Review and Recommendations for Slow the Flow Practices in Wisconsin's Lake Superior Basin

"Shore Bubbles" by Bill Carroll 2014 Great Lakes Photo Contest

Office of Great Waters -- Northern Region
Wisconsin Department of Natural Resources
In Collaboration with USEPA, UW-Ext,
and the Wisconsin Wetlands Association

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In Memory of Michele Wheeler

(1974 – 2020)

This report was conceived and largely written by Michele Wheeler, our colleague, mentor, and friend. Michele was passionate about protecting the Great Lakes and waterways of Northern Wisconsin, and dedicated her life to it for many years, as a fish biologist for the Great Lakes Fish and Wildlife Commission, a fisheries biologist for the Fish and Wildlife Service, the Executive Director for the Bad River Watershed Association, and as the Lake Superior Program Coordinator for the Lakewide Action & Management Plan (LAMP) for the Wisconsin Department of Natural Resources (WDNR). Besides being an exceptional biologist, Michele had extraordinary skills in listening, bringing stakeholders together, and making everyone feel like an equal partner. She was a real listener and had a talent for balancing diverse perspectives and finding common ground. We looked forward to meetings with Michele because of the energy she brought to her work. Michele made any day in the field feel like a fun adventure. She lived by her motto, "Work hard, have fun, and be nice to someone that needs it." Everyone loved Michele for her big, fun, and caring heart. Michele passed away in 2020 after a nine-year battle with cancer, which she courageously shared with the world through her blog, *Crack in the Wall: Letting in Light on Hard Times,* and memoir, *The Throbbing Moon and the Three Season Tango*. She leaves behind an inspiring legacy of work to restore and protect Lake Superior and northern Wisconsin's streams and rivers. It has been an honor to complete this paper to help Michele's legacy live on through continued conservation efforts in the basin that she was so passionate about.

- The Coauthors

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Executive summary

Watersheds in the Wisconsin portion of the Lake Superior basin, specifically those in the red clay plains, are susceptible to degraded water quality from eroding stream banks, which can impact in-stream habitat and result in excessive nutrient loading (WDNR, 2007a). Watershed conservation efforts in the region that seek to improve water quality in streams and rivers have largely focused on restoring and protecting hydrology by "slowing the flow." Slow the flow (STF) practices seek to reduce peak flows with a watershed-scale hydrologic restoration approach that increases in-channel roughness and sinuosity, surface roughness, water storage in wetlands, and infiltration. Recent efforts have sought to improve implementation of slow the flow across jurisdictions, agencies, land use, and land ownership types, and to identify priorities for conservation efforts across the basin. This report summarizes an extensive literature overview to inform strategic slow the flow efforts in Wisconsin's portion of the Lake Superior basin. This report focuses on research, monitoring, and management publications covering this region, but also includes work in other areas with similar hydrology, land use, and soils.

This report falls within the context of a long history of stewardship of the landscape and many recent conservation initiatives. The Lake Superior basin in Wisconsin is the traditional, ancestral, and modern home of the Anishinaabe. The Anishinaabe have been stewards of this land for centuries. Through treaties, the Anishinaabe ceded most of the basin to the U.S. in the mid-1800s, retaining rights to forage, hunt, fish, and practice traditional lifeways. Today the Bad River and Red Cliff Bands of Lake Superior Chippewa manage reservations within the Wisconsin portion of the Lake Superior basin, and the Great Lakes Indian Fish and Wildlife Commission works to support treaty rights in the ceded territories. Tribal nations and agencies are crucial partners in the work to manage water quality in the basin.

European land use practices from the mid-1800s to the mid-1900s greatly altered the hydrologic regimes in the basin. In the last 50 years, there have been diverse efforts to address these issues through restoration. The goal of this report is to move towards establishing consistent conservation goals and priorities across the basin based on the best available knowledge, to assist STF practitioners in planning projects. While outside the focus of this report, hydrologic restoration also has important implications for nutrient enrichment, sediment contamination, fish and wildlife habitat, and biodiversity. This report will also help identify synergistic opportunities to address these concerns.

Report Overview

This report includes background on slow the flow efforts in the Lake Superior Basin, with a focus on bringing together scientific knowledge to form recommendations for best practices. The section titled *Recommendations* includes STF recommendations for each land type based on a literature review, a framework for a watershed-scale strategic approach, and a discussion of how that framework could be implemented. The report concludes with a discussion of future needs. In Appendix 2, readers can find an extensive literature summary that includes background information about the Lake Superior basin in Wisconsin, including an introduction to the geomorphology, land cover, climate, and hydrology of the basin. This appendix also includes an overview of the relevant scientific literature organized largely by landscape characteristics, including watershed storage (wetlands), surface roughness, forest cover, agricultural, urban, and rural residential lands. These sections provide context for the recommendations provided in the main section of the report. This paper was a part of the Lake Superior Collaborative symposium held on April 29th, 2022, where partners were able to provide feedback on recommendations as next steps. This information is captured in Appendix 1, to influence future planning efforts.

Watershed-scale strategic approach

We recommend a watershed-scale strategic approach to hydrologic restoration whereby priorities for hydrologic restoration are considered within the context of the larger basin so funding and efforts can be focused in subwatersheds and locations where they will have the greatest impacts. We propose a set of parameters and ranking criteria identified from our literature review that constitutes a framework to implement a watershed-scale STF approach. Where available, we identify basin-wide datasets that could be used to implement that framework and prioritize STF efforts in the basin. We also identify data gaps and newly available data that could improve the STF framework.

We recommend the following hierarchical parameters for ranking subwatersheds for STF efforts:

1. **Primary Criteria**
    1.1. percent storage by subwatershed, and
    1.2. peak discharge/subwatershed area ratio, and
    1.3. percent open land by subwatershed.
2. **Secondary Criteria**
    2.1. percent of total wetland area with surface water attenuation by subwatershed, and
    2.2. proportion of riparian area not mapped as wetland by subwatershed, and
    2.3. proportion of forested riparian areas of total riparian area by subwatershed
3. **Tertiary Considerations**
    3.1. locations of inactive farmland,
    3.2. transition zone and soil permeability,
    3.3. downstream coastal ecosystem or habitat type, and
    3.4. land ownership type.

A multicriteria decision matrix could be used to incorporate these multiple metrics to prioritize among watersheds and subwatersheds. Where available, we present the data to do that in the report. However, we also describe additional desktop and field assessments that are needed to develop a complete, holistic decision matrix for prioritizing STF work in the basin.

Recommended STF Actions

The following list summarizes the recommendations identified based on a review of primary literature and work completed by resource managers. These are described in more detail in the report and the literature review in the report appendix. The report was created with and on the behalf of a broad partnership and published by the Wisconsin DNR. Note that this document does not represent any legal requirements. Some local jurisdictions might have more restrictive recommendations/requirements than what are discussed here, check with your local laws and restrictions when considering the implementation of these practices.

Watershed Storage

- Target wetland restoration efforts to maximize an increase in overall watershed storage, including where wetlands can maximize storage and help desynchronize flows. (This needs to be considered carefully as artificially raising water elevations to provide more storage causes more harm than good).
- Use Height Above Nearest Drainage (HAND) analysis to identify priority floodplain wetlands for restoration and protection.
- Protect high-functioning watershed storage and hydrologic processes in existing wetlands and floodplains.
- Investigate potential opportunities to install wetlands, grassed waterways, and two-stage ditches in agricultural fields.
- Install multiple smaller projects in headwater areas, in parallel along multiple tributaries, for a greater cumulative increase in storage as opposed to restoring a large single site lower in the watershed.
- Design low-tech process-based restoration approaches (Wheaton et al., 2019).
- Design wetland restoration sites to include flow dispersal and grade control structures that enable natural water level fluctuations, rewetting degraded areas with flood pulses and excess flows, and reconnecting other wetland areas to the site and stream channel.

Agriculture

- Pursue opportunities to harness transitional agricultural areas to increase interception, infiltration, and retention.
- Incentivize STF flow practices and non-point source runoff trading.
- Implement best management practices on intensive farmlands.

Upland and In-Channel Roughness

- Map gully type and apply appropriate restoration actions for groundwater- or surface water-driven gullies.
- Implement in-channel work consistent with geomorphic studies, with a focus on low-tech solutions.

Urban and Rural Residential

- Identify and prioritize STF efforts upstream of urban centers that will reduce peak flows and flooding in developed areas.
- Implement bioretention and stormwater management approaches to help protect urban infrastructure.
- Continue assessments to identify and prioritize replacement or upgrades of road-stream crossings that have undersized culverts, are barriers to organism passage, or have eroding soils.

Forestry

- Implement existing guidelines for Forestry BMPs.
- Establish an open lands percentage threshold for hydrology and water quality protection, and establish standard, repeatable methods for assessing open lands by subwatershed.
- Clarify the delineation of the Riparian Management Zones (RMZs) to determine consistent standards for width and allowable practices in RMZs.
- Establish a consistent definition of unproductive steep slopes for private and public lands and promote BMPs at those sites.

Receiving Waters

- Prioritize STF efforts in watersheds that drain to poor fen coastal wetlands.

Next steps

The multiple land ownership types and land uses in the basin make watershed planning and management challenging. To move forward with our recommendations, we identified several needs. These include continued support and funding for the ongoing monitoring that has informed decisions to date, formal assessment of the effectiveness of past restoration projects and agricultural BMPs, funding for new and ongoing research to understand the impacts of climate change and invasive or nuisance species like emerald ash borer, and improved capacity for data management and sharing.

Also needed are high-resolution land cover, high-resolution hydrologically corrected elevation data (from LiDAR) and an accurate delineation of open lands data, all collected at regular intervals. A basin-wide map of historic and modern ditch networks would also help to inform the prioritization of wetland restoration. Although this report has focused on prioritizing hydrologic restoration, our review of existing knowledge emphasizes the importance of protecting current watershed storage. Efforts to protect high-functioning wetlands and landscapes should also be incorporated formally into any strategic approach.

Lastly, implementing a strategic effort to slow the flow and improve water quality across the basin will require not just maintenance of the many wide and effective partnerships in the basin, but a further broadening of partnerships across industries, disciplines, and agencies.

Introduction

Background

To protect tributary and Great Lake water quality and habitat for aquatic organisms, conservation must address land cover and land use practices in uplands and the headwater portions of watersheds. Without work to reduce overland flow and runoff, any downstream efforts to promote healthy fisheries and water quality will have limited results.

Watershed hydrology and streamflow are major determinants of the composition, structure, and dynamics of aquatic and riparian ecosystems (Poff and Ward, 1989, Richards et al., 2002, Seeger et al., 2004, Harman et al., 2012). A combination of climate, geology, and landscape-scale watershed conditions affect the volume, velocity, and timing of streamflow. Air temperature, humidity, topography, land cover, and soil composition determine rates of evaporation, infiltration, and runoff that influence streamflow response to precipitation events (USGS, 2016). Contributions of groundwater to streams influence baseflow characteristics between runoff events. Low flow and high flow events, along with the variability in flow regime across seasons and years define the hydrologic character of streams and rivers.

Hydrology, in turn, affects sediment erosion and transport, water quality, and in-stream habitat for a huge number of species (Fitzpatrick and Knox 2000, Carpenter et al., 1998, Detenbeck et al., 2003, Brazner et al., 2004, and others). Both resident and migratory fish species are affected by hydrology in Lake Superior streams. High sediment loads carried by floodwaters are deposited on streambeds, smothering spawning gravel and filling in deep pools favored by fish. In-stream sedimentation also limits macroinvertebrate production, a food source for many fish species (Henley et al., 2010). Seasonal hydrologic patterns trigger life history events for many species, with high flows in spring triggering spawning runs for many species like walleye and sturgeon, and low flow events encouraging organisms to seek adequate habitat and preferred temperatures (Poff et al., 1997).

Changes in land use and land cover affect hydrology. At the time of European contact, the Ojibwe people inhabited the region for centuries, with lifestyles and economies based on forest and wetland resources. Ojibwe land management practices helped shape the ecosystems of the region (Steen-Adams et al., 2011). Today, there are two reservations within the Wisconsin region of the Lake Superior Chippewa reservations in the basin, the Bad River Reservation east of Chequamegon Bay, and the Red Cliff Reservation on the northern tip of the Bayfield Peninsula.

European settlers had a large impact on basin land cover starting in the late 1800s with extensive forest clearing, followed by agricultural development and repeated clear-cut logging. These practices have altered stream channels and streamflow patterns, as well as sediment dynamics of erosion and deposition in streams for nearly 200 years (Fitzpatrick et al., 1999, Fitzpatrick and Knox, 2000, Lenz et al., 2003, Fitzpatrick, 2005, Fitzpatrick et al., 2015). Fitzpatrick's studies implicate changes in flood magnitudes resulting from land cover change including forest conversion and wetland drainage as the main cause of valley bluff failures along steep stream channel segments. Consequently, sedimentation rates in river mouths at Lake Superior also increased.

Agencies in Wisconsin's Lake Superior basin began conservation efforts to improve watershed quality about 60 years ago (Red Clay Interagency Committee, 1964, 1971, 1979). The Red Clay Interagency Committee (RCIC) was formed in 1956 with members from many federal, state, and local agencies to identify solutions to erosion problems in the red clay area of the Lake Superior basin. In 1971, at the request of the Governor of Wisconsin, the RCIC developed a Wisconsin-wide plan to reduce erosion and sedimentation in Lake Superior tributaries, which later expanded to Minnesota for a total of 5 counties throughout the red clay region. The RCIC worked with private landowners to implement and assess the efficacy of a variety of projects intended to reduce erosion and sedimentation, (see review in Fitzpatrick et al., 2015). These efforts have largely focused on restoring and protecting hydrology by "slowing the flow." The slow the flow (STF) approach seeks to reduce peak stream flows by using a watershed-scale hydrologic restoration approach that increases in-channel roughness and channel sinuosity, subwatershed land surface roughness, water storage in wetlands, and infiltration. Local natural resource managers have implemented forest management, wetland restoration, channel restoration, agricultural best management practices (BMPs), and green infrastructure projects to restore a natural hydrologic regime, with an expectation of improvements to water quality and habitat. Demonstration and restoration projects in the Lake Superior basin have been implemented since the mid-20th century.

Many local organizations seek to continue STF efforts in the basin (Ashland County, 2010, Bayfield County, 2010, Bro and Fratt, 2011, BRWA 2011, Douglas County, 2009, Jereczek et al., 2011). Multiple partnerships have supported STF efforts in the Lake Superior basin of Wisconsin, including the Lake Superior Basin Partner Team (1998-2012), the Chequamegon Bay Area Partnership (2009-2017), and the Lake Superior Landscape Restoration Partnership or "Joint Chiefs' Project" (2014-2017). Through the Joint Chiefs' Landscape Restoration Partnership, the Forest Service (USFS) and Natural Resources Conservation Service (NRCS) worked together to improve the health of forest land connected to privately owned lands. This included restoring landscapes by reducing wildfire threats to communities and landowners and protecting water quality and enhancing wildlife habitat. Building on these prior partnerships, the Lake Superior Collaborative (LSC) was formed in 2018 to coordinate protection and restoration efforts in Wisconsin's Lake Superior watershed and promote climate resiliency.

Purpose and scope

DNR and many regional partners have sought to improve the strategic approach of slow the flow efforts through the Landscape Restoration Partnership and the Lake Superior Collaborative. A team of resource professionals from the region identified priority subwatersheds for restoration (Wheeler et al., 2014). The effort identified a few criteria for prioritizing subwatersheds including the amount of open land and its position in the watershed, with emphasis on watersheds with known hydrologic degradation and accelerated sedimentation. The team also identified best management practices for those locations. With landscape-scale maps of where to work, the team began to consider identifying the desired future condition of these subwatersheds and restoration activities to achieve these conditions. This led to questions about how to refine criteria, how to link criteria to priority actions, what level of change will result in the desired response in condition, and what the indicators of success should be.

To help answer these questions, this report compiles the existing scientific information on the causal links between watershed condition and streamflow, with an emphasis on research from the Lake Superior basin of northern Wisconsin (Figure 1). Hydrologic, geomorphic, chemical, and biological attributes of lotic systems are highly interdependent. A complete discussion of the relationships between hydrology and these other components is beyond the scope of this report. Instead, we intend that this report provides a useful overview of stream hydrology as a proximate driver of sediment and biological interactions in lotic systems. This paper focuses primarily on reviewing the hydrologic effects of land use and land cover from published studies. From this, we suggest a framework for prioritizing STF efforts across Wisconsin's Lake Superior basin.

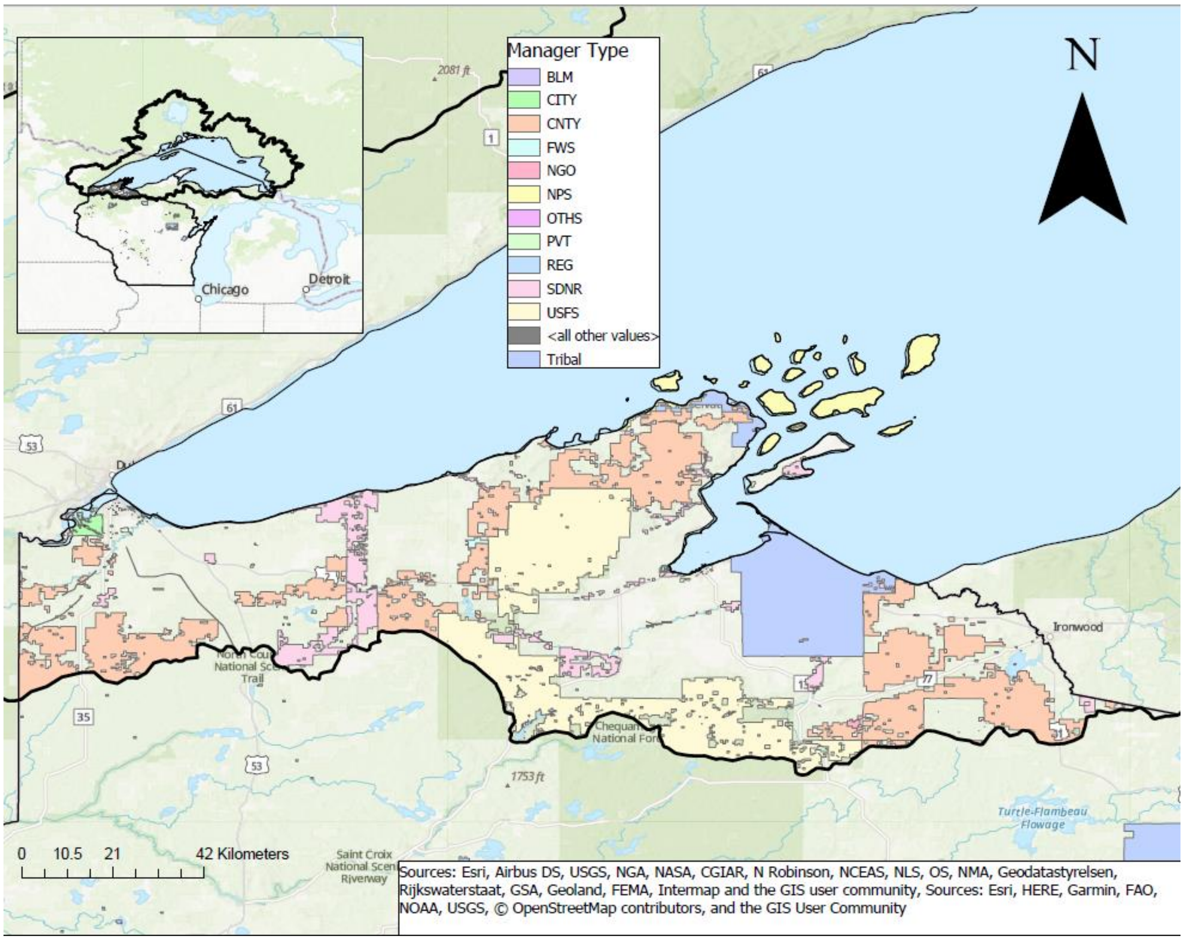

Figure 1. Land ownership in Wisconsin's Lake Superior basin. Source: https://maps.usgs.gov/padus/ USGS Protected Areas Database of the United States. Manager types from top to bottom include: Bureau of Land Management, City, County, U.S. Fish and Wildlife Service, Non-Governmental Organization, National Parks Service, Others, Private, Regional Agency, State DNR, U.S Forest Service, Tribal

Recommendations

We have summarized a substantial body of literature on the relationships among land use/land cover and hydrologic responses relevant for management of the Lake Superior basin in Wisconsin, this can be found in Appendix 2. In general, the best available practices seek to slow runoff and reduce peak flows through increasing upland infiltration, watershed storage, upland roughness, and in-channel roughness. In this chapter, we summarize our recommendations derived from this literature review by land use category. We discuss the need for a watershed-scale strategic approach and summarize the state of the science for identifying priority locations for slow the flow work in the basin. To implement this type of approach, a decision matrix could be used to incorporate multiple metrics and prioritize needs by subwatershed. We present some of the data needed to do that here. We also describe additional desktop and field assessments, and research that is needed to develop a complete, holistic decision matrix for prioritizing slow the flow efforts at the basin scale.

Established recommendations and work to date

Watershed storage and wetland restoration

Increasing watershed storage via wetland restoration or water and sediment control basins is a high priority throughout the basin (Bro and Fratt, 2011, BRWA 2011). The U.S. Fish and Wildlife Service has been a partner on 94 wetland restoration and/or enhancement projects within the basin over the last 15 years. Sites range in size from less than 0.2 hectares to 13.7 hectares and average 1.6 hectares (just over 16,000 square meters). The average depth of most restored and/or enhanced wetlands is 1 meter deep. Most of the projects have been implemented on the Lake Superior clay plain, but some have occurred in suitable areas of mixed glacial till in higher elevation areas as well as in sandier locations and barrens habitat. Typically, within the drier locations, groundwater near the surface is needed to provide a reasonable water source. Types of projects include levee construction to block drainage ditches and removing sediment from low depressional areas (Figure 2) and maintenance of water control structures on impounded wetlands and small flowages. Funding for these projects has been provided by a myriad of partners including private landowners, non-government organizations, county governments, and federal agencies. Wetland projects conducted in partnership with the U.S. Fish and Wildlife Service have focused on maximizing aquatic habitat for migratory birds and waterfowl that prefer water depths of 1 meter or less because these areas are inhabited by many types of aquatic invertebrates and produce rich aquatic plant growth. Most sites occur in agriculture fields that were previously hayed on an annual basis.

Figure 2. Wetland restoration project in Wisconsin's Lake Superior basin a) pasture and drainage ditches pre-restoration and b) seven years post-restoration.

We recommend targeting wetland restoration efforts to maximize an increase in overall watershed storage, including where wetlands can maximize storage and help desynchronize flows. In particular, we recommend the following:

- Use Height Above Nearest Drainage (HAND) analysis to identify priority floodplain wetlands for restoration and protection (see discussion under Parameter data sources and analysis below).
- Protect high-functioning watershed storage and hydrologic processes in existing wetlands and floodplains.
- Investigate potential opportunities to install wetlands, grassed waterways, and two-stage ditches in agricultural fields.
- Install multiple smaller projects in headwater areas, in parallel along multiple tributaries, for a greater cumulative increase in storage as opposed to restoring a large single site lower in the watershed.
- Design low-tech process-based restoration approaches (Wheaton et al., 2019).
- Design wetland restoration sites to include flow dispersal and grade control structures that enable natural water level fluctuations, rewetting degraded areas with flood pulses and excess flows, and reconnecting other wetland areas to the site and stream channel.

Additional recommendations:

We also recommend exploring the Wisconsin Wetland Conservation Trust (WWCT) as a potential source of funding for future wetland restoration work in the basin. It is the statewide in-lieu fee program administered by the Wisconsin DNR for the mitigation of wetlands. Through the purchase of credits from the WWCT, permitees can mitigate unavoidable impacts to wetlands. The WWCT then invests that funding in wetland restoration projects across the state. No restoration projects have been done in the Lake Superior service area since the WWCT was created in 2014. However, credits have been sold in the Lake Superior service area, and the WWCT is a potential source of funding for wetland restoration in the future.

Upland and in-channel roughness

To increase upland and in-channel roughness:

Implement forestry BMPs (Table 1) to maintain infiltration and vegetative cover.

Wisconsin DNR has made recommendations and described BMPs to maintain the filter function of the forest floor and protect the natural systems (WDNR, 2007a, WDNR, 2007b, WDNR, 2008 and others). Continued adherence to these BMPs is recommended.

Table 1. BMPs that reduce peak stream flows impacts on water system from Lewandowski et al., 2015.

	Effects					
BMPs	Increase spring transpiration	Increase filtration	Increase soil water holding capacity	Increase open water evaporation	Reduce peak flows	Reduce in-stream velocity
1. Infield: crop and soil management						
Perennial crops, and crop rotations with perennials or winter annuals	•	•	•		•	
Cover crops	•	•	•		•	
Reduced tillage, contour cropping, and residue management		•	•			
Compaction management		•	•			
Manure application		•	•			
2. Infield: drainage water management						
Alternative drainage design (depth, spacing, capacity)					•	
Controlled drainage					•	
Alternative tile inlets		•			•	
3. Infield and edge-of-field: surface flow management						
Grassed waterways	•	•			•	
Filter strips, contour buffer strips	•	•			•	
4. Infield and edge-of-field: water storage and infiltration						
Saturated buffers		•			•	
Restored and constructed wetlands		•		•	•	
WASCOBs, terraces, and detention basins		•			•	
Ponds and irrigation reservoirs				•	•	
Large retention basins		•		•	•	
5. Ditch channel: water retention						
Structures for water control, including weirs and restricted size culverts					•	•
Two-stage ditch with restricted size culverts					•	•
6: Riparian area: restoration and protection						
Riparian vegetation	•	•				
Streambank, bluff, and shoreline protection						
Restore channel meanders						•

Map gully type and apply appropriate restoration actions for groundwater- or surface water-driven gullies.

The type of gully erosion and sediment loading differs throughout the basin and has not yet been well characterized (Fithzpatrick et al., 2005) LIDAR data, which is available for many parts of the basin, should be used to locate and identify gully types as groundwater sapping or overland flow driven types. In groundwater-driven gullies, restoration should focus on increasing interception with coniferous tree planting. In surface water-driven gullies, increased roughness elements to promote increased infiltration should be prioritized. Vegetative filter strips that slow runoff and detention basins that store runoff are recommended for the head of ephemeral gullies.

Implement in-channel work consistent with geomorphic studies, with a focus on low-tech solutions.

In-channel projects to increase roughness should be used cautiously and selectively in the basin, based on the mixed success of previous projects. Sediment loading is substantial in many systems and installed roughness elements may be quickly buried, with little lasting ecological effect. Likewise, increasing peak flows due to a changing climate could wash out projects not designed for changing flow conditions. This type of restoration should only occur in watersheds and locations where geomorphic conditions and sediment dynamics are well-understood and should focus on low-tech designs simulating natural processes (Wheaton et al., 2019).

Forestry

We recommend working collaboratively with LS stakeholders to:

Implement existing guidelines for Forestry BMPs.

There are multiple guidelines and best management practices (BMPs) that have been developed to help land managers implement practices designed to protect natural systems at national, statewide, and Lake Superior basin scales (Table 2 of Appendix 4). Forestry-related BMPs that slow surface runoff in the Lake Superior basin include maintaining forest cover, promoting mature forest types, protecting adequate riparian zones, and managing steep, erodible slopes.

Establish an open lands percentage threshold for hydrology and water quality protection, and establish standard, repeatable methods for assessing open lands by subwatershed.

Several efforts have identified target minimum percent open land area thresholds for protecting hydrology and water quality in the basin (i.e., thresholds percentages of open land that should not be exceeded). In 2009, the Wisconsin DNR compiled the amount of open land in hydrologic units identified in Wheeler et. al., 2014 throughout Wisconsin's Lake Superior Basin. WDNR (2010) described open land as young forests, agricultural lands, and urban areas. In areas currently below 40% open land, timber harvest and forest opening were supported for a variety of benefits. Caution is recommended in subwatershed units currently with 40% to 55% open lands. Creating additional open land in areas currently greater than 55% open land is not recommended. WDNR (2010) emphasizes the importance of scale in evaluating the proportion of open lands. HUC 12 watersheds were used to determine larger focal areas, and smaller hydrologic units used in the analysis were delineated by Verry (approximately 2.5 km^2 in area, Benck et al., 2018) to evaluate the potential for open lands to have downstream effects on hydrologic integrity (WDNR 2010). The Nemadji Basin Plan established a target of less than 40% open land area in subwatersheds approximately 10 square miles in size (NRCS, 1998). Likewise, a target of less than 40% open land area was identified for the Marengo River watershed (BRWA, 2010). The Douglas County Land and Water Conservation Plan 2010 – 2020 (Douglas County, 2009) recommends converting open lands, particularly marginal pastures, to mature conifer forests to minimize the impacts of snowmelt runoff. The plan recommended maintaining a minimum of 40% forest cover in HUC 14 watersheds (Douglas County, 2019). Most recently, efforts to focus on watershed-scale hydrologic restoration under the Landscape Restoration Partnership targeted hydrologic units with 40 to 55% open lands using Verry's subwatersheds (Wheeler et al., 2014).

A single open lands threshold should be identified for consistency across the basin. In addition, standard, repeatable methods for assessing open lands should be identified. One issue with past analyses is that HUCs are not always full watersheds and sometimes have additional HUCs upstream or downstream that they flow to or receive flows from. Calculating the proportion of open lands for HUCs could result in misleading estimates of the proportion of open lands and how they might affect watershed hydrology. Instead, the percent open lands could be calculated using GLAHF hydrologic data layers, which are a standard nested Great Lakes hydrologic framework (see Forsyth et al., 2016 and "watersheds").

Clarify the delineation of the Riparian Management Zones (RMZs) to determine consistent standards for width and allowable practices in RMZs.

Recommendations from federal, state, and regional initiatives on the size of RMZs differ greatly (See Table 2 in Appendix 2), and a standard definition is needed to prioritize STF efforts. Most methods describe RMZs as a linear feature with a width that varies between 10 – 30 meters from the waterline or ordinary high-water mark (OHWM). The Nemadji River Basin Project defines riparian zones in the red clay plain as the entire floodplain and adjacent slopes that are 20% or greater, including intermittent channels (NRCS, 1998). Management approaches in RMZs also vary, but most existing recommendations include encouraging forest composition that mimics pre-European settlement mixtures of deciduous and coniferous trees, with an emphasis on mature, older-successional, and shade-tolerant species. Murphy and Koski (1989) found that nearly all large wood in stream channels is derived from within 30 meters of the stream channel. Interfluve (2003) therefore recommended no harvest of live or dead trees in this zone to promote wood recruitment to stream channels where it functions as a roughness element, promotes nutrient cycling, and provides habitat for many species. Interfluve (2003) also recommends buffers at the top of valley-edge erosion points to reduce surface runoff volumes, consistent with recommendations in the Fish Creek watershed to stabilize drainages from farmlands to waterways (Bro and Fratt, 2011).

Establish a consistent definition of unproductive steep slopes for private and public lands and promote BMPs at those sites.

The steep clay slopes in the Lake Superior basin are highly erodible. When adjacent to stream channels, mass wasting of these slopes leads to sediment inputs to stream channels. There is currently no consensus on the definition of steep erodible slopes, nor on appropriate BMPs for these sites. WDNR (2007a) defines steep slopes as areas with an overall rise of 15% over 15 meters or more *or* areas with greater than 27% slope over any distance. No commercial forest harvest is recommended for these slopes. These sites would benefit from BMPs that consider the stabilizing capacity of specific species; late successional species are found to have the greatest root tensile strength (Davidson et al., 1989).

Additional recommendations

As a secondary priority, the distribution of deciduous versus conifer tree species should be considered as they retain water at different rates (Nejadhashemi et al., 2012). A minimum percentage of coniferous cover should be established as a management target for the basin.

Agriculture

STF efforts on agricultural lands must accommodate the reality that the traditional crops that form the basis of the agricultural economy depend on rapidly removing excess moisture from farm fields. Within that context, we recommend the following prioritized approach:

Pursue opportunities to harness transitional agricultural areas to increase interception, infiltration, and retention

Some farmland in the basin is converting back to forestland (discussed further below). Such "transitional" land includes low-intensity hay production or pastureland that is farmed as a hobby or to maintain agricultural use assessment and lower property taxes (Figures 3 and 4). It also includes fields that are no longer actively farmed and are in the early stages of old field succession. These transitional lands are candidates for wetland restoration or for woody biomass crops that can provide economic returns to owners while also decreasing runoff. The effectiveness of such plantings could be increased if legacy soil compaction was addressed before planting and if the biomass crops were planted in concert with subsurface plowing to de-compact soils (i.e., keyline plowing, Duncan and Krawczyk, 2018). More research is needed to understand the potential of these methods.

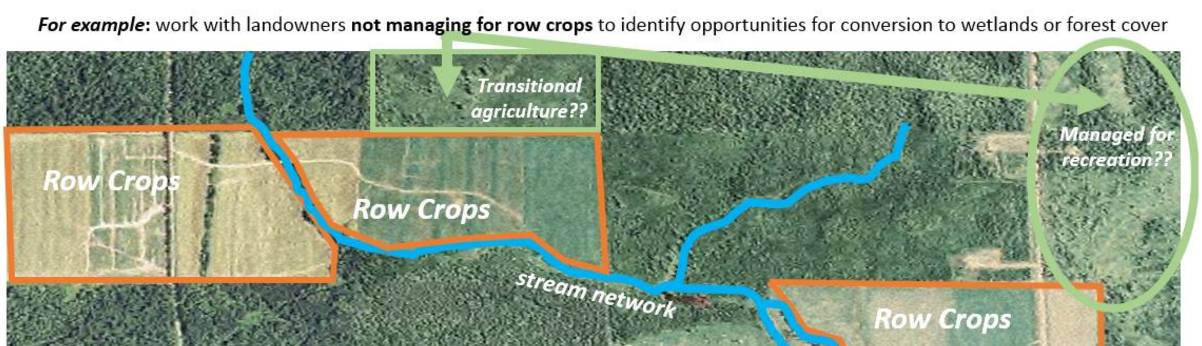

Figure 3. Example of identifying lands not managed for row crops to identify opportunities for wetland or forest conversion.

Figure 4. Fields in the early stages of transition out of agricultural production could be used to help slow the flow through wetland restoration or conversion to biomass plantings designed to improve infiltration, interception, and retention.

Incentivize STF flow practices and non-point source runoff trading

The trading of water quality credits is an established practice in many parts of the U.S. and typically involves point source discharges of pollutants (such as wastewater treatment plants) paying landowners within the same watershed to reduce the non-point discharge of pollutants (EPA, 2008). Such programs are most effective when the cost of reducing the non-point discharge is less than the cost of reducing the point source discharge. Phosphorus trading is the most common form of water quality trading (EPA, 2008). Typically, the non-point phosphorus credits are generated by farmers implementing best management practices to reduce soil erosion or by installing clean-water diversions to reduce manure and nutrient losses from barnyards (EPA, 2008). A phosphorus trading program for the Chequamegon Bay region (where agriculture in the Lake Superior basin is focused) would likely be structured differently. Studies indicate most of the phosphorus discharge occurs during storm events and most of that phosphorus comes not from agricultural lands themselves, but sediment eroded from within stream channels (EPA, 2008). The channel or bank erosion is caused, in part, by increased or rapid runoff from agricultural lands. Thus, generating phosphorus credits from agricultural lands in the Lake Superior basin could be done by implementing actions that slow the flow, reduce peak flow events, and reduce stream bank and bluff erosion.

The key to any water-quality trading program is sufficient monetization of the generated credits to provide an incentive for making land use changes or implementing the practices (EPA, 2008). Typically, the monetization results from point-source dischargers being compelled to reduce loading through a local, state, or federal permitting process. No point-source dischargers are currently facing such mandated reductions in the Chequamegon Bay region. Instead, one option to monetize phosphorus or slow the flow credits would be for local municipalities to implement either a mandated or voluntary no-net increase or reduction in phosphorus losses from permitted land uses. For example, an agricultural operation or new building project that would result in increased runoff rates could be compelled or asked to voluntarily offset such an increase by purchasing "slow the flow" credits from a landowner that implements practices to slow the flow such as wetland restoration or conversion of pasture to trees.

Another model to incentivize targeted BMPs for slow the flow efforts would be for resource managers/funders to focus cost-share dollars in areas known to have a high proportion of intensive agriculture and have flashy streams. For example, to focus wetland restoration on transitional agricultural lands within the same watersheds as those identified as having a greater percentage of intensive agriculture.

Implement best management practices on intensive farmlands

On high-intensity farmland involving tillage and production of annual row crops, there are well-established best management practices that should be encouraged to help reduce runoff rates. These recommended practices are summarized by Lewandowski et al. (2015) and listed in Table 1. Of all the listed practices, the production of perennial crops is likely the most effective as the perennial roots improve infiltration and the overwintering biomass improves surface roughness. The use of annual cover crops to "perennialize" the agricultural lands can also be effective, particularly after corn silage harvest where there are very little crop residue and harvesting equipment traffic compacts the soil.

Urban and rural residential

For urban and rural residential settings, we recommend focusing most slow the flow efforts in the upper portion of the basin, while also addressing important coastal resiliency needs to protect life and property in urban areas:

Identify and prioritize STF efforts upstream of urban centers that will reduce peak flows and flooding in developed areas.

Since the largest urban areas in the basin, Superior and Ashland, are in the lower portions of watersheds, the effects of urban BMPs would be limited to the local areas and Lake Superior's nearshore. Slow the flow efforts in the upper portions of the watershed would result in cumulative benefits for the urban communities downstream.

Implement bioretention and stormwater management approaches to help protect urban infrastructure.

Urban communities are, however, affected by their coastal locations. Flooding during storm events is exacerbated by high lake levels and storm surges, as well as by elevated peak flows. Existing urban infrastructure is often not designed to accommodate increasing peak flows, and damage to infrastructure due to storm events can and has had major costs to coastal communities. Bioretention systems can capture and store surface runoff in urban and rural settings. Simplistic designs can capture roof runoff in rain barrels and/or rain gardens. In more commercial sites, green roofs or stormwater storage ponds have the capacity for larger flows (Bro and Fratt, 2011). Implementation of green infrastructure projects would increase resiliency to storm events in urban areas.

Continue assessments to identify and prioritize replacement or upgrades of road-stream crossings that have undersized culverts, are barriers to organism passage, or have eroding soils.
There are several ongoing efforts in the basin to address the need for increasing the capacity of culverts to manage increased and increasing peak flows. The US Forest Service established standard methods for assessing road-stream crossings for capacity, effects on stream health, stability, aquatic organism passage, or erosion issues (USFS, 2020). These methods are currently used to inventory crossings in the Great Lakes including in the Lake Superior basin in Wisconsin. In addition, the University of Wisconsin and Wisconsin Coastal Management Program have established a culvert mapping community of practice to share data and methods (https://www.wicdi.org/). Continuing these efforts will contribute to reducing damage to infrastructure. and sources of erosion. Building a stream-crossing inventory has been a priority across the Great Lakes: https://great-lakes-stream-crossing-inventory-michigan.hub.arcgis.com/.

Receiving waters

Historically, upland work has focused on upland problems, however, protection or impairment of receiving waters may also be an important driver of upland conservation efforts. This could include communities identified as endangered, threatened, or of special concern such as poor fens, which are sedge-dominated wetlands found on strongly acid-saturated peat (Cohen et al., 2020). We recommend to:

Prioritize STF efforts in watersheds that drain to poor fen coastal wetlands.
Poor (acidic) fens commonly occur along the coast of Lake Superior but also occur in kettle depressions and flat areas of glacial outwash or lake plains (WDNR, 2015; Cohen et al., 2020). These ecosystems deserve protection because they contain high species diversity and provide spawning and nursery habitat for a rich assemblage of native and sport fishes (Epstein, 2017). Poor fens can be distinguished by their weakly minerotrophic peatland soils influenced by surface and/or groundwater and relatively high species diversity (Epstein, 2017). They are similar to open bogs, but have a higher pH and a decreased presence of leatherleaf and *Sphagnum* species (Epstein, 2017). In the Lake Superior basin, the vegetation in open bogs is slightly elevated above the influence of mineral-rich groundwater by the growth and influence of *Sphagnum* hummocks (Epstein, 2017). *Sphagnum* hummocks wick water upwards, but also actively acidify the rooting zone and causes nutrient availability to be extremely low (Epstein, 2017). Protection of fen hydrology is the paramount conservation consideration to ensure that water levels remain within a range of natural variability and that saturation of the peat is constant (Epstein, 2017). Runoff laden with sediment, nutrients, or pollutants can alter the chemistry of ground and surface waters and affect the suitability for the sensitive peatland biota (Epstein, 2017).

A watershed-scale strategic approach

The landscape-scale processes described above interact in complex ways to affect hydrology. Therefore, a strategic and targeted watershed approach is recommended to best reduce runoff and address corresponding habitat and water quality problems. By this, we mean that funding and effort should be focused on locations across the basin where they will have the greatest effect on water quality problems at a basin scale. In this section, we describe the capacity and precedent for taking a watershed-scale strategic approach in the Lake Superior basin in Wisconsin.

There is growing momentum and capacity for this type of approach to restoration and protection in the Lake Superior basin of Wisconsin. The Lake Superior Collaborative (https://fyi.extension.wisc.edu/lakesuperiorcollaborative/) was formed in 2018 from historical partnerships dedicated to partnered conservation and restoration work in northern Wisconsin. The LSC is currently coordinated by a UW-Extension staff position that is financially supported by UW-Extension, the US Forest Service, the Natural Resource Conservation Service, and the Lake Superior National Estuarine Research Reserve. The LSC was established to continue and sustain watershed-scale efforts to protect and restore Lake Superior and its basin in Wisconsin. It consists of government, academic, tribal, and non-profit organizations working in the basin. The shared vision of the partnership is: "The communities and ecosystems of Wisconsin's Lake Superior Basin are climate resilient and supported by sustained and collaborative conservation partnerships and projects." The organization aims to fulfill this vision by aligning conservation priorities with the Lake Superior Lakewide Action & Management Plan (LAMP), implementing projects to reduce pollution, improve habitat, and increase climate resiliency, facilitating exchange among partners, and conducting public outreach to encourage watershed stewardship. With the vision and partnerships established by the LSC, partners in the region are well-poised to develop and implement a strategic and targeted watershed approach to reduce runoff and address related habitat and water quality problems.

Funding is a key component of any implementation strategy. A major source of potential funding is Clean Water Act Section 303(d) funding, which addresses water quality issues and advocates a watershed approach to planning. In Wisconsin, to access Clean Water Act Section 303(d) funding, watersheds must first develop a "9 Key Element Plan," which includes specific requirements defined by the US Environmental Protection Agency. The state can approach a city and/or county to address TMDL or impaired waters. Cities and/or counties can also approach the state if they see a need for a 9 Key Element Plan in their jurisdiction. To create a 9 Key Element Plan for a watershed the local government and the state work together to solve common problems. The state assists with the development of the plan, by helping determine what the needs are, identifying areas of prioritization, and defining the scale of the watershed project. The state leads the project only when it is addressing a TMDL. The completion of a 9 Key Element Plan allows for cities and counties to apply for EPA 303(d) funds and restore their watershed. Wisconsin only has the capacity to conduct a limited number of 9 Key Element Plans at one time. To date, most of the plans have been focused on priority watersheds in the southern part of the state. In the Lake Superior basin, there are two 9 Key Element Plans efforts currently underway: The Marengo watershed which was completed in 2013 and Douglas County/City of Superior 9 Key Element Plans which is currently about 1 year into their planning.

The Marengo 9 Key Element Plan included multiple stakeholders organized into a Citizen Involvement Team, a Technical Team, and a Steering Committee. Nearly 30 different local state and federal agencies and organizations participated in the plan. The resulting Marengo River Watershed Action Plan (BRWA 2010) used a combination of open lands data and National Streamflow Statistics Program modeling outputs to identify priority locations for implementation of slow the flow practices. Analysis conducted for the plan estimated 2-year peak discharge normalized by watershed area in 30 nested, pour-point Marengo subwatersheds (Fig. 5) (Hollenhorst and Hudson, 2011) combined with a summary of the percent of open lands in those same 30 watersheds (Table 2). Results identified areas susceptible to excessive peak flow volumes and corresponding erosion and sedimentation (Fig.6). This approach used the 2003 USGS flood frequency regression equations that include evaluation of soil permeability, snowfall, percent storage, and slope (Walker and Krug, 2003).

Table 2. National Streamflow Statistics Program (Walker and Krug, 2003) model inputs predicted two-year peak discharge (cubic feet per second) results, and discharge results normalized per square mile of area for each of 30 subwatersheds within the Marengo River Watershed. Also included within each subwatershed is percent open land and forests <16 years old (Community GIS, 2009). Highlighted subwatersheds had a discharge greater than 20 cfs/mile^2 and greater than 20% open lands.

Watershed ID	Drainage area (sq. miles)	Soil Permeability	Annual Snowfall	Storage (%)	SLOPE (ft./mile)	Peak Discharge (2 yr.)	Discharge per mile	Percent open lands
1	217.3	1.16	85.20	14.50	21.56	2500	**11.507**	**20.9**
2	103.7	1.09	79.64	10.64	17.44	1330	**12.821**	**25.8**
3	84.8	1.47	88.41	21.14	27.15	1020	**12.032**	**10.0**
4	65.1	1.60	86.03	24.60	25.50	740	**11.373**	**4.4**
5	69.1	1.53	86.34	23.20	25.50	803	**11.620**	**7.1**
6	15.5	1.21	97.81	12.18	86.91	418	**27.054**	**23.4**
7	4.0	0.46	91.80	0.64	57.38	264	**66.218**	**50.1**
8	4.9	0.10	89.33	32.22	24.06	147	**29.982**	**30.4**
9	194.1	1.23	83.90	15.00	21.21	2190	**11.282**	**19.8**
10	200.5	1.20	84.07	15.31	21.21	2260	**11.273**	**20.3**
11	9.1	1.26	101.77	5.22	57.62	298	**32.684**	**31.0**
12	4.3	0.10	74.40	0.16	46.11	391	**90.123**	**44.4**
13	4.8	0.18	77.50	1.41	49.08	307	**63.859**	**41.0**
14	9.2	0.14	76.09	0.81	63.64	659	**72.005**	**42.6**
15	69.1	1.42	78.92	13.32	15.96	801	**11.599**	**11.6**
16	59.6	1.63	79.32	15.21	28.10	772	**12.954**	**6.8**
17	5.9	0.84	82.17	4.31	31.17	181	**30.572**	**31.8**
18	9.5	1.65	89.25	12.84	33.98	185	**19.374**	**5.0**
19	47.7	1.65	85.02	30.40	16.59	466	**9.771**	**1.3**
20	33.8	1.65	76.91	18.44	9.65	326	**9.651**	**1.5**
21	13.8	1.65	86.00	9.55	46.69	295	**21.453**	**4.7**
22	28.1	1.65	81.13	37.97	4.19	184	**6.538**	**1.2**
23	5.6	1.65	84.50	28.67	31.53	88	**15.788**	**1.9**
24	6.8	1.65	80.44	23.02	12.55	84	**12.308**	**0.3**
25	10.6	1.65	76.15	21.65	33.96	162	**15.307**	**0.2**
26	5.4	1.65	77.14	35.17	3.52	42	**7.786**	**1.7**
27	12.1	1.65	81.17	43.03	3.30	80	**6.625**	**2.0**
28	6.9	1.65	79.80	38.77	2.71	48	**6.919**	**2.6**
29	4.9	1.65	82.88	49.10	28.10	64	**13.183**	**1.3**
30	58.1	1.65	79.27	15.34	13.85	616	**10.605**	**6.2**

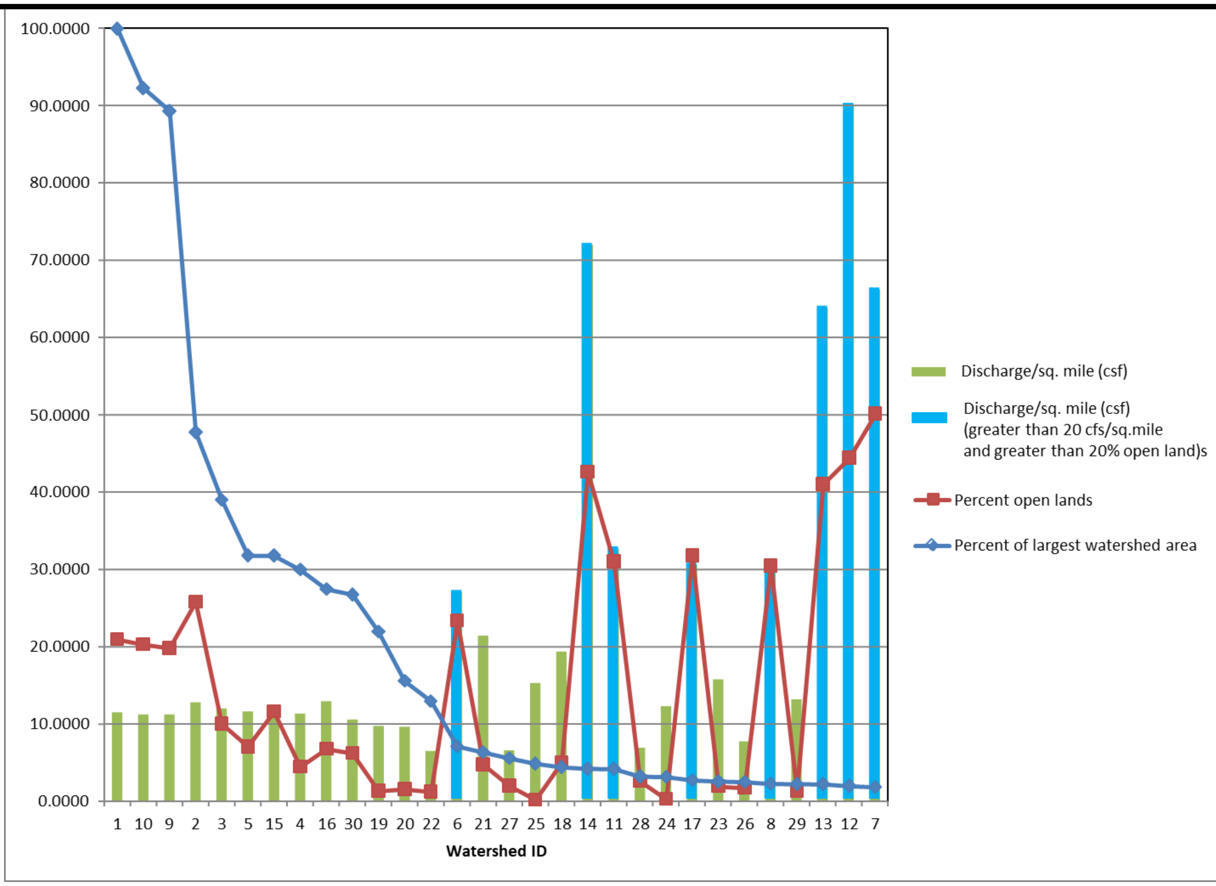

Figure 5. Results from National Streamflow Statistics Program (Walker and Krug, 2003) modeling for 30 subwatersheds in the Marengo River watershed ranked from largest to smallest. The plot shows the mean discharge (green bars), mean discharge greater than 20cfs/sq.mile and 20% open lands (blue bars), percent open lands (red squares), and each subwatershed's percentage (blue diamonds) of total Marengo River Watershed land area.

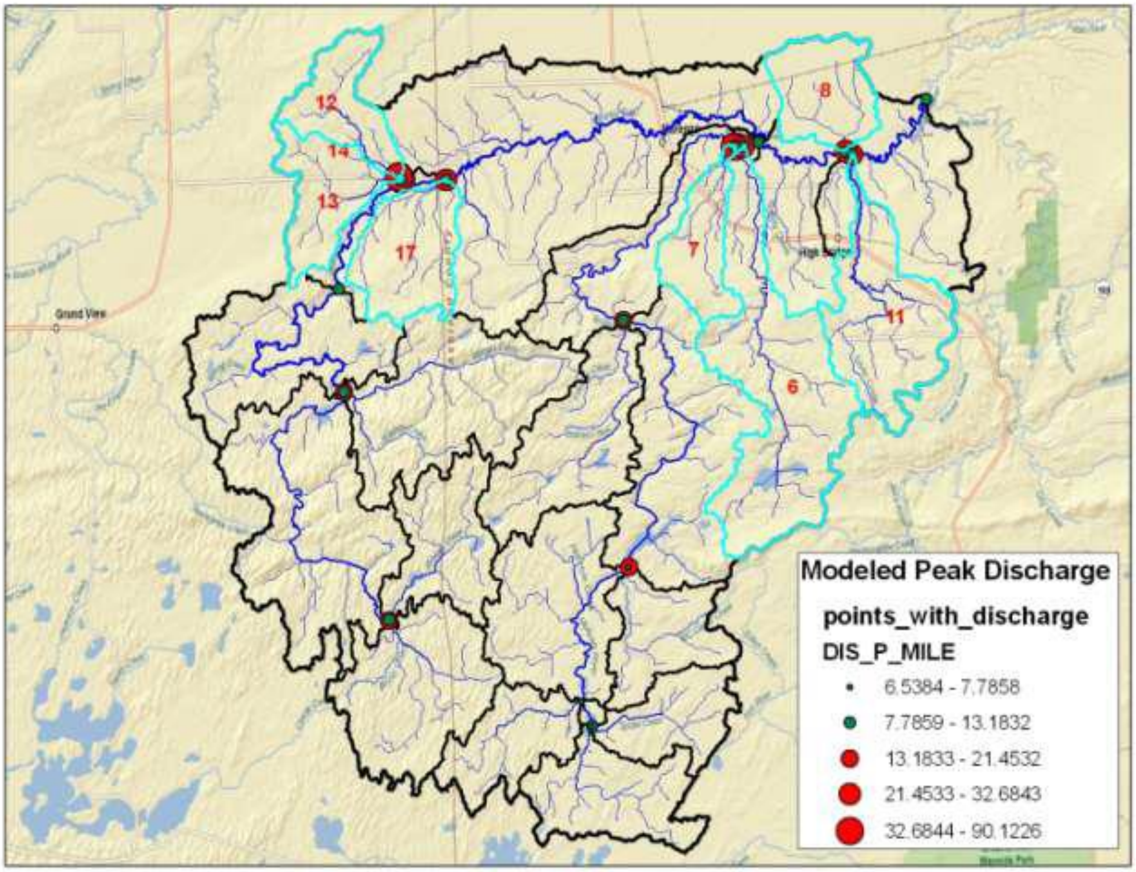

Figure 6. Results from National Streamflow Statistics Program (Walker and Krug, 2003) modeling for 30 subwatersheds in the Marengo River watershed. The dots, or "pour points" (many of which overlap) for each watershed are sized based on the predicted 2-year peak discharge per square mile. Blue highlighted subwatersheds are those with a predicted 2-year peak discharge per square mile greater than 20 cfs and that have at least 20% open lands.

Other regions are implementing effective approaches for strategic and targeted watershed management. The state of Vermont uses a similar STF approach based on applying the concepts described in this report to reduce flood risk by implementing measures that emulate the natural functions of subwatersheds, wetlands, floodplains, rivers, and coasts. Vermont has conducted more than 150 different stream geomorphic assessments with the data maintained in the Stream Geomorphic Assessment Data Management System (available at https://anrweb.vt.gov/DEC/SGA/default.aspx) and organized within the Vermont Flood Ready website (https://floodready.vermont.gov) which also maintains data about community flood risk assessments, funding sources, and other flood resiliency planning resources. Wisconsin Wetlands Association (WWA) is currently using Vermont's efforts as a model for a strategic approach to watershed management in the Lake Superior basin.

In the aftermath of the 2016 flood, the Wisconsin Wetlands Association (WWA) made the case for protecting vulnerable infrastructure through Natural Flood Management (NFM). NFM is an approach similar to "slow the flow" that originated in the UK and focuses on three methods: reducing the rate of runoff generated on uplands, storing water in uplands during high flow periods, and increasing roughness between runoff sources and potential flood inundation areas (Lane, 2017). NFM is effective at lowering peak flows in small subwatersheds, although study results are less conclusive at larger subwatershed scales and for managing extreme floods (Wilkinson et al., 2019; Dadson et al., 2017). For a review of NFM, see Dadson et al. (2017). With the help of Wisconsin Coastal Management Program's (WCMP) 309-funding and other funds, WWA has built partnerships to explore NFM, increase awareness, share solutions, and demonstrate results to community members, collaborators, and policymakers in Wisconsin. WWA recently completed a "ripple effects mapping" exercise, which measured how their efforts in NFM have improved or influenced the work of partners in the basin since 2016 (Wisconsin Extension, 2021).

Decision-making and prioritization

One objective of this report is to provide stakeholders and managers in the Lake Superior basin with the best available information and data to make decisions about how to address runoff and water quality problems. Based on our review of the literature, important metrics to address slow the flow include watershed storage, land cover, geologic setting, and downstream habitat. Additional logistic or social factors can also be considered, including the likelihood of future land use conversion and property ownership. In this section, we summarize and describe each of the parameters and relevant thresholds we have identified, along with the best available datasets and/or analyses available to evaluate those parameters for prioritizing slow the flow efforts. These results are summarized in Table 3.

These parameters can be used on their own or in a multi-metric decision matrix to prioritize where BMPs, restoration, and protection activities will be most effective and have the largest positive impact in the basin. Multi-metric decision matrices are a common approach to address the challenge of prioritizing restoration and protection efforts based on many complex and interacting variables (Velasquez and Hester, 2013, see an example of application in Srinivas et al., 2020). The use of a multi-metric decision support matrix would allow the evaluation of multiple metrics with relevant published thresholds by subwatershed. Weighting can be used if certain metrics are more judged important than others in a particular context. Based on the metrics and thresholds included, the priority subwatersheds for slow the flow work can then be identified.

Some of the parameters below have multiple criteria identified in the literature or management documents. Due to incomplete information and analyses, we do not identify single thresholds for these parameters to prioritize work at the basin scale. For now, threshold selection should be made based on context-specific decision-making needs. However, we outline additional research, analysis, and monitoring needs with the ultimate goal of identifying basin-wide thresholds to prioritize STF work at the basin scale. After desktop assessments, the next step would be to confirm priority project areas and subwatersheds with field assessments and site-specific project design and engineering plans.

Table 3. Summary of recommended parameters to consider for prioritization of STF efforts in the Lake Superior Basin. Parameters are listed in three groups: primary criteria that can be used to identify priority watersheds and subwatersheds; secondary criteria to rank subwatersheds within priority watersheds; tertiary considerations can be used to further narrow priorities. Wisconsin Wetland Inventory (WWI), Potentially restorable wetlands (PRW)

	Parameter	Data source	Criteria or ranking method	Criteria source
Primary ranking criteria				
1.1	Percent storage by subwatershed	WWI, NHD	<10%	Johnson et al., 1990
1.2	Peak discharge/subwatershed area ratio	USGS StreamStats	Ranked by subwatershed	Walker et al., 2017
1.3	Percent open lands by subwatershed	Community GIS analysis, ongoing data needs described in text	>40%(Douglas Co.)	Douglas County, 2016
Secondary ranking criteria				
2.1	Percent of total wetland area with surface water attenuation by subwatershed	Functional Wetland Assessment (only available in Nemadji and Marengo)	Ranked by subwatershed	Benck et al., 2018
2.2	Proportion of riparian area not mapped as wetland by subwatershed	Height above nearest drainage (HAND) analysis described in text	Ranked by subwatershed	Proposed by authors
2.3	Proportion of forested riparian areas of total riparian area	Uses output of HAND analysis	Ranked by subwatershed	Proposed by authors
Tertiary considerations				
3.1	Inactive farmland	Analysis described in text	Prioritize locations on inactive farmland	Proposed by authors
3.2	Transitional zone and soil permeability	Wisconsin ecological Land Type Association	Prioritize locations in the geologic transition zone (229 – 33 m)	Proposed by authors
3.3	Downstream coastal ecosystem/habitat type	DNR Natural Heritage Inventory	Prioritize wetlands draining to poor fen coastal wetlands	Proposed by authors
3.4	Land ownership type	USGS Protected Areas Database of the United States	Public, private, tribal	Proposed by authors.

Parameter data sources and analysis

Watershed storage parameters

Watershed storage-related criteria include the existing watershed storage, percentage of wetlands lost, and measures of existing wetland functions with an emphasis on wetlands that provide surface water attenuation benefits. Existing and potential acreage of wetlands that provide storage in Wisconsin's Lake Superior basin can be described by using two spatial wetland data layers: the Wisconsin Wetland Inventory (WWI), and Potentially Restorable Wetlands (PRW). The WWI describes the existing distribution and extent of wetlands digitized from leaf-off, black and white, and infrared aerial photos taken in 2012 for Douglas and Bayfield counties, and in 2013 for Ashland and Iron counties. Based on the WWI there are 393,224 acres of wetlands in the Lake Superior basin. The statewide Potentially Restorable Wetlands (PRW) layer uses mapped hydric soils, flow accumulation pathways, and slope from digital elevation models to identify areas that are not currently mapped as wetlands but were probably wetlands in the past. The PRW layer estimates 81,023 acres of original wetlands that have been drained and could potentially be restored. However, in the Lake Superior basin, soils (particularly in the clay plain) are mapped as soil complexes that lump clay soils in with other soil types, likely underestimating the extent of original wetlands. Combining the WWI and PRW produces an estimate of total pre-settlement wetlands of 486,918 acres or nearly 25% of Wisconsin's Lake Superior basin. Potentially restorable wetlands occur throughout the basin. There are significant opportunities to restore wetlands on private lands in the clay plain and headwaters areas, emphasizing the need for other socioeconomic factors to be considered in determining site-specific projects.

While nearly all wetlands contribute to slowing the flow in watersheds, some sites provide that function more than others. Functional wetland assessment techniques can be used to estimate and map the extent to which existing wetlands provide flood attenuation and peak flow reduction functions, as well as fish and wildlife habitat, streamflow maintenance, sediment retention, and nutrient transformation. Functional wetland assessments, which build on lower resolution statewide wetlands data, have been conducted in Douglas County and the Marengo Watershed, led by Saint Mary's University of Minnesota GeoSpatial Services (Saint Mary's GSS).

The National Wetland Inventory Plus (NWI+) classification, which is based on each wetland's geomorphology and relationship to the stream/lake network, was created through the conversion of the Wisconsin Wetland Inventory layer and additional photointerpretation. In NWI+, each wetland and waterbody is characterized by its landscape position, landform, water body type, and water flow path (referred to as LLWW). For Douglas County, Saint Mary's GSS used high-resolution imagery, aerial photograph interpretation, elevation data, land cover, and soil unit classification to produce a series of spatial datasets that can be used to characterize the contribution of individual wetlands and wetland complexes to surface flow attenuation (Stark and Robertson, 2014). This work improved the statewide PRW data layer by using aerial photograph interpretation to look for additional wetland indicators such as April flooding and August ponding, along with enhanced mapping of surface hydrology and ditch networks. One output of this work is a map that displays the location of PRWs that will likely provide surface water detention functions (Figure 8). NWI+ outputs that identify PRWs most likely to achieve surface water detention could improve the effectiveness of wetland restoration intended to reduce peak flows (Stark and Robertson, personal communication). The Height Above Nearest Drainage (HAND) method can also be used to more completely map riparian and floodplain wetlands for priority restoration and preservation efforts (Figure 7). Initial HAND Analyses in the Marengo River watershed used 10m elevation data, but future efforts could include higher resolution LiDAR-derived 1-3m elevation data.

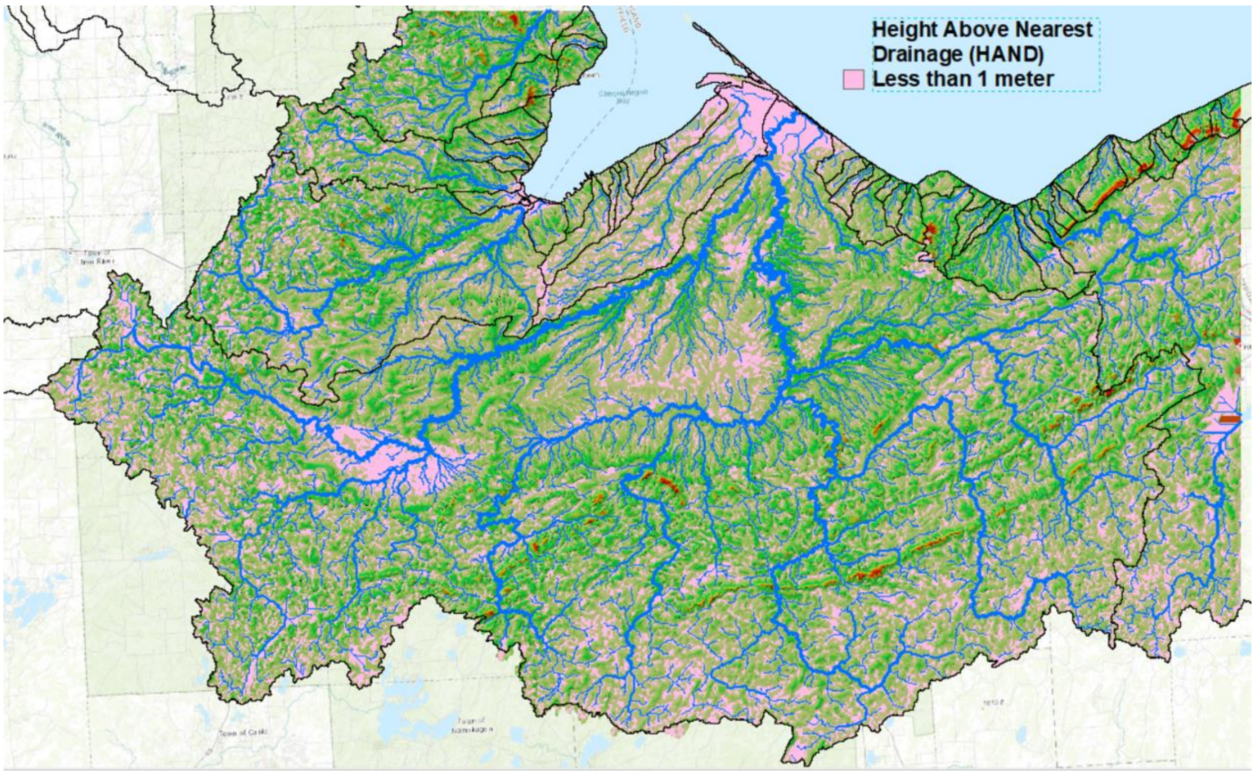

Figure 7. Height Above Drainage (HAND) analysis for south shore watersheds. Areas in pink are less than 1 meter above the nearest drainage.

The Wisconsin Department of Natural Resources and Saint Mary's GSS conducted a similar watershed-scale wetland functional assessment and restoration prioritization for the Marengo River Watershed, which is a focus of restoration efforts funded through the Great Lakes Restoration Initiative. They mapped agricultural surface ditches, existing wetlands, and potentially restorable wetlands following the methodology used by Stark and Robertson (2014). They also created functional assessments for existing wetlands aimed at advancing the ability to assess current wetland condition and function, assess changes over time, evaluate current restoration and protection options, and validate a GIS decision support tool developed to assess wetland functionality. The purpose of this project was to provide a strong scientific basis for a feasible wetland monitoring program.

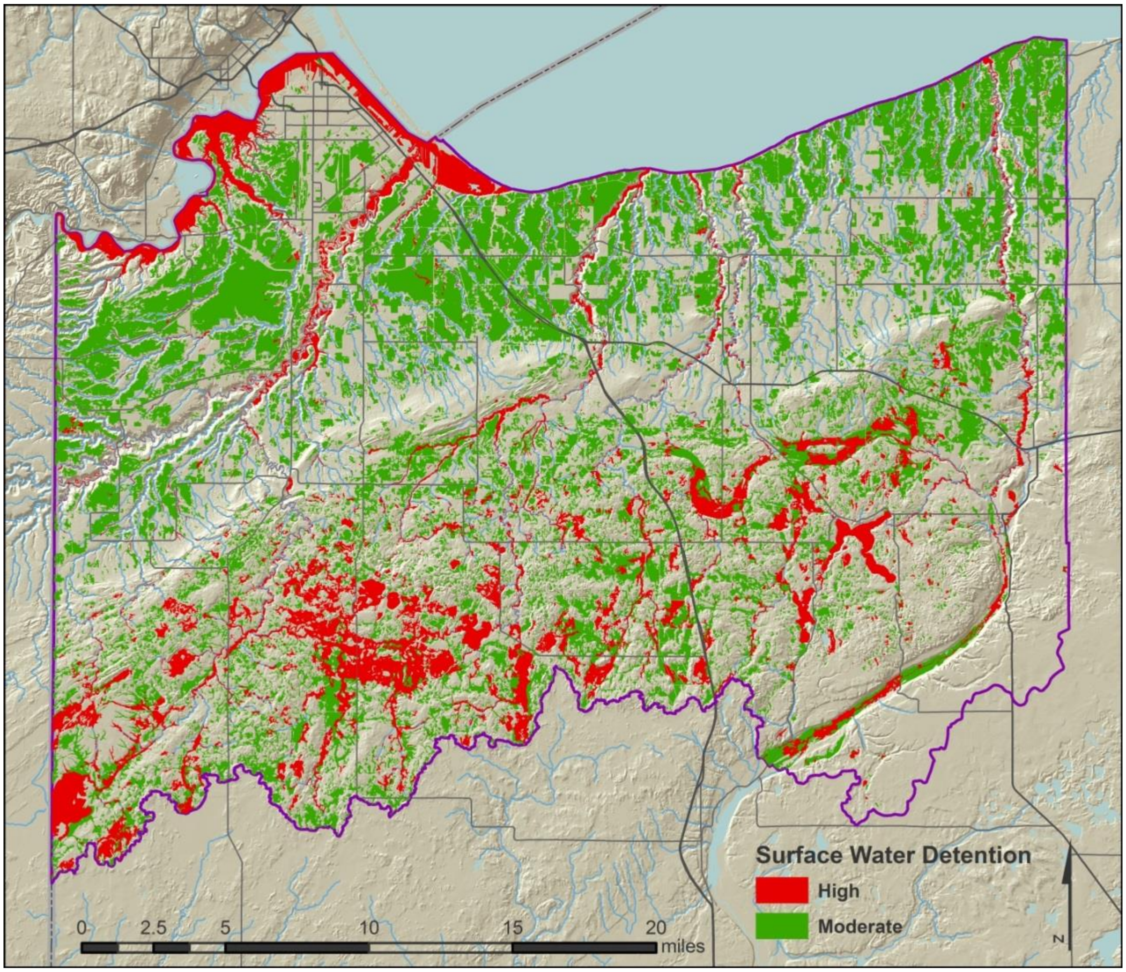

Figure 8. Potentially restorable wetland areas in Douglas County that are likely to provide water attenuation functions. Map created by Saint Mary's GSS.

In the Nemadji watershed in Douglas County, a cooperative project supporting the delisting of the St. Louis River Area of Concern (MNDNR, MPCA, and WDNR, 2020) focused on the analysis of LiDAR elevation data, as well as other existing datasets to assess how wetlands, conifer/native forest, and stream riparian corridors can be managed to address the STF concerns in the watershed (Benck et al., 2018). The objectives of the project were to identify priority habitat restoration and protection sites in the Nemadji River watershed using geographic information system (GIS) analysis to support a decision support system (Benck et al., 2018). The information from this project can be used to inform future restoration and protection efforts in the Nemadji River watershed. The key component of this project was a multi-criteria feasibility matrix used to assess habitat restoration and protection opportunities. This matrix helps prioritize and direct investments in restoration and protection actions based on factors such as watershed needs, available funding, local planning, land ownership, historic and predicted climate patterns, and habitat location. The matrix is comprised of a set of protection and restoration criteria and thresholds for identifying and/or prioritizing management actions for riparian, forest, and wetland habitats. The matrix can be used to target communications to landowners in priority restoration and protection locations and can provide government decision-makers with data to support planning, zoning, and bylaw decisions.

Subwatershed peak flow estimates

To identify watersheds with accelerated watershed runoff, we calculated 2-year peak discharge using the National Streamflow Statistics (NSS) program (Walker and Krug, 2003). The NSS is an easy-to-use program that provides regression equations for every state in the US to estimate streamflow statistics including peak discharge at ungauged sites. NSS uses multiple regression analysis on log-transformed data from continuous gaging stations and crest gage sites with at least 10 years of data to estimate relationships between flood peaks and watershed characteristics for regions within a state. The NSS regression equation for northern Wisconsin was calculated using data through the year 2000 from nearly all of Bayfield, Iron, Ashland, and Douglas Counties, and includes guage site data from northern portions of Burnett, Washburn, and Vilas Counties. Forest cover and precipitation were evaluated in developing this equation but were determined to not be significant terms in estimating discharge. Using this program, we calculated 2-year peak discharges using the equation:

$$\begin{aligned}\text{PeakQ2} = 2.69\ &\times (\text{Watershed shd. Area})^{0.864} \times (\text{Storage} + 1)^{0.296} \times (\text{Stream Slope})^{0.279} \\ &\times (\text{Soil Permeability})^{-0.25} \times (\text{Annual Snowfall})^{0.49}\end{aligned}$$

Where contributing drainage area is measured in square miles; storage, in percent of basin area plus 1.0; the main-channel slope is measured in feet per mile; soil permeability is for the least-permeable soil horizon in inches per hour; mean annual snowfall for 1961 through 1990 in inches; from Walker and Krug, 2003.

We evaluated NHD+ subwatersheds, hydrologic units defined by Wheeler et al. (2014), and pour point watersheds as potential summary units for watershed characterization and discharge estimation. We decided to use pour point watersheds because they encompass the entire contributing area to a given location and allow for consideration of the cumulative effects of multiple land uses throughout that contributing area. We used the ArcHydro toolbox to delineate watersheds using 30-meter resolution National Elevation Data across Wisconsin's four Lake Superior counties. We delineated and calculated the area for 1,615 nested and overlapping pour point watersheds in Wisconsin's portion of the Lake Superior basin. Storage was estimated as the surface area of wetlands (Wisconsin Wetlands Inventory) and lakes (WDNR Hydro data layer). Stream slope was calculated for each watershed as the difference in elevation at 15% and 85% of the watershed from the digital elevation model. Soil permeability data and annual snowfall data were from Walter & Krug, 2003.

The Wisconsin Lake Superior Basin Partner Team and Technical Work Group (Lake Superior Basin Partner Team, 2007) identified the peak discharge to watershed area ratio as an appropriate metric for identifying priority subwatersheds for STF efforts. This was based on Verry (2001) who showed that channel-forming flows occur at a peak discharge to drainage area ratio of greater than 15.

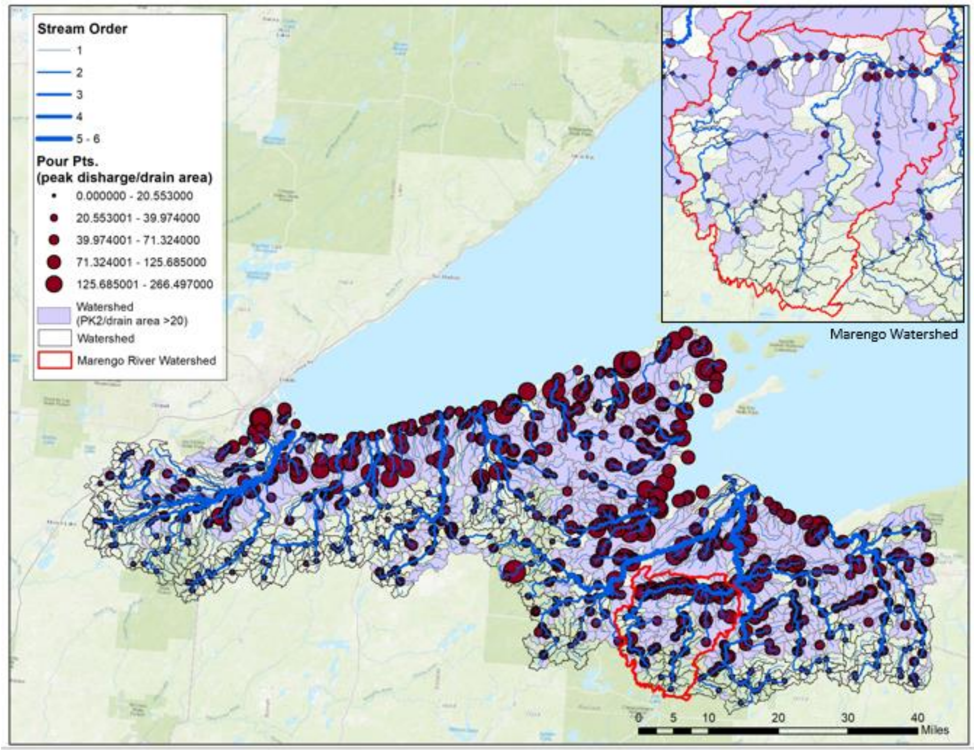

Figure 9. Modeled peak discharge to drainage area ratios (cubic feet/second)/square miles) for WI Lake Superior south shore watersheds. Symbol size for peak discharge/drainage area reflects subwatershed "flashiness."

A map of this metric (figure 7) shows smaller watersheds near the coast consistently had the highest discharge/drainage area ratios. The Marengo River had a series of small watersheds aligned along the Marengo's main stem with higher discharge/drainage ratios.

Open lands

Community GIS (2009 completed several analyses of the south shore in Wisconsin and portions thereof aimed to identify open areas (defined as developed areas, agricultural land, and forests less than 15 years in age), to estimate the proportion of area they occupy by subwatershed, and prioritize subwatersheds for STF efforts based on the threshold discussed above. Because recently harvested forests are typically managed for logging and rapidly re-forested with early successional species, they are only visible in remote imagery for a short period of time and thus are difficult to identify without intensive analysis. However, they are not negligible, with approximately 39% of all open lands in the south shore basin classified as recently harvested forest in 2008.

To analyze open lands, Community GIS collected LANDSAT imagery for the prior 15 years, and heads-up digitized any forest harvests in those 15 years, along with agricultural land and developed areas. Open lands were then summarized as percent area by subwatershed. This approach has several drawbacks. The analysis has been conducted and repeated based on need and funding availability at various spatial and temporal scales (Table 4). This results in incomplete and out-of-date assessments for a large portion of the basin. The assessment is difficult and expensive because it is extremely time-consuming to digitize 15 years of satellite data. Seeking funding to repeat the assessment regularly is not practical. The subwatersheds used in the assessment were derived by hand from topographic maps by the original researcher, Sandy Verry, and are not reproducible, nor compatible with standard hydrologic frameworks like the GLAHF framework (Forsyth et al., 2016) or USGS hydrologic map units. These factors limit the reproducibility and transparency of the assessment. Lastly, the subwatersheds used in the assessment are not cumulative along streams and rivers. In other words, subwatersheds in the upper basin with high percent open lands are not accounted for in subwatersheds downstream. For those reasons, an alternative affordable, regularly produced means of identifying open lands including young forests at multiple scales would be beneficial to managers. We evaluated several land cover datasets as potential options for this.

Table 4. Availability of Community GIS Open Lands analysis for the South Shore Lake Superior basin.

Name	Area of Coverage	Years of forest harvests evaluated	Completed by
Nemadji Open Lands Assessment	Nemadji Watershed	1999-2014	Community GIS
Nemadji Open Lands Assessment	Nemadji Watershed	1986-2002	Community GIS
Lake Superior Basin Open Lands Assessment	Entire Lake Superior basin in Wisconsin	1994-2008	Community GIS
Lake Superior Basin Open Lands Assessment	Entire Lake Superior basin in Wisconsin	1990-2004	Community GIS

There are several widely produced land use/land cover datasets. We reviewed the following datasets to evaluate if they could support the assessment of open lands:

- National Land Cover Database 2011 (NLCD – https://www.mrlc.gov/)
- WiscLand 2 (http://dnr.wi.gov/maps/gis/datalandcover.html)
- National Agriculture Statistics Service CropScape Cropland Data Layer (CropScape – https://nassgeodata.gmu.edu/CropScape)

We found that the CropScape dataset had the most potential for identifying open lands because it is produced annually and has the most detailed crop classifications (USDA, 2015). We used the CropScape data to identify open lands in 2014 based on the available CropScape data which included 2007 – 2014. We summarized the data for the subwatersheds used in the Community GIS analysis and compared the results to the Community GIS analysis for the same years. For additional details about the methods used in the comparison, see Appendix 3.

The summaries of open lands by subwatershed using the two methods present similar themes: steep narrow subwatersheds in the geologic transition zone between the main stem, and 1st order streams generally have the highest proportion of open lands (Figure 9). However, the percent open area of subwatersheds varied between the two estimates, often by more than 10%, with the CropScape data estimating lower percent open areas than the Community GIS analysis, especially in the upper basin.

These areas are commonly forested and logged. In a few small subwatersheds, the Community GIS analysis estimated about twice the percent open lands as the CropScape analysis.

The CropScape and Community GIS layers generally agree on agriculture and urban lands (Figure 10). However, the two datasets differ in young forests. Many young forests identified in the Community GIS analysis through an intensive review of satellite imagery were classified as forest in CropScape in all years, and thus not identified by the CropScape analysis. The Community GIS assessment was specifically designed to identify those lands directly from remote imagery, while the purpose of CropScape is generally focused on agricultural land uses, so CropScape is less accurate than the Community GIS analysis in identifying recent harvests/young forests. This is true for both the single year we reviewed (2014) as well as for the combined young forests identified using 2007 – 2014 satellite imagery.

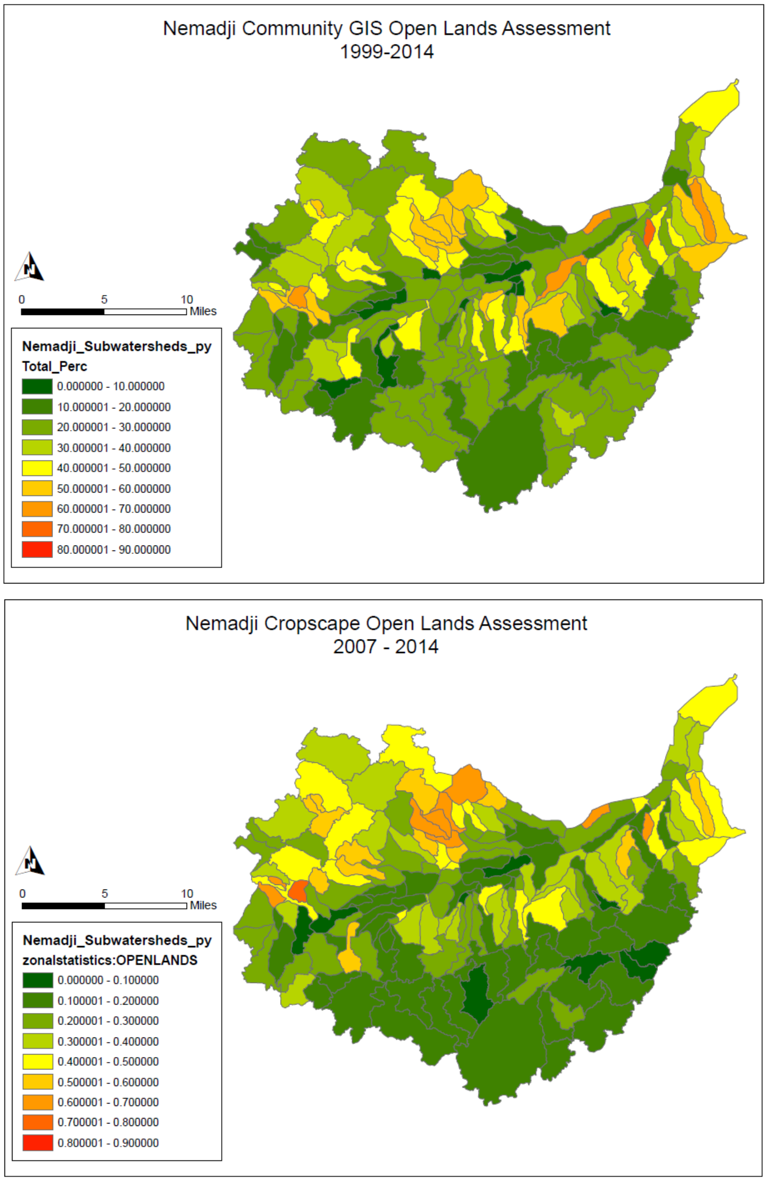

Figure 10. Summary of percent open lands in the Nemadji River watershed by subwatershed using the Community GIS analysis (top) and the CropScape data (bottom).

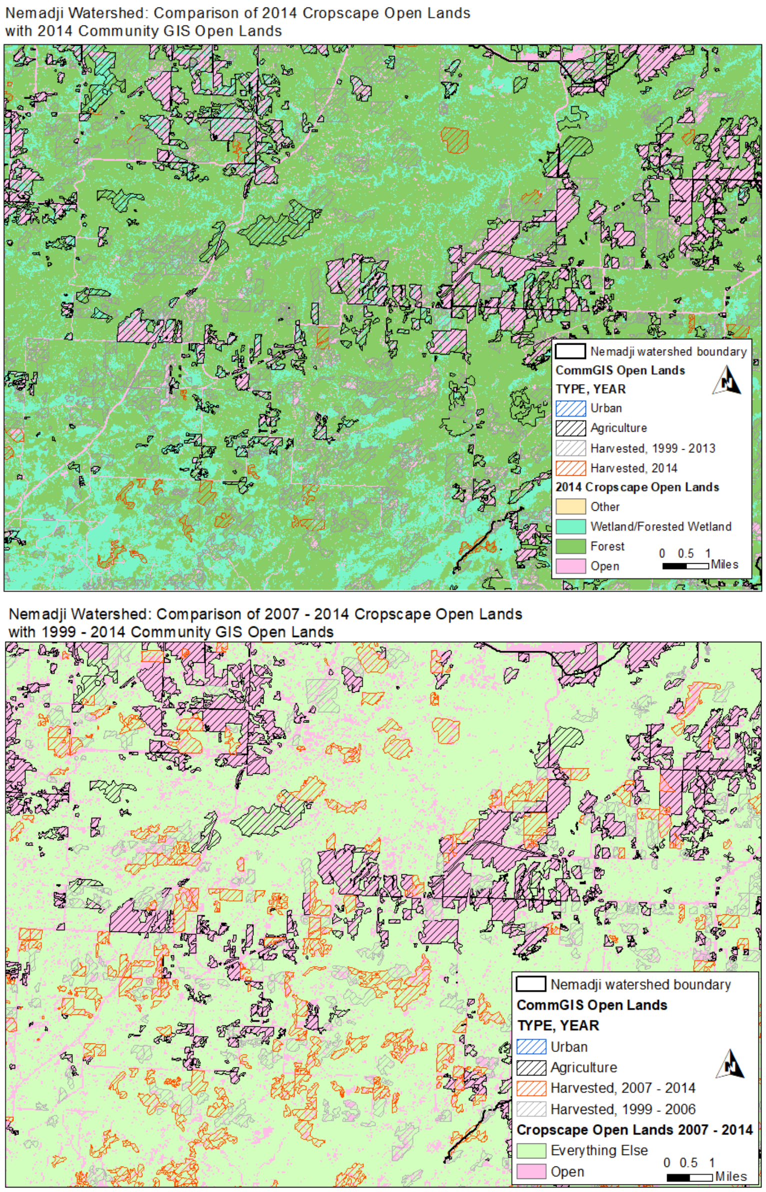

Figure 11. Comparison of CropScape open lands (pink) with urban, agricultural, and harvested lands digitized for the Community GIS analysis. The top map shows data for an individual year, 2014, while the lower map shows data for 2007 – 2014, with earlier harvest data from the Community GIS analysis shown in grey (1999 – 2006).

The WISCLAND 2 and NLCD land cover datasets also were challenged to consistently distinguish forested wetlands/shrubland/deciduous forest, so even if those datasets were reproduced regularly, they are unlikely to effectively identify young forest harvests. CropScape data may be useful for identifying watershed-wide priorities based on agricultural and developed land uses. However, if prioritization is based only on existing agriculture and developed lands, WISCLAND 2 is a higher quality dataset (with increased quality assurance and ground truthing) and should be used rather than CropScape.

Currently, the Community GIS analysis is the only available layer that includes young forests. However, it is cost-prohibitive, time-consuming, and impractical to reproduce regularly. Evaluating open lands based on agriculture and developed lands from satellite imagery, paired with recent forest harvest records, could allow managers to identify individual subwatersheds that are a priority for STF work. If this approach is used, managers should also evaluate subwatersheds in sequence, and prioritize watersheds with high open lands including recent forest harvest in the immediate subwatershed as well as in upstream subwatersheds.

Several additional methods to evaluate open lands could also be explored. Both classified LiDAR point clouds and surface elevation data can be used with thresholds to identify open lands at the time of data collection. Young forests could also potentially be classified if height (and/or density for point clouds) thresholds for young aspen stands can be determined. This continuous data could then be evaluated cumulatively to summarize the percent of open lands/young forests upstream at any location along the stream network. This effort could yield a highly accurate evaluation of open lands upstream, but still has the caveat of only representing the time of data collection and has a limited ability to be updated through time. Other methods that could be promising include the use of stereo pairs of National Agriculture Imagery Program (NAIP) imagery (collected annually), or high-resolution Digital Globe imagery to develop canopy surface elevation maps that could be analyzed to identify forest disturbance like clear cuts and wind falls (Betts et al., 2005).

Land use/land cover metrics

The same land use/land cover datasets mentioned above (WISCLAND 2, NASS CropScape, and NLCD 2016) can be used for standard metrics such as calculating the proportion of agriculture or forest by subwatershed or to identify subwatersheds that drain into certain land uses such as urban areas, poor fens, and coastal wetlands. Wisconsin Ecological Landscapes (WDNR, 2015) can be used to identify subwatersheds bridging the geologic transition zone between soil types. The Wisconsin Natural Heritage Inventory (https://dnr.wisconsin.gov/topic/NHI) can be used to identify sensitive and threatened ecosystems to help prioritize efforts.

While best management practices are important for agricultural areas, large amounts of land in high-intensity agriculture will increase peak flows within that subwatershed compared to the forest. By planning at a watershed scale, we can attempt to offset increases in peak flows on high-intensity agriculture by looking for opportunities to slow the flow on other land cover types within agricultural subwatersheds. We investigated these opportunities by identifying "transitional agriculture" lands. We define these as open land cover types that are not currently being utilized for high-intensity agriculture (row crops). These properties may be managed for open space to facilitate recreation or may have recently been taken out of agricultural production. In either case, these properties may have landowners amenable to integrating STF into their management to enhance the property's ability to retain water on the landscape.

To identify opportunities associated with transitional agriculture, we evaluated the same land cover datasets mentioned above and determined that CropScape was also the best dataset to use for this analysis. Despite the limited ground-truthing, CropScape data has more type classes for agriculture allowing us to break out high and low-intensity agriculture, and it is produced every year, which allows analysis of change through time. For this analysis, we assumed that properties not used for intensive crop production in the last five to ten years may be less likely to be used for production in the future, so these areas may be good targets for restoration. We first reclassified all the original CropScape classes present in the Lake Superior basin from 2003 – 2016 (Table 5).

Table 5 Reclassification of CropScape classes for transitional agriculture analysis.

Reclassified	**CropScape Classes (2003 – 2016)**		
Transitional Agriculture	Alfalfa Other Hay/Non-alfalfa Clover/Wildflowers	Fallow/Idle Cropland Barren Pasture/Grass	Shrubland Vetch
High-Intensity/ Row Crops	Barley Camelina Canola Corn Dbl Crop Barley/Sorghum Dbl Crop Soybeans/Oats Dbl Crop WinWht/Corn Dbl Crop WinWht/Soybeans Dry Beans Durum Wheat	Flaxseed Herbs Millet Misc Vegs & Fruits Oats Other Crops Other Small Grains Peas Potatoes Triticale Winter Wheat	Pumpkins Rye Safflower Sod/Grass Seed Sorghum Soybeans Spring Wheat Sunflower Sweet Corn
Other	Apples Aquaculture Background	Blueberries Christmas Trees Clouds/No Data	Cranberries Nonag/Undefined
Forest	Deciduous Forest Evergreen Forest	Forest Mixed Forest	
Developed	Developed Developed/High-Intensity	Developed/Low Intensity Developed/Med Intensity	Developed/Open space
Wet	Herbaceous Wetlands Open Water	Wetlands Woody Wetlands	

The most important reclassifications for this analysis include transitional agriculture and high-intensity agriculture. Transitional agriculture included all classes that represent open lands that are not intensively farmed (e.g., alfalfa, hay, prairie, idle cropland, pasture, barren, shrubland). High-intensity agriculture included all classes that represent row crops and intensive agriculture.

Based on our definition of transitional agriculture, recently logged lands could be included in the reclassification. For example, recently logged lands could be classified as barren or shrubland for 0 – 15 years after logging. These properties are managed for forestry and are typically reforested or allowed to naturally restock. Forestry BMPs should be applied, but that is not the focus of this analysis. To focus our analysis on opportunities to mitigate agricultural runoff, we also identified properties that are currently classified as transitional agriculture and were previously classified as high-intensity agriculture.

We can also overlay the results of this transitional agriculture analysis with property ownership like the Protected Areas Database, which is an inventory of protected lands in the U.S. in public ownership (Figure 15, PAD-US, produced by the USGS Gap Analysis Program, Gergely and McKerrow, 2016). From this layer, we can identify the priority transitional agricultural areas in public ownership to work with local, state, and federal government agencies for conservation efforts. For areas that do not fall within protected areas, we can work with local government units to identify and contact private landowners.

As of 2016, transitional agriculture was widespread throughout the basin, forming a swath generally corresponding to the geologic transition zone between clay and sandy soils (Figure 11). Areas that are currently classified as transitional agriculture located within Forest Service and county forest lands south of the Bayfield Peninsula and Chequamegon Bay are areas that have likely been recently logged. Areas that have been converted from high-intensity agriculture to transitional agriculture represent a reduced portion of the total current transitional agriculture and are focused in the Marengo watershed, where high-intensity agriculture is found (Figure 32). Most of the areas converted to transitional agriculture from high-intensity agriculture are on private lands, as would be expected. Approximately 27% of the areas classified as transitional agriculture in 2016 were classified as transitional agriculture for the entire period of analysis (2006 – 2016).

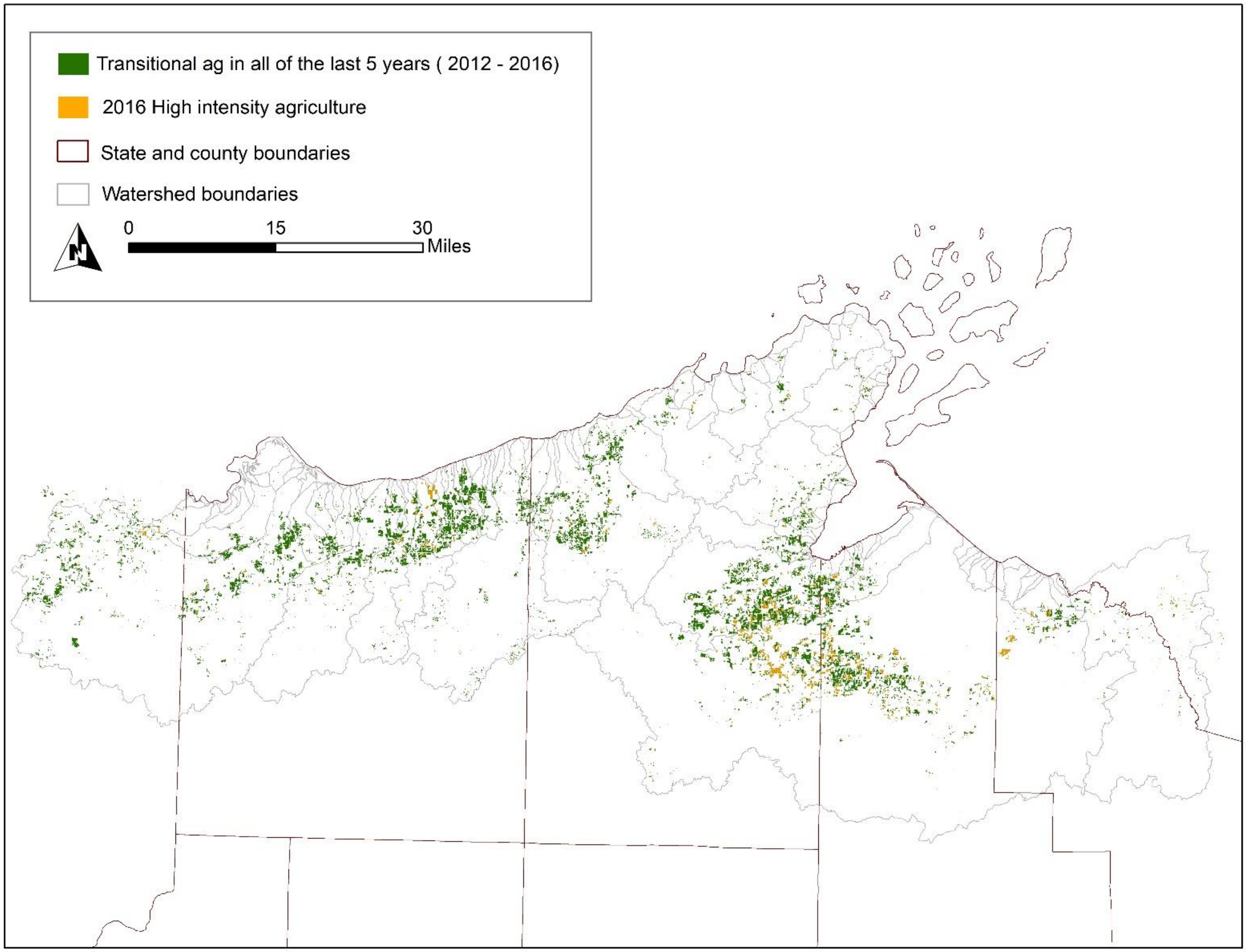

Figure 12. Properties that were classified as transitional agriculture classes in every year of the most recent five years (2012 – 2016)

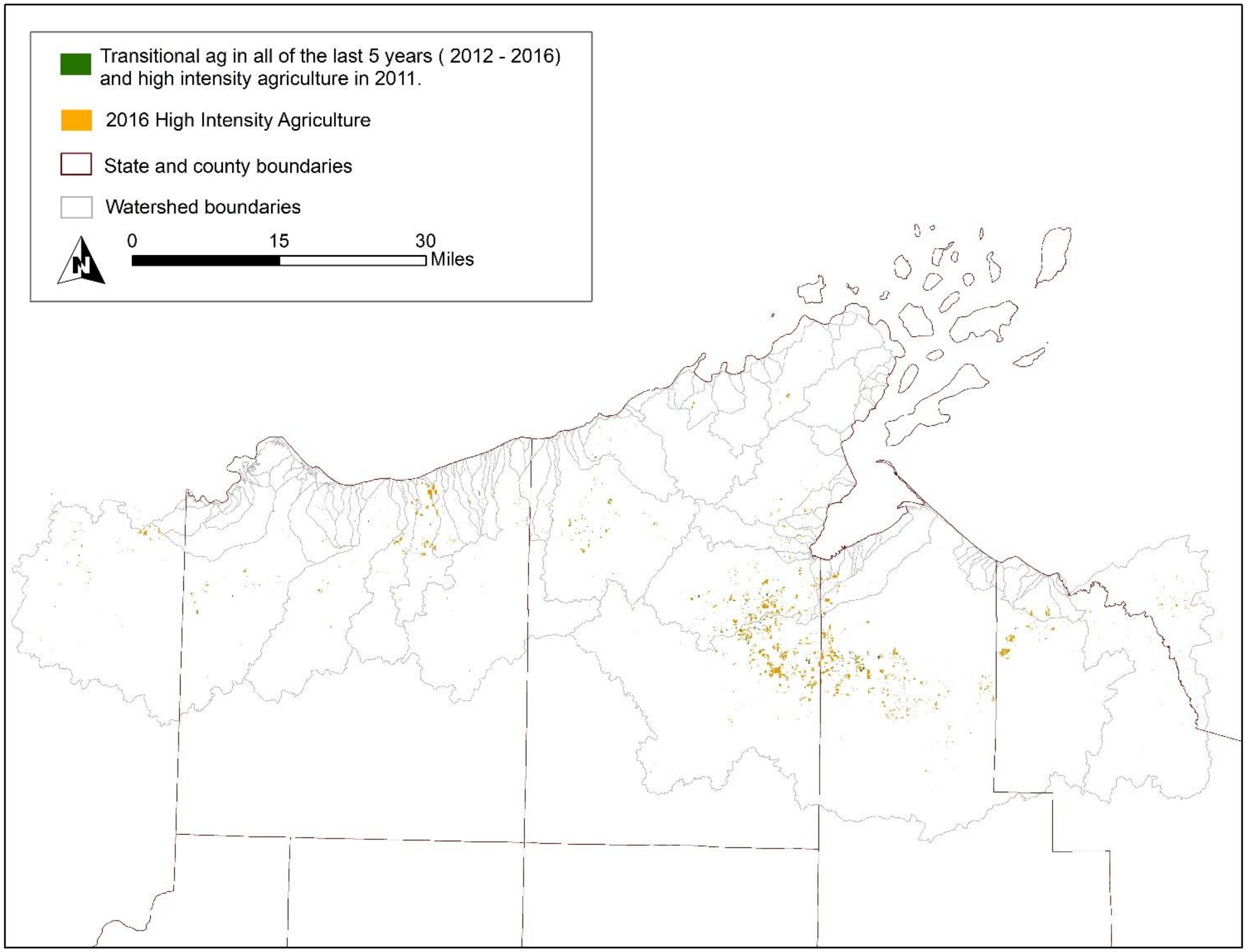

Figure 13. Properties that were classified as transitional agriculture classes in every year of the most recent five years (2012 – 2016) and were classified as high-intensity agriculture in the year prior (2011).

Future needs

There are many challenges to implementing a watershed-scale strategic approach to slowing the flow in Wisconsin's Lake Superior Basin. Here we summarize some of the biggest challenges and the research, monitoring, or collaboration needs to address them, by land use type. We received a lot of valuable ideas from reviewers and resource managers during a Slow the Flow discussion session at the April 2022 Lake Superior Collaborative Symposium. We were not able to incorporate all the feedback provided into this report, but we include documentation of this feedback in Appendix 1 to help inform future work.

Watershed storage and wetland restoration

We recommend identifying and mapping ditch networks throughout the Lake Superior Basin. The availability of high-resolution LiDAR data throughout the majority of the Lake Superior Basin will allow managers to remotely map current and historic ditch networks throughout the watershed (e.g., Bailly et al., 2008; Rapinel et al., 2015; Passalacqua et al., 2012; Trettin et al., 2009; Devereux et al., 2005). Generally, to map ditch networks, a drainage network is derived from the LiDAR-derived Digital Elevation Model (DEM) and then cross-checked with high-resolution imagery and LiDAR intensity data. Exact methods are generally developed for specific regions/watersheds and then field-verified, to account for differences in vegetative communities, soils, and other landscape characteristics. Once methods are established for a given region, procedures to delineate ditches can be semi-automated to increase efficiency. The derivation of an inventory of historic and current/active ditches would allow managers to identify areas that are unlikely to be used for agriculture in the future and target wetland re-establishment in historic ditches.

Limited monitoring has occurred on USFWS wetland restoration sites in the basin, mainly consisting of construction specification monitoring and before and after photos. We recommend enhanced monitoring to include and determine the surface water retention capacity of restored wetlands. Hapner (2006) published a protocol for monitoring wetland restoration sites that could be adopted to estimate the storage capacity of restored wetland sites.

There are many high-quality wetlands throughout the basin that should be prioritized for protection. Although this report focuses on the hydrologic restoration of streams, the protection of existing watershed storage is extremely important. The wetland datasets discussed herein could be used to identify priorities for the protection of existing watershed storage to incorporate into a watershed-scale strategic approach.

Forestry

The Lake Superior basin in Wisconsin is mostly forested. At a smaller spatial scale, there are areas of non-forest lands that have a disproportionate influence on stream flow in the region. To use the extent and composition of land cover and a dynamic management tool, we need a repeatable and readily available mechanism to characterize the amount of open land in the basin. The previous approach, described above in Parameter data sources: Open lands is time-consuming, requires specific expertise, and is expensive. Repeating this analysis regularly is not feasible. Obtaining reliable data for open lands and young forests may depend on establishing direct partnerships with the forestry community to map and understand where logging occurred to prioritize BMPs for these temporarily open lands.

LiDAR data was acquired in 2015 -2016 for all of the Lake Superior basin counties of Wisconsin. LiDAR data can be used to characterize many attributes of forest stands (see review in Muss, 2011), although it may be less useful for characterizing open lands. Other remote sensing techniques for characterizing land cover have been developed. NOAA's Office for Coastal Management supports a Coastal Change Analysis Program (C-CAP) that describes regional land cover and changes in land cover types. C-CAP datasets are updated every 5 years by deriving land cover type from remotely sensed Landsat imagery. Land cover is classified into 25 land use categories at 30-meter resolution. Online data visualization tools summarize change by HUC 8 watershed; however, data can be downloaded to examine conditions at smaller spatial scales. Recently NOAA has begun to provide high-resolution (1m) C-CAP data for selected areas. Currently, this is not yet available in our area of interest but may be in the future.

More research is needed on the effects of Emerald Ash Borer on streams including the effects of ash tree die-off on stream flow and sediment loading. Research should also continue focusing on the impacts of climate change on forest and riparian ecosystems especially projected shifts in forest species distributions, and how these impacts affect hydrology and streamflow.

Agriculture

Research is needed to better understand causal relationships between BMPs and hydrology. Long-term monitoring is required to detect changes in hydrology resulting from even the extensive implementation of BMPs (Meals and Dressing, 2016). Evaluation of the effectiveness of BMPs in influencing hydrology must consider that the effectiveness of BMPs may vary seasonally. For example, practices that increase overland roughness (grassed waterways, conservation tillage) may not be effective during early spring snowmelt or rain on snow events. Other practices, such as grade stabilization structures may be more effective during these time periods.

Specifically, we recommend implementing research and monitoring programs that will:

- Quantify the extent and severity of soil compaction in the agricultural regions on the clay soils within the Lake Superior basin with a focus on seasonal soil surface compaction and sub-soil compaction from traditional moldboard plowing.
- Quantify the change in infiltration rates achieved by various methods to remove the compaction and extrapolate the resultant impact on peak flows.
- Implement field-edge monitoring to develop a local understanding of the impacts of waterway management and the conversion of perennial forages to annual row crops on peak flows.
- Quantify the impact of short-rotation woody biomass plantings on snowmelt and runoff in comparison to early-succession fields, traditional agricultural crops, and young aspen stands.
- Investigate key-line (subsoil) plowing and other hardscape management practices that retain water on the landscape without forming ponds or other retention basins.
- Determine the extent to which concentrated flow areas have developed in existing filter strips.

Lastly, existing state and federal agricultural regulations do not prohibit the conversion of upland forests to agricultural lands, except as it relates to federal "swampbuster" rules. The swampbuster rules allow for farming former wetlands converted to farming before 1985. With the extensive drainage networks remaining in reverted forestlands in the basin, it is unclear whether new clearing of this forestland and maintenance of the drainage networks would fall under the prior converted provisions. Clarifying this issue is important. Prohibiting the clearing of forestlands that would be forested wetlands in the absence of the relic drainage networks would help mitigate the hydrologic impacts of new forest clearing. Since 1985, farmers that fill or drain wetlands, including forested wetlands, risk losing USDA program benefits. If additional forest clearing is anticipated in the region, it will be important for USDA and WDNR staff to inform farm producers of the federal swampbuster rules and ensure compliance.

Additional needs

Ongoing and increased collaboration

In general, for regulated industries like forestry and agriculture, complying with existing policies can undermine profitability. Expecting high compliance with additional watershed protection measures is unrealistic. It will require a major collaborative effort across the basin including education of land owners and managers on new approaches and tools to aid in the implementation of watershed management. Another major limitation is that 303(d) funding for watershed restoration work requires a 9 Key Element Plan, which requires initial resources and funding to develop.

To address these several challenges, it will be necessary to bring together stakeholders from all relevant fields. The Lake Superior Collaborative has the capacity to do this. The collaborative can begin establishing relationships and partnerships with forestry and agriculture managers and advocate for watershed considerations in land-use planning on forestry and agriculture lands, across the basin. The collaborative also can obtain funding to advance watershed planning efforts.

Building on existing relationships with Tribal natural resource agencies to support treaty rights is a priority. Both Bad River and Red Cliff have active environmental and natural resources departments in the basin that are regularly engaged in regional partnerships. Both departments work closely with EPA and other Federal agencies. The Bad River Tribe obtained CWA authority of 303(c)/401 in 2009 and has had EPA approved water quality standards since September 2011. Both Red Cliff and Bad River have a CWA 319 non-point source program, as well as CWA 106 authority (Bad River Band, 2011; VanBergen and Nguyen 2018).

This report and the recommendations herein are based on a review of primary scientific and institutional literature. We also recommend considering Indigenous and local community knowledge as equal to and complementary to institutional knowledge in decision-making. Indigenous Knowledge and traditional ecological knowledge are place-based and have evolved through generations of knowing and living in a place. These knowledge systems are held by local communities, are often sensitive, and can be sacred. Elevating the role of these ways of knowing in decision-making will also likely require building on existing relationships with Indigenous and local communities. It may be helpful to establish norms for the ethical incorporation of multiple ways of knowing in decision-making. In addition to supporting treaty rights, it is also important to fulfill trust responsibilities to tribes in areas where the state is implementing authority delegated from the federal government for, example, CWA and CAA delegated authority.

Monitoring and data management

Another major need is ongoing monitoring and data management so that the effectiveness of BMPs implemented at a watershed scale can be quantitatively evaluated. This means continued and possibly expanded funding for stream gauges and flow monitoring. Evaluation of slow the flow effort effectiveness should include characterization of full cost per acre benefits, including time to recruit and convince landowners to restore wetlands. This cost could then be projected to a scale at which such restoration projects would have a meaningful impact on slowing the flow. In addition, ecosystem service and human well-being indicators should be explored to evaluate how efforts translate to benefits for communities, especially in partnership with the Lake Superior Collaborative and basin-wide partners.

Funding and coordination of a data management system are also a need. Many existing systems host data relevant to slow the flow efforts but are unable to integrate multiple datasets in a single place where they can be easily reviewed, analyzed, or shared. There is potential with ArcGIS Online and other available platforms to manage existing and future datasets, but this requires staff time and funding, which have yet to be identified.

Conclusion

We advocate for a strategic watershed approach for implementing slow the flow efforts in the Lake Superior basin. Challenges to accomplishing this include variation across the basin in biophysical attributes of the landscape, (native land cover, geology), the socio-political culture, and the history of land use change. Watersheds within the basin differ in their recent history of public and private engagement in land conservation. These and other factors contribute to the complexity of carrying out a basin-scale strategic approach. In support of this goal, we have summarized the main parameters that can guide prioritization of slow the flow efforts across the basin. These parameters and criteria can be applied as needed for local management across the basin, or potentially combined in a decision support tool to provide basin-wide recommendations.

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Appendices

Appendix 1: Summary of Input

This paper has undergone the official DNR internal review required for publication. Along the way, we have also reached out to resource managers in the basin for feedback and review. This effort started in 2015 as a task of a work group that included managers who were interested in the creation of this document to summarize past work and provide information on how to prioritize work areas. This group of people has been included throughout the writing process. In 2020 as the draft became more final an opportunity for feedback was provided by WDNR and WWA. In 2022 the Slow the flow team was re-invigorated as a working group of the Lake Superior Collaborative. At the 2022 Lake Superior Collaborative Symposium, we shared a draft of the executive summary and recommendations with participants. Below is the feedback we received throughout the writing process. We include documentation of this feedback to help inform future work. We thank everyone who has provided feedback and support for this report.

<u>Lake Superior Collaborative Symposium feedback</u>

- Need to consider incorporating preventing the movement of seed banks from place to place when hauling fill, moving equipment, etc. for Slow the Flow projects, and properly cleaning equipment before moving into contracts.
- There is a lack of Traditional Ecological knowledge within this document. For future work, we would like to gain a better understanding of how these practices may integrate into STF efforts in the basin. More needs to be done to incorporate TEK in Decision making.
- There is a need to institute bankfull width as a standard for all stream crossing replacements.
- In the future, it would be interesting to connect slow the flow efforts with FEH to the susceptibility of flood energy overcoming the resistance potential of channels upstream of road crossings.
- It would be useful to connect the hydrologic hot spots found in slow the flow with erosion potential and then link to headwater wetlands, ditching, and mass-wasting potential.
- Moving forward it might be useful to work with UW extension, and others to distill Slow the Flow information for different sectors (Forest, Ag, Urban, etc.) and landowners, and managers.
    - This will aid in the implementation of recommendations. It is suggested that work groups are created for each sector under the L.S. Collaborative slow the flow work group.
    - Workshops to share information by sector may be helpful to share recommendations
    - Suggest the creation of topic-specific info pages to spark interest and make the larger doc more absorbable, such as factsheets targeted towards user groups.

Reviewers Comments:

It is known that soil health is connected to slow the flow and water quality. NPS recommendations focus on soil health, particularly increasing the % of organic matter in the soils. In other clay soils, more current WI NPS strategies include increasing the organic carbon content of the soils to increase infiltration, even in clay soils. This involves a suite of BMPs (mostly in row crop settings) that include continuous cover, no-till or low till, and low disturbance manure application. These relationships should be explored more in the future and how they apply in the Lake Superior Basin.

There are additional policy options that could be explored such as runoff trading. Wisconsin has an established P trading framework and an adaptive management strategy associated with WPDES permits. Streambank stabilization is included in the trading program framework and there are existing trades that include this practice. How this applies to slow the flow work in the Lake Superior basin should be investigated further.

Appendix 2: Background and additional information regarding Lake Superior's watershed

Wisconsin's portion of the Lake Superior basin covers 2 million acres or approximately 3,070 square miles (Turville-Heithz, 1999) and is bound by Lake Superior to the north at an elevation of approximately 183 meters and the continental divide between the Mississippi/Gulf of Mexico drainage to the south at an elevation of approximately 549 meters.

Bedrock and glacial geology

The Lake Superior basin was created during a period of extension known as the Midcontinent, or Keweenawan Rift about 1.1 billion years ago. The rifting resulted in the deposition of volcanic rocks varying from rhyolite to basalt, including flood basalts that can be seen along the north shore of Lake Superior (Miller and Nicholson, 2013). As rifting activity declined, a thick sequence (up to 7km) of Paleozoic sedimentary rocks were deposited in the region, including the Upper Keweenawan Bayfield sandstones that can be seen along the south shore of Lake Superior (Cannon et al., 1999; Nicholson, 2006).

Glacial action is largely responsible for the relief of Wisconsin's Lake Superior basin and forms the foundation over which land cover and the hydrologic network became established. The landform in the basin is strongly influenced by more recent pulses of glaciation during the Quaternary when the Laurentide Ice Sheet occupied the Keweenawan Rift Basin (Syverson and Colgan 2004). The most recent stage of the ice sheet, the Wisconsinan, occurred approximately 75,000- 9,500 radiocarbon years before present (BP). During the Wisconsinan stage, the Superior lobe advanced and retreated from the northeast to the southwest numerous times, carving the Lake Superior basin coincident with a portion of the Keweenawan Rift.

Five major phases of the Superior lobe have been identified based on local stratigraphy: the St. Croix, Automba, Split Rock, Nickerson, and Marquette phases (Need and Johnson, 1984). Earlier phases are not recorded in the sedimentary record due to the re-working of material by the ice sheet after subsequent advances. Each phase advanced less extensively to the southwest and deposited associated ground moraines (blankets of glacial till covering the landscape), end moraines at the furthest point of advance, and outwash deposits (Wright, 1971). Successive advances of the Superior lobe resulted in the deposition of glacial tills consisting of redder, more fine-grained sediments. During periods of retreat, proglacial lakes formed between the front of the ice lobe and the end moraine; and deposited fine-grained sediments in deep lacustrine environments and coarse-grained sediments in high-energy shoreline environments (Wright et al., 1969).

During the Marquette Phase, the final re-advancement of the Superior Lobe, about 9,900 years BP, the ice advanced to the Thompson and Nickerson moraines, which were formed during the prior Nickerson phase. As the ice sheet advanced, thick layers of till were deposited on top of the reworked lake and beach sediments were deposited in the proglacial lake during the retreat of the earlier Nickerson phase. As the ice retreated, a proglacial Lake Nemadji formed, draining to the south through the Portage Outlet, at the western edge of the present-day Nemadji watershed. The lake level at that stage was

1100 – 1150 ft. Once ice retreated further, Lake Nemadji coalesced with Lake Minong to the east and water began draining to the south along the lower Brule River outlet (Clayton, 1984, Carney, 1996). At this stage, the water level was 325 meters, and the proglacial lake is referred to as Glacial Lake Duluth. As the ice retreated further to the northeast, an outlet to the east through the St. Laurence Seaway eventually opened, resulting in a dramatic decrease in lake level to about 122 meters (Wright, 1971, Farrand, 1969).

Because of the repetitive advances of the Superior Lobe and subsequent proglacial lakes, the deposits along the southern margin of Lake Superior consist of interbedded ground and end moraine tills that become finer and redder up-section; beach and outwash sands and gravels; and red lake clays. Glacial advances into proglacial lakes reworked lacustrine deposits, making it difficult to distinguish between lacustrine clay and clay till (Olcott et al., 1978). The red clay plain blankets the area from Lake Superior inland for 8 – 20 miles throughout Wisconsin, with thin deposits near bedrock outcrops to deposits over 182 meters thick in lower parts of the watershed. In the upper watershed, a mix of glacial drift and glacial till results in soils that range from well drained to somewhat poorly drained and a greater proportion of sandy loam textures.

The base level for South Shore streams is defined by lake levels in Lake Superior, which dropped by 45 m during the Lake Minong phase (Breckenridge, 2013). The sudden drop in base level may have caused the tributaries of Lake Superior to incise their channels into the glacial tills and lacustrine sediments, carving steep-walled valleys, and dissecting the landscape (Breckenridge, 2013). The retreat of the Laurentide ice sheet has resulted in an isostatic rebound of the depressed continental crust, and an ongoing rise in base level for South Shore streams (Tushingham, 1992). Rates of isostatic rebound were fastest immediately after glaciation and have slowed since then (Neff and Nicholas, 2005). Rates are higher where the ice was the thickest in the northeastern portion of the Lake Superior basin (Neff and Nicholas, 2005). Lake Superior's outlet at Gros Cap on the northeastern side of Lake Superior experiences an average predicted uplift rate of 36 cm/century, while the southwestern end of Lake Superior in Duluth experiences about 5 cm/century (Tushingham, 1992). The current base level of about 183 meters was reached at about 5,500 BP. The rise in base level and tipping effect of isostatic rebound, with faster rates to the northeast, has resulted in the drowning of the river mouths of tributaries flowing into Lake Superior from the south. These shallow, drowned river mouth conditions resulted in the flooding of incised river valleys, and the presence of estuaries and coastal wetlands like Bark Bay and Fish Creek Slough along the southern margin of Lake Superior.

The soils in the south shore area are mainly derived from glacial deposits derived directly from ice transport, or indirectly from meltwater or wind transport (Schaetzl, 2015). Alfisols dominate in the coastal areas of Lake Superior, shown in Figure 2 as forested, red, clayey, or loamy soils (Schaetzl, 2015). Aquic soils, with low permeability and minimal runoff, are generally restricted to wetland areas (Schaetzl, 2015). Most bedrock is either buried by glacial drift or scraped clean by ice (Schaetzl, 2015).

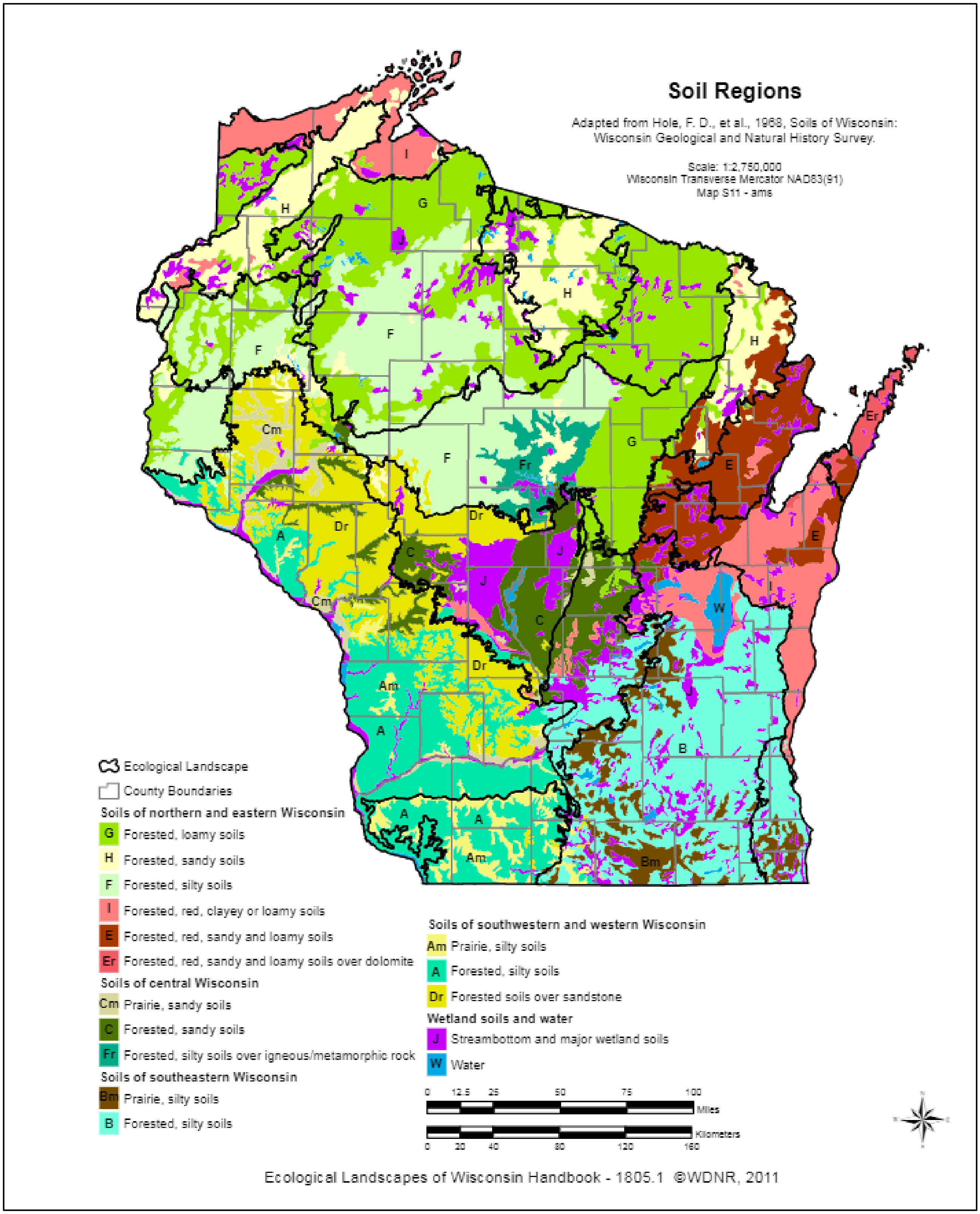

Figure 2. Soil Regimes of Wisconsin (from WDNR, 2015b).

The hills in the central portion of the Bayfield Peninsula are covered with 15-30 meters of glacial drift (WDNR, 2010), with some areas up to 182 meters of outwash material, primarily sand or sand mixed with gravel. This area is referred to as the Northwest Sands. Soils here drain rapidly, and as a result, 161 mi^2 in the central Bayfield peninsula does not contribute to surface runoff (Fitzpatrick et al., 2015; Figure 3) and is considered the primary groundwater recharge area in the region (Fitzpatrick et al., 2015). Cooper Falls and Miller Creek soil formations, sandy till material, and clayey glaciolacustrine deposits, respectively, overlay Bayfield group bedrock (Goebel et al., 1983; Clayton, 1984). These deposits are tens to hundreds of meters thick in the highlands and thin as they near Lake Superior (Fitzpatrick et al., 2015). Where the Miller Creek Formation is present it overlays both Cooper Falls and Bayfield bedrock (Fitzpatrick et al., 2015). The clayey Miller Creek deposits and sandy Cooper Falls formations are differentiated by a set of relict shorelines from glacial Lake Duluth (Fitzpatrick et al., 2015). In some areas Miller Creek deposits may have been removed by the wave action of Lake Duluth, exposing older Copper Falls deposits of sandy till or stream/shoreline sand and gravel (Clayton, 1984).

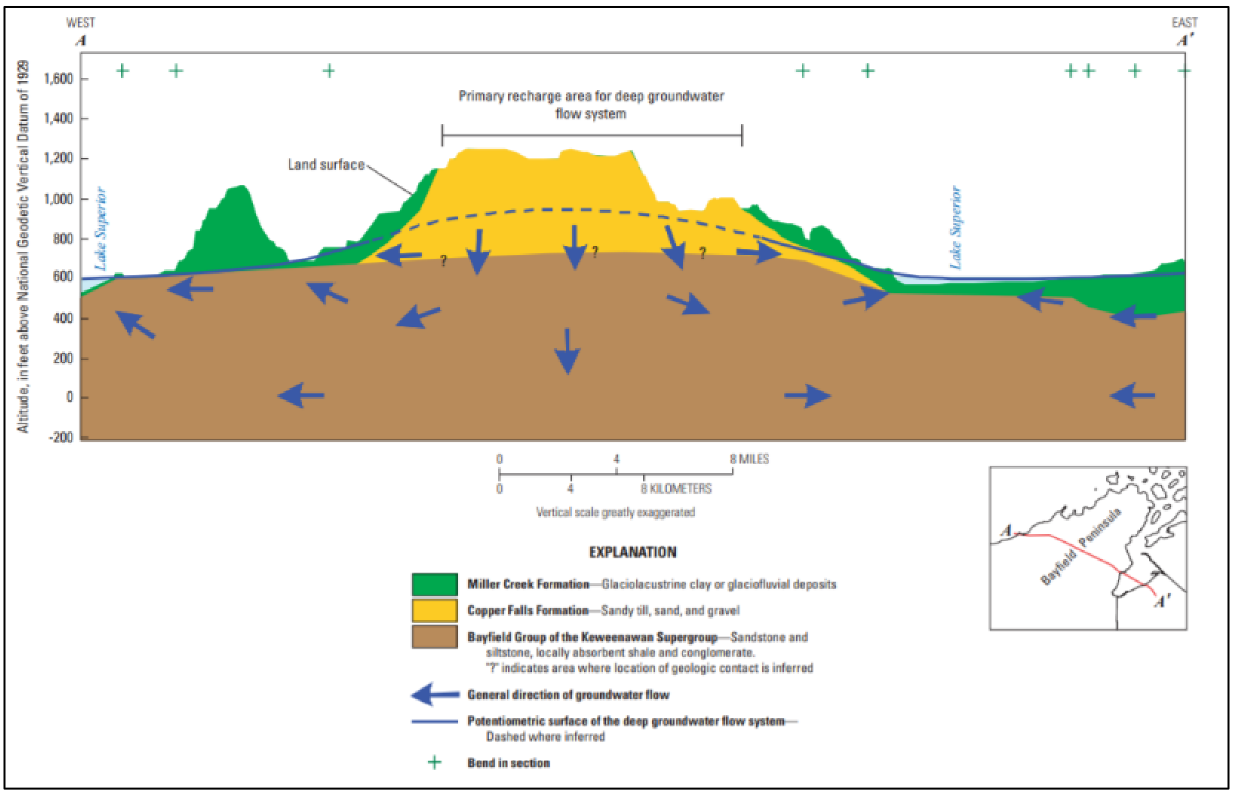

Figure 3. A schematic cross-section of the geology and groundwater flow patterns across the Bayfield Peninsula. Figure from Fitzpatrick et al., 2015.

Land cover

An understanding of land use in Wisconsin's portion of the Lake Superior basin since European settlement can help us understand associated hydrologic changes. However, returning to pre-settlement conditions is not feasible and is not a management objective for most areas in the Lake Superior basin.

Native American tribes have inhabited the region for centuries. The Ojibwe people migrated from eastern North America to the northern Great Lakes region in the late sixteenth or early seventeenth century (Danziger 1979). When they arrived in the area, the Ojibwe established economies and lifestyles based on forest and wetland resources, including paper birch, which was used for canoe building, sugar maple, woodland game, wild rice beds, fur-bearing mammals, fish, and small-scale, and semi-permanent gardens, which shaped the areas they lived in (Steen-Adams et al., 2011). While the impact that the Ojibwe way of life had on the landscape in the Lake Superior basin was much less than that of European settlers, they did transform the lands that they settled (Steen-Adams et al., 2011).

Pre-European settlement land cover was a mosaic of forest types dominated by mixed conifer-deciduous forest (Figure 4). The red clay plain was historically covered with boreal forest containing white spruce, white cedar, balsam fir, and white pine and mixed conifer forests of hemlock, sugar maple, yellow birch, and white pine (WDNR, 2010). Birch-aspen forests were present, with conifer bogs and wetland communities more common in upper watershed areas.

European settlers migrated to the region in the mid to late 1800s and began clearing forests for timber. After the cutover of Lake Superior basin forests in the late 19th and early 20th centuries by European settlers, immigrants moved to the region to begin farming. Settler land use practices (extensive historic logging, intense burning, and agriculture) resulted in the conversion of most boreal forests to aspen-dominated communities (Figure 5, WDNR, 2015a). Throughout the northern portion of the state including the Lake Superior basin, forest composition still reflects the legacy of European settlement. For example, hemlock and white pine forests have declined in the area from 22% to 1% since European settlement (Rhemtulla et al., 2009). The structure of the forests also shows substantial differences from pre-settlement times. The proportion of medium- and large-diameter trees of all species has declined from 71% to 27% (Rhemtulla et al., 2009).

Settlers found that the short growing season and challenging soils made farming difficult in the region. The number of farms and area of land in agricultural production in the region peaked in the 1920s and has been declining since then, with significant reversion to forestland and no widespread forest clearing since then (Krog, 1996). The first farms to fail were those located on the well-drained, sandy glacial tills along the margin of the Superior Clay Plain. These soils had very low organic matter and were prone to significant crop loss in dry years. After spring and fall rains, it can take 5-7 days, even with engineered drainage, for Clay Plain fields to dry enough to till. As a result, agriculture in the clay plain is dominated by perennial forage production that does not require an early-spring seeding or a late-fall harvest when soils are most challenging. Of the 52,000 cropland acres in Bayfield County, 87% are in grass hay, alfalfa, clover, or pasture (USDA, 2015). Although the soils and climate are conducive to producing high-quality forage, hay, beef, and dairy, enterprises have struggled to compete in the low-price commodity markets and the number of farms, particularly dairy farms, continues to decline. In Bayfield County, the most farmed county in the Wisconsin portion of the Lake Superior basin, there were 850 total farms in 1970, but by 2017, the number had declined to 427. There were 112 dairy farms in 1992 and fewer than 30 still in operation in 2015 (NASS 2012).

Agricultural production in the Lake Superior Basin is now concentrated in a few areas: along state highway 169 in Ashland and Iron County, the Marengo Valley near Ashland, the Benoit and Mason areas and between Iron River and Port Wing, and north of state highway 2 in Douglas County. Like elsewhere in the Upper Midwest, this remaining production is increasingly concentrated in large farms. From a watershed management standpoint, this means that management decisions by individual farmers have a significant local impact on the watershed. This potentially makes efforts to implement conservation practices more efficient as there are fewer managers to work with. All the Land and Water Conservation plans for the four counties across the basin identify slowing the flow of agricultural lands as a priority (Douglas County, 2009, Bayfield County, 2010, Ashland County, 2010, Iron County, 2010).

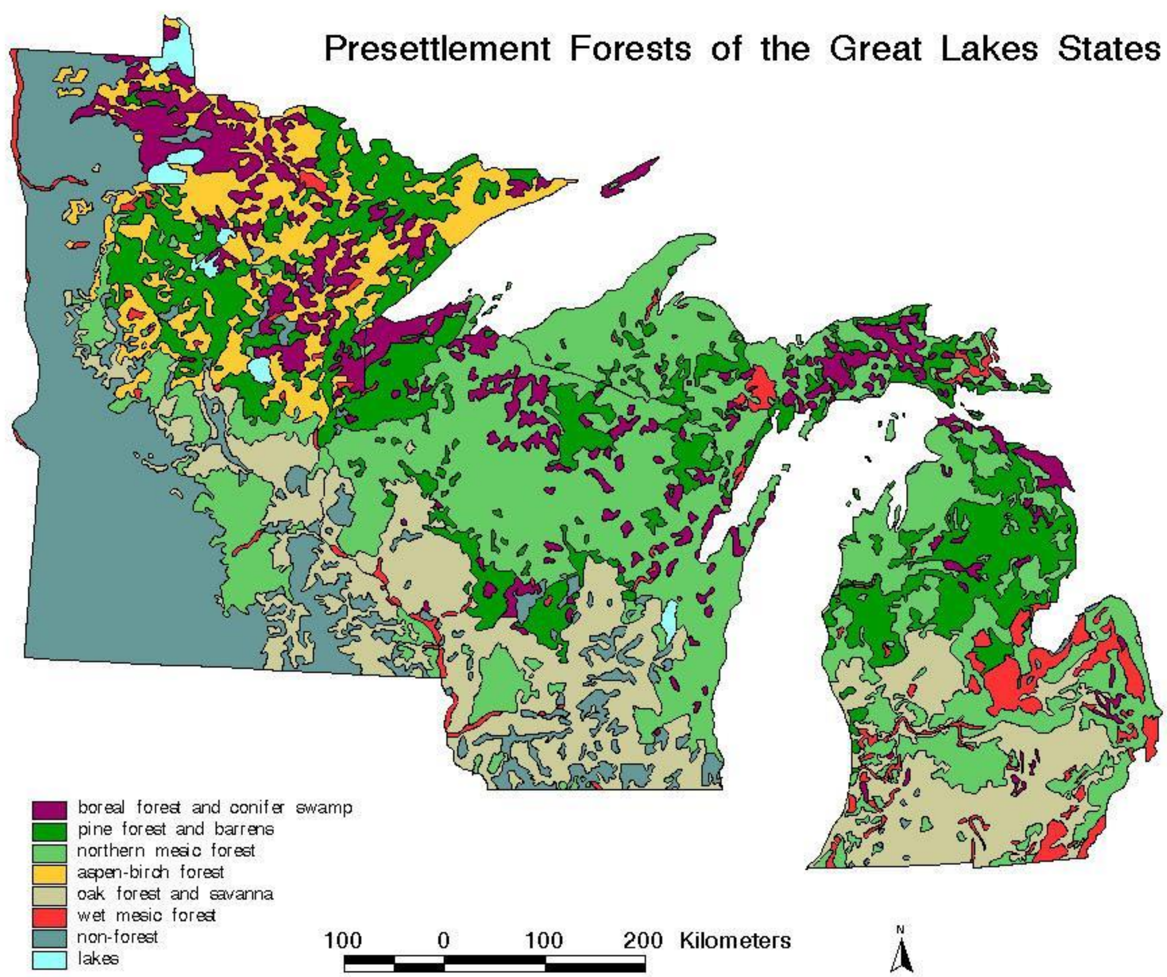

Figure 4. Pre-Generalized map of pre-settlement vegetation map of the western Great Lakes region. Note the prevalence of boreal forest and conifer swamps in the Lake Superior clay plain (see Figure 2). Map from Sisk, 1998.

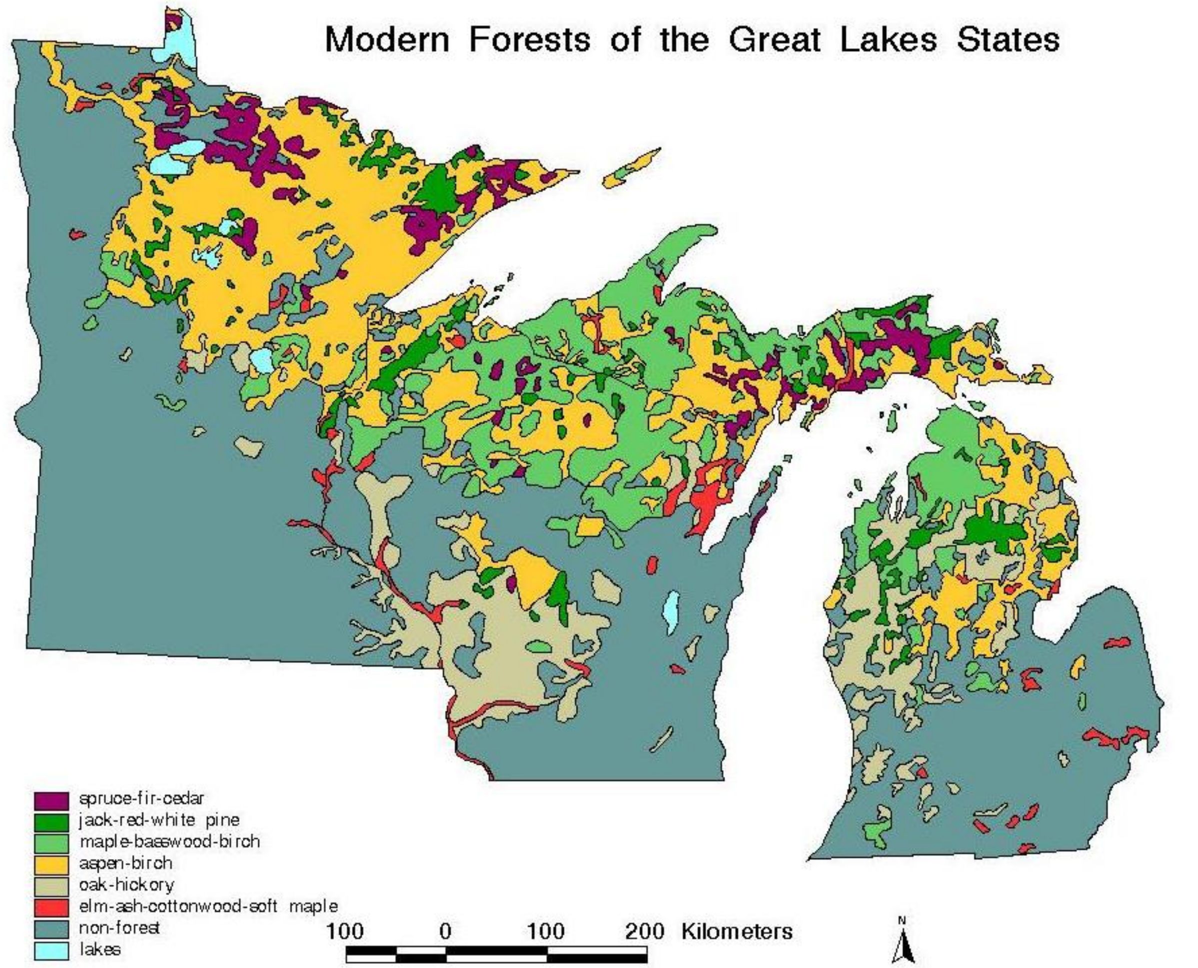

Figure 5. Contemporary vegetation map of the western Great Lakes region forest of the Lake Superior basin. Note the modern prevalence of aspen-birch forest on the Lake Superior clay plain (see Figure 2). Map from Sisk, 1998.

The xeric, well-drained soils of the Northwest Sands in the central part of the Bayfield Peninsula historically supported jack pine, white pine, and red pine barrens (Figure 4); this fire-prone landscape also supported scrub oak. Fire in this landscape was historically ignited by lightning. Ojibwe also used fire to enhance berry production (Martin, 2019). Today, the lack of fire on the landscape along with other land use practices (grazing by cattle and deer, rural development, and plantation forestry), has resulted in the conversion of these formerly pine-barren communities to forested communities (WDNR, 2015a).

Climate change projections

The Wisconsin Initiative on Climate Change Impacts (WICCI) Climate Working Group's downscaled climate models predict increases in air temperature under high and low emissions scenarios for the state. These models predict an increase in the average number of days per year with a minimum temperature of 21°C from 0 days (1981-2010) to 5 days (2041-2060) (Figure 6). WICCI (2011) projects an increase of 2 to 5°C by the mid-21st century, with most of this warming in winter (Figure 6). Overall, Wisconsin has become 1.2°C warmer since the 1950s (dnr.wisconsin.gov/climatechange/science). Air temperature projections mean changes in evaporation and transpiration which affect hydrologic patterns. The rate of warming may outpace the rate at which ecosystems are able to migrate and adapt (Loarie et al., 2009). An updated report was released in 2022 and analyses of historical climatic changes over the last 10 years, especially seasonal warming, precipitation changes, and increases in extreme climatic events, are qualitatively consistent with expectations from WICCI's 2011 Assessment Report. A few of the major takeaways from the updated report are that winters are warming more rapidly than any other season, and nighttime temperatures are rising more than daytime temperatures. It is anticipated that by mid-century, the number of extremely hot days (32°C or higher) in Wisconsin is likely to triple, and the frequency of extremely warm nights (low temperature of 21°C or above) is projected to quadruple.

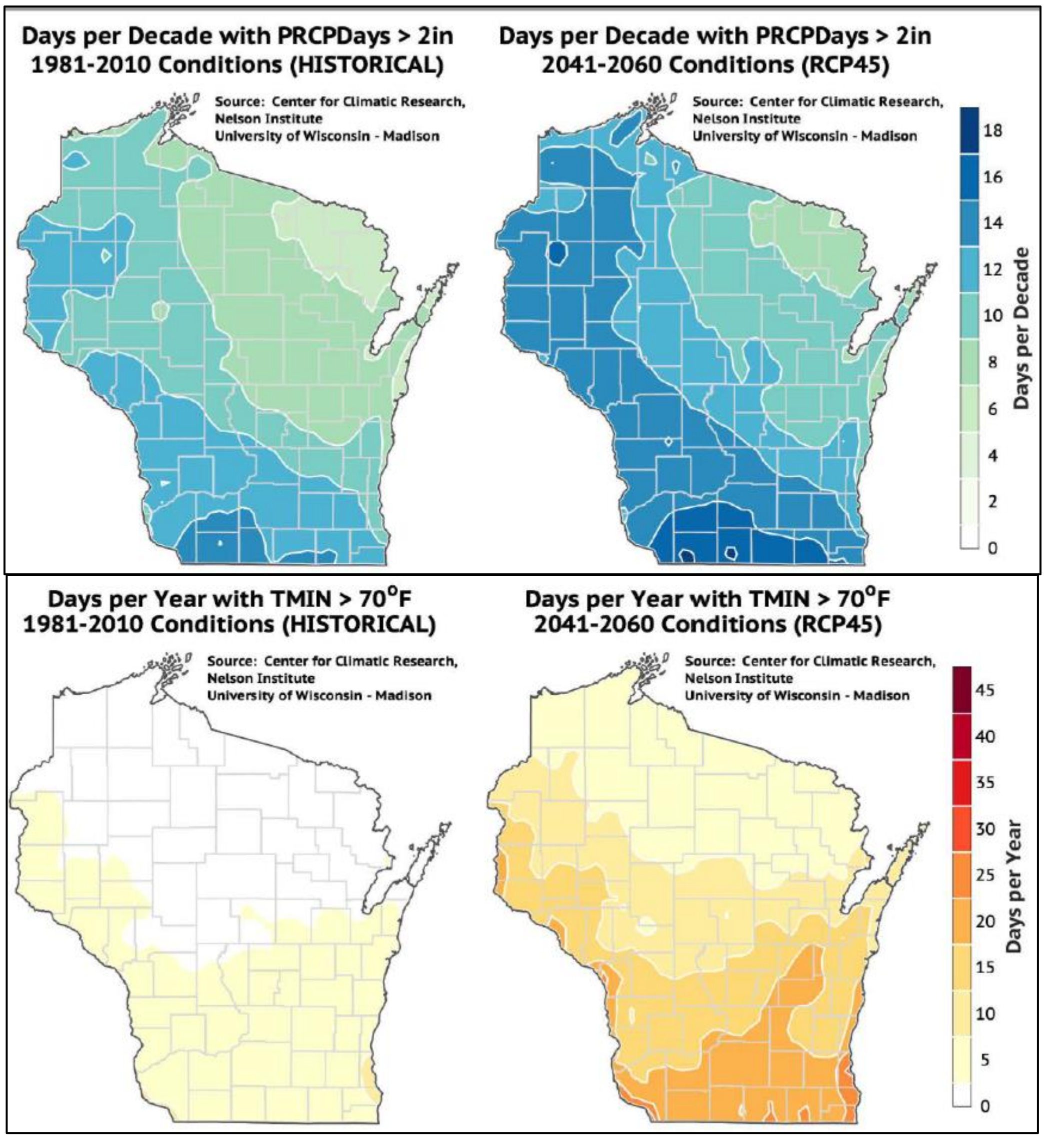

Figure 6 Maps comparing rain and temperature for historical data and modeled future conditions (Figure from WICCI, 2022).

Precipitation occurs rather evenly throughout the year in Wisconsin's Lake Superior basin, with some spatial variation across the basin in the amount of precipitation and the distribution of precipitation as snow or rain. Based on a 30-year record from 1981 – 2010, precipitation as snow occurs throughout the area generally from November through March and is greater in the eastern portion of the basin and at higher elevations. Snowfall averages 139 cm near Superior, WI at the west end of the basin and 422 cm near Hurley, WI, near the east end of the basin (NOAA and NWS, 2021). WICCI (2013) models project a 20 – 30% decrease in the amount of precipitation falling as snow by 2090 for the Ashland, WI area.

Based on a 30-year record from 1981 - 2010, the amount of average annual precipitation increases from west to east, with 78 cm per year at Superior and 92 cm per year near Hurley (NOAA and NWS, 2021). Individual studies on trends in precipitation patterns vary based on the period evaluated and the scale of the analysis. WICCI (2011) examined precipitation trends throughout Wisconsin from 1950 – 2006 and observed an increase in precipitation in the Chequamegon Bay area; in the eastern and western portions of Wisconsin's Lake Superior basin annual precipitation decreased during the same period. Annual precipitation in the southern part of the basin has decreased by 10-20 percent from 1980-2009, which included a period of drought from the late 1990s through the late 2000s (Fitzpatrick et al., 2013). The frequency and magnitude of large precipitation events in the region are projected to increase due to an increase in atmospheric moisture content. In Wisconsin's portion of the Lake Superior basin, models estimate 11 – 14 additional ≥2.5 cm rain events, ≥4 additional 5 cm events, and 1 – 2 additional ≥7.6 cm events annually (WICCI 2011). Perica et al. (2014) calculated an increase of up to 9 cm in 24-hour rainfall for 100-year recurrence interval events. Saunders et al. (2012) examined the number of ≥7.6 cm rain events in Wisconsin by decade, starting in 1961. They observed a 92% increase in the number of such storms over time and a 100% increase in the volume of precipitation during storm events. These expected changes in climate and precipitation will have impacts on seasonal hydrology and streamflow in the basin.

Hydrology and streamflow

Streams in the study region generally flow from south to north toward Lake Superior. The density of intermittent stream channels is lower in headwater areas than in the clay plain (Figure 7). Relic shorelines from glacial Lake Duluth occur at altitudes of 274 – 335 meters. This area contains wave-planed topography of sand deposits over the clay-rich glaciolacustrine Miller Creek formation soils that separate the lower clay plain from the headwater areas of the basin. A series of short steep stream channels occur in the geologic transition zone between the lower clay plain and upper areas of the basin (hereafter, geologic transition zone; Figure 7). In many areas, low-order stream channels in the geologic transition zone are intermittent; in a few areas (for instance, the western Marengo Basin) networks of groundwater-fed streams occur. In the Bayfield peninsula area, this zone separates the surface water contributing areas from the non-contributing areas of the watershed, because the sandy soils at higher elevations (the Northwest Sands, Figure 7) do not contribute to surface runoff (Figure 3).

The USGS maintains nine active gauging stations for measuring discharge and two that record peak flows in Wisconsin's Lake Superior basin (Table 1 of Appendix 4, Figure 8). Northland College initiated streamflow monitoring at 15 sites in tributaries that drain to the Bad River and Chequamegon Bay in 2013 and 2014, including one site previously monitored by USGS (Table 1, Figure 9). Streamflow data from these gauges show that hydrology generally reflects seasonal precipitation patterns, even among streams that are fed to different extents by snowmelt, surface runoff, and groundwater. As described by Swanston et al. (2010), winter is a period of low stream discharge with most water stored as ice or snow. Spring snowmelt and rain result in high-flow events, typically in April and May. The magnitude of these events is determined by the amount of snowpack and the rate of melt. Rain on snowpack can lead to rapid snowmelt during this time. The highest flow events of the year often occur during spring runoff periods (Figure 10).

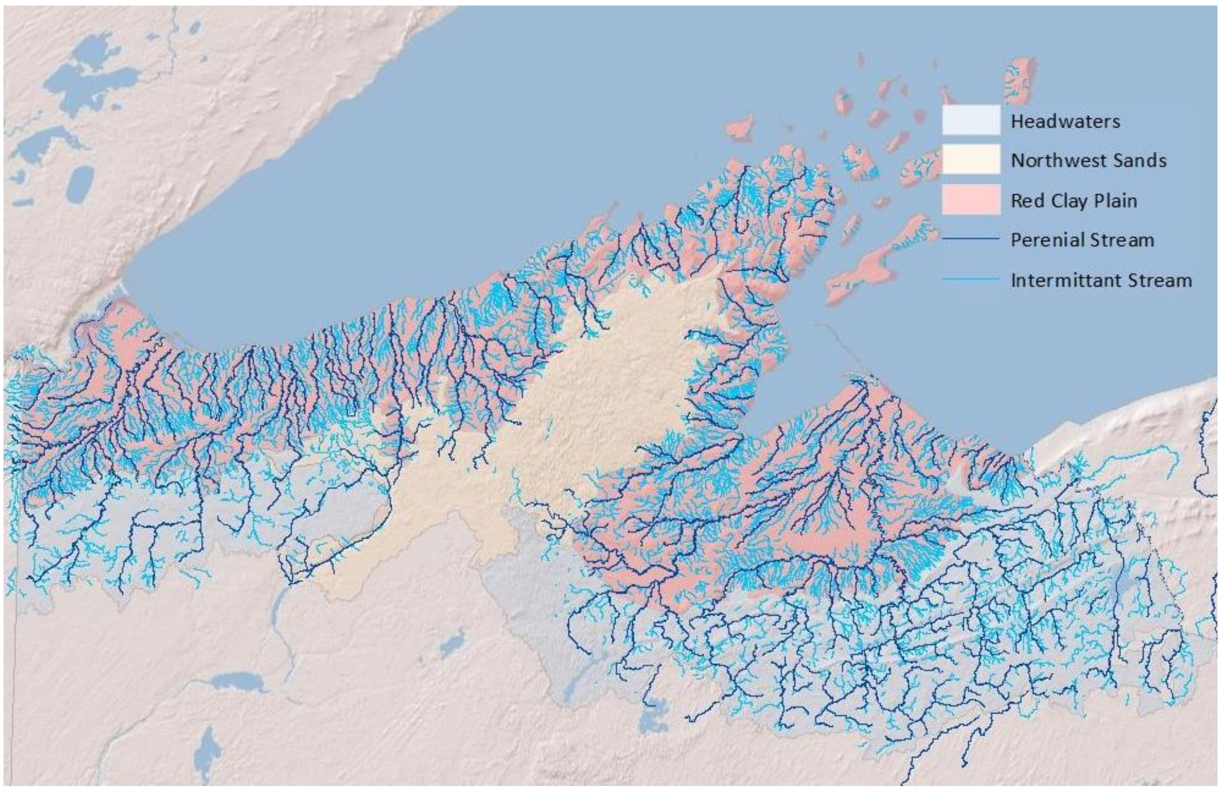

Figure 7. Stream networks in Wisconsin's portion of the Lake Superior basin. Red Clay Plain and Northwest Sands are land-type associations classified in WDNR (2015).

In the summer, base flows are generally lower because of high evapotranspiration, with runoff from occasional rainstorms increasing discharge. Heavily groundwater-fed streams like the Brule River and the streams draining the Bayfield peninsula (Fitzpatrick et al., 2015) experience higher base flows relative to Spring high flows (Figure 10). Lower evapotranspiration rates in fall result in higher base flow. Approximately a third of annual precipitation contributes to surface water streams, with the other two-thirds supporting evapotranspiration (Swanston et al., 2010).

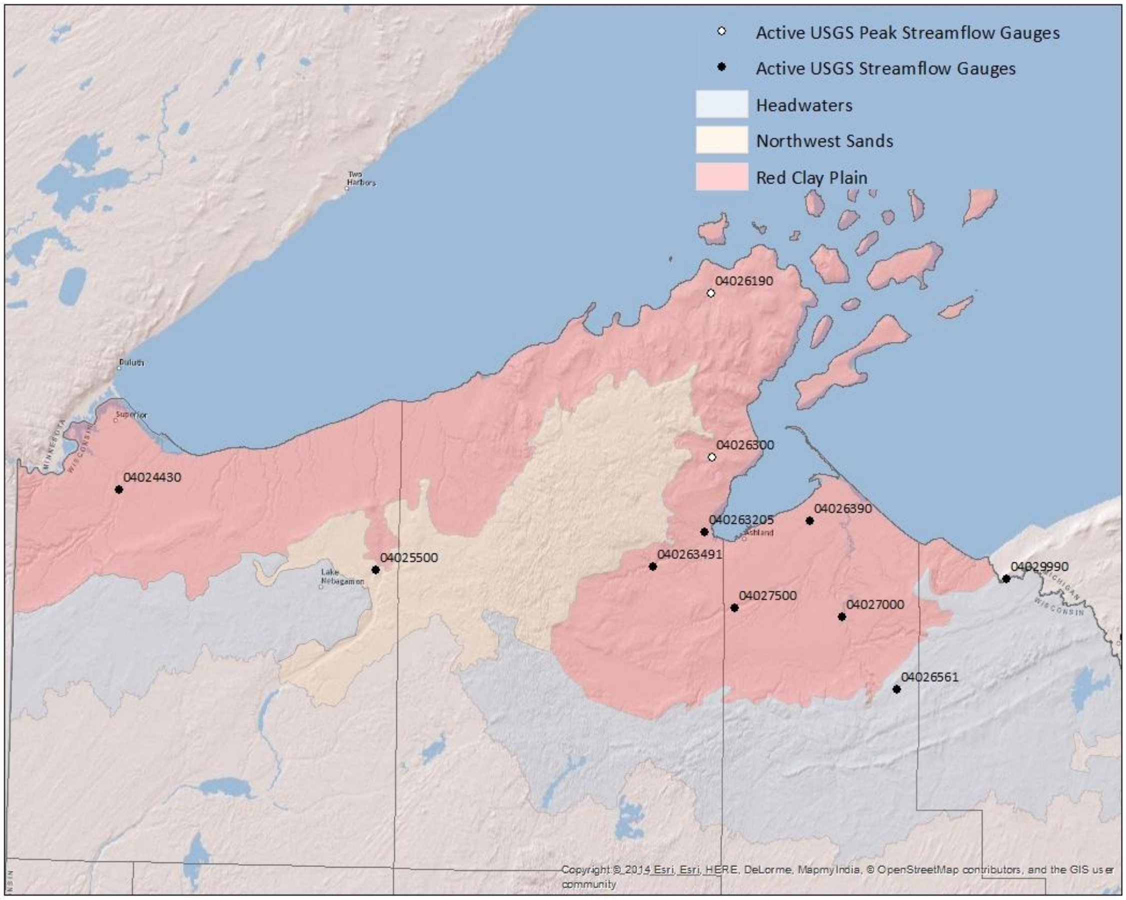

Figure 8. Active USGS stream gauge locations in Wisconsin's portion of the Lake Superior basin.

Table 1. Active discharge gauges operated by Northland College in the Bad River/ Chequamegon Bay region of Wisconsin's Lake Superior Basin.

Stream Gage Name	Gauge ID	Latitude	Longitude	Start Year
North Fish Creek near Moquah, WI	NF02	46.54888	-91.0621	1989
Sioux River at Big Rock Rd	SXBR	46.70999	-90.9258	2014
Thompsons Creek at W Bigelow St	TCBS	46.66653	-90.9155	2014
Bono Creek at Bjork Rd	BCBR	46.63359	-90.9477	2014
Bay City Creek at HWY 13	BCC	46.5816	-90.8748	2013
Little Sioux River near Friendly Valley Rd	LTLS	46.72677	-90.9072	2014
North Fish Creek at Hwy 2 near Ino	NF2I	46.53004	-91.1479	2014
Pine Creek at Old US Hwy 2	PCO2	46.5492	-91.0633	2014
South Fish Creek at Colby Rd	SFCR	46.54061	-91.0112	2014
Unnamed Tributary to North Fish Creek at Hwy 2	NFT2	46.52955	-91.1222	2014
Unnamed tributary to South Fish Creek at Colby Road	SFTC	46.5306	-91.0108	2015
Tyler Forks River at Caroline Lake Rd	TGCL	46.27724	-90.5034	2013
Bull Gus Creek at FR703	BGC	46.30304	-90.506	2013
Devils Creek at Lake Dr	DVLK	46.31827	-90.5808	2013
Javorsky Creek at Hwy 77	JV77	46.34133	-90.517	2013

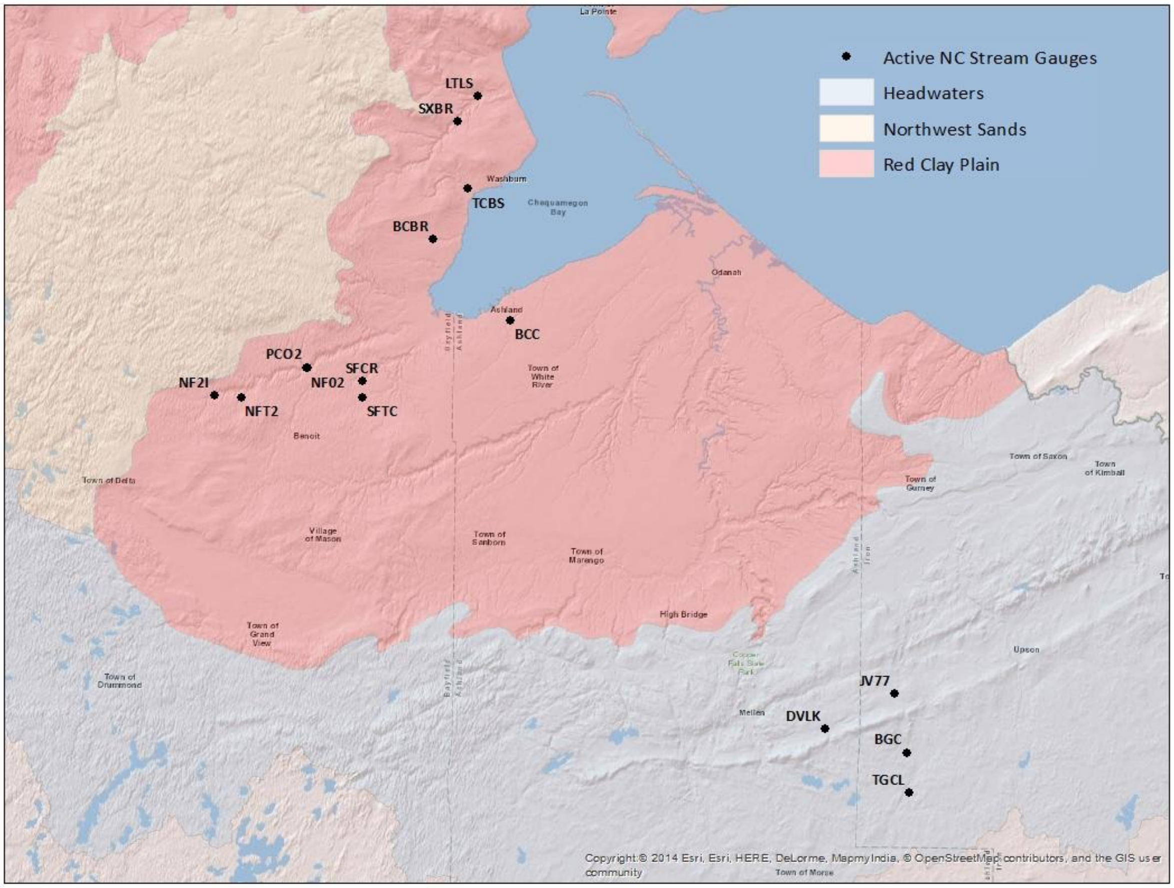

Figure 9. Generalized watershed regions defined by soil conditions and Northland College active stream gauge locations in the Bad River/Chequamegon Bay region of Wisconsin's Lake Superior basin. Red Clay Plain and Northwest Sands are land type associations classified in WDNR (2015).

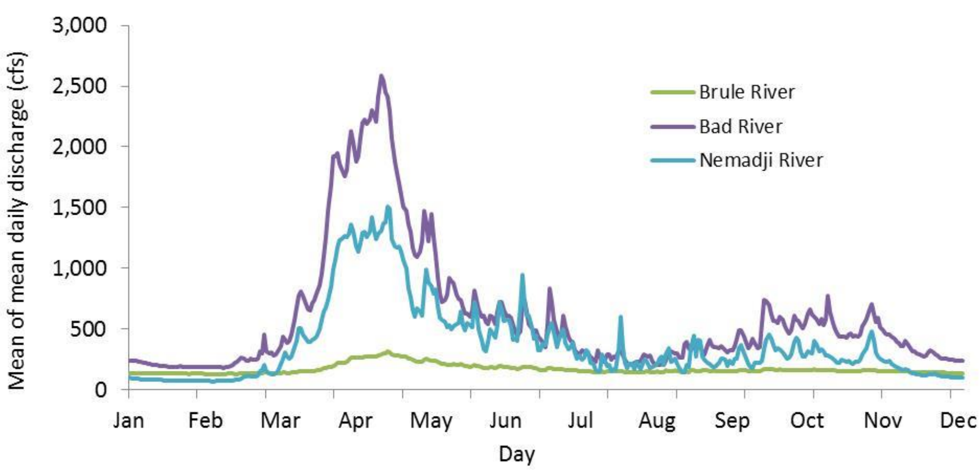

Figure 10. Mean of the mean daily streamflow from 1973 – 2015 for 3 major gauged tributaries to Lake Superior in Wisconsin.

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Patterns in streamflow vary over years across the Lake Superior Basin. Due to climate change, the annual highest peak flow events are increasing during summer storms rather than during spring runoff (Figure 11). For example, in the Bad River, peak flow data are available from 1915 - 1921 and 1949 - present (no data are available from 1922 - 1948). The highest annual peak flow events occurred most often in April and May and never occurred later than July 4th during the time periods 1915 - 1921 and 1950 - 1969. From 1970 - 2009, approximately a quarter of peak flow events occurred after July 4th during late summer or fall. From 2010 - 2016, 3 of 7 peak flow events occurred during the summer months. These summertime high-flow events may displace young-of-the-year fish from optimal rearing habitats.

Existing climate models forecast changes in precipitation patterns across the assessment area, and there are multiple lines of evidence that climate change will continue to alter streamflow patterns (Janowiak et al., 2014). Precisely how these changes to streams will manifest is poorly understood and will likely depend on the interaction of multiple factors. Two studies predict that climate change will lead to more winter rain and earlier peak streamflows (Croley, 2003; Lenters, 2004), which contradicts the trends observed above in the Bad River.

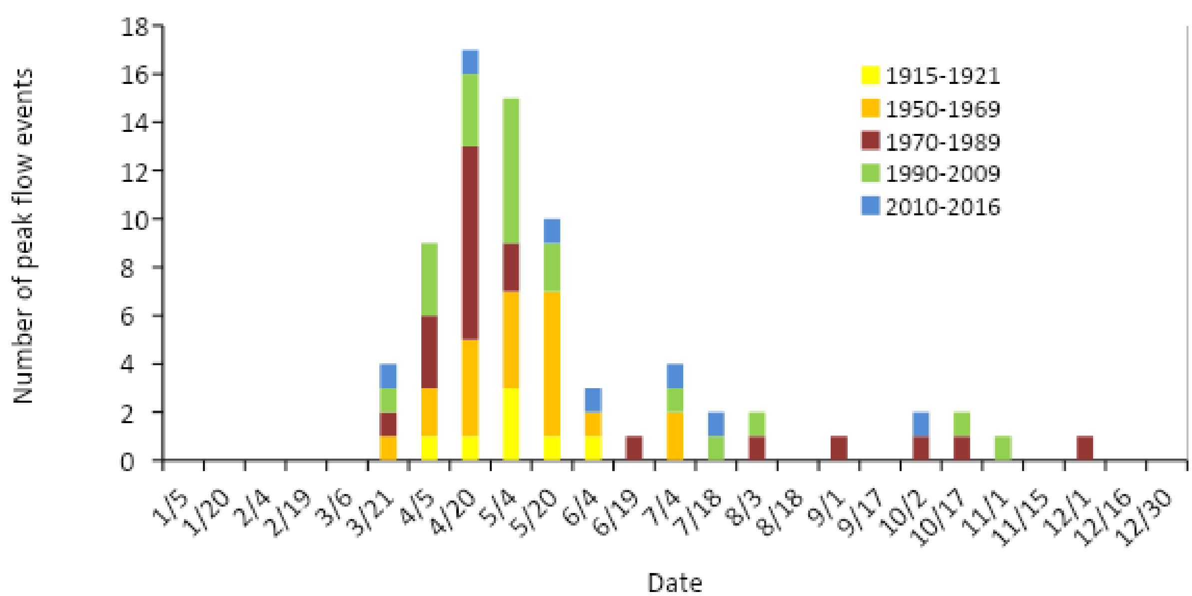

Figure 11. Frequency of annual max flow events by date in the Bad River, WI Wisconsin from 1915-2016 (USGS stream gage data). Events are stacked to show the total number of events occurring within a two-week period starting on the date listed.

Low flow hydrology

Low flow occurs during periods of prolonged lack of precipitation and high evapotranspiration. The magnitude and duration of low flow conditions affect the quality and availability of stream habitats during dry periods of the year. Shaake and Chunzhen (1989) suggest that climate change may have the greatest effect on the low flow period of the annual hydrograph because stream ecosystems are most vulnerable to increases in water temperature during low flow periods during late summer months. Based on a doubling of atmospheric carbon dioxide, Eaton and Scheller (1996) predicted that habitat for cold and cool water stream fish would be reduced by ~50%, with the greatest habitat loss in the central Midwest.

Hydrology during periods of low precipitation depends on base flow, or the total groundwater and other sub-surface discharge to streams. Base flow provides cold refugia to fish during warm seasons with low precipitation. Base flow is strongly influenced by subwatershed geology and geomorphology (Fitzpatrick et al., 2015). Primary factors that influence baseflow include stream connection to the water table, enough seasonal recharge to maintain that connection, and hydraulic conductivity (Smakhtin, 2001). These geologic factors vary greatly across Wisconsin's Lake Superior basin, creating variable stream conditions in the area. In some streams, wastewater discharges may augment base flow, which can aggravate water pollution problems during low flow periods. However, more data and monitoring are needed to investigate this issue in the study area.

Gebert (1979) described low-flow characteristics for Wisconsin's Lake Superior basin tributaries. He evaluated three analysis methods for calculating 7-day low flow estimates at 2-year and 10-year recurrence intervals at gauged sites and two types of ungauged sites, depending on the amount of low-flow discharge measurements recorded. For sites with limited discharge measurements, drainage area, basin storage, drift thickness, transmissivity (the product of drift thickness and rate of water movement by drift type for clay, moraine, sand, or outwash), and base flow index (discharge at the 90 percent flow duration) were found to be the most significant characteristics in explaining the differences in low flow. The standard error for the estimates was moderately high compared to other basins in the state, which he attributed to large variations in groundwater inflows depending on geologic or aquifer characteristics.

Gebert et al. (2011) estimated base flow that ranged from 0.01 to 8 cubic meters per second (cms) across 79 sites in the Lake Superior basin using continuous record streamflow gauging stations and partial record sites that measure only during low flow conditions. They also calculated the base flow index for those sites. The base flow index is the ratio of the volume of base flow to total runoff volume for the water year A relatively high base flow index indicates high groundwater recharge. A lower base flow index value indicates a greater contribution of surface water runoff to discharge, usually associated with lower infiltration rates. Base flow indices were highest in streams draining the Bayfield peninsula, and generally lower at the eastern and western edges of Wisconsin's portion of the basin. This is consistent with Fitzpatrick et al. (2015) who reports hydraulic conductivity metrics of the sand-rich Copper Falls Formation of the Bayfield peninsula that are double those of the glaciolacustrine deposits of the Miller Creek Formation in the clay plain. Major recharge zones may be at a slightly higher elevation for the Cranberry and Bark River areas of the north/western side of the peninsula than for the Sioux and Whittlesey Creek area on the east side of the peninsula (Interfluve, Inc. 2003).

Gebert et al. (2016) examined streamflow trends in the Bad River, from 1915-2008 and for a partial record from 1969-2008. They found no significant change in annual 7-day low flow or annual average flow over the full 66-year record at that site, nor did they find significant trends in the data in the partial record since 1969. However, in comparing the 1915-1968 and 1969-2008 records for the Bad River, they did find a significant increase of 14-16% in annual 7-day low flow discharge between periods. This change observed was smaller than the increase observed in most other watersheds (particularly agriculturally dominated watersheds) examined in the study. Conversely, Fitzpatrick et al. (2013) noted a decrease in annual mean flows of over 30 percent and a decrease in 7-day low flows of almost 30 percent in the Bad River from 1980 – 2009.

High flow hydrology

Climate change has increased peak flow events. For example, Fitzpatrick et al. (2013) noted a 10% increase in peak flows at the Bad River from 1980 – 2009, likely due to an increase in the intensity of precipitation events. The Chequamegon Bay region experienced the greatest flood on record in July 2016. Over 25 cm of rain fell in one day in some areas of the middle Bad River watershed (Fitzpatrick et al., 2017). Flooding was widespread throughout the region, and the Bad River rose from 300 to 40,000 cfs, its highest recorded discharge (Fitzpatrick et al., 2017). This storm caused more than 38 million dollars in damages to local infrastructure (Cushman, 2019). Flooding occurred again in June of 2018 when 16 cm fell in the Ashland area over 2 days (National Weather Service, 2021). The governor declared a state of emergency due to flooding that caused severe damage to roads, bridges, and culverts (National Weather Service, 2021).

The intensity and duration of large storm events have substantial effects on high-flow hydrology. This can affect in-channel and bluff erosion processes and sediment movement (Peppler, 2006). Blodgett (2009) showed that repeated high-flow events in North Fish Creek, near Ashland, saturated the soils, causing bank and bluff instability, and significant erosion.

Climate change can also affect the seasonality of high-flow events associated with snowmelt. Gebert et al. (2016) showed a decrease in annual peak discharge in the Bad River and suggested it may be due to a shift in the timing of spring snowmelt runoff, which is happening 5-10 days earlier in the Great Lakes Basin over the period 1953 - 2004 (Hodgkins et al., 2007). The shift likely relates to increased air temperatures in February and March reducing the thickness of the snowpack before the spring melt. Gyawali et al. (2015) noted similar seasonal trends in the monthly runoff for the Bad River over a similar time period. Notable increases in the monthly runoff between the periods 1951 - 1980 and 1981 - 2010 were observed for March and October with significantly less runoff in April and May. Fish life cycles are adapted to flow regimes, so changes in flow regimes have important implications for both resident and migratory native fish species including survival and habitat alterations that affect growth (Lytle and Poff, 2004; Poff et al., 2010).

Effects of land use and land cover on stream hydrology

Historic logging, burning, and conversion to agriculture by European settlers since the 1800s have altered stream hydrology in the basin (e.g., Verry, 1983, Pomeroy et al., 1997). In this section, we describe the relationships among the landscape attributes that affect hydrology in the Lake Superior basin, including the extent and type of forest cover, watershed storage, channel and upland roughness, agriculture and tile drainage, and urban runoff.

Watershed storage

Watershed storage generally refers to the surface area of wetlands, lakes, and ponds. The USGS identified watershed storage as one of the most significant parameters for predicting peak flows in Wisconsin (Walker and Krug, 2003). This work was updated in 2016 (Walker et al., 2017) with new regression models that included the percent forest in the watershed, but not watershed storage, which was no longer a significant predictor of peak flow. The USGS models for Minnesota (Lake Superior's north shore watersheds) include only the lake and drainage basin area.

Wetland area has been reduced more than lakes and ponds, due to conversion to other land uses (Walker et al., 2017). Wetlands function like natural sponges, storing either flood waters that overflow riverbanks or surface water that collects in isolated depressions. As flood waters recede, the collected water is released slowly from wetland soils. Wetlands can reduce the severity of downstream flooding and erosion by holding back some of the flood waters and slowing the rate at which water re-enters the stream channel (Vermont DEC, 2022). In watersheds where wetlands have been lost, peak flood discharge may increase by as much as 80 percent (Vermont DEC, 2022). Wetlands within and upstream of urban areas which have a high percentage of impervious land surface are particularly valuable for flood protection (Vermont DEC, 2022).

The effect of wetlands on water storage depends on the amount of runoff from the drainage basin to the wetland, slope, and soil infiltration rates, as well as pre-storm soil moisture and relative saturation (Walker et al., 2017). Johnson et al. (1990) examined relationships between 100-year storm events and watershed storage. Their data indicated that having at least 10% of the watershed area available for water storage is a critical threshold for the reduction of flood flows. They also note that even small decreases in wetland areas when the watershed is near or already below 10% wetland area can increase peak flows. In Minnesota, Verry et al. (1988) observed increases in peak flow with 30% of peatland mire wetlands drained. The amount and intensity of precipitation, antecedent conditions, and location of the peatland within the landscape were relevant to peak flow effects. Peak flows increase exponentially as wetland depression storage decreases below a threshold value of 5–10% watershed area (Jacques and Lorenz, 1988; Krug et al.,1992). Detenbeck et al. (2004) put the figure at 18 – 24% depression storage. Blodgett (2009) estimated a 25 - 40% reduction in peak flows with the installation of a network of dry dams and restored wetlands in the uplands of the North Fish Creek watershed. Blodgett emphasized the importance of considering the cost-effectiveness of measures to reduce peak flow in targeting BMP installation. Wetland storage capacities can also contribute to base flow (Bullock and Acreman, 2003).

Floodplains and riparian wetlands are important elements of a well-functioning watershed. Floodplains are the low-lying areas of land around a river where floodwaters extend when a river or stream exceeds its bank-full channel capacity. The floodplain of a river provides temporary storage for floodwaters and sediment produced in the watershed. The temporary storage serves to slow the downstream impacts of a flood. Floodplain soils absorb water from overfilled riverbanks and slowly release the moisture to floodplain vegetation and back into the stream channel. Streambank vegetation also helps cool surface water temperatures of small streams and supports high plant and animal production and diversity.

In all four Wisconsin counties of the basin, the Land and Water Conservation Department plans' identify wetland restoration as a priority to reduce peak runoff. A summary of best management practice guidelines for the region recommends "utilizing set aside programs to remove marginal agricultural lands from production and allow wetland characteristics to reestablish in drained areas" (Schultz, 2003). Douglas County utilized a landscape-scale approach to wetland restoration prioritization (Douglas County, 2016). Created with significant stakeholder involvement, this plan "utilizes the best available scientific information to identify watersheds that indicate high vulnerability to increased surface water runoff due to large storm events, recommends actions to reduce this risk, and is consistent with community land-use goals." Watershed-scale criteria used to identify high-priority sites included watersheds with the most wetland loss (HUC 12 scale) and more than 30 – 40% open land (HUC 14 scale). Site-specific restoration criteria include potentially restorable wetland (PRW) areas on or adjacent to lands transitioning out of agricultural use with hydrologic connection to waterways and proximity to other existing wetlands or public land.

Once priority watersheds are identified, project siting and the amount of additional storage capacity needed must be determined. Emerson (2005) suggested that approaches to peak runoff reduction should focus on volume-based control methods. Hapner (2006) estimated wetland storage as a function of surface area in southeastern Wisconsin and recommended wetlands be designed to retain a volume equivalent to a 1 cm rain event in the watershed of the wetland. Emerson (2003) found that the installation of detention basins for peak flow reduction in random locations did not notably reduce peak flows. However, Giudice et al. (2014) showed that adding detention basins in parallel (along separate "parallel" tributaries) was effective in reducing peak flows and that detention basins added in series (multiple basins along a single tributary) were less efficient in water storage. In Two Harbors, Minnesota, flooding in the Skunk Creek watershed was successfully mitigated using staged release culverts and 3 flood retention basins in the watershed (NOAA, 2019).

Research in incised rivers in southern Minnesota has focused on the potential for water retention to reduce peak flows to reduce erosion of near-channel sediment sources (bluffs and streambanks). There are many ways to hold water back on the landscape, including wetland restoration, in-ditch storage, and installation of control structures in subsurface tile networks. Mitchell (2015) explored the effectiveness of water retention on peak flow reduction using a SWAT (Soil and Water Assessment Tool) model for the Le Sueur watershed in south-central Minnesota. The model showed that water retention could lower peak flows and thus lower near-channel erosion rates (Mitchell et al., 2018). Water retention basins underlain with high hydraulic conductivity soils had a bigger impact than basins with low hydraulic conductivity because the water was able to infiltrate faster between storms (Mitchell et al., 2018). The study also found that water retention basins placed higher in the watershed were more effective than water retention basins closer to the mouth (Mitchell et al., 2018). Later work by Hansen et al. (2021) found that restoring the water retention capacity of floodplain wetlands was even more cost-effective than upland water retention basins at reducing erosion associated with peak flow events. Reductions in peak flow began with the first water retention site installed; no threshold had to be reached before peak flows were reduced (Mitchell et al., 2018). New methods for digitally delineating riparian and floodplain areas using the Height Above Drainage (HAND) technique have been used to map 100 yr flood inundation zones in Texas and North Carolina (Zheng et al., 2018). HAND delineated floodplains and inundation zones compared well with modeled delineations using more complex techniques (HEC-RAS 2D) and show potential for identifying disconnected floodplains (Afshari et al., 2018).

Upland and in-channel roughness

In-channel and overland roughness conditions can significantly affect watershed hydrology (Borah and Bera, 2003). Fitzpatrick et al., (2015) modeled peak flows as a function of land cover and soil type in the Cranberry River watershed of the Bayfield peninsula. Slope and roughness of both the stream channel and contributing uplands were considered in estimates of runoff volume across different land cover scenarios, including pre-settlement, and conditions during peak agriculture in the early 1900s peak agriculture (1928), late 20^{th} century, and developed conditions (25% urban). Modeled flood peaks were lower in magnitude and greater in duration pre-settlement compared to the late 20^{th} century conditions, largely attributed to higher overland and in-channel roughness during the pre-settlement period.

The watershed position is important for in-channel roughness projects. Pratt and Blust (2005) recommend focusing on in-channel roughness restoration projects in the upper reaches of streams. They found that in-channel structures in the lower reaches of Bayfield Peninsula streams were washed out during storm events or buried with sediment. The evaluation of some in-channel bank stabilization projects established by the RCIC found that the original structures installed were no longer present; however, it appears the structures persisted long enough to allow vegetation to become established (RCIC, 1964, 1977).

The Utah State University Restoration Consortium put together a design manual to provide restoration practitioners guidelines for implementing low-tech tools in wadable stream channels to increase roughness and simulate natural processes (Wheaton et al., 2019). They advocate for using simple, low unit-cost structural additions to riverscapes to mimic natural functions. They focus most of their efforts on promoting large woody debris in streams to influence hydraulic conditions. The large woody debris simulates the impact a beaver dam would have, creating a more complex stream habitat. The impacts of beaver on stream ecosystems have been well documented (Burchsted et al., 2010; Naiman et al., 1988). Their dams influence stream complexity by altering patterns of erosion and deposition. This heterogeneity increases lateral connectivity by promoting overbank flows, which are critical for creating and maintaining floodplain habitats and promoting groundwater recharge (Westbrook et al., 2006); and supports riparian vegetation. They argue that engineering-based methods tend to emphasize channel form and stability, rather than promoting the processes that create and maintain healthy riverscapes, which leads to increased costs and a limited ability to restore more miles of riverscapes.

Gullies can also be substantial areas of accelerated runoff and erosion. Gullies develop from surface water runoff or groundwater sapping. In surface water driven gullies, overland flow leads to the downcutting of steep, v-shaped gullies. In the geologic transition zone area of the basin, quick shallow groundwater flow (similar to piping) in areas with clay sediment overlaying sand can lead to u-shaped gully formation from the base of the drainage upwards, due to the higher erodibility of sand than clay. The type of gully influences the type of management action needed to improve hydrology. Increasing the interception of flow in gullies may be effective in the geologic transition zone area. In areas with more permeable soils, increasing roughness elements to improve infiltration may be appropriate. Fitzpatrick [WM1] tested rehabilitation techniques to slow flow, reduce erosion, and increase infiltration in gullies of the Bark River watershed. They installed a series of 1- to 1.2 meter-high porous check dams as grade control, filled gullies with large wood pieces, and planted herbaceous native species to stabilize and reduce runoff in steep gullies (Figure 13). Monitoring in 2010 indicated that the technique reduced incision at restoration sites and that the increased roughness slowed runoff.

Figure 12. Roughness elements (anchored wood) installed in upland gullies draining to the Bark River. Photo courtesy of Faith Fitzpatrick.

The Wisconsin Wetland Association (2018) documented how gullying, channel incision, and head cutting have contributed to erosion-induced wetland drainage and floodplain disconnection in Lake Superior watersheds. When fluvial erosion is intensified by changes in land cover or floods, channels can extend upslope into or form in areas that naturally store water. Erosion-induced drainage accelerates surface and sub-surface flows into these channels, lowering the water table, limiting access to floodplains, and causing upstream wetlands to be partially or fully drained. Public infrastructure can be at risk if flows are energized in incised channels, gullies, ravines, and existing wetlands, and if floodplains with limited reduced storage capacities cannot intercept and store water upstream of culverts and bridges (or unstable bluffs).

Forest cover

In addition to a multitude of benefits to water quality and aquatic ecosystems, forests influence stream hydrology by influencing channel roughness, base flow, snowpack accumulation, snow melt, interception of rain events, and evapotranspiration rates. The age, species composition, and structure of the forest affect the volume and timing of runoff in the channel. Methods to describe forest characteristics and define forest cover vary greatly in the literature, and include forest shading, percent canopy density, canopy closure, and crown coverage (Varhola et al., 2010).

WDNR (2010a) compiled an extensive review of forestry and hydrologic relationships in Wisconsin's portion of the Lake Superior basin, as part of a comprehensive project to strengthen the implementation of silvicultural best management practices (BMPs) on private and public lands in the area. The major objectives of the project focused on restoring and managing watersheds, streams, riparian areas, and wetlands for water quality protection, with an emphasis on non-point source pollution. Highlights from that work and additional literature are presented here.

Forest cover and base flow hydrology

Evidence for a relationship between landscape conditions in the Lake Superior basin and hydrology is mixed. Fitzpatrick et al. (2015) found that base flows in Bayfield peninsula streams are strongly influenced by groundwater recharge in the Northwest Sands area of the central portion of the peninsula. They found that the historic conversion of forest land to agriculture had little effect on groundwater inputs from the deep-water aquifer system. Similarly, Lenz et al. (2003) found that reductions in forest cover in the Whittlesey Creek watershed have little effect on base flow and average flow hydraulic conductivity. Model evaluation by Gerbert (1979) determined that forest cover in the mid to late 1970s was not a significant predictor of base flows in streams of the Lake Superior basin.

Other authors have reported relationships between forest cover and base flow in similar landscapes throughout the region and elsewhere in the country. Detenbeck et al. (2004) studied relationships between watershed conditions and a variety of flow metrics in Minnesota and Wisconsin streams in the Lake Superior basin. They found that reductions in mature forest cover depressed base flow measured as two metrics corrected to median discharge: discharge exceeded 90% of the time (Q_{90}) and mean annual minimum daily flow. Flynn (2003) found that forest cover type (deciduous vs. conifer) and summer air temperatures were related to 7-day average minimum flow during 2- and 10-year periods in New Hampshire streams. They presumed that greater interception and storage in conifer-dominated forests reduced base flows by increasing evapotranspiration, thereby reducing infiltration that would otherwise be discharged to streams (Dunne and Leopold, 1978). Nejadhashemi et al. (2012) used SWAT models to examine the effect of land use change at different scales in Wisconsin and Michigan watersheds of Lake Michigan tributaries. They compared pre-settlement, primarily forested conditions, with present-day conditions (nearly 50% of land in crop production, and with less than 20% urbanization). They found that these land uses changes resulted in an increase in evapotranspiration and a decrease in base flow by 50%. This research suggests that forest cover characteristics have a variable effect on baseflow throughout the basin, with a negligible effect in the Northwest Sands region.

Forest cover and high-flow hydrology

Forest cover influences high-flow events through its effect on snowpack accumulation (see review in Muss, 2011). In general, the amount of snow accumulation decreases as forest cover increases, as snowfall is intercepted by the canopy and some moisture is returned to the atmosphere via sublimation (Essery et al., 2003). A greater proportion of snowfall will be intercepted by forest canopy in low-intensity snowfall events. Murray and Buttle (2003) summarized findings from over 20 published papers on snow water equivalence (SWE, the amount of water contained in snowpack) in open sites and forest stands in northern hardwoods. SWE was consistently greater in open sites compared to forested sites, with the difference between cover types ranging from 4 to 300%. Most studies showed an increase in SWE of 15 and 60% in open sites over forested sites. In their central Ontario study, Murray and Buttle (2003) found increased snow accumulation and SWE in a cleared section of northern hardwood forest. The variation in SWE was driven by differences in canopy structure, stand age, and stand basal area, as well as snow event characteristics. Canopy closure and plant area index (area of all plant elements per unit ground area) are among the main determinants of snowpack accumulation (Muss, 2011).

The size of clear-cut or open areas also influences snow accumulation. Open sites that are only two to five tree-heights wide accumulate the most snow (Golding and Swanson, 1986, Troendle and Leaf, 1980). These smaller openings are sheltered by surrounding forests and protected from the wind that can redistribute snowpack. In areas with less wind, opening size is less of a factor in determining snow accumulation.

Forest type, age, and spatial arrangement (slope aspect) in a watershed affect the timing of spring snowmelt, and the resulting size and duration of peak or elevated streamflow (Buttle et al., 2005, Verry, 1983). Differences in shading among coniferous forests, deciduous forests, and open lands affect the amount of solar radiation and resulting hydrologic patterns. Muss (2011) studied these relationships in the Bark River watershed in the Bayfield peninsula. He utilized LIDAR data to characterize canopy cover in a 78-hectare subwatershed. He then modeled snowpack and melt in that subwatershed as a function of forest cover type and found substantial differences in peak discharge among the mature evergreen forest, mature broadleaf forest, and treeless cover scenarios, estimated as 12.5, 20.0, and 35.1 liters/second respectively. Total streamflow volume also differed greatly among sites, with treeless landscapes contributing 25% more than broadleaf forests, and 113% more than evergreen forests. His work found that canopy cover had the greatest influence on peak seasonal SWE and snowmelt, while both plant area index and canopy cover influenced the rate of delivery and timing of snowmelt.

Many authors have studied relationships between forest cover and hydrology elsewhere. Pomeroy et al. (1997) found greater infiltration of snowmelt, less surface runoff, and lower peak flows in coniferous forests of southern Saskatchewan compared to cleared areas. Verry (1983) conducted an 18-year paired watershed study of snowmelt and rainfall response to clearcutting in an 84-acre watershed in the Lake Superior basin in northern Minnesota. He found that peak storm flows doubled after clearcutting for three to five years, with elevated peak flows persistent for 9 years. Storm flow volume also doubled after clearcutting, but for only two years. At a watershed scale, he reported a 35% decrease in peak flow following clearcutting half of an 84-acre watershed, which they attributed to desynchronization of snowmelt runoff between cut and uncut areas of the watershed. Murray and Buttle (2003) found that forested and clear-cut sites lost snowpack simultaneously, but cleared sites had greater snowpack and higher melt rates, resulting in an increase in the volume and rate of runoff in the spring. However, aspect had a greater influence on snowmelt than clearcutting, with north-facing slopes having the most variability. They suggest estimating melt rates on south-facing slopes since relationships between tree cover and melt volume and timing were strongest there.

The effect of forest canopy on the fate of precipitation, as throughfall, stemflow, or interception, is relevant for watershed-scale hydrologic investigations. Throughfall is the amount of precipitation that reaches the forest floor. Stemflow is the amount of precipitation that flows down the trunk or stem of trees. Interception represents the amount of precipitation that is captured by the canopy and either absorbed or evaporated back into the atmosphere. Price and Moses (2003) studied precipitation and forest canopy dynamics in a mature red oak-sugar maple forest in southern Ontario. They found that during light rainfall events, 50% or more of precipitation is intercepted. As rainfall amount and intensity increase, a greater percentage of precipitation occurred as throughfall, with maximum amounts measured at 80% for events greater than 10 mm. Stemflow was a minor proportion of precipitation at all studied rain events. The amount of precipitation that reaches the ground can increase by as much as 30% with the removal of the tree canopy. Soil moisture levels can increase with decreasing evapotranspiration from fewer trees (Hibbert, 1969). The type of forest cover also influences the nature of flow events via interception and evapotranspiration. Needleleaf evergreen forests can intercept more of the annual precipitation than broadleaf deciduous forests (18% and 11%, respectively) due to higher surface area (Buttle et al., 2005). Riedel et al. (2005) describe an increase in peak streamflow in the Nemadji River due to a 15% loss in interception capacity with a shift from mature red pine to mature aspen. In general, conifer species use more water per year than deciduous trees, making less water available for runoff (e.g., Calder et al., 2003).

Thresholds for percentage loss of mature forest that results in altered streamflow have been estimated. Verry (1986) observed a slight decrease in peak flows in 1-2 km watersheds in northern Minnesota when clearcutting increased from 0 to 40% of the watershed, which he attributed to a staggering of snowmelt that also extends runoff duration. Bankfull flows, generally considered to occur at 1.5 to 2-year recurrence intervals in the region of interest, are described by Verry (2001) as "an index of the range of flows that shape the channel and build the valley floodplain over time." A doubling or tripling of bankfull flows (and concurrent increases in bankfull velocity and channel slope) occurred at a threshold of greater than 60% open lands, including young forest ≤16 years. Peak flow discharges were not found to be significantly higher below the threshold of 60% open lands (Figure 13). Further, when clear-cuts and open land cover in subwatershed scale units were below the 50% threshold, peak discharges were reduced by 20% due to the desynchronization of flows (Verry, 2005). Detenbeck et al. (2004) modeled peak flow response to a fraction of mature forest (defined as greater than 15 years in age) in second and third-order streams in Wisconsin's Lake Superior basin and found that above a threshold of 51 to 64% open lands, peak flows increased. Model results from Lenz et al. (2003) found that complete reforestation of the Whittlesey Creek watershed would reduce flood peaks by 12 to 14% for a 100-year event. The rate of land clearing and forest regrowth can also influence bankfull flows since recently cut forests have higher runoff rates compared to a mature forest (Lenz et al., 2003). Verry (2005) found that forest harvest rates greater than 1½% watershed area per year increased bankfull flows that adjusted the channel.

To promote open land species like sharp-tailed grouse in the agricultural areas of Ashland, Bayfield, and Douglas counties, Schultz (2003) recommends maintaining 15 to 30% open grass and brushlands. This recommendation is generally consistent with the hydrologic recommendation of maintaining open lands below 60% of the subwatershed area. However, sharp-tail grouse conservation efforts in areas that are already close to or above the 60% threshold due to the presence of urban or agricultural land use may be at odds with hydrologic targets.

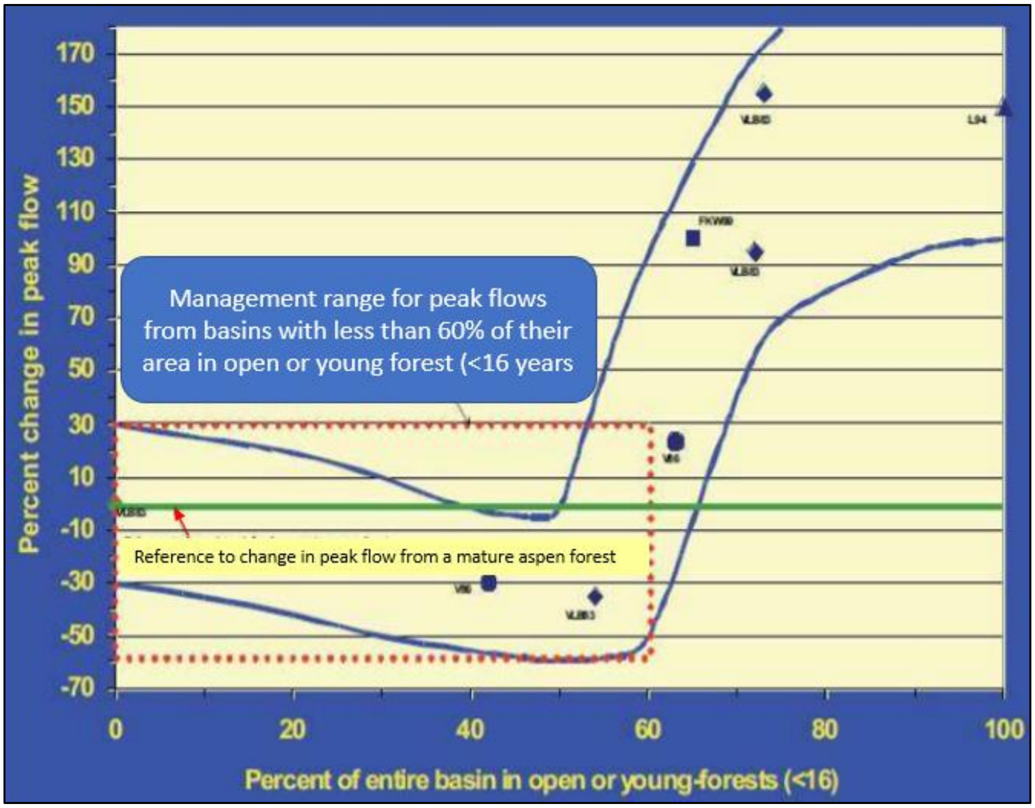

Figure 13. Relationship between the amount of open land in a subwatershed to change in peak flow (Verry, 2001). Blue lines define the range of variation in response to open land or young forest based on empirical measurements (symbols).

Riparian buffers

Riparian buffers can play an important role in stream hydrology. Wisconsin Forestry BMPs for Water Quality (2010) describe Riparian Management Zones (RMZ) as "areas next to lakes and streams, where forest management practices are modified to protect water quality, fish habitat, and other aquatic resources." RMZs have value for wildlife habitat, are a source of habitat-creating wood to streams, and help moderate stream temperatures. They are also critical in helping to minimize the effects of non-point source pollution (e.g., sediment, nutrients) on surface waters. In addition to these benefits, riparian buffer zones with forest cover can slow upland runoff and promote greater soil infiltration (WDNR, 2011).

However, the effectiveness of riparian buffers can be overwhelmed if direct drainage pathways to stream channels develop from roads or skid trails, gullies, or other concentrated flow areas (Dosskey et al., 2002). Equipment operations that compact soils in riparian areas can limit soil infiltration within riparian buffers (Hamza and Anderson, 2005). Reach-scale differences in soil type, topography, stream size, geology, and watershed size influence the size and shape of functional riparian zones. Site scale conditions and vegetation type also influence buffer effectiveness (Dosskey et al., 2002).

Additional considerations

Potential changes to forest stands outside of management prescriptions, like invasive species and climate change, are also important. The presence of emerald ash borer (EAB) has been confirmed in the study area in the City of Superior and Iron County (Oma, WI). to the east. Although the infestation is slow-moving, when the EAB attacks a tree, it is nearly 100% fatal. Ash trees make up a substantial portion of riparian areas along some stream reaches. Losing these trees to the EAB could have significant effects on hydrologic function and stream habitat, although effects are still poorly understood (e.g., Larson, 2020). Slesak et al. (2014) conducted experiments simulating EAB infestation and found the experimental plots had similar impacts on the water table as recent clear-cutting. Impacts on the water table were more pronounced when the water table was within 30 cm of the soil surface (Slesak et al., 2014).

Climate change may result in changes to forested habitats due to forest damage from wind events. Initial estimates from the U.S. Forest Service are that over 3,000 acres of forest land in the central Bayfield region were damaged during a high wind event in June of 2016. Private forest lands were certainly affected by this event as well. This event increased the proportion of open lands in this concentrated area.

Janowiak et al. (2014) provide an extensive review of additional potential impacts of climate change on forest resources including range and distribution projections for specific forest communities. Overall, they predict a reduction in boreal species, negative impacts on lowland conifers, and potential expansions of more southern species such as black cherry, northern red oak, and red maple. It is unclear yet how these projected changes will affect stream flow.

Agricultural lands

While forested lands are the dominant land use in the Lake Superior basin, agriculture is another important land use. Practices on agricultural land and their effects on watershed hydrology in the Lake Superior Basin fall into three main categories: conversion of forest to agricultural lands, ditching and drain tiling, and implementation of BMPs to protect water quality. Land conversion and drainage have the greatest effect on hydrology in the Lake Superior Basin. Agricultural BMPs primarily address what is *in* runoff rather than the volume or rate of runoff; however, some practices can be effective in reducing overland runoff volumes and rates.

Conversion of forest to agriculture

Many researchers have used modeling approaches to examine the effects of forest conversion to agriculture on stream hydrology. Fitzpatrick et al. (1999) found that increased agricultural activity in North Fish Creek increased the peak flow of above-bankfull events for the mid and upper reaches of the watershed, but not the lower reaches. Two-year peak discharge tripled during years of peak agriculture

(Fitzpatrick et al., 1999). The conversion of coniferous forest cover to agriculture increased peak flows in the Nemadji River watershed as well (Riedel et al., 2001, Riedel et al., 2005). Model results indicated that a return to row crop agriculture to 1920 levels in the Whittlesey Creek watershed would increase flood peaks by as much as 18% (Lenz et al., 2003).

Since the forest cutover and the peak of agricultural land use in the 1920s, the region has seen significant conversion back to forestland with minimal forest conversion to agriculture since then. However, since 2010 there has been some new forest clearing for agriculture, particularly in the Marengo Valley of Ashland County where the remaining dairy farms are expanding. WICCI models forecast an increase in the growing season and northern shift in plant hardiness zones that, combined with market forces, could potentially expand agricultural opportunities in the northern part of the state (WICCI, 2011).

Ditching and drain tiling

The low topographic relief clay soils of the Lake Superior Basin are almost impossible to farm without some form of engineered drainage like ditches, concentrated flow channels, or drain tile. Figure 14 shows a typical field in the Benoit area of Bayfield County with a network of maintained concentrated flow areas. Best management practices and regulations require producers to maintain these drainages in perennial vegetation to reduce runoff and erosion. However, 58% of runoff occurs between January 1st and March 31, when the flow channels are frozen and vegetation is flattened (Cooley, 2015). Stuntebeck et al. (2011) investigated runoff and constituent concentrations from 23 fields ranging in size from 2- to 75-acre subwatersheds from 2003 to 2008. They note that practices that rely on living vegetation are not effective during frozen ground conditions in late winter when a large portion of runoff occurred. While best management practices for maintaining the flow channels in perennial

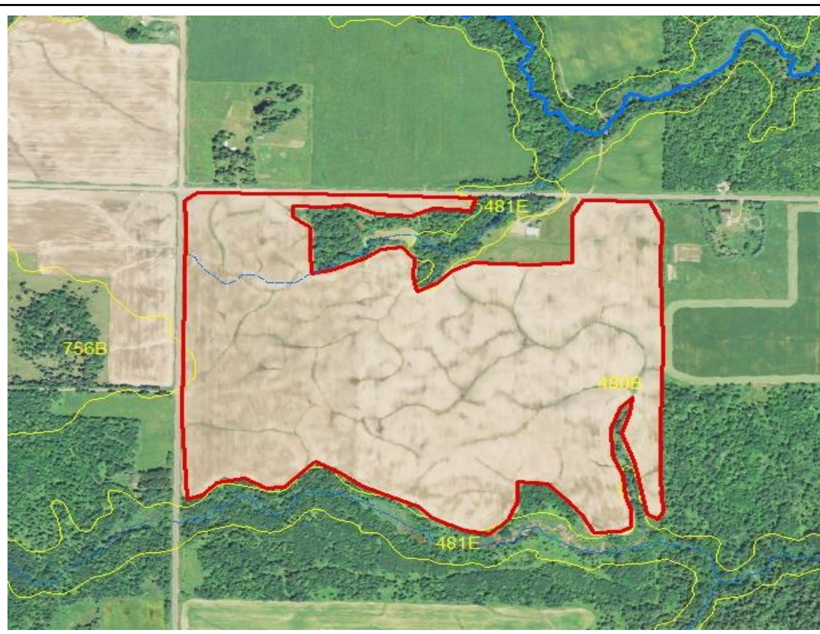

Figure 14. Typical agricultural field in Bayfield County with extensive surface drainage. Image courtesy of Jason Fischbach.

herbaceous vegetation have only a limited impact on reducing peak flow, they do provide other ecological benefits including wildlife habitat.

Ditching to re-route and concentrate landscape-derived runoff is ubiquitous throughout the Lake Superior basin. Ditches were created to drain wetlands in the low-relief red clay plain portion of the basin. Accelerated field drainage into ditch networks provides earlier access in the spring for tilling and planting. Verry (1988) notes that bankfull flows double when ditched agricultural lands or wetlands exceed one-third of a basin. The Nemadji Basin Plan states that while as much as 50% of agricultural lands in the Nemadji basin have been converted back to forest cover, substantial numbers of surface ditches installed on historic farm fields lands still drain the landscape today (Cooper and Lensch, 1998). Removing these relict ditches could represent a significant opportunity, especially in the Nemadji Basin but likely throughout the Lake Superior basin, to slow the flow of runoff to streams through the re-establishment of wetlands on currently drained land, with minimal effort and cost.

Although historically not extensively used in the Lake Superior basin, agricultural producers in the region have begun installing drain tiles. As competition for land increases, producers will likely find it more cost-effective to drain wet areas on their existing fields rather than purchase additional land. These subsurface drains remove water from fields at a fast rate in the spring and during prolonged saturation periods and respond quickly and effectively to rain events (Lam et al., 2016). The rate of drainage from fields in tile drains is a function of drain depth, spacing, size, arrangement, and management (Lewandowski et al., 2015).

Agricultural best management practices (BMPs)

There are many conservation practices available that can be applied in agricultural settings. Implementation of BMPs on farmland has been shown to increase fish abundance and improve fish habitat in lakes and rivers downstream (Wang et al., 2002). BMPs that reduce peak stream flows are largely intended to reduce overland flow and increase infiltration infield or at field edges. These practices are well summarized in Lewandowski et al. (2015) including a description of the practices and the mechanisms by which hydrology is influenced (Table 1). They emphasize the importance of implementing a suite of practices throughout a drainage network or farm operation to effectively influence stream flow. The specific types of BMPs and the extent to which they can be applied in any given location vary depending on the type of farming and local conditions. Highlights from Lewandowski et al. (2015) and additional literature are presented here to describe relationships between individual agricultural BMPs and their effects on hydrology.

Grassed waterways and two-stage ditches

Grassed waterways (GWWs) are common in the Lake Superior basin (Figure 15). These constructed and graded drainage ditches are planted with grasses and used to convey water off fields while slowing runoff and increasing infiltration rates. The effectiveness of GWWs is determined by the inflow rate, vegetation characteristics, channel cross-section, and channel length. Fiener and Auerswald (2003, 2005) compared the performance of unmanaged and managed (cut annually in August) GWWs. Damaging sedimentation in the GWW can be reduced by frequent mowing, but this process decreases the effectiveness of the GWW secondary functions such as the ability to retain sediments and reduce runoff volume. Annual mowing encouraged fast-growing grasses and significantly improved the performance of the waterway in slowing runoff during the growing season. They also found that flat-bottomed GWWs with stiff grasses and herbs at least 0.15 meters tall reduced runoff volume and peak discharge rates. Kalantari et al. (2014) reported a 28% decrease in peak flows associated with GWWs in silty clay soils during 50-year storm events in a 4.5 km^2 watershed. The width of a GWW can influence performance. A narrow GWW can be effective in preventing gully erosion; wider GWWs have added benefits of surface water runoff reduction. Mowing GWWs reduces overland roughness, and limits reductions in surface runoff rates. The RCIC (1977) tested grassed waterways and ditches extensively. They found GWWs to be very effective in reducing sediment delivery associated with increased runoff and noted the importance of preventing grazing in GWWs to ensure their effectiveness.

GWWs are typically 3 meters wide, consistent with bulldozer and scraper blade widths. Grassed waterways are challenging to maintain, especially when growing annual row crops that require regular crossing with farm machinery, which can create ruts and compact soils, reducing infiltration rates and impairing the function of a GWW to reduce runoff. GWWs are easier to maintain effectively with perennial forages.

Figure 15. Example of a grassed waterway. Photo courtesy of the NRCS.

Two-stage ditches are designed with elevated benches along each side (Figure 16, Powell et al., 2007). Two-stage ditches mimic a natural channel; the benches serve as a floodplain for the ditch. During low flow periods, they function as wetlands and absorb nutrient loads, and during high flow periods, they allow flow to spread out and slow, increasing ditch stability and reducing erosion and peak flows (Mahl, 2015). Two-stage ditches also improve in-field wildlife habitat compared to traditional ditches (DeZiel, 2019), and are also maintained with grass.

In Wisconsin's Lake Superior basin, the heavy clay soils require extensive ditching to adequately dry fields for planting in the spring. Installing grassed waterways or two-staged ditches on all ditches that drain fields would leave little room for production. As a result, when they exist, they are usually installed only on major or mainstem ditches.

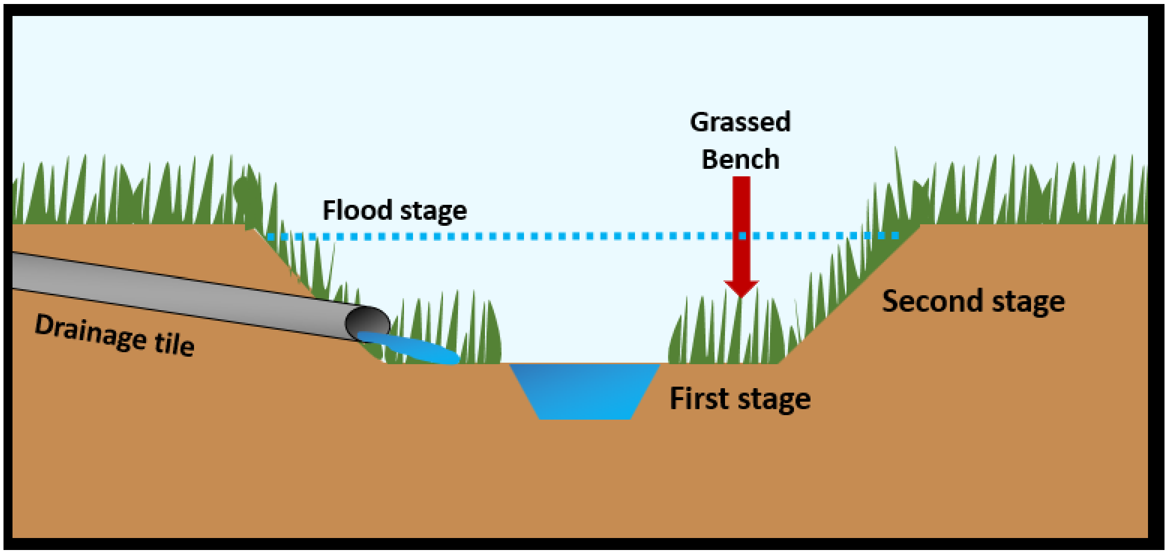

Figure 16. Schematic of a two-stage ditch (After Powell et al., 2007).

Vegetative filter strips

Vegetative filter strips (VFS) are typically installed to slow surface runoff within or from fields, thereby reducing or minimizing sedimentation or nutrient water quality degradation. The design width and arrangement of VFS varies based on site-specific conditions, including consideration of drainage area, contamination source areas, slope, and proximity to environmentally sensitive areas (NRCS, 2014). VFS are frequently installed on the contour within fields or at field edges to reduce runoff and promote infiltration. Seeding criteria for VFS are identified in NRCS Practice Standard 393 and include consideration of locally appropriate species selection, soil saturation, and proximity to waterways. VFS are most effective when sheet flow, rather than channelized flow occurs. To function as intended, filter strip maintenance includes redistribution of accumulated sediments, maintaining vegetative cover, and limiting heavy equipment operation within the VFS. Veum et al. (2009) investigated the effect of VFS width on performance in the clay pan region of Missouri and found that VFS that were 4.5 meters in width, comprising 8 to 10% of the field, reduced runoff by 8.4%.

Riparian Buffer Strips

Riparian buffer strips (RBS, also known as conservation buffer strips) provide a corridor of vegetation around waterways and function much like a filter strip along field edges where sheet flow is predominant. Chase et al. (2016) showed that a less than 20% increase in riparian forest cover relative to agricultural intensity reduced the severity of summer low flow periods and improved water quality. Sheridan et al. (1999) evaluated the effectiveness of RBS consistent with NRCS specifications (a three-zone system extending from the stream edge upland that includes no harvest, some forest harvest, and grass filter management zones). They found significant reductions in runoff and sediment transport utilizing this system, even with harvest in the intermediate forest zone. However, the development of concentrated flow areas within riparian areas allows surface runoff to bypass buffer zones, limiting the effectiveness. Flow concentration can be extensive in riparian buffer strips, likely leading to their varied infiltration efficiency from 9% to 100% (Helmers et al., 2006). Pankau et al. (2012) found that 82 to 100%

of drainage leaving farm fields occurred in concentrated flow areas, with greater occurrence in agricultural rather than in forested watersheds of southern Illinois. Concentrated flow areas that direct runoff through the buffer strip are common in the Lake Superior basin as well (Jason Fischbach, personal observation). As part of their watershed-scale wetlands management plan, Douglas County (2016) utilized aerial photo interpretation to identify evidence of channelization, quantify with woody riparian vegetation density, land use, and amount of grazing in the riparian zone to identify potentially restorable stream/riparian areas. Dosskey et al. (2002) recommend combining field observations of runoff pathways through VBS with model estimates of pathway dimensions to estimate buffer effectiveness. This provides an improved estimate of buffer value in reducing runoff and can guide restoration actions at a local scale.

Conservation tillage

No-till practices increase the amount of organic matter at the soil surface and have been shown to slow the amount of runoff on non-frozen soils, allowing for infiltration in fields (Discovery Farm, no date). Potter (1991) suggests that the increase in soil roughness associated with conservation tillage likely decreases spring runoff volumes and increases baseflow. Bro and Fratt (2011) recommend conservation tillage as an important agricultural practice for the Fish Creek watershed to reduce surface runoff.

The extent and severity of soil compaction in the Lake Superior Basin are unknown, but with the heavy clay soils and the necessity and/or the tendency of farmers to operate in wet fields, compaction is assumed to be severe and widespread. Breaking up the plow pan layer associated with moldboard plowing, would likely increase infiltration rates, and reduce the volume of runoff (Cooperative Extension Service, 1994). In high clay content soils, tillage is typically required to alleviate soil compaction. Compaction can be reduced through strip tillage and in-row subsoiling or paratilling (Naderman et al., 2006; Raper et al., 2005; Raper et al., 2007). Paratilling is a deep tillage technique in which the soil is loosened below the soil surface but not inverted (Langdale et al., 1990). Compaction can also be alleviated by certain deep-rooting cover crops, including cereal grains and radishes (Anguelov, 2020). These techniques are useful to reduce compaction while reducing the risk of erosion due to tillage.

Perennial crops/cover crops vs annual row crops

Efforts to perennialize the Midwestern agricultural landscape have existed since the 1930s when the extent and severity of soil erosion became evident. Recently, the Green Lands, Blue Waters Initiative in the Upper Mississippi River basin (www.greenlandsbluewaters.org) has been working to integrate the concept of continuous living cover into agricultural policy and production. Continuous living cover could include the use of cover crops in annual row crop systems, perennial forage crops, or new perennial grain and biomass crops. The objective is to have roots in the soil and vegetation on the surface 365 days a year. Perennial crops have better infiltration rates and greater surface roughness to slow runoff in addition to habitat benefits.

With 87% of the agricultural lands in the Lake Superior Basin currently in perennial forages, any conversion to annual row crops is likely to increase the impact of agricultural lands on runoff peak flows. This is particularly true for row crops harvested late in the season, such as corn. With such a short season, farmers in the basin must wait as long as possible in the fall for the corn to ripen and dry before harvest. Often, the fields are wet late in the fall due to lower temperatures and less evapotranspiration.

The corn must get harvested, despite the wet soils, and the result is significant surface compaction. This compaction persists throughout winter months resulting in significant surface runoff, particularly in the spring.

Short rotation woody crops (SRWC)

The production of short-rotation woody crops for bioenergy or pulp has been an area of active research in recent years. Cottonwood and willow species, including hybrids developed for rapid growth, extensive root systems, and hydraulic control potential, can be planted and harvested in cycles of less than 20 years, depending on the crop product (Zalesny et al., 2019). Bioenergy crops can be harvested on a 3–5 year rotation; pulp crops can be on a 10-12 year rotation or up to 20 years for saw timber. The trees grow back from the stump, so re-seeding or planting is not required, and soil disturbance is limited to harvest. Although Verry (1983) defined forest lands under 15 years of age as open land in his open lands definition, research by Perry et al. (2001) found that SRWCs do not perform similarly to open lands. They suggest that SRWC could reduce peak flows from both rainfall and snowmelt events because of the desynchronization of runoff.

SRWCs tend to have faster growth rates than native forest cover (Miller and Bender, 2008). Thus, the dominant trees in a 10-year-old hybrid poplar planting, for example, may be equivalent to a 20 to 30-year-old native aspen stand. That said, the first two years during the establishment of the SRWC plantings phase requires a weed-free condition that may contribute to a temporary increase in run-off and erosion. Even so, the impact of SRWCs should be evaluated in comparison to traditional agricultural crops rather than mature native forest cover, as SRWCs are more likely to be planted in agricultural fields rather than as a component of reforestation.

Figure 17. A coppiced hybrid poplar stand (background) with more spring snow retention than an uncoppiced mature hybrid poplar stand (foreground). Photo courtesy of Jason Fischbach.

Figure 18. A willow snow fence with spring snow retention. Photo courtesy of Jason Fischbach.

Cumulative effect of multiple best management practices

Research on the cumulative effect of BMPS on hydrology is limited by a lack of consistent data on practices utilized at a watershed scale. Potter (1991) evaluated changes in agricultural operations from 1940 to 1986 in the steep terrain and moderately drained soils of the Driftless area in southern Wisconsin. He notes that 83% of farmers in the study watersheds were involved in some conservation program with a variety of practices employed, but the type, extent, and location of specific practices were not available for their study. He found that both the peak and volume of winter/spring stream flow events decreased over the period of record independent of climate changes.

Inamdar et al. (2001) investigated the effects of strip cropping, conservation tillage, and nutrient management BMPs on hydrology and nutrient runoff in two Atlantic coastal plain watersheds. They found a significant increase in average streamflow between pre- and post-BMP periods, which they attributed to increases in baseflow. Corresponding significant decreases were also observed in nutrient concentrations and loads.

Other authors debate the effectiveness of agricultural BMPs on influencing hydrology, with some stating that precipitation changes influence streamflow more than land use (Gupta et al., 2016), and others showing that agricultural practices significantly increase runoff and concurrent streamflow (Schottler et al., 2016), particularly by reducing base flow (Schilling, 2016). Cho et al. (2019) examined the effectiveness of different management options to reduce sediment loading in the Le Sueur watershed, a large agricultural watershed in south-central Minnesota. They compared water retention to other sediment management practices including conservation tillage techniques, grassed waterways, buffers, ravine stabilization, and bluff stabilization. They found that the most cost-effective way to reduce sediment loading was through a combination of ravine head cut stabilization, bluff stabilization, and water retention in the upper basin. Water retention had the greatest potential in terms of the total mass of sediment removed; a >70% reduction of the initial fine sediment load was achievable with water retention alone.

Consideration of potential changes in temperature and precipitation due to climate change should influence strategic approaches to hydrologic restoration. In addition to the potential for expanded agricultural opportunities in the basin due to lengthened growing seasons and shifts in plant hardiness zones, the WICCI also notes that an increase in freeze/thaw events could increase soil tilth and infiltration (WICCI, 2011). However, these conditions may be overwhelmed by the increased intensity of rainstorms and higher runoff rates.

Urban and rural residential

Although constituting a relatively small surface area of most rural watersheds, urban areas can exert considerable influence on local hydrology. Impervious surfaces, much more extensive in developed areas, have smooth surfaces and allow no infiltration, resulting in greatly accelerating runoff. Accelerated runoff from urban areas can increase storm flows, decrease base flows, erode and incise stream channels, and create wider floodplains (WDNR, 1994). Increases in impervious surfaces can increase runoff volume, peak discharge in downstream rivers, runoff velocity, and flooding volume (MPCA, 2016).

The WISCLAND2 dataset displays the extent of urban and rural residential lands throughout the state of Wisconsin, classified as high or low intensity development (WDNR, 2019). High-intensity developed lands are areas with 50% or greater solid impervious cover. Low-intensity developed lands are areas with 25% to 50% solid impervious cover and may have some vegetation. The amount of high and low-intensity developed lands represent a small portion (<2%) of the entire Lake Superior Basin and are dominated by the cities of Ashland and Superior, located in the lower portions of watersheds (Figure 19).

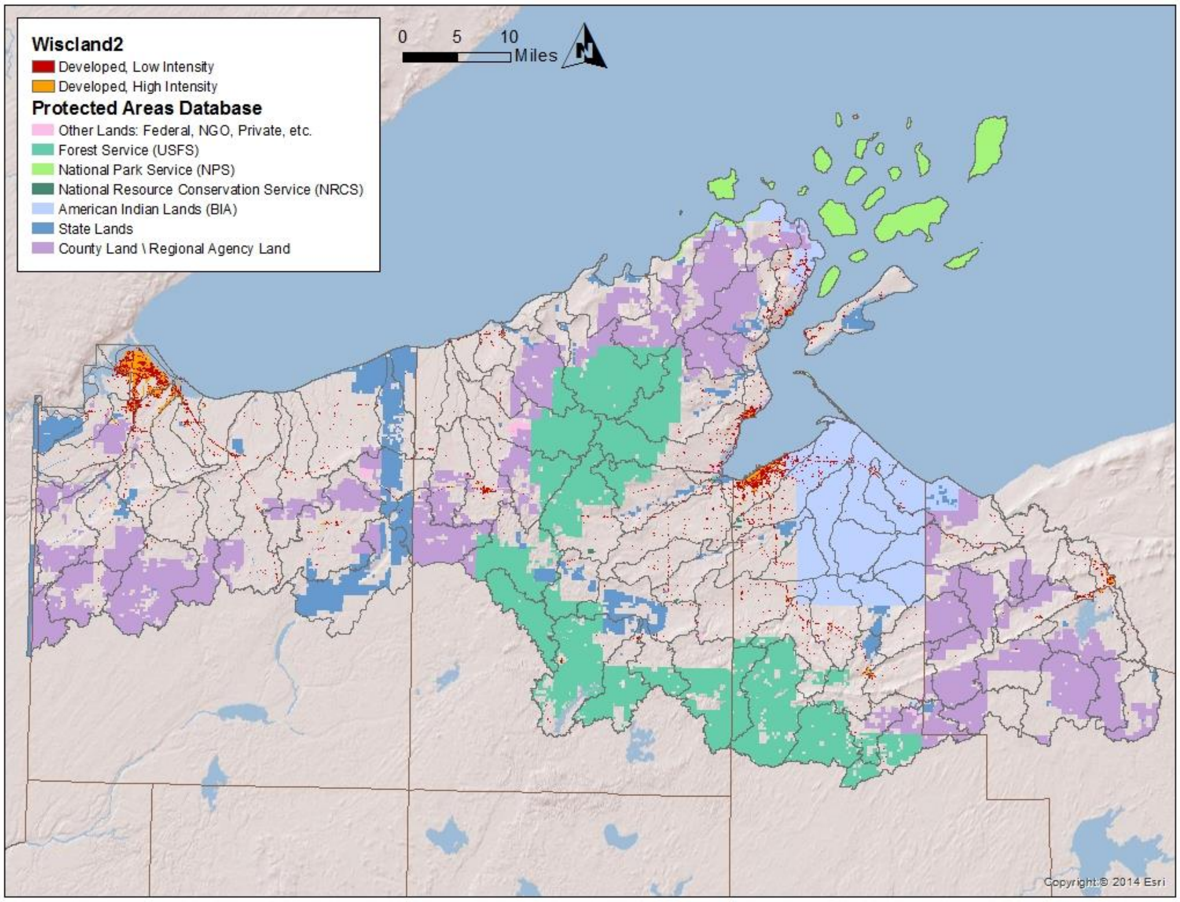

Figure 19. Distribution of developed and protected lands in Wisconsin's Lake Superior basin, based on the Protected Areas Database (PAD, Gergley and McKerrow, 2016). PAD is the official inventory of protected open space in the US. It includes lands held in trust by national, state, and some local governments and nonprofit conservation organizations. It includes fee-protected public parks and other lands, designated areas, conservation easements, and Marine Protected Areas. Note that the American Indian Lands include the Red Cliff Reservation at the north end of the Bayfield Peninsula and the Bad River Reservation east of Chequamegon Bay.

Stormwater management regulations of urban/residential areas exist at multiple jurisdictional levels. City and village governments are delegated authority from the State to administer erosion control programs for one to two dwelling construction projects. Permits issued by city or village governments generally address the placement of new structures with respect to property lines and waterways. By limiting the amount of impervious surface near waterways, these permits can help promote riparian buffers that promote infiltration and reduce accelerated runoff to streams. Counties can also develop ordinances that work to protect waterways by reducing the amount and rate of runoff.

Regulation of stormwater statewide is authorized by Chapter NR 216 of Wisconsin's Administrative Code. Construction projects involving one or more acres of land are required to include site-specific erosion control and stormwater management plans. Erosion control plans address sediment and erosion control during the construction period, and stormwater management plans specify the long-term management of runoff. Some light and heavy industrial activities are required to include a facility-specific stormwater pollution prevention plan, which identifies runoff management, spill response, and routine housekeeping practices. Larger communities (those typically with populations greater than 10,000) are subject to municipal stormwater permits, which require the development of local erosion control & stormwater ordinances, education, and outreach efforts concerning stormwater awareness, and community-wide treatment of urban runoff.

There are a variety of structures that can hold and store surface runoff from urban areas to increase infiltration and roughness. These approaches to mitigate the effects of urban lands on hydrology are well summarized at http://www.stormwatercenter.net/. These structures differ in the volume of runoff they can hold, and the way stored runoff is released from the structure. Wet detention ponds contain a single standing pool of water that is typically 1 to 2.5 meters deep. Water is released at a confined outlet. Infiltration basins can hold similar amounts of water, but stored water is released through the infiltration of the bottom and sides of the basin. Constructed wetlands are another type of water storage structure in urban settings that retain runoff and slowly release it via infiltration. All these practices are effective at storing water and trapping sediment but require ongoing maintenance. The appropriate structure to use depends on the soils, slope, geology, and hydrogeology of a given site (WDNR, 1994).

Built landscaping features that can be used to store overland runoff include rain gardens and other bioretention areas. These are typically used at smaller sites like areas adjacent to parking lots (Figure 20). Surface runoff is directed into depressions that hold water and allow infiltration. These structures can help store water during light rain events but can become quickly overwhelmed during heavier rains. Other urban stormwater management techniques not utilized extensively in Wisconsin's Lake Superior basin include green roofs, onsite water reuse, and porous pavement.

Figure 20. A newly-installed rain garden in Ashland stores runoff after a heavy rain event.

Ditching associated with road networks can lead to accelerated runoff and increased peak flow (Jones and Grant, 1996; Wemple et al., 1996). This is especially true with poorly installed and maintained ditches and culverts. When hydrologically connected to streams, roadside ditches essentially act as an extended stream network. This increases drainage density and consequently water delivery efficiency to streams, particularly during high runoff events (Figure 21). Water delivery from roadside ditches to stream channels, usually where the road crosses a stream channel, can affect the volume and timing of streamflow. At the watershed scale, road ditches have been found to increase the magnitude of mean floods by 2 to 12% and to increase peak discharge by 3 to over 300% (Buchanan et al., 2013). Effects on hydrology may be greater in watersheds where the area contributing to ditch drainage is greater than the area of stream drainage. Harr et al. (1975) found that road systems with an area that exceeds 15% of a watershed will increase streamflow. In addition, road ditches can also convert subsurface drainage to surface runoff (Wemple et al., 1996).

Figure 21. Roadside ditch during spring thaw carrying sediment-laden runoff to a stream or lake. Photo courtesy of Michele Wheeler.

Appendix 2 References

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Appendix 3: Methods for comparison of open lands methodology

There are several widely produced land use/land cover datasets. We reviewed the following datasets to evaluate if they could support evaluation of open lands to prioritize slow the flow work in the south shore basin.

- National Land Cover Database 2011 (NLCD - https://www.mrlc.gov/)
- WiscLand 2 (http://dnr.wi.gov/maps/gis/datalandcover.html)
- National Agriculture Statistics Service CropScape Cropland Data Layer (CropScape - https://nassgeodata.gmu.edu/CropScape)

The National Land Cover Database (NLCD) is a broad land cover database for the nation, with relatively limited land use classes compared to both WISCLAND and CropScape. It also has limited ground-truthing as it covers the entire country. WISLCAND 2 was developed as a broad land use/land cover database for the state of Wisconsin. Because of the smaller scale, WISLAND 2 and has higher levels of quality control and ground truthing compared to both NLCD and CropScape. It includes more classes for forest type, while CropScape is broken out into more classes of crop type than WISCLAND or NLCD. CropScape is designed for managing agricultural lands. WISCLAND is superior at mapping at a fine scale: it identifies entire fields as a single land use, while CropScape has a very grainy/patchy output which limits its use at a fine scale. The three datasets differ in their methods and outputs for identifying shrubland, woody wetlands, and deciduous forest, all of which are present in the south shore basin. WISCLAND is not reproduced or updated on a regular basis, but as needed. WISCLAND 1 was developed between 1991 - 1993 and updated to WISCLAND 2 in 2014. There are no current plans to update WISLCAND 2. NASS CropScape is produced every year from satellite data. NLCD is designed to provide updates every five years (this review considered NLCD 2011, but the most recent iteration is NLCD 2016).

We found NLCD has limited utility for evaluating open lands in the South Shore basin due to the limited number of classes and low resolution and quality assurance measures. While WISCLAND 2 is likely more accurate due to extensive ground-truthing and quality assurance, it is now five years old, and not currently planned to be updated. While CropScape has less quality assurance and is likely less accurate, it is produced annually, which allows us to potentially conduct a similar analysis to look at open lands in the last 15 years to identify harvests/young forest. That would not be possible with WISCLAND or NLCD. So, we used CropScape to identify open lands and compared those to the outputs from the Community GIS analysis. We compared the results of using each dataset to summarize percent open lands by subwatershed, and to evaluated how effective each method is at identifying different types of open lands: urban, agriculture, and young forests. Because the most recent Community GIS assessment for the entire south shore was done in 2008, but a more recent assessment was done in the Nemadji in 2014, we chose to use the more recent 2014 Nemadji assessment for this comparison.

While neither analysis is ground-truthed extensively in the region, the CropScape is a national data layer with limited quality assurance at the regional or local scale. The regional Community GIS analysis included extensive heads-up digitization of individual parcels of open lands from multiple satellite imagery for each year in the series and is therefore assumed to be a more accurate dataset. However, because of the lack of ground-truthing, it is impossible to assess how accurate the Community GIS analysis is.

First, we reclassified the CropScape dataset to aggregate the categories to open, forest, wetland, or other (Table 7). We then merged the 2007 – 2014 CropScape data into a single layer that identifies all lands that was classified as open in any year from 2007 to 2014. This step intends to include lands that were harvested but re-forested as young forest less than 15 years in age. While CropScape data go back to 2003, we chose to only use 2007 – 2014. Prior to 2007, CropScape data is not as robust, and the overall dataset only goes back to 2003. We chose to only use layers produced after methods used to derive CropScape layers improved in 2007 (https://www.nass.usda.gov/Research_and_Science/Cropland/metadata/meta.php).

Next, we found the percent open lands by subwatershed, based on the CropScape data. Because we wanted to have a direct comparison to the Community GIS Open Lands assessment, we summarized using the same subwatersheds delineated for the Community GIS assessment. For a qualitative assessment of the effectiveness of the CropScape data to identify young forest and recent harvests, we overlaid the reclassified CropScape data with the three classes (harvested, urban, and agriculture) of open lands parcels digitized in the Community GIS analysis. We did this both for an individual year, 2014; as well as for the cumulative open lands based on 2007 – 2014 data.

Table A1.1: All CropScape classes present in the south shore basin and how each was reclassified for comparison to the Community GIS analysis.

CropScape class name	**Reclassified class name**	**CropScape class name**	**Reclassified class name**
Background	Other	Fallow/Idle Cropland	Open
Corn	Open	Forest	forest
Sorghum	Open	Apples	forest
Soybeans	Open	Christmas Trees	forest
Sunflower	Open	Clouds/No Data	other
Sweet Corn	Open	Developed	Open
Barley	Open	Water	wetland
Durum Wheat	Open	Wetlands	wetland
Spring Wheat	Open	Nonag/Undefined	Other
Winter Wheat	Open	Aquaculture	Other
Other Small Grains	Open	Open Water	wetland
Dbl Crop WinWht/Soybeans	Open	Developed/Open Space	Open
Rye	Open	Developed/Low Intensity	Open
Oats	Open	Developed/Med Intensity	Open
Millet	Open	Developed/High Intensity	Open
Canola	Open	Barren	Open
Flaxseed	Open	Deciduous Forest	forest
Safflower	Open	Evergreen Forest	forest
Alfalfa	Open	Mixed Forest	forest

Other Hay/Non-Alfalfa	Open	Shrubland	Open
Camelina	Open	Grass/Pasture	Open
Sugarbeets	Open	Woody Wetlands	wetland
Dry Beans	Open	Herbaceous Wetlands	wetland
Potatoes	Open	Triticale	Open
Other Crops	Open	Vetch	Open
Misc Vegs & Fruits	Open	Dbl Crop WinWht/Corn	Open
Onions	Open	Pumpkins	Open
Peas	Open	Dbl Crop Barley/Sorghum	Open
Herbs	Open	Dbl Crop Soybeans/Oats	Open
Clover/Wildflowers	Open	Blueberries	Open
Sod/Grass Seed	Open	Cranberries	other

Appendix 4: Additional Data for decision making

Table A2.1. Active USGS continuous discharge stream gauges and peak flow gauge sites in Wisconsin's Lake Superior basin. Summary hydrologic statistics compiles from water year reports on http://waterdata.usgs.gov. *Maximum peak flow values include preliminary data from July 11, 2016 flood event for Beartrap Cr, Tyler Forks, Bad River, and White River.

Stream Gauge Name	ID	Latitude	Longitude	Start Year	Drainage Area mi^2	Contributing area mi^2	Max peak flow (cfs)*	Annual mean discharge cfs (low, high)	Annual runoff cfs/mi^2	Minimum annual 7 day discharge cfs	Baseflow index
USGS Continuous Discharge Stations											
Nemadji River Near Superior, WI	04024430	46.63330	-92.09410	1973	420	420	33000	381 (138, 786)	0.9	22	0.404
Bois Brule River at Brule, WI	04025500	46.53770	-91.59550	1942	118	118	1860	170 (129, 223)	1.4	89	0.871
Beartrap Creek at U.S. Highway 2 Near Ashland, Wi	04026390	46.60870	-90.75640	2007	23	23	3320	19 (6.2, 40)	0.8	0	n/a
Tyler Forks River at Stricker Road near Mellen, Wi	04026561	46.39460	-90.59010	2011	71	71	2,940	90 (63, 113)	1.2	3.9	n/a
Bad River Near Odanah, WI	04027000	46.48740	-90.69600	1914-1922,	597	597	39,200	608 (286, 951)	1.0	48	0.477
White River Near Ashland, Wi	04027500	46.49720	-90.90440	1948	301	301	8,590	273.1 (164, 426)	0.9	68	0.684
Whittlesey Creek Near Ashland, Wi	040263205	46.59446	-90.96310	1999	38	22	1010	22 (19, 26)	0.6	16	n/a
North Fish Creek near Moquah, WI	040263491	46.54888	-91.06210	1989	65	38	3740	73.8 (57.2, 87.9)	1.2	44.6	0.74
Montreal River at Saxon Falls Near Saxon, WI (04029990)	04029990	46.53690	-90.37990	1986	262	262	9880	298.6 (161.9, 468,1)	1.1	30	0.55
St. Louis River at Oliver, WI. (0402403250)	0402403250										
USGS Peak Streamflow Station											
Sand River Tributary near Red Cliff, WI	04026190	46.89990	-90.95570	1959	27	1	624				
Sioux River near Washburn, WI	04026300	46.68880	-90.95070	1964	34	14	1620				

Table A2.2: Recommendations from federal, state, and regional initiatives on the size of riparian management zones.

Source: National Management Measures to Control Nonpoint Source Pollution from Forestry - US EPA, 2005		
RMZ buffer size	**Harvest Restrictions**	**Other**
Varies by state - minimum width of 35-50 feet is generally recommended to be effective. A fixed width is recommended or prescribed. A variable width is determined based on-site conditions such as slope. Intermittent and ephemerals need to be given special consideration when determining boundaries.	Recommendations largely related to maintaining stream temperature. Examples: • Maintain quantity of trees that provide at least 50% of the summer midday shade. • Maintain 40% of the total volume of timber >6" DBH over a 10-year period, evenly distributed. • Maintain one-half the volume of a fully stocked stand.	Extended rotations, go to top of slopes, consider wind-firmness of the leave trees and strips. Leave slash on highly erodible soils. Revegetate bare surfaces with at least 70% or greater coverage. No skidders or other heavy machinery, landings, portable sawmills, and roads in the SMA. Minimize soil disturbance. Restrict mechanical site prep and encourage natural revegetation, seeding and hand planting.
Some states utilize stream type (intermittent, perennial, trout water, public water supplies, etc) and slope to define RMZ size, ranging from 50 - 200 feet.		Directionally fell trees away from streams and remove slash and debris unless recommended by fisheries. Apply harvesting restrictions in the SMA to maintain its integrity.
Source: Riparian Forest Buffer (NRCS conservation practice standard, 391)		
RMZ buffer size	**Harvest Restrictions**	**Other**
Forest Buffer Zone (1): No harvest zone minimum 15 feet wide.	Retain forest cover to provide shade to moderate and stabilize water temperature and contributes necessary detritus and large woody cover to the aquatic ecosystem.	Management limited to bank stabilization and removal of potential problem vegetation. Removal of trees on a case-by-case basis where habitat and water quality values are not compromised.

Forest Buffer Zone (2): Sustainable Management Zone: extends a minimum distance of 20 feet past zone 1. Minimum combined width of zone 1+2 is the lesser of 100 feet or 30% of the geomorphic flood plain. In no case will the combined width of 1+2 be less than 35 feet.	Sustainable timber management is permitted in accordance with the Wisconsin Forestry Best Management Practices, such that the original purpose of the forest buffer is not compromised by loss of vegetation or disturbance.	
Forest Buffer Zone (3): Upgradient Grass-Forb Zone: minimum width 20 feet.		Can be used to control soil movement in the upgradient area immediately adjacent to zone 2. Concentrated flow and sheet and rill erosion will be controlled within 300' up gradient of the buffer.
Source: Wisconsin's Forestry Best Management Practices for Water Quality, Field Manual, 2010		
RMZ buffer size	**Harvest Restrictions**	**Other**
100 feet for all Lakes, designated trout streams, and streams ≥ 3 feet wide	Harvesting should leave at least 60 ft^2 basal area in trees 5" DBH and larger, evenly distributed in RMZ. Harvest intervals minimum of 10 years. Develop trees 12" and larger. Use selection harvests and promote long-lived tree species appropriate to the site. No harvest of fine woody material within 50' of the OHWM.	Operate wheeled or tracked equipment within 15-50' of the OHWM only when the ground is frozen or dry. Do not operate equipment within 15' of the OHWM except on roads or crossings. Keep skid trail grades less than 15%, winch logs up steep slopes to prevent erosion.
35 feet for streams < 3 feet wide	Harvesting should leave at least 60 ft^2 basal area in trees 5" DBH and larger, evenly distributed in RMZ. Harvest intervals minimum of 10 years. Use selection harvests and promote long-lived tree species appropriate to the site. Do not harvest fine woody material within 15' of the OHWM.	Operate wheeled or tracked equipment within 15' of the OHWM only when ground is frozen or dry. keep skid trail grades less than 15%, winch logs up steep slopes to prevent erosion.
35 feet for streams < 1 foot wide	No minimum BA residual recommended. Do not harvest fine woody material within 15' of the OHWM.	Operate wheeled or tracked equipment within 15' of the OHWM only when ground is frozen or dry. keep skid trail grades less than 15%, winch logs up steep slopes to prevent erosion.

Source: **Management Recommendations for Forestry Practices on Wisconsin's Lake Superior Red Clay Plain - WI DNR Forestry Division, June 2007**		
RMZ buffer size	**Harvest Restrictions**	**Other**
100 feet on perennial navigable streams 35 feet on intermittent and non-navigable streams.	Maintain a minimum residual basal area of 80 ft^2 in trees 5 inches diameter at breast height and larger of long-lived shade tolerant species **in** riparian areas.	Identify, protect, and create large woody debris in headwater streams. Consider layout so that uncut stands can intercept runoff from harvested areas. Do not concentrate clear-cuts or new roads in a watershed or in erodible areas, such as steep slopes. Improve stocking of species that can be harvested by individual or group selection with long rotation ages; selective harvests should be a minimum of 15-20 years apart. Other considerations given as to effects of different harvesting methods.
	Maintain a minimum residual basal area of 60 ft^2 in trees 5 inches diameter at breast height and larger of long-lived shade tolerant species **outside** riparian areas.	
Source: **Management Recommendations for Forestry Practices along Wisconsin's Coastal Trout Streams - WI DNR Forestry Division, June 2007**		
RMZ buffer size	**Harvest Restrictions**	**Other**
100 feet on perennial navigable streams		Leave dead and down on all streams. Do not remove all large trees along streams. Identify, protect, and create large woody debris in headwater streams.
Appendix B: minimum of first 50 feet beyond OHWM	VERY limited selective harvesting leaving at least 90 ft2 of basal area in long lived species. Manage for large woody debris recruitment.	NO heavy equipment, promote conifer, large diameter, long-lived and down woody debris. In hardwood increase conifer component by hand planting if site allows.
Appendix B: within 50-200+ feet of OHWM	Leave at least 50 ft2 or at least 50% canopy cover.	NO rutting or scarification (ops during frozen ground), promote long lived species especially conifers, avoid clearcutting, use selective harvests or small patch cuts, manage on a longer rotation (20-25 years cut rotation), others.

Source: **Erosion and Sedimentation in the Nemadji River Basin - Nemadji River Basin Project Final Report, 1998**		
RMZ buffer size	**Harvest Restrictions**	**Other**
Width of riparian zone in red-clay portion of the watershed includes the entire floodplain plus adjacent slopes 20% or greater.	Thin stands to encourage large crown development. Immediately adjacent to stream, design for trees 30 feet apart. From 30 - 100 feet from the stream, design for trees 20-30 feet apart.	Manage for large, woody debris. Plant long-lived deciduous and coniferous trees in sparsely forested areas. Retain conifer and deciduous mix throughout riparian zone, favor long-lived trees, selective harvest for later successional species. Encourage diverse, complex landscape. Coordinate management between landowners, agencies. Take precautions to avoid blocking floodplains when building a road across a stream.
Source: **Bayfield Peninsula Stream Assessment**		
RMZ buffer size	**Harvest Restrictions**	**Other**
Maintain riparian buffers consistent with June 2007 WI DNR Management Recommendations for Forestry Practices on WI Lake Superior Red Clay Plain. Restrict timber harvest within 100 feet of perennial and navigable intermittent streams.	Manage for large woody debris recruitment to the stream channel	Restrict harvest on slopes >10%; maintain 100 selective cutting buffer near edges of high terraces to prevent slope erosion.
No harvest within 50 feet of non-navigable streams; Selective harvest only within 300 feet.		Encourage pre settlement species composition, with emphasis on white pine. restoration in riparian and headwater zones.
100-foot selective cut buffer from edge of high terraces.		

Source: **Best Management Practice Guidelines for the Wisconsin Portion of the Lake Superior Basin - Project Sponsors: Ashland, Bayfield, Douglas, Iron County Land Conservation Committees and WI DNR, Schultz, SD 2003.** Riparian Information in the Habitat Section of document, see diagrams on pg. 29, 23, 24		
RMZ buffer size	**Harvest Restrictions**	**Other**
Slopes < 10%:	Maintain minimum residual basal area of 80 ft^2 IN riparian area, maintain minimum residual basal area of 60 ft^2 OUTSIDE riparian areas.	Leave dead and down trees in the riparian area. Manage for a component of 50–200-year-old trees. Maintain a mature forest condition by encouraging older successional forest - high canopy, conifer understory, vertical structure, and woody debris. No wheeled or tracked equipment, only limited harvest for personal use allowed, use hand planting. Target permanent long-lived tree species to maintain soil stability, filter pollutants, provide shade for streams and slow melting of snow along streams.
0-50 feet from OHWM	NO timber harvest allowed, only limited harvest for personal use allowed.	
50-90 feet from OHWM	Winter harvest, operate only small equipment, encourage older succession forest, selective harvest.	
Slopes >10%:		
0-75 feet from OHWM	NO timber harvest allowed under county zoning. Maintain permanent long-lived tree species for soil stability, filter pollutants, provide shade for streams and slow melting of snow along streams.	Identify and avoid operating in intermittent drainages and streams.
75-100 feet from OHWM; Riparian guidelines must include small non-navigable streams and dry channels.	No harvest preferred on these slopes, however limited harvest of areas on the inside of a stream meander (where erosion is not occurring) can be done to encourage preferred forest composition. Encourage older succession forest. Selective harvest should be a minimum of 15-20 years apart. Retain stream shade.	Identify and avoid operating in intermittent drainages and streams. Operate only small equipment (ATV comparable). Fence setbacks. Accelerate shoreland buffer restoration by planting native plant species. Others.