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LakeLine

Volume 36, No. 1 • Spring 2016

Internal Loading

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Visit www.nalms.org for more information and to submit your abstract.

Conference Theme

There may be no locale more appropriate to host a discussion on the impact of development on natural spaces than Banff National Park, Alberta. Established in 1885, Banff is Canada's first national park. Hosting millions of visitors annually, Banff exemplifies the need for a sustainable balance between economic development and conservation. Alberta has undergone significant landscape change during the last hundred years. Intact ecosystems have been altered by rapid population growth and a thriving natural resource-based economy. However, there is a strong desire to improve lake management in Alberta, and the Alberta Lake Management Society celebrates its 25th anniversary this year. We invite you to join us at the 2016 NALMS Symposium to help us celebrate, explore the area, and engage in discussions about science, stewardship and finding a balance between the environment, economy and social goals in lake management.

Important Dates

May 6, 2016
Abstracts due.

September 2, 2016
Registration and payment from presenters of accepted abstracts due.

September 9, 2016
Early-bird registration deadline.

October 21, 2016
Regular registration deadline.

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Preliminary Session Topics

We encourage the submission of abstracts for papers or posters on any of the topics listed below, or abstracts that address topics of broad interest to the lake and reservoir management community.

Aquatic Invasive Species (AIS)
- Early Detection of AIS and Emergency Response
- Curbing the Spread of AIS - The Role of Outreach, Partnerships & Policy
- The Westward Spread of Dreissenid Mussels
- Control Strategies for Aquatic Invasive Plants
- Dealing with Flowering Rush Infestations
- Control Strategies for AIS
- Emerging Technologies & Innovation in AIS Management
- Water Use and Infrastructure Concerns for AIS
- Non-native Fish Impacts & Management
- Investing in Prevention of AIS
- Aquatic Invasive Cyanobacteria

Water Quality and Limnology
- Cyanobacteria and Cyanotoxins: Causes and Control
- Cyanobacteria and Cyanotoxins: Occurrence and Monitoring
- Rapid Detection of Cyanotoxins
- Paleolimnology 1: Understanding Multiple Stressor Effects on Lakes
- Paleolimnology 2: Applications for Lake Management
- Paleolimnology 3: Novel Approaches to Obtain Lake Histories
- Ecology of Shallow Lakes
- Water Quality Monitoring Methods
- Arctic and Alpine Lakes
- Fish ecology
- Lake Eutrophication
- Plastic Beads in Aquatic Ecosystems
- Traditional Ecological Knowledge

Lake and Watershed Management
- Building Novel Lake Ecosystems in the Oil Sands Region
- Wetland Restoration
- Adaptive Lake Management
- Phoslock Application and Case Studies
- Hypolimnetic Withdrawal Systems
- Community-based Lake and Watershed Stewardship
- Citizen Science - Lake Monitoring Protocols
- Citizen Science - Data Management and Analysis
- Management of Treatment Lakes and Wetlands
- Integrated Watershed Planning
- Pigeon Lake Case Study – Watershed and Cumulative effects
- Contaminated Sites and Spills: Cleanup and Response
- Progress in Irrigation and Water Use Efficiency in Alberta
- Case Studies in Artificial Lake Mixing
- Lake of the Woods Region
- Regulatory Progress and Regional Planning
- Valuing Ecosystem Services
- Ecosystem Resiliency Program
- Management of First Nations Land and Water
- Impacts of Recreational Lake Use on Human Health

LakeLine

Contents

Volume 36, No. 1 / Spring 2016

On the cover:
2015 NALMS Photography Contest, People's Choice Second Place winner – "Dragonflies under a Blue Moon, Lake Superior" by Dick Osgood

Advertisers Index

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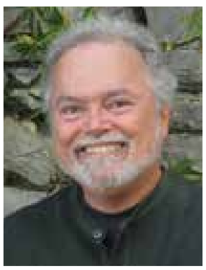
From the Editor

Bill Jones

LakeLine encourages letters to the editor. Do you have a lake-related question? Or, have you read something in *LakeLine* that stimulates your interest? We'd love to hear from you via e-mail, telephone, or postal letter.

The theme of this issue is "Internal Loading." This is appropriate for the spring issue because by the time you read this, many of our North American lakes have warmed up to the point where thermal stratification has occurred. Once the bottom waters of a lake or reservoir become isolated from the surface waters all sorts of changes are possible – some bad and some good.



Bacterial respiration and chemical reactions are two important processes that can consume oxygen in the hypolimnion of a productive lake containing an abundance of oxidizable substances. As dissolved oxygen is depleted, further reactions occur that can liberate phosphorus, manganese, and other substances from the sediment. This constitutes internal loading. These released substances are effectively trapped within the hypolimnion during summer stratification thereby unavailable to phytoplankton in the epilimnion (a good thing) during the growing season. They can be mixed throughout the lake during fall overturn but often this is too late to stimulate additional phytoplankton growth.

That each lake responds uniquely to thermal stratification and internal loading was made apparent to me during my very first lake assessment in Indiana. We were conducting a year-long assessment of Cedar Lake, a shallow 781-acre kettle lake in NW Indiana. The lake has a two-mile long wind fetch and winds off Lake Michigan keep the lake well-mixed. Results of our water sampling and loading models suggested that the lake was receiving more phosphorus than we could account for. The current literature we read stated that shallow lakes like Cedar shouldn't stratify so we didn't think internal loading was a problem. We then measured temperature and dissolved oxygen profiles every two hours over a 24-hour period and discovered that during calm overnights, the bottom waters went anoxic due to heavy respiration of highly-organic sediments. In the daytime, winds thoroughly mixed this P-loaded bottom water throughout the lake. The sediments were functioning like a nutrient pump on calm summer nights. P-release rates were then determined from intact sediment cores that confirmed that over 80 percent of total annual phosphorus load to Cedar Lake came from internal loading. (Access at: http://www.in.gov/dnr/fishwild/files/Cedar_Lake_Restor_Feas_Stdy_Lake_by_IUSPEA_Jan1984.pdf).

Bill James provides a great foundation for our exploration of the phenomenon of internal loading in our lead article. In it, he describes the dynamic physical, chemical and biological processes that contribute to internal loading and helps us better understand why internal loading can be such a persistent management problem. Then **Dick Osgood** weighs in with a discussion of what lake managers must focus on to effectively manage internal loading. The size of the affected lake's watershed relative to that lake's surface area is an important consideration. **Marc Beutel** reminds us that internal loading isn't only about phosphorus. He describes some of the mechanisms influencing the internal loading of nitrogen and mercury from lake sediments and their consequences. In our final theme article, **David Caron**, **Maxx Echt**, **James Folsom**, **Erica Seubert**, **Avery Tatters**, and **Alyssa Gellene** recount their study of Chinese Garden Lake, a small botanical garden lake in San Marino, CA. The unique features of this lake allowed them to implement several nutrient reduction measures that brought about improved water quality and a shift from a *Cylindrospermopsis*-dominated plankton community to one dominated by green algae.

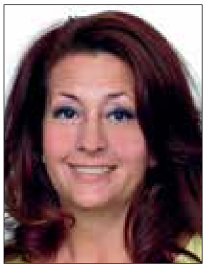
A bonus article by **John Rueter** is one that really intrigued me. In it, he presents several different views of a lake future that reflect different worldviews of stakeholders, to help guide them in discussions of the lake's future. This approach emphasizes positive views of the future rather than fear to foster civic cooperation in preparing a management plan.

In the "Student Corner" **Ted Harris** discusses his research into the role of persistent organic pollutants in the proliferation of cyanobacterial blooms.

NALMS President **Julie Chambers** shares her thoughts about internal loading in her column. We also include news from Indiana, Florida, Oklahoma, Oregon, Pennsylvania and South Carolina in "Affiliate News," the Call for Papers for this year's NALMS Symposium in Banff, the first announcement of the annual Photo Contest, and information on how you can celebrate Lakes Appreciation Month in July. We conclude this issue, as always, with "Literature Search."

Enjoy!

From Julie Chambers the President



As lake and watershed management become more integrated, it is critical that we have a good understanding of source contributions. This is necessary in order to employ best management practices whether it is in-lake or in the watershed. Lakes and reservoirs receive nutrient (particularly phosphorus) inputs from not only external sources in the surrounding watershed, but also from releases of bottom sediments. Sediments act as both a sink and a source of nutrient contributions to waterbodies. It is important to have a good understanding of this process and the role or contribution it has in terms of overall water quality and eutrophication. In order to do so, one must consider the processes in place that allow for the release of nutrients from the sediments. These can include water temperature, pH, dissolved oxygen concentration, and microbial activity. All can affect the rate and amount of release from the sediment.

Internal loading is often only estimated from other parameters, although this offers valuable insight in situations where measured rates are lacking, it can lead to misconceptions of lake function and potentially poor management decisions. If it's being measured, there are a lot of inherent challenges in accurately measuring it, and the methods chosen often only give a ballpark figure. This can lead to over- or under-estimates of nutrient concentrations, potentially impacting a multitude of decisions. Important source and transport mechanisms are often unaccounted for, such as equilibrium or pH mediated release from re-suspended or benthic sediments.

Internal loading is also used as a calibration parameter (through alteration of sediment release rates) in water quality models used for total maximum daily loads (TMDLs), watershed management plans, etc. With improvements in watershed management leading to lower external load contributions, a high internal load could maintain poor lake water quality conditions for years. When the models are calibrated, if the internal loading is set at a magnitude disparate to reality, then modeled improvements in watershed loadings could impact the lake model more than would actually be observed in reality. An example of this would be when a water quality model is not handling in-lake conditions such as stratification and dissolved oxygen levels appropriately. If these factors are not correct they can adversely impact internal loading calculations, which is sometimes accounted for by altering sediment release rates. Conceivably, the amount of BMPs needed to improve lake quality could be underestimated and expected water quality improvements would be unrealized. In tough budget times, it is especially critical that this information be captured accurately so that good management decisions can be made and put into place while making the most of funding available.

Julie Chambers is the Lakes Monitoring Coordinator for the Oklahoma Water Resources Board. She has been a part of the Water Quality division's monitoring section since 1999. Julie has been a member of the North American Lake Management Society (NALMS) for many years, has served on various committees, and was previously the Region 6 Director.

Internal P Loading: A Persistent Management Problem in Lake Recovery

William James

Phosphorus recycling between aquatic sediment and lake water

Internal phosphorus (P) loading is a term used to describe P movement and recycling between sediment in a lake and the water column. Phosphorus usually limits the growth of algae in freshwater systems and its enhanced availability via anthropogenic watershed runoff (i.e., external P loading) and internal P loading processes often leads to eutrophication and deterioration of ecosystem health such as frequent cyanobacterial blooms, dissolved oxygen depletion, poor water clarity, impaired fisheries, and declines in submersed aquatic plant communities that offer critical habitat for invertebrates and other biota. Since sediment P is ultimately derived from the watershed, land use practices that over-fertilize the soil and promote hydrological runoff can result in considerable deposition over decades and centuries of P-rich sediment in lake basins. Lakes are essentially traps for sediment and thus reflect the activities in its watershed. Internal P loading is, in essence, in-lake recycling of P that was derived from the watershed.

There are many mechanisms of internal P loading that can result in the movement of soluble P (i.e., the form of P that is readily assimilated by algae for growth) from sediment to the overlying water. The focus of this article will be on diffusion of P from the sediment porewater (i.e., interstitial water that surrounds sediment particles) directly into the water column (Figure 1). Rooted aquatic plants in the littoral can play an import role in promoting internal P loading by translocating P from the sediment into plant tissue during their growth phase, then releasing soluble P into the surrounding water during dieback. A myriad of aquatic invertebrates and

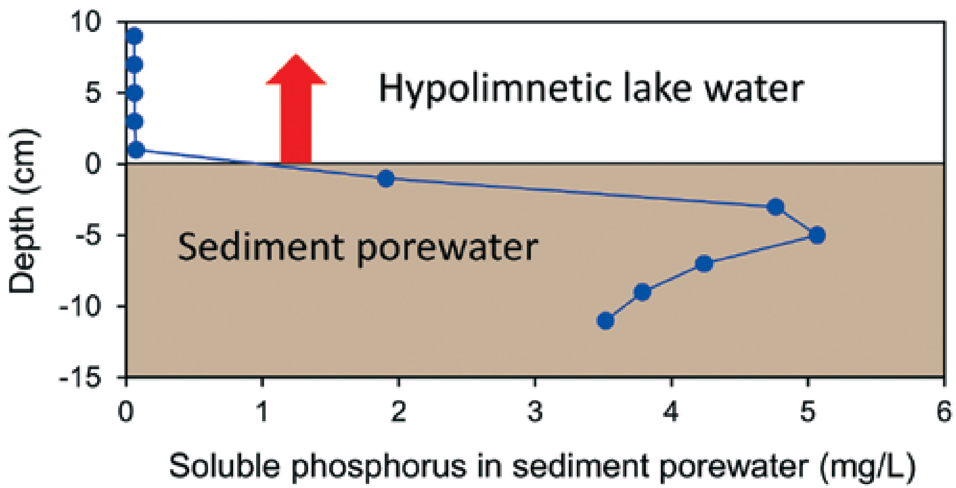


Figure 1. Variations in soluble phosphorus concentration (blue circles) in the overlying water and sediment porewater. The steep concentration differences at the sediment interface drive phosphorus diffusion toward the overlying water (direction of red arrow).

tubificid creatures inhabiting the sediment can cause internal P loading to the water by burrowing activities that mix sediment soluble P into the water. Benthic-feeding fish cause sediment disturbance and internal P loading on a larger scale. Finally, groundwater movement through P-rich sediments and wave-induced resuspension of sediment can result in transfer of soluble P from sediment to the water column for uptake by algae. P recycled to algae by any of these processes can become deposited back to the sediment in the form of algal remains or in fecal pellets from zooplankton or fish after being consumed.

Bacterial metabolism in the profundal and the role of iron reduction

Probably one of the most exciting areas of P recycling research, but a nemesis for lake managers, is internal P loading from the profundal sediment of lakes by diffusive flux from porewater (Nürnberg 2009). As lakes stratify during the summer into an epilimnion and hypolimnion divided by a thermocline, ecosystem metabolism and nutrient cycling processes become separated spatially and vertically. Movement and exchanges between these stratified layers becomes difficult and requires much work in the form of wind and heat transfer. In the euphotic (region receiving sunlight in the epilimnion) zone, algal photosynthesis and dissolved oxygen production maintains an aerobic environment for zooplankton, invertebrates, and fish populations.

However, biota inhabiting the dark aphotic (region where sunlight penetration is zero) zone rapidly deplete dissolved oxygen reserves in the hypolimnion as stratification progresses. Because water exchanges between the two zones are restricted by density stratification, there is little chance of dissolved oxygen replenishment and the hypolimnion becomes anoxic (i.e., devoid of oxygen).

However, life primarily in the form of bacteria thrives under anaerobic conditions in the hypolimnion. Instead of using oxygen as a final electron acceptor to release energy from organic matter (i.e., aerobic respiration), these organisms have evolved and adapted to use other electron acceptors such as nitrate (denitrification), manganese, iron, sulfate, and methane to survive and metabolize organic detritus (anaerobic respiration). Organic carbon produced in the euphotic zone rains downward into the hypolimnion and deposits onto profundal sediment as detritus, fueling anaerobic metabolism, which results in oxidation of organic matter to CO_2 (organic carbon loses an electron for energy production) with reduction (i.e., gains an electron) of an electron acceptor molecule other than oxygen.

What does this have to do with internal P loading? Oxidation-reduction reactions during anaerobic metabolism at the sediment-water interface drive the recycling of important elements like soluble P and iron that are in a form that can be taken up by algae for growth. Mortimer (1941) synthesized a scenario through his pioneering research that has become an important standard in our understanding of internal P loading from profundal sediment. Under aerobic and oxygenated conditions, phosphate (PO_4^{3-}) is adsorbed or precipitated with ferric (Fe^{3+}) iron oxyhydroxides (Fe-OOH~P) in the surface sediment. Freshly precipitated Fe-OOH is initially a very low molecular weight colloid particle consisting of iron and hydroxyl ions that polymerize (form chains). When associated with Fe-OOH, PO_4^{3-} is mostly removed from recycling pathways and in a form that cannot be taken up by algae. As hypolimnetic dissolved oxygen becomes depleted, anaerobic bacteria can use Fe-OOH as an alternate electron acceptor to produce energy from organic detritus. The bond between Fe-OOH and PO_4^{3-} becomes broken by bacterially mediated reduction of Fe-OOH to soluble Fe^{2+}, resulting in the diffusion of Fe^{2+} and PO_4^{3-} into the sediment porewater and eventually into the anoxic hypolimnion.

Phosphorus exchanges between the hypolimnion and epilimnion

As summer progresses, the slow process of diffusion at the sediment-water interface can lead to the accumulation of considerable soluble PO_4^{3-} and Fe^{2+} in the anoxic hypolimnion (Figure 2). By the end of summer stratification, soluble P concentrations may exceed 1 mg/L above the sediment surface with gradients of decreasing concentration extending up into the metalimnion. The availability of this hypolimnetic soluble P to algae residing in the epilimnion is dictated by several factors. Some algae and cyanobacteria can migrate vertically in the water column because they have flagella (a whip-like tail) or can regulate their buoyancy using gas vacuole structures within the cell. These features offer many competitive advantages including access to internal P loads by vertical migration into the upper hypolimnion. For instance, *Ceratium hirundinella* (a flagellated dinoflagellate) can migrate downward into the hypolimnion at night for nutrient uptake and then upward into the euphotic zone during the day for photosynthesis (Figure 3).

For other algae depending solely on water movement and turbulence to stay afloat in the euphotic zone, hypolimnetic soluble P must first become mixed into the epilimnion as PO_4^{3-} for uptake. Because density stratification is resistant to disruption and mixing, strong cold fronts, loss of heat from the lake's surface, and sustained winds are usually required for any chance of turbulence and entrainment

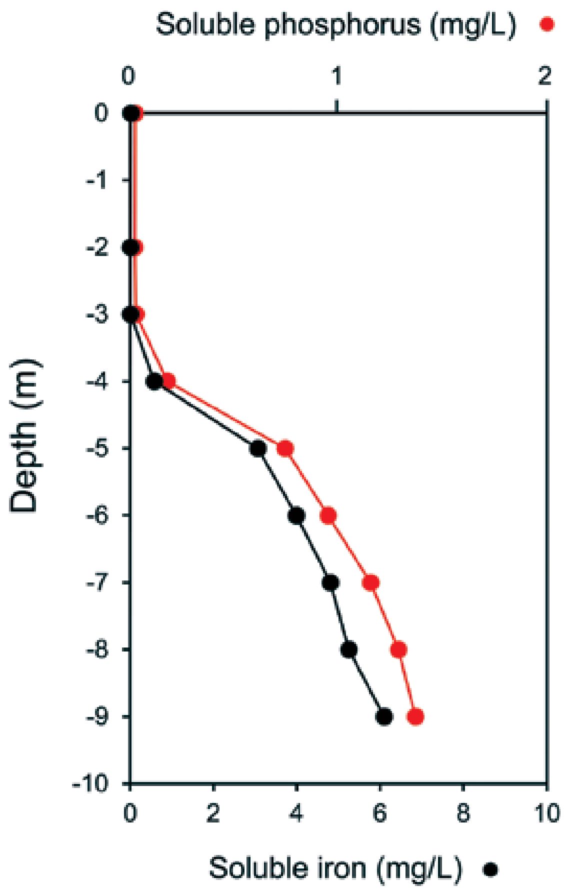


Figure 2. Vertical water column variations in soluble iron (black circles) and phosphorus (red circles) concentrations in Lake Desair, Wisconsin.

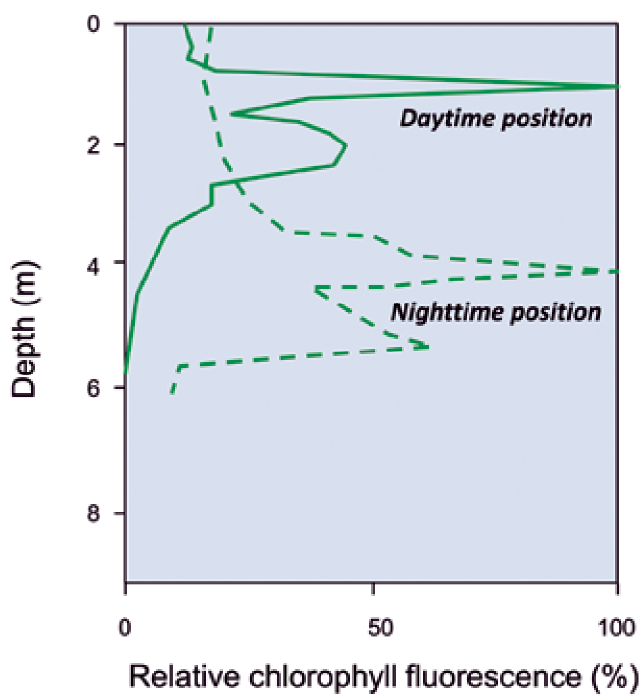


Figure 3. Daytime and nighttime depth position of a Ceratium hirundinella *bloom in Eau Galle Reservoir, Wisconsin (modified from James et al. 1992).*

of hypolimnetic soluble P into the surface waters. While water and nutrient exchanges can occur during summer stratification, cooling and heat loss is usually strongest during the fall and ultimately leads to complete water column mixing in a process known as autumnal overturn. During this event, hypolimnetic Fe^{2+} and PO_4^{3-} gradients become disturbed and both substances mix throughout the water column. In addition, dissolved oxygen mixes with and reoxygenates hypolimnetic water resulting in chemical oxidation of Fe^{2+} back to Fe-OOH and re-adsorption of PO_4^{3-}. Thus, the cycling of Fe from an oxidized state (Fe^{3+}) in the sediment to a reduced state (Fe^{2+}) in the anoxic hypolimnion back to an oxidized Fe-OOH colloidal precipitate during reoxygenation and eventual redeposition to the sediment is a process termed the Fe^{3+}– Fe^{2+} ferrous wheel (Campbell and Torgersen 1980).

Unfortunately for algae, chemical reaction to Fe-OOH sequesters PO_4^{3-}. The fate and availability of PO_4^{3-} after turnover events depends to a large extent on ratio of Fe^{2+} relative to PO_4^{3-} that previously accumulated in the anoxic hypolimnion. When there is sufficient Fe relative to P ("high" Fe:P ratio), most if not all of the PO_4^{3-} becomes coprecipitated or adsorbed to Fe-OOH during reaeration and deposits back to the sediment. The availability of PO_4^{3-} for algal uptake can be limited substantially under this scenario. An example of Fe – P interactions at a high Fe:P ratio is shown in Figure 4 for Lake Desair located in west-central Wisconsin. Although Fe and P concentrations were quite high in the hypolimnion as a result of internal P loading the Fe:P ratio was > 5:1 at the start of autumnal turnover suggesting adsorption of PO_4^{3-} and redeposition with little available PO_4^{3-} for uptake. Algal biomass, as chlorophyll, declined in late October as an apparent result of P-limitation of growth even though internal P loading was considerable.

In contrast, availability of profundal internal P loads to algae can be substantial when the Fe:P ratio is relatively low in the anoxic hypolimnion prior to reaeration. Incomplete binding and deposition of PO_4^{3-} by Fe-OOH can result in extensive and often toxic cyanobacterial blooms as PO_4^{3-} becomes entrained into the

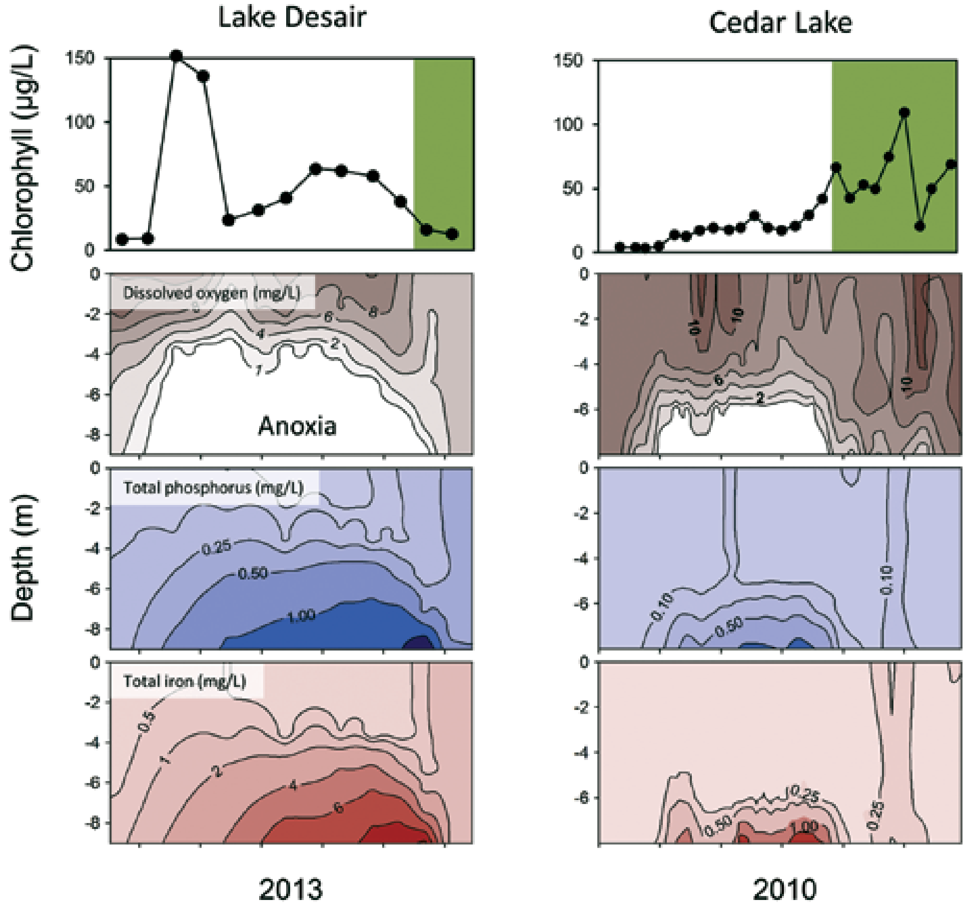


Figure 4. Seasonal variations in chlorophyll (upper panels) and contour profiles of dissolved oxygen, total phosphorus, and total iron versus depth in iron-rich (high Fe:P ratio) Lake Desair (left panels) and iron-poor (low Fe:P ratio) Cedar Lake (right panels; James et al. 2015). Chlorophyll concentration declined in Lake Desair while they increased in Cedar Lake during Autumnal turnover (green shaded areas).

surface waters and directly available for uptake and growth. Back at the sediment surface, Fe can become removed from recycling with PO_4^{3-} in the hypolimnion by reaction with sulfur to form inert and insoluble iron sulfide. Anaerobic bacteria residing in the sediment can promote FeS_x formation and burial by reducing sulfate to S (another metabolic reaction that releases energy from organic detritus). An example of Fe – P interactions at a low Fe:P ratio is shown in Figure 4 for Cedar Lake, Wisconsin (James et al. 2015). Although the sediment had very high Fe content, the buildup of Fe^{2+} in the anoxic hypolimnion was much less relative to PO_4^{3-}, resulting in an Fe:P ratio that was ~1:1. During and after Autumnal turnover and reoxygenation, chlorophyll concentrations reached seasonal peaks in conjunction with available PO_4^{3-} derived from sediment internal P loading.

Phosphorus management implications

Simply reducing watershed P loading to eutrophic lakes without also managing internal P loading may not be enough to reverse impaired water quality. Even though internal P loading is ultimately derived from the watershed, it can take years to decades to flush sediment P out of the system after watershed BMP implementation, resulting in delayed recovery and continued impairment. In addition, a symptom of decades of P retention as sediment in lakes is the buildup of a surface sediment P concentration bulge that is usually difficult to bury over time and persists as an important internal P source during hypolimnetic anoxia, stimulating and sustaining algal blooms despite other efforts of remediation (Figure 5). Unless controlled directly via P-adsorbing technologies such as aluminum salts, lanthanum-modified clays, or other

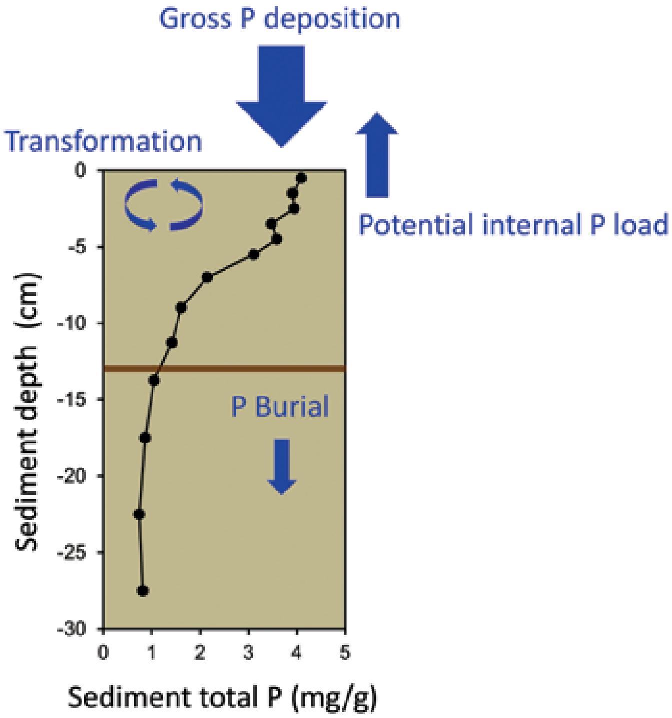


Figure 5. Variations in sediment total phosphorus concentration versus depth below the sediment-water interface. Development of a surface concentration peak in eutrophic lakes is a symptom of potential internal P loading from sediments (after Rydin et al. 2011).

measures, internal P loading from profundal sediments can provide a form of ecosystem feedback that maintains a eutrophic equilibrium that is resistant to management efforts.

References

Campbell, P. and T. Torgersen. 1980. Maintenance of iron meromixis by iron redeposition in a rapidly flushed monimolimnion. *Can J Fish Aquat Sci*, 37:1303-1313.

James, W.F., W.D. Taylor and J.W. Barko. 1992. Production and vertical migration of *Ceratium hirundinella* in relation to phosphorus availability in Eau Galle Reservoir, Wisconsin. *Can J Fish Aquat Sci*, 49:694-700.

James, W.F., P.W. Sorge and P.J. Garrison. 2015. Managing internal phosphorus loading and vertical entrainment in a weakly stratified eutrophic lake. *Lake Reserv Manage*, 31:292-305.

Mortimer, C.H. 1941. The exchange of dissolved substances between mud and water in lakes. *J Ecol*, 29:280-329.

Nürnberg, G.K. 2009. Assessing internal phosphorus load – Problems to be solved. *Lake Reserv Manage*, 25:419-432.

Rydin, E., J.M. Malmaeus, O.M. Karlsson and P. Jonsson. 2011. Phosphorus release from coastal Baltic Sea sediments as estimated from sediment profiles. *Est Coast Shelf Sci*, 92:111-117.

William (Bill) F. James is a professor and research aquatic ecologist at the University of Wisconsin – Stout. His research interests are in lake and reservoir phosphorus cycling and eutrophication management. His career in limnology spans 38 years with over 50 peer-reviewed publications. He is also an associate editor for *Lake and Reservoir Management*.

Internal Loading
Sustains Lake Phosphorus Impairments

Dick Osgood, CLM

When phosphorus (P) enters a lake – by any source or in any form – a large portion of it stays in the lake. For natural lakes, >90 percent retention is common. This excess P builds up in the lake bottom sediments. When the overall accumulation exceeds the burial rates, the pool of sediment P can recycle back into the water in a long-term, self-sustaining cycle – an unwanted gift that keeps on giving.

The phenomenon of internal nutrient loading (INL) has been long recognized. INL's confounding impacts relative to lake rehabilitation were first recognized with Shagawa Lake, MN. In that case, modeling estimated it would take 80 years for the lake to achieve a 90-percent recovery despite an 80-percent P reduction from wastewater effluent (Cooke et al. 2005).

INL is a significant sustaining factor in many eutrophic or phosphorus-impaired lakes.

With the clean-up of the nation's sewage-impacted lakes (for example, Lake Washington, WA), the overall lake restoration paradigm shifted to the mitigation of nonpoint phosphorus sources, that is, runoff from a lake's watershed. In the United States, mitigating eutrophication is driven largely through the administration of the Clean Water Act through the impaired waters designation and implementation of TMDLs (total maximum daily loads).

This shift in emphasis and strategy has largely been ineffectual – our lakes are not recovering.

At this time, half (50.1 percent) the nation's lakes remain eutrophic or hypereutrophic, 27-41 percent of lakes have moderate to high risk of exposure to algal toxins, and from 1972 through 2007, there has been no net change in lake trophic state (51 percent unchanged, 23 percent increased, 26 percent decreased; USEPA 2009).

There are two main reasons for this:

- Watershed management using best management practices (BMPs) is insufficient.
- INL is often a substantial factor.

The math is easy. In a typical case, a P-impairment results from a 10- to 20-fold increase (based on an un-impaired baseline) in P delivery to a lake following a period of agricultural or urban land conversion. Watershed management using BMPs *may* reduce this P load by 50 percent at best (in practice, this is much less). This leaves the P load at five to ten times over the baseline, meaning the lake impairment is sustained. When INL is involved, it must also be mitigated if the lake is to recover.

What phosphorus reductions need to occur and from what sources?

To restore a lake to a mesotrophic or un-impaired condition, phosphorus reductions from both external (watershed) and internal (INL) sources need to occur in most cases.

I have modeled (see Nürnberg 2009) hypothetical situations to illustrate guidelines and limitations of watershed management. Further, I have keyed this model to the watershed:lake surface area ratio. I have assigned moderate rates of phosphorus loading, comparable to suburban development densities (100 mgP°•year/m^2 or 1.1 pounds•year/acre; see Holdren et al. 2001; Shaver et al. 2007) and moderate rates of INL (6 mg•day/m^2; see Nürnberg 1988). In addition, I evaluated these scenarios for deep, mid-depth, and shallow lakes (Osgood Indices = 11, 7, and 3, respectively) (see Osgood 1988). Using these rates, applied to watershed:lake surface ratios, I estimated the percentage of external phosphorus reduction that would need to occur to achieve a lake phosphorus concentration [TP] of 30 parts per billion (ppb) or μg/L, the threshold for eutrophication. Figure 1 depicts the results.

There are several points to be made.

First, even with moderate intensities of phosphorus loading, substantial external phosphorus reductions are required to restore lakes, except for deep lakes in small watersheds. While beyond the scope of this article, I chose to illustrate the 50-percent watershed phosphorus threshold because in practice, this level of reduction *may* be achievable in ideal cases. More realistically, 25-percent reductions are the greatest practically attainable levels.

Second, shallow lakes with INL, are not sufficiently responsive to external phosphorus reductions. Even though internal phosphorus mobilization occurs by different mechanisms (turbulent mixing vs. redox mediated mobilization), its impacts are still large. External phosphorus reductions >90 percent are required to restore shallow lakes.

Finally, the watershed:lake surface area ratio can be used as an index to evaluate the potential for watershed management efficacy. Ratios > 5:1 to 10:1 indicate significant watershed management challenges, except for undisturbed watersheds. Watershed:lake surface area ratios from 7 to 10 are considered small (Holdren et al. 2001), so many lakes' watersheds are apt to be too large for a BMP strategy to be effective.

How can lake P be effectively restored?

When INL is in play, it will need to be mitigated. Below (in shaded box), I

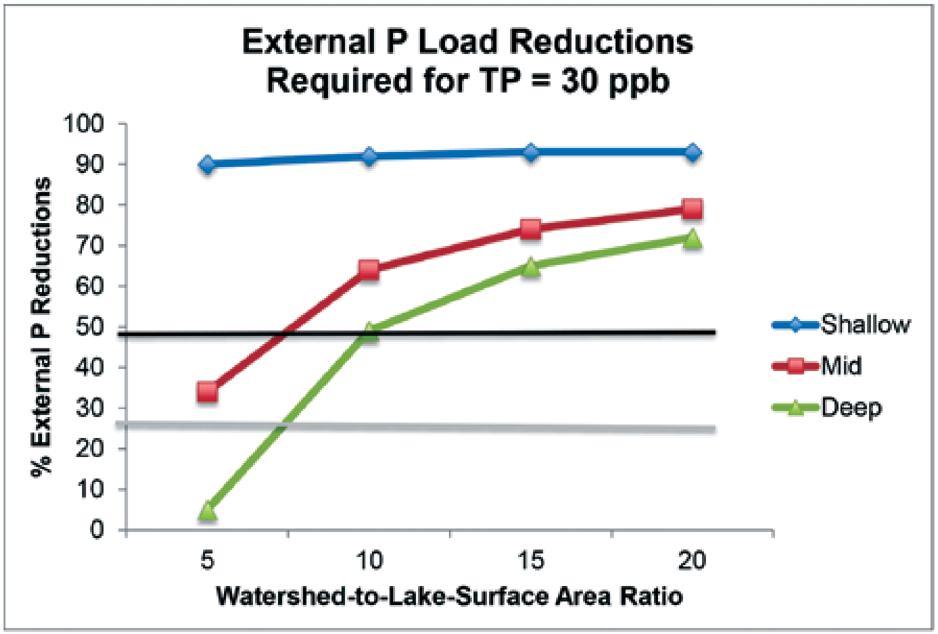


Figure 1. External phosphorus load reductions under various watershed to lake surface area ratios needed to achieve a [TP] = 30 µg/L. The horizontal lines in the figure, indicate 50 percent (black line) and 25 percent (grey line) external P reductions.

present a hypothetical example using the same loading rates (moderate external and internal P loading rates) and model as in the figure above.

There are several points to be made:

First, INL reductions are sufficient to meet the water quality criteria in the smallest (least impacted) watersheds.

Second, the combination of 25-percent external P reduction and 85-percent internal P reduction was chosen to represent realistic levels of P reductions from external and internal sources using available methods. Water quality criteria can be met using the combination strategy for somewhat more impacted deeper lakes.

Ratio*	External P Reductions (%)**	Internal P Reductions(%)***	Combo****
Shallow			
5	90	58	Yes
10	92	>99	No
15	93	>99	No
20	93	>99	No
Mid			
5	34	34	Yes
10	64	>99	Yes
15	74	>99	No
20	79	>99	No
Deep			
5	5	7	Yes
10	49	>99	Yes
15	65	>99	No
20	72	>99	No

*Ratio is watershed:lake surface area ratio.
**External P reductions required for [TP]=30 ppb (same as Fig. 1).
*** Internal P reductions required for [TP]=30 ppb.
****Will combination of 25 percent external and 85 percent internal P reductions meet [TP]=30 ppb?

Finally, for the most impacted lakes, extraordinary strategies will be required. Such chemical or engineering strategies may include intercepting runoff and treating it with alum, as is done in many Florida lakes (Harper 2013). Also, periodic water column phosphorus stripping treatments may be effective.

Summary

INL presents management challenges for restoring phosphorus-impaired lakes. The modeling presented here is meant as illustrative of a wide range of situations. This assessment can be useful for broad-scale policy and planning, but is not a substitute for evaluating each lake and watershed to be managed. Evaluating specific cases requires site-specific modeling and evaluation.

The overall lack of lake improvements in the United States suggests our reliance on watershed management is an incomplete or insufficient approach.

One explanation is the belief that external (watershed) phosphorus is the ultimate offending source and therefore it is most appropriate (at least philosophically) to address that source first and wait for a long enough time (but how long? Rissman and Carpenter [2015] estimated 250 years for Lake Mendota). In this context, INL has been referred to as a "symptom," implying it is a lessor or lower priority target for management.

Internally supplied phosphorus is no more a "symptom" then nonpoint source phosphorus is a "symptom" of excessive land alteration. Unless we are willing or able to reverse long-standing land uses on large scales, it is unproductive to apply this argument.

> We must stop calling internally supplied phosphorus a symptom – it is an equal part of the eutrophication syndrome as other phosphorus sources and should not be relegated to an afterthought.

As illustrated here, both external and internal phosphorus requires mitigation (in most cases) if we are to achieve lake water quality goals. Furthermore, our management strategies ought to be expanded to include all feasible and effective phosphorus reductions methods, evaluated based on feasibility, efficacy, costs and sustainability.

References

Cooke G.D., E.B. Welch, S.A. Peterson and S.A. Nichols. 2005. Restoration and Management of Lakes and Reservoirs. 3rd ed. Boca Raton (FL): CRC Press.

Harper, H. 2013. Control of watershed loadings using chemical treatment. *LakeLine*, 33:19-22.

Holdren G.C., W.W. Jones and J. Taggart. 2001. Managing Lakes and Reservoirs. N Am Lake Manage Soc and Terrene Inst, in cooperation with Office of Water Assessment Watershed Protection Division US EPA, Madison, WI.

Nürnberg, G.K. 1988. Prediction of phosphorus release rates from total and reductant-soluble phosphorus in anoxic lake sediments. *Can J Fish Aquat Sci*, 45:453-462.

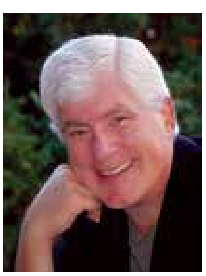
Nürnberg, G.K. 2009. Assessing internal phosphorus load – Problems to be solved. *Lake Res Manage*, 25:419–432.

Osgood R.A. 1988. Lake mixis and internal phosphorus dynamics. *Arch Hydrobiol*, 113:629-638

Rissman, A. and S.R. Carpenter. 2015. Progress on nonpoint pollution: Barriers and opportunities. *Daedalus*, 144(3):35-47.

Shaver, E., R. Horner, J. Skupien, C. May and G. Ridley. 2007. Fundamentals of Urban Runoff Management: Technical and Institutional Issues. N Am Lake Manage Soc. Madison, WI.

[USEPA] United States Environmental Protection Agency. 2009. National lakes assessment: A Collaborative Survey of the Nation's Lakes. EPA 841-R-09-001.



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The Other Internal Loading – A Look at Nitrogen and Mercury

Marc Beutel

Because it is such an important limiting nutrient in freshwaters, phosphorus has been the main focus of studies on internal loading and sediment-water interface processes in lakes and reservoirs. But the internal loading of a range of other compounds can profoundly affect water quality. Two obvious candidates are the redox-sensitive metals iron and manganese, which can complicate potable water treatment and distribution. In this brief paper, I discuss two additional compounds that are not typically linked with internal loading in lakes and reservoirs: nitrogen which, depending on its form, is a nutrient and toxin; and mercury, which in its toxic organic form can efficiently bioaccumulate in aquatic food webs.

Nitrogen

A compound of primary importance in surface water quality is nitrogen. Nitrogen limitation or co-limitation of nitrogen and phosphorus in lakes may be more common than generally recognized, making nitrogen a potentially significant driver of eutrophication in certain freshwater systems (Elser et al. 2007). Nitrogen in the form of ammonia is highly bioavailable and can stimulate phytoplankton growth in nitrogen-limited waters. The unionized form of ammonia (NH_3) is also toxic to aquatic biota, with the effects exacerbated at high pH and temperature. Finally, ammonia can exert an oxygen demand in waters as it is oxidized to nitrate via microbial nitrification. Nitrogen in the oxidized form of nitrate is highly mobile in the environment and is known to accumulate in groundwater below nitrogen-fertilized agricultural areas. In addition to its potential to stimulate eutrophication in nitrogen-limited waters, a concern with nitrate is the health threat it poses to infants. At concentrations above 10 mg-N/L, nitrate can induce methemoglobinemia, also known as blue baby syndrome. Nitrate ingestion promotes the conversion of hemoglobin, a ferrous-iron-containing molecule with high affinity for oxygen, to ferric-iron-containing methemoglobin, which has a low affinity for oxygen. Because infants have low levels of enzymes that reduce methemoglobin back to hemoglobin in their blood stream, their bodies can go hypoxic and turn a shade of blue – the "blue" in blue baby syndrome.

At the profundal sediment-water interface, nitrogen cycling is tightly coupled to the oxygen status of overlying water. Under oxic conditions, oxygen penetration into sediment promotes oxidation of organic matter, uptake of ammonia into fast-growing heterotrophic microbial biomass, and the oxidation of liberated ammonia to nitrate, which, in turn, is susceptible to conversion to nitrogen gas via microbial denitrification in deeper, anoxic sediment. Under anoxic conditions, the lack of oxygen represses these mechanisms and ammonia liberated from the decay of organic matter builds up in pore water and diffuses into overlying water. Studies at a range of lakes and reservoirs show that the potential for profundal sediment to release ammonia under anoxic conditions is strongly influenced by trophic status (Figure 1; Beutel 2006). A similar pattern between sediment anoxic release rate and trophic status is observed for phosphorus (Nürnberg 1988). Higher trophic status is associated with higher loading of organic matter into the profundal zone, which, in turn, enhances the supply of nitrogen to the sediment for subsequent release and promotes reduced conditions conducive to sediment release of ammonia. Typical release rates for oligo-mesotrophic, meso-eutrophic, and eutrophic-hypereutrophic sites measured in bench-scale sediment-water interface incubations are below 5, 5 to 10, and above 15 mg-N/m^2-d, respectively. Levels exceeding 50 mg-N/m^2-d have been measured in hypereutrophic systems. In Walker Lake, an alkaline terminal saline lake in Nevada, internal loading of ammonia resulted in chronically toxic concentrations of unionized ammonia to cutthroat trout, which were already under ecological pressure as a result of poor summer cold-water habitat (Beutel et al. 2001). In this strongly nitrogen-limited lake, the internal loading of ammonia also enhanced phytoplankton productivity, which, in turn, exacerbated hypolimnetic anoxia and reinforced ammonia release from anoxic profundal sediment. (*Ed. note:* for more on Walker Lake, see the fall 2014 issue of *LakeLine*.)

A handful of studies have documented the effect of oxygen addition to bottom waters on hypolimnetic ammonia accumulation. Bubble-plume oxygenation in Amisk Lake, Canada, resulted in a drop in average hypolimnetic ammonia concentrations from around 0.12 to 0.05 mg-N/L (Prepas et al. 1997). In Camanche Reservoir, a large multi-purpose reservoir located in northern California, Speece cone oxygenation resulted in a decrease in peak levels of hypolimnetic ammonia from around 1.4 to below 0.2 mg-N/L (Alex Horne, unpublished). In both Amisk Lake and Camanche Reservoir, the observed decrease in ammonia was not coupled with a concurrent increase in nitrate, thus oxygenation caused a net decrease in the mass of inorganic nitrogen in the lake's hypolimnion. In addition, in both water

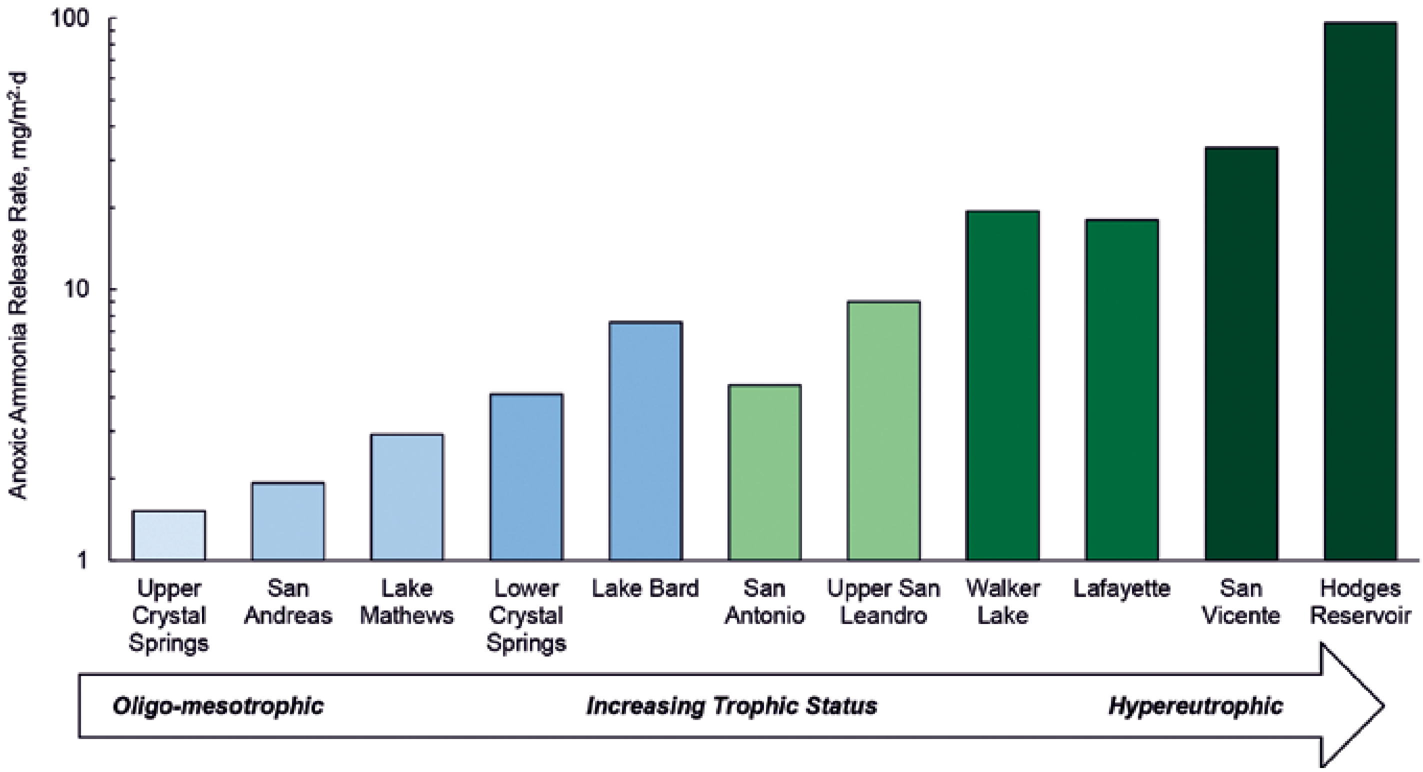


Figure 1. Average ammonia release rates measured in replicate anoxic sediment-water chamber incubations as a function of lake trophic status. All sites are raw water reservoirs in California, except for Walker Lake, a terminal saline lake in Nevada. Adapted from Beutel (2006).

bodies oxygenation resulted in a decrease in summertime chlorophyll *a*, presumably through the control of internal nutrient loading including phosphorus and/or nitrogen.

Mercury

Mercury contamination in aquatic ecosystems is a widespread threat to human and wildlife health. Key sources of inorganic mercury to aquatic ecosystems include atmospheric deposition of mercury emitted from coal combustion, releases from artisanal and small-scale gold mining, and point-source discharges from chlor-alkali plants and mercury mines. Inorganic mercury is converted to toxic organic methylmercury by bacteria in anaerobic sediment common in aquatic sediment. Methylmercury then accumulates in bacteria and algae, and then concentrates up the food web into zoobenthos, zooplankton, and fish.

Humans and wildlife are exposed to mercury mainly through consumption of mercury-contaminated fish. Methylmercury is a potent neurotoxin that impairs reproduction and fetal development. Dozens of U.S. states have statewide fish consumption advisories due mainly to Hg contamination and over six million hectares of U.S. lakes have fish consumption advisories in place because of elevated Hg concentrations in fish (USEPA 2011). A number of total maximum daily load (TMDL) programs are being implemented that dictate acceptable mercury load allocations to pollutant sources. In California, a mercury TMDL for the Guadalupe River Watershed, which includes a number of reservoirs polluted by the New Almaden Mining District, includes specific mercury criteria for a range of ecosystem compartments including creek waters, MeHg in bottom waters in reservoirs, and MeHg on wet weight basis in upper trophic level fish.

With increasing regulatory focus on mercury accumulation in aquatic ecosystems, there is growing interest in understanding the processes that control internal loading of methylmercury in the profundal zone of lakes, a key locale of methylmercury production. Whole lake mixing at fall destratification is a critical conduit of mercury into the food web in lakes and reservoirs. A unique study in Davis Lake, California, showed that upon destratification a pulse of methylmercury moved through the base of the food web and into zooplankton and small fish (Slotton et al. 1995). Bottom water methylmercury also finds its way into the base of the aquatic food web via diffusion across the thermocline and when zooplankton migrate into dark, methylmercury-rich bottom water to avoid predation (Beutel et al. 2014). Since methylmercury accumulation in bottom water is tied to anoxic conditions, researchers are exploring strategies to repress anoxia and decrease methylmercury bioaccumulation.

My recent work has explored how oxygen affects the magnitude of methylmercury from profundal lake sediments (Figure 2). At both a non-mercury polluted site (Hodges Reservoir, San Diego, California) and a mercury-polluted site (Almaden Lake, San Jose, California), the presence of oxygen in overlying water and the maintenance of a well-oxygenated sediment-water interface dramatically lowered methylmercury efflux from sediment. It is interesting to note in that the magnitude of anoxic methylmercury release was the same magnitude for both the non-polluted and polluted lake, reinforcing the non-linear and complex nature of mercury cycling in aquatic systems. The city of San Diego is installing a cone oxygenation

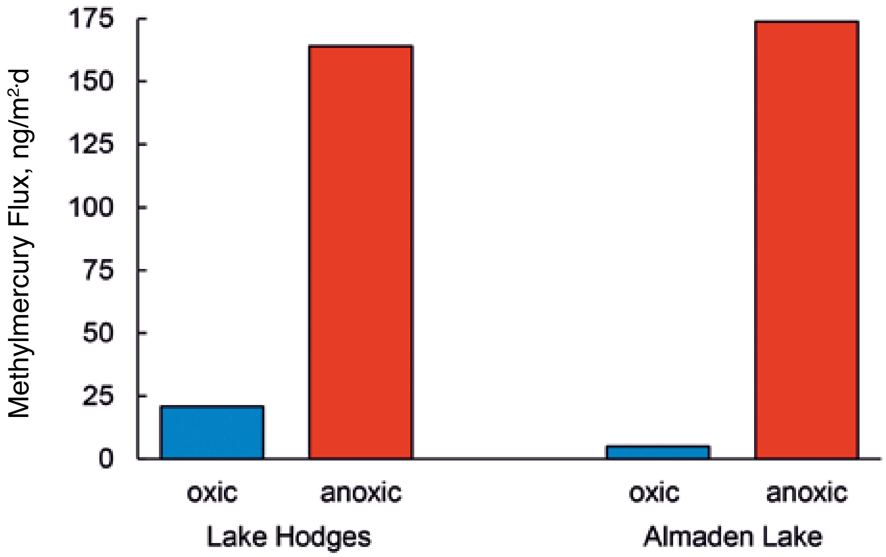


Figure 2. Average methylmercury release rates measured in replicate 9-day sediment-water chamber incubations under oxic and anoxic conditions. Lake Hodges is a hypereutrophic reservoir in San Diego, California. Almaden Lake is a mercury contaminated quarry lake in San Jose, California. Beutel (unpublished).

system in Hodges Reservoir with a delivery capacity of ~10 metric tons of dissolved oxygen per day with the goal of enhancing water quality in this backup water supply reservoir. While the main objective of oxygen addition is to lower internal nutrient loading, the California State Water Board is helping to fund monitoring of mercury cycling before and after oxygen addition. The Santa Clara Valley Water District, which manages Almaden Lake, has recently installed line diffuser oxygenation systems in a number of mercury-impacted reservoirs near San Jose, California with the specific goal of repressing methylmercury accumulation in bottom waters (McCord et al., in review). (*Ed. note:* See Moore et al. in the spring 2015 *LakeLine* for a comprehensive review of aeration technology.)

Other researchers have focused on the use of nitrate as a sediment oxidant to repress methylmercury buildup in bottom water. A bottom-water nitrate addition project in Onondaga Lake, a mercury-contaminated lake in Syracuse, New York, yielded a 95-percent decrease in methylmercury concentrations in bottom water (Matthews et al. 2013). Recently reported sediment-water chamber work at Onondaga Lake showed that presence of oxygen and nitrate, oxygen only, and nitrate only in water overlaying sediment lowered methylmercury release relative to anaerobic condition (Galicinao, in review).

Conclusion

Lake and reservoir managers generally agree that controlling internal loading of phosphorus is critical to improving water quality in many waterbodies, particularly those where external loading has been controlled but water quality improvements have not been achieved. But it is important to keep in mind that the phenomena of internal loading in lakes includes a range of other compounds, some of which were discussed here. Of particular importance is recognizing that anoxic sediment releases both phosphorus and ammonia, which together perhaps more than phosphorus alone, can exacerbate eutrophication in surface waters.

Recognizing that internal loading includes multiple pollutants paints a more complex picture of managing water quality in lakes. But the fundamental mechanism that controls phosphorus release from profundal sediment – low redox potential at the sediment-water interface – also controls the release of many other compounds, including ammonia, manganese, iron, and methylmercury. Thus, from a management perspective, strategies that control one compound may control others. But there are interesting caveats to this idea. The use of aluminum sulfate (alum), which represses anoxic phosphorus release from sediment by enhancing sorption capacity, will not repress ammonia, manganese, iron, and methylmercury release. And there is concern that sulfate addition with alum treatment may enhance methylmercury production by promoting the activity of sulfate-reducing bacteria that are known to methylate ionic mercury. Nitrate addition can repress the release of redox-sensitive compounds, including phosphorus and iron, by poising redox at the sediment-water interface. But because the redox potential of nitrate reduction overlaps with manganese reduction, nitrate may not be effective in repressing sediment release of manganese, a compound that can complicate water treatment and distribution. Nitrate addition will not repress ammonia release from sediment since the presence of oxygen is needed to promote nitrification. If nitrate undergoes microbial dissimilatory reduction to ammonia, nitrate addition could enhance ammonia production at the sediment-water interface. Perhaps the additive with the most comprehensive effect on internal loading of pollutants is oxygen – presuming that oxygen addition is done in such a way to penetrate into profundal sediment and maintain a well-oxygenated sediment-water interface. By poising redox at high levels, oxygenation can repress phosphorus, manganese, iron, and methylmercury release, while also promoting ammonia oxidation. Oxygen addition can also enhance cold-water habitat for zooplankton and fish.

References

Beutel, M.W. and others. 2014. Effects of hypolimnetic oxygen addition on mercury bioaccumulation in Twin Lakes, Washington, USA. *Sci Total Environ*, 496: 688-700.

Beutel, M.W. 2006. Inhibition of ammonia release from anoxic profundal sediments in lakes using hypolimnetic oxygenation. *Ecol Eng,* 28: 271-279.

Beutel, M.W. 2001. Oxygen consumption and ammonia accumulation in the hypolimnion of Walker Lake, Nevada. *Hydrobiologia,* 466: 107-117.

Elser, J.J. and others. 2007. Global analysis of nitrogen and phosphorus limitation of primary producers in freshwater, marine and terrestrial ecosystems. *Ecol Letters,* 10: 1135-1142.

Galicinao, G.A. and others. Microprofiling and microcosm studies of methylmercury flux inhibition in lake sediments amended with nitrate and oxygen. In review with *J Environ Research*.

Matthews, D. and others. 2013. Whole-lake nitrate addition for control of methylmercury in mercury-contaminated Onondaga Lake, NY. *Environ Res,* 125: 52-60.

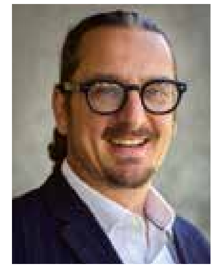
McCord, S.A., M.W. Beutel, S.R. Dent and S.G. Schladow. Evaluation of hypolimnetic oxygenation to control methylmercury bioaccumulation in mercury-impacted seasonally stratified reservoirs. In review with *Water Resources Research*.

Nürnberg, G.K. 1988. Prediction of phosphorus release rates from total and reductant-soluble phosphorus in anoxic lake sediments. *Can J Fish Aquat Sci,* 45: 453-462.

Prepas, E.E. and others. 1997. Introduction to the Amisk Lake Project: oxygenation of a deep, eutrophic lake. *Can J Fish Aquat Sci,* 54: 2105-2110.

Slotton, D., J. Reuter and C. Goldman. 1995. Mercury uptake patterns of biota in a seasonally anoxic northern California reservoir. *Water Air Soil Pollut,* 80: 841-850.

[USEPA] United State Environmental Protection Agency. 2011. Biennial National Listing of Fish Advisory. EPA-820-F-11-014, Washington, D.C.



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Managing Algal Blooms at a Botanical Garden Lake: **A Success Story**

David A. Caron, Maxx Echt, James Folsom, Erica L. Seubert, Avery O. Tatters, and Alyssa G. Gellene

Blooms of microscopic cyanobacteria and algae have become a major concern for inland water quality across the country and throughout the world (Brooks et al. 2016). These species are vital components of aquatic food webs, but excessive growth can lead to aesthetically unpleasing accumulations, disruption of food webs, and increased oxygen demand. Additionally, the growth of some toxic species can create conditions that may be harmful to aquatic wildlife and terrestrial animals (including humans) exposed to the blooms or contaminated water or food sources. Effective management of water quality to mitigate or prevent the development of such Harmful Algal Blooms (HABs) has become a top priority in the stewardship of U.S. inland waters.

The study site up to 2011

The Huntington Library, Art Collection and Botanical Gardens, San Marino, California is a private, non-profit institution founded in 1919 and open to the public in order to promote research and education in the arts, humanities, and botanical sciences. The botanical gardens of The Huntington cover 120 acres, and its collections are organized into more than a dozen specialized gardens. One of these, the Garden of Flowing Fragrance was opened to the public in 2008, and is one of the largest Chinese-style gardens outside China, including an artificial lake constructed with a concrete bottom in 2006 with a surface area of ≈1 acre. The lake holds approximately 877,000 gallons of water (≈3.3 million liters), and has a mean depth of 4.4 ft. (1.3 m). The lake was built with no natural inputs or outlets, and evaporative losses of water for most years constitute 2-3X the volume of the lake. These losses are compensated by the addition of water drawn from local deep wells. The lake is equipped with a gravel biofilter that controls ammonium levels in the lake by stimulating nitrification of ammonia to nitrate, but this process does not affect overall nitrogen and phosphorus loading.

Identifying the problem: nutrient inputs and outputs

Observations in the summer of 2011 indicated a massive accumulation of planktonic algal/cyanobacterial biomass in the lake three years after it was open to the public (Figure 1A-E,G; Table 1). While substantial amounts of microalgae were apparent in previous years, chlorophyll values in excess of 300 μg/liter were observed in some areas of the lake during 2011, indicating hypereutrophic conditions (Figure 1D; Table 1). Moreover, the plankton community at that time was strongly dominated by the cyanobacterium, *Cylindrospermopsis raciborskii* (Figure 1F), a cyanotoxin-producing species that is also capable of converting N_2 into cellular nitrogen (nitrogen fixation). Toxin analysis by HPLC, and confirmed by standards, demonstrated the presence of the cyanotoxin cylindrospermopsin, as well as saxitoxin and the saxitoxin analogue, 21-sulfosaxitoxin.

Total nitrogen and phosphate concentrations in the lake were high (Table 1), with the overwhelming percentages of those elements present as particulate material (biomass of suspended cyanobacteria, algae, and detritus). Dissolved nutrients were very minor components of the total concentration of those elements. Significantly, the water source for replenishing the ponds (from the Garden's deep wells) is low in phosphorus (6.2 μg/liter) but high in nitrogen (5,600 μg/liter). Despite the low phosphorus concentration in the well water, total phosphorus in the lake was ≈930 μg/liter, 150X the concentration in well water. This situation implied that more important sources of phosphorus must exist for the lake.

The concrete lining of the Chinese Garden Lake effectively keeps major nutrients entering the system within the water, biota, and sediment of the lake, with the obvious exception that nitrogen fixation and/or denitrification (conversion of ammonia to N_2) may occur. As a consequence, internal loading of nutrients has steadily progressed since the construction of the lake. There have been multiple sources of nutrients to the lake, in addition to nutrients entering from well water replenishment, and the rare and highly episodic rain events that characterize Southern California (regional rainfall is <15 inches, or 38 cm per year). Care was taken during design and construction to limit nuisance runoff from the lawn and botanical holdings within the drainage basin of the lake, and fertilizer is used sparingly in the catch area. Resident and transient populations of waterfowl and California Gulls also frequent the lake (it is estimated that ≈30 birds visit the lake daily). They are not intentionally fed, but contribute an unknown and possibly significant amount of excreta to the lake summed over multiple years.

The lake has also supported a substantial population of ornamental fish (≈100 koi) from the beginning, and fish food was identified as a potentially major source of nutrients to the lake, particularly for phosphorus. Phosphorus is generally a key element limiting the overall productivity of lakes (Elser et al. 2007). Although its concentration is relatively low in the well water used to replenish

Figure 1. The Huntington Garden's Chinese Lake in summer 2011. Hypereutrophic conditions dramatically affected water color and reduced transparency (A-C). Chlorophyll concentrations in lake water exceeded 300 µg/liter (D) due to the presence of high abundances of the toxin-producing cyanobacterium, Cylindrospermopsis raciborskii *(F). Resident and transient birds populations (E), ornamental fish (G) and their wastes contributed to nutrient loading in the lake.*

Table 1. Characteristics of the Huntington Garden's Chinese Lake in summer, 2011. Chlorophyll concentrations indicated hypereutrophic conditions in the lake. Most (≈99%) of the total nitrogen and phosphorus in the water column of the lake were contained in suspended particulate material (microalgae, cyanobacteria and detritus).

Sample Location in Lake	Chlorophyll Concentration (μg/liter)	Particulate Nitrogen (μg/liter)	Inorganic Nitrogen (μg/liter)	Particulate Phosphate (μg/liter)	Inorganic Phosphorus (μg/liter)
North end	252	6,500	83	900	8.0
South end	310	4,020	31	250	5.6

the lake as noted above, approximately 3.5 kg/week of fish food was added up to 2011, contributing 32 g phosphorus/week. That amount of phosphorus constitutes ≈465 μg/liter phosphorus addition annually to the lake, if distributed evenly throughout the lake volume. Therefore, fish food alone might account for total phosphorus concentrations in the water column of the lake within three years, although some immobilization in the sediments undoubtedly occurs.

Mechanical attempts to remediate the lake failed or proved unfeasible

As noted above, the biofilter installed in the lake at the time of construction did not maintain low algal biomass in the water column, but it was not designed to do so. A sand filtration platform containing the finest sand was deployed in the lake for several months in an attempt to reduce algal/cyanobacterial biomass, but water samples collected at the intake and output of the filter showed that *C. raciborskii* passed through the filter with very little reduction in abundance, presumably due to the narrow diameter of the cells. A bag filtration system equipped with 1 μm mesh bags did reduce algal/cyanobacterial abundances in the water passing through the filter, but the process was deemed financially impractical because hundreds of bags and considerable effort would be required to significantly impact overall abundance in the lake. Similarly, at the scale required to reduce and maintain low algal/cyanobacterial biomass, an industrial diatomaceous earth filtration system was also deemed impractical. The filter removed as much as 85 percent of the standing stock of algae and cyanobacteria from the lake water, but installation and maintenance would be expensive as a long-term solution.

Other solutions were considered but discarded: the application and removal of hay, sonication, UV light, flocculation and sedimentation, chemical treatments, increased shading, oxygenation, and enhanced circulation. It was deemed that these activities or additives might negatively impact the lake flora or fauna, its aesthetic value, and, more importantly, ultimately not address the basic issue of nutrient loading.

An evolving solution to nutrient loading: A three-pronged approach

Given that the filtration approaches tried in the lake proved either ineffective or impractical, a management strategy was devised for reducing nutrient loading and specifically targeting phosphorus loading in the lake (because the dominant cyanobacterium, *C. raciborskii*, is a nitrogen-fixing species, it was assumed that controlling nitrogen would be ineffective). The approach relied on (1) mechanically reducing existing nutrient loads in the lake, (2) reducing the rate of nutrient inputs by addressing the largest probable source (input of fish food), and (3) redesigning water handling for the lake to enact periodic removal of lake water as a means of achieving an acceptable steady-state nutrient concentration in the lake.

As a first step, during November 2011, the lake was drained and its sediment removed (Figure 2A). Nutrient loading of lake sediments, and subsequent release into the water column and bloom stimulation or prolongation, is a common phenomenon of shallow lakes. Sediment removal can be an effective strategy for reducing total phosphorus loading, if such activity is feasible (Bormans et al. 2015). Phosphorus removal as sediment was approximated from the depth and areal extent of the sediment, and estimated phosphorus content of the sediment (Søndergaard et al.), at >20 kg phosphorus. If the sediment-bound phosphorus were completely available to be remobilized into the water column of the lake, phosphorus in the sediment corresponded to an overall phosphorus concentration in the lake volume on the order of 1 mM phosphorus. Not all of the phosphorus in the sediment would be bioavailable to the algae and cyanobacteria in the lake, but sediment removal clearly constituted a massive reduction in phosphorus available to support planktonic algae in the lake (compare value to values in Table 1). The lake was refilled in late November 2011.

Our estimation of the amount of fish food added weekly to the lake (and subsequent excretion of nutrient wastes by the fish) clearly indicated an important source of nutrient loading. As a consequence, koi numbers were reduced by approximately half (≈50) in the lake, and the amount of fish food was reduced by a similar amount.

Periodic removal of lake water was also enacted to help reduce plankton and nutrient loads in the lake. The original design of the lake had no outlets, so internal nutrient buildup was inevitable. Removal was accomplished through the design and construction of a simple piping system that pumped lake water into the supply line used to irrigate the botanical holdings of The Huntington. Water pumped from the lake by this system has averaged approximately two-three lake volumes per year, with the water replaced with well water also used for restoring evaporative losses. Assuming a concentration of total phosphorus in the lake's water column during 2011 (930 μg/liter), removal of the lake water containing planktonic microorganisms, detritus and dissolved substances in the water could remove >10 kg phosphorus/year, less if clearer water persisted in the lake.

Lake status and lessons learned

The Chinese Garden Lake at The Huntington is a clear lake today with a minimal standing stock of suspended microalgae and cyanobacteria (Figure 2B). The initial status of the lake and overall changes enacted are depicted in Figure 3, indicating removal of sediment, reduction in fish and fish food, and periodic exchange of lake water. The combined effect of these activities has resulted in sustained high water quality and clarity. Moreover, the composition of the plankton community has shifted from dominance by toxin-producing cyanobacteria to a community dominated by innocuous green microalgae (specifically desmids), reducing health risks to fish and birds living in or frequenting the lake.

The experiences of The Huntington in addressing issues with their lake serve as an example of the multiple pathways and approaches that are available in developing and enacting effective lake management practices. A preliminary assessment of nutrient inputs to the lake identified several potentially important sources of nutrient elements, and a wide array of procedures and practices for reducing them. Preliminary efforts were able to quickly rule out many of these possible approaches as either ineffectiveness or impractical. In particular, physical removal by filtration was thwarted by the small cell diameter of the dominant cyanobacterium, and the cost associated with maintenance of the systems. Additionally, the Garden chose to avoid chemical treatments that might be effective in treating bloom outbreaks but would not address long-term internal nutrient loading. As a result, they adopted an approach that involved a combination of activities to address nutrient loading in the lake.

The small size of the Chinese Garden Lake (≈1 acre) was unquestionably an advantage in allowing activities that might not be feasible in larger artificial or natural lakes. Nevertheless, some approaches evaluated by the Garden were deemed impractical or too costly even for the relatively small aquatic ecosystem of their lake. Their situation also benefited from the unique need for substantial amounts of irrigation water for their botanical holdings. That enabled removal of the lake water (and the nutrient elements present as biota, dissolved organic compounds, and inorganic forms of nitrogen and phosphorus) to help counteract nutrient buildup in the lake, while also providing a use for that water that avoided the cost of treatment or disposal of the lake water.

Figure 2. Drainage of the lake and sediment removal in November 2011 (A) enacted to reduce nutrient loading in the lake. Five years following sediment removal and changes in nutrient management practices, the Chinese Lake (B) remains clear and virtually free of harmful algae and cyanobacteria.

These unique features place caveats on the extrapolation of the results from the Chinese Garden Lake of The Huntington to other lakes and ponds.

Each lake must be evaluated in light of its unique physical, chemical, and biological characteristics in order to develop and apply best management practices. However, we feel that the example presented here could be applied, in some form, to numerous water bodies of botanical gardens, zoos, parks, and other holdings that are manageable in size and suffer many of the same aspects of nutrient loading.

Selected References

Bormans, M., B. Maršálek and D. Jančula. 2015. Controlling internal phosphorus loading in lakes by physical methods to reduce cyanobacterial blooms: a review. *Aq Ecol*, 49: 1-16.

Brooks, B.W., J.M. Lazorchak, M.D.A. Howard, M.-V. Johnson, S.L. Morton, D.A.K. Perkins, E.D. Reavie, G.I. Scott, S.A. Smith and J.A. Steevens. 2016. Are harmful algal blooms becoming the

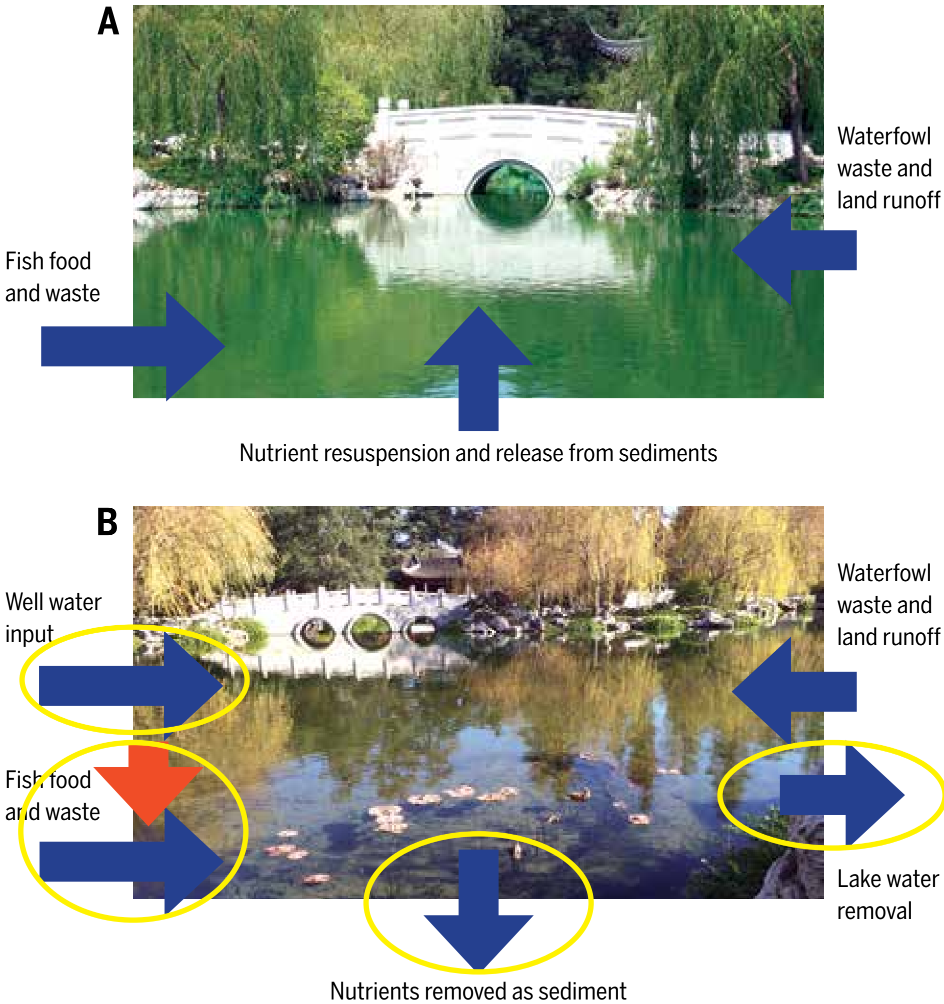

Figure 3. (A) The eutrophic state of The Huntington Garden's Chinese Lake resulting from internal loading of nutrients contained in fish, fish food, wildfowl, and land runoff. (B) Reductions in fish and fish food, removal of sediment to address accumulated internal nutrient loads, and periodic exchange of water are highlighted in the yellow circles.

greatest inland water quality threat to public health and aquatic ecosystems? *Environ Toxicol Chem*, 35: 6-13.

Elser, J.J., M.E.S. Bracken, E.E. Cleland, D.S. Gruner, W.S. Harpole, H. Hillebrand, J.T. Ngai, E.W. Seabloom, J.B. Shurin and J.E. Smith. 2007. Global analysis of nitrogen and phosphorus limitation of primary producers in freshwater, marine and terrestrial ecosystems. *Ecol Lett*, 10: 1135-1142.

Søndergaard, M., J.P. Jensen and E. Jeppesen. 2003. Role of sediment and internal loading of phosphorus in shallow lakes. *Hydrobiologia*, 506: 135-145.

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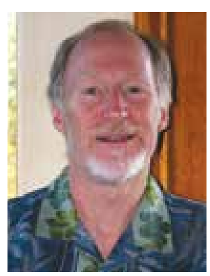

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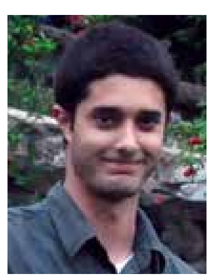

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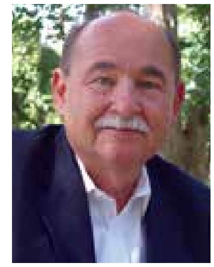

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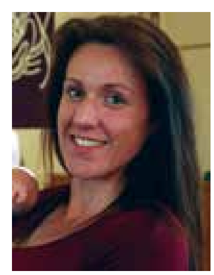

Worldview-Based Scenarios Highlight Stakeholder Values and Assumptions

John Rueter

Lake health is a value-laden issue

In our profession, we have the privilege and responsibility to work with the public on highly visible resources, lakes. Everybody has an opinion based on his or her personal values and observations. While we might sometimes consider this plethora of value statements as the bane of our existence, we all realize that public engagement is crucial for the health and future of lakes. Poor lake health is often caused by many little insults that stem from a wide range of legitimate views for how the lake should be treated as a resource. We need a framework to be able to deal with these differing values and assumptions for how lakes should be managed.

Scientific uncertainty and value conflicts lead to "wicked" problems

Many of the issues that arise in lakes are best described as "wicked problems" (Norton 2005). These types of problems contain dimensions of knowledge/uncertainty and some conflict between individual versus community values. Wicked problems don't have any solution, but rather require continuous adaptation and engagement. Wicked problems require both new knowledge and an understanding of how to deal with community values. These values are not static but will likely shift as more information becomes available. For example, more information on environmentally friendly lake restoration approaches can sway some people to favor green infrastructure over traditional engineering approaches. Wicked problems require a constant negotiation between the present and the future, with all the philosophical hazards that entails.

Our best hope for constructive engagement with wicked problems is to employ scientific and adaptive management. To do this we will need to make decisions based on evidence and we will have to treat values objectively (Norton 2005). Scientific adaptive management (as defined by the Department Of Interior) includes dealing with uncertainty and the degree of control that we have over implementation (Table 1). At the beginning of a project we are dealing with a situation in which we have low control (because we are just staging the problem) and a large degree of uncertainty. In these situations, scenarios are a good place to start. We can use scenarios to identify the assumptions and explore some possible future outcomes. Whereas scientific adaptive management is a rigorous process for designing management actions as experiments, creating scenarios is a community-oriented process that strives to bring in as many opinions and assumptions as possible. Optimal project management has more technocratic control and would follow after all the value-laden issues have been resolved. In order to begin constructing valuable scenarios we need to be able to unwrap value assumptions from the community and address these values objectively, which we do by discussing the values directly rather than judging the validity of the values.

Worldviews represent underlying assumptions

Values are intertwined with how we think the world operates, critical thinking skills that we employ, and the knowledge we seek to make meaning. You might want to have all decisions based on objective data but that is not how the rest of the non-scientific world operates. According to Culture Theory (Thompson et al. 1990; Elis and Thompson 1997), there are five dominant combinations of values and critical thinking that represent self-reinforcing and internally consistent sets. (It is beyond the scope of this article to discuss how and why there are only five.) These are called "worldviews" and they stem from myths of nature, beliefs about how people should interact with each other and views of uncertainty (van Asselt and Romans 1996, 2002). The five dominant worldviews are described in Table 2 and salient phrases that you might hear from holders of each worldview (List 1). You will probably recognize these types of statements from public discussions about lake management.

It doesn't always take surveys or sophisticated sociological research to uncover the range of values in a community. What is required is to listen for statements that are characteristic or indicative of the above worldviews. Clear examples of these value-laden worldviews were evident at a recent workshop that was organized to address

Table 1. Scientific adaptive management in the landscape of control vs. uncertainty (Williams et al. 2009).

	High control	Low control
Sufficient knowledge	Optimal project management	Hedging/diversification
Uncertainty	Scientific Adaptive Management	Scenarios

Table 2. Worldviews, key beliefs, and assumptions. A summary of some of the major differences between worldviews as they pertain to management of environmental projects is provided. Blank cells indicate that it is not clear for this category.

Name (Also known as)	Myth of Nature	Preferred action	Sustainability	Technology	Other
Individualists (Cornucopian)	Nature is independent of human activities	Take advantage of new opportunities using market forces	"Weak" – all capital is convertible	Optimistic	Individual and property rights
Hierarchists (Accommodating, Industrial ecologists)	Nature is robust and will recover	Control comes from well structured regulations	Most capital is convertible	Green economy and efficiency, use market incentives or taxes	Green economy, Instrumental value for nature
Egalitarian (Sectarians, Communalists, Committed environmentalists)	Nature is fragile and must be protected	Prevention, prudence and precaution	"Strong sustainability", i.e. that natural capital has special	Use to preserve resources	Collective interests take precedence over individual interests
Fatalist (1) (Technology skeptics)	------	No erosion of *status quo* for stakeholders	Restoration needed first	Pessimistic or skeptical of technology's potential	Fix what you have first
Fatalist (2) (Deep ecologists)	Nature has rights equal to those of humans	Severely limit any resource take	"Strong sustainability," natural capital must be preserved	Must be curtailed if it impacts natural systems	Broad definition of rights that includes animal, plant and earth

the technical and economic feasibility of different forms of restoration for Upper Klamath Lake (Stillwater Sciences et al. 2013). Even engineers, consultants, and managers have underlying worldviews that can be unwrapped and treated objectively. An example of proponents and salient statements is presented in List 1. Although some viewpoints may be dominant in different forums, even a heavily technical session such as this had the full representation. In this sense, the worldviews have a heuristic value in that they help us scan the discourse and listen for proponents of all worldviews and make sure that they are heard and acknowledged.

List 1: Statements from representatives of different stakeholder groups and salient worldview phrases.

> The statements from a representative of a tribal organization were very close to the "Deep Ecologist" world view, i.e., that restoring the system to a natural state more like pre-European influence levels would lead to a system that was self-regulating and healthy.
>
> A university professor presented ideas for restoring ecosystem functioning and "ecological engineering" that are similar to the "Egalitarian" worldview. In particular the idea that dramatic increases in energy costs should be considered and avoid those strategies that will require a high allocation of energy. This is the precautionary principle and is characteristic of the Egalitarian worldview.
>
> A representative from USGS remarks were close to the "Hierarchist" view, especially when he suggested that we identify the cause and work to eliminate the effect. Assuming that there is an identifiable cause and that industrial scale efforts are the most efficient approach is a characteristic of the Industrial Ecologist worldview.
>
> Someone who works with USDA was the closest to stating an "Individualist" worldview. He said that the ranchers have faced problems and always been able to solve them. He stated that respecting individual property rights is crucial to get any project to be successful.

Scenarios promote positive discussions

Creating and discussing future scenarios is a valuable exercise that can engage the community in possible approaches. Americans hold a range of philosophical views for the future, ranging from the perception that the future won't change the current state of things to the perception that the future will have unforeseen consequences. Most people are in between and consider that the future will only change incrementally and that there will be substantial continuity. It is important to remember that the general public's view of change is very simple compared to current theories in academics, which focus on post-modernity (future will be different with no authority) to second-modernity (the future will be different in ways we can't even understand or predict). These academic and philosophical views of the future are unsettling to the public and do not engender trust in the process. I call my view of the future "retro-modernity." "Retro-modernity" is the only version of the future that we can discuss and build trust with stakeholders because it is dominated by features and processes that people are currently familiar with (and thus trust), but those features and processes will be repurposed, rearranged, and re-proportioned. Dystopic futures will not build trust and cooperation but will heavily favor a turn toward skepticism and fatalism. Scenarios should be constructed in a way that makes all options seem as attractive as possible, and thus bring the most people into the conversation at an early stage.

I constructed a set of scenarios and worked with an artist (Lindsay Jordan) to turn them into pictures of what the Klamath Falls lakefront would look like under different worldviews. Each picture depicts the same scene with features that are characteristic of each worldview (Figures 1-5). When I have shown these to people familiar with Upper Klamath Lake and the city of Klamath Falls, they recognize all of the components and see the overall scenario as being a reasonable prediction for what the lake and community might look like in the future.

A range of stakeholder inputs is necessary for democracy

Seeking the input of stakeholders holding different worldviews is an important pluralistic process that supports liberal democracy. Rather than being a distraction, it is important to get a wide range of input early in the process in order to avoid surprises and traps in lake restoration projects (Gunderson and Hollings 2002). The creation of attractive future scenarios can help stimulate discussions. I used an artist to condense many features into one panel and to focus the attention on a single location. However, pictures of similar lakes with different outcomes can also be useful. You could use images of the shores of lakes in different regions that have either addressed the problem or have let the problem fester. Focusing on attractive versions of the future, rather than the fear of cataclysms, will also help build trust and engagement. Fear, and especially the fear of losing current status, can be counter productive and often leads to fatalistic, self-protective, and non-democratic behaviors. The discussions of the lake's future and how civic

Figure 1. "Economic Renaissance": the individualist's view. The key features in this drawing are the predominant building in the city that represents financial success, the large operation farm that relies on capital equipment and feedlots and the lake has utilitarian value for both irrigation and waste disposal.

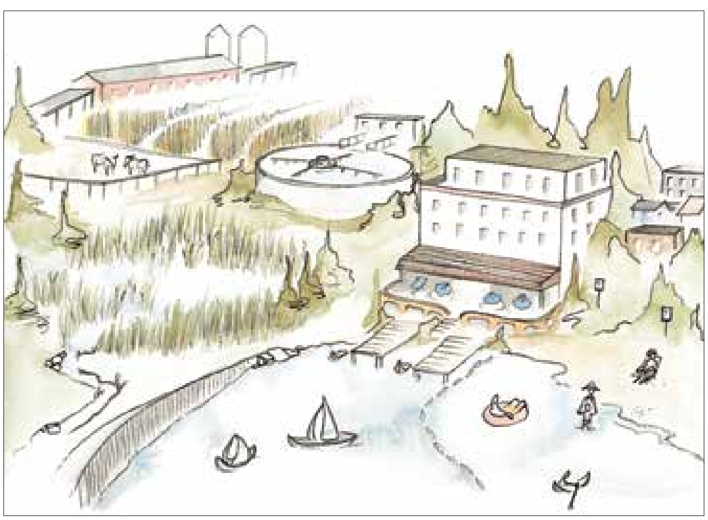

Figure 2. "Expert Lake Management": the hierarchist's view. The key features of this drawing are the orderliness, the tertiary treatment plant to handle all human wastes, the buffer between farms and the lake to protect the lake, the inviting waterfront with clean water for swimming and the café for enjoying the clean and well-managed lake. The signs on the beach are also indicative of the belief that the public will read and obey signs.

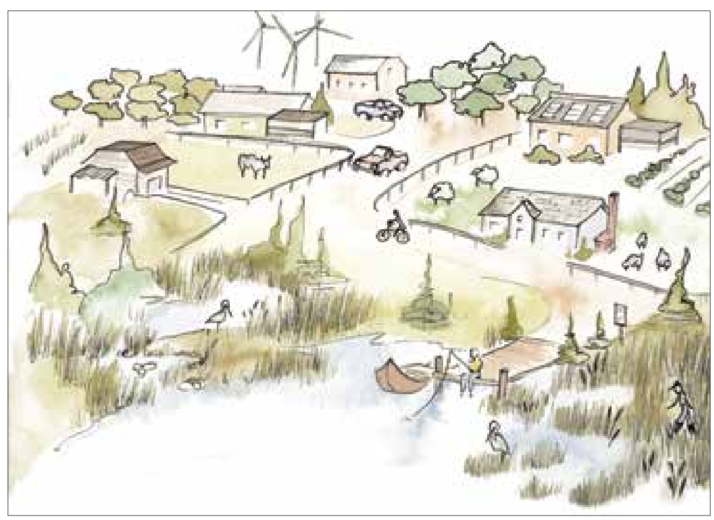

Figure 3. "Mosaic Community": the egalitarian's view. This community is a patchwork of small farms and natural capital drawing on ecosystem services. Although the farms might be small they are employing high technology (solar and wind power). The range of crops and livestock illustrate the interconnectedness and desire for self-sufficiency in the community. The sign on the dock probably proclaims that this is a community area with the assumption that people would know to keep it clean for others.

cooperation is necessary is an exercise in environmental stewardship that can improve overall community governance. Even though the challenges of lake restoration may be a wicked problem, the invitation and engagement of a range of worldviews is necessary work that can lead to a better future.

References

Gunderson, L.H. and C.S. Hollings [Eds]. 2002. Panarchy: Understanding transformations in human and natural systems. Island Press. Washington D.C.

Norton, B. G. 2005. *Sustainability: A philosophy of adaptive ecosystem management*. Chicago, University of Chicago Press.

Stillwater Sciences, Jones & Trimiew Design, Atkins, Tetra Tech, Riverbend Sciences, Aquatic Ecosystem Sciences, and NSI/Biohabitats. 2013. Water Quality Improvement, Techniques for the Upper Klamath Basin: A Technical Workshop and Project Conceptual Designs. Prepared for California State Coastal Conservancy, Oakland, California at http://www.stillwatersci.com/case_studies.php?cid=68

Thompson, M., R. Ellis and A. Wildavsky. 1990. Culture Theory. Boulder, CO, Westview Press.

van Asselt, M.B.A. and J. Rotmans. 1996. Uncertainty in perspective. *Global Environ Change,* 6(2): 121-157.

van Asselt, M.B.A. and J. Rotmans. 2002. Uncertainty in integrated assessment modelling: from positivism to pluralism. *Climate Change*, 54: 75-105.

Williams, B. K., R.C. Szaro and C.D. Shapiro. 2009. Adaptive Management. The U. S. Department of the Interior. Washington, D.C.

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Next Issue – Summer 2016 *LakeLine*

Shoreline Management

is receiving serious attention throughout North America.

In our next issue, we'll learn how public, private, and non-profit groups are all tackling a variety of shoreline issues.

Figure 4. "Return to Nature": the deep ecologist's view. This image illustrates a verdant scene that would fit with this vision. The shoreline is dominated by plant growth. The farms are probably small-scale with very light footprint on the environment. Deep ecology is often associated with a "hermit" lifestyle that retreats from public involvement. However, in the Klamath Falls region, a deep-ecology worldview is a strong statement of a holistic view that has interdependent ecosystem, ecology and social sub-systems.

Figure 5. "We like what we have": the fatalist/skeptic's view. This image represents that the community has created an oasis in one area and not tried to restore or preserve the whole area. In the fatalist's view, massive restoration is not possible and we shouldn't waste our effort and resources on lost causes. Instead, we should nurture a select area and make it as nice as possible and make sure that everything inside the fences is in working order.

Ted Harris

Student Corner

The role of persistent organic pollutants in cyanobacterial bloom proliferation

Cyanobacteria are a main component of the phytoplankton community in aquatic ecosystems. Although cyanobacteria look and function like algae to the naked eye, they are technically bacteria that can perform photosynthesis. Because cyanobacteria function like algae, they require nutrients and light to grow and reproduce, and thus compete with true algae for these growth-limiting resources.

Cyanobacteria produce a wide range of chemical compounds to compete with algae for growth-limiting resources. These include taste-and-odor compounds that degrade raw drinking water supplies and potent toxins that have caused the death of fish, birds, livestock, and in rare cases even humans. Large blooms of cyanobacteria can pose a health hazard to animals and humans, impair drinking and irrigation water supplies, and cause billions of dollars of economic damage (Paerl and Otten, 2013).

Unfortunately, increases in the frequency and intensity of cyanobacterial blooms are being noted worldwide (Taranu et al. 2015). Until recently, cyanobacterial blooms were primarily observed in nutrient-rich eutrophic and hypereutrophic systems, and were relatively rare in less nutrient-rich, oligotrophic to mesotrophic waters. Alarmingly, however, cyanobacterial blooms have recently been measured in oligotrophic to mesotrophic lakes (Taranu et al. 2015). Although the causes for these potential changes are not yet fully understood, the manuscript by Harris and Smith (2016) indicates that the loading of persistent organic pollutants (POPs) to aquatic systems may be an under-recognized contributor to cyanobacterial proliferation in the world's surface waters.

Persistent organic pollutants

For more than 60 years, a mixture of over 400 different herbicides, pesticides, and fungicides, along with a myriad of other unaccounted-for pharmaceuticals, personal care products, and industrial chemicals have unintentionally found their way into oceans, estuaries, rivers, streams, lakes, and reservoirs (Stone et al. 2014). These chemical compounds, which can exist in liquid, solid, or gas forms, are broadly termed persistent organic pollutants due to their ability to persist in the environment. Some degrade in a matter of days, while others take months, years, or decades to fully degrade. POPs can be transported thousands of miles from their sources by migrating animals, flowing waters, and atmospheric wind currents, and have contaminated even relatively pristine environments like the Arctic. As a result, POPs frequently co-occur and are detectable throughout the world's surface waters.

POPs can have devastating effects on non-target organisms. For example, studies have linked POP exposure to an increased risk of prostate and breast cancer, non-Hodgkin lymphoma, leukemia, and multiple myeloma in humans (Alavanja et al. 2013). POP exposure also causes adverse effects to aquatic organisms, including death (Stone et al. 2014). Thus, while POPs may be effective at eliminating their targeted organisms or be extremely useful as industrial chemicals, non-targeted organisms can be affected by the unintentional release of POPs to aquatic ecosystems.

Although substantial scientific research has been conducted on the non-target effects of POPs on specific individual aquatic organisms, less is known about effects of POPs on phytoplankton community composition. Harris and Smith (2016) assessed how phytoplankton community composition is effected by POPs by investigating if the current scientific literature indicated that cyanobacteria were favored relative to other phytoplankton taxa in the presence of environmentally relevant POP concentrations.

Methods

Google Scholar and Web of Science were searched for studies that explicitly compared cyanobacteria to other phytoplankton taxa from 1980-2015. A total of 107 publications, which included 217 experiments on various POPs, were found to compare cyanobacteria to their photosynthetic counterparts in the presence of POPs. The 217 experiments examined 133 distinctly different POPs, which included herbicides, pesticides, fungicides, pharmaceutical and personal care products, and industrial chemicals. A majority of these studies were conducted in the laboratory, or in small-scale outdoor experimental enclosures.

Frequency histograms were used to present results. The histograms grouped the 217 experiments into three distinct categories; positive, neutral, and negative (Figure 1). A denotation of positive indicates that in the presence of a POP cyanobacteria was favored over all over phytoplankton taxa tested within a single experiment. A neutral POP response was given if cyanobacteria had an intermediary response relative to other phytoplankton taxa. A negative POP response indicated that cyanobacteria were depressed compared to other phytoplankton taxa tested in a single experiment. In some cases, multiple experiments investigated a single unique POP (e.g., the active ingredient in the

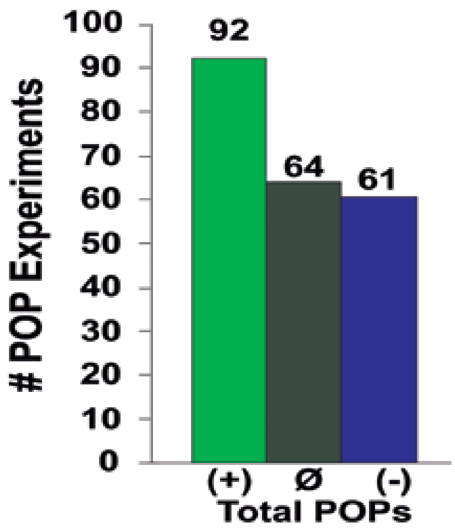


Figure 1. Histograms showing the effects of Persistent Organic Pollutants (POPs) on cyanobacteria. The positive (green), neutral (brown), and negative (blue) categories refer to POPs that favored cyanobacteria, showed taxa more and less sensitive than cyanobacteria, and did not favor cyanobacteria, respectively, in multi-phytoplankton species studies that examined more than one phytoplankton taxa group. Numbers above histogram bars represent the number of POPs in each category. Figure modified from Harris and Smith (2016).

herbicide RoundUp™ – glyphosate); each individual experimental response was counted in only one of the three distinct categories. Further methodological details can be found in Harris and Smith (2016).

Results and Discussion

Several trends were evident in the current literature. A distinct trend was especially evident in herbicides; POPs that are specifically designed to eliminate photosynthetic organisms. Of the 99 herbicide experiments that directly compared cyanobacteria to other algae, nearly half (46 percent) showed cyanobacteria were favored over true algae in the presence of herbicide POPs. Alarmingly, of the studies involving glyphosate, the active ingredient in the most widely used herbicide in the world, all seemed to favor cyanobacteria. Indeed, of the 13 glyphosate based experiments, 8 showed to favor cyanobacteria over all other phytoplankton taxa tested while 5 showed that cyanobacteria had an intermediary response relative to other phytoplankton taxa. Thus, the presence of most herbicides seemed to favor cyanobacteria species compared to true algae.

Harris and Smith (2016) showed other classes of POPs favored cyanobacteria over true algae. Unlike herbicides, the other classes of POPs do not specifically target photosynthetic organisms. For example, pesticides and fungicides target non-photosynthetic organisms. Yet, of the 46 pesticide and fungicide experiments surveyed 87 percent showed either a positive or neutral response of cyanobacteria compared to other phytoplankton taxa, indicating non-target compounds may favor cyanobacteria more than other phytoplankton community members.

Experiments surveyed using pharmaceutical and personal care products had two distinct responses. 27 experiments showed a positive result, while 36 showed a negative result when cyanobacteria were compared to other phytoplankton taxa in the presence of pharmaceutical and personal care product POPs. This strong distinction between pharmaceutical and personal care product experiments was due to experiments that tested antibiotics. Because cyanobacteria are technically bacteria, studies that experimented with antibiotics generally showed that cyanobacteria were not favored in their presence. However, more recent studies (e.g., Liu et al. 2012) have found that cyanobacteria are favored in the presence of some antibiotics, which may indicate that cyanobacteria are becoming more tolerant to antibiotics.

Few experimental results investigated how cyanobacteria faired compared to other algae in the presence of industrially generated POPs. Of the 7 studies, 4 showed a positive result and 3 showed a negative result. No broad conclusion can be made based on so few studies, and additional research is needed to unravel the complex relationship that exists between phytoplankton community composition and industrial POPs.

In total, 42 percent of the surveyed studies found that cyanobacteria were favored over true algae in the presence of POPs (Figure 1). Given that only 28 percent of the total experiments showed other phytoplankton dominated in the presence of POPs, Harris and Smith (2016) hypothesized that at a given nutrient load aquatic systems with relatively high POP loading will likely have a higher proportion of cyanobacteria in their phytoplankton communities compared to systems with low POP loading (Figure 2). Therefore, lakes and reservoirs with relatively high POP loading will likely be more "blue-green" than systems with relatively low POP loading (Figure 3). Because nutrient enrichment, warmer temperatures, and selective pressures from POPs already seem to be creating some of the world's largest cyanobacterial blooms to date, increased loading of nutrients and POPs, coupled with warmer surface water temperatures are only likely to worsen large-scale cyanobacterial proliferation in years to come.

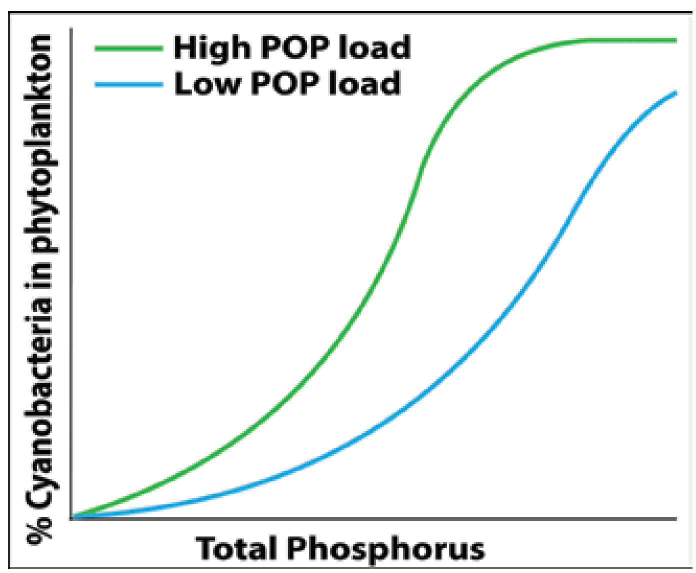


Figure 2. Hypothesized relationships between percent (%) cyanobacterial biomass in the phytoplankton community and water column concentrations of total phosphorus, under contrasting high and low loadings of cyanobacteria-promoting Persistent Organic Pollutants (POPs); the low POP line will reach its asymptote to the right of the shown graph.

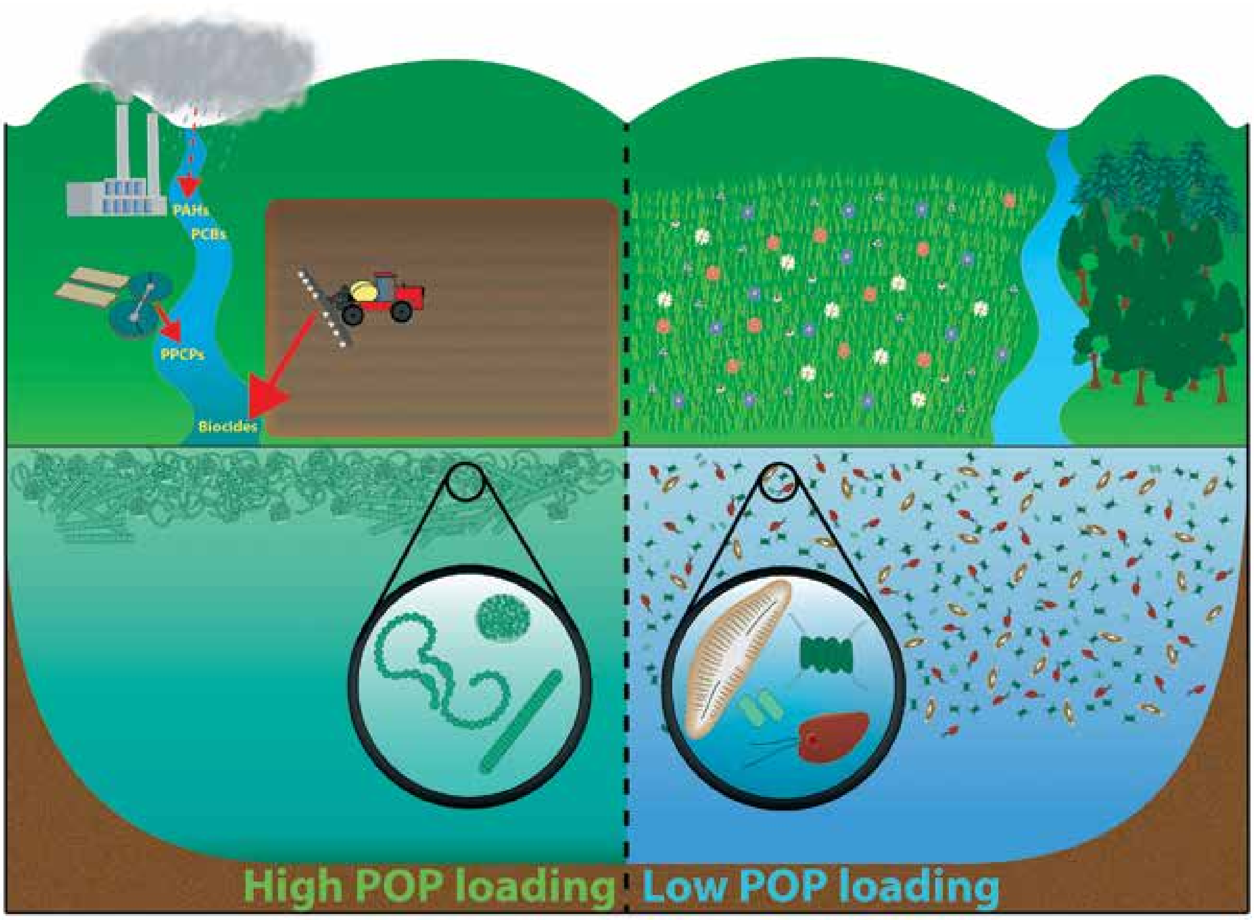


Figure 3. Contrasting responses of aquatic ecosystems that receive high and low Persistent Organic Pollutant (POP) loading. The presence of cyanobacteria-promoting POPs is hypothesized to increase the proportion of cyanobacteria at any given level of nutrient loading. These key POPs may include biocides; pharmaceutical and personal care products; and industrial chemicals.

References

Alavanja, M.C.R., M.K. Ross and M.R. Bonner. 2013. Increased cancer burden among pesticide applicators and others due to pesticide exposure. *CA Cancer J Clin*, 63: 120-142.

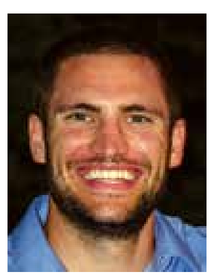
Harris, T.D. and V.H. Smith. 2016. Do persistent organic pollutants stimulate cyanobacterial blooms? *Inland Waters*, 6: 124-130.

Liu, Y., B. Gao, Q. Yue, Y. Guan, Y. Wang and L. Huang. 2012. Influences of two antibiotic contaminants on the production, release and toxicity of microcystins. *Ecotoxicol Environ Saf*, 77, 79-87.

Paerl, H.W. and T.G. Otten. 2013. Harmful cyanobacterial blooms: causes, consequences, and controls. *Microb Ecol*, 65: 995-1010.

Stone, W.W., R.J. Gilliom and K.R. Ryberg. 2014. Pesticides in U.S. streams and rivers: occurrence and trends during 1992-2011. *Environ Sci Technol*, 48: 11025-11030.

Taranu, Z.E., I. Gregory-Eaves, P.R. Leavitt, L. Bunting, T. Buchaca, J. Catalan, I. Domaizon, P. Guilizzoni, A. Lami, S. McGowan, H. Moorhouse, G. Morabito, F.R. Pick, M.A. Stevenson, P.L. Thompson and R.D. Vinebrooke. 2015. Acceleration of cyanobacterial dominance in north temperate-subarctic lakes during the Anthropocene. *Ecol Lett*, 18: 375-384.



Ted Harris is a Ph.D. student at the University of Kansas, advised by Jennifer Graham (USGS) and Val Smith. Ted's current research focuses on environmental and anthropogenic factors that favor toxic and taste-and-odor causing cyanobacterial blooms. Ted has bachelor's degrees from the University of Missouri and a master's degree from the University of Idaho. Ted's master's degree focused on finding applied management strategies to cyanobacteria blooms through the manipulation of nutrient ratios. He has been a member of NALMS since 2010 and just completed a term as the Student At-Large Director.

Affiliate News

Indiana Lakes Management Society (ILMS)

The Indiana Lakes Management Society hosted the 29th Annual Indiana Lake Management Conference on March 11 and 12 at the Swan Lake Resort. Unfortunately, there were no lakes at beautiful Swan Lake! More than 150 individuals attended the conference being treated to great presentations about local lakes, invasive plant management, pond management and rain garden design. More importantly, they spent time networking with other lake residents, managers and professionals (photo at right, top).

This year, ILMS honored three Indiana individuals and groups for the tireless work they do to improve conditions within their own backyard and throughout Indiana's lakes (photo at right, bottom).

- Jane Loomis with The Watershed Foundation and Upper Lakes of the Tippecanoe River Association. Jane was recognized for her tireless work to launch and manage daily operations of the Upper Lakes of the Tippecanoe River, developing many projects to educate lake residents, engage individuals in water quality testing, and improving water quality throughout northeast Indiana. For these efforts, Jane was recognized as the Volunteer of the Year.

- After intense blue-green algae blooms impacted the Salamonie Reservoir, the Upper and Lower Salamonie watershed groups, coordinated by the Huntington County SWCD and the Jay County Commissioners/SWCD, worked with the Army Corp and other local stakeholders to develop two watershed management plans for the Salamonie Reservoir watershed. The Lower Salamonie watershed group is implementing their WMP with a current 319 grant, and the Upper Salamonie watershed group is implementing their WMP with a Clean Water Indiana grant and will continue with a 319 grant this coming year. The nutrient issues in the Salamonie and subsequent blooms in the reservoir became a high profile issue when two dogs died after swimming in a blue-green bloom in 2012. Both watershed groups worked hard to bring together local stakeholders to drive the planning process and continue to do so now in implementation. For their effort, the Upper and Lower Salamonie watershed groups were recognized as the Outstanding Lake Association/ Group.

- ILMS awarded the outstanding implementation project award to the Indiana University School of Public and Environmental Affairs (SPEA). SPEA, under the direction of Melissa Laney Clark, has worked to gather information over the last two years at Griffy Lake in Bloomington, Indiana. Griffy Lake refilled in 2014, after an extended drawdown and Indiana University researchers saw this as an opportunity to study the impacts of full lake drawdown. Their research has included aquatic vegetation mapping, phytoplankton and zooplankton sampling, and extensive water quality data collection. With the help of students and volunteers, data have been collected on a monthly basis since the lake refilled. Data have been analyzed to compare how the trophic levels will recover and the impact on aquatic invasive plants. The lake has always been a plant-dominated lake and the question remains if that state will persist or if the lake will shift to an algal-dominated system.

  Despite lack of funding, monitoring continues as an in-kind project fueled by students, a City of Bloomington partnership, and personal research interest of SPEA faculty and staff. This unique opportunity to study drawdown effects on a lake system will help create a better understanding of the potential impacts of this management strategy.

ILMS would also like to recognize the student scholarship winners – Josiah Hartman from Grace College and Kristin Berger of Indiana University. Josiah and Kristin represent the future of lake management in Indiana. All student scholarship funding is provided through the conference silent auction - attendee donations totaled more than $1500 at the 2015 conference, which will allow ILMS to award three student scholarships at our 2016 conference!

Submitted by: Sara Peel

Florida Lake Management Society (FLMS)

Local chapters of the Florida Lake Management Society regularly host local day-long workshops. The FLMS Board feels these events are important to provide networking opportunities for members as well as to introduce non-members to the society.

The most recent event was hosted by the southwest chapter of FLMS at beautiful Weedon Island Preserve in St. Petersburg. The preserve is a 3,190-acre natural area located on Tampa Bay with an archaeological site that had been inhabited by indigenous people for thousands of years. The topics ranged from inhibiting cyanobacteria in Lake Hancock, a hypereutrophic lake in Central Florida to nutrient levels in stormwater ponds relative to Lee County's fertilizer ordinance to a discussion of the impacts of reuse water in the urban environment.

In March, the central chapter will host a day long NPDES-focused workshop with presentations from area NPDES coordinators as well as the state NPDES program manager. Often the workshops include a brief field trip or site visit. During the March meeting in Kissimmee, attendees will have the opportunity to view the completed shoreline revitalization project the City of Kissimmee had implemented two years ago. FLMS held a workshop at the site at the beginning of this project as well.

These workshops are free for current FLMS members and the nominal fee charged for non-members provides them with a FLMS membership for the remainder of the membership year. Attendance ranges from 30-60 people. Sponsors help defray the cost of providing lunch and are given the opportunity to be the sole exhibitor at the event with a few minutes to present information about their company to attendees. These events help keep the FLMS name on our members' minds and have enabled FLMS to reach many more professionals who may not have heard of the society, providing an opportunity to gain new long-term members.

Submitted by: Maryann Krisovitch

Oklahoma Clean Lakes and Watershed Association (OCLWA)

The OCLWA will hold its 25th annual conference on March 29-30th, 2016. Last year, the conference convened with over 200 attendees representing universities, tribes, state and federal agencies, municipalities, water districts, lake and watershed managers, and representatives from private industry.

The OCLWA continues to develop the conference format in support of its goal to convene the largest, most meaningful conference of its kind in the region. This year's efforts will comprise even stronger opportunities with concurrent presentation tracks, a large student poster competition, and an expansive professional exhibition area. The OCLWA's conference theme "Valuing Water" fits the current times very well. And to go along with his theme, the agenda will feature a special track of nine talks with speakers highlighting the economic, ecological and cultural importance of water. Other topics will include grassroots organizations and the work they do within the state, lake and watershed management, wetlands, water reuse and more. The two-day conference will be held at the Wes Watkins conference center on the campus of Oklahoma State University.

OCLWA will be sponsoring at least three clean up events at lakes across the state this spring. Additionally, the organization is planning a service project as a part of the Keep Oklahoma Beautiful state level *Great American Clean Up* event.

Submitted by: Julie Chambers

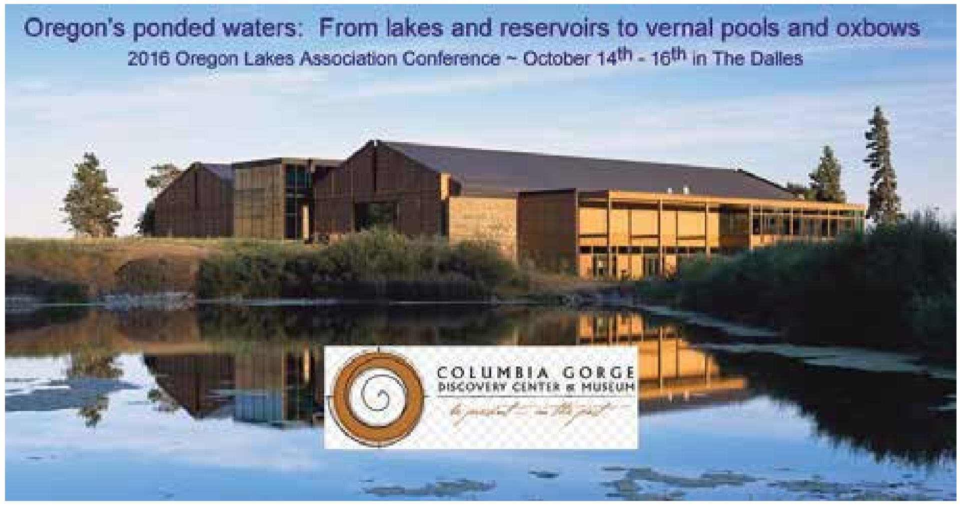
Oregon Lakes Association (OLA)

Oregon Lakes Association [oregonlakes.org] is planning their annual conference from October 14-16 at the Columbia Gorge Discovery Center & Museum in The Dalles, Oregon. The theme for this year is "Oregon's ponded waters: From lakes and reservoirs to vernal pools and oxbows." This year our primary objective is to gain and share a better understanding of impounded waters. Reservoirs and their hydrology are a dominant feature on the landscape in the Gorge, and what better spot to explore these dynamic systems than in The Dalles. Friday night we will sponsor an open public presentation from the Ice Age Flood Institute about the local impacts from the raging Missoula floods. Saturday features a full venue of talks, including a midday raffle and auction to support our scholarship program. For our always enjoyable Sunday field trip we are going exploring in the Gorge with local guides; on tap are columnar basalt cliffs, scabland ponds, petroglyphs, and locally produced beverages.

Sponsorship opportunities available! Get a booth, registration fees for one attendee, and bonus advertising packages through our Lake Wise newsletter.

If you have any questions please contact Rich Miller at richm@pdx.edu or (503) 725-9075.

Submitted by: Stephen Wille



Pennsylvania Lake Management Society (PALMS)

The 26th Annual PALMS Conference was held February 24 & 25, 2016 at the Ramada Conference Center, State College, PA. PALMS hosted another successful annual conference with record attendance! There were 143 attendees, 24 exhibitors, and 21 knowledgeable speakers including Keynote Speakers Lewis Molot and Dave Wick. PALMS is grateful for the support of Penn State Extension, Pennsylvania Water Resources Research Center, and our conference sponsors and exhibitors.

Board of Directors – Election Results

On February 25th at the PALMS Annual General Membership Meeting held at the Ramada Conference Center in State College, PA, the PALMS general membership approved the slate of candidates for the 2016-2017 Board of Directors. For a complete list of board members please see our website.

President Elect – Brian Pilarcik
Treasurer - Gretchen Schatschneider
Eastern Regional Director #1 – Nick Spinelli
Central Regional Director #1 – Jim Clark
Western Regional Director #1 – Tricia McIntire

Congratulations Photo Contest Winners

1st Place - $25 Mpix Gift Certificate
'Falling into January' by Quinn Bergeon
2nd Place - $15 Mpix Gift Certificate
'Fisherman's Oasis' by Quinn Bergeon
3rd Place - $10 Mpix Gift Certificate
'Winter Waterfall' by Amy Sipes

PALMS also recently completed an overhaul of our website. Please check out the new site at www.palakes.org.

Submitted by: Kerilynn Frey

Lake & Watershed Association of South Caroline (WASC)

FOLKS Participation as a stakeholder in the Keowee Toxawaway Relicensing

The Duke Energy Kewowee-Toxaway (KT) Hydroelectric Project (Lakes Keowee and Jocassee in NW South Carolina) was originally licensed by the Federal Power Commission in August 1966 for a period of 50 years. FOLKS (Friends of Lake Keowee Society), founded in 1993, has been active and visible in identifying and reducing pollution threats, both chemical and bacterial, to the major feeder streams of Lake Keowee since 1999 via a series of three SCDHEC grants 319.

FOLKS also became a major player in the evolution of the KT-Shoreline Management Plan. As a result, FOLKS was designated to be one of the seventeen stakeholders in the overall KT Relicensing process. Over the past five years, FOLKS worked with the sixteen other stakeholders to include provisions in the new license beneficial to the lakes. We are now approaching the time for the Federal Energy Regulatory Commission to issue a new license for 30-40 years.

Without describing the time and effort that those who have gone through the process well know, let us say that it was worth all of the meeting time, study, and travel to meetings. If any of you are embarking on a hydro relicensing, we will be happy to spend time with you to pass on some pointers - one of which is "If you don't ask for it you will not get it." In that vein, the "Trial Balloon" presented to the stakeholders by Duke Energy dot water quality included measuring dissolved oxygen in the tail races of the dams. FOLKS suggested that a more robust water quality monitoring program would be more appropriate, considering the very significant use of individual septic systems along the Lake Keowee and feeder streams shorelines. (In fact, there will be upwards of 9-10,000 of them alone when the 370 miles of the Lake Keowee shoreline is all built out.), not to mention that upwards of a million people will rely on drinking water by the end of the new license. After some discussion, we agreed that a year of physical and chemical property testing would be done at selected sites in Lake Keowee and at the outlets to the lake of its five major feeder streams during the relicensing period.

These data, along with measured stream flows, were used to provide estimates of pollutant loads to the lake. The in-lake data were used to calibrate a widely-used lake water quality model for use in estimating dissolved oxygen and other water quality constituent concentrations throughout the lake, and in the tail race, as a function of feeder stream pollutant loads. This model was used to simulate changes in lake and tailrace water quality constituent concentrations as a function of various assumed stream loads, including the construction of a hypothetical wastewater treatment plant on one of the feeder streams.

As a result of these relicensing studies, Duke Energy committed to provide $1 million for a Source Water Protection Program (SWPP). The SWPP would have several elements: developing publically-available, calibrated feeder streams pollutant loading models and linking same to the calibrated Lake Keowee water quality model to provide a comprehensive lake water quality assessment capability responsive to watersheds' development and weather; finding and assisting in the fixing of failed septic systems, prioritizing those adjacent to the lake and feeder streams; and making residents aware of the need for regular septic system maintenance. Since there are approximately 30-40,000 septic systems around Lake Keowee, a 5% failure rate (lower than most estimates) would yield 1,500 to 2,000 failures over a period of time. Our experience with two SCDHEC 319 programs is that the average "fix" is about $3,000. With a 50% cost share, we would need between $2 and $3 million minimum for this part of SWPP. Obviously, the "making residents aware of the need for regular septic system maintenance" takes on a tremendous emphasis.

A second success was FOLKS' spearheading of a Habitat Enhancement Program (HEP) to be initially funded with another $1 million by Duke Energy. Additional funds, estimated to be upwards of $2 million, will come from a new $500 additional fee for shoreline stabilization and dock installation. This program was initiated on September 1, 2014 and the first proposals have been received, scored, and projects approved. The first two projects: installation of an osprey platform in the southern part of Lake Keowee and the installation of fish attractors in two of the Oconee County Parks.

Submitted by: Dr. Robert Swank & Ben Turetzky

We'd like to hear from you! Tell us what you think of *LakeLine*. We welcome your comments about specific articles and about the magazine in general. What would you like to see in *LakeLine*?

Send comments by letter or e-mail to editor Bill Jones (see page 3 for contact information).

Lakes Appreciation Month

The month of July is Lakes Appreciation Month!

You work on them. Play on them. Drink from them.
But do you take time to really appreciate your local lake, pond, or reservoir?

Lakes Appreciation Month is a time to think about where you would be without water. It is also a time to think about the threats facing your lakes and reservoirs. Growing population, development, and invasive plants and animals put stress on these waterbodies. All life relies water. And as you know, we can no longer afford to take for granted that these water resources will always be there and always be usable.

You can help NALMS make the most out of Lakes Appreciation Month

- You can sign a letter to US Governors asking that they proclaim July as lakes appreciation month in your state.
- You can pursue media coverage for your local Lakes Appreciation events.
- You can join the Secchi Dip-In and help track water quality trends in your local lake or reservoir.
- You can help promote Lakes Appreciation by sharing your experiences through our Show You Lakes Appreciation Challenge. Check it out online at www.nalms.org/home/programs/lakes-appreciation-month/.

Lakes Appreciation Month is also a good time to set aside a week, a day or even just an hour to celebrate your favorite waterbody. Here are some more ideas:

- You can help monitor your local waterbody or watershed
- You can visit a local lake, pond, or reservoir with friends and family
- You can go boating, kayaking, canoeing, sailing or rowing
- You can go swimming
- You can go SCUBA diving
- You can cast your line in and go fishing
- If you manage a lake you can host an activity in your office or on a local waterbody. Bring enough sampling gear, id keys and other materials for everyone to join in.
- If you don't manage a lake, you ask your local lake agency about shadowing a lake manager for a day
- You can arrange a lake or watershed clean-up event
- You can start a watershed storm drain stenciling program
- You can have your septic system pumped if you live close to a waterbody
- You can go birding or take pictures at a lake or pond
- You can tap into your artistic side and draw or paint a lake scene for your home or office. Be sure to send us a copy!
- You can organize a lake field trip for students

LAKE APPRECIATION MONTH AT THE AIRPORT

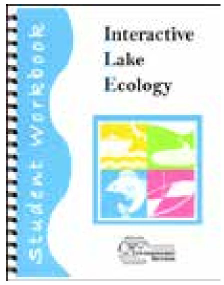
People love to travel during July. According to AAA, 41.9 million Americans traveled just on Fourth of July weekend in 2015. How many of these travelers are heading to a fireworks show over a lake or to the airport to fly to their summer get away?

The brief time in the airport is a great time for water-loving vacationers to learn about Lake Appreciation Month. Many airports provide educational displays and advertisement space for non-profit groups. For Lake Appreciation Month, contact your airport to see about putting up a sign, display, or brochures about lakes.

Denver International Airport will have their first lake appreciation display this July. If you are flying through Denver, check it out. The glass displays will be near the east side baggage claim.

NALMS BookStore

Interactive Lake Ecology

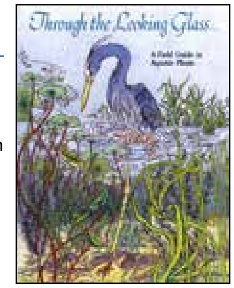


This workbook, created by the New Hampshire Dept. of Environmental Services, introduces students to elements of a lake ecosystem, including basic scientific concepts of water, the water cycle, how lakes are formed, food chains & watersheds and introduces students to problems facing lakes. The workbook also looks at monitoring lakes for water quality.

Appropriate for grades 5-8, but adaptable to lake associations and volunteers.

Student Workbook: $4 NALMS Members / $5 Non-Members
Teachers' Reference: $6 NALMS Members / $7 Non-Members
+ $4 Shipping & Handling
Receive 1 free Teachers' Reference with each order of 20 Student Workbooks

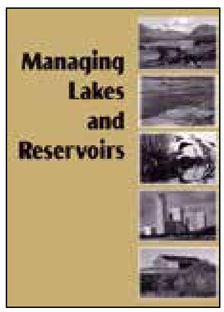
Through the Looking Glass...A Field Guide to Aquatic Plants



This book from the Wisconsin Lakes Partnership contains detailed and highly accurate information needed to identify aquatic plants. This 248-page guide contains over 200 original illustrations of North American aquatic plants. The precise pen and ink drawings that grace these pages combined with detailed descriptions, natural history and folklore of many aquatic plants found in North America make this guide one of a kind.

$20 NALMS Members / $25 Non-Members
+ $6 shipping & handling

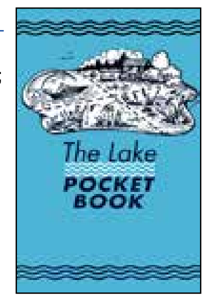
Managing Lakes and Reservoirs



Third edition of a manual originally titled *The Lake and Reservoir Restoration Guidance Manual*, this 382-page edition builds on and updates the material in the original to include new state-of-the-art information on how to manage lakes and reservoirs. Many of today's experts in the field of lake management authored chapters in this book.

$45 + $6 shipping & handling

The Lake Pocket Book



The Lake Pocket Book is a 176-page guide that provides explanations of aquatic chemistry; lake ecology and biology; collecting lake information and how to use it; developing lake management plans and organizing a lake association–all presented in plain English. This easy-to-understand style combined with its in-depth information has made The Lake Pocket Book an extremely popular publication among citizen lake lovers.

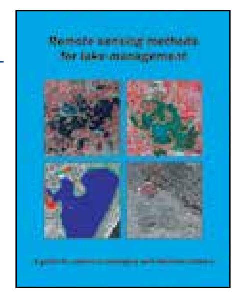
$8 NALMS Members / $10 Non-Members
+ $4 shipping & handling

Your Lake & You!

This tabloid size NALMS publication has been described as "simply incredible." The 8-page publication explains how homeowners can do their part to protect their lake. It is also loaded with descriptions of resource publications.

75¢ per copy
Bulk rates available. Contact the NALMS Office for details.

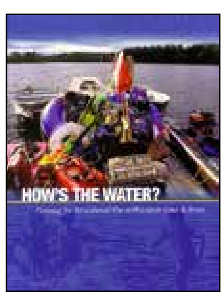
Remote Sensing Methods for Lake Management



Remote sensing holds great promise for lake assessment. While remote sensing cannot, in all cases, replace on the ground sampling it can serve to complement existing sampling programs and often allow for broader extrapolation of existing information. This manual provides detailed explanations of the various platforms currently in use, discusses preferred applications, limitations, costs and other factors that will assist those who are considering the use of remote sensing to select the platform that best suits their data needs.

Manual: $49 + $6 Shipping & Handling
CD w/PDF of Manual: $15 + $3 Shipping & Handling

How's the Water?



One of the top issues facing our lakes involves recreational use conflicts. With an increase in use comes a growing concern with the quality of the recreational experience. This informative 306-page manual from the Wisconsin Lakes Partnership addresses the relevant issues and research on water recreation and related activities. This text was created as a tool to assist in the process of building a healthy lake and river ecosystem and a strong lake community.

$18 NALMS Members / $22 Non-Members
+ $6 shipping & handling

Visit www.nalms.org for complete information on back issues of NALMS' two quarterly publications...

LAKELINE

LakeLine Magazine is NALMS' quarterly lakes information and education publication. Each issue contains news, views and interesting information on lakes and reservoirs, and their watersheds and tributaries, from around your neighborhood and around the world.

Lake and Reservoir Management

Lake and Reservoir Management is NALMS' peer-reviewed journal, which includes papers on the latest lake and reservoir research issues, as well as case studies reflecting NALMS' commitment to applied lake management.

NALMS Membership Form

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(Electronic-Only Rates in Parentheses)

Individual	North American	International
College Student	$40 ❑	$48 ❑
Lake Leader	$65 ❑ ($55 ❑)	$78 ❑ ($68 ❑)
Lake Leader Emeritus *	$55 ❑ ($46 ❑)	$68 ❑ ($59 ❑)
Professional	$125 ❑	$150 ❑
Professional Emeritus *	$106 ❑	$131 ❑
Lifetime	$4,600 ❑	

Organization

Affiliate **	$290 ❑
Non-Profit	$290 ❑
Corporate	$575 ❑

* only for those who are retired, over 60, and have been members for 5 years.
** For approved organizations only – call 608.233.2836 before joining as a new member

Do you want to help protect lakes? A donation will help ensure that NALMS' mission to foster the management and protection of lakes continues.

Eberhardt Memorial Student Fund .... $______

G. Dennis Cooke Symposium Fund .... $______

Lake Givers Club (for general donations) .... $______

Payment Information

☐ Check or money order enclosed in the amount of US$____________

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Mail or fax application and payment in US funds to:

NALMS, PO Box 5443, Madison, WI 53705-0443
Fax: 608.233.3186

Rev. 1/16

Bill Jones

Literature Search

Ecology Letters

Driscoll, W.W., J.D. Hackett and R. Ferrière. 2016. Eco-evolutionary feedbacks between private and public goods: evidence from toxic algal blooms. *Ecol Letters*, 19(1): 81-97.

Environmental Microbiology

Paerl, Hans W. and T.G. Otten. 2016. Duelling 'CyanoHABs': unravelling the environmental drivers controlling dominance and succession among diazotrophic and non-N2-fixing harmful cyanobacteria. *Environ Microbiol,* 18(2): 316-324.

Environmental Research Letters

Scanlon, B.R., R.C. Reedy, C.C. Faunt, D. Pool and K. Uhlman. 2016. Enhancing drought resilience with conjunctive use and managed aquifer recharge in California and Arizona. *Environ Res Letters*, 11(3): 35013-35027.

Environmental Toxicology and Chemistry

Brooks, B.W., J.M. Lazorchak, M.D.A. Howard, M-V Johnson, S.L. Morton, D.A.K. Perkins, E.D. Reavie, G.I. Scott, S.A. Smith and J.A. Steevens. 2016. Are harmful algal blooms becoming the greatest inland water quality threat to public health and aquatic ecosystems? *Environ Toxicol Chem*, 35(1): 6-13.

Fisheries

Hilborn, R. 2016. Correlation and causation in fisheries and watershed management. *Fisheries*, 41(1): 18-25.

Freshwater Biology

Evtimova, V.V. and I. Donohue. 2016. Water-level fluctuations regulate the structure and functioning of natural lakes. *Fresh Biol*, 61(2): 251-264.

Global Change and Biology

Gallardo, B., M. Clavero, M.I. Sánchez and M. Vilà. 2016. Global ecological impacts of invasive species in aquatic ecosystems. *Global Chang Biol*, 22(1): 151-163.

Binzer, A., C. Guill, B.C. Rall and U. Brose. 2016. Interactive effects of warming, eutrophication and size structure: impacts on biodiversity and food web structure. *Global Chang Biol*, 22(1): 220-227.

Maheaux, H., P.R. Leavitt and L.J. Jackson. 2016. Asynchronous onset of eutrophication among shallow prairie lakes of the Northern Great Plains, Alberta, Canada. *Global Chang Biol,* 22(1): 271-283.

Hydrological Sciences

Chattopadhyay, Jha. 2016. Hydrological response due to projected climate variability in Haw River watershed, North Carolina, USA. *Hydrol Sci J*, 61(3): 495-506.

Integrated Environmental Assessment and Management

Chapman, P.M. and C.A. McPherson. 2016. Development of a total dissolved solids (TDS) chronic effects benchmark for a northern Canadian lake. *Integrated Environ Assess Manage*, 12(2): 371-379.

Journal of the American Water Resources Association

Castro, A.J., C.C. Vaughn, J.P. Julian and M. García-Llorente. 2016. Social demand for ecosystem services and implications for watershed management. *J Am Water Resour Assoc*, 52(1): 209-221.

Null, S.E. 2016. Water supply reliability tradeoffs between removing reservoir storage and improving water conveyance in California. *J Am Water Resour Assoc*, 52(2): 350-366.

Bachman, M., S. Inamdar, S. Barton, J.M. Duke, D. Tallamy and J.A. Bruck. 2016. A comparative assessment of runoff nitrogen from turf, forest, meadow, and mixed landuse watersheds. *J Am Water Resour Assoc*, 52(2): 397-408.

Journal of Freshwater Ecology

Liu, L. and M. Xu. 2016. Microbial biomass in sediments affects greenhouse gas effluxes in Poyang Lake in China. *J Fresh Ecol*, 31(1): 109-121.

Society and Natural Resources

Prokopy, L.S. and K. Genskow. 2016. Social indicator variations across watersheds: Implications for developing outreach and technical assistance programs. *Soc Nat Resour*, 29(5): 617-627.

Zoonoses and Public Health

Gorham, T. J. and J. Lee. 2016. Pathogen loading from Canada Geese faeces in freshwater: potential risks to human health through recreational water exposure. *Zoonoses Public Health*, 63(3): 177-190.

William (Bill) Jones, is *LakeLine*'s editor and a former NALMS president, and clinical professor (retired) from Indiana University's School of Public and Environmental Affairs. He can be reached at: 1305 East Richland Drive, Bloomington, IN 47408; e-mail: joneswi@indiana.edu.


Picture this!
YOU could be the winner of the 2016 NALMS Annual Photo Contest.
Two winning images will be selected, a Member's Choice winner selected by Symposium attendees and an Editors' Choice winner selected by the editor and production editor for the entry that will make the best *LakeLine* cover. We have secured sponsorship for the Photo Contest so a *$250 gift card* will be awarded to each winner.
Your favorite lake or reservoir photo could grace a cover of *LakeLine*!
Entries will be judged during the 2016 NALMS Symposium . . . in historic Banff, Canada!
Only electronic submissions will be accepted. You must be a NALMS member to submit an entry. Photos should be of sufficient resolution to print from (approximately 300 dpi at 8.5" x 11").
Maximum of one submission per person.
Entries must be received by October 15, 2016.
Send your entry to:
Bill Jones, Editor, *LakeLine*
joneswi@indiana.edu
photo: ©Riverwind91

NALMS 2016
Banff • Canada

36th Annual Symposium of the North American Lake Management Society

Science to Stewardship: Balancing Economic Growth with Lake Sustainability

NOVEMBER 1 - 4, 2016

BANFF SPRINGS HOTEL • BANFF, CANADA

There may be no locale more appropriate to host a discussion on the impact of development on natural spaces than Banff National Park.

Established in 1885, Banff is Canada's first national park. Hosting millions of visitors annually, Banff exemplifies the need for a sustainable balance between economic development and conservation.

Symposium guests will enjoy the vast natural splendour of the region, and are invited to participate in a field tour, pub crawl and other conference events. Local amenities boast a wide range of recreational activities including the world-famous Banff Hot Springs and shopping in the picturesque townsite.

PROPOSED SESSIONS INCLUDE:

- Paleolimnology
- Eutrophication
- Citizen Science
- Integrated Watershed Management
- Lake Remediation and Restoration
- Sessions on the Ecology of Alpine, Arctic and Prairie Lakes
- Aquatic Invasive Species - Detection, response and control
- Cyanobacteria and Cyanotoxins
- Contaminated Sites and Spill Response
- Water Quality Monitoring
- Hydrogeology Perspectives on Lake Management
- Valuing Ecosystem Services
- Climate Change Impacts
- First Nations Management of Land and Water

PROPOSE A SESSION OF YOUR OWN!
Call for papers will be available at **nalms.org** January 2016.

For sponsorship or general conference information, contact NALMS: nalms.org
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nalms@alms.ca