2019 STATE OF THE RIVER REPORT

TOMORROW RIVER

PORTAGE COUNTY, WISCONSIN

Center for Watershed Science and Education
College of Natural Resources
University of Wisconsin-Stevens Point

Cover photo: contributed

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ACKNOWLEDGMENTS

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The authors acknowledge those in the Tomorrow River watershed who have made land management decisions that help maintain or improve the river's water quality and aquatic ecosystems. Healthy streams, lakes, and wetlands need stewards who will serve as their voices and work to help them thrive. The Tomorrow River has benefitted from the stewardship of local organizations, including the Bill Cook Chapter of the Izaak Walton League, Friends of the Tomorrow/Waupaca River, and the Frank Hornberg Chapter of Trout Unlimited.

Figure 1. The Tomorrow River system is cherished for its natural areas and abundance of trout (contributed).

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Information about the Tomorrow River and its tributaries exists due to the hard work of professional and citizen scientists. We hope their continued enthusiasm will fuel data collection efforts that will enable future generations to make informed decisions about the protection and restoration of this cherished river system.

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INTRODUCTION

The Tomorrow River is recognized locally and statewide as a natural resource treasure. Its clear, cold waters support native trout, wildlife, recreational opportunities and regional economic development.

Through the years, public and private interests have worked to protect and preserve this riparian gem. Over 70 years ago, the Izaak Walton League began its stream restoration projects along the Tomorrow River. More recently, a large scale watershed project was undertaken by the State of Wisconsin and local counties to reduce the amount of pollution entering the water. The local Trout Unlimited chapter has also put decades of effort into the stream's overall health. And students in the Tomorrow River School District have for years been doing hands-on water quality studies.

The reason for this report is to encourage stewardship efforts by all Portage County stakeholders. The report's contributors summarize existing studies and reports into one document. By providing a present-day report of the Tomorrow River's ecological system, local and regional decision-makers now have a benchmark for stewardship outcomes today and for future generations. Finally, this report can serve as a model for other Wisconsin river communities to emulate.

Links to this report and many of the resources listed at the end of this report are available on the Portage County website: http://www.co.portage.wi.us.

Originating in Portage County, the Tomorrow River flows 31 miles before it reaches the Waupaca County line. After another 32 miles, it joins the Wolf River at Fremont. Along the way, its name changes to "Waupaca." Depending on who is asked, this name change occurs either at the Portage-Waupaca county line or at the confluence with Bear Creek in Portage County.

Figure 2. Visitors to the Tomorrow River value its scenic beauty and fishery (contributed).

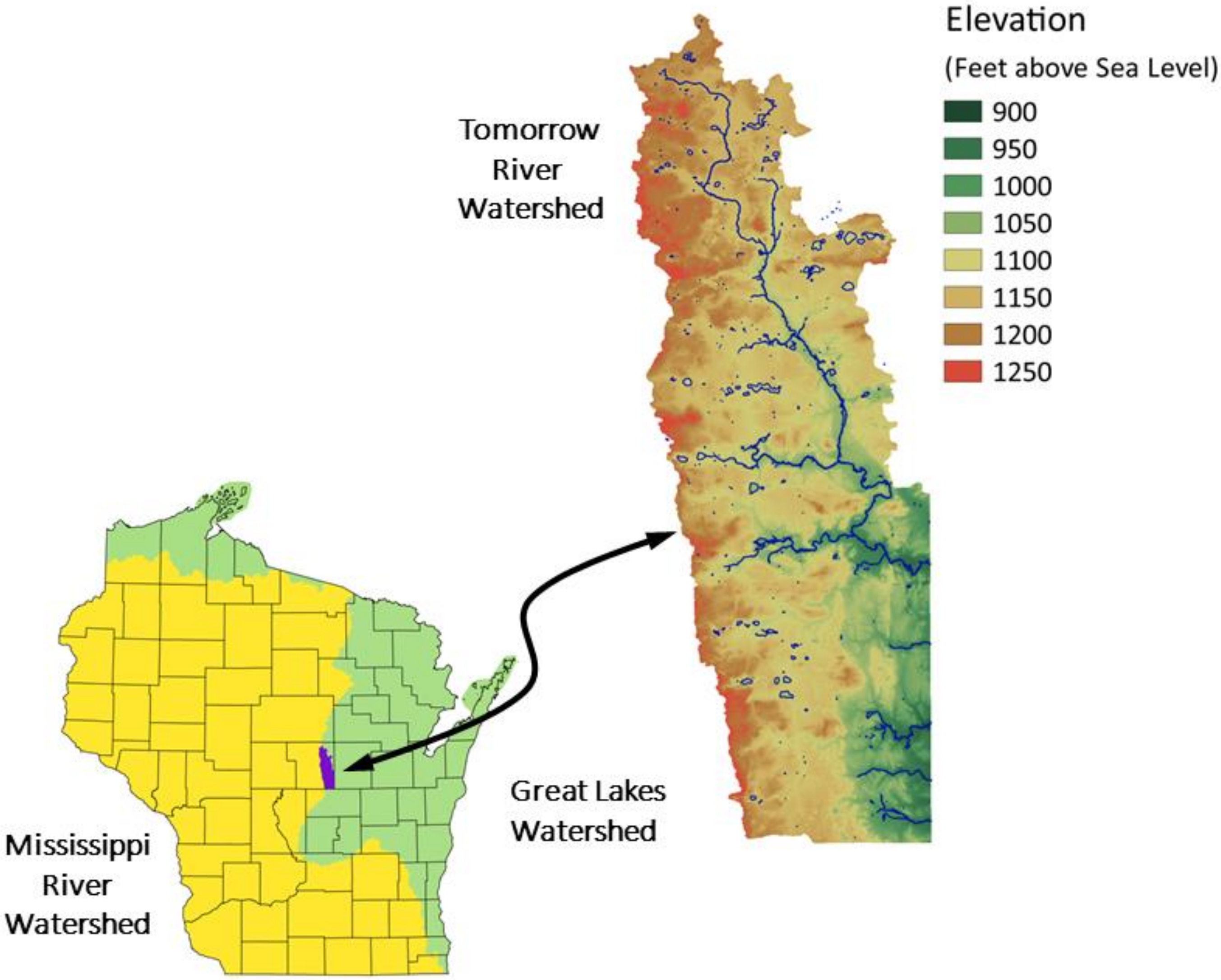


Figure 3. Tomorrow River watershed in Portage County, Wisconsin.

The Tomorrow River drops more than 200 feet as it makes its way through Portage County. Water in the Tomorrow River flows to the Wolf River and on to Lake Michigan, eventually making its way to the St. Lawrence Seaway and Atlantic Ocean.

Along the western edge of the Tomorrow watershed, a slight rise in the landscape marks a great divide where water falling west of the divide flows to the Wisconsin River and discharges to the Mississippi River and Gulf of Mexico.

THE PEOPLE OF THE TOMORROW RIVER

People have always been drawn to live near rivers. River corridors were the earliest “highways,” providing trading routes and locations for settlements. The earliest people who settled along the banks of the Tomorrow River found land that provided plentiful food and shelter. Later inhabitants used the river for hydropower to operate mills and generate electricity. Today, numerous public access points provide opportunities for people who are drawn to the river to paddle, view wildlife, hike, fish, and hunt.

The Earliest People

The first humans arrived in central Wisconsin around 14,500 years ago, likely migrating from the southeast while following retreating glaciers. They hunted caribou, Bison antiquus, and mammoths (Figure 4).

Food sources changed over time as the landscape changed. Around 8,500 years ago, open savanna-type woodlands interspersed with prairie became home to browsing animals such as elk and deer. Eventually, farming began to supplement hunting. Prehistoric corn hills found in Waupaca and Portage counties serve as evidence of the earliest farming activities. Early people built fairly large, permanent villages on area lakes and small seasonal campsites on sandy ridges overlooking marshes or streams where game would have been plentiful.

Figure 4. Hunting artifacts from Tomorrow River watershed (credit: Ray Reser).

Modern Communities

Today, the Tomorrow River watershed in Portage County is home to approximately 9,400 people who reside in 12 municipalites (Table 1). Each of the municipalities occupies at least part of the watershed. Nelsonville, Amherst Junction, and Amherst are the densest population centers.

Table 1. Local government jurisdictions in the Tomorrow River watershed, Portage County, Wisconsin.

Local Government Jurisdictions in the Tomorrow River Watershed in Portage County	
Towns	**Villages**
Alban	Amherst
Almond	Amherst Junction
Amherst	Nelsonville
Belmont	
Buena Vista	**County**
Lanark	Portage
New Hope	
Sharon	
Stockton	

Municipal governments affect the Tomorrow River through decisions regarding land use management, road maintenance and construction, runoff management, and in the case of the Village of Amherst, river flow management (Amherst Dam and Millpond). Such decisions can affect the river’s habitat and water quality which, in turn, affect the attractiveness of the river to its users and aquatic inhabitants.

Figure 5. Amherst Dam, 2018 (credit: UWSP).

Municipalities often own land on lakes and rivers, and decide how it is managed. Public lands make good sites for demonstration projects to inform and educate the public. These lands can also be used to provide public access to the Tomorrow River.

Town and village boards enjoy close relationships with their residents and can be highly effective in distributing information to shoreland property owners. It can be especially important to reach new residents.

Incorporating concerns for the river's health into municipal responsibilities can reap benefits for both the river and municipalities. While some municipalities are already incorporating river concerns into their local decision-making, coordination among municipalities can help achieve a greater good.

Figure 6. The Tomorrow River flows through the former site of the Nelsonville Dam (contributed).

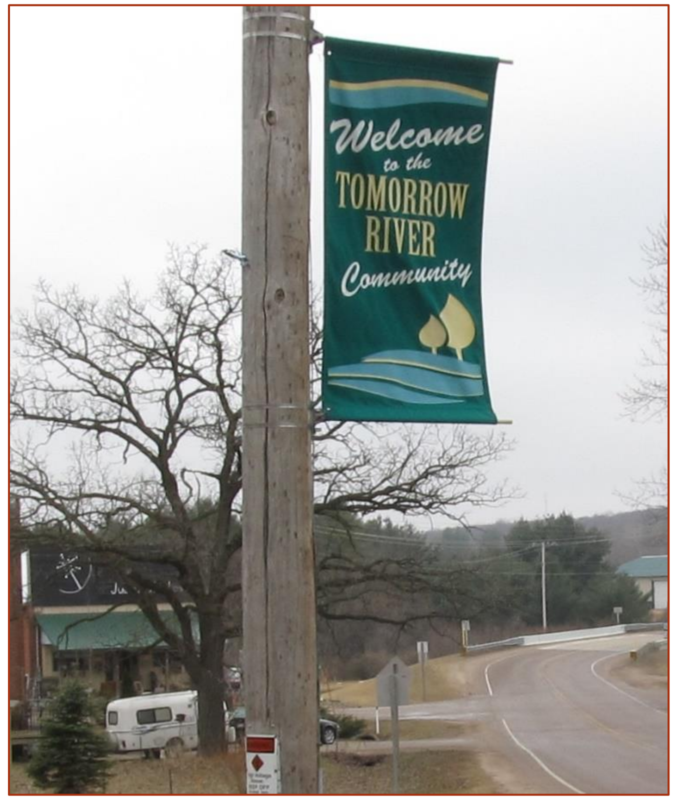


Figure 7. The Tomorrow River flows through the villages of Nelsonville (upper) and Amherst (lower) (credit: UWSP).

Volunteers

Individuals, businesses and groups are actively engaged in caring for the Tomorrow River watershed. Individuals participate in stream monitoring programs such as Water Action Volunteers (WAV). Lake groups, like the Rinehart Lake Association and Friends of Lake Emily, participate in the Citizen Lake Monitoring Network (CLMN). Both WAV and CLMN are programs administered by UW-Extension/WDNR.

The groups listed below focus on river stewardship activities and protecting groundwater.

Izaak Walton League
The Bill Cook Chapter of the Izaak Walton League has conducted stream habitat improvement projects in the Tomorrow River and Poncho Creek since the 1940s. While techniques have changed, the projects are typically designed to narrow the stream, providing deeper and cooler water for the fishery.

Friends of the Tomorrow/Waupaca River
Organized in 2004, Friends of the Tomorrow/Waupaca River (FOTWR) has focused on river advocacy and conservation-related activities, including river clean-ups, educational events, riverbank restoration, and creating and installing river protection signs.

Frank Hornberg Chapter of Trout Unlimited
Trout Unlimited has been active in stream restoration projects. Current activities include in-stream habitat improvements, community fly-tying and fly-fishing workshops, and assisting FOTWR with the annual river cleanup. In 1988, the WDNR removed the Nelsonville Dam and Trout Unlimited volunteers helped restore the river corridor with a narrow, deeper channel that helps provide cooler water for trout. Almost one mile of the Tomorrow River was restored to a Class I trout stream.

Farmers for Tomorrow Watershed Council
Formed in 2017, Farmers for Tomorrow Watershed Council members work to reduce nitrate entering the groundwater in the Tomorrow/Waupaca River watershed from farm fields and barnyards by educating themselves and their neighbors on agricultural best management practices.

Figure 8. Each year, Friends of the Tomorrow/Waupaca River, Trout Unlimited, and others join together to make stretches of the river passable and free of trash. Volunteers from Trout Unlimited and the Izaak Walton League have conducted a number of in-stream habitat improvement projects on the Tomorrow River and its tributaries. Most of the projects were intended to improve the habitat for trout, but the projects may also improve conditions for other aquatic biota (contributed).

In the 1940s, the Izaak Walton League began work in the Tomorrow River and Poncho Creek to improve habitat that was degraded by logging activities, sedimentation, and direct access by cattle.

Logging and farming activities left the river shallow and degraded.

The Izaak Walton League worked with the Wisconsin Conservation Department (now WDNR) to install fencing to prevent cattle access, and deflector logs and wing dams. They also reared and stocked fish.

Deflector logs and installing a wing dam. (Photos courtesy of Dan Kohler)

Today, their work continues as they focus on areas near Grayson Road and the Richard Hemp Fishery Area, and in Poncho Creek from County Highway D to its confluence with the Tomorrow River.

November to Remember

November
A somber,
Melancholy
Time…
With an exception:
Trout spawning
Over polished gravel
In a river
Appropriately named…
"Tomorrow."

November
A somber,
Melancholy
Time…
Except we know
We rehabilitated
A river…
Giving it,
And the trout,
A better tomorrow.

-- Dan Holland, 2017

THE LAND OF THE TOMORROW RIVER

The Tomorrow River watershed covers 120,000 acres in Portage County. About a third of the precipitation falling on the watershed eventually drains to the Tomorrow River, with the remainder leaving mostly by plant evapotranspiration. The soil, vegetation, topography, structures and land management all influence how the precipitation moves to the river. The undulating landscape formed 15,000 years ago by receding glaciers is continually being altered. Today, almost one-third of the watershed is covered by agriculture and urban/developed areas (Figure 9).

According to a 1995 WDNR report, the "greatest overall water quality threat in the watershed is excess nutrients, specifically nitrates, entering groundwater." The sandy soils of the Tomorrow River watershed allow precipitation to readily percolate into the ground, rendering the watershed sensitive to groundwater pollution.

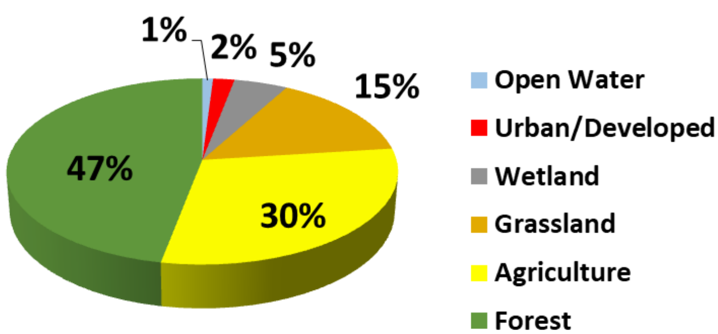


Figure 9. Land cover percentages in the Tomorrow River watershed in Portage County, Wisconsin, 2016.

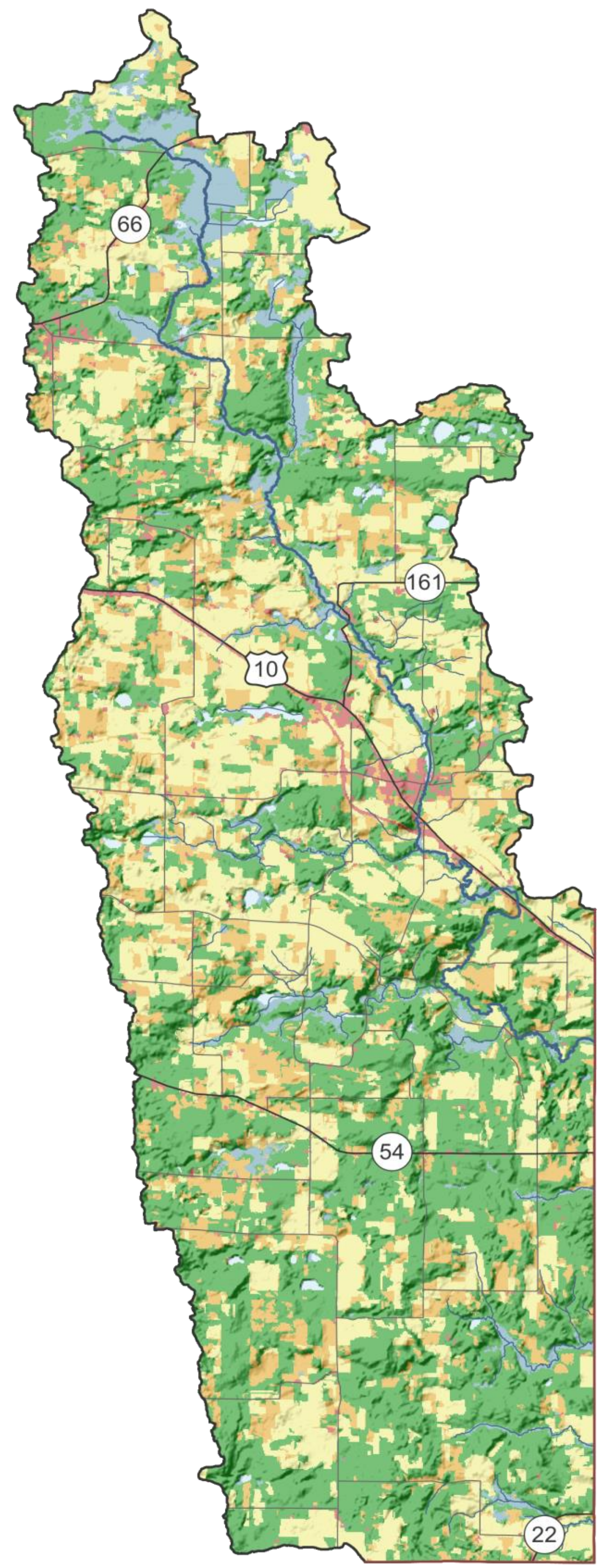


Figure 10. Land cover in the Tomorrow River watershed in Portage County, Wisconsin, 2016.

Franklin's Ground Squirrel (credit: T. Schultz)

Karner Blue Butterfly (credit: S. Apps)

Bina Flower Moth (credit: L. Ferge)

Persius Dusky Wing (credit: M. Reese)

Least Darter (credit: J. Lyons)

Blanchard's Cricket Frog (credit: A.B. Sheldon)

Wood Turtle (credit: A.B. Sheldon)

Sioux (Sand) Snaketail (credit: D. Paulson)

Figure 11. The Tomorrow River watershed is home to many animals. These are some of the rare species found in the Tomorrow River watershed, listed on the Wisconsin Natural Heritage Inventory.

Shorelands

Shorelands are important to the Tomorrow River. Shorelands in good condition can improve water quality in the river by filtering and reducing runoff, preventing erosion, and providing shade. Some aquatic organisms in the river rely on the shoreland for leaves and insects that fall into the river, and others use fallen woody material and overhanging vegetation for cover.

The stream corridor has a variety of habitats that are home to an array of aquatic and terrestrial plant and wildlife species. Some species make their homes exclusively in the water, such as trout and other fish, aquatic insects, and mussels. Others make their homes almost exclusively in uplands and use the stream corridor as a thoroughfare for migrating to up- and downstream habitats – deer, turkey, and bald eagles to name a few. In between are species that live their lives both in and out of the water, such as waterfowl, turtles, salamanders, mink, river otters, and kingfishers. The wider the healthy shorelands in the stream corridor, the better it is for water quality and wildlife connectivity.

Eroded or paved shorelands can be sources of phosphorus and sediment, as well as conduits for these pollutants to reach the river. Lawns or cultivated land at the water's edge may direct warm surface runoff directly into streams and reduce habitat for creatures that live at the water's edge.

Figure 12. River otter (credit: Shane Rucker).

Land Management

Land management directly influences how water moves to the Tomorrow River and the quality of that water. In 1993, the Tomorrow/Waupaca watershed was selected by the State of Wisconsin as a "Priority Watershed Project" and a plan to reduce the amount of nutrients entering the surface water and groundwater from agricultural land was developed (Figure 13). The plan was a cooperative effort between the Wisconsin Department of Natural Resources (WDNR), the Wisconsin Department of Agriculture, Trade and Consumer Protection (DATCP), UW-Extension, the Portage County Land Conservation Department, the Waupaca County Land and Water Conservation Department, and the Waushara County Land Conservation Department.

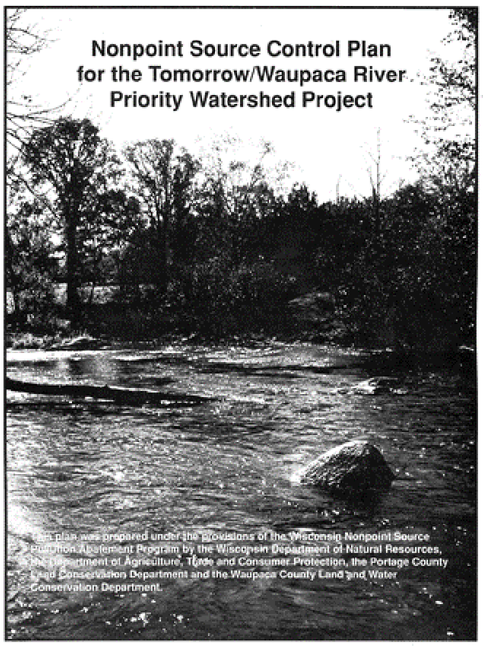


Figure 13. A plan to reduce the amount of nutrients entering the Tomorrow River was developed in the 1990s.

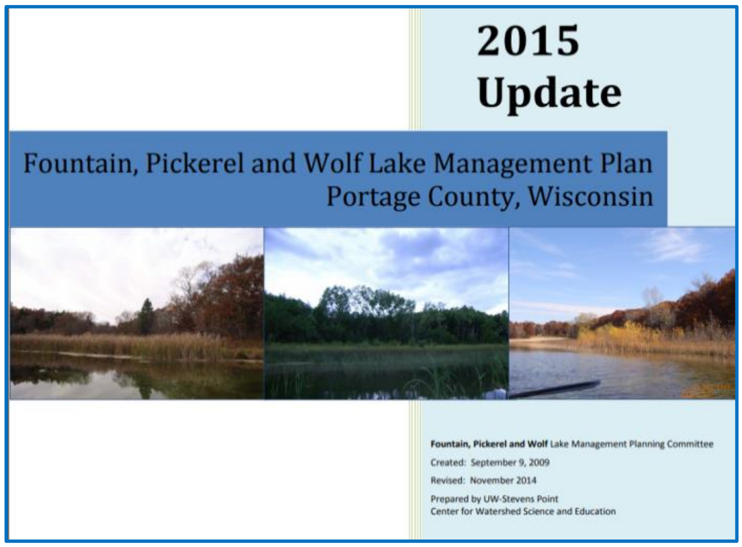
Over the next 20 years, Portage County staff worked with 70 landowners to voluntarily install 136 management practices to reduce their environmental impact. One example is a "complete containment" barnyard system to store manure and barnyard runoff (Figure 14). This system eliminates storage of manure on the ground, preventing barnyard runoff from moving directly into streams. Farmers can choose when to apply manure to their fields, avoiding times when the ground is frozen as spring runoff will later carry the manure directly into nearby surface waters.

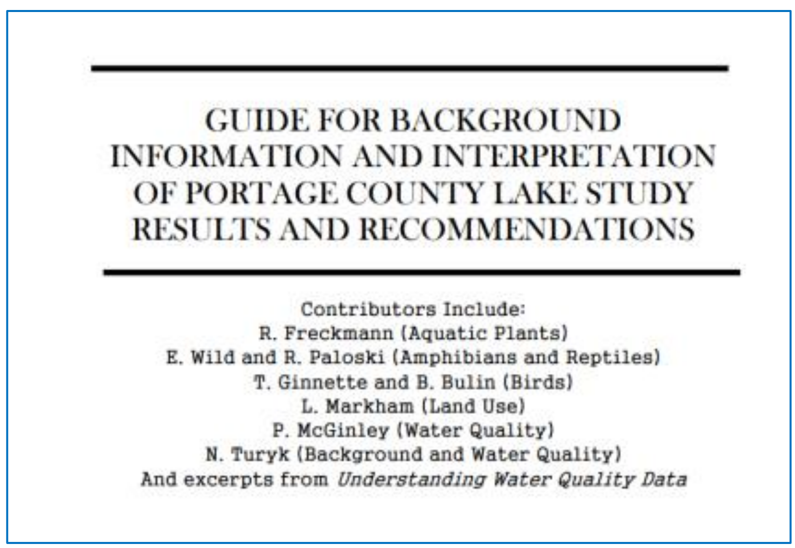
County staff also provided one-on-one nutrient management education to 55 farmers cropping 17,700 acres. These efforts aimed to identify opportunities specific to each farm to reduce nitrogen application on cropland and encourage the implementation of other practices to reduce runoff and groundwater pollution.

Figure 14. Elements of a containment system include the barnyard shown under construction (upper) and the storage pit (lower) (credit: Portage County).

Land management was also a focus of the Portage County Lakes Study, which has been an ongoing collaboration between Portage County, the WDNR, Portage County citizens and UW-Stevens Point. This study evaluated many of the lakes in the Tomorrow River watershed during several years of monitoring and study, and then facilitated the development of management plans for the lakes. Many of those plans were updated in 2015 (Figure 15).

Lakes in the Tomorrow River Watershed in the Portage County Lakes Study
Adams Lake
Amherst Millpond
Bear Lake
Boelter Lake
Collins Lake
Ebert Lake
Fountain Lake
Lake Emily
Lake Thomas
Lime Lake
Onland Lake
Pickerel Lake
Skunk Lake
Spring Lake
Sunset Lake
Wolf Lake
https://www.co.portage.wi.us/department/planning-zoning/land-and-water-conservation/lakes-study




GUIDE FOR BACKGROUND INFORMATION AND INTERPRETATION OF PORTAGE COUNTY LAKE STUDY RESULTS AND RECOMMENDATIONS

Contributors Include:
R. Freckmann (Aquatic Plants)
E. Wild and R. Paloski (Amphibians and Reptiles)
T. Ginnette and B. Bulin (Birds)
L. Markham (Land Use)
P. McGinley (Water Quality)
N. Turyk (Background and Water Quality)
And excerpts from *Understanding Water Quality Data*

Figure 15. Lake reports and management plans were developed for some of the lakes in the Tomorrow River watershed. Those reports are available on the Portage County website: https://www.co.portage.wi.us/department/planning-zoning/land-and-water-conservation/lakes-study

THE WATER OF THE TOMORROW RIVER

Groundwater

Most of the water in the Tomorrow River is groundwater. Groundwater originates as the precipitation that percolates past plant roots and then moves slowly through the watershed from areas of higher elevation to areas of lower elevation. Almost one-third of the precipitation that falls on the Tomorrow River watershed becomes groundwater (most of the other two-thirds is used by plants).

Figure 16 shows water table elevations and directions that groundwater flows. Groundwater in central Wisconsin is typically 50°F. The permeable sandy soils result in a relatively high groundwater contribution to the Tomorrow River, which results in its classification as a coldwater stream.

The river increases in size as it moves downstream. What starts as a flow of less than a few cubic feet per second (cfs) where it crosses Highway 66 becomes almost 30 cfs at Clementson Road and more than 100 cfs by the time it leaves Portage County.

The time it takes for the precipitation that becomes groundwater to enter the Tomorrow River varies. Precipitation that falls near the river may take only days to reach the river. Precipitation that falls near the edge of the watershed may take more than 50 years to reach the river.

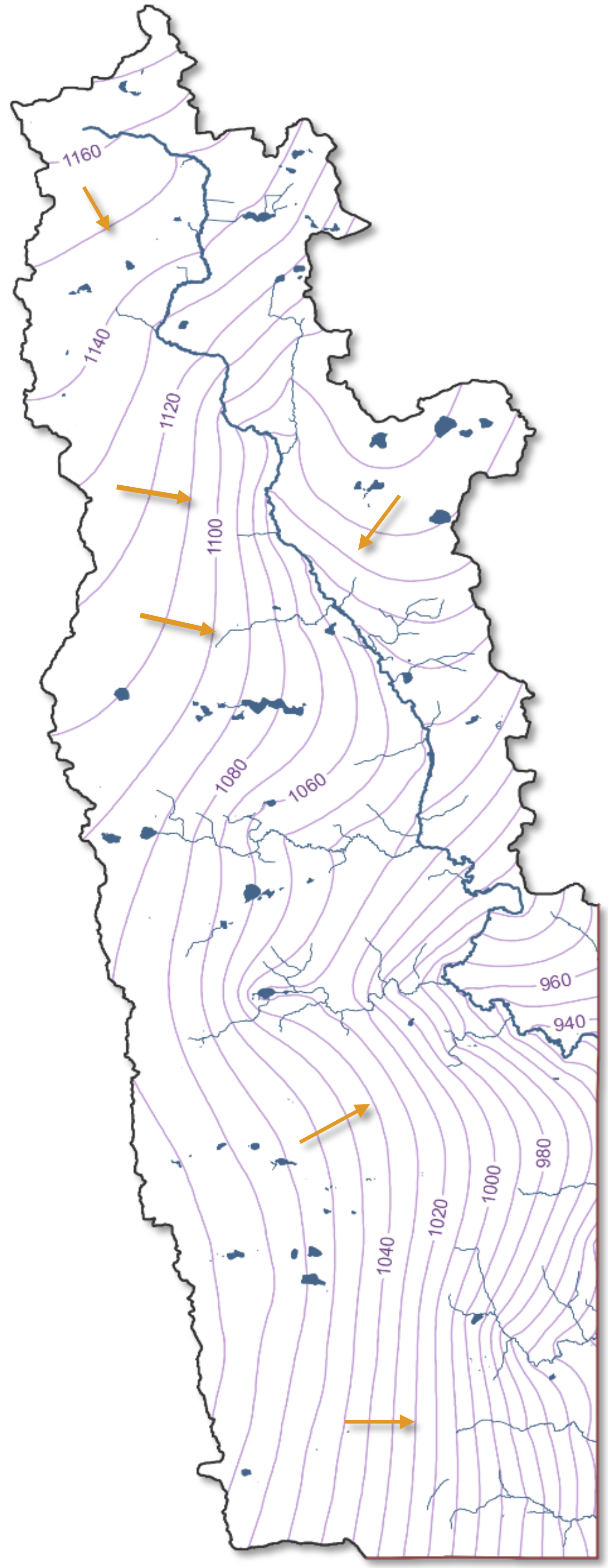


Figure 16. Water table elevations (number of feet above sea level) and examples of groundwater flow directions (yellow arrows).

Groundwater provides drinking water for all the residents of the watershed. It is also used for commercial and industrial activity, and is accessed for agriculture by approximately one hundred high capacity wells.

When groundwater is not returned to where it was pumped, groundwater levels are lowered. Scientific studies show water use for agricultural irrigation lowers groundwater levels. Figure 18 shows how the water table in the Tomorrow River watershed is lowered by pumping from high capacity wells.

Because groundwater is the primary source of water for the Tomorrow River and its tributaries, less groundwater means less streamflow. A recent study of the groundwater in the watershed calculated that streamflow in the Tomorrow River is reduced 3% to 13% by high capacity well pumping, depending on location. That study projected that an increase in irrigated land (from the current 9% of the total land to 38%) could reduce flow in the Tomorrow River 9-28%, depending on location. Tributaries to the river originate in areas that will experience greater water table reductions, so their streamflow reductions will be larger and drying in the headwaters is likely to become more common.

Figure 17. A stretch of Stoltenburg Creek downstream of Five Corners Road that was dry during the summer of 2014 (credit: UWSP).

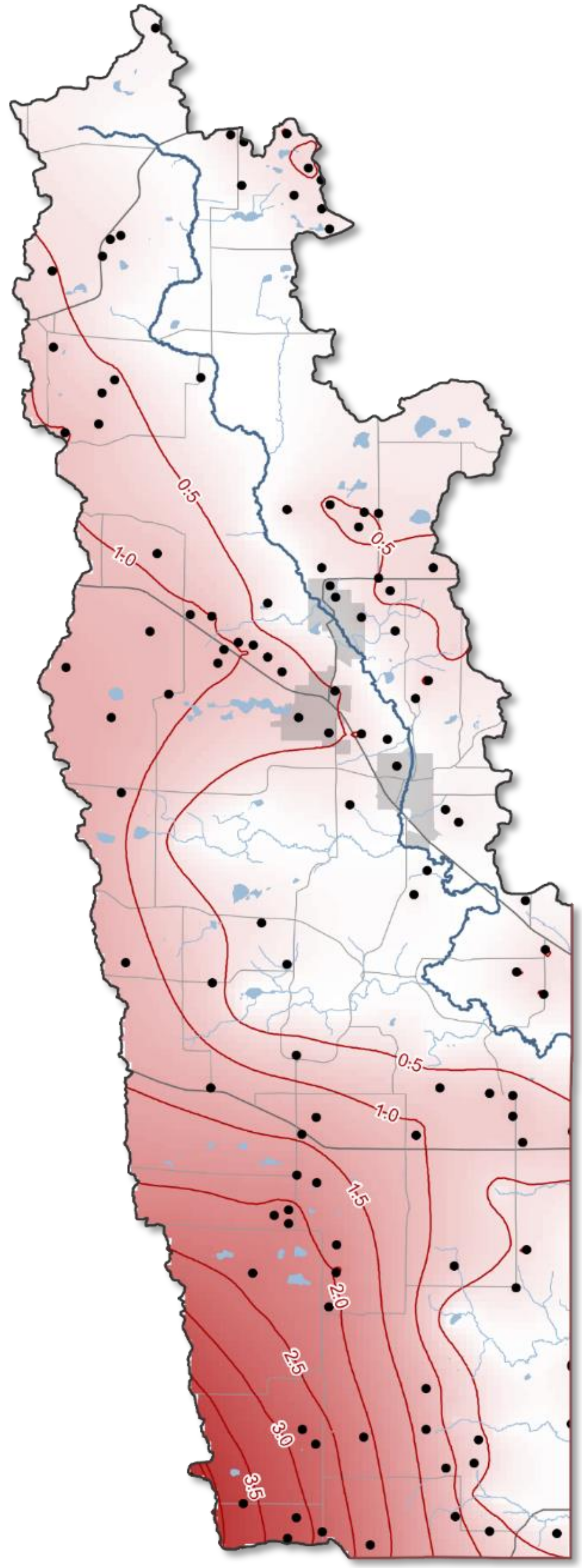


Figure 18. High capacity wells (black markers) and water table drawdowns due to pumping, 1999-2008. Greater drawdowns are displayed with darker pink shading, with maximum drawdowns of 3 feet in the southwestern corner.

Streams and Lakes

The Tomorrow River watershed (Figure 20) includes numerous surface water bodies in addition to the Tomorrow River. These streams and lakes, along with wetlands, occupy the low spots in the watershed where the ground surface dips below the groundwater level. They receive water that originates as groundwater or as surface runoff, which then flows through them as it moves downstream and out of Portage County.

Tributaries of the Tomorrow River include streams that drain directly to the river within Portage County (such as Poncho Creek, Stoltenburg Creek, Bear Creek and Spring Creek), and streams that eventually enter the river further downstream in Waupaca County (such as Emmons Creek, Murry Creek and Radley Creek). These and the other tributaries flow from areas of higher to lower groundwater elevation and gain flow as they get closer to the Tomorrow River. These are groundwater-dominated streams that provide habitat for coldwater fish, such as the trout that are so important to many users of the Tomorrow River.

Figure 19. Groundwater-fed streams provide coldwater habitat for this brown trout (Bear Creek at Highway Q, 2018) (credit: UWSP).

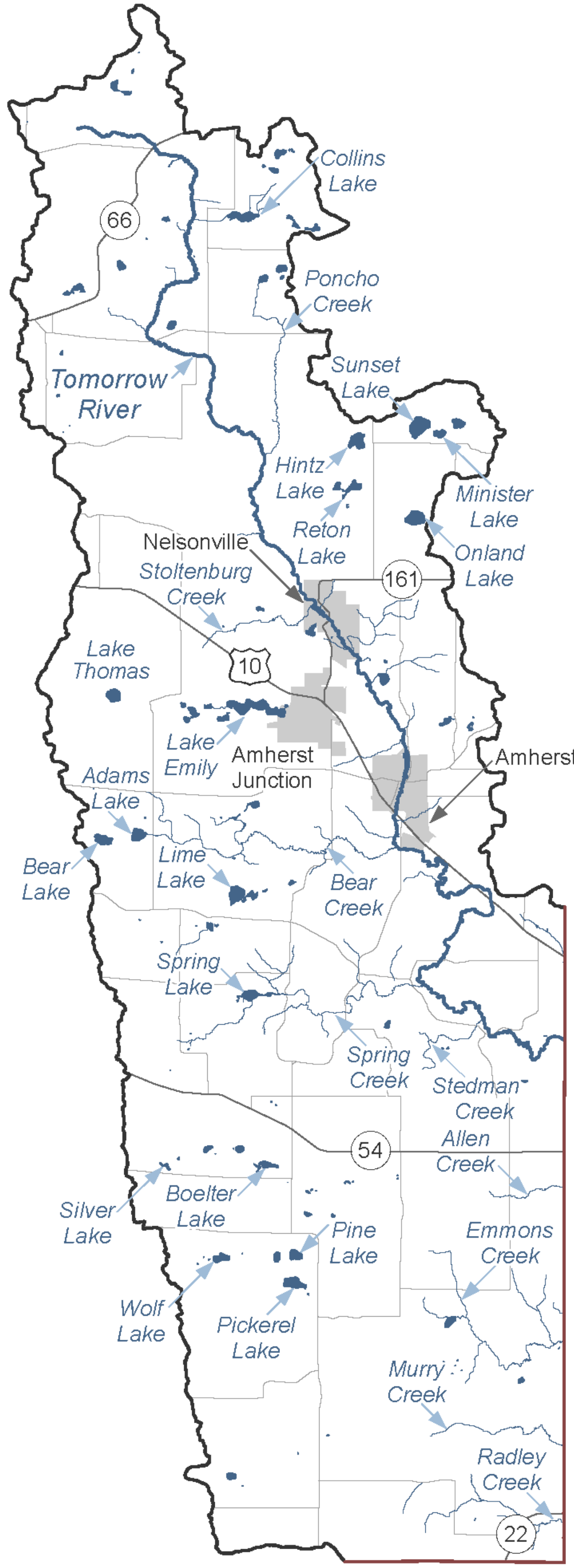


Figure 20. Tomorrow River watershed, Portage County, Wisconsin.

Figure 21. Because the groundwater temperature is approximately 50°F, it leads to open water in the Tomorrow River during the winter (contributed).

There are 25 lakes greater than 10 acres in size in the Tomorrow River watershed in Portage County. Many of these lakes are referred to as seepage lakes because groundwater enters through the side of the lakes. The seepage lakes are found where glacially-created depressions extend below the current groundwater level. As groundwater flows towards the Tomorrow River, it also enters and flows through these lakes.

Figure 22. Sunset Lake is a seepage lake in the Tomorrow River watershed (credit: UWSP).

Because the water level in a seepage lake reflects the groundwater level, lower groundwater levels lead to lower lake levels. Lakes in areas with the greatest groundwater reductions (Figure 18) had the largest reductions in water level several years ago (Figure 23, Figure 24).

Figure 23. Lower lake level viewed at the County beach at Wolf Lake, c. 2014 (credit: UWSP).

Figure 24. The boat landing at Pickerel Lake did not reach the water in 2014 (credit: UWSP).

Other types of lakes in the watershed have streams that leave the lake ("groundwater drainage lakes"), or both enter and leave the lake ("drainage lakes"). These lakes are influenced by how the streams above them change and the lakes will influence the streams below them. Three lakes have dams that create wider areas of water behind them. The three dams in the Tomorrow River watershed are at Amherst Millpond on the Tomorrow River in Amherst, on Fountain Lake at the headwaters of Emmons Creek, and Palmers Pond in Spring Creek before it joins the Tomorrow River.

Water Quality

Water quality describes how the chemical, physical and biological characteristics of the water measure up to requirements or needs. In the Tomorrow River and its watershed, water is needed for drinking, agriculture, industry and commercial activity – and it is essential to the biological communities that inhabit the river, lakes and wetlands. This report focuses on four water quality measures: nitrate, pesticides, phosphorus and temperature.

Nitrate

A 1995 WDNR report on the Tomorrow River stated the "greatest overall water quality threat in the watershed is excess nutrients, specifically nitrates, entering groundwater." Nitrate is a mobile form of nitrogen that moves readily from soil into the groundwater. At high concentrations it is a surface water pollutant that can excessively fuel the growth of algae and plants, and a drinking water pollutant that can cause health effects in humans and animals. Consuming water with high nitrate reduces the blood's ability to deliver oxygen. In infants, this can lead to a condition called methemoglobinemia or "blue baby syndrome." There is also research that suggests high concentrations of nitrate may cause birth defects, thyroid problems and some cancers.

The Tomorrow River carries more than 700,000 pounds of nitrogen dissolved in its waters out of Portage County every year.

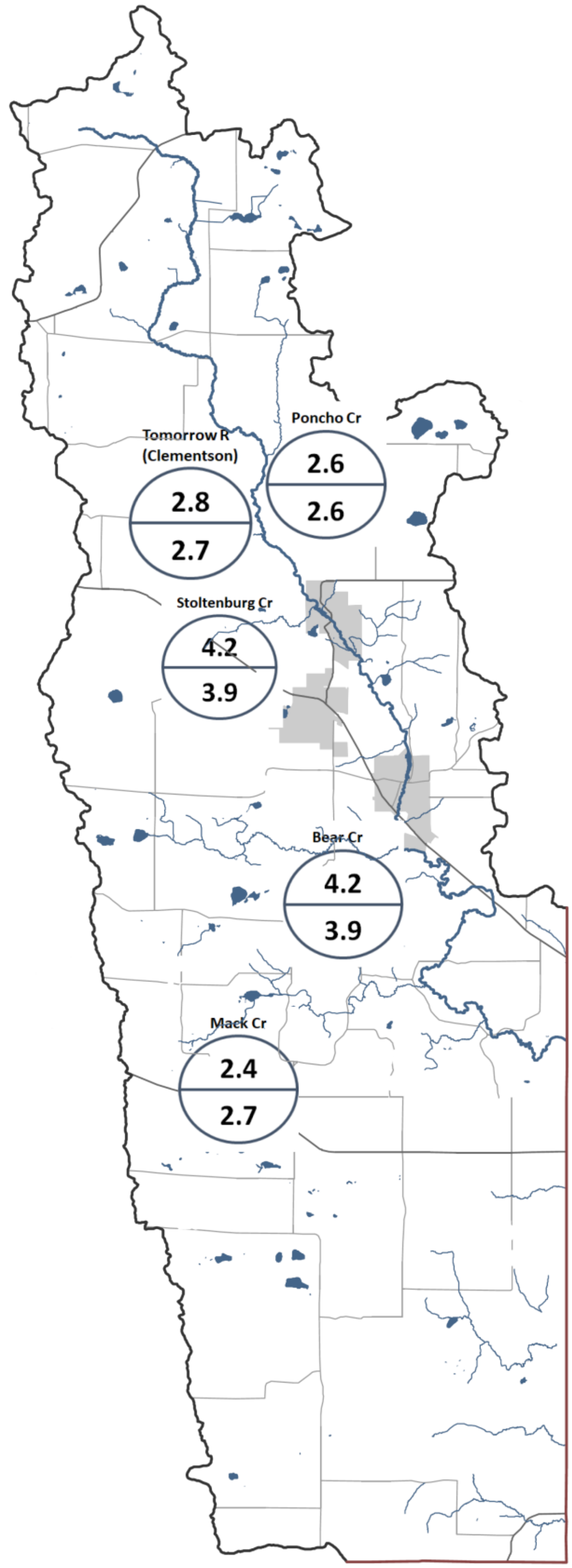


Figure 25. Stream nitrate concentrations in 2016 (upper number) and in 1994-1999 (lower number). All concentrations are in ppm N. 2016 samples were collected during the growing season while 1990s samples were collected during low flow in winter and summer.

Nitrate from fertilizer, manure, septic systems, and natural sources can be lost to percolating water and enter the groundwater. Nitrate in the Tomorrow River is above background concentrations, reflecting the movement of nitrate from the land surface to groundwater and into the river. Nitrate concentrations in the watershed's residential wells range from less than 0.1 to 45.8 ppm, and 16% of sampled locales exceed the nitrate standard of 10 ppm as nitrate nitrogen.

Nitrate remains a water quality challenge in the Tomorrow River watershed even after decades of implementing land management practices designed to reduce nitrate concentrations. Figure 25 shows that stream nitrate concentrations changed little between the late 1990s and today. To some extent this is a reflection of how difficult it is to significantly reduce nitrogen loss to groundwater, but in addition, increases in fertilizer and manure nitrogen applied to land in some places have likely offset reduced nitrogen loading to groundwater in others.

Pesticides

Pesticides used in the Tomorrow River watershed include herbicides, insecticides and fungicides. Pesticide data for the Tomorrow River watershed are sparse except for atrazine. Wisconsin surveys (DATCP, 2017) indicate 42% of Wisconsin wells contain at least one pesticide or pesticide degradation product, with detections being greater in more highly agricultural areas. The most common pesticide degradation products in Wisconsin groundwater are those of atrazine (23% of Wisconsin wells), alachlor (about 22% of Wisconsin wells), acetochlor (7% of Wisconsin wells), and metolachlor (about 32% of Wisconsin wells). Where found, pesticide and pesticide degradation products rarely exceed groundwater standards; however, detections of atrazine residues in concentrations exceeding groundwater standards have led to the prohibition of atrazine use in several areas of the Tomorrow River watershed (Figure 26).

The extent to which pesticides impact aquatic life in the Tomorrow River remains unknown. Studies have suggested that even low concentrations of atrazine can affect amphibian health. It is also important to evaluate the mixture of pesticide residues to understand how pesticides impact biological activity in streams.

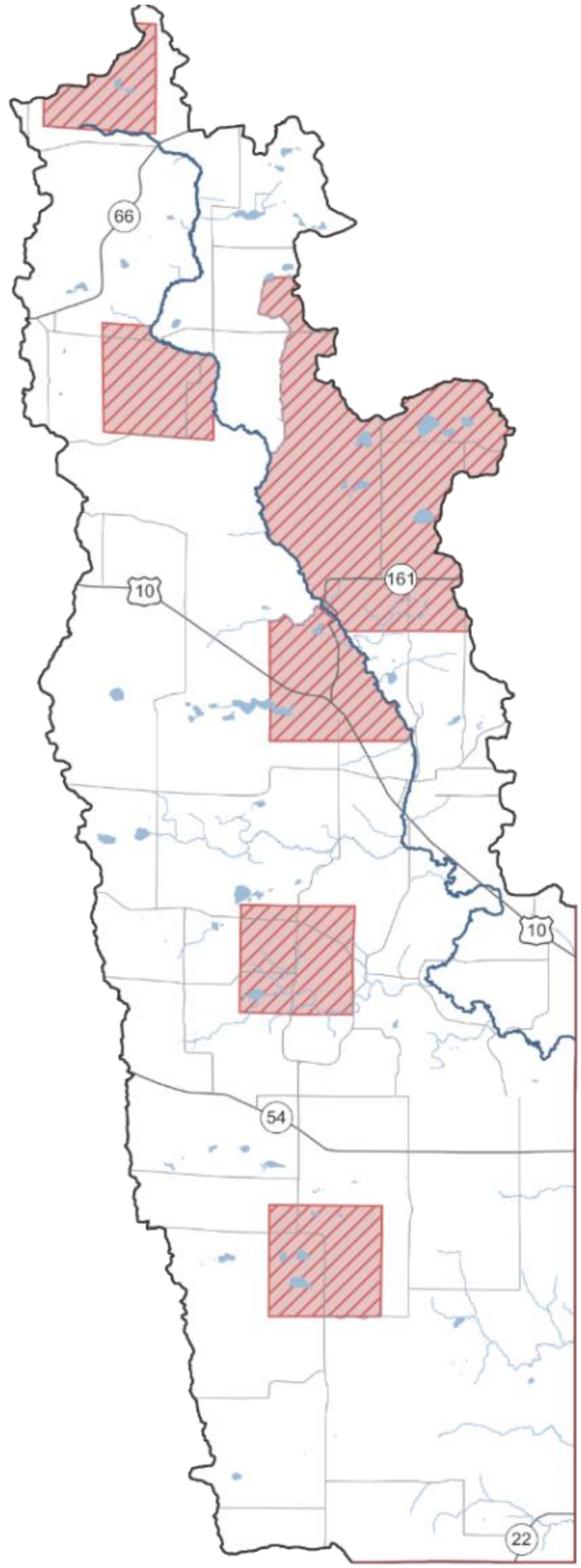


Figure 26. Atrazine prohibition areas (pink shading).

Another important challenge to understanding how pesticides impact the Tomorrow River is that the pesticides that are used change over time. For example, a recent study in central Wisconsin found several neonicotinoid insecticides in groundwater. The use of these insecticides has increased in the last decade.

Phosphorus

Phosphorus is the element most closely tied to algal growth in lakes and streams. Phosphorus is required for aquatic life, but too much phosphorus creates excessive algae and plant growth that degrades habitats and aesthetics, and depletes dissolved oxygen as it decomposes.

Phosphorus in soil, plants, fertilizer and manure moves to streams in surface runoff that carries sediment, organic matter and dissolved phosphate. Phosphorus is much less likely to be carried in groundwater because it can be held by reactions within the soil. The Tomorrow River watershed generates little surface runoff and has high groundwater flow because of its permeable soils. As a result, most of the streams in the watershed have phosphorus concentrations below 75 ppb (the standard for streams), and most of the lakes in the watershed have concentrations below 20-40 ppb (the standards for lakes vary by lake type).

Figure 27 summarizes phosphorus monitoring in streams in the Tomorrow River watershed in 2016. WDNR uses a statistical evaluation of a series of measurements to determine if a stream or lake should be added to the Impaired Waters List (303d). Based on that analysis, Mack Creek was proposed to be added to this list in 2016 for phosphorus. Stoltenburg Creek also had high phosphorus concentrations and will continue to be evaluated to determine if it should be added to the Impaired Waters List.

Mack Creek discharges to Spring Lake, which has high nutrient concentrations and exceeds Wisconsin's phosphorus standard for this type of lake. Two other lakes in the watershed, Collins Lake and Wolf Lake, are also considered impaired due to high phosphorus levels.

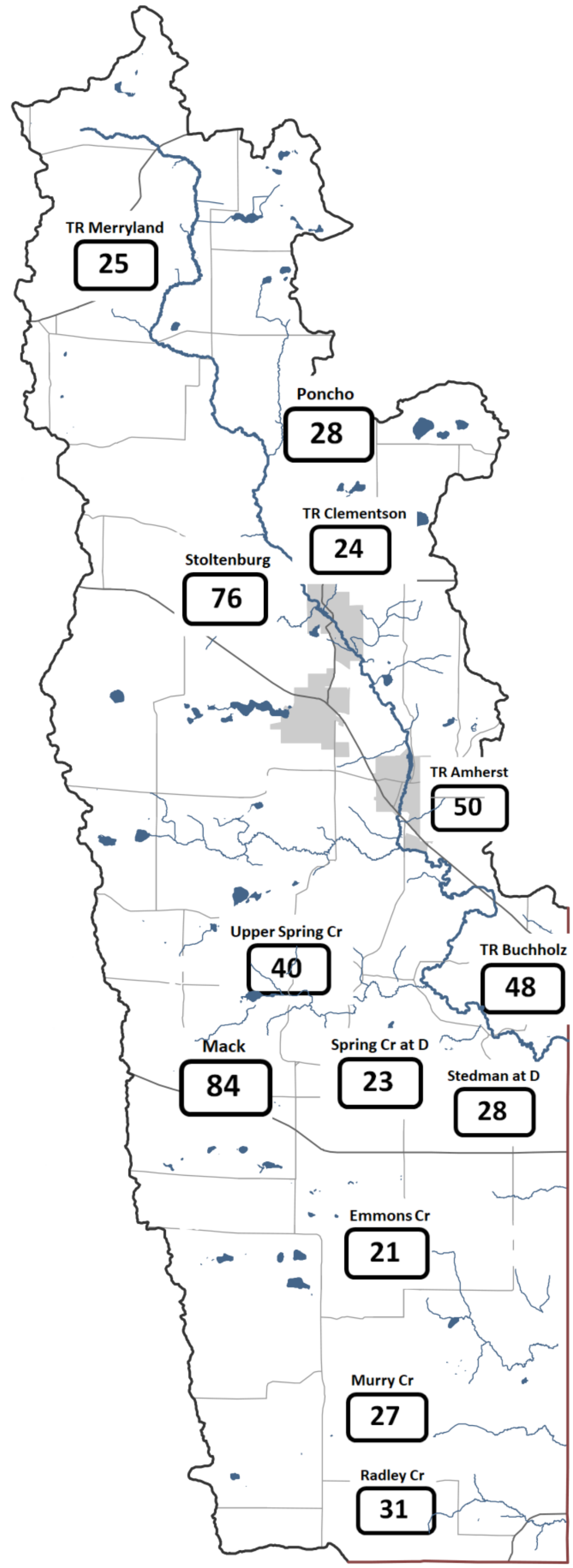


Figure 27. Total phosphorus concentrations in 2016 in the Tomorrow River and its tributaries (shown as the median of six measurements collected between May and September).

When high phosphorus concentrations are combined with sunlight and enough time, greater amounts of algae and plants are produced. Figure 28 and Figure 30 show highly visible algae and plant growth in the Amherst Millpond and Spring Lake. The effects of high concentrations of phosphorus and nitrogen in other parts of the Tomorrow River may be less conspicuous because shading and water movement reduce visible algae suspended in the water and attached to rocks (Figure 29); however, research studies have shown that high nitrogen and phosphorus concentrations increase attached algae growth and reduce habitat quality in streams.

Figure 28. Slow-moving water and longer residence time promote algae accumulation (Amherst Millpond, 2018 (credit: UWSP).

Figure 29. Shade and fast-moving water help limit algal growth in the Tomorrow River (Clementson Road, 2018) (credit: UWSP).

Figure 30. Accumulations of filamentous algae and plants in Spring Lake (upper photo) and the Amherst Millpond (lower photo). (credit: UWSP).

Temperature

The water temperature in the Tomorrow River is perhaps the major water quality factor limiting the river's coldwater ecosystem and fishery. Temperature directly influences an organism's metabolism, respiration, growth and reproduction. It also indirectly affects organisms by influencing the rate of biological reactions and the amount of oxygen available (cold water can "hold" more dissolved oxygen than warm water).

Stream temperature is influenced by many factors, but groundwater in central Wisconsin is typically 50°F, so its input is key to keeping stream temperatures cooler in summer. Trout have optimal summer temperature ranges of around 52 – 61°F (brook trout) and 54 – 66°F (brown trout), and are unable to tolerate temperatures above 75°F for extended periods.

Detailed summer temperature surveys (June through September) conducted by WDNR fisheries biologists provide a picture of temperature conditions in the Tomorrow River. Monitors continuously recorded temperatures at 12 locations on the mainstem of the river in 1998, and at 12 locations on the mainstem plus 7 locations on tributaries in 2016 (Figure 31).

Temperatures are displayed in Figure 32 as the daily average minimums and average maximums for the 1998 study period. The surveys revealed that the uppermost reaches, from the Tomorrow River's source to about County Road I (sites 1-3), had summer temperatures sufficiently warm to limit trout. Middle reaches (sites 4-7), from about County Road I to the Amherst impoundment, had near-optimal temperatures for trout. Temperatures warmed considerably starting at the Amherst Dam and Millpond (probes 8-12), where average daily minimum temperatures were warmer than optimal for brook trout and average daily maximums were above optimal for either brook or brown trout.

Brook trout were absent below the dam and brown trout numbers below the dam were one-third of those observed above the dam (Figure 33).

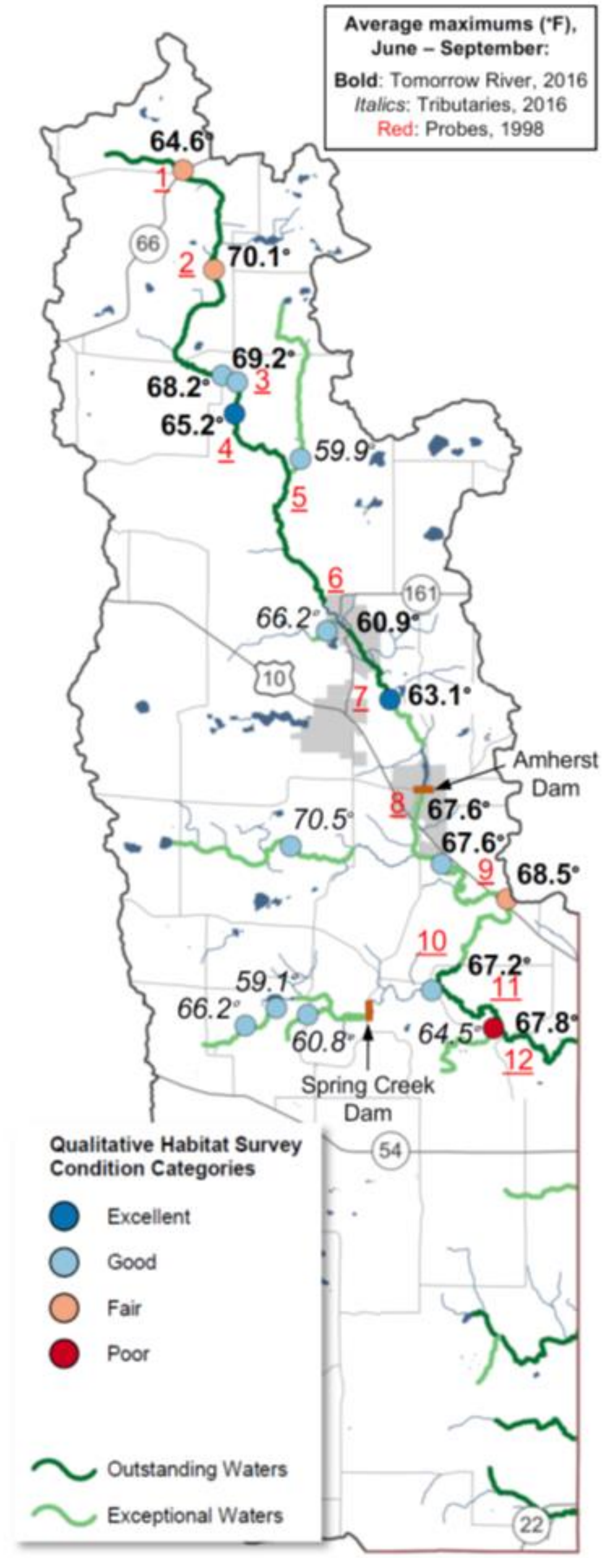


Figure 31. Average daily maximum temperatures in the mainstem of the Tomorrow River (bold) and its tributaries (italic) for summer 2016, locations of temperature probes for 1998 study, and Qualitative Habitat Survey results.

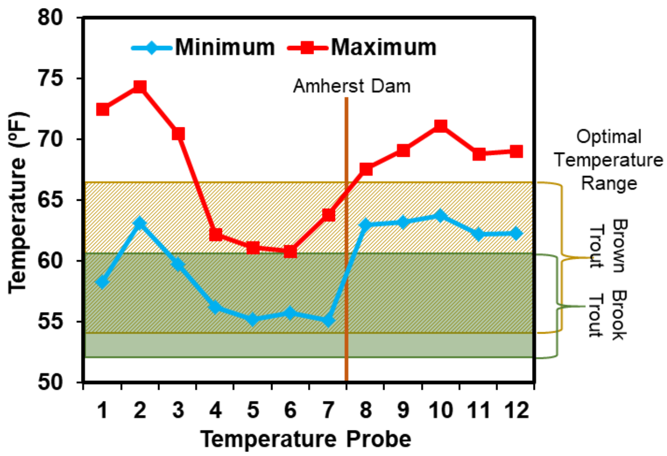


Figure 32. Tomorrow River average minimum and maximum temperatures, June-Sept 1998 with trout optimal temperatures.

Additional temperature data gathered by WDNR staff from 2007 through 2012 found summer water temperatures were warmer than the brook trout optimum 48% of the time above the Amherst impoundment and 92% of the time below the dam.

Summer 2016 tributary temperatures indicated Poncho, Stoltenburg, Mack, Spring, and Stedman Creeks had cool (59 – 66°F) maximum observed temperatures, while Bear Creek was warm (70.5°F). The Wisconsin Impaired Water List (303d) for elevated water temperatures include Bear Creek, the Tomorrow River between Highways 66 and 161, and the Tomorrow River from the Amherst Millpond into Waupaca County.

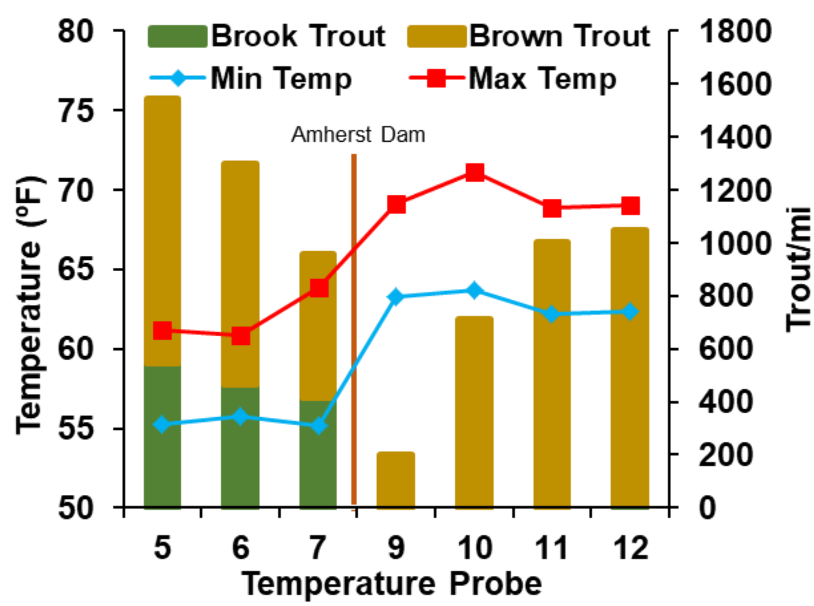


Figure 33. Tomorrow River daily average minimum and maximum temperatures for June-Sept 1998 and trout abundance. Note temperatures produced at the Amherst Dam persist downstream and the concurrent disappearance of brook trout and reduction in brown trout.

THE FISHERY OF THE TOMORROW RIVER

The Tomorrow River is a popular trout stream, but a number of other fish species also call it home. The upper reaches of the Tomorrow River and its tributaries are often dominated by coldwater trout and mottled sculpin along with white suckers. As the river increases in size and warms downstream, more minnows, darters, and even other gamefish are found. A total of 26 species with varying temperature preferences and tolerance levels were found in the Tomorrow River in Portage County during WDNR surveys in 2016 (Table 2). That same year, a species of special concern, the Redside Dace, was found in a tributary of the river (Figure 34).

Figure 34. Redside Dace, Wisconsin Special Concern Species, collected in Bear Creek, 2016 (credit: D. Bolha).

Table 2. Fish species found in the Portage County reaches of the Tomorrow River, 2016.

Species	Temperature	Tolerance	Native
Brook Trout	Cold	Sensitive	Yes
Brown Trout	Cold	Intermediate	No
Mottled Sculpin	Cold	Sensitive	Yes
Rainbow Trout	Cold	Intermediate	No
Brook Stickleback	Cool	Intermediate	Yes
Lamprey	Cool	Sensitive	Yes
Redbelly Dace	Cool	Intermediate	Yes
Blacknose Dace	Cool-Warm	Tolerant	Yes
Blacknose Shiner	Cool-Warm	Sensitive	Yes
Central Mudminnow	Cool-Warm	Tolerant	Yes
Central Stoneroller	Cool-Warm	Intermediate	Yes
Common Shiner	Cool-Warm	Intermediate	Yes
Creek Chub	Cool-Warm	Tolerant	Yes
Hornyhead Chub	Cool-Warm	Intermediate	Yes
Johnny Darter	Cool-Warm	Intermediate	Yes
Largescale Stoneroller	Cool-Warm	Intermediate	Yes
Longnose Dace	Cool-Warm	Intermediate	Yes
Northern Hog Sucker	Cool-Warm	Sensitive	Yes
Northern Pike	Cool-Warm	Intermediate	Yes
Rainbow Darter	Cool-Warm	Sensitive	Yes
Smallmouth Bass	Cool-Warm	Sensitive	Yes
Walleye	Cool-Warm	Intermediate	Yes
White Sucker	Cool-Warm	Tolerant	Yes
Black Bullhead	Warm	Intermediate	Yes
Bluegill	Warm	Intermediate	Yes
Green Sunfish	Warm	Tolerant	Yes
Source: WDNR, 2016 surveys			

Aquatic Habitat

Fish in the Tomorrow River depend on the river's aquatic habitat characteristics, which include streamflow, water temperature, dissolved and suspended constituents, and physical structure (Figure 35). Together, they determine how organisms in the river feed, grow, and reproduce, and ultimately whether they thrive or are absent.

Native fish and invertebrates are adapted to seasonal flow patterns. Flow rates influence the channel, depth, velocity, water temperature, oxygen, substrates, and aquatic plants. Streamflow carries food to organisms and forces organisms to use energy to move or simply stay in place. Both groundwater quantity and land management influence streamflow in the Tomorrow River.

Physical structure, such as streambed material (sand, gravel, muck, etc.), woody matter, plants, and undercut banks are important to spawning, foraging, resting, and finding cover from predators. In 2016, WDNR staff used the "Qualitative Habitat Survey" tool to evaluate physical habitat. They found good to excellent habitat at most sites, although several sites were evaluated as fair, and Stedman Creek was evaluated as poor (Figure 31).

(contributed)

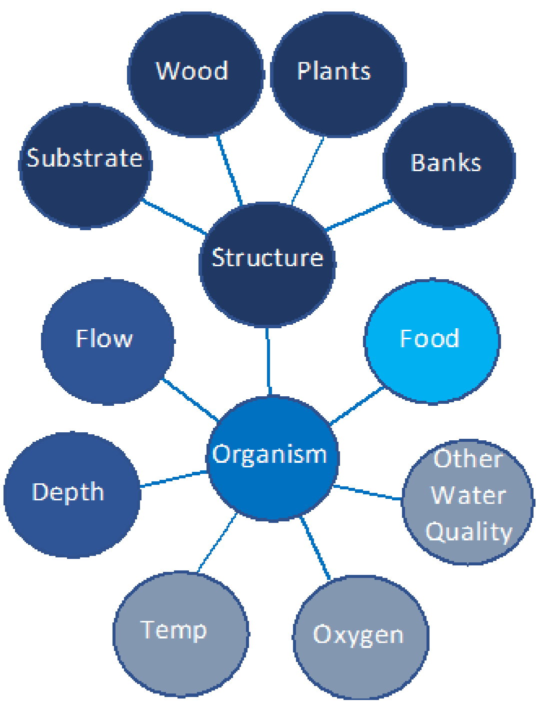


Figure 35. Characteristics of aquatic in-stream habitat that influence an organism.

Figure 36. The Tomorrow River and its tributaries provide variations in aquatic habitat characteristics (Spring Creek at Highway D, summer 2018 (credit: UWSP).

Brook and brown trout are top predators, feeding on other fish along with aquatic and terrestrial invertebrates. They use cover such as undercut banks, fallen and overhanging trees, and boulders to rest, feed, and avoid predators. Deep, cool, slow-moving pools are prime locations for larger adults, while young often can be found near riffles, aquatic plants, and other cover. Both trout species construct their spawning "redds" in fall to early winter, burying eggs with small gravel and sand. The eggs incubate all winter, hatching in early spring.

Brook trout are native to Wisconsin. They are sensitive and require cold, clean water with high oxygen levels. They seek out groundwater inflow areas for spawning. Brown trout were introduced into Wisconsin from Europe. They grow larger, are more aggressive, and can tolerate slightly warmer water and lower oxygen levels than brook trout.

The tributaries and mainstem of the Tomorrow River are categorized by WDNR as Class I trout water (all natural reproduction) above Lake Meyers Road, Class II (natural reproduction supplemented with stocking) between Lake Meyers Road to about Spring Creek, and then Class I to the Waupaca County line. No stocking is done in the Class II waters between Lake Meyers Road and the Amherst impoundment because reproduction has been deemed adequate.

Figure 37. Brook trout (upper photo) and brown trout (lower photo).

Trout Survey Results

WDNR surveys indicate abundance for both trout has increased or remained stable over the last two decades in the Tomorrow River (Figure 39). Noticeable increases include brook trout in the upstream portion of the Richard Hemp Fishery Area and brown trout near Nelsonville and Amherst.

In 2016, brook trout abundance was high (top 30% of Wisconsin streams) in the upstream portion of the Richard Hemp Fishery Area and in Poncho Creek, the only locations where they outnumbered brown trout. Brook trout abundance was moderate in the downstream portion of the Richard Hemp Fishery Area and near Nelsonville, with very few or no individuals near Amherst and in Bear and Spring Creeks (Figure 38, Figure 39). In 2016, brown trout abundance was high (top 30% of Wisconsin streams) near Nelsonville and in Spring Creek. Brown trout abundance was at least moderate at all others sites except Poncho Creek (bottom 40%).

Brown trout appear to be outcompeting brook trout at most sites, although downstream sites may not be suitable for the more sensitive brook trout.

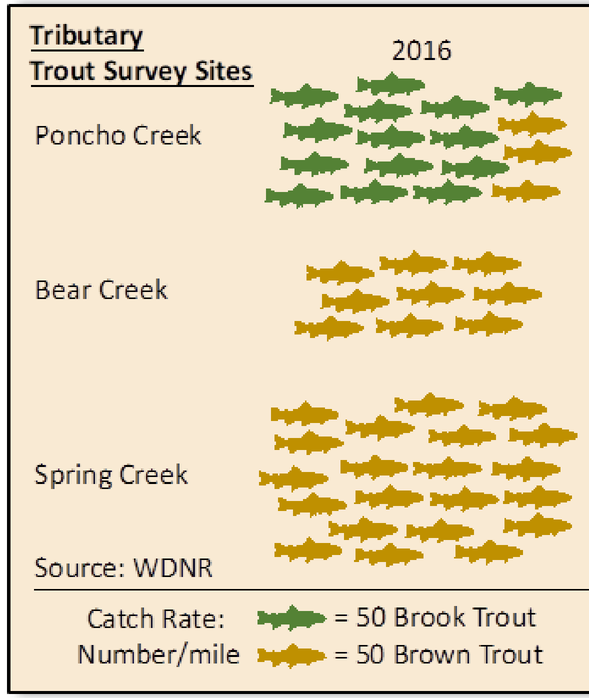


Figure 38. Trout survey catch rate in Tomorrow River tributaries (number/mile), 2016.

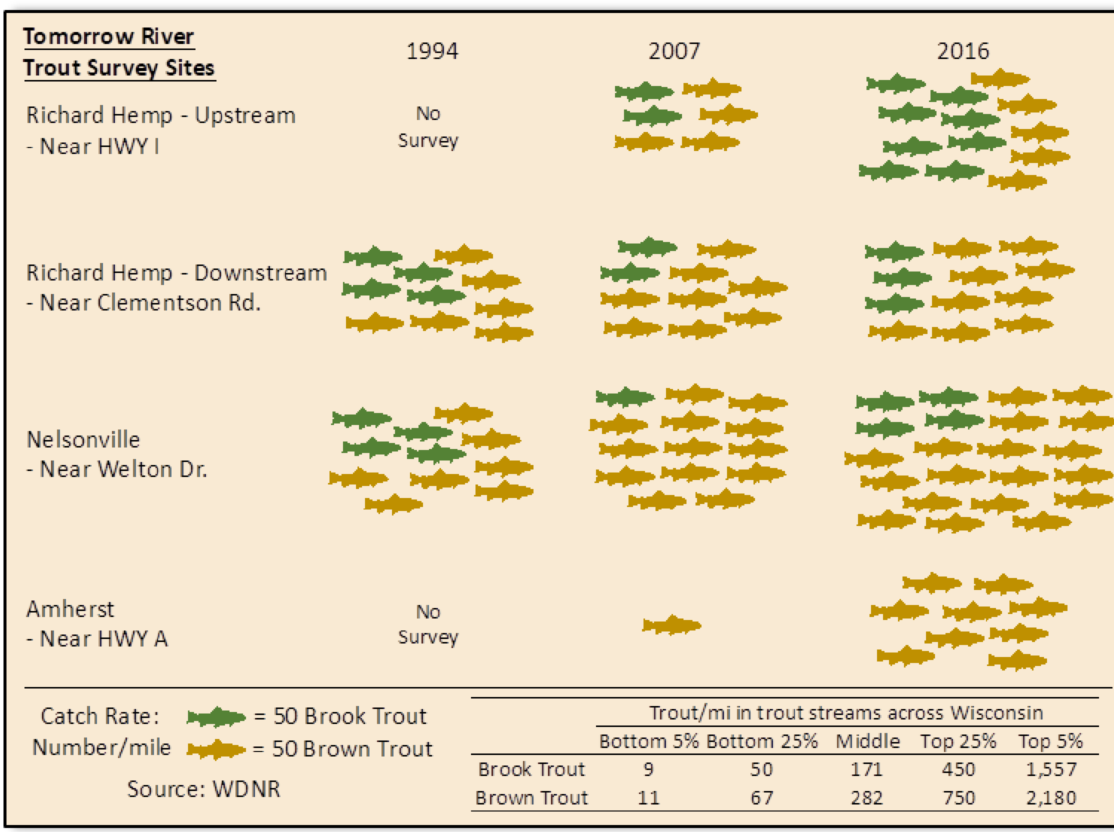


Figure 39. Trout survey catch rate in the Tomorrow River (number/mile) by year.

THE FUTURE OF THE TOMORROW RIVER

Those who live in the Tomorrow River watershed as well as other local citizens and leaders are the vanguard in protecting and preserving the Tomorrow River for future generations.

This report connects the Tomorrow River watershed and the river, and emphasizes the importance of dialogue, education and collaboration in maintaining and improving the river's health. Citizens and leaders can undertake actions and make decisions that will protect the river's headwaters, improve buffer zones for shorelines, lower nutrient and pollutant loads, and monitor changes in temperature, chemistry, water levels, streamflow and the fishery.

Collecting water quality data on a consistent basis will be important in guiding future watershed decisions. Temperature, nutrients, and pollutants should be included in any monitoring strategy. More studies are needed to determine causes of stream warming in the river's upper stretches and tributaries, as well as high phosphorus concentrations in the tributaries. Monitoring the Amherst Millpond's channel depth and its effect on temperature and phosphorus levels would help determine the Millpond's impact on the river and its fishery.

Public and private citizens, including the business community, can coordinate their efforts to improve and protect the watershed. The local Izaak Walton League and Trout Unlimited organizations continue to protect the river's shoreline and in-stream habitat in their work with the WDNR. Coordination between county, city, village and town governments in the watershed will also benefit the river's health.

The Priority Watershed Program provides a template for how government and land owners can work together. Additional collaborative work is needed to develop and implement land management practices that will reduce nitrate concentrations in surface waters and drinking water. Collaborations are also needed to manage the use of groundwater for agriculture so that it does not negatively impact streamflow.

The Tomorrow River is an integrated system of land, groundwater, and surface waters. The citizens of Portage County are fortunate to have this world-class coldwater stream in our backyard. The mission remains for all of us to work together towards a better tomorrow for the Tomorrow River.

REFERENCES AND RESOURCES

THE PEOPLE OF THE TOMORROW RIVER

The Earliest People	Reser, R. P. A Brief Overview of Early Native American Occupation in Waupaca, Marathon and Portage Counties, Wisconsin: A report submitted to the Planning and Zoning Committee, New Hope Town Board (see Appendix A).
Volunteers	Bill Cook Chapter of the Izaak Walton League: https://www.iwla.org/billcook Kohler, D. 2008. History of the Bill Cook Chapter Izaak Walton League Stream Improvement (see Appendix B). Friends of the Tomorrow/Waupaca River: https://www.wisconsinrivers.org/watersheds/friends-tomorrow-waupaca-river/ Frank Hornberg Chapter of Trout Unlimited: https://hornberg-tu.org/

THE LAND OF THE TOMORROW RIVER

Shorelands	*Interactive web-mapping including watershed boundaries*: WDNR Surface Water Data Viewer https://dnr.wi.gov/topic/SurfaceWater/swdv/ https://dnr.wi.gov/topic/nhi/ (*Natural Heritage Inventory*) *USDA information on stream corridors:* https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1043460.pdf *WDNR information on shoreland buffers:* https://dnr.wi.gov/topic/ShorelandZoning/Research/ShorelandBuffers.html
Land Management	*Portage County Land and Water Resource Management Plan* prepared by the Portage County Planning and Zoning Department Land Conservation Division. Revised December 2014. *Tomorrow/Waupaca River Priority Watershed Project:* Tomorrow/Waupaca River Priority Watershed Project Study Design for Project Development. Final Draft August 1994; and, Nonpoint Source Control Plan for the Tomorrow/Waupaca River Priority Watershed Project. Approved October 1995. WDNR Publication WR-434-95. *Portage County Lakes Project Reports are accessed at:* https://www.co.portage.wi.us/department/planning-zoning/land-and-water-conservation/lakes-study *UW-Extension publications* on water quality and land management: http://clean-water.uwex.edu/pubs/

THE WATER OF THE TOMORROW RIVER

Groundwater	*Studies on groundwater in central Wisconsin:* Kraft, G.J., K. Clancy, D.J. Mechenich, and J. Haucke. 2012. Irrigation Effects in the Northern Lake States: Wisconsin Central Sands Revisited. Ground Water Journal 50 (2):308-318. Kraft, G.J., Mechenich, D.J., Haucke, J. 2012. Information Support for Groundwater Management in the Wisconsin Central Sands, 2009-2011. Project completion report to the Wisconsin Department of Natural Resources. *Study on the impact of well pumping on streamflow in the Tomorrow River:* Mechenich, D.J., Kraft, G.J., Haucke, J. 2014. Assessing the Impacts of Future Irrigation Development – A Demonstration in the Tomorrow-Waupaca River Headwaters Area. Appendix B in Kraft, G.J., Mechenich, D.J., Haucke, J. “Information Support for Groundwater Management in the Wisconsin Central Sands, 2011-2013” Report to the WDNR. *WDNR resources related to high capacity wells:* https://dnr.wi.gov/topic/Wells/HighCap/
Streams and Lakes	*Evaluating impacts of flow reduction on streams (Minnesota DNR):* https://files.dnr.state.mn.us/waters/gwmp/thresholds/gw-thresholds-project_report.pdf *Interactive webmapping and access to data for chemical and biological monitoring*: WDNR Surface Water Data Viewer https://dnr.wi.gov/topic/SurfaceWater/swdv/ *Early review of Tomorrow River lakes and streams:* Fassbender, R.L. and L.M. Nelson. 1971. Surface water resources of Portage County. WDNR. *WDNR Watershed Summaries include:* Wisconsin DNR, 2011. Waupaca River Watershed 2011 Water Quality Management Plan Update *Before and after evaluation of the Tomorrow River Priority Watershed Project:* Wisconsin DNR, 1995. Tomorrow/Waupaca River Priority Watershed Surface Water Resources Appraisal Report prepared by Jim Klosiewski. Bolha, D. 2017. Priority Watershed Water Quality Evaluation for the Tomorrow-Waupaca River Watershed, Portage and Waupaca County, Wisconsin. WDNR. *Portage County Lakes Study includes individual reports describing the assessment and management plans for Collins Lake, Adams Lake, Amherst Millpond, Bear Lake, Boelter Lake, Collins Lake, Fountain Lake, Ebert Lake, Lake Emily, Lime Lake, Onland Lake, Pickerel Lake, Skunk Lake, Spring Lake, Sunset Lake, Lake Thomas and Wolf Lake:* https://www.co.portage.wi.us/department/planning-zoning/land-and-water-conservation/lakes-study *Resources related to the Amherst Millpond:* Amherst Millpond Management Plan (2015 Update), Portage County, Wisconsin. UW-Stevens Point Center for Watershed Science and Education. Amherst Millpond from Portage County Lake Study Final Report June 2007: https://www.co.portage.wi.us/department/planning-zoning/land-and-water-conservation/lakes-study/Amherst-Mill-Pond https://dnr.wi.gov/topic/Dams/DamsOverview.html https://www.fema.gov/media-library-data/20130726-1849-25045-6913/02_hydrosafetydam_ch_2_4.pdf

Summary of Private Well Testing in Portage County: Portage County Well Water Quality Project, https://www.co.portage.wi.us/department/planning-zoning/portage-county-well-water-quality-project

Interactive mapping of summarized private well water quality: https://www.uwsp.edu/cnr-ap/watershed/Pages/wellwaterviewer.aspx

Information from the Wisconsin Department of Health Services on Nitrate in Private Wells is available at: https://www.dhs.wisconsin.gov/water/nitrate.htm

Research from the 1990s that included Tomorrow River monitoring: Cook, R. 2000. Relationships between Private Well Water, Stream Base Flow Water, and Land Use in the Tomorrow-Waupaca River Watershed. University of Wisconsin-Stevens Point Thesis.

Research report on the Tomorrow River including groundwater and stream nitrate: Guldan, N.M. 2004. Relationships between Groundwater Recharge Dates, Nitrate Levels, and Denitrification in a Central Wisconsin Watershed. University of Wisconsin-Stevens Point Thesis.

Groundwater travel time to the Tomorrow River: Tesoriero, A.J., Duff, J.H., Saad, D.A., Spahr, N.E., Wolock, D.M. 2013. Vulnerability of streams to legacy nitrate sources. Environmental Science and Technology 47:3623-3629 (*USGS study*)

Water Quality

Impacts of nutrients (nitrogen and phosphorus) on streams:
Robertson, D.M., Graczyk, D.J., Garrison, P.J., Wang, L., LaLiberte, G., Bannerman, R. 2006. Nutrient concentrations and their relations to the biotic integrity of wadeable streams in Wisconsin. USGS Professional Paper 1722.

Munn, M.D., Frey, J.W., Tesoriero, A.J., Black, R.W., Duff, J.H., Lee, Kathy, Maret, T.R., Mebane, C.A., Waite, I.R., and Zelt, R.B., 2018, Understanding the influence of nutrients on stream ecosystems in agricultural landscapes: U.S. Geological Survey Circular 1437, 80 p., https://doi.org/10.3133/cir1437.

Occurrence of neonicotinoid insecticides in central Wisconsin groundwater:
Huseth, A.S., Groves, R.L. 2014. Environmental fate of soil applied neonicotinoid insecticides in an irrigated potato agroecosystem. PLoS ONE 9(5): e97081. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0097081.

Relationship between seepage lake water quality and land management: McGinley, P.M. 2008. Modeling the Influence of Land Use on Groundwater Chloride Loading to Lakes. Lake and Reservoir Management 24:112-121.

Resources on phosphorus and temperature impairment listings for lakes and streams: WDNR Surface Water Data Viewer: https://dnr.wi.gov/topic/SurfaceWater/swdv/

Impaired waters list (303d): https://dnr.wi.gov/topic/ImpairedWaters/

Methods for assessing surface water quality (WisCALM): https://dnr.wi.gov/topic/SurfaceWater/assessments.html

THE FISHERY OF THE TOMORROW RIVER

Wisconsin Trout Stream Maps: https://dnr.wi.gov/topic/fishing/trout/streammaps.html

Physical habitat evaluation: Bolha, D. 2017. Priority Watershed Water Quality Evaluation for the Tomorrow-Waupaca River Watershed, Portage and Waupaca County, Wisconsin. WDNR.

Research on trout habitat: Hunt, R.L. 1979. Removal of woody streambank vegetation to improve trout habitat. Tech. Bull. 115. WDNR.

GLOSSARY

Algae:
One-celled (phytoplankton) or multicellular plants either suspended in water (plankton) or attached to rocks and other substrates (periphyton). Their abundance, as measured by the amount of chlorophyll a (green pigment) in an open water sample, is commonly used to classify the trophic status of a lake. Numerous species occur. Algae are an essential part of the lake ecosystem and provide the food base for most lake organisms, including fish. Phytoplankton populations vary widely from day to day, as life cycles are short.

Alkalinity:
A measure of the amounts of carbonates, bicarbonates, and hydroxide present in water. Low alkalinity is the main indicator of susceptibility to acid rain. Increasing alkalinity is often related to increased algae productivity. Expressed as milligrams per liter (mg/L) of calcium carbonate ($CaCO_3$), or as microequivalents per liter (ueq/l). 20 ueq/l = 1 mg/L of $CaCO_3$.

Ammonia, Ammonium:
A form of nitrogen found in organic materials and many fertilizers. It is the first form of nitrogen released when organic matter decays. It can be used by most aquatic plants and is therefore an important nutrient. It converts rapidly to nitrate (NO_3) if oxygen is present. The conversion rate is related to water temperature. Ammonia is toxic to fish at relatively low concentrations in pH-neutral or alkaline water. Under acid conditions, nontoxic ammonium ions (NH_4^+) form, but at high pH values the toxic ammonium hydroxide (NH_4OH) occurs. The water quality standard for fish and aquatic life is 0.02 mg/L of NH_4OH. At a pH of 7 and a temperature of 68^{o}F (20^{o}C), the ratio of ammonium ions to ammonium hydroxide is 250:1; at pH 8, the ratio is 26:1.

Atrazine:
The nation's most widely used weed killer for both grassy and broadleaf weeds.

Blue-Green Algae:
Algae that are often associated with problem blooms in lakes. Some produce chemicals toxic to other organisms, including humans. They often form floating scum as they die. Many can fix nitrogen (N_2) from the air to provide their own nutrient.

Chloride (Cl-):
Chlorine in the chloride ion (Cl^-) form has very different properties from chlorine gas (Cl_2), which is used for disinfecting. The chloride ion (Cl^-) in lake water is commonly considered an indicator of human activity. Agricultural chemicals, human and animal wastes, and road salt are the major sources of chloride in lake water.

Chlorophyll *a*:
Green pigment present in all plant life and necessary for photosynthesis. The amount present in lake water depends on the amount of algae and is therefore used as a common indicator of water quality.

Color:
Measured in color units that relate to a standard. A yellow-brown natural color is associated with lakes or rivers receiving wetland drainage. The average color value for Wisconsin lakes is 39 units, with the color of state lakes ranging from zero to 320 units. Color also affects light penetration and therefore the depth at which plants can grow.

Concentration Units:
Express the amount of a chemical dissolved in water. The most common ways chemical data is expressed is in milligrams per liter (mg/L) and micrograms per liter (ug/L). One milligram per liter is equal to one part per million (ppm). To convert micrograms per liter (ug/L) to milligrams per liter (mg/L), divide by 1000 (e.g. 30 ug/l = 0.03 mg/L). To convert milligrams per liter (mg/L) to micrograms per liter (ug/L), multiply by 1000 (e.g. 0.5 mg/L = 500 ug/L). Microequivalents per liter (ueq/L) is also sometimes used, especially for alkalinity; it is calculated by dividing the weight of the compound by 1000 and then dividing that number into the mg/L.

Drainage Basin:
The total land area that drains toward the lake.

Drainage Lakes:
Lakes fed primarily by streams and with outlets into streams or rivers. They are more subject to surface runoff problems but generally have shorter retention times than seepage lakes. Watershed protection is usually needed to manage lake water quality.

Endocrine:
An integrated system of small organs that involve the release of extracellular signaling molecules known as hormones. The endocrine system is instrumental in regulating metabolism, growth, development and puberty, tissue function, and also plays a part in determining mood.

Erosion:
The lowering of the land surface by weathering, corrosion, and transportation, under the influence of gravity, wind, and running water.

Eutrophic:
Eutrophic lakes are high in nutrients and support a large biomass (all the plants and animals living in a lake). They are usually either weedy or subject to frequent algae blooms, or both. Eutrophic lakes often support large fish populations but are also susceptible to oxygen depletion. Small, shallow, eutrophic lakes are especially vulnerable to winterkill which can reduce the number and variety of fish. Rough fish are commonly found in eutrophic lakes.

Eutrophication:
The process by which lakes and streams are enriched by nutrients, and the resulting increase in plants and algae. The extent to which this process has occurred is reflected in a lake's trophic classification: oligotrophic (nutrient poor), mesotrophic (moderately productive), and eutrophic (very productive and fertile).

Groundwater:
Water found below the land surface in pore spaces between soil particles or in cracks in rock. It moves slowly from higher to lower areas on the landscape and may provide water to a lake.

Groundwater Drainage Lake:
Often referred to a spring-fed lake, has large amounts of groundwater as its source, and a surface outlet. Areas of high groundwater inflow may be visible as springs or sand boils. Groundwater drainage lakes often have intermediate retention times with water quality dependent on groundwater quality.

Impoundment:
Manmade lake or reservoir usually characterized by stream inflow and always by a stream outlet. Because of nutrient and soil loss from upstream land use practices, impoundments ordinarily have higher nutrient concentrations and faster sedimentation rates than natural lakes. Their retention times are relatively short.

Mesotrophic:
Mesotrophic lakes lie between the oligotrophic and eutrophic trophic stages. In late summer, they lose oxygen at depth, limiting coldwater fish and causing phosphorus release from sediments.

mg/L:
see “Concentration units”

Nitrate (NO_3^-):
An inorganic form of nitrogen important for plant growth. Nitrogen is in this stable form when oxygen is present. Nitrate often contaminates groundwater when water originates from manure pits, fertilized fields, lawns or septic systems. High levels of nitrate-nitrogen (over 10 mg/L) are dangerous to infants and expectant mothers. A concentration of nitrate-nitrogen (NO_3-N) plus ammonium-nitrogen (NH_4-N) of 0.3 mg/L in spring will support summer algae blooms if enough phosphorus is present.

Nitrite (NO_2-):
A form of nitrogen that rapidly converts to nitrate (NO_3-) and is usually included in the NO_3- analysis.

Nitrogen:
A chemical element that is an essential plant nutrient and may occur in the form of nitrate, nitrite, ammonium, or organic nitrogen in lakes.

Oligotrophic:
A trophic state in which lakes are generally clear, deep and free of weeds or large algae blooms. Though beautiful, they are low in nutrients and do not support large fish populations. However, oligotrophic lakes often develop a food chain capable of sustaining a very desirable fishery of large game fish.

Phosphorus:
Key nutrient influencing plant growth in more than 80% of Wisconsin lakes. Soluble reactive phosphorus is the amount of phosphorus in solution that is available to plants. Total phosphorus includes the amount of phosphorus in solution (reactive) and in particulate form.

Photosynthesis:
The process by which green plants convert carbon dioxide (CO_2) dissolved in water to sugar and oxygen using sunlight for energy. Photosynthesis is essential in producing a lake's food base and is an important source of oxygen for many lakes.

Retention Time: (Turnover Rate or Flushing Rate)
The average length of time water resides in a lake, ranging from several days in small impoundments to many years in large seepage lakes. Retention time is important in determining the impact of nutrient inputs. Long retention times result in recycling and greater nutrient retention in most lakes. Calculate retention time by dividing the volume of water passing through the lake per year by the lake volume.

Rooted Aquatic Plants: (Macrophytes)
Refers to higher (multi-celled) plants growing in or near water. Macrophytes are beneficial to lakes because they produce oxygen and provide substrate for fish habitat and aquatic insects. Overabundance of such plants, especially problem species, is related to shallow water depth and high nutrient levels.

Secchi Disc (Secchi Disk):
An 8-inch diameter plate with alternating quadrants painted black and white that is used to measure water clarity (light penetration). The disc is lowered into water until it disappears from view. It is then raised until just visible. An average of the two depths, taken from the shaded side of the boat, is recorded as the Secchi disc reading. For best results, the readings should be taken on sunny, calm days.

Sedimentation:
Accumulated organic and inorganic matter on the lake bottom. Sediment includes decaying algae and weeds, marl, and soil and organic matter eroded from the lake's watershed.

Seepage Lakes:
Lakes without a significant inlet or outlet, fed by rainfall and groundwater. Seepage lakes lose water through evaporation and groundwater moving on a down gradient. Lakes with little groundwater inflow tend to be naturally acidic and most susceptible to the effects of acid rain. Seepage lakes often have long retention times, and lake levels fluctuate with local groundwater levels. Water quality is affected by groundwater quality and the use of land on the shoreline.

Sodium:
A chemical element that may enter lakes from runoff of road salt, fertilizers, and human and animal wastes.

Stratification, Stratified:
The layering of water due to differences in density. Water's greatest density occurs at 39^{o}F (4^{o}C). As water warms during the summer, it remains near the surface while colder water remains near the bottom. Wind mixing determines the thickness of the warm surface water layer (epilimnion), which usually extends to a depth of about 20 ft. The narrow transition zone between the epilimnion and cold bottom water (hypolimnion) is called the metalimnion or thermocline.

Sulfate (SO_4^{--}):
The most common form of sulfur in natural waters. The amounts relate primarily to soil minerals in the watershed. Sulfate (SO_4^{--}) can be reduced to sulfide (S_2^{--}) and hydrogen sulfide (H_2S) under low or zero oxygen conditions. Hydrogen sulfide smells like rotten eggs and harms fish. Sulfate input from acid rain is a major indicator of sulfur dioxide (SO_2) air pollution. Sulfate concentration is used as a chemical fingerprint to distinguish acid lakes acidified by acid rain from those acidified by organic acids from bogs.

Substrate:
The material found at the bottom of a lake, such as silt, mud, sand, clay, marl, gravel, etc.

Suspended Solids:
A measure of the particulate matter in a water sample, expressed in milligrams per liter. When measured on inflowing streams, it can be used to estimate the sedimentation rate of lakes or impoundments.

Turbidity:
The “cloudiness” or “murkiness” of water, caused by total suspended solids.

Watershed:
The total land area that drains either surface water or groundwater toward a lake.