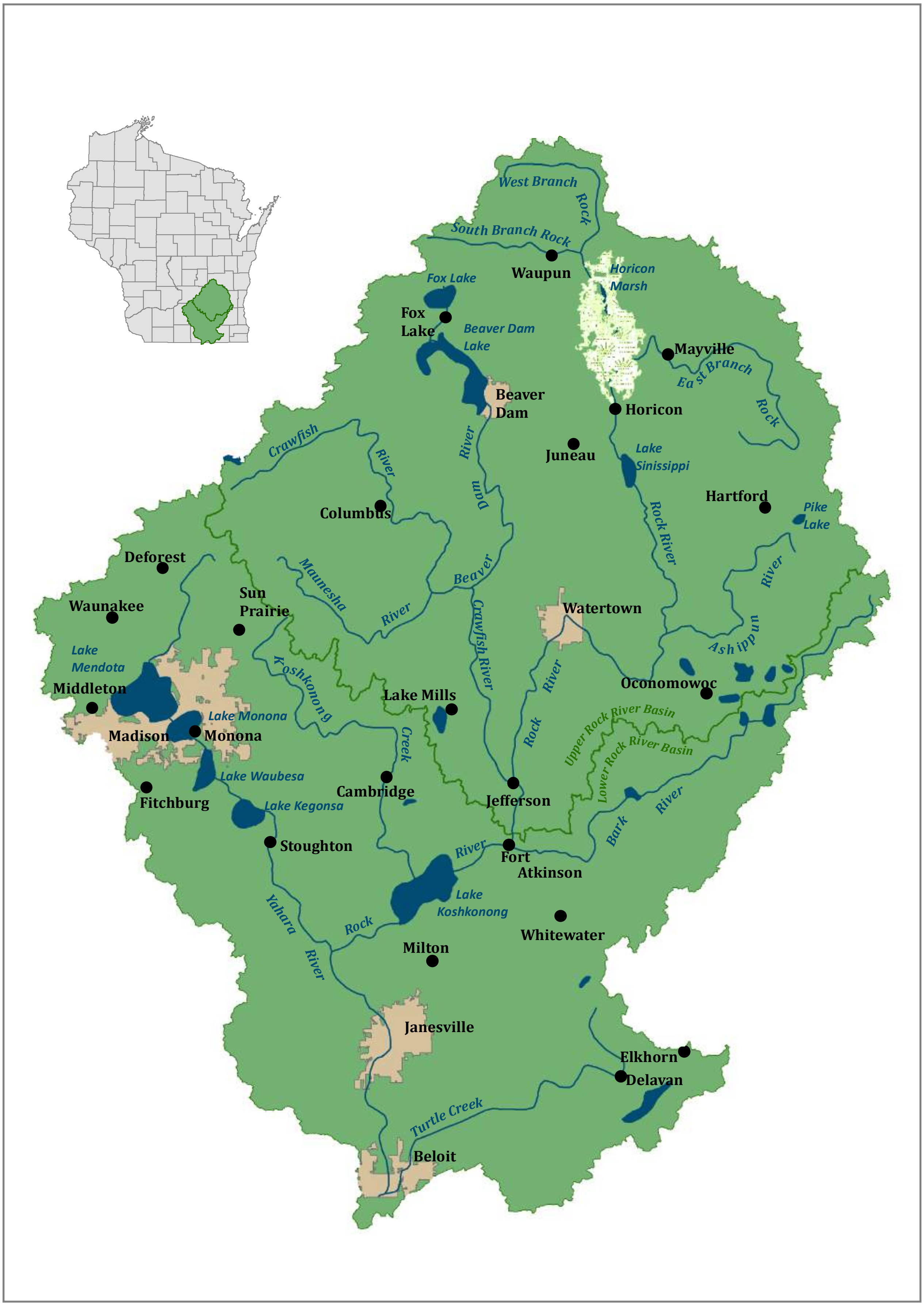


Figure 2.1 Rock River Watershed.

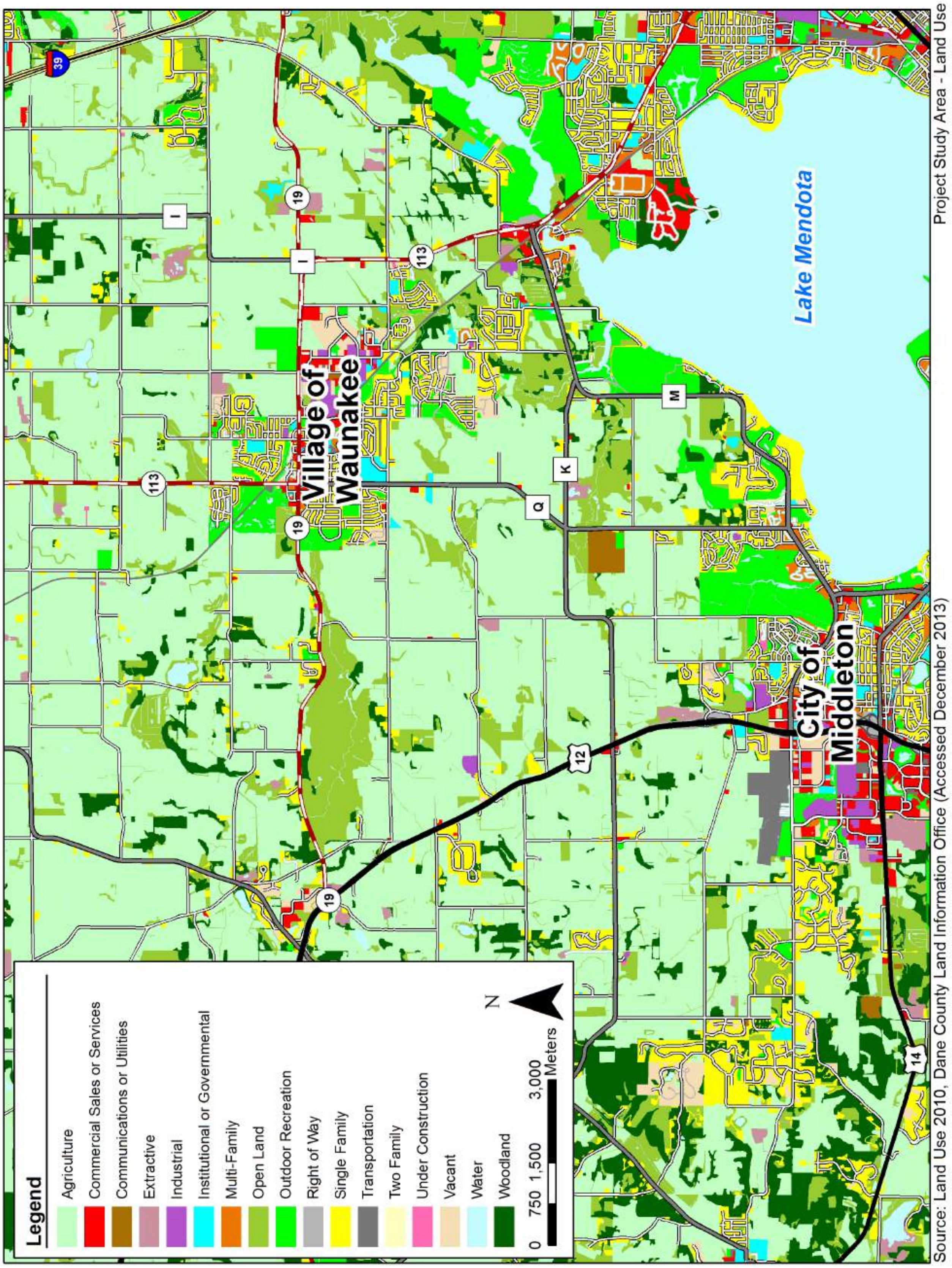


Figure 2.2 2010 Land Use.

Figure 2.3 Upper Dorn Creek Wetland along Dorn Creek and Six-Mile Creek.

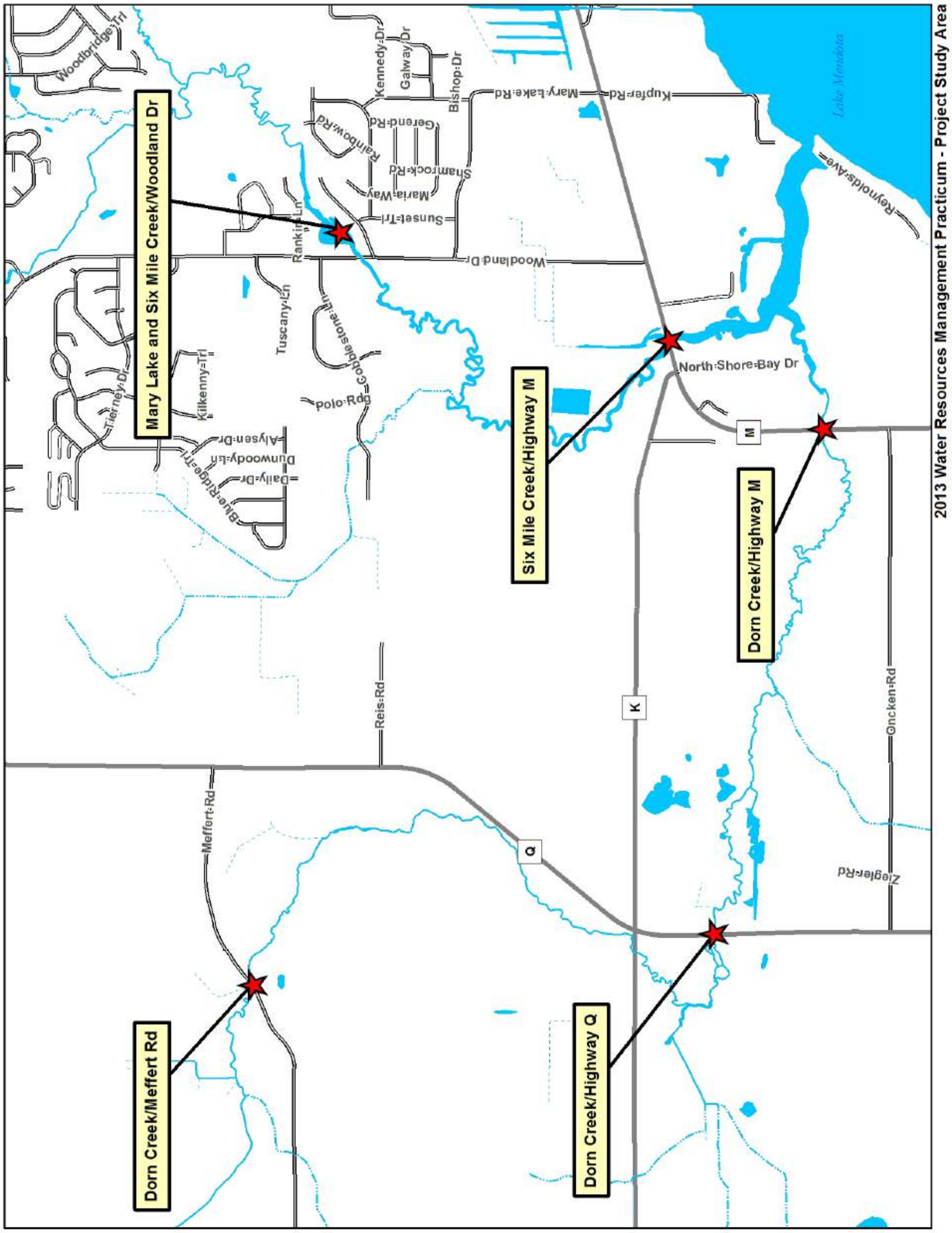


Figure 2.4 Study locations along Dorn Creek and Six-Mile Creek.

Note that the Upper Dorn Creek Wetland is bisected by Meffert Road in the northwestern portion of the map.

Figure 2.5 View of Upper Dorn Creek Wetland North of the Meffert Road Bridge Crossing on Dorn Creek.

The Dorn Creek wetland sites were selected due to previous research by Penn et al. (2005), which indicated their ability to retain or transport transient sediments (Figure 2.5). The sites along Six-Mile Creek were selected due to their proximity to road crossings and low position in the watershed. Pre-study sampling also indicated that large sediment volumes may travel through these sites and would offer the best opportunity to study transient sediment.

2.2 Previous Research and Other Criteria

The Dorn Creek watershed was the focus of a University of Wisconsin (UW) research project from 2003 to 2006 that examined the movement of sediment and phosphorus from agricultural fields into and through the stream-wetland complex (Lathrop et al., 2007). During runoff events, sediment from the watershed area is predominantly deposited in the low gradient stream channel, agricultural drainage ditches, and the wetland (Rogers et al., 2009). An inventory of sediment within the stream channel of Dorn Creek confirmed the presence of substantial amounts of sediment containing elevated levels of phosphorus (Penn, Hoffman, Armstrong, & Lathrop, 2005). During heavier rainfall, sediment is then re-suspended and washed out of the stream channel (Rogers et al., 2009). This happens when the force of the moving water against the bed of the channel – the shear stress – is large enough to move the sediment. Large shear stresses occur only during the initial phase of a runoff event (Rogers et al., 2009). Critical shear stress, measured in the top 5 centimeters (cm) of the sediment in the stream channel, suggests a susceptibility to re-suspend when it is under 10-20 centimeters per second (cm/s) flow velocity (Rogers et al., 2009). Shear stress increased below this level, suggesting that deeper sediments are less likely to re-suspend even during large events (Rogers et al., 2009).

Radionuclide studies of sediment age, conducted during the UW project, revealed that new sediment from the watershed deposits during storm events at both depositional sites and non-depositional (temporary) sites. Mixing of the new sediment with sediment already present in the stream channel generally occurs within the upper few centimeters, although it can also occur at deeper depths during large events. This mixing causes an enhanced exchange of phosphate between stream sediment and stream water. However, the mixing does not occur rapidly enough to preclude the natural conversion of organic phosphorus into inorganic forms of phosphorus (Lathrop, 2007). Since the inorganic forms of phosphorus are bioavailable – directly available for uptake by organisms – such mixing can have negative consequences downstream.

Dorn Creek is a tributary to Lake Mendota; consequently, sediment and phosphorus derived from the Dorn Creek watershed are likely to be transported to Lake Mendota. The form of phosphorus that is transported to Lake Mendota determines the extent to which the water quality is altered in the lake. The UW research demonstrated that the wetland is a net source of bioavailable phosphorus (BAP) and the levels of BAP correspond linearly with total phosphorus levels in the channel sediments, averaging 53% of total phosphorus (Hoffman, 2008). Increased concentrations of BAP occur in downstream depositional zones and are believed to be due to the preferential re-suspension and transport of fine-textured sediments, which are able to carry more phosphorus (Hoffman, 2008). The consequence is the potential for large quantities of BAP-rich sediments to be washed further downstream to Lake Mendota, thus contributing immediately available phosphorus to organisms, especially algae (Hoffman, 2008). High levels of algae growth contribute directly to water quality degradation in Lake Mendota.

Table 2.1 Stakeholders Contacted for WRM Project

Town of Westport
Yahara WINs board
Yahara Pride Executive Committee
Private landowners at Meffert Rd and Highway Q (Upper Dorn Creek Wetland)

The UW research suggests that the Dorn Creek wetlands are an opportune location for trapping and removing sediment before it can be washed downstream into Lake Mendota. Based on these previous studies, we focused on quantifying the phosphorus concentrations in shallow, temporary sediment depositions within the stream channel. By developing a novel strategy to prevent this phosphorus-laden sediment from entering the lake, we hope to improve the water quality in downstream Lake Mendota. Locating other sites of sediment deposition within the Six-Mile Creek watershed could provide additional opportunities for sediment removal, resulting in additional reductions in phosphorus input to Lake Mendota.

2.3 Stakeholder Identification

Key stakeholders for this project include landowners, farm operator collectives, Yahara WINs members and several municipalities (Table 2.1). The WRM team gave presentations to the organized groups and held informational meetings for landowners in the target study areas. The informational meetings provided a forum to discuss the project, solicit feedback from landowners on potential solutions, and to obtain a better understanding of the local natural history of the land.

The landowners in the Upper Dorn Creek Wetland (near Meffert Road and Highway Q) were contacted through mailings and by phone. The landowners met with the WRM team multiple times and most gave permission for land access during the research study. The majority of landowners in this area own several large parcels (greater than 5 acres) for dairy cattle or to grow row crops on family farms. The landowners were very willing to discuss potential solutions and any future work in this area of the watershed should include this group.

Landowners near the bridge sites were not contacted due to time constraints. In most instances, the study area for the bridge sites included the bridge right-of-way and 15 meters upstream and downstream of the bridge. Several of these areas are on public land within Governor Nelson State Park.

Landowners surrounding the area of Mary Lake on Six-Mile Creek were not contacted for this practicum; however, the Town of Westport was consulted. Future projects on Mary Lake should include public input.

3 Fieldwork and Findings

3.1 Introduction

Fieldwork and sampling activities conducted in the summer of 2013 quantified the volume of sediment and associated phosphorus stored in low gradient reaches of the Six-Mile Creek watershed. This sampling focused on the Upper Dorn Creek Wetland but also included four bridge crossings on Six-Mile and Dorn Creeks and Mary Lake on Six-Mile Creek. An in-stream sediment mobility study conducted within the Upper Dorn Creek Wetland also demonstrated the dynamics of sediment deposition and scour in the wetland-stream complex (Figure 3.1). Soil cores from the Upper Dorn Creek Wetland, including a deep two-meter sample, were collected to understand the soil profile of the wetland and for phosphorus analysis (Figure 3.2). Additional activities in the Upper Dorn Creek Wetland included measuring in-stream nitrate and phosphate concentrations and an informal vegetation survey (Appendices D, E, F, and G).

Figure 3.1 In-Stream Sediment Sampling along Dorn Creek.

Figure 3.2 Sediment Core from In-Stream Sampling.

3.2 In-Stream Sediment Volume and Phosphorus Load

The in-stream sediment volume in the Upper Dorn Creek Wetland, bridge sites and Mary Lake were quantified for a single point in time using measurements of stream width and depth to streambed refusal. Each sampling site followed a standard sampling protocol (Appendix E). A generic soil bulk density was also calculated from an in-stream soil sample to convert sediment volume into weight for estimation purposes. Sediment data by stream reach or site thus included both a volume and estimated weight.

Following sediment volume and weight quantification, in-stream sediment samples were collected to determine the phosphorus concentration and amount associated with each site. Twenty-four sediment samples were submitted to the UW Soil and Plant Analysis Laboratory (SPAL) for total phosphorus analysis. Eleven sub-samples were also analyzed for particle (grain) size (Appendix E). A phosphorus amount (dry weight) for each reach was then calculated from the phosphorus concentrations and sediment weight. The following three sub-sections highlight the results and findings of sediment quantification, phosphorus concentration and load calculations for each site.

3.2.1 Upper Dorn Creek Wetland Complex

The sediment in the reach of Dorn Creek that flows through the Upper Dorn Creek Wetland and in the associated agricultural ditches was quantified during the week of June 2, 2013, through June 9, 2013. No appreciable rainfall occurred during this time. Since permission to access the entire reach of Dorn Creek within the Upper Dorn Creek Wetland was not obtained, measurements were taken at individual reaches as noted in Appendix D and Figure 3.3. All field data and volume calculations are summarized in Appendix D.

Overall, sediment was irregularly deposited within the stream channel of Dorn Creek and the associated agricultural ditches. This irregular deposition is likely caused by longitudinal variability in the stream channel morphology and elevation gradient. Trees along the stream banks and vegetative debris within the stream channel also act as natural dams behind which sediment accumulates. The confluence of the stream channel and an agricultural ditch north of the Meffert Road bridge was a significant site of sediment deposition (Site D, 170 cubic meters [m^3] across the 45 meter ditch). Sediment depths within the stream channel and agricultural ditches varied from 0 to 1.1 meters and averaged 0.28 meters. Total sediment quantified within the accessible reaches and ditches was 792.8 m^3 across 1,000 meters of stream.

Depth (cm)	Phosphorus (%)	Phosphorus (mg/kg)
1 - 2.9	0.26	2,620.02
3 - 7.9	0.31	3,076.81
8 - 12.9	0.18	1,834.41
13 - 17.9	0.19	1,866.82
18 - 24.9	0.07	724.81
25 - 29.9	0.07	715.23
30 - 37	0.06	589.54

Note: Sample was taken 8 m upstream from the Meffert Road bridge

Table 3.1 Typical Soil Core Phosphorus Concentration by Depth in Dorn Creek in Upper Dorn Creek Wetland.

The highest total phosphorus concentrations were found in the upper 0-17 cubic centimeters (cm^3) of the sediment layer in Dorn Creek (Table 3.1). In the portion of the channel passing through the Upper Dorn Creek Wetland, the concentrations ranged from 1,054 milligrams phosphorus per kilogram (mg P/kg) to 3,076 mg P/kg (upper 17 cm^3 of sediment), with the highest total phosphorus values found in Site D and Site B (Figure 3.3). The soil texture associated with the areas of high total phosphorus was a silt loam (Table 3.1).

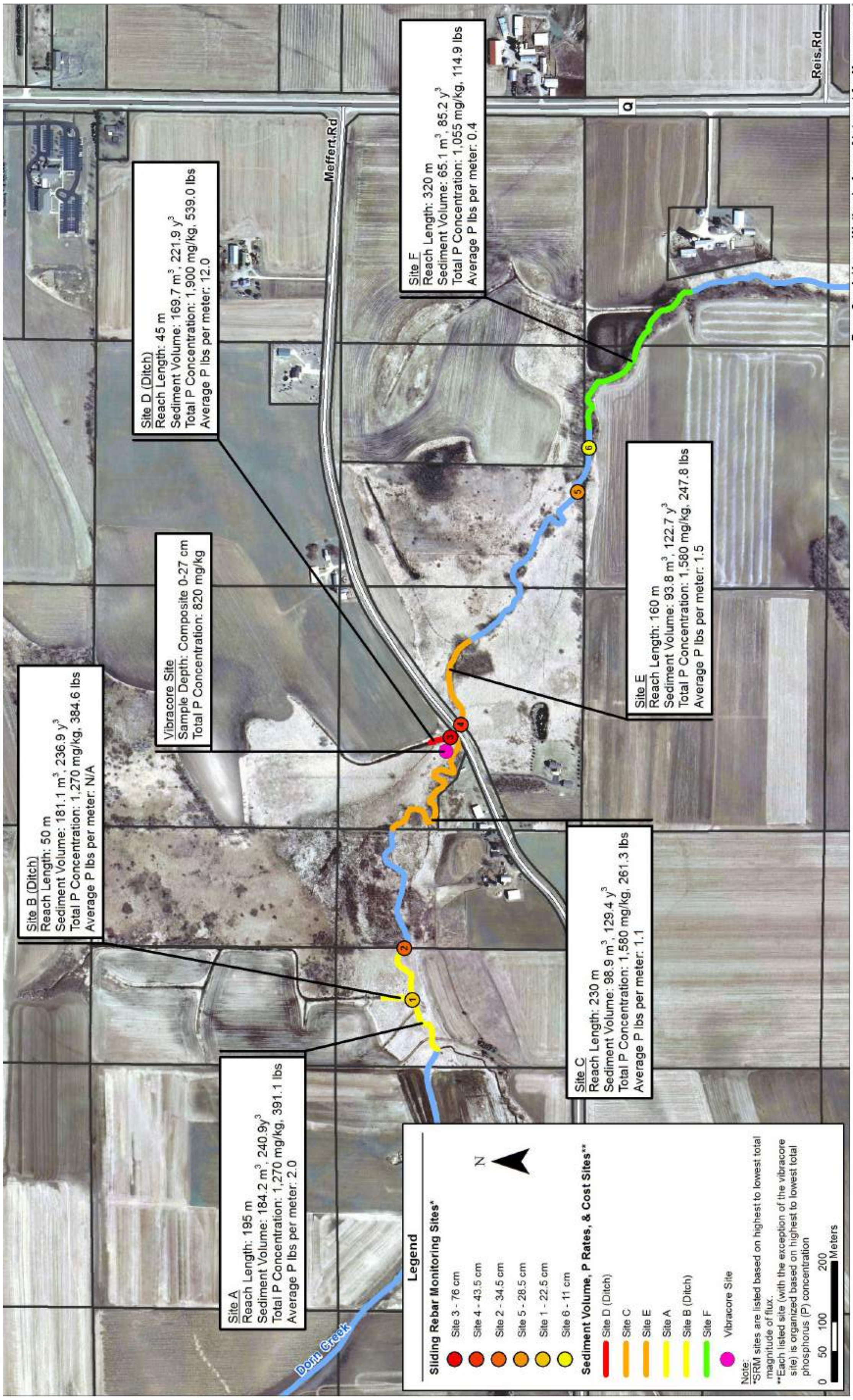


Figure 3.3 Sediment Volume and Phosphorus Amounts.

Site	Reach Length (m)	Volume (m^3)	Weight (kg)	Average TP concentration (P mg/kg)	P (lbs. Dry)	Average P lbs/meter
A	195	184	139,979	1,270	391.10	2.01
B (ditch)	50	181	137,665	1,270	384.60	7.69
C	230	99	75,170	1,580	261.30	1.10
D (ditch)	45	170	128,945	1,900	539.00	11.97
E	160	94	71,282	1,580	247.80	1.50
F	320	65	49,505	1,055	114.90	0.40
Totals	**1,000**	**793**	**602,546**		**1,938.70**	

Note: Weight data was derived using an average bulk density for an onsite sample. Average TP concentration was calculated from the top 3-15 cm of an in-stream sediment sample. See Appendix E for more details on calculations.

Table 3.2 Sediment Volume, Weight & Associated Phosphorus Load for Select Reaches of Dorn Creek in Upper Dorn Creek Wetland.

Across the stream channel in the Upper Dorn Creek Wetland, the areas with the highest phosphorus concentrations included Site D (11.9 pounds phosphorus per meter) and Site A (2.0 pounds phosphorus per meter) in the upper wetland. The lowest concentration of phosphorus was found on the Site F reach (0.4 pounds per meter) at the downstream end of the Upper Dorn Creek Wetland. Overall, there is an estimated total of 1,940 pounds of phosphorus associated with sediment in the stream channel within the Upper Dorn Creek Wetland at the time of sampling (Table 3.2).

Tributary	Length (km)	Average Sediment TP Concentration (mg/kg)	WRM Study TP Range (mg/kg)
Dorn Creek	10	1,300	720-2,500
Six-Mile Creek	21	660	315-1,400
Yahara River	26	410	
Token Creek	18	460	
Pheasant Branch	10	140	
Cattle Manure	N/A	3,600	

Note: Data for tributaries courtesy of Penn et al. (2012). Data for manure concentrations from Gilley et al. (2007). See Appendix E for sites on Dorn Creek and Six-Mile Creek included in the WRM range. Sampling on Six-Mile Creek for WRM project was extremely limited.

Table 3.3 Comparision of TP Concentrations across Yahara Lakes Tributaries.

These total phosphorus concentrations generally follow those found in in-stream sediment core data from Hoffman (2008) and Penn et al. (2005) for the Dorn Creek watershed. Total phosphorus and accumulation of sediment is extremely high in the Dorn Creek system in contrast to other Yahara Lakes stream tributaries (Table 3.3).

Capturing this sediment in Dorn Creek could yield significant removal of total phosphorus from the Yahara system. However, estimates of volume and phosphorus load are specific only to the time of sampling. Therefore, a sediment mobility survey was implemented following volume sampling to determine the degree to which this sediment is accumulating and dispersing (Section 3.3).

3.2.2 Bridge Sites

Results from bridge sites indicate average sediment depths of 40 cm, with volumes ranging from 24 to 67 m^3 (Figure 3.4). Dorn Creek/Hwy Q and Dorn Creek/Hwy M had an average sediment volume of 24 m^3 and 42 m^3, respectively. Six-Mile Creek upstream of Hwy M and downstream of Hwy M had an average sediment volume of 67.5 m^3, and Six-Mile Creek/Woodland Drive had a sediment volume of 39 m^3.

Of the four sampling bridge locations, Dorn Creek/Hwy Q and Dorn Creek/Hwy M had the highest average phosphorus concentrations at 1,938 mg P/kg and 1,598 mg P/kg, respectively. Six-Mile Creek upstream of Hwy M and downstream of Hwy M had average phosphorus

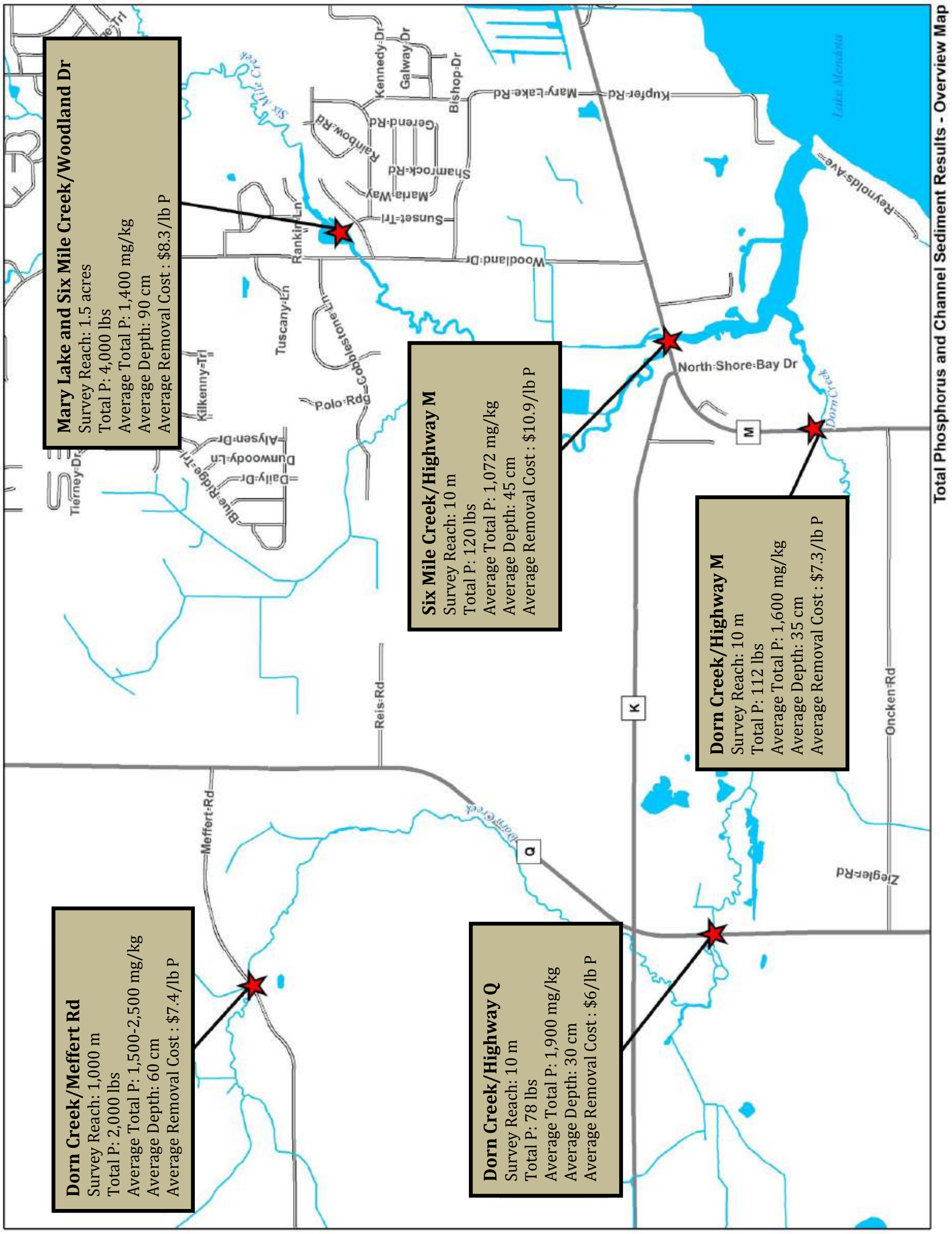


Figure 3.4 Overview of Sediment Volume of TP at Bridge Sites.

Site	Volume (m^3)	Weight (kg)	Average TP concentration (P mg/kg)	P (lbs. dry)	Soil Texture 0-15 cm depth
Six-Mile Creek at Hwy M	68	51,300	1,072	120.99	Loam
Dorn Creek at Hwy M	42	31,920	1,600	112.36	Loam
Dorn Creek at Hwy Q	24	18,240	1,938	77.77	Silt loam
Six-Mile Creek at Woodland Dr	39	29,640	1,072	69.90	Loam
Totals	**173**	**131,100**		**381.02**	

Note: All sediment volumes were calculated for a 10 meter stretch with a given stream width. Average TP concentration was typically calculated from the top 3-15 cm of an in-stream sediment sample. See Appendix E for more details on calculations.

Table 3.4 Sediment Volume, Weight & Associated Phosporus Load for Bridge Sites in Six-Mile Creek Watershed.

concentrations of 1,072 mg P/kg and 409 mg P/kg, respectively. The sample at Six-Mile Creek/Woodland Drive had a phosphorus concentration of 415 mg P/kg.

The phosphorus amount at each of the four bridge sites was estimated for a ten-meter length at each bridge (Table 3.4). Phosphorus amounts ranged from 70 to 120 pounds of phosphorus (dry). The bridge at Six-Mile Creek/Hwy M had the greatest amount with 120 pounds while the lowest amount, 70 pounds, was found at Six-Mile Creek/Woodland Drive.

3.2.3 Mary Lake

Due to time constraints and the large size of Mary Lake (Figure 3.5), only preliminary estimates of sediment volume were made in this area. Sediment depths within Mary Lake were approximately 90 cm. Based on an area of 4,856 square meters (m^2) derived from aerial photos, the estimated sediment volume within the lake area was 4,370 m^3 (Figure 3.6 and Appendix E). Assuming a phosphorus concentration of 1,400 mg P/kg, the volume of phosphorus on the lakebed was approximately 4,000 pounds. Mary Lake will require further study to determine the potential benefits of dredging the lake.

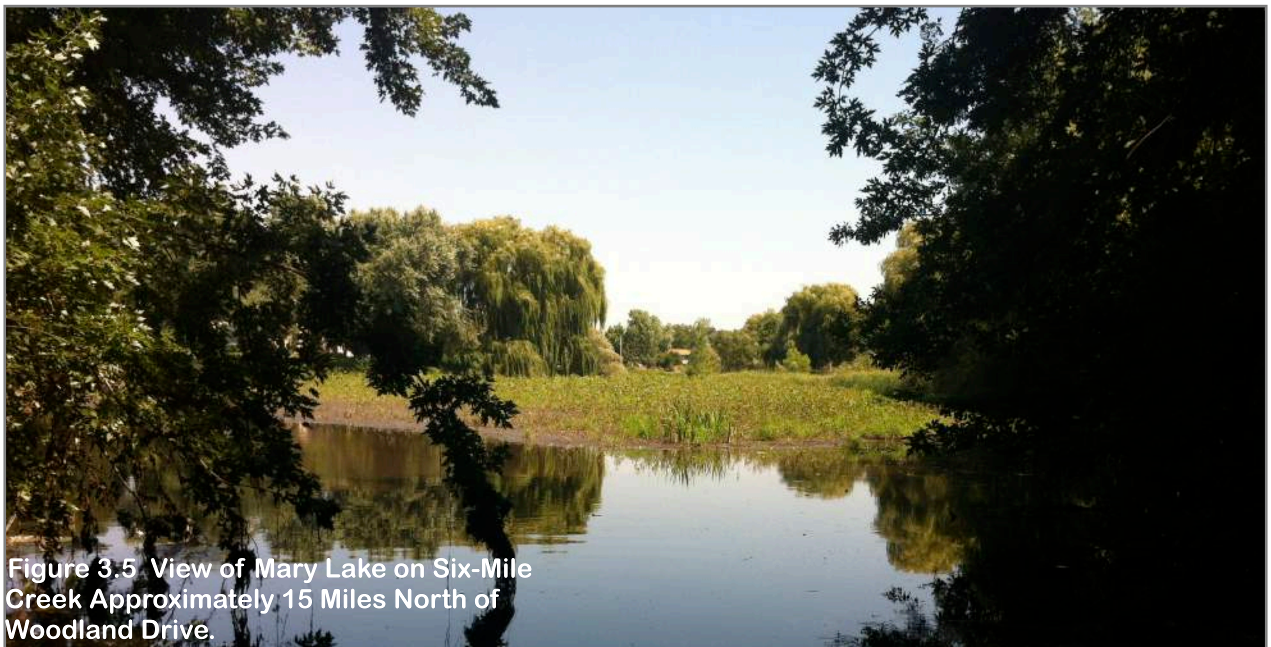


Figure 3.5 View of Mary Lake on Six-Mile Creek Approximately 15 Miles North of Woodland Drive.

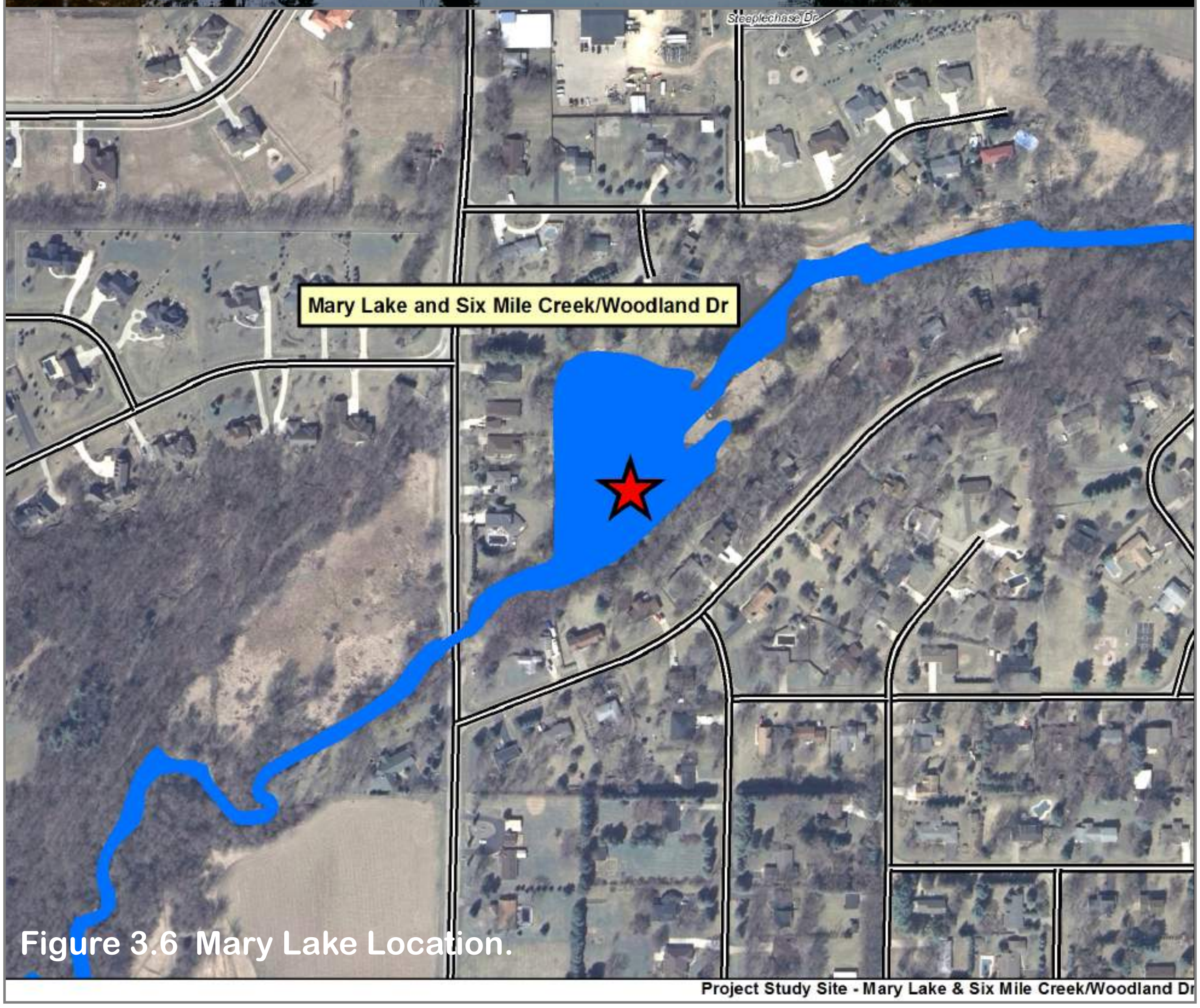


Figure 3.6 Mary Lake Location.

3.3 In-Stream Sediment Mobility in Upper Dorn Creek Wetland

An in-stream sediment mobility study was conducted to get an idea of sediment deposition and scour at selected sites along Dorn Creek as it flows through the Upper Dorn Creek Wetland. Sliding rebar monitors, used to measure in-stream scour and deposition, were selected based on a pilot study of different methods (Figure 3.7 and Appendix E). Sliding rebar monitors were installed at six locations along Dorn Creek in early June 2013 (Figure 3.3 and 3.8) Sediment deposition and scour was measured from June 14 to September 20, 2013. Measurements were made only after storms that resulted in stream discharges greater than 40 cubic feet per second (cfs). Real time discharge data from the United States Geological Survey (USGS) gauges at Dorn Creek and Hwy M were used to determine discharges greater than 40 cfs.

Sediment mobility is characterized by scour (removal of material), deposition (addition of material), or an active mix of both. The magnitude in change of material is useful for evaluating sediment transport. Heavy deposition occurred upstream in the wetland-stream complex where vegetation is thick and the flow is slow due to the low stream gradient (Sites 1 and 2). Scour primarily occurred in the downstream reach where the channel is constrained and the slope increases, further increasing flow (Sites 5 and 6). A mix of both scour and deposition occurred at the sites upstream and downstream of the bridge at Meffert Road (Sites 3 and 4). The site surrounding the

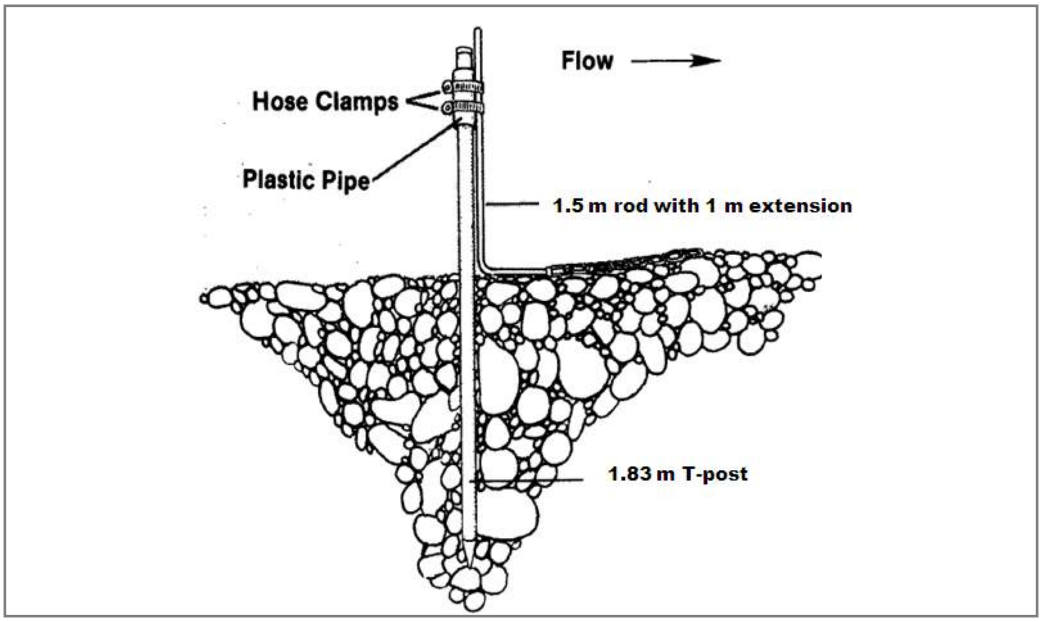


Figure 3.7 Sliding Rebar Sediment Monitoring Device.

bridge demonstrated over 70 cm of change during the observation period, indicating a site of significant transient sediment storage and subsequent erosion (Figure 3.9, Figure 3.10, and Figure 3.11).

These data demonstrate that both scour and deposition of sediment occurs in the channel. Deposition above the Meffert Road bridge is likely facilitated by the constraint of flow by the culvert. Deposition below the bridge is facilitated by over-widening of the channel during exceptionally high flows, leading to deposition at more normal high flows.

The results of the mobility and in-stream sediment volume study demonstrate that large amounts of sediment are intermittently deposited on and eroded from the streambed throughout the Dorn Creek wetland and that there are preferential sites for erosion and deposition. These results support the findings of Rogers et al. (2006) and Hoffman (2006) and indicate that there are key locations within the wetland to capture sediment and focus management efforts.

Figure 3.8 Sliding Rebar Installation by WRM Team Member Karen Bednar.

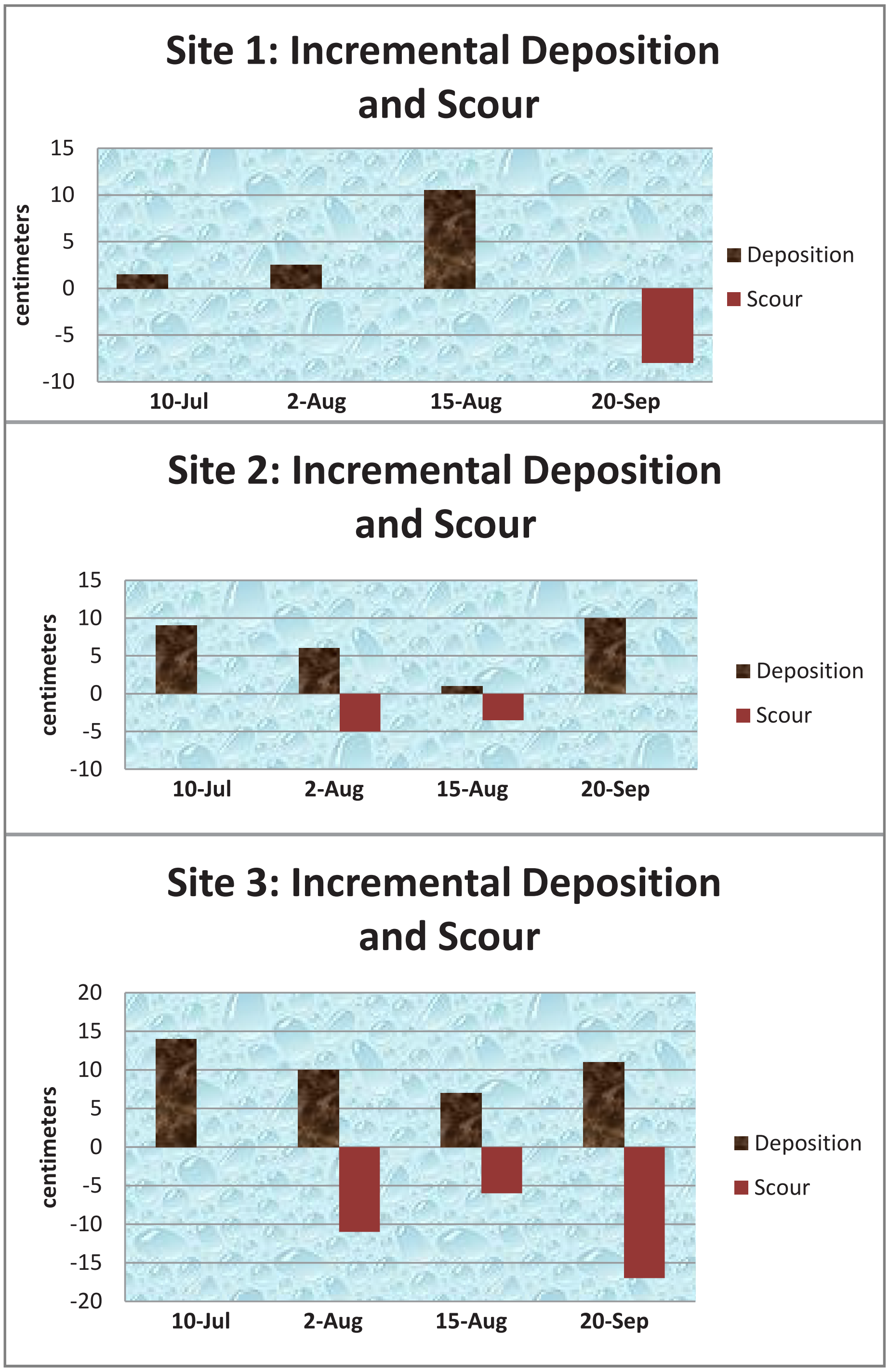


Figure 3.9 Site Based Mobility (Sites 1-3).

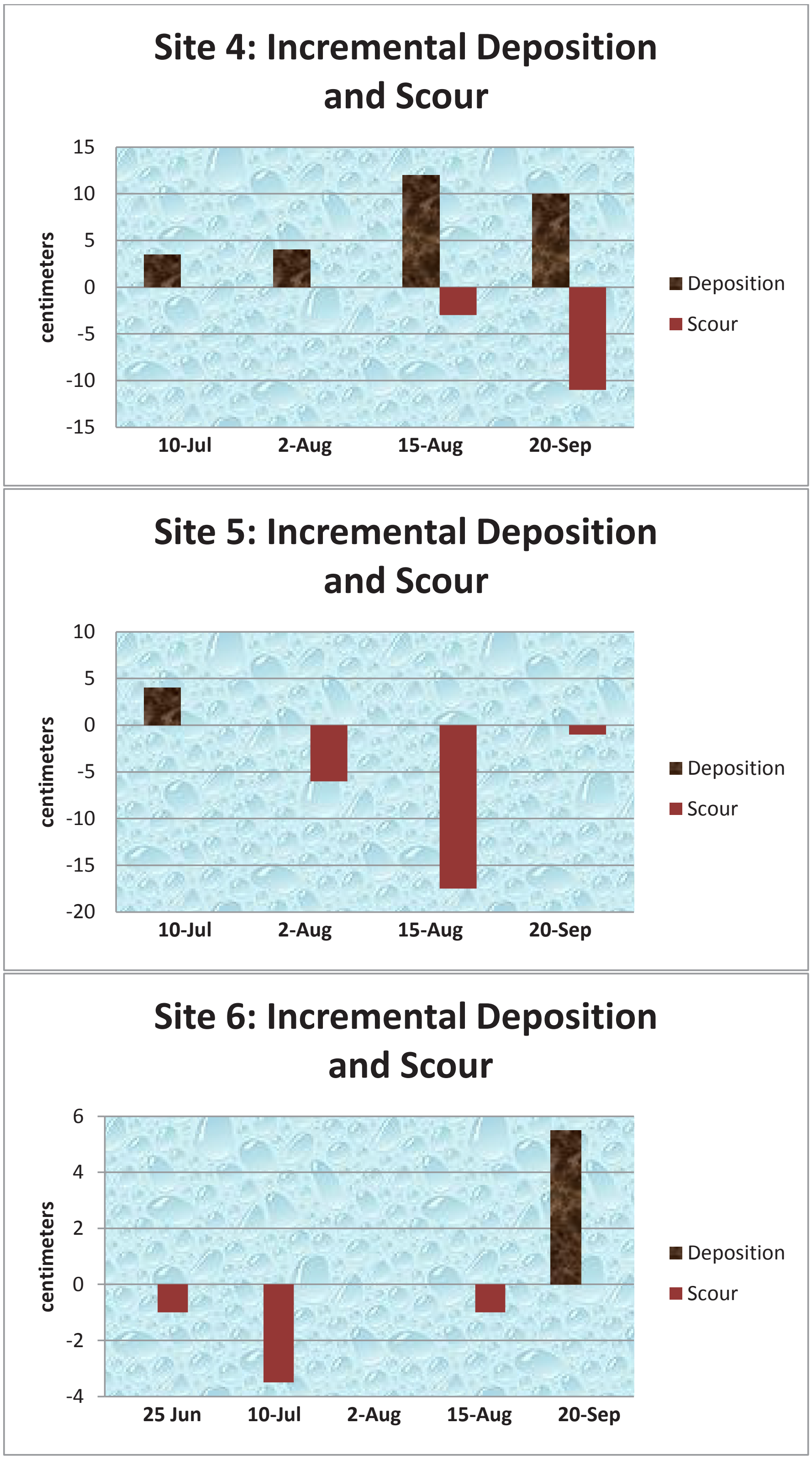


Figure 3.10 Site Based Mobility (Sites 4-6).

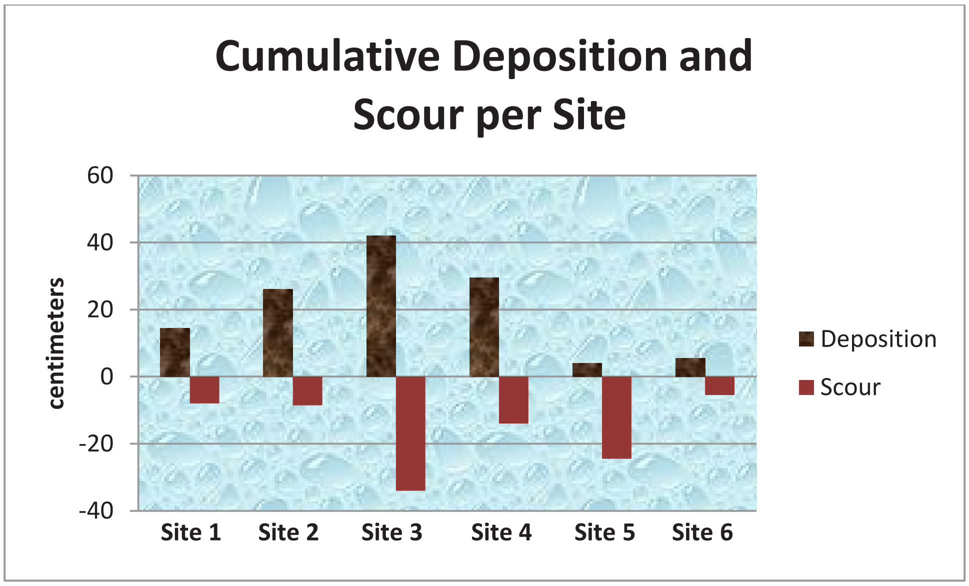


Figure 3.11 Cumulative Sediment Mobility Measured from Sliding Rebar Monitors in Dorn Creek from June 14, 2013 to September 20, 2013.

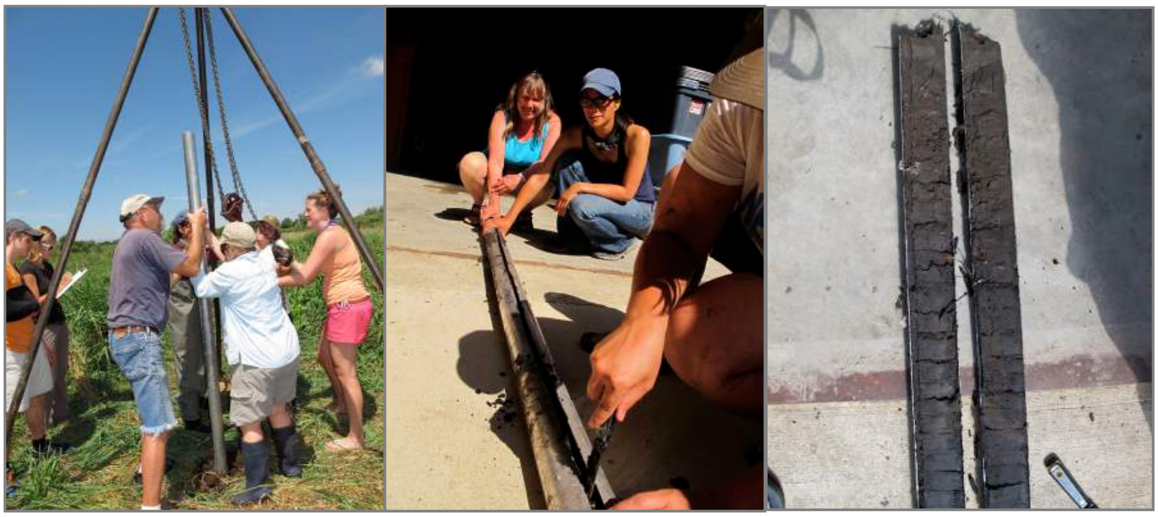
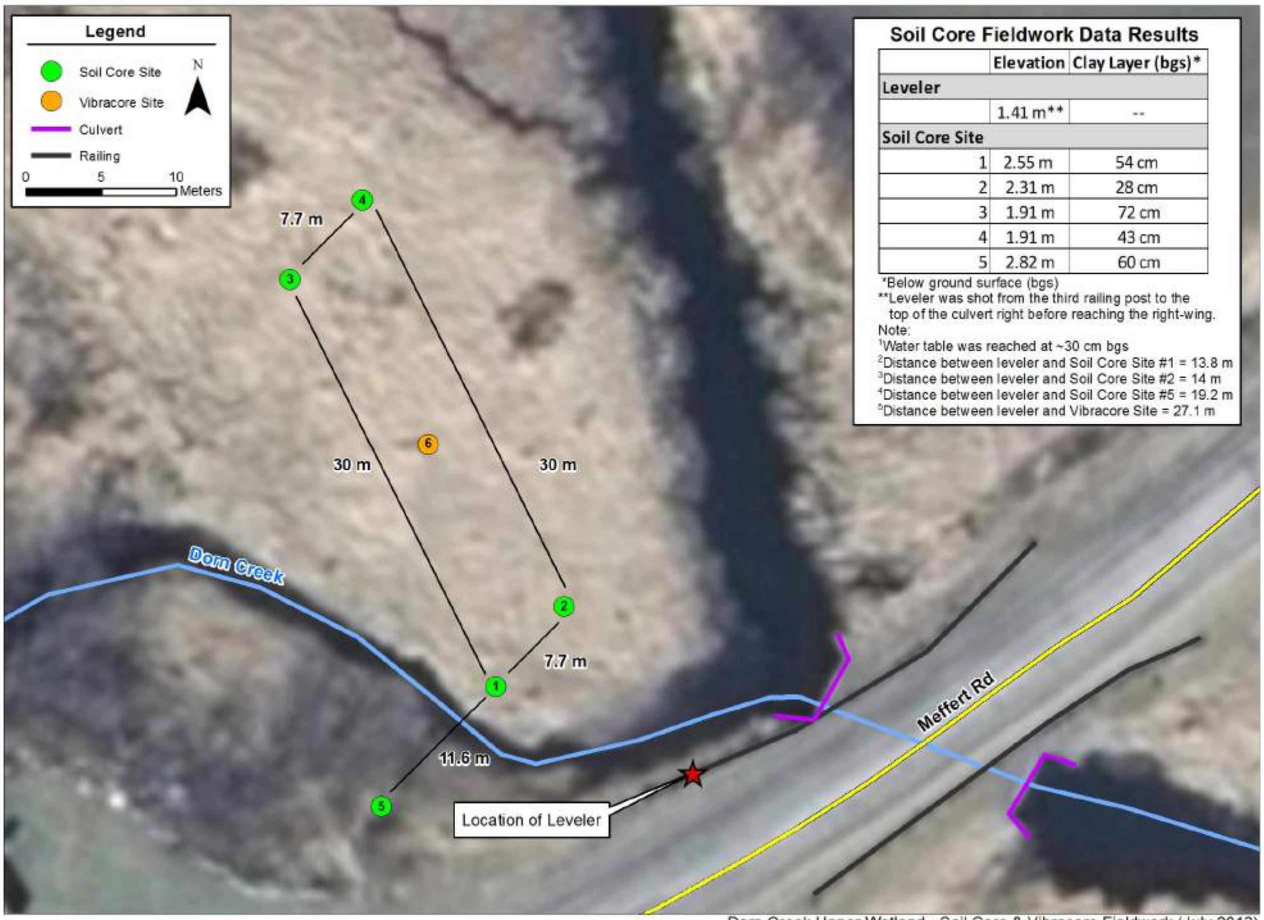


Figure 3.12 Wetland Soil Coring with the Vibracore Device.

3.4 Wetland Soil Coring

Given the high phosphorus loads and mobility of the in-stream sediment, the WRM team conducted a preliminary investigation of sediment accumulation onto the floodplain wetland from overbank flooding (Figure 3.12). A single sample was taken using a Vibracore sampler following a standard protocol (Appendix E).

The sample was taken approximately 15 m from the stream in the Upper Dorn Creek Wetland near Site D (Figure 3.13). Recovery included 1.94 m of sediment and revealed a water table depth of 30 cm.



Dorn Creek Upper Wetland - Soil Core & Vibracore Fieldwork (July 2013)

Figure 3.13 Wetland Vibracore Fieldwork.

Section ID	Depth (cm)	Sample range	Soil Texture	% Sand	% Silt	% Clay	TP (mg/kg)
A	0-27	10-19	Silt Loam	21	65	14	820.72
B	28-65	40-50	Silty Clay Loam	15	56	29	359.26
C	66-110	76-91	Silt Loam	31	54	15	440.30
D	110-125	133-145	Loam	41	48	11	385.26
E	126-191	170-182	Silt Loam	22	62	16	494.86
F	191-194	191-194	Silt Loam	13	70	17	633.72

Note: Sample was taken approximately 15 m from the stream in Upper Dorn Creek Wetland. See Appendix E for methodology.

Table 3.5 Wetland Vibracore Sampling Data.

The phosphorus concentration in the core ranged from 385 mg P/kg to 820 mg P/kg (Table 3.5). This is a lower range than in-stream sediment but still quite high as typical values in wetlands range from 50 to 300 mg/kg (Dunne & Reddy, 2005). The highest TP values were found in the first 25 cm of the soil profile. The texture of the wetland soil core was predominately a silt loam, similar to the in-stream cores. Contrary to expectations, there was no evidence of a transition to peat. However, there was an impeding layer at the bottom of the core that prevented deeper coring. Additional soil cores would be required to better understand the depositional history of the wetland. However, it is clear that the wetland has been accumulating sediment during overbank flows.

3.5 Stream Phosphate and Nitrate

Dissolved phosphorus and nitrate were measured (Appendix E) in Dorn Creek at the six scour device installations. This auxiliary data was collected to describe nutrient dynamics in creek. The data was collected on August 2, 2013, August 15, 2013, and September 20, 2013, each after intervals of varying rainfall intensities and proximities, to understand the nutrient response during rain events or during drought periods. A discussion of the results is located in Appendix G.

3.6 Vegetation Characteristics

The vegetation within each area was informally surveyed to determine the strata, dominate species within each stratum, and other relevant vegetation data. Data from Rogers et al. (2009), the Wisconsin Wetland Inventory, and Hillegas (2006) were also examined to determine wetland vegetation characteristics. The survey was not intended to be exhaustive but to catalog the dominant vegetative cover and any issues with invasive plant species. The dominant herbaceous cover in the Upper Dorn Creek Wetland is reed canary grass (*Phalaris arundinaceae*) and this invasive species has densely infested most areas of the wetland. Further results of the survey can be found in Appendix F.

3.7 Conclusions from Fieldwork and Findings

The high phosphorus load and sediment mobility in the stream channel in the Upper Dorn Creek Wetland indicate that the wetland is a promising location for management practices, such as a partial removal of sediment. In the next chapter we present modeling results and analysis to provide information on the potential effectiveness of such practices. Additional practices could also focus on the bridge sites, though the sediment load is lower.

4 Modeling Sediment and Phosphorus Trapping Potential in the Upper Dorn Creek Wetland

4.1 A Novel Approach to Sediment Trapping

The Upper Dorn Creek Wetland presents a unique opportunity to increase sediment retention functions by increasing storage volume and trapping efficiency through a floodplain restoration project. Results from the field sampling indicate that there is a large and mobile sediment source in the Dorn Creek streambed. If the stream flow from Dorn Creek can be reconnected to the Upper Dorn Creek Wetland, then there is a potential to trap this transient sediment within the wetland. To increase connectivity to the wetland the banks of the stream must be lowered by mechanical excavation. Following bank lowering, the wetland area surrounding the creek would also be lowered by excavating the wetland soil to increase sediment storage capacity in the wetland. During storm events, overbank flooding from Dorn Creek could then flow into the Upper Dorn Creek Wetland and deposit the sediment, resulting in a reduction of phosphorus delivered downstream.

The inspiration for this recommendation comes from a similar project implemented on the East Branch Pecatonica River near Barneveld, Wisconsin in 2009 (Booth & Loheide, 2009). A deep layer of eroded upland soil has covered and impacted many wetlands in the Pecatonica watershed prior to improved soil conservation practices. Soil coring at this project site revealed a thick layer of legacy sediment deposited over historic floodplain wetlands. This sediment buried and terraced the floodplain wetlands, disconnecting them from the stream while raising them further from the water table. The result of this terracing was an increase in downstream flooding and a reduction in the quality of wet-prairie habitat. Due to these impacts, land managers used the novel approach of sediment removal in the floodplain to restore native vegetation, increase flood storage and improve water quality. In a single project, excavating equipment removed over 10,856 cubic yards (yd^3) of this legacy sediment at a depth of one to four feet. The excavated sediment was donated to the county highway department or sold as topsoil to an excavating company. Following soil removal the site was planted with native wet-prairie species. To date, the project has been effective at re-establishing native vegetation and ongoing research continues to document the results of this approach (Booth & Loheide, 2012; Booth & Loheide, 2010).

Based on the success of this project, the WRM team explored the potential to apply this novel approach to the floodplain wetlands on Dorn Creek at Meffert Road. The floodplain wetlands on Dorn Creek were selected as study sites because previous research by Rogers et al. (2009) provided extensive data about the hydrology of this system. A combination of modeling techniques was employed to test the efficacy of this application. A restoration area of five acres located directly north of the Meffert Road bridge, a significant site of sediment deposition, and a removal depth of one foot were selected as a realistic scenario to model.

4.2 Modeling Approach

We developed a novel modeling approach (Figure 4.1) to evaluate the potential trapping efficiency of sediment and phosphorus in the Upper Dorn Creek Wetland through restoration activities and removal of sediment that has been deposited over the past 100+ years. This modeling approach integrates information from watershed modeling with sedimentation analysis to estimate the amount of sediment and phosphorus that would be trapped in the restored wetland. The results indicate that a five-acre wetland restoration at a one-foot removal depth would annually trap about 187,000 pounds of sediment and 281 pounds of phosphorus. The modeling approach is summarized below and presented in detail in Appendix A.

Step 1. Prediction of Flows and Sediment/Phosphorus Concentrations

We used the Soil and Water Assessment Tool (ArcSWAT version 2012.10.1.9) to model the daily inflows to the Upper Dorn Creek Wetland, as well as the associated sediment and phosphorus concentrations. We ran the model for the period January 1, 1943 through May 2, 2009, the period for which rainfall data are available from the National Weather Service rain gage at the Dane County Regional Airport. No systematic flow data are available for Dorn Creek; the model was calibrated using flow data from the Yahara River at Windsor, WI. Appendix A has further information on model calibration.

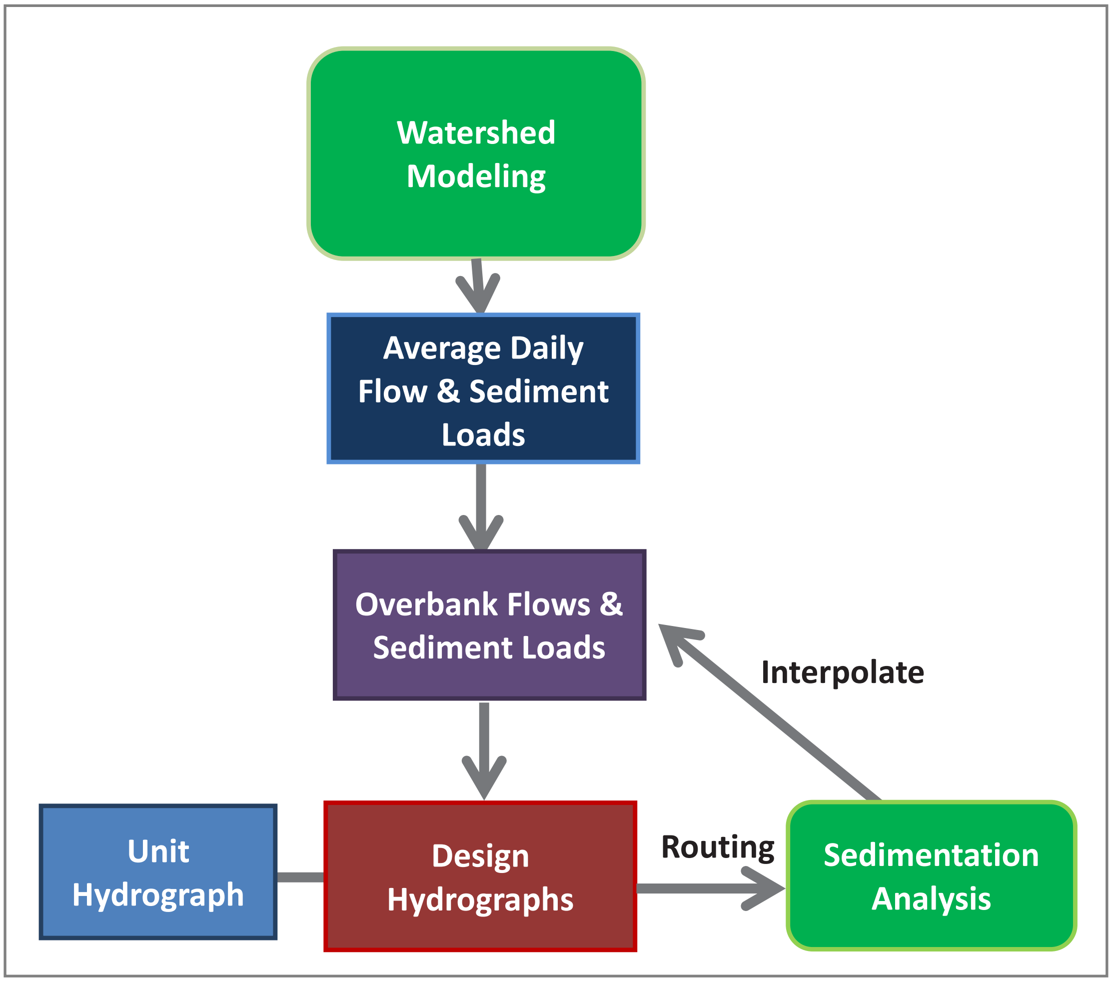
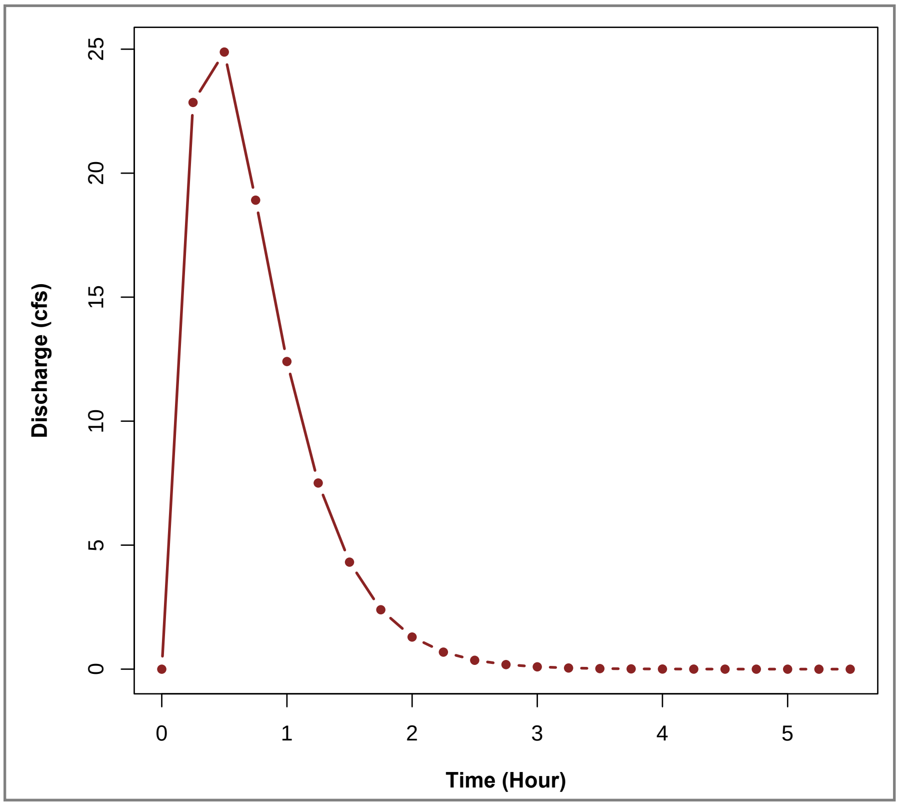


Figure 4.1 Conceptual Diagram of Modeling Effort for this Project.
A multi-faceted approach was taken starting with the development of a SWAT model, the derivation of stormflow hydrographs, and wetland performance evaluation using WinDETPOND.



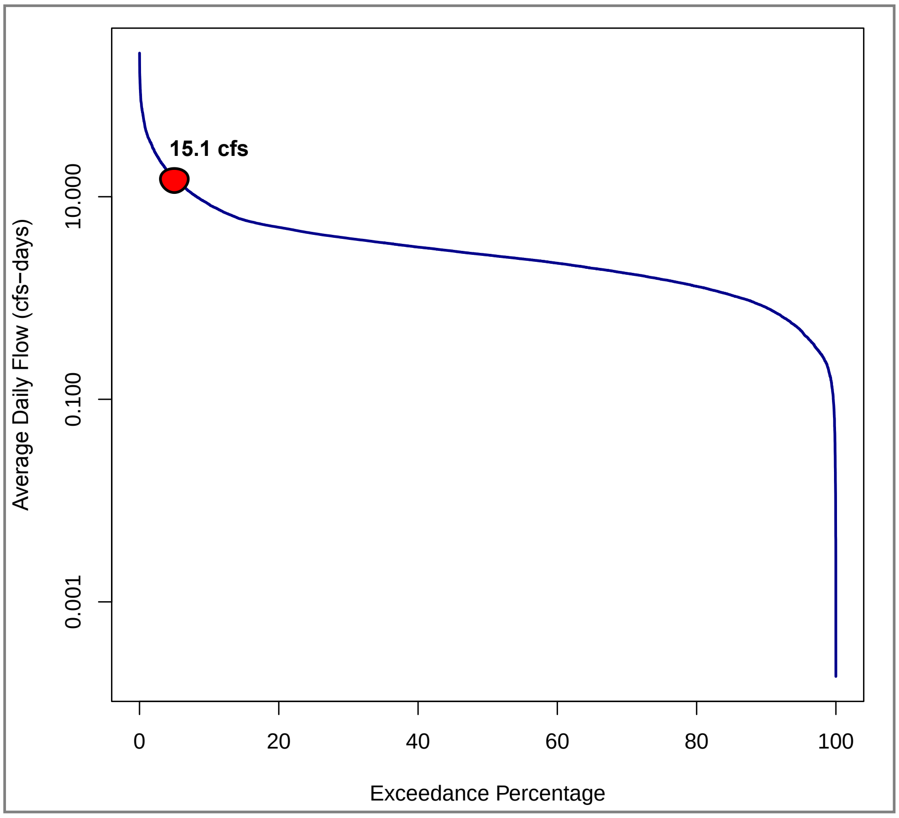
Equation 4.1a SCS Curvilinear Hydrograph Formula

$$\frac{q(t)}{q_p} = \left[\frac{t}{0.4} e^{1-\frac{t}{0.4}}\right]^{1.25}$$

Figure 4.2 Unit Hydrograph for Dorn Creek Watershed.
This unit hydrograph was produced using the synthetic curvilinear hydrograph approach in conjunction with TR-55.

Step 2. Hydrograph Development

The SWAT model streamflows are daily, but estimation of sediment trapping requires flow information at a finer timescale. To improve the temporal resolution of streamflows during storm events we developed a standardized hydrograph for the Upper Dorn Creek Watershed (Figure 4.2). A standardized hydrograph is a tool used by hydrologists to visualize streamflow through time. This hydrograph was based on the curvilinear Soil Conservation Service (SCS) unit hydrograph (Equation 4.1a) and on data collected by Rogers et al. (2009). Specifically, the hydrograph was developed using data from storm event 5 in Rogers et al. (2009) because this event had uniform rainfall and sediment erosion. Note that the unit hydrograph (Figure 4.2) has a relatively short duration and high peak. Its use was conservative in that a longer duration standardized hydrograph would have resulted in greater sediment and phosphorus trapping.



Equation 4.1b

$$Q_{wi} = Q_i - Q_{0.05}$$

Figure 4.3 Flow-Duration Curve.

Flow duration curve for Dorn Creek displaying the percentage of time (x-axis) that a given daily flow (y-axis) is equaled or exceeded. The red dot indicates that a flow of 15.1 cfs is the flow that is equaled or exceeded 5% of the time in Dorn Creek.

Step 3. Sedimentation Analysis

We used WinDETPOND (verison 8.5.3) to evaluate the trap efficiency of the Upper Dorn Creek Wetland, based on the storm-event hydrographs. The culvert at Meffert Road was used as the outlet control for the restored wetland. A custom stage-discharge relationship was produced using the dimensions of this outlet and the Hy-8 software program (Appendix A, Table A.7). We assumed the wetland to be vertically sided and developed the stage-area table accordingly, with 0.25 foot increments for an area of 5 acres (Appendix A, Table A.4). Furthermore, we determined the bank flow discharge (i.e., the discharge at which flows reach the height of the left and right bank) as all flows greater than 15.1 cfs, the daily SWAT flow which is equaled or exceeded 5% of the time (Figure 4.3, Equation 4.1b). The particle size distribution file Midwest.cpz (Pitt & Voorhees, 2013) was used, as this is representative of the agricultural soils in the Midwest (Appendix A, Table A.8).

Flow Quantile	Average Daily Flow (cfs-day)	% Particles Trapped
5	0.422	100
10	0.769	100
15	1.038	100
20	1.283	100
25	1.509	94.8
30	1.732	90.9
35	1.954	88.5
40	2.189	85.6
84.4145	2.416	84.41
50	2.643	83.4
55	2.890	81.9
60	3.167	79.7
65	3.500	77.3
70	3.866	75.8
75	4.322	75.4
80	4.975	73.8
85	5.875	71.3
90	8.340	66.6
95	15.111	60.8
100	262.212	31.8

Table 4.1 Trap Efficiency.

The trap efficiency (%) for each average daily flow wetland design area of 5 acres.

Equation 4.1c

$$S_{wi} = \frac{Q_o}{Q} * S_i$$

S_{wi}= sediment load (lbs) at a given overbank flow (Q_{wi})

Q_i= original average daily flow (cfs-day) from SWAT model

S_i= original sediment load (lbs) transported at a given Q_i

Q_{wi}= overbank SWAT flow d (cfs-day) derived from subtracting $Q_{0.05}$

We used WinDETPOND to determine the trap efficiency of the wetland for each storm hydrograph. The sediment load at a given daily flow was weighted by flow (Equation 4.1c). We then used these trap efficiencies to estimate the potential effectiveness of the proposed wetland design for removing sediment and associated phosphorous from the Dorn Creek watershed. The results of the sedimentation analysis are summarized in Table 4.1 and Figure 4.4, which display the trap efficiency obtained at a given wetland restoration area and overbank flow. The trap efficiency for the 5-acre wetland restoration is 100% for the 0-20% overbank flow quantiles, but the trap efficiency drops from 94.8% to 31.8% trapping for the 25-100% flow quantile (Table 4.1).

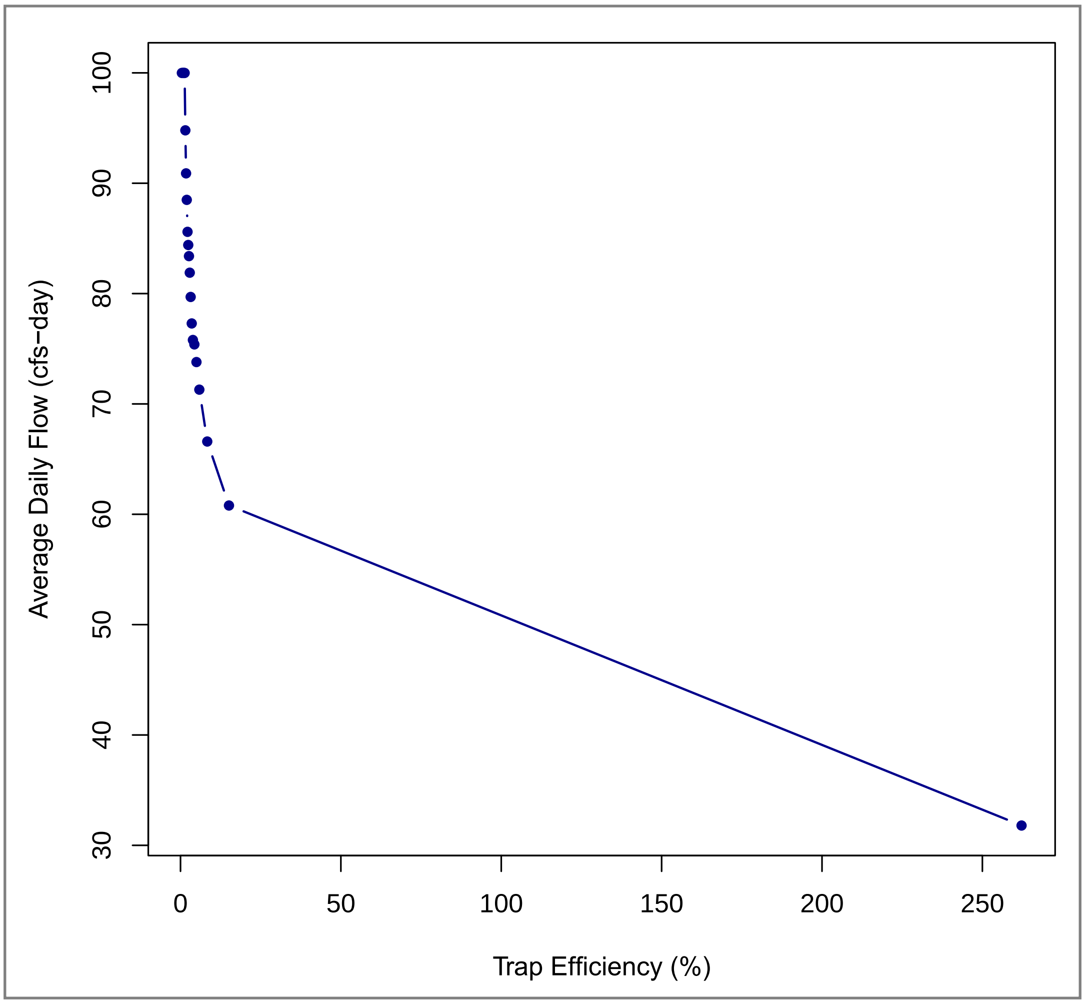


Figure 4.4 Trap Efficiency Curve.

Trap Efficiency Curve displayed above is the average Daily Flow (cfs-days) versus Trap Efficiency (%) curve produced using the SWAT flows in conjunction with DETPOND (sedimentation analysis).

Equation 4.1d	Equation 4.1e	Equation 4.1f
$S = \sum_{i=1}^{n} S_i$	$S_T = \sum_{i=1}^{n} (E_i * S_{Wi})$	Effective Trap Efficiency = $\frac{S_T}{S}$

Step 4. Combined Analyses for Prediction of Sediment and Phosphorus Trapping

The total quantity of sediment contributed to the wetland from the Dorn Creek watershed is 43.6 million pounds over the 66.4 year length of the SWAT model (Equation 4.1d). Sedimentation analysis reveals that the restored wetland traps 12.4 million pounds of the contributed sediment (Equation 4.1e), resulting in an effective trap efficiency of 29% (Equation 4.1f). Furthermore, the restored 5-acre wetland traps 18,600 pounds of phosphorus over the 66.4 year period (Appendix B). Thus, the 5-acre wetland can trap 187,000 pounds of sediment and 281 pounds of phosphorus annually. The restored wetland will vary in trapping capacity based on the depth of sediment removed, and experts should run other removal scenarios.

Assuming the prior annual sediment and phosphorous loading rates and a sediment bulk density of 0.7 g/cm^3, we predict that under a one-foot removal scenario the wetland will have to be dredged at least every 50.79 years, or approximately every 50 years (Appendix B).

4.3 Modeling Uncertainties

This modeling effort provides an estimate of the sediment trap efficiency of the Upper Dorn Creek Wetland under a floodplain restoration scenario. We used SWAT to model sediment transport in the Dorn Creek watershed and DETPOND to model sedimentation in the Upper Dorn Creek Wetland. These physical processes are inherently difficult to model, resulting in model uncertainties. The SWAT model produces daily flow and sediment loading estimates that are uncertain because there is no calibration data specifically for the Dorn Creek watershed. In addition, the sedimentation modeling is uncertain because we utilized a model intended for sedimentation basins and not wetlands. Furthermore, our approach may overestimate sedimentation because we assume that sediment is uniformly distributed in the water column and that the particle settling rate is linear with depth. In reality, sediment is not uniformly distributed in the water column, and the particle settling rate is non-linear. Despite these uncertainties this modeling effort provides a first estimate of the sediment trap efficiency of a wetland floodplain restoration. Future modeling efforts should aim to address these uncertainties in the interest of obtaining better sediment trap efficiency estimates.

5 Analysis of Two Options for Phosphorus Removal

Based on the findings of this study, we recommend several management options for the Dorn Creek and Six-Mile Creek watersheds to reduce transport of sediment and phosphorus to Lake Mendota.

The first management option is a floodplain restoration project in the Upper Dorn Creek Wetland to reconnect the wetland to the stream. A restored wetland would result in a significant reduction in the transport of sediment and phosphorus from the Upper Dorn Creek watershed.

The second management option is the periodic dredging of sediment from bridge or other easily accessible stream crossings to routinely remove phosphorus-laden sediment either by mechanical or hydraulic equipment. This broad method could be used in both the Dorn Creek and Six-Mile Creek watersheds.

Other management options discussed in this report are for the Mary Lake section of Six-Mile Creek, which includes dredging sediment from the lake, leaving it as an open water system, and wetland restoration.

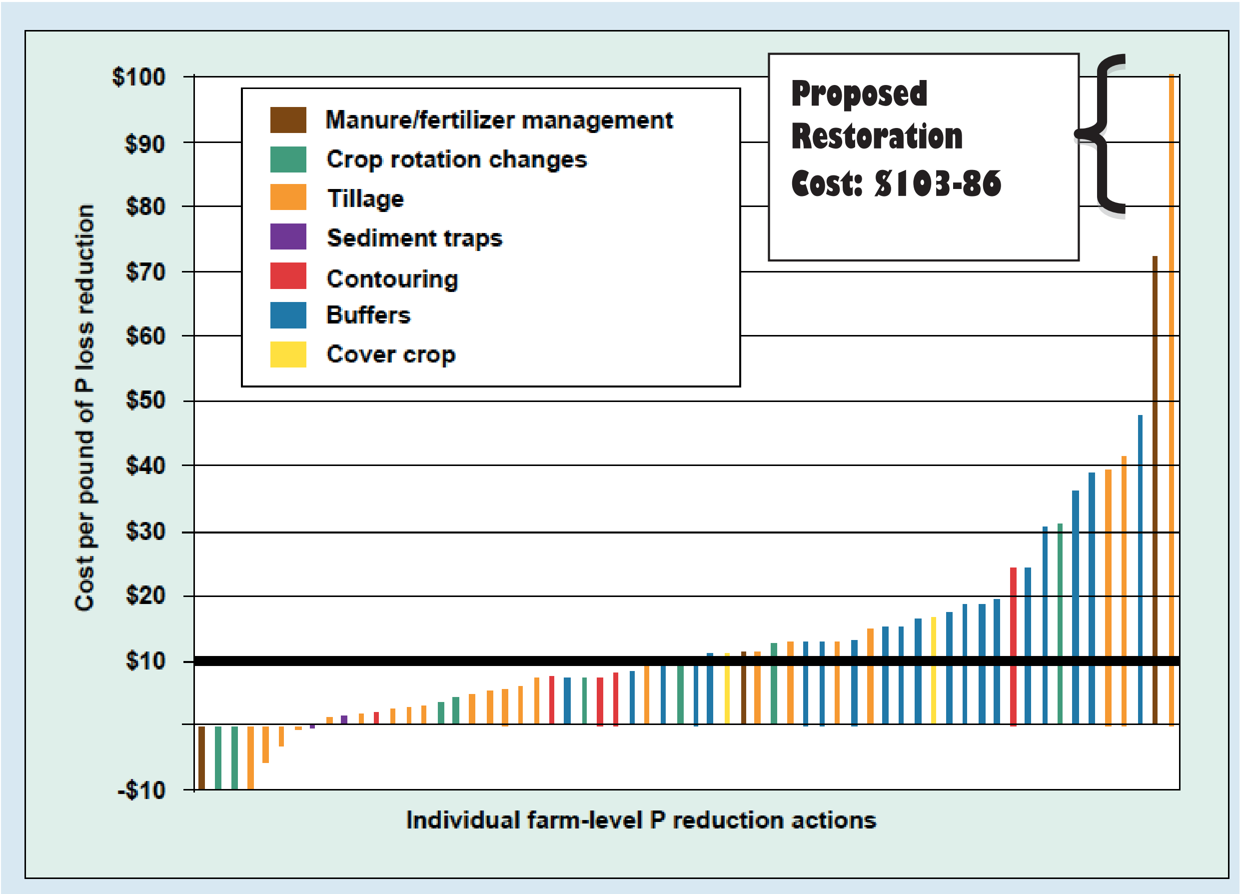


Figure 5.1 Cost Estimation Scenarios for Upper Dorn Creek Restoration.

5.1 Costs and Activities of Management Options 1 & 2

5.1.1 Management Option 1: Upper Dorn Creek Floodplain Restoration

The estimated cost for the proposed floodplain restoration is $28,876 annually, over a 25-year lifespan (with a predicted $15/yd^3 sediment removal cost) (Figure 5.1). Given the annual phosphorus reduction from sediment, this results in a range of cost for phosphorus removal from $103 per pounds phosphorus removed (at $15/yd^3 sediment removal cost) to $82 per pounds phosphorus removed (at $5/yd^3 sediment removal cost).

This rough estimation includes capital costs of land acquisition, soil work, re-vegetation and limited design costs. Land acquisition was an estimate generated from previous purchases by the Dane County Land and Water Resources Department (L. Guyer, personal communication, November 5, 2013). Land prices in this area can range between $5,000 per acre for wetlands to $20,000 per acre for upland areas. A price of $7,500 per acre was used for estimation based on the location of the project site. To provide a base estimation, only 5 acres were estimated in the price of the land acquisition, though this may not be an economic reality for the seller.

Soil work for this project would include excavation, grading and disposal. Typical project costs for mechanical dredging range from $8 to $30 per yd^3 (Hutton, 2003). The Pecatonica site mentioned above cost approximately $1 per yd^3 for these services (E. Booth, personal communication, August 19, 2013). Critical to managing costs for that project was the low transport and soil disposal expenses. Disposal was free or reduced in cost by selling the sediment following removal. Prices were calculated for soil work at a cost of $5 per yd^3 and $15 per yd^3 for this estimation, though costs could be reduced if the soil can be transferred to a party willing to transport the material. An estimated total soil volume of 24,200 cubic yards will need to be removed. Modeling indicates that the restored floodplain will not completely fill with sediment for over 50 years, thus no major earth-moving maintenance costs were included in the 25-year lifespan of the project.

Re-vegetation for this project will require an adaptive restoration approach and likely would include re-seeding following soil work or maintenance. Costs for re-seeding were based on seed cost estimates from Prairie Moon Nursery (Winona, Minnesota) and Prairie Restorations Inc. (Princeton, Minnesota). Labor was calculated as a function of seed costs, for a total estimated initial re-vegetation cost of $6,000/acre. Costs could be reduced with the use of volunteer labor, though the potential costs for ongoing maintenance and adaptive planning should not be underestimated. This estimate includes maintenance and monitoring for the project at $2,000 per acre and $1,000 per acre, respectively.

Using the estimates indicated above, an economic analysis was conducted to determine the yearly costs associated with this restoration project. The project estimate is presented here in terms of annual costs to determine the budget associated with this capital project. Costs presented in the annualized format use the A/P factor, a multiplier applied to a payment in the present time period that yields an annual payment that would be required to pay off that initial investment in the life of the project. This factor is then applied to the initial capital costs of the project to present

Equation 5.1 A/P Factor or Capital Recovery Factor
$\text{Capital recovery factor} = \frac{r(1+r)^t}{(1+r)^t - 1}$

costs in an annualized format. Above is the formula for computing the A/P factor, also known as the capital recovery factor, for a project (Equation 5.1). Both the interest rate (r) applied to the project and the lifetime of the project (t) are represented in Equation 5.1.

For the Upper Dorn Creek Wetland, the use of the annualized cost format provides an estimated yearly cost for the restoration project over a proposed 25-year lifetime. Figure 5.1 shows the two cost scenarios for the Upper Dorn Creek Wetland based on differing soil removal costs. Costs are displayed in both annual payment and total cost over the 25-year lifespan of the project.

The recommended wetland restoration is estimated to cost $103 per pound of phosphorus (lb P), based on the modeling and cost analysis. In comparison to other best management practices (BMPs), such as changes in tillage, fertilizer management or cover crop planting, this proposed project is higher in cost than most BMP practices (Figure 5.1). For example, in a study by the USDA in northern Iowa, the cost for BMPs to reduce phosphorus ranged from $10 to $100 with a great deal of variation even within each practice (Wortman, Morton, Devlin, McCann, & Van Liew, 2011). In the Iowa study, fertilizer management cost over $70 per lb P whereas field contouring is estimated to cost below $25 per lb P reduced. The recommended restoration practice thus falls on the higher end of costs as a BMP, though all of the BMPs in the Iowa study were highly variable. BMP costs can be very site specific and project costs for this recommendation may be reduced if a suitable solution for soil disposal is found.

5.1.2 Management Option 2: Dredging at Bridges

The cost of dredging is estimated to be approximately $1 to $15 per cubic yard depending on contractor, type (hydraulic or mechanical), and transportation to a disposal site. Using this range, the total cost of sediment removal at the Dorn Creek at Meffert Road bridge area could range from $300 ($2 per lb P) to $3,700 ($28 per lb P). This estimate includes transport but not re-seeding or stabilization of removed sediment. Figure 3.4 has a cost breakdown by location.

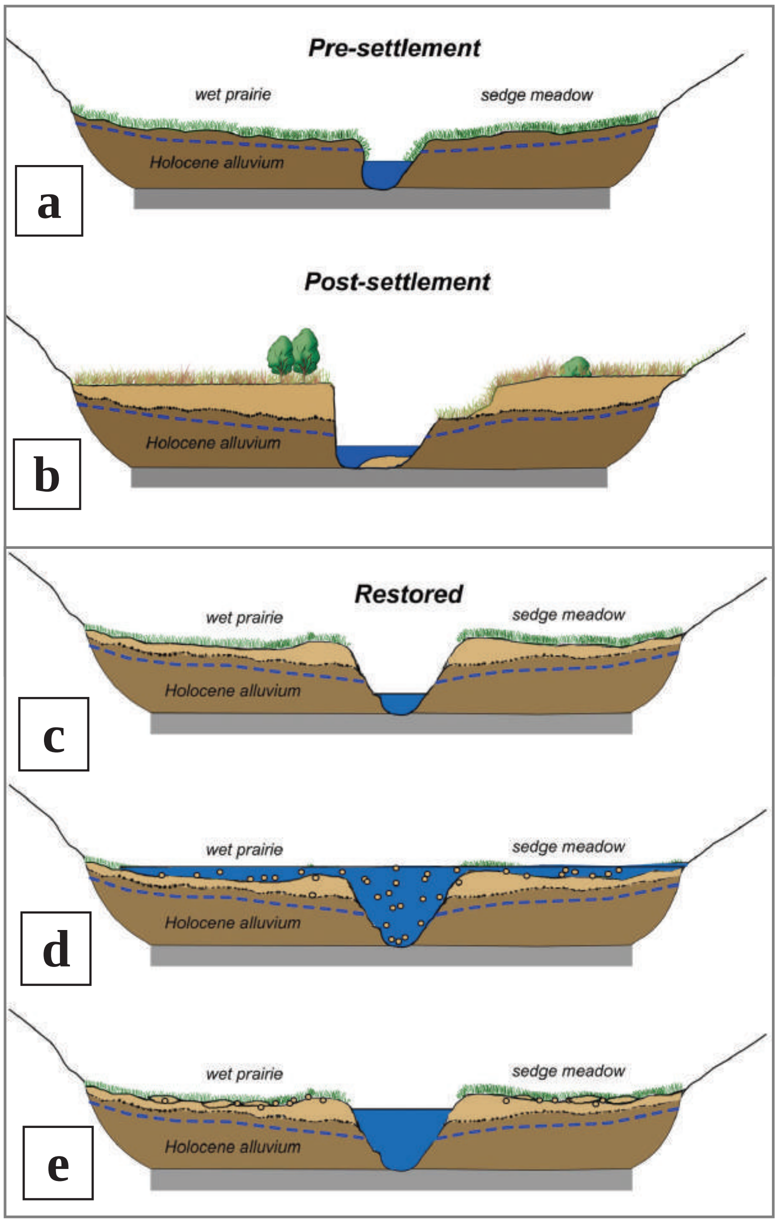
5.2 Management Option 1: Upper Dorn Creek Floodplain Restoration

The Upper Dorn Creek Wetland presents a unique opportunity to increase sediment retention functions by increasing storage volume and trapping efficiency through floodplain restoration. To increase the sediment storage capacity, we recommend excavating approximately one foot of soil across five acres in the floodplain wetland north of the Meffert Road bridge. We also recommend that this removal be done strategically to enhance the trap efficiency of the project. Re-vegetation through seeding and planting should follow the soil grading to assist the recovery of the wetland.

The results from the field surveys and modeling in the Dorn Creek Wetland Complex support this option. Field quantification of the sediment volume and phosphorus indicates that over 1.3 million pounds of sediment and 1,900 pounds of associated phosphorus were stored in the channel at the time of sampling. Much of this sediment is just upstream of the Meffert Road bridge. Sediment mobility data indicates that the in-channel sediment is actively transported. Based on the wetland soil core data, we hypothesize that the proposed soil to be removed has been deposited from upland erosion and subsequent stream transport over half a century. The modeling data reaffirms these assumptions as the SWAT model predicts an annual contribution of 43.6 million pounds of sediment from the watershed. Based on these results, a permanent solution, to trap the sediment within the wetland near the Meffert Road bridge with a restoration project, has high potential.

The primary goal of this floodplain restoration is to increase the sediment retention function in the wetland. The lowering of the wetland substrate will reconnect the stream to the wetland, a connection that has been reduced by years of sediment accrual. Figure 5.2 illustrates the current conditions and the potential conditions following restoration. The removal of accrued sediment should increase overbank flooding during smaller rainfall events and assist in the capture of more sediment. Results from the WinDETPOND modeling indicate that with a one-foot soil scrape, a 5-acre restoration site can trap 187,000 pounds of sediment and 281 pounds of P per year with a 29% trapping efficiency across a 66.4 year period.

As illustrated in Figure 5.2, the design of the wetland restoration includes scraping of the current soil and vegetation with heavy machinery and removing this material offsite. Site grading should include



Conceptual model of site conditions
(a) before Euro-American settlement and (b) post Euro-American settlement where agriculture and pasture practices have caused runoff and erosion

Dashed line represents the water table.

Conceptual model of hydrologic wetland restoration.
Ideally, (c) the wetland design would have a natural levy so that when water passes into the wetland, (d) the water and sediment is trapped, (e) while water levels in the channel decreases with time after a storm.

Dashed line represents the water table.

Figure 5.2 Cross-Section of Current and Proposed Conditions for a Five-Acre Restoration Project in the Upper Dorn Creek Wetland near Meffert Road Bridge.

Figure modified from Booth and Loheide (2009).

creating a small berm at the stream edge and a gentle backslope leading down into the restored wetland. This shape will help retain sediment and reduce re-suspension into the creek. Though the modeling was constrained to testing a straight-sided scrape with a homogenous bottom, it may be ecologically beneficial to grade a heterogeneous wetland surface with small micro-topography. However, this grading may increase the complexity and cost of maintenance. At the time of soil work, the stream could also be dredged to remove the existing sediment load. Further consultation with a design consultant will be needed to implement this restoration project.

The vegetation across the Upper Dorn Creek Wetland is dominated by reed canary grass, an invasive wetland species, as well as fire intolerant woody species, such as box elder and willow, along the stream corridor. Reed canary grass forms monotypic stands at the exclusion of native species by forming dense root mats and thrives under increased sedimentation and nutrient loads (Kercher, Herr-Turoff, & Zedler, 2007). Due to these negative impacts on ecosystem services, it is preferable (though not often possible) to decrease reed canary grass cover on wetland sites and re-establish native plant cover. Scraping the wetland at a depth greater than nine inches should remove the existing cover of reed canary grass and allow ecologists to attempt to re-establish native perennial plant cover. Given the significant cover of reed canary grass elsewhere in the watershed, preventing re-establishment will be challenging. An adaptive restoration plan created by a restoration ecologist should allow for the testing and application of various re-vegetation techniques.

Another option for further phosphorus reduction in the restored wetland is the harvesting of wetland plants. Removal of the vegetation will result in greater phosphorus removal as decaying vegetation slowly releases nutrients in the fall. Recent estimates of reed canary grass harvest in the state of Wisconsin by Jakubowski, Casler, and Jackson (2010) indicate that significant nutrient removal could occur via harvesting (i.e. mowing) of above ground biomass. Using the estimations of biomass and phosphorus content from Jakubiowski's study, approximately 16,400 pounds phosphorus could be removed with the single, one-year harvest of the reed canary grass across a 5-acre site with 100% removal. This does not include the removal of the below ground biomass and this rough approximation would require field data to affirm the conditions in the Upper Dorn Creek Wetland. Any type of harvesting plan beyond initial removal of reed canary grass should balance the integrity of the native flora and fauna with the need to remove phosphorus. Wetland harvesting can be challenging for equipment operators, but given the necessity of ongoing maintenance this does provide another opportunity to reduce phosphorus export.

Maintenance of this restored system will be required. Modeling results indicate that the restored wetland could fill with sediment between 50 and 80 years. Re-dredging may be required within this timeframe to maintain sediment retention. Ideally, a reduction in upland sources of sediment in the watershed will lengthen the lifespan of the initial restoration. Re-seeding or other re-vegetation will be required following any dredging. Ongoing yearly maintenance to reduce noxious weeds and woody encroachment will also be necessary.

In addition to sediment retention functions, this restoration may have other co-benefits, including the reduction of peak flows and an increase in the denitrification potential in the creek system. Though it was not the focus of the modeling or design, the denitrification potential of the wetland may increase by creating a large flat area that can alternate between aerobic and anaerobic conditions.

Overall, the results from our soil volume, phosphorus sampling, mobility, vegetation studies, and modeling efforts all lead to a wetland restoration option that can retain sediment and phosphorus while potentially providing other benefits.

5.2.1 Regulatory Permitting

Various permits may be required for the wetland restoration activities suggested for the Upper Dorn Creek Wetland, which include soil excavation to increase the sediment storage capacity, removal of invasive wetland vegetation, and re-vegetation (Appendix C). Coordination with the Army Corps of Engineers (ACOE), Wisconsin Department of Natural Resources (WDNR), and Dane County and Town of Westport planning agencies will be necessary early in the project phase to determine which type of wetland restoration, or other, permits will be required. Coordination with the agencies will also be needed to ensure no significant impacts occur to Federal or State listed threatened or endangered species, or to historical or cultural resources.

5.3 Management Option 2: Dredging at Bridges

As discussed in Section 5.2, the practicum findings support previous studies (Rogers et al., 2009; Hoffman, 2008; & Penn et al., 2005) that phosphorus-laden sediment is abundant throughout the Upper Dorn Creek Wetland Complex. Much of the sediment with the highest concentrations of phosphorus is trapped near the bridges during depositional periods, when weather is calm and no major rain events occur. Bridge construction within streams can create confinement or narrowing of the stream channel, which in turn can result in water pooling upstream and widening stream channels downstream. Our in-stream mobility results indicate these processes occur in the Upper Dorn Creek Wetland Complex, with the highest change of scour and deposition occurring up and downstream of the Meffert Road bridge.

Because most bridge sites across Six-Mile Creek and Dorn Creek are fairly accessible, dredging is recommended as a cheap alternative to remove this phosphorus-laden sediment. Inventoried sediments at the four bridge sites indicate that by removing the transient loam and silt loam layer throughout approximately 10 meter reaches up and downstream of each bridge, approximately 226.28 yd^3 of sediment could be eliminated, resulting in a reduction of 381 pounds of phosphorus from the stream system (Table 3.4). Estimations are approximate due to the highly transient nature of the system.

Because the sediment deposition is dependent on rain events, which are highly variable, the fall season, when precipitation is low on average, may produce the highest yields. To best capture the most sediment, this method will require sampling the sediment depth in the channels prior to dredging. Until BMPs aimed at minimizing soil erosion begin showing significant results, it is recommended to dredge accumulated sediment annually to effectively reduce the amount of phosphorus flowing downstream. In addition to the bridge locations, an inventory of the Dorn Creek Wetland Complex indicates significant pockets of sediment are also being stored throughout the system near downed woody debris and in areas of confluence with large agricultural ditches. With landowner agreement, there is potential to eliminate approximately 1,900 pounds of phosphorus in the Dorn Creek Wetland Complex through this type of dredging. This could be an alternative to the restoration project proposed above. Table 3.2 has an inventory of dredging opportunities.

5.3.1 Regulatory Permitting

Dredging activities within Dorn Creek and/or clearing of farm drainage ditches may require various permits (Appendix C). Dorn Creek is not listed as a navigable water of the United States within the state of Wisconsin and, as a result, a Section 10 permit from the ACOE would not be required for dredging activities within Dorn Creek. However, a General Permit to Remove Accumulated Plant and Animal Nuisance Deposits from Beds of Navigable Waters would most likely be required from WDNR for dredging activities since Dorn Creek is designated as an Area of Special Natural Resources Interest (ASNRI) – Endangered Threatened or Special Concern Waters. Coordination should be conducted with WDNR to determine if dredging within Dorn Creek would require a General Permit or Individual Permit, or any other permits.

Per Wisconsin Administrative Code NR 345.04, dredging of a farm drainage ditch, which was not a navigable stream before ditching, would be exempt from requirements of a General Permit to Remove Accumulated Plant and Animal Nuisance Deposits from Beds of Navigable Waters. If dredging of farm drainages is selected as the preferred method to remove sediment, then coordination should be conducted with WDNR to ensure the project meets all standards and requirements of NR 345 for permit exemption.

5.4 Other Management Options

5.4.1 Mary Lake

Based on the findings in this report, the Mary Lake section of Six-Mile Creek has the potential to temporarily capture over 4,000 pounds of phosphorus across a 1.5-acre site. Thus, Mary Lake presents a significant opportunity for sediment entrapment and phosphorus removal. Management of this site could include options to either dredge sediment from the lake, leaving it as an open water system, or to restore the wetland at Mary Lake and stabilize the sediment currently stored in the lake. Either of these management options would require public outreach and input from the landowners in the vicinity and in the Town of Westport.

Regardless of the management options selected, much more research is recommended for the Mary Lake site. Future research could develop a clearer approximation of the sediment load as well as determine the mobility of the sediment that is contained in the system. This research, coupled with outreach to the community, could produce a management plan that provides significant benefits from sediment and phosphorus trapping.

6 Conclusion

Substantial deposits of phosphorus-laden sediment are found within the Six-Mile Creek watershed. Sites in the Upper Dorn Creek Wetland contain sediment phosphorus concentrations ranging from 700 mg/kg to greater than 3,000 mg/kg. Sediment volumes at sites within the Upper Dorn Creek Wetland represent a substantial cache of highly mobile phosphorus. There is a great opportunity in the Upper Dorn Creek Wetland to diminish phosphorus influx into the Yahara Lakes.

Modeling indicates that reconnecting the hydrology of a degraded floodplain wetland through restoration will enhance sediment capture and allow for storage of the sediment and associated phosphorus. Cost estimates for the recommended Upper Dorn Creek Wetland restoration includes a $28,876 annual payment, over a 25-year lifespan. This restoration could remove 281 pounds of phosphorus per year, resulting in a cost range of $103 to $82 per pounds phosphorus.

Bridge sites on Six-Mile Creek and Dorn Creek, as well as Mary Lake on Six-Mile Creek, are also accessible sediment harvest sites. A program to remove sediment at these locations could annually remove 381 pounds of phosphorus. A similar modeling and field approach could be used to assess other wetlands and bridge crossings within the greater Yahara watershed for floodplain restoration or sediment harvest.

This practicum demonstrates that sediment is highly mobile in the Dorn Creek system and this sediment is a significant source of nutrient influx to the Yahara Lakes. Implementation of best management practices to prevent upland sediment erosion is critical to reduce future nutrient loading and would in turn reduce the long-term costs of these recommended projects. Using the recommendations in this report, the watershed adaptive management program has the opportunity to partner with landowners and significantly reduce nutrient loading into the Yahara Lakes system.

Glossary

Bank flow: movement of water at the sides of a channel

Bioavailable phosphorus: the sum of immediately available phosphorus and the phosphorus that can be transformed into an available form by naturally occurring processes that is available for uptake and use by aquatic organisms, typically algae

Confluence: a meeting of two or more bodies of water

Culvert: a tunnel carrying a stream or open drain under a road or railroad

Denitrification: the biological conversion of nitrate to nitrogen gas, nitric oxide or nitrous oxide

Deposition: sediment dropped to the streambed from the water as the current slows

Herbaceous: relating to the characteristics of plants with leaves and stems that die down to the soil level at the end of the growing season

Hydrograph: a plot showing the variation in the rate of water flow (discharge) versus the time past a point in a channel or conduit carrying water flow

Longitudinal variability: changes in a stream's characteristics at points up and down stream

Low gradient: a nearly level streambed with a small drop in elevation per unit of horizontal distance

Phosphorus: a chemical element, occurring in mineral (inorganic) forms and organic forms, that is essential to animal and plant cell growth and development

Reach: a uniform section of stream

Runoff event: an episode when water drains or flows off the surface of the land

Scouring: the erosive action of flowing water in streams that removes and carries away material from the streambed and banks

Sediment: particles carried and deposited by the stream current

Sediment Transport: the act of carrying sediment by the stream current

Stream channel morphology: the form and structure of a waterway that contains moving water; it is defined by the area above the streambed and between the banks

Streambed refusal: when a probe reaches the maximum refusal (point at which penetration by a probe cannot continue) depth within the streambed

Vegetation Strata: layers of plant material in a plant community defined by similar heights

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Appendix A: Hydrologic Modeling

A.1 SWAT Model

In 2009 Montgomery Associates, Resource Solutions, LLC (MARS) of Madison, WI, began a consulting project for the Dane County Land and Water Resources Department (LWRD). This consulting project, completed in 2011, involved using the Soil and Water Assessment Tool (SWAT) to model monthly phosphorus and sediment loading in the Yahara watershed from 1950-2008 (MARS, 2011). In developing a SWAT model, the user can define sub-watersheds within the larger watershed and also define sub-basins. A sub-basin has a uniform climate input, only one time of concentration, and only one set of calculations for water routing. Sub-basins are typically delineated by a spatially-referenced polygon shapefile, although they can be automatically derived. In SWAT, sub-basins are further divided into unique Hydrologic Response Units (HRUs), which define unique areas of land use, soil type, and/or management.

The 2009 SWAT model developed by MARS consists of 25 unique sub-basins and 132 unique HRUs that were derived by spatially-referenced polygon shapefiles (MARS, 2011). Collectively these sub-basins and associated HRUs are representative of the entire Yahara watershed, which includes Lake Mendota, Lake Monona, Lake Waubesa, Lake Kegonsa, and all tributaries that drain into these lakes. This model also includes the Dorn Creek watershed, which is a subwatershed of the larger Yahara watershed. This model is a powerful tool for predicting monthly flow, as well as monthly sediment and phosphorus loadings within and across sub-basins. However, the 2009 MARS SWAT model is temporally constrained to monthly flows and loadings across a large spatial scale like the entire Yahara watershed. Consequently, a SWAT model developed specifically for the Dorn Creek watershed was developed to achieve greater temporal resolution (daily flows, loadings) at a finer spatial scale (the Dorn Creek watershed).

ArcSWAT version 2012.10.1.9, a module designed for ArcGIS 10.1, allows users to build a SWAT model from spatially-referenced input files. ArcSWAT was used to construct a SWAT model for the Dorn Creek watershed with outputs of daily flow, sediment, and phosphorus loadings. In this modeling effort, the 2009 MARS SWAT model was scaled down to the Dorn Creek watershed, which was further divided into finer scale sub-basins and HRUs. In ArcSWAT, the "Automatic Watershed Delineator" feature was used to define the Dorn Creek watershed based on a 10 meter Digital Elevation Model (DEM), which is a three dimensional image of the surface of the earth. This 10 meter DEM was obtained from the National Elevation dataset (NED) and is derived from survey contours that are available for most of the continental U.S. The NED DEM for the state of Wisconsin was downloaded from ftp://dnrftp01.wi.gov/geodata/elevation/ on 5/21/2012 (Gesh, 2007; Gesh et al., 2002).

The Dorn Creek watershed was manually delineated to encompass Dorn Creek, in addition to the Upper and Lower Dorn Creek Wetlands. The stream definition was inputted as a DEM based with a total area of 600 hectares. Shapefiles, derived from the 2009 SWAT model developed by MARS in conjunction with the Dane County Land and Water Resources Department, were used to improve model accuracy regarding stream locations. The shapefiles developed by MARS are available for download at the Wisconsin Department of Natural Resources (WDNR) website and were derived from the published hydrography layer for Wisconsin. As previously mentioned, in a SWAT model the primary watershed is divided into sub-basins and HRUs. In developing a SWAT model, sub-basins are defined spatially and thus have a spatial reference. In contrast, HRUs are not defined spatially. The model calculations such as water/sediment/nutrient yields, evapotranspiration, infiltration, and percolation are made at the HRU level. In this modeling effort, three unique sub-basins, and by extension three unique outlets, were automatically delineated for the Dorn Creek watershed by using the manual outlet and inlet definition in ArcSWAT.

To derive HRUs, land use, soil, and slope data had to be specified in ArcSWAT. Data from the National Land Cover Database 2006 (NLCD) was used to specify land use in the Dorn Creek watershed. The NLCD data can be downloaded from http://www.mrlc.gov/nlcd2006.php (accessed on 11/1/2012) and was chosen because it is the most compatible land use data for ArcSWAT. The soil data used in this modeling effort are from the State Soil Geographic (STATSGO) database available from the U.S. Department of Agriculture online at http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053629 (accessed on 3/6/2013). Slope information for the Dorn

Creek watershed was specified using the multiple slope option in ArcSWAT where an upper limit of 9999 and lower limit of 5 was entered.

The next step in creating HRUs via ArcSWAT is to create the HRU definition. For this project, multiple HRUs were chosen. In developing a SWAT model, the user specifies threshold of areal coverage below which a given land use/land cover, soil, or slope class will be excluded from the HRU definition. In this modeling effort, thresholds for land use/land cover and soil classes were set at 5% areal coverage. In total, 26 HRUs were defined in creating this SWAT model, along with five unique land use and land cover (LULC) classes.

The next step in building a SWAT model for the Dorn Creek watershed was to specify climate data. These climate data included daily precipitation, daily maximum and minimum temperature, wind, and relative humidity data from the National Weather Service (NWS) gage located at the Dane County Regional Airport in Madison, Wisconsin (WI) from 1/1/1943-5/2/2009. Daily precipitation and daily maximum and minimum temperature data from the NWS gages at Arlington, Wisconsin from 1/1/1943-5/2/2009 were also used for climate data. In addition, daily maximum and minimum temperate data from 1/1/1943-5/2/2009 at the NWS gage at Stoughton, Wisconsin was also used for climate data in this modeling project. The remaining climate variable required by ArcSWAT is solar radiation, and this was obtained from The National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR).

After the base model was finished and the output harvested, the final step was to calibrate the SWAT model that was developed for the Dorn Creek watershed. Model calibration was required to obtain results that more closely match existing data from the Dorn Creek watershed. The process of model calibration involved adjusting the SWAT model input files that were initially written by the ArcSWAT interface. Since in most cases existing data was not available for the Dorn Creek watershed, we calibrated our model with the same calibration parameters that MARS (2011) used in the consulting project for the Dane County Land and Water Resources Department. More specifically, the model developed in this project was calibrated with the MARS (2011) calibration parameters developed for Pheasant Branch Creek at Middleton, which is gauged by the USGS. These calibration factors are listed in Tables A.1–A.3.

PARAMETER	SWAT VARIABLE	DESCRIPTION	CALIBRATION NUMBER
Table A.1-FLOW	ALPHA_BF	Baseflow recession factor	0.002
	GW_DELAY	Groundwater Delay	90
	RCHRG_DP	Deep Aquifer Percolation	0.9
	GW_SPYLD	Specific Yield	0.25
	PET METHOD	Potential Evaportranspiration	Hargreaves
	CN METHOD	Daily Curve Number Prediction Method	Soil Moisture
	ESCO 1	Soil Evaporation Factor	0.6
	EPCO 1	Plant Uptake Factor	1
	SURLAG	Surface Runoff Lag Coefficient	1
	SMTMP	Base Snowmelt temperature	2
	SMFMX	Maximum Melt Factor	2
	SMFMIN	Minimum Melt Factor	2
	TMIP	Snowpack Temperature Lag Factor	0.4
	MSK_CO1	Muskingham Coefficient for Normal Flow	1
	MSK_CO2	Muskingham Coefficient for Low Flow	1
	MSK_X	Muskingham Routing Factor	0.2
	CH_N	Saturated Hydraulic Conductivity	0.07
Table A.2-SEDIMENT	ADJ_PKR	Peak Rate Adjustment for Subbasins	0.5
	PRF	Peak Rate Adjustment for Main Channel	0.5
	SPCON	Linear Parameter for Sediment Routing	0.002
	SPEXP	Expoential Parameter for Sediment Routing	1.1
	P FACTOR	USLE Support Practice Factor	0.5
	FILTERW	Filter Width	9
	USLE_K	USLE Soil Erodibility Factor	0.28
	USLE_C	USLE Cover Factor	Default
	CH_EROD	Channel Erodibility Factor	0.1
	CH_COV	Channel Cover Factor	0.1
Table A.3-PHOSPHORUS	P_UPDIS	P Uptake Distribution Parameter	20
	PPERCO	P Percolation Coefficient	10
	PHOSKD	P Soil Partitioning Coefficient	20
	PSP	Phosphorus Availability Index	0.1
	RSDCO	Residue Decomposition Coefficient	0.02
	GWSOLP	Soluble P in Groundwater	0.1
	SOL_SOLP	Initial Soluble P	0
	ERORP	Phosphorus Enrichment Ratio	0.1

Tables A.1 to A.3 Calibration Values for the SWAT Model of the Dorn Creek Watershed Produced in this Modeling Effort.

The "SWAT VARIABLE" represents the variable in SWAT that was calibrated, and "DESCRIPTION" provides a short summary of each variable. The "CALIBRATION NUMBER" field lists the value that we used for each variable. These calibration numbers were produced by MARS using data from the Yahara River at Windsor, which represents a drainage area similar to the Dorn Creek watershed.

Stage (H) (feet)	Area (A) (acres)	Storage (S) (acre-feet)
0	5	0
4.35	5	21.75
4.75	5	23.75
5.37	5	26.85
5.77	5	28.85
6.23	5	31.15
6.73	5	33.65
7.28	5	36.4
7.87	5	39.35
8.59	5	42.95
9.5	5	47.5
11.8	5	59
16.31	5	81.55
19.82	5	99.1
22.92	5	114.6
25.77	5	128.85

Table A.4 Stage-Area Table.

Stage-area table used for the DETPOND sedimentation analysis.

A.2 WinDETPOND Analysis

DETPOND was developed by Bob Pitt and John Vorhees to continuously simulate wet stormwater detention ponds. The analyses performed in DETPOND are similar to those of SLAMM, the Source Loading and Management Model, and inputs used for SLAMM routines can be used in DETPOND (Pitt, 2002). The stage-area table describes how the area of the pond changes with the stage given the influence of slope. In this modeling effort, it was assumed that the wetland was vertically sided, and, as such, slope was not taken into account in generating the stage-area relationship. The stage-area table we used is displayed in Table A.4. Rainfall information is entered into DETPOND under "Rain Information" via long-term rainfall records, a Soil Conservation Service (SCS) design storm, or a user-defined hydrograph. A design storm can be defined as a statistical representation of streamflow based on precipitation data. This decision was made because DETPOND normally uses a simple triangular hydrograph, which is suitable for small rains (Pitt, 2002); however, a hydrograph representative of larger storms provides more robust results. In addition, the hydrographs derived from long-term rainfall records may not be truly representative of those actually observed in the Dorn Creek watershed. Thus, the hydrographs that were developed from the SWAT daily flows (Table A.5) were used in this modeling effort since they are most accurately representative of hydrographs that would be observed in the Dorn Creek watershed. These hydrographs were produced by scaling the unit hydrograph by the 5% flow quantiles determined from the SWAT daily flows (Table A.6).

Time (minutes)	Discharge (cfs)
0	0.00
15	60.41
30	65.78
45	49.99
60	32.79
75	19.84
90	11.41
105	6.33
120	3.43
135	1.82
150	0.95
165	0.49
180	0.25
195	0.13
210	0.06
225	0.03
240	0.02
255	0.01
270	0.00
285	0.00
300	0.00
315	0.00
330	0.00
345	0.00

Table A.5 Hydrographs Table.

One of the twenty design hydrographs which were used in the DETPOND sedimentation analysis. This is the design hydrograph which was produced by scaling the unit hydrograph by the 50% overbank flow quantile.

Quantile	Average Daily Flow
%	cfs-days
5	0.4224488
10	0.7693343
15	1.0381140
20	1.2831654
25	1.5091494
30	1.7324498
35	1.9543379
40	2.1899968
45	2.4164752
50	2.6433066
55	2.8897704
60	3.1675895
65	3.5002803
70	3.8664450
75	4.3219440
80	4.9751790
85	5.8748778
90	8.3402220
95	15.1105614
100	262.2120600

Table A.6 Five Percent Flow Quantiles.

The twenty 5% average daily flow quantiles which were used to produce 20 design inflow hydrographs (by scaling the unit hydrograph).

Stage (H) (feet)	Outflow (O) (cfs)
0	0
7.43	700
11.8	1400
14.25	2100
16.31	2800
18.13	3500
19.35	4000
21.42	4900
22.92	5600
24.38	6300
25.77	7000

Table A.7 Stage-Discharge Table.

Constructed using Hy-8 for the culvert control structure at Meffert Road. This was used as a user-defined stage–discharge table in the DETPOND sedimentation analysis.

To more accurately derive final trap efficiencies for the wetland restoration, a stage-discharge relationship was constructed for the Meffert Road bridge and culvert system (Table A.7). A stage-discharge relationship is the outflow resulting from water depth at a specified point. In the case of the Upper Dorn Creek Wetland area, a stage-discharge relationship was created for the outlet of the Meffert Road bridge. For a more accurate stage-discharge relationship, the HY-8 Culvert Analysis Program was used. The HY-8 is a widely used and well recognized program and is commonly used by the Federal Highway Administration.

To develop a stage-discharge relationship in the HY-8 program, a downstream cross-section is critical in determining what flows the stream channel can actually hold without overbanking. For Dorn Creek, an irregular channel design was used to more accurately resemble the natural conditions. In constructing the channel, elevations are user-defined for floodplain height and length, bank height, channel depth and width, and elevation of inlet and outlet. These elevations are critical in determining the culvert slope and the stage-discharge that will be found in the stream. To derive a stage-discharge relationship, other critical inputs that must be defined are settings for the water flows that will occur in the stream. For Dorn Creek, flows were chosen on the flow data gained from the ArcSWAT modeling. The critical flow inputs are minimum, design, and maximum, with design flow being the flow that creates the stage-discharge relationship. For this project, a design flow of 98 cubic feet per second (cfs) was used because it most closely represented the flows found in the Dorn Creek area. Maximum flow is typically set at the 100-year flow, a flow with a recurrence interval of 100 years. Finally, the dimensions of the Meffert Road culvert define the resulting stage-discharge relationship. The HY-8 program has numerous designs built into the program and calculates all aspects such as Manning's n, based on the design chosen. For the Dorn Creek project, a 14 foot (span) by 6.75 foot (rise) concrete open-arch culvert was used.

Finally, a particle size distribution is required for any sedimentation analysis. We chose Midwest.cpz (Table A.8), which comes with the WinDetpond version 8.5.3 download package. This particle size distribution is characteristic of agricultural silt loam soils found in the upper Midwest and, thus, can be used as an approximation for soils in the Dorn Creek watershed.

Particle Size (µm)	% Greater
0	100
1	99.9
2	97
3	93
4	91
5	89
6	86
7	84
8	82
9	80
10	78
11	75
12	73
13	71
14	69
15	68
20	62
25	57
30	53
35	49
40	47
50	42
60	38
80	33
100	28
150	22
200	18
300	12
500	7
800	4
1000	3
2000	0

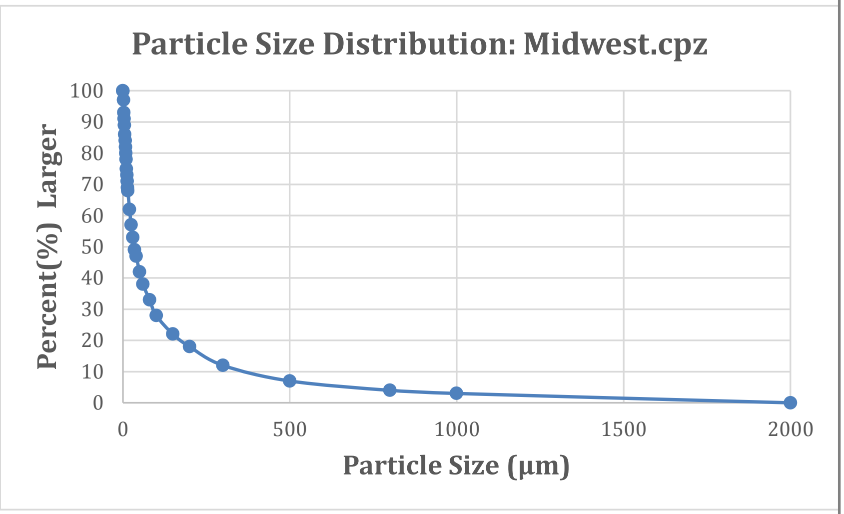

Table A.8 Particle Size Distribution.

Particle size distribution used for the DETPOND sedimentation analysis (Midwest.cpz). This particle distribution comes with the WinDETPOND version 8.5.3 download package.

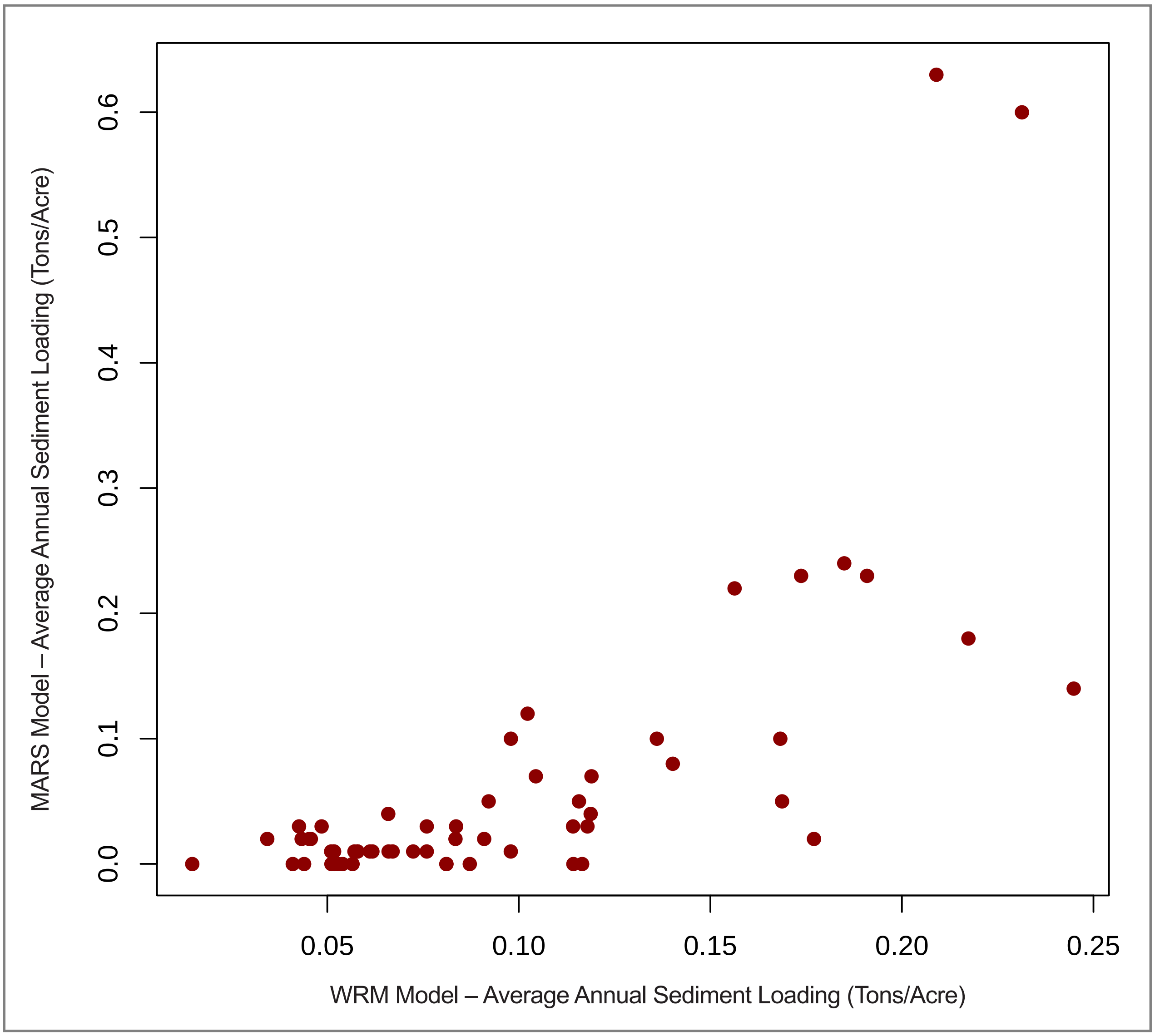

Figure A.1 MARS SWAT Model v. WRM SWAT Model – Average Annual Sediment Loading 1950 - 2009.

A.3 Quality Control Check

To determine how accurate the WRM SWAT model is we performed a few quality control checks. First, we compared the average annual sediment loading (tons/acre) rate from the WRM model to the MARS model (Figure A.1). Second, we compared the WRM SWAT model daily flows (cfs), normalized by drainage area (square miles), to the Yahara River at Windsor (Figure A.2). Flow values from the Yahara River were

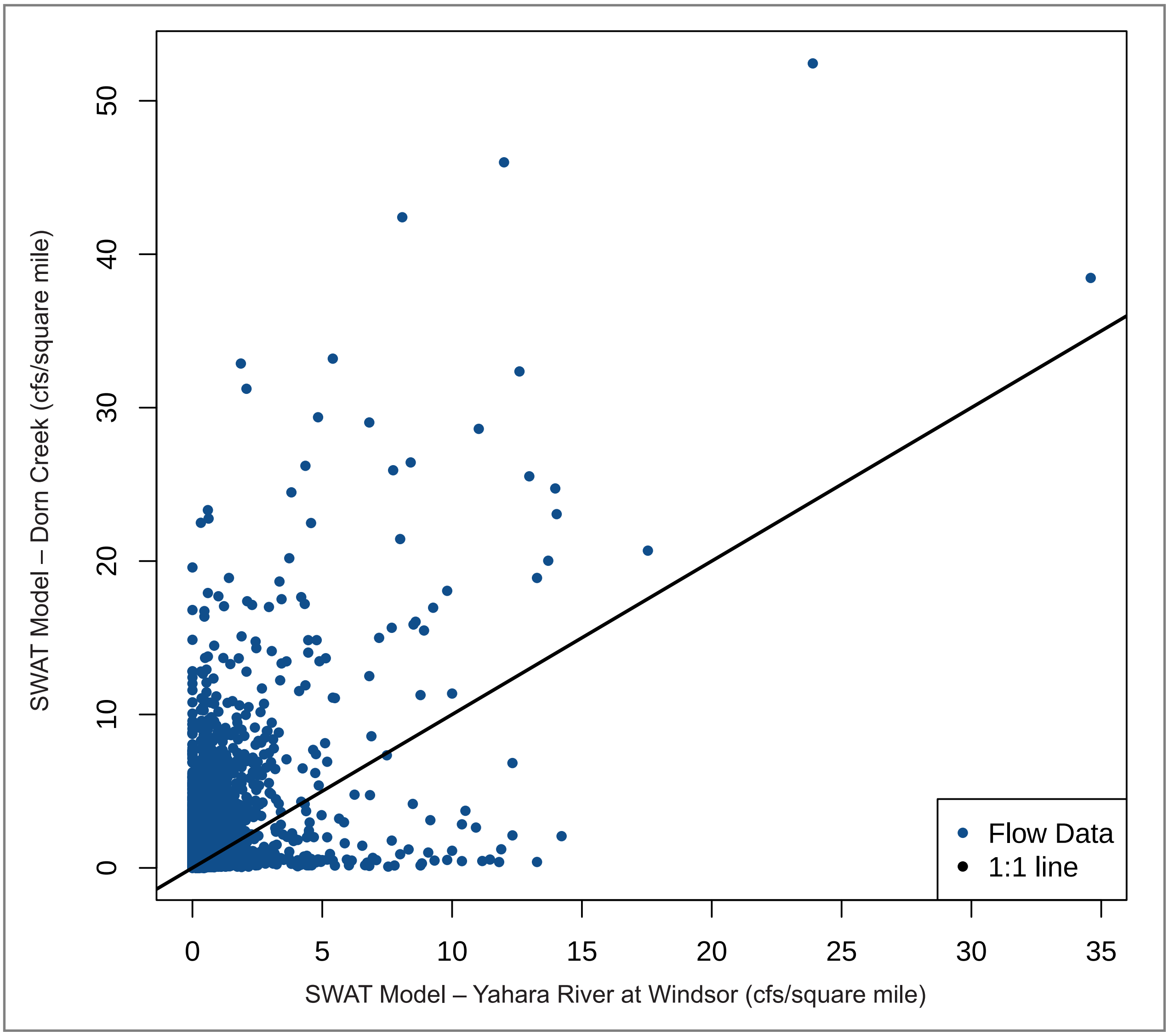

Figure A.2 WRM SWAT Model v. Yahara River at Windsor – Daily Flows (February 1976 - May 2009).

obtained from the USGS. The sediment values from the WRM SWAT model are higher than MARS in a couple cases, but otherwise they matched well (Figure A.1). The daily flow values from the WRM SWAT model appear higher than those obtained from the Yahara River at Windsor (Figure A.2). However, this does not necessarily mean the WRM model is inaccurate since many other watershed variables (besides drainage area) influence streamflow.

Equation A.1

$$S_2 + \frac{\Delta t}{2} * Q_{O2} = S_1 - \frac{\Delta t}{2} * Q_{O1} + \frac{\Delta t}{2} * (Q_{t1} + Q_{t2})$$

S_1= Storage at t=1

S_2= Storage at t=2

Q_{O1}= Outflow at t=1

Q_{O2}= Outflow at t=2

Q_{t1} = Inflow at t=1

Q_{t2}= Inflow at t=2

A.4 Reservoir Routing

Reservoir routing was used to predict how a given wetland design might reduce hydrograph peak flows out of the stream-wetland complex. Our approach was to use the storage-indication method for each 25% WRM SWAT flow quantile (Equation A.1). This revealed that under a 5-acre scenario the wetland is not very effective at reducing peak flows (Figures A.3-A.6). For example, the peak flow for the 50% quantile hydrograph is 66 cfs, and, after routing through the 5-acre wetland, this peak is reduced to 58 cfs (Figure A.4). Nevertheless, increasing the area of the wetland will greatly increase the potential for reducing peak flows.

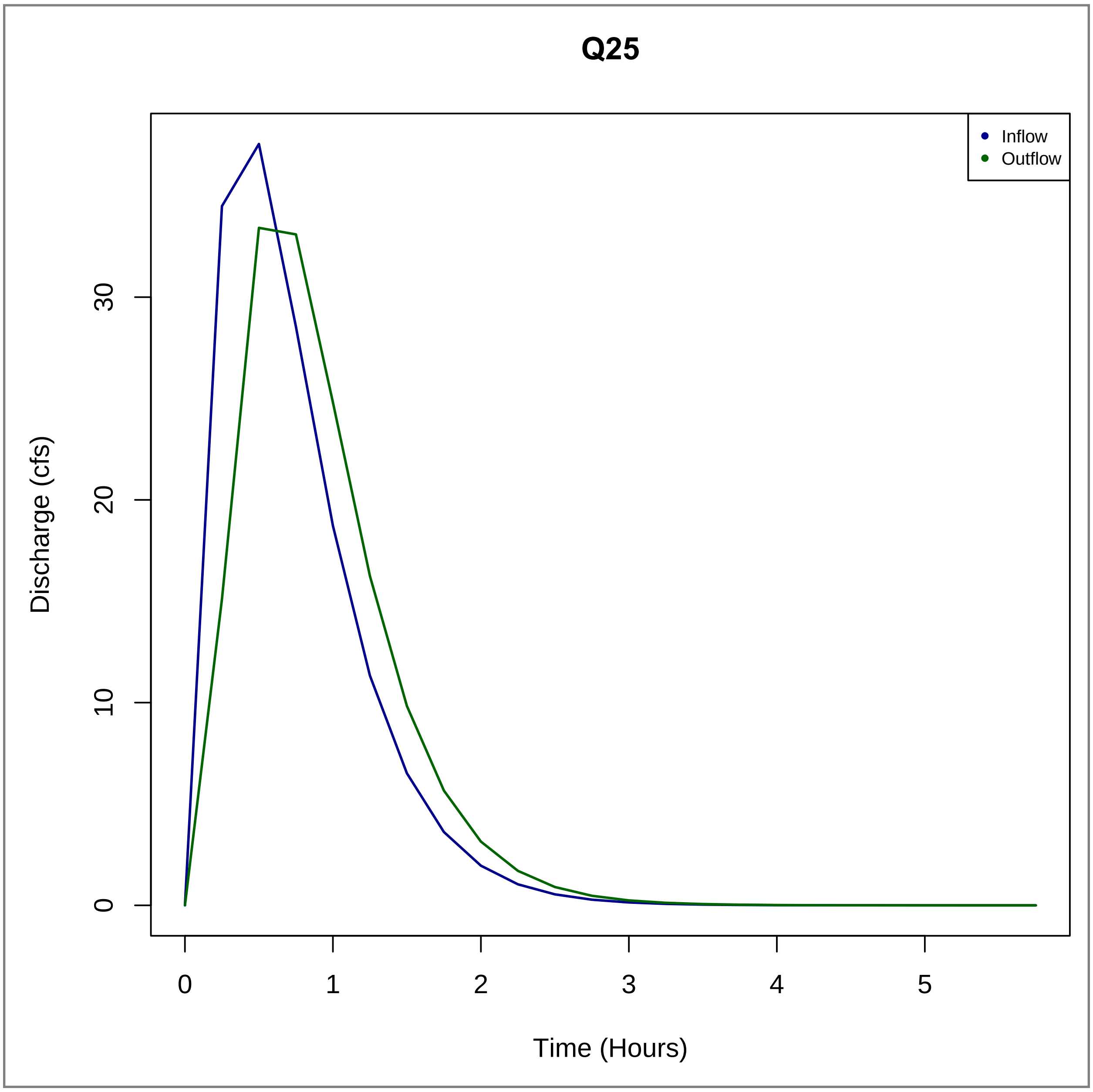

Figure A.3 Reservoir Routing. Q25.

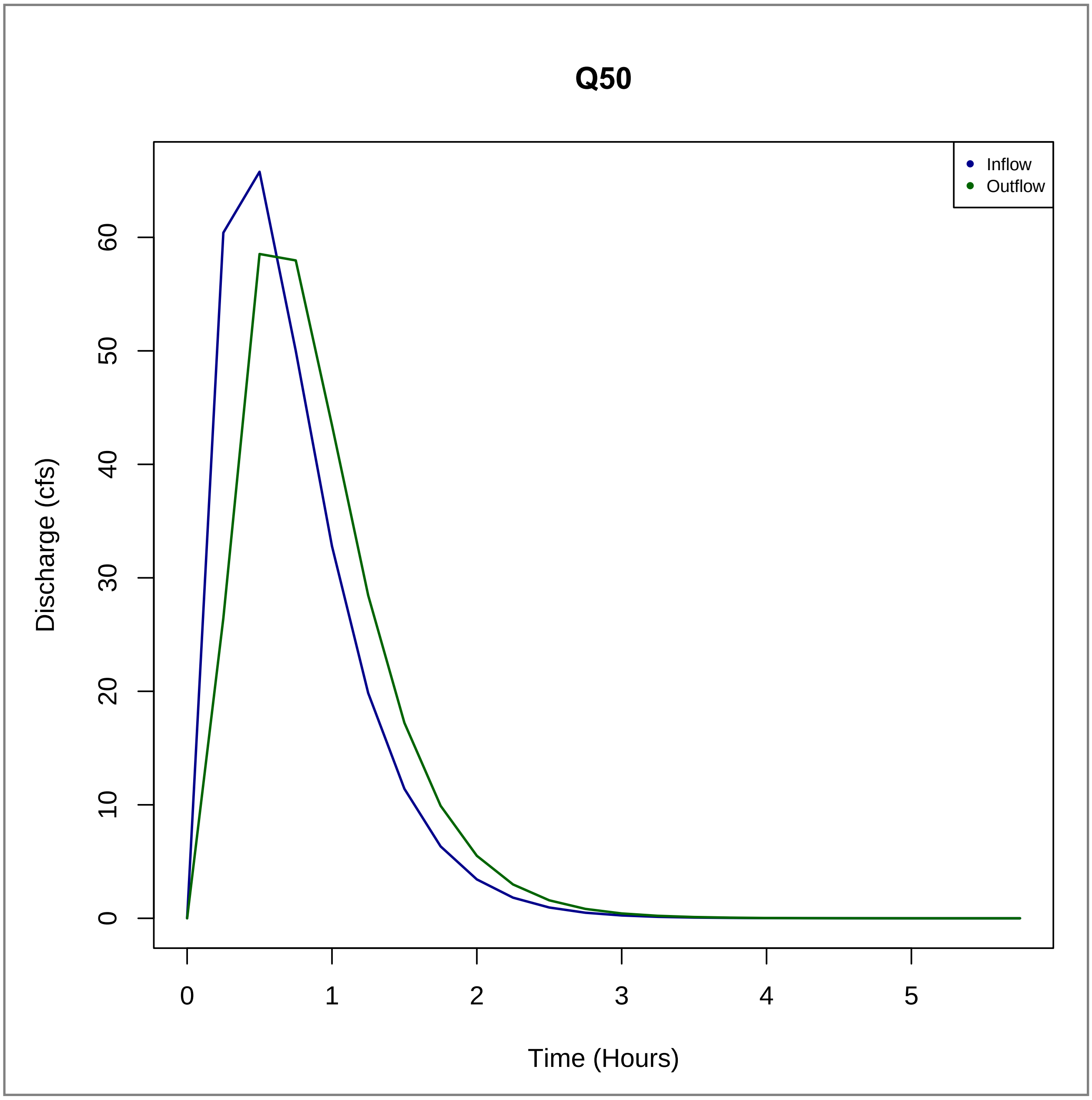

Figure A.4 Reservoir Routing. Q50.

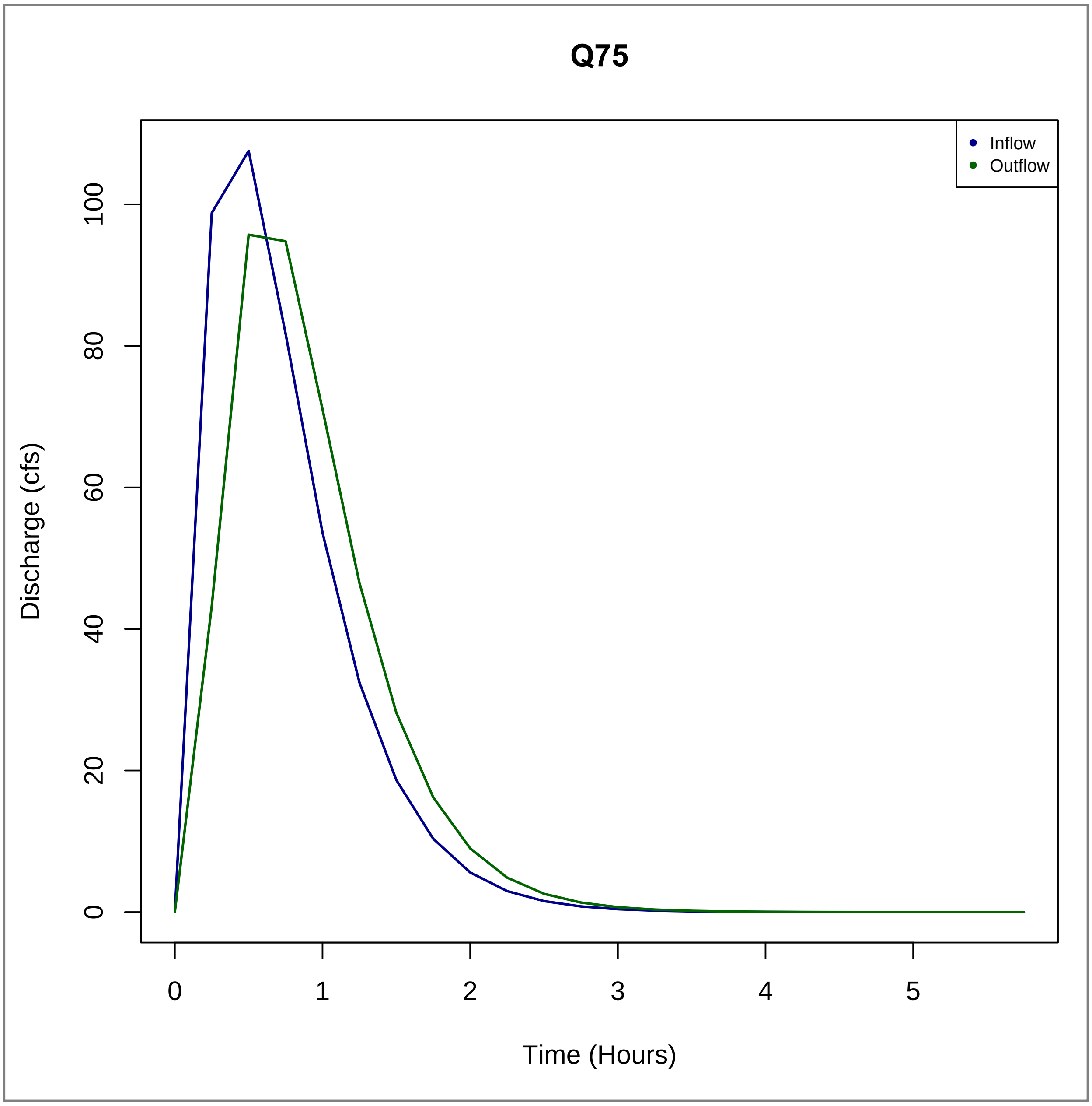

Figure A.5 Reservoir Routing. Q75.

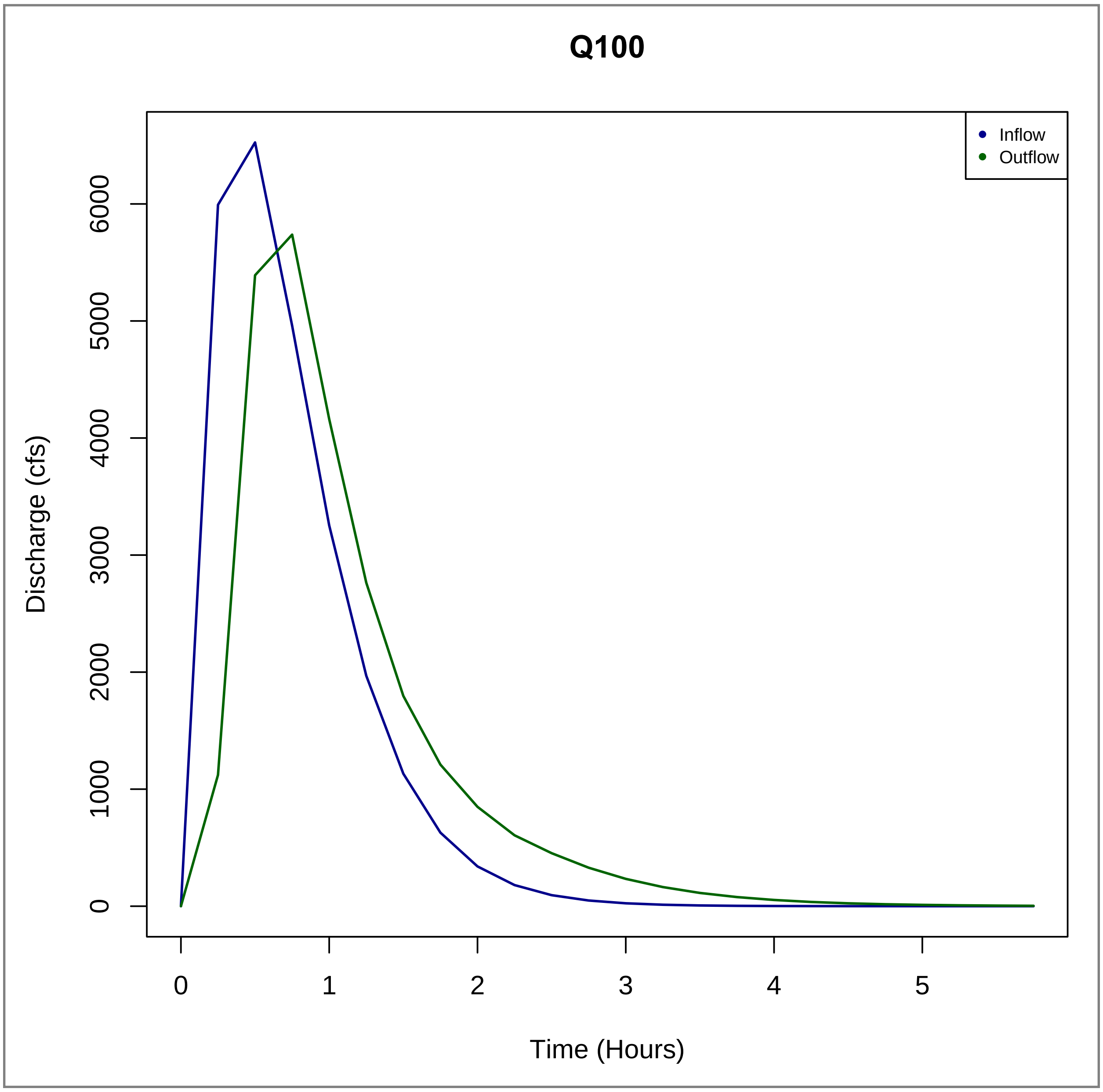

Figure A.6 Reservoir Routing. Q100.

Appendix B: Hydrologic Modeling Calculations

Parameter Definitions

In making these calculations we define the following parameters as follows:

Q_i = a daily SWAT flow (cfs-days) on day (i)

Q_{wi} = a daily SWAT flow (cfs-days) that goes over bank and inundates the wetland on day (i). Derived by taking $Q_i - Q_{0.05}$ for every i.

$Q_{0.05}$ = The flow which is equaled or exceeded 5% of the time = 15.1 cfs (a constant)

S_i = the sediment load (lbs) transported by each daily SWAT flow on day (i)

S_{wi} = flow weighted sediment load. The sediment load (lbs) transported to the wetland by each daily SWAT flow that is an overbank flow (Q_{wi}) on a day (i)

E_i = the sediment trap efficiency (unit less) of the wetland for each daily SWAT flow that is an overbank flow on a day i (S_{wi}). E_i for each overbank flow Q_{wi} can be determined by linear interpolation of Figure 4.4, which was derived from the sedimentation analysis.

S = the total sediment (lbs) contributed from the Dorn Creek watershed over a 66.4 year period.

S_T = the sum of the sediment trapped (lbs) in the wetland for each daily SWAT flow that is an overbank flow on a day (i) over a 66.4 year period.

Total Sediment Contributed and Sediment Trapped by the Wetland

$S = \sum_{i=1}^{24230} S_i = 4.36 \times 10^7$ lbs sediment

$S_T = \sum_{i=1}^{24230} = (E_i * S_{wi}) = 1.24 \times 10^7$ lbs sediment

Note: The length of the SWAT model is 66.4 years (24,230 days).

Effective Trap Efficiency

$\frac{S_T}{S} = \frac{1.24 \times 10^9 \text{ lbs sediment}}{3.16 \times 10^9 \text{ lbs sediment}}$ = .29 or 29% sediment trapped over a 66.4 year period.

P Trapped Over 66 Years

$(1.24 \times 10^9$ lbs sediment$) \times (0.453592 \frac{kg}{lb}) =$ 5.65×10^6 kg sediment

$(5.64 \times 10^8$ kg sediment$) \times (\frac{1500 \text{ mg P}}{\text{kg sediment}}) =$ 8.47×10^9 mg P $\times (\frac{10^6 \text{ mg}}{\text{kg}}) = (8.47 \times 10^3$ kg P$) \times (\frac{2.20462 \text{ lbs}}{\text{kg}}) = 1.86 \times 10^4$ lbs P trapped over a 66.4 year period

Trapping Rates

$\frac{1.24 \times 10^7 \text{ lbs sediment}}{66.4 \text{ years}} = 1.87 \times 10^5$ lbs of sediment trapped/year

$\frac{1.86 \times 10^4 \text{ lbs P}}{66.4 \text{ years}} = 281$ lbs of P trapped/year

1-Foot Removal Scenario

(5 acres) $\times (\frac{43560 \text{ ft}^2}{\text{acre}}) \times$ (1 ft sediment removal) $= 2.18 \times 10^5$ ft^3 sediment

$(2.18 \times 10^5$ ft^3 sediment$) \times (\frac{28316.85 \text{ cm}^3}{\text{ft}^3}) =$ 6.17×10^9 cm^3 sediment

$(6.17 \times 10^9$ cm^3 sediment$) \times (\frac{0.7 \text{ g}}{\text{cm}^3}) = 4.32 \times 10^9$ g sediment

Note: The bulk density of the sediment in the wetland area is estimated to be 0.7 g/cm^3

$(4.32 \times 10^9$ g sediment$) \times (\frac{0.00220462 \text{ lbs}}{\text{g}}) =$ 1.00×10^7 lbs of sediment

$\frac{1.00 \times 10^7 \text{ lbs of sediment}}{1.87 \times 10^5 \text{ lbs of sediment trapped/year}} = 50.79$ years to replace 1 foot of sediment removed across 5 acres

Appendix C: Regulatory Permitting

C.1 Upper Dorn Creek Floodplain Restoration

Wetland restoration activities in the Upper Dorn Creek Wetland may require a combination of various permits from federal, state, and local agencies. Below is a list of federal and state permitting agencies and a description of their responsibilities, as well as a list of permits that are applicable to wetland restoration activities.

Regulatory Agency Responsibilities

Federal

- United States Fish and Wildlife Service (USFWS) – USFWS has trust responsibility for federally listed threatened and endangered species and migratory birds.
- United States Department of Agriculture Natural Resources Conservation Service (NRCS) – NRCS has responsibility for wildlife habitation restoration and water quality improvement on agricultural lands.
- United States Army Corps of Engineers (ACOE) – ACOE has responsibility to regulate most activities within Federal navigable waters, as well as discharges of dredged and fill materials into waters of the United States.

Wisconsin

- Wisconsin Department of Natural Resources (WDNR) – WDNR has responsibility for fish and wildlife management and trust responsibility for public rights in navigable waters.

Wetland Restoration Permits

Federal

There are four common ACOE (federal) permit mechanisms available to authorize wetland restoration projects pursuant to Section 404 of the Clean Water Act (CWA) in Wisconsin, which can be found below. This does not necessarily include authorizations which may be required pursuant to Section 10 of the Rivers and Harbors Act of 1899 for work in federally navigable waters of the U.S.

1. Non-Reporting General Permit (GP) GP-002-WI – This permit applies to stream and wetland restoration activities sponsored by federal or state agencies and covers discharges of dredged or fill materials in waters of the United States (U.S.) associated with wetland restoration activities.
2. Reporting General Permit (GP-002-WI) – This permit may require a wetland delineation.
3. Letter of Permission (LOP-06-WI) – This permit applies to activities where

the discharge of dredged or fill material does not cause the loss of greater than two acres of waters of the U.S., including wetlands.

4. Individual Permit (IP) – This permit applies to projects that will exceed thresholds, or otherwise do not meet the terms or conditions of the previously listed three federal permits pertaining to wetland restoration activities.

Wisconsin

There are 5 state permit mechanisms available for wetland restoration projects, which can be found below. WDNR is the lead agency in implementing these permits.

1. NR 353 Water Conservation Permit – This permit is meant to streamline the permitting process if the project site and restoration activities meet specific conditions. The project purpose must be for wetland conservation. The project cannot involve any activities in navigable waters with prior stream history, or be otherwise determined to not cause significant adverse impacts to those waters.
2. Wetland Restoration General Permit (WRGP-2011-WI) – This permit applies to certain wetland restoration activities that are sponsored by the NRCS or USFWS. Project activities are required to only occur within artificial ditches that have no prior stream history and will not occur in navigable waters with stream history.
3. Wetland Conservation General Permit (GP) – This permit is meant for projects that propose activities in navigable waters with stream history that will have no significant adverse impacts (e.g. threatened and engendered species, historical or cultural resources).
4. Individual Permit (IP) – This permit is meant for projects that require more detailed review and/or special permit conditions to ensure the project does not result in significant adverse impacts.
5. Maintenance – This permit is meant for pre-existing wetland conservation projects that were constructed before August 1, 1991, and would only allow for maintenance of the original project design.

Other Regulations and Permits to Consider

1. Federal Listed Threatened & Endangered Species – Impacts to federally listed threatened or endangered species would require Section 7 consultation with USFWS.
2. Federal Listed Historic & Cultural Resources – Impacts to federally listed historic or cultural resources would require Section 106 consultation with the Wisconsin Historical Society, the federally designated State Historic Preservation Office.

3. Additional WDNR Permits – Additional permits from WDNR may be required for restoration activities that result in the lowering of the water table, reconnection of the stream to the wetland, dewatering, and soil erosion. Impacts to State listed threatened or endangered species or historic or cultural resources may also require additional permits from WDNR.
4. Aquatic Plant Management Permit – Management activities involving the control of aquatic plants (i.e. plants in water, including wetlands) – such as controlling reed canary grass by the use of chemicals, manual or mechanical removal, or by using biological control agents – may need a valid aquatic plant management permit under state administrative rules NR 107, NR 109, and NR 353. Coordination should be conducted with WDNR to ensure the method of removing reed canary grass and other invasive wetland vegetation is in compliance with state administrative rules NR 107, NR 109, and NR 353.
5. County and Local Floodplain Zoning Ordinances – According to FEMA's Flood Insurance Rate Map (Map No. 55025C0236G, revised January 2, 2009), the proposed wetland restoration site is located within a floodplain designated as Zone AE, a special flood hazard area subject to inundation by the 1% annual chance flood (100-year flood). Coordination should be conducted with Dane County and the Town of Westport planning agencies to ensure compliance with all floodplain ordinances.
6. County and Local Wetland Ordinances – The proposed wetland restoration site is identified by the Wisconsin Wetland Inventory maps as an "emergent/wet meadow" wetland. All designated wetlands by the Wisconsin Wetland Inventory maps that fall within the jurisdiction of Dane County are regulated by Chapter 11 Shoreland, Shoreland-Wetland, and Inland-Wetland Regulations. Coordination should be conducted with Dane County and the Town of Westport planning agencies to ensure compliance with all wetland ordinances.

Streamlining the Permitting Process

In addition to obtaining an NR 353 Wetland Conservation Permit, there are other ways to streamline the permit process through participating in a program or working with a private organization that can provide technical assistance and facilitate acquiring the necessary permits. For example, since the proposed wetland restoration site is located in an agricultural setting, the project might qualify for one or more government wetland restoration programs, such as the Conservation Reserve

Program (USDA), Wetland Reserve Program (NRCS), or Partners for Fish and Wildlife Program (USFWS). Private organizations like the Wisconsin Waterfowl Association or Ducks Unlimited may also have wetland restoration efforts in the project area. These programs and private organizations can provide technical assistance and help with the permitting process.

C.2 Dredging at Bridges

Below is a list of permits that may be applicable to dredging activities within Dorn Creek and/or clearing of farm drainage ditches.

Federal

1. Section 10 of the Rivers and Harbors Act of 1899 – This permit is administered by the ACOE and is required for:
   a) construction of any structure in or over any navigable water of the U.S.;
   b) excavation of dredge, or deposition of, fill material; and
   c) the accomplishment of any other work affecting the course, location, condition, or capacity of such waters.

Wisconsin

1. General Permit to Remove Accumulated Plant and Animal Nuisance Deposits from Beds of Navigable Waters GP5-2013-WI (WDNR-GP5-2013) – This permit applies to removal of accumulated plant and animal nuisance deposits from the bed of any lake, outlying water, or navigable stream of the State. A project is exempt from this permit if:
   a) the removal is a total of less than 2 cubic yards of bottom material in any given year;
   b) bottom material is dredged from a farm drainage ditch that was not a navigable stream before it was ditched (per NR 345.04);
   c) manual dredging is done with handheld devices that have no auxiliary power and remove a total of less than 3 cubic yards of material; and
   d) the project is not designated as an Area of Special Natural Resources Interest (ASNRI), does not have Public Rights Features (PRF), or is not a perennial tributary to a trout stream.
2. Stream Dredging Individual Permit (Form 3500-053) – For plant and animal nuisance removal projects that do not quality for WDNR-GP5-2013, application for an Individual Permit would be required.

Appendix D: Sediment Deposition and Stream Characteristics of Dorn Creek

Measurements were taken during the week of June 2, 2013, through June 9, 2013 (Tables D.1 to D.7 at the end of this appendix). No appreciable rainfall occurred during this time. Unable to secure permission to access the entirety of the creek within the upper wetland, measurements were taken by reach as noted below. Refer to Figure 3.3 for the locations listed.

Site A & B Reach

This segment of the creek flows through the western portion of the upper wetland, which contains primarily reed canary grass. Before entering the wetland, the creek flows through agricultural fields and is joined, an estimated 20-30 meters upstream of the wetland, by an ephemeral stream. The ephemeral stream was flowing at the time measurements were made within the wetland creek. Measurements on this reach were made from the creek bank due to the depth of sediment and water and the sticky consistency of the sediment. The initial measurement was made immediately east of an access road which crosses through the creek near the western edge of the Site A Reach. Walking west to east on the southern bank of the creek, depth of sediment measurements were taken every 5 meters, with transects every 20 to 30 meters on average.

A densely vegetated ditch with 0.1 meters of water was noted entering the creek from the north at 65 meters. Within the ditch at 5 meters from the creek, 0.7 meters of sediment were measured. The presence of the dense vegetation suggests this sediment is less likely to contribute to sedimentation within the creek. Further assessment of this sediment was not pursued.

At 85 meters, another ditch enters the creek from the north. Sediment has deposited at the juncture, narrowing the ditch channel. Transects were possible across the ditch within 20 meters of its entry into the creek. Vegetation on the deposited sediment provided sufficient cohesiveness to the sediment to support a person to make these measurements. Farther up the ditch the width was estimated to be 5 to 6 meters. Water depths were 0.15 to 0.2 meters along the western side of the ditch, increasing to 0.4 meters after 70 meters north. Sediment depths ranged from 0.8 to 1.15 meters within the proximal 50 meters of the ditch. Past 70 meters, one measurement of sediment depth was 0.4 meters. The ditch had no obvious flow at this point and was covered with pondweed. A sizeable turtle was noted in the ditch at this point. A survey of the ditch further north was not undertaken.

At 130 meters, the creek turns abruptly northeast. The creek bed is rocky and without sedimentation at the bend. Sedimentation resumes after the bend.

At 195 meters, the eastern border of the property is reached. Water depth is 0.5 meters and sediment depth is 0.7 meters. The vegetation north and east along the creek becomes dominated by shrubs and willows.

DT Property Reach (Unmapped)

This segment is between the Site A Reach and Site C Reach. Unable to obtain permission to access this property, this segment was not measured. With 1.2 meters of water and sediment within the creek at the western edge of this reach, measurements via water only access were not thought to be safely achievable. Concern also existed that debris within the creek would limit water access.

Site C Reach

This segment of the creek lies east of the DT Property Reach and north of the Meffert Road bridge. Measurements were initiated at the concrete base of the bridge where the creek meets the bridge at its northwest edge. Transects were taken at 0, 5, 25, 30, 45, 70, and 230 meters with segment lengths of 5 meters through 115 meters followed by 10 meters through 230 meters. Beginning at 50 meters, willows and shrubs – along the creek, over the creek, or as debris within the creek – confounded access to the creek. Their presence was associated with sediment deposition at or upstream from the obstruction. Upstream of 230 meters the willows appear more numerous.

Site D Ditch

This agricultural ditch extends north of the Meffert Road bridge along the eastern border of the wetland where it abuts an agricultural field. The ditch was accessed directly via wading and via boat. No significant impediments to measuring sediment were noted.

Site E Reach

This segment extends southeast of the Meffert Road bridge, flowing initially through land covered by predominantly reed canary grass. Unable to obtain permission to access the creek by land through this property, measurements were taken by canoe, kayak and with in-stream wading. Four transects were measured within the initial 10 meters of the creek below the bridge. From here, three depth measurements were taken within each 5 meter segment of the creek, with transects at variable distances based on creek morphology. Sediment depths ranged from 0.03 to 0.73 meters within the initial 10 meters of the creek. Sediment depths dropped to low levels – 0 to 0.07 meters – between 25 and 45-50 meters along the creek. Sedimentation increased past this point generally, averaging 0.1 to 0.4 meters, until 105 meters, where sediment was noted up to 0.5 meters in spots between 105 and 110 meters. Downstream at 120 meters, a large tree was down in and over the creek. At this location, the channel is less well defined, with an area of water to the south of the channel extending at least 2.4 meters under the tree. Access via boat and wading was difficult past this point. Sediment measurements were limited to mid-channel depths of 0.08 to 0.15 meters from 122 to 140 meters. Trees and shrubs were present on both banks, along with in-channel debris. Sediment increased again at 150 to 160 meters, up to 0.4 meters in depth. A large tree and other shrubs and debris blocked the channel past 160 meters.

KB Property Reach (unmapped)

This segment extends from the beginning of the Site E Reach southeast of the Meffert Road bridge to the western edge of the Site F Reach. Unable to obtain permission to access the creek by land through this property, only the Site E Reach was accessible for sediment measurements.

Site F Reach

This segment of the creek extends from the eastern edge of the KB Property Reach to the point where the creek exits the upper wetland. Measurements were initiated at the north side of a culvert, over which a farm access road passes, on the property behind the farm where the creek exits the upper wetland. Here the creek is wadeable. The creek bed is rock and clay for 200 meters upstream with minimal sediment, generally 0 to 0.1 meters with variable deposition. The water flows well with an occasional riffle. The banks are lined with trees, shrubs, and other vegetation such as grass and wild blackberries. Measurements of sediment depth were taken at 5 to10 meter lengths along the creek. At 15 meters a small drainage ditch enters the creek from the east, depositing a minor patch of 0.1 meter deep sediment.

At 55 meters, a ditch contributes water to the creek via a culvert. The culvert enters from the north. The water depth at the ditch entry is 0.1 meters with sediment ranging across the ditch from 0 to 0.2 meters. Across the creek at the ditch entry, the water is up to 0.2 meters deep with 0.15 to 0.25 meters of sediment. The ditch itself is wadeable north of the culvert and well vegetated. Sediment in the ditch is stable for wading.

Between 60 and 140 meters, there is an occasional deposit of sediment, 0.1 to 0.3 meters in depth, along the edge of the creek and often associated with trees/debris in the creek. From 140 meters until a tree over the creek blocks access through the creek at 190 meters, sediment is minimal at 0.01 to 0.03 meters. Upstream of the tree at 200 meters, sediment increases to 0.32 meters, then decreases in depth over the next 20 meters to 0.05 meters.

Sample Date	Location	Distance (m)	Width (m)	Sediment Depth (m)	Volume (m^3)
2013-06-04	upper wetland	0	0.9	0.9	
2013-06-04	upper wetland	10	2.6	1.016666667	16.77083333
2013-06-04	upper wetland	20	2.6	1.1	27.51666667
2013-06-04	upper wetland	30	5	0.8	36.1
2013-06-04	upper wetland	40	6	0.9	46.75
2013-06-04	upper wetland	50	6	0.9	54
Total					**181.14**
The entire ditch was not quantified. This is for the proximal 50 meters: adding the 5.62 m^3 at The entry to the creek (triangular deposit 5 m x 2.5 m x 0.9 m x 1/2) brings the total to 181.14 + 5.62 = **186.76 m^3**.					

Table D.1 Sediment Quantification for Site B Ditch.

The creek past 220 meters to 320 meters has more consistent sedimentation and less of a gradient than downstream. Sediment depths are generally 0.05 to 0.2 meters. There are more trees and debris in the water. At 275 meters a ditch enters from the north. There is no water in the ditch but 0.1 meters of sediment. Upstream from 320 meters trees are down and blocking the creek. Exiting the creek and reentering upstream, a depth of 0.1 meters of sediment was noted. Further contiguous measuring was prohibited due to tree debris. The final measurement was east of the KB Property Reach.

Sample Date	Location	Distance (m)	Width (m)	Sediment Depth (m)	Volume (m^3)	Volume (m^3) (30m intervals)
2013-06-04	upper wetland	0	2.3	0.15		
2013-06-04	upper wetland	5	2	0.466666667	3.314583333	
2013-06-04	upper wetland	10	2.5	0.4	4.875	
2013-06-04	upper wetland	15	1.9	0.34	4.07	
2013-06-04	upper wetland	20	2.5	0.35	3.795	
2013-06-04	upper wetland	25	2.5	0.215	3.53125	
2013-06-04	upper wetland	30	2.5	0.3	3.21875	22.80
2013-06-04	upper wetland	35	2.2	0.25	3.23125	
2013-06-04	upper wetland	40	2	0.3	2.8875	
2013-06-04	upper wetland	45	2.5	0.35	3.65625	
2013-06-04	upper wetland	50	2.3	0.35	4.2	
2013-06-04	upper wetland	55	2.1	0.4	4.125	
2013-06-04	upper wetland	60	2.5	0.25	3.7375	21.84
2013-06-04	upper wetland	65	2.6	0.625	5.578125	
2013-06-04	upper wetland	70	2.2	0.4	6.15	
2013-06-04	upper wetland	75	2.5	0.3	4.1125	
2013-06-04	upper wetland	80	2.5	0.5	5	
2013-06-04	upper wetland	85	2.4	0.475	5.971875	
2013-06-04	upper wetland	90	1.9	0.62	5.885625	32.70
2013-06-04	upper wetland	95	1.95	0.725	6.4728125	
2013-06-04	upper wetland	100	2.4	0.65	7.4765625	
2013-06-04	upper wetland	105	2.4	0.716666667	8.2	
2013-06-04	upper wetland	110	2.5	0.386666667	6.757916667	
2013-06-04	upper wetland	115	2.5	0.533333333	5.75	
2013-06-04	upper wetland	120	2.2	0.4	5.483333333	40.14
2013-06-04	upper wetland	125	2.4	0.333333333	4.216666667	
2013-06-04	upper wetland	130	2.2	0	1.916666667	
2013-06-04	upper wetland	135	2.2	0.25	1.375	
2013-06-04	upper wetland	140	2.1	0.3	2.95625	
2013-06-04	upper wetland	145	2.4	0.5	4.5	
2013-06-04	upper wetland	150	2.1	0.35	4.78125	19.74

Table D.2 Sediment Quantification for Site A Reach.

Sample Date	Location	Distance (m)	Width (m)	Sediment Depth (m)	Volume (m^3)	Volume (m^3) (30m intervals)
2013-06-04	upper wetland	155	2.05	0.375	3.7609375	
2013-06-04	upper wetland	160	2.1	0.3	3.5015625	
2013-06-04	upper wetland	165	2.5	0.15	2.5875	
2013-06-04	upper wetland	170	2.4	0.3	2.75625	
2013-06-04	upper wetland	175	2.4	0.35	3.9	
2013-06-04	upper wetland	180	2.4	0.5	5.1	21.61
2013-06-04	upper wetland	185	2.4	0.7	7.2	
2013-06-04	upper wetland	190	2.4	0.95	9.9	
2013-06-04	upper wetland	195	1.6	0.7	8.25	25.35
Total						**184.18**
Additional sediment in the form of a ledge at 165 m brings total to 2.1 + 184.18 = **186.28 m^3.**						

Table D.2 Sediment Quantification for Site A Reach (continued).

Sample Date	Location	Distance (m)	Width (m)	Sediment Depth (m)	Volume (m^3)	Volume (m^3) (30m intervals)
2013-06-03	upper wetland	0	1.3	0.883333333		
2013-06-03	upper wetland	5	1.25	0.625	4.8078125	
2013-06-03	upper wetland	10	1.3	0.35	3.1078125	
2013-06-03	upper wetland	15	1.5	0.3	2.275	
2013-06-03	upper wetland	20	1.5	0.15	1.6875	
2013-06-03	upper wetland	25	1.6	0.35	1.9375	
2013-06-03	upper wetland	30	1.65	0.675	4.1640625	17.98
2013-06-03	upper wetland	35	1.8	0.1	3.3421875	
2013-06-03	upper wetland	40	1.8	0.36	2.07	
2013-06-03	upper wetland	45	1.75	0.425	3.4834375	
2013-06-03	upper wetland	50	1.95	0.15	2.659375	
2013-06-03	upper wetland	55	2	0.15	1.48125	
2013-06-03	upper wetland	60	2.1	0.05	1.025	14.06
2013-06-03	upper wetland	65	2.2	0.05	0.5375	
2013-06-03	upper wetland	70	2.2	0.533333333	3.208333333	
2013-06-03	upper wetland	75	2.2	0.3	4.583333333	
2013-06-03	upper wetland	80	1.5	0.35	3.00625	
2013-06-03	upper wetland	85	1.8	0.2	2.26875	
2013-06-03	upper wetland	90	1.6	0	0.85	14.45
2013-06-03	upper wetland	95	1.55	0.12	0.4725	
2013-06-03	upper wetland	100	1.8	0.25	1.549375	
2013-06-03	upper wetland	105	1.5	0	1.03125	
2013-06-03	upper wetland	110	1.55	0.3	1.14375	
2013-06-03	upper wetland	115	1.5	0.24	2.05875	
2013-06-03	upper wetland	125	1.4	0.2	3.19	9.45
2013-06-03	upper wetland	135	1.9	0.25	3.7125	
2013-06-03	upper wetland	150	2	0.3	8.04375	
2013-06-03	upper wetland	160	1.9	0.25	5.3625	17.12
2013-06-03	upper wetland	170	2	0.3	5.3625	
2013-06-03	upper wetland	180	1.7	0.05	3.2375	
2013-06-03	upper wetland	190	1.65	0.15	1.675	10.28
2013-06-03	upper wetland	200	1.7	0.1	2.09375	
2013-06-03	upper wetland	210	1.9	0.1	1.8	
2013-06-03	upper wetland	220	1.8	0.35	4.1625	
2013-06-03	upper wetland	230	2.3	0.383333333	7.516666667	15.57
Total						**98.91**
Additional 1.37 m^3 deposit at 75 m yields final total = **100.28 m^3**.						

Table D.3 Sediment Quantification for Dorn Creek above Meffert Road (Site Reaches A-D).

Sample Date	Location	Distance (m)	Width (m)	Sediment Depth (m)	Volume (m^3)	Volume (m^3) (30m intervals)
2013-06-02	upper wetland	1.2	5.7	0.383333333		
2013-06-02	upper wetland	5	9	0.426666667	11.31165	
2013-06-02	upper wetland	7.5	10	0.316666667	8.827083333	
2013-06-02	upper wetland	10	8.3	0.156666667	5.41375	
2013-06-02	upper wetland	11.5	5.4	0.4	2.859875	
2013-06-02	upper wetland	13	5.4	0.38	3.159	
2013-06-02	upper wetland	15	5.4	0.15	2.862	
2013-06-02	upper wetland	16.5	4.85	0.13	1.07625	
2013-06-02	upper wetland	18	4.9	0.18	1.1334375	
2013-06-02	upper wetland	20	4	0.216666667	1.765166667	
2013-06-02	upper wetland	21.5	2.9	0.05	0.69	
2013-06-02	upper wetland	23.2	2.9	0.02	0.17255	
2013-06-02	upper wetland	25	3.2	0.02	0.1098	
2013-06-02	upper wetland	27.2	2.6	0.07	0.2871	
2013-06-02	upper wetland	28.7	2.8	0.06	0.26325	
2013-06-02	upper wetland	30	2.4	0.033333333	0.157733333	40.09
2013-06-02	upper wetland	32	2.5	0	0.081666667	
2013-06-02	upper wetland	33.5	2.7	0.053333333	0.104	
2013-06-02	upper wetland	35	2.3	0.12	0.325	
2013-06-02	upper wetland	37	2.6	0	0.294	
2013-06-02	upper wetland	38.5	2.2	0	0	
2013-06-02	upper wetland	40	2.6	0	0	
2013-06-02	upper wetland	42	2	0	0	
2013-06-02	upper wetland	43.5	2	0	0	
2013-06-02	upper wetland	45	2	0.06	0.09	
2013-06-02	upper wetland	47	1.6	0	0.108	
2013-06-02	upper wetland	48.5	2.8	0.096666667	0.1595	
2013-06-02	upper wetland	50	3.7	0.143333333	0.585	
2013-06-02	upper wetland	52	2.2	0.15	0.865333333	
2013-06-02	upper wetland	53.5	2	0.07	0.3465	
2013-06-02	upper wetland	55	2.9	0.16	0.422625	
2013-06-02	upper wetland	57	2.2	0.15	0.7905	
2013-06-02	upper wetland	58.5	2.5	0.34	0.863625	
2013-06-02	upper wetland	60	2	0.196666667	0.905625	5.94

Table D.4 Sediment Quantification for Dorn Creek below Meffert Road (Site Reaches E-F).

Sample Date	Location	Distance (m)	Width (m)	Sediment Depth (m)	Volume (m^3)	Volume (m^3) (30m intervals)
2013-06-02	upper wetland	122	1.7	0.08	0.496	
2013-06-02	upper wetland	123.5	3	0.1	0.31725	
2013-06-02	upper wetland	125	2.7	0.13	0.491625	
2013-06-02	upper wetland	127	2	0.11	0.564	
2013-06-02	upper wetland	128.5	2.4	0.15	0.429	
2013-06-02	upper wetland	130	1.9	0.15	0.48375	
2013-06-06	upper wetland	140	2.7	0.15	3.45	
2013-06-06	upper wetland	150	2.3	0.28	5.375	
2013-06-06	upper wetland	160	6	0.243333333	10.85916667	22.47
Total						**93.79**
Add 1.575 m^3 noted at 35-38.5 m brings total = **95.37 m^3**.						

Table D.4 Sediment Quantification for Dorn Creek below Meffert Road (Site Reaches E-F) (continued).

Sample Date	Location	Distance (m)	Width (m)	Sediment Depth (m)	Volume (m^3)	Volume (m^3) (30m intervals)
2013-06-08	upper wetland	0	2.4	0		
2013-06-08	upper wetland	5	2.5	0.01	0.06125	
2013-06-08	upper wetland	10	2.5	0.01	0.125	
2013-06-08	upper wetland	15	2.9	0.043333333	0.36	
2013-06-08	upper wetland	20	2.6	0	0.297916667	
2013-06-08	upper wetland	30	2.7	0.1	1.325	2.17
2013-06-08	upper wetland	35	3	0.07	1.21125	
2013-06-08	upper wetland	45	2.7	0.14	2.9925	
2013-06-08	upper wetland	50	2.5	0.126666667	1.733333333	
2013-06-08	upper wetland	55	2.9	0.196666667	2.1825	
2013-06-08	upper wetland	60	2.9	0.12	2.295833333	10.42
2013-06-08	upper wetland	70	2.5	0.05	2.295	
2013-06-08	upper wetland	80	1.6	0.07	1.23	
2013-06-08	upper wetland	90	3	0.05	1.38	4.90
2013-06-08	upper wetland	100	2.6	0	0.7	
2013-06-08	upper wetland	110	2.4	0.01	0.125	
2013-06-08	upper wetland	120	3	0.01	0.27	1.09
2013-06-08	upper wetland	130	3.1	0.153333333	2.490833333	
2013-06-08	upper wetland	140	2.2	0.01	2.164166667	
2013-06-08	upper wetland	150	2.8	0.01	0.25	4.91
2013-06-08	upper wetland	160	2.5	0.03	0.53	
2013-06-08	upper wetland	170	2.3	0.01	0.48	
2013-06-08	upper wetland	180	1.9	0.01	0.21	1.22
2013-06-08	upper wetland	195	2.3	0.05	0.945	
2013-06-08	upper wetland	200	2.5	0.32	2.22	
2013-06-08	upper wetland	205	2.1	0.15	2.7025	5.87
2013-06-08	upper wetland	215	2.5	0.16	3.565	
2013-06-08	upper wetland	220	2.1	0.05	1.2075	
2013-06-08	upper wetland	232	3	0.05	1.53	6.30
2013-06-08	upper wetland	240	2.4	0.116666667	1.8	
2013-06-08	upper wetland	250	2.4	0.15	3.2	
2013-06-08	upper wetland	260	2	0.2	3.85	8.85
2013-06-08	upper wetland	275	2.9	0.01	3.85875	
2013-06-08	upper wetland	285	2.4	0.15	2.12	
2013-06-08	upper wetland	295	2.2	0.17	3.68	9.66
2013-06-08	upper wetland	310	2.3	0.15	5.4	
2013-06-08	upper wetland	320	3.5	0.15	4.35	9.75
Total						**65.14**
Additional deposits noted at 55 m, 60 m, 80 m, 90 m, 120 m, and 120-130 m: 0.19 + 0.90 + 2.37 + 0.63 + 0.10 + 2.00 = 6.19 brings the total to: 65.14 + 6.19 = **71.33 m^3**.						

Table D.5 Sediment Quantification for Site F Reach of Dorn Creek.

Sample Date	Location	Distance (m)	Width (m)	Sediment Depth (m)	Volume (m^3) (15m Intervals)
2013-06-02	dorn ditch	1.67	7.77	0.82	
2013-06-02	dorn ditch	3.34	7.8	0.85	
2013-06-02	dorn ditch	5	7.28	0.75	
2013-06-02	dorn ditch	6.68	9.4	0.82	
2013-06-02	dorn ditch	8.35	9	0.95	
2013-06-02	dorn ditch	10	10.46	0.62	
2013-06-02	dorn ditch	11.7	6.3	0.49	
2013-06-02	dorn ditch	13.37	6.98	0.63	
2013-06-02	dorn ditch	15	6.4	0.42	83.95
2013-06-02	dorn ditch	16.67	7.46	0.47	
2013-06-02	dorn ditch	18.34	7.44	0.29	
2013-06-02	dorn ditch	20	7.2	0.25	
2013-06-02	dorn ditch	21.68	7.92	0.54	
2013-06-02	dorn ditch	23.35	8.61	0.35	
2013-06-02	dorn ditch	25	6.85	0.5	
2013-06-02	dorn ditch	26.67	6.4	0.4	
2013-06-02	dorn ditch	28.3	6.16	0.5	
2013-06-02	dorn ditch	30	7.12	0.3	43.44
2013-06-02	dorn ditch	31.7	7.24	0.4	
2013-06-02	dorn ditch	33.3	6.75	0.55	
2013-06-02	dorn ditch	35	7.5	0.5	
2013-06-02	dorn ditch	36.7	7	0.5	
2013-06-02	dorn ditch	38.4	7.2	0.37	
2013-06-02	dorn ditch	40	6.55	0.35	
2013-06-02	dorn ditch	41.7	6.1	0.34	
2013-06-02	dorn ditch	43.4	6.2	0.43	
2013-06-02	dorn ditch	45	6.3	0.44	
2013-06-02	dorn ditch		5.85	0.36	42.28
Total					**169.67**

Table D.6 Sediment Quantification for Site D Ditch above Meffert Road.

Sample date	Location	Distance from bridge (m)	Width (m)	Sediment Depth (m)
2013-06-02	bridge grid up	25.0	7.4	0.6025
2013-06-02	bridge grid up	20.0	8.8	0.6375
2013-06-02	bridge grid up	15.0	9.5	0.625
2013-06-02	bridge grid up	10.0	10	0.606
2013-06-02	bridge grid up	5.0	9.8	0.52
2013-06-02	bridge grid up	0.0	5	0.683333333
Total sediment for the bridge grid: average width x average depth of sediment x length = 8.416666667 x 0.612388889 x 15 = **128.86 m^3.**				

Table D.7 Sediment Quantification for the Site D Ditch above the Meffert Road Bridge.

Appendix E: Fieldwork and Sampling Methods

E.1 Sediment Quantification Method

Upper Dorn Creek Wetland Complex

The sediment in Dorn Creek and associated ditches within the upper wetland was quantified using a standard method whereby a segment of the creek/ditch was measured for length and width using a flexible measuring tape. Within each segment, measurements of sediment depth were taken using a rigid pole marked off in 10 centimeter sections. For each measurement, the pole was lightly placed on the top of the sediment layer. The level of the water at the pole was recorded. The pole was then pushed into the sediment until firm bottom was reached. The level of the water at the pole was again recorded. The difference between these two measurements is the depth of the sediment. The quantity of sediment for each creek/ditch segment was calculated by multiplying length by width by depth of sediment. However, due to variations in the creek/ditch morphology and position within the wetland, as well as variations in sediment deposition within a given segment of the creek/ditch, the width used for the calculation is an average of the two ends of the segment or an average of three widths per segment, depending upon the reach measured. Sediment depth used for the calculation for a given segment of creek/ditch is also an average. The average is based on averaging midstream depth measurements along the segment and/or as determined by a transect across the creek/ditch, whereby three measurements across the width of the creek/ditch area were taken and averaged.

Bridge Sites

The in-stream sediment located at bridge crossings on Dorn Creek and Six-Mile Creek were measured by a method comparable to that used for the Upper Dorn Creek Wetland. Transects were taken within ten meters of the bridge – upstream and downstream – to calculate the sediment volume near the bridge. The decision to quantify the sediment within ten meters of the bridge was based on the feasibility of dredging material from the stream channel with equipment located near the bridge. All measurements were made during the same week in July 2013.

Mary Lake

Due to the large size of Mary Lake cursory estimates of sediment volume were made in this area. Lake depth was assessed at three locations at the downstream end of the ponded area, approximately 20 meters upstream from the outfall of the confined stream channel. Aerial photos were utilized to estimate the area of the lake. The area and depth values were then used to estimate the volume of sediment constrained in Mary Lake.

E.2 Sediment Mobility Measurement Method

To measure sediment scour, a pilot study was conducted to determine the most appropriate method for use in Dorn Creek. In the pilot study, a scour chain, sliding ball monitor, and sliding rebar monitor were installed in Willow Creek on silt substrate that is prone to similar scour and deposition to that found in Dorn Creek. After a number of rain events, the monitors were evaluated for function and feasibility to be applied to Dorn Creek. The sliding rebar monitor method was found to be most practical for relocation and excavation, whereas the other two methods were found to be too difficult to use in deep water and the high turbidity that ensued after rain events.

The sliding rebar monitors were easiest to install in Willow Creek and Dorn Creek. This was done according to Duncan and Ward (1985) (Figure 3.7). Devices were constructed using 6 foot T-posts with a sliding L-shaped PVC appendage. The "L" measured 1.5 meters in length, with 1 meter PVC extended perpendicularly for stabilization, and was intended to move down the T-post as the streambed lowers, marking the lowest point of scour and accumulated deposition above. To install the devices in six locations in the middle of the streambed in Dorn Creek, the metal T-post was driven into the ground with the "L" assembly attached, set flush to the substrate. The difference between the heights of the "L" and the T-post was recorded as the baseline for tracking scour/deposition.

E.3 Sediment and Soil Core Sampling

Stream Sediment

Sediment samples were collected using a six-foot, 1.5-inch diameter clear polycarbonate tubing, which was hand-driven to refusal. The sample was extracted by pulling the tube back to the surface; a waterline stub plug was pushed through the tube to extract the sample to a tray.

Wetland Soil Cores

Soil Auger

Using a metal soil hand auger, a total of five soil cores were drilled slightly northwest of the intersection of Meffert Road and Dorn Creek to determine the depth of the clay layer and the depth to the water table. The auger was hand-drilled into the soil until it reached the water table and/or clay layer, to which depth measurements were then recorded. The elevation for each soil core site was determined by using a leveler.

Vibracore

A team effort was employed to extract a deep soil sample from the Upper Dorn Creek Wetland. To recover the continuous sample of sediment for analysis, a vibrating 10-foot aluminum pipe, or Vibracore, was pushed into the ground, jagged edge first, through cleared vegetation. A motor provided power to vibrate the pipe while it was manually twisted and agitated to drive it to the deepest possible depth into the substrate. When resistance was reached and the pipe could go no further, exploration of the barrier ensued and a new location was selected to avoid the rock that was hit upon the initial attempt. A successful deployment of the Vibracore, a few feet from the original site, reached the water table. The depth reached was calculated by subtracting the distance between the top of the soil and the top of the pipe from the total length of the pipe. A wench from a giant iron tripod and pulley cranked the aluminum pipe with the encased soil core out of the wetland. Once out, the hot pipe was removed from the hot motor using wet rags, and the now full pipe was trimmed and sealed with duct tape. The core was sliced lengthwise with a saw to provide two halves for observation and analysis. Halves were protected with plastic wrap during the period of study. Careful consideration went into ensuring the safety of participants and towards minimizing disturbance to the surrounding habitat. The intent was to avoid collateral damage to both workers and the study site.

E.4 Water Quality – Nitrate and Phosphate

Phosphate CHEMets Kit K-8510/R-8510 and Nitrate Kit K-6904 provided calibrated in-field procedures for assessing phosphate and nitrate levels of 15-25 milliliter samples taken in undisturbed areas of the creek. The detection range for dissolved phosphate was 0-1 parts per million (ppm) by tenths and 1-10 ppm by ones. Phosphate in the samples reacted with ammonium molybdate that was added to the samples and different hues of the color blue were produced after a stannous chloride reduction. This change in color allowed for a colorimetric assessment of the sample phosphate level. Sample nitrate concentrations were also assessed colorimetrically, using a pink comparator from which the nitrate concentration was visually estimated following a cadmium reduction of nitrate to nitrite.

E.5 Phosphorus and Particle Size Analysis

Phosphorus was analyzed by the University of Wisconsin Soil and Plant Analysis Laboratory as part of the Element Analysis 1 panel. The procedure utilized is available at http://uwlab.soils.wisc.edu/elemental-analysis/. The hydrometer analysis procedure for grain size is available at http://uwlab.soils.wisc.edu/files/procedures/particle_size.pdf. Table E.1, In-stream Sampling Data, has all sample results.

E.6 Bulk Density

Calculated sediment volumes and the sediment phosphorus concentrations were used to calculate the weight of phosphorus associated with a volume of sediment (Chapter 3). To convert phosphorus loads from volume-based to weight-based measures, a dry bulk density was determined by first drying a soil sample of known volume and wet weight for ten days at 500 degrees Fahrenheit and then weighing the dry material. The dry bulk density is the dry soil weight divided by the known volume. With a dry weight of 109 grams and a volume of 142.7 cm^3, the bulk density of our samples was 0.76 g/cm^3. Silt loams are characteristic of the soils at the project sites and typically have a bulk density close to 1.3 g/cm^3. However, Ruehlmann and Korschens (2009) found that submersed sediments with high organic content and fine textured particles can have lower bulk densities. The Dorn Creek and Six-Mile Creek sediments are consistent with those described and, therefore, the calculated dry bulk density was utilized for the phosphorus load conversion.

Soil Core ID	Location	Sample (cm)	% Sand	% Silt	% Clay	Soil Texture	TP (mg/kg)
Upper Dorn Creek Complex							
UDC-1A	Upstream Meffert Rd	1-2.9	--	--	--	--	2620.02
UDC-1BC	Upstream Meffert Rd - Combined sample	B: 3-4.9/ C: 5-7.9	--	--	--	--	3076.81
UDC-1D	Upstream Meffert Rd	8-12.9	--	--	--	--	1834.41
UDC-1E	Upstream Meffert Rd	13-17.9	--	--	--	--	1866.82
UDC-1F	Upstream Meffert Rd	18-24.9	--	--	--	--	724.81
UDC-1G	Upstream Meffert Rd	25-29.9	--	--	--	--	715.23
UDC-1H	Upstream Meffert Rd	30-37	--	--	--	--	589.54
UDC-2	Upstream Meffert Rd	1-8	34	52	14	Silt Loam	--
UDC-2	Upstream Meffert Rd	8-25	10	59	31	Silty Clay Loam	--
UDC-2	Upstream Meffert Rd	23-32	6	69	25	Silt Loam	--
UDC-3	Meffert Rd Ditch	1-10	--	--	--	--	1902.1
UDC-4	Site A, 58 m from big ditch	1-8	--	--	--	--	1271.8
UDC-5	Site F	1-8	--	--	--	--	1054.69
Dorn Creek at Hwy M							
DCM-1A	Upstream Hwy M	1-13	--	--	--	--	1992.32
DCM-1B	Upstream Hwy M	14-24	--	--	--	--	913.87
DCM-2A	Upstream Hwy M	1-11	--	--	--	--	1205.74
DCM-2B	Upstream Hwy M	12-19	--	--	--	--	385.7
DCM-3A	Upstream Hwy M	1-12	44	46	10	Loam	--
DCM-3B	Upstream Hwy M	13-20	67	22	11	Sandy Loam	--
Dorn Creek at Hwy Q							
DCQ-1	Upstream	1-17	18	64	18	Silt Loam	1938.95
Six-Mile Creek at Hwy M							
SMCM-1A	Upstream Hwy M	1-18	39	50	11	Loam	1072.53
SMCM-1B	Upstream Hwy M	18-30	68	25	7	Sandy Loam	315.23
SMCM-3	Downstream Hwy M	1-18	23	66	11	Silt Loam	409.19
Six-Mile Creek at Woodland Dr							
SMCW-1	Upstream of Woodland Dr	1-35	49	38	13	Loam	415.99
Mary Lake							
ML-1	Upstream of Mary Lake	1-10	11	75	14	Silt Loam	1425.65
ML-2	Upstream of Mary Lake	10-30	--	--	--	--	354
ML-3	Downstream of Mary Lake	2-15	--	--	--	--	1113.83
ML-4	Downstream of Mary Lake	2-10	--	--	--	--	1463.07
ML-5	Downstream of Mary Lake	2-15	--	--	--	--	1406.37

Note: See Appendix E for methodology.

Table E.1 In-stream Sampling Data.

Appendix F: Vegetation Survey

The results of the informal vegetation assessment and literature review for each of the target study areas are described below.

Upper Dorn Creek Wetland

The Upper Dorn Wetland Complex is predominately a palustrine wet meadow with some limited palustrine scrub-shrub areas. The wet meadow is dominated by reed canary grass (*Phalaris arundinace*) and cattails (*Typha sp.*) with some small patches of sedge species (*Carex sp.*) and black elderberry (*Sambucus canadensis*). The following species are also present throughout the wetland: nightshade (*Solanum dulcamara*), wild cucumber (*Echinocystis lobata*), jewelweed (*Impatiens capensis*), black currant (*Ribes americanum*) and nettle (*Urtica dioica*). Limited native wetland species were found including: swamp milkweed (*Esclapias incarnate*), common milkweed (*Esclapias syriaca*), false bonset (*Brickellia eupotorioides*), blue vervain (*Verbena hastata*), green bulrush (*Scirpus atrovirens*), and daisy fleabane (*Erigeron annuus*).

The canopies of the scrub-shrub areas are dominated by willow (*Salix sp.*) and primarily occur in linear patches adjacent to the stream. The understory of these areas includes species from the wet meadow, as well as red osier dogwood (*Cornus stolonifera*), box elder (*Acer negundo*), and high bush cranberry (*Viburnum trilobum*). Reed canary grass is the dominant understory plant in these scrub-shrub areas.

Bridge Sites

Bridge site areas along Dorn Creek consist of forested and scrub-shrub stream corridors dominated by box elder and willow in the tree canopy and dogwood or willow in the shrub layer. The bridge site areas at Highway M and Six-Mile Creek (near Highway K) include the open water stream of Six-Mile Creek. Emergent marsh vegetation in the stream corridor is dominated by cattail (*Typha sp.*).

Mary Lake

The Mary Lake area was not extensively surveyed and needs further examination.

Stream Corridor and Outlet

The stream corridor and outlet on the west-end of the lake near Woodland Drive is dominated by silver maple (*Acer saccharinum*) and box elder. Several non-native willow and other unidentified horticultural species surround the edge of the lake and the stream at the inlet on the northeast-end of the lake. Large patches of emergent vegetation are present along the stream edge and on sediment bars within the lake.

Appendix G: Survey of Stream Nitrates and Phosphates

Results of the phosphate and nitrate surveys refer to locations on Figure 3.3.

While our pilot survey was not thorough enough for statistical tests, we consistently measured the highest phosphate levels at Site 3 and the lowest levels at Site 1, furthest upstream. Nitrates were highest at Site 4, after Dorn Creek passes under Meffert Road, and lowest at Site 3, in a ditch north of Meffert Road. These concentrations are consistent with more comprehensive studies on Dorn Creek. In 2006, Sarah Hillegas found a similar spike in nitrate concentration just south of the Meffert Road bridge. In Michael Penn's 2005 study, the area immediately surrounding the Meffert Road bridge is referred to as a "true depositional zone" wetland. In addition, Penn's inventory of sediment suggests that approximately 10% of phosphorus resides in the top 5 centimeters. Significant spikes in concentrations of both nutrients were detected on September 13, 2013. This is noteworthy because samples were taken within 12 hours of a storm event and a tremendous amount of scour and deposition activity was also noted.

Sites 3 and 4 are of interest because of the maximum and minimum nutrient values measured. These sites, where Dorn Creek flows under Meffert Road, have both high levels of phosphates suspended in the stream channel and high levels of phosphorus in channel sediment. These sites also exhibited the most scour and deposition activity during storm events. Penn's study found that total phosphorus levels were highest here, which is comparable to our findings of the highest measured levels of phosphates in the same area. High nitrates, phosphates, and phosphorus in the sediment in this area justify this as a management opportunity to both reduce nutrient levels through short-term remediation efforts, as well as long-term restoration for nutrient mitigation.

A more comprehensive nutrient evaluation of this site may be valuable. The main nutrients of concern, nitrogen and phosphorus, can both be measured in several forms. Phosphorus can be measured as total phosphorus (TP) or soluble reactive phosphate (SRP), also sometimes called phosphate (PO4) or orthophosphate (ortho-P). The last three represent different terms used to describe the fraction of TP that is soluble or available to organisms for growth.

Nitrogen can be measured as total nitrogen (TN), total Kjeldahl nitrogen (TKN), nitrate-nitrogen (NO3), nitrite-nitrogen (NO2) [these are usually measured as nitrate-nitrite-nitrogen (NO3–NO2)], or ammonia-nitrogen (NH4). TN is similar to TP and is used to represent the total amount of nitrogen in a sample. TKN represents the fraction of TN that is unavailable for growth or bound up in organic form but also includes NH_4. The remaining fractions (NO_3–NO_2 and NH_4) represent bioavailable forms of nitrogen. If they are summed, they can be compared to the SRP fraction of phosphorus.

The total concentration of a nutrient (e.g., TP or TN) is not necessarily the most useful measurement. For example, if a sample is analyzed for TP, all forms of the element are measured, including the phosphorus "locked up" in biological tissue and insoluble mineral particles. It may be more useful to know the concentration of phosphorus that is actually available for growth. SRP better reflects bioavailability (Joy, 1994).