Fundamental Concepts on Water Quality of the Yahara Chain of Lakes (Mendota, Monona, Wingra, Waubesa, and Kegonsa)

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Purpose

The intent of this document is to summarize key concepts related to the water quality of the Yahara lakes in southern Wisconsin. For each concept a brief explanation is provided along with a description of its relevance to planning and decision making. References and notes are provided for those interested in more detail. The intent is to break down the issues into individual parts to facilitate a better understanding of the factors affecting water quality. In the end, these components are all parts of a whole and are tied together. The authors of this document are technical experts in water quality with experience working on the Yahara Lakes. This document is not meant to address policy or specific solutions, but rather to summarize the state of the science on water quality in the Yahara lakes.

Fundamental Concepts

1. Algal blooms, poor water clarity, excessive aquatic plants, and high bacteria concentrations are the primary water quality concerns in the Yahara lakes.

Algal abundance, water clarity, bacteria concentrations, and aquatic plants strongly influence the perception of water quality and the suitability of lakes for recreation.[1] Algal blooms can also harm aquatic life by depleting dissolved oxygen when they decompose and by shading aquatic plants that serve as habitat. Cyanobacterial blooms (commonly referred to as blue-green algal blooms), in particular, are a problem because of their tendency to form scums that accumulate along shorelines and their potential to produce toxins. Algal blooms can be very patchy and their severity can change from day to day based on weather and other factors. High enteric bacterial concentrations occur at many beaches on the Yahara lakes, and can cause illness when water is ingested while swimming.[2] Monitoring data indicate that bacterial contamination is mainly delivered by runoff from storm sewer outfalls near beaches, although dense geese populations near beaches (e.g., Vilas Beach at Lake Wingra) are also a source of contamination. Abundant invasive aquatic weeds (e.g., Eurasian water milfoil) are a nuisance for many kinds of

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recreation, although native plants do not usually cause problems and are a natural and important part of lake ecosystems. Invasive plants and animals have also caused undesirable changes in the lakes, and some species thrive in poor water quality conditions.

2. Reducing phosphorus input to the Yahara lakes has the greatest potential to control algal blooms and related problems.

Algae require phosphorus to grow. Numerous studies have shown that controlling algal blooms in lakes depends on reducing phosphorus inputs.[3] The types and abundance of algae can also be influenced by other factors, including nitrogen, light, and food web effects, but these factors have weaker effects relative to phosphorus, and are more difficult to control.[3] During extended dry periods (1987-88, 2002-03, 2011-2012) with low phosphorus inputs to the Yahara lakes, lake phosphorus concentrations declined substantially and water clarity improved, indicating that the lakes should respond relatively rapidly to sustained reductions in phosphorus inputs.[4] Feasible reductions in phosphorus will likely not reduce aquatic plant abundance because aquatic plants get most of their nutrients from the bottom sediments, and reduced algae may actually increase plant cover, particularly in shallow areas, because of increased penetration of sunlight.[5]

3. Most of the phosphorus input to the Yahara lakes is in runoff from agricultural and urban lands.

Phosphorus inputs from some of the main tributaries to Lake Mendota have been monitored intensively for 30 years.[6] These data were used to calibrate a watershed model for all of the Yahara lakes. Although there is some uncertainty in the precise proportions of phosphorus sources, the latest estimates for the entire watershed are 52% from agricultural areas, 40% from urban areas, and 8% from natural areas.[7] For the Lake Mendota watershed, the proportions are 62% from agricultural areas, 33% from urban areas, and 5% from natural areas. Most phosphorus is delivered in overland rainfall and snowmelt runoff to streams and drainage ditches that carry it to the lakes. Phosphorus from municipal wastewater treatment plants is minimal because discharges to the lakes were discontinued in 1971. Some parts of the watershed contribute more phosphorus to the lakes than others.[8] This variation is caused by differences in phosphorus sources such as fertilizer and manure, landscape factors such as soil type and slope, and characteristics of flow paths such as depressions and distance to the lakes. From USGS monitoring data collected at the Yahara River at Windsor station representing a primarily agricultural watershed, on average about 40% of the phosphorus enters Lake Mendota in January to March when the ground is mostly frozen, and about 30% during April-June when agricultural crops are not fully grown.[9] The largest contribution of phosphorus from urban areas comes in autumn, mainly as dissolved phosphorus leached by rainwater from leaves left exposed in streets (i.e., a “tea-bag” effect). Phosphorus stored in wetlands and streambanks and streambeds also contributes to lake inputs, but most of this phosphorus originally came from agricultural and urban runoff. While the downstream lakes (Monona, Waubesa, and Kegonsa) receive some phosphorus from their direct drainage basins, the majority of their phosphorus comes from the upstream lake(s) through the Yahara River.[10] Phosphorus is recycled from the bottom sediments in all of the lakes, although this process contributes more to poorer summer water quality in the shallow lakes (Wingra, Waubesa, and Kegonsa) due to wind-driven mixing of the water column in contact with the bottom sediments than in deeper lakes (Mendota and Monona).[11] This internal recycling of phosphorus is enhanced by abundant carp populations. Commercial harvesting of carp from Lake Wingra in 2008 resulted in a dramatic increase in water clarity, although increased growth of aquatic plants and filamentous algae created other lake management problems.

4. Annual phosphorus inputs to the Yahara lakes are highly variable and there has been no trend in inputs over the last 30 years.

Over the last 30 years, the average annual phosphorus input to Lake Mendota was about 76,000 pounds, and ranged from about 23,000 pounds in 2003 to 171,000 pounds in 2019.[12] This wide range is mainly caused by large variations among years in rainfall, snowmelt, and resulting stream flow.[13] Phosphorus concentrations in runoff increase greatly during large runoff events, which means that these events deliver the majority of phosphorus to the lakes in a relatively short amount of time each year.[14] After factoring out the year-to-year variation, there has been an increase in precipitation that led to increasing runoff and stream flow over the last 30 years. If stream flow was the same every year, it is estimated that phosphorus inputs to Lake Mendota would have decreased by about 36% during this period.[15] This indicates that land management practices would have been effective in an unchanging climate, but that wet weather can more than offset the benefits of those practices.

5. Management practices on agricultural and urban lands can reduce phosphorus runoff.

Primary sources of phosphorus in cropland runoff are manure, fertilizer, and phosphorus stored in the soil from past fertilizer and manure applications that exceeded crop removal. Manure has caused much of the soil phosphorus buildup because applications often contain more phosphorus than the crop will use. Agricultural management practices to reduce runoff phosphorus can involve changes in crops and soil tillage to reduce runoff and erosion. They can also be changes in manure and fertilizer applications to reduce the amount of phosphorus on the soil surface. Another approach is identifying areas with a manure phosphorus surplus and using techniques that concentrate the phosphorus in manure solids so it is easier to transport to areas that need it for crop growth. Research comparisons of individual and combined practices show that changes in land management can reduce phosphorus (and soil) in runoff.[16] Some cropland management changes can lead to reductions in erosion and transport of phosphorus attached to eroding particles while increasing dissolved phosphorus losses and vice versa. Urban water quality management practices in the Yahara watershed primarily involve reduction of phosphorus sources such as by leaf collection, erosion control on construction sites, and detention and infiltration of runoff. The amount of phosphorus reduction caused by a management change at a particular location is related to the same factors that affect phosphorus input to the lakes (see concept 3). The expected location-specific performance of a wide variety of practices has been packaged into tools such as SnapPlus[17] for agricultural soil and nutrient management and WinSLAMM[18] for urban practices. These tools allow watershed managers to estimate the aggregate contributions of practices at many locations toward water quality goals. However, the methods used to estimate practice performance at specific locations are not easily translated into changes at the watershed scale (see concepts 6 and 7).

6. There can be long lag times between management interventions and water quality responses in the lakes.

Despite the documented effectiveness of management practices at small scales, their aggregate effects at larger watershed scales have been difficult to demonstrate.[19] Many of the reasons for this apparent disconnect across scales are related to lag times in the movement of phosphorus through watersheds. There are many environments in a watershed where phosphorus can be stored, including upland soils[20], wetland sediment and vegetation, stream banks and bed sediments[21], and lake-bottom sediments.[22] When phosphorus inputs in a watershed are reduced, or the movement of phosphorus from one of these environments is controlled, release of phosphorus from another environment may offset or dramatically delay the effects of that intervention. Ultimately though, managing the balance between phosphorus inputs and outputs[23] will lead to a reduction in stored phosphorus across the landscape and improve water quality (see concept 2). Another reason for this apparent disconnect across scales is that some practices are implemented on land with a weak hydrologic connection to the lakes (e.g., land with surface runoff draining into a closed depression). In addition, practices that were originally implemented long ago may no longer be effective because of lack of maintenance or landscape changes that were not planned for in the original design.

7. Many factors that affect water quality change simultaneously.

Management practices that aim to improve water quality are only one of several classes of changes occurring in the Yahara lakes watershed, including precipitation, land use, and lake ecology.[24] Along with the lag times described above, this reality means that water quality will not always respond in a predictable way, even when management efforts are extensive. For example, the string of years with wet weather since 2013 has probably reduced the effectiveness of conservation practices implemented over that time period. Also, new invasive species have colonized the Yahara lakes in the last decade and are changing how algae respond to phosphorus. For example, zebra mussels filter microscopic forms of algae from the water, which in other lakes has resulted in more scum-forming blooms of cyanobacteria and nuisance growths of filamentous algae in shallow waters. Also, spiny water fleas have contributed to poor water clarity in Lake Mendota recently by consuming the zooplankton that normally control algae.[25] Finally, the many effective conservation practices implemented over the last several decades coincided with urbanization and intensification of agricultural production in some areas, which has exacerbated the manure management problem described in concept 5.

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Notes

[1] Smeltzer & Heiskary (1990) found strong relationships between user perception of water quality and Secchi depth and chlorophyll *a* in Minnesota and Vermont lakes. Unpublished research by M. Diebel on Wisconsin lakes found similar relationships.

[2] Bacteria are a natural part of lake ecosystems, and many are harmless to humans. However, some types of bacteria and viruses, particularly those found in animal feces, can cause gastrointestinal illness when ingested. *E. coli* is a common bacterium in feces and is therefore used as an indicator of potential

health risks of swimming. *E. coli* is monitored regularly during the summer at the most popular beaches on the Yahara Lakes, and results are used to issue swimming advisories.

[3] Schindler et al. 2016.

[4] Lathrop & Carpenter 2014.

[5] Lathrop et al. 2013.

[6] Lathrop & Carpenter 2014; USGS Dane County water quality monitoring program.

[7] Montgomery Associates 2014, Table 3.1 (reaches 62-66). Land cover of the Yahara lakes watershed (excluding open water) in 2019 (USDA Cropland Data Layer) was 54% agriculture, 30% developed, and 16% natural.

[8] Montgomery Associates 2014, Figure 3.6. Phosphorus loading rate varies from <0.19 to 1.02 lb/acre/year among sub-basins in the Yahara watershed.

[9] Lathrop 2007.

[10] Lathrop & Carpenter 2014, Table 2.

[11] Lathrop & Carpenter 2014, p. 6.

[12] Estimated by the authors of this document, using data from U.S. Geological Survey monitoring stations, with extrapolation to unmonitored areas.

[13] Lathrop & Carpenter 2014, Figure 2.

[14] Carpenter et al. 2018.

[15] The effects of variation in streamflow can be factored out of the history of phosphorus loading with a statistical model called Weighted Regressions on Time, Discharge, and Season (WRTDS, Hirsch et al. 2010). This method estimates the flow-normalized load for each year, which is essentially what the load would have been if flow was average every year. Based on a preliminary analysis by M. Diebel, flow-normalized phosphorus loads from Pheasant Branch Creek and Yahara River to Lake Mendota decreased by 36% from 1990 to 2019.

[16] There are numerous examples of field-scale studies of how management is related to phosphorus loss. Zopp et al. (2019) contains many references to other studies and is a recent example that uses data from Wisconsin farms.

[17] SnapPlus is Wisconsin's nutrient management planning software and contains the Wisconsin P Index. The WI P index uses information supplied for nutrient management planning (soil test phosphorus and organic matter; soil type; slope and slope length; crop rotation and yields; tillage system; and timing, placement and rates of manure and fertilizer phosphorus to estimate average annual dissolved and particulate phosphorus loads from cropland. It takes both frozen and non-frozen soil runoff into account. The P Index can be used for comparing potential dissolved and particulate phosphorus reductions in runoff with changes in field management on specific fields.

[18] WinSLAMM (Source Loading and Management Model for Windows) is a computer model that estimates runoff volume and pollution loading for urban areas and can be used to estimate water quality effects of control measures including detention ponds, infiltration basins, street cleaning, and many others.

[19] Sharpley et al. 2013.

[20] The portion of soil phosphorus available for crop growth is routinely measured on cropland to assess the need for fertilization. For the primary crops and soils in the Yahara lakes watershed, levels of soil test phosphorus above 35 ppm are considered excessive with no additional phosphorus recommended. In 2019, the average soil test phosphorus in the Yahara watershed was 62 ppm. Soil test phosphorus is also an indicator of runoff phosphorus concentrations (Good et al. 2012) Bringing soil test phosphorus down

from excessive levels through decreased fertilization and crop removal will reduce phosphorus in runoff. Drawdown, however, is a slow process. In this watershed, the maximum average annual reduction in soil test phosphorus that can be expected through crop removal is approximately 4 ppm (for corn silage).

[21] Stream bed sediment analysis in preparation for the Dane County "Suck the Muck" project estimated that a 2-mile section of the stream bed of Dorn Creek contained approximately 75,000 pounds of phosphorus.

[22] Only about 27% of the phosphorus input to Lake Mendota leaves the lake through the Yahara River (Lathrop & Carpenter, 2014). The remaining 73% is stored in the bottom sediments of the lake, and some of this stored phosphorus is recycled into the lake water when the lake is stratified.

[23] The main inputs of phosphorus into the Yahara watershed are fertilizer for crops and feed supplements for livestock and the main outputs are harvested crops, dairy products, and cattle (Kara et al. 2012).

[24] Gillon et al. 2016.

[25] Walsh et al. 2017.