Toxic Cyanobacterial Blooms in Lake Winnebago

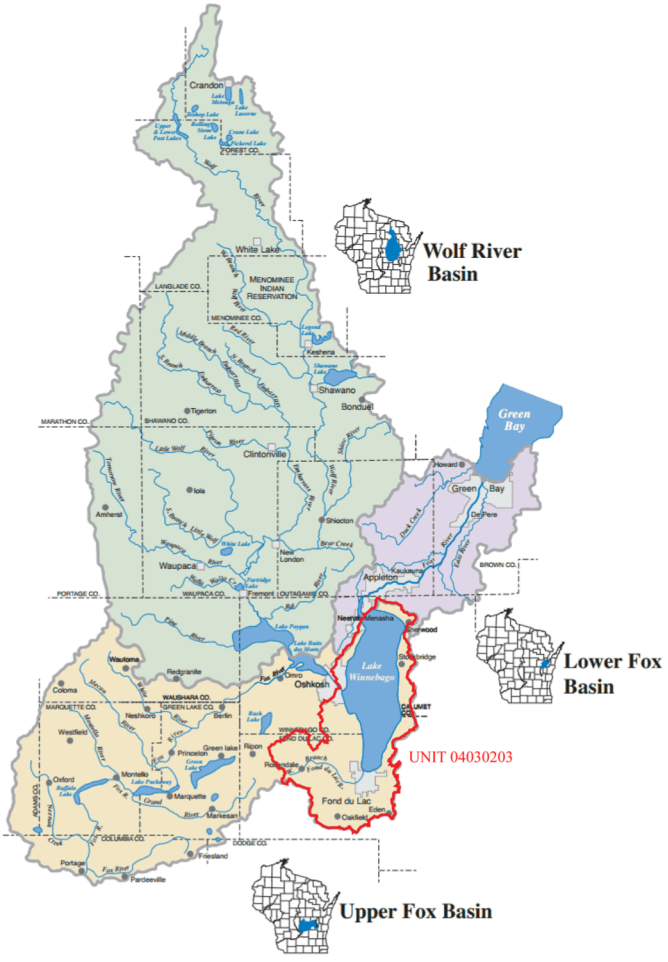
Lake Winnebago was named by the Native American Indians and translates to the poingnant phrase “filthy water”. The watershed to the west of Wisconsin’s largest lake is densely populated and subject to intensive agriculture, while the steep and erodible slopes of the Niagara Escarpment form the eastern boundary of its watershed. Nutrient-rich runoff and its shallowness make the lake a hypertrophic environment and lead to annually recurring intense toxic cyanobacterial blooms. Its function as a drinking water resource and recreational area bring forth an increasing interest in understanding the timing of algal toxin events in this lake by drinking water treatment managers and other stakeholders.

Filamentous algae bloom in Lake Winnebago, 2010 (image courtesy of Chuck Fitzgibbon, Wisconsin Dept. of Natural Resources).

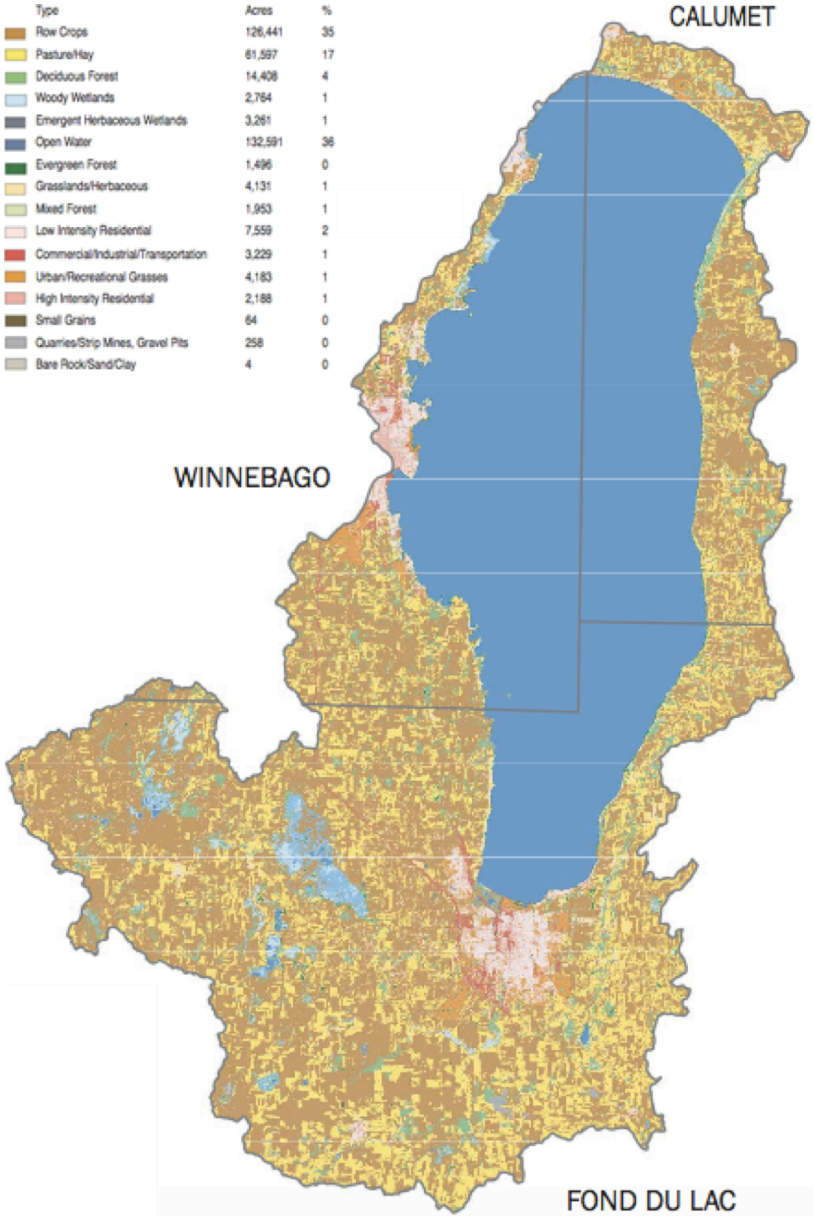
Watershed properties and land use

Lake Winnebago is shallow with an average and maximum depth of 4.4 m and 6.5 m, respectively. It is located between the Upper and Lower Fox River, which together with the upstream Wolf River drain an area of 16.650 km^2 of fertile corn and soybean farmland as well as the most highly productive dairy industrial operations of Wisconsin. The Upper Fox River drains Lake Butte des Morts into Lake Winnebago and is Lake Winnebago’s main tributary. The Lower Fox River is the largest source of water to Green Bay and accounts for one third of all phosphrous entering Lake Michigan.

The actual Lake Winnebago watershed (Hydrologic Unit Code 04030203) covers 1.500 km^2 and includes the cities of Menasha, Oshkosh, and Fond du Lac, as the primary urbanized areas, as well as the 4.6 km^2 High Cliff State



Overview of the main river basins and waterways around Lake Winnebago (modified from Calumet County Land Information Office, 2015).



Land cover and land use classification for the Lake Winnebago watershed (U.S. Department of Agriculture, 2007).

Park located in Calumet County. The watershed is above a sandstone aquifer and is primarily a glacial plain. The Niagara Escarpment, a bedrock ridge, forms the eastern boundary of the Lake Winnebago Watershed. Between 1996 and 2001, there has been a slight increase in developed land, grassland, and wetlands, and a slight decrease in farmland and forest within the watershed. The basin hosts resident and migratory neo-tropical songbirds in its open grassland and agricultural habitat. A Glacial Habitat Restoration Area (GHRA) is located in the watershed in Winnebago and Fond du Lac counties. The GHRA is an area where the state is restoring a patchwork of grasslands and wetlands over a large rural landscape enabling wildlife to coexist side-by-side with agriculture.

Socio-economic value and use

The lake is vital to the economics of the region, providing a wealth of recreational activities for residents and tourists (e.g., boating, swimming, site-seeing). Lake Winnebago serves as a drinking water resource to more than a quarter of a million people in four cities including Neenah, Menasha, Appleton, and Oshkosh. It is lined with 20 public boat landings and 14 public parks or beaches.

Angling in Wisconsin is a $2-3 billion/year industry, and Lake Winnebago is one of the most heavily fished lakes in the state. Aside from prized fish like walleye and pan fish, the lake and surrounding areas support one of the largest sturgeon fisheries in the United States. Lake sturgeon are a prehistoric species of sturgeon (there are 27 species worldwide) and thrive in Wisconsin's Winnebago lake system including Lake Winnebago, Poygan, Winneconne, and Butte des Morts. They are bottom dwellers and have some shark-like features including scaleless skin. Sturgeon spearing is an 79-year-old tradition held on Wisconsin's Winnebago lake system every February. The season begins on the second Saturday in February and lasts

until the harvest cap of sturgeon is met for that season or until the scheduled cut-off date (whichever comes first). The harvest cap varies by season and a license and tag are required to participate in each season.

Water quality issues

There is several water quality issues associated with the watershed for numerous sources ranging from urban runoff to agriculture. Several studies have been completed to identify the sources responsible for water quality issues. On one hand, urban stormwater outfalls discharge to Lake Winnebago from portions of the Cities of Oshkosh, Neenah, and Menasha. Runoff from peak storm events from commercial, industrial, and residential construction sites, and from plat developments in rapidly developing sections of these cities have been identified as sources of nonpoint source pollution problems. On the other hand, water quality modeling done by Northeast Wisconsin Waters of Tomorrow (NEWWT) has indicated that the the steep slopes along the Niagara Escarpment are a major contributor of phosphorus from critical animal waste and suspended solids from soil erosion. For example, average soil loss in Calumet County is estimated to be 2.7 tons per acre. These factors accelerate nutrient and sediment delivery to Lake Winnebago. Based on this data, both the Winnebago Comprehensive Management Plan and the Lower Green Bay Remedial Action Plan have identified the eastern portion of the watershed as a high priority for the control of non-point sources of pollution. It was selected as a nonpoint source priority watershed project in 1989. The primary goal of this watershed project was to reduce phosphorus and sediment loading to Lake Winnebago and decrease the loading of heavy metals from urban nonpoint sources. A detailed GIS- based phosphorous and suspended solids source model is available in Baumgart (Baumgart, 2002).

Nutrients from all mentioned sources fuel algal growth as well as associated liver and neurotoxin produced by cyanobacteria in Lake Winnebago. These algae and their toxins flow into Green Bay, Lake Michigan via the Fox River. Cyanobacterial accumulations occur in Lake Winnebago on an annual basis and unfortunately annual average total phosphorus levels as of 2013 make this a hypereutrophic environment. The Wisconsin Department of Natural Resources is warning swimmers and boaters to watch out for blue-green algae blooms. The agency says bloom reports typically spike in August because the water has

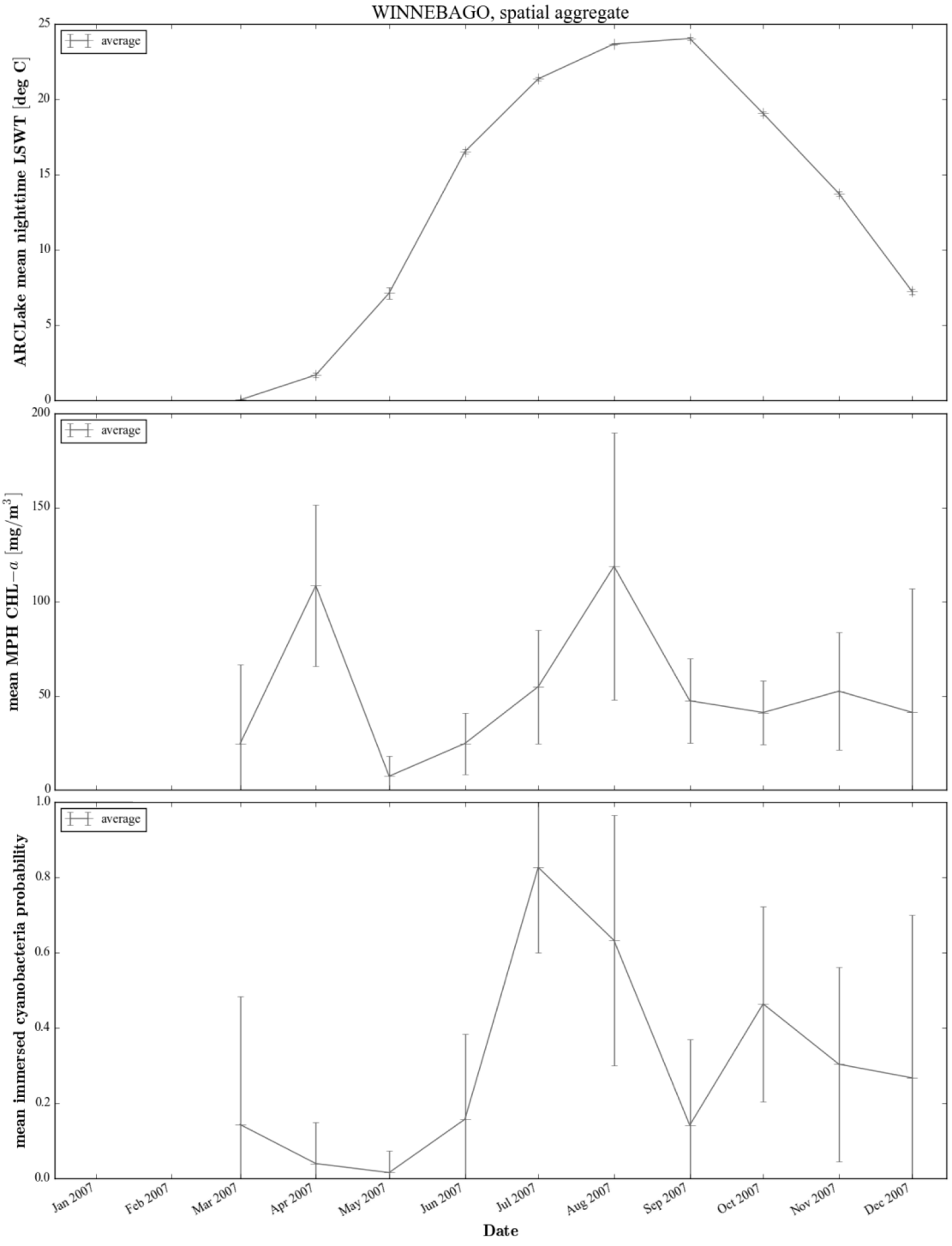
John Skahen registered a 161.0 pound, 77.1" sturgeon at Quinney. It was the largest fish taken in the 2014 season (image courtesy of Wisconsin Dept. of Natural Resources).

This Landsat-7 image, acquired on September 8, 2000, shows a large, wind-blown algal bloom in the central portion of Lake Winnebago. Note the plume of dark, relatively clear water at left, where the Fox River enters the lake (courtesy of USGS, UW SSEC and WisconsinView, 2015).

warmed up and conditions are most conducive for algae growth. Some algae species produce toxins that can cause ailments including stomach aches, flu-like symptoms, rashes and hives.

Satellite observed algal blooms in 2003-2011 Diversity II products

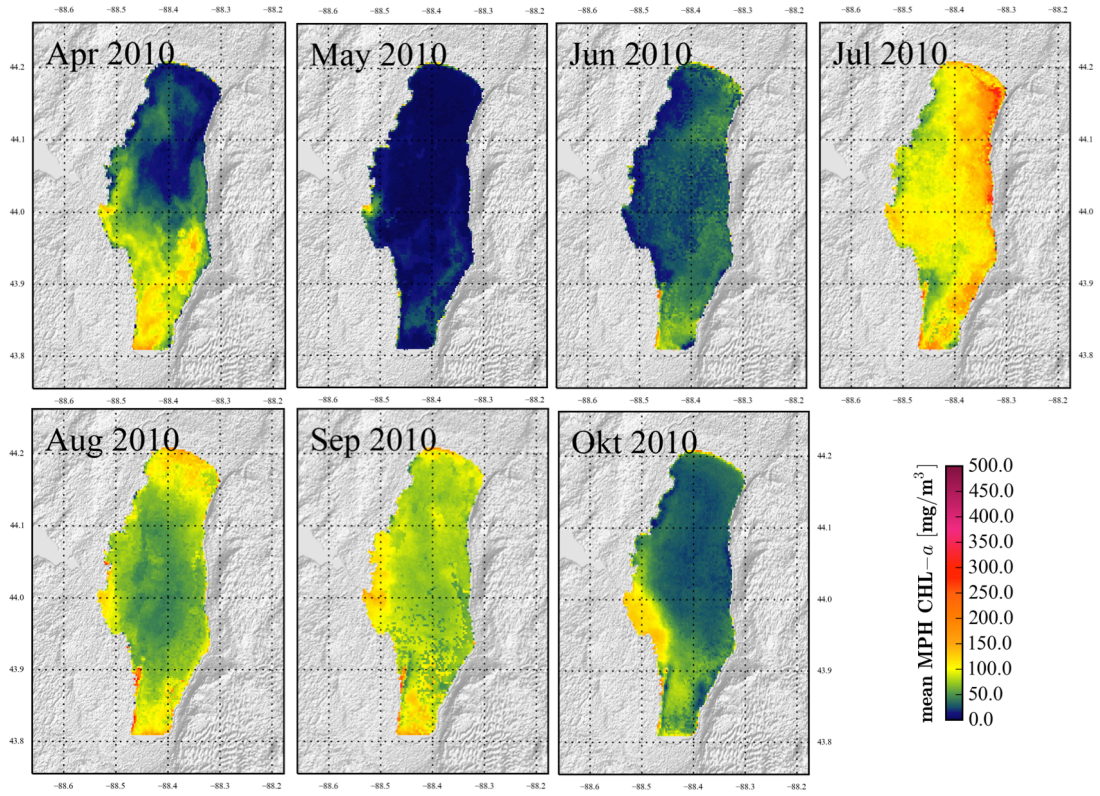
Monthly Earth observation products of Lake Winnebago indicate a steady warming of the lake water surface temperature (LWST) from April to August (2004, 2006, 2010, 2011) or September (2003, 2005, 2007-2009), in the range of 0 to 25°C. The first algal blooms indicated by peak chlorophyll-*a* concentrations of 50-120 mg/m^3 in April or May occur at



Spatially averaged surface water temperature, chlorophyll-a and cyanobacteria probability for Lake Winnebago in 2007, derived using Diversity II monthly L3 products. Error bars indicate spatial standard deviation from mean.

temperatures below 10° C and with only few cyanobacteria observations. Starting in the algae depleated early summer months, the system shifts from green algae dominance to cyanobacteria dominance. In the earlier years of the time series (2003 to 2008), cyanobacteria dominance lasts several months between July and October, and achieves at least 80% probability in every year. From 2009 to 2011, the situation has eased, with no more than one month of cyanobacteria dominance per year, and maximum probabilites below 80%. However, chlorophyll-*a* concentrations estimated for this second half of the year peaked more regularly in a late summer or autumn maximum, with extraordinary concentrations up to 500 mg/m^3 recorded in September 2011.

In less extreme cases, the spatial patterns visible in Earth observation retrieved water quality parameters indicate how the influence of the above mentioned tributaries vary throughout the year. In the year 2010, the spring bloom forms in the estuary of the Fond du Lac River, and northwards along both shores. After the early summer depletion, diffuse input from the Niagara Escarpment drives the year's second, rather untypical mid-summer algal bloom event, while autumn growth dynamics concentrate around the Fox River estuary. Such patterns are observed in every year, but differ significantly amont different years.



Chlorophyll-*a* maps of Lake Winnebago, for the summer half-year of 2010.

Outlook

The University of Wisconsin-Milwaukee (UWM) is testing the water quality of Lake Winnebago to find out whether blue-green algae produces toxins in drinking water. Dr. Todd Miller is directing research efforts at understanding cyanobacteria toxin dynamics in lakes relative to the molecular ecology of cyanobacteria and is also developing new autonomous monitoring systems for cyanobacteria and their toxins based on sensor-equipped buoy platforms. Their goal is developing models of cyanobacterial growth and toxin production, which will aid in reducing human exposure to algal toxins. They require near real-time cyanobacteria indicators of Lake Winnebago, showing both the growth and distribution of cyanobacteria. This would provide the basis for an early warning system for public water

supply facilities that have their intakes at points in the lake. Products would be anticipated growth and movement of algae blooms.

Further reading

Baumgart, P. (2002). Simulated TSS and Phosphorous Export to Lake Winnebago and Green Bay from the Fox-Wolf River Basin (Appleton, Wisconsin).

Calumet County Land Information Office (2015). Winnebago Waterways - The Watershed (http://calmaps.co.calumet.wi.us/serversites/WinWaterways/Watershed.html, accessed 10 January 2015).

U.S. Department of Agriculture (2007). Rapid Watershed Assessment Lake Winnebago Watershed (Washington, D.C.).

UW SSEC and WisconsinView (2015). Landsat Satellite Image Gallery of Wisconsin Lakes (http://www.lakesat.org/galleryindex.php, accessed 10 January 2015).