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Wetlands by Design
A Watershed Approach for Wisconsin

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Wetlands by Design

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Wetlands by Design, and the associated online Decision Support System, the *Wetlands and Watersheds Explorer*, provide prioritized choices for where to invest in both voluntary and regulatory wetland and watershed conservation. The Explorer's priorities are based on modeling and analysis of state-wide data, and a watershed approach to wetland planning. A watershed approach is a requirement under the Clean Water Act's 2008 Mitigation Rule (33CFR 332), and has advantages for guiding general land use planning. Field based assessments alone cannot provide these watershed scale perspectives. Before investing in a site, however, whether for regulatory or voluntary conservation efforts, field-based assessments must always be conducted to verify and complement Explorer results.

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EXECUTIVE SUMMARY

Wetlands by Design is the first watershed-based analysis to guide wetland conservation efforts throughout the state of Wisconsin. It was developed to support a watershed approach for wetland mitigation, as required by the 2008 Mitigation Rule of the Clean Water Act, and to support voluntary wetland conservation efforts. *Wetlands by Design* draws upon methods and lessons learned from similar efforts piloted, implemented, and researched in Wisconsin and nationwide. It involves extensive Geographic Information System (GIS) analysis of land and water features to identify both wetlands, and potentially restorable wetlands, that are most likely to provide substantial ecosystem services. The ecosystem services considered include those that benefit downstream waters and communities, such as flood storage, water supply, water quality treatment, and shoreline protection from erosion, and also those that provide habitat for fish, aquatic life, wildlife, and plant communities.

Wetlands by Design ranks watersheds and site-based conservation opportunities. The results are organized by watersheds, with smaller watersheds (12-digit Hydrologic Units, on average about 40,000 acres) nested within successively larger ones, up to the level of the large river basins (6-digit Hydrologic Units, averaging almost 6 million acres). At each watershed level, wetland loss has led to a loss of ecosystem services. *Wetlands by Design* uses the position of each potentially restorable wetland in the landscape to assess what services the wetland provides. Collectively, these assessments indicate both a watershed's need to replace lost services and the opportunity to do so. Individually, these assessments can be used to identify and plan for top-tier wetland protection and restoration opportunities to benefit people, watersheds, and wildlife.

Rankings are accessible through a web-based decision support tool, the *Wetlands and Watersheds Explorer*. Through interactive maps, the *Explorer* allows the user to choose which services or restoration opportunities to view in the watershed of primary interest. The *Explorer* can be used in two directions. Beginning with large watersheds, one can compare successively smaller sub-watersheds to establish ecosystem service goals for wetland protection or for restoration, and then select sites to achieve those goals. Alternatively, one can start with a wetland, or potential wetland restoration site, to determine what services the site may provide, and then evaluate the need for those services in the watershed in which it occurs.

While the many models that are the foundation for the *Explorer* incorporate the best available statewide data, the rankings reflect the limitations inherent in the data. As statewide data continue to improve, the models are available to update the *Explorer*, or to incorporate existing data with greater precision for a smaller geographic area.

Using the *Explorer* will enable decision-makers to capitalize on the ecosystem service benefits that wetlands can provide using wetlands as a tool to achieve a broad range of goals. The *Explorer*, combined with local plans and field-based assessments, can guide investments in wetland protection and restoration toward sites that are most likely to result in service gains that go beyond the site to affect the entire watershed.

The *Explorer* was designed to assist a broad range of users by making the extensive data related to wetland planning more accessible. Potential users include watershed and land use planners, wetland regulators, local communities, land trusts and other conservation groups, with goals that range from traditional habitat conservation to using nature to solve societal challenges. Using the *Explorer*, users can prioritize potential wetland mitigation sites; site green infrastructure projects; develop watershed, wildlife, and water quality plans; decide where to invest limited conservation resources; and support statewide wetland, watershed and ecosystem service initiatives.

Finally, new stand-alone datasets, such as an enhanced wetland inventory and wetland assessment layer, which were created for the *Explorer*, can be incorporated into other wetland and land use planning applications.

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A. INTRODUCTION

Strategic restoration and preservation of wetlands across Wisconsin's watersheds can help grow the state's economy, secure the health and welfare of our communities, and keep fish and wildlife thriving.

The *Wetlands & Watersheds Explorer*, a product of *Wetlands by Design: A Watershed Approach for Wisconsin*, is an online decision support tool that can guide conservationists, wetland regulators, land use planners, and other users toward sites likely to support their wetland conservation goals, such as improving water quality, reducing flood damage, or providing habitat for wildlife. The *Explorer* identifies where current wetlands (preservation opportunities) are providing these services throughout all of Wisconsin's watersheds and shows which former wetlands (drained and converted to upland) have the greatest potential to increase these services through wetland restoration. This online tool also ranks watersheds based on how wetlands' ecosystem services have declined in response to wetland loss. In combination, this information can be used in watershed and wetland planning to help determine watershed needs, and to identify top-tier preservation or restoration sites that can address watershed needs.

Wetlands by Design and the *Explorer* were designed to support a watershed approach to wetland mitigation, which is a requirement under the *2008 Federal Mitigation Rule*[1] of the Clean Water Act, when making compensatory mitigation decisions that support sustainability or improvement of aquatic resources within a watershed (see also the U.S. Army Corps of Engineers' *Watershed Approach to Compensatory Mitigation Projects* fact sheet[2]). In addition to helping prioritize potential wetland mitigation sites, the *Explorer* supports siting of public natural infrastructure projects; development of watershed, wildlife, and water quality plans; decisions by land trusts and other conservation organizations about where to invest resources; education about the state's wetlands, watersheds, and ecosystem services; and landscape-scale research.

While the *Explorer* can inform watershed planning and enhance siting decisions, it does not pre-select sites for restoration or preservation. Rather, it helps to winnow options from the hundreds or thousands found in a watershed to a manageable number with the highest service potential. The *Explorer* provides a starting point for further assessments and priorities for field visits to sites to determine whether a project is feasible.

This report is divided into several sections, each with different aims and intended audiences:

- This *Introduction* states the goals of *Wetlands by Design*, defines terms, and provides rationale for developing a watershed approach.
- The *Project Context and Overview* provides information for all users of the *Explorer* to gain an understanding of the regulatory and watershed planning contexts, the overarching structure of this watershed approach, and how watersheds and wetlands were assessed.
- *Methods* is intended for readers interested in the analytical process of how ecosystem services and habitats were assessed within watersheds and at sites, and for those considering a watershed approach for wetland conservation in other geographies.
- *Results* introduces the *Explorer*, highlights new datasets created, and presents outcomes of comparing *Explorer* ranks with field observations.
- *Discussion* contains further suggestions for how *Explorer* data may be used, provides climate change considerations, and proposes opportunities to improve on the methods used in this approach.

A.1. Why wetlands?

Although wetlands cover only a small fraction of the surface of the land (between 5 and 8 percent globally[3] and approximately 15 percent of Wisconsin[4]) they are powerhouses of the natural world. Wetlands play a pivotal role for wildlife; 50 percent of animals listed as endangered and threatened in the U.S. require wetland habitat[5]. And they provide "natural infrastructure" for people through protection of water quality and quantity, flood reduction, and other ecosystem services.[6]

Wetlands function in a variety of ways (e.g., reducing nutrient loads in streams), and many of these functions provide ecosystem services that benefit people (e.g., improving drinking water quality). All three terms – "functions," "services," and "benefits" – are referred to in this document as "services."

Wetlands support our economies, and wetland conservation provides clear financial benefits for communities, businesses, and property owners. Globally, the *annually renewable* value of swamps and floodplain wetlands has been estimated at over $25,000 per acre.[7] In the Midwest, similar analyses conducted for lands in the U.S. National Wildlife Refuge System estimated wetland value to be over $1.6 million per acre each year.[8] In both studies, the economic value of wetlands was estimated to be higher than that of any other inland land cover class. A recent statewide economic assessment of Wisconsin's wetlands estimated a cumulative value of between $3.3 and $152.6 billion per year.[9] The figures vary among the studies due to the number of ecosystem services considered as well as source data and assessment methods.

In the Mississippi Valley, the value of restoring wetlands—considering three ecosystem services: reducing greenhouse gas, reducing excess nitrogen, and waterfowl production—was estimated to be close to $600 per acre each year above current land uses.[10] Zooming in to a small Vermont town and its watershed, the value of flood abatement, alone, provided by wetlands and associated floodplains was determined to be between $126,000 annually and possibly as high as $450,000 in some years.[11] A single constructed treatment wetland was estimated to save a Texas corporation $282 million, relative to the cost of installing built infrastructure for water treatment.[12]

Wetland preservation sustains our economies; and through careful planning and design, wetland restoration can return many wetland services—and their economic values—back to our watersheds.

A.1.1. Wetlands and Climate Change

Wetland conservation, both preservation and restoration, presents us with opportunities to reduce and to adapt to the effects of climate change**.**

Wetlands may help reduce climate change: Wetlands emit methane, a greenhouse gas, but also store carbon in organic soils and vegetation. In the long-term, most natural, unconverted wetlands play a positive role in helping to reduce climate change.[13] Despite their relatively small global footprint (5-8%), wetlands may play a disproportionate role in climate regulation relative to other habitats, sequestering an estimated 830 million metric tons of carbon each year.[14] Wetland restorations may store carbon at a higher rate than existing wetlands[15] and could provide a nature-based solution to help curb climate change. *Wetlands by Design* prioritizes wetlands that have the greatest likelihood of maintaining and increasing the carbon storage capacity of our landscape.

Wetlands can help us adapt to climate change impacts: With ongoing and projected increases in temperature averages and extremes, increased intensity and frequency of storms, and other consequences of climate change, many aspects of Wisconsin's lands and waters will be fundamentally altered over the coming decades,[16] impacting ecosystem services. For example, agricultural and urban runoff are expected to increase, leading to lower water quality.[17] The importance of strategically siting wetland restoration and preservation for water quality is only amplified given climate change, and this is true for flood abatement and many other wetland services. Wetland conservation can help us adapt to ongoing and future effects of climate change.

A.2. Why a Watershed Approach?

The term "watershed approach" describes many conservation initiatives that recognize the influence of broader watershed-scale context on sites and processes, including initiatives related to groundwater, rivers and streams, nutrient management and other Best Management Practices for agricultural lands, and urban runoff. Our application of a watershed approach in Wisconsin focuses specifically on wetlands. This watershed approach uses an analytical process to identify ways to support sustainability or improvement of aquatic resources in a watershed, taking into consideration watershed needs (defined in this project in terms of ecosystem services), as well as the relative potential of individual sites to meet watershed needs. The *Watershed Approach Handbook* of the Environmental Law Institute and The Nature Conservancy provides examples and recommendations for developing a watershed approach within wetland and stream regulatory contexts.[18] Region 5 of the U.S. Environmental Protection Agency has also developed guidance for integrating wetlands into watershed plans.[19]

Many wetlands provide important services, whether for wildlife or people, but they are not all important in the same way. Wetlands vary widely in the number, type, and degree of services they provide. This variability is a result of many factors including the dominant type of vegetation, how water flows through wetlands, the seasonal availability of water, soil characteristics, whether a wetland is connected to a stream or waterbody, and the land-use and condition of the surrounding upland. Watershed context and relative position play major roles in how services are distributed among wetlands.[20,21,22] A 5-acre forested wetland at the top of a watershed may play a larger role in keeping streams flowing during drought than a similar 5-acre forested wetland at the bottom of the watershed. A 2-acre marsh surrounded by cropland likely has greater opportunity to improve water quality than a similar 2-acre marsh embedded in a more natural, forested landscape. Streamside wetlands located upstream from cities can be crucial for flood reduction and public safety, relative to wetlands not connected to streams or those that flow directly into a major waterbody.

In the absence of a watershed approach, it is difficult to compare the relative potential of different wetland restoration and protection projects. In a more traditional approach that does not include a watershed perspective, sites may be selected based on field assessments of their individual attributes, land availability and cost, accessibility, and other feasibility factors. **These site-level aspects are essential to success and a watershed approach is not intended to replace them**. Instead, a watershed approach complements and improves the site selection process, leading to higher efficiency, cost-effectiveness, and greater likelihood of generating wetland service returns.

In keeping with US EPA's multi-level approach to wetland assessment (see box at right), which includes both landscape-level and field-based assessments, we recommend selecting wetlands for restoration and protection in Wisconsin by combining a watershed approach, provided by the *Wetlands and Watersheds Explorer*, with field-based investigations (see Figures 1a and 1b). This holistic approach, which encompasses both watershed- and site-level information, capitalizes on the strengths of each scale while minimizing weaknesses. For example, while watershed-scale evaluations are necessary to locate areas and sites with the greatest potential to provide services, they rely on broad-scale datasets that may have low precision at the site level. Field-based evaluations can help to supplement coarser data, and they are necessary for developing site-specific plans, but they do not allow for comparison of the ecosystem service potential of the field-visited sites against all opportunities within a watershed.

USEPA's Multi-Level Approach to Wetland Assessment

US EPA recommends a three-level approach to assessing wetlands which has been adopted in Wisconsin by DNR.

- In **Level 1**, landscape-scale assessments are conducted using remote sensing and other coarse-scale datasets in a Geographic Information System (GIS). The *Wetlands and Watersheds Explorer* is an example of a Level 1 assessment, using GIS models and broad-scale spatial data to assess and compare the full range of wetland restoration and protection opportunities at a watershed scale.

- **Level 2** assessments, also known as rapid assessments, are conducted in the field on a site-by-site basis. Rapid assessments can be used to evaluate sites individually or to validate and improve the results of a Level 1 assessment. The *Wisconsin Wetland Rapid Assessment Method version 2*, or *WWRAMv2*, is an example of a Level 2 assessment.

- **Level 3** may include any of a variety of intensive site assessments, often research-derived, to confirm the results of a Level 2 assessment or to provide more detailed information about wetland condition and ecosystem services. Examples include site-based hydrology studies and biological assessments such as the Floristic Quality Assessments underway in Wisconsin. In the context of *Wetlands by Design*, Level 3 assessments may be conducted to inform development of a site-specific restoration or protection plan.

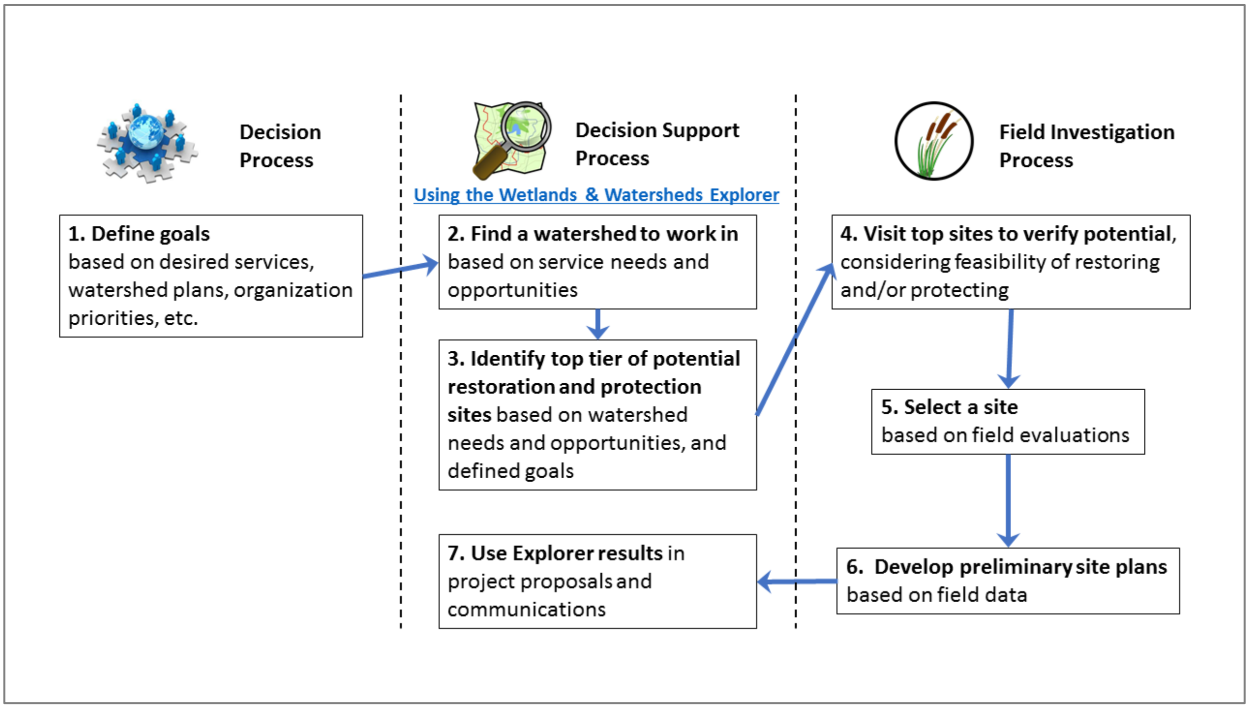


Figure 1a. Recommended sequence for ***finding a site*** using the *Wetlands & Watersheds Explorer*

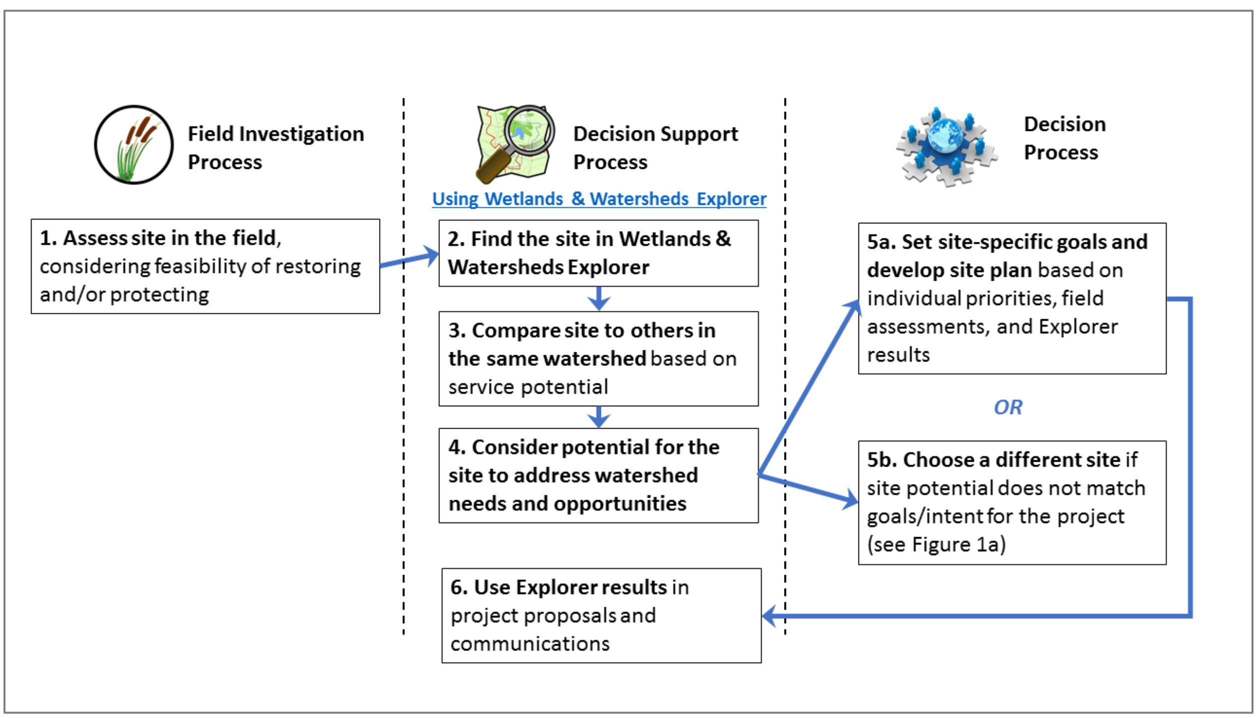


Figure 1b. Recommended sequence for ***evaluating a site*** using the *Wetlands & Watersheds Explorer*

B. PROJECT CONTEXT AND OVERVIEW

B.1. History of the Watershed Approach in Wisconsin

Wetlands by Design is the first watershed approach analysis undertaken to guide wetland conservation for the entire state of Wisconsin. It draws upon methods and lessons learned from related projects piloted, implemented, and researched in Wisconsin and nationwide. The [*Watershed Approach Handbook*]() gives an overview[23], and the box below lists some examples.

> *In Wisconsin:*
> - Duck-Pensaukee Watershed[24]
> - Milwaukee River Basin[25]
> - Sheboygan River Basin[26]
> - Stockbridge-Munsee Reservation[27]
> - Des Plaines river watershed and Lower Fox subwatersheds[28]
> - Amnicon and Bois Brule (Douglas County and St. Mary's Geospatial Services)
> - Marengo River Watershed (St. Mary's Geospatial Services and WDNR)
>
> *In other states and nationally:*
> - Wetland Evaluation Technique[29]
> - NWI Plus[30][31]
> - Landscape Level Wetland Functional Assessment[32]
> - US EPA's Wetland Supplement: Incorporating Wetlands into Watershed Planning[33]
> - Oregon's Rapid Wetland Assessment Protocol[34]
> - Rhode Island's freshwater restoration strategy[35]

In aggregate, these projects constitute an evolution in watershed-scale wetland planning and assessment. *Wetlands by Design: A Watershed Approach for Wisconsin* contributes toward this evolution with:

- Emphasis on the importance of landscape condition and land-use context to wetland service potential;
- Assessment of the relative loss of ecosystem services across watersheds, to establish watershed needs and opportunities for watershed planning;
- Creation of a new decision support system – an online mapping tool – to assist users in identifying watersheds and sites to meet defined goals;
- GIS modeling methods to automate steps previously conducted manually, enabling application at broader scales;
- Water quality improvement treated as three distinct services (phosphorus retention, sediment retention, and nitrogen reduction);
- New methods to assess remotely whether a wetland has been hydrologically disconnected from streamflow due to stream incision; and whether a wetland has a strong connection to shallow groundwater;
- New datasets, such as improved mapping of potentially restorable wetlands,[36] new land-use and landcover data,[37] and the results of Wisconsin's *Healthy Watershed Assessment*.[38]

The *Discussion and Recommendations* section of this report outlines areas for improvement, data needs, and potential next steps to encourage further evolution in strategic watershed analysis and planning.

B.2. Types of Wetland Conservation Opportunities

Wetland resources may be conserved or established through a variety of activities, which US EPA groups into four major categories: preservation, restoration, creation, and enhancement.[39] US EPA distinguishes two kinds of restoration: re-establishment (restoring former wetlands that have been converted to upland) and rehabilitation (restoring current wetlands that have been degraded or impaired). *Wetlands by Design* focuses on wetland preservation and reestablishment opportunities, collectively referred to as "sites" in this report.

Wetland creation and enhancement opportunities were not identified in this project because available GIS data do not support identification of the best opportunities. Wetland creation requires hydrologic alterations in uplands, which are best identified through on-the-ground site assessments. Wetland enhancement, which involves boosting one or more services of an existing wetland, requires considering potential trade-offs with current services, and is also best evaluated on-the-ground.[40] For example, increasing water levels in an existing wetland to increase habitat for a narrow range of species may adversely affect other species, or reduce the wetland's flood storage capacity.

B.3. Regulatory Context

Although the vision of *Wetlands by Design* combines goals, intent, and funding across regulatory and non-regulatory contexts, this project has regulatory roots. In 2008 USEPA and the U.S. Army Corps of Engineers (Corps) issued new regulations for compensatory mitigation under §404 of the Clean Water Act (CWA). The "2008 Mitigation Rule" reaffirmed the mitigation sequence for regulatory protection of wetlands: first *avoid* impacts, then *minimize* those that are unavoidable, and finally, if there are no significant adverse impacts, *compensate* for lost resources. Wisconsin's wetland laws generally mirror this federal process.

Based on recommendations made after a study of compensation effectiveness under the CWA,[41] the Rule favors wetland compensation in locations that consider the needs of the watershed where wetland loss will occur. Furthermore, compensation sites should consider not just the areal extent of wetland loss, but also lost ecosystem services, such as water quality protection, flood abatement, and provision of habitat. The 2008 Mitigation Rule states that when an appropriate watershed plan is in place (for example, one that identifies priorities for aquatic resource restoration, establishment, enhancement, and preservation) the regulatory agency should use it to guide decision-making. When such a plan does not exist, the rule outlines the types of information that should be considered to support a watershed approach.

Conducting watershed-scale analyses and developing watershed plans enables the subsequent selection and comparison of top-tier sites across a watershed, and thus provides a distinct advantage over a site-by-site approach.

Wetlands by Design: A Watershed Approach and the *Wetlands and Watersheds Explorer* resulting from this project incorporate and align with requirements of the 2008 Mitigation Rule. Project results can be used to guide investments of the Wisconsin Wetland Conservation Trust (WWCT),[42] the State's in-lieu fee (ILF) wetland mitigation program, and of potential mitigation bank sponsors. Analyses of watershed-scale wetland service losses, opportunities, and needs can add value to WWCT's Compensation Planning Frameworks (CPF), helping to define watershed-based wetland mitigation goals; in addition, site-specific rankings can help to identify a range of opportunities to meet CPF-defined watershed goals. It is important to note that the *Explorer* does not rank potential mitigation sites quantitatively; rather, it identifies a range of options for potential mitigation applicants to consider and provides information, which must be supplemented by field-collected information, to justify site selection based on watershed context.

Release of this report and the *Explorer* does not imply approval by the Corps, state agencies, or other regulatory agencies. The authority to determine whether a watershed plan is appropriate for use in the §404 program lies with the Corps District Engineers.[43]

A watershed approach can be used to guide regulatory decisions about the most important wetland resources to avoid and where best to direct compensatory mitigation.[44] By linking mitigation outcomes to local, non-regulatory conservation goals, a watershed approach can achieve wetland conservation objectives beyond those of the Clean Water Act, to the benefit of both. Combining regulatory and non-regulatory conservation efforts within a watershed approach will contribute to larger-scale wetland and watershed conservation goals.

B.4. Assessment Overview

Wetlands by Design combines three steps to assist in planning for wetland preservation and restoration:

1. First, watersheds were assessed to determine relative loss of ecosystem services; results can be used to determine which watersheds have the greatest service needs and opportunities.
2. Next, individual sites (current and potentially restorable wetlands) were prioritized according to their ecosystem service potential to meet watershed needs and address watershed opportunities.
3. Finally, the wildlife habitat value of current and potentially restorable wetlands was assessed to further inform site assessments.

B.4.1. Assessing Watersheds: Ecosystem Service Losses, Needs, and Opportunities (Step 1)

Understanding the relative need for wetland services in a watershed, and opportunities to provide them, is the first step in a watershed plan. *Wetlands by Design* began by assessing every watershed across the state to determine the relative decline in ecosystem services that can be attributed to historical wetland loss. This assessment was conducted at several scales: from major river basins, to watersheds within those basins, down to small sub-watersheds. Figure 2 explains what determines these nested watersheds with examples from the Rock River Basin.

At each watershed level, *Wetlands by Design* assessed:

- flood abatement
- fish and aquatic habitat
- sediment reduction
- nutrient transformation, and
- surface water supply.

These services were selected based on their relevance to land-use decisions, the ability to assess them using a GIS, and their connection to watershed-scale factors. This last criterion excluded services such as shoreline protection, which is highly site-specific; carbon storage, which affects a global rather than a watershed scale; and wildlife habitat, which may be determined by landscape-scale factors that cross watershed boundaries. In addition, each watershed's assessment result for each service was combined to provide users with the total number and degree of services lost within that watershed.

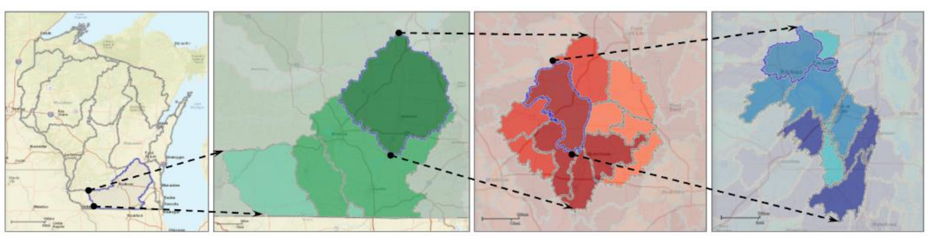
What's a Watershed?

A watershed, or Hydrologic Unit (HU), is an area of land that drains surface water to a specific point on a river, stream, or another surface water.

The Water Boundary Dataset, maintained by USGS nationwide, delineates watershed areas using hydrographic and topographic criteria. Large HUs, such as the Mississippi River Basin, are divided and subdivided into successively smaller subwatersheds, forming a multi-level, nested drainage system.

For each HU, a hydrologic unit code, or HUC, identifies the drainage area and its place in the drainage hierarchy.

The maps below, taken from the ***Wetlands and Watersheds Explorer***, use the Rock River 6-digit hydrologic unit as an example to illustrate how a watershed is divided into successively smaller subwatersheds, each of which is suited to a different planning scale.



Watershed Name:	***Rock River***	***Upper Rock River***	***Beaver Dam River***	***Fox Lake***
Hydrologic Unit Level:	6-digit	8-digit	10-digit	12-digit
Hydrologic Unit Code:	0709 00	0709 0001	0709 0001 09	0709 0001 0902
Subwatersheds:	4	12	9	
Area (sq. mi.)	5845	1892	322	51
Typical Planning Scale	State and Regional plans	Regional and County plans	Regional and County plans	Local community plans

Figure 2. The Rock River Watershed, or 6-digit Hydrologic Unit, divided into successively smaller sub-watersheds

B.4.2. Assessing Sites: Wetland Service Potential (Step 2)
Within each watershed, the second step is to prioritize current and potentially restorable wetlands, collectively referred to as "sites," based on their potential to provide wetland services.

As with the watershed level functional assessment, we selected services based on the importance of each service to people; the role the service plays in maintaining watershed health; the degree to which wetlands, specifically, may provide the service; and the ability to assess the service using a GIS. At the site level, however, we expanded the assessment beyond the five services considered at the watershed level to include a total of nine services:

- flood abatement
- sediment retention
- phosphorous retention
- nitrogen reduction
- shoreline protection
- surface water supply
- carbon storage
- fish and aquatic habitat
- floristic integrity

This expanded list is due to two factors. First, site-level assessment can incorporate current land use condition and site context, which is not available to a watershed scale assessment that relies on hydrogeomorphic features to compare current and historical conditions. Secondly, services such as floristic integrity and carbon storage can be assessed at a site, but are not relevant at a watershed scale.

Wildlife habitat assessment is discussed in the following section. All other services were assessed using criteria in three categories:

- The *opportunity* for the service to be performed,
- The *effectiveness* of the wetland in providing the service, and
- The *significance* of the site in providing services for people.

For example, a site surrounded by steep slopes or impervious surfaces has the *opportunity* to perform the flood abatement service. If that same site is situated in a geographic depression and has dense vegetation, it is likely *effective* at slowing and temporarily storing floodwaters. And, if it is situated above developed flood-prone areas, it *significantly* benefits people. The potential for an individual site to provide each service, relative to other sites, was calculated by measuring factors in each of these three categories, and then combining results into a final score.

Sites were ranked as "very high," "high," or "moderate" for each service relative to all sites in the same watershed. Sites were also prioritized for their potential to provide multiple services where each service rank was "high" or "very high." Selecting sites for restoration requires considering the range and level of service provision at individual sites in combination with watershed opportunities (as described above) and user-specific objectives.

Wetlands not prioritized as "very high," "high," or "moderate" for one or more services may still be of value. For example, small sites may be omitted in some areas due to limited source data; numerous wetlands that individually provide services at a low level may, collectively, be of high value within a watershed; and wetlands may provide additional services that were not assessed as part of this project.

Figure 3. Wetlands adjacent to large rivers store floodwaters and also may reduce damage to homes and cropland.

B.4.3. Assessing Wildlife Habitat Potential (Step 3)
The importance of wetlands to wildlife depends on what types of habitats are available, the size of habitat patches, and their proximity to other suitable habitats. Since suitable habitat often includes uplands, wildlife habitat differs from the other wetland services in that its assessment crosses watershed boundaries. As a result, wildlife habitat potential was assessed without regard to

watersheds. We adapted the Wildlife Tool[45, 46] to identify and rank key habitats relevant to four wetland wildlife habitat guilds, where each guild is a group of species that use the same or similar habitats and resources. The four guilds and example species are:

- Shallow marsh guild (blue-winged teal, American bittern),
- Open water guild (terns, diving ducks),
- Shrub swamp guild (willow and alder flycatchers), and
- Forest-interior guild (Canada warbler and northern flying squirrel).

The criteria used to identify suitable habitat for each guild emphasized birds because many bird species have landscape-scale habitat requirements, readily assessed using a GIS, and because birds serve as excellent species umbrellas,[47] representing the habitat needs of other wildlife, including reptiles, amphibians, mammals, and invertebrates.

The Wildlife Tool recognizes that individual wetlands do not function as islands, but instead function as parts of an interconnected system that includes multiple wetland types as well as uplands. Therefore, prioritized "sites" include current wetlands, potentially restorable wetlands, *and* associated upland habitats relevant to wetland wildlife. In addition to ranking based on the four wildlife habitat guilds, sites were also ranked based on their potential to provide habitat for multiple guilds.

C. METHODS

Implementing the three steps of the watershed approach to wetland assessment involved six major elements:

1. Gather and integrate statewide geospatial datasets
2. Identify potential locations to preserve or re-establish wetlands
3. Assess watershed needs and opportunities: compare current and historic wetland service potential across watersheds
4. Assess and rank individual sites for wetland service potential
5. Assess sites for wildlife habitat potential
6. Compare GIS model results with independent on-site field observations

Each of these elements is described below.

C.1. Gather and integrate statewide geospatial datasets

Appendix A lists each dataset used in this project with its source, a brief description, publication date, spatial resolution, and where the dataset was applied.

C.2. Identify potential locations to preserve or re-establish wetlands

The current extent of wetlands in Wisconsin is mapped by the Wisconsin Wetland Inventory (WWI)[48] These mapped wetlands are considered as preservation opportunities.

Wetland re-establishment opportunities are former wetlands, converted to other uses by drainage or filling, that have the potential to be restored. That potential is based on their current soils, landcover, and land use. For example, land with hydric soils that are currently in agricultural use may be restorable, while, generally, land with non-hydric soils or in most urban land uses do not present viable restoration opportunities. Using GIS data to identify these potentially restorable wetlands (PRWs) began in Wisconsin using a single attribute of soil data, the hydric soil class, and current land use.[49] Since then, methods to identify PRWs have evolved to include topography and additional soil attributes related to hydrology.

Two topographic features that influence hydrologic conditions at a site are slope and the extent of the contributing drainage area. These were combined into a single number, the Compound Topographic Index (CTI), where higher values represent drainage depressions and lower values represent crests and ridges.[50] Sites that have not been mapped in the Wisconsin Wetland Inventory, but have hydric soil or hydric inclusions, the same range of CTI values as wetlands, and are in land use classes where restoration is typically practical, such as agriculture, are considered PRWs. Forest lands were not excluded, as in previous PRW layers, since some may have restoration potential.

In addition to the hydric rating, soil attributes that help to identify PRWs are geomorphic position, parent material, water table depth, drainage class, texture, depth to restrictive layer, flooding frequency, and ponding frequency. These data can be used individually or in combination to identify areas that may contain hydric soils or soils with the potential to become hydric.[51]

DNR's current PRW data layer is a result of applying the CTI to areas with multiple soil attributes. Wetlands identified in the Wisconsin Wetland Tracking Database that were restored after the date of the last wetland mapping are excluded from the PRW layer.

C.3. Assess watershed needs and opportunities: compare current and historical wetland service potential across watersheds

The basis of a watershed management plan is an assessment of watershed needs and opportunities. Our assessment of watershed need uses wetland loss and alteration, in terms of wetland services, on a watershed basis at multiple scales.

The wetland service potential of the current landscape was compared with that of the landscape of the mid-1800s when the original wetlands were intact. The difference between the provision of current and historical wetland services indicates "functional deficits," or "watershed needs." Watershed opportunities occur where wetlands can be re-established to meet these needs.

We compared current and historical wetland services at three watershed scales using the hierarchy developed for the Watershed Boundary Dataset. We chose the 8, 10 and 12-digit Hydrologic Units as those with scales most appropriate for statewide, regional, and local planning (Figure 2).

The wetland services used for this comparison were developed by enhancing the WWI and PRW datasets with additional attributes that describe hydrogeomorphic features, such as how a wetland interacts with surface water, and its position in the landscape. Developing these enhanced datasets is described below. The attributes in the enhanced WWI and PRW datasets were then correlated with wetland services.

C.3.1. Wetland Watershed Assessment Layer: Enhancing the WWI and PRW Datasets

The WWI and PRW datasets were enhanced using similar methods. Enhanced PRW data necessarily lack some attributes, such as vegetation type and hydrologic regime, both of which depend on a site-specific restoration plan. Enhancing the WWI is described below.

WWI data include the size, shape and location of a wetland, and assign a type that describes its vegetation and hydrologic regime.[52] WWI data, considered along with additional data about the surrounding landscape, are often sufficient for a functional assessment of an individual wetland, but they do not allow assessing wetland services across a watershed, or across any large planning unit.

Landscape level analysis requires an expanded classification of individual wetlands. Attributes that describe the position of the wetland on a 3-D landscape, its connectivity to waterbodies and to other wetlands, and the directional flow of water all influence a wetland's ability to provide ecosystem services (Figure 4.). The result of adding these hydrogeomorphic attributes to the WWI is an enhanced WWI, or Wetland Watershed Assessment Layer (WWAL).

WWAL is based on the approach US Fish and Wildlife Service (USFWS) developed and applied to the National Wetland Inventory (NWI) to create its enhanced wetland dataset, NWI Plus. Attributes in WWAL, beyond those in WWI, describe:

- **L**andscape position or the relation of a wetland to a waterbody
- **L**andform or the physical shape of the wetland
- **W**ater flow path, such as inflow, outflow, or through-flow
- **W**aterbody type, such as rivers, streams, or lakes

Collectively these new attributes are known as LLWW descriptors, which stands for the first letter in each of the main attributes. Additional landscape level factors, such as landcover and land use, also affect wetland services. These are considered later, in the assessment of individual wetlands, but are not part of WWAL.

USFWS developed dichotomous keys to assign LLWW attributes to mapped wetlands by combining NWI maps with other datasets, such as stream flow networks and topography.[53] USFWS also developed regional correlations between the attributes in the enhanced wetland database, or NWI Plus (the analog to Wisconsin's WWAL), and several wetland functions.[54]

This project draws on the USFWS approach beginning with statewide data layers: WWI, the 24K Hydrography Database, and topography based on 30m Digital Elevation Model (DEM). Differences between NWI and WWI attributes, such as NWI's more detailed hydrologic modifiers, required modifying the USFWS methods to develop WWAL. The resolution of our baseline data allowed us to refine and expand on USFWS Landform and Waterflow Path attributes.

Figure 4. An emergent palustrine wetland surrounded by upland (top) provides different functions than one along a stream and exposed to flowing water (bottom). LLWW modifiers add features like these to a wetland's classification.

In addition, statewide models to identify headwaters, entrenched waterways, and areas of potential wetland-groundwater interaction[55], allowed us to add modifiers for some wetlands. Model results for all three modifiers are not applicable statewide. For example, the ability to detect entrenched waterways depends on the resolution of topographic data, which varies widely across the state. Areas of potential shallow groundwater interaction are identified using the Michigan Rivers Inventory subsurface flux model (MRI-DARCY), which is based on topography and hydraulic conductivity inferred from mapped surficial geology. As a result, the model is more applicable in ecoregions with extensive sand and gravel deposits, than in those where fine soils predominate. The same consideration applies to the headwater modifier, since it depends in part on shallow groundwater interaction.

Appendix B lists the LLWW descriptors developed for Wisconsin. Assignment of the LLWW attributes for each wetland was accomplished by automated GIS-based classifications.

Using WWAL, and again following the USFWS approach, we developed correlations between WWAL attributes and several wetland functions or services. We chose the following five wetland services based on their importance to people and overall watershed health; the degree to which wetlands, specifically, provide them; and the extent to which we can evaluate them with available data.

Flood Abatement – After heavy rainfall, many wetlands detain storm water runoff and overbank flooding from rivers, which can slow the flow of excess water downstream.

Sediment Retention – Wetlands draining to waterways can retain sediment that would otherwise move downstream. Excess sediment in streams impairs water quality and aquatic habitat.

Nutrient Transformation – Wetlands can remove nutrients from the water and convert them into plants, soil, or harmless gas.

Surface Water Supply – Many wetlands contribute water to streams and rivers, especially during dry periods.

Fish and Aquatic Habitat – Wetlands support some part of the full life cycle for most fish and aquatic life.

Additional landscape setting and landscape condition characteristics that are not included in the WWAL also influence how wetlands provide services. The absence of historical data for these characteristics prevents a comparison with current conditions. Consequently, they are not included in the assessment of watershed needs. Additional characteristic that depend on landscape setting and condition are considered later in the assessment of individual sites, which relies only on current conditions.

Each service correlation, and the criteria used to assign a High or Moderate level of service significance to each wetland, is explained below. Other wetlands may also provide each service to some extent, but at a lower level, and they are not considered in the functional analysis.

Each table associated with a service correlation translates the narrative description of the significance levels into the specific LLWW (or WWAL) attributes that correspond to each rank. For example, a wetland that occurs in the shallow water zone of a large river, where the river flows through the wetland in natural channels, will rank High for flood abatement. The wetland's corresponding LLWW code, LRFRTH, (Appendix B) is a shorthand label for that description. An asterisk in the code sequence indicates a wildcard.

Note that the LLWW codes associated with floodplains are not based solely on the regulatory floodplain, i.e. the area susceptible to inundation during a flood event with a 1% annual chance of occurrence, and which is shown on Flood Insurance Rate Maps. The LLWW Floodplain code (FP) applies to the Active River Area, or the area where physical and ecological processes important to the waterway occur. The LLWW codes Fringe (FR) and Floodplain Fringe (FF) are based on topographic models within the Active River Area, and do not coincide with the regulatory flood way or flood fringe.

C.3.1.1 Flood Abatement

Storing floodwater reduces the extent of downstream flooding and lowers flood heights, both of which reduce damage from flooding events. All wetlands store some flood water. Here we identify those wetland types that perform a substantial level of flood abatement. These include wetlands along streams and rivers that can hold excess water until the stream or river can regain its capacity to move this excess water downstream. Wetlands with dense vegetation help to reduce water flow velocity. Ponds that are not artificially drained also provide this service. These depressions collect storm water runoff from adjacent lands, which prevents the water from flooding surrounding areas.

Wetlands of the types listed above are ranked Moderate, rather than High, if they are artificially drained or adjacent to an entrenched stream or river, since they provide flood abatement only during extreme flood events.

Wetlands are excluded if they occur on slopes, and so are unable to retain water; if they lack vegetation; and if they are completely isolated from a stream or river.

C.3.1.2. Sediment & Phosphorus Retention

Sediment and particulate phosphorus are considered together since some phosphate ions readily attach to sediment particles suspended in water. Wetland vegetation filters these particles, which then settle out of suspension in slowly moving water. If left undisturbed, the trapped sediment and phosphorus become part of the soil. Dissolved phosphorus, which also contributes to the phosphorus in surface water, is not attached to sediment particles and is considered separately.

The simple mechanical process of sediment removal is most effective in shallow water wetlands since they support dense vegetation in combination with low water flow velocity. Sediment retention increases with the amount of time water remains in the wetland, and with the size of the wetland relative to the inflow rate.

Table 1. Ecosystem Service Correlations: Flood Abatement

Service Level	Wetland Type Descriptions	LLWW or WWI Code Inclusions	LLWW or WWI Code Exclusions
High	Vegetated lentic and lotic wetlands Island wetlands Ponds, terrene basin and terrene flat wetlands that have inflow, throughflow, or intermittent throughflow	LE***, LR***, LS**** IL** **PDIN, **PDTH, **PDTI, TEBA*IN, TEBA*TH, TEBA*TI, TEFL*IN, TEFL*TH, TEFL*TI	*SL**, ***IS TEBA*BI TEFP*, TEFF*, TEFR* TEFL*OU, TEFL*OI, TEFL*CI WWI Class = F, unvegetated flats
Moderate	Wetlands with artificial throughflow Wetlands associated with an entrenched stream or river Terrene basin wetlands with connection intermittent Open water wetlands (except Ponds that are ranked "High")	***TA ****en TEBA*CI, TEBA*OU, TEBA*OI WWI Class = W, open water wetlands	

Table 2. Ecosystem Service Correlations: Sediment & Phosphorus Retention

Service Level	Wetland Type Descriptions	LLWW or WWI Code Inclusions	LLWW or WWI Code Exclusions
High	Lentic and lotic basin wetlands having inflow or throughflow intermittent	LEBA*IN, LEBA*TI, LRBA*IN, LRBA*TI, LSBA*IN, LSBA*TI, TEBA*TI	LRIL**, LSIL**, ***OU, ***OI, ***OA, *FR**, *SL**
	Floodplain wetlands	*FP**	
	Terrene basin wetlands that have connection intermittent	TEBA*CI, LSBA*CI, LRBA*CI	
Moderate	Lentic and lotic basin wetlands having throughflow artificial or throughflow	LEBA*TA, LRBA*TA, LSBA*TA, LEBA*TH, LRBA*TH, LSBA*TH,	
	Floodplain Fringe wetlands	*FF**	
	Lentic and lotic flat wetlands having throughflow or throughflow intermittent	LEFL*TH, LRFL*TH, LSFL*TH, LEFL*TI, LRFL*TI, LSFL*TI	
	Lentic island wetlands	LEIL**	
	Terrene basin wetlands that are isolated or outflow intermittent	TEBA*IS, TEBA*OI	
	All ponds	**PD1*, **PD2*, **PD3*	
	Artificial wetlands or wetlands associated with an entrenched stream or river	***TA, ****en	

Consequently, removal efficiency also increases as the ratio of the wetland area to watershed area increases (a factor addressed within the GISRAM, described below, but not part of the LLWW process).

Wetlands ranked High for this service are vegetated, shallow water wetlands able to receive surface water runoff and filter it before discharging to a waterbody. Wetlands ranked Moderate include those lower in the floodplain, where water flow is likely to re-suspend particles; ponds and other open water wetlands; wetlands that are isolated from waterways; and those associated with artificial or entrenched streams.

Wetlands are excluded if they lack surface water inflow, occur on slopes over 5%, or occur within river channels.

Additional factors, which are not part the LLWW assessment, also influence phosphorus retention. Two examples are the wetland soil type and the amount of phosphorus that reaches the wetland. Fine grain mineral soils have more capacity to bind phosphate than sandy soils. Both sediment and phosphorous at high levels can exceed a wetland's retention capacity, lower its effectiveness, and reduce overall wetland quality. These additional factors are considered later in assessing how specific wetlands function.

Figure 5. Dense wetland vegetation contributes to a wetland's ability to improve water quality. Plants absorb nutrients and slow flowing water, causing nutrients that are bound to sediment particles to settle to the bottom.

wetlands connected to surface water are in the best landscape position to reduce nutrient concentrations downstream.

Wetlands are ranked High where they are vegetated and associated with frequent flooding or overbank flow.

Table 3. Ecosystem Service Correlations: Nutrient Transformation

Service Level	Wetland Type Descriptions	LLWW or WWI Code Inclusions	LLWW or WWI Code Exclusions
High	Vegetated lentic and lotic wetlands that are flat, floodplain, floodplain fringe, or basin	LEFL**, LRFL**, LSFL**, LEFP**, LRFP**, LSFP**, LEFF**, LRFF**, LSFF**, LEBA**, LRBA**, LSBA**	***IS, ****en, ***OA, ***TA DWWI Class F, unvegetated flats
Moderate	Fringe wetlands Terrene wetlands	*FR** TE***	

Wetlands are ranked Moderate if they are associated with moving water, and consequently have lower retention time than those ranked High; or if they are surrounded by upland, and able to receive nutrients that would otherwise reach a waterway.

Wetlands that lack vegetation, which is essential for nutrient cycling, are excluded. Also excluded are wetlands that have no connection to surface water, or where the wetland/surface water interaction is reduced by hydrologic alterations.

C.3.1.4. Surface Water Supply (Lakes, Rivers, Streams, & Ponds)

Groundwater discharge during dry periods sustains water levels in streams, rivers, and lakes, which supports aquatic life. Wetlands discharge this water where groundwater flows through the wetland to the waterway. Floodplain wetlands also store water and then slowly release it to the waterway once flood waters recede.

Wetlands ranked High for this service include wetlands associated with groundwater discharge, and headwater wetlands, which also have perennial flow to waterways. Headwater wetlands are those adjacent to 1st and 2nd order streams. Wetlands associated with groundwater discharge from the wetland are identified using the DARCY Model.[56]

Wetlands ranked Moderate are headwater wetlands on intermittent streams, floodplain wetlands, as well as wetlands associated with ponds or lakes that discharge to rivers or streams and that are not already ranked High.

Wetlands that have no outflow to rivers or streams, and non-headwater wetlands with only an intermittent connection are excluded.

Table 4. Ecosystem Service Correlations: Surface Water Supply

Service Level	Wetland Type Descriptions	LLWW or WWI Code Inclusions	LLWW or WWI Code Exclusions
High	All headwater wetlands except those with an intermittent connection Lentic and lotic wetlands having outflow or throughflow that discharge groundwater.	****hw, not TI LE**OUgw, LE**THgw, LR**OUgw, LR**THgw, LS**OUgw, LS**THgw	***IN, ***IS, ***OI, TE**CI *FL** w/o gw, TEBAOU w/o gw, LSBATH w/o gw
Moderate	Floodplain wetlands Floodplain fringe wetlands Fringe wetlands Terrene wetlands having outflow and that discharge groundwater Non-headwater wetlands associated with ponds and lakes with throughflow and outflow Headwater wetlands associated with intermittent streams Lentic island, Basins, or Flats with bidirectional flow and groundwater discharge	*FP** *FF** *FR** TE**OUgw **PDTH, **PDOU, **LKTH, **LKOU ***TIhw LEIL*BIgw, LEBA*BIgw, LEFL*BIgw	

C.3.1.5. Fish and Aquatic Habitat

In addition to fish, aquatic dependent fauna include several turtles, snakes and frogs, muskrat, and many invertebrates, such as dragonflies and mussels. All freshwater species are to some degree dependent on wetlands for part of their life cycle. Fish spawn in marshes bordering lakes, or in riparian forested wetlands during high water in spring, and wetlands are a primary food source for most aquatic species.

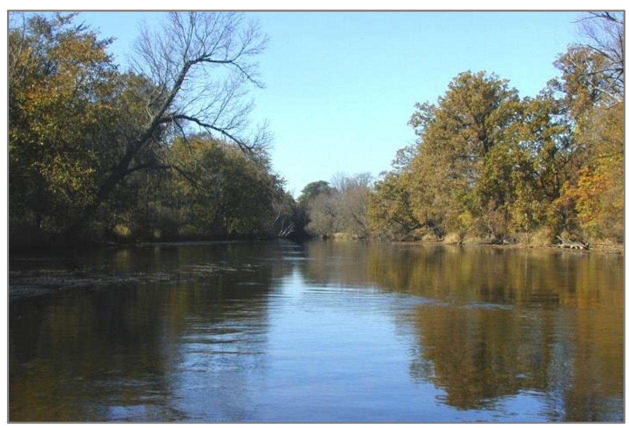


Fig. 6. Wetlands bordering waterways are a food source for fish and other aquatic animals. They provide shade and cover from predators.

Wetlands ranked High are those that are part of, or in close contact with, waterways. These are the shallow water zone of lakes, rivers and stream, and nearby wetlands that are most likely to supply these waterways with the nutrients and organic debris that form the base of the aquatic food web (Figure 6).

Wetlands ranked Moderate are those with artificial or intermittent connections to waterways, and wetlands in the floodplain, but at higher elevations than those ranked High.

Wetlands associated with entrenched rivers and streams, and not hydrologically connected, are excluded.

Table 5. Ecosystem Service Correlations: Fish and Aquatic Habitat

Service Level	Wetland Type Descriptions	LLWW or WWI Code Inclusions	LLWW or WWI Code Exclusions
High	Lentic wetlands Fringe wetlands Floodplain fringe wetlands Lotic wetlands with outflow, outflow intermittent, throughflow and throughflow intermittent	LE*** *FR** *FF** LR**OU, LR**OI, LR**TH, LR**TI, LS**OU, LS**OI, LS**TH, LS**TI	****en
Moderate	Lotic wetlands with outflow artificial and throughflow artificial Floodplain wetlands Terrene and lotic basin wetlands with connection intermittent	LR**OA, LR**TA, LS**OA, LS**TA *FP** TEBA*CI, LSBA*CE, LRBA*CI	

C.4. Assess and rank individual sites for wetland service potential (GISRAM)

Assessing sites for wetland service potential relies on both a desktop review of remotely sensed data and observing physical and biotic features on the ground. The *Wisconsin Wetland Rapid Assessment Methodology version2* (WWRAMv2)[57], a Level 2 method, uses both types of data to assess individual wetlands. GISRAM, or GIS Rapid Assessment Methodology, is similar to WWRAMv2 WRAM, but, as a Level 1 method, relies solely on GIS data to assess and compare the potential for wetland services, on a relative basis, for all sites across a watershed.

Like WWRAMv2, GISRAM determines the potential for individual sites to perform wetland services using multiple criteria for each service. GISRAM differs from WWRAMv2 in that it incorporates additional GIS data and modeling, and in that it allows an objective, relative comparison of all sites across a watershed. GISRAM may also be used to assess PRWs; however, without a specific restoration plan, PRW assessment is limited to the criteria that do not involve vegetation type or hydrologic regime.

Because GISRAM, like WWAL, relies on remotely sensed data, it has similar limitations. GISRAM differs from WWAL in considering additional site and context aspects such as soil type, condition of the surrounding landscape, and land use classes. These aspects enable GISRAM to provide a more in-depth assessment of the relative service potential of individual sites than that using WWAL alone.

GISRAM considers a suite of nine wetland services:

- flood abatement
- fish and aquatic habitat
- phosphorus retention
- sediment retention
- nitrogen reduction
- surface water supply
- shoreline protection
- carbon storage
- floristic integrity

Methods used to apply the criteria for each service are presented in Appendix C, along with the underlying rationale for each criterion. This approach is based on methods developed in Rhode Island[58, 59] and further refined and applied in the Sheboygan River Watershed, Wisconsin.[60] Criteria were developed from reviews of wetland functional assessment methods developed by the US Army Corps of Engineers,[61] Miller and Golet,[62] and in consultation with ecologists of partner agencies and organizations.

C.4.1. Ranking sites: Scoring rubric for GISRAM

Once the criteria were applied to each site for each service, the sites were scored using the following rubric and ranked relative to others in the same watershed:

- For some services, certain criteria were determined to be necessary for a site to provide the service. For sites that failed to meet a necessary criterion, its rank for that service was considered "not applicable."
- For each service, criteria were assigned to three categories: 1) *Opportunity (O)* for the service to be performed, 2) *Effectiveness (E)* of the wetland in providing the service, and 3) *Social significance (S)* of the site in providing services for people.
- For each service, the total number of O and E criteria that a site met was divided by the total possible number of O and E criteria for a value between zero and one. Scores were then increased by 0.1 for each S criterion that the site met.
- For services that increase with wetland size (flood abatement, phosphorus retention, sediment retention, nitrogen reduction, surface water supply, fish and aquatic habitat, and carbon storage) site scores were multiplied by size factors. Each wetland was compared to all other wetlands within the HUC-8 in which they reside, and each PRW was compared all other PRW's within the HUC8 in which they reside. Scores of wetlands or PRWs in the top third of sizes were multiplied by 2; scores for sites in the second third were multiplied by 1.5; and scores for those in the smallest third were multiplied by one.
- Within each 12-digit HUC, sites were ranked by score quantiles and designated as Very High, High, Moderate, or Low/Not Applicable for each service.
- Sites were also ranked for their potential to provide multiple services by counting how many of the nine services were provided at a Very High or High level.

The last two types of ranks are displayed within each 12-digit HUC in the *Explorer*.

C.5. Assessing sites for wildlife habitat potential

Wildlife species generally require specific habitats and landscape settings, and benefit from access to more than one land cover type during their life cycle. GISRAM and LLWW, which are focused on individual wetlands, aren't well suited to identifying desirable associations of multiple habitat types. The Wildlife Tool was originally developed to fill this gap and used to rank sites for their relative fish and wildlife habitat potential for species important within small geographic regions[63,64,65,66].

Wetlands by Design applies the Wildlife Tool to assess the potential for wetlands, PRWs, and associated upland habitats to meet the needs of a broad range of wetland wildlife species statewide. Sites were assessed based on their potential to provide habitat for a suite of species in these guilds:

> ***Forest Interior Guild:*** Species that require large forested wetlands, or smaller sites embedded within heavily forested landscapes. These include black-and-white warbler, northern waterthrush, Canada warbler, and northern flying squirrels.
>
> ***Shallow Marsh Guild:*** Species that require shallow water or saturated open canopy wetlands, and adjacent open canopy uplands that are important for nesting or foraging. These include many birds, such as American bittern, rails, and blue-winged teal, and amphibians, some reptiles, and many aquatic invertebrates.
>
> ***Open Waters Guild:*** Species such as terns, grebes, and diving ducks that use wetlands near open water or that prefer longer term or deeper water than a shallow marsh.
>
> ***Shrub Swamp Guild:*** Species that require dense thickets over wet soils that usually flood in spring, such as willow and alder flycatchers.

Wildlife represented by these guilds include many rare species, Species of Greatest Conservation Need (SGCN) identified in the Wisconsin Wildlife Action Plan, and Species of Local Conservation Interest (SLCI) identified in local community plans.

Table 6 shows the level of association between each guild and different land cover classes.

Land cover classes relevant to each guild were based on these existing statewide datasets: Wiscland 2, Wisconsin Wetland Inventory, WDNR's Reed Canarygrass Cover, and 24K Hydrolayer, and a dataset developed to describe roadway corridors (Appendix A). Each landcover class is described in Appendix D.

The first step in applying the Wildlife Tool was to assign a measure of association to each combination of guild and landcover class. These measures of association, listed in Table 6, are defined as follows:

- 3 – core, land cover class is essential to most guild members
- 2 – secondary, land cover class is important to some aspect of guild members' full-life cycles
- 1 – supporting, land cover class has an incidental association with most guild members, but not essential to full-life cycles
- 0 – land cover class has no association with most guild members

For each guild, its association value with a land cover type may rely on its spatial relationship to other land cover types. For example, diving ducks in the Open Water Guild will use a large shallow marsh, only if the marsh is near other open water or a deep-water wetland. In Table 6, these required spatial relationships or proximity factors, are indicated by an asterisk (*) or hash sign (#). Table 7 describes how these spatial relationships between different land cover types were used to assign wildlife habitat significance for each guild.

For the first three guilds, the models identify primary habitat as core land cover types (association = 3), and ancillary habitat as cover types with a lower association if they occur nearby. We chose 100 m as the distance within which to consider other land cover types for each guild. Different taxa within each guild may regularly travel distances that warrant considering smaller or larger areas.

Fig. 7. Most wildlife species rely on different habitat types nearby to complete their life cycle. Some species will only survive in large habitat patches.

Primary habitat for the Forest Interior Guild requires an initial size criterion regardless of land cover type and includes patches larger than 75 ha (185 acres). Smaller patches are identified as primary habitat if the forest cover within 1 km of the patch was greater than 50%. As for the other three guilds, Forest Interior ancillary habitat was identified as cover types with a lower association that occur nearby.

Raster-based models for each guild were developed based on Tables 6 and 7, and preliminary results were reviewed visually for comparison with selected known wildlife occurrences. Since terrestrial wildlife habitat depends on ecological regions, which generally don't correspond to watersheds, the wildlife models were applied within Wisconsin's sixteen distinct ecological landscapes, rather than within Hydrologic Units.

Habitat for multiple guilds was also considered. Each pixel in the raster dataset was assigned a value of 0-4, based on the number of guilds for which the pixel was relevant. For example, a pixel assessed as providing primary or ancillary habitat for 3 of the 4 guilds received a score of 3.

PRWs within 100m of identified wildlife habitat were also considered for their wildlife habitat potential. When a PRW is restored, its land cover class is determined by a site-specific restoration plan. In the absence of such a plan, PRW habitat potential scores (0 to 4) are based on the number of guilds represented in pixels within 100 meters.

Table 6. Wetland Wildlife Habitat Matrix, indicating degree of association between wetland wildlife guilds and land cover types. 3 = core, 2 = secondary, 1 = supporting, 0 = no association. Additional analysis on the spatial relationship of these habitats is described in Table 7.

Land Cover Types		Wetland Wildlife Habitat Guilds			
		Open Water	**Shallow Marsh**	**Shrub Swamp**	**Forest Interior**
UPLAND	Urban/Developed, high intensity	0	0	0	0
	Urban/Developed, low intensity	0	0	0	0
	Grasslands and Pasture	0	2*	0	0
	Forest, evergreen	0	0	0	1*
	Forest, deciduous	0	0	0	1*
	Forest, mixed	0	0	0	1*
	Shrub Land (not shrub-carr)	0	0	0	0
	Cultivated Land	0	0	0	0
LARGE OPEN WATER	Surface Water, rivers	0	1	0	0
	Surface Water, lakes	3	1	0	0
WETLAND	Open Water Wetlands	1*	3	0	0
	Aquatic Bed/Deep Marsh	3	3	0	0
	Shallow Marsh <= 5 acres	2*	3	0	0
	Shallow Marsh > 5 acres	3*	3	0	0
	Wetland Meadows	1*	3	2*	0
	Wetland Forest, broad leaved	0	2*	0	3#*
	Wetland Forest, coniferous	0	2*	0	3#*
	Wetland Forest, mixed	0	2*	0	3#
	Shrub Bog, evergreen	0	0	2*	0
	Shrub-carr, deciduous	0	2*	3	2#*
	Cultivated flat	0	0	0	0
	Natural flats	0	0	0	0
SPECIAL TYPES	Reed canarygrass	0	1	0	0
	Cattail	2*	3	0	0
	Road corridor	1	1	1	1

* and # indicate where spatial criteria are required for the association to apply. These are described below.

Table 7. Sequence of spatial criteria used to determine primary and ancillary habitat in the Wildlife Tool

Guild	Primary Habitat Selection	Additional Primary Habitat (#) for Forest Interior Guild	Ancillary Habitat (*) Selection
Open Water	Combine all rank 3 land cover types.		Selected Rank 1* and 2* cover within 100 m of primary habitat is added.
Shallow Marsh	Combine all rank 3 land cover types.		Selected Rank 2* cover within 100 m of primary habitat is added.
Shrub Swamp	Combine all rank 3 land cover types.		Selected Rank 2* cover within 100 m of primary habitat is added.
Forest Interior	Combine all rank 3 land cover types. Combined patches must be >75 ha.	Patches of rank 2 and 3 cover types less than 75 ha if forest cover within 1 km of the patch is greater than 50%.	Selected Rank 1* and 2* cover within 100 m of primary habitat is added.

* and # refer to the association values for a land cover class in Table 6

C.6. Compare GIS model results with independent on-site field observations

As described above, GIS models were used to assign LLWW attributes to WWI polygons to enhance the WWI data and create the Wetland Watershed Assessment Layer (WWAL). This enhanced dataset enabled an assessment of watershed needs. GIS models were also used to assess individual sites for wetland service potential using GISRAM, creating the Wetland Site Assessment Layer (WSAL).

GIS model results for WWAL and WSAL were compared with independent Level 2 assessments of existing wetlands across one 8-digit Hydrologic Unit, the Milwaukee River Basin, which encompasses about 900 sq. mi. in southeastern Wisconsin. This watershed was selected for a preliminary evaluation of the models because it includes large areas of urban, rural, and natural land cover; three distinct ecological regions; and conservation partners who made many properties available for field inspections.

The wetland polygons used for the comparisons were selected to include the range of LLWW attributes and wetland types in this region. We selected fifty properties that included 157 wetland polygons and 155 wetland assessment areas. Comparisons for 136 polygons were based on both field observations and desktop map review. Comparisons for the remaining 21 polygons were based on desktop map review only. All Level 2 assessments occurred during the growing season of 2015, prior to model development.

The Level 2 “rapid assessment” was based on WWRAMv2 with additional data resources for the desktop map review component, and additional field observations that influence wetland services. Data layers used for the Level 2 desktop map review included aerial photographs and all the generally available GIS data listed in Appendix A, supplemented with more detailed data from county and regional planners. It did not include the CTI flow accumulation grid or groundwater model results.

First, we compared assigned LLWW attributes with those expected based on Level 2 site-specific observations. Based on these comparisons, we improved LLWW models for Waterflow Path, and groundwater (gw) and headwater (hw) modifiers.

Once the LLWW model results (WWAL) were improved to the limits imposed by the accuracy of the source data, these results were used to apply the GISRAM criteria. GISRAM assessments were evaluated by comparison with the Level 2 assessments for the same sites in the Milwaukee River Basin mentioned above.

D. RESULTS

D.1. GIS Products and Processes

The results of this project are the Decision Support System (DSS), *Wetlands and Watersheds Explorer,* and new statewide GIS layers, analytic processes, and models used to create the *Explorer's* four major components:

1. The Wetlands Watershed Assessment Layer (WWAL), based on wetlands' **L**andscape position, **L**andform, **W**ater flow path, and **W**aterbody type (LLWW), as developed by USFWS,[67, 68] and an expert-derived set of Ecosystem Service Correlation Tables (Tables 1 – 5), to assign levels of service to WWAL classes. These correlations between LLWW attributes and ecosystem services were used to identify the services once provided by lost wetlands in the pre-settlement landscape, which becomes the basis for determining watershed-level ecosystem service needs and opportunities.
2. The GISRAM Matrix and the Wetlands Site Assessment Layer (WSAL), an adaptation of the field-based (Level 2) *Wisconsin Wetland Rapid Assessment Methodology version 2 (WWRAMv2)*[69] into a GIS environment to enable a Level 1 assessment of the range and degree of ecosystem services provided by individual wetlands. It uses the WWAL classes as a starting point, and adds an expert group's consideration of the opportunity, effectiveness, and social significance factors that affect a wetland's level of service performance (Appendix C). Each expert-derived criterion was translated into one or more queries of available GIS data. The result is an assignment to qualitative ranks of ecosystem service performance for all mapped wetlands across the state.
3. Nested Watershed Zoom Capability built into the *Explorer* that allows the user to zoom in and out of watersheds, among WDNR's 8-digit, 10-digit and 12-digit Hydrologic Units, to support watershed-level planning through comparison of relative ecosystem service losses, needs, and opportunities.
4. Wildlife Habitat Tool, which allows the user to view the suitable habitat provided by existing wetlands and associated uplands for guilds of wetland dependent wildlife. Four guilds were selected to represent a range of habitat types, with an expert group assigning a level of habitat association to land-cover classes. Models for each guild take basic landscape-scale habitat requirements of guild members into account. Potentially Restorable Wetlands (PRWs) are scored based on their spatial relationship to existing wildlife habitat providing the user with a means to compare the habitat improvement potential of different restoration sites.

Several of the GIS products described above, in addition to their role in the *Explorer,* have applications to future GIS wetland analyses:

1. Enhancement of WWI data to produce the Wetlands Watershed Assessment Layer, (WWAL) using a hydrogeomorphic classification system. WWAL is immediately available for any application that currently uses WWI. When linked to Ecosystem Services Correlation Tables (Tables 1 – 5) it provides a Level 1 assessment of wetland services. The models built to enhance the Wisconsin Wetland Inventory could be incorporated into future WWI products.
2. Groundwater Influenced Wetlands are those where groundwater is a sufficiently large component of wetland hydrology that it affects wetland ecosystem services. This layer remains preliminary, but is the first of its kind at a statewide extent.
3. Entrenched Stream/Ditch Identification is a process for identifying stream or ditch segments that are deeply incised, below the level of adjacent wetland or upland, and as a result are hydrologically disconnected from adjacent land. While the process is applicable statewide, its accuracy is highly dependent on the resolution of topographic data, which continues to improve and varies widely across the state. Consequently, there is no stand-alone statewide layer yet.
4. Active River Area Cross-Sectional Analysis is a process to better classify wetlands in river floodplains in relation to their flooding frequency and duration. One outcome of this analysis was the creation of a new LLWW class, that of "Floodplain Fringe", or the area

between the shallow water zone of a permanent waterbody and the highest elevations in the floodplain.

D.2. Model Validation through Field Assessments

The two major modeling efforts for the project involved generating the LLWW codes for WWAL, and the GISRAM assessment of ecosystem services to produce WSAL. The validity of the new LLWW codes was tested in the Milwaukee River Basin by conducting field surveys to assign LLWW codes directly based on observed physical conditions and desktop map review. We assessed the validity of GISRAM ecosystem service ranks by conducting Level 2 assessments using a protocol based on the *Wisconsin Wetland Rapid Assessment Methodology version 2* (WWRAMv2)[70] and comparing the service ranks for the same sites.

D.2.1. Comparison of Modeled LLWW Codes with Observed Field Conditions

Results of the comparison between model results for the LLWW codes and site-specific independent observations are shown in Table 8. Agreement between the LLWW codes that were assigned by GIS models, and those assigned by Level 2 assessment occurred for 123, or 78%, of 157 of wetland polygons. Among the 34 wetlands where one or more of the LLWW codes varied, differences due to limitations in the source data accounted for 21 (13%). Differences due to model limitations occurred for 13 (8%). Figure 8 shows and example of a limitation in the Landscape Position Model.

Table 8. Comparison of LLWW model results with site-specific independent observations, Milwaukee River Basin, n = 157

		Source Data Limitations	Model Limitations
LLWW confirmed	123 (78%)		
LLWW error	34 (22%)	21 (13%)	13 (8%)

Landform codes FR (fringe wetland), FF (floodplain-fringe wetland), and FP (floodplain) were considered to match observations if the code appeared accurate for at least half of the polygon. Most wetlands observed within a floodplain appeared to be a combination of codes, such as FR and FF. Floodplain Landform codes were also considered to match if they generally agreed with the Flood Insurance Rate Map (FIRM)[71] zones and the Active River Area (ARA)[72]. Waterflow Path was considered to match, even where a hydro flowline was missing or misaligned, if the Compound Topographic Index[73] flow was sufficient to assign Waterflow Path = Connection Intermittent (CI).

Limitations in the base data that contributed to LLWW code errors, in decreasing order of occurrence, are:

- Resolution of elevation data (21)
- Alignment of the regulatory floodplain and Active River Area (10)
- Alignment of 24K Hydrography and Wisconsin Wetland Inventory data (9)
- Linear extent of 24K Hydrography data (7)
- Areal extent of Wisconsin Wetland Inventory data (2)

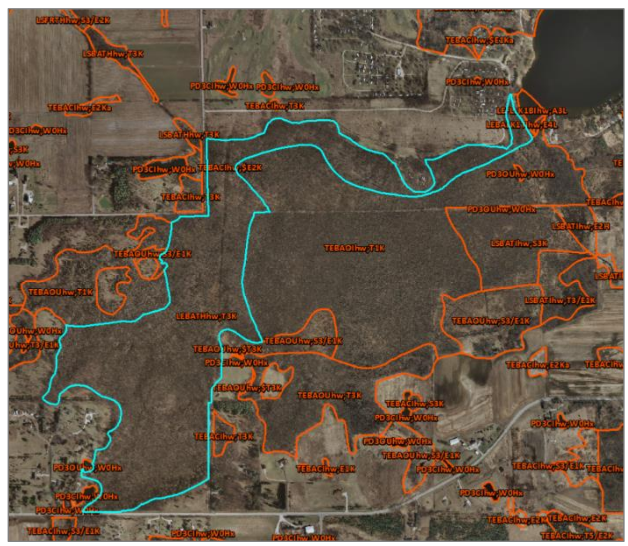


Figure 8. An example of a limitation in the Landscape Position Model. The model assigns the highlighted wetland polygon the code Lentic (LE), because it reaches the shoreline of the lake in the upper right. Most of the wetland, however, has little connection with the lake, and is more appropriately coded as Terrene (TE), like its neighbors.

D.2.2. Groundwater Modifier Comparison with Field Conditions
A groundwater modifier (gw) was assigned to WWAL polygons that were identified as areas of potential shallow groundwater interaction using the Michigan Rivers Inventory subsurface flux model (MRI-DARCY).

Indicators of groundwater interaction were noted at 136 wetlands with field observations, and these indicators were compared with the gw assignment for the wetland polygon. Field observations were in 4 classes:

- no apparent evidence of groundwater interaction
- wetland water level appears to match that of the local water table, such as water level of a nearby lake or stream
- indirect evidence of groundwater discharge, such as marl deposits or the type of vegetation
- direct evidence of groundwater discharge, such as flowing springs or seeps

Fens, like the one in Figure 9 below, have both direct and indirect indicators. Correspondence between the groundwater model results and observations are shown in Figure 10. Of 28 sites with no field indicators of groundwater, the model predicted 27 (96%) correctly. Of 21 sites with groundwater discharge indicators, the model predicted 13 (62%) correctly. Of the 86 sites where the only evidence of groundwater interaction was connection with the water table, the model predicted 27 (31%) correctly. Comparisons were more favorable at sites within the Southeast Glacial Plains Ecological Landscape, where coarse material dominates the surficial geology, than within the Lake Michigan Coastal Plain, which is dominated by clay.

Figure 9. This fen is Waukesha County has flowing springs and marl deposits, and vegetation associated with groundwater discharge, such as Ohio goldenrod and grass-of-Parnassus.

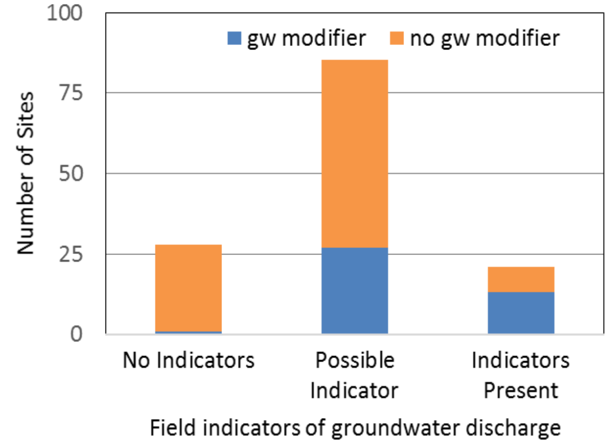


Fig. 10. Correspondence between modeled gw modifier and field indicators of groundwater interaction. Possible Indicator = water level approximates that of the local water table. Indicators Present = direct or indirect evidence of groundwater

D.2.3. Comparison of Modeled GISRAM Ecosystem Service Ranks with On-site Assessments
GISRAM ranks the level of ecosystem services provided by individual wetlands into qualitative categories of Very High, High, Moderate, and Low or Not Applicable. Surveyors conducted independent Level 2 on-site assessments at 155 sites. The results of both assessment methods for six ecosystem services are compared below.

Flood Abatement
Figure 11a shows a comparison of the GISRAM and on-site ranks for flood abatement potential significance. Ranks were the same for 110 of the 155 sites, for 71% agreement, the highest level of agreement of the six services that were tested. Where the GISRAM and on-site assessment ranks differed, GISRAM ranks were higher in 27% of all sites, and lower in 2% of all sites.

Figure 11b shows the distribution of sites by rank for each assessment method. Both assessments resulted in a similar distribution of ranks, with GISRAM ranking higher overall, and ranks for both methods skewed to the high end.

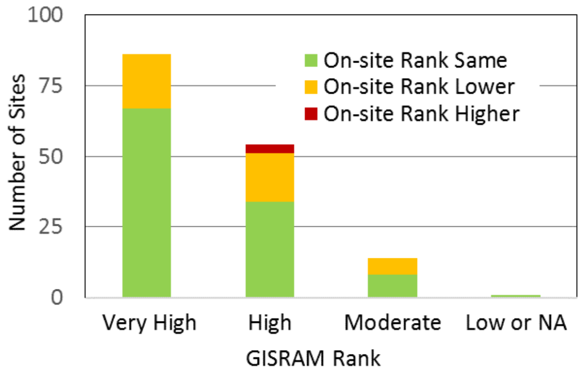


Fig. 11a. GISRAM and on-site methods compared for assessing ***flood abatement*** significance.

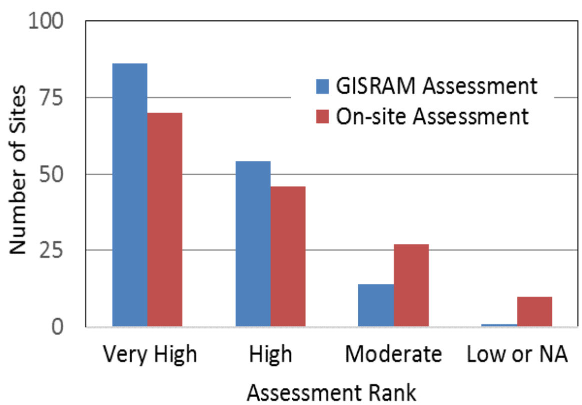


Fig. 11b. The distribution of ***flood abatement*** ranks using GISRAM and on-site methods at the same sites.

Water Quality

The on-site assessments considered water quality protection as one service. GISRAM considered three separate water quality-related services: sediment retention, phosphorus retention, and nitrogen reduction. To compare the results of the two methods, the GISRAM-modeled "water quality" rank was assigned as that for the service with the highest rank. For example, the GISRAM rank was assigned as Very High if at least one of the services related to water quality—sediment retention, phosphorus reduction, or nitrogen reduction—ranked Very High.

Water quality ranks were the same for 92 (59%) of the 155 sites. Where GISRAM and on-site ranks differed, the GISRAM ranks were higher in 37%, and lower in 4% of all sites (Figure 12a).

The distribution of ranks for water quality using both methods is similar to that for flood abatement. The ranks for both assessments skew the high end, with GISRAM ranking higher overall (Figure 12b).

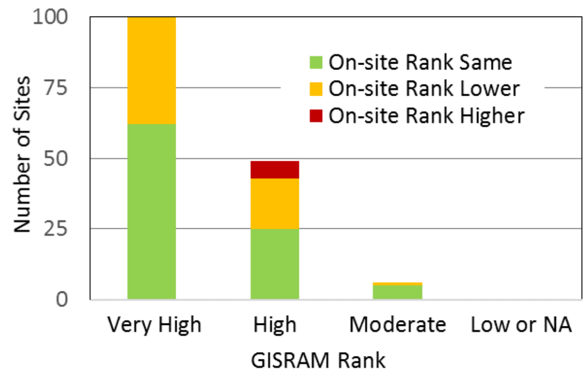


Fig. 12a. GISRAM and on-site methods compared for assessing ***water quality*** significance.

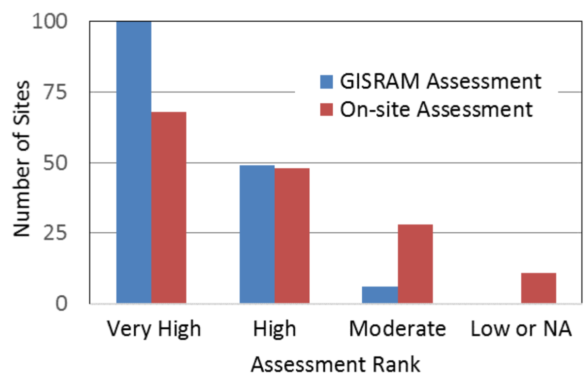


Fig. 12b. The distribution of ***water quality*** ranks using GISRAM and on-site methods at the same sites.

Shoreline Protection

Assessment ranks for shoreline protection potential significance were the same for 91 (59%) of 155 sites. Where the two methods differed, the GISRAM ranks were higher for 33%, and lower for 8% (Figure 13a).

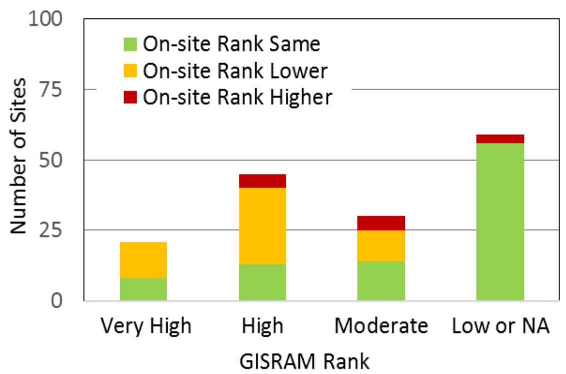


Fig. 13a. GISRAM and on-site methods compared for assessing ***shoreline protection*** significance.

The distribution of sites by rank for each assessment method is similar. Both skew to the low end, which is a consequence of relatively few large lakes and rivers in the test area, however GISRAM again ranks higher overall (Figure 13b).

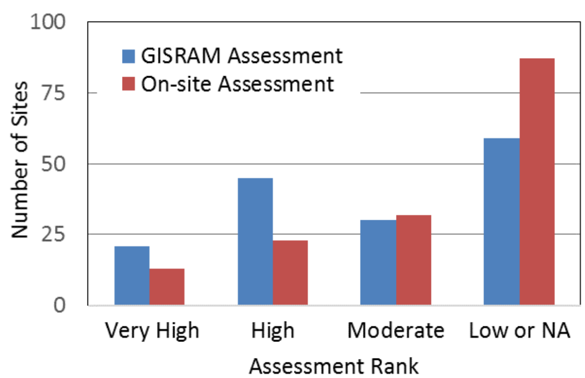


Fig. 13b. The distribution of ***shoreline protection*** ranks using GISRAM and on-site methods at the same sites.

Surface Water Supply

Assessment ranks for surface water supply potential significance were the same for 90 (58%) of 155 sites. Where GISRAM and on-site assessment ranks differed, GISRAM ranks were higher for 35%, and lower for 7%, of the sites (Figure 14a).

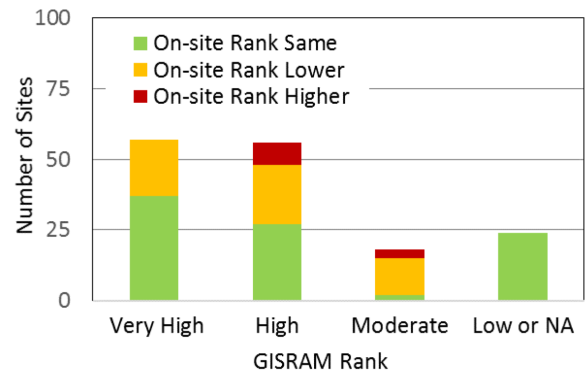


Fig. 14a. GISRAM and on-site methods compared for assessing ***surface water supply***.

Figure 14b shows the distribution of sites by rank for each assessment method. On-site method ranks are more evenly distributed that the GISRAM ranks, with GISRAM skewed to the high end, and GISRAM ranks are higher overall.

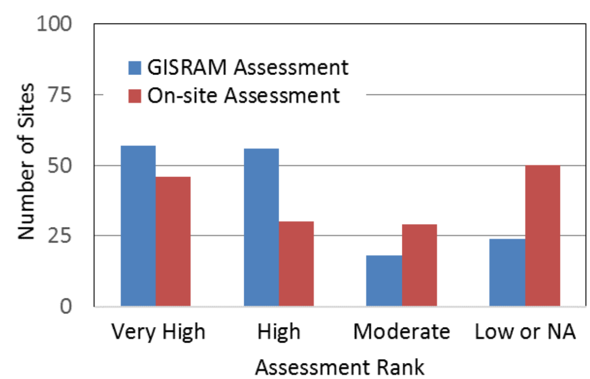


Fig. 14b. The distribution of ***surface water supply*** ranks using GISRAM and on-site methods at the same sites.

Fish and Aquatic Habitat

Figure 15a shows a comparison of the GISRAM and on-site ranks for fish and aquatic habitat potential. Ranks were the same for 67 (43%) of 155 sites. Where the GISRAM and on-site ranks differed, GISRAM ranks were higher in 46%, and lower in 10% of all sites.

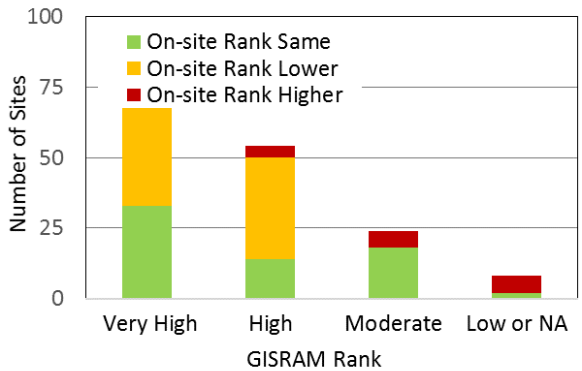


Fig. 15a. GISRAM and on-site methods compared for assessing ***fish and aquatic habitat*** significance.

Figure 15b shows the distribution of sites by rank for each assessment method. GISRAM ranks are generally higher. The most common on-site rank was Moderate.

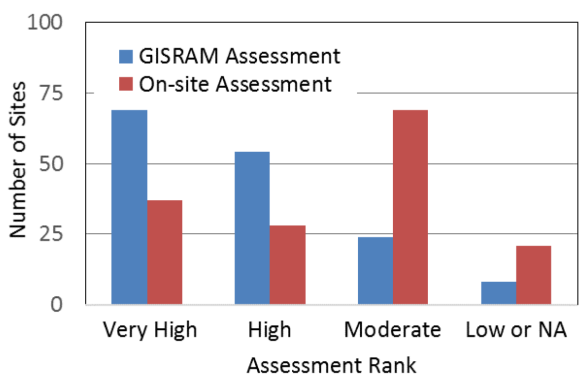


Fig. 15b. The distribution of ***fish and aquatic habitat*** ranks using GISRAM and on-site methods at the same sites.

Floristic Quality

Figure 16a shows a comparison of the GISRAM and on-site ranks for floristic quality. Ranks were the same for 41 of the 155 sites, for 26% agreement, the lowest level of agreement for the six services tested. Where the GISRAM and on-site ranks differed, GISRAM ranks were higher in 62%, and lower in 12% of all sites.

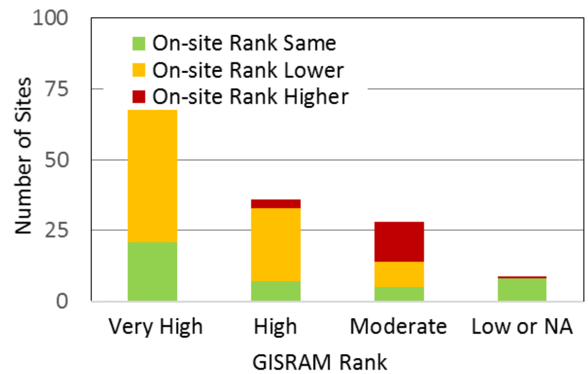


Fig. 16a. GISRAM and on-site methods compared for assessing ***floristic quality*** significance.

Figure 16b shows the distribution of sites by rank for each assessment method. As with all other services, GISRAM ranks higher. On-site ranks are evenly distributed.

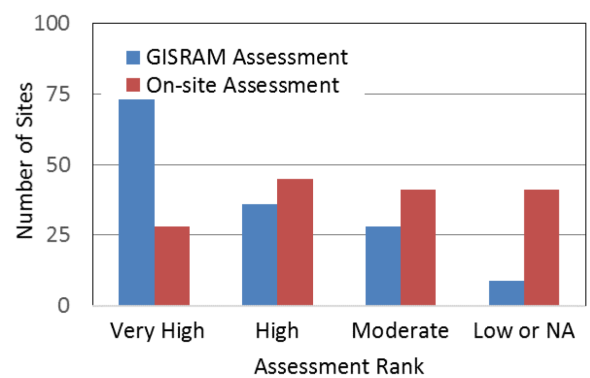


Fig. 16b. The distribution of ***floristic quality*** ranks using GISRAM and on-site methods at the same sites.

E. DISCUSSION

E.1. Applications of the *Wetlands and Watersheds Explorer*

The *Wetlands and Watersheds Explorer* is intended to serve anyone making decisions about where to preserve and restore wetlands.

Results presented in the *Explorer*, in combination with field-based assessments, and other planning tools, will enable decision-makers to capitalize on the ecosystem service benefits that wetland preservation and restoration can provide, using wetlands to achieve their goals. Most importantly, the *Explorer* can guide investments toward sites that are most likely to result in conservation and service gains by comparing their relative potential across an entire watershed.

Where communities experience damaging floods, county planners can use the *Explorer* to look upstream for the best places to protect and restore wetlands that will store water and help with flood control. Those focused on clean water for fish and for river-based recreation might be more interested in protecting and restoring wetlands that help filter pollutants from urban and agricultural runoff as well. The *Explorer* can help them decide which of several existing sites would do the best job of providing these services.

Prospective wetland mitigation bankers or applicants to the state's in-lieu fee mitigation program, the Wisconsin Wetland Conservation Trust, for a given service area, may use the *Explorer* as a first step in identifying sites with substantial restoration potential, in terms of both area and wetland services that improve service area watersheds. Wildlife advocates could use the on-line version of the Wildlife Tool, within the *Explorer*, to identify suitable sites for increasing wetland-dependent wildlife habitat. Table 9 lists potential users and applications of *the Explorer*.

E.1.1. Application Limits and Integration with Other Efforts

Source data used to enhance WWI and PRW data and to apply the GISRAM are the primary limiting factor for the assessments. All wetland mapping has limitations due to scale, photo quality and date, and the difficulty of photo-interpreting certain wetland types. The assessment of services provided by each site is a preliminary one based on additional characteristics also interpreted from remotely sensed datasets, each with its own limitations, and the professional judgment used to develop assessment criteria.

Table 9. Summary of potential users and applications of the *Explorer*

Potential *Explorer* Users	**Potential Applications of the Tool**
Local Governments	Development of watershed plans for water quality, e.g. 9 Key Element Plans; siting of natural infrastructure projects
Land Trusts	Strategic conservation planning; prioritizing projects; grant proposals; wetland education & outreach
Compensatory Mitigation Project Sponsors/Wetland Regulators	Identify and analyze potential restoration sites; guide project selection; support mitigation goals and improve outcomes
County Planners/Regional Planning Commissions	Aid in developing local and regional comprehensive plans; parks and open space plans; flood control and water quality improvements
Private Businesses	Wetland restoration as one component of meeting regulatory requirements, e.g. water quality trading and Adaptive Management programs
Wetland Consultants	Wetland restoration planning and design
Watershed Planners	Watershed assessments, water quality planning
Nutrient Management Specialists	Nutrient management planning
Wildlife/Other Resource Managers	Prioritize projects; identify and analyze sites; wetland restoration planning and design
Agricultural Producers	Nutrient management planning; habitat improvement
Lake Associations	Lake management plans; shoreline protection; water quality improvement; education and outreach
Universities/University Extensions	Wetland research; education and outreach; economic valuation of wetland ecosystem services

The preliminary assessments based on remotely sensed information do not replace the need for field evaluations on a case-by-case basis, either by considering observed features or by actual measurement of performance. For a watershed analysis, however, basin-wide field-derived assessments are not practical, cost-effective, or even possible given time and access constraints. For watershed planning purposes, a more generalized assessment is essential to identify sites with the potential to provide certain services, especially for those services that depend on many variables, or on a site's landscape context. Subsequently, these results can be field-verified to evaluate wetlands or potential restoration sites for meeting conservation objectives, or, for regulatory purposes, to assess the potential effects of a proposed project.

Even when the *Explorer* results and field observations are combined, the *Explorer* is not intended to be prescriptive. Decisions also must consider site-specific restoration feasibility factors, such as property boundaries and drainage easements, and local plans that identify protected lands, farmland preservation areas, and anticipated land uses. Nutrient management planning may also benefit from the *Explorer*. However, *Wetlands by Design* cautions against overloading wetlands identified as having a high potential to improve water quality, thereby degrading the wetland and compromising other services.

While the *Explorer* helps the user to envision *where* to restore, based on potential returns in ecosystem services, it does not answer the question of *how* to restore wetlands. This too depends on many site-specific factors and the biological and hydrological assessments needed to develop restoration plans.

In areas of Wisconsin where there is geographic overlap with other Level 1 wetland assessment tools, these tools will complement each other and lead to better decisions. Finally, new analytical processes and new stand-alone datasets, especially the enhanced WWI (WWAL), may be used elsewhere to complement other efforts and benefit future GIS analyses.

E.1.2. Wetland Preservation

Wetlands by Design guides wetland preservation efforts toward larger and potentially high-performing wetlands by identifying sites that perform one or several services at a high or very high level.

The Wildlife Tool, as presented in the *Explorer*, identifies complexes of habitat—both wetlands and uplands—important to wildlife. The *Explorer* may be used to preserve existing upland/wetland complexes that are likely of high value to wildlife, or to strategically restore more upland/wetland connectivity in the landscape. Preservation and restoration of uplands adjacent to wetlands also enhance other services, such as water quality protection.

Other factors relevant to preservation are beyond the scope of *Wetlands by Design*, but are still important to consider:

- *Very small wetlands*, such as wooded ephemeral ponds, are often too small to be included in wetland mapping, but provide habitat for a unique assemblage of species, including salamanders and invertebrates, that require fishless ponds. Preserving several small sites can be as important to conservation and wetland services as one large site.

- *Rare and/or irreplaceable* wetlands – Wisconsin has about 35 different types of wetland communities. Restoration of any wetland type is difficult and some, such as calcareous fens, interdunal wetlands, and ridge and swale complexes are irreplaceable.[74, 75] Wisconsin Natural Heritage Inventory assigns each wetland type a state rank that indicates its conservation priority. Wetland types that are vulnerable (S3), imperiled (S2), or critically imperiled (S1) are the most important to protect.

- *Critical wetland habitats* – Wetland types that are known to provide critical habitat (nesting, foraging, denning, etc.) for Species of Greatest Conservation Need (SGCN) are identified in the Wisconsin Wildlife Action Plan. Preservation and enhancement of habitats for SGCN populations will ensure these species persist.

- *Great Lakes Coastal Wetlands* – Freshwater estuaries associated with the Great Lakes are unique, at a global level. While coastal wetlands may appear to be abundant in some watersheds, their extent has greatly declined due to drainage for agriculture and expanded development in coastal areas. These wetlands protect coastal communities from storm surges. They also provide food and habitat for estuarine fish and wildlife specially adapted to these systems, they play crucial roles in the Great Lakes food web, and they are part of global migratory corridors essential for birds and other wildlife. These services ensure a strong foundation for fishing, tourism, and the economic well-being of coastal communities in our region.

E.2. Evaluation: Comparison of *Explorer* results with Level 2 assessments

GIS-model assignments of LLWW codes to individual wetlands had a 78% accuracy rate in the test area. Improving accuracy statewide will require advances in the WWI and the 24K Hydro layer, and resolving inconsistencies between them. For applications within a single watershed, where desktop review is feasible, the current model results provide a starting place for making manual improvements.

The GISRAM modeled assessments vary in accuracy from a high of 71% for the significance of flood abatement potential, to a low of 26% for floristic quality. When modeled results did not correspond with field observations, the modeled assessments were generally higher than field assessments for all the ecosystem services that were compared. Consequently, the user can expect GISRAM assessments *to match or over-estimate* the level of performance measured by higher level assessments. Similar distributions of ranks across sites, for both assessment methods, also supports a higher confidence in the *qualitative* model results. This higher confidence applies to flood abatement, water quality, and shore protection.

The two GISRAM models with the poorest performance are for the two ecosystem services related to biological features -- floristic quality and fish and aquatic life. This may be a consequence of the ability of remotely sensed data to capture physical features more reliably than biological ones. The role of water flow, geomorphic position and fetch relative to flood abatement, water quality protection and shoreline protection are easier to capture with remotely sensed data, than are vegetative composition and habitat structure. Vegetative composition in woodlands in particular is limited by the lack of information on common invasive plant species such as buckthorn or garlic mustard.

E.3. The Next Steps

The *Explorer* is not a collection of watershed plans, but it is a sound basis for watershed planning, because it identifies needs, and ranks preservation and restoration opportunities within watersheds based on multiple wetland services. An important next step is to use *Explorer* results in the development and implementation of local watershed plans, including those approved by the Corps to guide compensatory wetland mitigation decisions.

Further evaluation of *Explorer* results, within ecoregions beyond those where the initial testing occurred in southeast Wisconsin, and evaluation of the *Explorer* on-line user experience are needed, and undoubtedly will lead to improvements. Individual GISRAM criteria for each wetland service remain to be tested for predictive reliability and redundancy, and additional criteria may be useful, especially for biological services.

The most severe data limitations in developing the enhanced WWI, or WWAL, are related to inconsistencies between the wetland and waterway datasets and the resolution of the 24K Hydro layer. Integrating these datasets and incorporating higher resolution topographic data would improve the *Explorer's* reliability statewide.

Biological, chemical, and physical attributes of aquatic ecosystems including wetlands are often strongly influenced by groundwater sources. Wetlands where this interaction occurs are generally higher quality than wetlands dominated by surface water. Nonetheless, predictions of shallow subsurface groundwater contributions to these systems at a scale useful to environmental analysis or management are lacking in Wisconsin. The Michigan Rivers Inventory subsurface flux model (MRI-DARCY), used in the *Explorer* to identify wetlands with the potential for groundwater interaction, has a much higher predictive value in Michigan than in our test area. Michigan's surficial geology is dominated by coarse and medium textured material, as is the Wisconsin Southeast Glacial Plains ecoregion, where the model had the best results. Widespread application of the Michigan model may not be suited to Wisconsin, but the need for a predictor of wetland and groundwater interaction remains.

E.3.1. Include Rehabilitation Opportunities

Opportunities to restore wetlands in a watershed include *re-establishment,* or restoring wetlands that have been destroyed and converted to upland; and *rehabilitation,* or improving the condition of current wetlands that have been degraded, for example through changes in vegetation, hydrology or other disturbance.

Wetland disturbance, whether intentional or incidental, has had adverse effects on current wetlands across the state and reduced their service levels. Wetlands compromised by ditching artificial channels, for example, have less capacity to abate floods and protect water quality.

Rehabilitation opportunities are not identified in the *Explorer*, because the available GIS data layers don't support consistent identification of all rehabilitation opportunities. There are, however, several GIS data sources that could be included to identify wetlands degraded in some way, and, consequently, potential rehabilitation projects:

- Although drainage ditches were not specifically mapped during this project, wetlands with "artificial flow" were identified as part of the ecosystem service assessments. Wetland services could be returned to watersheds by restoring natural channels in these wetlands.
- Using mapped drainage ditches, or again "artificial flow", wetlands that were historically naturally isolated from river systems, and connected artificially, could be restored hydrologically to provide services unique to isolated wetlands. Removing artificial connections between waterways and these historically isolated wetlands also has the potential to improve surface water quality and reduce flooding.
- Reed canarygrass dominated wetlands can be identified using WDNR's Reed Canarygrass data layer.
- Cattail dominated wetlands can be identified using WISCLAND v.2 that includes wetlands with more than 50% cattail cover.
- Wetlands ranked "low" for floristic integrity in the *Explorer* are potential rehabilitation opportunities for wetland plant community condition. As with any *Explorer* result, a decision to improve a wetland plant community requires field assessment. WDNR's field-based Floristic Quality Assessment (FQA) method can be used to confirm the *Explorer's* results. Benchmark values for FQA metrics are being developed to condition classes, based on analysis of statewide wetland survey data.
- Entrenched Streams identified in this project, especially where high resolution topographic data are available to increase accuracy, may help locate wetlands that are partially removed from their floodplain and as a result have reduced water quality improvement and flood abatement capacity.

E.3.2. Incorporate Data to Evaluate Restoration Feasibility

After an *Explorer* user identifies high priority sites, the next step is to gather more detailed data at each site and to do a thorough field evaluation. Some desktop evaluation of both re-establishment and re-habilitation sites that one does in preparation for a site visit could be incorporated into the *Explorer*, or a separate Restoration Feasibility Tool. This would allow for a comparative evaluation across watersheds of interest.

Some examples of data layers that would be useful include:

1. Invasive or problematic species in or near a site
    - Reed canarygrass using WDNR's Reed Canarygrass dominated wetlands layer
    - Cattails using the WISCLAND v.2, land cover class for cattail dominated wetlands
    - Aquatic invasive species observation database with occurrence records of invasive plant species statewide, currently available as tabular, but not spatial data.
2. Logistical barriers to restoration:
    - Parcel and ownership boundaries to identify sites in single or multiple ownership and sites near developed areas
    - Airport locations with restrictions beyond the airport boundary that may prohibit wetland restoration

- Drainage District boundaries to identify sites where drainage may have to be maintained
- Dam and floodplain hazard locations

3. Nearby land cover or land use limitations
    - Established farmland preservation areas
    - Current county or regional land cover and proposed land use data

APPENDICES

Appendix A. Project Datasets

Appendix B. LLWW Code Definitions

Appendix C. GIS Rapid Assessment Methodology (GISRAM)

Appendix D. Wildlife Habitat Landcover Classes

NOTES

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Appendix A. Project Datasets

Layer Name / Data Source	Description	Application
Wisconsin Wetland Inventory (WWI) Wisconsin DNR http://dnr.wi.gov/topic/wetlands/inventory.html	Wetlands digitized from base maps of 1:24000 or greater. Mapping scale and date vary by county.	LLWW / GISRAM, Wildlife
Potentially Restorable Wetlands (PRW) Wisconsin DNR http://dnr.wi.gov/topic/surfacewater/datasets/PRW/	Former wetland areas where the current land use can be converted, e.g. agricultural land (2016)	LLWW / GISRAM, Wildlife
WDNR 24K Hydrography Geodatabase Wisconsin DNR http://dnr.wi.gov/maps/gis/datahydro.html	Statewide hydrography dataset	LLWW / GISRAM
Hydrography 24K Value Added Wisconsin DNR ftp://dnrftp01.wi.gov/geodata/hydro_va_24k/	This project attributed channel, riparian, and watershed level data for streams in the 24K hydrogeodatabase (24KGDB) with a variety of geologic, land cover, and other base data.	GISRAM
Watershed Boundary Dataset (WBD) USDA-USGS https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/water/watersheds/dataset/?cid=nrcs143_021616	Watersheds delineated using USGS topo maps of 1:24000 or greater; accessed 2015. Edited to be used in this assessment. Table M4.	LLWW / GISRAM
DARCY Groundwater Movement Model Wisconsin DNR	Predicts strength of groundwater interaction with surface water & wetlands based on surficial geology and topography	LLWW / GISRAM
WI Healthy Watershed Assessment Wisconsin DNR http://dnr.wi.gov/topic/watersheds/hwa.html	This assessment ranks each watershed based on many aspects of watershed condition, including water quality, hydrology, habitat, and biological condition. The assessment results are a modeled prediction of both overall watershed health and vulnerability.	GISRAM
WI Wind Dataset Wisconsin State Climatology Office http://www.aos.wisc	Wind speed frequency tables for selected cities in Wisconsin.	GISRAM
Wiscland 2 Wisconsin DNR http://dnr.wi.gov/maps/gis/datalandcover.html	30m raster of Wisconsin landcover 2016	GISRAM, Wildlife

Layer Name / Data Source	Description	Application
Digital Elevation Model USGS - 3D Elevation Program https://nationalmap.gov/3DEP/	10m Digital Elevation Model	GISRAM
Active River Area (ARA) TNC	Estimates the floodplain area using cost(slope)-distance analysis. Calculated from 24k Hydrography and 3DEP – 10m	GISRAM
SSURGO Soil Surveys Natural Resources Conservation Service http://www.arcgis.com/home/item.html?id=4dbfecc52f1442eeb368c435251591ec http://datagateway.nrcs.usda.gov/	Digitized from 1:24000 base maps; accessed through ArcGIS Online and NRCS data gateway	GISRAM
TIGER Roads US Census Bureau https://www.census.gov/geo/maps-data/data/tiger-line.html	2015 dataset	GISRAM, Wildlife
Minor Civil Divisions State Cartographers Office http://www.sco.wisc.edu/find-data/mcd.html	Cities, Towns and Villages jurisdictions	GISRAM
303d Impaired Waters List Wisconsin DNR http://dnr.wi.gov/topic/impairedwaters/2016ir_iwlist.html	Section 303(d) of the Clean Water Act 2016 required list of all waters that are not meeting water quality standards.	GISRAM
WPDES Permits Database/CAFO Permit database Wisconsin DNR http://dnr.wi.gov/topic/wastewater/PermitLists.html http://dnr.wi.gov/topic/AgBusiness/CAFO/StatsMap.html	Permitted surface water discharges of pollutants to waters of the state with monitoring requirements, special reports, and compliance schedules appropriate to the facility in question.	GISRAM

Appendix B. LLWW Code Definitions

	Code	Description
Landscape Position		The relation of the wetland to a water body
Terrene	TE	Not influenced by hydrologic inputs from a stream, river or lake.
Lentic	LE	Adjacent to a lake or within a lake's basin
Lotic River	LR	Periodically flooded by a river (stream order 3 or greater)
Lotic Stream	LS	Periodically flooded by a stream (stream order 2 or less)
Landform		The physical shape of the wetland
Slope	SL	Occurs on a slope >= 5%
Island	IL	Surrounded by open water
Fringe	FR	Occurs in the shallow water zone of a permanent stream, river or lake
Floodplain	FP	Occurs on an active alluvial plain along a river or stream
Floodplain Fringe	FF	Encompasses elements of both Fringe and Floodplain
Basin	BA	Occurs in a topographic depression
Flat	FL	Extensive, level wetlands
Waterbody Type		The type of waterbody associated with the wetland
Natural Pond	PD1	Natural waterbody <10 ac
Impounded Pond	PD2	Diked or impounded waterbody <10 ac
Excavated Pond	PD3	Excavated waterbody <10 ac
Natural Lake	LK1	Natural waterbody >10 ac
Dammed Lake	LK2	Dammed waterbody >10 ac
Excavated Lake	LK3	Excavated waterbody >10 ac
Waterflow Path		Waterflow path relative to the wetland
Isolated	IS	Wetland has no surface water connection to other wetlands and waters
Inflow	IN	Receives concentrated surface-water with no outflow
Outflow	OU	Surface-water outflow via natural channels; no channelized inflow
Outflow Intermittent	OI	Surface-water outflow via intermittent channels; no channelized inflow
Outflow Artificial	OA	Surface-water outflow via artificially manipulated or created channels; no channelized inflow
Throughflow	TH	Surface-water inflow and outflow via natural channels
Throughflow Intermittent	TI	Surface-water inflow and outflow via intermittent channels
Throughflow Artificial	TA	Surface-water inflow and outflow via artificially straightened or created channels
Bidirectional	BI	Adjacent to lake; wetland hydrology influenced by changing lake levels
Connection Intermittent	CI	Intermittent unmapped surface connection to a stream, river or lake
Modifiers		
Entrenched	en	A wetland associated with a stream vertically contained within its banks sufficient to reduce its connection with the floodplain
Groundwater	gw	A wetland with a substantial groundwater connection
Headwater	hw	A wetland associated with the origins of a stream such that the wetland contributes baseflow support

GIS-RAM: Flood Abatement (FA)

Code	Criterion	Rationale	Assessment Resource		Unit of Analysis			Datasets	GIS-based Criterion
			Wetland	PRW	Polygon	Complex	Catchment		
FA_O1	Site is connected to a lake, stream, or river, OR receives concentrated inflow and/or outflow or is connected through an existing wetland to outflow. **This criterion is necessary to the service.**	Runoff accumulated at a point or channel contributes to more stream flow during storm events. Wetlands connected to streams can help to slow floodwaters.	X	X		X		WWI/PRW Plus	LLWW Functional Significance is High or Moderate = YES
FA_O2	Local topography near a site includes steep slopes.	Steep slopes contribute to rapid runoff and increased stream flow during storm events. Wetlands below these slopes will intercept and slow more stormwater runoff and floodwater.	X	X			X	WWI/PRW, WI DNR 24k VA dataset,	Slopes within the site's catchment exceed the median slope value for the WHUC 10 = YES
FA_O3	Site is in a catchment with high runoff potential	Land cover and soil type in the catchment determine runoff volume.	X	X		X	X	WWI/PRW Plus, WDNR 24K Hydrography Value Added	Site is in a catchment whose runoff Curve Number value exceeds the median Curve Number value for the WHUC 10 = YES
FA_E2	Dominant vegetation of site is dense and persistent	Dense wetland vegetation impedes water flow. Persistent vegetation (e.g. woody plants, robust persistent emergent species) can provide this service even outside of the growing season.	X		X			WWI	Forest, scrub-shrub and persistent emergent marsh wetland types, with modified wetlands (f, g, v and x) excluded = YES
FA_E3	Site is in a topographic depression or floodplain setting	Floodplain wetlands store floodwaters temporarily after storms.	X	X	X			WWI/PRW Plus, Active River Area	Landform = BA, FR, FF, FP, and inside ARA = YES
FA_E4	Internal flow path distance within a site	The longer the flow path within the site, the greater the friction that will slow water movement.	X	X		X		WWI/PRW Plus, WDNR 24K Hydrography Geodatabase	Length of a site's shoreline interface exceeds the WHUC10 non-zero median interface length, with entreched and artifical waterways excluded = YES

GIS-RAM: Flood Abatement (FA)

Code	Criterion	Rationale	Assessment Resource		Unit of Analysis			Datasets	GIS-based Criterion
			Wetland	PRW	Polygon	Complex	Catchment		
FA_E5	Ratio of catchment area to site area	The largest sites, less likely to overflow after a storm, are more effective in storing floodwater.	X	X		X		WWI, WDNR 24K Hydrography Value Added	Wet units that intersect stream/river network used to create the upstream area measures were compared to the area of the catchments above them, wetunits not directly connected to the network were compared to their immediate catchment area. Sites whose ratio is in the most favorable 1/3 of ratios for the WHUC10 = YES
FA_E9	Site is connected to waterways with Strahler Stream Order higher than 2	Wetlands that occur at a lower topographic elevation within the watershed than the contributing uplands will receive more floodwater.	X	X		X		WDNR 24K Hydrography Geodatabase	Stream Order >2 = Yes
FA_S1	Site outflow contributes to downstream developed flood-prone areas	Wetlands that contribute to flood abatement upstream of economically valuable flood-prone areas reduce downstream flood damage.	X	X		X		WWI/PRW Plus, Minor Civil Divisions, Dams, WDNR 24K Hydrography Value Added (HUC-16, topographic network & topology)	Identify all catchments upstream of all of the Cities and Villages in Wisconsin; sites in catchments not upstream of a Dam catagorized with a Potential Hazard of High or Significant = YES.

GIS-RAM: Sediment Retention (SS)

Code	Criterion	Rationale	Assessment Resource		Unit of Analysis			Datasets	GIS-based Criterion
			Wetland	PRW	Polygon	Complex	Catchment		
SS_O1	Site is connected to a surface water directly or through an existing wetland. **This criterion is necessary to the service.**	Wetlands connected to surface water have more opportunity to influence water quality.	X	X		X		WWI/PRW Plus	LLWW Functional Significance is High or Moderate = YES
SS_O2	Lack of vegetated buffer around site	Wetland buffers in natural cover serve as filters for overland flow before it enters wetlands; wetlands lacking such buffers play a larger role in protecting water quality.	X	X	PRW only	WWI only		Wiscland 2	Less that 50% of the landover within 60 m of a site is natural vegetation = YES
SS_O3	Proximity of roadway sediment source to site	Crossing of road right of way over sites and streams; Sediment found on roadways will be washed off during rain events and flow downstream where wetlands are typically located.	X	X		X		WWI/PRW Plus, TIGER Roads (2015)	Wetunit and road within a buffered selection = YES
SS_O4	Predicted Total suspended sediment concentration is high.	Higher runoff volume and velocity is capable of dislodging more sediment as it travels across the landscape resulting in more sediment transport downslope.	X	X		X		Healthy Watershed Assessment, WDNR 24K Hydrography Value Added	Concentration in the complex (area-weighted average of catchment values) exceeds the median concentration for the WHUC 12 = YES
SS_E1	Internal flow path distance within site	The longer the hydrologic path length, the greater the friction provided and this the more effective a wetland is at slowing flow and settling sediment particles. Don't include artificial through flow from NWI + The longer the flow path within the site, the greater the friction that will slow the movement of water and increase its settling ability.	X	X		X		WWI/PRW Plus, WDNR 24K Hydrography Geodatabase	Length of a site's shoreline interface exceeds the WHUC10 non-zero median interface length, with entreched and artifical waterways excluded = YES (Same as FA_E4)

GIS-RAM: Sediment Retention (SS)

Code	Criterion	Rationale	Assessment Resource		Unit of Analysis			Datasets	GIS-based Criterion
			Wetland	PRW	Polygon	Complex	Catchment		
SS_E2	Dominant vegetation of site is dense and persistent	Dense wetland vegetation impedes water flow, causing suspended sediment to settle, even outside of the growing season.	X		X			WWI	Forest, scrub-shrub and persistent emergent marsh wetland types, with modified wetlands (f, g, v and x) excluded = YES (Same as FA_E2)
SS_E3	Site occurs in a topographic depression	Depression wetlands retain water which allows suspended particles to settle.	X	X	X			WWI/PRW Plus	Landform is BA = YES
SS_E4	Ratio of catchment area to site area	Larger wetlands, less likely to overflow, can trap more sediment.	X	X		X		WWI, WDNR 24K Hydrography Value Added	Wet units that intersect stream/river network used to create the upstream area measures were compared to the area of the catchments above them, wetunits not directly connected to the network were compared to their immediate catchment area. Sites whose ratio is in the most favorable 1/3 of ratios for the WHUC10 = YES (Same as FA_E5)
SS_E5	Bank or shoreline upstream or in site is subject to erosion; Stream Power Index (SPI) measures the erosive power of overland flow as a function of local slope and upstream drainage area.	Wetlands or wetlands restored mitigate erosion due to moving water.	X	X	X			USGS - 3D Elevation Program, 10m DEM.	The complex contains an area of SPI(>7) that is greater than the median area of SPI for the WHUC10 = YES

GIS-RAM: Phosphorus Retention (PR)

Code	Criterion	Rationale	Assessment Resource		Unit of Analysis			Datasets	GIS-based Criterion
			Wetland	PRW	Polygon	Complex	Catchment		
PR_O2	Lack of vegetated buffer around site	Wetland buffers in natural cover serve as filters for overland flow before it enters wetlands; wetlands lacking such buffers play a larger role in protecting water quality.	X	X	WWI, only	PRW, only			Less that 50% of the landover within 60 m of a site is natural vegetation = YES; Same as SS_O2
PR_O4	Stream total phosphorus concentration is high.	Higher phosphorus concentrations in surface waters increases P loading of downstream wetlands.	X	X		X		Healthy Watershed Assessment, WDNR 24K Hydrography Value Added	Concentration in the complex (area-weighted average of catchment values) exceeds the median concentration for the WHUC 12 = YES
PR_O5	High animal unit density	Crop fields near livestock concentrations receive phosphorous as a result of manure spreading.	X	X		X		CAFO permits, Wiscland 2	Site is adjacent to dairy rotation fields that are within 10 miles of a permitted CAFO = YES
PR_O6	Site receives nutrients from a point source	Sites downstream of pollution sources have a greater opportunity to affect water quality than those upstream	X	X		X		WWI, PRW, WDNR 24K Value Added, Wisconsin Pollutant Discharge Elimination System (WPDES) , CAFO permits	Site is on a flowline within a catchment that is downstream of a cathcmernt with a pont source = YES
PR_E2	Dominant vegetation of site is dense and persistent	Dense vegetation slows the flow of water, which increases settling of suspended sediment. During the growing season, dense vegetation also uses dissolved phosphorous for plant growth.	X		X			WWI	Forest, scrub-shrub and persistent emergent marsh wetland types, with modified wetlands (f, g, v and x) excluded = YES; Same as FA_E2

GIS-RAM: Phosphorus Retention (PR)

Code	Criterion	Rationale	Assessment Resource		Unit of Analysis			Datasets	GIS-based Criterion
			Wetland	PRW	Polygon	Complex	Catchment		
PR_E3	Soil at the site has the capacity to absorb phosphorous.	Fine textured and organic soil types retain more phosphorous than course, sandy soils.	X	X	X			SSURGO Soils	Soil textures of Clay, Clay loam, Sandy clay, Silt, Silt loam, Silty clay, or Silty clay loam within the A or O are prevalent at the site = YES
PR_E4	Site does not have anaerobic conditions	Aerobic conditions increase phosphorous retention in the sediment and the uptake of phosphorus by vegetation	X		X			WWI, SSURGO Soils	Based on the WWI Hydrologic Modifier. Wetland has wet soil (K), or wetland has proplonged standing water (H), but is not formed over organic soil = YES
PR_E5	Site has shallow slope	The lower the slope of a site, the longer it retains water.	X	X		X		USGS - 3D Elevation Program, 10m DEM.	Slope of site is less than the median slope of sites in the WHUC 10 =YES
PR_E6	Ratio of catchment area to site area	The largest sites, less likely to overflow after a storm, are more effective in retaining stormwater runoff, and removing phosphorous either by allowing sediment to settle, or by plant uptake.	X	X		X		WWI, WDNR 24K Hydrography Value Added	Wet units that intersect stream/river network used to create the upstream area measures were compared to the area of the catchments above them, wetunits not directly connected to the network were compared to their immediate catchment area. Sites whose ratio is in the most favorable 1/3 of ratios for the WHUC10 = YES
PR_E8	Site occurs in topographical depression	Depression wetlands retain water longer that sloped or flat wetlands. Longer retention time increases settling of suspended solids and phosphorous uptake.	X	X	X			WWI/PRW Plus	LLWW Landform is BA = YES

GIS-RAM: Nitrogen Reduction (NR)

Code	Criterion	Rationale	Assessment Resource		Unit of Analysis			Datasets	GIS-based Criterion
			Wetland	PRW	Polygon	Complex	Catchment		
NR_O1	Site is connected to a surface water directly or through an existing wetland. **This criterion is necessary to the service.**	Wetlands connected to surface water have a greater ability to affect water quality.	X	X		X		WWI/PRW Plus	LLWW Functional Significance is High or Moderate = YES
NR_O2	Stream nitrate/nitrite concentration is high.	Wetlands with higher levels pollution potential have a greater opportunity to improve water quality than wetlands not receiving such inputs.;	X	X		X		Healthy Watershed Assessment	Concentration in the complex (area-weighted average of catchment values) exceeds the median concentration for the WHUC 12 = YES (Same as PR_O4)
NR_O3	Site receives nutrients from a point source	Sites downstream of pollution sources have a greater opportunity to affect water quality than those upstream	X	X		X		WWI, PRW, WDNR 24K Value Added, Wisconsin Pollutant Discharge Elimination System (WPDES) , CAFO permits	Site is on a flowline within a catchment that is downstream of a cathcmernt with a pont source = YES
NR_O4	High animal unit density	Crop fields near livestock concentrations receive nitrogen as a result of manure spreading.	X	X		X		CAFO permits, Wiscland 2	Site is adjacent to dairy rotation fields that are within 10 miles of a permitted CAFO = YES; Same as PR_O5
NR_E1	Site has seasonally fluctuating water levels	Transforation of nitrate nitrogen to nitrogen gas is most efficient under alternating aerobic and anaerobic conditions.	X	X		X		WWI/PRW Plus	Site is a floodplain wetland (Landform is FR, FF or FP) and not associated with a Lake or Pond = YES
NR_E2	Soil types at the site are rich in carbon	Sites with organic soil types are more effective at denitrification, which depends on the availability of carbon	X	X		X		SSURGO Soils	Soil map units for at least 50% of the area of a site are Histosols = YES; Same as SWS_E3
NR_E3	Dominant vegetation of site is dense and persistent	Dense vegetation slows the flow of water, which increases settling of suspended sediment. During the growing season, dense vegetation also uses nitrogen for plant growth.	X		X			WWI	Forest, scrub-shrub and persistent emergent marsh wetland types, with modified wetlands (f, g, v and x) excluded = YES; Same as FA_E2

GIS-RAM: Surface Water Supply (SWS)

Code	Criterion	Rationale	Assessment Resource		Unit of Analysis			Datasets	GIS-based Criterion
			Wetland	PRW	Polygon	Complex	Catchment		
SWS_O1	Site is connected to surface waters when baseflow supply is most needed.	Sites that discharge water, even during dry periods, contribute to downstream surface water. Sites with an intermittent connection are typically dry when surface water supply is most needed.	X	X		X		WWI/PRW Plus	LLWW Water Flow Path is not intermittent or isolated = YES
SWS_O2	Site is in a headwater setting	Headwater wetlands are the source of streams.	X	X		X		WWI/PRW Plus	LLWW Headwater modifier is hw = YES
SWS_O3	Site receives groundwater	Wetlands that receive groundwater discharge that water to streams even during dry periods	X	X		X		WWI/PRW Plus	LLWW Groundwater modifier is gw = YES
SWS_E1	Site is in a floodplain setting	Floodplain wetlands supply waterways between storm events by slowly releasing stored water once flood waters recede.	X	X		X		WWI/PRW Plus	LLWW Landscape Position is FP, FF, or FR = YES
SWS_E2	Site is a pond or lake with perennial through flow or outflow	Waterbodies with perennial outflow discharge water downstream	X			X		WWI/PRW Plus	LLWW Waterbody type is Outflow ot Throughflow = YES
SWS_E3	Soil at the site is high in organic material	Organic soils, compared with mineral soils, retain water longer, and release it more slowly, which extends the discharge period.	X	X		X		SSURGO Soils	Soil map units for at least 50% of the area of a site are Histosols = YES
SWS_S1	Site is connected to a stream with impaired baseflow	Streams that are compromised during dry periods by low flow condtions rely on what wetlands remain.	X	X		X		WDNR 24K Hydrography Value Added (Temperature / Flow Model)	Compare the pre-settlement flow with the current annual 90% exceedance flow to represent where baseflow has been depleted. Site's catchment has a the model value less than the median value for the WHUC 12 = YES
SWS_S2	Site's catchment has high capacity wells	Streams that are compromised by groundwater withdrawals are supported by what wetlands remain.	X	X			X	Healthy Watershed Assesment	Site's catchment has groundwater withdrawals greater than the median value for the WHUC12 = YES

GIS-RAM: Shoreline Protection (SP)

Code	Criterion	Rationale	Assessment Resource: Wetland	Assessment Resource: PRW	Unit of Analysis: Polygon	Unit of Analysis: Complex	Unit of Analysis: Catchment	Datasets	GIS-based Criterion
SP_O1	Site is adjacent to or within a river, stream or lake. **This criterion is necessary to the service.**	To protect shorelines, wetlands must be situated along a waterbody.	X	X	X			WWI/PRW Plus, WDNR 24K Hydrography Geodatabase	Site is adjacent to or within 10 m of a river, stream, or lake larger than 10 acres, and does not have an artificial, outflow, or connection intermittent waterflow path outside the floodplain = YES
SP_O2	Site is exposed to a large area of open water	Wetlands along large areas of open water are exposed to wind fetch and dissipate the resulting wave energy.	X	X	X			Wisconsin Wind Dataset, WDNR 24K Hydrography Geodatabase	Developed a model that quantifies the distance of open water from the site along the two most prevailing wind diretions. Model value exceeds the WHUC10 non-zero median = YES
SP_O3	Site connected to a lake used recreationally	Wetlands located on lakes where slow-no-wake protection is limited will mitigate shoreline erosion due to recreational boat activity.	X	X	X			WDNR Lakes	Mississippi River Pools and any Lake larger than 50 acres = YES
SP_E1	Dominant vegetation at the site is dense and persistent.	Banks stabilized by dense root systems are less likely to erode.	X		X			WWI	Forest, scrub-shrub and persistent emergent marsh wetland types, with modified wetlands (f, g, v and x) excluded = YES (Same as FA_E2)
SP_E2	Length of site interface along waterbody connection	The longer the interface between a wetland and a waterbody, the more shoreline protection the wetland provides.	X	X		X		WWI/PRW Plus, WDNR 24K Hydrography Geodatabase	Length of a site's shoreline interface exceeds the WHUC10 non-zero median interface length, with entreched and artifical waterways excluded = YES
SP_S1	Site is located between a developed area and open water	Wetlands that shelter developed areas from shoreline erosion have particular significance.	X	X		X		Wiscland 2	Site meets SP_O1 criterion and is adjacent to urban/developed land cover areas greater than 3600 sq. m = YES

GIS-RAM: Fish & Aquatic Habitat (FAH)

Code	Criterion	Rationale	Assessment Resource		Unit of Analysis			Datasets	GIS-based Criterion
			Wetland	PRW	Polygon	Complex	Catchment		
FAH_O1	Site is connected to a perennial stream or lake. **This criterion is necessary to the service.**	Wetlands connected to perennial surface water have the oportunity to provide fish & aquatic habitat	X	X		X		WWI/PRW Plus	Site is not isolated or entrenched = YES
FAH_E1	Site is inundated in spring	Wetlands flooded in spring provide habitat for reproduction and food chain support	X	X		X		WWI/PRW Plus; Active River Area	Site Landform is BA, FR, FF, or FP and within ARA = YES
FAH_E2	Site is not associated with a waterbody impaired for fish & aquatic life	Viable populations require clean water	X	X		X		Impaired Waters, Clean Water Act 303(d) List	Site is on a waterway not impaired for fish and aquatic life factors (e.g. mercury), or is upstream of an impaired waterway = YES
FAH_E3	Site is accociated with a waterbody bordered by natural landcover	Natural shorelines increase available habitat for fish & aquatic life	X	X		X		Wiscland 2; WDNR 24K Hydrography Geodatabase	Site is adjacent to a waterway whose percent natural cover within 60 meters exceeds the median for the WHUC 12 = YES
FAH_E4	Catchment supports a healthy macroinvertebrate community	Wetlands support the presence of healthy aquatic macroinvertebrates communities	X	X			X	WI Healthy Watershed Assessment	Catchment Macroinvertebrate Index of Biological Integrity (IBI) exceeds the median for the WHUC 12 = YES
FAH_E5	Site is connected to a waterbody with few barriers to fish passage	Wetlands assocaited with barrier-free waterways are more likely to support complete and sustainable populations.	X	X		X		WI Healthy Watershed Assessment	Wetunit associated with waterbody whose Stream Patch Size is greater than the median Stream Patch Size of the WHUC 10 = YES
FAH_S1	Site is associated with a waterbody accessible for public fishing	Wetlands assocaited with waterways accessible to anglers are more likely to benefit the fishing public	X	X		X		WI DNR Lakes/reservoir waterbody dataset	Wetunit is associated with a waterbody that has a public boat landing = YES

GIS-RAM: Carbon Storage (CS)

Code	Criterion	Rationale	Assessment Resource		Unit of Analysis			Datasets	GIS-based Criterion
			Wetland	PRW	Polygon	Complex	Catchment		
CS_E1	Site contains deep peat or muck layers	Peat and muck type soils form when the soilis saturated for much of the growing season, and where buried organic materail decomposes slowly.	X			X		SSURGO Soils	Complex has a soil type within the Histosol Order for at least 50% of its area = YES
CS_E2	Site is dominated by persistent vegetation with high biomass	Carbon storage increases with plant biomass. Plant biomass increases with plant size.	X			X		WWI	Wetlands with trees or shrubs that do not include open water = YES
CS_E4	Site is likely to retain stored carbon	Sites with less water leaving the site lose less material suspended in the water.	X	X		X		WWI Plus	Water Flow Path is Isolated or Inflow = YES

GIS-RAM: Floristic Integrity (FI)

Code	Criterion	Rationale	Assessment Resource		Unit of Analysis			Datasets	GIS-based Criterion
			Wetland	PRW	Polygon	Complex	Catchment		
FI_O1	Site is vegetated. **This criterion is necessary to the service.**	Floristic integrity requires the presnece of vegetation.	X		X			WWI	WWI with current wetcode not Flats or Open Water = YES
FI_O2	Site does not have documented invasives	Wetlands without documented invasive plant species have the potential of higher floristic integrity than those with documented invasions.	X		X			WDNR Invasive Plants Database, WWI	Site is more than 50 m from a documented occurrence of invasive species aassociated with wetlands (reed canarygrass, Phragmites, cattail, purple loosestrife, flowering rush) = YES
FI_O3	Site receives groundwater discharge	Wetlands that receive more groundwater, relative to surface water, tend to receive lower levels of sediment and surface water pollutants that encourgage the spread of invasive plant species.	X			X		WWI Plus	Groundwatermodifier is gw = YES
FI_O4	Dominant landcover near a site is natural vegetation	Natural landcover contributes less to the spread of invasive plant species than does developed or disturbed land.	X				X	Wiscland 2, WWI, WDNR 24K Hydrography Value Added (HUC-16)	Natural landcover within the wetland's catchment exceeds the median valuie for the WHUC 10 = YES
FI_O5	Site not within dispersal zone of invasive plant species	Wetlands outside the dispersal zone of an invasive plant species propagule have less chance to be colonized.	X				X	WDNR Invasive Plants Database, WWI, WDNR 24K Hydrography Value Added (networks)	Lotic or lentic wetlands within catchments with invasive plant species associated with wetlands (reed canarygrass, Phragmites, cattail, purple loosestrife, flowering rush), or within catchments immediately downstream of a catchment with these invasives = YES
FI_O7	Site recognized as high quality plant community	High quality plant communities generally have greater floristic integrity.	X		X			Natural Heritage Inventory, State Natural Areas	Wetlands intersect NHI wetland communities or State Natural Areas = YES

GIS-RAM: Floristic Integrity (FI)

Code	Criterion	Rationale	Assessment Resource		Unit of Analysis			Datasets	GIS-based Criterion
			Wetland	PRW	Polygon	Complex	Catchment		
FI_E1	Land cover surrounding the site is dominated by natural vegetation.	Natural land cover around wetlands is a potential barrier to invasive plant species.	X			X		Wiscland2, WWI PRW	Percent natural landcover within 100 m of a sites exceeds the median vlaue for the WHUC 10 = YES

Appendix D. Wildlife Habitat Land Cover Classifications

Upland	
Urban/Developed, high intensity	Wiscland 2 Level 2
Urban/Developed, low intensity	Wiscland 2 Level 2
Grasslands (including Pasture)	Wiscland 2 Level 2: Grassland & Idle Grass
Forest, evergreen	Wiscland 2 Level 2: Coniferous
Forest, deciduous	Wiscland 2 Level 2: Broad-leaved
Forest, mixed	Wiscland 2 Level 2: Mixed Deciduous/Coniferous
Shrubland (not shrub-carr)	Wiscland 2 Level 2: Shrubland
Cultivated Land	Wiscland 2 Level 2: Crop Rotation, Cranberries, Forage Grass, Barren
Large Open Water	
Surface Water, rivers	24K Hydro Layer: double line streams and main channels
Surface Water, lakes	24K Hydro Layer: lake, pond and flowage features greater than 5 acres
Wetland	**Wisconsin Wetland Inventory Classifications**
Open Water Wetlands	All Open Water Class (W), plus any lakes, ponds, flowages <= 5 acres from 25K Hydro Layer
Aquatic Bed/Deep Marsh	All Aquatic Bed Class (A)
Shallow Marsh, <= 5 acres	All Emergent/wet meadow Class (E) with Standing Water Modifier (H), <= 5 acres
Shallow Marsh, > 5 acres	All Emergent/wet meadow Class (E) with Standing Water Modifier (H), > 5 acres
Wetland Meadows	All Emergent/wet meadow Class (E) with Wet Soil Modifier (K), and Flats Class (F) if grazed and not Cattail
Wetland Forest, broad-leaved	Forested Class (T): T1, T3
Wetland Forest, coniferous	Forested Class (T): T2, T5, T8
Wetland Forest, mixed	Wiscland 2 Level 2: Mixed Deciduous/Coniferous, unless another Wetland Forest type
Shrub Bog, evergreen	Scrub-shrub Class (S): S2, 4, 5, 6
Shrub-carr, deciduous	Scrub-shrub Class (S): S1, 3, 9
Cultivated flat	Flats Class, if farmed
Natural flat	Flats Class (F)
Special Types	
Reed Canarygrass	http://dnr.wi.gov/topic/wetlands/documents/RCGFinalReport10_08.pdf
Cattail	Wiscland 2 Level 3
Road Corridor	2015 Wisconsin DOT Roads layer with the lines buffered to the standard width based on roadway classification

Wiscland2: http://dnr.wi.gov/maps/gis/datalandcover.html
Wisconsin 24K Hydro Layer: http://dnr.wi.gov/maps/gis/datahydro.html
Wisconsin Wetland Inventory: http://dnr.wi.gov/topic/wetlands/inventory.html