# Waubesa Wetlands

## New Look at an Old Gem

Joy Zedler

2019. *Waubesa Wetlands: New Look at an Old Gem,* 2nd edition.

Free eBook at Town of Dunn (http://www.town.dunn.wi.us/land-use/historic-documents/)

Paperback version (2018) available at Dunn Town Hall, 4156 County Road B, McFarland, WI

Cover photo: Licensed to print by Tom Lynn Photography LLC.

In preparing for their southward migration, Sandhill cranes congregate and feed before migrating to their overwintering grounds. The nine cranes on the cover were looking for a landing place along the Wisconsin River staging area when captured on camera by Tom Lynn.

Those of us who have found landing places near the Waubesa Wetlands revere the Sandhill cranes for their beauty; for their complex ecology that links wetlands, uplands and international wintering grounds; and for having rebounded from near-extirpation by overhunting.

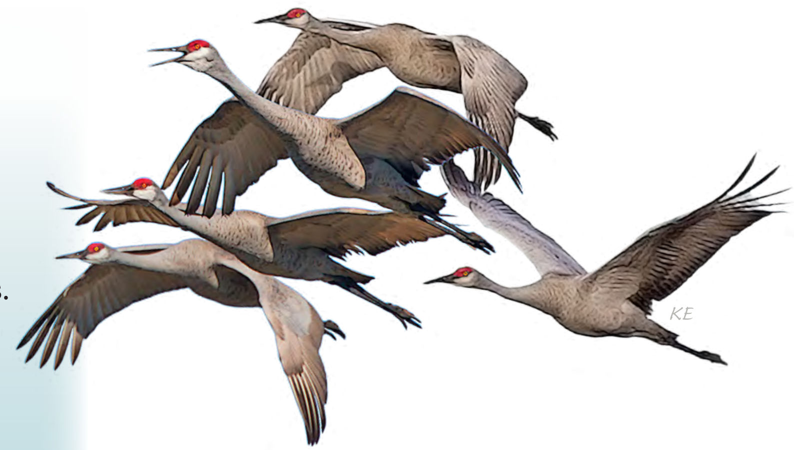
Aldo Leopold wrote in *Marshland Elegy*,
"The ultimate value in these marshes is wildness, and the crane is wildness incarnate."

**News**: Waubesa Wetlands are now a **Wetland of Distinction,** designated by the The Society of Wetland Scientists (SWS).

SWS has over 3,000 members in the United States and other countries (http://sws.org). Designating Wetlands of Distinction advances SWS goals of wetland education and public awareness. SWS included Waubesa Wetlands in its first 20 Wetlands of Distinction. SWS considers it a step toward recognition as a Ramsar Site (see Preface).

# Sandhills

John Herm
*Poet Laureate, Town of Dunn*




There's nothing quite like those sandhill cranes.
No other bird is really the same,
High in the sky on outstretched cruise,
Back on land they seem to muse.

I hear them coming a mile away
With squawk-chatter thing they always say.

They're just majestic in soaring flight
My favorite, though, is their a-light
When they set their wings and sink straight down
Extend long legs and land aground.

Funny thing, though, about these cranes
In mating season, they go insane,
The things they do with love on the brain!
They shriek and scream and jump around,
Soon there they are… two eggs aground.

Cranes give comfort to me and you
I love those cranes and Ed does too.

# Waubesa Wetlands

## New Look at an Old Gem

**Joy B. Zedler**
**Aldo Leopold Professor Emerita, University of Wisconsin–Madison**

**2019 • 2nd edition**

This book was inspired by studies and teachings of Dr. Calvin B. DeWitt, former Chair of the Town of Dunn and University of Wisconsin-Madison Professor Emeritus. Since moving here in 1972, Cal and his wife Ruth have been resident naturalists, wetland advocates, and land caregivers.

Thank you for sharing your knowledge of Waubesa Wetlands!

CREDITS:

Kandis Elliot, Graphic Designer: Original art, illustrations, layout, expertise and more

Cal DeWitt, PhD: Wetland studies, Town of Dunn history, photos, species lists and wisdom

Madeline Fisher, PhD, Editor: Writing for a broad audience, expertise, corrections

Ben Kollenbroich, Town of Dunn Website: Posting chapters, archiving information

Groundswell Conservancy (formerly Natural Heritage Land Trust), Wisconsin Department of Natural Resources: Conserving wetlands, supporting science

Alex Wenthe, Waubesa Wetlands Volunteer steward: Quantifying mapped vegetation

James W. Jaeger: Advice on stream ecology

Photos: Nadia Olker, Cal DeWitt, Paul Zedler, Dan Jackson; others as noted

Monitoring data: Rock River Coalition (streams), International Crane Foundation (Sandhill cranes); Environmental Defense Fund (Monarch butterfly summary)

Town of Dunn: Wetland conservation, Purchased Development Rights program; unwavering land ethic

Landowners with Conservation Easements and all who support protection of Waubesa Wetlands

Bur Oak in November
*Photo: P. Zedler*

# Foreword

In celebrating 20 years of "permanently preserving fragile landscapes and productive farmland," Town Chair Ed Minihan applauded the first small group of people who began protecting the land (Town of Dunn Fall 2017 Newsletter):

> "That group of dedicated citizens changed the dynamics of development pressure on the Town in such a major way that we can now have a planning horizon that spans 200 years. That is actually a realistic time frame in the Town of Dunn. It is very difficult for most communities to even fathom such a horizon….What has happened here is the result of ideas generated by citizens and brought to the local government for the implementation of the mechanisms necessary to make those ideas a reality.
>
> "And so it has happened, in stages, with new ideas over time. More time than I ever thought it would take. But it is a dynamic process, and we are not nearly done. You can expect the Town of Dunn to proceed forward in keeping this a great place in which to live. There has been attrition in that small group of dedicated individuals, but they have been replaced by younger ones who carry forward the seeking of a path that leads to a truly sustainable community. The dedication is to the land. Once the land is saved, all else follows to sustain us."

# Waubesa Wetlands: New Look at an Old Gem

# Preface

## What catalyzed this book?

While filling out a 50-page form to nominate Waubesa Wetlands for **international recognition** under the **Ramsar Convention,** it seemed that half a year's work should be shared with local residents, not just reviewers at the U.S. Fish and Wildlife Service and the Ramsar Secretariat. Residents who have loved and cared for Waubesa Wetlands deserve their own compendium—but not just dense fact sheets. Instead, I envisioned a celebration of all that Waubesa Wetlands offer. And, when University of Wisconsin-Madison scientist Cal DeWitt offered his photos and stories, this book was launched.

And **what catalyzed the Ramsar nomination?** The idea occurred after a local politician said, "I doubt that Waubesa Wetlands have a significant effect on the global nitrogen cycle." Knowing how important wetlands are to nitrogen cycling, I immediately thought the opposite: "Why *wouldn't* Waubesa Wetlands have a significant effect on global nitrogen?" Wetlands are the world's transformers of nitrates to nitrogen gas, and nitrogen gas makes up ~79% of Earth's air. No other type of ecosystem comes close to wetlands in reversing the damages we humans have caused by converting nitrogen gas to nitrate fertilizer. While we need fertilizers for crops, we don't need excess nitrates in our wells, streams, and lakes. We can thank wetlands for taking up excess nitrates and releasing nitrogen gas, which is called **denitrification.**

Waubesa Wetlands are internationally important in my opinion. But that doesn't mean a politician or the public or the Ramsar Secretariat would agree. So I delved into the **criteria** in the Ramsar Convention handbooks and guidelines. After decades of studying Tijuana Estuary, California, I had helped nominate it to be a Wetland of International Importance in 2005. However, Tijuana Estuary sits at the US-Mexico Border, so it is obviously international. If you have a taste for salt, there's a free eBook on *Salt Marsh Secrets* uncovered by my students and other collaborators (Zedler 2015). Our research and the thousands of waterbirds that migrate across the California-Mexico boundary propelled Tijuana Estuary to recognition as a Ramsar Site.

Surely Cal DeWitt's decades of research and teaching, and our internationally-migrating cranes would confer the same international importance for Waubesa Wetlands…. Simple? Well, not exactly. Nominators were allowed to choose from nine criteria to justify such recognition. Having a global impact on the nitrogen cycle was

### The Ramsar Convention

The Ramsar Convention on Wetlands of International Importance, especially as Waterfowl Habitat, is an international treaty for the conservation and sustainable use of wetlands. It is also known as the Convention on Wetlands. It is named after the city of Ramsar in Iran, where the Convention was signed in 1971.

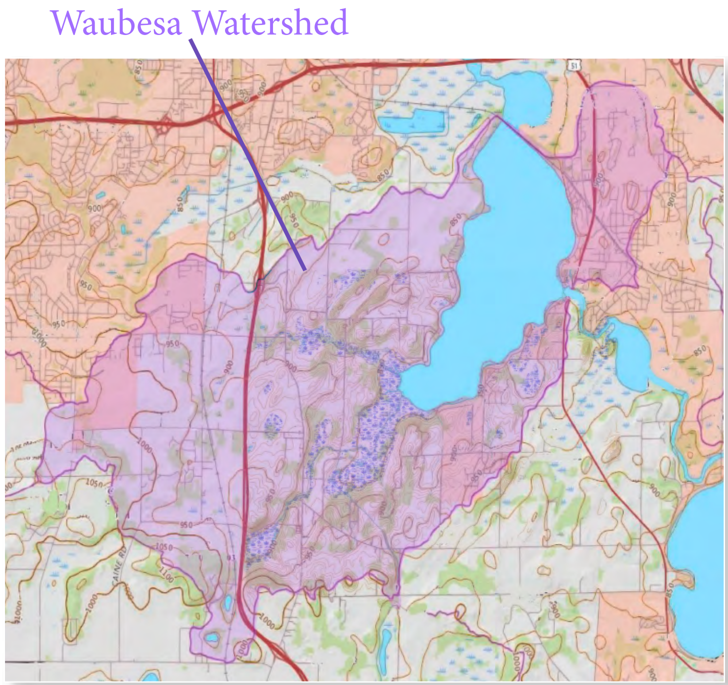
The U.S. signed the treaty and joined the Convention in 1986.

not on the list. That's understandable, because virtually all wetlands have bacteria that convert nitrates to nitrogen gas. Nor were migratory Sandhill cranes sufficient justification. But four biodiversity criteria seemed to apply, because Waubesa Wetlands (1) have rare natural community types; (2) support endangered species and threatened ecological communities; (3) support plants and animals that are important to maintaining biological diversity in the region; and (4) support animal species at a critical stage in their life cycle.

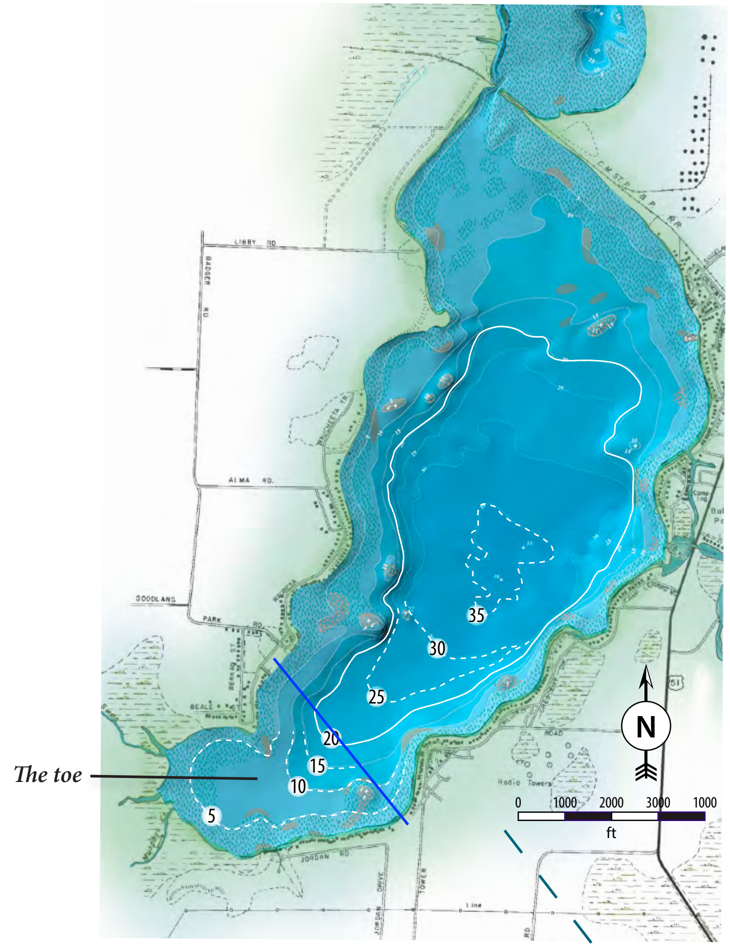
**Why is international recognition desirable?** Ramsar Sites are connected to a global network of wetland conservationists who share knowledge and ideas about management and restoration. International recognition can also attract funding for activities such as monitoring and restoration. In 2017, the world had 2,247 Ramsar Sites, of which only 38 were in the U.S. Recognizing this disparity, the U.S. Fish and Wildlife Service encourages nominations. Much of the evidence submitted to achieve Ramsar Site status is captured in this book

Southern end of Lake Waubesa.
*Photo: C. DeWitt and N. Olker*

*Photo: Nadia Olker*




Adapted from TNC (USGS hydrologic unit code [HUC] 12) https://water.usgs.gov/wsc/reg/07.html 07090001




The 20-foot depth contour signals the end of the 100-hectare parcel that we call "toe" of Lake Waubesa and the lower limit of a "Ramsar wetland." Waubesa wetlands are more familiar to Wisconsinites as wet land, rather than open water.

## Waubesa Wetlands

If you are a resident in the Town of Dunn, County of Dane, and State of Wisconsin, or if you are a nearby neighbor, or a visitor with an interest in nature, you should know that an extraordinary **natural wetland ecosystem** exists just down the road. Of course, if you're visiting by boat or canoe, you'll cross into the wetlands as you enter the toe of Lake Waubesa, which is part of the wetland, according to the Ramsar Convention.

**Are you confused yet? "Wetland" has many definitions.** Definitions are useful so people know they're talking about the same thing, and they are essential for drawing lines around them on maps, for governments to regulate and protect wetlands, and for the Ramsar Secretariat to judge nominations for wetlands of international importance. In general, wetlands are defined by what they are not—not uplands, not deep water. First called wet lands, the two words gradually merged but didn't become a "household word" until the 1970s. Then suddenly, everyone was reading about wetlands in the New York Times, as my graduate students and I learned by searching four prominent newspapers.

Wetlands became newsworthy for being abused as wastelands, which people and agencies began to see as a serious health problem. Where wetlands were no longer intact, water quality was impaired. Voila! Wastelands morphed into precious resources with protection under federal, state, and local laws (Zedler and Kercher 2005).

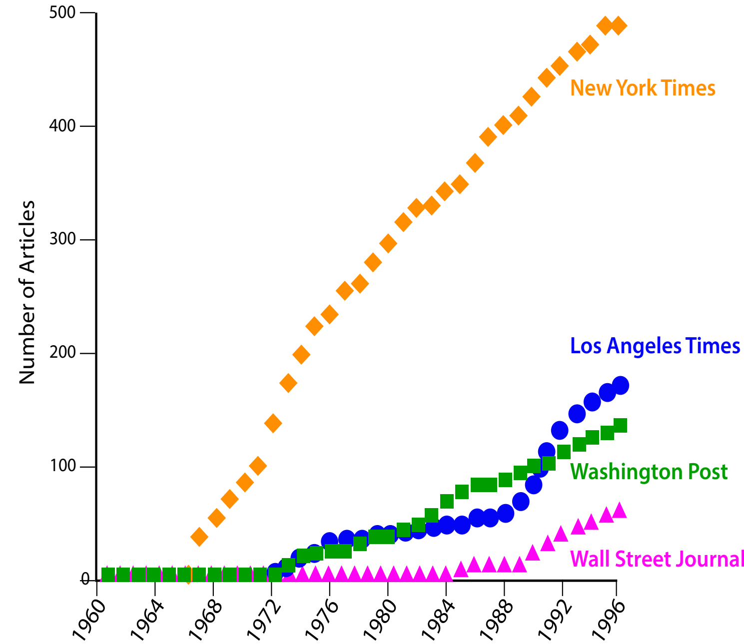
In the U.S., areas called wetlands have wetland **hydrology,** wetland **soil,** or wetland **vegetation.** At the wetter extreme, Ramsar Sites are wet places that are no more than 6 meters (~20 ft) deep. This depth exceeds that of the U.S. regulatory definition, which is so complicated it takes books to explain (e.g., Lewis 2001). One government book that I helped write (NRC 1995) focused on the **upper edge** of wetlands, because deeper waters are unquestionably "waters of the U.S." and the boundary between wetland and upland is often contested by opponents of environmental regulation. After lengthy deliberations by a national panel, the wetlands regulated under the U.S. Clean Water Act were limited to those with wetland hydrology, wetland soil, **and** wetland vegetation (all three characteristics). Meanwhile, the Fish and Wildlife Service maps wetlands as areas with wetland hydrology, wetland soil, or wetland vegetation. These three common definitions differ in inclusiveness, from broad to narrow:

Wetlands included under the international Ramsar Convention extend ~20 feet (6 meters) deep in a pond or lake. For Waubesa Wetlands, the 20-ft limit corresponds to Lake Waubesa's 'toe,' depicted as a line from Goodland Park to Heritage Park

U.S. Fish and Wildlife Service wetlands are shallow-water places that support either wetland hydrology, wetland soil, OR wetland vegetation (at least 1 of the 3).

U.S.'s regulated wetlands have wetland hydrology, wetland soil, AND wetland vegetation (all 3).

Additional books describe precisely how to delimit boundaries around areas with wetland hydrology, soil, and vegetation. Such boundaries can stand up in court if their status as Waters of the U.S. is challenged. In short, wetland definitions go well beyond "soggy places" and beyond "transitions" between uplands and deep water. Upon a closer look, they are **identifiable ecosystems** in their own right—not too dry, not too wet.

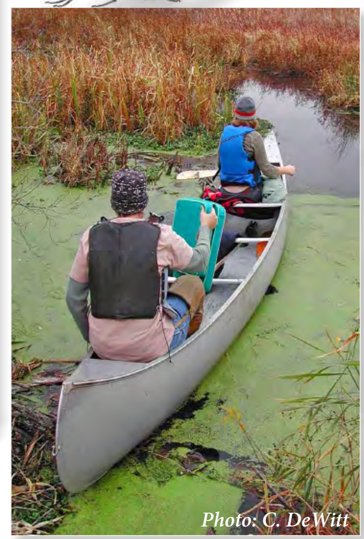



Number of articles about wetlands over time in 4 prominent newspapers.

*Adapted from Zedler et al. 1998*

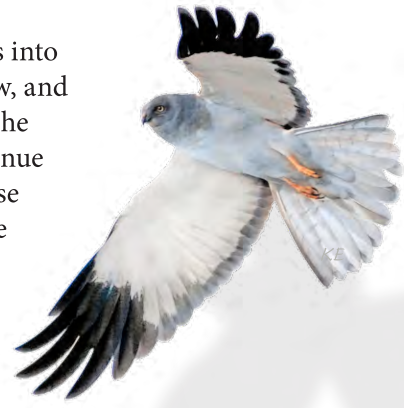
In Chapter 2, you can read about 8 aquatic and 11 wetland community types that occur in the Town of Dunn.

Waubesa wetlands are accessible from the land, e.g., on Lalor Road, or from the water by canoe into the lake's toe.



**Waubesa Wetlands are treasures,** with a magnificent Deep Spring, many smaller springs, and a diversity of wetland communities, fish nurseries, wildlife, and migratory birds, including Sandhill cranes. Waubesa Wetlands might be Dane County's best kept secret amid farms and rural homes. You can drive north or south on the 2.3-mile long Lalor Road—**Rustic Road #19** in the state's registry. At the top of a hill, you will see The Nature Conservancy sign and the vast wetland landscape. If you're on a bike, stop and appreciate the beauty and catch your breath by inhaling clean air. Just a few yards north on Lalor Road, you can park your car or bike in The Nature Conservancy's road-side lot and walk east along a row of scraggly "open-grown" oak trees. You'll pass a restored prairie on the right and eventually enter the wet woods where gaps in the vegetation offer sneak previews of the open, herbaceous wetlands to the east. There's no boardwalk in this wild place, but there is canoe access. For that, you'll need to visit Goodland Park, admire the effigy mounds, and use the boat ramp.



Back on Lalor Road, two creeks flow through culverts into the wetlands. Swan Creek is north of the hill with the view, and Murphy's Creek is south. Looking down as you intersect the culverts, you can usually see clear water. Feel free to continue breathing clean air, but don't drink from the creek, because **clear water is not the same as *clean* water.** Our creeks are monitored for their stream organisms, and the volunteers who take monthly water samples find few aquatic invertebrates—except for pollutant-tolerant species. And if pollution-sensitive invertebrates, like stoneflies and mayflies, can't live in the water, you certainly don't want to drink it!

While contaminants repel native aquatic species, and while the exotic Reed canary grass and Buckthorn continually invade the streambanks, the "signature attribute" of Waubesa Wetlands persists—**groundwater** comes to the surface from deep springs and seepages along both creeks and throughout the soggy wetlands that you viewed from the hilltop. Both Swan and Murphy's Creeks and the Sedge meadows and Fens remain wet all year because of abundant groundwater.

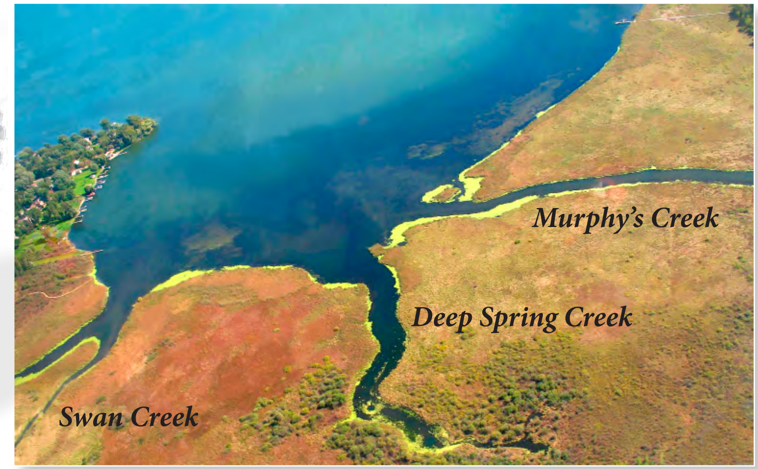



*Photo: C. DeWitt and N. Olker*

**Phenomenal groundwater:** A lot of Waubesa Wetlands' water comes from deep water-bearing rocks, which we call **aquifers.** The regional groundwater is under pressure, and it escapes to the surface all year long through springs and seepages. It has a constant temperature of ~54°F, and is not only clear and cool, but also clean. It's no wonder that Native Americans attributed spiritual aspects to springs in a landscape that is frozen in winter and hot in summer. Our springs release clean groundwater, which then becomes surface water that takes on qualities of its surroundings as it flows downstream. It becomes warmer or cooler, depending on air and ground temperatures; it becomes turbid as it picks up particles and microorganisms; and it becomes unclean (unfit to drink) when it receives contaminants and pathogens from its new environment. Clear, cool, clean water is a priceless resource.

Waubesa Wetlands are considered a **gem.** Officially, the site is one of 100 wetland gems given special recognition by the Wisconsin Wetlands Association (WWA 2010). Waubesa Wetlands are representative of the state's southeast geographic region.

Even though more than half the globe is covered by water, most of it is saline and undrinkable. Marine and estuarine organisms can handle seawater, but people and most inland species cannot.

Salt (NaCl) is not only toxic, it also dehydrates cells by drawing freshwater through permeable membranes. Adding salt to our streets and roads reduces vehicle accidents, but it also makes downstream water salty.

Only 2.5% of Earth's water is fresh, and much of that is either below ground or frozen in glaciers. Only 1.2% of Earth's freshwater is available for the biosphere.

Wisconsin lakes have increasing concentrations of chloride in watersheds having only 1% impervious surfaces, e.g., roads and rooftops (Dugan et al. 2017). So, in a world with minimal freshwater, we are inadvertently making it salty.

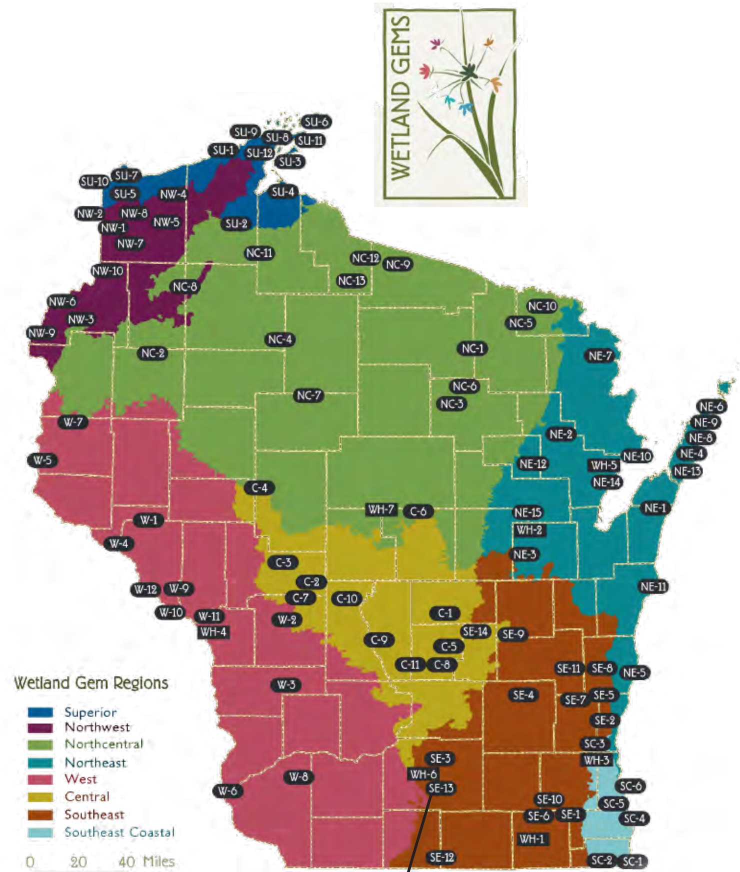
## New look at an old gem

**This book offers a broad perspective on Waubesa Wetlands in both time and space.** The chapters and stories about Waubesa Wetlands are intended to enhance appreciation for a wet place that **remains relatively intact.** You don't need to be a scientist, and there won't be a quiz at the end. Technical stuff is trapped in boxes so it doesn't spill across the page. **References** to published literature are confined to parentheses. For multiple authors, the convention is "et al.," meaning "and others." References are included so doubters can check facts, and curious readers can pursue interests that this book might spark.

**A repeated theme is the need to take care of our water.** There's not much freshwater available for our use, and it's a finite supply, so we'd better not take it for granted. Too many people turn on the faucet, use our potable water once, and throw it away. How long will Waubesa Wetlands remain a naturally functioning ecosystem if we keep pumping more groundwater to more sinks, showers, bathtubs, dishwashers, and toilets? There's a net loss of water **quantity** in our watershed, because after we send "used water" down the drain to Nine Springs Treatment Plant, the treated water is piped to Badfish Creek, and from there it flows to the Rock and Mississippi Rivers. Let's acknowledge that each of us has a responsibility not to waste water and to make sure that nature gets its fair share of clear, cool, clean water.

**This book is also about the landscape's history, our beautiful surroundings, the things we can't see, and our internationally migrating birds.** It describes the threats to Waubesa Wetlands and the need to manage our watersheds adaptively. I include what I learned about the Town of Dunn and Waubesa Wetlands while compiling data for the Ramsar nomination and while listening to fellow scientist Cal DeWitt. We agree that knowledge of natural resources should be more accessible to all who live here, and not sequestered in scientific journals. Our hope is that greater knowledge and understanding of this place will inspire greater appreciation for nature in general, and Waubesa Wetlands in particular.


**Waubesa Wetlands are gems.** Let's make sure nothing degrades their precious resources. A look back at the site's history should help you appreciate its present condition and values.




Waubesa Wetlands are "site SE13" on the Wisconsin Wetlands Association map of 100 statewide gems. In all, 93 sites represent high native biodiversity and 7 are working wetlands that provide critical functions. All are Wetland Gems.

# Chapter 1 • Looking back

Try to imagine this landscape as European immigrants found it in the mid 1800s—when it was being used by Native Americans who depended on clean air, clean water and plentiful fish and wildlife. Waubesa Wetlands had attracted Native Americans since the region emerged from under the last glacial lobe, which melted about 12,500 years ago. These early visitors didn't homestead the land; instead, archeological studies indicate mobile people who moved in, around, and beyond the wetlands in search of food and probably other people. Waubesa Wetlands did not support ***residents*** until Woodland Indians began to grow crops in recent millennia. And while crops quickly dominated the uplands of what is now the Town of Dunn, the deep springs and wetlands likely remain similar to what the first Europeans witnessed upon settling in 1843.


## The Ice Age

Before people came to south central Wisconsin—and before there were wetlands or a lake called Waubesa—the region was covered by a huge glacier called the Green Bay Lobe.

Imagine a 200-foot-thick block of ice covering much of eastern Wisconsin. The glacier had slowly grown and moved toward the southwest from the northeast. It wasn't pure frozen water, because it carried dust, rocks, debris and large boulders that would later be deposited near and in Waubesa Wetlands. We call the imported boulders "glacial erratics." Erratics remind us that the current land surface took form during the Wisconsin Glaciation, at its maximum about 15,000 years ago.

The ice didn't simply smooth the land surface and drop boulders, it also left behind drumlins and lakes and streams and ponds. Drumlins are long hills that formed under and near the glacier, in uncertain ways, but parallel to the ebb and flow of ice. Now that the globe is warming, the process of glacier melting and landform development is being studied in Iceland (McCracken et al. 2016).

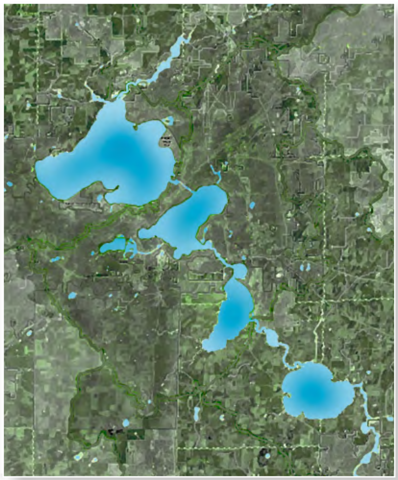
The Icelandic landscape below shows drumlins that are currently forming. Iceland has the only known active drumlin field, and it brings to mind Wisconsin's Yahara chain of lakes, which also formed adjacent to a glacier.

Large boulders in Waubesa Wetlands are "glacial erratics," deposited over 10,000 years ago.

***Photo: Joy Zedler***

Mulajokull glacier and active drumlin field that was covered by ice in 1995.

***Photo: Ivar Örn Benediktsson***

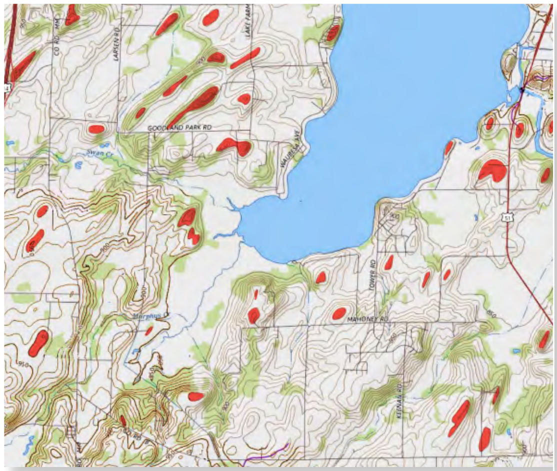


Yahara Chain of 4 Lakes.

***Adapted from Google maps***

A conceptual model that might apply to our terminal glacier edges that have experienced surges:

The active drumlin field in Iceland suggests how drumlins form. First, crevasses radiate out along the front of the glacier and form patchy surfaces. Then sediments accumulate beneath the crevasses to form humps, and erosion occurs adjacent to crevasses. By such hypothesized processes, bigger, elongated humps (drumlins) could form. As the glacier advances and retreats, drumlins get longer and the ratio of length:width increases as the glacier erodes the drumlin's sides and deposits new till in successive cycles (McCracken et al. 2016).



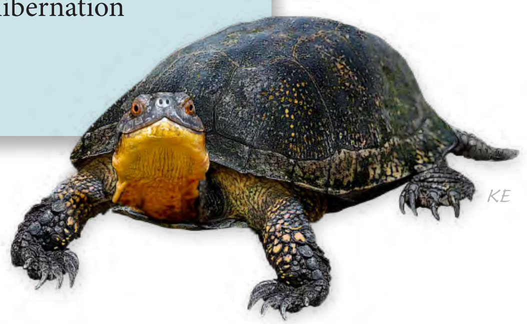
Drumlins (red ovals) within and near Waubesa Wetlands. ***Adapted from USGS map***

## Paleo-Indian view (~10,000 to ~6,000 BC)

Who were the first people to see the emerging Waubesa Wetlands? Imagine it is 12,000 years ago. The Green Bay lobe of the glacier is melting (increased thawing, decreased freezing), and what is now Dane County is being exposed. A Paleo-Indian walking along the edge of the glacier would find mounds of rocks and gravel (which we call moraines). Algae, mosses, and bacteria would have been quick to form mats (biofilms) that would trap dust and hold moisture. Wind-dispersed seeds would have germinated and produced tender seedlings. Might these shoots be edible? No doubt the first visitors tasted what this sumptuous buffet had on offer.

With the first plant foods in place, herbivores would not have been far behind. Ponds and lakes that formed from meltwater in depressions would have attracted insects to feed on the biofilms and pollen, while depositing eggs and producing larvae. A diversity of animals would have left droppings behind, providing nitrogen (N) and phosphorus (P) to the soil and aiding plant growth. Small mammals would have arrived as soon as their feet could carry them, or in the case of bats, as soon as they could find insects for food and caves for shelter. Reptiles and amphibians probably came more slowly, limited by cold temperatures and their inactivity during winter. Omnivores and carnivores would have attracted Paleo-Indian visitors. Like early people, large mammals would have visited the area alone or in herds as the plants grew and provided forage.

Just how long it would take for reptiles to colonize the edge of a glacier is debatable. The Nature Conservancy reports that Blanding's turtle can sometimes be seen swimming under lake ice in winter—taking a break from its underwater hibernation burrow (https://www.nature.org/).

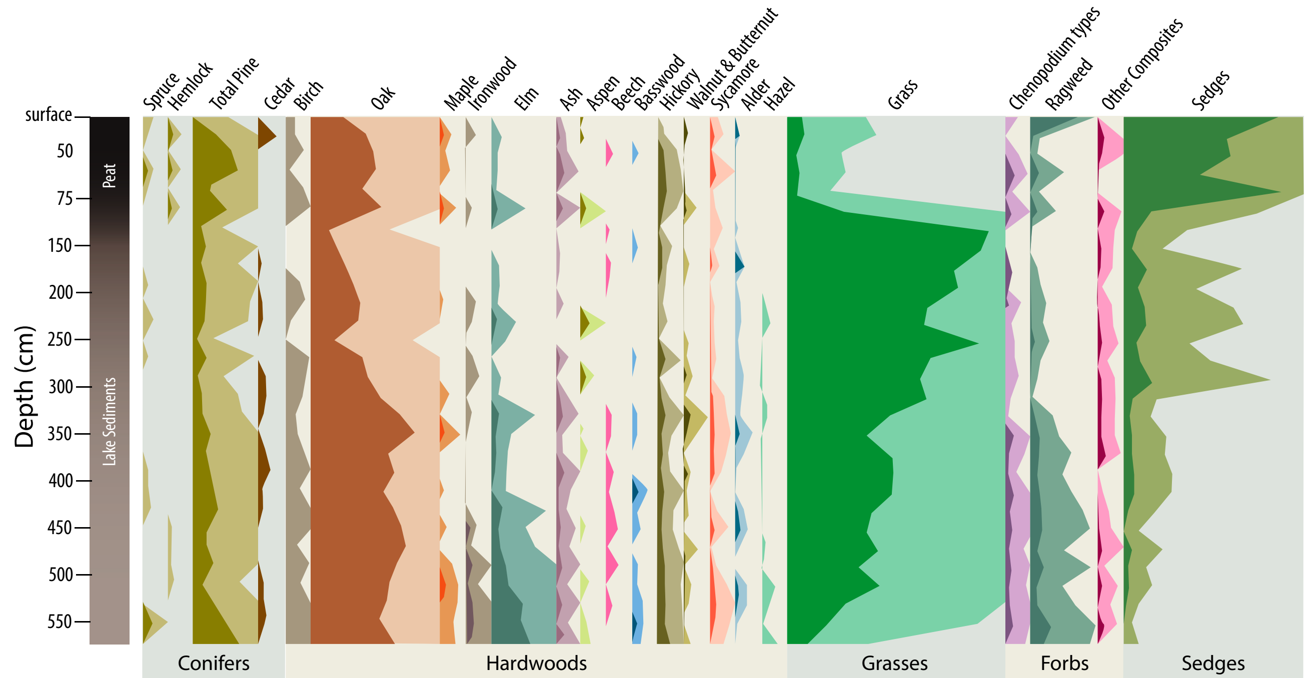



Soil formation has "feedback loops": As soil begins to form in cracks between rocks, the seeds of trees, herbaceous plants and grasses establish and expand, including some that spread by runners above the soil (e.g., strawberry stolons) or rhizomes below ground (many grasses and sedges, but also goldenrods and other flowering plants). The colonizers with deep roots and robust rhizomes exert pressure and accelerate cracking. Also, small cracks become big cracks as organic matter accumulates and traps water. When that water freezes, it forces cracks to expand. Larger cracks allow more plants to establish and perpetuate the process. Scientists call it a positive feedback when rooting leads to more rooting and cracking leads to greater cracking. With positive feedbacks, a linear (straight-line) process can become exponential. Over millennia, giant boulders break into smaller particles, which make up soil, i.e., sand, silt and clay.

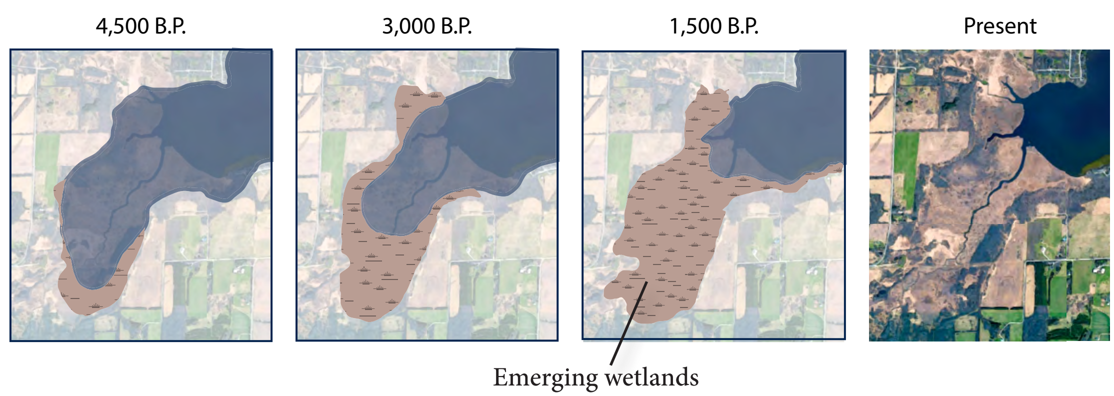
*Photo: Joy Zedler*

As the melting glacier continued to recede, tundra vegetation was replaced by spruce and fir trees, later yielding to deciduous trees, grasses, forbs and sedges. Waubesa Wetlands' vegetation shifts were verified by Robert Friedman, Cal DeWitt and Tim Kratz (1979). This team of scientists drove a sharp-edged cylinder ~19 feet (5.9 meters) deep into the peat (i.e., dead organic matter mostly from mosses, sedges) and extracted a peat core for other specialists (paleoecologists) to analyze at UW's Center for Climatic Research. Margaret Winkler and Al Swain counted at least 300 pollen grains from each of the layers plotted at right. As the researchers plotted the pollen in peat, a progression of vegetation emerged, with sedge-dominated wetlands at the surface.

Together with additional, deeper peat cores, Dr. DeWitt and his collaborators developed the following sequence: In Lake Waubesa's toe, a ~98 ft (30-meter) deep valley was gradually vegetated, from southwest to northeast, as plants produced large quantities of biomass. Continuously wet and anoxic conditions slowed decomposition, so dead leaves, stems and roots accumulated. Thus, peat accumulated under the cover of wetland vegetation. Over 6,500 years, wetland vegetation shifted the southwest extension of the lake to a wetland—*Voila!* Waubesa Wetlands emerged. And as the wetland crept across southwest Lake Waubesa, what looked like a droopy sock on the early map gradually filled in with sedges and peat to form a toe.




Comparative Pollen Percentages (darker color)
(Lighter color = % x 5 for visibility)



Friedman et al. (1979, p. 44) described it as follows: "From the time of the glacier's retreat from this region until 6,500 years ago, the present-day wetland was a bay in Lake Waubesa, receiving considerable lake sediment input. During this period, the deepest portion of the bay filled from a depth of 30 meters to about six or seven meters. Approximately 6,500 years ago, the shoreline slopes became gradual enough to allow the invasion of wetland vegetation along the edges of the bay. The newly established vegetation produced peat sediments, which as they accumulated, provided new habitat suitable for the spread of wetland vegetation. This vegetation, in turn, was the source of more organic sediments (peat), which in combination with the continued lake sedimentation, altered the configuration of the lake bay.

The wetland expanded primarily into the shallower areas of the basin, the southern and eastern edges of the lake bay. By approximately 3,000 years ago, the bay had shortened and narrowed considerably. The most rapid expansion of the wetland occurred during the period from 3,500 to 2,000 B.P. The shallow, isolated bay surrounded by an expanse of wetland provided optimum conditions for the continued formation. By 1,500 B.P. most of the present-day wetland had already formed. The wetland continued to expand, but at a slower rate as the edge approached the main body of the lake. The combination of the present morphometry of the lake basin, the circulation patterns within the lake, and the activities of man (artificial lake level manipulation, dredging, etc.) all serve to maintain the present extent of the wetland."

*Photo: C. DeWitt*


**Northern pike** ***(Esox lucius)***

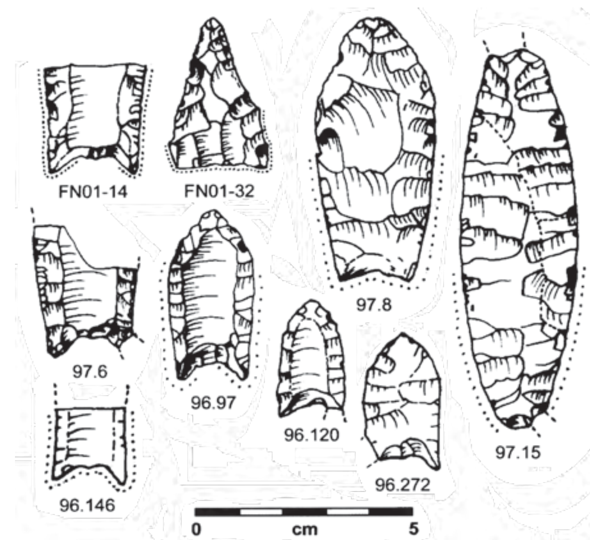
**People arrive.** Now imagine the climate warming, and you are among the first visitors to the "future Town of Dunn." Dr. Sissel Schroeder's (2007) anthropological and archeological studies tell us that Paleo-Indians gradually migrated toward the Lake Waubesa shoreline around 10,000 B.P., when the area supported spruce-fir forest, or possibly as early as 11,000–12,000 B.P., when the vegetation would have been tundra. Paleo-Indians were highly mobile, not looking to settle down or grow crops. They followed the fish and wildlife, hunting and scavenging food and fiber from streams, lakes, and wetlands. Open spaces where predators could be seen from afar were likely attractive to these early people. Paleo-Indians likely used spears to kill game, fibers of milkweed and other plants to weave nets to capture fish, leaves of cattails and bulrushes to fabricate canoes, and fresh green shoots of forbs to supplement their diets in spring. People began visiting Waubesa Wetlands as soon as it was possible—the area became an "aggregation site" for hunter-gatherers from the west and south and eastern regions as well. As we know from studies of Traditional Ecological Knowledge, early Americans valued the land and received value in return.

Much of what is known of Paleo-Indians at Waubesa Wetlands comes from the Skare archeological dig, which is just south of Lake Waubesa along the Yahara River. Dr. Schroeder studied this site and collections from 762 other Wisconsin sites (archived in the Office of the State Archeologist at the Wisconsin Historical Society). Overall they support her description of rapid colonization by Paleo-Indians—nomadic people who likely followed river valleys and set up camp along lakes, not necessarily hunting big game, as in the West, but capturing smaller mammals.

**What was the big attraction here?** Once again, imagine the Paleo-Indian, exploring the landscape and looking for food. Would you stumble over the tundra with its hummocks and unseen rocks, or would you attempt to hike through a dense forest with no view, tripping on fallen branches? Instead, how about walking along a moraine and climbing on top to gain a view or wading along a lakeshore marsh to search for nests filled with eggs? I suspect that Waubesa Wetlands attracted people then for many of the same reasons that it does now—an abundance of diverse habitats, wildlife and fish, as well as productive edges between uplands and wetlands.

In this "aggregation place," Paleo-Indians from other regions encountered one another. Imagine them trading goods, admiring each other's clothes and possessions, discovering new plants and animals, learning new uses for familiar species and objects, and using sign language to describe distant places. Because Dane County does not have high quality stone for spear points or the diversity of other tool forms found at the Skare site, the raw materials indicate that Paleo-Indians came to Waubesa Wetlands from distances greater than 125 miles (200 km; Schroeder 2007).

Traditional Ecological Knowledge *is a way of knowing that involves learning through experience. Over time, Native people likely learned to avoid overharvesting, weed out unwanted plants, and transplant desired species.*

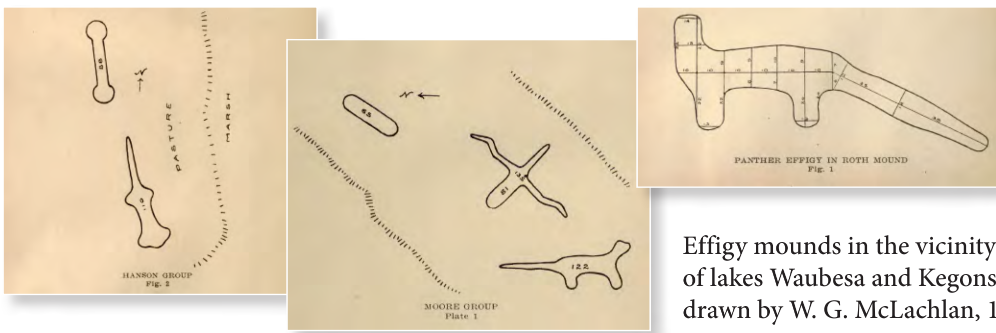



That diverse people gathered in and near Waubesa Wetlands is supported by archeological evidence from the Skare site. Few states have all three types of spear points that were unearthed here. Technically, these are "fluted bifaces," because they were either spear points or knives. In these drawings, 97.15 is possibly an Agate basin biface; 96.146 is a fluted Folsum biface (Schroeder 2007).

## Woodland Indian view

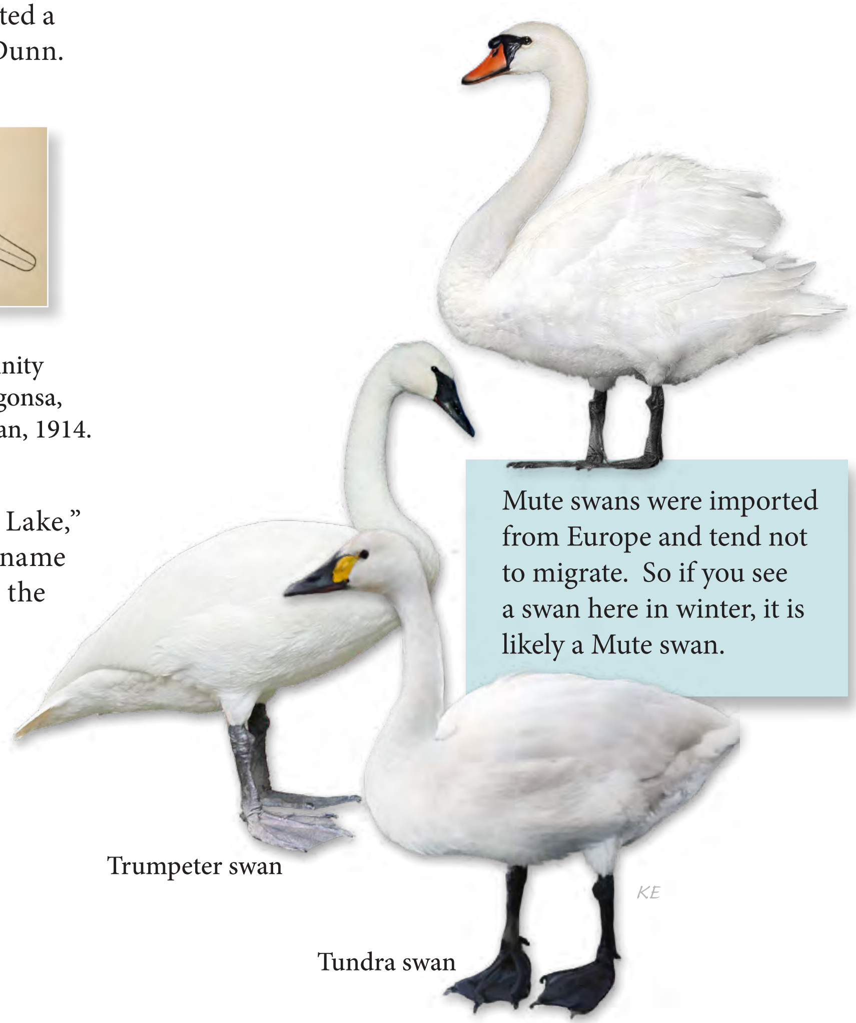
### (1,000 B.P.–1,100 A.D., after the Archaic period, 6,000-1,000 B.C.)

Over millennia, the people who gathered at Waubesa Wetlands and used its abundant, renewable resources gave way to competition from less nomadic Indians who established villages and began to grow corn. Their presence is evident from effigy mounds. Effigy Mound Culture was especially active in Wisconsin from ~300 B.P. to 1500 A.D. In 1914, W. G. McLachlan, an amateur anthropologist/archeologist, mapped and described 188 effigy mounds around Lake Waubesa, and an Indian agent noted a Ho-Chunk village that persisted until Euro-Americans dominated the Town of Dunn.




Effigy mounds in the vicinity of lakes Waubesa and Kegonsa, drawn by W. G. McLachlan, 1914.

**Naming the lake.** The Ho-Chunk called the lake Sahoochatela, or "Rushes Lake," but the name 'Waubesa' was attributed to an Ojibwe word meaning Swan. The name Waubesa was formalized in 1855 after Governor Leonard Farwell declared that the four Yahara lakes should have Indian names. Lyman Draper of the Wisconsin Historical Society found the Ojibwa name. Both Trumpeter swans and Tundra swans might have stopped over in Lake Waubesa en route to breeding sites in northwestern Wisconsin and the Arctic, respectively. Both are large native swans with 6-foot wingspreads.




Mute swans were imported from Europe and tend not to migrate. So if you see a swan here in winter, it is likely a Mute swan.

Trumpeter swan

Tundra swan

## Settlers' view

The first Europeans who settled in what is now the Town of Dunn also found a land of plenty—cheap land that was easily cleared for crops. Alvin Wetherby and his family established a farm in 1843 in Section 21 near the present Town Hall. Wheat was the crop of choice, and abundant harvests attracted other settlers from Europe. Five years later, in 1848, Wisconsin became a state, and our Town was established. A clerk misread the name "Dover" as "Dunn," which is how we became the Town of Dunn (Land Use Plan 1998).

Wheat was widely grown by settlers, until the Chinch bug *(Blissus leucopterus)* damaged crops. In 1870, farmers shifted to other crops, including tobacco. Later, agriculture became dominated by corn, soybeans, and cattle, especially milk cows. By the mid-1880s, immigrants from New England, Scotland and Ireland had settled the western part of the Town. Meanwhile, Norwegians chose the eastern side and founded nearby Stoughton. This town still celebrates its heritage with a festival on Syttende Mai (May 17), commemorating the 1814 signing of Norway's Constitution. Not to be outdone, McFarland, at the north edge of our Town, boasts a Norwegian-style Log House, a Museum, and more than 1,000 Norwegian artifacts.


In the early 1900s, rich farmland along the shore of Lake Waubesa was divided into lots for summer cottages. Later, most residents lived there year-round. Development did not include the shoreline wetlands around the toe of Lake Waubesa, however. This was wise, as the "ground" (vegetation floating over water and peat) would have been too unstable to support construction.

The landscape would be very different now if early settlers had drained and farmed Waubesa Wetlands. No doubt it would have taken substantial effort to drain a site that continuously oozes groundwater. But just as Dutch engineers diked The Netherlands seashores and converted marshes to farms, our predecessors could have found ways to drain and pump and convert wet land to arable fields. Why didn't that happen? I suspect there were many reasons, beginning with the extremely wet soil and peat. Since the flat landscape had no nearby place to siphon or pump water into, engineers would have needed to pump drainage water out of the region.

Farming was profitable and several landowners built fashionable houses in Greek revival and other styles. The State Historical Society's Architecture and History Inventory (AHI) lists 59 properties in the Town of Dunn (Comprehensive Plan A-36). More information on the Town of Dunn's cultural heritage is provided in its Bicentennial Tour booklet.

Waubesa lakeshore development today.
*Photo: Nadia Olker*

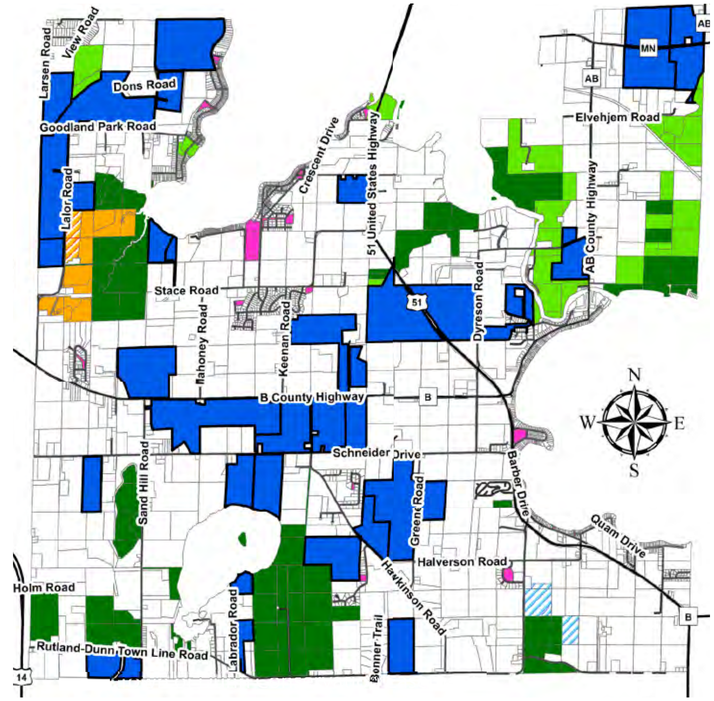

The "Greek Revival" design inspired several homes in the Town of Dunn.

## Town of Dunn view

Waubesa Wetlands' main plant communities include more than 700 acres of Fens, Sedge meadows, Shallow marsh, Deep marsh and Shrub carr, all of which lie on a deep bed of peat. Swan Creek is approximately 3 miles long and its **watershed** covers approximately 7 square miles, including some urban lands that discharge stormwater runoff. Murphy's Creek is south of Swan Creek and its roughly parallel **watershed** is approximately 5 square miles. Historically, the creeks had high-quality water, but monitoring data from culverts under Lalor Road reveal poor-quality water and a lack of pollution-sensitive invertebrates. Chapter 6 describes the importance of managing upstream watersheds to protect downstream waters and wetlands. Chapter 7 addresses solutions, including adaptive watershed management.

Over 1,000 acres of wetland and adjacent buffers have been set aside for conservation by the Wisconsin DNR, the Nature Conservancy of Wisconsin, Dane County, the Natural Heritage Land Trust, The Town of Dunn, and private landowners. The tradition began around 1974, when vegetation mappers noted that "Two landowners have donated a total of approximately 127 acres to the Department of Natural Resources ***for preservation"*** (emphasis added; Bedford et al. 1974, p. 497). Thanks to strong conservation leadership and willing citizens, such as the Bogholt family who donated the deep spring, the Town of Dunn has large areas of protected lands owned by many stakeholders. The public lands have grown in area and in ecosystem services, with most available for nature appreciation, study and teaching.

Protected Lands




Town of Dunn Land
Department of Natural Resources
Dane County
The Nature Conservancy
The Nature Conservancy Restrictions
U.S. Fish and Wildlife Service


Waubesa Wetlands showing the Bogholt Deep Spring, which forms a third creek in between Swan and Murphy Creeks.
*Photo: C. DeWitt and N. Olker*

Many small springs and seepages keep the wetland wet.
*Photo: Joy Zedler*

Waubesa Wetlands is a gem. Other wetlands in Dane County and Wisconsin are publicly owned or have conservation easements, but Waubesa Wetlands have the wholehearted support of the Town of Dunn—citizens who share a wetland ethic that puts Nature first. Today, about 5,000 people live in the Town, which is led by Town Chair Edmond P. Minihan. Dr. Minihan's efforts in wetland protection were preceded by those of Dr. Calvin DeWitt. This expert team continues to co-lead conservation efforts for the award-winning Town. Like trunks of mighty oaks, they and the Town Board sustain the Town's extraordinary conservation programs.

The Town Chair represents citizens who value its streams and wetlands because these natural resources:

- provide habitat and food for birds (esp. Sandhill cranes) and diverse wildlife,
- store surface and ground waters and release them slowly,
- serve as groundwater recharge and discharge areas,
- beautify an expansive and scenic landscape,
- provide a nursery for fish that anglers and Osprey catch in the adjacent lake, streams and river.

Town Chair Edmond P. Minihan

## Awards to the Town of Dunn

In 1995, the Town of Dunn won Renew America's annual National Award for Environmental Sustainability in the category "Growth Management / Regional Planning".

On Earth Day 2000, the Town of Dunn's Purchase of Development Rights (PDR) program was honored at the "best of the best" ceremony. Edmond P. Minihan, said, "this recognition of the Town of Dunn's PDR Program, the only one in the State, is important for farmland protection efforts throughout Wisconsin. For our township, the combination of our Land Use Plan and the PDR Program has helped to maintain farming as a viable economic activity, keep taxes low, and retain a rural quality of life. Our goal is to protect farmland, open space, and food resources for future generations."

In September 2001 Ed Minihan accepted a Grassroots Government Leadership Award from the National Association of Towns and Townships. This award (and $5,000 for the Town) recognizes one local government leader who has had a significant positive impact on the community. Ed's 24 years of service to the Town included maintaining responsible land use policies, initiating the innovative PDR program, developing parks, cutting costs by sharing equipment with other municipalities, defeating a proposed landfill near Lake Waubesa, and challenging a petition for another municipality to annex 400 acres. The Town of Dunn appeared in photos and maps viewed by hundreds of local government officials from across the U.S. during the award ceremony (from http://www.town.dunn.wi.us/land-use/awards/).

In April 2017, Ed Minihan was overwhelmingly re-elected Town Chair, with 96% of the vote.

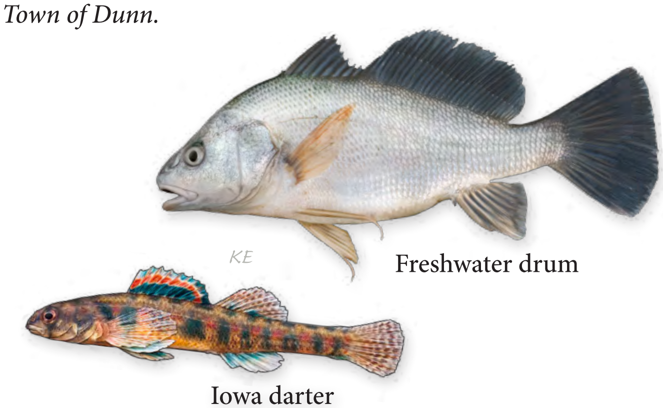
## Researchers' views

Scientists have been studying Waubesa Wetlands for over a century. What captures their attention? The attractions are much the same as what catches others' eyes and ears: Sandhill cranes' bugling calls, graceful flight, and courtship dances. Cal DeWitt admires the beautiful Iowa darter, *Etheostoma exile,* less than 3 inches long (~7.2 cm), seen below in its breeding splendor. He also likes the Freshwater drum, *Aplodinotus grunniens,* which grows to 3 feet (95 cm) long. Cal says this noisy fish repeats its regular drumming sound 11 times per second. Plants don't talk much, but they do stand still to be measured, which is one reason to encourage short-term student projects on fascinating plant structure and functions. Wetland scientists study plants and animals individually and wetland ecosystems holistically.

Scientists undertake research in Waubesa Wetlands to achieve a graduate degree and focus their career. For W. G. Lachlan, it was the abundance of effigy mounds that attracted his detailed anthropological inventory. For Cal DeWitt, it was a diverse place just waiting for interdisciplinary students to answer questions about ecosystem development through field studies. Rare fen vegetation, which depends on abundant groundwater outflows, attracted Quentin Carpenter to study the ecology of fens. Early studies led to more questions, which led to more research. For my students, it was the opportunity to compare vegetation with and without invaders and to test methods that might control them.

Studies of Waubesa Wetlands generated dozens of published research papers and graduate student degrees. DeWitt's graduate class at UW–Madison taught students the methods of scientific investigations, resulting in over 100 reports about Waubesa Wetlands. Students found jobs and careers in wetland and water conservation as a result of their interdisciplinary knowledge and diverse skills. Seeds from Waubesa Wetlands also made their way around the country. That is, Tussock sedge seeds were collected to grow thousands of plants for research in UW–Madison greenhouses (Prasser and Zedler 2010), and Arboretum experiments (Gallagher 2009, Lawrence and Zedler 2011), Arboretum adaptive restoration plantings (Doherty and Zedler 2015), and greenhouse tests at Texas Tech University (Waring 2017).

*Dr. Calvin DeWitt: ecosystem scientist, researcher, educator, conservationist, wetland advocate, long-term resident, architect of the Purchase of Development Rights program, and former Chair of the Town of Dunn.*



**Examples of work that spans a century of research, from 1914 to present**

As researchers learned about Waubesa Wetlands, their experiences and knowledge advanced science, policy, and management of wetlands internationally. Their many papers were distributed in diverse publications. Complete references appear in Chapter 9.

1914 • W. G. McLachlan mapped and described 188 effigy mounds around Lake Waubesa, published in The Wisconsin Archeologist.

1937 • A. W. Schorger tracked the range of bison in Dane County until ~1800; records show that bison were rare in the Town of Dunn.

1973–2003 • DeWitt taught Field Investigations in Wetland Ecology at U.W.–Madison. Over 100 graduate students conducted field projects, spoke at Waubesa Conferences on Wetlands (at U.W.–Madison), and went on to jobs and careers in wetlands and water.

1974 • Barbara Bedford, Libby Zimmerman, and Jim Zimmerman mapped and described the Waubesa Wetlands and published their vegetation map in The Wetlands of Dane County.

1975 • The Town of Dunn published its Open Space Handbook. Cal DeWitt became Town Chair after two years as a Town Board member.

1976 • The Town of Dunn marked USA's 200th Anniversary with Rural America Revisited and township-wide farms on display.

1979 • Robert Friedman, Calvin DeWitt, and Timothy Kratz simulated postglacial wetland formation and published a quantitative reconstruction of Waubesa Marsh.

1981 • Timothy Kratz, Marge Winkler and Calvin DeWitt described the peat mound's hydrology and chronology, published in the Transactions of the Wisconsin Academy of Sciences, Arts and Letters.

1981 • Calvin DeWitt documented "Waubesa Wetlands: A case study of wetlands preservation."

1995 • Quentin Carpenter completed his Ph.D. dissertation, Toward a New Definition of Calcareous Fen for Wisconsin, with Calvin DeWitt.

2004 • Chris Reyes completed her U.W. M.S. thesis, supervised by Paul Zedler, on the feasibility of using prescribed burning to control Reed canary grass.

2006 • Michelle Peach and Joy Zedler published their study of "How tussocks structure sedge meadow vegetation" in Wetlands.

2007 • Sissel Schroeder published evidence of Paleo-Indians in Waubesa Wetlands from excavations at the Skare Site.

2010 • Michael Healy and Joy Zedler reported limited herbicide effects on Reed canary grass as "Setbacks in replacing Phalaris arundinace monotypes in sedge meadow vegetation" in Restoration Ecology.

2013 • Susan K. Swanson published "Wisconsin's spring resources: An overview" in Geoscience Wisconsin. In her words, the work "aims to summarize their geologic and geomorphic context, the habitats that they create and support, their influence on Wisconsin culture over time, and the policies that affect their management and use."

2015 • Isabel Rojas and Joy Zedler reported that the invasive Reed canary grass reduced sedge meadow species richness by half in Wetlands Ecology and Management. Their Waubesa Wetlands site received nitrogen in runoff from an agricultural field.

2016 • Joy Zedler published her 11-year study on the phenology of *Carex stricta* (Tussock sedge) in Wetland Science & Practice. The site was a groundwater seepage next to a Waubesa Wetland headwater spring.

2016 • Cory McDonald and Richard Lathrop published "Seasonal shifts in the relative importance of local versus upstream sources of phosphorus to individual lakes in a chain" in Aquatic Sciences.

2017 • Upon receiving the 2016 Lifetime Achievement Award from the international Coastal & Estuarine Research Federation, Joy Zedler wrote the Odum essay on "What's new in the adaptive management and restoration of estuaries and coasts?"

**How do Waubesa Wetlands researchers form international links?** In part it happens when the science achieves global recognition. Earlier, I wrote about the peat mound and Winkler and Swain's pollen core, which represented 6,500 years of accumulated peat (recall the pollen diagram on page 4). That study was the first to document in detail how artesian springs can form a mound of peat by accumulating biomass from mosses and sedges. The research stimulated 30 years of UW class projects and studies with Professor DeWitt. The peat mound's artesian water source was documented using 37 hydrologic stations that allowed groundwater monitoring and education. The mound and surrounding wetlands are still an outdoor classroom for researchers in Wisconsin and around the world. All who work here learn about wetland ecosystems from first-hand experience and from published work. Links also form around the globe: e.g., when **international students** take their knowledge back to their home countries—India, Brazil, Indonesia, South Korea, Mexico, Chile, France, and China—and when **advice on wetland restoration** extends to Australia, South Korea, Japan, Iraq and South Africa (Appendix 1).

*Photo: Paula Lindig-Lara*

Restoration ecologist Roberto Lindig-Cisneros (PhD 2001) was recognized by the Nelson Institute as its 2016 Distinguished Alumnus. As a student, Lindig-Cisneros learned how Reed canary grass invades our wetlands. Now a professor at UNAM-Morelia, Michoacán, he addresses problems closer to Morelia, such as restoring springs used for drinking water and reforesting soils covered by volcanic ash. The Nelson Institute commended Lindig-Cisneros for conducting field experiments with indigenous people to advance restoration science and practice.

**Waubesa Wetlands is a Living Museum.** The existence of earlier research allows scientists to move forward because there are supportive data and ideas for new studies. Like the peat mound, invasive Cattails and Reed canary grass are better known than ever, thanks to research at Waubesa Wetlands. Once a place becomes a well-known research site, it creates opportunities, including studies of change. Ecosystems are dynamic, even those that are established as benchmarks. Some changes are natural, some are directly caused by humans, and some are the indirect result of a growing human population. As a "living museum" the historical record remains in existence for further fact-checking and discovery.

Place-based research at Waubesa Wetlands has produced data that catalyze new questions and allow scientists to evaluate long-term patterns. For scientists to capitalize further on this wealth of early information, including evidence from over 10,000 years ago (Schroeder 2007), Waubesa Wetlands should have a long-term, strategic monitoring program and an archive to store and locate data. One effort is underway, namely, annual citizen-based monitoring of stream water quality and invertebrates. Two sampling stations are where Swan and Murphy's creeks flow under Lalor Road. In another, much-less-frequent effort, vegetation that was mapped in 1974 is being resampled in 2017. Many more indicators need to be sampled systematically to track ecosystem condition and to characterize what wetlands do that benefits human well-being. As discussed in Chapter 7, the existing database should be extended in time and space and inclusive of more species and ecosystem services.

**Place-based Research**

In their book *The Ecology of Place,* Mary Price, Nick Waser, and others attribute many benefits to a strong place-based research program. Place-based research and models lead to:

- Enhanced understanding of the ecosystem under study.
- General understanding, hypotheses about larger systems interpretations of data from elsewhere, methods to approach problems, and new theories.
- Advances in ecological understanding and templates for research elsewhere

*(Billick and Price 2010)*

No other Wisconsin wetland has such a history of study. As a State Scientific Area, Waubesa Wetland's role is to serve as a benchmark. Without long-term data to learn how our wetlands are responding to changes upstream land use and climate, we won't know how to manage this proposed Ramsar Site, our ecological communities, or regional wetland resources.

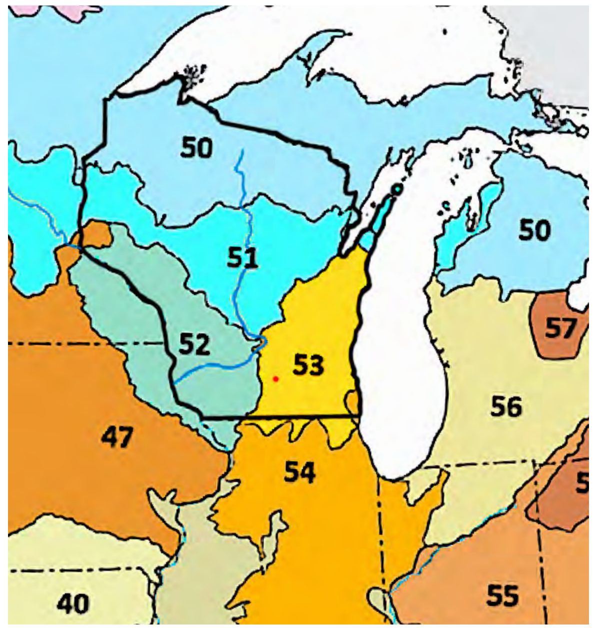
The wetlands and cranes, and all they represent, do more than support human well-being; they are our inspiration and icon. Note that the letterhead for the Town of Dunn (also the header for the town's Newsletter) features cranes flying over wetlands amid woodlands and farms, with the Wisconsin Capitol just five miles away.


# Chapter 2 • Looking Around

Waubesa Wetlands are highly valued remnants of the Wisconsin Till Plain Ecoregion. Our wetlands support biodiversity in four ways that echo the Ramsar Convention criteria for internationally important wetlands: They (A) have rare natural communities—8 aquatic and 11 wetland types; (B) support 9 endangered species and threatened ecological communities, specifically Calcareous fens and Southern sedge meadows; (C) support species that are important to maintaining biological diversity in an ecoregion that suffered heavy wetland loss; and (D) support critical reproductive stages of animals in a major nursery for fish and diverse nesting habitat for birds.

### Waubesa Wetlands' setting

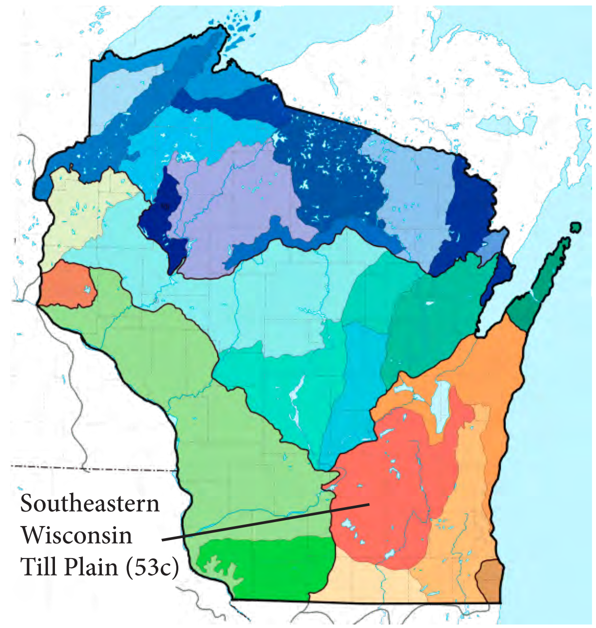
Biogeographers have divided North America into ecoregions, which are large areas with similar geology, physiography, climate, hydrology, soils, vegetation, wildlife, and land use. The Environmental Protection Agency (EPA) adopted a mapping scheme with 15 major (Level-1) types for our entire continent. Of these, Waubesa Wetlands fall within the Eastern Temperate Forest ecoregion, which is so broad that the name doesn't seem to describe our wetlands at all. But if we skip over the 50 Level-II subdivisions and jump to the 182 Level-III ecoregions, Waubesa Wetlands represents the **Southeastern Wisconsin Till Plains Ecoregion**. "Till Plains" are relatively flat places where glacial advances and retreats deposited rocks, gravel, and sand (collectively, till). South of us are the Western, Central, and Eastern Corn Belt ecoregions, where ~**85% of the wetland area was lost over a century ago**, mostly by being drained for agriculture. Reasons for the lower rate of loss in Wisconsin are discussed under item D, where I argue that Waubesa Wetlands warrant international recognition for regional support of biodiversity.




Level-III Ecoregions of the Upper Midwest

Waubesa Wetlands falls within Ecoregion 53, Southeastern Wisconsin Till Plains, and is flanked by Corn Belt Plains Ecoregions 47, 54, 55, except for the Driftless Area, 52.

*Adapted from https://en.wikipedia.org/wiki/List_of_ecoregions_in_the_United_States_(EPA)*




Level-IV Ecoregions in Wisconsin

*Adapted from EPA ecoregion map https://www.epa.gov/eco-research/ecoregion-download-files-state-region-5#pane-47*

By the 1980s, about half of Wisconsin's historical (1780s) wetland area had been drained, filled, destroyed, or damaged (Dahl 1990). In total, the state lost an estimated 46% of its historical 9,800,000 acres of wetlands—less up north and more in southern Wisconsin, where wetlands were drained for the same reasons as in the Corn Belt (Dahl 1990, Wisconsin DNR 1990). The remaining wetlands are often smaller than historically and far from pristine. As a result, many native wetland communities, plants and animals are now rare. But **Waubesa Wetlands** remain **relatively undisturbed,** large in area, and well connected from one habitat to another. Waubesa Wetlands were too wet to plow; they persisted because ample **groundwater** flows from numerous springs and seepages across the peaty wetland. The same force that built the wetlands—the subterranean aquifer—is still present. If people over exploit the groundwater, the wetland complex will shrink in area and in biodiversity. Surface water is also a concern. Please read on.

## Water circulation and Lake Waubesa's toe

From a boat, you might think the most important source of water for the toe of Lake Waubesa is the upstream lakes. However, the position of the Yahara River outlet tends to divert inflows from Lakes Mendota and Monona to Lake Waubesa's outflow, the Yahara River. The early exit of nutrient-rich waters from agricultural watersheds upstream (McDonald and Lathrop 2016) the first step in a "one-two punch" that repels nutrient-rich water from the toe. The second is abundant groundwater discharged by Waubesa Wetlands' springs into the toe of Lake Waubesa. The toe receives less eutrophic water from upstream lakes and abundant clean inflows from year-round coldwater springs. The **toe is cleaner, clearer, and cooler** than it would be without Waubesa Wetlands' large and numerous springs. The clear water makes it possible for the shallow toe to support submersed aquatic vegetation. The clearer the water, the deeper plants can grow in the lake bottom. With murky water, it's too dark down there! Pictures needed—SCUBA, anyone?

The cleaner the water, the more diverse the submersed and wet-meadow vegetation can be. With low-nutrient water, many plants grow at moderate rates. Contrast that with high nutrient conditions that allow a single weed to take over and displace its neighbors. Like people, when there are riches to squabble over, there is more squabbling, until there's one winner and many losers.

The combined wetland-upland **ecosystem** is necessary to support Waubesa Wetlands' extraordinary biodiversity. Over 500 acres of high quality Sedge meadow, Calcareous fen, Marsh and Shrub carr support diverse plants and provide habitat for Muskrat, Mink, Coyote, Beaver, Raccoon, Skunk, and Otter. Whitetail deer, Turkey, Woodchucks,

Aerial photos of Lake Waubesa's toe and wetlands seen from north (above) and south. *Photos by Nadia Olker*

Cottontail rabbits and other charismatic animals all co-exist in the larger ecosystem, which includes adjacent upland grasslands and woodlands. For example, Fox and Gray squirrels are common in woodlots, especially near cornfields. Many wetland animals forage in adjacent habitat or bed down where it's not so wet. Sandhill cranes nest in the Marsh and Sedge meadows and forage as omnivores in uplands, including recently-harvested fields. Frogs breed in shallow water but spend more of their time in uplands.

The presence of predatory birds indicates that prey are plentiful. Molted feathers and pellets indicate that owls reside here, even if we don't see many in the daytime. A huge Osprey nest on top of a power tower has been occupied for 5+ years, indicating habitat for fish-eating birds, including the endangered Black tern. Numerous waterfowl come and go with the seasons; ducks and geese and other waterbirds thrive. Native butterflies, dragonflies and damselflies, amphibians and reptiles are diverse. The Plains garter snake (*Thamnophis radix*) is a state species of concern, which DNR lists for Waubesa Wetlands.

Muskrats build marsh huts out of cattails

Black and yellow *Argiope*

*Photo: J. Zedler*

### Checklist online

This book complements plant and animal species lists and photos that appear online. The "iNaturalist.org" checklist for the Waubesa Watershed has photos of 212 plants, 13 mammals, 4 reptiles, 5 amphibians, 3 ray-finned fishes, 92 birds, 3 arachnids, 97 insects, and more. See: https://www.inaturalist.org/check_lists/447403-Lake-Waubesa-Watershed-Check-List. With such online resources already available, I decided to use this space to explain why biodiversity is of local to global importance. The first of four main reasons is that Waubesa Wetlands support 8 aquatic communities and 11 wetland communities—an amazing diversity of habitats, which in turn support high diversity of species.

Below, I explain why this biodiversity is of global importance. The first of four main reasons is that Waubesa Wetlands support 8 aquatic communities and 11 wetland communities—amazing diversity at the local scale. These communities in turn support high plant and animal diversity.

Sandhill cranes often forage in Cal Dewitt's lawn; grasshoppers for dessert?

*Photo: C. DeWitt*

## A. Waubesa Wetlands' internationally important rare natural communities

Glaciers left behind a varied landscape that now supports Dane County's greatest concentration of high-quality wetlands. Nothing matches Waubesa Wetlands' collection of 19 ecological communities: 8 in aquatic areas and 11 dominated by **wetland** vegetation. The toe of Lake Waubesa could be considered either aquatic or wetland, since Ramsar wetlands extend to 20 feet (6 m) in depth. Submerged and emergent aquatic vegetation covers the lake-bottom substrate. In deeper water, some plants send up stems with floating leaves—a very clever adaptation to deep water. These aquatic systems join creeks, streams, and ponds to comprise 8 aquatic communities. Each of Waubesa Wetlands' communities is recognizable by its plant species, canopy height, vegetation cover, plant form, and hydroperiod—but don't expect to see discrete boundaries. The ecosystems grade from one to another and sometimes defy strict classification. Discrete units are more of a convenience for mappers than a natural reality.

## Aquatic communities

When the water gets too deep for a field ecologist to survey a wetland on foot, we call the ecosystem **aquatic.** The Ramsar definition generously includes waters up to 20-feet deep in the definition of "wetland." Because deep water makes research difficult, the aquatic habitats of Waubesa Wetlands are not well known. We do know that clear water is critical for dabbling ducks and geese that look for prey among the submersed vegetation, and that shallow-water habitats are of great importance to the entire lake food web. Diving ducks, geese, and water birds need to see their prey, as do diving gulls, terns, and the Osprey that fly overhead. We know that the submersed and emergent plants create habitat for tiny invertebrates that in turn feed fish. Fish mature and spawn, and their offspring (fish larvae) forage in the "nursery." Because the clear groundwater is also cool (54° F ≈ 12° C), fish that are sensitive to warm water can thrive.

*Photo: C. DeWitt and N. Olker*

People often value aquatic habitats for more than pretty views and open space. Anglers, duck hunters, and trappers share the top-predator role in the food web, along with Osprey and Coyotes. Birdwatchers, paddlers, artists and photographers and students of nature all find treasures (nuggets of knowledge) in Waubesa Wetlands

Bogholt Deep Spring originates below the creek that its outflow forms. Its inverted 15-foot-diameter cone extends ~15 feet into peat. Purple bacteria coat the edges, and the alga Spirogyra forms a green ring at the surface. *Photo: C. DeWitt and N. Olker*

## The eight aquatic communities of Waubesa Wetlands are:

1 • **Springs** (Bogholt Deep Spring and 15 others were mapped in 1974). The springs are highlighted because of their overwhelming importance to the entire hydrological system!

2 • **Creeks and streams** (Swan and Murphy's Creeks, and small spring-fed creeks within sedge meadows and marshes)

3 • **Peat mound**

4 • **Spring ponds**

5 • **Littoral waters** at the interface of the wetland and lake

6 • **Submersed aquatic vegetation**

7 • **Great floating marsh mat**

8 • **Mudflats** (a seasonal habitat related to lake drawdown)

Blue water in the toe of Lake Waubesa near the marshes shown here at the top of the photo.
*Aerial photo: C. DeWitt*

## 1 • Springs

Springs are numerous and widely distributed in and around Waubesa Wetlands. One is very large (Bogholt Deep Spring) and 15 more are noted on the 1974 vegetation map (in Chapter 1). Many smaller springs and seepages are unmapped. Some are upstream in Murphy's and Swan Creeks; others are within the mapped wetlands. They are variable in their discharge, although flow rates are not monitored.

### Why are springs so important? Count the ways:

- They provide clean water that keeps the toe of Lake Waubesa clear. Springs seem to keep algal blooms at bay. Without major spring discharges, Lake Waubesa's toe would be hypereutrophic (extremely nutrient-rich).
- Groundwater with a constant temperature of ~54° F (12° C) has a moderating effect that is critical for fish that are heat sensitive in summer and cold sensitive in winter. Wisconsin's diverse sport fish include warmwater species (needing water over 22.6° C max daily temperature in July) and coolwater species (needing waters for spawning that do not exceed 17.0–20.7° C max daily temperature, June-July). Examples of warmwater fish are minnows (Cyprinidae), suckers (Catastomidae), catfish (Ictaluridae), sunfish (Centrarchidae), and darters (Percidae). An exemplary coolwater species is the Brown trout (*Salmo trutta*). We don't know how water temperature will change with urbanization upstream and a warmer climate with more stormwater runoff. Are current conditions near a "tipping point" (sudden shift toward a warmer toe)?
- Clean spring water that flows into the lakeshore marshes supports submersed vegetation, where Northern pike lay their eggs in the flooded vegetation, and fish larvae find a nursery full of food.
- Groundwater outflows keeps parts of the lake's toe unfrozen in winter, attracting Canada geese, ducks and other water birds that are slow to migrate in fall, or early to return in spring in spring. For example: "Several hundred **waterfowl** winter over on the big springs…in some years over 2000 duck" (Bedford et al. 1974).
- Shallow springs and seepages support aquatic species.
- The Bogholt Deep Spring's funnel cone supports purple bacteria and unknown co-existing micro-organisms. Research needed!
- The soil overlying peat is kept wet by low-nutrient groundwater. Low-nutrient (oligotrophic) soils resist invasion by weeds and favor fens and sedge meadows (see below).

Clean, clear water flowing toward the upper left in one of Waubesa Wetlands' small coldwater springs. Hundreds of Caddisfly larvae, scuds, stoneflies and mayflies are hiding under the rocks and among protective plants.

*Photos: J. Zedler.*

Caddisfly larvae in "turtle-shape" houses (flat next to the rock, domed on top.

## 2 • Creeks

Swan and Murphy's Creeks flow into Waubesa Wetlands from the upstream watershed. Many smaller spring-fed creeks occur, but are hard to see, under the wetland vegetation. Which species live in the streams of Waubesa Wetlands? Which species would live there if the creeks were pristine? Let's explore these questions in reverse order.

"Pristine streams." A study of 20 relatively undamaged streams in WI and MI (Rheaume et al. 1996) characterized the benthos (definition) as having all the major orders of aquatic invertebrates, 56 families, 151 genera and 217 species. Wow—the stream invertebrates are at least as diverse as the wetland vegetation. The three most well-represented orders were flies (Diptera, with 96 species), caddisflies (Trichoptera, 42 spp.) and mayflies (Ephemeroptera, 26 spp.). After exploring the similarity of streams and relating invertebrate composition to a range of environmental variables, Rheaume et al. found that the highest quality and most diverse benthic communities were found in cold, pristine headwater streams. The proportion of agricultural land use was not a major factor, but the degree of protection from agricultural runoff was critical.

Species in Swan and Murphy's Creeks. The Rock River Coalition (RRC) trains volunteers to sample both Swan and Murphy's creeks at Lalor Road, and to look specifically for benthic invertebrates—those that don't easily swim away when you try to capture them. The report card after several years of monitoring was "F" for both stream segments. Yes, that's **F as in Failing.** How did the samplers arrive at such a low grade? By finding a preponderance of the most pollution-tolerant species.

Benthic invertebrates (bottom-dwelling or living among logs and stones) have been shown to range in pollution tolerance from sensitive to tolerant.

- Those classified as **most sensitive to pollution** are the larvae of stoneflies, dobsonflies, alderflies, and Water snipe (a fly).
- **Semi-sensitive** species are larvae of caddisflies, dragonflies, water pennies, riffle beetles, crane flies, mayflies, and damselflies, as well as our native freshwater fingernail clams and crawfish.
- **Semi-tolerant** species are Black fly larvae (ouch; the adults are vicious biters), non-red midge larvae, amphipods (scuds), and a pond snail (*Lymnaea*, with its opening on the right side).
- **Most tolerant** are the Pouch snail (*Physa*, opening on the left), isopods (sowbugs), bloodworms (red midge larvae), leeches, and tubifex worms that make vertical tubes on the stream bottom.

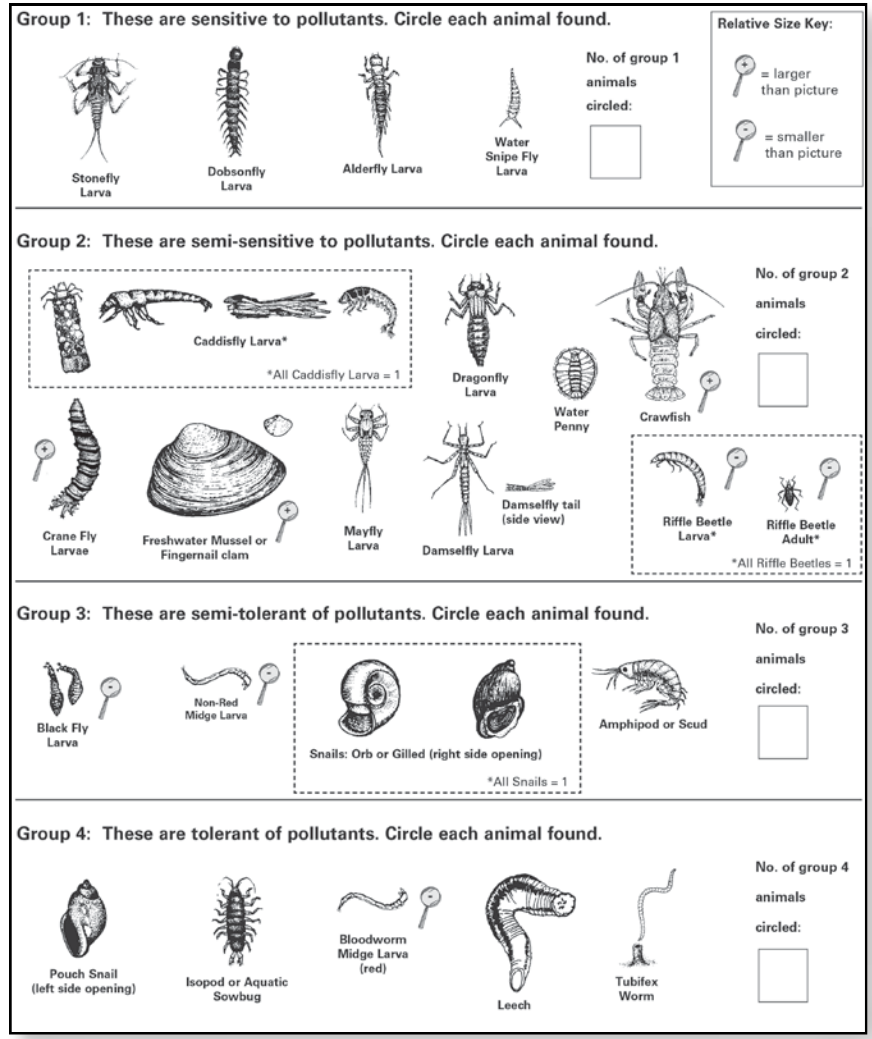
*Photos: J. Zedler*

A Tributary to Murphy's Creek.

Water flows from the bottom toward the top of these photos in a headwater spring in Waubesa Wetlands. Green plants are Watercress *(Nasturtium officinale),* which is naturalized in Wisconsin; here it overwintered below the water and was frozen wherever it poked its leaves above water. In summer, it expands vegetatively to cover most of this spring, and branches extend 1–2 feet above the water. This creek doesn't get an F because it has both stoneflies and mayflies.

RRC volunteers monitoring creek water quality.

*From: Nancy Sheehan*
*https://goo.gl/photos/ERMLacY2616bJACi9*



Group 1: These are sensitive to pollutants. Circle each animal found.

Stonefly Larva
Dobsonfly Larva
Alderfly Larva
Water Snipe Fly Larva

No. of group 1 animals circled:

Relative Size Key:
= larger than picture
= smaller than picture

Group 2: These are semi-sensitive to pollutants. Circle each animal found.

Caddisfly Larva*
*All Caddisfly Larva = 1
Dragonfly Larva
Water Penny
Crawfish
Crane Fly Larvae
Freshwater Mussel or Fingernail clam
Mayfly Larva
Damselfly Larva
Damselfly tail (side view)
Riffle Beetle Larva*
Riffle Beetle Adult*
*All Riffle Beetles = 1

No. of group 2 animals circled:

Group 3: These are semi-tolerant of pollutants. Circle each animal found.

Black Fly Larva
Non-Red Midge Larva
Snails: Orb or Gilled (right side opening)
*All Snails = 1
Amphipod or Scud

No. of group 3 animals circled:

Group 4: These are tolerant of pollutants. Circle each animal found.

Pouch Snail (left side opening)
Isopod or Aquatic Sowbug
Bloodworm Midge Larva (red)
Leech
Tubifex Worm

No. of group 4 animals circled:

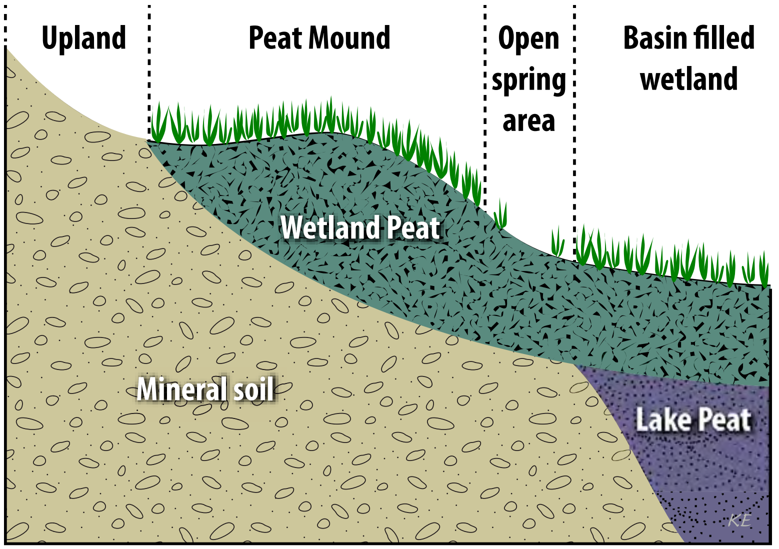
The data sheet that RRC volunteers use to score stream condition makes field identification easy.

## 3 • The Peat Mound

With a 6,770-year history, this 7.4-acre (3-ha) mound has several unique features, most notably that it did not form in a depression but instead is a **"hilltop wetland".** The hydrological phenomenon was described on the basis of 37 hydrologic stations, of which 35 documented an artesian source of water (Kratz et al. 1981). In other words, the peat formed in response to upwelling groundwater. The mound has a steep slope (2 m high x 40 m long), and there are no lake sediments under the peat mound. In contrast, the adjacent wetlands formed in a basin (depression) with underlying lake sediments (gyttja). The site is near the terminal moraine of the Wisconsin glaciation. Over millennia, 1–2 m of fibrous sedge peat accumulated to create the mound. Based on pollen analyses, the earliest deposition was over mineral soil with spruce pollen, about 6,770 years ago. Closer to the lake, charcoal layers indicate fires that likely sustained oak savannas.

The peat mound supports fen vegetation, which Quentin Carpenter sampled using ten 10-m² plots (Carpenter 1995). He recorded 29 species, which was fewer than in the nearby Calcareous fen, reflecting the peat mound's history of cultivation and a farmer's planting of reed canary grass (RCG) during a prolonged drought (DeWitt pers. comm.). Remarkably, as the drought receded, so did RCG, and fen species slowly regained dominance.

Among the criteria for a Ramsar Wetland of International Importance is the occurrence of a **refugium** for species during extreme conditions. The peat mound served as a refugium during the prolonged drought—while plants in the rest of the area were senescent, artesian water sustained fen vegetation and allowed fen species to recover.




Cross section of peat mound
*Redrafted from Friedman et al. (1979)*

## 4 • Spring Ponds

Waubesa Wetlands include Blanding's Pond, which was named for a turtle on the International Union for the Conservation of Nature's (IUCN) endangered list, recently removed from Wisconsin endangered status. These ponds support Blanding's turtles and Snapping turtles. Painted turtles (*Chrysemys picta*) also occur in the Town of Dunn, which is unusual for this part of the state. This is likely because Waubesa Wetlands provide ponds near woodland habitat, where the turtles can feed on berries, fruits, insect larvae, and earthworms.

Painted turtles *Photo: Joe Veltman*

**Blanding's turtle** requires wetland habitats, corridors, and terrestrial nesting sites. Foods include snails, insects, frogs, and crayfish. The turtle feeds mostly underwater, so its prey species are aquatic—like soup! A substantial portion of this rare turtle's population in Dane County might live in Waubesa Wetlands. In a 1975 census, one pond in Waubesa Wetlands hosted 38 Blanding's turtles. The Blanding's life cycle is a bit of a handicap in keeping it off the Threatened list, because it reproduces late in life: Females are not sexually mature until ~18 years old and males in ~12 years. Species that reproduce later in life produce fewer offspring. Consistent with delayed reproduction is a long lifespan; in this species, adults can live 70+ years. Blanding's turtles move among water bodies, so road mortality is high. Hatchlings have additional threats, such as predation by owls, raccoons, fox, and skunks.

**Odonata** (dragonflies and damselflies) are linked to ponds by their aquatic, carnivorous larvae. The adults are beautiful, with large eyes and straight, sometimes colorful, abdomens. Dragonflies rest with their wings horizontal, **so wait till they rest to identify them.** The first of four examples is the large, common Twelve-spotted skimmer (*Libellula pulchella*), which has 3 black spots on each of its 4 wings. They're easily seen flying over our wetlands and adjacent prairies. Wisconsin Wetlands Association says that "When not patrolling, the males land on conspicuous perches near open water and will often return to the same perch if flushed." Between July and mid-November, weather permitting, you might see the small Autumn meadowhawk (*Sympetrum vicinum*), a red dragonfly with yellowish legs and clear wings. It occurs near wetlands and woodlands. Kennedy's emerald (*Somatochlora kennedyi*) might occur near slow-flowing streams in our shrub carrs. Look for a dark chocolate brown body, and if you happen upon a mature male, its emerald-green eyes will explain its name. If you happen to see a Ringed boghaunter (*Williamsonia lintneri*) in our wetlands, please let me know, because they are not yet recorded for Waubesa Wetlands, although they were recently found in central Wisconsin fens.

Because damselflies rest with their wings folded vertically, they are hard to see when perched on a twig or stem of similar color. See if you can find the small Sedge sprite (*Nehalennia irene*) flying over our large sedge meadows. It's an emerald-green damselfly, and if it's a male, it will also have blue markings on the tip of its abdomen. (Also see https://wisconsinwetlands.org/updates/6-dragonflies-and-damselflies-to-know/)

**Blanding's turtle** (*Emydoidea blandingii*) was removed from Wisconsin's Threatened list on January 1, 2014. However, Blanding's turtle remains Endangered on the IUCN Red List (van Dijk and Rhodin 2013). While this turtle has "graduated" from the Threatened list, it is still a Protected Wild Animal in Wisconsin.

Blanding's turtles also hibernate in water—typically in lakes, streams or rivers greater than 3 ft (1m) deep, where they can avoid freezing under the winter ice. Turtles are inactive from late October or early November until early spring, nestled in organic ooze, with slowed metabolism and little need for oxygen… except when they wake up. They have actually been seen swimming (albeit slowly) underneath the ice in their wintering area. Just how a cold-blooded reptile remains active in near-freezing water is yet to be discovered.

Once the turtles are of age, breeding usually occurs in spring with nesting from May through early July, depending on temperature. With warmer temperatures, the young are mostly female; with cooler temperature, mostly male! The turtles nest on land, preferably in sandy soil, even if they have to travel ~1,000 ft (300 m) from a wetland or water body to find a suitable nest site. Once they have homesteaded, females appear to return annually to natal sites to lay eggs. Hatching occurs from early August through mid-October. Read more at http://dnr.wi.gov/files/pdf/pubs/er/er0683.pdf.


KE

**Odonata phenomena**: Can you imagine enormous ancestral Odonata that thrived before dinosaurs? Some fossil relatives had **huge wingspans** (30 inches = 75 cm). While dragonflies have been around for over 300 million years, sadly, none of these historical giants survived to thrill people. **Fossils are all that remain.** As I watch our typical modern species with 3-inch (~8-cm) wingspans zoom over the prairie, I can't picture how a dragonfly ten times as large would land and take off. Pilots of drones might care to speculate!


Here's a new dragonfly **discovery**: Female Sedge darners (*Aeshna juncea*) that are being pursued by an unwanted male can crash to the ground and play dead! The pursuing male flies off, and the female revives. It occurs when a female is ovipositing (laying eggs) or leaving its egg-laying sites. This rare insect behavior is called **"faking death to avoid male coercion."** Khalifa (2017) discovered this form of "conflict resolution" in Swiss Alp ponds. For details, read his field notes and illustrations in the journal, *Ecology*, cited in Chapter 9.


*Dragonfly photos: Dan Jackson*

## 5 • Littoral waters

Littoral zones occur at the wetland-lake edge, where Odonata reproduce and find larval nurseries. Common emergent plants are sedges and cattails. Much less common is the American lotus (*Nelumbo lutea*), which has an S3 ranking in Wisconsin, meaning its persistence is threatened. I did not find any Wisflora (Wisconsin State Herbarium) collections of this species from Lake Waubesa. Boaters, have you seen this upright plant among the floating-leaved water lilies along the shoreline?

Diverse littoral plants fuel the food web while also providing shallow-water hiding places for invertebrates and fish. Consider a habitat with a mix of growth forms: The duckweed (*Lemna* spp.) has leaves and roots that float. Some submersed aquatic plants are rooted; others are submersed but not rooted; still others are rooted and have floating leaves.


The green layer in this photo is not an algal bloom but duckweed.


Birdwatchers are attracted to littoral waters where the plant cover and foods attract large birds: Sandhill crane (*Grus* [aka *Antigone*] *canadensis*), Least bittern (*Ixobrychus exilis*), American bittern (*Botaurus lentiginosus*), Great blue heron (*Ardea herodias*), Green heron (*Butorides virescens*), Blue-winged teal (*Anas discors*), and Green-winged teal (*Anas acuta*)**,** as well as Black tern (*Chlidonias niger*) (WDNR fact sheet on SNA 114; see also Appendix 3).


***Macrophyte photos: C. Lipke***

## 6 • Submersed aquatic vegetation

A plant that lives underwater is part of the shallow, open water community that supports waterfowl, terns, furbearers, fish, frogs, turtles and aquatic invertebrates (Eggers and Reed 1997). Submersed plants are confined to the shallowest waters, because they require light, which diminishes exponentially in the water column. Where the water is eutrophic (nutrient-rich) and filled with algae, very little light penetrates to rooted submersed plants. No wonder so many aquatic plants produce leaves that float on the surface, e.g., water lilies and some pondweeds. They are stuck where they are rooted, so they need long stems or peduncles for their leaves to grow into a space with ample light.

At Waubesa Wetlands, the pondweeds (Pota*mogeton* spp.), Water milfoil (*Myriophyllum sibiricum*), and Coontail (*Ceratophyllum demersum*) are abundant submersed plants, but we lack details of other species and the extent of their distributions. Typically, species composition relates to water depth.

Unlike typical lakes, the toe of Lake Waubesa is not completely frozen in winter. This must increase plant productivity and the food supply for invertebrates and fish, because water without ice would transmit more light and increase photosynthesis to greater depths over much of the year.

If floating is an effective growth strategy, why aren't there more floating plants? Globally, there are notable floatables that have become nuisance species—so abundant that they clog waterways and disrupt boat motor blades. Water hyacinth (*Eichornia crassipes*, native to the Amazon) is such a creature; Water lettuce (*Pista stratiotes*) and Water ferns (*Salvinia* spp., *Azolla* spp.) are also pests where they occur outside their native environments. Floating invaders thrive in eutrophic waters, growing thick mats that clog waterways. They can become extremely invasive in the absence of native herbivores.

How do weeds and seeds travel abroad? If not able to float there on their own, they can hitchhike on a ship's bow; be sold and grown in horticultural gardens, then escape; or get dumped from an aquarium into a local stream.

## 7 • Great floating marsh mat

How do we know when a marsh is floating? Calvin DeWitt learned by experience, standing in a marsh and gradually realizing that he was sinking. Perhaps after a similar experience, Bedford et al. (1974) mapped a floating mat of bur reed (*Sparganium eurycarpum*) and cattail (*Typha latifolia*) in Waubesa Wetlands (see map in Chapter 3). Some people jump up and down to see if the mat reverberates, but this is unwise if the mat cannot support the jumper.

Floating mats are not connected to the lake sediments and are not limited by rooting depths, but they still tend to be restricted to near-shore locations, usually in response to prevailing winds that move plants and flotsam. Floating mats can be trapped in winter ice, whereas rooted plants can remain dormant in the benthos (bottom sediments).

## 8 • Mudflats

Along oceanic coastlines, shorebirds, such as plovers and sandpipers, are well supplied with intertidal mudflats during daily low tides, but they can't always find mudflats along lakes. Low water levels occur with **seiches** (wind-blown lowering of water on one side that piles up water on the leeward side), and when enough water evaporates from the lake, this exposes the unvegetated sediment. In the Yahara Lakes, mudflats appear when water levels are manually lowered to protect homeowners' docks and boats from winter ice.

When Lake Waubesa's water level is drawn down, the exposed, unvegetated substrates become mudflats. During winter, the mudflats at Waubesa Wetlands are kept from freezing over by 54° F spring-fed water. The exposed, non-frozen mudflats create an opportunity for late-departing migrating birds and overwintering geese to endure the cold weather. Mudflats also produce abundant benthic (bottom-dwelling) invertebrates, especially worms. If the flats are islands, the surrounding moat offers protection from water-shy predators. Or maybe birds simply rest on mudflats while digesting their prey and dumping guano. Geese seem to do so, as is evident from large droppings that are easily seen from a canoe. Guano in turn provides nutrients for biofilms that feed various invertebrates.

**What happens to the nitrogen in guano deposited on mudflats?** If not assimilated (taken up) by the mudflat bacteria, algae, and invertebrates, nitrogen (N) could be moved alongshore and inland when the lake level is elevated again in spring (see "redux" box). The mixing of N and phosphorus (P) by shallow waves could enrich the otherwise mesotrophic lake-marsh edge. A redux process could explain the expansion of Reed canary grass and Giant reed south from the mouth of Swan Creek to Murphy's Creek.

**Why would a mudflat remain bare for weeks at a time?** Patches of exposed ground tend to become vegetated unless they are too dry or too contaminated to support plants. Ice damage might explain bare mud in springtime. The key is timing—a mudflat that is exposed will be bare until plants establish, which won't take long. Brief exposure seems to be the key along the Lake Waubesa toe shoreline. But other factors can slow vegetation, e.g., grazing by geese. This system still harbors secrets. Perhaps investigators with drones will help us discover them.

Armed with the above knowledge, you can understand why mudflats and sandflats occur in the lower intertidal zones of the world's coasts, and why some lakeshores that experience seiches (windblown "tides") have bare substrates next to permanent water—and why those places attract so many shorebirds. The flats are home to dozens of species of worms and insect larvae and other invertebrates that eat the algae and bacteria. Mudflats offer shorebirds a buffet during long migration routes.

The Natural Heritage Inventory listed 11 rare communities at Waubesa Wetlands

*photo: C. DeWitt and N. Olker*

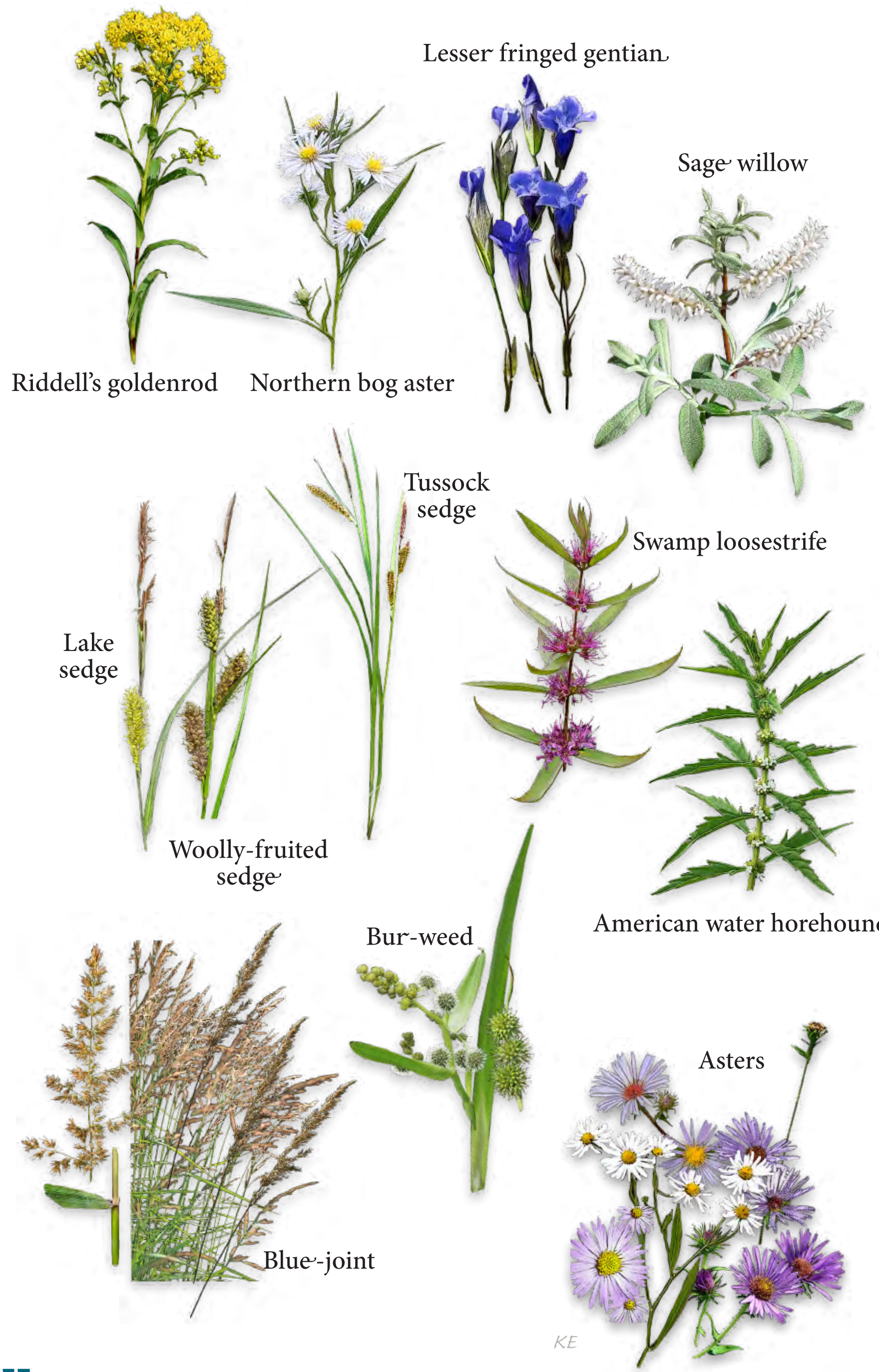
## Wetland communities

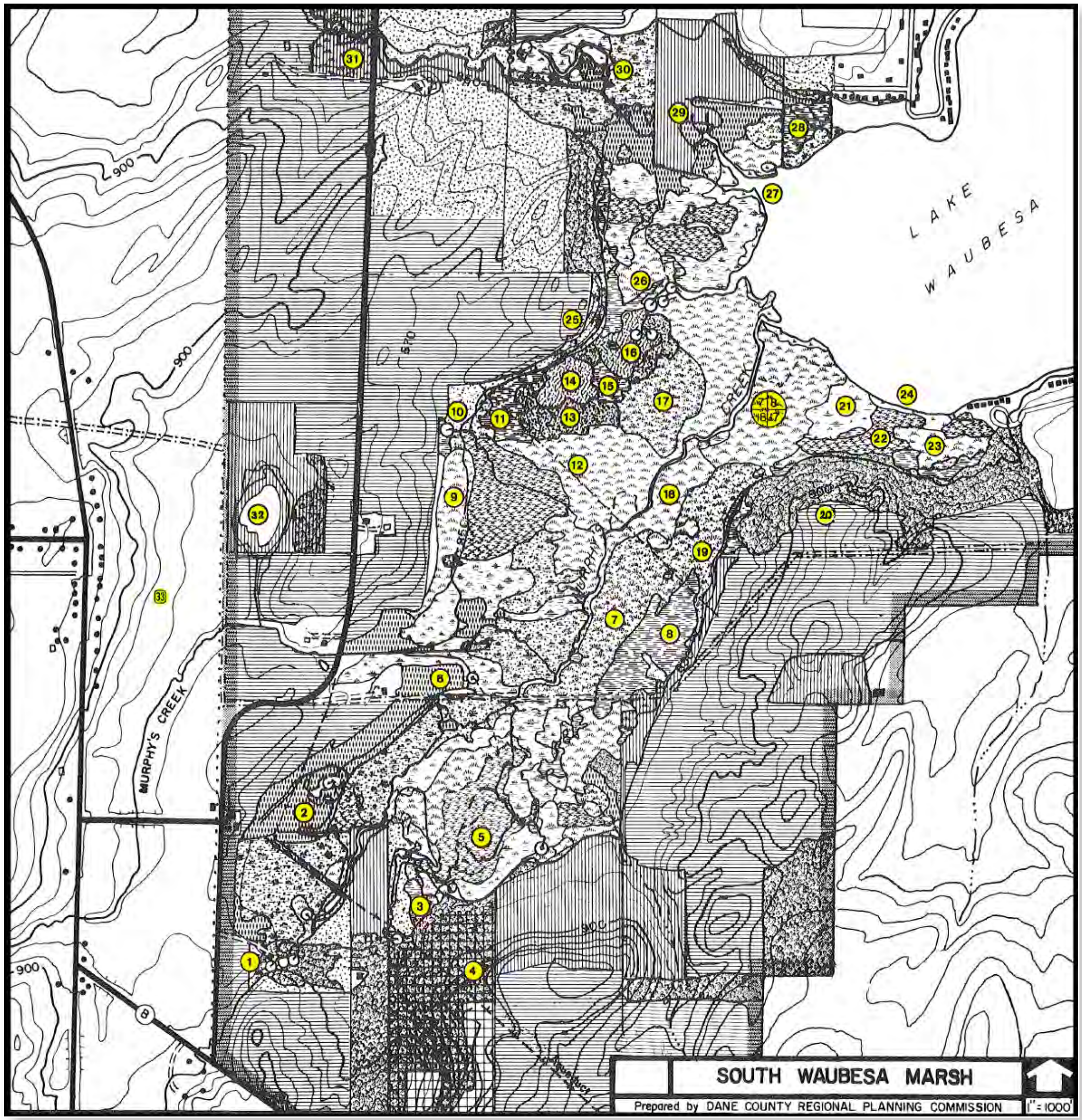
As explained in the preface, our U.S. wetland definitions are more restrictive than the Ramsar definition. U.S. restrictions are relatively recent, dating to agency decisions about which wetlands to protect under the Clean Water Act, as well as the need to standardize lines on maps (NRC 1995). Edges of wetlands are difficult to discern, because species distributions do not begin and end abruptly across environmental gradients.

Also confusing are community names. Ecologists name communities for their dominant native species, recognizing that many species occur in more than one community. The DNR lists the following species for Waubesa Wetlands State Natural Area without committing them to named communities: Riddell's goldenrod (*Solidago ridellii*), Northern bog aster (*Symphiotrichum boreale*), Lesser fringed gentian (*Gentianopsis virgata*), Sage willow (*Salix candida*), Common lake sedge (*Carex lacustris*), Tussock sedge (*Carex stricta*), American woolly-fruited sedge (*Carex pellita*), Common bur-reed (*Sparganium eurycarpum*), Swamp loosestrife (*Decodon verticillatus*), American water horehound (*Lycopus americanus*), Blue-joint grass (*Calamagrostis canadensis*), and numerous asters.

The Natural Heritage Inventory listed 11 rare communities at Waubesa Wetlands as: Lake (shallow, hard, drainage), Floating-leaved marsh, Emergent marsh, Springs and Spring runs, Streams (slow, hard, warm), Southern sedge meadow, Calcareous fen, Wet-mesic prairie, Southern Tamarack swamp, Shrub-carr, Southern dry-mesic forest. Of these, high-quality Fens and Sedge meadows are especially rare in the region but very well represented at Waubesa Wetlands. These names differ somewhat from those of DNR's wetland community list (http://dnr.wi.gov/topic/EndangeredResources/Communities.asp?mode=group&Type=Wetland), which distinguishes Submergent marsh, Oligotrophic marsh, Southern sedge meadow, Calcareous fen, Poor fen, Alder thicket, Shrub-carr, Wet prairie, Wet-mesic prairie, Southern hardwood swamp, and Southern Tamarack swamp.

Zoologists will note that animals are usually ignored in naming ecological communities. Ecologists focus on habitat, usually meaning vegetation, except for bare mudflats. Still, that doesn't make us consistent in naming plant communities.






Bedford et al. (1974) named and mapped the vegetation as listed at right.
See appendix 2 to read their field notes on species composition and other observations.

**Mapped plant communities and their areas (rounded to acre) in 1974.** Map includes 175 upland acres

| | |
|---|---|
| Sedge meadow/blue joint | 117 |
| Tussock sedge meadow | 103 |
| Wet prairie | 84 |
| [Disturbed wetland with Reed canary grass | 80] |
| Mixed wetland | 69 |
| Deep water sedge meadow | 56 |
| Shrub carr | 24 |
| Calcareous fen | 20 |
| Floating mat | 6 |
| Emergent marsh | 5 |

Springs: 16 mapped; total area estimated at less than an acre

Abbreviated Key

1 • Major spring area
2 • Spring area ponded since 1962
3 • Black willow and sandbar willow area
4 • Wooded area now under development
5 • Floating mat of bur reed
6 • Pond with large population of Blanding's turtles
7 • Sedge meadow with forbs
8 • Largest shrub area in the marsh
9 • Sedge-grass area
10 • Large spring
11 • Shrub area
12 • Sedge-grass area
13 • South edge of fen area.
14 • Fen.bog birch and lesser fringed gentian
15 • Red-osier dogwood
16 • Fen and spring.
17 • Sedge-grass area
18 • Sedge-grass
19 • Area of mud flow
20 • Area of proposed development.
21 • Possible floating mat
22 • *Carex lacustris* area
23 • Bluejoint grass
24 • Narrow-leaf cattail
25 • Steep grazed hillside
26 • *Carex lacustris, c. stricta,* bluejoint grass area.
27 • Muddy stream flow
28 • Shrubs invading *Carex stricta*
29 • Horse pasture, mostly reed canary grass.
30 • Spring and meander cut off by ditching.
31 • Grazed sedge meadow
32 • Small wetland area.
33 • Additional hillside buffer.

What was the predominant vegetation when mapped by Bedford et al. (1974)? Alex Wenthe measured the areas of each mapping unit and summed them by community type. His data show that the three Sedge meadow types dominate over half the total wetland area (276 of ~564 acres). Recall that the pollen diagram in Chapter 1 shows sedges beginning to dominate Waubesa Wetlands' peat mound about 1200 years ago (about 4 feet [1.2 m] deep in the peat core). Today, sedges are still significant components of Fens and Shrub carrs. In other words, Waubesa Wetlands were formed by sedge-based peat (see Chapter 1), and they remain dominated by sedges. The area data also show that the Calcareous fen is especially large at 20 acres. Most of Wisconsin's remaining fens are small areas around remnant springs.

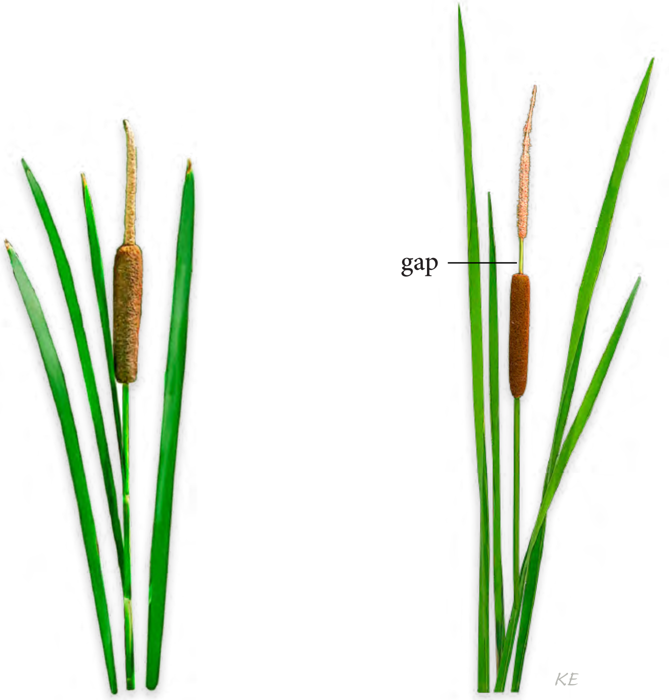
The most "disturbing" category on the 1974 map are the 80 acres of "disturbed" wetlands, which were largely—but not entirely—dominated by Reed canary grass (*Phalaris arundinacea*). This invader has earned its fame as "Wisconsin's worst wetland weed." With drone photography and aerial photo analysis, we'll be able to assess changes in disturbed vegetation in the future. An exception will be invasive cattails, which are difficult to distinguish from native cattails. Hybridization and back crossing, e.g., hybrid offspring crossing with either parent or with other hybrids, leads to mixed stands of plants (Marburger and Travis 2013). Cattails range from the wide-leaved native to the narrow-leaved alien, and flowering stalks can appear intermediate between parents, i.e., natives have no gap between male and female flowers while the alien has a wide gap.

Later, the community names used by Bedford et al. (1974) were standardized for the Natural Heritage Inventory list. If you are confused by too many names and lists, don't worry; they won't be on the quiz. What's important to know is that **Waubesa Wetlands support a high diversity of rare wetland community types that**, for the most part, are in **extremely good condition**, and that they support diverse species, many of which are **rare and restricted** in their regional distributions.

Sedge meadow

*Photo: J. Zedler*

Reed Canary grass stand




Native wide-leaf cattail
*Typha latifolia*

Introduced narrow-leaf cattail
*Typha augustifolia*

## Let's explore Waubesa Wetlands' rare communities a bit further

We know where various plant communities were in the 1970s, thanks to the detailed field work of Bedford et al. (1974), and we anticipate a DNR resurvey in 2018 to assess current distributions and measure changes over decades. Why should we appreciate these communities? In Chapter 3, you can learn about their many ecosystem services and how they facilitate human well-being. But first, let's see what grows in our local wetlands and why such vegetation is increasingly rare. Lacking agreement on community names, I've listed types in order of decreasing area on the 1974 map, they are 1. Sedge meadows (3 variations), 2. Wet prairie (probably also Wet-mesic prairie), 3. Mixed wetland, 4. Shrub-carr, 5. Calcareous fen and Poor fen, and 6. Emergent marsh (shallow and deep). Floating mat, Submergents, Springs, and Streams are Ramsar wetland types, treated here as aquatic communities.

### 1 • Sedge meadow

Our species-rich southern Sedge meadow is a state-threatened community that thrives on oligotrophic (nutrient poor) peat and soils (Amon et al. 2002, Green and Galatowitsch 2001, 2002). Forty years ago, Sedge meadows were already considered uncommon in the region, with the remaining acres "seriously degraded by grazing, drainage, and cultivation" (Bedford et al. 1974). In contrast, Waubesa Wetlands' Sedge meadows and Fens are still intact. They are benchmark representatives of native wetlands, with a rich flora indicative of natural areas. Low-nutrient groundwater is critical to sustaining native plants over aggressive invaders.

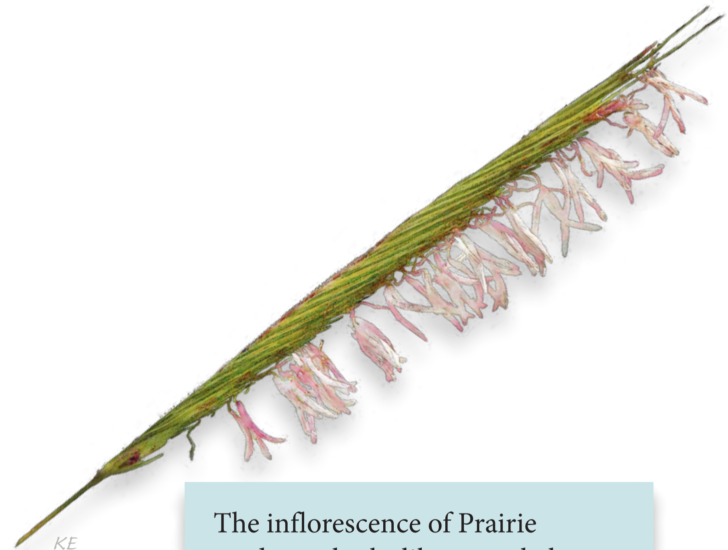
Waubesa Wetlands' Sedge meadows are rich in species. The iconic Tussock sedge, *Carex stricta*, is a dominant in many Sedge meadows, also occurring along some streams and alongside cattails, indicating tolerance of variable water levels. The list, besides Tussock sedge, includes Canada bluejoint (*Calamagrostis canadensis*), Lake sedge (*Carex lacustris*), Turk's cap lily (*Lilium superbum*), Water sedge (*C. aquatilis*), goldenrods (*Solidago* spp.), asters (e.g., *Symphyotrichum novae-angliae*), Great water dock (*Rumex orbiculatus*), Marsh milkweed (*Asclepias incarnata*), and Bottlebrush sedge (*C. hystericina*). The species that co-occur with Tussock sedge are highly variable, in part due to varied environmental conditions and in part related to the adjacent vegetation (Peach and Zedler 2006). No wonder Bedford et al. (1974) mapped multiple types of Sedge meadow.

Tussock sedges create miniature mountains (tussocks) about 1-2 feet high, described further in Chapter 3.

*Photos: J. Zedler*

### 2 • Wet and wet-mesic prairie

Where the hydroperiod is shorter than in Sedge meadows, and the water doesn't get as deep, sedge dominance yields to grasses. Most grasses aren't quite as tolerant of anaerobic soils as sedges. One indicator of a shift from sedge to grass dominance is canopy height; many grasses grow much taller than sedges. The height difference becomes most visible in August, when the grasses send up tall flowering stalks, often well over my head. Examples are Big bluestem (*Andropogon gerardi*), Indian grass (*Sorghastrum nutans*), and what I consider Wisconsin's most beautiful grass, Prairie cordgrass.(*Spartina pectinata*). The latter species is a good indicator—Where there's a lot of Prairie cordgrass, the community is a Wet or Wet-mesic prairie, not upland.




The inflorescence of Prairie cordgrass looks like a comb, hence the species name *"pectinata."*

Native wet prairies are very hard to find, because over 99% of their area in Minnesota, Wisconsin, and the Corn Belt Ecoregion was converted to crops. DNR wrote that "It was most abundant on level or gently rolling glacial moraine or outwash landforms where there were few natural barriers to wild fire, and where the upland vegetation was composed mostly of fire-dependent communities" (http://dnr.wi.gov/topic/EndangeredResources/Communities.asp?mode=detail&Code=CPHER076WI). Slightly-less-wet areas were quick to be plowed and replaced with familiar crops, which are also grasses: wheat and corn. What was good for native grasses was even better for cultivated ones, especially after adding fertilizers and herbicides.

Waubesa Wetlands have 84 acres of native Wet prairie, as mapped in 1974. It's uncertain whether two rare orchids are present; surveys are needed to locate the Western prairie fringed orchid (*Platanthera praeclara*) and the White lady-slilpper (*Cypripedium candidum*).


Mixed meadow in foreground; RCG invasion in middle (downstream from a culvert that drains a corn/bean field), Shrub carr near back, and Cottonwoods on high ground (raised soil over an aqueduct).

***Photo: J. Zedler***

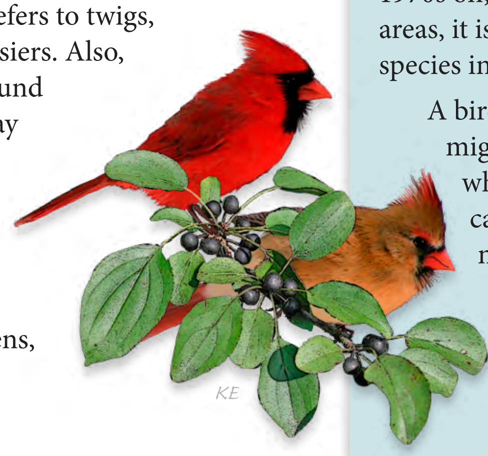
### 3 • Mixed shallow wetland

This is a catch-all category for sites with water that is easy to navigate wearing knee boots and for mixtures that a field ecologist can't easily classify into one type or another. In some cases, a single conspicuous species can be named, and in other places two or three plants might be dominant. I suspect this explains two terms used by Bedford et al. (1974), namely, "with giant reed" (*Phragmites australis*; a very tall grass) and "with forbs" (various plants with broad leaves; not grasses).

What's the "underlying cause" of mixtures? In general, wetlands experience hydrological **gradients**, rather than sharp changes over space. In response, the **vegetation changes gradually**, rather than forming abrupt boundaries. When there are sharp edges to a plant community, it usually signals either a "discontinuity" belowground, like a hidden rock shelf, or dominance by a clonal plant that is expanding vegetatively. Some people joke about needing to clone themselves; perhaps they envy the many plants that can do just that. Some clonal plants form a "virtual wall" of shoots that are tightly packed. This means that their rhizomes have growing points that are close together (short internodes). Examples are hybrid cattails, Reed canary grass, and the alien, invasive Giant reed. The native Giant reed has a cousin from Eurasia that is more aggressive, grows to 12 feet tall, and forms dense stands. Just as composition is mixed in most wetlands, so are canopy heights and conspicuous species.

### 4 • Shrub carrs (aka Lowland shrubs)

Carrs grow in slightly drier soil than fens and sedge meadows—dry enough for deciduous shrubs to establish and thrive. Willows (*Salix* spp.) and Red-osier dogwood (*Cornus stolonifera*) are common dominants. The name "osier" refers to twigs, which are used in basketry, and this species is valued for its red osiers. Also, stolonifera refers to vegetative propagation via stolons (belowground stems). Other woody plants in a Shrub carr include the native gray dogwood (*Cornus racemosa*), native *Spiraea alba*, and, all too often, alien buckthorns, *Rhamnus cathartica* and *R. frangula*. A wide range of understory forbs can occur in Sedge meadows and Shrub carrs, and in both cases, Reed canary grass becomes abundant with disturbance, especially nitrogen addition. Dense woody vegetation attracts nesting by Marsh wrens and Sedge wrens, Willow flycatchers, and Cardinals. Might Cardinals play a role in spreading shrubs about the region*?



*Cardinals (*Cardinalis cardinalis*) are newcomers to Wisconsin. In 1903, they occurred only along our border with Illinois (Robbins 1990). Just 60 years later, nearly every county in Wisconsin had recorded this "hard-to-miss" species. People who attract this beautiful bird to feeders year-round likely contribute to its expanding population. Yes, I'm guilty; sometimes I get to see the male feeding a seed to the female.

There are other causes for their northward movement, however, including warmer climate. My hypothesis about their rapid expansion is that they have been facilitated by the increasing abundance of berry-producing shrubs. About the time that cardinals were being seen often in Wisconsin, European buckthorn (*Rhamnus cathartica*) was being sold as cheap "fencing" hedge, because it rapidly forms a dense and thorny barrier after planting in rows. Next to pastures, it confines livestock and, along fields, it acts as a windbreak. Widespread planting of buckthorn until the 1930s led to invasions into native plant communities, especially Shrub carrs and Riparian woodlands. Aggressive invasions were increasingly noticed from the 1970s on, and Buckthorn is now a major pest. In wetter areas, it is accompanied by a more recent arrival of a species in the same genus (*Rhamnus frangula*).

A bird that likes both dense shrubs and berries might have set up a "positive feedback" in which more shrubs and berries attracted more cardinals, which ate more berries and dispersed more shrub seeds:

More Buckthorn ⟷ More Cardinals

## 5 • Calcareous fen

Two decades after the vegetation of Waubesa Wetlands was mapped by Bedford et al. (1974), Quentin Carpenter studied Wisconsin fens in detail and redefined Calcareous fens. He recognized species that were high in cover and restricted to fens, and he identified them as Calcareous-fen indicator species* (Carpenter 1995). Two sedges, *Carex sterilis* and *C. leptalea*, met these criteria, but not Tussock sedge (*C. stricta*) which was abundant but not restricted to fens. Waubesa Wetlands' unusually large (20-acre) Calcareous fen also has the lovely native Brome grass (*Bromus ciliatus*), asters, goldenrods and Sage willow (*Salix candida*). Carpenter called this a "Great Fen" for being a unique natural resource with high species diversity.


Brome grass

In 1974, Bedford et al. described other Dane County fens as "almost totally destroyed." What happened elsewhere that did not happen at Waubesa Wetlands? Near municipalities, groundwater pumping lowered the water table, dried up springs, and depleted artesian aquifers. Cathy Owen (1999) described the plight of the Monona Wetlands Conservancy (box, page 44), just north of Waubesa Wetlands. There, groundwater was depleted and urbanization increased surface water runoff into the conservancy by 20-fold. Owen documented large-scale changes in vegetation, with increased dominance by Reed canary grass and aggressive cattails, and decreased abundance of native plant species.

In contrast, Waubesa Wetlands' Calcareous fen remains rich in species. Of 33 calcareous-fen-indicator species for the region, 17 species were found in our fen (see box on right). A large number of indicators in a single ~30-acre site is ample evidence of diverse vegetation. Even though Carpenter's sample was small (10 plots @10 m²; less than 1% of the fen's area), he recorded 67 species. A larger sample would likely produce a longer species list. Indeed, Carpenter reported a total of 144 species from 54 fens across Wisconsin. More species are typically found across larger areas, especially if broader sampling includes more variations in hydroperiod and soil chemistry. The richness of Waubesa Wetlands' Calcareous fen is not fully documented.

**Indicator species.** Carpenter (1995) listed 144 plant species in 54 Wisconsin fens, confirming the diversity of this plant community, which is restricted to groundwater outflows—typically confined to small areas. The species included 8 members of the daisy family (Asteraceae), 6 sedges (Cyperaceae), 6 grasses (Poaceae), 3 from the rose family (Rosaceae), and 2 dogwoods (Cornaceae). Sedges were important in fens but were not as dominant as in sedge meadows. Carpenter then developed 33 fen indicators based on the species' importance (percent cover) and fidelity to fens (found primarily in fens but not in other wetland types). He rated importance and fidelity as high (H), moderate (M) or low (L). So, for a species with both high importance and high fidelity, its rating was HH. For a species with H importance and M fidelity, its rating was HM, etc. Here are his 33 indicators and ratings, with * denoting the 17 he recorded in Waubesa Wetlands fens: *Aster junciformis* HH, **Betula pumila* HM, **Bromus ciliatus* HM, **Campylium stellatum* HH, *Carex leptalea* HM, **Carex sterilis* HH, **Cladium mariscoides* HH, *Eleocharis rostellata* LH, **Epilobium leptophyllum* LH, *Eriophorum angustifolium* LH, **Gentiana procera* HH, *Hypericum kalmianum* LH, *Juncus brachycephalus* LH, *Lobelia kalmia* HH, **Lysimachia quadriflora* HM, **Muhlenbergia glomerata* HM, **Oxypolis rigidior* HM, **Panicum flexile* LH, **Parnassia glauca* HH, *Potentilla fruticosa* HH, *Rhynchospora capillacea* LH, *Sarracenia purpurea* LH, *Scirpus caespitosus* LH, *Scleria verticellata* LH, *Selaginella apoda* LH, *Solidago ohioensis* HH, **Solidago riddellii* HM, **Solidago uliginosa* HH, *Tofieldia glutinosa* LH, **Triglochin maritima* LH, *Triglochin palustre* LH, *Valeriana edulis* HM, **Viola nephrophylla* HM. Our fens are diverse in species and fen indicators!

## 6 • Emergent marshes: deep- and shallow-water.

"Emergent" refers to marsh plants that poke their leaves above the water along the shore of Lake Waubesa. Cattails are probably the most widely recognized emergent wetland plants, owing to their use in wetland logos, tee-shirts, letterheads, artwork, and jewelry. When I entered "cattail image" in a Google search, I obtained 5,480,000 results in 0.67 seconds. What makes cattail marshes so popular? I suspect it is their widespread, global occurrence, tall stature, and recognizable "tail," as illustrated earlier. The male flowers break off, and the female flowers mature into the dark-brown tail. When ready to disperse, the "fluff" (millions of tiny seeds with "parachutes") float with the wind to new wet places. This helps explain why cattails are so widespread.

Cattail leaves emerge from energy-packed rhizomes (starchy stems below ground) that grow in soil under standing water. The air-filled leaf shoots are perfect structures for growing tall and skinny (minimal biomass for stem bases to support). Just break off part of a long leaf, and you can see the air chambers in cross-section, separated by "I-beams" that hold the leaf together. The skinny, air-filled leaves are not only a "cheap" way to grow fast; they also allow oxygen to diffuse quickly from leaves to rhizomes and roots.

Other emergent plants have a similar structure (tall, narrow leaves with lots of air tissue, called aerenchyma), so they might be missed among the cattails. Bur reed (*Sparganium eurycarpum*) is an example.

Giant reed (*Phragmites australis*) is hard to ignore, however, as it overtops all others with its tall, air-filled stems—the same buoyant stems that led early people and modern marsh dwellers (Alwash 2013) to build boats of grass!


*Photo: J. Zedler*

**Monona Wetland Conservancy**

"There is also evidence to indicate that groundwater flow into the wetland has been diverted as a result of groundwater pumping in municipal wells next to the wetland. Driller's logs from 1947 (Wisconsin Geologic and Natural History Survey 1947) showed that groundwater flowed upward, occasionally in artesian flow, into the areas around the wetland; however, recent hydrologic studies in the wetland (Wisconsin Dept. of Transportation (WDOT), 1978; Owen 1995) showed that, in some parts of the wetland, there are weak downward gradients, or recharge, from the wetland to the clay below. Two high-capacity municipal wells were drilled within 0.5 mile of the wetland in the mid-1960's. Computer simulation models showed a 23 m drawdown in the sandstone aquifer and a 3–6 m drawdown in the surface water table resulting from groundwater pumping (McLeod, 1978). Current maps of the aquifers do confirm the existence of this cone of depression. Groundwater represented 2% and 1% of the total inputs and 3% and 5% of the total outputs in 1990 and 1991 (Owen, 1995)."

*(Owen 1999)*
*See Owen's maps in Chapter 6*

Other companions of tall dominant plants are understory forbs—broad-leaved plants that tolerate some shade. Towards the deeper end of the marsh, floating aquatic plants become visible. Examples are water lilies (e.g., *Nymphaea odorata*), which root in the soil but send their leaves to the water surface via a long petiole that floats upward, thanks to aerenchyma. Also abundant on the lakeshore are floating Duckweeds (*Lemna* spp.). En masse, they might look like a mat of floating algae, but a closer look will reveal individual plants with leaves, plus roots so tiny you might need a hand lens to see them.

Where excess nutrients flow into emergent marshes and other disturbances allow weeds to establish, the native vegetation yields to more productive plants, often non-native invaders. Native, broad-leaved cattails (*Typha latifolia*) often hybridize with invasive, narrow-leaved cattail (*T. angustifolia*) resulting in a vigorous hybrid (*T. x glauca*). Hybrid plants are often more vigorous than either of their parents, and it is certainly true for our cattails. Where it has been studied, the hybrid grows taller and in deeper water, thereby covering more area and outcompeting natives. It's not clear how much of our lakeshore marshes are native, alien or hybrid cattails. It is likely, however, that invasive cattails are reducing the diversity of native species in our Emergent marshes, just as invasive Reed canary grass is reducing native species in our Sedge meadows (Rojas and Zedler 2015). We're not likely to eradicate such widespread invaders, but we can minimize their spread by tackling the cause: Excess nutrients carried in runoff to Swan and Murphy's creeks and other inflows to Lake Waubesa. Both N and P can stimulate cattail invasions.

Shrub carr *Photo: J. Zedler*

### 7 • Other rare communities

Rare communities include Floating-leaved marsh, Springs and Streams (considered aquatic communities, above), two kinds of swamps (Southern hardwood and Southern tamarack swamps), and Southern dry-mesic forest. To an ecologist, a swamp is a wetland with trees. Bedford et al. (1974) mentioned patches of willows (*Salix* spp.) but did not map any areas as “Alder thicket” or “Swamp.” Acidic wetlands, some with Tamarack (*Larix laricina*) trees*, are rare in southern Wisconsin, and remnants are declining in quality. In neutral-pH (non-acidic), fertile wet places, hardwood trees can dominate.

At Waubesa Wetlands, the nearby savannas and woodlands are important nesting and foraging sites for wetland birds and wildlife. Southern dry-mesic forest occurs on adjacent high ground, including drumlins, with Red oak (*Quercus rubra*) and Red maple (*Acer rubrum*) as representative species. In all cases, we lack inventories of these communities at Waubesa Wetlands.

## What is the underlying cause of different wetland types?

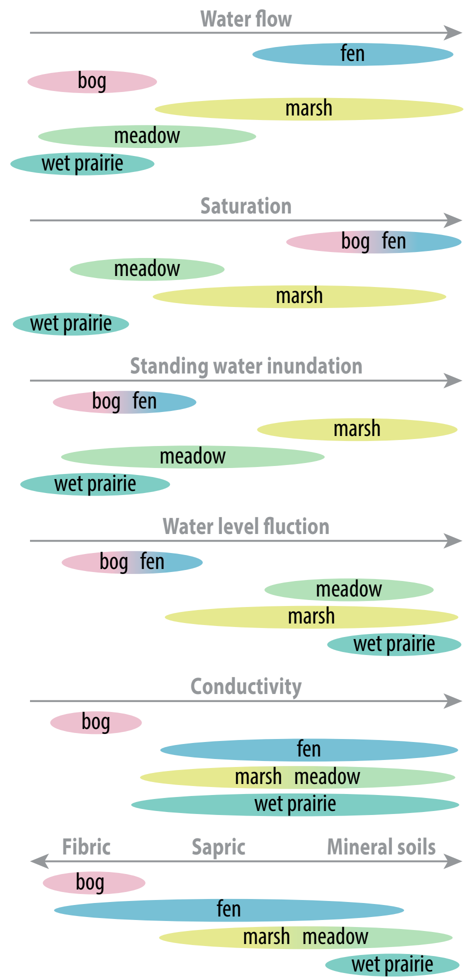
We don’t have a detailed answer for Waubesa Wetlands, but we can suggest reasons based on studies elsewhere. A side-trip to the scientific literature produces new meaning to the phrase “underlying cause,” namely that the cause often lies **under** the wetland.

Let’s start with fens and see how they compare to other wetland types in our Midwestern temperate zone. Amon and others (2002) concluded that fens differ from bogs, marshes, meadows and wet prairie in their **water source and hydroperiod**. Check their drawing to see how water flow, soil saturation, standing water, water-level fluctuation, and electrical conductivity (a measure of calcium content) characterize fens. It’s clear in the top row that fens need more continuous flowing groundwater than other wetland types—especially bogs that thrive in non-flowing water. Dependable groundwater is what keeps fen root zones saturated with water (2nd row). Also, fens tolerate high levels of dissolved minerals (high conductivity from calcium and magnesium bicarbonates); fen pH ranges from 5.5–7.4 (Swanson 2013), unlike acidic bogs. As a result of their unusual conditions, Carbonate-rich fens feature numerous species that are rare in the region and U.S.

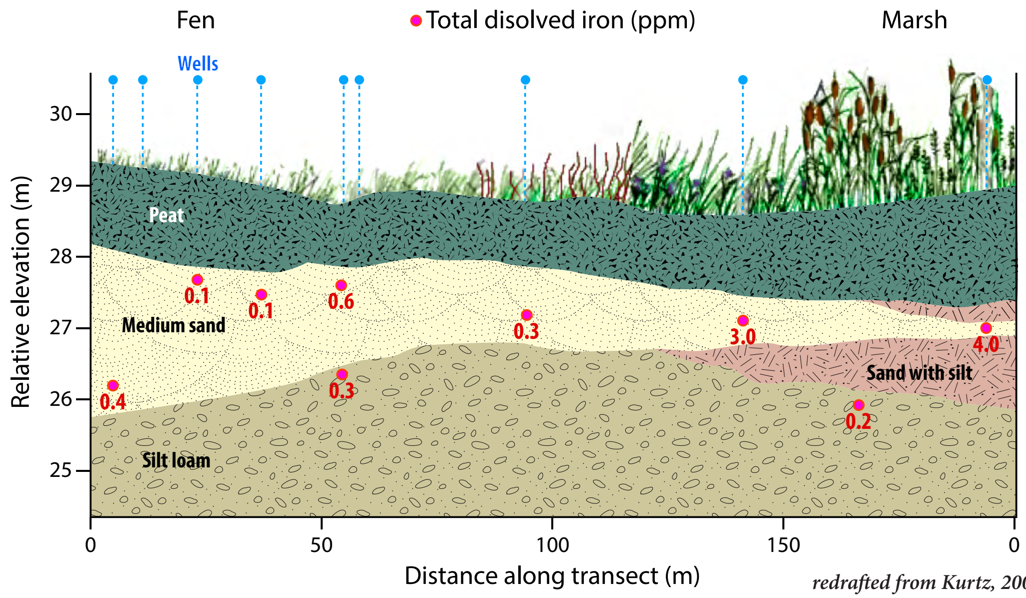
A study in nearby Cherokee Marsh by Abby Kurtz (nee McDermott) and her advisor, Dr. Jean Bahr, was enlightening. The two set out to explain why fen, sedge meadow, and cattail marsh vegetation occurred in sequence from west to east across a wet area. I was also puzzled by the vegetation changes, because the land appeared to be flat. It seemed that there should be a peat mound to the west to support a fen, and a depression to the right to impound water for cattails. However, elevation measurements confirmed flat

*Conifers (cone-bearing trees) grow tall and straight and would have been in great demand for early house construction. In Wisconsin, Tamarack is a wetland conifer that dominates acidic peat and muck soils that are nutrient-poor and hold standing water. A small stand occurs at nearby Hook Lake Wildlife Area.

Were Tamarack logs used to build early homes? The ~1860 Skare log cabin (mcfarlandhistorical.org/log-cabin/) is preserved at the McFarland Historical Museum. Are those logs Tamarack? If so, did they come from Hook Lake Bog?


Water source and hydroperiod differences in wetland communities




*redrafted from Kurtz, 2007*

*Belowground secrets: "Specific conductance and total dissolved iron increased by an order of magnitude from the fen to the marsh. The change in porewater chemistry is attributed to lower ground-water inflow from below and increased influence of transpiration concentration as a result of the presence of the silt loam unit." (Kurtz et al. 2007, p. 201). Dissolved iron was greater under the marsh because water residence time was prolonged by a silt-loam confining layer.

topography (see figure above). Kurtz hypothesized a hydrological gradient belowground, and she spent the summer collecting soil cores, analyzing soil water chemistry, monitoring water levels, and documenting patchy distributions of peat and till deposits. A patch of silt-loam impounded water under the Marsh despite flat topography. Voila! All clues supported the conclusion that Fen, Sedge meadow, and Marsh related to decreased groundwater discharge and increased importance of surface water*.

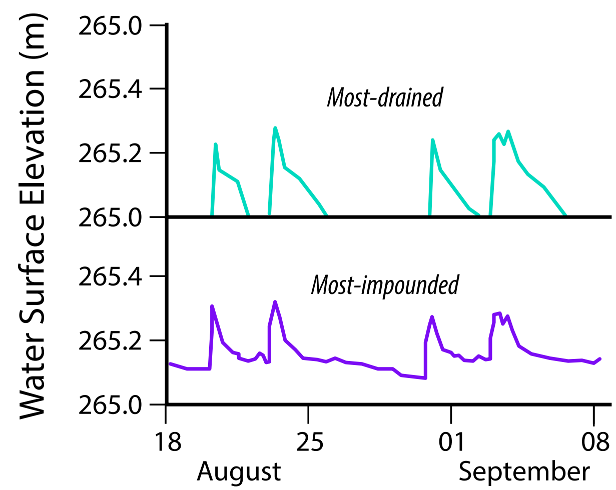
Unseen differences belowground were also the key to differing vegetation in each of three swales at the Arboretum. The swales were constructed to be identical, and **overall differences in hydroperiod were small** (see graph). The unseen surprise was varied "leakiness" of the subsoil. In the leakiest swale, we found this chain of effects:

Porous subsoil → More water infiltrated → Fewer nutrients were available to plants → Lower productivity More species

In the wettest swale that ponded water we found:

Confining clay → Impounded water → Ample soluble nutrients → Cattail dominance

In summary, small differences in hydroperiod led to big differences in plant composition, species diversity, and productivity (Doherty et al. 2014; also Leaflets #27–28).




Hydroperiods from the most-drained and most-ponded swales (Doherty et al. 2014). These hydroperiods differ in both magnitude and duration of high water.

## Isn't it amazing that…?

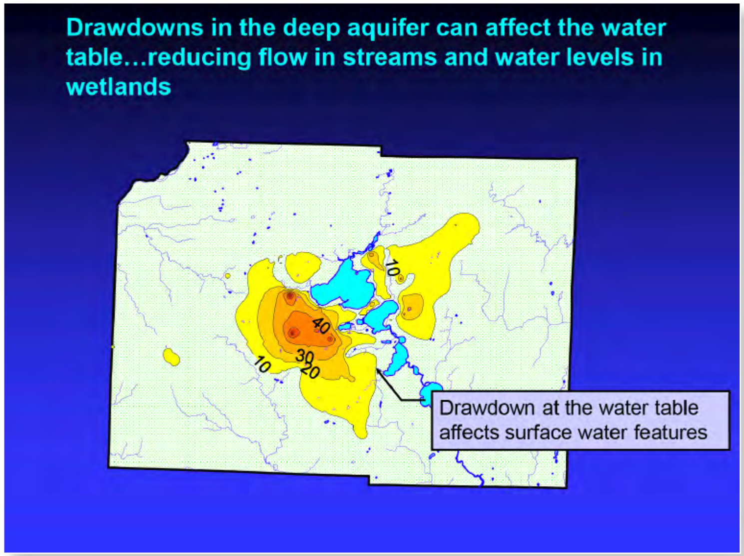
(1) Features we can't see because they are underground ("underlying causes") can lead to different hydroperiods. In Cherokee Marsh, water ponded where there was a buried silt-loam layer; in the swales it was a buried clay layer.

(2) Small differences in hydroperiods can lead to very different vegetation. **Fens** have continuously outpouring groundwater, which keeps soil saturated and nutrients diluted. **Meadows** are wetter in spring, but usually experience a summer drawdown (have a high fluctuation in water levels). **Wet prairies** retain less water. **Cattail marshes** develop where water ponds and accumulates nutrients.

(3) Small differences in hydroperiod can lead to **very different ecosystem functions**. In the Arboretum swales, we measured the most N and P in water that flowed out of the ponded swale. With ponded water, the soil becomes anaerobic, P becomes soluble, and soluble P is readily taken up by Cattail roots (Boers and Zedler 2007, 2008). Cattails thrive where there are ample nutrients (Woo and Zedler 2002).

(4) **Hydroperiod is a complex environmental factor***. Hydroperiods can vary in depth, duration, and fluctuations—and fluctuations can differ in frequency, magnitude, and regularity. Wetlands with oceanic tides are the only type with regular water-level fluctuations; you can read about them another free eBook (Zedler 2015).

*__Hydroperiods__ vary. Reed (2002) concluded that water levels in the root zones of **Sedge fens** were saturated during more than 75% of the later growing season and for over 60% of the time. **Calcareous fens, on the other hand**, were similar in seasonal saturation but saturated only 45–60% of the time, while **prairie fens** had saturated root zones less than 55% of the later growing season for less than 33% of the time. Similarly, Skalbeck et al. (2009) distinguished Wet prairie root zones as having less-continuous water saturation than Sedge meadows, based on six sites along Lake Michigan (Kenosha County, WI).




Many maps and illustrations are in Ken Bradbury's pptx at: https://www.cityofmadison.com/sites/default/files/city-of-madison/water-utility/documents/Projects/East%20Side%20Water%20Supply%20Project/TalkforEastMadison1_29_11.pdf

## B. Waubesa Wetlands' internationally important rare plants and animals

Habitat loss and degradation of wetlands are the primary causes of declining plant and animal populations. Of Wisconsin's listed threatened and endangered species, 32% depend on wetlands. Habitat loss and degradation are the primary causes of declining populations. An exception is the Sandhill crane population. We know it was depleted by hunting, in part, because it rebounded once hunting was regulated.

Waubesa Wetlands supports 27 rare species within an 8-km radius. Of those 27, **9 are endangered, 5 are threatened, 13 are species of concern** (see table below). Some are species of the uplands, but that benefit from adjacent large areas of low-growing vegetation in the Waubesa Wetlands landscape.

**Rare species documented in The Town of Dunn (at and near Waubesa Wetlands), from Wisconsin's Natural Heritage Inventory.**

| | |
|---|---|
| **Endangered animals** | |
| Peregrine falcon | *Falco peregrinus* |
| Black tern | *Chlidonias niger* |
| Blanchard's cricket frog | *Acris blanchardi* |
| Silphium borer moth | *Papaipema silphii* |
| Rusty patched bumble bee | *Bombus affinis* |
| **Threatened animals** | |
| Henslow's sparrow | *Ammodramus henslowii* |
| Northern long-eared bat | *Myotis septentrionalis* |
| **Animals of Special Concern** | |
| Blanding's turtle | *Emydoidea blandingii* |
| Lake sturgeon | *Acipenser fulvescens* |
| Plains gartersnake | *Thamnophis radix* |
| Prairie vole | *Microtus ochrogaster* |
| **Endangered plants** | |
| Hairy wild petunia | *Ruellia humilis* |
| Purple milkweed | *Asclepias purpurascens* |
| Eastern prairie white fringed orchid | *Platanthera leucophaea* |
| Hall's bulrush | *Schoenoplectus hallii* |
| **Threatened plants** | |
| Pale purple coneflower | *Echinacea pallida* |
| Prairie parsley | *Polytaenia nuttallii* |
| White lady's-slipper | *Cypripedium candidum* |
| **Plants of Special Concern** | |
| Gold-eye lichen | *Teloschistes chrysophthalmus* |
| Azure bluets | *Houstonia caerulea* |
| Prairie false-dandelion | *Nothocalais cuspidata* |
| Short's rock-cress | *Boechera dentata* |
| Wilcox's panic grass | *Dichanthelium wilcoxianum* |
| Wild licorice | *Glycyrrhiza lepidota* |
| Engelmann's spike-rush | *Eleocharis engelmannii* |
| Many-headed sedge | *Carex sychnocephala* |
| Snowy campion | *Silene nivea* |

## Here are a few highlights about our rare animals and plants.

***A new endangered species.*** **The U.S. Fish and Wildlife Service** (FWS) listed the **Rusty patched bumble bee** (*Bombus affinis*) as Endangered in March 2017. Although common in the late 1990s, this bumble bee is the first bumble bee ever declared endangered in the U.S. Only a few small, scattered populations remain in 9 states (and 1 Canadian province). One of those remnant populations is centered at the Arboretum, where staff monitor its sightings. Waubesa Wetlands are well within its potential range, as shown on the Dane County map (https://www.fws.gov/midwest/endangered/insects/rpbb/guidance.html#map). Photo by D. Mullen: https://www.fws.gov/midwest/endangered/insects/rpbb/factsheetrpbb.html

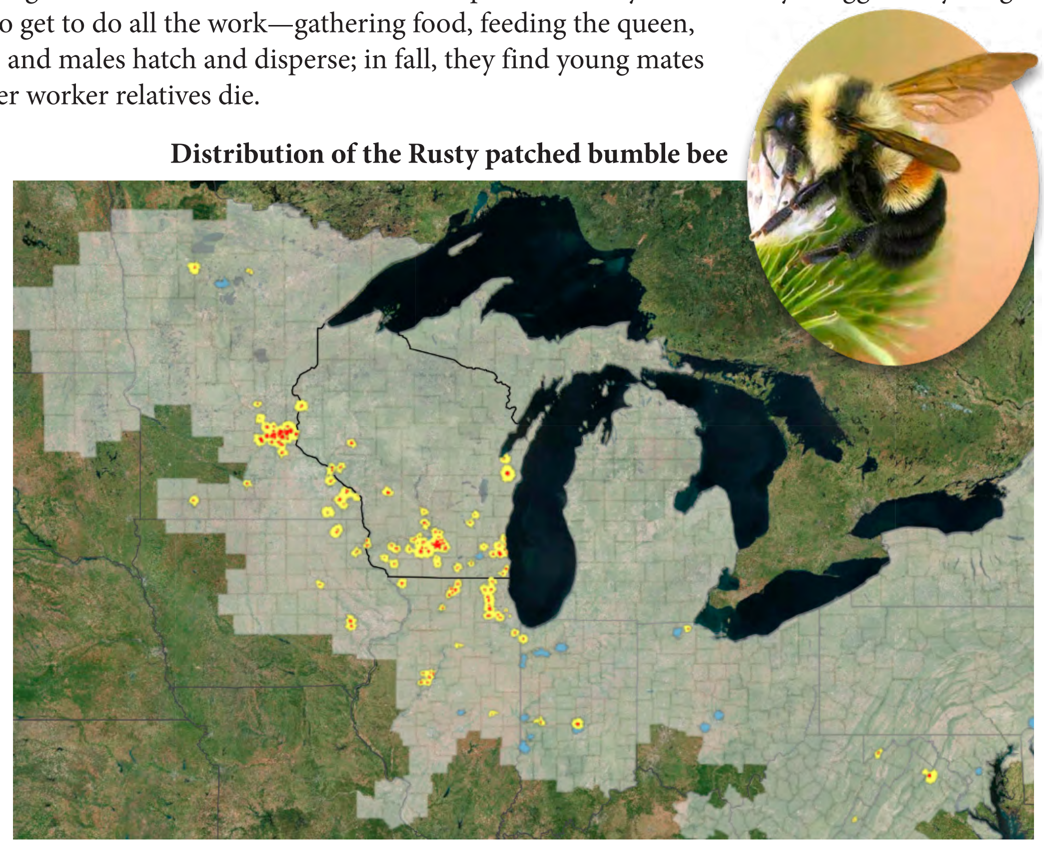
The Rusty patched bumble bee is an "annual insect," i.e., young queens are a bit like fruits full of seeds. In fall, they go dormant (hibernate) below ground while carrying fertilized eggs. In spring, solitary queens emerge, find a nest site, feed on nectar and pollen, and lay their bounty of eggs that young males fertilized the previous fall. The first to hatch are workers, who get to do all the work—gathering food, feeding the queen, defending and caring for young. Then, in late summer, new queens and males hatch and disperse; in fall, they find young mates from other colonies. At the same time their queen (now old) and her worker relatives die.

Where and when might we see the Rusty patched bumble bee? Top habitats are grasslands with plants that flower from April through October. The bees emerge early in the growing season and stay active late through September. Nesting sites include underground cavities and abandoned rodent tunnels or clumps of grass above ground. Queens hibernate overwinter in undisturbed soil (Szymanski, et al. 2016).

How can we identify this bee? Look for a rusty patch in the middle of the back of workers and males (but not on queens, which will rarely be seen anyway).

What can we do to prevent its extinction? ***1. Provide food:*** We can grow plants that provide foods, namely, nectar and pollen throughout the growing season. Good bets, according to FWS, are lupines, asters, bee balm, native prairie plants and spring ephemerals. But, showy shrubs and pussy willows also offer foods as nectar or pollen. ***2. Provide nesting and hibernating habitats:*** In summer, we can leave grasslands unmowed. In fall, we can leave litter on the soil in gardens and grasslands. In winter, we can leave plant stems standing. We can avoid using pesticides.

**Distribution of the Rusty patched bumble bee**



- High Potential Zones (presence should be presumed)
- Low Potential Zones identified for Scientific Recovery Permits and conservation efforts
- Historical Range

The **Silphium borer moth** (*Papapaima silphii*) is listed by the state of Wisconsin as Endangered, although it is not on the federal list. The loss of prairie habitats and connectivity among prairie patches is a likely cause of diminished populations in Wisconsin. The species has a strong host preference for four *Silphium* species, namely, Prairie dock (*S. terebinthinaceum*), Cup plant (*S. perfoliatum*), Rosinweed (*S. integrifolium*), and Compass plant (*S. laciniatum*). These host plants are large, coarse "sunflowers" that grow in wet to dry-mesic prairies, as well as Sedge meadows and openings in wooded areas. These spectacular plants are popular among native plant gardeners, so it would seem that habitat could be easily improved—or that we don't yet understand what has endangered this species.

Like the endangered Rusty patched bumble bee, the Silphium borer moth is an "annual." It's not surprising that species with annual life cycles are susceptible to population declines, compared to insects that lay eggs continuously on more than one host plant.

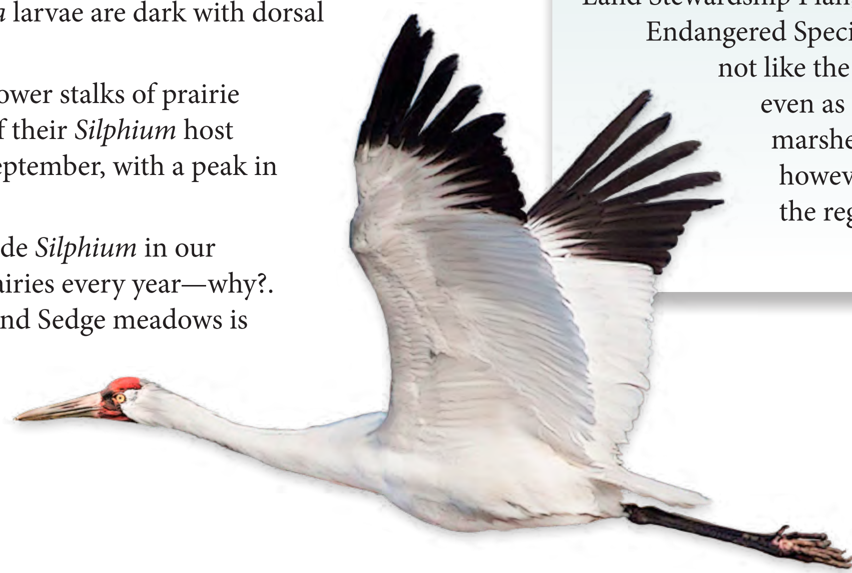
When and where should we look for the moth? DNR describes adults as medium-size with 1.5–2.0 inch (38–50 mm) wingspans. Their dull brown forewings are frosted with broad white scales. Young *Papaipema* larvae are dark with dorsal and sub-dorsal white lines.

Larvae hatch in the spring and bore into the lower stalks of prairie dock, causing withering and browning of leaves of their *Silphium* host plants. Adults fly from late August through late September, with a peak in early September.

How can we prevent its extinction? Let's include *Silphium* in our garden and restoration projects. Let's not burn prairies every year—why?. A rule of thumb for Wet and Wet-mesic prairies and Sedge meadows is not to burn the vegetation unless there is a need. If woody plants are encroaching, use fire over part of the site and alternate burning so Lepidoptera and other native insects will always have an unburned refuge.

**Whooping crane** sightings: Cal DeWitt first saw an endangered Whooping crane at Waubesa Wetlands in 1972; then, in 2013, he recorded 5 whooping cranes resting just south of Waubesa Wetlands during their spring migration. The birds rested and fed for 4 days before continuing their migration north. Here's his account of an extraordinary visit:

"Five Whooping Cranes, to my greatest-ever surprise and delight, recently stopped near my marsh on their springtime journey north. Over four days there were two of the world's total of 15 species of crane in my own rural town! One was the most common, the other, the rarest of all! Three miles south of Waubesa Wetlands they foraged in and around a small marsh, refueling before completing their trip to Necedah National Wildlife Refuge, a short distance north. Unknown to them, they benefitted locally from the Dunn Land Ethic, our Land Stewardship Plan, and nationally from the Endangered Species Act. The Sandhills did not like the incursion of "Whoopers" even as they returned to lands and marshes once shared; Dunnites, however, and people throughout the region were thrilled!"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**Henslow's sparrow** is a marsh/wet meadow specialist that is no longer common in Wisconsin (Robbins 1990). In fact, it is threatened with extinction in our state (see species profile at http://dnr.wi.gov/topic/EndangeredResources/Animals.asp?mode=detail&SpecCode=ABPBXA0030). It is known from southern Sedge meadows, Central poor (low-nutrient) fens, Wet to Wet-mesic prairies, and other grasslands.

*Photo: Tom Schultz*

The birds lay 2 to 5 cream-colored eggs between late April and late July. As a ground-nesting bird, its eggs and young are vulnerable to many predators, such as snakes and mammals (including dogs and cats). To fledge young, the nests need to be undisturbed for about 3 weeks—11 days to hatch and 9–10 days to fledge. Young are fed insects. Adults also eat spiders, and seeds.

Where might we see one? Look in wet meadows, undisturbed pastures and fallow fields. Robbins (1990) recommends listening for its "unobtrusive little vocal effort" at night, from 10 pm to midnight or from 2 to 4 am.

What can we do to prevent its extinction? We can continiue to preserve Waubesa Wetlands' large open, uncultivated landscapes. This bird declined as cultivated fields replaced tall, dense grasslands. Henslow's sparrow specializes in marsh/wet meadow with dense litter layers to form its deep cup-like nest, which it weaves at the base of a thick grass clump. It can tolerate some woody vegetation, but WDNR recommends controlled burning. I recommend a caveat: Keep large areas unburned each year to provide insect foods and nesting habitat. Also limit pet intrusions during the nesting season.

**Species yet to discover.** Wetlands support long lists of plants and animals, as presented above. In addition, new species might be hiding in the water. By new species, I mean new to Waubesa Wetlands or new to science.

**Miniature clams**. Tiny clams that are the size of your smallest fingernail might occur among the tussocks of our Sedge meadows. They were abundant when observed by Calvin DeWitt's students several years ago (see Appendix 4). A zoologist friend, Dr. Nancy McCartney, who curates the zoology museum (and its many collections of clams) at the University of Arkansas, referred me to a web site on "fingernail clams," There, I learned that "Sphaeriids are most common in the sandy or muddy sediments of lakes, slow-flowing streams, seepages and swampy habitats."


Fingernail clams
aka Pea clams

The Graphic Designer for this book, Kandis Elliot, recently illustrated all 58 Wisconsin mussels and clams, at full life size. Her 10-foot-wide poster is available at https://charge.wisc.edu/zoology/items.aspx

**New microbial species** could well occur in the cone of Bogholt Deep Spring. The few cold springs that have been studied reveal diverse microbial communities. A study of two cold springs on the Qinghai-Tibetan Plateau of China (elevation 4600 m; Li et al. 2017) used molecular techniques to uncover 66 archaeal and 117 bacterial clones. How many await discovery in our springs? More importantly, what do they do all day? Their functional diversity might be as great as their genetic diversity.

**A new study of rare wetland-dependent birds** asked how the landscape influences Sedge wrens (*Cistothorus platensis*) and Marsh wrens (*Cistothorus palustris*)—two species that migrate to, and nest in, Waubesa Wetlands. By considering what influences these birds in a nearby region, we might learn why they still nest at Waubesa Wetlands. The investigators used aerial photos to study 840 points around the Great Lakes and analyzed conditions (land use and configuration, temperature, precipitation and vegetation) in the surrounding 2000 m. Of the 840 points around 5 Great Lakes, the researchers found Sedge wrens at only 93 points (11%) and Marsh wrens at 194 points (23%). The two co-occurred at only 14 points (2%). Sedge wrens were associated with emergent herbaceous wetland within 500 m and sedge within 100 m; they were unlikely to occur where more than 11 km of roads occur within 1000 m. Marsh wrens were associated with emergent herbaceous wetland within 500 m and cattails within 100 m; they were unlikely to occur where more than 42% land within 500 m was developed. The authors concluded: "Sedge wrens were negatively affected by road density within 1000 m, and Marsh wrens were negatively affected by development within 500 m" (Panci et al. 2017, p. 454). The impact of humans on these species supports other lines of evidence that **development needs to be limited to conserve bird diversity**.

Sedge wren

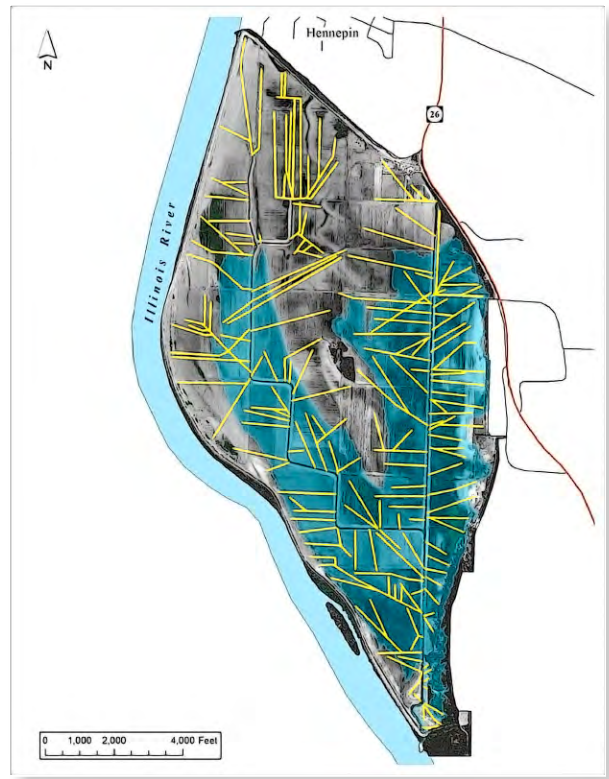

Marsh wren

## C. Waubesa Wetlands' international importance in maintaining regional biodiversity

Massive wetland-drainage projects, mostly for agriculture, have eliminated the bulk of our ecoregion's historical (1780s) wetlands, thereby depleting regional biodiversity. Wisconsin lost 46% of its wetland area by the 1980s, but our neighboring states lost far more (Dahl 1990). Ohio, Indiana, Illinois, and Iowa lost a total of ~20 million acres (~85%) of their historical wetland area, and losses were notable by 1860. **How did so much drainage happen so fast?** We owe it to the invention of drain pipes and drain fields. Small pipes were laid in rows underground, leading to larger pipes that drained groundwater into drainage ditches. These ditches eventually carried the "waste" to the Misssippi River.

Sample of pipes that were found while restoring groundwater to Midewin National Tallgrass Prairie.

Now, look closely at Illinois' Dixon Waterfowl Refuge map and you'll see lines that mark a total of 40 miles of clay pipes. Because the site was diked, water that the pipes collected had to be pumped up and over the levee and into the Illinois River. To restore water and wetlands to this site, all these buried pipes had to be located, then disabled. Read the full story by The Wetlands Initiative (http://www.wetlands-initiative.org/how-the-midwest-lost-its-wetlands/).




Dixon Waterfowl Refuge

Together, these four Corn Belt states retained only ~3 million acres of wetlands—which is substantially less than the ~5 million acres that Wisconsin alone retained.

| State | 1780s acres | Loss | Acres lost | 1980s acres |
|---|---|---|---|---|
| Ohio | 5,000,000 | 90% | 4,500,000 | 482,800 |
| Indiana | 5,600,000 | 87% | 4,872,000 | 750,633 |
| Illinois | 8,212,000 | 85% | 6,980,200 | 1,254,500 |
| Iowa | 4,000,000 | 89% | 3,560,000 | 421,900 |
| TOTAL | 22,812,000 | 87% | 19,912,200 | 2,909,833 |
| | | | | |
| Wisconsin | 9,800,000 | 46% | 4,508,000 | 5,331,392 |

Lake Michigan and the Great Black Swamp in northwestern Ohio were both in the path of "progress*." The Great Black Swamp was drained, "improving" access to Michigan. However, Wisconsin was further away, had a colder climate, bumpier topography, fewer drain-tile factories, and probably more tree stumps for workhorses to clear. All in all, it was easier to break prairie sod, so settlements bypassed our state and moved west across the Great Plains. From 1800 to 1860, Ohio, Indiana, and Illinois experienced "notable wetland loss" as farmers pushed west; this occurred a century earlier than in Wisconsin*. No wonder ~85% of wetland area was lost very early in the race to convert wetland (hydric) soils to arable land. Lucky for Wisconsin, steam shovels and tractors did not meet the technological challenges of large-scale wetland drainage until after people began to appreciate the many ecosystem services provided by wetlands.

*Wetlands got in the way of settlers who saw the potential of farming further and further west as they populated Ohio, Indiana, Illinois and Iowa. Population growth, technological advances, and agricultural drainage turned swamps and herbaceous wetlands into what is now the nation's Corn Belt. Several factors explain the millions of acres of wetland lost to drainage for agriculture (Dahl and Allord 1994):

- Between 1810 and 1830, the U.S. population rose from 7.2 to 12.8 million.
- From 1849 to 1860, Congress passed Swamp Land Acts that promoted wetland drainage.
- Mid-century: Swamps were logged for lumber (wooden buildings) and firewood (heating, steam engines).
- 1861–1865: Civil War experiences called attention to wetlands as impediments to travel.
- 1859–1885: Ohio's 40x120-mile Black Swamp was logged and its soils were drained.
- 1900–1950: Ditching and tiling became affordable as the technology of wetland drainage improved.
  - —Excavation became steam-powered; drain tiles were mass produced.
  - —By 1880, Ohio, Indiana, and Illinois hosted most of the nation's 1,140 drain-tile factories.
- ~1920–1954: Tractors replaced workhorses, mules; forage crops (oats) were replaced with corn and soybeans.
- 1922–1933: Agricultural subsidies began; over time, corn and soybeans became highly subsidized crops.
- 1930s–40s: The U.S. government organized drainage districts that helped farmers plan and pay for drainage.
- 1950–1990: Michigan, Wisconsin, and Minnesota had "notable wetland loss"—a century later than OH, IN, and IL, and with less loss.
- 1960s: Federal laws continued to facilitate wetland loss.

Wetlands lost 1780s–mid1980s


< 50% 50–85 % > 85%

*Adapted from Dahl & Allord 1994*

Why did Wisconsin and other northerly Midwestern states escape the 85% losses in wetland area that occurred further south between the 1780s and the 1980s? Minnesota lost half as much (~42%), Wisconsin lost ~46%, and Michigan ~50%. Here's my hypothesis: Wisconsin and other northerly states were "off the beaten path" of settlement and agriculture that steadily slogged its way west across what became the Corn Belt Plains (Ohio, Indiana, Illinois, and Iowa).

Much of Wisconsin's remaining wetland area is in northern counties where it's a bit cold for corn. In contrast, Dane County is flat and farmable, with rich soils that followed drainage of 56% of the county's historical wetland area. Wetlands were drained as follows: ~36,000 acres from 1901–1936, 22,678 acres from 1939–1961, and another 8,050 from 1962–2008, for a total of 66,728 acres lost (CARPC 2008). This large loss magnifies the importance of Waubesa Wetlands to the Till Plains and Corn Belt ecoregions where much less wetland remains intact and diverse. The 51,400 acres of wetland left in Dane County in 2007 included sites that were degraded in biodiversity and water quality. Waubesa Wetlands are tops among the few remaining species-rich wetlands, which include Cherokee Marsh and Pheasant Branch Conservancy, both adjacent to Lake Mendota.

Waubesa Wetlands are left to do much of the work of the 66,728 acres lost in Dane County, or the 20 million acres lost from the Midwest Corn Belt ecoregions. By "work," I mean perform the long list of ecosystem services provided by high quality wetlands (see Chapter 3). Clearly, Waubesa Wetlands are a major biodiversity support system for its watershed, the Southeastern Wisconsin "Level IV" ecoregion, and the larger "Level III" ecoregion and adjacent Corn Belt ecoregions. We cannot afford any further losses in wetland quantity or quality.

**Attitudes began to change toward conserving natural resources in the 1930s.** As agriculture expanded west across Wisconsin, so did soil erosion. Cultivated fields lost their topsoil; compacted soils shed more runoff; streambanks eroded; and trout streams were muddied. A move to conserve topsoil began in 1933, following 70 years of unwise farming practices in western Wisconsin's Coon Valley. The Soil Erosion Service (now the Natural Resources Conservation Service) began offering individual farmers assistance in curbing soil loss from their fields. At the same time, Aldo Leopold offered a much broader perspective that encompassed soil loss throughout the watershed. "Coon Valley…through the abuse of its originally rich soil, has not only filled the national dinner pail, but has created the Mississippi flood problem, the navigation problem, and the problem of its own future continuity" (Leopold, 1935). Leopold advocated addressing flood problems at the source (which he called the "bull") rather than the sink (downstream), recognizing that the "endless building of dykes, levees, dams, and harbors on the lower river are attempts to put a halter on the same bull after he has already gone wild" (Leopold, 1935). Preserving upland soil prevents flooding by enhancing the infiltration of rainfall, slowing runoff, and reducing flood peaks. Farmers saw the logic and signed up 40,000 acres for federal assistance to hold soil on their uplands.

Waubesa Wetlands escaped large-scale sedimentation, yet Leopold's (1935) wisdom is well worth rereading in considering future threats. Both bare cultivated fields and urban hardscapes shed excess water and sediment. We can learn from history in finding ways to protect Waubesa Wetlands as an internationally important resource.

Another sign of changing attitudes was the 1934 Migratory Bird Hunting Stamp Act. The prolonged drought and "dust bowl" years led duck hunters to realize that the nation's wetlands were diminishing in area and quality. At the same time, the price of many farmlands dropped when the dry soil couldn't support thirsty crops. Conservationists saw that such lands could be purchased cheaply to create National Wildlife Refuges. The Stamp Act required hunters to pay a fee to hunt, and fees were used to purchase and restore wetlands. The prolonged drought was bad for waterfowl in the short term but good for wetlands in the long term.

Waubesa Wetlands also escaped shifting attitudes that modified Horicon Marsh over a 150-year history.* In this case, damming and flooding reduced plant diversity but led to water-level management that attracts waterfowl. The Marsh's large size and extensive use by waterbirds led it to receive early recognition under the Ramsar Treaty.

Finally, in 1948, the Federal Water Pollution Control Act became the first step toward the Clean Water Act of 1972. Gradually, wetlands became a "household word" (see Preface). However, net losses in wetland area continued until the 1990s, when restoration acreages finally exceeded wetland losses. However, some gains were over-reported (Griffin and Dahl 2016).

**Despite wetland losses, impacts, and negative attitudes,** Waubesa Wetlands escaped massive drainage, filling, damming and flooding, thanks to **conservation-minded leaders**. The Town of Dunn encouraged the donation of the Bogholt Deep Spring, which sustains so much of the groundwater supplies. Town leaders opposed the widening of a county highway and a proposal to create a landfill that would have leached contaminants in its runoff. Town leaders instead created Conservation Easements and restored fish nurseries. Town residents took pride in conserving high quality Waubesa Wetlands. At the same time, the Town took on a responsibility for the Wetlands' future.

Canada geese and ducks in Horicon Marsh,
*Photo: Milwaukee Journal Sentinal*

*__Horicon Marsh__, ~60 miles northeast of Madison, survived multiple shifts in policy and ecological condition:

- 1840s: Horicon (in Mohican = pure, clean water) Marsh was considered an impediment to transportation.
- 1846: The marsh was dammed and flooded to create a 4x14-mile lake for steamboats and commercial fishing.
- 1869: The dam was removed, and the lake reverted to a marsh with ample duck habitat. However, overhunting depleted wildlife.
- 1904: Farmers tried to drain Horicon Marsh; some muck-farming occurred. Peat fires became widespread.
- 1934: Horicon Marsh was re-dammed to control peat fires; dam used to regulate water levels, which continues to date.
- 1941: Horicon Marsh became a 22,000-acre National Wildlife Refuge for migratory birds.
- 1990: Horicon Marsh became a Wetland of International Importance under the Ramsar Convention.

*(See https://www.fws.gov/refuge/Horicon/about.html.)*

The persistence of a biologically diverse wetland with **rare aquatic** and **wetland community types** has **international significance** and makes us responsible for their long-term protection for the ecosystem and as a source for species to spread to restoration sites across its ecoregion. The wetlands support diverse **animals** that can disperse widely either on land or by water, downstream to restoration sites in Illinois and beyond. Diverse vegetation creates complex **habitat for animals and plants**, from bare Mudflat during the winter drawdown to low-growing herbaceous plants to Shrub carrs, Willow thickets, and adjacent Oak woodland. Diversity extends from **belowground** (deep peat, lake benthos, deep springs) to high **aboveground** (Osprey nest on a power-line tower). Protecting these natural resources will require the cooperation of all who live in the Waubesa Wetlands watershed (see Chapter 7).

*Photo: C. DeWitt*

## Waubesa Wetlands' internationally important nesting and rearing habitats

The wetter parts of Waubesa Wetlands are a "Giant Nursery" (ssshhhhh; do not disturb). Fish spawn in the shallow aquatic vegetation, and their larvae use the marshes as a nursery. Wetlands and adjacent upland ecosystems provide nesting habitat for 72 species of birds, of which 57 migrate internationally to overwinter in the Caribbean, Mexico, and Central and South America. Frogs and toads lay eggs in ponds, and one Snapping turtle helped herself to Cal DeWitt's front-step to incubate her eggs. Monarch butterflies and charismatic dragonflies lay eggs here, and their hatchlings feed on native vegetation. These nursery functions are internationally significant for sustaining global biodiversity.

**The fish nursery.** Shallow vegetated waters are noted for their fish spawning and nursery habitat. Some local residents call it "The Great Nursery." Northern pike (*Esox lucius*) is a prized sport fish and a top predator of the lake food web. Not surprisingly, Lake Waubesa is a top Northern pike lake in Wisconsin's southern counties. The pike grow to 20 cm in the nursery before migrating to the lake. The Town of Dunn took an extra step to support this species by restoring a former cornfield* to expand spawning and nursery habitat.

"Muskies" (Muskellunge, *Esox masquinongy*) are also top predators prized for their large size and fighting behavior when hooked. This northern species is stocked in Lake Waubesa, where it hides among the submersed aquatic vegetation in order to "ambush" its prey (mostly smaller fish).

*__Nursery-habitat restoration__ along the shore of Lake Waubesa significantly improved habitat for fish spawning.: In the 1960s a 30-acre (11.3-ha) area was ditched and drained for crop production, which created a direct path for sediment and accompanying pollutants to enter the lake. The Town of Dunn's wetland restoration renewed the site's filtering ability by diverting surface runoff through grass channels and retention ponds. Two wildlife ponds were also excavated for northern pike spawning. Now, the 30-acre Dunn Heritage Park provides canoe pull-ups, trails, and shore fishing.


Musky (*Esox masquinongy)*

**The waterbird "nursery."** The Sedge meadows, Shrub carrs, and Marshes of Waubesa Wetlands and nearby lakes attract ducks and other waterbirds to the Town of Dunn. "Several hundred **waterfowl** winter over on the big springs…in some years over 2000 duck" (Bedford et al. 1974). Mallards, Blue-wing teal and Wood ducks are commonly found in the area. Uplands adjacent to small wetlands (up to 1/10th of an acre in size) are areas where these ducks nest and rear their young, especially if the wetland is associated with larger areas of open water nearby. Puddle ducks (e.g., Mallard, Gadwall) feed in shallow areas, while diving ducks (e.g., Ruddy duck) feed in deeper waters.

**Amphibian reproduction**. Frogs need shallow water to lay eggs and hatch tadpoles. Those that are common in Waubesa Wetlands are the Leopard frog, Green frog, Chorus frog, Spring peeper, Cricket frog, Tree frog and Pickerel frog. Leopard frogs live in meadows and open grassy areas, whereas the Green frog remains in wetlands and ponds year around. Other frog and toad species don't live in wetlands permanently, but migrate to wetlands or ponds in spring to breed. For example, the American toad breeds in wetlands but inhabits woods and fields in the summer, while Chorus frogs and Spring peepers remain in woodlands the rest of the year. Salamanders are not common; Calvin DeWitt reports seeing only one in more than three decades of observations. The eggs and larvae of salamanders are preyed upon by fish, so it is unlikely that they are abundant in Waubesa Wetlands.

*Photo: J. Zedler*

**A surprise guest.** Calvin DeWitt's house is near a spring-fed pond that supports turtles, so he was not surprised one mid-June day to see a large, old Snapping turtle (*Chelydra serpentine*) hiking up the hill to his front stairway, then making the rounds to his asparagus patch. However, he was quite surprised when it (now identifiable as "she") returned to dig a nest and lay eggs next to the concrete landing on his front steps. Cal figured that she had been searching for just the right heat sink to incubate her eggs, which probably don't like cold nights during their 80–90-day gestation period. Cal also noted that Ms. Turtle replanted some of the plants to camouflage her nest after she covered the eggs with excavated soil. Chipmunks (*Tamias striatus*), however, were not fooled by the restored vegetation; they were quick to start digging, so Cal added a cage to cover the "nursery" and weighted it to thwart intruders.

*Photo: C. DeWitt*

**Midwestern milkweeds for Monarch butterflies.** I remember when Milkweeds were abundant along Midwestern roadsides and fields, and when billions of Monarchs (*Danaus plexippus*) could lay their eggs on them so that their caterpillars could feed on the milky leaves—Yum! [But toxic to humans, so don't taste them—Yuck!] Today, however, agricultural weed control has changed the landscape and the nursery. Too much spraying of pesticides and too much mowing of roadsides favors grasses over forbs and keeps milkweeds from flowering. Some of the uplands around Waubesa Wetlands have small patches of milkweed, but it takes a large area to attract a species that migrates from Mexico to Wisconsin.

The Environmental Defense Fund (EDF) has a target to re-establish 1.4 billion milkweeds and save this at-risk species (Klebnikov 2017). That's an ambitious goal. In 2016, EDF created a habitat exchange program—landowners who create and conserve habitat can earn credits for growing milkweed, then sell credits to private and public entities that want to assist monarch recovery (Klebnikov 2017) Efforts to plant milkweeds in Midwestern backyards, schoolyards and rights-of-way are also underway.

**Wetlands and nearby uplands are life-support systems.** Some 75% of the state's wildlife relies on wetlands at some point in their lives. The dependence includes nursery functions but also corridors to travel from wetland to wetland. Waubesa Wetlands' streams serve as corridors, as do fence rows and woodlots that offer a protective path of cover. We can compare bird diversity where Minnesota's pothole wetlands are and are not "connected." Fewer bird species occur when the wetlands are more isolated, that is, where habitat is more fragmented (Whited et al. 2000). Extrapolating from that situation, the importance of Waubesa Wetlands' nurseries has likely increased as other wetlands have become more fragmented.

White-tail deer also use Waubesa Wetlands as a corridor to move among wetland patches. The deer find cover and forage in shrubs and dense vegetation; they rely on wetland-wooded edges to move between resting, feeding, and watering locations. Birdwatchers, duck hunters, and deer hunters are all rewarded by Waubesa Wetlands' nurseries and corridors.

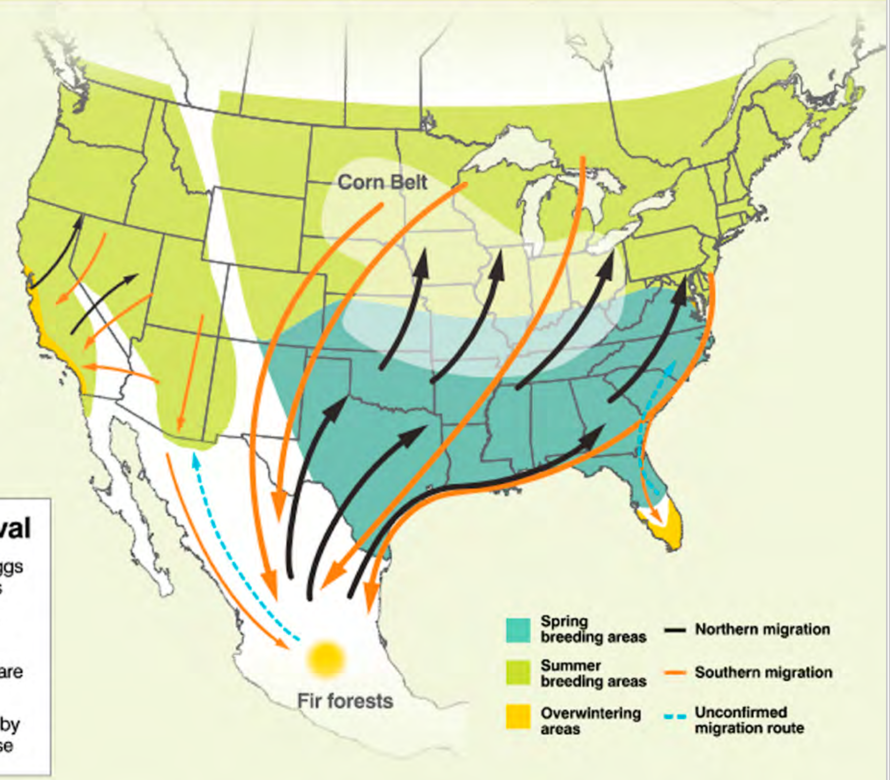
Waubesa Wetlands has a hidden world, too, and that's the focus of the next chapter. Among the many things we can't see are the glaciers that formed the land, the aquifers that ooze life-giving clean water, and the abundant ecosystem services that wetlands provide. The features that we can't see are just as important as the landscape, communities, and species that we can see.


Opposite: Map of Monarch migration and graph from Environmental Defense Fund, with permission.

# A humble plant powers an epic migration

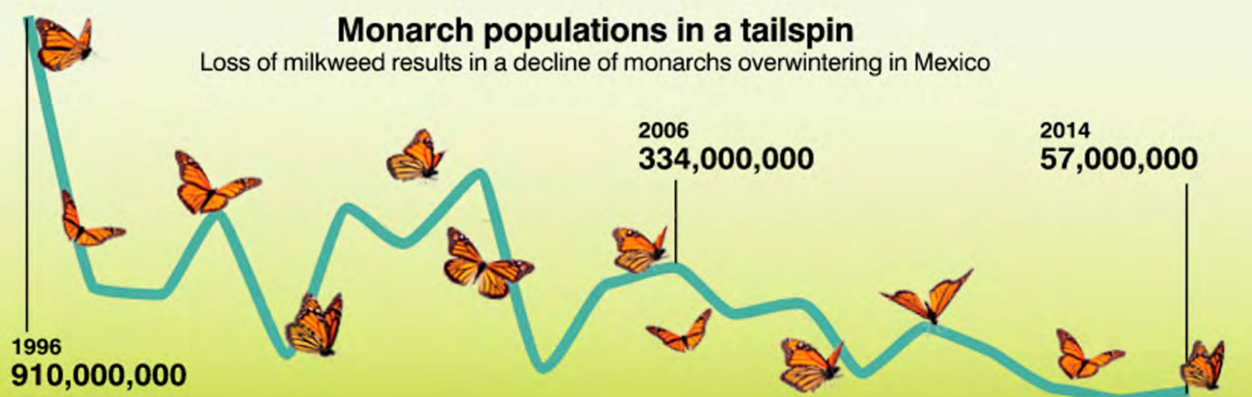
The migration of monarchs is one of nature's wonders. It's also shrouded in mystery. The Aztecs believed monarchs were the souls of dead warriors, returning to their homeland in full battle colors. Today we know that monarchs fly from the U.S. and Canada to Mexico and back, a trek that takes four generations to complete.

We also know that monarchs navigate by using their complex eyes to follow the sun and their antennae to track the time of day. This explains why off-course monarchs always "recalibrate" by turning full 360s in the air before they make course corrections. But we still have no clue why monarchs that fly south live longer than those flying north.




## Milkweed, the key to survival

- Female monarchs lay eggs only on milkweed leaves
- Monarch larvae eat only milkweed leaves
- 73 species of milkweed are native to the U.S.
- Milkweed is being killed by widespread herbicide use

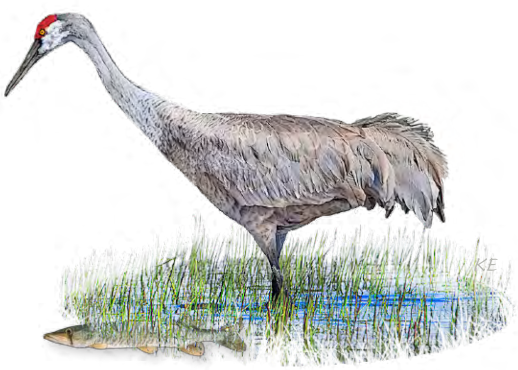


Mulajokull glacier and its active drumlin field were covered by ice in 1995. As it melts, it forms lakes and ponds.

*Photo: Ivar Örn Benediktsson*

# Chapter 3 • Looking for what is hard to see

It's a great thrill to see a glacier face to face, but it's hard to see the effects of the long-gone Wisconsin ice. Geologists have learned about its impacts on the land by interpreting signs left behind and by extrapolating from glaciers elsewhere. Similarly, we can see groundwater emerging from Waubesa Wetlands' springs, but we can't see our aquifers deep below ground. Hydrologists use models to estimate how they are changing. We can see clear water and feel that it's cool, but we can't see if it's clean. Chemical engineers need to analyze it extensively to find out what it contains besides $H_2O$. In addition, we can see the surface of the wetland soil, but we can't see its many critical functions. In fact, most ecosystem functions that people value (called ecosystem services) are roughly estimated by ecologists. Only a few of us have actually measured them. Even though many components of wetlands are hard to see, it's important to know what our eyes are missing.



## We can't see the glaciers that formed the topography

But, we can see signs of historical glacial action. Thanks to glacial geologists, we know how the topography developed. The University of Wisconsin was an early leader in glacial geology, because many signs, like drumlins, inspired Dr. T. C. Chamberlain to investigate glacial impacts. The Town's Comprehensive Plan spells it out:

> "The Town of Dunn lies within two topographic regions: the glacial moraine area, in the southern one-third of the Town, and the Yahara River Valley area, which makes up the northern two-thirds of the Town.
>
> "The moraine area in Dane County is perpendicular to the south-southwest movement of the region's most recent glacier. It is composed of material that was pushed in front of the glacier as it advanced southward, and represents the furthest reaches of the last glacial period, which ended about 12,000 years ago. The moraine in Dunn is characterized by knobby hills and ridges that consist of rock fragment ranging in size from clay to boulders. Layers of sorted sands and gravels that were deposited by glacial meltwaters are also evident in the area.
>
> "Some small kettle-holes exist in the moraine area, most less than 20 feet in depth. These kettles were formed by the accumulation of glacial material around isolated ice blocks left behind from a glacial advance or retreat. The blocks, which slowly melted away, then left a depression in the ground. These depressions, or kettles, occasionally contain a small lake or wetland. The Yahara River Valley region includes Lake Waubesa, Lake Kegonsa and Upper and Lower Mud Lakes. The lowlands adjacent to these lakes and the Yahara River are marshy while the upland areas are generally well-drained. The topography of the area varies from flat and rolling to hilly and hummocky" (from the Town of Dunn Comprehensive Plan A-25 VI. Natural Resources Inventory).

Still, it would be exciting to see the process underway. Possible? Yes! All we have to do (an understatement) is visit the middle of Iceland, which has the only known active drumlin-forming field, as described in Chapter 1. Pulses of advancing and retreating ice hone mounds into drumlins (Benediktsson et al. 2016, McCracken et al. 2016).

## We can't see the aquifers that make our lands wet

Our aquifers are layers of soil and rock **below ground** that function as groundwater reservoirs—indispensable to the maintenance of Waubesa Wetlands. Groundwater in an aquifer moves from recharge areas in higher elevations to discharge points at lower elevations, forming springs, streams, lakes, and drainage ditches (Verbeten 2017).

Waubesa Wetlands have two layers of groundwater that are separated to an uncertain extent by an impermeable layer, called an aquitard:

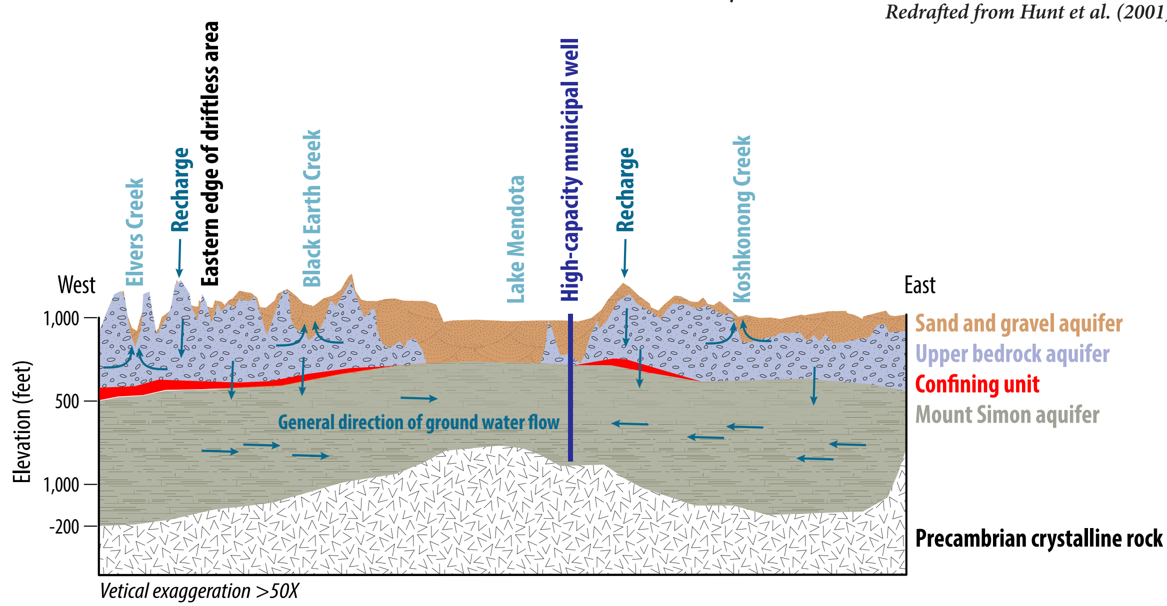
- The **upper sand and gravel aquife**r is composed of materials that were ground up by the glacier and deposited as ice melted or rivers and winds moved the particles. These deposits include topsoil plus variable depths of sand and gravel.

- The **lower sandstone and dolomite aquifer** is much older; it was deposited over 425 million years ago. It is composed of various rock types that yield varied amounts of water. "In dolomite, groundwater mainly exists in cracks and fractures. In sandstone, water occurs in pore spaces between loosely cemented sand grains" (Verbeten 2017). This deeper aquifer is the target for high-capacity municipal wells in eastern Wisconsin.

The upper and lower "layers" have connections and vulnerabilities that are **not fully understood**. We're not sure which aquifer is the source of our springs; perhaps it is both. We know that groundwater flows from the west and southwest toward Lake Waubesa. We know that it flows upward under pressure and that it flows out of at least 16 springs year-round. Plus it oozes out of the soil in widespread seepages.

West–East cross section showing the upper aquifers and the lower (Mount Simon) aquifer. Schematic flow-lines also are included to illustrate the local and regional ground-water flow that occurs in the county.

*Redrafted from Hunt et al. (2001)*



Some speculate that the two aquifers are separated by a continuous, unbroken aquitard, and they argue that new deep municipal wells wouldn't deplete the springs. Others point to areas where breaks in the "barrier" have been identified (as illustrated by Hunt et al. 2001), and they argue that, **where there are breaks, deeper water can move vertically, between aquifers.** A threat for wetlands would be **a nearby deep, high-capacity well that would** deplete both aquifers by forming a **"cone of depression."** In the process, it would **dewater our springs**. This has already occurred in nearby Monona Wetland Conservancy.

Is our deeper aquifer connected to our upper aquifer in ways that could cause our springs to dry up? If engineers were to drill cores to inspect the confining layer, they would create leaks and defeat the purpose. As an alternative to creating new holes in the confining layer, existing wells were sampled. Regrettably, a human virus was found in water from deep wells (Ken Bradbury online slides, 2011; WGCC 2011). Such evidence indicates that the deep well interacts with surface water, and it also supports concerns that excess pumping of the deep aquifer can draw down the upper aquifer. In turn, this means that springs could dry up due to withdrawals from either the upper or the lower aquifer.

With every step in the Town of Dunn, we walk on water, even if we can't see it deep beneath our feet. It will take firm leadership among policy makers and water managers to keep it that way.

"In order to know what is happening with water at the faucet, it's essential to know what we're dealing with under-ground…We need to understand how different geologic formations interact with water and how water moves through them" (Hydrogeologist Larry Lynch quoted by Verbeten 2017).

## We can't see whether or not clear, cool water is clean

Groundwater pumping brings clear, cool, clean water to the surface, where it joins rainfall and runoff from street and fields. As clean groundwater becomes surface water, it picks up contaminants, including soil particles, nutrients, pesticides, and heavy metals. The "less-clean" surface water moves from the west to form Swan and Murphy's Creeks, which carry water toward the wetlands and then into Lake Waubesa. In between the two creek outflows is Big Spring Creek, where Bogholt Deep Spring and other smaller springs coalesce to form a third outflow to the lake that is more than ~55 ft (17 m) wide. We need to monitor these three creek outflows to track water volume, flow rates, and contaminants. The best news would be that Lake Waubesa receives only clear, cool, clean water. This is unlikely, as reasoned in the next paragraph and in Chapter 6.

A Waubesa Wetlands spring

*Photo: J. Zedler*

**Clear** water allows fish and water birds to see their aquatic prey, and **cool** water keeps the lake's toe habitable for thermally-sensitive fish to feed and spawn. **Clean** water is low in contaminants, including nutrients; as a result, algae can't grow well enough to form "blooms" that cloud the water. In the toe of Lake Waubesa, clean water with just enough nutrients to support low levels of algae and high levels of zooplankton makes a good nursery for fish larvae. Fish production and other high-value ecosystem services derive from Waubesa Wetlands' outflows of clear, cool, clean water. But the water will remain clean, cool and clear only if enough water is discharged from the underlying aquifers to keep algal blooms away from Lake Waubesa's toe. Those algal blooms are fed by excessive nutrients from upstream lakes (Monona and Mendota).

Looking south: Yahara River (lower right),Upper Mud Lake, Lake Waubesa (the largest water body), Mud Lake, Lake Kegonsa.
*Photo: Nadia Olker*

Does the lake have a **temperature** or a **thermal regime**? Steel et al. (2017) describe the many inexpensive sensors that can measure water temperature as frequently as needed (hour, minute, or second). While some devices are placed in specific locations, it is now possible to install fiber optic cables for long distance monitoring or to use remote sensing technology to assess the surface temperature of stream and lake waters. Thermal imaging cameras can map the temperatures of entire stream and floodplain surfaces, and drones can map daily water fluctuations at small spatial scale, such as any shifts in location of refuges for fish. The concept of "the lake's temperature" is quickly becoming obsolete.

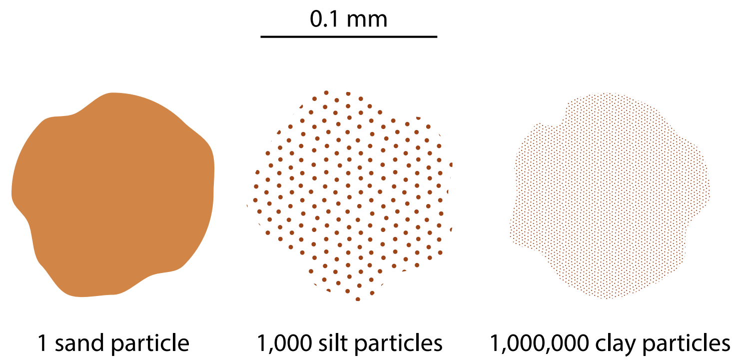
Rather than referring to *water temperature*, Steel et al. (2017) suggest using the term thermal regime to describe the complex spatial and temporal variations that new technology is uncovering. They conclude that "Fluctuating water temperature regimes may alter growth patterns, reproductive rates, disease resistance, and community structure in aquatic environments…and impacts of thermal variability may ripple through food webs."

The toe: note blue water near shore, algal bloom farther out.
*Photo: Nadia Olker*

## We can't see what's hidden in the soil

Soil is a precious resource that is more than what we can see after a crop is harvested. When a farmer plows up a field to mix in dead stems, we can see that the surface layer is brown or dark-brown. The rest of the world beneath our feet is hidden except along fresh road cuts, edges of active gravel pits, or other cuts in the soil.

Soil is complex, but its texture has been simplified by describing its gradient of particles into three "classes": Sand, silt, and clay. Soils are characterized by their proportions of these three categories. Loams, defined as having similar proportions of sand, silt, and clay, make good agricultural soils, but loams don't hold enough water to form wetlands. The soils of wetlands have much more clay, which helps them hold water—their tiny particles have a lot of surface area per unit volume, so when clay particles get wet, they stick together and slow the flow of water. Of course, soil is much more than just mineral particles!




Conceptual drawing of soil particles

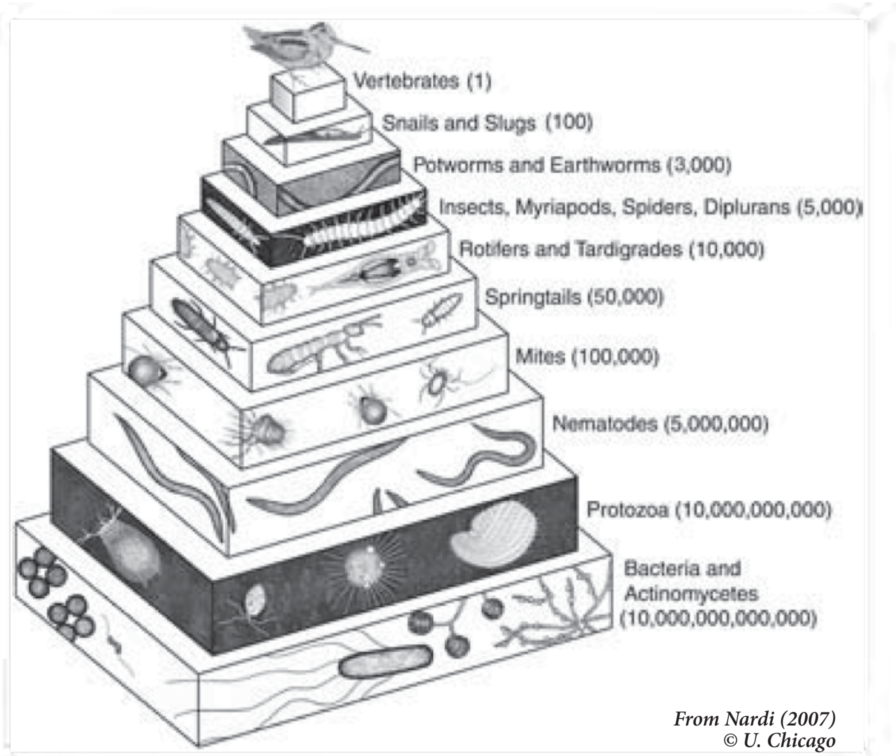
Mineral particles become soil when the material develops biota and structure. The process involves plants, animals and micro-organisms. In Wisconsin, we can picture soil development by observing ants that build mounds. Ant colonies create structure, add **organic matter** (OM), change soil chemistry, and affect soil moisture and temperature. A restored prairie (~3 acres) in Waubesa Wetlands has over 90 tall ant mounds that were built within a decade. But they didn't start "from scratch." The site was a cultivated field and pasture and already had a layer of "topsoil." The accumulation of organic matter from a mineral base ("from scratch") is very slow. It might take a century to accumulate OM, so it's critical to keep rich soil from washing downstream during rainstorms.

Although prairie ants can build OM-rich anthills in a few years, OM is often the slowest attribute to develop in a wetland restoration site. Why? Because the entire soil food web has to develop in order to shred big pieces of plant material into smaller and smaller pieces, enrich it with microbial proteins, leach out dissolved OM, and reprocess the material until the least digestible molecules remain ("recalcitrant" OM). This is **stored carbon**—taken from the air where it would contribute to global warming, used by plants to manufacture organic matter, then incorporated into soil where it has a useful purpose. Soil that is rich in OM can hold more moisture, feed more organisms, support more plants, provide more nutrients for roots to take up, and decompose even more OM. Together, the mineral and biological components create multi-functional soil.

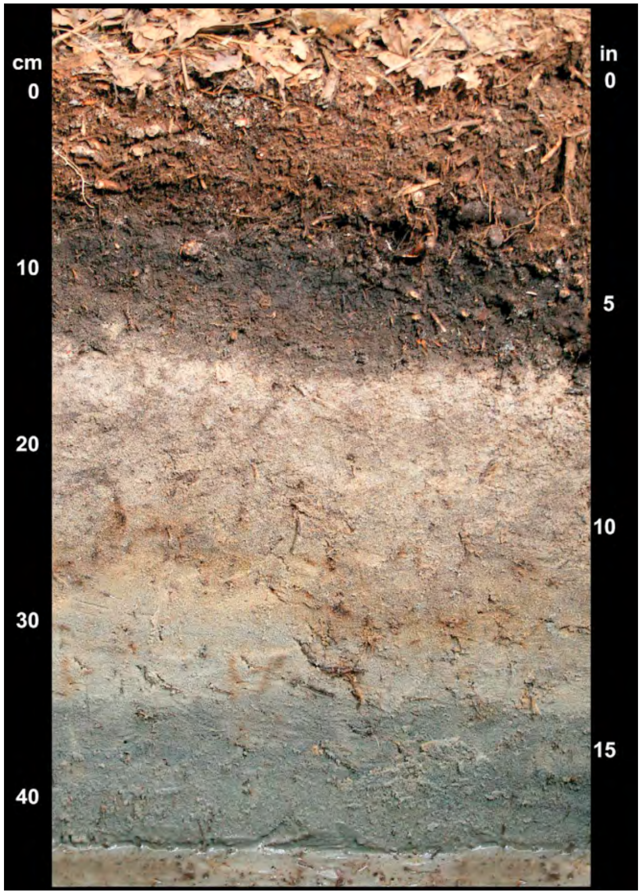
Most of the soil biota are micro-organisms. The soil-dwelling species that we can easily see are certainly a tiny minority. This is true for both numbers of individuals and numbers of species. The visible species that live on an acre of soil are vastly outnumbered by hidden soil bacteria, actinobacteria, protozoa, nematodes, mites, springtails, rotifers, tardigrades, insects, spiders, worms, snails and slugs (Nardi 2007). A square yard of soil likely houses $10^{12}$ bacteria alone. The **soil is alive** with roots, rhizomes, micro-organisms, and microscopic animals. Organic matter is both an indicator of rich, mature soil and an essential life-giving component.

Young ant hill, over 16 inches (40 cm) tall, in a restored prairie within Waubesa Wetland.

*Photo: P. Zedler.*




*From Nardi (2007)*
*© U. Chicago*

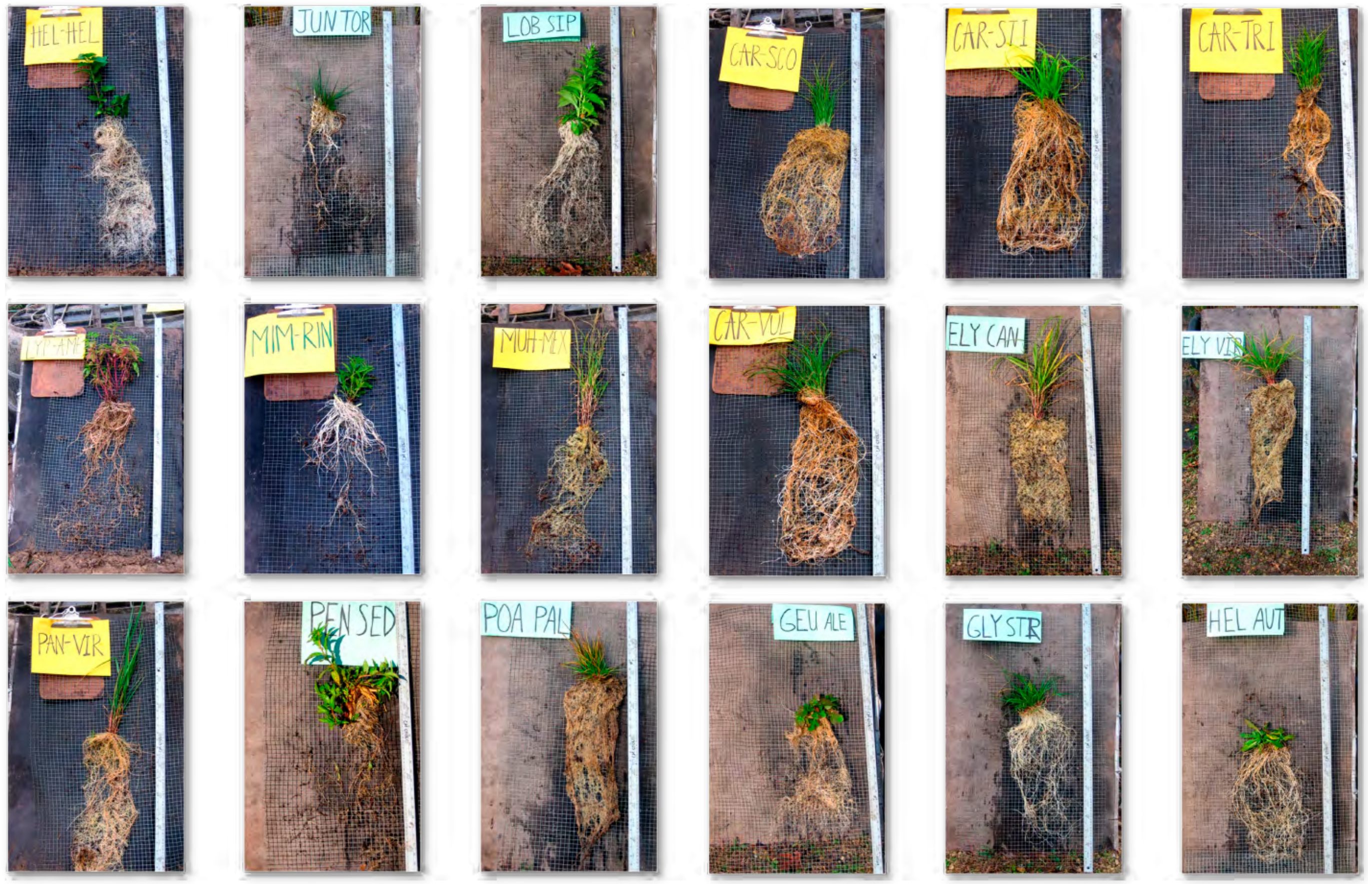



Wetland soil profile with thick, black surface layer.
*From NRCS (2017)*

Topsoil has the most OM. Why? Because it has supported fine-to-coarse plant roots for millennia. One gets a sense of how long it takes for topsoil to accumulate organic matter by monitoring restoration sites that have lost their topsoil. **A century may be needed** for soil organisms to develop, partially break down, and retain soil organic matter (Moreno-Mateos et al. 2012). Are roots important to soil OM? Yes. A plant that looks large aboveground might have more biomass below ground.


Root Washing

1. Choosing a pot
2. De-potted rootball
3. Washing the roots with a coarse sieve (for photos)
4. Washing with a fine sieve (for data)




Washed Roots

In tall pots, wetland plant roots were free to grow deep, but in wetlands, the deeper soil is anaerobic, and plant roots grow best in the top 6 inches. These photos show rooting potential in well-drained topsoil.

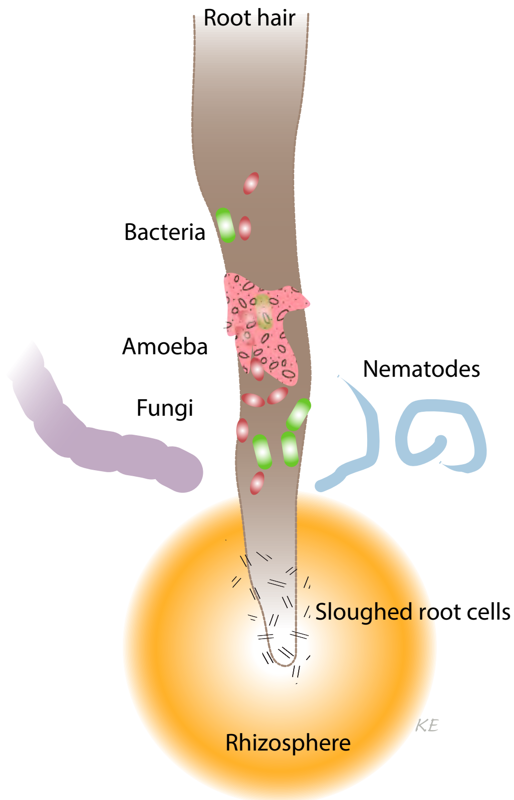
*Photos from Leaflet #15*

If you strain topsoil through a sieve, you'll collect a range of soil aggregates and plant parts, and have a pile of finer particles and fine roots that moved through the mesh. At the Arboretum, we constructed sieves using hardware cloth ($^1/_4$-inch mesh) to separate soil from live roots of 48 native prairie plants in microcosms (tall tree pots). The purpose was to characterize the diverse rooting depths and root architectures of species that might be compatible for restoring wetland ecosystem services (Leaflet #15). We found an amazing diversity of rooting strategies, some shallow, some more than a foot deep; some dense, some sparse. I am grateful to my helpful, and *initially enthusiastic*, U.W. students, who found root washing to be very tedious!

If those same plants had been grown in buckets with water-saturated soil, few roots would have grown a foot deep. The soil would have been anaerobic except close to roots where oxygen would have "leaked" into the soil. Wetland plants are adapted to exploit wet soils. The rhizosphere (see figure on right) not only contains water, and nutrients but also "wetland-specialized organisms. These organisms, which include viruses, bacteria and archaea (such as N-fixers, nitrifiers and methanotrophs), fungi (such as mycorrhizal fungi), protozoa and animals, determine the ecological functioning of the vegetated wetland through their interactions with the roots, with each other and with their inanimate environment" (Neori and Agami 2017).

Low levels of oxygen, high levels of carbon dioxide, hydrogen sulfide and ammonia make wetland soils inhospitable for most other organisms. But bacteria that tolerate anoxia (e.g., methanogens, denitrifiers, sulfate reducers, fermenters) carry out globally important processes. Those that occupy rhizosphere niches where oxygen moves from roots to the soil, increase the diversity and activity of wetland soil biota. Microbial oxidation of ferrous iron and ammonia produces nutrients for the wetland plants, which in turn leak oxygen for the microbes. Soil biota also break down pollutants into non-toxic components (called bioremediation).

The recent review of **rhizosphere biota** (Neori and Agami 2017) identifies an "unrecognized reservoir of wetlands-specific **viruses**" that infect cells of other organisms in unknown ways. "This relatively recent realization has been profoundly changing the perception of biogeochemistry in the wetland ecosystem." Meanwhile, the **bacteria and archaea** are busy producing and breaking down methane (methanogens and methanotrophs) and nitrous oxide (nitrifiers and denitrifiers), and the **fungi** are interacting with selected species to improve plant growth in a mutually beneficial ways. The plant roots provide food to fungi, while the fungi augment nutrient supplies to roots. Those of you who grow orchids know that fungi supply critical nutrients to young seedlings that have not yet developed chlorophyll. The same is true for orchids in native wetlands. Fungi can also detoxify metals (detoxification). Rhizosphere **protozoa and invertebrates** feed on some of the organic leakage from roots (exudates), contributing to the biogeochemical reactor described by Marton et al. (2015). Included among the invertebrates known to like peaty soils are oligochaetes (segmented worms), dipterids (fly larvae), mites, beetle larvae, springtails, and plant-parasitic and free-living nematodes (tiny worms). Wetlands also support uncounted copepods, cladocerans, coleopterans, rotifers, ostracods, chironomid (midge) larvae and molluscs, based on extrapolations from rice paddies, where tube-building (tubificid) worms and chironomid larvae influence wetland functions by burrowing. Burrows can oxygenate water-saturated soils, and




The rhizosphere is the area influenced by leakage from a root. With food on tap, the rhizosphere attracts amoeba, bacteria, fungi, nematodes, small and large bacteria, and more.

*Adapted from Neori and Agami (2017)*

wastes deposited by burrowers can fuel plant growth. With every species making use of most other species' wastes, the task of drawing a food web would challenge even the smartest computer. "The wetland rhizospheres contain specialized microbial and animal populations, which live in symbioses and have various interactions with each other and with the roots. Our understanding of the wetland is incomplete as long as we do not understand these interactions" (Neori and Agami 2017).

Compared to a mostly-mineral subsoil, the wetland topsoil has more organic matter and holds onto more soil moisture. Wetland soils can store more water than upland soils because they accumulate more OM. In return, OM holds water which slows down decomposition, in a positive feedback relationship:


We liken organic soils to "sponges." And we know that, when those sponges are drained and cultivated, their water-holding service is greatly diminished. In explaining why the Mississippi River Basin historically retained much more water than it does today, Hey and Phillipi (1995) estimated that the **topsoil** (upper 18 inches) **absorbed about a third of each inch of rainfall.** Today, the capacity is a mere 0.04 inch of each inch of rainfall, because so much wetland area and its organic soil has been lost.

Historically, the 15,000-year-old Yahara River watershed converted the surface of glacial till into OM-rich soil. In the wetter areas, productive sedges deposited litter that accumulated as peat (see map in Chapter 1). Like the persistent OM of many soils, the peat in sedge meadows is **stored carbon**. How much peat? In Waubesa Wetlands, Friedman et al. (1979) measured depth of the peat, obtained carbon-dates from the oldest, deepest peat, and modeled the rates of peat accumulation. The answer was ~180,000 metric tons of peat biomass. And the peat stored more than carbon; every year Waubesa Wetlands also sequestered ~85 kg of phosphorus. All this occurred as the ancient lake bed gradually filled with peat, and the sedge meadow crept lakeward ~3.6 m/yr.

**Soils surrounding the peat in Waubesa Wetland** belong to the Batavia-Houghton-Dresden Series. Following is the Soil Conservation Service's (1978) formal description of Houghton soils, which are common in wet and formerly-wet areas: "The Houghton series consists of deep, very poorly drained, nearly level soils on low benches and bottoms of stream valleys. These soils formed under sedge grasses. Mineral soil material is below the muck at a depth of more than 5 feet. Undrained areas of these soils are frequently flooded for long periods. In a representative profile the surface layer is black muck (sapric material) about 15 inches thick. The middle layer is very dark brown and dark yellowish-brown muck (sapric material) about 23 inches thick. The lower layer is very dark grayish-brown and dark yellowish-brown muck (sapric material). These soils have medium fertility. The available water capacity is very high, and permeability is moderately rapid. The seasonal high water table is at or near the surface. These soils are very severely limited by wetness." Of course, the writer meant "limited use for agriculture." The **Houghton soils support wetlands and help absorb flood waters.**

## We can't see most ecosystem services

In 2005, over 1,300 scientists from 95 countries documented the many amazing things that ecosystems do. Thus appeared the first-ever global Millennium Ecosystem Assessment (MEA 2005). The MEA authors assessed the status of all Earth's ecosystems and "told it like it is." The results for wetlands were alarming: Global **wetland area had diminished by over 50%,** mostly to drainage for agriculture, and remaining wetlands were highly modified by human actions. For example, so much **nitrogen (N)** fertilizer had been manufactured for use in agriculture and on lawns that microbial denitrifiers could not turn it back into harmless air as fast as it eroded from fields. So much **phosphorus (P)** had been mined from the Earth and used to fertilize crops that surface water runoff was conveying excess amounts to lakes. Substantial amounts of N and P consumed by livestock were being returned to pastures as manure at rates greater than microbes could handle. Ultimately, downstream lakes became eutrophic and algae "bloomed," making the water murky. Disease organisms and organic contaminants, such as pesticides, also spread faster than remnant ecosystems could disperse, sequester, or denature them. **Earth's loss of historical wetlands and their ecosystem services had substantial, global impacts.**

Places where ample wetlands remained could still carry out critical ecosystem services, including trapping nutrients, preventing algal blooms, slowing the flow of flood waters, and reducing erosion. Even though Waubesa Wetlands remained intact, nearby upstream wetlands were drained, cultivated and lost. At right are photos of erosion following recent heavy rainfalls in the Swan Creek watershed. The land is indeed "shedding water," and plenty of soil along with it.

Additional ecosystem services of Waubesa Wetlands are the support of **biodiversity** and **human well-being** (MEA 2005). Each of these general categories involves many specific services, which become clear as soon as a scientist tries to quantify them. As an example in Wisconsin, The Nature Conservancy, DNR and other partners (Miller et al. 2012) used local knowledge of wildlife, topography and hydrological setting to estimate seven ecosystem services (column 1, table next page) for hundreds of wetlands within three Green Bay watersheds. Column 2 lists key attributes used to indicate high levels of each service. Waubesa Wetlands have all these attributes and provide all seven ecosystem services (column 3).

Top: Mud on Larsen Road, flowing toward Swan Creek in July 2014. Bottom: Muddy Swan Creek at Lalor Road in August 2014. The creek is at flood stage and full of suspended clay and silt particles that make the water turbid. *Photos: David Johnson*

| Wetland ecosystem service | Attributes that give wetlands high scores | How we know that Waubesa Wetlands perform these services |
|---|---|---|
| Wildlife habitat* | Varied habitats available, large habitat patches, near other suitable habitats; presence of key species that indicate watershed health | Sustainable presence of diverse birds, mammals, and reptiles; large areas of diverse wetlands and aquatic habitats |
| Fish habitat** | Connected to clean water bodies that are flooded during spawning; adjacent natural land cover for shading and nutrients; the wetland's drainage has substantial natural habitat | Waubesa Wetlands' waters are cool and clean; the marshes are flooded during spawning; shading keeps the water cool; the watershed has woodland and grassland habitats; anglers catch diverse fish |
| Flood abatement | Sites can abate floods if they receive floodwaters due to steep slopes, concrete surfaces, and inflowing creeks; wetlands in depressions with dense vegetation can slow floods | Murphy's Creek has large areas of adjacent wetlands that can absorb agricultural runoff; Swan Creek is more altered; runoff has less wetland area to flood, so water flow is likely rapid |
| Surface water supply | Headwater wetlands discharge groundwater; floodplains retain floodwater and release it slowly | Big springs and seeps convey groundwater to wetlands and Lake Waubesa's toe |
| Water quality protection | Sites can treat surface water if they receive urban and agricultural runoff. Densely vegetated wetlands with fluctuating water levels can remove contaminants | Waubesa Wetlands' large wetlands can "treat" some of the agricultural runoff; Swan Creek has less wetland area, but restoration is underway upstream |
| Carbon (C) storage | Deep, organic soils store ample C below ground; dense woody vegetation stores C above ground | Waubesa Wetlands has up to 95 feet of peat in places; woody vegetation and sedge tussocks store C above ground |
| Shoreline protection | Wetland vegetation can protect shorelines that are adjacent to lakes with waves or fast-flowing rivers | Waubesa Wetlands' rooted and floating vegetation anchors Lake Waubesa's shoreline |

*For wildlife habitat, Miller et al. (2012) used the Wildlife Tool (Kline et al. 2006) and local expertise to locate key habitats of representative birds, mammals, and reptiles. The Wildlife Tool anticipates likely areas for target species, then ranks sites based on likely habitat and life-history needs for those species using DNR's Natural Heritage Inventory and other sources.

**For other services, Miller et al. (2012) considered opportunity for, effectiveness of, and likelihood that a site benefits people.

It is common to read long lists of services performed by wetlands, but **not every wetland provides every service**, and **the amount of each service varies among wetlands** (Woodward and Wui 2001). Tussock meadows, however, supply multiple ecosystem services, described at the end of this chapter. First, however, let's see what can be learned about six ecosystem services that we actually measured in our Arboretum study of vegetated swales (Doherty et al. 2014, Leaflets 27–28). This study is unique, because investigators from three disciplines (ecohydrology, plant ecology, and bioengineering) collaborated to measure six ecosystem services:

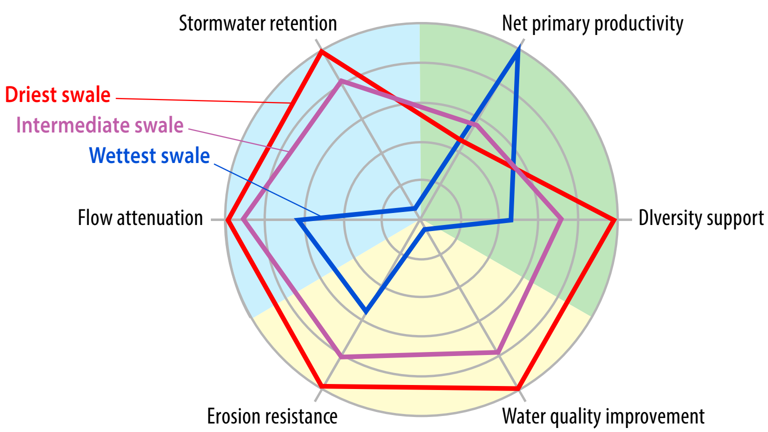
1. Flood peak reduction
2. Surface water retention
3. Plant productivity
4. Plant diversity support
5. N and P retention
6. Erosion resistance

We found a trade-off, namely that productivity was high when all five other services were low (see radar diagram at right). The wettest swale was dominated by cattails and highly productive, while the other swales reduced flood peaks more effectively, supported more plant species, retained more N and P, and more effectively reduced erosion. Plant productivity is often considered desirable for its ability to support food chains, but in this case high productivity of cattails suppressed plant diversity.

In the Millennium Ecosystem Assessment (MEA 2005), ecosystem services were grouped into 4 categories: Provisioning, supporting, regulating, and cultural. Like most attempts to classify functions into separate categories, the lines that separate them are blurry. One issue is where to put "biodiversity support," which depends on other ecosystem services. Here, you'll find it under supporting services with some cross-referencing.

**Provisioning** services supply useful products, such as water, food and building materials. In Madison, most drinking water is provided by deep wells that draw groundwater from precious aquifers underground. The toe of Lake Waubesa receives clean groundwater from Bogholt Deep Spring. The permanently flowing springs are cool and prevent the lake's toe from freezing, thereby adding overwintering habitat for fish, ducks and geese (Bedford et al. 1974). Waubesa Wetlands supply ample fish (for anglers) and game (for hunters and trappers). Game (ducks, geese, turkeys, and deer) is estimated from DNR hunting licenses. Waterfowl include both migratory and nesting species. Mallard, Blue-wing teal and Wood duck all use productive habitat adjacent to open water.

Healthy wetlands supply multiple ecosystem services.
*Photo: Nadia Olker*




Radar diagram of six ecosystem services showing a tradeoff between high plant productivity and the other five measured services
*From Doherty et al. (2012)*

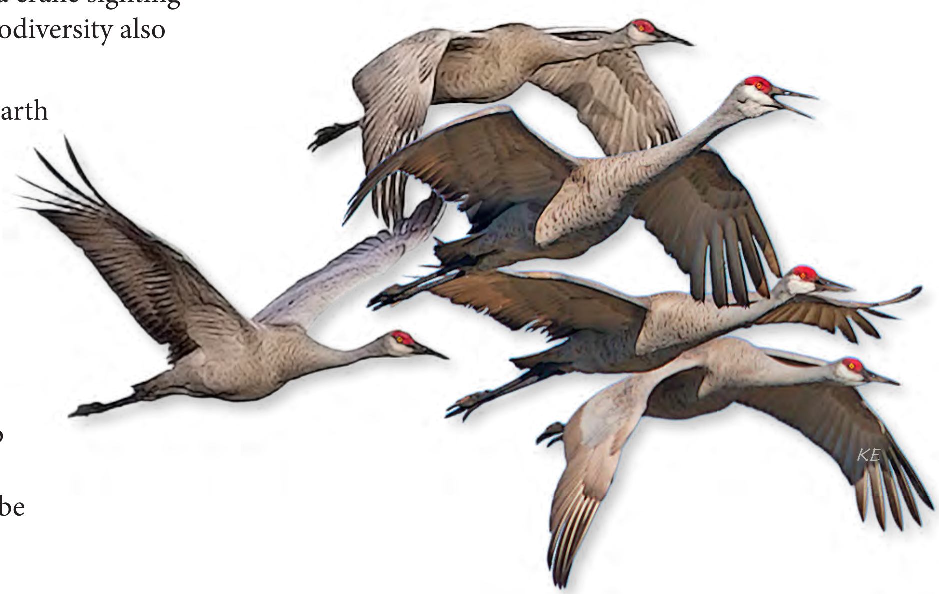
**Supporting** services are basic processes, like cycling nutrients, forming peat, and capturing sunlight to produce biomass. If you watch sedge meadows weekly, as I do, you can almost see the leaves grow from March to late June (Zedler 2016). But if you only glance at the canopy a few times, you can still see increases in canopy thickness from a few overwintering spikes in early spring to a mass of green leaves in late June. To quantify the process, ecologists harvest, dry and weigh biomass at the end of the growing season.

Sedge meadow canopy in Waubesa Wetlands

*Photo: J. Zedler*

Groundwater-fed wetlands support high biodiversity, with some species mentioned above as provisions for people. The continuous outflowing of clean, clear, cool waters supports diverse wetland communities that in turn support diverse species. Nine **endangered species** use the area: Black tern, Peregrine falcon, Blanchard's cricket frog, Silphium borer moth, Rusty patched bumblebee, Eastern prairie white-fringed orchid, Hall's bulrush, Purple milkweed, and Hairy wild petunia. So, if you enjoy spotting rare species, birdwatching, hunting, fishing, trapping, canoeing, or boating, Waubesa Wetlands have lots for you to see and appreciate. For many residents of the Town of Dunn, it is the Sandhill cranes that are most appreciated—even when we can't spot a pair or small group flying overhead, we can hear the cranes' unique bugling calls. Sandhill cranes were close to being extirpated in Wisconsin during my graduate school years at UW-Madison; as a result, a crane sighting or a call in the distance always makes me smile. These are reasons why biodiversity also belongs in the cultural service category.

**Regulating** services span a range of processes that tend to keep the Earth stable, such as protecting shorelines, storing carbon in peat and tussocks, reducing flood peaks, and improving the quality of surface water. Wetlands and clean water depend on each other: Wetlands occur only where water accumulates, and the water that accumulates allows microbes to denature contaminants, making dirty water cleaner. Both anaerobic and aerobic species contribute to this process, as anaerobic soils have pockets of oxygen near leaky roots and animal burrows. Throughout Wisconsin, wetlands work to provide clean lakes where we can swim without getting sick. But because microbes can't always keep up with the "dirt" that gets into our surface waters, the U.S. Environmental Protection Agency regulates the types and amounts of materials that can be dumped into surface waters, including wetlands.



As soon as Madisonians turn on a faucet, groundwater becomes surface water. What happens next? Whether that water gets wasted or used carefully, it soon gets "dirty." Some cleansing occurs at the treatment plant, but even treated water is not as pure as our groundwater, because treated water contains nutrients and other contaminants. When treated water leaves the Nine Springs Treatment Plant, there is still plenty of work for microbes in downstream wetlands. That work is one of the regulating services.

Note the murky water offshore *Photo: Nadia Olker*

Cleaning surface water is a major service provided by wetlands. Clean water is the basis for legally regulating the "waters of the U.S." We don't protect wetlands just for the fun of it or just to slap on regulations. **We protect wetlands to sustain our own health and well-being.**

Germ-reduction services might also occur, but those processes are really hidden. A recent study of submersed aquatic vegetation in Malaysia (Lamb et al. 2017) revealed for the first time that seagrass beds purify coastal water that is contaminated with human pathogens. Water flowing around densely populated islands with seagrass beds had far fewer pathogens than islands without seagrass beds, as estimated from pathogen indicators. What other priceless ecosystem services await our discovery in the submersed vegetation of Waubesa Wetlands? Do other wetland types have this or other hidden services?

Floodwater is absorbed by the organic, water-absorbent tussocks and all their surface area (40% greater surface area than flat land). Their abundant litter also absorbs and slows flows.

Tussock meadow *Photo: J. Zedler*

**Cultural** services include recreation, aesthetic and spiritual benefits, all of which are provided by Waubesa Wetlands. Consider its historical artifacts in peat and effigy mounds (a living museum), its open space and scenic views, and opportunities for birdwatching, canoeing, research, and education. For all these services, citizens voluntarily protect Waubesa Wetlands with conservation easements. "The Town's natural resources are extremely important to its character and the health and vitality of the entire region. The Town is blessed with abundant water, wetland and wildlife amenities and it has worked hard to protect these important resources and will continue to do so. Town residents support open space conservation and resource protection. There are many opportunities to safeguard the features people love about Dunn…" (Comprehensive Plan A-25 VI. Natural Resources Inventory).

The wetlands support human well-being by providing green surroundings, open space, aesthetic views, quiet walks, and an escape from the stresses of the office. They also attract ecotourism, including boating, canoeing, and a lakefront restaurant. Plus, they have supported a century of science and education (Chapter 1).

## Globally-significant ecosystem services deserve extra attention

**Carbon storage** and **denitrification** are ecosystem services that Waubesa Wetlands supply. Both are critical for human well-being; both have global effects, and both tend to be wetland dependent, in that their rates tend to be especially high where conditions are anaerobic. At the same time, studies of these services are evidence of a third globally-important cultural service, namely, the support of **research**.

*Photo: Nadia Olker*

**Peat stores carbon and helps slow global warming.** The Marsh, Sedge meadows, Fen, and Shrub-carr communities occur on top of deep peat deposits (up to ~95 feet thick). Storage occurs because major springs and seepages keep the peat wet and anaerobic continuously, so the organic matter does not decompose. So long as the peat stays wet, it will permanently store carbon.

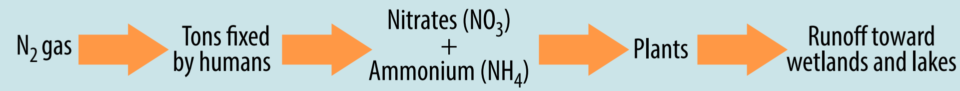
Where does all that peat come from? Refer to the pollen diagram in Chapter 1, and note the abundant sedge pollen in the most recent peat deposits (top of graph). The pollen tells us that sedges have been dominant in recent centuries. Sedges support animals, but more as habitat than food, as there is little evidence of grazing. Less grazing means more litter production and more storage of carbon as peat. High productivity of tussocks leads to lots of litter with carbon that can be stored long-term belowground. And Tussock sedges also store substantial carbon aboveground in their tussocks (Lawrence and Zedler 2011, 2013). Our 2013 study found that naturally-occurring tussocks were tall (6.8 inches; 17.2 cm), large (about 1.5 cubic ft; 4,113 $cm^3$), and mostly organic (95%). Tussocks were second only to soil in containing C; they comprised 41–62% of the C present in biomass. Lawrence also found that more C was stored in natural tussock meadows than urban and restored meadows. That justifies the need to protect tussock meadows for C storage, as well as for other ecosystem services.

**Hydrological research on peat mounds catalyzed ecosystem science.** Kratz, Winkler and DeWitt (1981) were among the first researchers to report peat mound formation in the U.S., and their work stimulated others to learn how ecosystems develop—ecosystem science emerged with a focus on processes, not just biodiversity. The phenomenon of a large (7.4-acre) “wetland on a hilltop” caught the researchers’ attention—how could that be when wetlands were supposed to develop in depressions? They learned that groundwater upwelled near the terminal moraine of the Wisconsin glaciation, and the wetlands accumulated litter and peat vertically over thousands of years. The peat mound has a steep slope (~6 feet high: 40 m long) but no underlying lake sediments, while adjacent wetlands formed in a lake basin. A 16-foot-deep core extracted from the peat mound was dated using standard methods, and its pollen composition recorded 6,770 years of vegetation change (Friedman et al. 1979; see pollen diagram in Chapter 1).

Over the adjacent former bed of Lake Waubesa, cores of even deeper peat provide a virtual library of wetland-formation history dating back over 12,500 yrs. The earliest deposition was mineral soil with spruce pollen. Peat began forming about 7,500 years ago. Charcoal layers indicated fires that likely sustained nearby oak savannas. This early research on peat formation and pollen deposition was globally significant in catalyzing subsequent studies of ecosystem functioning.

**Biogeochemical reactors.** Waubesa Wetlands occur in the low point of two watersheds (Swan and Murphy’s creeks), where inflowing surface water and outpouring groundwater keep the soil wet. Where the soil is aerobic, plants mostly take up nitrates ($NO_3$); where it’s anaerobic, plants mostly take up ammonium ($NH_4$). Either way, the plants incorporate the N into organic matter and supply food to hungry consumers. In the soil and water, consumers excrete N in organic forms. Wetland micro-organisms are unique in being able to return nitrates and ammonium to nitrogen gas ($N_2$), which comprises ~80% of the air we breathe.

Fertilizer factories fix enormous quantities of nitrogen gas ($N_2$) into nitrate ($NO_3$) and ammonium ($NH_4$) fertilizers, that farmers add to crops and city-dwellers add to their lawns:




When the “fixed N” flows into a wetland, the denitrifying bacteria can reverse that process:


**Denitrification reverses some of the harm caused by manufactured fertilizers**. Recall that a comment about nitrogen is what led me to nominate Waubesa Wetlands to become a Ramsar Wetland of International Importance and then to write this book (see preface). I thought: Why wouldn’t Waubesa Wetlands have a global influence on nitrogen? Wetlands are not just biodiversity hotspots; they are also “biogeochemical reactors” (Marton et al. 2015).

We don’t face a shortage of $N_2$ in the air, but we do face an excess of fixed N on land and in the water. Denitrifiers do what they can but are overwhelmed by the rate of human fixation of N to make fertilizers. The N problem gets more publicity along marine coasts, where excess N causes dead zones. But with increasing episodes of toxic algal blooms, the press is beginning to mention that N pollutes streams and lakes. They still don’t mention that N pollutes wetlands, but eventually, they’ll learn that **eutrophication is not just about P, but also N, and not just about lakes but also wetlands.** Here’s progress: The need to manage both N and P was recently acknowledged by EPA (2017).

Wetland soils can denitrify nitrates and ammonium, but upland soils cannot, because upland soils are aerobic most of the time. Denitrification depends on anaerobic bacteria in anaerobic conditions, although it's not quite as simple as that sounds. The denitrification ecosystem service is a specialty of the biogeochemical reactors that we know as wetlands. And, because wetlands cover less than 10% of the Earth, the critical job of denitrification is left to a small fraction of the Earth. In relative terms, we think of uplands and oceans as globally important, but wetlands are at least an order of magnitude more important per acre for their denitrification work. Wetlands keep loads of nitrates from contaminating our drinking water, from polluting our streams, from eutrophying our lakes, and from causing even larger dead zones (see box) along our coastlines. The regulatory standard for nitrate in drinking water is 10 mg per liter; to achieve that level, we need help from denitrifying microbes.

**Why the Gulf of Mexico has a Dead Zone the size of ~~Massachusetts~~ Oops; in 2017 it grew to the size of New Jersey**.

First, the Mississippi River basin is immense; it covers 41% of the lower 48 states, including most of Wisconsin. Whatever is dumped onto the land or into the waters of that enormous basin can potentially make its way to the Gulf of Mexico. That includes nutrients and manure dumped on fields, fertilizers dumped on lawns, nutrient-rich leaves that are swept into street gutters, and nutrient-containing wastes that we flush down our drains. Even though wastewater flows first to treatment plants, for pathogen removal and some nutrient removal, plenty of nutrients are left to flow downstream toward the Gulf.

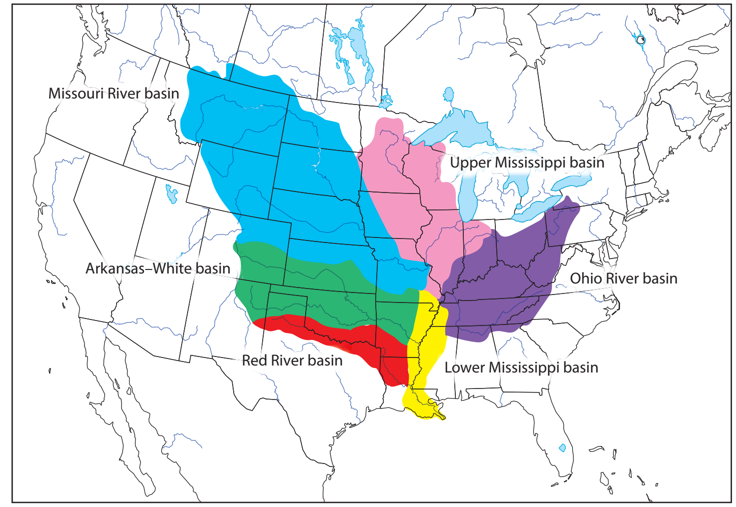
Second, the extensive Midwestern wetlands that would have denitrified nitrates and settled out phosphorus were drained and mostly converted to agriculture. From the 1780s–1980s, over 35 million acres (14.1 million ha) of wetlands were lost in just 7 states (IN, IL, IA, MN, MO, OH, and WI) of the 31 states that contribute runoff to the Mississippi River Several of Wisconsin's neighboring states lost ~80% of their historical wetland areas (Dahl 1990)—along with their biogeochemical reactors. With wetlands drained, large "nutrient sinks" were lost, and with farming, they became sources of N and P.

Third, the N in water that enters the Gulf is primarily what causes marine algal blooms, because there is already plenty of P in coastal waters. So algae flourish, then die and decay. Then, as the bacteria responsible for decomposition consume all the available oxygen, the Gulf becomes anoxic. It doesn't help that the inflowing, N-rich water has been warmed during its journey down the Mississippi River—since warm water floats and holds less oxygen than cold water. The result of decomposition and warm water is a low-oxygen (hypoxic) zone. Although it is full of microbial life, it is called "dead" because fish and shellfish can't survive there. In short:

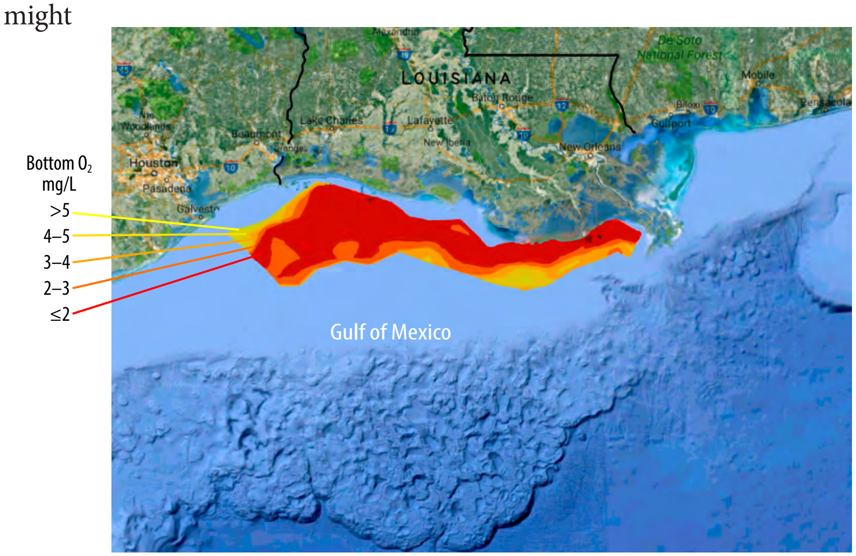
Nutrients → Algal blooms → Decomposition → Hypoxia → Dead Zone

**On June 16, 2017,** Professor Nancy Rabalais of Louisiana State University updated the estimate for this year's Dead Zone. Due to above-average nitrogen loading (higher N concentrations and higher water levels) flowing from the Mississippi River into the Gulf, she expects the Dead Zone to cover over 10,000 square miles (26,000 $km^2$) (www.livescience.com/59594-gulf-of-mexico-dead-zone-could-double.html). Fishing and shellfishing will be impaired along the Louisiana and Texas coasts. Can such a huge problem be solved? In August, a new model predicted that 59% reduction of the Mississippi River's nitrogen load would be needed to meet the 5,000-$km^2$ target of an intergovernmental task force (Scavia et al. 2017).

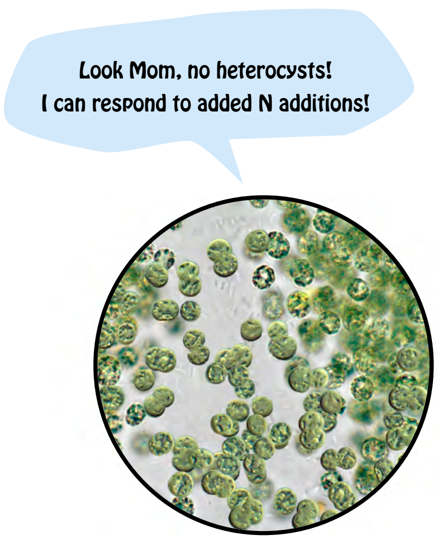
**How might adding N trigger *toxic* bluegreen blooms?** Bluegreen algae (cyanobacteria) can fix their own N, so there should be plenty of N in our lakes. However, not all bluegreen algae can fix N—the ones that lack **heterocysts** (chlorophyll-free cells where N-fixation can occur in anaerobic conditions) can't fix N. *Microcystis* is an example. It is common in Lake Waubesa, and if *Microcystis* is present, some of its strains can be triggered to produce toxins. When the *Microcystis* population grows rapidly, it can use up the lake's dissolved N and "run out." If P is still abundant, any inflow of N-rich water can stimulate further bluegreen algal growth (Paerl 2015). When and why does an algal bloom produce toxin? The answer might occupy entire careers of future algae specialists (phycologists)!



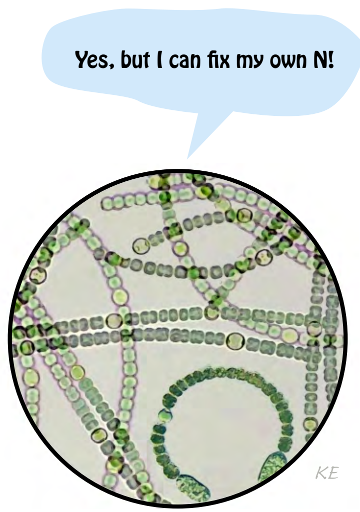

Mississippi River basin




The Dead Zone in late July–early August 2017; red equals most anoxic
*Adapted from King (2017) and Google Maps*




*Microcystis*




*Anabaena*

Toxins are a real and growing threat, not just to ecosystems but also to human health. Several years ago, a Wisconsin teenager died from bluegreen algal toxins in a golf-course pond, according to the online coroner's report. And in 2014, Toledo lost its drinking water when Lake Erie developed a toxic bluegreen bloom. Toxic algae were sucked into the intake pipe, and microcystin or other cyanobacterial toxins poisoned the city's water supply (IJC 2014). In summer (June 2017), a toxic bloom in a reservoir in Lake County, Oregon, killed 32 cattle (https://www.epa.gov/sites/production/files/2017-07/documents/habs-newsletter-jul-2017.pdf).


Closer to Waubesa Wetlands, Lake Mendota experienced a toxic bluegreen bloom on June 16, 2017, after heavy rains washed excess agricultural fertilizers, manure and other contaminants into the lake. Fish and ducklings were killed by anoxia and toxins.

The risk of toxic algal blooms increases with the area and duration of eutrophic conditions. Lake managers can only reduce risks of toxic blooms by controlling inflows of both **N and P** (EPA 2015).

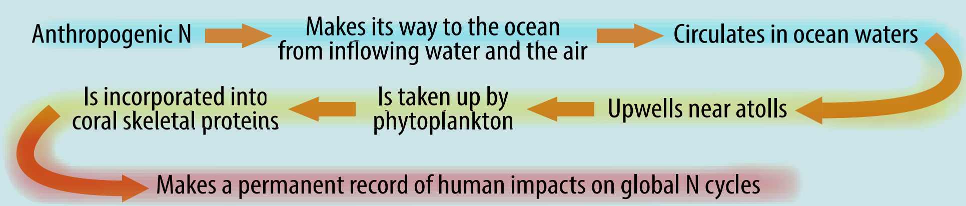
Authors who monitor Southern California coastal waters wrote, "The global proliferation of toxin producing cyanobacterial blooms has gained international attention in recent years. These increases have been attributed to a wide variety of environmental factors including nutrient pollution, increased temperature, salinity, water residence time, vertical stratification, and pH, many of which will likely be exacerbated by climate change" (Howard et al. 2017). Their alarm bell on climate change echoes earlier warnings from Hans Paerl (Paerl and Huisman 2009, Paerl and Paul 2012).

**Nitrogen loading will increase with climate change.** In July 2017, researchers from Stanford and Princeton universities used a new simulation model to predict that increased rainfall extremes, i.e., more precipitation and more frequent, more intense storms, will lead to much greater N loading at both watershed and regional scales: "We conclude that changes in precipitation patterns will have substantial impacts on nitrogen loading within the continental United States" (Sinha et al. 2017). Other studies had predicted increased N loading based on increased use of N fertilizers and land use intensification,


Death by algal bloom

*Photo: J. Vander Zanden at: blog.limnology.wisc.edu/madison-in-bloom-blue-green-algae-hits-lake-mendota/*

**"Nitrogen pollution knows no bounds"** (Boyle 2017). In *Science*, marine geochemists explained how increasing pollution of the ocean is caused by anthropogenic N. N from fertilizers and fossil fuel combustion has a characteristic isotopic "signature" (meaning that compounds with N have more of the light isotope, $^{14}$N, relative to the heavier isotope, $^{15}$N; Boyle 2017). Where could researchers find a record of increasing anthropogenic N? They'd have to look in some structure that incorporated N over decades without decaying. Where to look? How about corals in the South China Sea? Ren et al. (2017) looked in proteins in coral skeletons in Dongsha Atoll and measured isotopes of N over a 50-year core. Sure enough, they found increased anthropogenic N from 2000 to present, and the annual increases were as much as 20% per year. In short, the Dongsha Atoll coral has **more anthropogenic N now than historically.** The conceptual model is that:



which led these authors to focus on effects of increasing rainfall during three climate-change scenarios. For our **Upper Mississippi River Basin**, the model predicted a **24% increase in N loading.** "Overall, we find that regions with high historical loading (which correspond to regions with high nitrogen inputs and high precipitation) and a robust projected increase in precipitation are most likely to experience a large and robust future increase in nitrogen loading, at both the watershed and regional scales." These results are important, because farmers and lawn managers can alter their applications of N and other practices, but no one can control rainfall. Knowing that future rainfall alone will increase N loading makes it more important for humans to reduce N additions and loss through erosion.

Waubesa Wetlands' role in denitrification is globally important and increasingly so (Sinha et al. 2017). Why? Because humans keep "fixing" $N_2$ from the air to manufacture more N-fertilizers, which are applied to crops around the world. We also use vehicles and planes that emit nitrogen oxides, and we burn fossil fuel in power plants. All release "anthropogenic N" to the water or air, making a big job for denitrifiers. As we humans expand our impacts, and as the world's wetlands continue to shrink in area, Waubesa Wetlands become ever more important…regionally, nationally, and globally. Bottom line: **We humans are really altering the global N cycle, so it's globally important that Waubesa Wetlands' denitrifiers help reverse the problem.**

## Wetlands provide more ecosystem service than other ecosystems

**Can this be true?** Yes! On a global basis, the estimate of Costanza et al. (1997) was that all ecosystems provided services worth $33.268 trillion per year—with $13.165 trillion per year of that total coming from wetlands! Thus, 39.6% of annually renewable ecosystem services were estimated to come from wetlands that occupy less than 10% of the Earth's surface! And while many readers were skeptical about that $33 trillion number, the same authors reaffirmed their calculations in 2014. Their new estimates are actually higher, based on new data on land uses from 1997 to 2011 and more information on ecosystem services (Costanza et al. 2014).

**The Value of Wetland Services** (based on Costanza et al. 1997)

| Renewable ecosystem service | | $/ha/yr | $billion/yr |
|---|---|---|---|
| Hydrologic services | Water regulation | 15–30 | |
| | Water supply | 3,800–7,600 | |
| | Gas regulation | 38–265 | |
| Water quality services | Nutrient cycling | 3,677–21,100 | |
| | Waste treatment | 58–6,696 | |
| Biodiversity services | Biological control | 5–78 | |
| | Habitat/refugia | 8–439 | |
| | Food production | 47–521 | |
| | Raw materials | 2–162 | |
| | Recreation | 82–3,008 | |
| | Cultural | 1–1761 | |
| | Disturbance regulation | 567–7240 | |
| Global totals | Coastal wetlands | | 8,286 |
| | Inland wetlands | | 4,879 |
| | Total for global wetlands | | 13,165 |
| Total global ecosystem services for entire globe | | | 33,268 |
| Percentage from wetlands | | | 39.6% |

*All shallow water habitats (tidal marshes and mangroves, swamps and floodplains, estuaries, seagrass/algal beds, and coral reefs) are included in this calculation.*

*From: Zedler (2003)*

"Wetlands are the powerhouses of the natural world. They provide critical habitat for wildlife and play pivotal roles in ecosystem processes, often to a much greater degree than the lands that surround them. Wetlands provide the 'green infrastructure' necessary to sustain healthy communities and economies—protecting water quality, maintaining water supplies, and reducing flooding issues. All wetlands provide important ecological services for people and wildlife, and the benefits of a wetland-rich landscape are valuable and varied. Clearly, loss of wetlands through draining or filling has high costs for people and nature."

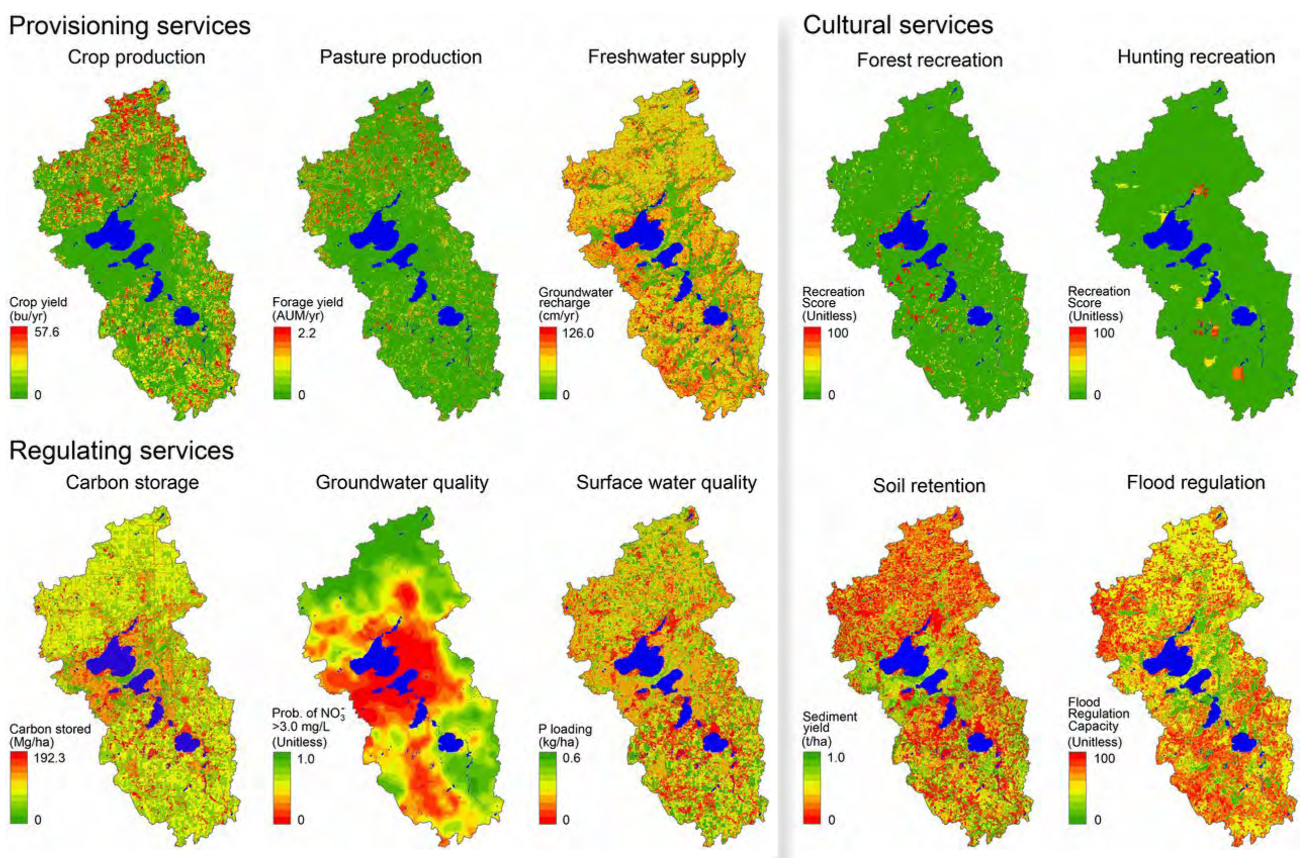
*From: Miller et al. (2012)*

## Returning from global to regional estimates of ecosystem services

**Ten ecosystem services were estimated for the Yahara River Basin.** Qiu and Turner (2013) used a variety of methods to estimate 10 ecosystem services for wetlands and uplands throughout the watersheds of the chain of four lakes. Look for Waubesa Wetlands in the upper right map; note the yellow dot that indicates high levels of the "Hunting recreation" service in a basin with large areas of private, cultivated and urban land.

Maps that are based on estimates don't always agree with other definitions and measures of ecosystem services. Their value is in suggesting broad patterns. For example, crop production and water quality are usually not found in the same location, "indicating that management to sustain freshwater services along with other ecosystem services will not be simple" (Qiu and Turner 2013). Finding the key to co-existence of agriculture and clean water is a priority for future research.

Overall, the authors documented varied spatial patterns of ecosystem services—no single spot or subregion was greatest in all services or lowest in all services. This led them to recommend "managing over large areas to sustain multiple ecosystem services." I couldn't agree more! Watershed approaches are essential for determining effects of upstream land uses and climate change (see Chapter 6) and for developing solutions to negative impacts (see Chapter 7).




Supplies of 10 ecosystem services estimated by Qiu and Turner (2013, using ~100-ft [30-m] pixels) throughout the Yahara River Basin. Red indicates high supply (i.e., hotspots—sometimes considered positive, sometimes negative); green indicates low supply.

*From: Jiangxiao Qiu and Monica G. Turner. 2013. Spatial interactions among ecosystem services in an urbanizing agricultural watershed. PNAS 110[29]: 12149–12154*

## From regional to Waubesa Wetlands' services

Why do Waubesa Wetlands provide so many services? One reason is **tussocks!** Tussocks are most conspicuous in winter, when sedge leaves and associated plant species have collapsed, but they are even more obvious after a "management burn" (deliberate use of fire to curb shrub and tree invasions). The components of Tussock sedge (*Carex stricta*) tussocks were recently quantified in natural Sedge meadows of nearby Cherokee Marsh and a site in Walworth County (Lawrence and Zedler 2013). As Lawrence's pie chart shows, the tussocks are **primarily organic**, composed of roots, rhizomes, stem bases, leaf bases, and undecomposed duff; they are not accumulations of soil particles (as in ant mounds).

The tussocks make Tussock sedge a "talented species" that simultaneously **stores carbon, supports biodiversity, improves water quality, and attenuates flood peaks:**

• Because tussocks are mostly (90%) organic, and because half of the Waubesa Wetlands' area is Sedge meadow dominated by Tussock sedge (see Chapter 2), Waubesa Wetlands gain global importance in carbon storage (Lawrence and Zedler 2013).

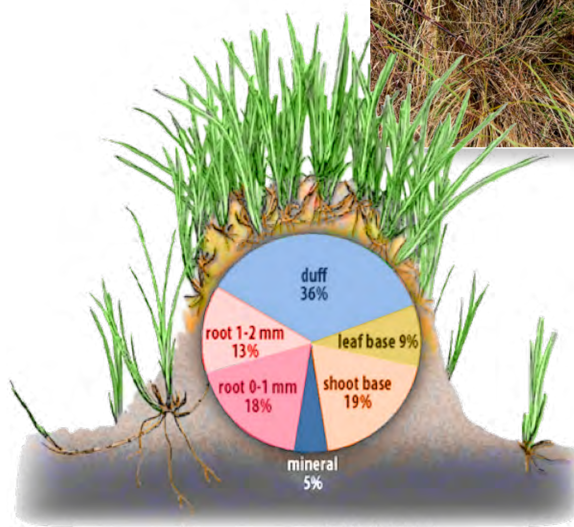
• Tussock topography adds ecosystem services. A tussock meadow averages 4–5 tussocks per square yard, each half a foot tall on average, and adds ~40% surface area to an otherwise flat plot (Peach and Zedler 2006). The bumpy land surface slows surface water flows, allowing more rainfall and runoff to infiltrate than would occur on a flat surface.

• Tussock microtopography facilitates the removal of N through denitrification (Wolf et al. 2011).


• Tussocks of a related species (*Carex acuta*) suppress methane emissions when water levels are low but not when soils are flooded (Jitka et al. 2017). This new study from the Czech Republic indicates that tussocks' aboveground air spaces are part of a "ventilation system" that includes roots that transport oxygen from aboveground to the soil during low water levels. Methane is an especially potent greenhouse gas that wetlands can emit when soils are anoxic. In the presence of oxygen, methane is readily oxidized to harmless carbon dioxide and water. I hypothesize that Waubesa Wetlands' tussock meadows reduce methane emissions, relative to continuously-inundated marshes, by having a short early-spring inundation and long summer-drawdown period. Local research is needed to test this idea.

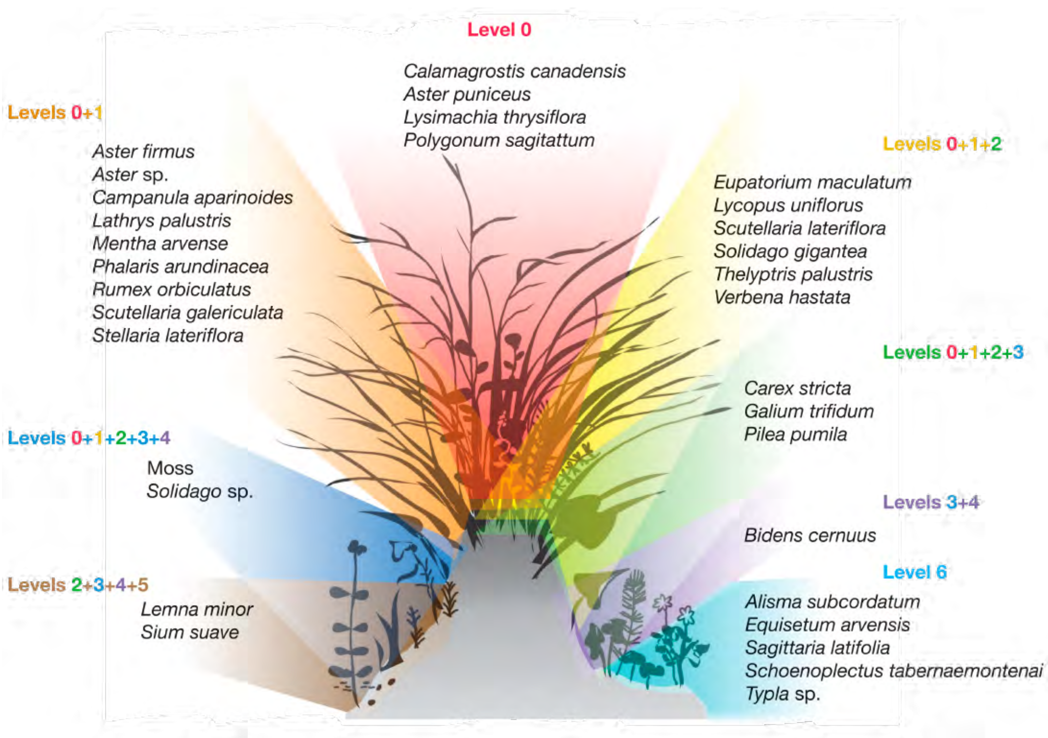
Tussocks in spring and fall

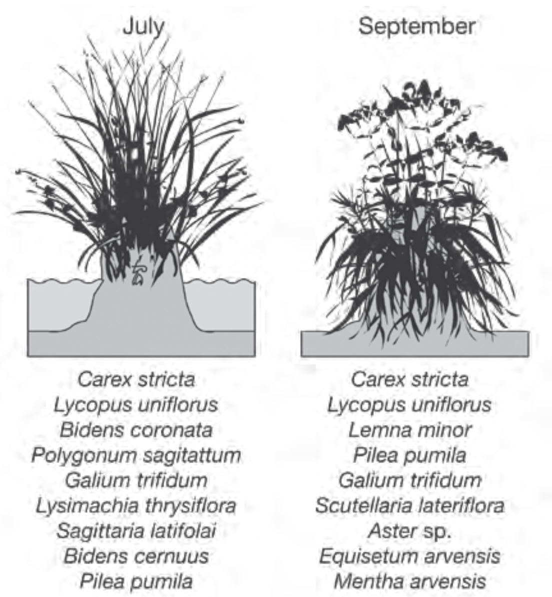
*Photos: J. and P. Zedler*



• The tussocks of Tussock sedge support biodiversity by providing diverse microsites that are used by up to 16 additional plant species (Peach and Zedler 2006). Tussock meadows form a matrix for a diverse plant community (Frieswyk et al. 2000). Tussock sedge also shares the growing season—dominating early and achieving maximum leaf length by June, then yielding to other forbs, such as asters and goldenrods, that overtop the sedge leaves in late summer (data in Zedler 2016). Biodiversity support also extends to small mammals, such as voles, which nest at the tussock bases, and some birds that nest on tussock tops.


Meadow vole




*From: Peach and Zedler (2006)*

## How might the Midwest regain more wetland ecosystem services?

**Let's restore tussock meadows!** Recall that Bedford et al. mapped ~80 acres of Waubesa Wetlands as disturbed by cultivation, followed by invasions of Reed canary grass. While invaders are notoriously difficult to eradicate, new approaches could be tested in small plots and promising actions implemented at larger scales. Michael Healy tested a grass-specific herbicide in small plots in a near-monoculture of Reed canary grass that had invaded a tussock meadow in Waubesa Wetlands, and while the results were not overwhelming in the short-term, the long-term outcome is greater plant diversity (Healy and Zedler 2010; plus a decade of observations by JZ).

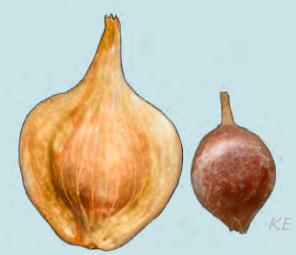
Would sedges be a suitable restoration target? Many of Earth's **~2,000 sedges*** produce **tussocks**. The champion in Wisconsin is Tussock sedge (*Carex stricta*). It's no accident that this species has such widespread dominance in our near-pristine wetlands—it grows very well where water levels are high in springtime and lower as the growing season progresses. This species' historical dominance across the Upper Midwest region is further evidence that it is competitive—but, unlike invaders, it doesn't displace other species. Frieswyk et al. (2008) called it a "matrix dominant" because it could dominate without excluding other species.

I call Tussock sedge **a restoration superplant** because it has several attributes that it make a high priority for wetland restoration in Wisconsin and nearby states. Its useful attributes begin with its ease in germination, propagation from seedlings and plugs containing rhizomes, rapid establishment and vegetative (clonal) expansion. Advice on propagation was developed by Gallagher (2009; Leaflet #22).

The many ecosystem services of tussocks suggest to me that Sedge meadows should be protected from grazing, trampling, and routine prescribed burning (e.g., when tussocks are dry). I reason that if small tussocks are functional, taller tussocks will be more functional. And my study of tussock phenology in Waubesa Wetlands verified that tall tussocks produced more flowers and seeds than short tussocks (Zedler 2016)—it pays to be tall!

As an initial test of the importance of being tall, Jim Doherty and I devised a field experiment at the Arboretum (see next page), where he planted Tussock sedge seedlings (~2-year-old plugs) in a wetland with a flat soil surface, a short mound of soil, or a tall mound of soil. (Thanks heaps to Americorps workers for heaping the soil into buckets to create the required mounds.) Over the two-year experiment, short-mound plantings thrived in the year with an unusually dry June, and tall-mound plantings thrived in the year with an unusually wet June.

*Why so many sedges? *Carex* is an unusually diverse genus, with species distributed widely among temperate-zone ecosystems (Hipp 2008). In Wisconsin and Minnesota there are "only" about 150 species, and individual habitats likely have fewer than a dozen (Eggers and Reed 1997). Carpenter (1995) listed 12 *Carex* species from 56 Wisconsin calcareous fens. Even this number is daunting for an ecologist to identify in the field, especially when they are not flowering or fruiting. Those that occur in wetlands often fruit early in the growing season and then disperse their seeds, making identification even harder. Key characters are the size and shape of the perigynium, a tiny but lovely structure that surrounds and includes each seed.




Perigynium and achene (seed) of *C. brevior*

Jim Doherty's field test compared square-yard plots with 5 short mounds to and 5 tall mounds. Tussock sedge seedling plugs were planted to each mound (1 plug/mound).

We concluded that topographic heterogeneity is an effective bet-hedging strategy for restoring Sedge meadow vegetation (Doherty and Zedler 2015). If you plant Tussock sedge over a range of topographic microsites, some plantings should thrive regardless of variable, almost unpredictable, weather.

More field research is needed, with more plantings in a wider variety of restoration sites. In addition, more research is needed on how best to manage and sustain Sedge meadows once restoration is underway. A current issue concerns where and how often to burn meadows with tussocks.

Volunteers helped plant Tussock sedge into a former Sedge meadow that was cleared of invasive woody plants.

*Photos: J. Zedler*

Given the ecosystem services provided by tussocks, should tussock meadows be burned routinely?

**Pro-fire arguments to manage Sedge meadows in general:**

- Prescribe burning to control woody invaders, and confine it to areas where woody plants have invaded and cannot be readily managed by cutting. Even then, keep some areas unburned as refuges.
- Fire releases nutrients, so burning could increase the next season's growth and/or flowering.

**Con-fire arguments for tussock meadows:**

- Tussocks are nearly entirely organic, so fire could consume all parts that are not fully saturated with water. Burning tussocks would release carbon that is or could be stored (Lawrence and Zedler 2013; Lawrence et al. 2013).
- Newly measured spikes emerge in fall and overwinter as stiff shoots up to 5 cm tall (see photo); shoots could lose an early-growth advantage. Short tussocks have disadvantages (Zedler 2016).
- Fire releases nutrients, which could increase invasions of RCG and Cattails, which germinate well on exposed soil.
- Small native animals live among tussocks; fires would incinerate their habitat.
- Tussock microtopography enhances N removal via denitrification (Wolf et al. 2011).
- Tussocks are vulnerable to deer trampling and bedding (Zedler 2016), which we cannot control; fire could add to the disturbances that have already diminished tussock meadows in southern Wisconsin (Zedler and Potter 2008).


Tussock shoots

**In summary**, there is much about Waubesa Wetlands that is difficult to see. I've mentioned the glaciers, the aquifers, water that's clear but not necessarily clean, what's in the soil and what it's doing, and a long list of wetland ecosystem services of local, regional, and global significance. In the coming years, researchers will uncover many more secrets that are hard to see, especially about micro-organisms, such as the sulfur bacteria in Bogholt Deep Spring.

While carbon storage, denitrification, and wetland research all have global significance, it is the sighting of a Sandhill crane, a Comma (butterfly), or a Green darner (dragonfly) that makes my day. I'm sure I'm not alone in being partial to birds and charismatic insects, so let's see what we can learn by "Looking up" (Chapter 4).

# Chapter 4 • Looking up

Let's look upward and learn about the many kinds of birds that can be seen at Waubesa Wetlands, while we figure out how so many flying species can co-exist. Of course, bats use the airways, too, but they come out at night when most birds rest (except for our Owls and Nighthawks). Birds offer endless daytime entertainment, whether you see them from a canoe or on a walk along The Nature Conservancy trail.

## How do so many bird species co-exist in Waubesa Wetlands?

A whopping 194 species of birds are known to occur in Waubesa Wetlands and surrounding habitats and open spaces. Do they compete with one another or complement one another, i.e., do they avoid overlap by using the wetlands at different times and different places? We can't know for sure without experiments, but we can reason how they interact based on observations and studies elsewhere.

Of the 194 birds on record, **73** species **nest** in this wetland and its immediately adjoining lands. And of the 73 nesting birds, **57** species are **international migrants** whose "homes away from the nest" include Mexico, the Caribbean, Central America, South America, and Canada. Another **16** species are **domestic nesters** that live year-round in Wisconsin or move about within the United States.

Birds!

This 2x2 table compares **strategies of nesting** (rows) and **migration** (columns) of 194 species of birds that use Waubesa Wetlands (species lists in Appendix 4, by Calvin DeWitt). Note that in both nesting and non-nesting categories, there are more international migrants than domestic species.

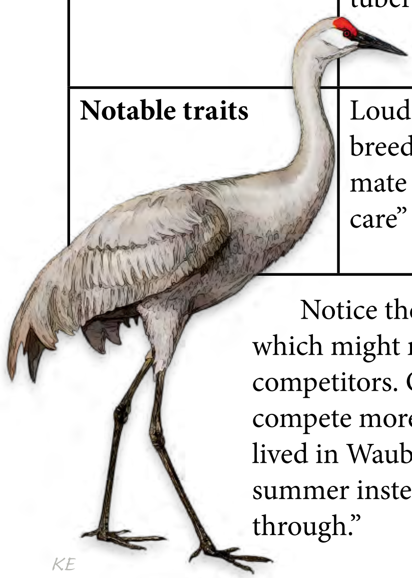
| | Domestic | International migrants | Totals |
|---|---|---|---|
| **Nesting** | 16 domestic nesters (e.g., Wood duck) | 57 international nesters (e.g., Sandhill crane) | 73 |
| **Non-nesting** | 48 domestic visitors (e.g., Tundra swan) | 73 international stopovers (e.g., Northern pintail) | 121 |
| **Totals** | 64 | 130 | 194 |

*Life styles for*
**International migrant nester** • Sandhill crane (*Grus canadensis*)
**Domestic non-nester** • Tundra swan (*Cygnus columbianus*)
**International migrant non-nester** • Northern pintail (*Anas acuta*)
**Domestic nester** • Wood duck (*Aix sponse*)

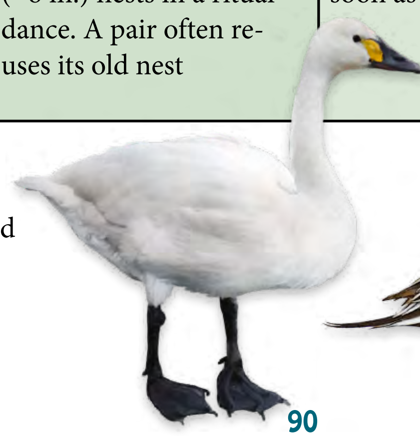
= Non-nester

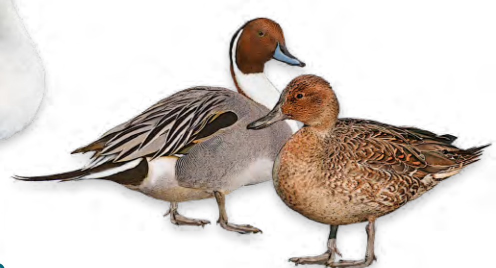
Data from Cornell University's Ornithology Lab (https://www.allaboutbirds.org/guide)

| | Sandhill crane | Tundra swan | Northern pintail | Wood duck |
|---|---|---|---|---|
| **Main breeding area** | Canada north to Arctic | Arctic coastal fringe of North America | West and north of WI to Arctic | Northern U.S., southern Canada |
| **Main wintering area** | Southern U.S., Mexico, Caribbean | Western U.S., Mid-Atlantic U.S. | Southern U.S., Mexico, Central America, Caribbean, Bolivia | Year-round in eastern and western U.S., Southwest, into Mexico |
| **Wingspan** | ~79 inches | ~66 inches | ~31–37 inches | ~26–29 inches |
| **Length** | ~47 inches | ~47–58 inches | ~10–30 inches | ~18–21 inches |
| **Weight** | ~120–173 ounces | ~134–370 ounces | ~18–51 ounces | ~16–30 ounces |
| **Life span** | 20–30+ years | A banded bird lived at least 22.6 years | Live up to 22 years | A banded bird lived at least 22.5 years |
| **Number of eggs** | 1–3 eggs | 3–5 eggs | 3–12 eggs | 6–16 eggs |
| **Main foods** | Seeds, grains, berries, tubers, small animals | Aquatic plant tubers, stems and leaves; molluscs, arthropods | Seeds, plants, aquatic insects, crustaceans, snails | Aquatic seeds, fruits, and arthropods; will forage for nuts, grain |
| **Notable traits** | Loud bugle duets, breed at age 2–7 yr; mate for life; "child care" for 9–10 months | Mate for life; build tall (~8 in.) nests in a ritual dance. A pair often re-uses its old nest | This early migrant heads north as soon as surface waters begin to thaw | Nests 2–60 ft high in trees, within ~a mile of water; produces 2 broods per year. 1-day-old ducklings leap to the ground |



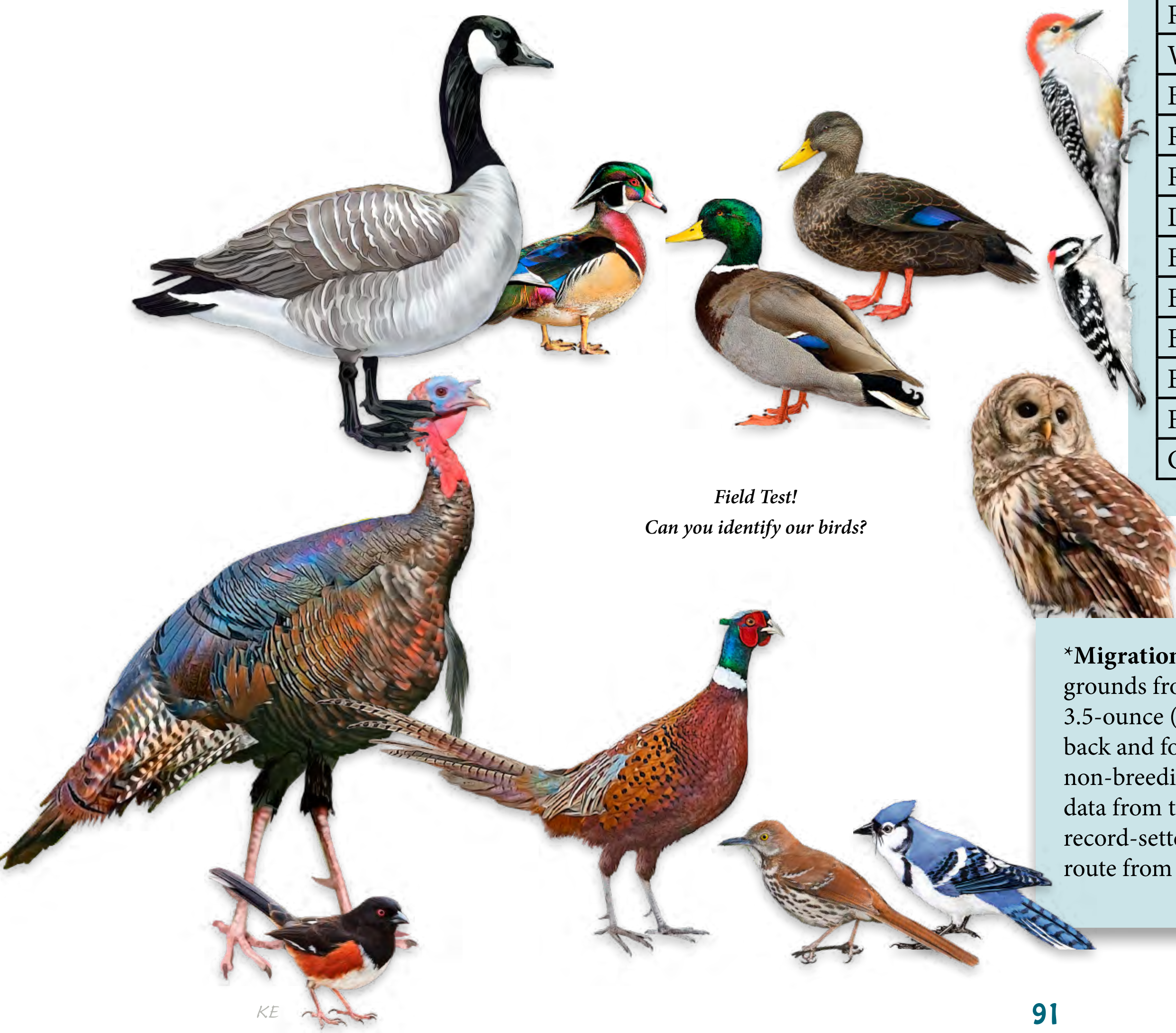
Notice the overlap in foods, which might make these species competitors. Of course, they would compete more if the **non-nesters** lived in Waubesa Wetlands all summer instead of just "passing through."

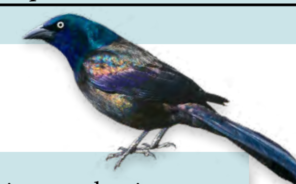




Next, let's consider all 16 **domestic nesters** that breed and rear young in and near Waubesa Wetlands and overwinter here or elsewhere in the U.S. Which resources might those 16 birds compete for—if they are actually competitors? It could be food, foraging space, and/or nesting sites. Also, keep in mind that some patterns can be explained by predator avoidance. For example, the Wood duck nests off the ground in tree trunks—perhaps to reduce predation on eggs and chicks.

| 16 domestic bird species that nest in Waubesa Wetlands | |
|---|---|
| Canada goose | *Branta canadensis* |
| Wood duck | *Aix sponsa* |
| American black duck | *Anas rubripes* |
| Mallard | *Anas platyrhynchos* |
| Ring-necked pheasant | *Phasianus colchicus* |
| Wild turkey | *Meleagris gallopavo* |
| Barred owl | *Strix varia* |
| Red-headed woodpecker | *Melanerpes erythrocephalus* |
| Red-bellied woodpecker | *Melanerpes carolinus* |
| Downy woodpecker | *Picoides pubescens* |
| Blue jay | *Cyanocitta cristata* |
| Black-capped chickadee | *Poecile atricapillus* |
| Brown thrasher | *Toxostoma rufum* |
| Eastern towhee | *Pipilo erythrophthalmus* |
| Field sparrow | *Spizella pusilla* |
| Common grackle | *Quiscalus quiscula* |



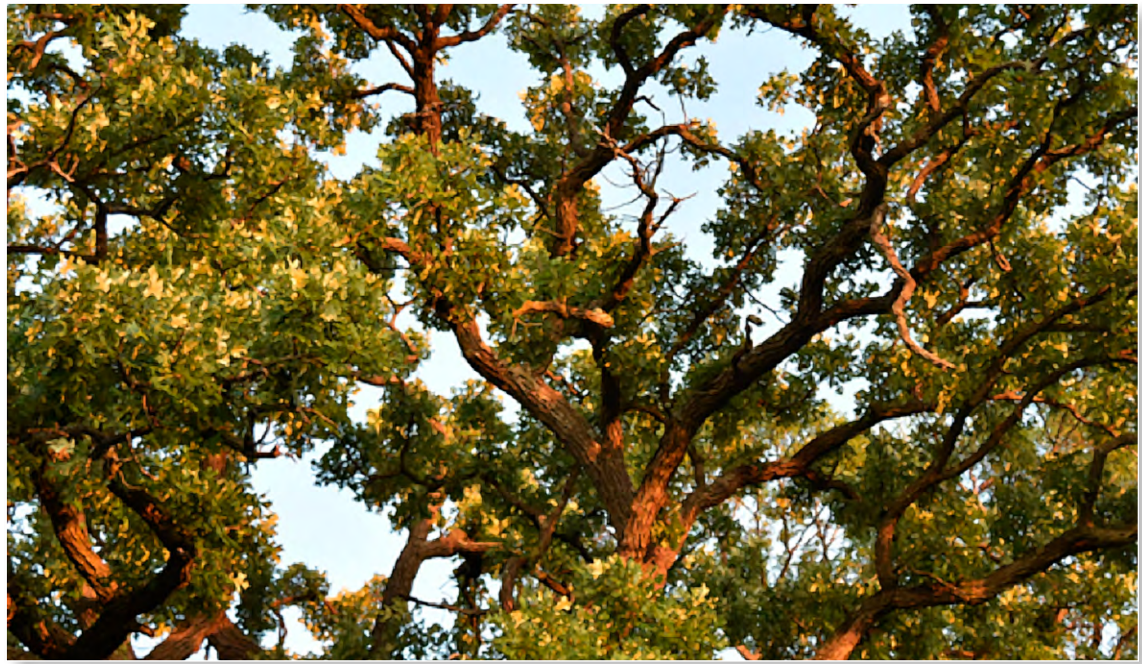


*Field Test!*
*Can you identify our birds?*

***Migration** is the mass movement of species to their reproductive grounds from their overwintering places. A record-setter is the 3.5-ounce (100-gram) Arctic tern (*Sterna paradisaea*), which journeys back and forth between its Arctic breeding grounds and its Antarctic non-breeding sites (Egevang et al. 2010). These researchers obtained data from tiny [1.4 g] geolocators attached to 11 terns. Other global record-setters are shorebirds, some of which stop over in Wisconsin en route from Patagonia in South America to Arctic breeding grounds.

**One answer** to the question (How do 194 bird species co-exist?) is that many just **migrate*** through Waubesa Wetlands en route to nesting grounds farther north.

As indicated in the 2 x 2 table on page 89, 121 species move on to alternative feeding and breeding grounds. Of these species, **48 are domestic non-nesters**, and **73 are international visitors** from foreign lands, in both cases, stopping over to refuel and rest in Waubesa Wetlands before continuing north to their breeding grounds in Canada and the Arctic. Birds that stop to rest or feed in Waubesa Wetlands might compete with nesting species, but only temporarily. The effort involved in migration must be adaptive, or it would not be such a common phenomenon!



Flight is a marvelous "invention" that allows birds and bats to use habitats that most ground-dwellers find hard to access. Here's a close look at the amazing canopy of a large Bur oak (*Quercus macrocarpa*), which birds use for courting, nesting, foraging, and as refuges to escape predators. They might compete with squirrels (for nesting sites and food) and chipmunks (for food), however.

*Photos: P. Zedler*

**A second answer** is that the birds that most likely compete for food seem to use different strategies that might reduce, but not eliminate, competition. The nesting ducks likely compete for foraging areas; and the three woodpeckers seem to compete for insects, hammering holes in dead tree branches in search of prey under the bark. Because woodpecker feet are adapted for vertical landings on tree trunks, they are unlikely to compete for foraging sites with birds that can grab onto twigs, like Chickadees. And if the foraging area is instead a goldenrod inflorescence full of tiny seeds, small birds can more easily handle small seeds and their light weight allows them to land on plant stems that would break if visited by larger species.

Foraging involves both feeding in situ or caching for later consumption, as in dine-in vs. take-out. In my back yard, I watch Downy woodpeckers steal seeds that Nuthatches took from my bird feeders and cached in the bark of trees. Ecologists call that **direct competition**, i.e., one species prevents another species from using a resource. Squirrels and Chipmunks deserve mention here too, as they also steal seeds that were cached in tree trunks. And, need I mention their direct competition at bird feeders?

**A third answer** to the question is the vertical dimension that birds divide up, i.e., nesting "real estate" ranges from the ground to treetops. Birds can avoid competition for airspace if they fly, court, and nest at different elevations. Blue jays prefer treetops; sparrows make use of flight space near the ground.

**A fourth answer** is timing. **Resources can be segregated** over time as well as across space. Nesters might feed at different times (day vs. night) or nest in early vs. mid-season. When many species of birds use the same site at different times, ecologists call it **temporal segregation**. One can observe this behavior among people at a café when some customers arrive early or late to avoid the rush hour. An alternative is **spatial segregation**. If all the tables are occupied, customers might still find space at the counter. At my bird feeders, cardinals seem to prefer sunflower seeds, but when that feeder is occupied, they switch to the suet block, where it seems harder for them to land. Also, timing seems to influence bird communications. They don't all call at the same time, although there is some overlap during the mating season.

The species that nest here should thrive if they have compatible nesting places and transportation routes that **reduce** competition. The night-hunting owl probably avoids competition for food by feeding at night and on small mammals. Still, it would likely compete with other nocturnal predators such as coyotes and fox. We can imagine how birds reduce competition, but it takes quantitative data to test our hypotheses. One of the benefits of becoming part of an international network of important wetlands is the opportunity to learn methods of study and monitoring from other global conservationists.

**Research on resource segregation**. The table below shows the results of one study of complementary habitats for waterbirds in the U.S. northern prairie pothole region. The study showed that several species use the same general place at the same time while using slightly different resources. The five habitat types examined in the study differed in the degree of emergent vegetation, the amount of open water, and the hydrological conditions (in bold). Even though differences are slight, the separations listed here might allow birds to co-exist.

### Water habitat preferences for 17 waterbirds in Prairie pothole wetlands

| **• Substantial emergent vegetation • Variable open water** | **• Emergent vegetation • Partial open water** | **• Emergent vegetation • Extensive open water** | **• Emergent vegetation • Open water • Nesting trees** | **• Lake or river • Barren ground • Islands** |
|---|---|---|---|---|
| American bittern | Sandhill crane | Common loon | Great blue heron | American white pelican |
| Least bittern | Horned grebe | Pied-billed grebe | Great egret | Double-crested cormorant |
| Bonaparte's gull | | American coot | Ring-billed gull | |
| Forster's tern | | White-faced Ibis | | |
| Black tern | | | | |
| Virginia rail | | | | |

Note that the study included more species, but to simplify the table, I omitted those that are not known from Waubesa Wetlands.
Modified from the table of Beyersbergen et al. (2004, p. 25).


The Prairie pothole gang

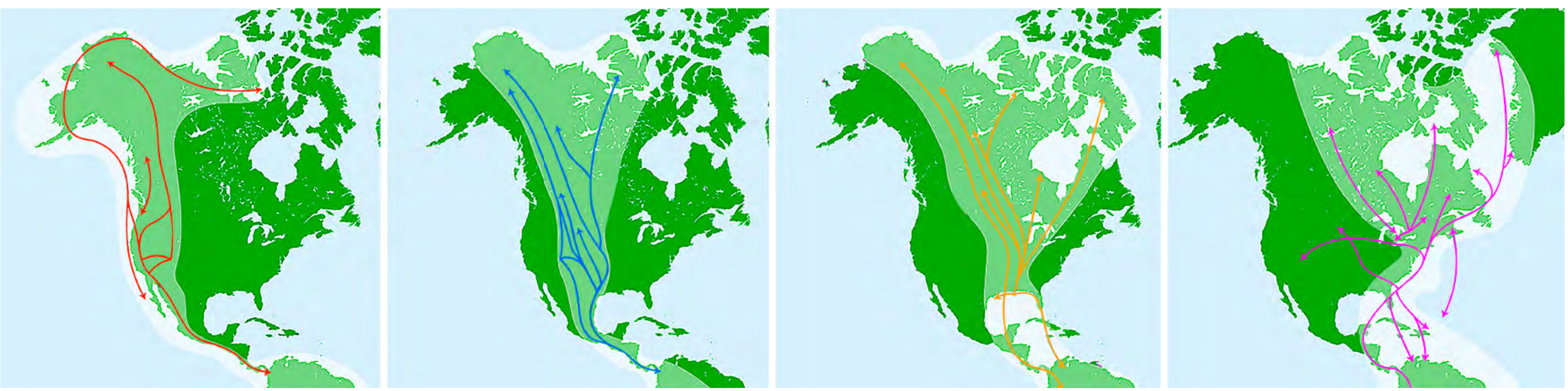
**Migratory patterns differ among bird species.** Waubesa Wetlands support twice as many migrants (130 species) as domestic (64) species (see the 2x2 table). If all 130 migrants came to Waubesa Wetlands at once, I envision a lot of squabbling for flight space, landing pads, food and sound spaces—the noise might be deafening, with individual birds finding it difficult to attract or keep track of mates.

Birds reduce competition by **migrating along different routes**. Although Yellowlegs and Least sandpipers nest at Waubesa Wetlands, most of the shorebird "distance medalists" migrate along ocean coasts, where there are ample mud- and sandflat refueling spots along the way to more northerly nesting sites. Despite variations in flight patterns, global migratory routes are similar enough to distinguish the Pacific, Atlantic, Central and Mississippi flyways.

Waubesa Wetlands are centrally located along the Mississippi River Flyway, which suggests they are valuable **stopovers*** for resting and refueling during the critical migratory season. Waubesa Wetlands attract as many international migrants (73) as there are nesting species (73). En route to nesting homes, migrating shorebirds need stopovers with diverse, productive vegetation, gently-sloped shorelines with shallow water, plentiful invertebrate foods, and cover to avoid predation—like an outdoor café that offers a varied menu, views and shelter. To come here, international migrants are challenged by oceans (long stretches over water), deserts (scarce water), mountain ranges (preferably with uplifting winds), agricultural fields with pesticides, and urban centers with no landing pads. Presumably, shorebirds that stop at Waubesa Wetlands find enough fuel to complete their trip and arrive at northern nesting sites in healthy condition. Once they're at their nesting home, migrants still need enough energy reserve to find new sources of food, produce eggs, and feed young.

*__Stopovers__. Why do some birds continue migrating to Canada and the Arctic, when Waubesa Wetlands have so much to offer? One reason is that birds can search for prey 24/7 in the Arctic Circle, because it's non-stop daylight. Waubesa Wetlands' maximum day length, in contrast, is ~15.3 hours.


North American Migratory Bird Flyways



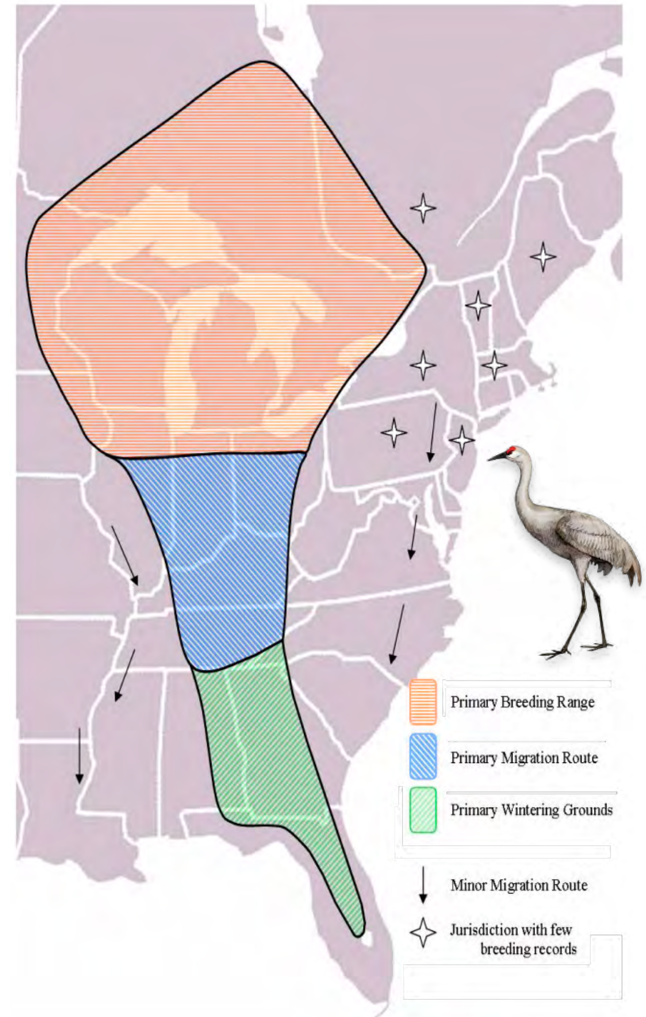
Pacific Central Mississippi Atlantic

**Migrants spread their departures over time**, such that earlier species head north well before other later migrants. When early migrants stop for "fuel" in the Prairie pothole region, west of Wisconsin, they can deplete invertebrate food supplies in small pools, but those invertebrate populations might recover from early predation before later migrants show up for lunch. Shallow potholes thaw and develop invertebrate foods first; these attract the early migrants, such as Northern pintail. When deeper pools thaw, diverse aquatic invertebrate populations "explode," and the potholes become "feeding oases" for later migrants. While shallow pools dry up in summer, deeper waters persist long enough to support nesting birds. The nesters differ among potholes, depending on the vegetation and prey species.

The Prairie pothole region west of Wisconsin is considered the most important waterfowl production area in North America (Beyersbergen et al. 2004). In Wisconsin, geese and ducks also arrive early, followed by waders and songbirds. Some of these waterbirds congregate in large numbers to forage and rest in sites with abundant foods. For example, ~100,000 canvasback ducks use Lake Onalaska north of La Crosse, Wisconsin, as a spring staging area (Matteson and Volkert 2002).

Canvasbacks

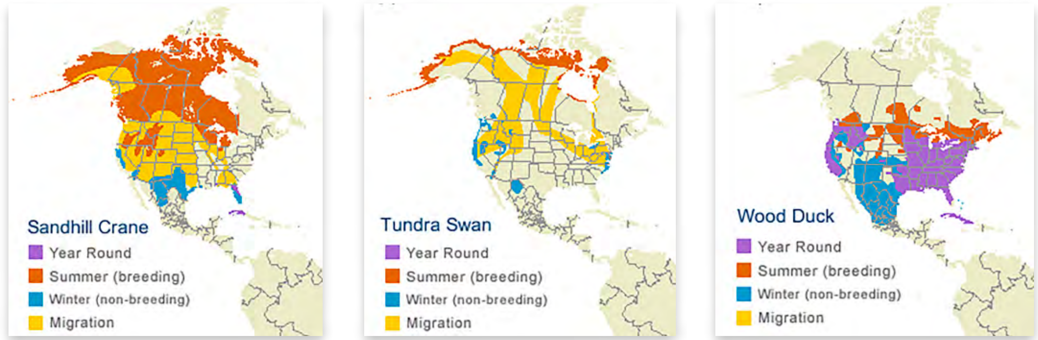
The most notable migratory gathering is the fall staging of ~500,000 Sandhill cranes that "tank up" along Nebraska's Platte River before flying south. However, Wisconsin's 60,000–70,000 Sandhill cranes take a different route. Our cranes are part of the Eastern Population (see map). The cover photo for this book shows Sandhill cranes gathering along the Wisconsin River, getting ready to migrate south. Waubesa Wetlands' cranes don't join this group but instead fly south to Indiana's Jasper-Pulaski Fish and Wildlife Area to join other Sandhill cranes from Wisconsin, Michigan, Ontario, and Minnesota (C. DeWitt, pers. comm.). After a couple of weeks of feeding, they're ready to continue south. Midwinter surveys indicate that some of our cranes are not wintering as far south as historically, e.g., landing in Kentucky and Tennessee instead of Florida and the Caribbean (Kruse et al. 2012). Another effect of global warming?




Approximate wintering, migration and breeding ranges of the Eastern Population of Greater Sandhill Cranes. We consider this species an international migrant because banded migrants have linked Waubesa Wetlands to Mexico and the Caribbean.

*From: Kruse et al. (2012)*

**Climate changes** are expected to affect migratory species. The animals that move around the Earth will experience global conditions, and any change in the timing of cues to migrate (e.g., warm or cold temperature) could affect the date that animals depart from their summer or overwintering location, and the date that they arrive at their destination.



Migration maps showing wintering and nesting locations

Over millennia, migratory insectivorous birds timed their arrival to coincide with the presence of their insect prey, and they timed the hatching of eggs to times of abundant prey so that chicks could be well-fed. Simultaneously, insect prey species timed their presence to the availability of their foods, such as pollen and nectar, which means that the timing of flowering was also coordinated with the presence of pollinating insects, all through evolutionary processes (Kristensen et al. 2015). Thus, if a plant flowers two weeks earlier than it did 60 years ago (as documented by Bradley et al. 1999), or if an insectivorous bird arrives at Waubesa Wetlands 1–2 weeks ahead of its prey, what might seem like a simple shift in timing affects the bird's entire food chain. In southern Wisconsin, mismatches in the timing of flowers to feed insects, hatching of insects, peak abundance of prey, food for chicks could jeopardize the fledging of offspring.

A recent study of aphids in the United Kingdom showed that some insects are already responding to warmer climate. Specifically, a 50-year data set for 55 aphid species documented progressively earlier occurrences of aphids in flight, collected using suction traps positioned throughout U.K. (Bell et al. 2014, Satterfield et al. 2015, Seebacher and Post. 2015).

**In summary, it's hard to know how 194 species co-occur at Waubesa Wetlands.** We can sort species into four migratory and nesting "strategies," but the separations are blurry due to many variations. Some continue flying to other destinations at different times and along different routes; some are adapted to forage for different foods in different places; some divide up the vertical space, which reduces encounters; and some use resources at different times. Next time you visit Waubesa Wetlands, listen and watch for birds and think about how they might compete for resources or avoid competition, as well as responding to other factors that affect their behavior, such as avoiding predators. There is much to learn about our 194 feathered friends. Help keep track of their abundances and activities! Also needed are data on the arrival and departure dates of species to learn how birds are adjusting to climate change. Perhaps a few readers would like to initiate or join a comprehensive bird-monitoring program, perhaps building on the Sandhill crane annual census. Citizen scientists are needed!

Our local "sedentary" subpopulation of Canada geese doesn't migrate at all; instead, the birds take advantage of warm waters from power plant effluent and unfrozen waters that flow from Waubesa Wetlands' springs year-round. They'll be ready for the warmer climate that is predicted.

### The Role of Wind

When many species follow similar routes, the pattern suggests a common driver—is it the wind? Yes: A recent study tested the hypothesis that migratory birds optimize their migratory route to follow favorable winds (Kranstauber et al. 2015). The authors used 21 years of global wind data to identify routes with minimum travel time based on shortest distance vs. favorable winds. In their model that predicted energy use, bird survival was greater for favorable-wind routes than shortest-distance routes. They suggest that the global network of aerial migratory pathways results from "low-cost flyways." Compare to people who drive further to take the faster freeway instead of taking the shorter but slower city-street route across town.

## Nighthawks

John Herm
*Town of Dunn Poet Laureate*

When the Queen Anne's lace was folded brown
And the sedums burst their purple crown,
The dusk was turning a cloudy sky
When up came a neighbor stopping by.

Soon I knew such reason why
Some striped'd wings were flashing bright
Oh! The joy of it all…in the crisp air fall
At the stunning sight of a Nighthawk flight.

The squadrons banked and swerved and dived,
The bluegrass prairie had come alive,
We marveled amidst the acrobat throng,
Their mouths agape in silent song.

We ducked our heads from darting swoops,
We wondered what had flocked the group,
They must be headed south somewhere
Bolstered by them feasting there.

The following days I hoped they'd show
But they had come to whither go…

I shan't forget so rare a night,
I dream them now in dusky light,
Our quiet world in surreal surprise,
That mystic time when Nighthawks fly.

# Chapter 5 • Looking down

## A bird's-eye view—What do Osprey see in Waubesa Wetlands?

An Osprey's perspective is needed to manage Waubesa Wetlands holistically. While in residence, our Osprey look down from their nest on a power line tower, where they can see the clear waters of the spring creeks and the lake's toe, as well as the wetlands and surrounding upland buffers. The Osprey is an "umbrella species," because it needs multiple habitats and because protecting this species' habitats indirectly protects many other species. Osprey need uplands with tall trees* and watersheds that have marshes, lakes and streams that support their diet of fish. When Waubesa Wetlands support Osprey, we know that other valued communities and species are also being conserved. To gain a similar holistic perspective, people also need to look down from on high, using aerial imagery and geographic information systems (GIS).

Dane County has only six Osprey nests, so it's quite special to find one high above Waubesa Wetlands. What brings our Osprey back year after year? Let's look at Waubesa Wetlands from an Osprey's perspective and hypothesize their critical needs for survival and rearing of young:

- Waubesa Wetlands are large and include a wetland-lake complex—a large area of green space is just what Osprey need to avoid humans and predators.
- The streams and lakeshore marshes serve as spawning habitat and nurseries, so there are plenty of fish to eat.
- The toe of Lake Waubesa has clear water—so Osprey can see and catch fish.
- There are nearby trees and tall towers to support perching and nesting high above the ground.

*Osprey are opportunistic, so a human-made tower in a suitable wetland can serve as a strategic perch and nest site.

Waubesa Wetlands: Everything an Osprey could wish for (if they could wish).
*Photo: C. DeWitt*

Given ample space, food, and a choice tower, Osprey have nested annually at Waubesa Wetlands for six years (Calvin DeWitt, pers. observations). The Osprey family could be increasing annually, because they begin breeding at age 3 and live ~20 years. Yet the number of nests in Waubesa Wetlands and Dane County do not seem to be increasing. Assuming that young Osprey could find mates, what might keep them from adding nests at Waubesa Wetlands? Do they need larger home ranges to find food? Perhaps it is one of the many hazards that Osprey encounter during their extensive migration, including:

- Hunting, predation, stopovers with inadequate food
- Storms that blow birds off course or cause harm
- Attraction to suitable habitat en route, so Osprey young don't return to their natal home
- Predation on eggs and chicks after returning home, e.g., by eagles and hawks
- Altered behavior due to contaminants, such as methyl mercury which concentrates in fish
- Algal blooms in eutrophic lakes so prey species are harder to see and catch

Genetically, it would be good for young to leave their natal home and find unrelated mates and new breeding sites. Perhaps future offspring of Waubesa Wetlands' Osprey will survive hazards and add nests elsewhere. Thanks to the DNR, readers can keep track of Osprey online (see: dnr.wi.gov/files/pdf/pubs/er/er0680.pdf).

## People also need aerial views of Waubesa Wetlands

Resource managers need to view the wetlands holistically, to see the "big picture" and consider all the natural resources and how they interact at the watershed scale. So people use airplanes, ultralight aircraft, and drones to obtain near-surface views of watersheds and wetlands, plus aerial photography and remote sensing by satellite for even larger views. Such tools aid large-scale mapping—a process that required a lot of footwork when Bedford et al. (1974) drew the first map of Waubesa Wetlands (see Chapter 2). I wondered how they did it, so I emailed Barbara, now a professor at Cornell University. In her 2016 email, she said they worked from Natural Resources Conservation Service 9 x 9 inch black-and-white aerial photos. "We checked out all the photos of the site from the NRCS office each morning on our way to the field. We then went to each distinct patch evident on the photo and altered the shapes of

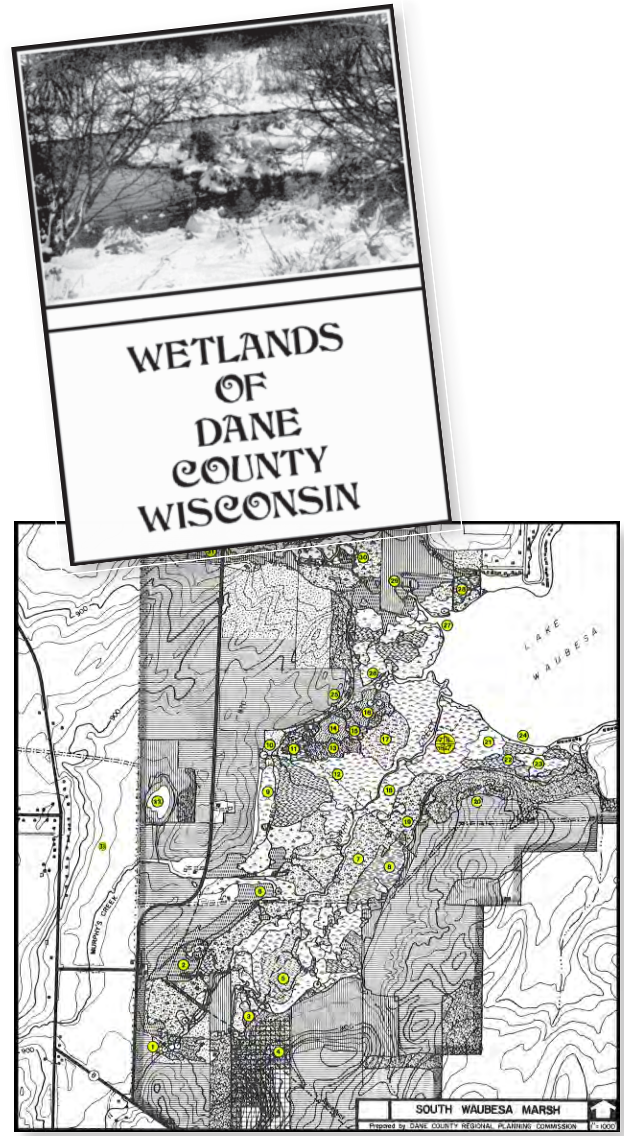

Osprey must overcome hazards during their annual migration.
*Map adapted from Cornell Lab of Ornithology NatureServe range data*

the patches as we observed on the ground, and identified the vegetation in each patch. Quite ‘primitive’ methods relative to what soon became available in terms of infrared aerial photography and other remote methods. But at least we knew the vegetation had been identified correctly.”

Because the Ramsar Site nomination required basic data on wetland types and areas, we used the 1974 map and GIS technology to measure the areas of each plant community. Alex Wenthe* had the essential skills to create a detailed database from the 1974 map. He digitized the map, outlined each wetland patch, added up patches of wetlands with the same names and totaled their areas. The total areas for the largest wetland communities are in Chapter 2. Those new data showed that over half the mapped wetland is Sedge meadow, with variations, Domination by Sedge meadow is consistent with pollen data over recent millennia (Chapter 1).

Having quantitative data on vegetation did more than fill in blanks on the Ramsar nomination for Waubesa Wetlands; it quantified the importance of sedges, which provide many ecosystem services that enhance human well-being (Chapter 3).

*Alex Wenthe is a volunteer steward for the Waubesa Wetlands Scientific Natural Area and a DNR employee who works with landowners to promote natural resource conservation. He is also an MS student in Botany. When Alex entered UW Botany’s non-thesis track in Ecological Restoration as a Waubesa Wetlands steward, it seemed inevitable that he would help focus on the wetland vegetation for his practicum, while compiling data for the Ramsar nomination!




The Waubesa Wetlands map (reprinted in Chapter 2; field notes in Appendix 2) is part of a thick volume of wetlands for all of Dane County.

Even larger perspectives are provided by **satellite imagery**, which brings views of Earth to our desks with just a few clicks on the keyboard. A global view* of wetlands and their conservation status is provided by Reis et al. (2017):

### *Global view

"Wetlands have been extensively modified by human activities worldwide. We provide a global-scale portrait of the threats and protection status of the world's inland wetlands by combining a global map of inundation extent derived from satellite images with data on threats from human influence and on protected areas. Currently, seasonal inland wetlands represent approximately 6% of the world's land surface, and about 89% of these are unprotected (as defined by protected areas IUCN I–VI and Ramsar sites). Wetland protection ranges from 20% in Central [America] and 18% in South America to only 8% in Asia. Particularly high human influence was found in Asia, which contains the largest wetland area of the world. High human influence on wetlands even within protected areas underscores the urgent need for more effective conservation measures" (Reis et al. 2017).

Google Earth provides a watershed perspective on Waubesa Wetlands, although watershed boundaries are hard to see because the landscape has been subdivided by varied land uses.

*Google Earth watershed view*

The need to conserve and protect Waubesa Wetlands is urgent, especially knowing that global wetland protection is inadequate. Waubesa Wetlands can still be protected, even though our local watersheds are threatened with both global climate change and local urbanization. When you drive south down Lalor Road, you don't see any signs that announce:

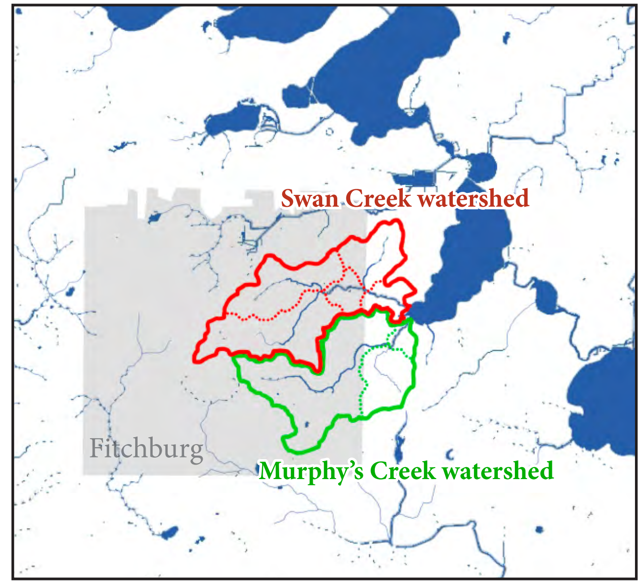

Nor are there signs naming either creek, with the exception of Murphy's Creek on Hwy MM near CTH B in the City of Fitchburg.

For these reasons, local residents and visitors are understandably oblivious to watersheds—what they are, where they are, and why they should care. Let's fix that: Here's a **definition**; Watersheds are **bounded by high terrain and contribute runoff water toward a downstream outflow**, in this case, Swan Creek and Murphy's Creek. Note that watersheds come in many sizes, with the smallest forming rivulets that flow into streams, and the largest that flow into rivers that flow into lakes or oceans.

**Why should we care about watersheds?** Waubesa Wetlands are part of the Yahara River watershed, which includes the Yahara chain of four lakes. While each lake has many watersheds with agricultural and urban runoff that flows into adjacent and nearby wetlands, the Waubesa Wetlands remain protected from "northern runoff" because much of the water from upstream lakes flows into northern Lake Waubesa and out the Yahara River, thus bypassing the toe. (Still, nutrients from the northern watersheds accumulate in Lake Waubesa, but at a slow pace.) At the same time, outflows from Bogholt Deep Spring help keep the lake's toe from becoming eutrophic (nutrient rich) and plagued with algal blooms. Yet another reason is that "western runoff" from agricultural lands is somewhat filtered by wetlands along Murphy's Creek. These three features: northern runoff bypassing the toe, spring water diluting eutrophic water in the toe, and wetlands along Murphy's Creek removing some nutrients, all protect Waubesa Wetlands. As a result, biodiversity is sustained; young fish can use this waterway, and people are less threatened by toxic algal blooms. More will follow in Chapter 6.

The Town of Dunn has managed the land from a holistic, watershed perspective for decades. Efforts to reduce sediment and nutrient loading into the creeks, wetlands and lake include the following:

- Restoration projects undertaken to intercept agricultural runoff and settle out sediments:
  - Third Street Marsh,
  - Esox Marsh, and
  - Fourth Street Marsh.
- The Town bought Heritage Park on the south lakeshore and restored the land to intercept runoff.
- Along the west lakeshore, leaky septic systems were replaced by sanitary sewers.
- Metropolitan wastewater was treated and diverted via an aqueduct around Lake Waubesa.
- The Town rejected the proposed Libby Landfill west of Lake Waubesa to prevent leaching of contaminants from the landfill to the lake.




**Boundaries** for Swan Creek and Murphy's Creek, both within the City of Fitchburg. Note that both watersheds have sub-watersheds with smaller creeks. These maps illustrate that watersheds do not correspond to political boundaries—a universal reality that challenges efforts to manage watershed systems as holistically.

*Watershed outlines by C. DeWitt*

## The need for a bird's-eye perspective on Waubesa Wetlands.

If we could fly overhead each day and land on top of a power tower like an Osprey and if we could see the details of our watershed with the precision of a remote-sensing camera, we would all be better equipped to manage and protect Waubesa Wetlands.

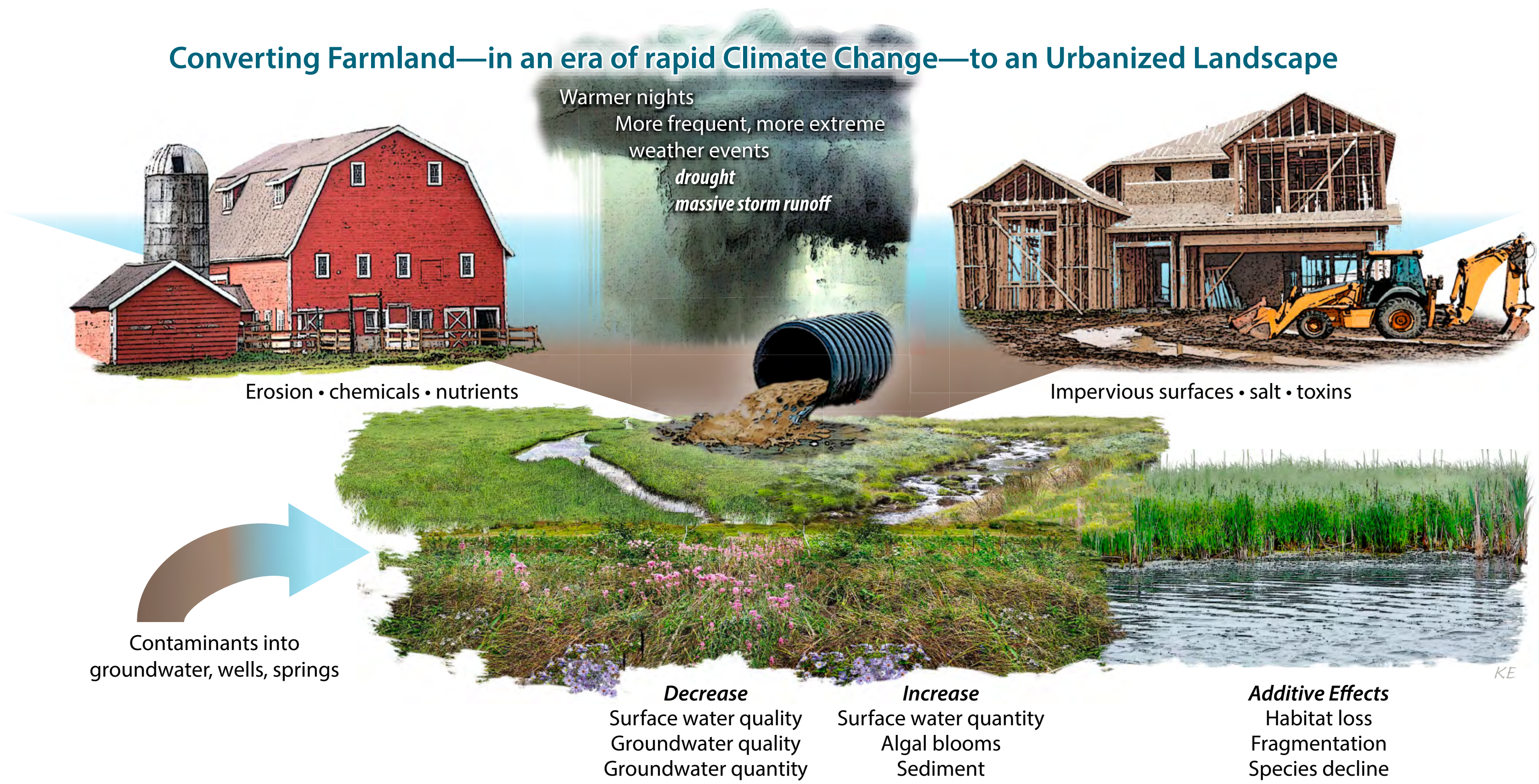
A large, holistic view is needed to address processes that cross political boundaries, like surface-water runoff. Water flows downhill, oblivious to townships on a county map. From the perspective of upstream residents and decision-makers, many natural amenities that attract people to the City of Fitchburg are downstream, beyond the City's boundaries. And from the perspective of those in the Town of Dunn, problems associated with urbanization have their origins upstream, beyond the boundary of the Town of Dunn.

It's time to manage Waubesa Wetlands with a watershed perspective. In Chapter 6, please join me in looking ahead to future changes in land use and climate, and learn how six lines of evidence address the effects of upstream urbanization on downstream wetlands. Then, in Chapter 7, I'll summarize many actions that citizens of a watershed can take to sustain their mutually appreciated and valued downstream wetlands.

# Chapter 6 • Looking ahead

The future of Waubesa Wetlands depends on our care of their watershed. The main threats are increased development upstream in the City of Fitchburg and an uncertain future climate. We can learn about the impacts of urbanization from nearby Monona Wetland Conservancy, where native vegetation was overgrown by weeds, and where springs dried up after deep wells depleted the aquifer. But our wetlands are also affected by nitrogen fertilizers used on farms and lawns, noise, lights, roads, culverts, and a warmer and stormier climate. Six lines of evidence agree that development upstream has negative impacts on downstream wetlands. While the changing climate adds uncertainties, we know enough to avoid impacts that alter hydroperiods and contaminate water, and we know enough to apply the precautionary principle when uncertainties remain.

## Converting Farmland—in an era of rapid Climate Change—to an Urbanized Landscape



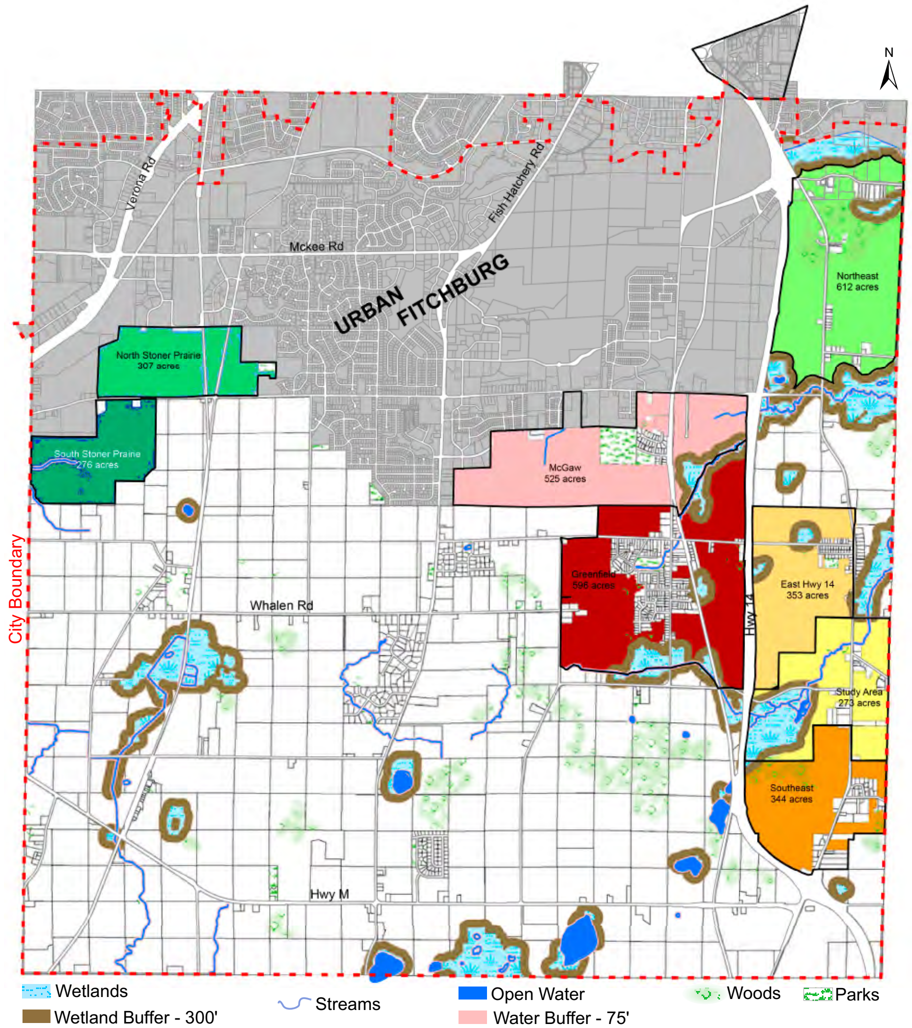
## Threats to wetlands

For Waubesa Wetlands, the two big threats are **urbanization** upstream and **climate change,** acting alone and in combination. Waubesa Wetlands depend on having just the “right amount” and just the “right quality” of ground- and surface water to sustain 19 natural aquatic and wetland communities. Thus, most of the threats are direct or indirect effects of changes in **water quantity** and **water quality.** For this to make sense, we need to think at the **watershed** scale. In a watershed, soil and other materials that get moved about upstream can make their way downstream, potentially reaching Waubesa Wetlands and causing damage.

Upstream from Waubesa Wetlands, several developments are being considered for the City of Fitchburg. In Chapter 5, maps of Swan and Murphy’s Creek watersheds show that both creeks transport runoff from our upstream, Fitchburg neighbors. On the map to the right, 5,910 acres (shown in gray) were already developed or approved for development by 2015. Most developments were for residential use and most were constructed north of the Swan and Murphy’s Creek watersheds.

What would future development replace upstream? The southern 2/3 of Fitchburg now supports productive agriculture and open space with scattered small residential neighborhoods. Eco-friendly agriculture is promoted by the Town of Dunn, but there are concerns about urbanization. Scientists make two major predictions:

1. **Urbanization upstream will have negative impacts on downstream wetlands.**
2. **A warmer and stormier climate will add negative impacts on downstream wetlands.**




**Map of Future Urban Growth Area Neighborhoods**

With the 2016 approval of the first project in the 612-acre Northeast Neighborhood (lime green color), a dense collection of 1600 dwellings is being added on 95 acres of former farmland as a first phase. Some of the development will drain into Nine Springs Creek, which flows into Lake Monona, and some will flow directly into Swan Creek. More developments (other colors) are in various stages of planning as urban Fitchburg creeps south.

*from www.fitchburgwi.gov/DocumentCenter/Home/View/4003*

Major stressors, such as urbanization and climate change, cause ecosystems to change, but the details of cause and effect are not always predictable or testable. It's too hard to create landscape-scale experiments, like comparing watersheds with and without urbanization. It's also hard to test for effects of climate change. Still, decisions will be needed, and "Waiting for scientific certainty is neither a safe nor prudent option" (Griggs et al. 2017). So, researchers proceed by summarizing several **lines of evidence** and determine whether all lines agree on outcomes. This chapter presents six lines of scientific evidence concerning effects of upstream land use and climate changes on downstream wetlands. If uncertainties remain after these lines of evidence are explored, planners should adopt the **precautionary principle** (Elton et al. 2011) and take the least risky approach, which is to curtail development or require zero impact growth.

How can we test watershed-scale hypotheses using lines of evidence? Here's an example from the Columbia River Estuary, where managers were uncertain whether they should continue restoring tidal wetlands because they were not sure the efforts were benefiting salmon. Researchers hypothesized that multiple restoration projects in the Columbia River were benefiting juvenile salmon. They developed **seven lines of evidence** from multiple disciplines, and all lines supported the hypothesis that salmon benefit from tidal wetland restoration (Diefenderfer et al. 2016). That consensus supported the continuation of tidal wetland restoration.

**Lines of evidence** are now considered a formal approach for testing landscape-scale hypotheses. For the Columbia River example, Diefenderfer et al. (2016) explored evidence from ecosystem modeling, modeling of environmental factors, combined analyses of multiple studies (meta-analysis of restoration actions), data for target species, research on critical uncertainties, literature review, and changes to the landscape. Prior to their work, Webb et al. (2012) had described how "pieces of evidence from the literature, which although individually weak may collectively provide a strong case for causality." Similar arguments were made earlier by Peppin et al. (2010), Greet et al. (2011), and Norris et al. (2012).



Left, Swan Creek development (Swan Creek drainage area highlighted). Above, Swan Creek aerial photo.
*Photo: Nadia Olker*

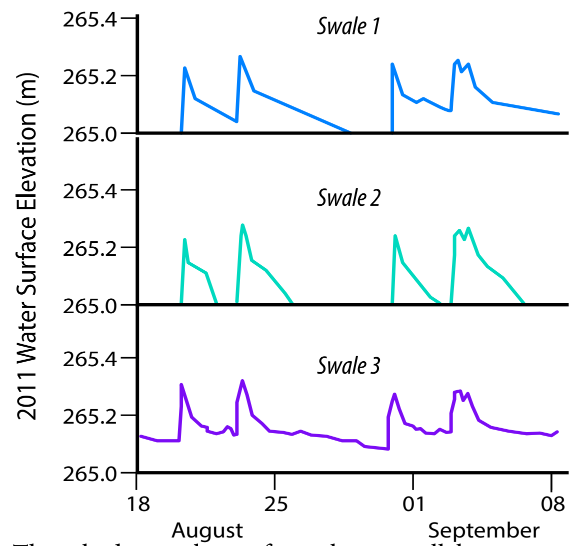
## Six lines of evidence—Does upstream land use affect downstream wetlands?

Here are six lines of evidence to test the hypothesis that upstream land use affects downstream wetlands. The lines are: surface water quantity, surface water quality, groundwater quantity, groundwater quality, climate change interacting with surface water, and interactions between land use shifts (i.e., urbanization) and climate change.

### First line of evidence

**Surface water quantity increases substantially** with urbanization, according to multiple reviews of local research in the scientific literature (NRC 2009, Azous and Horner 2000, Brabec et al. 2002, Lougheed et al. 2008, Dugan et al. 2017). Roofs, streets, sidewalks, and other impervious **"hardscapes"** prevent water from soaking into the ground, thereby increasing the volume of surface runoff and causing flashier (faster, more powerful) flows. Stormwater flows might seem simple to describe, but the **flow regime** is a bit complex. A complete description includes the distribution and sequence of flows, the frequency of high flows, the increased volume, in-stream velocities, the rate of rise and fall of flows (the hydrograph, see graph), and the season of the year when high flows occur (NRC 2009).

**Hardscaping** causes impacts. Damage is commonly seen after a **third** to a **half** of the **watershed** is covered with **impervious** surfaces, especially roads and parking lots, according to the National Research Council (NRC 2009). Along with increased quantity of surface water flows, **the timing** of flows also changes when farmland is paved and developed. Moreover, runoff is flashier when rain falls on hardscapes, and many human **structures,** such as ditches, levees, straight channels, and concrete lined streams, greatly increase flow rates (NRC 2009).




These hydrographs are from three parallel stormwater-treatment swales at the U.W.–Madison Arboretum. The timing of peak flows is similar, because all three received water from the same pond. However, the hydroperiods differ in the duration of water and the peak flows because one swale (bottom graph) ponded more water due to a continuous subsurface clay layer. The drier swale (middle graph) was "leakier," which is one way that wetlands reduce flooding. Subsoil conditions affect the amount of runoff.

*Hydrograph redrafted from Doherty et al. 2014*

### NRC's Impervious Cover Model made these predictions:

- Where impervious cover is less than 10% in the surrounding watershed, sensitive streams can retain their hydrologic functions and high aquatic diversity.
- Stream segments in watersheds that have 10 to 25% impervious cover have declining stream health.
- Those in watersheds with 25 to 60% impervious cover no longer support their historical stable channel habitat, water quality, or biodiversity, and are not fully recoverable.
- Stream segments in watersheds with more than 60% impervious cover have the poorest water quality, highly unstable channels, and low biodiversity; they convey flood waters in open channels or enclosed storm-drains (NRC 2009).

Nearby, Owen (1999) found a 20-fold increase in surface-water flows to the Monona Wetland Conservancy as hardscaping expanded to cover 63% of its watershed. Her evidence supports NRC's (2009) conclusion, namely, that urbanization increases the amount of impervious surface with a proportional increase in runoff—both flow rates and volumes.

Land cover directly affects the biological condition of downstream receiving waters. Wetter conditions allow weeds to invade, and invaders tend to expand aggressively, and it doesn't require a huge change in hydroperiod to shift an ecosystem from one state to another.*

**We measured six ecosystem services, and all six differed with hydroperiod.** As in a review of 100 studies of urbanization, some effects were direct and others were indirect (Wright et al. 2006). In our swales study, some effects on ecosystem services were direct: Peak flows were more attenuated and stormwater was retained longer in the driest swale. Other effects were indirect: The prolonged hydroperiod (wettest swale) caused Cattails to dominate, and these productive plants reduced diversity. Also, ponding reduced erosion.


*Illustration adapted from Leaflet #28, arboretum.wisc.edu/science/research/leaflets)*

***Small changes to hydroperiods matter.** My colleagues and I measured the effects of minor differences in hydroperiod in three swales designed to capture stormwater that were constructed to be identical, i.e., created equal. All received the same urban runoff, and all were sown with the same seed mixes, although planted species failed to establish. Instead, each swale developed weedy vegetation in response to the different hydroperiods, which conveniently ranged from ponded to well-drained (see hydrograph). Cattails quickly dominated the ponded wetland (bottom hydrograph), while a greater diversity of species occupied the swale with an intermediate hydroperiod, and the highest diversity developed in the "driest" wetland (middle graph). Wetland functions (ecosystem services) also developed differently, shown in the aerial photo as large star > small stars > ovals > no symbol.

in the wettest swale favored Cattail invasion, and Cattails had the highest net primary productivity (NPP), while the best-drained (middle) swale had the lowest NPP. To our surprise, the swale with the lowest NPP had the highest values for 5 other measured functions.

Symbols represent the amount of 6 ecosystem services (white font) that we measured in each swale. The top swale was intermediate in ponding/draining; the second swale was well drained, and the swale at the bottom of the photo ponded water during the entire growing season (Doherty et al. 2014).

*Q. Which hydroperiod provided the most ecosystem services?*

*A. The middle swale, which infiltrated the most urban runoff.*

**A California study adds evidence.** Urbanization upstream from Los Peñasquitos Lagoon affected one of my long-term study sites in San Diego County. Over 33 years, agriculture and open land shifted to urban uses, which increased from 9 to 37% of a ~38,941-acre (~15,759 ha) watershed. Rapid urbanization caused streamside (riparian) vegetation and the salt marsh to shift to weedy cattails in response to excess freshwater, nutrients and sediments. Development accelerated in the later 12 years, while rainfall was similar. The authors concluded that urbanization of Los Peñasquitos Creek watershed caused (1) more runoff and unnatural dry-season runoff; (2) larger floods; (3) eroding stream channels; and (4) expansion of Willows along the stream. The increased runoff of stormwater followed increased impervious surface area, and the dry-season runoff came from imported water used to irrigate urban landscaping (White and Greer 2006).

## Second line of evidence

**Urbanization affects surface water *quality*.** An extensive research review (NRC 2009) found that stormwater from urban areas "is well characterized, with the common pollutants being sediment, metals, bacteria, nutrients, pesticides, trash, and polycyclic aromatic hydrocarbons. These results come from many thousands of storm events from across the nation." Locally, the suite of pollutants that accompanies urbanization also includes road salt (data for Madison, WI, from House et al. 1993 in NRC 2009, p. 200).

An early finding was that water quality deteriorates when 10% of the watershed area is impervious to rainfall (Johnston et al. 1990). The most common process of water quality decline is called **eutrophication*** (nutrient enrichment), but toxic contaminants, which are harder to measure, also contribute in uncertain ways. Also, urbanization commonly involves ditching, channel straightening, and bank stabilization; these actions are designed to improve drainage, but outcomes include increased erosion and greater sediment delivery downstream (NRC 2009).

A **chain of impacts** occurs when urban hardscaping causes more runoff to carry more nutrients, which cause more impacts downstream

Urbanization *leads to* More runoff *leads to* Eutrophication *leads to* Weedy wetlands + Algal blooms in lakes

Our inland aquatic ecosystems are vulnerable to eutrophication (Detenbeck et al. 1993). Numerous multi-year studies in nearby wetlands and mesocosm experiments support the hypothesis that Waubesa Wetlands are threatened by upstream development as has occurred in wetlands and lakes in other watersheds (Woo and Zedler 2002, Drexler and Bedford 2002, Kercher et al. 2007, Lathrop 2007, Lewis et al. 2011). Swan and Murphy's Creeks have recently been shown to carry nutrients from their subwatersheds into Waubesa Wetlands. The data for 2015–2016 on stream biota and nutrients in Swan

*Eutrophication is not a new discovery; it was the focus of an international symposium held at U.W.–Madison 50 years ago (June 1967). The proceedings were summarized in the 1969 book, **Eutrophication**, and provided wisdom that is still timely. "Man's [sic] activities, which introduce excess nutrients, along with other pollutants, into lakes, streams, and estuaries, are causing significant changes in aquatic environments…. The pollution problem is critical because of increased population, industrial growth, intensification of agricultural production, river-basin development, recreational use of waters, and domestic and industrial exploitation of shore properties…. A common change is excessive growth of algae and larger aquatic plants. Such growth chokes the open water, may make it nonpotable, and may greatly increase the cost of filtration."

NRC 1969, p. 3.

and Murphy's Creeks at Lalor Road led the Rock River Coalition to issue stream-quality grades of "F" for both of those sampling stations.

Typically, phosphorus is blamed for eutrophication, but several studies conducted in our region indicate that **both phosphorus** (P) **and nitrogen** (N) are threats to wetland vegetation (Green and Galatowitsch 2002, Woo and Zedler 2002, Kercher et al. 2007, Boers and Zedler 2008) and to lake phytoplankton (Lathrop 2007, Lewis and Wurtsbaugh 2008, Lewis et al. 2011). Most of the surface water impacts are well known for lakes, but the wetlands that occur between lakes and runoff sources are typically ignored. Unfortunately, we don't have adequate nutrient data for surface water flowing into our Calcareous fens and Sedge meadows, and we don't have data for the lake's toe, which qualifies as a Ramsar wetland (water up to ~20 feet deep; see Preface). The long-term nutrient data are for Lake Waubesa's deeper water, which receives eutrophic inflows from Lakes Mendota and Monona (McDonald and Lathrop 2016).

Urbanization is a threat, but "leaky" **agricultural practices also cause eutrophication at the regional scale.** A century of data from Mississippi River sampling stations shows increasing nitrate concentrations from 1945 to 1980, which reflects increasing use of human-made N fertilizers on crops. And not all that N stays in the field. From 1981 to 2008, nitrates in river water leveled off but remained especially high in the Midwest. Agricultural production is strongly linked to elevated river nitrate concentrations in the Midwest in contrast to other U.S. river basins (Stets et al. 2015). Long-term data such as these are essential for revealing strong trends, as year-to-year variability and place-to-place variability can be high. That's a reason not to draw strong conclusions from just two years of detailed nutrient data from Swan and Murphy's Creeks.

With recognition of the chain of impacts, why is **eutrophication still a problem** in the Yahara River basin? In part, it's because the most easily-corrected source of nutrients (sewage) was addressed early on by constructing wastewater treatment facilities and diverting the treated effluent around the Yahara lakes. While that was very helpful, the remaining, more diffuse (non-point) sources, are very hard to regulate. Major contributors of nutrients today are concentrated animal feeding operations (CAFOs) and heaps of **livestock manure** that must be processed in some way that keeps the waters clean (Gillon et al. 2015). Questions remain about where to store manure over the winter, and where and when some can be used to fertilize crops. Buffers along streams, manure digesters, and other corrective measures are helping to reduce N and P in runoff, but excess nutrients continue to flow toward streams, rivers, and wetlands. Innovations are needed to re-use manure and avoid human-made N fertilizers.

Where municipal wells draw down the groundwater and create a "cone of depression," the prolonged hydroperiod needed by these Tussock sedge tussocks disappears, making weed invasion likely.

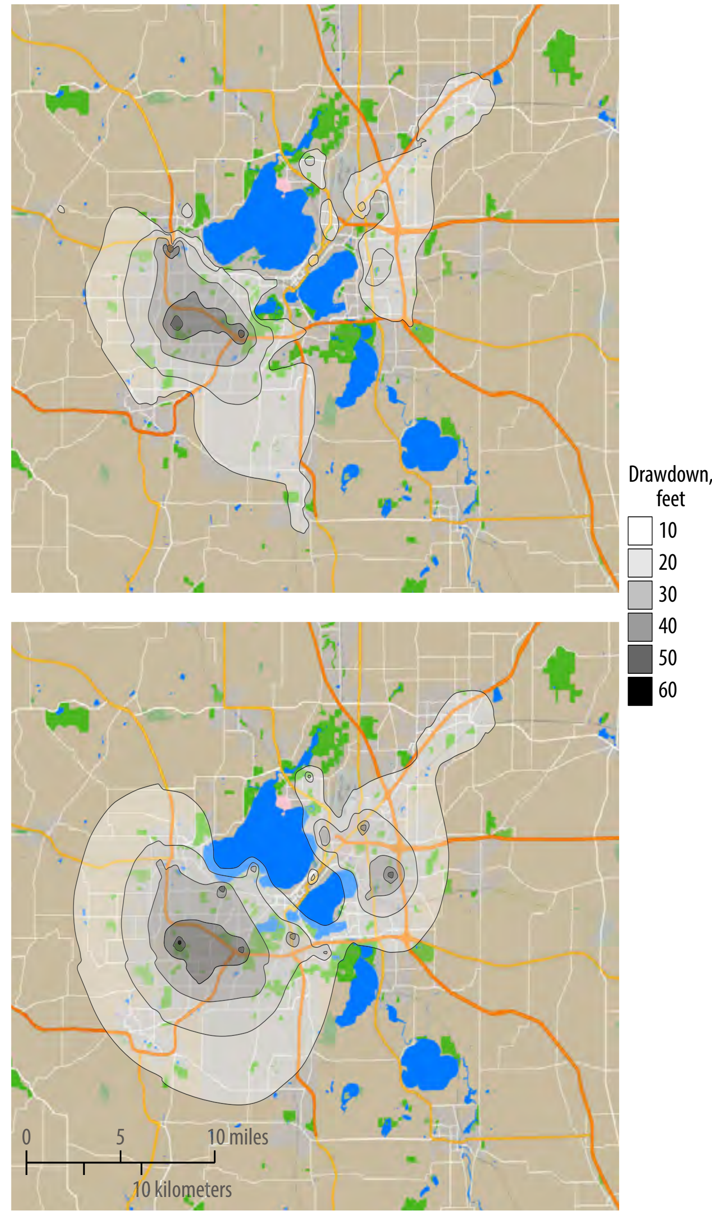
***Photo: P. Zedler***

## Third line of evidence

**Urbanization affects groundwater** ***quantity*** by withdrawing millions of gallons per day from deep high-capacity wells. We know that wetlands depend on having just the right amounts of groundwater and surface water. Every wetland depends on its natural hydroperiod to persist. So how much less groundwater and how much more surface water can a wetland accommodate? To answer that question, it's important to acknowledge that **increased surface water inflows do not compensate for reduced groundwater.** But specific limits are not yet known: How much is too little or too much? In the face of uncertainty, the precautionary principle says not to push the limits, because impacts could be costly and irreversible.

Urbanization increases groundwater withdrawal. Deep municipal wells deplete groundwater and create cones of depression. Madison might seem to have an endless supply of water in the Mount Simon sandstone aquifer. It's 300–700 feet thick and saturated with water. However, computer models indicate that pumping of groundwater by municipal wells has drawn the water table down by 10–60 feet, creating two "cones of depression" (one on each side of Lake Mendota, mapped here). That's a lot of water being moved from deep aquifers to the wastewater treatment plant downstream of the Yahara Lakes! As a result, groundwater flow to streams, wetlands, and lakes has decreased. This has negatively impacted groundwater-dependent ecosystems. During dry periods, it becomes hard to navigate a boat in Yahara River and along the shores of the Yahara Lakes (Eric Booth, 2014/06/27/the-brief-story-of-the-madison-areas-drinking-water/).

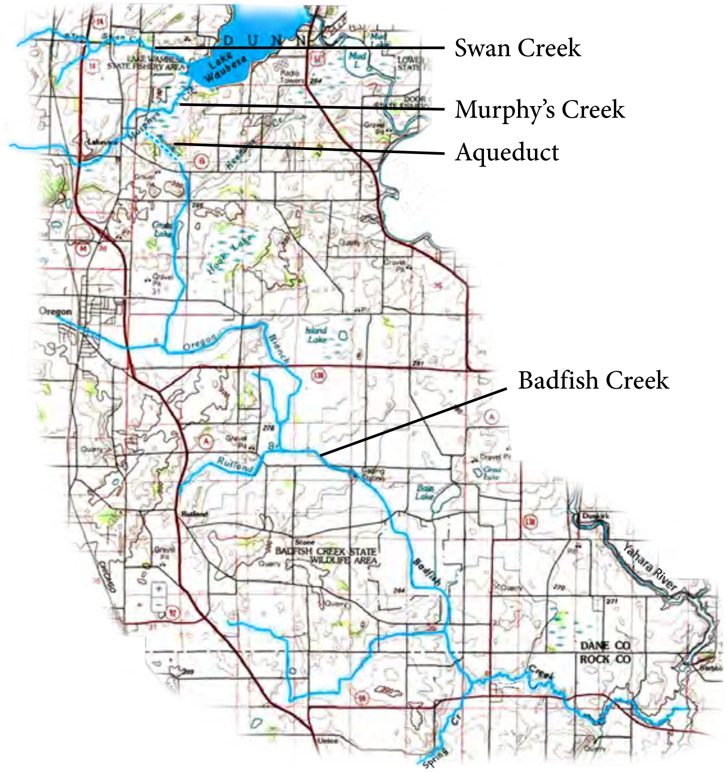
The maps are from Hunt et al. (2001, USGS Fact Sheet FS-127-01), and they show cones of depression both for the upper sandstone bedrock (above) and lower Mount Simon aquifer (below). Both cones are estimated to extend into the groundwatershed of Waubesa Wetlands. Note that groundwatersheds are not the same as surface watersheds. The impacts of groundwater depletion are most obvious in lost flows from springs and streams (Owen 1999 gives data for nearby Monona Wetland Conservancy). Most springs that historically flowed around the Yahara Lakes are now dry or reduced to trickles.



**The threat to wetlands:** Madison's upper sandstone bedrock and lower Mount Simon aquifers have long been thought as being separated by a confining layer (the Eau Claire shale). If true, deep municipal wells that penetrate the lower aquifer should not dry up the springs that depend on the upper aquifer. As shown by the USGS, however, there are gaps in the shale, and it is now clear that deep pumping can deplete the upper aquifer and dry up springs.

Impacts on the aquifers were anticipated by those who wrote the Town of Dunn Comprehensive Plan: "High priority should be given to safeguarding existing groundwater quality from further degradation" (Comp. Plan Appendix A-17). The aquifers will be sustained only if the amount of water that is pumped (groundwater withdrawal) equals the amount that is returned to the aquifer (groundwater recharge). However, most water in the Madison Metropolitan Area is used and sent to the treatment plant, where it is treated and piped to Badfish Creek. **Because the used-and-treated water is exported out of the basin, there's a net loss in the Town's groundwater.** How much is our groundwater resource declining? We aren't sure. In a review of 100 studies, Wright et al. (2006, p. 60), stated that "Perhaps the most **critical research gap** is the lack of understanding about wetlands whose water balance is dominated by groundwater, and more specifically, how these wetlands are impacted by upland changes in groundwater recharge rate due to land development…indirect impacts on wetlands from land development can have devastating and long-lasting impacts on many different wetlands, especially sensitive ones."

Deep municipal wells and Waubesa Wetlands all depend on groundwater. Drilling more deep wells upstream for more housing developments will further reduce groundwater reserves and have uncertain impacts on Waubesa Wetlands' springs and creeks. To avoid conflict, we should avoid competition for water **between people and nature.** That requires careful planning and governance at the watershed-scale. All species need water, but only humans can decide to use less of it and keep it clean




"Groundwater and surface-water systems are linked in much of Wisconsin, and groundwater can be utilized both for drinking water and as a source of water for sustaining lakes, streams, springs, and wetlands…. The supplies of groundwater are finite, however, and, in many cases groundwater used for one purpose cannot be used for another" (Hunt et al. 2016).

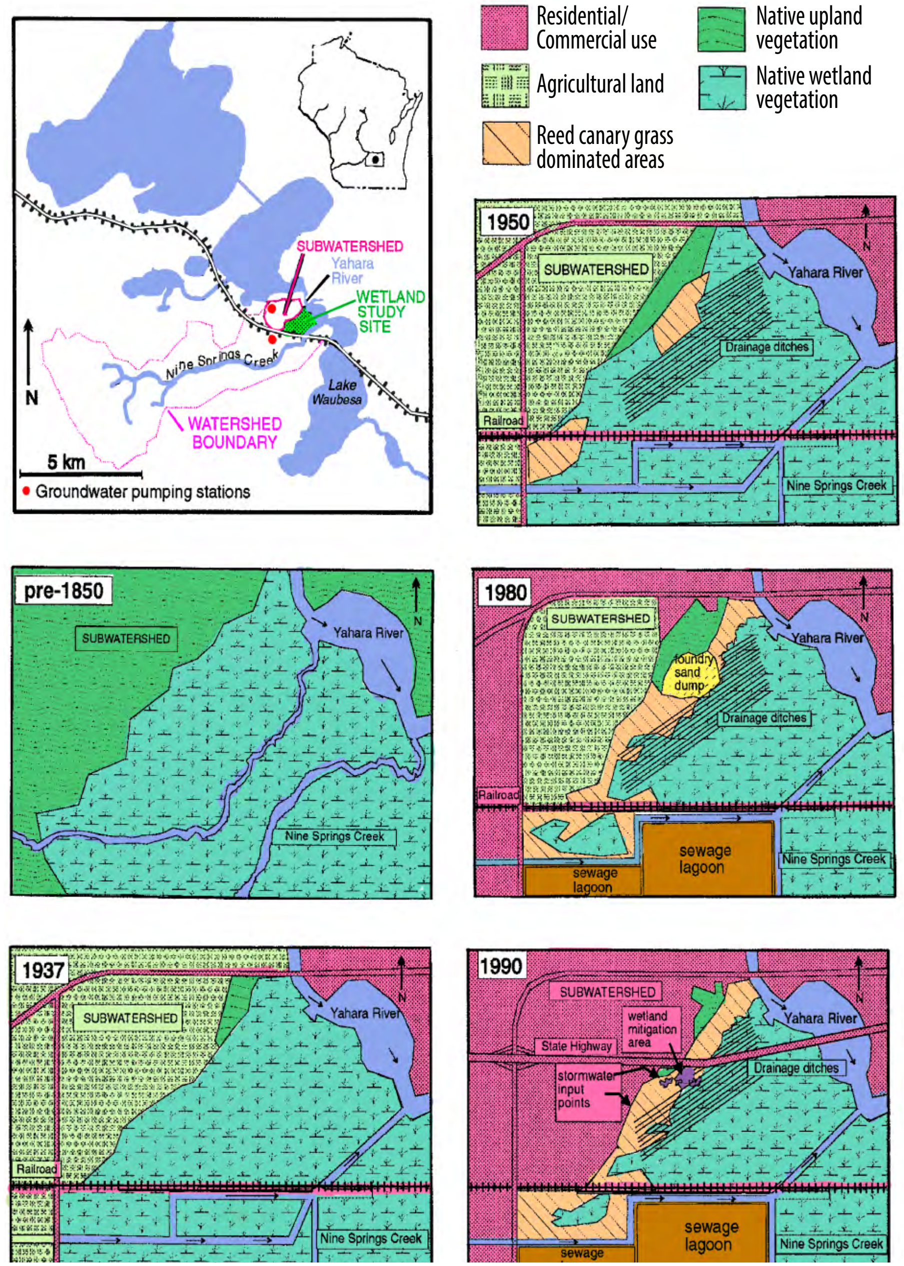
## Fourth line of evidence

**Urbanization threatens groundwater** ***quality.*** The shallow glacial material and the upper bedrock aquifer supply drinking water for most rural landowners. The upper aquifer also intersects our streams and lakes and affects water supplies throughout the watershed. The groundwater quality is good: rich in calcium, magnesium and bicarbonate, but with some bacteria, pesticides, volatile organic chemicals, and nitrates. Thus, well owners are encouraged to test their water for bacteria and nitrates annually (the drinking-water standard = 10 mg of nitrate per liter).

Future urbanization would further threaten groundwater quality in the upper aquifer by allowing contaminants from surface waters to move downward. The lower aquifer is also at risk if high-capacity wells are permitted to be drilled through the dense shale confining layer, which, as discussed earlier, already has gaps. As noted in Chapter 3, researchers found a human virus in a deep well, indicating that the deeper aquifer is not isolated from shallower waters (Ken Bradbury online presentation, 2011). A cone of depression around a well could suck contaminated water from the upper aquifer into the lower aquifer. At the same time that the aquifer is being depleted, contaminants in surface water can move downward into drinking-water wells—if not now, then in the future, as groundwater depletion continues.

All this might already seem too complicated, but there are additional problems when all four lines of evidence are considered together—changes in quantity and quality of both surface- and groundwater. An example is too close for comfort:

The Monona Wetland Conservancy* case is highly relevant, because the 227-acre (92-ha) site is just north of Waubesa Wetlands. What happened there supports two chains of impacts: Hardscapes caused too much runoff, too many nutrients were carried downstream by the surface runoff, and the downstream wetland converted to weeds. At the same time, well pumping decreased groundwater and eliminated springs.




Degradation of Monona Wetlands Conservancy over 140 years from maps, aerial photos, and field studies of Owen (1999).

*Lessons from the Monona Wetland Conservancy

Cathy Owen (1999) found that urbanization, water-level stabilization, and channelized creeks, increased surface water inflows to the wetland 20-fold! What were her lines of evidence? By using maps and aerial photos from 1850–1990, she tracked changes in land use, hydrology, and vegetation. On the ground, she installed pipes to track water levels (piezometers) biweekly over 2 years. Over 140 years, runoff into the wetland from the subwatershed increased 20-fold.

Causes included additional effects of urbanization, namely, construction of a railroad and other roads, channelization and diversion of two streams, and an altered watershed area—in this case, reducing an 8320-acre (3367-ha) watershed to 257 acres (104 ha). In addition, Owen documented a sand dump, tiling to drain and develop wetland, and ditching to convey stormwater downstream.

These factors and the 1937 Lake Waubesa dam elevated water levels in the wetland (by ~1.0–1.5 feet [~30–50 cm]). She also documented 3 ground fires, which likely had negative effects on peat, plus construction of sewage lagoons, and pumping of groundwater by municipal wells. No wonder Reed canary grass invaded and formed nearly monotypic stands, while remnant plots with the native dominant Bluejoint grass (*Calamagrostis canadensis*) coexisted with 11 other native plants (*Carex aquatilis, C. lacustris, Impatiens capensis, Lysimachia thrysiflora, Sagittaria latifolia, Solanum dulcamara, Galium tinctorium, Rumex orbiculatus, Polygonum sagitattum, P. punctatum and Typha latifolia)* (Owen 1999). Owen's thorough work and sobering findings have many lessons for future managers of Waubesa Wetlands and the upstream watersheds.

## Fifth line of evidence

**Warmer, stormier weather will affect downstream wetlands.** Wisconsinites have more evidence about changes in climate than most Americans, thanks to U.W. scientists. As Dr. Chris Kucharik likes to say, "Wisconsin isn't getting warmer, it's getting less cold," meaning that the number of really hot summer days is not increasing; instead, night-time temperatures aren't as low as they used to be. Furthermore, the changes in weather described for **1950-on* are predicted to continue to at least 2055.** We can appreciate that climate is changing, because we're experiencing it!

Not everyone agrees about how climate is changing. While Serbin and Kucharik described Wisconsin as becoming "less cold," others have predicted much colder winters. How can winters get colder if the climate is warming? A very new study explains that the Arctic is warming at shockingly high rates, and that winter air masses are responding by dipping lower into the temperate zone (Francis et al. 2017). These authors expect winter cold air masses to return but are unable to make precise predictions.

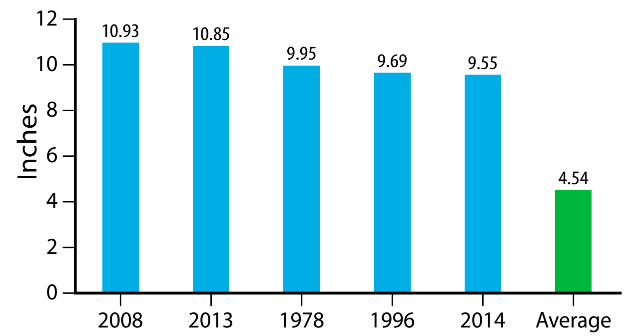
*Shawn Serbin and Dr. Chris Kucharik studied **historical weather patterns** over 57 years (1950–2006) and found clear trends in four components of weather: Daily and monthly precipitation, maximum temperature, and minimum temperature (Serbin and Kucharik 2009). For the Waubesa Wetlands area, average daily temperature has increased 0.5–1.0 ˚ F; nights have gotten warmer; and springtime precipitation has increased by 3 inches over 57 years (Kucharik et al. 2010). To learn how climate has been changing, these investigators synthesized data from 176 climate stations around the state and over half a century. At the same time, Dr. Dan Vimont used a fine-scale (5 x 5-mi, 8 x 8-km) grid to model the **future** (1980–2055). For Waubesa Wetlands, his model predicts: Average temperature increases of 6.5 ˚ F, especially in winter; fewer extremely cold winter nights; more hot summer days; and 1.5 inches more annual precipitation (WICCI 2011).

**Extreme events.** In addition to gradual shifts in temperature and rainfall, we can expect more extreme weather events at the local scale, like bigger storms and more intense droughts (Gallant et al. 2012). Many extremes can be related to climate change (Herring et al. 2016), and models of climate change include predictions of more extreme weather events. **Storms will be more frequent and more intense.** Kucharik et al. (2010) predicted that the number of extreme rainfall events (more than 3 inches in 24 hr) in spring and fall will increase during this century. We've already seen examples in total June precipitation for Madison.* Record rainfalls have occurred more often since 1978.

Weather extremes are easier to notice than gradual changes in climate, but harder to predict. As shown by June rainfall patterns, the historical data are not likely to predict future rainfall or, in turn, future patterns of urban runoff. It is common for computer models to rely on "design" storms. If the computer is programmed to predict how often a 10-year storm will occur, it won't tell us how often a 100-year storm will occur. "A single **design storm cannot adequately capture the variability** of rain and how that translates into runoff or pollutant loadings, and thus is not suitable for addressing the multiple objectives of stormwater management… the whole distribution of storm size needs to be evaluated for most urban receiving waters…" (NRC 2009). Unfortunately, **extreme events** are what can cause the greatest impacts to downstream wetlands (Reinelt et al. 2000, Griggs et al. 2017). For example, a record toxic algal bloom and fish kill in Lake Mendota in mid-June 2017 was preceded by above-average rainfall, followed by intense rainstorms and large pulses of runoff.

While studying California salt marshes, I witnessed numerous catastrophic floods that dumped tons of sediment in wetland channels and on the tidal marsh plain. Plants and animals were wiped out, and most took years to decades to recover—incompletely (Zedler 2010, Safran et al. 2017). Models of rainfall and runoff will likely **fail to predict the catastrophes** that will have the greatest impacts on Waubesa Wetlands. Models can come closer, however, if fed data that are up-to-date, including recent and current conditions.

Flooding is one extreme; drought is another. Future droughts and **series of drought years** should be anticipated as climate changes toward more frequent extremes. During droughts, people compete with nature for surface water. Droughts can also dry up and compress peaty soils in an irreversible process. Dry peat can burn spontaneously, as happened in the 1930s Dust Bowl years (Aldo Leopold, Wetland Elegy). As peat dries and decomposes or burns, it releases carbon dioxide, in a positive feedback:


*Madison's total rainfall for June 2008 (10.93") not only broke a record, it included a sequence of record-breaking rainfalls. The June 7 rainfall of 2.23" broke the 1993 record (2.01") for that date; the June 8 rainfall of 4.11" broke the 1874 record (1.40") for that date; and the June 12 rainfall of 2.57" broke the 1877 record (1.20") rainfall for that date. From June 7–8, Madison's 24-hour rainfall total of 5.27" was second only to that of September 7–8, 1941 (5.31") (https://www.weather.gov/mkx/0608flooding).

*Redrafted from National Weather Service Forecast Office, July 2, 2014; DeWitt presentation to CARPC.*

Given future extremes of both flooding and drought, will local water supplies fill the needs of both people and nature? People can store water in a reservoir and remove it as needed, but native species need tolerable **amounts, timing,** and **frequency** of rainfalls to thrive and resist invaders. In other words, the ecosystem needs its **natural hydroperiod.** During extreme droughts, some animals might be able to move away from harsh conditions, if there's a place for them to go. But the high rates of historical wetland losses in the Corn Belt states and in Dane County suggest there are few suitable habitats that can support native species, and those that remain might not support crowding—like a fully-occupied apartment building that can't house more tenants.

To prepare for the future, we need to bear in mind the impacts of record-breaking extreme events in the past and consider how such events might become more frequent and even more extreme. Recall the prolonged droughts of the 1930s, the major Mississippi River flood in 1993 (Hey and Philippi 1995), multiple heavy rains in 2008, and unseasonal freezing and unseasonal thawing in February 2017. A single extreme can have extensive and lasting impacts. In preparing for climate change, we should plan for the extremes. This is a variation on the precautionary principle. For Waubesa Wetlands, it means taking precautions so that groundwater is not depleted, as a buffer against drought, and that upstream urban runoff is infiltrated, harvested, and stored upstream (see Chapter 7), as a buffer against flooding.

Larsen Road flooding. *Photo: David Johnson*

## Sixth line of evidence

**Urbanization will interact with climate changes to increase impacts on downstream wetlands.** When two stressors interact, their combined impact is greater than the sum of two separate stressors would be. For Waubesa Wetlands and elsewhere, land-uses that cause **habitat loss and fragmentation** are the main causes of declining diversity (Sala et al. 2000). However, when we add climate change to the mix, the extreme events interact with land-use stressors to degrade biodiversity across genetic, species and habitat levels (Mantyka-Pringle et al. 2012). Envision a major rainfall event—or a series of rainfalls—occurring during the construction of an upstream housing complex involving bulldozers, grading, and temporarily-stockpiled soil. More sediment and contaminants would move downstream than if the same storm or the same development occurred independently.

How will the combination of climate and land-cover change affect downstream wetlands? An example concerns restoration of stream and riparian habitats to protect macroinvertebrate and fish richness (Mantyka-Pringle et al. 2016). The climate-urbanization interactions* in Australia are relevance to Waubesa Wetlands.

Contaminants can be as great a threat as nutrients. In considering how storms will carry increased loads of pollutants, a national panel of experts (NRC 2009) emphasized the need to understand effects of **combinations** of storm characteristics, conditions between storms, land use, the natural and built drainage system, and any stormwater control measures that have been implemented. Runoff and flows of pollutants depend on the storm magnitude but also the moisture conditions in the watershed before the storm. Therefore, we need to predict the **frequency** distribution of storms with different characteristics in order to understand where and how much pollution to expect in future stormwater discharges. In northern climates, runoff is often delayed by the accumulation of snow, with certain pollutants released in a pulse when snow melts. Accurate predictions require **data on** precipitation, potential accumulation, and discharge to assess stormwater assessment. The same experts also note that: "Nontraditional sources of stormwater pollution must be taken into consideration when assessing the overall impact of urbanization on receiving waterbodies…[the sources] include **atmospheric deposition, snowmelt, and dry weather discharges**…" NRC (2009).

**In summary all six lines of evidence agree that urbanization and a stormier climate will affect downstream wetlands and waters.** Waubesa Wetlands will be negatively affected unless (1) agricultural and urban impacts are minimized, and (2) extreme events are anticipated and measures taken to minimize their impacts. Obviously our plans for large-scale, long-term management of biodiversity need to consider interactions between changes in climate and land use. We need to manage resources at the watershed scale and to learn as we experience extreme events and their impacts (adaptive management; see Chapter 7). First, let's summarize wetland responses to negative impacts.

## How wetlands respond to upstream urbanization

**More invaders, fewer natives.** It's very clear that invasive species become more dominant and native species less prevalent as watersheds experience urban development. In Puget Sound, urbanization had whole-ecosystem effects on wetland hydroperiods, water quality, soils, vegetation, and animals (Horner 2000). In reviewing more than 100 studies of urbanization effects, Wright et al. (2006) found **sharp declines** in the diversity of the **native** plant and animal community and an **increase in invasive** plant species that can tolerate conditions that stress natives. Their review explored cumulative impacts on wetland plant communities, aquatic invertebrates, amphibians, reptiles, birds, and mammals. For example, mammals need complex vegetation structure, so they lose habitat when an invasive plant monoculture takes

*__Interactions__ in South East Queensland, Australia: Aquatic macroinvertebrates and fish declined in relation to maximum temperature of the warmest month and mean decline in precipitation over 100 years. At the small scale, declines in macroinvertebrates and fish resulted from the **combination of urbanization**, which caused high nutrients and high runoff, and **climate-change,** which caused high nutrients and high water temperature. Using a new statistical approach (a Bayesian Decision Network), the research team developed a decision-making model that included **interactions** between land use and climate change. They also incorporated field data and expert opinions, and prioritized management actions to abate both land-cover changes and climate changes. Their approach **prioritized management actions for adapting to climate change and urbanization.** In the **short term,** farmland management was the top priority and most cost-effective action. But over the **long term, restoration** of streams and riparian habitats was the priority for sustaining aquatic biodiversity (Mantyka-Pringle et al. 2014, 2016).

Their global synthesis of 168 publications in 2015 (Mantyka-Pringle et al. 2015) found that wildlife (birds, arthropods, mammals, plants, reptiles and amphibians) responded more to land use change, namely, habitat fragmentation, in warm regions that had experienced decreasing rainfall over a century. Of broad interest is their verification of interactions: **Effects of habitat loss on species were more negative where temperatures were higher and rainfall was lower than average.**

over. And because animals depend on plants for food, the degradation of diverse wetlands can affect the entire food web (Lougheed et al. 2008).

**Specific responses depend on each wetland's sensitivity,** so let's consider a range of wetland types. There is consensus that bogs and fens are highly susceptible to urbanization because they require a narrow range of environmental conditions (Wright, et al. 2006). Thus, Waubesa Wetlands' Calcareous fens can be expected to respond to very minor changes in hydroperiod, as we found in our study of swales (Doherty et al. 2014). In Waubesa Wetlands, native sedge meadows were rapidly invaded by Reed canary grass, which reduced diversity by half at the invasion front (Rojas and Zedler 2015). This supports observations elsewhere, that diversity drops sharply when an invader, particularly an aggressive clonal (vegetatively-reproducing) plant. Indeed, there is a **global trend,** that **inland freshwaters** are experiencing the **fastest biodiversity losses** of the world's major biomes (Loh et al. 2005).

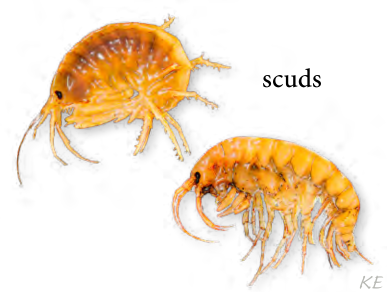
Ponds in and near Madison: Dr. Stan Dodson (2008) studied 23 urban stormwater ponds. Where urban watersheds had more lawn cover, ponds tended to have lower aquatic plant abundance and lower zooplankton diversity, and to lack mollusks and amphibians. In particular, amphibians were missing in ponds surrounded by more than 30% lawn cover. After ruling out nutrients as a likely cause, he proposed that lawn pesticides were at fault, as in this chain of degradation: **Urbanization → Managed lawns → Pesticides in runoff → Low aquatic biodiversity.**

Streams: It doesn't take a pesticide to kill stream invertebrates. On the contrary, very low concentrations of nitrate are toxic to many stream invertebrates. The drinking water standard for people is less than 10 mg $NO_3$/L, but that same level of pollution is toxic to gammarid amphipods ("scuds"); in fact, levels of less than 2 mg $NO_3$/L are recommended for the most sensitive freshwater stream invertebrates (Camargo et al. 2005). Nitrate prevents animal and human babies' oxygen-carrying pigments (like hemoglobin) from carrying oxygen. Yikes! I don't know about you, but it worries me that I'm allowed to drink water that a lowly scud would reject.

In **France,** data from an impressive monitoring network of 1100 stream-sampling locations led investigators to link inflows of nutrients and organic matter to declines in biotic indices of benthic macroinvertebrates, diatoms and fish (Villeneuve et al. 2015). Intensive agriculture was the most important factor across France. Two things inspire me about this study: the extensive national monitoring effort and the intensive examination of biological responses. *Vive la* [stream biota of] France!

In southeastern **Wisconsin,** Stepenuck et al. (2002) studied 43 streams, and found the familiar pattern that with more hardscape area per watershed, there was lower diversity and a lower proportion of pollution-intolerant mayflies (Ephemeroptera, which are scrapers or

**Freshwater** biodiversity has declined over 30 years (1970–2000) at about twice the rate of marine or terrestrial biomes, according to a **Living Planet Index,** developed by Jonathan Loh et al. (2005). This is a global concern. Hence, the Convention on Biological Diversity encourages long-term monitoring of freshwater clarity, chemistry, and biota to assess changes and provide impetus for improved management of surface waters (Revenga and Kura. 2003).



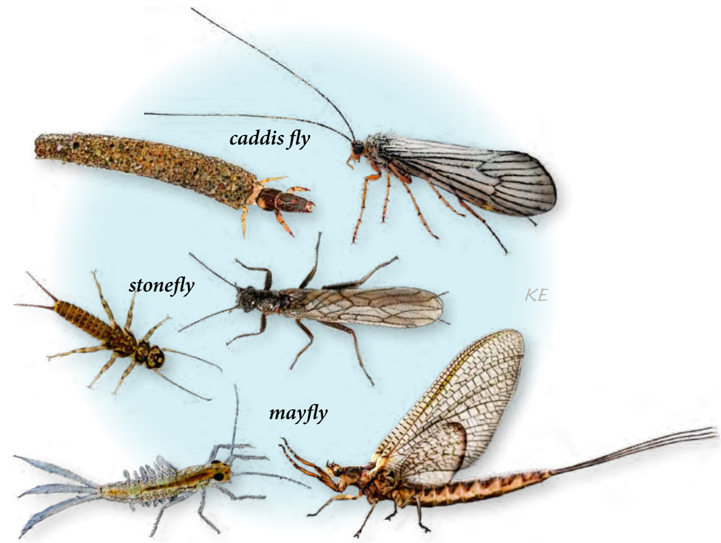

scuds

collectors), stoneflies (Plecoptera, predators), and caddis flies (Trichoptera, scrapers, collectors or shredders). Because these three groups of stream invertebrates are sensitive to pollution, their presence indicates high water quality. In this study, **good** stream quality occurred where imperviousness was **less than 8 percent of the watershed,** but there was a threshold between 8 and 12 percent, where sharp declines in stream quality followed minor increases in urbanization (Stepenuck et al. 2002, p. 1041). A widely used index of biotic integrity showed that stream quality declined with increasing urbanization. As noted above, urbanization changes entire stream entire food webs. Urban streams have more collectors and gatherers and a lower proportion of filterers, scrapers, and shredders. Macroinvertebrate communities and overall stream quality are severely degraded.

Rock River Coalition volunteers track stream biota using a straightforward index based on the number of indicator macroinvertebrates found in a stream. As noted earlier, both Lalor Road sampling stations for Swan and Murphy's Creeks were graded **"F"** in **stream quality.** Might this loss of diversity be due to nitrates, herbicides used to control weeds, insecticides used on crops, or all three? If we had funding, the Town of Dunn could test the water for lawn and crop biocides. And if residents within the watershed would report pesticide uses, the Town could specify testing for chemicals that are in use.

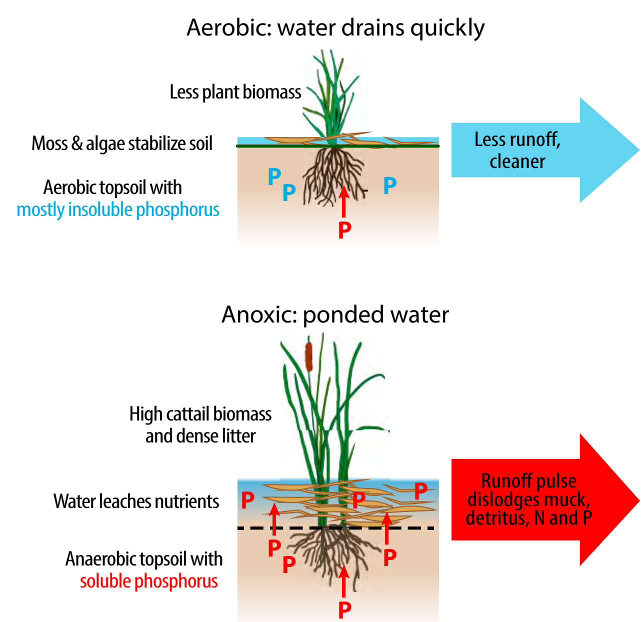
Wetland vegetation: With urbanization, natives take a hit both directly from disturbances and indirectly by being outcompeted by invaders. First, let's explore how altered hydroperiods and excess nutrients affect invasive plants. Early research showed that wetland plants can enrich their habitat by slurping up dissolved phosphorus from anoxic, or oxygen-depleted, sediments, then transporting it up stems and leaves to lake water. Ecologists call this "**internal eutrophicatio**n." In nearby Lake Wingra, Eurasian milfoil (*Myriophyllum spicatum*, a submersed aquatic plant) took up P from sediment and moved it into the lake water. Note that plants can mobilize P from wet, anaerobic sediment, which makes P soluble (see conceptual model). The amount of P added to Lake Wingra by plants was greater than the amount of P discharged into the lake by the entire urban watershed (Loucks 1978). How did it do that? By growing roots that tolerate anoxic sediments. It doesn't happen in uplands where soils are aerobic (well aerated). Under these conditions, P becomes insoluble and sticks to suspended particles, thus resisting uptake by plants.

Along the Mukwonago River in southeastern Wisconsin, invasive cattails thrived with stable water levels. For his dissertation on cattail invasiveness, Aaron Boers documented cattail expansion with stable water behind a dam in Eagle Lake but not



Pollution-intolerant stream insects

Phosphorus in aerobic and anoxic conditions

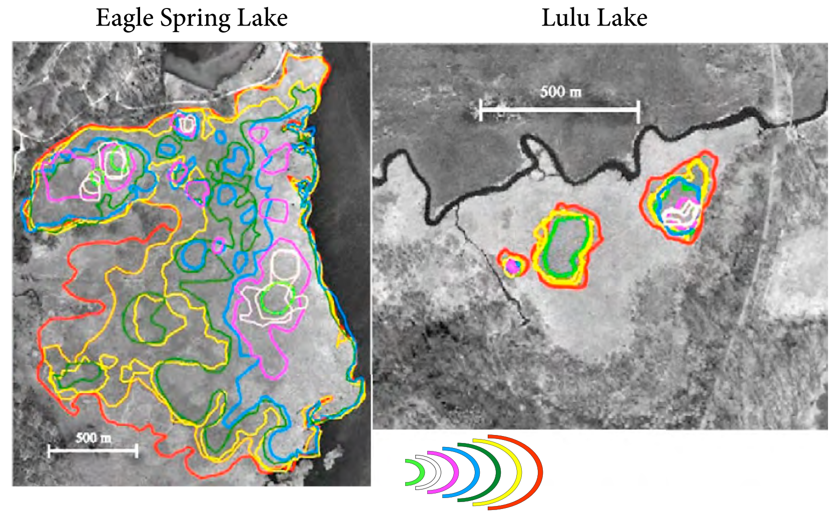


where water levels fluctuated naturally at Lulu Lake. He also tested for cattails' ability to enrich their habitat in flooded vs. fluctuating water levels in microcosms (a.k.a. nursery pots). As expected, invasive cattails extracted more P from soils in **standing water** than from fluctuating water (Boers and Zedler 2008; Leaflets #7, #27-28). With flowing water, sediments are more aerated and P is less-easily taken up by plants. No wonder **cattails love ponds.** Stabilized water levels promote P uptake.

Here's more evidence for a chain of cause-effect processes. In northeastern Illinois, invasive cattails replaced native species, especially in deeper water (Boers et al. 2007). In a vegetated swale at the Arboretum, cattails mobilized more P where the hydroperiod was prolonged than in adjacent swales with better drainage and less ponding (Doherty et al. 2014). In general,

Stable water level → More P is soluble → Cattails take up more P (and other nutrients) → Cattails outgrow natives

Nutrients alone can promote cattail growth—as if they need much help. Graduate student Isa Woo wondered whether invasive cattails (the hybrid, *Typha x glauca*) were expanding into a Sedge meadow in the Arboretum's Gardner Marsh, in response to nutrient-rich urban runoff. She added an N+P fertilizer and watched the cattails grow well over her head in response to nutrient addition. The experimental plots were at the edge of a former diverse Sedge meadow. The Sedge meadow had little chance of persisting after a dam stabilized the marsh water level. We learned that, yes, nutrients alone can trigger aggressive cattail growth and expansion (Woo and Zedler 2002). Kristin Frieswyk called invasive cattails "monotype dominants"—unable to support a diverse plant community—in her study of Green Bay marshes (Frieswyk et al. 2008).



Colored boundaries indicate spread of cattails over 37 years.
Eagle Spring Lake has stable water levels. Lulu Lake has fluctuating water levels.
*From Boers et al. 2007*

A diverse Sedge meadow at the Arboretum (Irwin 1974) succumbed to both stabilized water levels and nutrient influxes: Invasive cattails followed this chain of degradation:

Urbanization
↓
Excess, nutrient-rich runoff + Stable water levels
↓
Invasive cattails
↓
Native plants outcompeted
↓
Biodiversity lost


Recent photo of Gardner Marsh experimental plot area, with remnant sedges in foreground. *Photo: J. Zedler*

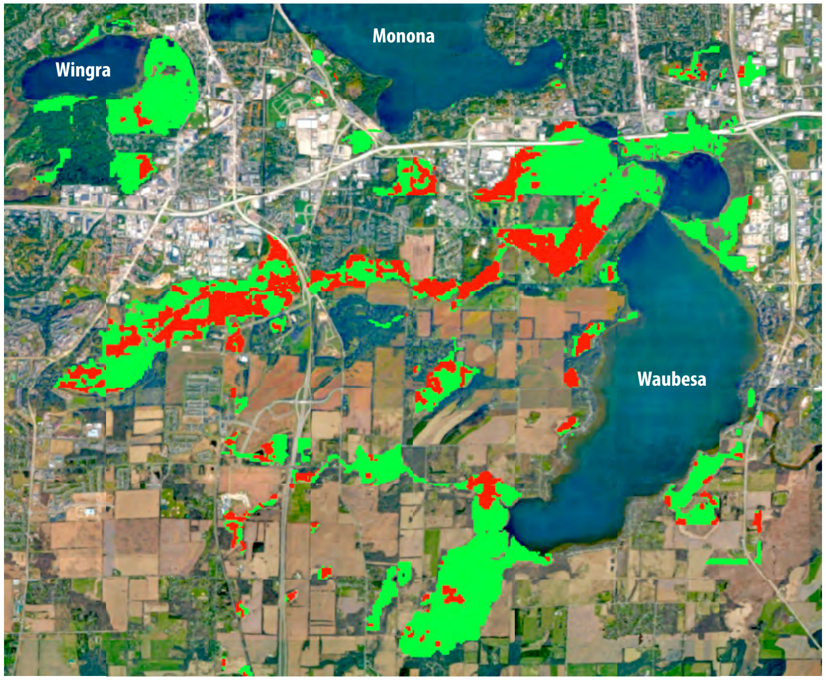
You might conclude that all the problems with invaders concern cattails, but no, **Reed canary grass** is "Wisconsin's Worst Wetland Weed." RCG dominates about a half million acres of wetlands in Wisconsin (Hatch and Bernthal 2008), and in the process it displaces native vegetation. Evidence comes both from outdoor experiments and field observations, where the trick is to find a wet place where RCG doesn't grow.

**Nitrogen is the culprit.** Field experiments by Emily Green and Dr. Sue Galatowitsch (2002) at the University of Minnesota showed that RCG responded to additions of N alone. They controlled nitrate additions and water levels in constructed wetlands. As predicted, RCG outgrew the native sedge meadow vegetation where they added more N, and fewer native plants persisted. They concluded that it is essential to reduce N loadings to minimize negative impacts to diverse vegetation. This means that wetland managers must control N, not just P, to sustain native vegetation—and stream invertebrates.

Wet prairie with about a dozen plant species, one of the replicate "mesocosms" used to test N-retention ability.

Former wet prairie, invaded by Reed canary grass.

Suzanne Kercher's test of nutrient (N+P) additions, substrate additions (topsoil vs. sand), and hydroperiods (water levels) in 160 outdoor mesocosms (livestock water tanks) showed that nutrients, both as fertilizer and topsoil, allowed RCG to take over species-rich assemblages of native plants within a growing season (Kercher and Zedler 2004). Then, Andrea Herr-Turoff helped extend the experiment, and it became clear that longer hydroperiods and excess nutrients were **synergistic** (worked together) in accelerating RCG invasion (Kercher et al. 2007).




Abundance of Reed Canary Grass
Less than 50% More than 50%
*From: Hatch and Bernthal 2008*

RCG is widespread in Monona Wetland Conservancy and less widespread in Waubesa Wetlands except in a disturbed area along Swan Creek (Bedford et al. 1974, Hatch and Bernthal 2008).

Need more evidence? We still wanted to know RCG's inner (physiological) secrets. So, when a doctoral student inquired about doing physiological studies on invasive plants, I saw an opportunity to find out why RCG is so competitive when fed nitrogen. It wasn't the kind of research I could direct, so I suggested that she work with Dr. Scott Holaday, whose lab at Texas Tech had already shown that RCG stored more carbon, used water more efficiently, and produced more leaf area per shoot than Tussock sedge (He et al. 2011). It was likely that RCG also used N more efficiently. The rest is history.*

For 60+ years and counting, lake managers have focused almost entirely on managing phosphorus (NRC 1969). Sometimes that is defensible if the only concern is inland lakes, where excess P causes algal blooms that turn lakes into pea soup ("P soup"!). Mostly it's the scientists who study coastal deltas, estuaries and ocean edges who worry about nitrogen, because those waters respond more to N than to P. The nutrient that is in shorter supply relative to need (called the limiting nutrient) is the one that is predicted to trigger a bloom. Note that algae and other plants need about 15 times as much N as P, so the comparisons of N to P are relative to the organism's need for each nutrient. For inland lakes, influxes of P tend* to set off algal blooms. Inland wetlands tend to respond to influxes of N.

***Reed canary grass knows what to do with added N**. Elizabeth Waring and Dr. Scott Holaday figured out that slightly different ways of processing and moving nitrogen within the plant explained why RCG outcompetes Tussock sedge. It might sound easy to research, but even focusing on a single nutrient and just two species of plants required several years of experimentation, plus guidance from advisors with more-or-less expertise in plant physiology. I was in the "less" category, but I provided seeds from Waubesa Wetlands to grow Tussock sedge for the experiments in Texas. In April 2017, Waring completed her dissertation and reported that RCG grew more per N available than Tussock sedge. RCG took better advantage of seasonal pulses of nitrogen in soil; its roots were better able to take up N and allocate it to leaves, and its rate of photosynthesis (carbon assimilation) exceeded that of Tussock sedge.

***N can also limit lake algae.** Limnologists are learning more about the role of N in eutrophying lakes, and several now recommend that both N and P be managed to control algal blooms: "N is at least as likely as P to be limiting to phytoplankton (algae)" and that several flaws in field studies have led to "an unrealistic degree of focus on phosphorus as a controlling element" (Lewis and Wurtsbaugh 2008; see also Lathrop 2007, Lewis et al. 2011).

Lake Waubesa is shallow and hypereutrophic (really nutrient-rich; Lathrop and Carpenter 2013), and both N and P seem to be limiting. Still, it is uncertain when and where N limits or N+P co-limit algal blooms (Lathrop 2007). Most likely, N limits summer algal blooms:

(1) when little iron (Fe) is available. This is because cyanobacteria (bluegreen algae) need Fe to fix N, they might not capture enough N from the air, and N in the lake could be used up. At such times, adding N would stimulate an algal bloom.

(2) when denitrification rates are high throughout a lake-river-wetland system. At such times, enough N could be removed for it to limit algal growth.

(3) where P loading is especially high. If there's excess P, the supply of N could be limiting.

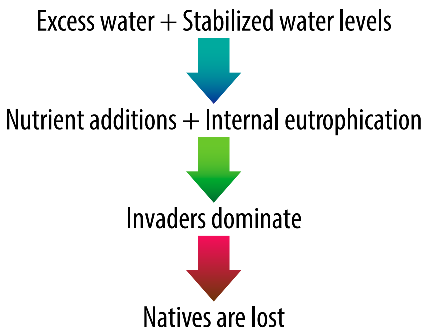
**Here's my mantra:**

**"Manage not just lakes, but also wetlands,**

**Not just phosphorus, but also nitrogen"**

## Summary

Wetlands respond to urbanization by responding to increased runoff and additions of nutrients:




Cattails thrive on plenty of P, but also respond to additions of N+P. RCG responds to additions of N and also to additions of N+P. **Invasive cattails** are already present along the lake edge of the marsh, possibly responding to influxes of nutrients as lake levels are raised after the winter drawdown.* **RCG** and other invaders are already widespread along Swan Creek, **poised to expand** with more runoff and nutrients from upstream.

*__Redux?__ Nutrients that reach Lake Waubesa might flow upstream as the lake's water-level is raised in spring after being lowered in winter. The lowered level exposes mudflats in winter, when they are used by non-migratory waterbirds. "Redux" means the upstream movement of nutrients from the shallow water and mudflats as the lake is allowed to refill to its summer high level. Included in the nutrient load would be inflowing nutrients from upstream and aerial deposition, as well as waterbird guano. It's a hypothesis that could explain why the marsh edges are being invaded by hybrid cattails and RCG. Note that lake levels are managed by DNR.

Urbanization has lasting, detrimental effects on wetlands. By favoring invasive plants over natives, eutrophication indirectly degrades native vegetation, but diversity is also lost in the **seed bank.** Frieswyk collected soil samples from cattail marshes along Green Bay and found that the seed bank had also lost its diverse natives; it was dominated by invasive purple loosestrife (*Lythrum salicaria*) (Frieswyk and Zedler 2006). What does this mean? If we were able to remove the invasive cattails, another invader would take over. Thus, **restoration** would require **both removal of invaders and reestablishing natives.** However, this might take several efforts, because removing invasive cattails and seeding natives might work in the short term, with cattail reinvasion in the long term (Boers et al. 2007).

## How invasive species will likely respond to changes in climate

**Many plant distributions will likely change under a warmer climate.** Several native and invasive species are already shifting the **timing** of their growth and reproduction (called **phenology***) as growing seasons become longer. Some respond to earlier warm-up in the spring; some respond to later frost; some take advantage of both. Species that can extend their growing season in spring or fall or both will have an advantage as climate becomes warmer. And if invasive plants thrive with climate and land use changes, the effects on native species will be both direct (eliminated by adverse conditions) and indirect (eliminated by expanding, more competitive invaders). Direct effects will be hard to detect (see example for Tussock sedge, below).

**Invasive species will have advantages with warmer and stormier climate.** We don't monitor RCG, but it will certainly have an advantage given earlier spring warm-up, owing to its European origins (see below). A short-term study of RCG documented its early sprouting and flowering, and late senescence (dieback), relative to a dominant prairie grass at the Arboretum (Leaflet #13). RCG will likely benefit from longer growing seasons, due to early thawing and later frosts. This invader remains green well into November, long after native herbaceous plants have senesced. Urban heat sinks will warm the runoff and warm, nutrient-rich water will further enhance RCG growth (Kercher and Zedler 2004).

RCG has a flexible growth pattern (high plasticity) in its canopy architecture in response to flooding and nutrients (Herr-Turoff and Zedler 2007). It forms tussocks in deeper water, which elevates its roots and stems above water. As a result, we can predict that RCG will respond positively to greater rainfall and runoff, as well as to longer growing seasons.

RCG sends up new shoots before our native Canada bluejoint, and two invasive Buckthorns produce new leaves weeks before the native shrubs. The invaders can lengthen their growing seasons; they seem "preadapted" to take advantage of a longer growing season.

**Native species are not likely to fare as well as invaders in a changing climate.** Native species are less aggressive than invasive species, almost by definition. As described earlier, Sedge meadow species richness in front of an RCG invasion was twice as rich in species as behind the invasion front (Rojas and Zedler 2015). Will such effects magnify with warmer climate? I predict they will. If you observe our native Canada bluejoint and our native woodland shrubs, you'll notice that they break dormancy in the spring later than European invaders of similar structure. Tussock sedge, Big bluestem and other

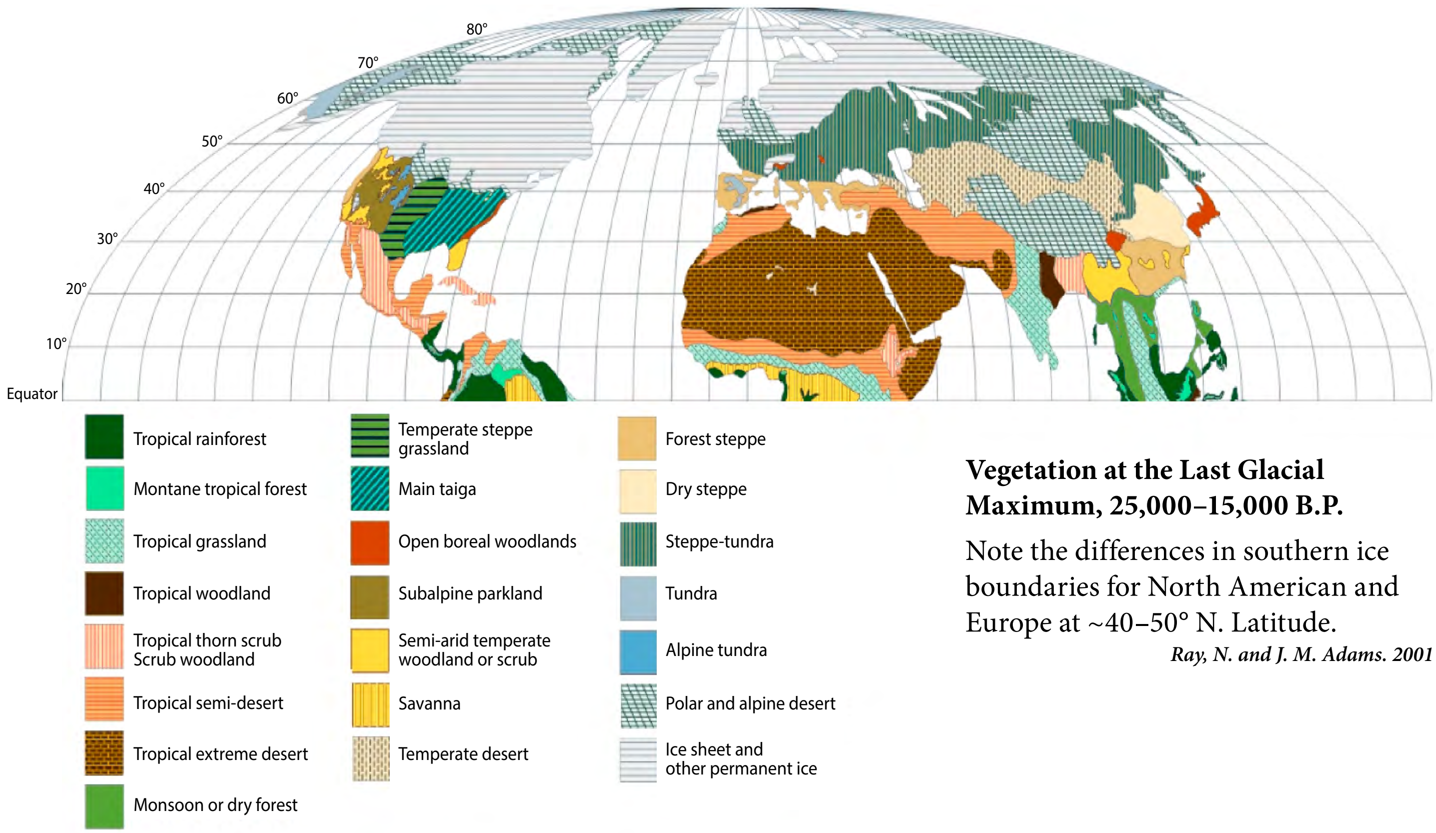
***Phenology.** Since 1971, scientists have followed trees in temperate climates and documented increasingly early "spring events" of 2.5 days per decade (Körner and Basler 2010). But a plant that responds only to early spring warm-up could have a growth spurt and then be killed by a late frost. Increasingly variable weather will cause such havoc. We need to know more about the adaptive value of plants responding to daylength (photoperiod) vs. global warming. Daylength tends to control when dormancy breaks, when growth begins, when reproduction occurs, when leaves fall, and when winter buds form. Temperature has a lesser, but still visible, effect on phenology, for example when leaves turn color in fall. Fall colors are not just due to daylength.

Tussock: new spring growth *Photo: J. Zedler* natives are "conservative" and senesce earlier in fall, so their growing season is shortened at both ends. We can test for long-term trends by monitoring phenology (of growth and reproduction) of native and invasive species over the next several decades.

Natives' "hesitancy" about growing early and late might have something to do with the last glaciation. About 12,500 years ago, the ice was melting over Waubesa Wetlands, and the cold climate would have selected for species with "cautious behavior"; that is, species that wait to resume growth until the threat of a late frost is minimal. For example, Tussock sedge has overwintering spikes, they do not "jumpstart" the growing season with the first warm days of spring (Zedler 2016).

In Europe, plants at the same latitude as Waubesa Wetlands (~42° N.) have been busy adapting to warmer spring and fall weather. When European plants, such as Buckthorn and RCG were imported to Wisconsin in the 1800s, they were poised to outcompete our natives.

**Monitoring must be long-term to detect effects of gradual changes in climate.** It is difficult to pinpoint climate effects in short-term studies, because many factors affect interactions between native and invasive species. I learned this the hard way by monitoring Tussock sedge (*Carex stricta*) phenology for 11 years. I didn't find a clear effect of time. Instead, I found differences between tall and short tussocks in leaf elongation, flowering, tussock survival and plant canopy height. Each tussock has a unique growth curve; those that were taller at the beginning of the study tended to grow taller for 11 years, but with variations. Those variations blurred any long-term pattern. Effects of increased frequency and magnitude of extreme events are easier to document.




**Vegetation at the Last Glacial Maximum, 25,000–15,000 B.P.**

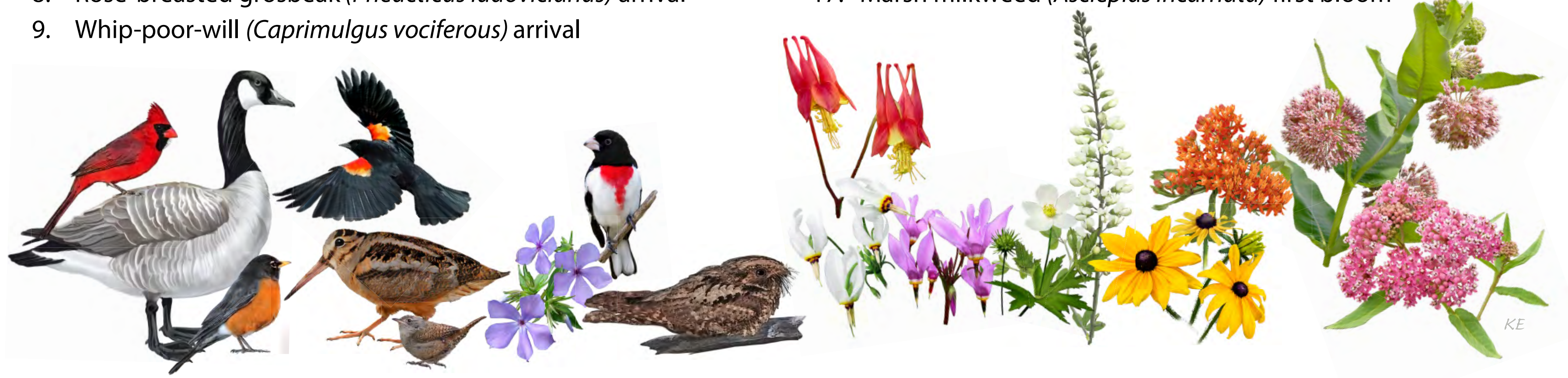
Note the differences in southern ice boundaries for North American and Europe at ~40–50° N. Latitude.

*Ray, N. and J. M. Adams. 2001*

Also, early-season phenological events are easier to record than any extension of a plant or animal's behavior at the end of the growing season in fall. Migratory nesting birds, for example, announce their arrival in spring by calling and setting up territories, but who knows when the last bird departs in fall? Similarly, flowers that bloom early in spring are easy to spot among brown litter and dead leaves, but when does the last leaf of each species senesce? I tried to monitor senescence of Tussock sedge but found it tough to count or measure hundreds of partially-senesced leaves per tussock. **We won't fully understand phenological responses to prolonged growing seasons until we monitor indicators of plant and animal activities—when they begin and when they end.**

Do all native species change their phenology in response to changing climate? No, the timing of events for some species responds to daylength, which does not change as climate warms. Several native species do respond to early spring warm-up. Thanks to Aldo Leopold and his daughter Nina Leopold Bradley, southern Wisconsin has a 61-year, 55-species record of increasingly early flowering of plants and migrations of birds (Bradley et al. 1999). Of the 55 species, 17 events (below) were significantly earlier, 20 did not respond, and the remaining events had uncertain pattern over time. The 17 events that responded were, in chronological order from February 15 to June 30, with bird arrivals preceding plant flowers, except for #7:

1. Cardinal *(Cardinalis cardinalis)* first song
2. Geese *(Branta canadensis)* arrival
3. Redwinged blackbird *(Agelaius phoeniceus)* arrival
4. Robin arrival *(Turdus migratorius)* arrival
5. Woodcock *(Scolopax minor)* first peent
6. House wren *(Troglodytes aedon)* arrival
7. Forest phlox *(Phlox divaricata)* first bloom
8. Rose-breasted grosbeak *(Pheucticus ludovicianus)* arrival
9. Whip-poor-will *(Caprimulgus vociferous)* arrival
10. Columbine *(Aquilegia canadensis)* first bloom
11. Shooting star *(Dodecatheon media)* first bloom
12. Canadian anemone *(Anemone canadensis)* first bloom
13. Baptisia *(Baptisia leucantha)* first bloom
14. Rudbeckia *(Rudbeckia hirta)* first bloom
15. Butterfly weed *(Asclepias tuberosa)* first bloom
16. Common milkweed *(Asclepias syriaca)* first bloom
17. Marsh milkweed *(Asclepias incarnata)* first bloom



**Microbes might be the first to respond to upstream effects on downstream wetlands.**

Micro-organisms arguably have the most important roles in purifying water, recycling nutrients (especially nitrogen) and contributing to food web functions. Microbes decompose organic matter, creating N-enriched detritus, which feeds tiny invertebrates that are food for fish. Sometimes detritus makes up more of an invertebrates diet than algae.

Waubesa Wetlands' Deep Spring has purple biofilms with undescribed microbes that might provide valuable ecosystem services or potential benefits for humans. However, because they are too tiny to see in the field and their identification requires laboratory methods, we know far too little about pathogens and beneficial microbes that are responsible for plant and animal health and critical biogeochemical (nutrient) cycles. Still, we can speculate. Microorganisms reproduce extremely rapidly and are famous for their ability to evolve—note, for example, the development of pathogen resistance to medicines. Why then, wouldn't plant and animal diseases become more prevalent during a changing climate? Why wouldn't the microbiological communities shift rapidly to accommodate new environmental conditions?

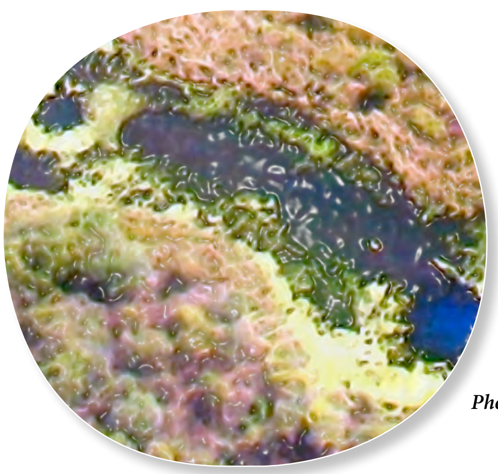


*Photo: C. DeWitt*

Purple bacteria

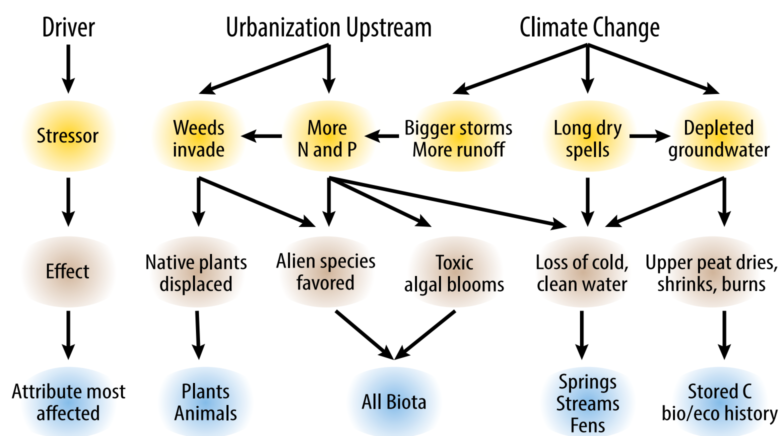
A study of soil microbiota (Lee et al. 2017) gives us a hint that microbes might not accommodate all human impacts. For example, since the 1970s the worldwide use of N fertilizers has been shifting away from inorganic (nitrate). Urea now makes up more than 50% of agricultural fertilizer applications. While wetlands are great transformers of nitrates to harmless nitrogen gas, **the form of nitrogen can be important.** A test of the ability of coastal wetland soils to remove excess N added as **urea vs. nitrate** showed the microbiota were far better at removing N in the nitrate form (Lee et al. 2017). The experiment, conducted in lab microcosms, suggests that coastal wetlands won't be as efficient in abating urea pollution as they could be with nitrate pollution. Like picky eaters?

Research is needed on our inland wetland microbes. One study is not sufficient evidence to declare a pattern, but it does alert us to the need for further understanding of the pathways by which microbes remove excess nitrogen in coastal—and all other—wetlands. Too often, we don't know what we're losing when we fail to protect wetlands.

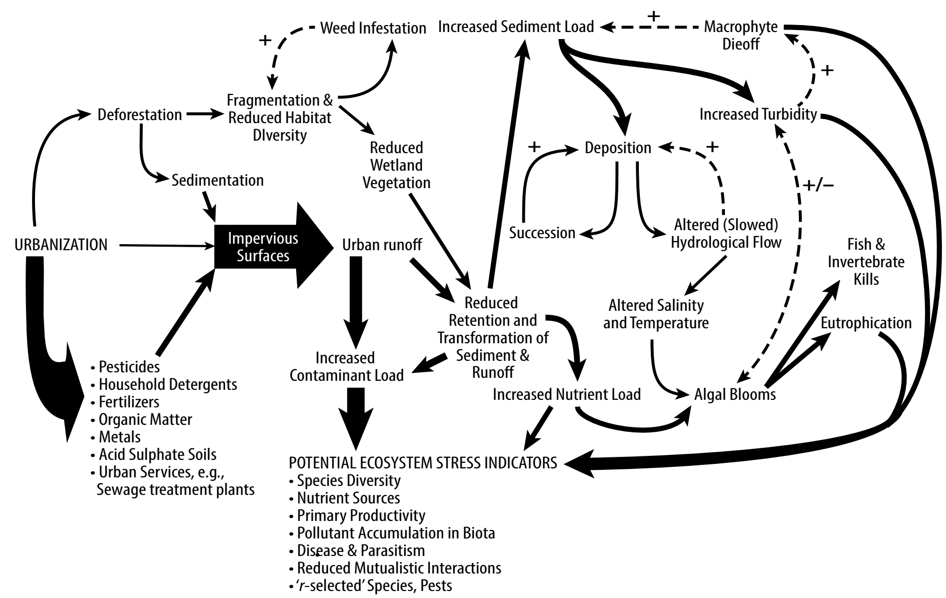
## Summary of negative effects of land use and climate change on wetlands

A conceptual model of threats to Waubesa Wetlands was requested for the Ramsar Site nomination. Using their format, the two main drivers (= threats) are **urbanization** and **climate change**. Both are "off-site" threats, meaning that we as Town of Dunn residents cannot manage our own actions to prevent them from happening.

The **stressors (yellow)** are the causes: urbanization causes weeds and higher loads of nitrogen (N) and phosphorus (P), which interact with one another. Climate change causes bigger storms that, in turn, cause more runoff and even more N and P in runoff. Climate changes can also include long dry periods and groundwater depletion. The **effects (brown)** are displaced native species, invasive species, toxic algal blooms, degraded water, and drying peat that shrinks and becomes flammable. The **affected attributes** include all biota, all wetlands, stores of carbon and historical artifacts.




The model above is simple but not realistic enough to predict details.




A more detailed model by Lee et al. (2006) was based on an extensive literature review of the impacts of urbanization on wetland hydrology and water quality. Here, wide arrows indicate strong effects and interactions, dashed lines are positive (+) or negative (-) **feedbacks.** A positive feedback simply means that more of a factor leads to even more of that factor; a negative feedback means that a factor is diminishing and continues to diminish through internal mechanisms. I include this mainly to help explain why we don't have quantitative models of cause and effect for most biological systems responding to complex environmental changes. It's difficult just to draw pathways; it's even harder to estimate changes in rates for every path at every moment.

So far, we don't have models that allow us to plug in a change in urbanization rate and spit out a list of outcomes for each wetland community/ecosystem. Physical models for groundwater and surface water can provide quantitative predictions if they ignore biological components. This is a polite way of saying that physical models need to include the biota. And relative to the physical world, the **plants, animals, and microbes are far more complex**—by leaps and bounds!

Unfortunately, decision-makers tend to accept the output of physical models because of their quantitative output. Following are wise conclusions from Sharpley et al. (2015):

- Clear output "must be tempered by responsible use of the models, such that model computations or 'estimates' are not over-sold or given more weight than they deserve…a false sense of accuracy and definitive graphics can easily mask model limitations."
- Because models have limitations, "it is a crucial responsibility of scientists (modelers) to 'educate' regulators and policy makers on complexity."
- Most importantly, **"modeling is not a substitute for monitoring,** which is essential to define, calibrate, and validate modeled scenarios."

A **word model** might be easier to comprehend and remember: As watersheds are increasingly occupied and used by humans, lands are first cultivated, then urbanized and covered with impervious surfaces. Thus, more water runs off urban land than before, and the water likely contains more sediment, nutrients, pathogens, pesticides, petroleum products, and road salt. In response, streams, wetlands, and lakes lose their natural integrity.

*Photo: J. Zedler*

Early spring creek

## There is still much to learn about impacts to Waubesa Wetlands

**How rapidly do wetlands degrade?** Davies and Jackson (2006) characterized the degradation (decline) of biological conditions as a **gradient,** not a threshold or sudden response. Natural, biologically diverse ecosystems lose species and functions and yield to dominance by more tolerant species. The result is "wholesale changes" in species and ecosystem functions. We have yet to know whether Waubesa Wetlands will succumb to a major extreme event or continue to shift almost imperceptibly over time. In my experience, extreme events are major stressors that cause sudden changes that challenge even the most thorough monitoring programs (Zedler 2010). Will we be ready to monitor the stressors, effects, and affected components of Waubesa Wetlands when the next big storm or storm series occurs?

**Are Waubesa Wetlands threatened by hypereutrophic conditions in upper Lake Waubesa?** The watersheds that drain into Lake Waubesa will also experience changes in land use and climate, but the details of our regional lakes warrant another book by another author. Key points are that eutrophication is well studied in upstream Lake Mendota, which discharges nutrient-rich water to Lake Monona, then Lake Waubesa, before the water exits to Lake Kegonsa*. Because the Yahara River outlet is in northeastern Lake Waubesa, and because springs keep the toe of Lake Waubesa relatively clear, some impacts of runoff on these upper lakes and their watersheds seem to bypass the toe of Lake Waubesa. But we'd like to know for sure. Lake Waubesa is shallow, and nutrients that accumulate on the bottom are easily churned up to the lake surface where algae can absorb light and "bloom." In July 2017, all three of the lakes mentioned experienced toxic algal blooms. To reduce contact with unsafe water, the swimming beach at Goodland Park, north of the toe, was often closed due to unsafe water. Unacceptable!

**If nutrients are mobilized mainly in spring and fall, why is Lake Waubesa *always* hypereutrophic?**

There are several possibilities:

(1) Lake Waubesa is shallow (maximum depth ~38 feet) and the wind can mix the water column from top to bottom, keeping some of the P from accumulating in the sediment, like it does in deeper lakes. Without stable layers, the wind causes vertical mixing, which moves P and other nutrients and substances throughout the water column. Lake Waubesa is frequently mixed (polymictic), while the two upper, deeper

bubbling blooms


***Whose nutrients are responsible?** A recent study of Lake Waubesa found that 80% of the P entering upper Lake Waubesa comes from the watersheds of the two northern lakes (Mendota and Monona) when they are not **stratified** (layered due to warm water floating over colder, deeper water, i.e., warm **epilimnion** overlying the cold [39°F] **hypolimnion).** During summer stratification, the upper two lakes tend to store P in the hypolimnion, while surface waters with seasonally low concentrations of P flow into Lake Waubesa and on to Lake Kegonsa (McDonald and Lathrop 2016). ["Tend" means there can be some summer mixing, at least in parts of these deeper lakes.]

lakes **tend** to be mixed just twice (dimictic), i.e., in spring when the ice melts and water warms to ~39°F, eliminating resistance to wind-mixing; and again in fall, when the warm epilimnion cools to the temperature of the hypolimnion.

(2) Organisms can move P from sediments into the water column. Alien carp *(Cyprinus carpio)* stir up the lake bottom while feeding. Their movements mobilize (release) P, some of which has become soluble in anoxic sediments. Nearshore, as described for Lake Wingra, rooted aquatic plants take up soluble (dissolved) P and move it into stems and leaves. Such plants are "leaky," especially when they senesce (die back). Decomposers are also effective mobilizers of P and N that is temporarily stored in dead organic matter. [A fish filet spoils readily, as cooks know from trying to hold raw seafood in refrigerators.]

(3) Lake Waubesa might receive enough nutrients from its own watersheds (Swan and Murphy's Creeks) to keep it eutrophic year-round.

(4) Sewage spills from the Nine Springs treatment plant flow into Lake Waubesa. This happened when lighting struck a sewerage pump station at East Clayton Road at 3 a.m. on June 9, 2017. During the 2.5-hour electric power loss, an estimated 2 million gallons of untreated sewage flowed into Nine Springs Creek and into upper Lake Waubesa (http://www.channel3000.com/news/2-million-gallons-of-wastewater-spill-into-creek-after-power-outage-officials-say/584812863).

Many contributors around the lake, up the Yahara River, and upstream in Swan and Murphy's Creeks affect the quality of water that affects Waubesa Wetlands, including the lake's toe. But we are not certain which contributors could most reduce their impacts to improve and protect water quality. Six lines of evidence indicate that the main impacts and further impacts of urbanization will come from Swan and Murphy's Creeks. Funding for water-quality monitoring is needed to add sampling stations and to include more chemical analysis. If we knew which contaminants, e.g., fertilizers and pesticides, were being used upstream, we could focus on analyzing their surface water to find pollution hotspots. We might also find coolspots—places where clean spring water emerges and dilutes contaminants along the way. In the meantime, local citizens can spread existing knowledge—how upstream impacts affect downstream wetlands.

*Photo: C. DeWitt*

## The Future: Bleak or bright?

The concerns and evidence presented in this chapter suggest a bleak road ahead for Waubesa Wetlands. However, there are pathways for restoring and sustaining the upstream watershed to protect the downstream wetland gem. Residents of the Town of Dunn are among the fortunate few who have near-pristine wetlands in our back yards. Our conservation model (Purchased Development Rights) confirms our dedication to conservation—citizens pay taxes so our township can purchase development rights and create conservation easements.

Let's take on the challenge and extend **voluntary approaches upstream** to achieve watershed restoration goals and protect downstream wetland gems.

The outlook is **bleak** if we expect top-down governance to provide solutions in this state—or in this country at this time. The outlook will be **bright** if we envision and promote bottom-up watershed-care based on strong science and an inner wetland ethic. Chapters 7 and 8 offer hope.

Air photo of Murphy's Creek
***Photo: Nadia Olker***

*Marsh Marigolds in artesian outflow*

# Chapter 7 • Looking for solutions

**All who live in the watersheds of Waubesa Wetlands** can help reduce threats to natural resources downstream. We can take many initiatives without having to ask permission or invoke regulations. Simplest is just to apply less fertilizer and pesticide—and avoid them completely whenever possible. Also, we can spread knowledge about our wetlands and promote conservation. But, because the waters in our aquifers and in surface runoff cross political boundaries, we need cooperative management at the watershed scale. And, because the future holds many uncertainties, watershed management needs to be adaptive (responsive to new information).

The debate over which wetlands have national protection seems to resurface with each shift in political influence. This makes it difficult for citizens to rely on regulations alone to protect natural resources. Nor can the citizenry expect the Supreme Court to protect wetlands in perpetuity. The previous Court expanded jurisdictional boundaries to include wetlands that seem isolated but have a "significant nexus" (an undefined connection) with navigable waters. At present, however, leaders of the Environmental Protection Agency and Army Corps of Engineers are reviewing the rules and threatening to reduce protection of "isolated wetlands." The push by the current administration is to deregulate more wetlands.

Deregulating and reducing wetland protection makes no sense, since we know that wetlands are essential for absorbing and cleaning the nation's surface water. If someone is being harmed by current wetland protections, there are alternative solutions. For example, if a farmer is denied permission to drain a wetland to grow more corn, it's true that there would be less income from the crop. But the same farmer could be compensated for allowing the wetland to collect stormwater runoff and remove nutrients and other contaminants. Such a program is called Payment for Ecosystem Services.

Nor does it make sense to risk overusing our groundwater. Citizens who knew that Deep Spring outflows created a fish nursery in Lake Waubesa's toe convinced decision-makers not to drill more deep wells near Waubesa Wetlands (Hunt et al. 2001). What this shows is that science-based protection, supported by local citizens, is a model for managing Waubesa Wetlands. Science-based watershed care is within our reach.

**Houston's Hurricane Harvey** (August 2017) offered a lesson: During major floods, "isolated" lowlands become connected by surface floodwaters. Applying that lesson to a future with stormier weather, I suggest reviewing floodplain maps, enforcing regulations restricting construction in floodplains, and establishing broad buffers in low-lying lands that have to accommodate future flooding. Climate changes will likely involve more frequent, more extreme flooding.

A **bright** chain of action is achievable, expressed in shorthand below and at right in paragraph form:

Science-based knowledge of threats + Understanding of cause-effect

↓

Spreading the word

↓

Broad awareness among watershed residents

↓

Wetland ethics (Chapter 8)

↓

Local land and water care

↓

Engaged decision makers

↓

Watershed care

↓

Protection of Waubesa Wetlands

Two primary **threats,** namely, upstream development and a stormier climate, were identified in Chapter 6, along with six lines of scientific evidence that upstream urbanization will **cause** negative **effects** in downstream wetlands. The six lines concerned increased surface water runoff, decreased surface water quality, groundwater depleted by deep-well withdrawal and export, decreased groundwater quality, and climate change and urbanization acting alone and together. More runoff of lower quality, and depleted, contaminated groundwater are major threats to both the integrity of Waubesa Wetlands ecosystems and to our own well-being.

Now, with the **understanding** of wetland ecosystem services provided in Chapter 3, we can spread the word and increase awareness of the need to take better care of our watersheds, as suggested here in Chapter 7. Then, if the **citizenry** develops and shares a wetland **ethic** (Chapter 8) and works to improve **local** land and water care, we expect **decision makers** will more readily work across township boundaries to promote **watershed**-scale initiatives to protect **Waubesa Wetlands.**

*Photo: Nadia Olker*

## Waubesa Wetlands have global importance

**Protection begins by acknowledging the importance of our resources.** We're among the fortunate few who have near-pristine wetlands in our Town's "back yard." A basic step is to recognize that Waubesa Wetlands are of international importance. Here are eight arguments for such importance. Are there more?

1 • Clear, cool, **clean groundwater** emerges from major springs. It sustains wetland plant communities and keeps algal blooms away from Lake Waubesa's toe, where fish, Osprey and other visual predators can see their prey. Outpouring groundwater also dilutes the lake's eutrophic water and lessens concentrations of contaminants that flow to the Gulf of Mexico.

2 • **Biodiversity** of global significance is sustained by high-quality plant communities.

3 • **Migratory birds** and Monarch butterflies link our wetlands to international nesting and overwintering sites.

4 • **Carbon** is stored below ground in peat, ~90 feet deep in places, and aboveground in sedge tussocks, helping to abate global warming.

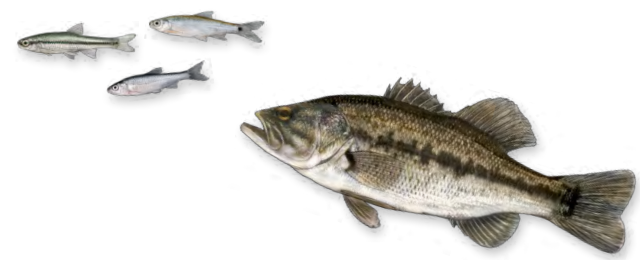
5 • **Denitrifying bacteria** convert harmful nitrates to harmless $N_2$ gas, a critical step in the global nitrogen cycle. Wetlands have Earth's highest rates of denitrification, in part due to the bumpy topography created by Tussock sedge.

6 • Native American legacies comprise a **Living Museum** (a 10,000-year archive in peat and effigy mounds).

7 • A century of strong **science and education** has grown from the wetlands and is used internationally.

8 • **Conservation easements** protect land, water, springs, and environmentally-friendly agriculture, which in turn sustain Waubesa Wetlands. To purchase development rights from landowners, Town of Dunn citizens voluntarily tax themselves.

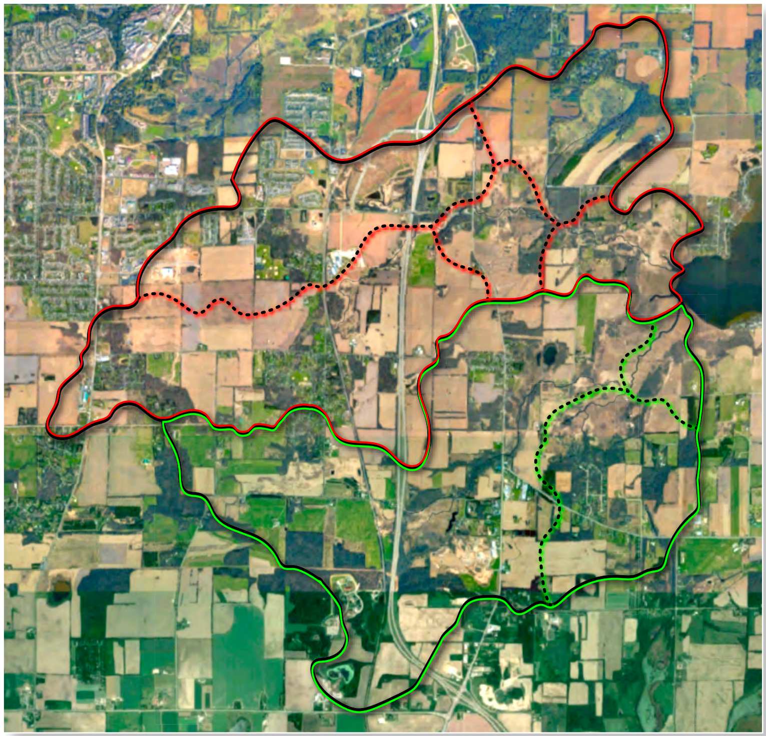
Deep Spring Creek has no watershed; instead, it is formed by outflows from multiple springs. *Photo: Cal DeWitt and Nadia Olker*



Largemouth bass—a visual predator

**Acknowledge the threats, causes and effects.** All of Waubesa Wetlands' values are threatened by inadequate resource management. Imagine losing our clean water, biodiversity, migratory species, stored peat, and more. Stormier weather will certainly interact with urban hardscaping to deliver more sediment and contaminants downstream. And while sediment-retention ponds can be built to collect some of the runoff, the effectiveness of such structures is rarely quantified. Such downstream "band-aids" won't prevent the greater impacts that are expected under stormier conditions. Nor will retention ponds handle the additional impacts of dust, airborne nitrogen deposits, and disturbances to wildlife (human noise, lights, and movements).

It's time to find ways to prevent future threats, or at least minimize threats, preferably using approaches that citizens can take without governmental regulation. The 8th attribute in the list above is a global—and local—conservation model, so let's expand this unique **citizen-based approach** to residents in the City of Fitchburg. Citizens upstream who live in Waubesa Wetlands' watersheds (Swan Creek and Murphy's Creek) can join downstream residents in adopting science-based conservation (Chapter 8).



Watersheds and sub-watersheds of Swan Creek (red) and Murphy's Creek (green). *Redrafted from C. DeWitt and Google Maps.*

**Anticipate the likely outcomes of unabated threats.** If we do nothing, we can expect:

- expanding weed invasions,
- decreasing populations of native species, and
- impaired ecosystem services.

More **solutions** must be found **upstream** (Zedler et al. 2014).

## Four paths toward solutions

As citizens, we can pursue four paths toward solutions. These are not alternative or consecutive paths but complementary actions that can proceed at the same time: We can help decision-makers **enforce** existing regulations; help **monitor** the indicators of pollution sources; help developers and new residents "**act green**," i.e., avoid and minimize downstream impacts; and sustain wetlands by **adaptively managing watersheds**. Let's explore each of these paths.

### A • Enforce: help regulators enforce existing protections for Waubesa Wetlands.

I introduced **jurisdictional wetlands** in the Preface and made the point that the Clean Water Act only covers narrowly defined wetlands—those with federally-specified vegetation, soil and hydrological conditions. While most of Waubesa Wetlands, including Swan Creek and Murphy's Creek, qualify as jurisdictional wetlands and are protected under the law, "protection" is still far from complete. The law covers the dumping of materials into jurisdictional wetlands, but not tree cutting or mowing or grazing. And being "covered" doesn't prevent impacts; instead, the Clean Water Act **regulates*** discharges of liquids and solids into the "Waters of the United States" (WOTUS), which include wetlands. That means that permits can be issued to fill wetlands if regulations are followed. In the best cases, people follow the law and apply for permits in advance of discharging materials into wetlands, and harmful discharges are not permitted.

*Regulators. The US Army Corps of Engineers (ACE) is in charge of the nation's waters. For Wisconsin, ACE delegates work to Wisconsin Department of Natural Resources (DNR). Historically, DNR staff proceeded carefully on the slippery slope from avoidance to compensation, using science-based information to reject proposals involving avoidable impacts. In recent years, however, DNR developed formal guidelines for mitigation. Today, our DNR wetland experts **delineate** jurisdictional wetlands and review each proposed discharge to see if impacts can be avoided or minimized, and if not, whether the impacts could be **compensated** by the applicant's proposed mitigating measures. This process is called **sequencing**, i.e., actions are to be explored in order: (1) **avoid**, (2) **minimize**, (3) **compensate**. Yet across the nation (NRC 2001), project proponents have skipped steps 1–2 and proposed to fill an existing wetland and construct a new wetland to compensate. Wetland regulation is often contentious and political, and whether or not a permit is granted can depend on more than environmental factors (NRC 2001).

A jurisdictional wetland can be filled if (1) dischargers demonstrate that they cannot avoid or minimize all impacts, (2) adequate compensation is proposed (NRC 2001), and (3) the project receives the necessary permit. What does **compensation** mean? Usually it means reducing negative impacts and including a safety factor such as multiplying the acres that will be damaged by a "mitigation ratio" (e.g., 3:1 = 3 acres restored for each acre filled). The intent is to make up for delays in recovering wetland services and to compensate for the **"recovery debt"*** (Moreno-Mateos et al. 2017).

Although wetlands are regulated with the intent to protect them from discharges of sediments and contaminants, regulators still need our help as "watershed watchdogs." Here are several reasons:

**Our watershed** will experience larger and more frequent surface-water pulses as climate continues to change. Examples are the repeated heavy rains of June 2008 and July 2017, during which surface runoff and stream flows mobilized sediments, fertilizer and manure from fields and lawns and eroded sediments and contaminants from construction sites.

Here are some mistakes and violations that watchdogs should report: Manure is sometimes dumped onto a frozen field, and silt fences at construction sites are often torn and flattened. Deliberate or accidental release of contaminants (such as cement, fuel, weed seeds on dirty equipment) allows harmful materials to flow to the nearest

*Recovery debt. Can humans fully restore nature once it's damaged? **Not entirely**. In 2017, David Moreno-Mateos et al. compared 3,035 sampling plots in a global review, asking how well recovering ecosystems match their undisturbed counterparts. The authors quantified biodiversity and ecological functions and found serious shortfalls in recovering systems: 46–51% lower abundances of targeted species, 27–33% lower species diversity, 32–42% less carbon cycling and 31–41% less nitrogen cycling. They called the shortfall a "recovery debt." Earlier, NRC (2001) documented many examples of compensation actions that were required in exchange for permits to fill wetlands, and the panel reported that most of these mitigation actions failed to achieve their goals. Some actions met a few of the compensation criteria, but many requirements weren't even attempted (Turner et al. 2001). The lesson here is that it isn't sufficient to have laws; they must be enforced.

stream. Spills and damages can be corrected if authorities welcome input from watchdogs. Watchdogs* should also report noxious weeds establishing along roadsides and associated with grading during construction projects. It's hard to predict all the things that can go wrong, but we could keep a running inventory and archive photos online.

The Clean Water Act is essential and very good legislation, but rules about which waters of the U.S. (WOTUS) should be covered under the act continue to be debated. Not everyone wants to protect all the WOTUS, yet the guidelines and enforcement actions need to be stronger, not weaker. Regrettably, in late

bad news

June 2017, leaders of EPA and ACE announced their intent to roll back regulation of WOTUS to 2015 rules. If the rollback is enacted, it will be harder to protect "isolated wetlands," which have hard-to-see hydrological connections. The rules say that WOTUS include wetlands that are connected to navigable waters, so the debate is over what constitutes a connection (significant nexus). Many argue that geographically-isolated wetlands should not be regulated, even though such wetlands provide critical functions that lead to human well-being (Tiner et al. 2002, Tiner 2003).

More bad news and some intrigue

Furthermore, the benefit:cost evaluation of the services provided by the nation's waters is now under debate, following a recent revelation that benefits calculated in 2017 were ~90% lower than benefits calculated in 2015. This reduction was accomplished by excluding wetland benefits—claiming that wetland studies were too old (i.e., older than 2000—a criterion applied only to wetland valuations, according to Boyle et al. 2017).

Watchdogs need to keep up with policies; citizens can help…please read on.

***Watchdogs**

When we see a wetland being damaged, we can alert authorities and photo-document and report impacts, such as failing silt fences, spilled wash water during the cleaning of equipment, and manure dumped on frozen fields. In Ontario, Canada, Elton et al. (2011) described two projects where contractors ignored negative findings from formal monitoring and reported no significant negative impacts.

At the Arboretum, watchdogs reported three examples of weed invasions during the construction of stormwater-management facilities: (1) At the runoff-treatment swales, a weed that was new to the site (hairy vetch, *Vicia villosa*) was apparently introduced from seeds on unwashed construction equipment. The weed quickly established on berms between swales. When alerted, Arboretum staff repeatedly herbicided the weeds. (2) At Stormwater Pond 4, the ~1-km-long shoreline was planted with native plants, but weedy cattails (*Typha angustifolia* and/or the hybrid *Typha × glauca*) rapidly dominated all 96 shoreline plots (Leaflet #23). In this case, little could be done except to track the invasion. (3) In June 2011 an unwashed bulldozer was delivered to a stormwater-pond construction site (Leaflet #23). When the contractor was reminded of the requirement to clean equipment off site, the hazard was corrected.

The Arboretum had no authority to prevent such impacts, but watchdogs helped reduce damages. Likewise, in the Town of Dunn, we can't prevent mistakes and violations, but we can report problems and violations so that authorities can enforce regulations.

**Beyond being watchdogs**. To protect Waubesa Wetlands, the watchdog role needs to go beyond reporting spills to **lobbying for greater enforcement of existing regulations** and for **stronger**—not weaker—environmental rules. Here are some examples:

- It's time to **protect all waters** of the United States, including wetlands connected to navigable waters. In 2006, Supreme Court Justice Kennedy was wise to call for a "significant nexus" between a geographically isolated wetland and a wetland that is connected to a navigable water. Kennedy's opinion generated research and publications that showed how isolated wetlands do have strong hydrological and biological connections to navigable waters, and such wetlands are important to Nature and humans.

  Waubesa Wetlands are a benchmark for biodiversity in part because of their connections with various geographically isolated—but hydrologically and biologically connected—wetlands. As an example, Sandhill cranes are oblivious to the origin of their foods; they don't check a frog's "hatch certificate" before eating it. But when they eat frogs that hatched in a geographically isolated pond, the cranes become a biological connection to Waubesa Wetlands' deeper waters. Citizen birdwatchers can help quantify the use of isolated wetlands by wildlife of Waubesa Wetlands. Let's be ready with data for use in countering the next challenge to WOTUS.

- It's time to enforce the 35-mph speed limit and rules against littering on Lalor Road. We need to re-earn the road's "Rustic" status; Lalor Road is not just a place to toss empty beer cans. Upstream signs could inform passersby when they enter or leave each sensitive watershed. Interpretive signs could educate the public and promote conservation. Downstream signs could highlight Murphy's Creek and Swan Creek crossings as aquatic gateways to Waubesa Wetlands.

- It's time to **control nitrogen** flows to wetlands. Regrettably, regulations don't keep up with research on contaminants, eutrophication, and climate change. Even though excess nitrogen significantly damages wetlands, phosphorus has held the spotlight for 50 years, because it causes eutrophication in lakes (NRC 1969). Today, however, there is compelling evidence that controlling nitrogen will help protect wetlands (Chapter 6; Sinha et al. 2017). Citizens can push decision-makers to manage the nitrogen and phosphorus (not just P) entering both **wetlands** and lakes (not just lakes).

- It's time to develop a **comprehensive monitoring program** as recommended by national experts: "The protection of aquatic life in urban streams requires an approach that **incorporates all stressors**… altered hydrology in urban streams, altered habitat, and polluted runoff" (NRC 2009).

## B. Monitor key indicators to track important changes.

Globally, ecosystems are monitored to document baseline conditions, assess changes, track progress of restoration efforts, and improve predictive models (i.e., calibrate, validate or reject). Because Waubesa Wetlands is a benchmark for Dane County wetlands, long-term monitoring is needed both for the **site** and its **watersheds**. We need to characterize changes with shifts in climate, arrival of new invasive species, and altered land use. Where **restoration** is set up as part of an adaptive management plan, monitoring is especially useful for checking progress so that managers can learn which actions are effective and where more tests are needed. While **monitoring** Waubesa Wetlands is **not a solution** to problems, it is a basic way to track changes that indicate **cause-effect** patterns, like increased nutrient discharges upstream and increased weed invasions downstream.

**Here's some guidance** for setting up a watershed monitoring program to track urbanization upstream and assess impacts downstream:

- **Select indicators** of the impacts of urbanization on ecosystems. Watershed managers rely on indicators, because it's tough to measure "urbanization" and exactly what causes impacts downstream. A standard indicator of urbanization is the total area of hardscaping, because impervious land surfaces "seal" the soil (FAO and ITPS 2015), thereby preventing percolation of rainfall and snow melt and increasing the flashiness of surface water runoff. An increase in the total area of roofs, streets, sidewalks, and other impervious surfaces causes an increase in runoff. As a result, peak flows are greater and occur more rapidly in watersheds with hardscaping, causing multiple impacts.

Hardscaping is not a perfect indicator, however, as two cities with similar hardscaped areas can differ in runoff depending on where and how the hardscaping is positioned. Also, many environmental conditions can change at the same time as concrete surfaces expand. For example, contaminants might be released by a spill or a disturbed area might release more sediment during stormy weather, or a slug of weed seeds might be brought in on vehicle tires. Even an end-of-season sale on lawn fertilizer could spark fertilizer applications at a time when roots can't take up and hold nutrients on site. [Note that human behavior is hard to predict.] So, when weeds take over downstream, it's not always clear how much of the blame should be placed on hardscaping. But there will likely be a general correlation between the area of hardscaping and urbanization, which is why hardscaping is a useful indicator.


Rock River Basin

*Map and photo: https://rockrivercoalition.org/*

RRC monitoring team member

Is there an indicator that can tell us when an ecosystem is about to shift to weeds in time to avoid that shift? Only rarely. Ecologists use the term **tipping point** to indicate when an ecosystem exceeds some threshold of disturbance that triggers a sudden change to an **"alternative state"**—such as dominance by weeds. Tipping points and alternative states make a nice theory, but theorists also predict a reversal once the cause of the shift is corrected. That is, if conditions are reversed to favor the previous state, the ecosystem should follow suit. In reality, only a few ecosystem shifts are actually reversible. For example, in southern California, Kelp bed and Sea urchin dominance flip back and forth in response to predation on urchins by Sea otters and/or urchin disease (Selkoe et al. 2015).

Unlike this marine example, there's little evidence that wetlands can revert to native vegetation if we stop adding nutrients. In part, it's because nutrients remain in the soil. It's not easy to remove the legacy of agriculture's nutrient-enriched soil. Here's an example from The Netherlands: Fen restoration can require topsoil removal to eliminate enough nutrients to restore native plants (Patzelt et al. 2001).

In our region, downstream wetlands shift from native vegetation to invasive species, and then resist reversal: It's a one-way trip:

Sedge meadows + Marshes → invasive Cattails + Reed canary grass

If there's a threshold for weed establishment, we don't know what it is, because environmental factors vary and interact. This means we might not even see the invasion until it's too late to eradicate weeds. Managers who can set certain aspects of the environment, such controlling water levels in Crex Meadows and Horicon Marsh, know how to manage habitat to attract desired waterbirds. But water levels and birds are easier to monitor than **nutrient loading.** For that reason, the standard is to monitor the area of hardscaping and estimate (model) nutrients in runoff.

Intermittent sampling of a field site can document change* but regular monitoring (systematic sampling) is more informative. In the example at right, we have *circumstantial* evidence that a site shifted to weeds due to flooding. But we don't know how much flooding or nutrient loading occurred, so we *hypothesize* that vegetation changed *because* of the flood.

### *A nearby restoration site shifted to weeds.

Restoration ecologists made a heroic attempt to prevent a shift to weeds during construction of the Monona Causeway in Madison by salvaging Sedge meadow soil that was being disturbed. Native soil was transported to a mitigation site at the intersection of Stoughton Road and the Beltline. The aim was to preserve the native seed bank along with the soils, thereby conferring the ability of the wetland to resist invasion (a form of resilience). Initially, a species-rich Sedge meadow developed, and it persisted for a few years (Hey and Philipp 1991). Then, a big flood occurred, presumably with a pulse of nutrients and weed seeds. Sometime thereafter, the Sedge meadow shifted to a monotype of invasive cattails (Hart 2007), which have dominated ever since. The cattails are visible from the Beltline at Stoughton Road. See also the Monona Conservancy and Madison's E-Way, where cattails dominate the wetter areas and Reed canary grass dominates the edges. Persistence of these two major invaders is further supported by experiments that attempt (but fail) to remove them (Healy et al. 2015, Boers et al. 2007).

The general points are that:

- **systematic monitoring is needed** and
- **wetlands resist reversal once tipped to weeds.**

• **Plan for *strategic* monitoring.** Many guidelines have been published for watershed monitoring programs, and we will need a coordinated effort with a central data repository. We can begin with the guidance for Wetlands of International Importance, where the focus is biodiversity. The Ramsar Convention's *Handbook 13: Inventory, assessment, and monitoring* is a great resource. Also, Azous and Horner (2000) and Horner et al. (2000) described an integrated watershed approach to evaluate urbanization impacts on wetland condition and functions, with **guidelines** for monitoring multiple indicators. And, additional guidelines are available for managing stormwater at the watershed scale (NRC 2009, pages 346 and following). It's up to us to implement the most relevant guidance.

In addition to selecting and monitoring indicators of watershed change (upstream land use and impacts to Waubesa Wetlands), we will need to summarize data in consistent, well-documented formats; that is, to archive data in a central "bank" for data distribution and storage. And of course, we will need funding. A **watershed-care** organization could involve stakeholders from up- and downstream; and a watershed support staff could work within a non-governmental organization, perhaps expanding the West Waubesa Protection Coalition. Staff would manage the volunteers and data bank and write proposals, e.g., for costly analyses of pollutants.

• **Track urbanization and associated changes.** As explained above, the standard approach is to monitor the area of impervious surfaces as an indicator of "urbanization." This is needed for each watershed (Swan and Murphy's creeks). How much hardscaping is too much*?

While runoff is not determined by hardscape area alone, the area of hardscaping is a useful indicator of upstream development and associated surface-water runoff. Moreover, the locations of impervious surfaces (Brabec et al. 2002) should also be recorded, as well as the connections between hardscaped areas (Steve Loheide, UW–Madison), since some runoff might have a chance to infiltrate rather than flowing downstream.

Upstream factors that can reduce runoff should also be monitored; these are buffers, detention ponds, the area of wooded vegetation, and wetland area and location, including restored wetlands. For example, restored wetlands can compensate for some hardscaping, but the loss of wetlands will have the opposite effect. Restored wetlands will affect hydrology, water quality, soils and biological resources, but their ecosystem services depend on where they are located within a watershed (Horner et al. 2000). For example, near Minneapolis, where nonpoint sources of contaminants affect water quality, Detenbeck et al. (1993) recommended restoring wetlands close to the lake of interest.

### *How much is too much impervious land cover?

Studies have shown effects with 1, 8,10, and 30% hardscaping, but note other causal factors (in *italics*).

**1%** Hardscapes increase concentrations of chlorides downstream where salt is added to streets and roads. Dugan et al. (2017) found chlorides increasing in Wisconsin watersheds with less than 1% impervious surface. Lougheed et al. (2008) found higher chloride levels and fewer species in *isolated developed wetlands* than in undeveloped areas.

**8%** For a watershed to remain healthy, Azous et al. (2000) recommended no more than 8% impervious surface in the watershed.

**10%** For Puget Sound wetlands, watersheds with 10% impervious cover had altered channel morphology and reduced fish and amphibian populations. Reinelt et al. (1998) found that *water level fluctuations* of more than ~8 inches (0.2 m) significantly reduced the average number of amphibian species (see also Schueler and Holland 2000).

**30%** Lawns and compact soils repel heavy rainfall, and Dodson (2008) found that Madison-area ponds had "few zooplankton species, no macrophytes, no snails, and no amphibians" in watersheds with more than 30% lawn cover. He ruled out *nutrients* and attributed biodiversity loss to pesticide applications.

Finally, the **timing of sampling** is important. In Minnesota, Johnston and Detenbeck (1990) and Detenbeck et al. (1993) documented the cumulative effects of multiple wetlands for each season, allowing them to show that nutrient uptake by plants during the growing season could be followed by nutrient discharges during the dormant season. Because wetlands and their effects are complex, any models that aim to predict runoff and its effects will need testing by *measuring* runoff volume and water quality. Thus, monitoring is necessary to understand how changes in land use and climate affect waters downstream and to improve models for longer-term predictions.

**• Monitor *effects* of urbanization and associated changes on Waubesa Wetlands.** Here is a starter list:

—**Multiple indicators.** Monitoring both downstream environmental conditions and biota is needed help explain changes to ecosystems. For example, freshwater macroinvertebrates and fish respond to both land-use and climate effects. In Queensland: Urban runoff, elevated water temperatures and eutrophication were the leading causes of decline (Mantyka-Pringle 2014, 2016). "Nutrient loading has also been linked to a decrease in invertebrate diversity, especially in areas that also have high concentrations of chloride" (Wright et al., 2006). These authors found 5–20 times the nutrient load in urban wetlands compared to wetlands in undeveloped watersheds.

—**Water level fluctuation** (WLF) in the Calcareous fens and Sedge meadows. WLF, i.e., depth, frequency, and duration of inundation, and the timing and duration of any dry period, "is perhaps the best indicator of wetland hydrology, because it integrates nearly all hydrologic factors" (Reinelt and Taylor 2000). While two fens in Reinelt's and Taylor's study naturally received only rainfall and groundwater, the one in an urban watershed received inflows more quickly and in larger short-term volumes; in other words, it had greater and more rapid WLF. Flashy hydroperiods indicate impacts of hardscaping and suggest the need to monitor nutrients, other contaminants, and species composition.

—**Water temperature and thermal regime.** Compared to surface-water streams, groundwaters have constant temperatures (~54°F) that, when exposed to air, become colder in winter, warmer in summer. Measuring the temperature along several segments of our creeks and lake-toe waters would help us locate underwater springs and influences of hardscaping. [Note that concrete is a heat sink.]

Many **inexpensive sensors** can measure water temperature at desired frequencies and specific locations (Steel et al. 2017). The Rock River Coalition hopes to transition its continuous stream temperature gages to HOBO MX2203 TidbiT water temperature data loggers that use the Bluetooth Low Energy (BLE) to deliver high-accuracy temperature measurements straight to iOS or Android mobile devices.

But to capture more of the complexities of variations over time and space, thermal imaging cameras can be placed on permanent structures or mobile drones to map surface-water temperatures of stream and lakes. When such variations are assessed, Steel et al. (2017) prefer the term **thermal regime** in place of the concept of water temperature.

—**Storm intensity and flashy hydroperiods**. Azous et al. (2000) concluded that hydroperiod changes were more detrimental to vegetation and amphibians than were other monitored conditions, including water quality. **Hydroperiod** means water level fluctuations during flow events, across seasons, and at the onset and duration of any dry period (Reinelt et al. 2000). In Puget Sound wetlands, species richness dropped where there were more than 3 flooding events per month and prolonged inundation.

Flashy hydroperiods are also known to threaten native plants and favor invaders (Schueler and Holland 2000), and the review by Wright et al. (2006, p. 30) concluded that wetland communities are especially vulnerable to excessive stormwater runoff and that increased water level fluctuations favor the spread of invasive plants. Here in Dane County, Kercher et al. (2004a) tested the effects of three factors (water level, nutrient addition, and soil manipulation); using 27 treatments, 160 wetland mesocosms, and diverse vegetation. While high levels of each factor had significant effects, it was the **synergistic interaction** of high water levels and nutrients (as fertilizer + topsoil) that caused the most rapid and complete invasion of Reed canary grass.

—**Quality of stream water flowing into Waubesa Wetlands.** Extensive and important monitoring takes place near Waubesa Wetlands, thanks to the Rock River Coalition (RRC). RRC volunteers are well-trained and coordinated by Nancy Sheehan (http://rockrivercoalition.org/projects-2/citizen-stream-monitoring/). The volunteers' data are collated, summarized, and posted online for research and education. What would we do without volunteers? Appropriately, the work of citizen scientists was recently acclaimed in a national journal (Kosmala et al. 2016).

RRC volunteers assess chemical and biological indicators throughout the Rock River Basin, which covers about 6% of Wisconsin (3,747 mi$^2$). Each team of volunteers collects water samples at assigned stations and searches for biological indicators of clean water (see Chapter 2). Notably, **both N and P** in water samples are analyzed by the Madison Metropolitan Sewerage District, providing much-needed data on spatial and temporal patterns of nutrients. When I learned about these data, I asked Dr. Anita Thompson (UW–Madison) if she might have a student to analyze data from Waubesa Wetlands' watersheds. Serendipity: Graduate student Yu Li is synthesizing the results for part of her graduate-program research.

—**Extent of algal blooms,** measured as distance along a line from central Lake Waubesa toward the lake's toe. Aerial imagery would make this an interesting task for a remote-sensing buff. The "edge" of the algal bloom would need to be defined as a rapid change in water color.

### Lessons from salt marshes

With long-term data, it is possible to identify **sequence effects,** i.e., those that depend on the order of events. After 2 decades of research in salt marshes, I noticed that a drought year followed by a sea storm had no effect, but a major sea storm followed by a year with no rainfall was catastrophic: The storm pushed sand into the river mouth and closed access to tidal flows, and the subsequent drought year caused marsh soil to dry, become twice as salty as seawater, and lose biodiversity, including endangered birds (Zedler 2010).

One endangered plant in San Diego Bay tidal marshes responds to **drought,** as we learned from our 20-year monitoring of Salt marsh bird's beak (*Cordylanthus maritimus* ssp. *maritimus*). The population was greatly reduced twice in 2 years of low rainfall (e.g., <100 plants in 2014). This small (6-inch-tall) annual plant needs springtime rains to reduce soil salinity so that its seeds can germinate and produce flowering plants, which they do in most years (e.g., a peak population of >14,000 in 2016). A shorter monitoring record would not have revealed the response to drought.

Salt marsh bird's beak *Photo: J. Zedler*

—**Toxic pollutants** upstream and in Swan and Murphy's creeks. Even though chemical analyses are expensive, it's important to monitor toxins so sources can be located and eliminated. To reduce costs, sampling for maximum loads should occur at strategic times—after storms and where urbanization is underway—as suggested by two studies: Lee et al. (2006) found that pulsed runoff increased pollutant loading over time and distance; and Wright et al. (2006) concluded that concentrations of sediments, nutrients, chlorides, and other **contaminants** are typically 1–2 orders of magnitude greater in stormwater following development.

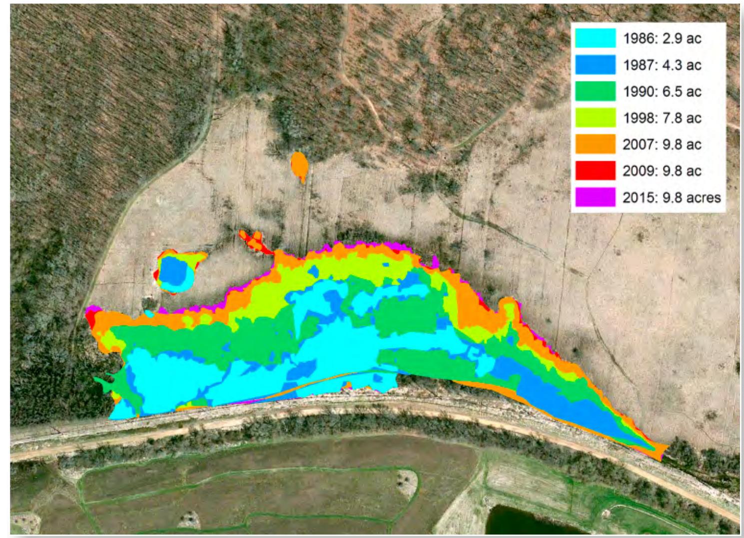
—**Stream macroinvertebrates.** The RRC teams search for stream macroinvertebrates that are known indicators of good-to-poor water quality. Additional volunteers could augment the five stations on Swan and Murphy's creeks and add more sampling times to capture effects of major storm flows. If we know where stream biodiversity is most impaired, we can find and correct likely causes.

—**Wetland vegetation.** Plants sit still, which makes them much easier to map and track than mobile animals. Many of our dominant grasses and sedges are clonal; they reproduce vegetatively, which makes them hard to count on the ground but easy to see as patches on aerial imagery. So, instead of counting plants, we measure their cover (% of area). Recall that Alex Wenthe, our State Natural Area volunteer steward, digitized the Bedford et al. (1974) map (Chapter 1). His emerging protocol for remapping and assessing vegetation changes over 40+ years should be repeated every 10 years, using drones and remotely-sensed imagery.

—**Boundaries of invasive clonal plants.** Monitoring of exotic species is of critical importance (NRC 2009). Because our two major invaders are clonal, it should be possible to monitor areas of Reed canary grass and Cattails using drones and GIS technology (as in Hall and Zedler 2010).

—**Charismatic insects.** Butterflies and dragonflies have captured the attention of artists, naturalists, and wetland advocates, but we lack data for Waubesa Wetlands. We could establish paths to walk and count sightings of species that are easily identified "on the wing." Insect watchers could focus on easily-identified dragonflies and damselflies, and, of course, the Monarch butterfly, which is an indicator of regional-to-continental habitat condition.

Two endangered insects, the Rusty patched bumble bee and Silphium borer moth are very rare, so it might be best to monitor host plants in their potential habitats and document absence or, if lucky, presence. We could compare data on insects with those of the UW Arboretum, where the Director, as of October 2017, is Dr. Karen Oberhauser—an expert on Monarchs and citizen monitoring.




Reed canary grass is monitored most years in the Arboretum's Lower Greene Prairie by walking along the clonal boundary with a GPS unit. *(redrafted) Data and image: Mark Wegener*

Rusty patched bumble bee on Purple prairie clover

—**Harvested fish.** Catches by recreational fishers are recorded by DNR at boat landings, but online data are difficult to access. More frequent sampling of fish harvests and lake conditions (especially algal blooms) where fish were caught would help identify the value of the clear, cool water that flows from Waubesa Wetlands into the toe of Lake Waubesa.

—**Noise levels, night lighting, and vehicles.** These indicators of human disturbance should be assessed around the edges of Waubesa Wetlands, as wildlife will be affected and limitations on traffic could be imposed and enforced (Altman et al. 2011, Panci et al. 2017).

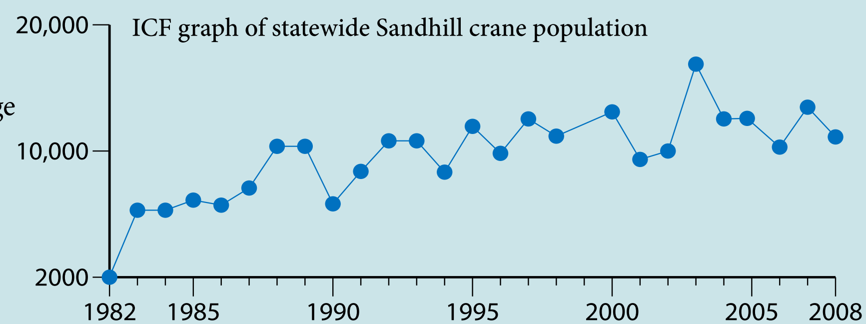
—**Bird species.** Without very broad buffers, Waubesa Wetlands birds will follow patterns seen in Puget Sound, namely, (a) aggressive, exotic, disturbance-tolerant birds will occupy disturbed wetlands and (b) wetlands within developed watersheds will lose native species that have distinct habitat preferences. We need baseline data to determine which wetland habitats provide nesting and foraging sites. We also need long-term monitoring to determine how urbanization adds disturbance-tolerant birds (adapters, exploiters, and exotics) to Waubesa Wetlands, and which disturbance-intolerant, native wetland birds are lost (Richter and Azous 2000a,b).

—**Sandhill cranes.** Our iconic cranes nest in Marshes and Sedge meadows, as well as other habitats near water. Several pairs likely nest every year in Waubesa Wetlands, but only pre-nesting occurrences are monitored annually by the International Crane Foundation* (ICF). The extensive, well-buffered wetlands and abundant foods of Waubesa Wetlands contributed substantially to this species' recovery from near-extinction in Wisconsin. Sandhill cranes are now commonly heard, if not seen, in and around Waubesa Wetlands.

***Monitoring data for Sandhill cranes** in Waubesa Wetlands were provided by the International Crane Foundation from 1983–2007, except for no counts in 1999. Over those 24 years, counts along two stations on Lalor Road totaled 48 sightings of pairs of cranes, for a low average of 2 pairs seen/year. Deeper into the wetland, under the power line, counts totaled 66 pairs over 24 years, ranging from zero in 1983–86, to a maximum of 10 pairs in March 1998. For all 3 stations, counts of "singles" added 396 sightings over 24 years. Further east along the power line, the marsh vegetation is taller and might provide better crane habitat; at the same time, it would be harder to see the birds.

It would be great to learn how many of "our" crane pairs reproduced and added to the state-wide population. Once threatened with extinction due to overhunting, their dramatic rebound is seen by averaging total numbers of individuals spotted locally in the '80s (mean = 12) compared with the 1990s (mean = 31), followed by the 2000s (mean = 29). The trend was bumpy but upward. After 2007, the Waubesa Wetlands data were no longer reported separately from state totals. We can work with ICF to expand sampling to make sure we have adequate and consistent annual counts for Waubesa Wetlands.

In his recent message on "A risky climate for cranes, wetlands and our world," Dr. Rich Beilfulss (President of ICF) wrote, "Cranes are one of the most endangered families of birds in the world, and highly vulnerable to climate change —especially in the places where habitat loss, water resources development and invasive species are already taking a toll on crane populations. Changing climate already affects cranes across large parts of Asia, Africa, Australia and North America." …"At the International Crane Foundation…We believe that a future with cranes means a future with a healthier and more livable planet for all."



We need **benchmark data on birds** to improve the species lists in Appendix 4. In addition, it would useful to know who nests *where* in Waubesa Wetlands to determine which habitats are used by species that live here all summer. Citizen scientists could help, even if we only listen for cranes and other distinguishable vocalists. Who has a feeder full of sunflower seeds that attracts Red breasted grosbeaks? Mine attracted one pair in 2016 and two pairs in 2017. Systematic monitoring of several feeders could determine if these beautiful birds are expanding their local population.


Red breasted grosbeaks

**Monitoring is not the solution but a description of change**. Tracking urbanization and downstream response variables will document long-term changes upstream and downstream, but not annual causes and effects. Recall that the 10-year study in Puget Sound (Azous and Horner 2000) was too short to document impacts of urbanization within individual watersheds; however, the impacts were obvious in regional comparisons of watersheds that ranged from little to substantial urban development. So, 10 years won't likely be long enough to determine when there is "too much" urbanization upstream. The precautionary principle is relevant: **Take preventative actions now, based on six lines of evidence** (Chapter 6).

Ten or more years of monitoring should help agencies decide when Waubesa Wetlands might be shifting away from their status as a regional benchmark. **Long-term** trends associated with weather patterns might appear, as in the graph of Sandhill cranes. Other indicators, like the loss of a species, can take longer. In Florida, for example, frogs and toads indicated wetland health in rural areas in the short term; however, amphibian species richness was greatly reduced over the long term, as urbanization eliminated the sensitive species (Guzy et al. 2012).


Spring peeper

While monitoring cannot solve problems by itself, it is essential to track key indicators in order to document important changes and to learn while managing the land. Those who conduct monitoring can turn up surprises, like new species or lost species, spills of toxic materials, or mistakes in land care actions. By having a record of previous events, all those concerned can double check their recollections and invent ways to test cause-effect relationships. Because the future has many uncertainties in both climate and urbanization, it is important to observe how key factors change. In summary, monitoring can inform management, as in adaptive management (section D).

## C. Act green; minimize impacts and restore Nature

**Greener (environmentally friendly) land care upstream can reduce impacts on downstream wetlands**. Think about that **"F" grade** given to Swan Creek and Murphy's Creek at Lalor Road, because they lack stoneflies and mayflies and other pollution-sensitive species. Something is wrong with our creeks. How can we fix it? Urbanization should not expand unless and until existing impacts are eliminated. Some ideas follow, with a check list* on page 152 that summarizes green actions.

- **Minimize all upstream impacts**. Urbanization causes more than the degradation and loss of habitat; additional impacts include noise, night-lighting, dust and air pollution, and movements of people and vehicles. In planning for no-impact development in our watershed, watershed managers could aim for broad buffers around habitats used by "umbrella" species that need adjacent uplands and broad buffers from urbanization. Suitable examples are the Sandhill crane, the Sedge wren, and the Marsh wren. Recent data for the wrens indicate they need 1500-foot buffers (undeveloped space from sampling points where they were present). Likewise, Sandhill cranes need uplands for foraging to augment their wetland nesting habitat. Even beyond broad buffers, there is need to minimize vehicle traffic. A viable alternative, biking, would be facilitated by secure bike racks and routes to the Capital City Trail.

- **Improve estimates of surface water impacts**. A surface-water model is part of a range of planning tools, but such models are estimates based on assumptions. Therefore, it's important to update models to include uncertain future climates. For example, we need models that predict effects of extreme events—such as a series of storms. It would be useful to know if any models predicted the extent and magnitude of flooding in Houston, Texas, in August 2017. Unexpected events are expected to become more frequent and more extreme, so we should plan accordingly. Perhaps there are places upstream from Waubesa Wetlands where hardscapes can be retrofitted with materials that can infiltrate more water and reduce runoff.

- **Reduce surface runoff**. In the U.S., low-impact development (LID) refers to stormwater management, and there are extensive studies and guidance on how to reduce urban runoff. "To apply LID to any land use is simply a matter of developing numerous ways to creatively prevent, retain, detain, use, and treat runoff within multifunctional landscape features unique to that land use." (PGC 1999). LID designs involve clusters of homes, grass-lined swales, rain gardens/bioretention areas, and porous pavement. A recent review of the scientific literature (Dietz 2007) produced these findings: (a) Bioretention areas retain substantial runoff and pollutants (e.g., metals) but are less


Wrens and Great blue lobelia

### *Pesticide toxicity

In laboratory tests, 9 pesticides including glyphosate were toxic to human cells; fungicides were the most toxic at concentrations much lower than agricultural dilutions; herbicides were second, then insecticides. Furthermore, most pesticide applications had more toxic formulations than used in the experimental studies (Mesnage et al. 2014). [Note that toxicity is usually based on the active ingredient, not the carrier.]

effective in removing nitrates and phosphorus. (b) Porous pavements infiltrate storm-water runoff. (c) Groundwater contamination is not usually a problem when LID designs are implemented, although chloride needs to be studied. (d) Green roofs absorb 60–70% of rainfall on average. (e) P is exported from urban areas despite efforts to trap it. (f) Bioretention infrastructure and porous pavements infiltrate runoff even when the ground is frozen. Of course, long-term studies are needed.

● **Reduce contaminants at their sources**. It is easier to prevent pollution than to clean it up afterwards. We experience this truism every time we knock something off a table. Agricultural practices can be improved by fertilizing only when and where nutrients are needed and by never applying manure on frozen soil. Farm and urban yard care can be improved by a variety of **green** actions (see Cuttle et al. 2019 for advice for U.K.). In Dane County, a switch from lawns to native Prairie plants would reduce maintenance and attract more butterflies, but in urban areas, such a switch might require a change in lawn-height ordinances.

Toxic contaminants might explain why pollution-sensitive macroinvertebrates are missing in both Swan Creek and Murphy's Creek at Lalor Road. We've known for some time that herbicides harm more than their target weeds. The most widely used herbicide, glyphosate, has especially negative impacts on amphibians (Relyea 2005). And, chemicals designed to kill pests are also harmful to humans*.

Why risk impacts to Nature and yourself? Even leaves falling from our trees have impacts, so every "litter bit" helps. Avoid piling leaves where nutrients will leach into stormwater—i.e., keep leaves out of street gutters. Compost horticultural litter and use it as mulch. For streambanks and lakeshores, consider using root wads to reduce erosion. There's an example at Swan Creek, just downstream from the culvert on Lalor Road.

● **Provide payments for ecosystem services** (PES) as incentives for low/no-impact development. My Sedge meadow receives nutrients and other contaminants from an upstream corn/bean field. The lack of a requirement to treat runoff suggests the need for incentives. A penalty to dischargers would likely encourage reduced discharges upstream, and PES could pay the cost of managing/addressing the impacts downstream, in this case, eradicating Reed canary grass. While PES is yet to flourish, three U.S. compensation programs already exist for ecosystem services: Conservation Reserve Program (CRP), Conservation Security Program (CSP), and Environmental Quality Incentives Program (EQIP). PES could reward no-till agriculture, planting of overwinter cover crops, and higher nutrient-use efficiency. Since ~2004, the literature on PES has grown exponentially (Schomers and Matzdorf 2013). Upstream-downstream cases involving leadership by local stakeholders can guide future efforts (Rawlins and Westby 2013).

● **Treat runoff before it reaches streams, wetlands and lakes**. A variety of approaches can be used to i prove the quality of surface runoff. Restoring wetlands is high on the list (Ardón et al. 2010, Miller et al. 2012), but not all sensitive downstream resources have restorable wetlands upstream. Wide buffers around streams and wetlands are helpful. The Sandhill crane's needs for upland habitat would also be served by very broad buffers with soil stabilized by native vegetation. In the case of specific small-scale discharges from individual farm fields, there are digesters that can trap runoff and allow bacteria to convert nitrates to harmless $N_2$ gas. Wood chips serve as the organic food for denitrifiers, so some maintenance is needed when the wood chips have decomposed and need to be replaced. In all cases, surface-water treatment facilities should be placed on the land being developed, not left for downstream citizens to install and maintain.

Low-impact development is feasible, and decision-makers could set a high bar, namely, no impact for downstream gems such as Waubesa Wetlands.

**Regulations seem easier to accept when self-imposed.** In **Colorado**, hundreds of farmers in the San Luis Valley voted to pay well pumping fees to encourage groundwater conservation after a major drought in 2002. Subsequently, farmers shifted to crops with higher water-use efficiency, acquired more efficient equipment, or paid for extra water. Overall, farmers reduced their water use by about a third per year on average (Smith et al. 2017).

In the **Town of Dunn**, voters **agreed to tax themselves** to fund the Purchased Development Rights (PDR) program. So far, there are about 35 land parcels with Conservation Easements. This approach to protection is a model worthy of global attention and emulation. Tops among other volunteer actions was the donation of land that included what is now the Bogholt Deep Spring. Dr. Carl Bogholt, a philosopher, gave the land to the Town of Dunn instead of developing a marina and housing.

The Town's current policy (Comprehensive Plan p. 2–9) is to "Utilize the Town's PDR program to preserve environmental, archaeological, scenic and historic resources." Additional policies are to "Encourage the preservation of areas needed to support local wildlife…Minimize habitat fragmentation and ensure that a larger area is available for wildlife populations…and Support all other levels of government in acquiring natural features in this area, especially those within the identified environmental corridors, for public use and protection consistent with the objectives and policies of this Plan."

### *Check list of actions to minimize impacts of urbanization upstream on downstream wetlands

**Extend predictions beyond water to all impacts of urbanization**

- Use an umbrella species such as Sandhill cranes to plan buffers that minimize effects of light, noise, motion
- Minimize vehicle traffic; provide secure bike racks; connect to the Capital City Trail

**Improve estimates of impact**

- Model runoff expected with extreme events and interactions between hardscapes and sequential storms
- Measure the volumes of outflows to streams and lakes
- Monitor nutrients (reactive forms of N and P + total N and P); calculate loadings to Swan and Murphy's Creeks
- Use realistic data to predict climate change; estimate worst-case scenarios

**Reduce runoff**—aim for no net increase in runoff (no-impact development)

- Plan low-impact development; learn from others' experience
- Install rain barrels and rain gardens; use boulevards as sumps for runoff
- Harvest stormwater (capture and store in underground tanks for later use in irrigation)
- Require permeable hardscaping (streets, sidewalks, patios)
- Create green roofs to absorb rainfall

**Reduce contaminants** at the sources

- Eliminate the need for lawn fertilizers with N or P or both; dispose of pet feces responsibly
- Plant native vegetation; update height restrictions to allow native vegetation
- Minimize the use of pesticides (herbicide, insecticide, other pesticides)
- For ag lands, enforce ban on applying manure on frozen soil
- Require timely clean-up of leaf litter and compost it for use as a soil amendment
- Use root wads to stabilize eroding creek banks

**Provide payments** for ecosystem services

- Require upstream polluters to pay costs of downstream pollution
- Promote and reward no-till agriculture and cover crops; aim for high nutrient-use efficiency

**Treat runoff** before it reaches streams, wetlands and lakes

- Establish broad buffers around fields and urban hardscapes to absorb runoff
- Install woodchip digesters to intercept and treat agricultural and street runoff; maintain them
- Establish treatment swales at construction-project outflows—on project land, not downstream

## D. Manage watersheds adaptively

Everyone practices **adaptive management** at some level—when you plan a hike but are uncertain whether it will rain or be cold, you might dress in layers, then remove or add layers as you "collect data" on how wet and how cold it becomes as the day progresses. Uncertainty generates the need to be adaptive—to learn while monitoring conditions and determining what works best.

The need to manage **watersheds adaptively** arises from **uncertainties** about how best to protect downstream wetlands from upstream events (Chapter 6) in ways that serve both people and Nature. We have ample knowledge to address and prevent minor impacts of surface water runoff, to search and eliminate minor sources of N and P and other contaminants, and to protect our high-quality groundwater. It's the larger impacts that cause uncertainty and give us "trouble." From the perspective of Waubesa Wetlands, the **greatest uncertainties** concern *large* impacts caused by **extreme events** that interact with major construction projects and agricultural fields during their most vulnerable (bare-soil) condition.

The most well-known examples of **watershed-scale extreme events** are floods during/following extreme storms or a series of heavy rainfalls. Other extreme events with widespread impacts are tornadoes, damaged stormwater reservoirs, early-spring thaws, late-spring frosts, plant and animal diseases, insect outbreaks, and even earthquakes—yes, in the Midwest; Missouri experienced 3 major quakes in December–February 1811–1812 (https://earthquake.usgs.gov/earthquakes/events/1811-1812newmadrid/).

How much information about impacts is "enough" to take action and limit development, or to restore degraded wetlands, or to conduct any management activity? Menz et al. (2013) concluded that "…there are few ecosystems on Earth for which the knowledge required for landscape-scale ecological restoration already exists." Thus, we need to learn while managing our watersheds.

**Being adaptive includes learning while managing.** "Whatever strategies are implemented, they should be done in an adaptive manner because the complexities imparted by spatially variable landscapes, climate, and system response will require site-specific iterative solutions" (Sharpley et al. 2015). Land managers can set up alternative actions to solve a problem (e.g., alternative ways to stabilize streambanks to reduce stream erosion). Then, they can compare effectiveness by collecting information on how well each action reduces the problem, and finally use the new knowledge as future problems develop. Regular surveillance, perhaps using drones, could track projects, check for invasive species, and monitor distributions of native species. The **adaptive** part is: Collecting evidence, using new data, and being flexible—i.e., willing to change policies and practices, given new understanding.

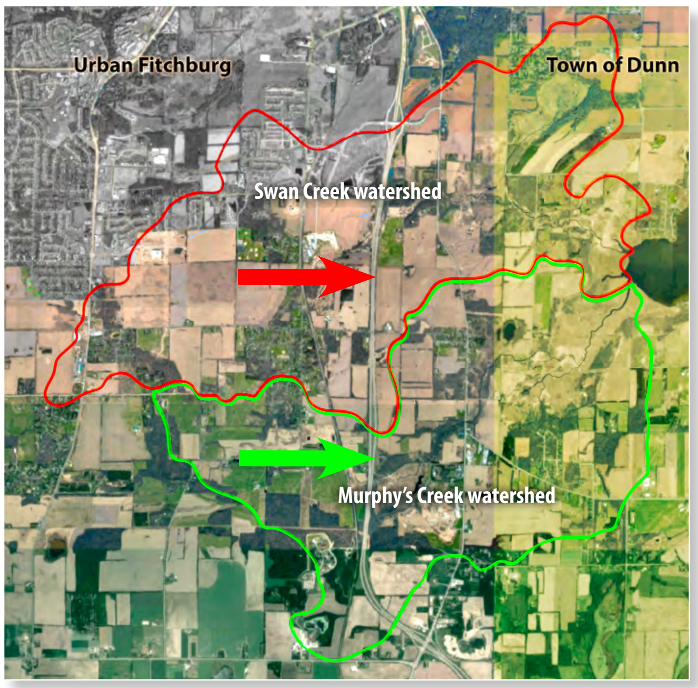
The **watershed** part requires cooperation between people upstream (City of Fitchburg) and downstream (Town of Dunn). Despite separate governance bodies, a joint management team for the watershed could consider ideas for reducing upstream impacts on downstream wetland gems, and to study existing guidelines and propose a way forward. A user-friendly **manual** by Fischenich et al. (2012) illustrates essential steps and benefits of adaptive watershed management. In a recent review of adaptive management, I presented examples from around the world that can help teams develop adaptive, watershed-scale approaches (Zedler 2017). A more recent paper (Ebberts et al. online) describes in detail how adaptive watershed management was accomplished in the Columbia River Estuary. If they can do it, so can we!

**Adaptive watershed management begins** by bringing upstream and downstream stakeholders together to agree on the issues, rank uncertainties, facilitate decision-making, and share resources. In the absence of cross-township governance, citizens could establish voluntary approaches, such as a community **Stewardship Center** to facilitate green living. The City of Colorado Springs has an example in place. A Stewardship Center could feature a prairie garden, demonstration plots for native landscaping, and Community Supported Agriculture. Local growers already facilitate a local Farmer's Market. Knowledgeable citizens could offer watershed-scale education on natural resource conservation. Watershed managers could offer incentives, advice, ordinances, and enforcement.

Citizens could also invite decision-makers to establish a **Watershed District** to facilitate shared governance. The watershed district's "Adaptive

Watershed Management Team" could decide how, where and when to stabilize eroding lands by planting buffers, where to create wetlands to filter contaminants and reduce runoff; and whether to shade streams to reduce water temperatures and provide habitat and food for stream biota.

But if shared governance isn't supported, there's another, potentially better, option. Citizens could establish a **Watershed Trust** that would link upstream/downstream neighbors with all stakeholders (landowners, land managers, nongovernmental organizations, etc.). Such a Trust could involve watchdogs to track the operation of infrastructure, such as culverts and roads; report maintenance needs, and inform the public of hazards in a timely manner. The watchdogs would be a stakeholder rule-enforcement group that reports to watershed leaders. The Trust could also work with governmental agencies to enforce rules with carrots/sticks, reward compliance and offer additional rewards for exceeding goals.




Surface water flow from Fitchburg to Dunn.

*Redrafted from DeWitt and Google Maps*

**Let's wade in** with some examples of watershed approaches. Illustrated at right is the rural Eden River watershed in northern England, a demonstration area for improving surface water quality. This **treatment train** (a series of features) was designed to reduce sediment and P-rich runoff from grasslands grazed to produce dairy, beef and sheep. The 888-square-mile (2,300 km$^2$) area was fitted with impoundments to slow runoff; interventions to reduce contaminant loading; cross drains to slow water; a modified ditch with rock check dams to entrain sediments; retention ponds; a fenced riparian area with tree planting; and a side ditch to attenuate surface flow. Farmers cooperated to allow construction, monitoring, research, and simulation modeling in this ~10-year project. Short-term removal rates were posted online. (Barber et al. 2016.)

**KEY to TREATMENT TRAIN**

**1** • Farmyard interventions: reduce pollutant mobilization risk

**2** • Runoff interception, temporary storage

**3** • Cross-drains reduce flow of water along track

**4** • Field runoff converging to form surface flow path

**5** • Slow surface and drain flows to modified ditch

**6, 7** • Slow ditch and surface flows

**8** • Intercept and temporarily store track runoff

**9** • Riparian area fencing and tree planting

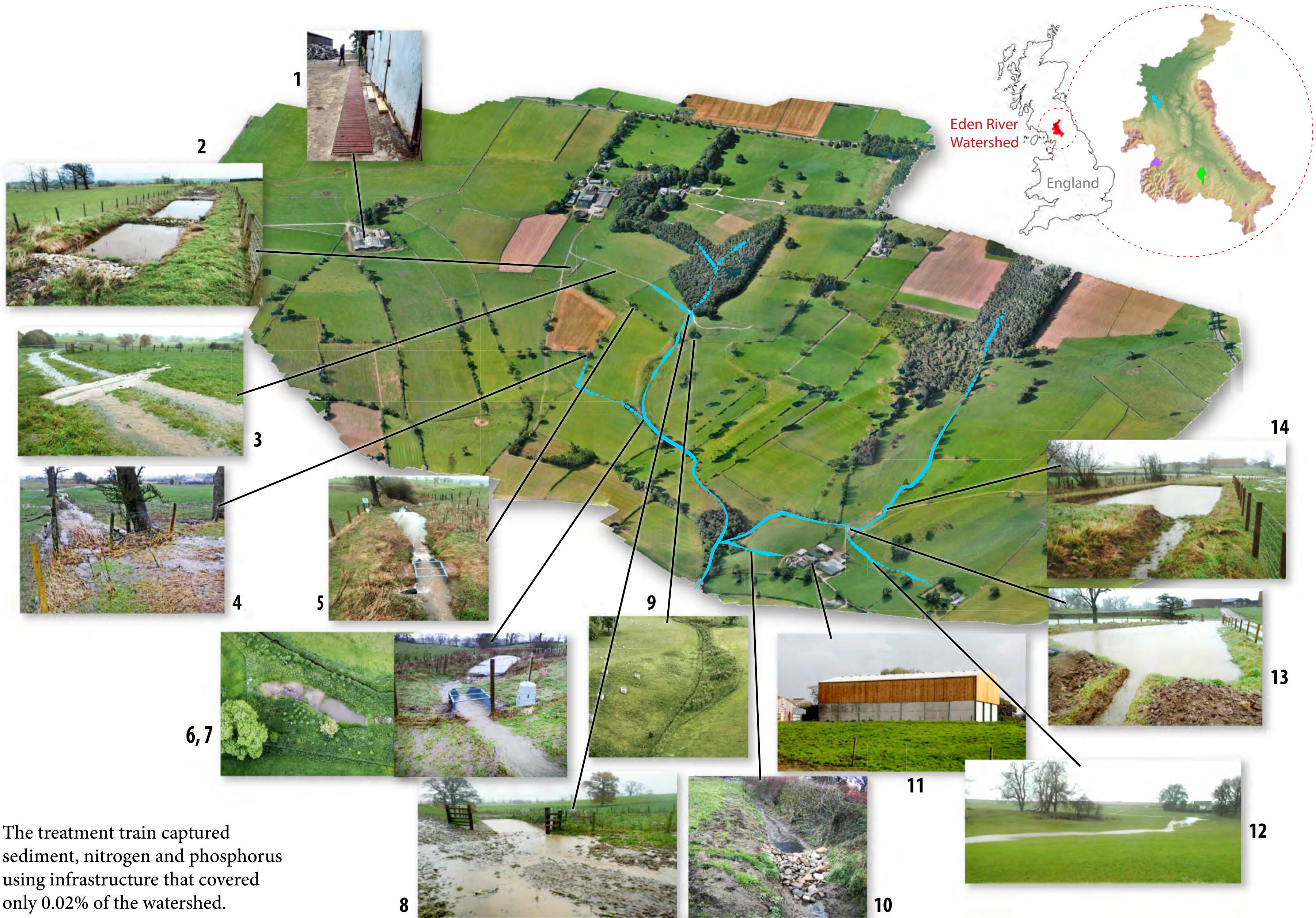
**10** • Series of in-ditch rock check dams

**11** • Farmyard interventions: Increased slurry storage

**12** • Surface runoff flowing towards temporary storage pond

**13** • Runoff collection pond

**14** • Temporarily store runoff during high flows.



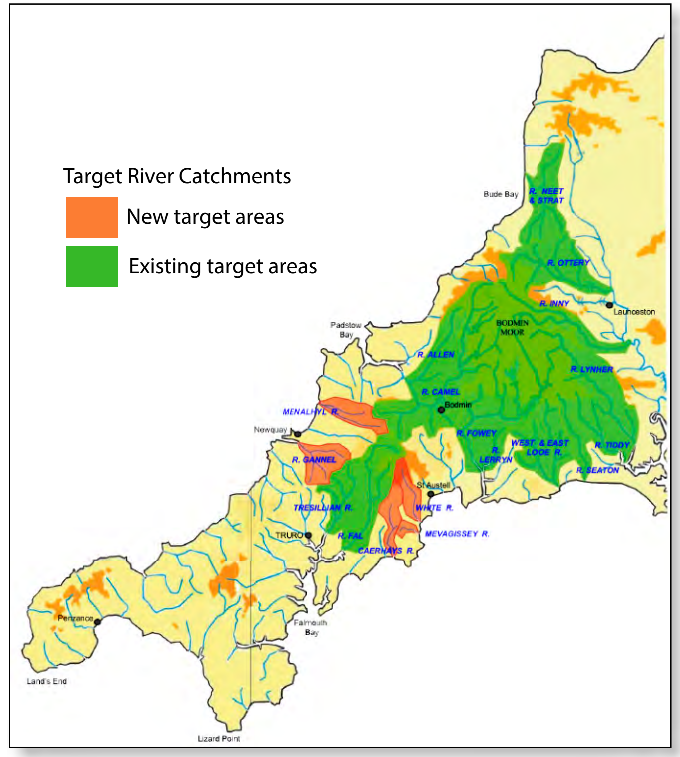

The treatment train captured sediment, nitrogen and phosphorus using infrastructure that covered only 0.02% of the watershed.
*Barber et al. 2016*

Another case in Cornwall is inspiring citizen-based land-care throughout the U.K. Citizens decided to clean up their watershed's rivers, and a local collaboration, the Westcountry Rivers Trust* is replacing attempts at top-down governance. The most effective Trusts: (1) are able to generate funding and (2) are stable institutions (Meijerink and Huitema 2017). My short summary of the case study in Cook et al. (2016) follows:

*__Westcountry Rivers Trust__ arose from a 1993 meeting in Cornwall, U.K., of local people who were concerned about declining river water quality due to industrial pollution, agricultural impacts of fertilizers and livestock, and heavy metals from former mine spoils. Local citizens decided to organize to improve river quality, increase biodiversity, protect natural habitats, and educate the broader public. In 1995, they established the Westcountry Rivers Trust as a non-profit organization. With a framework in place and non-profit status, the trustees sought and obtained funds from the European Union, the U.K. government, and donors. Their pilot project aimed to reduce nonpoint surface water pollution in the watershed. To do so, they:

- Identified "champion farmers" and demonstration sites to educate others;
- Advised owners of wetlands along rivers on how to manage riparian ecosystems;
- Tailored assessments, plans, and advice for farmers to reduce river pollution; and
- Surveyed river reaches and fenced buffer zones to exclude livestock.

The Trust relies on sound science to manage adaptively, and leaders solicit input from farmers, businesses, and the public to design and implement projects. The Trust inspires citizens from neighboring watersheds to join larger efforts, namely bioregional planning and Payments for Ecosystem Services. In the latter, an entity that would benefit from high-quality water pays for the actions needed to improve water quality. The Trust's core principles emphasize a holistic approach to catchment management, local leadership and support, funding from direct beneficiaries of environmental improvements, and engaging the public.



Westcountry Rivers Trust Cornwall watershed.

*wrt.org.uk*

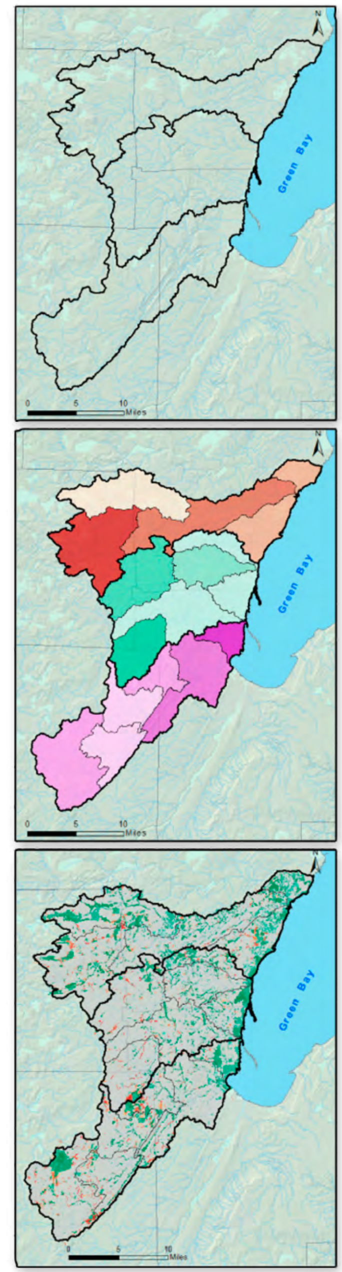
**A Waubesa Wetlands Watershed Trust?**

The watersheds of Swan Creek and Murphy's Creek don't match any existing governance unit. Still, citizens could develop ways to self-impose approaches to reduce impacts on downstream wetlands. A non-governmental organization is already registered with the state: The West Waubesa Preservation Coalition has a mission "to preserve the rural character, natural environment and beauty of Dane County, Wisconsin, west of Lake Waubesa, and to protect the preserved region and its inhabitants from intrusive development, including the adverse health effects which may be suffered as a result of inappropriate development. Our mission includes educating ourselves and the general public about the causes and effects of inappropriate development, and promoting the transformation of theory and vision into a sustainable reality."

**Now, let's jump into a watershed-scale approach** and ask where wetlands might be restored along Swan Creek to improve the quality of water flowing downstream. To do so, we can use a new "tool" to identify restorable wetlands that can improve water quality. The pilot tool was developed for three watersheds that drain into Green Bay, Wisconsin (Miller et al. 2012). But watch for the state-wide roll-out:


**State-wide maps are about to be released** along with an interactive decision-tool. Soon, we can use the tool to consider alternative wetland-restoration scenarios for the Swan Creek subwatershed. Meanwhile, we'll use Green Bay maps in Miller et al. (2012) to illustrate how a watershed approach can help identify suitable **restorable wetlands to improve stream water quality**.

Focusing on the northern watershed (top map), let's ask, "Where can we restore wetlands to provide best improve water quality?" We consult the water quality service map (center map) and find the darkest subwatershed. That's where Miller et al. found the most loss of that service, which is now the area where the most gains could be made by restoring wetlands. Then, to locate actual restorable wetlands (sites for possible restoration projects), we go to the map on the bottom to see all the restorable wetlands (red polygons) and upland habitats (green polygons) in our selected subwatershed. *Voila!* Possible restoration sites emerge. One or more of these might be suitable for further planning, once ownership and owner participation are explored.




Green Bay watershed maps from TNC, reprinted from Zedler 2017.

**Finally, let's dive into adaptive approaches.** Restoration sites are usually suitable for some experimentation, so let's say we purchased a plot that is part-agricultural, part-weedy wetland, and located just downstream from a proposed housing development. How can we restore the wetland at this site when we know it will receive pulsed flows of surface runoff?

First, we need to prioritize the unknowns (a.k.a. uncertainties): An upstream swale could trap some sediments and other contaminants before the water flows into the restoration site. However, a top unknown for restoring downstream wetlands is how to configure "treatment swales" upstream to provide the cleanest possible surface-water inflows downstream. I like to start with a topographic map with 1–2 -foot elevation contours and a site visit to suggest alternative ways to create treatment swales. I also use lessons from personal experience, case studies, and science-based literature (e.g., ASWM 2017).

Another major *unknown* is how to vegetate the treatment swales, not knowing how wet future hydroperiods will be or which native species would thrive. To address this uncertainty, the swale might be vegetated with experimental plantings of different native species to test their ability to establish in the short-term and their long-term resilience to weed invasions.

For the *wetland downstream from the swales*, restoration *unknowns* will depend on the site, its history, and its potential future structure and functioning. It might be useful to test alternative plantings in a large field experiment. It also might be wise to leave the surface soil rough to add small-scale topography. Or, restorationists might test plantings of Tussock sedge, the "restoration superplant" (Chapter 3, Leaflet #22), along with Bluejoint grass, a strong dominant (Frieswyk et al. 2007), and the common Fox sedge (*Carex stipata*), which persisted in one restoration site despite a Reed canary grass invasion (Healy et al. 2015). A well-designed experiment and monitoring data would allow managers to learn which species tolerate the site. It might also indicate *why* they tolerate it—a key advantage of experimentation over trial-and-error. If each test species performs best in a different microsite (ridge vs. depression), data on plant growth in relation to soil conditions would inform future plantings. Each restoration effort can use knowledge from previous efforts, while at the same time addressing other unknowns.

**Management targets**. The above example had a clear target—restoring wetlands to clean up surface runoff. What about targets that are longer-term and more comprehensive? Early proponents of evaluating cumulative impacts on wetlands advised using watershed approaches (Bedford and Preston 1988, Whigham et al. 1988). A decade later, a panel of experts (NRC 2009) made four suggestions for holistic ways to address effects of urbanization on **watersheds**:

- **All stressors** need to be considered to protect urban streams—altered hydrology, altered habitat, polluted runoff, water temperature, and more.
- Predictions of storm effects need to **capture the variability** of rain, runoff and pollutant loadings by evaluating the full range of storm sizes. A single "design storm" (like one predicted to recur every 10 years) will not suffice.
- **Monitoring** the impacts of urbanization on streams needs to include **biota**, not just physical attributes.
- Studies are needed to relate **human health risks**, such as toxic materials and germs in urban stormwater.

The above advice from NRC (2009) was a wake-up call, and policy- and decision-makers are still wrestling to know how best to respond. In summer 2017, local stakeholders attempted to advise Dane County's Capital Area Regional Planning Commission (CARPC), the DNR, and the City of Fitchburg to take a holistic approach to prevent impacts of upstream development on downstream Waubesa Wetlands. Citizen stakeholders argued that many answers already appear in the scientific literature and can be tailored for Waubesa Wetlands. We also know that each watershed, each development scenario, and each downstream wetland has its own characteristics, such that "business as usual" will not protect downstream wetland gems. At the end of summer, DNR opted to continue simulation modeling to improve estimates of surface water quality and/or groundwater supplies. The next steps are uncertain, but I recommend adopting the precautionary principle and moving forward toward adaptive watershed management. "When an activity raises threats of harm to the environment or human health, **precautionary** measures should be taken even if some cause and effect relationships are not fully established scientifically" (Wingspread Statement on the Precautionary Principle 1998; Racine, WI). My advice: "When in doubt, avoid damaging wetlands." I am not alone in offering such advice.*

Note that implementing BMPs (see box) does not mean they will perform as needed. The Arboretum swales are a clear example. Despite being designed to trap total suspended solids (TSS), N, and P; they actually discharged those contaminants (Leaflets #27–28, Doherty et al. 2014). Why? Engineers/designers refused to accept 30 years of scientific research that explained why adding nutrient-rich topsoil to the restoration site would shift plant growth from roots to shoots, when the aim for reducing erosion would be root growth to stabilize soil. Our mesocosm experiment had already tested the effect of topsoil addition, and we knew the added nutrients would stimulate weed invasions (Kercher et al. 2007). We also knew that standing water would allow cattails to mobilize phosphorus (Boers and Zedler 2008). Despite evidence and advice, the designers called for topsoil. So topsoil was added to each swale, and the swales exported N and P instead of trapping nutrients. The lesson here is that deciding which actions are actually BMPs requires **qualified advisors** from **relevant disciplines**.

## In summary

A broad, visionary precaution is to join others in promoting wetland restoration throughout our biogeographic region. Recall that Waubesa Wetlands have a big role to play because other states in the region have lost far more wetland area than Wisconsin (data in Chapter 2). Those same data on wetland loss support the need for wetland restoration region-wide. Large projects in Illinois, accomplished by The Wetlands Initiative (TWI), offer inspiration and practical guidance.

Support for large-scale wetland restoration and long-term protection also comes from a **human-health** perspective: "Climate-driven changes in species distributions, or range shifts, affect human well-being both directly (for example, through emerging diseases and changes in food supply) and indirectly (by degrading ecosystem health)….We argue that the negative effects of climate change cannot be adequately anticipated or prepared for unless species responses are explicitly included in decision-making and global strategic frameworks" (Pecl et al. 2017, p. 1389). Diseases will be among the hard-to-predict events. "Epidemiological studies on the human health risks of swimming in freshwater and marine waters contaminated by urban stormwater discharges in temperate and warm climates are needed" (NRC 2009).

*__Advice to The City of Toronto__, Ontario, from Elton et al. (2011): "Use the precautionary principle. Impacts to wetlands caused by urbanization are clear in all studies, illustrating that it is important to make every effort possible to protect wetlands with current techniques, BMPs [best management practices] and available legislation. It should be noted that current BMPs, such as stormwater management ponds, have not been able to maintain the pre-development hydrological regime or water quality in receiving wetlands and natural systems. **New and innovative strategies, such as low impact development, should be implemented in all developments that will impact the natural system**. These measures represent the best available technology to resolve outstanding concerns…. The only true way to protect these resources is to limit imperviousness and the loss of natural cover by instituting new and innovative approaches for mitigating impacts" (Elton et al. 2011, emphasis added).

My bottom line: **Minimize hardscaping; employ adaptive watershed management.**


Award-winning volunteers helped restore "Secret ridge" at Midewin National Tallgrass Prairie near Chicago, where thousands of acres of former military land are being replanted to native vegetation.

*Photo: The Wetlands Initiative, June 2017. http://www.wetlands-initiative.org/midewin/*

Chapter 7 ends where it began, with four conclusions. We need to **enforce, monitor, act green,** and **manage the watershed adaptively.** Where do we get the will to do so? It has to come from within (Chapter 8).

# Chapter 8 • Looking inward

Advice for setting up **adaptive watershed management** for Waubesa Wetlands comes from both scientific and traditional ways of learning. From Science we can learn how to manage and sustain wetland services, while Traditional Learning shows us why we should care for the lands and waters that serve us. These ways are complementary: Science is rich in rigor and objectivity, and Traditional Learning is embedded in a culture of **reciprocity,** which provides deep meaning and personal incentive to give back to the Earth that sustains us. Scientists increasingly turn to Aldo Leopold's land ethic to find that missing piece. Indeed, we'll need more than Science to carry out the ideas presented in this book. We'll need an ethic that is based on both science and deep commitment. We'll need to look inward.

## Traditional and Scientific ways of learning are complementary

**Traditional ways of knowing** describe a Native American way to learn how to treat the Earth's wetlands, uplands, lakes, rivers and streams. The first peoples learned to use but not abuse the Earth long before there was Science. I don't claim to know enough about Native American culture (for that, please consult experts, such as Berkes et al. 2000, Anderson 2005, and Kimmerer 2013), and I don't expect to convey its full meaning in these final pages. What I hope is that readers will capture a key concept, that Native people learned to deal with uncertainties about their environment and to take care of the land so the land could take care of them. The many uncertainties involved weather, unpredictable animal behavior, poisonous plants, and other potentially life-threatening hazards. Yet people learned how to harvest resources with gratitude and without widespread overexploitation.

Traditional Learning involves repeated trials, often over generations. Suppose a tribe wanted to know whether harvesting willows in a new place would result in straighter resprouts. Trial cuttings in the first year would require follow-up observations to assess willow responses and resilience. New trials and assessments over time helped tribes adopt what worked, correct what didn't, and pass on knowledge to the next generation. Around the world, there are diverse examples of how local traditional practices improve ecosystem management via "feedback learning" (Berkes et al. 2000).

Equally important is the associated **culture of reciprocity**. Here's a description from the author of *Braiding Sweetgrass*: "It is a culture of gratitude; everyone knows that gifts will follow the circle of reciprocity and flow back to you again. This time you give and next time you receive. Both the honor of giving and the humility of receiving are necessary halves of the equation. The grass in the ring is trodden down in a path from gratitude to reciprocity. We dance in a circle, not in a line" (Wall Kimmerer 2013, p. 381). In caring for the land and water, people offer their gratitude and take only *necessary* resources, knowing that Earth is resilient to careful harvesting. Resources cannot recover from wonton greed. That lesson was learned long before European settlement.

**Western Science is a newer way of knowing,** with emphasis on experimentation, quantitative comparisons, statistical tests, rigorous peer review, and usually, rapid publication. Our modern attempts to "learn by doing" parallel ancient traditions of trying something with uncertain outcomes. And in the land care arena, this approach involves tests of alternative actions within **Adaptive management** frameworks (Zedler 2017). Both Adaptive and **Traditional** management are ways of learning how to care for the land. Here I argue that they are complementary.

Sweetgrass
(*Hierochloe odorata*)

Adaptive management is widely used to deal with uncertainties, and cases concerning hardscaping illustrate its utility. The unknown is: how much of a watershed can be impervious and still absorb local surface-water runoff? A manager can work with hydrologists to reduce uncertainties—both by measuring urban runoff in several areas and by modeling the water flow based on hardscape area. Statistical comparisons of actual data with a model's predictions then suggest how to improve the model. Learning comes through testing, experimentation, and modeling. Further improvements would come by predicting impacts of more frequent, more intense storms and even catastrophes, like the 2017 hurricanes (Harvey, Irma, Jose, and Maria). Keep in mind that models are *estimates* that can help us prepare for an uncertain future—but they need continual updating. When new knowledge is accepted and built into management, the decision-making process becomes adaptive. In the best cases, scientific data are used even if reality is inconvenient.*

From Western science, we have learned how the care and protection of wetlands sets in motion positive feedbacks (e,g., Cleaner water ↔ Healthier people). Still, knowledge about what is good for us doesn't always result in self-restraint, so care and protection are not always sufficient. What we don't seem to have learned is how to curtail our desire for more—we take more from the land than we need, and we lose sight of the scale of our disruptions to Earth. With modern machinery and billions of people, we completely modify the land and, in the process, degrade the natural resources that are responsible for our own well-being. Four such resources are healthy land, clean water, clean air, and biodiversity (MEA 2005). Nowadays, land is modified to optimize profit, not watershed integrity, and many landowners and politicians begrudge regulations that limit the taking of resources. A current case in point concerns wetlands—Earth's most valuable ecosystems on a per-acre basis. Why are politicians attacking these treasure chests of ecosystem services? Rolling back regulations is indefensible. Because wetlands occupy less than 10% of global surface area, every tiny loss matters (Zedler and Kercher 2005).

**Complementary Learning.** Our culture of exploitation is missing something critical—something that could lead to sustainability. Traditional learners and Western scientists agree that wetland ecosystem services are essential for human well-being, despite different ways of learning, but Traditional ways embrace sustainability in a culture of reciprocity (Wall Kimmerer 2013). In a new review of the global condition of soil, I noted an encouraging outcome: Two *international agencies* stated as a *basic principle* that local indigenous knowledge is critical for sustaining our Earth's soil (FAO and ITPS 2015). I'd go further than this to say that the Earth in total and wetlands in particular need the benefits of Traditional learning.

*__Our study of Arboretum swales__ offered decision makers two breakthroughs, but neither influenced decision making. First we provided actual ***measures* of six ecosystem services,** and second we showed how and why a facility that was designed **to be a sink** for nutrients was in reality a **source** of nutrients (both N and P). Research and monitoring explained why (Doherty et al. 2014, Leaflets #27–28).

**Regardless,** a signed agreement required only that the swales be built, assuming that when they were built as specified, they would function as planned, i.e., total maximum daily loads (TMDLs) would be reduced. The agreement took precedence over the science! The outcome? Malfunctioning swales had to be operated, and they have been for years.

The basis for adaptive management existed (a research team and data), and the swales could have been fixed. But adaptive management was not used. In an adaptive framework, decision-makers would have been trained to look for shortcomings, listen to scientists, correct shortcomings, and find ways to improve regulations. Scientists would have had an influence.

Scientific approaches by themselves won't achieve reciprocity.

Wetland care and protection ↔ Human well-being

Western scientists are increasingly turning to Aldo Leopold's writings to find the missing piece—the missing incentive. In *Marshland Elegy* Leopold wrote, "The ultimate value in these marshes [wetlands] is wildness, and the crane is wildness incarnate."

Leopold's words provide part of the missing piece—he saw the cranes as inherently valuable, not just a resource to exploit.

For many of people who live in the Town of Dunn, the Sandhill crane is "a valuable symbol of what has been and could be. The crane is a neighbor worthy of notice, of protection, of record. Town residents have given land for the cranes, have counted them, recorded their comings and goings, named their homesteads for the crane, written stories about them, and dotted their homes with crane-inspired art. Sandhills are clearly more than a part of the local landscape. In Dunn the crane represents a town that has stopped to notice what it has and taken steps to maintain those resources" (quote from a resident interviewed by Elkin and Murcier for a 1996 class report).

Our Town's care for wetlands—and cranes—sets a global example. As part of the Town of Dunn's land ethic, landowners voluntarily sell their right to develop their land, and their land becomes protected in perpetuity under a conservation easement. This model practice is sustainable because it is **reciprocal:** People **sustain the land and the land sustains human well-being.** The program of Purchased Development Rights is an example of reciprocity. We have a beginning; we need broader participation.

Everyone can learn to be grateful for precious, natural resources, scenic views, the sight of Sandhill cranes and wildlife, and opportunities to hunt and fish, and we can all learn to give back to the land more than what we take. We can all learn why to protect the land from negative impacts and to show gratitude. If we accidentally damage the land, we can overcompensate for negative impacts. There is hope for **reciprocity** if we look inward.

Contemplating a Waubesa Wetlands spring with Skunk cabbages (native) alongside and Watercress (naturalized). We need to sustain natural resources to sustain our well-being.

*Photos: Joy Rifkin*

Skunk cabbage in bloom

## We could develop a wetland ethic.

The following essay was published in the National Wetlands Newsletter (Zedler 2015).

Aldo Leopold (1949) encouraged a land ethic, wherein people would choose to live in harmony with the land in order to sustain natural resources. Much later, Jim Bohnsack (2003), a NOAA Fisheries Manager, advocated an ocean ethic to gain support for marine reserves to protect ocean fisheries, concluding that "Marine reserves not only protect marine resources but can help restore human expectations and provide a basis for new conservation ethics by providing a window to the past and a vision for the future." And geologist Mary Anderson (2007) added that "an ethic defined under the Land Ethic requires a shift in focus from the human good to the good of 'the land' including groundwater."

**Do we also need a wetland ethic?** Yes, we do, even though Leopold wrote comprehensively about the "land." Wetlands differ from both the drier land and the deeper waters in providing far more ecosystem services per area. Those services include biodiversity support, water quality improvement, flood abatement and carbon storage, plus aesthetic, recreational, educational and scientific values.

What sets wetlands apart from drier lands and deeper waters is the amount of services provided per area (data in Costanza et al. 2014). Thanks to wetlands, the earth supports more biodiversity. And thanks to large wetlands, floodwaters are detained and absorbed, protecting downstream lands. Wetlands provide disproportionately more services, in large part by collecting water and materials from uplands and accumulating, storing, and transforming a wide variety of materials, then discharging cleaner water. Often called "nature's kidneys," wetland vegetation and soils remove both organic and inorganic matter. As wetlands accumulate sediment, they become flat, and water flows slowly. The ecosystem processes more materials where water-residence times are prolonged.

The ability of wetlands to remove nitrogen is especially notable. Wetland bacteria convert nitrate to harmless nitrogen gas (which makes up ~80% of the air we breathe). We call the amazing bacteria that are responsible, denitrifiers. A bit like Goldilocks, denitrifiers cannot do their job where soils have too much oxygen, as in uplands, or too little oxygen, as in deep waters. Wetland conditions are just right. Our wetlands are denitrification powerhouses that make downstream water safer for drinking. Given more and larger wetlands, all of these services could further improve human well-being.

**Is a wetland ethic necessary? Yes. First, the lower 48 states have lost half their wetland area.** Wetlands warrant extra protection for their high efficiency—providing more services per area while occupying less than 10% of Earth's land area (Zedler and Kercher 2005). The loss of half our wetland area simultaneously eliminated their services

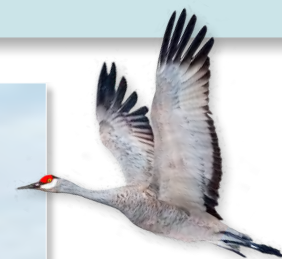
**Second, we are not fully protecting or restoring our remaining wetlands.** While the U.S. Clean Water Act protects some wetlands from filling and discharges of pollutants, the regulations apply only to a subset, called jurisdictional wetlands. Ecologists and the US Fish and Wildlife Service consider a broader range of habitats to be wetlands. So, existing laws do not protect all wetlands. Nor do regulations under the law reduce damages enough to sustain historical wetland services. And even where regulations are set, the management measures are not monitored to enforce regulations. Because the law protects only a subset of wetlands, the damages regulated are only a subset of the actual damages, and the regulations that are enforced are only a subset of what should be enforced, the overall outcomes fall short of adequate protection.

Aldo Leopold said, "The land relation is still strictly economic, entailing privileges but no obligations." He went on to criticize the "clear tendency in American conservation to relegate to government all necessary jobs that private landowners fail to perform," Instead Leopold called for "a land ethic, or some other force which assigns more obligation to the private landowner." He argued that "a system of conservation based solely on economic self-interest is hopelessly lopsided. It tends to ignore, and thus eventually to eliminate, many elements in the land community that lack commercial value, but that are (as far as we know) essential to its healthy functioning.… It tends to relegate to government many functions eventually too large, too complex, or too widely dispersed to be performed by government." He concluded that, "An ethical obligation on the part of the private owner is the only visible remedy for these situations."

Leopold also said that an ethic evolves; it is not written. Thus, a wetland ethic need not be restricted to private landowners or even to landowners. All people in all organizations benefit from wetlands; in return we can all respect wetlands and facilitate their ecosystem services.

Here are **four ways to facilitate the evolution of a wetland ethic**: (1) acknowledge that wetlands provide multiple functions that enhance human well-being at rates far greater than their global area indicates; (2) accept our obligations to wetlands along with the benefits of wetlands; (3) support conservation and restoration of wetland biota and natural functions for posterity; and (4) realize that watersheds upstream will also need restoration, in order for downstream wetlands to be more restorable.

A wetland ethic would foster understanding that protection means more than setting regulations and promising enforcement. A wetland ethic would add voluntary responsibility for ecosystems because they provide services well beyond the small area of earth that they occupy. At the same time, wetland restoration efforts could be expanded and strengthened.



After interviewing residents of the Town, Elkin & Murcier (1996) wrote, "the crane comes back every year to remind us, in a voice both prehistoric and demanding, of the tenuous hold we all have on the future…. It is useful to have such a reminder."

New gates at the Town of Dunn Burying Ground proudly display cranes.
*Photo P. Zedler*

# Chapter 9 • Looking for more information?

**Here are over 200 references that are relevant to Waubesa Wetlands.**
**Nearly all are cited in the book; a few were added because they have related content.**
**Happy reading!**

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