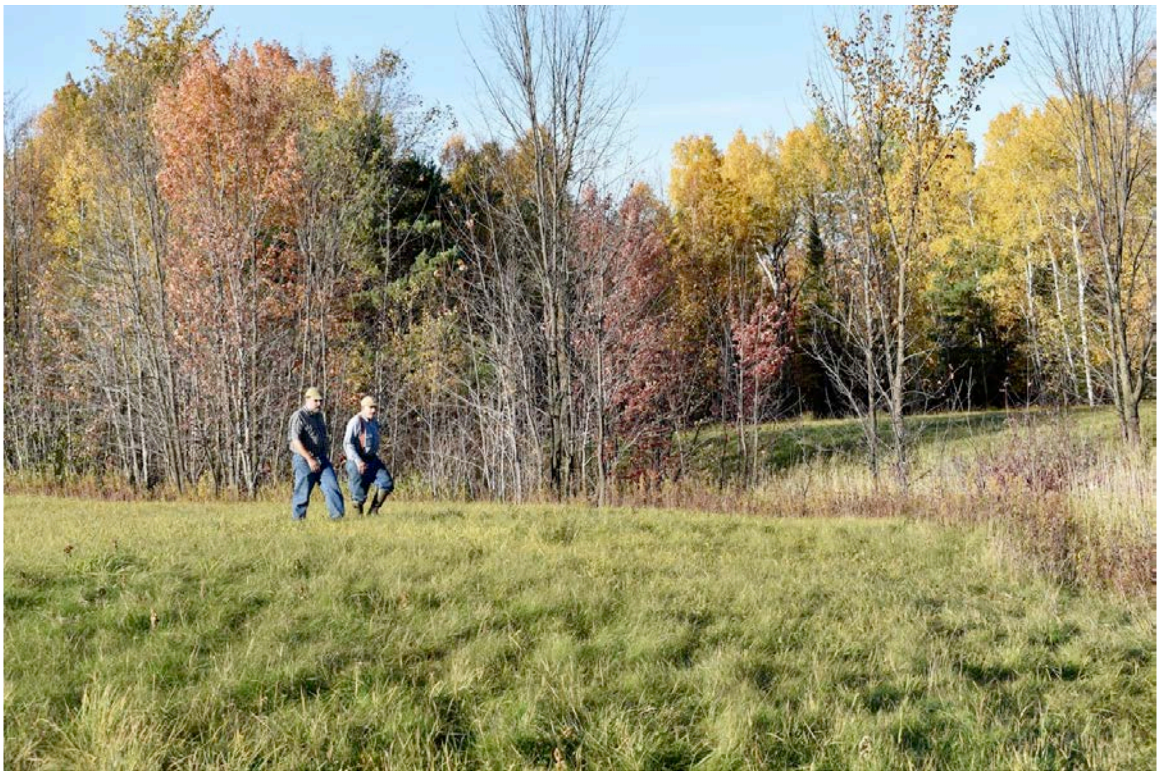
Exploring the Relationship between Wetlands and Flood Hazards in the Lake Superior Basin



Wisconsin Wetlands Association

June 2018

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The following individuals provided valuable feedback and support to this project including but not limited to sharing and helping interpret data and insights on how this inquiry relates to other local and regional research and initiatives:

- Ashland County Land and Water Conservation Department (Tom Fratt)
- Association of State Floodplain Managers (Alan Lulloff, Jeff Stone, Bill Brown)
- Bad River Tribal Natural Resources Department (Naomi Tillison, Jessica Strand, Ed Wiggins)
- Bayfield County Land and Water Conservation Department (Ben Dufford)
- Iron County Land and Water Conservation Department (Heather Palmquist)
- Natural Resources Conservation Service (Kent Peña)
- National Park Service – Great Lakes Network (Ulf Gafvert, Al Kirschbaum)
- Northwest Regional Planning Commission (Jason Laumann)
- St. Mary's of University of Minnesota Geospatial Services (Andy Robertson, Kevin Stark, Kevin Benck)
- Superior Rivers Watershed Association (Tony Janisch, Kevin Brewster)
- United States Environmental Protection Agency (Tom Hollenhorst)
- United States Forest Service (Dale Higgins)
- United States Geological Survey (Faith Fitzpatrick, Andrew Leaf)
- University of Wisconsin Sea Grant Institute (David Hart)
- Wisconsin Department of Administration (Jim Giglierano)
- Wisconsin Coastal Management Program (Kathleen Angel)
- Wisconsin Department of Natural Resources (Michele Wheeler, Tom Bernthal, Chris Smith)

Funding for this project was provided by the Wisconsin Coastal Management Program, and the National Oceanic & Atmospheric Administration, Office of Ocean and Coastal Resource Management under the Coastal Zone Management Act Grant # NA16NOS4190108.

WISCONSIN COASTAL MANAGEMENT PROGRAM

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1. Introduction

Project Background, Purpose, and Need

Wetlands are an integral part of Wisconsin's landscape. They are particularly abundant in the north, where the retreat of the glaciers scoured the land and established an extensive, interconnected, and interdependent network of wetlands and streams.

Figure 1. *Isolated wetlands like this lowland hardwood swamp reduce flood peaks by capturing and infiltrating runoff.*

In healthy watersheds, historic wetlands remain relatively intact and work in aggregate across the landscape to help manage water. The work these wetlands do depends largely on wetland type, location, and condition. For example, geographically isolated wetlands in upper watershed areas reduce runoff by capturing, storing, and infiltrating vast quantities of rain and snowmelt (Figure 1). Further downstream, when storms cause a river's banks to overflow, the water spreads out across riparian and floodplain wetlands where it is held and filtered before slowly returning to the river (Figure 2).

Figure 2. *Healthy floodplain wetlands reduce the energy of runoff events by allowing the stream to spread out and slow down during high flow events. Photo: Eric Epstein*

While it is conceptually understood that wetland loss through development and drainage can reduce water storage capacity and other protective water management functions that wetlands provide, specific examples of cause and effect are not well documented in Wisconsin. The questions of how land use practices and watershed condition further disrupt wetland functions, and how these disruptions influence storm response are also rarely considered.

Figure 3. *Road and culvert washouts were extensive and costly during the July 2016 storm.*

The purpose of this project was to explore the relationship between wetlands, land use, and storm related infrastructure damage in Bayfield, Ashland, and Iron counties, with a particular emphasis on how degraded watershed conditions and disruptions to wetland hydrology influenced damages associated with the July 2016 storms.

Between July 11-13, 2016, a foot or more of water dropped across a large portion of Wisconsin's Lake Superior Basin, causing more than $35 million in damage. Roads washed out, homes and businesses were inundated, and two lives were lost (Figure 3).

Short-term project goals were to:

- Develop and test an approach to document the relationships between intact and disrupted wetland hydrology and storm response;
- Produce and share vignettes that illustrate and explain these relationships;
- Identify improvements in data and decision support tools that are needed to support broader consideration and implementation of wetland practices.

The purpose of this report is to document project needs, methods, findings, and recommendations for future work. It concludes the first phase of a longer-term effort to help northern Wisconsin communities identify and implement wetland and stream restoration practices to reduce flood risks and improve water quality and watershed health.

Lake Superior Basin Conditions and Hazards

The initial Area of Interest (AOI) for this project included Wisconsin's Lake Superior Basin (Figure 4), primarily portions of the Bad River Watershed and the Marengo River Subwatershed, which are believed to be among the largest U.S. based contributors of sediment to Lake Superior.

Figure 4. *Wisconsin's Lake Superior Basin, shown here in blue.*

The characteristics of the larger Lake Superior Basin (LSB) are well studied and well documented (Stable Solutions, 2007; The Lake Superior Partnership, 2016). Surface and gully erosion, channel incision, bank slumping, and other instabilities are common across the region. These conditions are a response to geologic landscape features and historic and current land use practices.

For example, a natural mosaic of poorly and erratically drained clay-rich soils, glacially deposited sands and sediments, steep-gradient stream networks, and other features contribute to a flashy, erosion-prone landscape.

Land clearing that began in the late 1800s, land conversions and ditching to support agricultural, forestry, and urban uses, and the construction of roads and other impervious surfaces often accelerate and occasionally impede the velocity and volume of water that flows downstream.

This combination of a fragile landscape and widespread land use conversion diminishes the capacity of the region's wetlands to manage water in two distinct ways:

- **Direct loss of storage through wetland development and agricultural drainage –** These activities employ ditches and tiles to intentionally redirect water away from naturally occurring wetlands and discharge it to downstream waters or man-made stormwater ponds.

- **Indirect loss of storage through erosion-induced wetland drainage and floodplain disconnection –** Incised channels are a major cause of local floodplain and wetland deterioration. Channel incision accelerates surface and sub-surface flows into lower-elevation channels causing adjacent wetlands to be fully or partially drained. In cases where wetlands are adjacent to a stream, the incision can also result in a situation where the waterway can no longer interact with the former floodplain (Figure 5).

Figure 5. *A wetland complex (upper left) is partially drained and substantially disconnected from the stream due to channel incision.*

Common processes causing erosion-induced wetland drainage include but are not limited to:

- Downcutting – incision from too much water in a constricted channel;
- Headcutting – incision upslope from pinch points such as culverts, bridges, and roads (Figure 6);
- Gully formation - incision from accelerated runoff and erratic groundwater flows through unstable soils.

Figure 6. *Headcutting is developing upslope from an undersized culvert, threatening to drain adjacent wetlands.*

The direct and indirect loss of wetland storage is widespread across Wisconsin's LSB. It makes the system "flashy" by increasing the volume and velocity of water that moves downstream during storm events. This further exacerbates channel erosion, incision, and flooding, creating a negative feedback loop that renders the natural and built environments in the LSB less capable of handling rain and snowmelt with each passing storm.

Integration with Local Priorities

Two distinct but separate groups are heavily invested in understanding and responding to the water management challenges associated with excessive runoff and flooding in Wisconsin's LSB:

1. For decades, local **Natural Resource Managers** in the LSB have coordinated their watershed conservation activities under a strategy to "slow the flow." The goal is to address problems associated with rapid runoff (i.e., soil loss, erosion, and the delivery of sediment and nutrients to Lake Superior) by installing practices to slow the movement of water.

2. Emergency Managers and Transportation Engineers help local governments with the design, maintenance, repair, and replacement of storm damaged public infrastructure, particularly roads, bridges, and culverts.

While both groups recognize the connections between loss of wetland storage and accelerated runoff, installation of wetland practices that "slow the flow" have not yet been an emphasis of their work. Many barriers exist (see Key Findings, p. 10).

2. Project Methods

Our methods for exploring the relationship between 2016 flood damages and wetland conditions in Wisconsin's LSB consisted of the following steps:

Step 1: Establish a Preliminary Area of Interest

A preliminary Area of Interest (AOI) was established to include the HUC 12 subwatersheds (HUC 12s) that received between 8-9 inches of rainfall on July 12, 2016, or 12-15 inches over the course of entire storm (based on precipitation contours provided by a U.S. Forest Service hydrologist and derived from National Weather Service data).

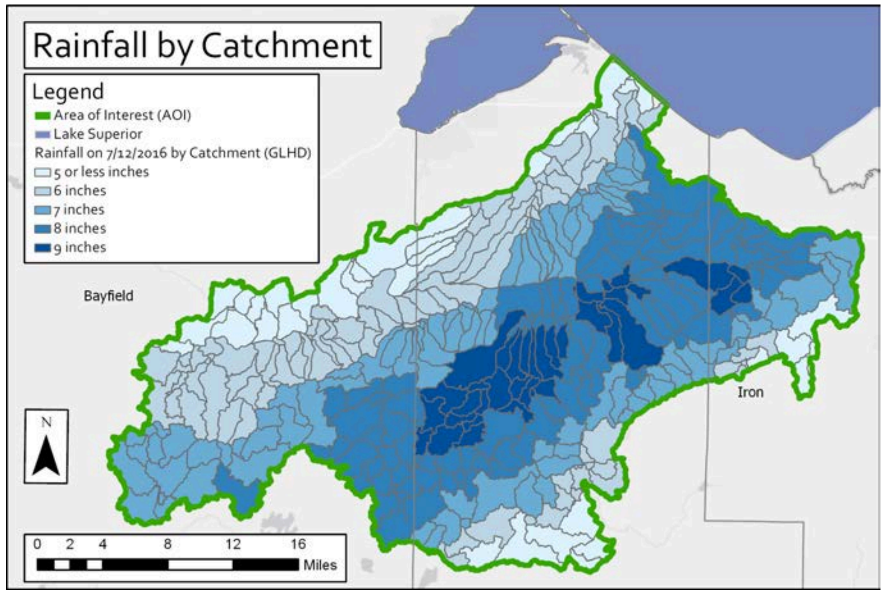

Figure 7. *Preliminary Area of Interest.*

This area was further refined to exclude subwatersheds outside of the LSB and include HUC 12s that serve as headwaters to the subwatersheds that remained.

This resulted in an area larger than what we had capacity to explore so we used the Great Lakes Hydrography Dataset to further narrow the scope of our analysis. These catchments are comparable to the HUC 14 subwatersheds produced by USGS in the National Hydrography Dataset. Figure 7 shows the preliminary AOI.

Step 2: Collect and Create Data

Infrastructure damages:
To explore the relationship between wetland condition and flood damage, we needed the locations of damaged infrastructure. A comprehensive geodataset was not available, so we iteratively created our own from the following sources:

- Story maps produced by Wisconsin Emergency Management (WEM) and counties showing the locations of road closures.
- Partial inventories of damaged culverts in the Marengo and Bad River Watersheds completed by the Superior Rivers Watershed Association (SRWA) and the Bad River Tribal Natural Resources Department.

- A WEM shapefile showing points for damages repaired with federal and state disaster declaration funds.

Figure 8 depicts the aggregated damage data points. Though this compilation is incomplete, it reasonably represents the extent of the damage. This assumption was validated in part through discussions with local stakeholders.

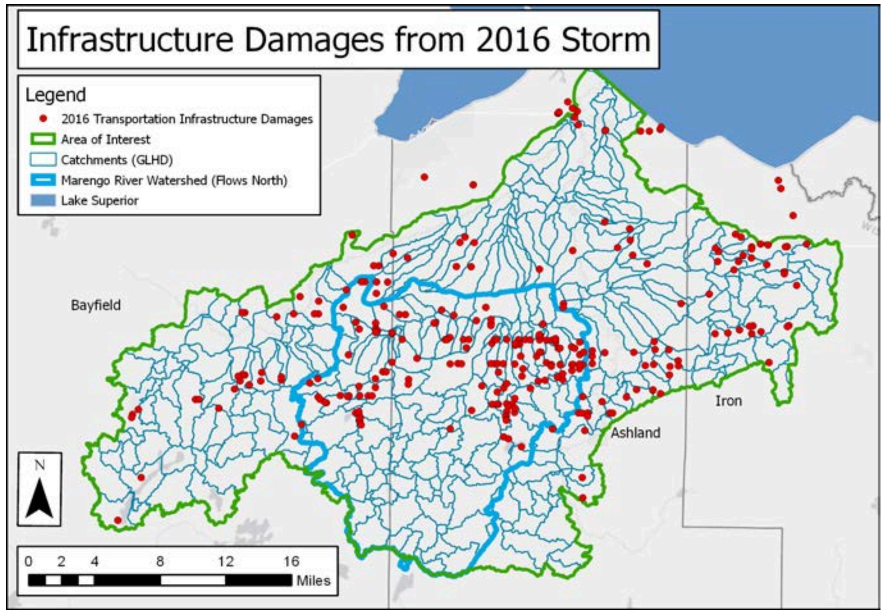

Figure 8. *Infrastructure damages across Area of Interest and Marengo River Watershed.*

Landscape Features

We consulted with local partners to identify, obtain, and import a variety of relevant land cover/landscape feature data sets, with a particular emphasis on wetlands, soils, and landscape features identified by local experts as being correlated with accelerated erosion, sedimentation, and culvert damage (Wheeler et al., 2014; K. Brewster, personal communication, May 11, 2017).

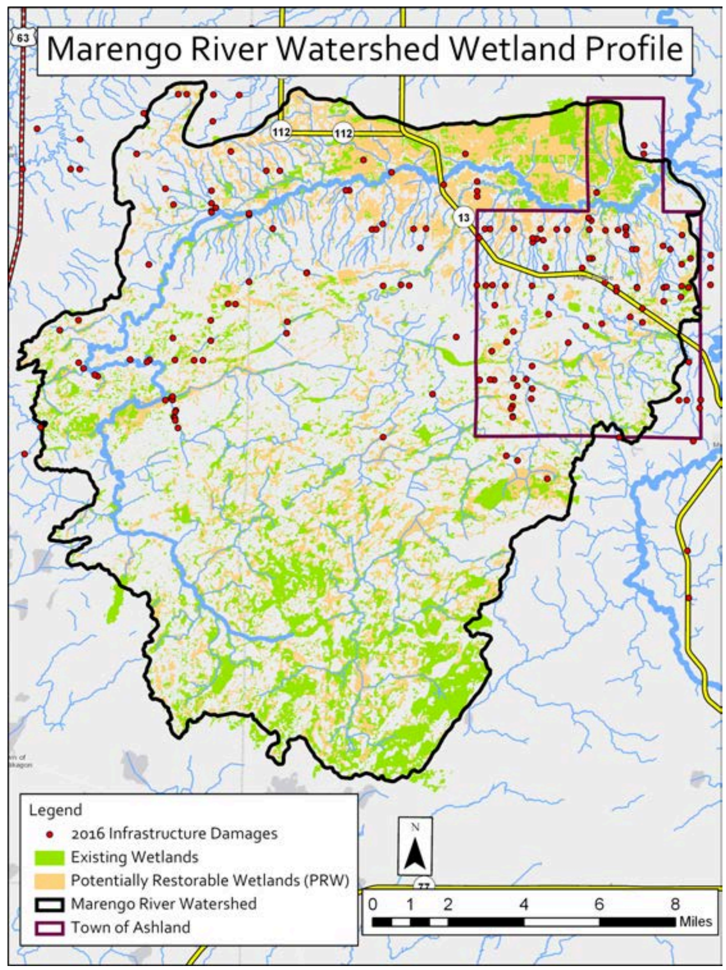

Figure 9. *Wetlands, potentially restorable wetlands – combined WDNR and St. Mary's GSS geodatasets – and infrastructure damage in the Marengo River Watershed.*

Data sources included:

a. Open Lands (Verry 2009).

b. Wiscland2 Land Cover Data (2016).

c. "Slow the flow" priority catchments identified by the Lake Superior Landscape Restoration Partnership (LSLRP) Slow the Flow Team (2014).

d. NRCS SSURGO soils database maps – emphasizing erosion-prone areas in the red clay plain and soil transition zone.

e. Wisconsin Wetland Inventory maps (WDNR).

f. Potentially restorable wetlands (PRW) maps (WDNR 2016).

g. Data produced by St. Mary's University Geospatial Services (St. Mary's GSS) and published as part of the *Wetland Functional Assessment and Wetland*

Restoration Prioritization Framework, Marengo River Watershed, Wisconsin (Benck 2017).

Relevant St. Mary's GSS products included:

i. Wetland Functional Assessment (WFA) of mapped wetlands with an emphasis on areas that ranked high or moderate for surface water detention, sediment retention, and shoreline stabilization.

ii. A potentially restorable wetlands geodataset developed using protocols that improved the identification of potential wetlands in clay soils, agricultural drainage features, and other metrics to best represent local conditions (Stark and Robertson 2013, Benck 2017).

iii. A Stream Power Index (SPI) to help identify stream segments that may be erosive and unstable due to high-energy peak flows.

iv. Synthetic drainage networks depicting drainage ditches, drainage paths, swales, and ephemeral streams that convey water into mapped stream networks.

Step 3: Data Synthesis

The geodatasets described above were combined and reviewed in various configurations to narrow our AOI for field reconnaissance. Working on the assumption that we would see a strong relationship between wetland loss and infrastructure damage, our goal was to identify and explore catchments with high densities of *known* road and culvert washouts and mapped PRWs.

This exercise led us to focus on the lower or northern portion of the Marengo River Watershed which included a heavy concentration of washouts along U.S. Highway 13 and County Highway C in the Town of Ashland, and large concentrations of PRWs directly north and south of the river.

This area also overlapped with catchments identified as high priority by the Lake Superior Landscape Restoration Partnership, based on sensitive landscape features known to contribute to erosion and sedimentation (Figure 10).

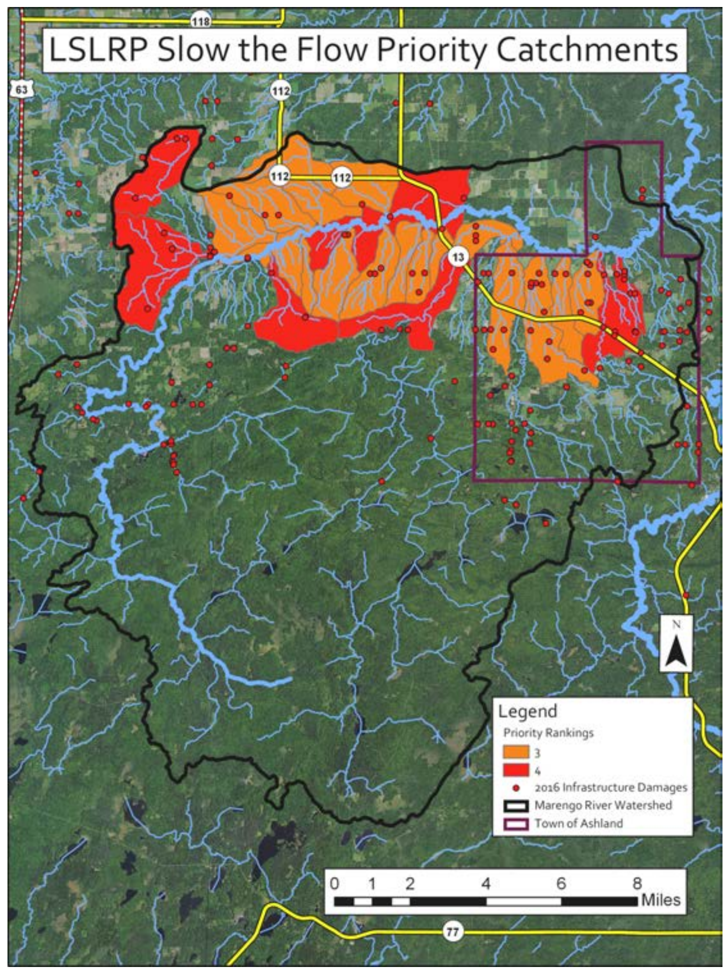

Figure 10. *Infrastructure damages in priority catchments identified by the Lake Superior Landscape Restoration Partnership. Priorities were scored 3 – 4 points based on the catchment's flashiness, position upstream of the red clay plain, and prevalence of open lands.*

Catchments located within the Town of Ashland were of particular interest due to the extensive culvert washouts and amount of wetlands and PRWs upstream of the flood damages (Figures 9 & 10).

Step 4: Field Observations

Information on other landscape features such as transitional soils and topography helped us further formulate ideas on how wetland hydrologic alteration across a range of conditions may affect stormwater flow and influence downstream flood damages. With these ideas in mind, we began our field observations in and upstream of the priority areas depicted in Figure 10.

A combination of field observations and local interviews were used to confirm and better understand observations from the spatial analysis and to identify landscape conditions to highlight in case-study vignettes. This exploration included:

- Watershed tours to observe wetland and waterway conditions at damaged sites.
- Site visits to select properties to observe stream network conditions, the extent and condition of wetlands and PRWs, stream-wetland interactions, and evidence of their potential relationship to nearby flood damages.
- Interviews with local officials and roads maintenance staff in the Town of Ashland, where 2016 damage was extensive and repetitive losses have been common for many years.

3. Key Findings

Our key findings about the relationships between wetlands and flood hazards in the Wisconsin's LSB are best characterized through descriptions of what we observed in the field. We identified several sites in the Town of Ashland, Ashland County, that illustrate how degraded wetland conditions contribute to storm-related infrastructure damages across the basin. For contrast, we also identified and described examples of areas elsewhere in the region where healthier wetlands and better infrastructure design have helped to reduce infrastructure vulnerabilities.

We conclude with a discussion about barriers to evaluating the relationships between wetland conditions and storm response, and barriers to implementation of wetland practices that can reduce flood peaks and help achieve slow the flow goals.

Key Finding #1: Healthy wetlands contribute to resilient watersheds

The best of what's left

Bibon Swamp is Bayfield County's largest wetland complex (10,000+ acres). It is fed by groundwater, the meandering White River, and a number of other small streams and tributaries that flow through the red clay plain. Its lack of roads make it a rare example of how a relatively undisturbed wetland landscape helps manage water in severe storms.

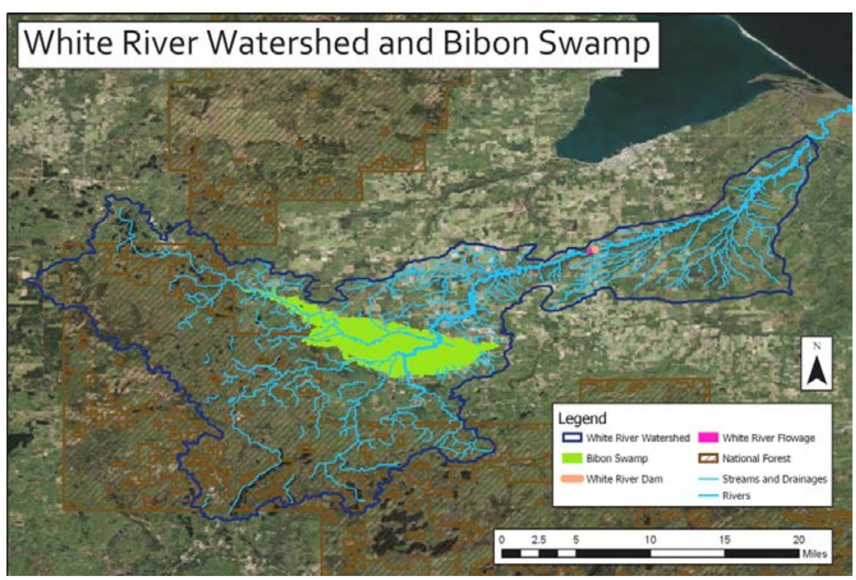

Figure 11. *The healthy wetland complex – Bibon Swamp – may have saved the downstream White River Dam because of its tremendous capacity to store and slowly release water.*

During the July 2016 storm, Bibon Swamp played a key role in managing floodwaters by capturing and retaining large volumes of rainfall and runoff. Water levels in Bibon initially rose almost six feet and excessive flows were slowly released over the course of a week after the storm (Fitzpatrick et al., 2017).

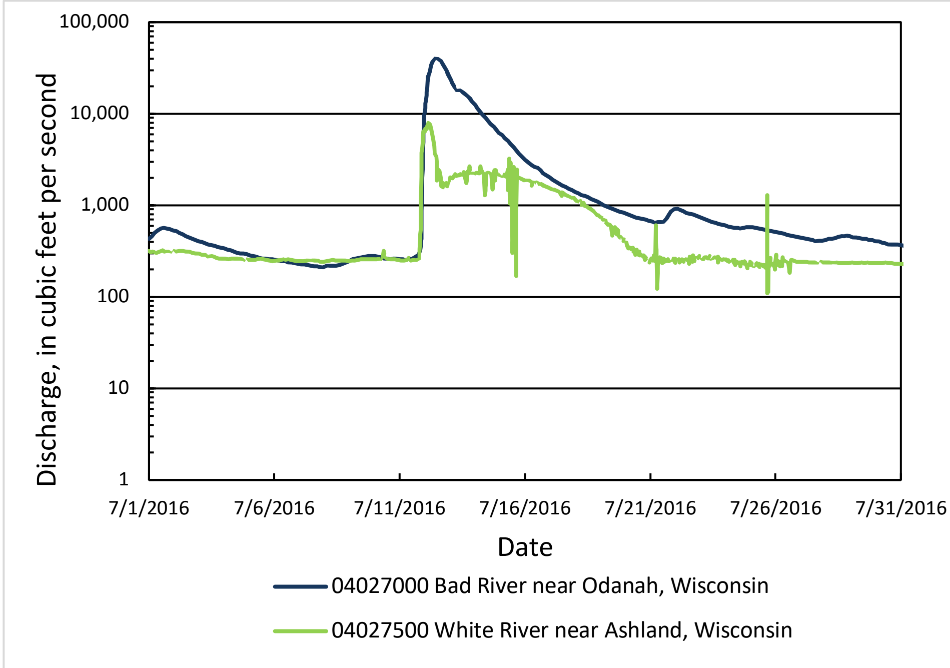

Figure 12. *Without the storage provided by Bibon Swamp, the White River hydrograph would have had a much higher flood peak on July 12, 2016, and a rapid release of higher-energy, post-peak flows after rainfall ended. Adapted from: Fitzpatrick et al., 2017, p. 10.*

This prolonged retention period was evident in the hydrograph for the White River, which was a substantially smoother hydrograph compared to the high-energy flood peak recorded in the Bad River Watershed – a larger hydrologic system with similar characteristics (Figure 12).

The USGS gaging station located below Bibon Swamp in part confirms that the healthy wetland complex reduced the flood peak in the White River Watershed. Roads were still inundated, but not washed out, with minor scouring that led to shorter-term closures and relatively affordable repairs. Locals speculate that without the storage provided by Bibon Swamp, the White River hydroelectric dam four miles downstream may have failed, with catastrophic consequences to downstream communities (Figures 11 and 12).

Key Finding #2: Erosion-induced wetland drainage substantially contributes to downstream infrastructure vulnerabilities.

In this project, we learned of many situations where channel incision, gully formation, and headcutting are threatening the resilience of watersheds in the LSB. We provide a case study of the Town of Ashland to explain the relationship of altered wetland hydrology and infrastructure vulnerabilities. The Town contains multiple catchments prioritized for restoration actions

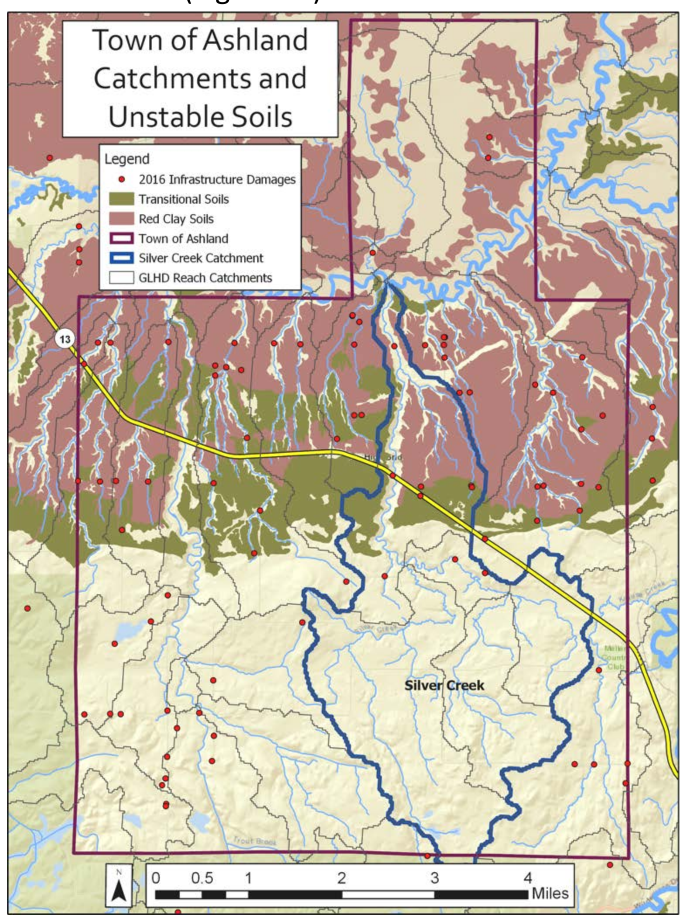

Figure 13. *Erosion-prone areas, including the soil transition zone and red clay plain, in the Town of Ashland.*

(Figure 10, p. 8). As shown on Figure 13, the infrastructure damages from 2016 storm were common in these erosion-prone areas – including the transitional soils, which are a blend of sand and clay, and the more uniform red clay plain.

Town of Ashland: Small Community, Big Problems

The Town of Ashland is a small community of approximately 600 residents located south of Lake Superior, in Ashland County and the Marengo River Watershed. The Town was hard hit by the July 2016 storm, with more than a half-million dollars in damage to local infrastructure, culverts, and roads – an amount twice as large as the Town's limited annual budget. Though the 2016 storm was particularly severe, storm-related damages are common for the Town. Infrastructure maintenance and repair consumes nearly 75% of the Town's budget each year.

When roads, culverts, and bridges wash out, there is never just one reason. To understand infrastructure vulnerabilities and reduce repetitive damages, it is important to evaluate where the water is coming from and the condition of the whole hydrologic system.

We do that here with two Vignettes (Figure 14) in the Town of Ashland that describe degraded and rapidly deteriorating conditions of the northeastern-most tributary to Silver Creek, starting in the upper portions (Vignette #1) and moving downstream (Vignette #2).

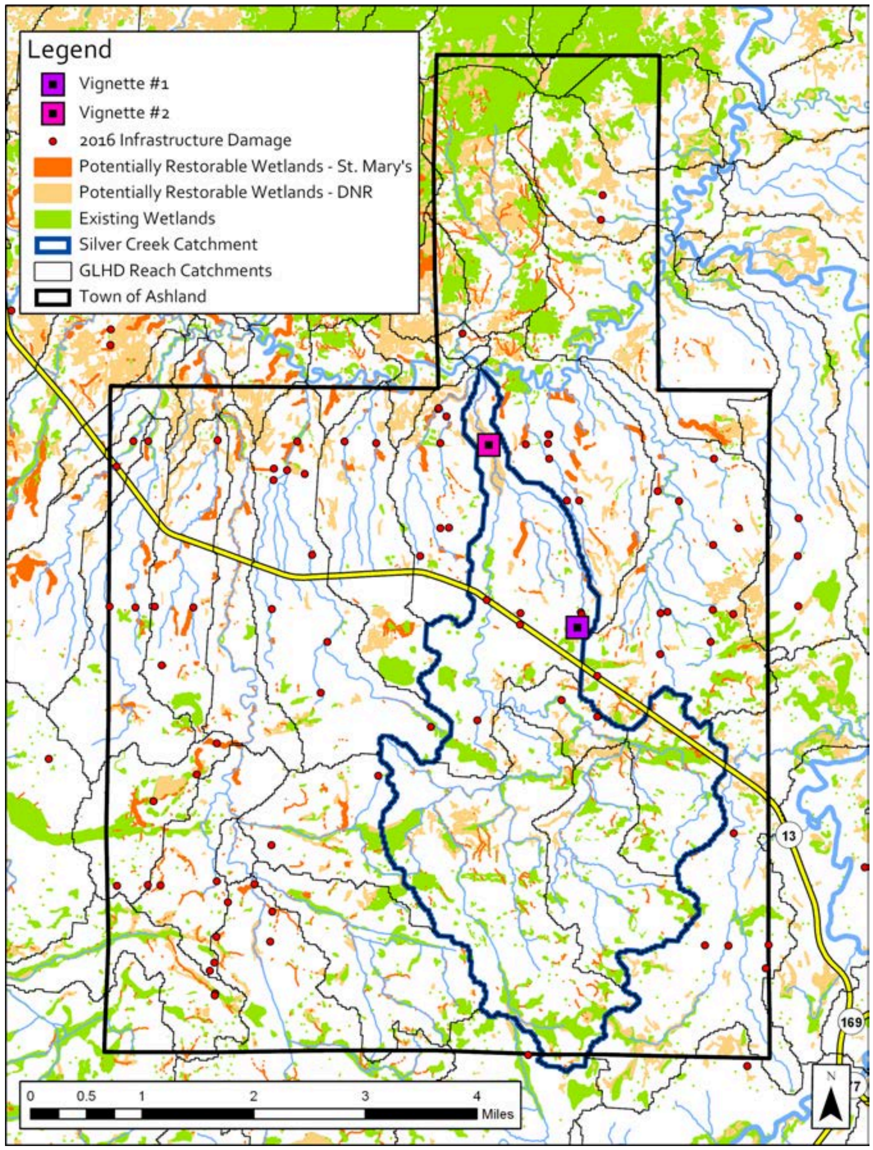

Figure 14. *Location of featured vulnerable sites (i.e., Vignettes) in the Silver Creek Watershed and the extent of mapped wetlands and potentially restorable wetlands.*

Vignette #1: Upper Reach Wetlands and Implications of Erosion-Induced Drainage

A large wetland complex serves as the headwaters to an unnamed tributary to Silver Creek (Figure 15). This parcel provides numerous ecological functions and provides a tremendous amount of storage. Rain and snowmelt is held and slowly infiltrated. Until recently, any water running off the property was minimal, low energy, and dispersed through overland flow (Figure 16).

This parcel also supports a productive cattle grazing operation, with the water stored by the wetlands helping to produce abundant forage and the tree canopy offering shade for the cattle.

Figure 15. *An intact upper watershed wetland complex. Portions are grazed and hayed.*

Figure 16. *The wetland complex has historically been drained by low-energy channels that help to control runoff.*

Just down gradient, a headcut had been incrementally progressing upslope from an undersized culvert at Coria Road. Runoff from the 2016 storm alone accelerated this erosion, deepened the existing channel, and advanced the headcut to where it finally reached and carved a channel into the wetland (Figure 17 and 18). The culvert also washed out by the end of the storm.

Post-storm, the channel is now accelerating surface and sub-surface flows out of the wetland complex (Figure 17). The farmer has observed sustained flows in the channel and drier conditions in the adjacent wetland complex.

Figure 17. *An incised channel is developing at an outlet of the wetland complex in response to the 2016 storm.*

Figure 18. *Gully formation threatens to drain the upslope wetlands and worsen downstream conditions.*

Left unaddressed, the incised channel will continue developing into the wetland complex. The loss of wetland storage combined with the progressively deepening channel incrementally increases the volume and velocity of water flowing downstream in storm events. This will exacerbate the already degraded downstream conditions and vulnerable infrastructure (See Vignette #2 below).

While this example highlights a single disturbance in progress, these kinds of erosion-processes have been ongoing across the Lake Superior Basin since the extensive land conversions in the late 1800s. Untold acres of upper watershed wetlands have been already drained by erosion-induced channel development.

While there have been no published studies to *quantify* how this loss of wetland storage affects peak flows or increases flood damages, a recent hydrologic assessment by Chequamegon National Forest personnel found evidence of a strong relationship between upper watershed storage, including wetlands, and reduction of peak flows and damages at downstream culverts in the same catchments (D. Higgins, personal communication, May 10, 2017). Additional studies are needed.

Vignette #2: Downstream Consequences of Upper Reach Wetland Alterations

The conditions described in Vignette 1 tend to occur at multiple locations within a stream network. As upper watershed storage decreases and the volume and energy of flow increases, it contributes to additional erosion downstream. When higher order (i.e., larger) streams become incised, two things happen:

- The channel drops beneath the adjacent wetlands and begins to act like a drain;
- The stream can no longer interact with its floodplain during all but the largest runoff events.

In other words, *more* watershed storage is lost and the ability of floodplain wetlands to receive water and sediment and slow the flow is also reduced. These incised conditions are common across Wisconsin's LSB, including long stretches of the unnamed tributary downstream of the site described in Vignette #1.

Figure 19. *This misaligned and undersized culvert is vulnerable due to upper watershed hydrologic disturbances.*

This brings us to a vulnerable culvert at Delafield Road just below the confluence of this unnamed tributary and Silver Creek (Figure 19). This culvert and the associated road repeatedly wash out during storms events. In addition to the upstream conditions described above, several site-specific factors contribute to this instability.

For example, the floodplain just above the culvert is disconnected by in-stream channel incision, preventing flood flows from spreading out across the floodplain. Natural stream system features such as meanders, oxbows, and anabranches that help water take the path of least resistance are not forming, or available, to manage flows.

The built-up, higher-elevation road also acts like a dam. Flood flows back up behind it, placing a tremendous amount of pressure on the road itself. The adjacent streambanks and road fill are scouring away since flows are forced to take a sharp turn into the misaligned culvert. Because channel migration is accelerated in streams disconnected from their floodplains, repetitive road and culvert failure will remain highly probable until infrastructure is aligned appropriately and designed to improve stream-floodplain connectivity.

These types of misalignments and undersized infrastructure are common across the region. Note that upstream, where flows are less on Silver Creek, a large girder bridge was constructed to replace former undersized culverts that washed out on U.S. Highway 13.

Alternative Approach: Designing Roads to Maintain Floodplain Functions

Northeast of the Town of Ashland, a long stretch of U.S. Highway 2 emerged from the 2016 storms with minimal infrastructure failures in Ashland County and the Bad River Reservation. Damages were limited to minor scouring and washouts of pavement and road fill. This was remarkable given that the highway crosses the Bad River lower in the watershed, in a high-flow area just above the mouth and within range of the Lake Superior storm surge.

Upstream from U.S. Highway 2, the Bad River has a more intact floodplain than many other local waters – so runoff was able to spread out and slow down as flows migrated downstream. Also, unlike the Delafield Road site (Vignette #2, p. 14), U.S. Highway 2 is a low-lying road that acts like a spillway in allowing flood flows to overtop the road surface across much of the corridor.

When flood flows became too much for existing culverts and bridges to handle, the flows easily overtopped the road surface and were readily absorbed by wetlands surrounding the highway. The storm surge from Lake Superior itself was also buffered by the Kakagon and Bad River Sloughs, a large wetland complex at the mouth of the Bad River.

This combination of intact floodplain and wetland functions upstream and downstream of the highway, and good road design, renders much of this U.S. Highway 2 corridor notably more resilient than other local roads, culverts, and bridges.

Figure 20. *The low-lying elevation of U.S. Highway 2 and intact floodplain allowed flood flows to spread out and overtop the road without causing major damage. Photo: WI Emergency Management*

Key Finding #3: Wetland restoration opportunities are abundant, but not widely used. Demonstration projects are needed to encourage implementation.

Though we observed extensive erosion-induced wetland drainage upstream from mapped 2016 infrastructure damages, we found limited awareness of how watershed-scale wetland storage could be restored to slow the flow and help protect vulnerable infrastructure in future storms. Additionally, we did not learn of any prior community-led examples of where wetland hydrology was restored to improve the resilience of their infrastructure systems. Reliance solely on site-specific structural approaches to water management has left the Town of Ashland, and many communities in the Lake Superior Basin, perpetually vulnerable to extreme weather.

Most of the storm response activities we observed were focused on reinforcing or upsizing infrastructure where damage occurred. This is important work during emergency recovery efforts; however, this typical response only addresses the stormwater management needs at specific road crossings and does not factor in where and how storage areas may be underperforming upstream (i.e., wetlands). Proactive investments are needed in developing the types of practical, cost-effective Slow the Flow (STF) wetland practices that can increase watershed storage, reduce flood risks, and protect vulnerable infrastructure. Watershed-scale planning that is informed by the best available geodatasets and field investigations can help identify where these STF wetland practices may be most needed.

With ample opportunity, but no proven examples, demonstration projects are needed to show and quantify the benefits of various STF wetland practices. Demonstration projects can be guided by and build upon an emerging body of research quantifying how wetlands can reduce flood damages and costs (e.g., Narayan et al., 2017; Watson et al., 2016).

Ideally, these wetland demonstration projects would be designed to accomplish all of the following:

- Improve community understanding of how upper watershed wetland condition relates to erosion, sedimentation, and flood risks;
- Quantify the hydrologic and economic benefits of various wetland restoration practices;
- Advance professional knowledge about how and where integration of wetland practices could help address local resource and emergency management needs;
- Increase landowner interest and local investments in wetlands restoration.

Installed practices will vary depending upon the specific water management need. They can also be tailored to address landowner preferences and meet multiple objectives. Examples of the types wetland practices that could be evaluated and promoted through demonstration projects include but are not limited to:

- Grade stabilization to arrest erosion and reverse drainage near headwaters, with target flow reduction goals in mind.
- In-stream grade-stabilization immediately up and down slope from culverts to help raise stream beds and reconnect channels to their historic floodplains (Figure 20).
- Improved stormwater passage at sites where roads intersect and/or alter floodplain connectivity.
- Engineered structures to divert upper watershed runoff into off-channel areas that could revert to wetlands or be enhanced by flood pulses.

Figure 21. *In-stream grade stabilization structures, such as this one installed downstream of a culvert on the Chequamegon National Forest, can help to reconnect surface water with upstream riparian and floodplain wetlands.*

- On-farm water management to *selectively* re-wet upper watershed agricultural lands to increase storage and optimize grazing and haying conditions.

Potential Applications of STF Wetland Practices

Culvert Design and In-Channel Grade Stabilization

A perched and undersized culvert (left) obstructs flows into riparian wetlands (right) along an upper watershed stream network. Flows currently seep under the road fill and inconsistently provide pulses that promote healthy hydrology and vegetation conditions. During future road repairs, grade stabilization, improved stormwater passage, and engineered structures could help divert flows into drier portions of the larger wetland complex and stimulate further wetland generation (i.e., providing more storage).

On-farm Water Management

A productive hay field (left) has begun to drain due to gully erosion (right). Efforts to armor the channel with rock have not arrested the headcutting in the gully/ravine system. Grade stabilization and a water control structure could help lift the gully to grade and hold more water on the fields during snowmelt, spring rainfall, or when runoff is highest and hay production will not be harmed. These practices maintain land productivity and would also match well within a grazing operation.

Key Finding #4: Existing data sets underrepresent historic wetland acreage and do not depict the full extent of disrupted wetland functions.

Though we began our field observations with tours of areas that had large amounts of mapped potentially restorable wetlands (PRW) upstream of damaged infrastructure, the maps told only a small part of the story. Here's why:

In general, maps tend to underrepresent wetland acreages. This is due to limitations in remote sensing data and methods, including aerial photo interpretation and the time of year when photos were taken, and how much field verification was conducted.

PRW geodatasets are informed by remotely sensed data and tend to depict larger areas of potential wetland restoration opportunities in agricultural landscapes. They were developed to predict where wetlands were once located based on data inputs such as the location of ditch and tile networks and areas where flows accumulate and wetland soils or other wetland characteristics are likely present.

PRW geodatasets are less reliable in detecting restoration opportunities in the forested, clay-rich, and steep-gradient catchments common in Wisconsin's LSB. In the clay-rich soils it is very difficult for PRW mapping methodologies to differentiate between upland and wetlands soils and certain vegetation types. PRW mapping methodologies were also not designed to detect historic wetlands that may have eroded or been destroyed during the large-scale land conversions decades ago. These historic areas, especially in upper watersheds and along smaller stream networks, may now contain different soil types and features that are not readily detected by *current* PRW methodologies.

Finally, and perhaps most importantly, none of the wetland geodatasets that we worked with (see Methods, p. 7) were designed to help identify areas with erosion-induced wetland drainage. Consequently, these areas were undervalued in a recent assessment designed to rank and prioritize opportunities to improve wetland functions, including storage and retention (Benck, 2017).

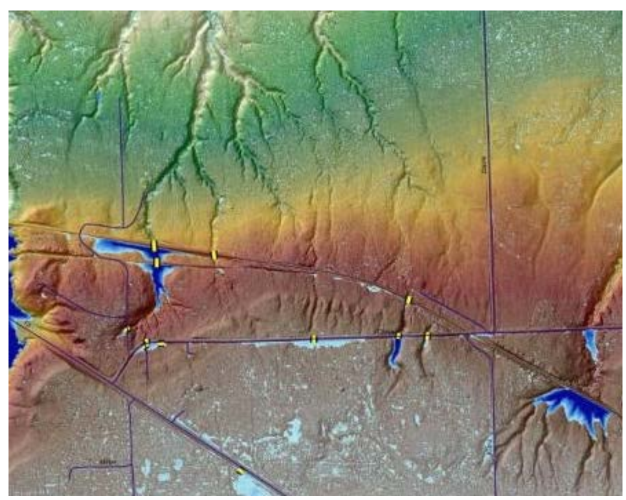

Figure 22. *New tools and better elevation data make it easier to identify areas where channel incision and infrastructure alter wetland hydrology.*

Given these constraints, extensive field investigation was needed to evaluate the extent of wetland loss and erosion-induced wetland drainage in upper watershed and floodplain situations. As is always the case, field investigations are critical for developing informed observations on the relationship(s) between degraded conditions and infrastructure vulnerabilities.

Though field reconnaissance and local knowledge will always be an essential part of efforts to identify strategic wetland restoration opportunities, better data and decision-support tools are also needed. Integrated stream and wetland assessments could help produce data that helps identify degraded upper reach wetlands. As shown in Figure 22, existing LiDAR products and hydrologic modeling tools could also be used to identify areas degraded by headcutting and channel incision, as well as where wetland hydrology is disrupted by road systems.

Development and use of improved data and decision support tools, along with the previously recommended demonstration projects, will go a long way towards improving understanding of wetland conditions across Wisconsin's LSB and improving implementation of STF wetland practices to improve the resilience of local watersheds.

4. Next Steps

This exploration of the relationship between wetlands and flood hazards in Wisconsin's Lake Superior Basin was the first step in a larger effort to help northern Wisconsin communities identify and implement wetland and stream restoration practices to reduce flood risks and improve water quality and watershed health.

As discussed above, a number of barriers hinder communities' capacity to invest in wetland practices, first and foremost that the connections between upper watershed wetland condition and downstream infrastructure vulnerabilities are not commonly understood, nor well-studied. Data deficiencies, a lack of demonstration sites, and limited access to trainings on the design and implementation of wetland practices also contribute.

Our goals in the next phase of this project are to use outreach, education, and training to begin to address these barriers. Activities will include, but not be limited to:

1. Synthesize, build upon, and export findings from this report to key audiences such as: local elected officials; town and county conservation staff, emergency managers, transportation engineers, and their contractors; natural resources professionals working to address Lake Superior Basin water management concerns; and local wetland landowners.
2. Promote the benefits and opportunities associated with implementation of Slow the Flow (STF) wetland practices.
3. Explore and support opportunities to identify, plan, and implement STF wetland practice demonstration projects.
4. Help build local capacity to identify, prioritize, plan, and implement STF wetland practices.

Questions about the findings in this report or next steps should be directed to

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