Water Sustainability and Climate
In the Yahara Watershed
UNIVERSITY OF WISCONSIN–MADISON

Meeting Our Future Water Needs

Key lessons and opportunities

Our watersheds provide us many natural benefits, or ecosystem services, that are essential to our well-being. Given that environmental change can be long-term, unexpected, and riddled with uncertainty, ensuring our watersheds can meet the needs of future generations requires adopting a holistic and long-term approach in research, policy, and management.

An exemplar for this challenge is Wisconsin's Yahara watershed. An important natural benefit in the Yahara is the water quality of its five lakes, which is arguably a barometer of the region's resilience. While phosphorus pollution is one of the most direct threats to the lakes, this threat is a truly "wicked problem," nested within layers of social and environmental challenges that impact the capacity for water sustainability in the region.

Since the 1960s, there has been much effort to reduce phosphorus pollution and improve lake water quality. Despite this persistence, there has been no improvement.

While the lack of progress does not mean the effort has been in vain, as water quality has not gotten worse, it does indicate there are barriers to meeting our goals that we must overcome moving forward, such as the following:

- Project goals and modeling are not accounting for changes in climate, land use, and agriculture that are making it more difficult to reduce phosphorus pollution. These changes include increasing precipitation, more urban development and the intensification of livestock operations (Gillon et al, 2015).
- There is a mismatch between places where most water quality policies are implemented and the locations of the major sources of phosphorus pollution. As a result, policies are missing some of the areas of greatest concern (Wardropper et al, 2015; Qiu et al, 2016).
- In many places within the watershed, the level of phosphorus in the soil far exceeds the amount crops need, resulting in a buildup referred to here as the soil phosphorus legacy. These high levels of soil phosphorus are leading to high dissolved phosphorus in runoff. The slow release of this phosphorus buildup into our waterways is counteracting the effects of conservation practices, like no-till farming (Motew et al, 2017).
- Incremental change and short time horizons dominate strategies and decision-making. There is a need to think on longer time scales to address the long-term nature of environmental change (Carpenter et al, 2015).

The Water Sustainability and Climate project at the University of Wisconsin-Madison has been focused on uncovering barriers and opportunities to improving water quality and sustaining other natural benefits for future generations in the Yahara watershed and beyond. Their approach entailed developing future scenarios of socio-ecological change in the region, which peer two generations into the future and are called Yahara 2070. The research team then used an innovative suite of computer models to simulate the changes in land-use, nutrient management, and climate that occur in the scenarios, the outputs of which are estimated future conditions for seven ecosystem services in the year 2070.

By understanding a range of possible changes and their outcomes, the project sought to help organize the uncertainty of the future and reveal potential vulnerabilities to prepare for and opportunities to pursue. This big-picture approach can then inform subsequent efforts to identify strategic, on-the-ground solutions that can be undertaken today to achieve a desirable future.

This report outlines some of the key messages from the project's model results. It also presents further opportunities that emerged from a workshop held on May 2nd, 2017, which convened professionals in land and water management who work in the Yahara watershed and statewide to discuss implications of the results. These findings and opportunities are important steps toward solutions that will enable the watershed to meet the needs of future generations.

For more information about the Water Sustainability and Climate project and Yahara 2070, visit wsc.limnology.wisc.edu and/or yahara2070.org.

KEY MESSAGE: **We must manage our watersheds holistically.**

Watersheds like the Yahara produce many ecosystem services, or the natural benefits people depend on for their well being, such as crop production, clean water for drinking and recreation, and flood mitigation.

There are both tradeoffs and synergies between these benefits. For example, there is a tradeoff between crop production and water quality, making it difficult to have both intensive crop production and clean surface waters. Conversely, managing land to mitigate flooding can synergistically help to replenish the groundwater supply,

Ultimately, we can get different benefit bundles from our watersheds depending on how we manage our landscape.

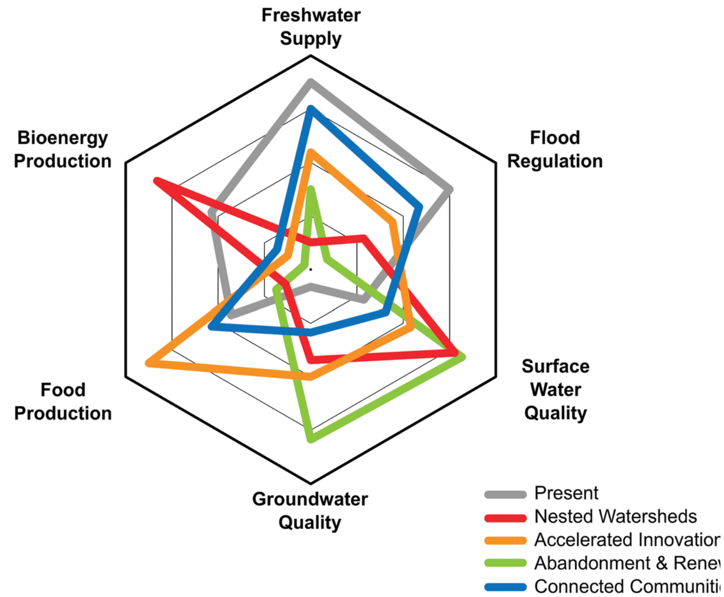


Figure 1: This spider diagram shows the tradeoffs and synergies between six of the ecosystem services modeled for all four scenarios and present day (gray). Points at the outer edges indicate higher amounts of these benefits, while those toward the center indicate lower amounts. As an example of a tradeoff, notice how high surface and groundwater quality accompany low food production in Abandonment & Renewal (green).

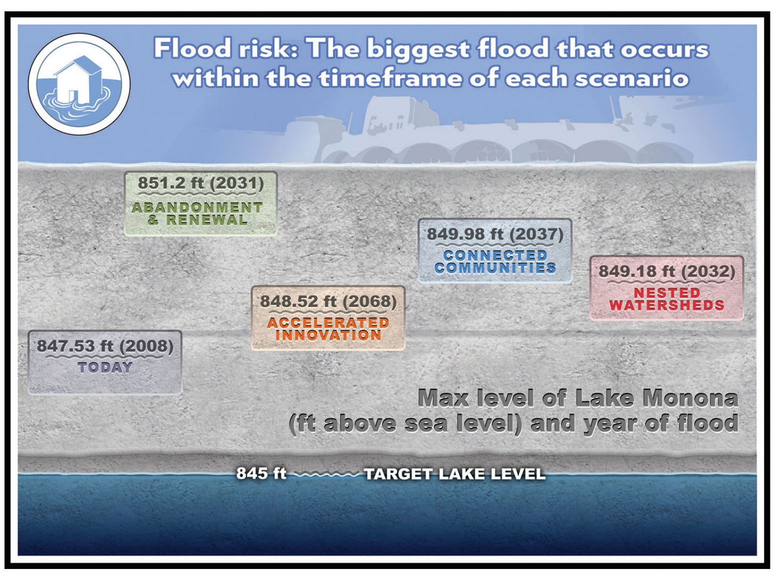


Figure 2: This illustration of the Monona Terrace sea wall shows Lake Monona's maximum water levels in the biggest flood to occur in each of the Yahara 2070 scenarios, compared with a record flood from 2008. The graphic is part of a larger infographic of the model results, which can be viewed at wsc.limnology.wisc.edu/yahara2070-ecosystem-benefits*. (The illustration's proportions are drawn for explanatory purposes.)*

KEY MESSAGE: **The climate will be a dominant force on our ability to mitigate flooding, regardless of what we do on our landscapes.**

How we use our land will have an influence on our ability to mitigate flooding in cases of medium to large flood events. However, climate change will almost exclusively drive extreme flood events, and we will be susceptible to such extremes. Regardless of how we manage our landscapes to reduce our flood risk, we could still experience significant flooding due to increasing precipitation under climate change. This amplifies the importance of flood preparation.

Low-lying areas surrounding Lake Monona will be especially vulnerable to substantial flooding as precipitation increases from a warming climate. Furthermore, low-lying agricultural and natural areas will likely experience more frequent flooding due to elevated groundwater tables; this could pose additional challenges to farmers and their ability to cope with crop losses.

KEY MESSAGE: If we want to improve water quality, we must deal with the soil phosphorus legacy and increasing precipitation from climate change.

The Yahara watershed has a significant buildup of soil phosphorus – the nutrient has accumulated in agricultural soils and sediments as a result of long-term over-application of fertilizer and manure in excess of crop needs. This legacy will impede our ability to improve lake and river water quality if not addressed.

To avoid accumulating more soil phosphorus, farms will need to implement precise phosphorus budgeting.

To reduce the soil phosphorus legacy, we will need to employ strategies to draw down existing soil phosphorus reserves.

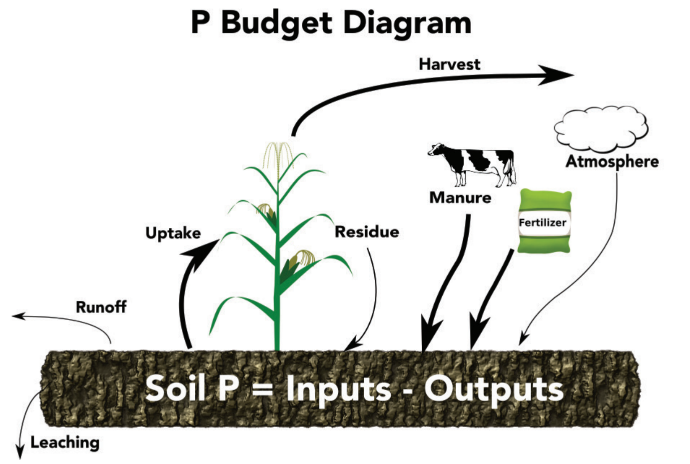


Figure 3: In the soil phosphorus (P) budget, inputs include manure, fertilizer, and to a lesser extent, phosphorus that falls from the atmosphere attached to dust. Outputs include crop harvest, losses in runoff, and subsurface leaching. Manure, fertilizer, and harvest amounts are generally much larger than the other fluxes to and from the system. When there are more inputs than outputs, such as in many places within the Yahara, excess phosphorus is left over and builds up over time. This phosphorus is vulnerable to losses in runoff. Even a small fraction of phosphorus lost in runoff can cause eutrophication.

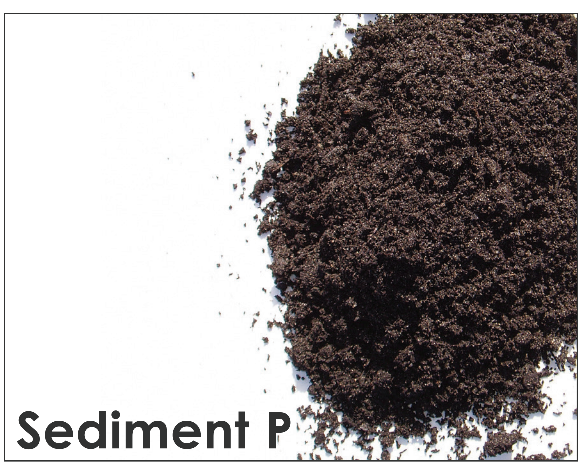


Figure 4: Dissolved phosphorus (top) is the nutrient dissolved in water. Sediment phosphorus (bottom) is attached to particulate matter, such as soils.

KEY MESSAGE: Land management should be mindful of the different forms of phosphorus, and dissolved phosphorus may need more attention if we want to improve water quality. Each form should be addressed strategically with different conservation practices.

Dissolved phosphorus is an important factor affecting water quality. Algae can use it more easily to grow, as the nutrient passes through their cell walls. Also, dissolved phosphorus moves quickly through river systems, unlike sediment phosphorus, which moves slowly and at the mercy of erosion and deposition. Despite the impact dissolved phosphorus has on water quality, it is sometimes overlooked in land management.

Traditional conservation approaches, such as no-till, are effective for reducing the amount of sediment phosphorus loss during runoff events, but less effective for reducing the loss of dissolved phosphorus. We can still harness the strength of these traditional approaches, but we also need solutions that address their weaknesses.

On land with high amounts of soil phosphorus, large amounts of dissolved phosphorus can be lost during runoff events, even if that land has been converted to perennial systems, for example. To prevent this, it will be necessary to draw down soil phosphorus.

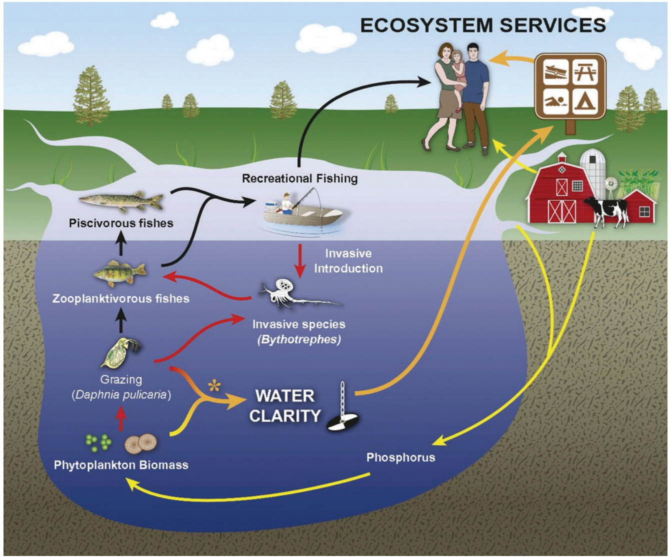


Figure 5: People introduce invasive species, often unintentionally, to lakes through recreation. Some of these species can impact water quality. For example, the spiny water flea can impact a lake's food chain, as it eats Daphnia, a grazer of algae. In lakes that suffer from phosphorus pollution, like Lake Mendota, a loss of Daphnia can result in an increase in lake phosphorus concentrations and, thus, a reduction in water clarity. Illustration from Walsh et al, 2016.

KEY MESSAGE: **Some invasive species could be game-changers for water quality.**

Non-native species with the potential to change lake ecosystems could complicate progress on cleaning up lakes and rivers. There are two recent invasive species in the Yahara that may impact efforts: spiny water fleas and zebra mussels.

Spiny water fleas eat Daphnia, a native "grazer" that is key for controlling nuisance algae and improving water quality. A serious decline in Daphnia populations would make water quality worse.

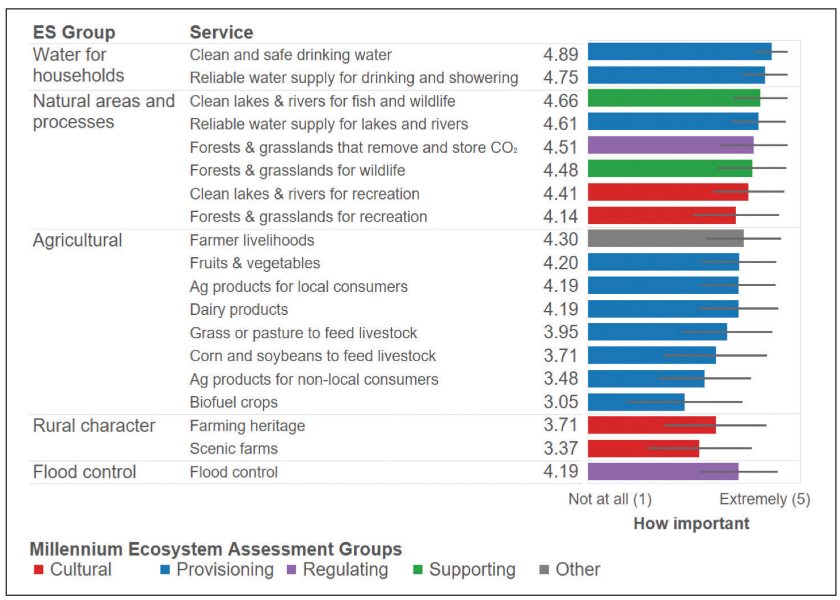
The zebra mussel is a more recent invader, and its effects are still unknown, but the species could also make it more difficult to improve water quality.

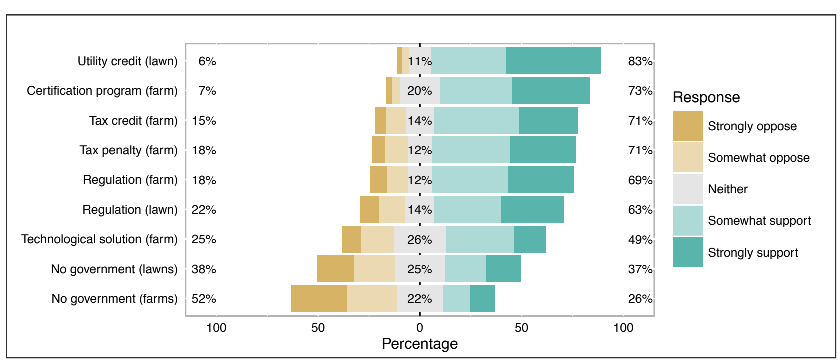
Preventing new invasions will be key to minimizing the complicating effects of invasive species. Moreover, managers should be ready for surprises like invasive species. Solutions for prevention and preparation may require collaborations between water quality managers and fisheries managers.

KEY MESSAGE: **Residents view clean water as very to extremely important and support policies aimed at protecting water quality.**

The figures to the right show results from a 2015 survey of 1100 urban and rural residents of Dane County, the county that encompasses most of the Yahara watershed. The first figure shows respondents' preferences for ecosystem services (ES). Clean drinking water received the highest importance. Residents also value agricultural production.

In terms of policy support (see second figure), residents generally oppose relying on voluntary action without government intervention. They also tend to favor "carrot" policies like incentives over "stick" policies like taxes.





Further opportunities in pursuit of solutions

On May 2nd, 2017, the Water Sustainability and Climate project convened over 40 professionals in land and water management who work in the Yahara watershed and statewide to discuss implications of the model results. The following is a summary of the new questions, opportunities, or ideas that fruited from these discussions and could aid the pursuit of solutions for meeting future water needs.

Model specific land use/land management scenarios to uncover what practices could net the most improvement to water quality.

- What practices will best reduce the phosphorus build-up in our soils?
- What practices will leave our waters and landscapes most resilient to climate change?
- How far does management and policy need to go to meet the Total Maximum Daily Load (TMDL), the maximum amount of nutrient pollution allowable in waterways?
- What would the average soil phosphorus level need to be to maintain acceptable phosphorus concentrations in the lakes?
- Can the project's models help us target places in the Yahara that could make the biggest difference to water quality?
- What urban land-use changes could reduce urban contributions of phosphorus?
- What are the effects of gradual ag-to-urban growth, and are there thresholds when big environmental changes could happen as a result?

Model scenarios of shorter-term or incremental changes and trends over which we have more immediate control.

- What changes can be made in the more immediate term – zero to 10 years – that will help us better reach our goals?
- How can we best marry what needs to happen over the long term with what needs to happen in medium term?
- If we modeled current policies and practices, such as those outlined in the Yahara CLEAN plan, would they help us reach our water quality goals?

Model different economic scenarios to understand the implications of various economic pathways for water quality.

- What impacts do current agricultural subsidies have on water quality?

Quantify tradeoffs, costs, and benefits of various practices to reduce runoff and soil phosphorus while preserving farmer livelihoods.

- What are the long- and short-term costs and benefits of the various approaches to reduce soil phosphorus and/or the movement of phosphorus from land to water?
- Can we quantify the benefits to farmers versus downstream users to see whether they are compatible?
- What are the opportunities for mining phosphorus from the watershed – i.e., extracting it from the soil and exporting it to places that are phosphorus deficient – and the associated costs and benefits?

Ground truth model results to enhance their application to policymaking.

- Model practices at smaller scales, such as sub-watersheds or individual farms, and ground truth them with pilot studies or demonstration projects.
- Use the models to simulate the land-use, climate, and nutrient management changes that have occurred from 1970 to today to see if they show present-day best management practices are making a difference in water quality.

Apply modeling insights to everyday land and nutrient management tools.

- Update other models used in the watershed and state with climate data.
- Use the existing nutrient management planning framework as a starting point to address soil phosphorus legacy management.
- Enhance SnapPlus, the software used in Wisconsin to develop farm nutrient management plans, to make it easier to examine the long-term effects of applying excess phosphorus on losses of phosphorus to cropland runoff.
- Improve existing modeling practices used on farms to help farmers.
- Explore the potential for collaboration between the project research team and the Greater Madison Vision project, a local scenarios initiative by the Capital Area Regional Planning Commission (CARPC).
- Expand and/or adapt watershed monitoring to ensure efforts are strategically placed and are measuring the different forms of phosphorus to best inform decision-making and respond to new insights.

Translate model results into pathways for solutions.

- What are the viable solutions for addressing the soil phosphorus legacy?
- How can the Yahara become a net exporter of phosphorus?
- What are the no-regret, low-hanging-fruit options that we should pursue to achieve clean lakes and preserve farmer livelihoods?
- What are the opportunities to incorporate the perspectives of farmers and minority communities into solutions?

Explore policy and management considerations elicited by the model results.

- At what point do we need to ramp up regulatory approach? Are there tweaks that could be made to regulations in light of our awareness of the challenges to meeting water quality goals?
- Can the project's models help Dane County make decisions in how to use funds to reduce soil phosphorus that exceeds crop needs and balance soil nutrient levels?
- How can we implement practices to reduce soil phosphorus without relying on financial incentives? What combination of approaches is needed to make changes?
- Are there ways to incentivize farmers for not applying too much phosphorus?
- Given the tradeoffs between ecosystem services, do we need to reevaluate water quality goals – e.g., what is realistic and how clean is clean enough?
- What solutions will not create "losers"?
- What are our communities willing to pay for clean water?

Improve our communication of model results to diverse audiences.

- Convey the connection between land management and consumers to policymakers.
- Manage public expectations and patience over the long-term, while maintaining a focus on solutions and hope and avoiding a narrative of "there's no way out."
- Communicate the limitations of models to the public.
- Connect the model results with farmers' values and concerns, such as soil health.
- Measure stakeholders' appetites for risk taking.

References

Carpenter, S. R. et al. Plausible futures of a social-ecological system: Yahara watershed, Wisconsin, USA. *Ecology and Society* 20 (2015).

Gillon, S., E.G. Booth, and A.R. Rissman. Shifting drivers and static baselines in environmental governance: challenges for improving and proving water quality outcomes. *Regional Environmental Change* 16 (2016): 759-775.

Motew, M. et al. The Influence of Legacy P on Lake Water Quality in a Midwestern Agricultural Watershed. *Ecosystems* (2017): 1-15.

Qiu, J. and M.G. Turner. Spatial interactions among ecosystem services in an urbanizing agricultural landscape. *PNAS* 110 (2013): 12149–12154.

Qiu, J., C.B. Wardropper, A.R. Rissman, and M.G. Turner. Spatial fit between water quality policies and hydrologic ecosystem services in an urbanizing agricultural landscape. *Landscape Ecology* 32 (2017): 59-75.

Rissman, A.R. and S.R. Carpenter. Progress on Nonpoint Pollution: Barriers & Opportunities. *Daedalus* 144 (2015): 35-47.

Rissman, A.R., P.A. Kohl, and C.B. Wardropper. Public support for carrot, stick, and no-government water quality policies. *Environmental Science and Policy* 76 (2017): 82-89.

Walsh, J.R., S.R. Carpenter and M.J. Vander Zanden. Invasive species triggers a massive loss of ecosystem services through a trophic cascade. *PNAS* 113 (2016): 4081-4085.

Wardropper, C.B., C. Chang, and A.R. Rissman. Fragmented water quality governance: Constraints to spatial targeting for nutrient reduction in a Midwestern USA watershed. *Landscape and Urban Planning* 137 (2015): 64-75.

Credits

This report was written by Jenny Seifert with input from Eric Booth, Stephen Carpenter, Chris Kucharik, Melissa Motew, Adena Rissman, Gregory Fries, Laura Good, and John Panuska.

Research sponsor

This material is based upon work supported by the National Science Foundation under grant DEB-1038759. Any opinions, findings, conclusions, or recommendations expressed in the material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Water Sustainability and Climate Project

The Water Sustainability and Climate Project (WSC) at the University of Wisconsin-Madison is an integrated effort to understand how water and the many other benefits people derive from nature could change over time. The five-year project (2011–2016) focused on the Yahara Watershed in southern Wisconsin and funded by the National Science Foundation. Visit wsc.limnology.wisc.edu.