This is NALMS

A special electronic publication from the North American Lake Management Society • Fall 2010

This is NALMS

From the *LakeLine* Editor

LakeLine is the flagship publication of the North American Lake Management Society (NALMS). Every member receives it and we use that quarterly magazine to inform and educate our readers about current, relevant issues related to lake management. *LakeLine* also keeps NALMS members informed on the Society's business and activities. So it is fitting that the "This is NALMS" publication features articles from recent issues of *LakeLine*.

Both NALMS and *LakeLine* are celebrating 30 years in 2010. *LakeLine* has grown with NALMS from a fledgling newsletter-style publication in 1980 to a full-color, professionally produced magazine. One thing that hasn't changed over the years is the willingness of NALMS members, lake researchers and practitioners to share their knowledge with others within the pages of *LakeLine*. Without the unqualified participation of these talented authors we could not produce a quality publication.

Each issue of *LakeLine* has a theme, around which articles are written. We select themes representing current issues related to lakes and lake management. In this publication, we've selected and re-printed a set of articles published in *LakeLine* over the past three years. These articles not only represent a wide variety of issues in lake management but also showcase the publication quality of *LakeLine* articles.

We hope you enjoy and learn from the content selected for "This is NALMS". If you do enjoy it, please share this special electronic issue with your friends who may be interested in protecting North America's lakes and reservoirs. There is also membership information in the back of this issue if you would like to joins NALMS and further help our efforts to protect lakes and reservoirs.

Bill Jones
Editor, *LakeLine*

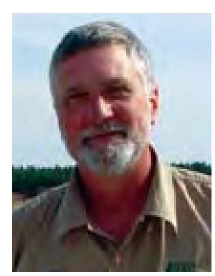
From the President of NALMS

NALMS is a society of like-minded individuals who have goals of protecting and managing aquatic resources with a focus on lakes and reservoirs. The North American Lake Management Society (NALMS) was founded in 1980 when a group of aquatic scientists realized that information was lacking on how to use science to actually manage lakes and reservoirs. Now, almost 30 years later, NALMS is a thousand members strong, and growing. Our members are as diverse as the lakes we try to protect and manage, including lakeside homeowners, anglers, citizen scientists, local, state and federal professions, and many academic professionals and students. This diversity is the greatest strength of NALMS because it brings together a collective wisdom to help with lake management issues and problems.

NALMS has many programs that benefit its membership and mission but the following are the three strongest and most visible programs:

1. **Annual Conference**: Every year the membership gets together for a collection of professional presentations, general workshops and non-stop discussions on managing lakes and reservoirs. Vendors are present with the latest lake management tools displayed. The lion's share of NALMS networking occurs at this conference and life-long friendships are forged.
2. **Professional Peer-Reviewed Journal, *Lake and Reservoir Management***: Over the last 30 years this journal has published hundreds of articles on the latest information regarding lake and reservoir science and management, including but not limited to the following topics: toxic algae, bacteria concentration, exotic species like zebra mussels and hydrilla, eutrophication, muck accumulation and removal, fish management, aquatic birds, water level fluctuation, herbicide use, climate change, and more. Just last year this journal added an electronic format to the standard hard copies, making it easily accessible from your home computer.
3. ***LakeLine* Magazine**: *LakeLine* also has articles that can be used by citizen scientist as well as professionals to help protect and manage lakes. In addition, *LakeLine* keeps the NALMS membership informed on what its members are up to with society news and news from Affiliates around the country, times of meeting, book reviews, literature searches, current legislative information regarding lakes and reservoirs, and even a kids' corner to help educate future lake lovers.

I know that there are many individuals that do not know that NALMS exists but would like to help with its mission to protect and manage lakes and reservoirs. To help spread the word, and recruit help, NALMS has put together this special electronic compilation of articles published in *LakeLine* over the last several years. Please enjoy it and send it to anyone you feel has a love for lakes and reservoirs. If, after you have read the compilation, you would like to help, please consider becoming a NALMS member, all the information for you to become a member is listed at the back of this special publication. Even if you do not become a NALMS member, get involved in protecting and managing our precious aquatic resources.



Mark V. Hoyer
President, NALMS
2009-2010

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.

This is NALMS

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On the cover:
Our cover photo, called "Reflections of Glimmerglass – Otsego Lake," taken by Jessica Harman, was the #3 placement in the 2009 NALMS Photo Contest.

Advertisers Index

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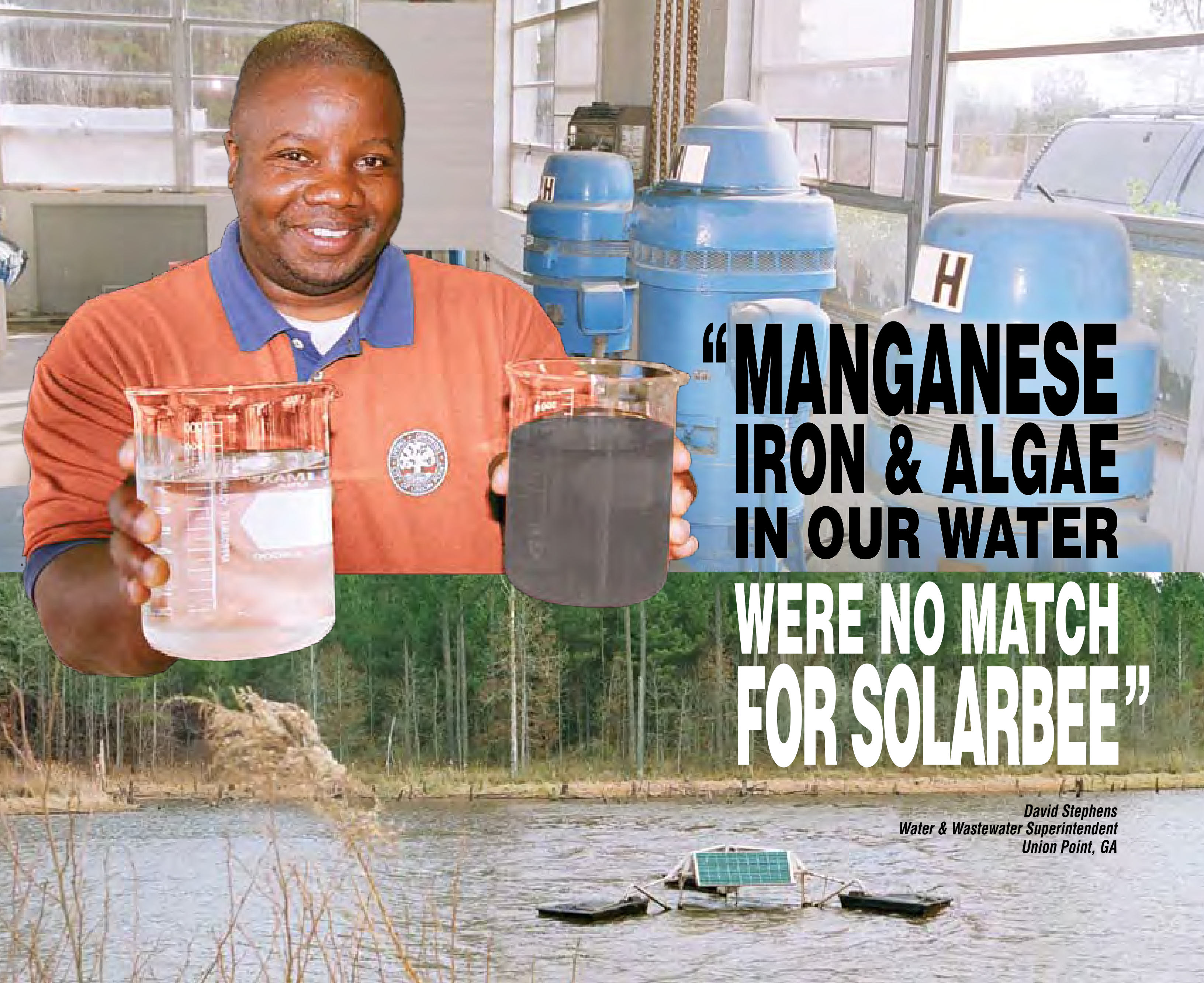

Sherrills Creek Reservoir in Union Point, GA had a triple dose of problems. This 48-acre lake was laden with high levels of manganese and iron, giving the water an unnatural dark color and causing it to stain their customers' clothes and plumbing fixtures. Also, a proliferation of blue-green algae blooms resulted in finished water with an unpleasant taste and odor.

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A Maine Success Story

Dave Halliwell and Melissa Evers

Bioremediation Study of a Shallow Lake in South-Central Maine:

Combining top-down and bottom-up approaches to improve water quality

Figure 1. Nuisance blue-green algal bloom on East Pond (Alden Camps) during late summer 2006 (photo credit: Dave Halliwell, Maine DEP*).*

Introduction

Lake management agencies have traditionally focused efforts on controlling external sources of nutrients to lakes to remediate water quality issues. Despite these efforts, improvement of water quality can be slow, particularly in shallow lakes that exhibit resistance to returning to a clear-water stable state. Studies in Europe and North America suggest that manipulating food web structure to favor fish populations with lower planktivory can lead to responses that cascade down through lake food webs – improving water clarity by releasing herbivorous zooplankton from predation.

The Maine Department of Environmental Protection (Maine DEP) included 34 lakes on the 2006 list of state impaired waters – requiring a Total Maximum Daily Load (TMDL) under Section 303(d) of the Clean Water Act (CWA). Aside minimal Secchi disk transparencies (less than 2.0 meters water clarity) due to the prevalence of nuisance summer blue-green algal blooms (Figure 1), a common biological feature in many of the Maine TMDL lakes is the dominance of introduced populations of landlocked white perch (Figure 2). Relationships between altered fish assemblages and water quality have been studied extensively in Europe (Germany, Denmark, and the Netherlands) during the past several decades (summary papers by Mehner et al. 2004; Sondergaard et al. 2007).

East Pond, one of these 303(d) listed lakes, had a TMDL report prepared by Maine DEP and the Maine Association of Conservation Districts (MACD) approved in 2001 by the United States Environmental Protection Agency (USEPA) – New England Region I. Based on the results of this TMDL, best watershed management practices to control/reduce non-point sources of phosphorus were implemented through USEPA Section 319 (CWA) funding in recent years (1999-2007 – $195,365). A recently completed *Watershed Based Management Plan* (Kennebec County Soil & Water Conservation District – April 2007) further detailed a strategic plan of recommended actions to ensure that East Pond will attain acceptable Maine DEP Class GPA water quality standards over the next ten years.

East Pond is located directly upstream of North Pond, a lake that has much less severe algal blooms despite having similar shallow morphometry and mesotrophic nutrient status. The lakes differ in their fish assemblages, with East Pond having a higher density of planktivorous-sized white perch, while North Pond has an illegally introduced top predator – northern pike – not found in East Pond. These differences led us to hypothesize that food web structure may be responsible, at least in part, for the higher frequency of summertime nuisance algal blooms in East Pond (Figure 3).

Based on the results from studies in Europe, as well as preliminary

Figure 2. Boatload of adult white perch captured by trap-netting and removed from East Pond during the early spring of 2007 (photo credit: Ryan Burton, Maine DEP).

investigations conducted during 1982-92 by Mills and Green (1992) in nearby lakes Cobbossee and Annabessacook, the Maine DEP initiated a demonstration biomanipulation project in East Pond, which is part of the Belgrade lakes system of south-central Maine (Kennebec River drainage). North Pond is being used as a downstream comparison lake. Given the poor water quality conditions and altered biotic community in East Pond, the overall goal is to improve lake water quality by the implementation of technically sound nonpoint source controls within the East Pond watershed coincident with an in-lake biomanipulation (food web alteration). Following two years of (Phase I) baseline evaluation, including estimates of fish populations and other limnological studies in 2004-06 (University of Maine and Colby College), target fish species removal and disposal commenced in East Pond during the spring of 2007 and will continue in 2008. A minimal 50-percent and up to 75-percent removal of fish biomass over a two-year period was found to be effective for water quality improvement in past European biomanipulation studies (Mehner et al. 2004).

Our primary objectives here are to: (1) provide background on the water quality and fish assemblages in the two study lakes; (2) discuss first-year fish removal and assessment methods; and (3) to acknowledge the cooperative partnerships among funding agencies, lake scientists, fish managers, aquatic biologists, and citizens to effectively implement a different approach to fisheries management and water quality remediation.

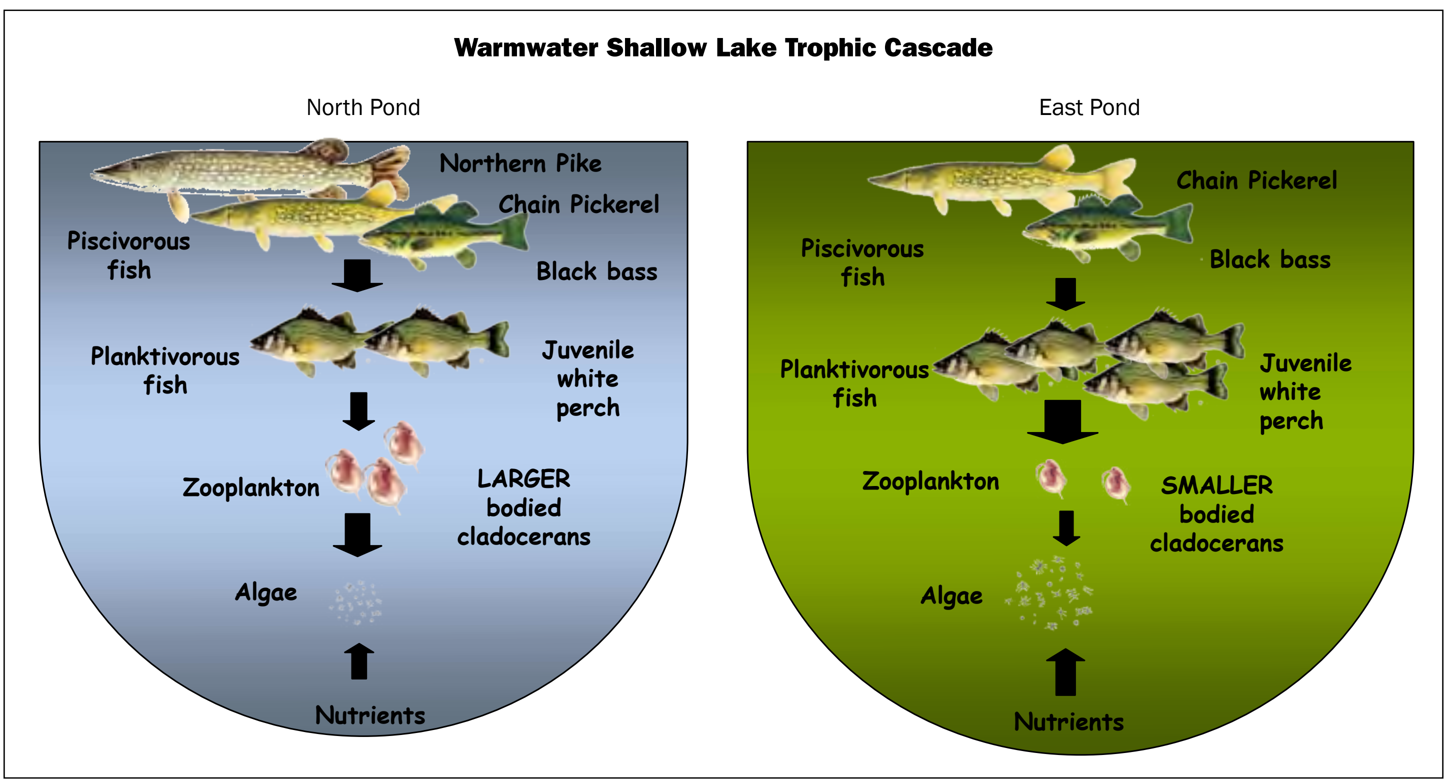

Figure 3. East and North pond trophic cascade (graphic design by Tara Trinko, University of Maine, Orono).

Lake Watershed and Water Quality

East Pond, with a surface area of 1,725 acres (698 hectares) and a mean depth of 18 feet (5 meters), is the headwater lake in the Belgrade Lakes system located in south-central Maine (Figure 4). This 303(d) listed lake is also characterized by a relatively small direct drainage area (4.3 sq. mi. or 11.2 sq. km) with no major inlets and a wetland dominated outlet, Serpentine Stream, which tends to backflow during storm events, particularly in the spring and fall months. East Pond has a relatively slow turnover rate of only once every four years (0.25 flushes per year) and is classified as a fairly shallow and weakly stratified, wind-disturbed aquatic system.

The Serpentine Stream flows over a low-head dam into downstream North Pond, with a surface area of 2,251 acres (911 hectares), a mean depth of 13 feet (4 meters), and a much larger direct drainage area (14.6 sq. mi. or 37.7 sq. km.). North Pond has an annual hydraulic turnover rate of 1.0 flushes per year and is also classified as a relatively shallow and generally non-stratified, wind-driven lake.

East Pond water quality has been assessed since 1975, including 19 years of basic chemical information and 32 years of Secchi disk transparency (SDT) measurements. The lake has low color (average 15 SPUs) and a long-term average SDT of 4.3 meters (14.1 feet). The upper water column (epilimnion) total phosphorus in East Pond has ranged from 12-29 ppb with an average of 19 ppb while chlorophyll-*a* ranged from 0.4-27.8 ppb with an average of 9.2 ppb. East Pond has experienced nuisance blue-green algal blooms, with the exception of only four years since 1993 (1996-97 and 2000-01).

North Pond water quality has been assessed since 1970, including 12 years of basic chemical information and 27 years of Secchi disk transparency measurements. Similar to East Pond, North Pond has an average color of 16 SPUs, a long-term average SDT of 4.2 meters (13.8 feet), an epilimnetic total phosphorus range of 10-22 ppb with an average of 17 ppb, and chlorophyll-*a* ranging from 2.2-6.9 ppb, with an average of 3.7 ppb. In direct contrast to East Pond, however, North Pond has experienced nuisance blue-green algal blooms during only four years since 1993 (1994, 1997, and 2006-07 – Figure 5).

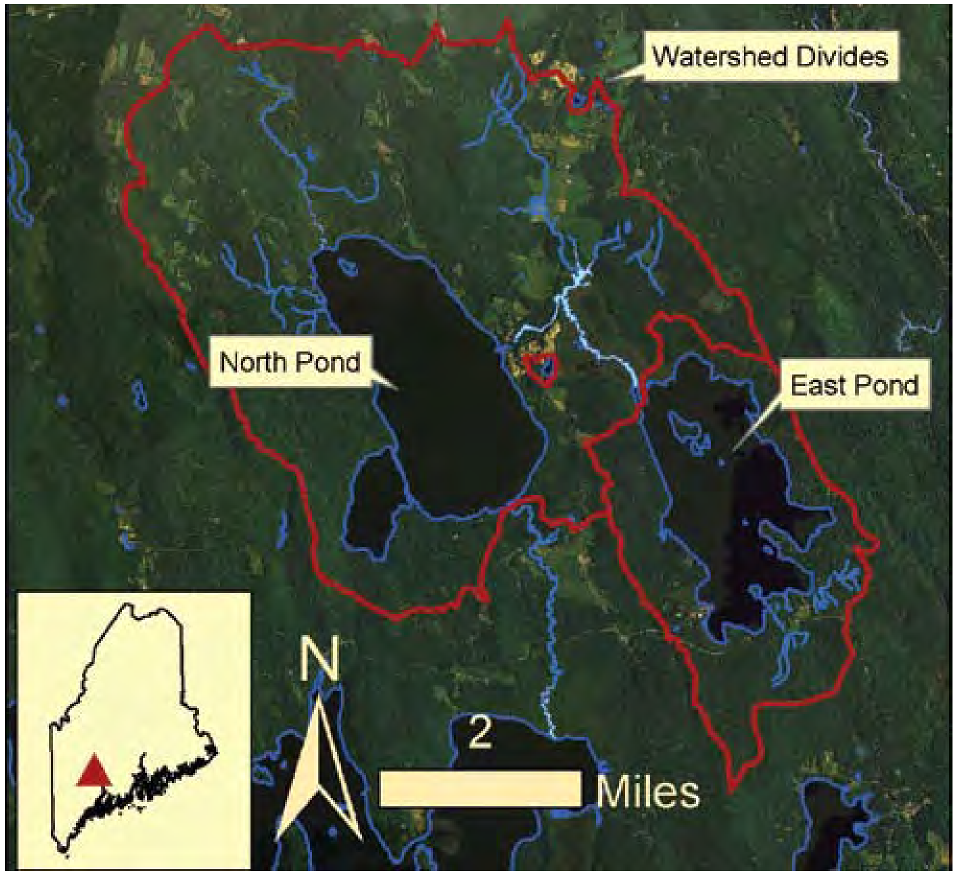

Figure 4. Map of East and North ponds in south-central Maine, depicting watershed drainage divides (graphic design by Melissa Evers, Maine DEP).

"We found an abundance of non-native planktivores."

Resident Fish Assemblages

The fish assemblages in East and North Ponds are comprised of 16-17 species, including 9-11 indigenous species and 6-7 introduced species (Table 1). North Pond is somewhat more diverse, having native fallfish and brook stickleback, along with non-native northern pike, originally introduced illegally into associated Little North Pond in the late 1960s (personal communication, Bill Woodward, Maine DIF&W, Figure 6).

Fish biomass in both of the ponds are dominated by a single non-native species, land-locked white perch, introduced prior to the 1940s as a sport fish introduction, as was the common practice in New England during that time. Illegally introduced black crappie and native yellow perch comprise the bulk of the secondary fish biomass and are included as targeted fish species (Figure 7), along with white perch and landlocked alewife – the latter, which are well-established in North Pond are, however, uncommonly found and probably recent illegal introductions to the resident fish assemblage in East Pond.

Fish population (mark-recapture) studies carried out in the spring of 2004 and 2005 provided adult white perch estimates of 173,500 (+/- 23,700) in East Pond and considerably less (77,000, +/- 11,500) in North Pond. Fewer recaptures of associated target species (e.g., yellow perch and black crappie) provided less reliable population estimates. A hard-water (ice) creel survey was conducted by Maine DIF&W Region B biologists in 2005 to establish baseline ice-fishery statistics and will be repeated in 2010, following several continuous years of targeted fish removal (2007-08) in East Pond.

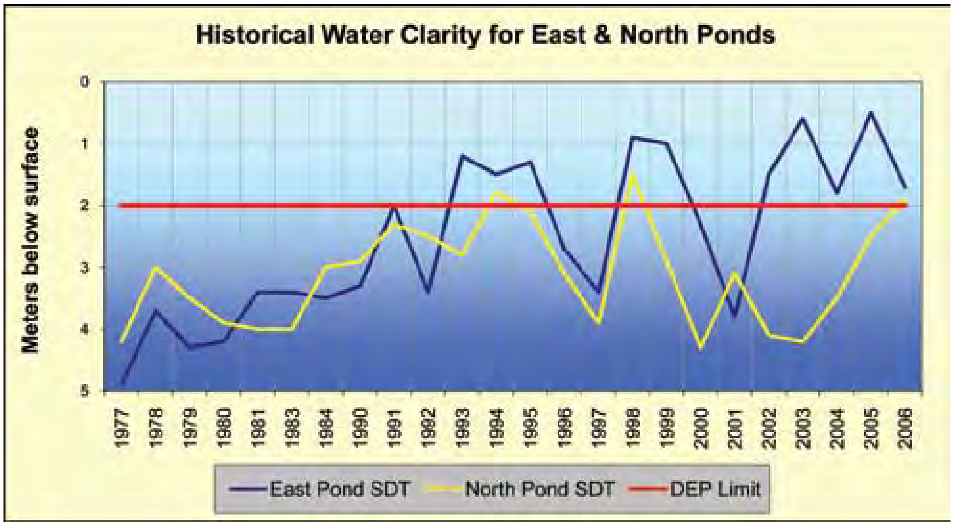

Figure 5. Historical water clarity for East and North ponds in south-central Maine (graphic design by Fred Dillon, Maine Association of Conservation Districts).

Table 1. Species Composition and Relative Abundance of Fish During Spring Pre-removal Trapnetting in East and North Ponds, South-central Maine.

Fish Species	*Scientific Nomenclature*	*Relative Abundance*	
Introduced Non-Native		**East Pond '04**	**North Pond '05**
White perch (Target-1)	*Morone americana*	16,066	8,261
Black crappie (Target-2)	*Pomoxis nigromaculatus*	539	219
Landlocked alewife (Target-4)	*Alosa pseudoharengus*	0	9
Smallmouth bass	*Micropterus dolomieu*	0	0
Largemouth bass	*Micropterus salmoides*	12	1
Northern pike	*Esox lucius*	N/P	32
Brown trout (stocked)	*Salmo trutta*	1	N/P
Brook trout (stocked)	*Salvelinus fontinalis*	0	N/P
Indigenous Native			
Yellow perch (Target-3)	*Perca flavescens*	1,315	180
Pumpkinseed	*Lepomis gibbosus*	45	0
Redbreast sunfish	*Lepomis auratus*	1	0
Golden shiner	*Notemigonus crysoleucas*	52	3
American eel	*Anguilla rostrata*	0	1
White sucker	*Catostomus commersoni*	99	96
Brown bullhead	*Ictalurus nebulosus*	1	3
Chain pickerel	*Esox niger*	29	0
Banded killifish	*Fundulus diaphanus*	0	0
Fallfish	*Semotilus corporalis*	N/P	0
Brook stickleback	*Eucalia inconstans*	N/P	0
Fish Species Richness		**16**	**17**

"This is what we are doing to help solve the problem."

Targeted Fish Removal and Disposal

Following three years of baseline study of the water quality, fish, zooplankton, and phytoplankton relationships in East and North Ponds, fish removal and disposal activities commenced in East Pond following ice-out in early spring 2007. A total of 40,570 fish were captured during the period April 19 through May 15 using five trap nets fished over 134 trap nights (Figure 8). Of this total, 98 percent by number were targeted fish species, comprised of 86 PERCENT white perch, 6.6 percent yellow perch, and 5.4 percent black crappie. The released non-target fish species (2 percent) were comprised of golden shiner, chain pickerel, white sucker, and sunfish, in association with small numbers of black bass (largemouth and smallmouth), brown bullhead, and just a few stocked brook and brown trout.

Adult white perch dominated the removal biomass both in terms of number (34,959) and weight (9 tons) harvested (Table 2). A large number of juvenile (1+) white perch were also captured and removed by open water seining on several occasions (Figure 9). Two- to three-year-old classes of white perch were not generally observed nor captured during this sampling period. During the summer months, the assemblage of surviving resident fishes was assessed on a monthly basis using a standard catch per unit effort deploying a combination of active fishing gear types (sinking gill nets, expert baitfish angling, and nighttime beach seining – Figure 10).

The ten tons of target fish removed were disposed of at a local organic farm (Figure 11) as part of a composting study

Figure 6. Gill-netted northern pike – illegally introduced into Little North Pond in the late 1960s (photo credit: Dave Halliwell, Maine DEP).

Figure 7. Fish species targeted for removal include introduced white perch, black crappie, and landlocked alewife – as well as resident yellow perch (photo credit: Dave Halliwell, Maine DEP).

with Maine DEP (Division of Solid Waste Management) to compare the effectiveness of turned windrow vs. static pile methodologies. Preliminary results suggest that composting with turned windrow is an efficient means to dispose of the fish carcasses with complete disintegration and minimal odor (Mark King, Maine DEP, Maine Compost Team).

"On-going and future studies."

Zooplankton, Fishes, and Water Clarity Improvement

In the pre-treatment phase (2004-07), Trinko (University of Maine MSc thesis 2008) examined relationships between zooplankton biomass and body size, juvenile fish prey selectivity, and algal biomass in East-North Ponds to address the hypothesis that differing aquatic food web structures mediate water quality dynamics within these two shallow hydrologically connected mesotrophic lakes. The focus on zooplankton body size follows findings by Stemberger and Miller (2003) that cladoceran body length was an important predictor of water clarity and was well correlated to temporal variation in transparency within lakes in the northeastern United States (1991-94 EMAP-Surface Waters Program). This is because the larger-bodied cladocerans have a higher water filtering rate, consume more phytoplankton, and can capture larger phytoplankton cells. Further, they concluded that "monitoring cladoceran body length helps to distinguish changes

Figure 8. Springtime trap-netting on East Pond with Maine DEP fisheries specialists, John Reynolds and Joe Glowa (photo credit: Dave Halliwell, Maine DEP***).***

Table 2. East Pond Fish Capture and Removal Summary (Spring 2007).

Fish Species	**Number Captured**		**% Weight Contribution**
	Adults	**Juveniles**	**Adults**
White Perch	34,959	57,436	89.0%
Yellow Perch	2,678		5.3%
Black Crappie	2,175		5.7%
Total	**39,812**		**10 tons**

Figure 9. Large number of juvenile (1+ zooplanktivorous) white perch removed by open-water seining from East Pond in south-central Maine (photo credit: Ryan Burton, Maine DEP).

Figure 10. Late afternoon beach seining on East Pond in south-central Maine (photo credit: Dave Halliwell, Maine DEP).

Figure 11. Organic composting of disposed fish (primarily white perch) from East Pond by Maine DEP fisheries specialist Joe Glowa (photo credit: Ryan Burton, Maine DEP).

in lake transparency due to nutrient loading from changes that reflect fish population size structure and predation intensity on zooplankton."

Two additional graduate student projects have been recently initiated at the University of Maine to continue the demonstration initiated in the pre-treatment phase – to study and evaluate the response of both target and non-target fish species and plankton populations to the effects of ongoing biomanipulation. These studies will determine if the reduction in planktivorous fish leads to future improvements in the water clarity of East Pond – by favoring large-bodied cladocerans and increased cladoceran grazing pressure on nuisance cyanobacteria (blue-green algae). Other interesting questions arise, including whether or not white perch productivity and reproductive adjustments will occur to offset initial biomass reductions and whether or not other resident non-target fish species will benefit from the biomanipulation. Watch for study results and water quality updates published in future issues of NALMS *LakeLine* or *Lake and Reservoir Management*.

Future Study Plans

1. Monthly ice fishing trips on East and North Ponds to evaluate annual changes in the ice-fishery – and to document gonad condition (proportion of maturing fish) and age characteristics in targeted fish populations.
2. Repeat targeted fish removal efforts in East Pond following ice-out in the spring of 2008 – using Oneida-style trap nets to capture adults and open-water purse seining to capture juveniles – particularly introduced white perch.
3. Continue to dispose of fish at area farm in support of ongoing composting studies.
4. Continue annual tagging of 2,000 adult white perch to assess population status.
5. Monitor water quality and plankton assemblages on a bi-weekly basis (May through September) on three established sites on both East and North Ponds.
6. Assess resident fish assemblages in East and North ponds in 2008 – utilizing standard CPUE methods developed during the summer of 2007.
7. Initiate study of water quality, fish, and plankton assemblages in four to six additional eutrophic to oligotrophic lakes in Maine.

Acknowledgments

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Disclaimer

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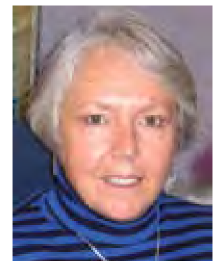

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CyanoHABs and Climate Change

Hans. W. Paerl

Managing Harmful Cyanobacterial Blooms (CyanoHABs) in the Face of Anthropogenic and Climatic Change

Nutrient over-enrichment from urbanization, agricultural and industrial expansion is a serious threat to the ecological integrity, sustainability and safe use (drinking water, recreational, fishing) of aquatic ecosystems. A very troublesome symptom of nutrient over-enrichment is the proliferation of blue-green algal or cyanobacterial blooms as unsightly, odoriferous, green-yellow paint-like scums (Figure 1). These blooms are problematic from ecological, economic and health perspectives; hence the designation "harmful" (Chorus and Bartram 1999; Huisman et al. 2005; Paerl and Fulton 2006). Toxic, food web-altering, hypoxia-generating harmful cyanobacterial blooms, or CyanoHABs, are geographically expanding and proliferating in large lakes, reservoirs and river systems at alarming rates. In the U.S., recurring CyanoHABs in three of the five Great Lakes, other large lake systems (Lakes Okeechobee and Ponchartrain, Great Salt Lake), reservoirs, wetlands, and estuaries all point to the potential problems resource managers will face in coming decades (Hudnell 2008). Identifying environmental factors driving the rapid rise in CyanoHABs is paramount to developing management strategies aimed at protecting and ensuring sustainability of impacted lakes and reservoirs, which contain a bulk of the world's drinking and irrigation water supply.

Figure 1. Large water bodies that have experienced recent increases in frequencies, magnitudes, and duration of CyanoHABs. Left to right, starting at top; Neuse River Estuary, NC; Lake Volkerak, The Netherlands (courtesy of J. Huisman); Lake Taihu, China; St. Johns River, FL (courtesy of J. Burns); Lake Okeechobee, FL, (courtesy of K. Havens); Baltic Sea-Gulf of Finland (courtesy of Finnish Frontier Guard / Air Patrol Squadron, Finland).

While nutrient over-enrichment plays a central role in CyanoHAB proliferation, the amounts and proportions of the nutrients nitrogen (N) and phosphorus (P) controlling algal production and composition are also changing in human-dominated watersheds. This has major ramifications for eutrophication and bloom dynamics. Other environmental changes may also affect these dynamics; particularly global warming, which alters physical-chemical conditions and may enhance cyanobacterial growth. Here, I discuss the interactive effects and management implications of these changing anthropogenic and climatic "drivers" of CyanoHABs.

The Players

Cyanobacteria are the oldest known oxygen-evolving photosynthetic organisms; they were first present in the Precambrian period, some three billion years ago. Their proliferation during this period is largely responsible for the formation of an oxygen-rich atmosphere, paving the way for the evolution of higher plant and animal life. Today, the cyanobacteria remain a remarkable evolutionary success story. They exploit anthropogenic nutrient enrichment, and some genera can convert "inert" atmospheric nitrogen (N_2) into biologically usable ammonia, via nitrogen fixation (Paerl 1990), thus providing their own nitrogen source when needed. The CyanoHABs include three major morphologically distinct groups (Figure 2): (1) Coccoid cells, often aggregated in colonies. Most of these genera do not fix N_2 (e.g. *Microcystis*). (2) Filaments of largely undifferentiated cells. This group is mostly comprised of non-N_2 fixing genera (e.g. *Oscillatoria*, *Planktothrix*); however, a few N_2 fixers, capable of toxin production exist (e.g. *Lyngbya*). (3) Filamentous with differentiated, biochemically specialized, cells called heterocysts. There are numerous CyanoHAB genera in this group (e.g., *Anabaena*, *Aphanizomenon*, *Cylindrospermopsis, Nodularia*). In addition to planktonic bloom formers, benthic genera (*Calothrix*, *Rivularia*, *Scytonema*, *Lyngbya*, *Oscillatoria*) can undergo explosive growths as epiphytes, mats and biofilms.

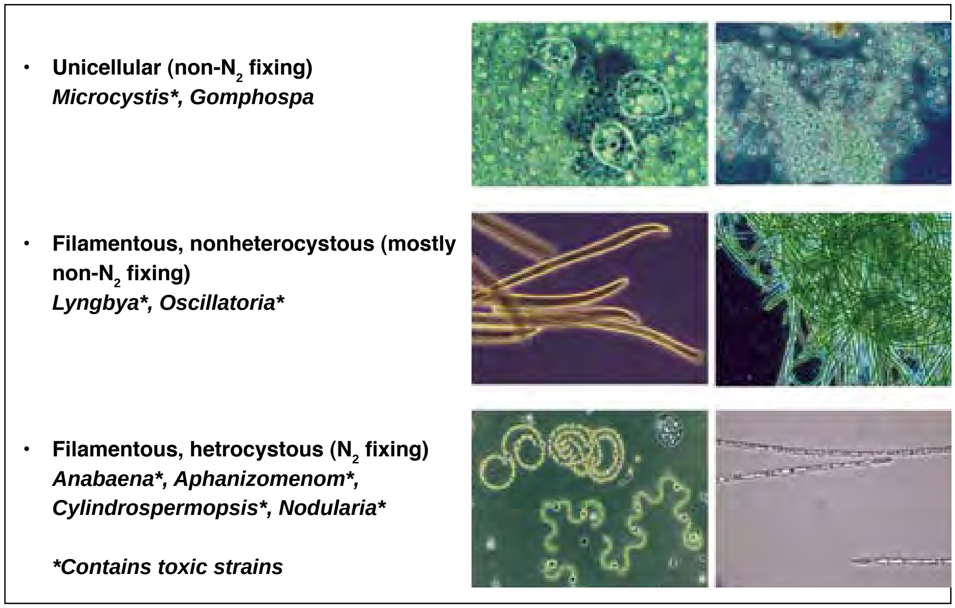

Figure 2. Photomicrographs of genera representing the three major CyanoHAB groups.

The Human (Nutrient) Connection

CyanoHABs are stimulated by excessive anthropogenic nutrient loading (Paerl 1988). In freshwater ecosystems, the causative agent of advanced eutrophication and CyanoHABs has traditionally been identified as phosphorus (P) (c.f. Likens 1972). Accordingly, control of this element has been the "holy grail" for resource managers; indeed, it has met with some success in well-described cases: For example, the enactment of the North American Water Quality Agreement led to a drop in bloom-forming cyanobacteria in many small lake and reservoir systems. The early emphasis on P reductions for CyanoHAB control is based on the fact that some CyanoHAB genera are capable of N_2 fixation, which is P-limited in many aquatic ecosystems (Paerl and Fulton 2006). Indeed, studies pursuing controls on CyanoHABs in the 1960s and '70s showed that reducing P inputs and maintaining relatively high nitrogen:P input ratios were effective in controlling CyanoHABs in lakes where such inputs could be manipulated (Smith 1990).

Nutrient loading-wise however, things have changed a great deal since the 1960s. While P reductions have been aggressively pursued, human population growth, agricultural and urban expansion in watersheds has led to huge increases in nitrogen (N) released to the environment. This has led to a dramatic rise in reactive N in the biosphere, with significant consequences for N-sensitive waters.

Excessive N loads are now as large a concern as P loads as stimulants of freshwater, estuarine and marine eutrophication and harmful algal (including CyanoHAB) blooms (Paerl and Fulton 2006). Recent studies in diverse systems are showing that controls on *both* N and P input will be needed for effective, long term control of eutrophication, associated CyanoHAB outbreaks and their ecological, biogeochemical and human health impacts. One example is the Baltic Sea region, where Elmgren and Larsson (in Paerl and Fulton 2006) showed that effective control of eutrophication and HAB outbreaks required considering total amounts *and* ratios of N and P discharged to nutrient-sensitive river-fjord-sea continuum. Similarly, Paerl et al. (2004) pointed out that single nutrient input reductions, including a P-detergent ban and improved wastewater treatment for P during the 1980s in North Carolina's Neuse River System, helped solve one problem (freshwater CyanoHABs), but exacerbated blooms in downstream N-sensitive waters. In this case, parallel N input reductions were required in addition to P reductions to stem eutrophication and HAB potentials along the *entire* freshwater to marine continuum.

In Florida's inland waters, excessive N loading, much of it from rapidly expanding wastewater and agricultural discharges has been identified (in addition to P) as a key culprit in eutrophication and CyanoHAB expansion (Kratzer and Brezonik 1981). In some of these waters, dominance by N_2 fixing CyanoHABs (which were largely controlled by P input reductions) has been replaced by co-dominance with non N_2 fixing genera (e.g. *Microcystis*), as well as "switch hitter" CyanoHABs (e.g., *Cylindrospermopsis*, *Lyngbya*) that effectively compete for reactive N when it is available and then fix N_2 when N is depleted. In these cases, *both* N and P reductions are likely needed to reduce and control CyanoHAB bloom potentials.

In the Great Lakes, the CyanoHAB problem has manifested itself as the resurgence of non-N_2 fixing *Microcystis* populations during the last decade. Since 1995, blooms of *Microcystis* have annually reoccurred throughout Lake Erie (a lake thought "recovered" from eutrophication due to well-managed P-abatement programs) as N levels have remained unchecked.

By what means and mechanisms have CyanoHABs re-emerged, despite concerted efforts to control P? Large lake systems, especially shallow eutrophic ones like Lake Taihu, China, the Florida large lakes (e.g., Lakes George and Okeechobee), and Lake Erie tend to be co-limited by N and P because a bulk of previously loaded P is effectively retained and recycled, thereby optimizing internal P availability. Hence, when N is added, it can stimulate primary production and algal biomass formation. The resultant increase in organic matter stimulates decomposition and nutrient regeneration (i.e., internal recycling), thereby enhancing P (and N) availability. A key to controlling and ultimately managing enhanced internal nutrient recycling is controlling *both* N and P inputs.

The Role of Climate Change (Warming)

In addition to nutrient over-enrichment, other environmental changes may play critical roles in a recent upsurge of CyanoHABs. Climate change, specifically global warming, is one such factor. Rising temperatures favor CyanoHABs in several ways. As a group, cyanobacteria exhibit optimal growth rates at relatively high temperatures, usually in excess of 25°C. At these elevated temperatures, CyanoHABs compete very effectively with eukaryotic algae. Thus, as the growth rates of these eukaryotic taxa decline, cyanobacterial growth rates reach their optima (Figure 3).

Warming of surface waters also intensifies vertical density stratification and thus suppresses vertical mixing. Furthermore, warming lengthens the period of stratification. Some CyanoHABs form gas vesicles, which provide buoyancy. Under strong and persistent vertically stratified conditions, buoyant cyanobacteria can float upwards to form dense surface blooms that shade deeper upon non-buoyant eukaryotic phytoplankton, thus optimizing the CyanoHAB's competitive advantage (Huisman et al. 2006). Increased water temperatures also decrease the viscosity of water. Therefore, rising temperatures will decrease the water's resistance to vertical migration of phytoplankton. This will facilitate upward (optimizing photosynthetic production) and downward (optimizing nutrient acquisition) migration by CyanoHAB species, further enhancing their competitive advantages in stratified waters.

Dense surface blooms of cyanobacteria may locally increase water temperatures, through the intense absorption of light by their photosynthetic and photoprotective pigments. For example, Baltic Sea and large lake (Ijsselmeer, Netherlands) surface blooms are warmer than ambient waters (Paerl and Huisman, in press). This represents a potential positive feedback mechanism, whereby CyanoHABs favor their own competitive dominance over eukaryotic phytoplankton.

A key driver of global warming is the rising level of the atmospheric greenhouse gas carbon dioxide (CO_2), emitted from rising rates of fossil fuel combustion and biomass burning. In nutrient-enriched waters, algal blooms exhibit a strong demand for CO_2 to support photosynthetic growth; to the extent that the rate of CO_2 supply can at times control the rate of algal biomass production (Shapiro 1990). High rates of photosynthesis and, hence, high demand for CO_2 will also increase the pH of affected waters, thereby restricting availability of free CO_2. If and when this occurs, buoyant CyanoHABs have a distinct advantage over sub-surface phytoplankton populations, since surface-dwelling taxa can directly intercept CO_2 from the atmosphere, thus minimizing dissolved inorganic carbon (DIC) limitation of photosynthetic growth (Paerl 1988). Under conditions of DIC limitation, subsurface eukaryotic algal populations are dependent on relatively slow diffusional processes to supply new CO_2, hence, they are at a disadvantage.

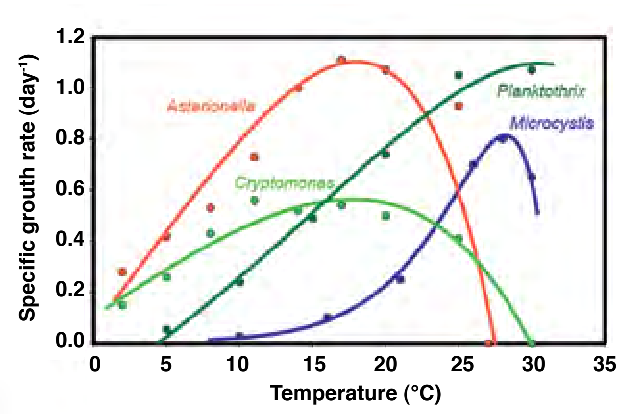

Figure 3. Temperature dependence of the specific growth rates of the cyanobacteria Microcystis aeruginosa *and* Planktothrix agardhii *(Foy et al. 1976), the diatom* Asterionella formosa *(Butterwick et al. 2005), and the cryptophyte* Cryptomonas marssonii *(Butterwick et al. 2005). The data are from controlled laboratory experiments using light-saturated and nutrient-saturated conditions. Solid lines are least-squares fits of the data to the temperature response curve of Stasio et al. 1996. Figure courtesy of J. Huisman, University of Amsterdam.*

Summer droughts appear to be increasing in intensity and duration, possibly another symptom of global warming. This, combined with increased use of freshwater for irrigation has led to rising salinities around the world. Increased salination is a serious threat to freshwater supplies; it also has major impacts on freshwater plankton composition and possibly CyanoHAB potentials. One impact of salination is increased vertical density stratification, which would benefit buoyant, scum-forming CyanoHABs. In addition, some species of common CyanoHAB genera such as *Anabaena*, *Microcystis* and *Nodularia* are more salt-tolerant than their eukaryotic freshwater algal counterparts. For example, the growth rate of toxic strains of *Microcystis aeruginosa* remains unaffected by salinities ranging from 0 g L^{-1} up to 10 g L^{-1}, which is 30 percent of the salinity of seawater. Temporary salinity fluctuations of up to 15-20 g L^{-1} may still allow survival of *Microcystis* populations, but causes salt stress leading to leakage of cells and excretion of intracellular microcystin. Likewise, *Anabaena aphanizominoides* can withstand salt levels up to 15 g L^{-1}, while *Anabaenopsis* and toxic *Nodularia spumigena* even tolerate salinities ranging from 0 g L^{-1} to more than 20 g L^{-1} (Paerl and Huisman, in press). Laboratory experiments indicate that the nodularin (toxin) content of *Nodularia* correlates positively with salinity. Salt-tolerant CyanoHABs appear responsible for expanding blooms in brackish waters, including the Baltic Sea; the Caspian Sea; Patos Lagoon Estuary, Brazil; the Swan River Estuary, Australia; San Francisco Bay Delta, California; and Lake Ponchartrain, Louisiana.

Global warming and associated changes in climatic oscillations affect patterns, intensities and duration of precipitation and droughts. These hydrologic changes may enhance CyanoHAB dominance. For example, larger and more intense precipitation events will increase enrichment of water bodies with land-derived nutrients through enhanced surface runoff and groundwater discharge. Freshwater discharge to downstream waters would also increase, which in the short-term may prevent blooms by promoting flushing. However, as the discharge subsides and water residence time increases, nutrient loads will be captured and cycled by receiving water bodies, promoting bloom potentials. This scenario exists in geographically distinct places including the Swan River, Australia; and Hartbeespoortdam, South Africa; the Neuse River Estuary, North Carolina; and the Potomac Estuary, Maryland. In addition, attempts to control fluctuations in the discharge of rivers and lakes by dams and sluices may increase the residence time, and thereby further aggravate problems with cyanobacterial blooms.

Overall, it appears that increases in hydrologic variability and "extremeness" such as protracted droughts benefit CyanoHABs. If conditions get so extreme as to dry up lakes and reservoirs, most CyanoHAB species can survive such extremeness for long periods (up to many years) as dormant cysts in sediments, soils, or desiccated mats.

Some CyanoHABs appear to be particularly successful in exploiting climatic change. The planktonic, toxin-producing, N_2 fixer *Cylindrospermopsis raciborskii* and the benthic filamentous N_2 fixing genus *Lyngbya* have shown remarkable expansion of their geographical ranges, and this expansion may be linked to warming and associated hydrodynamic changes. *Cylindrospermopsis* was originally described as a tropical and subtropical species. However, *C. raciborskii* appeared in Europe during the 1930s, and has shown a progressive colonization from Greece and Hungary toward higher latitudes near the end of the 20th century. *C. raciborskii* was first identified in the United States in Midwest lakes in the 1950s. *C. raciborskii* has probably existed in Florida inland waters for many years, but it wasn't until the 1980s that it began to aggressively proliferate in lake and river systems throughout central Florida (Chapman and Schelske 1997). More recently, this CyanoHAB has spread throughout U.S. Southeast and Midwest reservoirs and lakes, especially those undergoing eutrophication accompanied by a loss of water clarity. The mechanisms of invasion and proliferation have been elusive. However, it is known that *C. raciborskii*, which is typically dispersed throughout the water column, is adapted to low light conditions encountered in many turbid eutrophic waters. It also prefers water temperature conditions in excess of 20^{o}C.

The filamentous toxin-producing CyanoHAB genus *Lyngbya* has likewise exhibited remarkable abilities to proliferate in a range of aquatic ecosystems, including streams, springs, rivers, lakes, reservoirs, estuarine, and coastal waters. Nutrient enrichment has been implicated in its expansion (Paerl and Fulton 2006). *Lyngbya* species often form periphytic or benthic mats, though some species, such as *L. birgei*, are planktonic. *L. majuscula* produces a large suite of bioactive compounds, including the dermatoxic aplysiatoxins and lyngbyatoxin A, as well as the potent neurotoxins kalkitoxin and antillatoxin. In freshwater environments, *L. wollei* has been associated with the production of paralytic shellfish poisoning (PSP) toxins (Carmichael 1997).

There is little doubt that *Lyngbya* blooms are occurring at increasing frequencies in nutrient-enriched waters. In these eutrophying waters, both *L. majuscula* (marine) and *L. wollei* (freshwater) have proven to be opportunistic invaders and bloom-formers when environmental conditions permit. Following large climatic and hydrologic perturbations such as hurricanes, *L. wollei* is an aggressive initial colonizer of flushed systems. *Lyngbya* blooms can proliferate as dense floating mats that shade other algae, thus promoting their ability to compete for light. This CyanoHAB appears to be able to take advantage of *both* human and climatically induced environmental change.

Conclusions

In addition to the well-documented promotion of CyanoHABs by human nutrient enrichment, there is an increasingly important connection between rising levels of atmospheric CO_2, regional and global warming, and the intensification of these problematic blooms as conceptualized in Figure 4. The expansion of cyanobacterial blooms has serious consequences for human drinking water supplies, fisheries and recreational resources. This has ramifications for water management. In addition to nutrient reduction, water authorities fighting harmful algal blooms will have to accommodate the hydrological and physical-chemical effects of climatic change in their management strategies, with particular focus on surface water heating, density stratification, freshwater runoff, residence time, and even the rising atmospheric CO_2 content.

It is speculated that these climate change scenarios will play into the hands of CyanoHAB species. These species are able to capitalize on ecosystem-level biogeochemical responses (increased primary production, enhanced internal nutrient cycling) to a burgeoning load of *both* nutrients in an increasing number of riverine, lacustrine, estuarine, and coastal systems. Therefore, *both* N and P inputs are likely to require reductions for effective long-term control of CyanoHABs. Traditionally, water quality managers have addressed eutrophication and HAB problems by developing nutrient-bloom threshold relationships for setting targets nutrients load reductions. However, these relationships are confounded by coinciding physical-hydrologic changes resulting from climatic change, including warming and changes in precipitation amounts/patterns. This introduces a great deal of non-linearity into nutrient-eutrophication-bloom relationships, which calls for increased emphasis on space-time intensive monitoring able to capture both the event scale and longer-term trends. In this regard, water quality models designed to improve CyanoHAB predictability will need to synthesize nutrient and climatic drivers so that they can serve managers in meaningful and practical ways.

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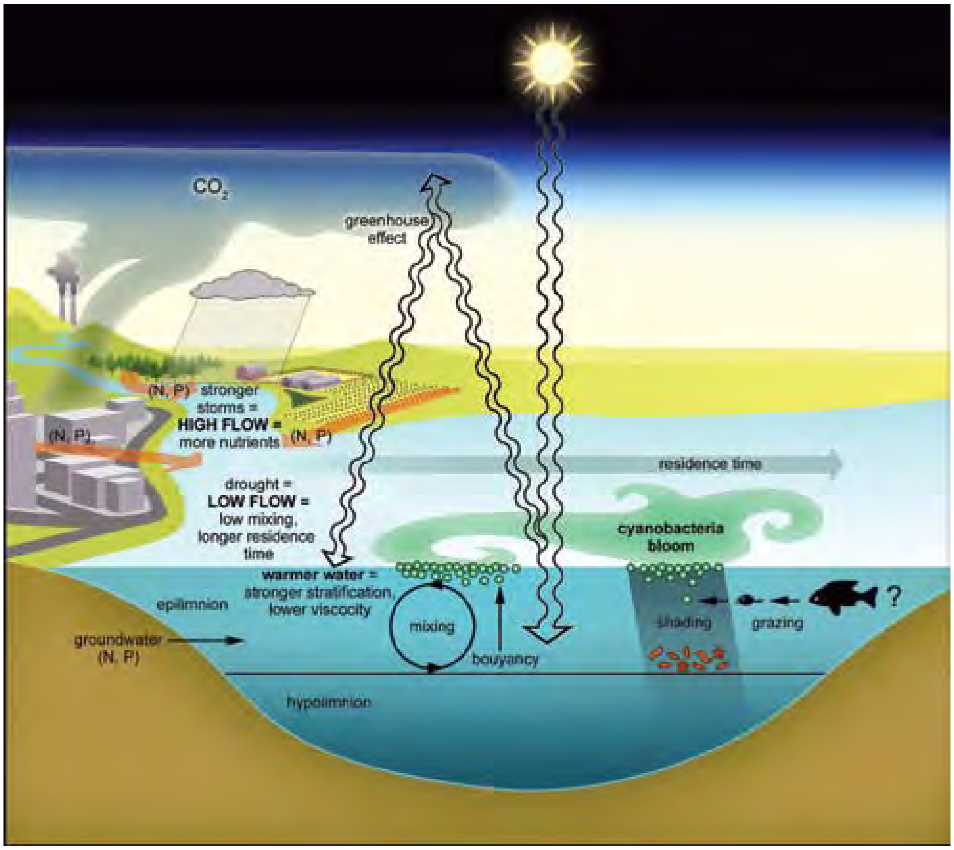

Figure 4. Conceptual figure, illustrating the environmental controls of CyanoHAB bloom dynamics, and the impacts climate change (warming) and physical and hydrologic ramifications of warming will have on these dynamics.

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From Pilot **to Statewide**

Barb Welch and Christine Smith

Moving Maine's LakeSmart from Pilot to Statewide: Lessons Learned

Situation/Background

Maine has a reputation for beautiful pristine lakes, clear blue waters, loons calling, and pointed firs framing the shores. But Maine lakes have been showing signs of declining water quality over the past 20 years. We are losing the clear water, the loons, and the pointed firs. Development has hit Maine, along with the polluted stormwater runoff that accompanies it.

Lawns are replacing the forested shorelines, mini malls are supplanting the back fields, seasonal camps are being converted into year-round homes, and miles of camp roads and ditches circle the lakes. Research shows levels of phosphorus runoff are five to ten times higher in the developed watersheds.

Maine lakes need a program to halt the tide of urban/suburban landscaping practices that have begun to circle our lakes and to encourage best management practices (BMPs): less lawn, effective buffers, erosion control, etc. In 2001, the Maine Department of Environmental Protection (DEP) staff began meeting with lake protection leaders from around the state to develop a new program.

Our goal was to make lake-friendly landscaping practices the norm on lakes throughout the state. We planned to change the norm by offering a program to encourage BMP adoption that incorporated rewards, recognition, and peer pressure to hasten the adoption.

Designing the program using social data. We used social marketing principles to help design our program. In particular, we used Doug McKenzie-Mohr's Behavior Change Matrix (with a few tweaks) to help us sort out the issues, audiences, solutions, etc. (*Fostering Sustainable Behavior: An Introduction to Community-based Social Marketing* by Doug McKenzie-Mohr, William Smith, 1999; New Society Publishers; see also, http://www.toolsofchange.com and http://www.cbsm.com/).

The matrix gives a framework for analyzing and prioritizing approaches. They require the user to look at very specific actions. For example, although the stakeholder group started with the broad category of lawn care, the matrix forced us to examine very specific actions for homeowners (e.g., grow less lawn, use less fertilizer, spoon feed lawn) (see Table 1). The matrix leads a reader through an analysis not only of what actions give the greatest bang for the buck but what realistically is likely to get implemented. Reducing lawn size, for example, would be good for water quality, but we've found few lawn aficionados willing to give up lawn. The matrix also helps figure out audiences, incentives and barriers, and outreach tools.

We decided our target audience was lakeshore residents and we left municipal code enforcement officers, lawn care companies, and building contractors for another time. We used the 2000 Maine Lake Users Survey, statewide quantitative phone surveys from 1996-2006 (which are posted on our Website: http://www.maine.gov/dep/blwq/doceducation/nps/outreach.htm), and our experience to characterize our audience as "concerned but lacking knowledge on cause and effect, looking for easy fixes, retired."

After creating multiple matrices representing many options, we decided to offer a comprehensive program focused at changing landscaping, yard care, and structural housekeeping practices of shorefront residents. The program would offer

- free workshops to train residents in good practices;
- site visits by trained and neutral third parties (usually Soil & Water Conservation District staff) to evaluate properties and offer advice on specific BMPs to fix erosion and polluted stormwater runoff problems; and
- awards (signs) for good land use practices both as an incentive and to increase visibility of the program and the homeowners' new practices.

The Behavior Change matrices also helped us decide which BMPs to evaluate during the site visits. We picked the ones that would make the greatest impact on the lake regardless of how easy they would be to implement (e.g., reducing amount of lawn, creating buffers, replacing old septic systems). But we also included easier but more palatable ones that people might adopt more easily (e.g., reducing the amount of fertilizer/pesticides, pumping septic tanks, fixing chronically eroding areas). The reason for easier BMPs was to encourage our target audience to feel that they were lake conservationists and then it would be easier to motivate them to undertake more difficult practices.

As with any program we needed a name, slogan, and logo. We tested various names and slogans before selecting "LakeSmart: Living lightly on the land for the sake of our lake." Offering several names and designs, we asked potential audiences for feedback. We used e-mail to individuals and mini focus groups of lake property owners at meetings to get responses to a series of questions relating to the name, logo, and the design for the

Table 1. Example of Behavior Change Matrix for the Creation of an Effective Social Marketing Campaign (Lawn Care).

General description of the area of concern? Homeowner purchases of lawn (turf) products that contain pesticides, fertilizers, or both doubled in Maine from 1994 thru 1999. Trends in residential sprawl, increased retailers including big-box outlets and aggressive marketing/advertising by manufacturers in an environment of little regulatory oversight of at-home applicator behavior invite risk to state waters. Further, storm-event surface water monitoring efforts by Friends of Casco Bay have detected several pesticides and all three major nutrients in freshwater swales adjacent to residential developments that feed directly into Casco Bay.

What are the components that make up the area of concern? List and then fill out the following table.

Component:

Activity (Specific behaviors/ activities that people could do).	*Competing Behaviors* What do people currently do? Use focus groups or observations.	*Impact* Identify & quantify the impact each positive activity has on water x what programs have been the most effective in getting people to adopt the behavior = cumulative impact.	*Barriers* What will stand in our way of getting people to do what we would like them to do?	*Perception* Check the accuracy of people's perceived barriers to change. Use focus groups.	*Benefits* Benefits from the new/ desirable behavior or how to make the competing behavior less desirable.	*Type* One time activity or repetitive?	*Tool or Action* PSA/ Activity/ Workshop/ Brochure/ Demonstration/ Partnership Message crafting
Grow less turf	Turf fills property, boundary to boundary. People like lawns for recreation and just for looks. Turf seen as "clean" look to property; tidiness	Impact on water quality? LakeSmart has achieved ~ 40% success in getting shorefront folks to lessen lawns and instead plant buffers (which is higher than those away from the shoreline).	Folks unaware of alternatives in landscape/horticulture design. Have landscaped once – don't intend to do it again.	Alternatives are for "green thumbs" only. But be careful how tell them less lawn – our focus groups (04) thought we meant pave more. One of the hardest practices to get people to do (LakeSmart survey 07).	Less turf = less chemicals, less lawn mowing, less time, labor in general.	One-time installation of aesthetically and environmentally sound groundcover, shrubs, trees suited to site and climate demands minimal (but not zero) care.	Show them what a limited lawn looks like – demonstrations. An isolated message suggesting one should dispatch their lawn is of little use.
Use: good management: proper watering (1-1 ½"/ week); mow high (set blade 2 1/2- 3"); mow frequently; leave clippings; sharpen blade; thatch and aerate in fall	Mow short and water frequently. Bag clippings because they cause thatch and neater appearance.	Impact? Yardscaping and Bayscaping	Folks have been doing yard care since kids – know how to do it. Need to keep up with neighbors. Shorter is neater. Can't let lawn brown up (go dormant) in summer.	Some believed that lawn needs to be short like golf green. Important to keep up neighborhood standards – ask neighbors for advice. Not asking questions of any experts. (New England CES survey 08).	These actions interconnect. Followed thru properly, turf becomes vibrant, less stressed and less vulnerable to weed problems. Fertilizer needs alone are halved simply by mowing properly, returning clippings to lawn.	Routine, repetitive	Easy-to-read/follow guide, that's visible. Say as decal-sticker for lawn mower, fertilizer bag closure, point of sale, or laminated checklist. Currently project underway by New England CES.
Use pesticides/fertilizers only when needed (September in Maine) and in amounts only as required. Maine soils are rich in phosphorus – don't need to add it.	In Maine ~1/3 of homeowners don't fertilize, 1/3 fertilizer 1-2 times/year and 1/3 fertilize 3-5 times/year. (Municipal Employees survey 04)	Impact? Dept. of Ag – Board of Pesticide Control – "Think First, Spray Last" program. New law in Maine that requires signs in stores selling fertilizer that discourage use of fertilizers containing phosphorus for lawns seems to be ~30-50% effective in reducing phosphorus fertilizer (qualitative analysis so far).	Habit of fertilizing. Risk to environment and people are not recognized, so what's the problem? Also, saying "buy less" isn't good for business, especially for big-box retailers. ~50% of Mainers don't think or don't know that stormwater leaves their yard (Municipal employees survey 04)	~30% of Mainers don't recognize weed and feed products as having pesticides. Most folks ignore/don't care that herbicides are pesticides. Fifteen percent of respondents to a 1994 BPC survey who said they never use pesticides listed herbicides as products they routinely apply around the yard. Most people don't think about affect on water quality unless in sight of water (focus groups 07).	Save consumers from wasting money. Also, reduce opportunities for accidents involving pesticides and children, spills, and eventual household waste collection program costs for unused products. Make lawns safe for pets and children.	Repetitive. Folks forget and return to old habits.	TV and radio ads Easy-to-read/follow guide, that's visible. Say as decal-sticker for lawn mower, fertilizer bag closure, point of sale, or laminated checklist. Currently project underway by New England CES. Link to water quality of a local water body (New England CES survey 08).

Figure 1. The LakeSmart sign.

Figure 2. The LakeSmart sign in location. Photo: Laura Wilson.

Figures 3. A model LakeSmart property and our first award winner. Photo: Laura Wilson.

award sign. We did not ask what name or design they liked best but what message they got from the samples we offered. This process took many months with numerous revisions. Also, we thought we wanted to use signs to make the "new" social norm visible, so we checked with our audience first to see if they thought it was a good idea. We found that homeowners embraced the idea of posting a visually appealing sign on their properties.

As DEP and other lake protection experts field-tested our site evaluation form, we decided four categories would be scored: Road, Driveway, and Parking Areas; Structures and Septic System; Lawn, Recreation Areas, and Footpaths; and Shorefront and Beach Areas. In order to get the LakeSmart Award and sign, the property needs to pass all four categories. If a property is not ready for an award, it usually passes one or more categories and DEP sends recognition certificates and recommendations with the follow-up letter to property owners.

In 2003, we began to publicize LakeSmart and hold workshops. Anyone who attended a workshop and wanted a shorefront property evaluation, as well as anyone else who requested an evaluation, got one. Trained conservation district staff (contracted by DEP) responded to individuals' requests for evaluations, using the survey form that the stakeholder group developed. Awards, recognitions, and advice on BMPs were given out and LakeSmart signs began to appear around the shorelines. By the spring of 2006, the pilot phase for LakeSmart consisted of 17 lakes that had at least three evaluations on each plus a number of other lakes with only one or two evaluations, spread out across much of southern Maine.

Figure 4. This homeowner did the best with an old property built before the 100 foot zoning set-back by allowing the natural vegetation to grow in around the house, using several BMPs for erosion control and drastically reducing her lawn area. Photo: Christine Smith.

Evaluation and Measuring Results

After running the program as a pilot for two years, we had many more requests from lake associations and individuals to participate in the LakeSmart program than we could service. It was time to evaluate the program. We looked at process, impact, and context assessment. We did phone surveys, mail surveys, interviews, and mini focus groups to collect data to evaluate the various components. When the evaluation was complete, we discovered ways to improve the program, trim costs, and raise efficiencies.

Evaluation of the program questions. Initially, we were concerned with the effectiveness of our workshops beyond the traditional "end of workshop" evaluation form. People generally stated the workshops were good and helpful. We knew our *process indicators*: the number of workshops and attendees and the number of property evaluations.

We were doing okay by our initial objectives, though low on numbers of workshop participants, especially considering the relatively large expense of putting on these six-hour workshops. Were we spending our money and our participants' time wisely? Besides educating one or two dozen people per workshop, how many site visits/evaluations of lake watershed properties could be attributed to the workshop? How many people actually changed their behavior and/or installed a Best Management Practice that was taught in the workshop? We realized that we needed to pay attention to the *impact evaluation*: the number of people who actually did something as a result of the program. We analyzed the database of evaluations and workshop attendance. It seemed that sometimes the workshop promoted the program (generated requests for evaluations), but sometimes the workshop didn't result in a flurry of evaluations. There were also lakes in the program where only one person or nobody had attended a workshop but we still had requests (often a lot) for evaluations. So what was most critical in getting people to take action?

Another question was how to use the Social Diffusion theory (Rogers 2003) to our advantage. We would aim for 15 percent of the lakeshore community to adopt the program and hoped this would be enough momentum to carry the message to other lakeshore residents and eventually to those in the watershed? For this to work, we needed 15 percent of homeowners to be LakeSmart by embracing the landscaping BMPs. Furthermore, lake friendly practices needed to be visible and highlighted by the LakeSmart sign. Thus, we arrived at our new objective – 15 percent of lake watershed properties on a project lake will be LakeSmart and have LakeSmart signs. To meet this new objective, we had to consider *context evaluation*: who is responding, who is getting awards, why others are not, what support is needed, why are some lakes successful and others not?

We also wondered what BMPs were most and least likely to be used? Did we need to reduce the number of practices that we were evaluating and focus only on a few key practices?

To be able to answer the impact and context evaluation questions, we undertook some market research and analysis. We did a phone survey of those who had registered for workshops – whether they attended or not. The survey asked if they had learned something new, if they had implemented a new BMP, if they needed more support and what type of support. If they hadn't attended, why not and what would be an incentive to do so? It also asked questions about the person's involvement in other lake-oriented activities and how much time they spent at the lake. We also did a paper survey to lake associations to determine what type of training they wanted, when, where, and what might be incentives. We interviewed the third-party evaluators and the local lake association contacts to get their perspectives on what worked and what didn't. And most recently, we sent a mail survey to everyone that had a property evaluation to see what actions, if any, they had taken and what would be helpful if they hadn't acted yet.

Results of the research. Our analysis showed that up to a year later, 72 percent of people who attended a workshop could describe something new they learned and 83 percent reported or were observed to have installed BMPs. But people preferred a much shorter workshop and closer to home. Did we need the workshop? In the beginning, the workshop was also a marketing tool. Once the program became known, it seemed an expensive way to educate a small group of people. We found that workshops did not necessarily move people to action. (Education and/or knowledge do *not* always result in action.) For some lakes, no workshop was necessary; for example, at one lake, a brief presentation at the lake association meeting was enough to generate 12 requests for evaluations on a lake with 54 houses. Two years later, that lake had reached the objective of 15 percent LakeSmart.

We also wanted to know what motivated folks to improve their yard care to more lake-friendly practices. We needed to look more closely at context evaluation to determine what factors we could attribute to behavior change, specifically why LakeSmart was popular in some areas and not in other areas. This is what we learned:

- Lake associations that were most successful had a member that was a "sparkplug" to kindle interest and action among members.
- Their board members were willing to be leaders.
- The group offered some incentive/support to members.
- The property evaluators were very important and not just for the process of completing evaluations in a timely and efficient manner. They helped reinforce the need for BMPs, gave concrete suggestions for improvements, and sometimes became the sparkplug who promoted the program.
- Pumping or fixing malfunctioning septic systems (70 percent) and erosion problems (68 percent) were the most frequently corrected problems. The least likely to be fixed included reducing lawn size (40 percent) and stabilizing the shoreline (17 percent). We found the barriers to fixing problems most frequently included the cost involved in the project, followed by the idea that the project wasn't necessary or the property owner didn't want to give up the lawn, need for extra parking. Occasionally, they didn't understand how to fix the problem or couldn't find the right materials. What the respondents thought would be most helpful in getting them to the LakeSmart Award was technical assistance, funding, and materials (see Table 2).

Table 2. Compilation of LakeSmart Survey Results.*

Action or problem area	*Was this a problem?*	*Corrected after LakeSmart evaluation*	
Fix eroding areas in driveway or parking area	Yes 41	Yes 32	No 5
Divert roof runoff into stable vegetated area or infiltration well	Yes 24	17	6
Maintain septic system or connect to sewer	Yes 6	4	0
Define and limit recreation areas in yard	Yes 13	5	4
Stabilize any eroding areas in yard	Yes 38	26	7
Establish stable winding path to lake	Yes 25	11	8
Establish, enhance or protect shoreline buffer	Yes 42	22	11
Stabilize shoreline	Yes 24	4	8

* Note: *284 surveys sent out; 135 returned. The second and third columns don't always add up to the number in the first column as they should if everyone replied to all questions. Sometimes the correction was in progress, sometimes the respondent marked that it was a problem but not whether they had fixed it.*

Lessons Learned and Applied

Rather than following a shotgun approach to expanding statewide, we have decided to focus on lakes that meet what we consider key elements for success. Instead of responding to requests for evaluations anywhere, we only pay for evaluations on "project lakes." To get accepted into the program as a project lake, lake associations must apply through a process that addresses these key elements. Here are examples of what our application requires:

1. A minimum three-year commitment from the lake association to promote LakeSmart and to achieve a minimum of 15 percent LakeSmart Award properties in those three years.
2. A local "sparkplug" to help promote the program and someone else to schedule evaluations.
3. An active lake association, as demonstrated by projects, educational programs, newsletters, and/or Website.
4. No other big projects going on around the lake that would be competition for their attention and energy.
5. To overcome some of the barriers we found to owners fixing problems on their properties, we give extra credit to a lake association willing to offer incentives (some form of matching grants, free plants, discounts at nurseries, pledge forms, or Youth Conservation Corps – high school students who supply inexpensive labor for homeowners who buy the materials).
6. A high percentage of shorefront property owners are members of the lake association.
7. Support from the local Soil and Water Conservation District or similarly qualified neutral organization with personnel willing to be the trained LakeSmart evaluators.

We realized the expensive workshops were no longer necessary. Instead, DEP or evaluators give presentations at lake association meetings to promote the program, and we offer associations that are accepted into the program a shortened workshop called "LakeSmart Walk 'N Talk." This is a two-hour tour of two properties to familiarize the attendees with the evaluation process and explain how the BMPs protect water quality.

The ensuing informal discussion allows homeowners to ask questions and begin to problem solve for their own property in preparation for their evaluation and possible award. The walking and observing real landscaping problems and solutions is more fun than sitting inside looking at slides. The measurable objective for this training is that 75 percent of Walk 'N Talks participants will take action – either requesting an evaluation or implementing a BMP within two years.

There has been an annual review of the form evaluators use on the site visit in an effort to cover the many types of properties most equitably. Although some practices are more frequently adopted by homeowners than other BMPs, we have decided to continue offering the full suite of yard and structure BMPs to address different problems and situations.

Other Lessons Learned as Byproducts of Our Evaluation

On large lakes, a more narrow focus on road associations (a formal or informal group of landowners who join together to maintain their private road) is more effective. You can reach the tipping point of 15 percent of a community sooner if there are lots of signs in that area. People take notice if they see three or four signs on one road as opposed to one sign here and another sign a mile away. So, we encourage large lakes to focus on implementing LakeSmart through the road associations or on a portion of the lake, e.g., a bay, south end, or some other geographic or cultural unit that makes sense for that lake.

Competition is a driving force for some. We heard about friendly competition between road associations on one lake and between lake associations statewide to see who had the most awards. We don't encourage competition, but we drop a few hints that it works in some places.

The follow-up phone surveys acted as prompts/reinforcement for the program. It reminded participants of their original plans and gave us a chance to offer support or suggest an evaluation. Now we tell participants at presentations and evaluations that we will call them in a year to see how they are doing and if they need help.

What's Next?

We will continue to do all the types of evaluation as the program grows and presents us with new and exciting challenges. Such intensive assessment takes a lot of time but we plan to complete another assessment in three to five years as the program evolves. It has been rewarding to see the enthusiasm of our lakeshore audience making these lake-friendly behavior changes. The lakes in Maine are eternally thankful to all homeowners, evaluators, and stakeholders who have made LakeSmart a success.

More information about the LakeSmart program can be found at http://www.maine.gov/dep/blwq/doclake/lakesmart/index.htm.

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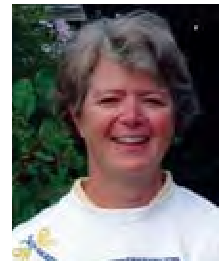

Barbara Welch has worked as an aquatic biologist for the Maine Department of Environmental Protection for 34 years. For the past 18 years, Barbara has focused on education and outreach on water quality issues including lakes, streams, stormwater, and habitat issues. In particular, she has worked on statewide stormwater outreach and behavior change campaigns with regulated entities under Phase II of the Clean Water Act and coordinated social marketing efforts for the Land & Water Bureau. She can be reached at barb.welch@maine.gov.

Christine Smith worked at Maine DEP as the Lakes Education Coordinator for the last nine years. In those years she collaborated often with Barb Welch in the development of several outreach programs: LakeSmart, watershed protection grants for grades 6-12, Lake Education Days for schools and summer camps, and the promotion of phosphorus-free fertilizer culminating in 2007 legislation requiring stores to post a sign warning of the water quality impact of phosphorus in lawn fertilizer. Christine can be reached at chrisbradsmith@gmail.com.

The **Salton Sea**

Barbara Berry and Michael A. Anderson

"I stopped Kaweah and glanced back at the Salton Sea, which I was now leaving for a time. It is at best a rather cheerless object, beautiful in a pale, placid way, but the beauty is like that of the mirage, the placidity that of stagnation and death. Charm of color it has, but none of sentiment; mystery, but not romance. Loneliness has its own attraction and it is a deep one; but this is not so much loneliness as abandonment, not a solitude sacred but a solitude shunned. Even the gulls that drift and flicker over it seem to have a spectral air, like bird-ghosts banished from the wholesome ocean."

– J. Smeaton Chase, 1919 (deBuys 1999)

Figure 1. Satellite image showing the Salton Sea (center of image) in relation to the Pacific Ocean and the Gulf of California (lower right corner of image). Photo courtesy of Liam Gumley, Space Science and Engineering Center, University of Wisconsin-Madison.

The Salton Sea is a saline lake 229 feet below sea level. It is surrounded by salt flats and the stark desert landscape of southeastern California, where the annual rainfall is 2.7 inches/yr and daytime air temperatures routinely exceed 100° F for over four months each year. At 59 km in length, roughly 20 km across and with a surface area of nearly 1,000 km^2, it is the largest lake in California and dominates the landscape in this region (Marti-Cardona 2008). Although the scene seems barren, the Salton Sea provides refuge for nearly 400 species of birds and is an extremely productive fishery. Like many inland bodies of water, its future is threatened, with the fate of the Salton Sea unclear (Figure 1).

Geology and Early History

The Salton Sea covers an ancient seabed that, were it not for sediment carried into the Salton Trough by the Colorado River, would remain part of the Gulf of California. The region includes the Coachella and Imperial Valleys of southern California, the western half of the Mexicali Valley, and the Colorado River delta in Mexico. The Salton Trough is an area of intense geological activity, being the locus of a complex transition zone between the San Andreas and Gulf of California fault systems. The region is also geothermally active, with superheated water (approximately 360° C) a comparatively modest 1.5 – 2.5 km below the earth's surface. Geothermal production wells tap into this magmatically heated water; ten generating plants located at the southern end of the Salton Sea have a combined capacity of 327 MW.

At just 2 m above the elevation of Death Valley, the Salton Trough is the world's largest below sea level depression at 7720 km^2 (Oglesby 2005). The Salton Trough has periodically been inundated with flows from the Colorado River forming a series of lakes and inland seas over recent geologic history. In the last 2000 years, at least three large lakes filled the basin, while numerous smaller and more transient lakes have also existed here. Evidence indicates that a large lake (named Lake Cahuilla, after local Native American groups) occupied the basin from approximately 1000 A.D. to 1500 A.D. (Figure 2). Human intervention would be responsible for the next major inundation of the Salton Trough, however.

While surveying possible train routes through the Salton Trough, William Blake noted in 1858 wide salt flats with little water in the basin. He also noted fertile soil in the valley, commenting that "… it becomes evident that the alluvial soil of the Desert is capable of sustaining a vigorous vegetation. The only apparent reason for its sterility is the absence of water." (deBuys 1999).

His comments did not fall on deaf ears, and schemes were soon devised to bring water to the fertile valley. A developer and water engineer named Charles R. Rockwood (Figure 3) created the California Development Company in 1896 with hopes of bringing Colorado River water to the Salton Trough to irrigate the valley (deBuys 1999). The Imperial Canal was built in 1901, and diverted a portion of the Colorado River through northern Mexico, then back to the U.S. into the Salton Trough.

Figure 2. A view of the ancient shoreline of Lake Cahuilla and the current lake level. Photo courtesy of Barbara Barry.

Farms thrived in the area with a constant supply of water, and for many years the canal systems were praised. Problems arose, however, with water delivery at the end of 1903 and into 1904. The large amounts of silt in the Colorado had deposited in the main intake to the canal, preventing water from reaching the valley. With thousands of farmers in uproar about their wilting crops, Rockwell made the hasty decision of making an unprotected opening in the canal (deBuys 1999). At this time, the level of the river was low enough for the cut to not pose an immediate threat, and plans were made to correct the opening during the following winter. However, 1905 brought several storms to the Colorado River watershed that had been unprecedented in recorded history until this point. The level of the river rose, more powerful than before, and widened the cut (Figure). Eventually most of the Colorado River was flowing directly to the Salton Trough, destroying railroad tracks, flooding the farms and new homesteads. For two years, much of the Colorado River flowed into the basin, creating the Salton Sea we know today. The canal opening was finally repaired in 1907 after many failed attempts, but the basin was forever changed (Carpelan 1958).

Figure 3. Charles R. Rockwood (Cory 1915).

Agriculture Grows and the Salton Sea Gains Interest (1907 – 1960s)

With the creation of the Imperial Irrigation District in 1911, safer canals were constructed to bring fresh water for irrigation, and the construction of the Hoover Dam further controlled the flooding of the Colorado. Agriculture once again flourished in the basin, and excess irrigation water and drainage water fed the lake. President Coolidge designated the Salton Sea as a permanent irrigation drainage area in 1924. Despite the large amount of water evaporated from the lake (1.8 m/yr), the water levels were maintained with these agricultural contributions.

After the successful introduction of several marine fish species, the lake became a popular recreation area for

Figure 4. The Colorado River flowed through existing river banks, but the force of the river widened the banks to half a mile (Cory 1915).

southern Californians (Figure 5). Huge investments were made in new cities and boating resorts around the Salton Sea. Housing developments sprang up along the lake shore. At the peak of popularity, the Salton Sea state recreation area had more visitors than Yosemite National Park (Figure 5).

Decline of Salton Sea Popularity ('70s to '90s)

The 1970s brought two powerful tropical storms to the Salton Sea, causing the lake to flood and severely damage the resorts and new communities. Many choose not to reinvest in the area, and the popularity of the lake declined. Huge fish-die offs added to bad publicity. Popularity of the Sea was further eroded after a State Health advisory recommended consumption of fish caught in the Salton Sea should be limited due to high trace element concentrations (Moreau 2007). The 1990s also saw several disease outbreaks among the avian populations inhabiting the lake. In 1992, 150,000 eared grebes died of a still unknown cause, and 1996 saw the spread of botulism in pelicans, killing thousands. By now, the Salton Sea had gained the reputation as a breeding ground for disease and death (Figure 6).

Figure 5: Boat races were common during the 1950s and 1960s, and several speed records were set at the Salton Sea. Photo courtesy of the Salton Sea Authority.

Current Characteristics

The lake's current elevation is 229 feet below sea level. As previously noted, it is situated in the lowest area in the region and has no surface outflow besides evaporation. As a result, salts, nutrients, pesticides, and other contaminants brought into the Sea from agricultural and, to a lesser extent, municipal sources, and natural flows never leave the basin. An estimated 3.4×10^6 tonnes yr^{-1} of salt are deposited in the Salton Sea each year (Holdren and Montano 2002). Much of that salt originates from the agricultural drains under the fields that allow farmers to flush water through the soil, removing excess salt and carrying it to the Salton Sea. The salinity of the lake has thus been steadily increasing since its creation. The average total dissolved solids concentration in the Salton Sea was 44 ppt in 1999 (Table 1) and has increased over the past nine years to a current salinity level of approximately 49 ppt (Barry, unpublished). The Salton Sea is now about 40 percent more saline than the oceans.

Interestingly, the chemical composition of the Sea has evolved to a chemistry that differs in some significant ways from marine systems (Table 1). Sodium is the dominant cation in the waters of the Salton Sea, followed by lower concentrations of Mg^{2+}, Ca^{2+} and K^+. These cations are balanced by high concentrations of both Cl^- (17,240 mg L^{-1}) and sulfate (10,500 mg L^{-1}). Comparing these concentrations with those in the ocean, we see proportionally higher Ca^{2+} levels and much higher levels of sulfate (Table 1). Sulfate is thus an important electron acceptor in the Salton Sea, with extensive sulfate reduction and accumulation of hydrogen sulfide in the lower portions of the water column (Reese et al. 2008).

Trace metals like selenium are somewhat of a concern for local wildlife. The Colorado River watershed has naturally high levels of selenium, which become concentrated in agricultural

Figure 6. Salton Sea on the decline. Used by permission of *The* (Palm Springs, CA) *Desert Sun.*

runoff with evaporation. Levels of selenium in the Salton Sea have been low (1.1–2.1 µg L^{-1}) (Holdren and Montano 2002), but found at higher and potentially hazardous levels in the agricultural drains (5.9–6.6 µg L^{-1}), although damage to wildlife, as was seen at the Kesterson reservoir, has not been observed. The concentrations of Se and other trace elements continue to be monitored in lake water, sediments, as well as biota there (see Table 1).

Irrigation runoff comprises 94.8 percent of the inflow, while contributions from the watershed and direct precipitation account for only 5.2 percent of the water inputs to the Sea (DWR, 2006). Inflow into the lake is approximately 1.3 million acre-feet yr^{-1}, with a loss of around 1.29 million acre-feet yr^{-1} from evaporation. With this water balance, the level of the lake has remained relatively stable, depending on irrigation practices.

Table 1. Concentrations of Major Ions and Nutrients in Salton Sea in 1999 (Holdren and Montano, 2002) and Ocean Water (Stumm and Morgan 1981).

Constituent	***Salton Sea (mg L^{-1})***	***Ocean Water (mg L^{-1})[a]***
TDS	44,090	35,000
Ca^{2+}	944	412
Mg^{2+}	1,400	1,290
Na^{+}	12,370	10,770
K^{+}	258	399
Cl^{-}	17,240	19,354
SO_4^{2-}	10,500	2,712
HCO_3^{-}	245	142
Ortho-P	0.021	NA
Total-P	0.069	NA
NH_3-N	1.16	NA
NO_2+NO_3-N	0.12	NA
Total Kjeldahl N	3.5	NA

[a]*Ocean water composition approximated as mg L^{-1}, although should strictly be reported as mg kg^{-1}.*

The extreme summer heat in this area results in very warm water temperatures in the Sea (Fig. 7a). Daytime surface temperatures in the Sea exceed 32° C (90° F) in the summer, with rapid heating during the spring resulting in stratification, although periodic mixing warms the lower water column until isothermal conditions are in place in late summer (Figure 7a). Stratification maintains anoxic conditions in the hypolimnion from May-September, with mixing events in late July and August of 2006 resulting in very low DO concentrations throughout the water column (Figure 7b). Hydrogen sulfide levels near 1 mmol L^{-1} were present in the bottom waters through most of the summer of 2006, with a mixing event in late July yielding sulfide concentrations throughout the water column near 0.1 mmol L^{-1}, exceeding the toxicity threshold for tilapia (*Oreochromis mossambicus*) by a factor of almost 3 (Reese *et al.*, 2008). This mixing event also resulted in a fish kill of 3 to 4 million tilapia (Figure 8). The lack of oxygen and high sulfide concentrations following mixing has resulted in fish kills becoming a regular occurrence in the summer.

The link between the physics of the Salton Sea and fish kills has recently been demonstrated using satellite imagery. Marti-Cardona et al. (2008) demonstrated that the fish kills observed at the Salton Sea were associated with upwellings identified from surface temperature maps derived from MODIS/Terra images at the Sea. Surface temperature anomalies of up to ±5° C were present in the satellite images and preceded fish kills by one to five days. In addition to these upwelling events, acoustic Doppler current profile measurements and 3-D hydrodynamic modeling demonstrated a strong counter-clockwise gyre present in the south basin, with velocities often approaching or exceeding 20 cm s^{-1} (Cook et al. 2002). Strong winds and the wave action set up by these winds are responsible for periodic sediment resuspension events that are thought to drive nutrient loading to the water column (Chung et al. 2008). Sediment characterization found little

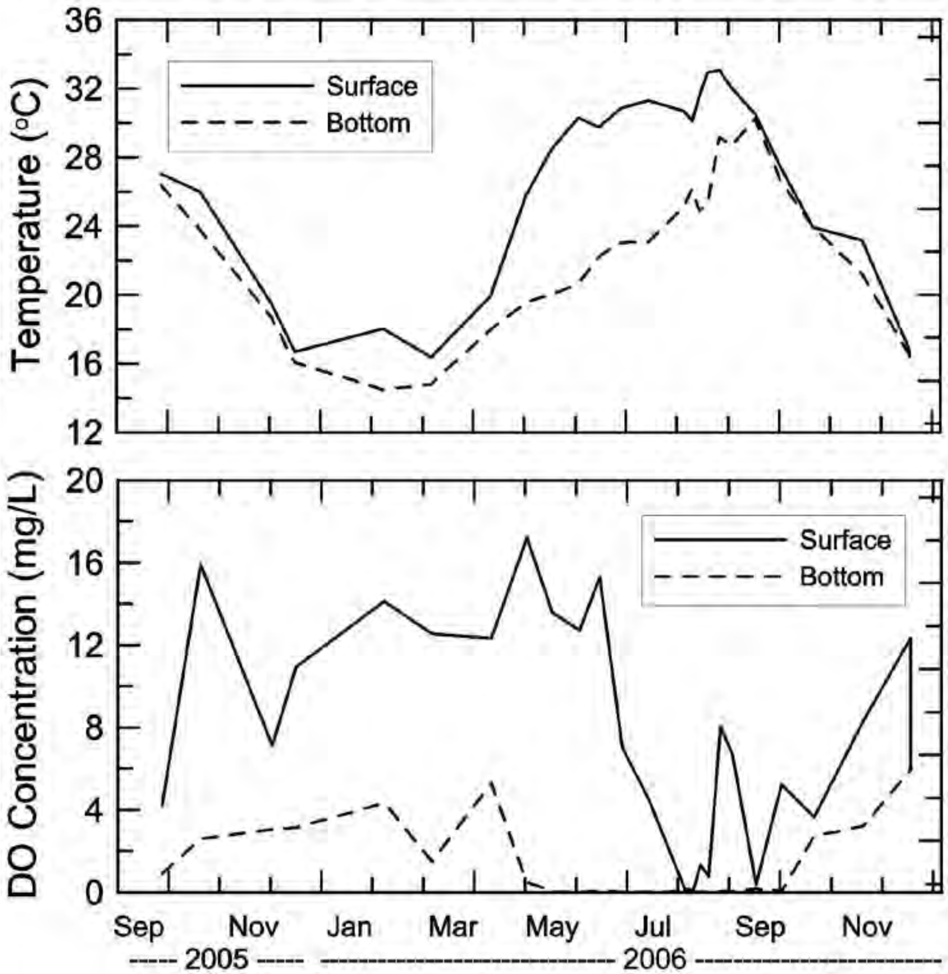

Figure 7. Time series showing (a) temperature and (b) dissolved oxygen over time (Reese, unpublished data).

organic matter accumulation at depths <8-9 m, with wave theory calculations suggesting that winds occurring <1% of the time are sufficient to minimize accumulation of organic there (Anderson et al. 2008).

Biota

The Colorado River introduced several species of fish during the creation of the Salton Sea, but most were not able to survive the rise in salinity, especially when combined with the high summertime temperatures. The California Department of Fish and Game made several attempts to stock the lake, trying everything from salmon to anchovies, but had little success. In the 1950s, they tried again with fish from the Gulf of California, and successfully established large fisheries. The most productive were orangemouth corvina (*Cynoscion xanthulus*), croaker (*Bairdella icistia*), and sargo (*Anistremus davidsoni*). With high productivity in the lake, as well as the absence of predators, conditions were favorable for these fish to thrive. Increasing salinity and eutrophication came to challenge these species as well, however.

After a massive fish-kill in 1999, few corvina, croaker, or sargo were reported in the Sea. Gill-netting conducted by the California Department of Fish and Game has yielded none of these fish for several years. The only surviving fish species presently in the Salton Sea is tilapia. These fish were originally farmed in a nearby hatchery, and managed to escape through drainage ditches into the lake. Tilapia currently number in the millions at the Salton Sea, although their average size is small. Despite the yearly fish kills in the summer, the population always managed to bounce back. The increasing salinity is expected to soon extirpate the tilapia, however. A very different ecosystem will eventually take hold here.

Tilapia are planktivorous fish, and consume both the phytoplankton and zooplankton in the Salton Sea. Some of the phytoplankton population is comprised of species typical of saline aquatic systems in North America, but is mostly comprised of marine species of flagellates, diatoms, and dinoflagellates. They were most likely introduced during the addition of invertebrate and fish species in the 1950s. Seasonal changes in temperature as well as DO and sulfide concentrations determine which species is dominant, with flagellates being abundant during the summer, and diatoms and dinoflagellates dominating in the winter. Cyanobacteria blooms occur frequently in the summer, being able to withstand

Figure 8. Fish die-off in 2006. Used by permission of *The* (Palm Springs, CA) *Desert Sun.*

high water temperatures and poor water quality. These blooms often contribute to the annual tilapia die-off during the summer. The dominant zooplankton species in the Sea are the copepod, *Apocyclops dengizicus*, and the rotifer *Brachionus rotundiformis* (Tiffany et al. 2002). These populations are also affected by seasonal changes, with the summertime turn-over causing severe crashes in both populations. Also present in the lake are the barnacle, *Balanus amphitrite,* and the polychaete worm, *Neanthes succinea.* These invertebrates are an important part of the food web of the Salton Sea, although continued increases in salinity will also deleteriously affect invertebrate populations (Simpson and Hurlbert 1998).

Along with being an extremely productive, if not also challenged, aquatic ecosystem, it is a refuge for nearly 400 species of birds. Some just pass through on the Pacific Flyway; others make a permanent home on the lake's shores. Several endangered species have found refuge here, including the Clapper rail (*Rallus longirostris obsoletus*) and brown pelican (*Pelecanus occidentalis*). The Salton Sea is now a very important stop on the Pacific Flyway, since most of the estuarine and wetland habitat in California has been lost. The Sea has also, unfortunately, been the site of large bird kills. Botulism C has been implicated as the cause of thousands of pelican deaths, and is a major concern for government resource officials (Figure 9).

Figure 9. The Salton Sea provides critical habitat for a large number of birds, including several endangered species. Used by permission of *The* (Palm Springs, CA) *Desert Sun.*

Future

The irrigation waters that feed the Salton Sea will soon be drastically reduced. The Colorado River Quantification Settlement Agreement (QSA), signed in 2003, establishes a water transfer from agricultural water users to urban water users in Southern California. With significantly reduced inflows, the Salton Sea is projected to drop 20 feet, and increase in salinity to 308,000 mg/L by 2078. Lake productivity will decrease, habitat will be lost, and the decrease in water level will expose thousands of acres of emissive sediments to winds, exacerbating air quality and public health in the region. Recognizing the potential ecological and public health implications of the QSA, the state legislature also passed the Salton Sea Restoration Act to facilitate environmental mitigation and allocate responsibility among water agencies and the state. The outcome of that evaluation was the development of an $8.9B "Preferred Alternative," which will establish a 62,000 acre "Species Conservation Habitat" to provide habitat for migratory and resident avian fauna, a 45,000-acre marine sea, a 17,000-acre brine sink, and air quality management facilities to reduce particulate emissions from the exposed lakebed. Under the current economic condition in the state of California, however, it is unclear of the fate of the Preferred Alternative. Whether or not this plan is enacted, less water will be used to irrigate the Imperial Valley and inflows to the Sea will necessarily diminish. The future Salton Sea will thus likely be much smaller, more rapidly salinized, and may join the numerous prior lakes in the Salton Trough and be desert once more (Figure 10).

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Figure 10. Sunset falls on the Salton Sea. Photo courtesy of Douglas Barnum, USGS.

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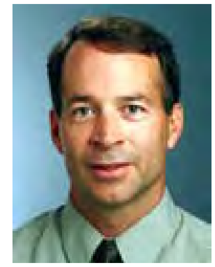

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Wisconsin Lakeshore **Restoration**

Patrick O. Goggin, Daniel Haskell, and Michael M. Meyer

The Wisconsin Lakeshore Restoration Project: A Growing Solution to Degraded Shorelines

For many of us, our lakeshore represents the sweep of one's heart, a place filled with memories of growing up, catching fish, watching frogs, and whiling away the sweet summer days. However, during the past few decades especially, the domestication of our shoreland buffers has altered the character of our shores in damaging ways (Bernthal 1997). But do not despair, change is afoot!

People around Wisconsin and beyond have been rethinking what is best for the lakes and for their families. They are taking on the task of restoring their shorelands to a more natural state. Lake residents and organizations, natural resource agencies from the Wisconsin Department of Natural Resources (WDNR) to local land conservation districts, as well as tribal entities, energy companies, and businesses such as resorts and restaurants, have all embraced the idea of restoring shoreland buffers. A lot of great things can come from this effort.

Reestablished shoreland buffers improve wildlife habitat so there is more for our families to enjoy. These shoreland buffers enhance water quality, helping our lakes become healthier and more satisfying for everyone. Often these projects form teams, including local contractors, nurseries, consultants, and others specializing in shoreland work. Miles of shoreline have been returned to more naturalized habitat, with the full complement of structure including trees, shrubs, and ground layers of native sedges, grasses, ferns, and wildflowers.

People have done so, in part, because the restored shores hold a promise of revitalized habitat, and of new areas that are more inviting to green frogs, turtles, mink, otters, and young fish (Cunningham 2000). These renewed shorelands also buffer lakes from increased nutrients and sediments that can reach them through surface water runoff. But how successful have we been at improving ecological conditions, biological diversity, or productivity of damaged lakeshores?

Growth of a Restoration Partnership

Lakeshore property owners and other practitioners are enthusiastic and committed to shoreland buffer reestablishment. But they need additional help from researchers in the form of new data on effective techniques, planting strategies, erosion control measures, and other details of successful restorations. The origins of this project go back to informal discussions between WDNR researchers, land and water conservation staff, and zoning department folks in northern Wisconsin a few years ago. Together they realized that shoreland restoration activities were going on all over the state, yet our understanding of the science behind these endeavors was lacking.

Over the last two years, researchers working with the Wisconsin Lakeshore Restoration Project have been trying to get some answers. This project seeks to quantify the ecological and water quality benefits associated with buffer renewal by measuring the value of fish and wildlife habitat restoration. It is a collaborative partnership that includes shoreland property owners, lake groups, state and county agencies, local plant nurseries, academia, and other partners.

The project compares and contrasts habitat and water quality data between developed and undeveloped lakes that were identified by WDNR researchers for the study. These pairings of lakes share similar lake characteristics like chemistry, size, type, and landscape positioning. Through the project partnership, four developed lakes in the study are getting significant stretches of shoreland buffer restored. Baseline data from these lakes are then compared to untreated controlled sites on the same lake and to reference sites on undeveloped lakes.

This project started in 2007 with several shoreland buffer restorations on Found Lake in Vilas County, an area of Wisconsin that is home to the third-largest concentration of freshwater glacial lakes on the planet. Back in 1999, this 326-acre drainage lake was hit with high winds on the northern shoreline from a major storm. The wind event produced many downed trees, including old growth red and white pines. Several shoreland property owners were left with large gaps in their lakeshore buffer areas. In the aftermath of this storm, lakeshore landowners, natural resource professionals, local lake organizations, area businesses, and others decided they could make a difference for their lake by trying shoreland buffer reestablishment through the Wisconsin Shoreland Restoration Project. The response from the area's lake community was incredible.

First, the project leaders set up a study design between WDNR researchers, Vilas County Land and Water Conservation staff, and Department of Agriculture, Trade and Consumer Protection (DATCP) engineers. Lake group representatives assisted as well. Organizers started pitching the idea of doing shoreland restoration and erosion control work on waterfront properties using their resources to help riparians. They went to lake association meetings to ask prospective landowners if they would commit to the ten-year length of the study through a conservation contract with county officials.

Several families signed contracts for the conservation plans to move forward. By the spring of 2007, over $40,000 in state grants and other funding had been raised to be used for restoring multiple shoreland buffers. Some 4,500 native plants were placed on different properties located on the north shore of Found Lake during the first field season. Despite a historic drought, curious white-tailed deer, and hungry bunnies, the first six shoreland restoration sites of the Wisconsin Shoreland Restoration Project were established and thriving. An additional eight sites were designed and installed in the 2008 field season. In the first two years of the project, nearly 1,300 feet of continuous shoreline frontage was reestablished.

Another aspect of the project had DATCP staff leading a team in designing shoreline erosion control treatments for some property owners. The team worked together on testing the effectiveness of different treatments on several Found Lake sites, from biologs to ShoreSox®, EnviroLok® bags to soil lifts, rain gardens to straw matting (see Figures 1 and 2).

Figure 1. Hvam site on Found Lake before shot; notice spotty turf grass, exposed soil, and erosion problem caused by asphalt boat access.

Figure 2. Hvam site on Found Lake after shot; straw matting with native seed mix woven in replaces boat access and other erosion control and native species plantings in 2008 field season.

So What is the Study Measuring for the Benefit of Fish and Wildlife Habitat?

Biotic surveys included baseline inventories done before the conservation work began. Each portion of targeted shoreline, including restoration, control, and reference sites, was sampled for vegetation characteristics. Surveys for herptiles, breeding birds, small mammals, and furbearers were also completed initially, and then they are repeated annually as the conservation projects continue over the ten-year period of the study. Motion-sensing cameras were deployed on shorelines to record presence and absence of mid- to large-size mammals.

The project also examined the use of woody material on restored plantings. Researchers randomly assembled a set of three-meter by three-meter experimental plots, varying the percentage of woody material area cover from high (50%), to low (25%), to no cover. Woody material was defined as branches $\geq$ 2.5 cm and $\leq$ 10 cm in diameter and $\leq$ 3-meter in length. It was acquired from a recent logging site nearby (see Figure 3).

Each of these woody material plots had an identical suite of native shrubs, grasses, and forbs planted including: two shrubs, sweet-fern (*Comptonia peregrina*) and snowberry (*Symphoricarpos albus*); the grass little bluestem (*Schizachyrium scoparium*); and several wildflowers, barren-strawberry (*Waldsteinia fragarioides*), bee balm (*Monarda fistulosa*), big-leaf aster (*Aster macrophyllus*), and pearly everlasting (*Anaphalis margaritacea*). A total of 30 shrubs and 750 ground cover species

Figure 3. Kobelt site on Found Lake post planting in summer 2007; note woody material plots next to paper birch trees.

were uniquely identified with a numbered metal tag on a wire ring placed around the base of the shrubs and with a six penny nail secured near the ground cover species. The preliminary results indicate that sites with a higher percentage of woody material area covered retain more moisture. Further, soil temperatures varied less on plots with woody material versus no cover (see Figure 4).

The balance of the plantings on these initial sites included native trees, shrubs, grasses, sedges, ferns, and wildflowers that one would expect to encounter on dry, sandy shorelines around northeastern Wisconsin lakes. The plant material also had to be available from local nurseries and growers (i.e., propagation friendly species) and its seed source needed to be from within approximately 150 miles of the study area.

After factoring in the existing vegetation for each site, planting plans and erosion control measures were developed by local planners using the standards laid out in the Natural Resources Conservation Service 580 and 643A codes (NRCS 2005 and 2001). Planting density guidelines for woodland shoreland habitat were used as outlined in the Wisconsin Biology Technical Note 1: Shoreland Habitat (NRCS 2002). Plant numbers were calculated based on the area in square feet to be reestablished and the planting densities in the guidelines (see Table 1). The herbaceous cover layer was comprised of a minimum of 30 percent native grasses (*Poaceae*) and/or sedges (*Carex* species). Sites that had significant amounts of established non-native turf grass were smothered with tarps and black plastic fo rfour to eight weeks. Some sites also had minimal preparation against invasive species like reed canary grass (*Phalaris arundinacea*).

Two essential steps each landowner agreed to in their contracts were temporary fencing and a careful watering regime for the plantings. The restoration team used eight-foot plastic mesh fencing to protect the plantings following their installation. This fencing was held up from above using braided cable extended from t-post to t-post with 12-15 foot spacing between the posts; an occasional existing tree was also used to help anchor the cable, along with corners fortified with 2 x 4" wood supports. Attached to each t-post was a plastic extender fastened to it using inexpensive hose clamps. Zip ties were used to hang the fencing from the cable and to fasten the fencing to the t-posts. Six-inch landscape staples were used to hold the bottom portion of the fencing in place. An overlap (~2 inches) on the ground proved handy in helping to navigate uneven terrain. Rabbits chewed occasional holes in some of the fencing, such that a two-foot strand of chicken wire was needed. It was fastened to the existing fence at ground level all the way around the perimeter. Makeshift doors were fabricated to allow for access.

As one might expect, the watering regime for each site proved essential, especially the first two to four weeks after

Figure 4. Volunteers get an overview and planting directions from project staff prior to a planting in July 2007; note small plastic pool used to temporarily keep bare root stock wet and compost used to help trees and shrubs with organic matter.

Table 1. Shoreland Habitat Planting Densities Used in the Wisconsin Lakeshore Restoration Project.		
Layer	*Woodland density*	*Wetland or barrens / Dry prairie / Wet prairie density*
Tree	0.5 - 5 per 100 sq. ft.	0 - 0.2 per 100 sq. ft.
Shrub	1 - 4 per 100 sq. ft.	0.2 - 0.5 per 100 sq. ft.
Herbaceous cover/ground layer	25 - 75 plants per 100 sq. ft.	50 - 100 plants per 100 sq. ft.

Source: Wisconsin Biology Technical Note 1: Shoreland Habitat, p. 4.

planting and through the remainder of the growing season. Plantings were watered a minimum of one to two inches per week, preferably in the early morning or evening hours. Typically, rotary sprinklers were used. For sites without access to a spigot, a portable gas-run generator was set up in the lake to provide water. Project crew members checked the generators and sprinkling systems regularly to maintain good coverage and saturation.

Some of the Lessons Learned

Landowners willing to participate in shoreland restoration were essential partners in the project. Some came to the project looking to address erosion control concerns or to replace the decimated tree canopy from the 1999 storm. Others were interested in enhancing fishing around their near-shore zone. Still others were excited to be doing something along the shoreline that would enhance and maintain water quality in the lake for future generations.

All the landowners in the project to date were excited about the immediate visual changes to their shorelines following the plantings. Where scraggly lawn once met the water's edge now stood appealing native trees, shrubs, and wildflowers. The property owners enjoyed the wildflowers, grasses, and sedges because they attracted birds, butterflies, and other wildlife. One of the landowner's granddaughters even assisted with digging in the plantings at their site, as she was eager to see the trees and shrubs grow with her through the years (see Figure 5).

Another landowner and his family participating in the project have owned their modest lakeside resort since the 1960s. The wind event in 1999 toppled red pines over 100 years old on their site and downed other trees like paper birch, oak, and maple. The family was in awe of the reestablished area, impressed by the scale of the shoreland restoration and by the return of structure to their waterfront vacation retreat.

Other lessons learned from the project include confirmation that 200 ft. (or greater) lot sizes typically provide landowners with enough room to live on the lake comfortably while still maintaining adequate wildlife habitat and suitable water quality. In any case, getting people to change their behavior and finding landowners receptive to the idea of participating in the lakeshore restoration process was an ongoing issue.

Building local expertise with contractors and nurseries for effective shoreland buffer designs and installations was another way this project was put to the test. In addition, creating a reliable funding mechanism for the ten-year duration of the study between multiple agencies was a major hurdle made all the more difficult in today's economic times. Preliminary cost breakdowns were estimated at between \$50 and \$100 per linear foot of restored buffer back 35 feet from the ordinary high-water mark. Biocontrol and other erosion control techniques were typically costly and logistically challenging on top of these initial buffer expenses.

In 2008, year two of the project, several additional sites were included in the study. Again, all the properties were located on Found Lake. Preliminary work and extensive planning for project sites began on the second and third water bodies in the study, Moon and Lost Lakes, each also in Vilas County. For both of these new lakes, researchers are seeking a minimum of 1500 feet of continuous developed shoreline that can be planted into native shoreland buffer. To date, the Wisconsin Lakeshore Restoration Project has been a growing solution to degraded shorelines. Much of the information from this study is still being analyzed, but soon researchers will have more data on how these reestablished shoreland buffers have contributed to bolstering wildlife habitat and enhancing water quality.

Figure 5. The Kloepfers, accompanied by their granddaughter, at the first site in the Wisconsin Lakeshore Restoration Project in June 2007.

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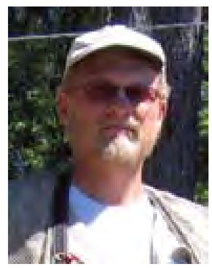

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The **Nebraska** Experience

Paul A. Brakhage

Nebraska agencies and public health organizations collaboratively addressed cyanobacteria issues for the first time after two dogs died within hours of drinking water from a small private lake south of Omaha on May 4, 2004. A water sample and a necropsy revealed that the dog deaths were due to high concentrations of the cyanobacteria toxin Microcystin LR. Meetings were held between the Nebraska Department of Environmental Quality (NDEQ), Nebraska Health and Human Services (NHHS), Nebraska Game and Parks Commission (NGPC), and the University of Nebraska-Lincoln (UNL). Excellent cooperation and quick action were demonstrated by these agencies in developing unified strategies for cyanobacteria monitoring and public notification within two weeks after the dog deaths occurred (Figure 1). Even with monitoring and notification networks in place, by the end of the 2004 recreation season there were three reported dog deaths, numerous wildlife and livestock deaths, and more than 50 accounts of human skin rashes, lesions, or gastrointestinal illnesses reported at Nebraska lakes.

Figure 1. Signage used to notify the public of unsafe conditions for contact with the water.

Monitoring Cyanobacteria Toxins

Weekly sampling of public lakes for cyanobacteria toxins was initiated during the week of May 17, 2004. Initial monitoring efforts targeted lakes with known or suspected cyanobacteria problems. Citizen complaints were important in providing information on lakes where algae blooms were occurring. Monitoring in 2004 consisted of 671 microcystin samples being collected from 111 different waterbodies, with most of these being sampled only a few times.

In 2005, the algae toxin monitoring was combined with the "swimming beach" bacteria network where weekly sampling was conducted. By 2008, with financial assistance from the U.S. Environmental Protection Agency and staff assistance from Nebraska Natural Resources Districts, Nebraska Game and Parks Commission, Nebraska Public Power District, U.S. Army Corp of Engineers, University of Nebraska-Lincoln, and local health agencies, the cyanobacteria monitoring network had expanded to weekly sampling from May through September at 47 lakes and reservoirs, all of which are publicly owned. Concerns and questions on privately owned lakes are addressed through UNL extension programs.

Laboratory Analysis

After sending initial samples to outside laboratories it was soon realized that the cost of laboratory analysis greatly limited the number of samples that could be collected and the time between sample collection and receiving results was not conducive to quick public notification. As such, NDEQ purchased Abraxis LLC Microcystins Enzyme-Linked Immunosorbent Assay (ELISA) laboratory test kits for "in-house" analysis of total microcystins concentrations. ELISA kits provided a low cost, semi-quantitative analytical method for measuring concentrations of total microcystins, the most common toxin released by cyanobacteria. Using ELISA test kits instead of High Performance

Liquid Chromatography (HPLC) or Liquid Chromatography/Mass Spectrometry (LC/MS) analyses resulted in an estimated savings of $77,000, just in 2004. Additionally, analyzing water samples with ELISA kits provided for a quick turnaround time, which allowed weekly updates of lake conditions and public health alerts and advisories prior to each weekend's recreational activities.

Extent of the Problem

A total of 671 microcystin samples were collected from 111 different lakes in 2004, resulting in health alerts for 26 lakes and health advisories for 69 lakes. A total of 22 of the 26 health alert lakes (84.6%) were located in the eastern one-third of Nebraska. In 2004, triggers for health advisories and health alerts were 2 µg/L and 15 µg/L respectively. In 2005, health advisories were dropped from the protocol and the trigger for health alerts was raised from 15 µg/L to 20 µg/L to align with World Health Organization (WHO) recommendations (WHO 2003). From 2005 through 2008, more than 3,625 samples have been collected on 65 lakes across the state. Of these 65 lakes, 43 (66%) had toxin concentrations greater than the method reporting limit of 0.15 µg/L and 18 lakes (28%) had at least one sample with concentrations above 20 µg/L, which is the trigger for issuing health alerts and posting beaches.

Seasonal and Spatial Variability

NDEQ and other resource agencies had and still have concerns about the spatial variability in cyanobacteria populations with regard to samples being representative and issuing public advisories. NDEQ's current beach sampling protocol relies on a single, mid-beach grab sample to represent the condition and/or quality of an entire beach area. Recognizing the importance of protecting human health and the far-reaching implications of beach closures, NDEQ initiated a beach sampling representativeness study. The objective of this study was to determine if statistically significant differences exists between "single sample" and "multiple sample" beach monitoring approaches for microcystin toxin. To meet this objective, a "multiple sample" monitoring approach was implemented at several lakes where seasonal beach monitoring was already being conducted. Statistical tests indicated microcystin concentrations were distributed similarly at all beach sampling locations and changes to NDEQ single sample beach sampling protocol were not warranted.

Special studies were initiated in 2005 to better identify causes and ecological consequences of cyanobacteria blooms and evaluate seasonal variability. NDEQ contracted with the Center for Advanced Land Management Information Technologies at UNL to conduct a cyanobacteria remote sensing project. Preliminary remote sensing data indicated that algae succession in lakes varied significantly throughout the year, even among lakes located in close proximity to one another. The project also documented a significant amount of spatial variability within individual lakes (Figures 2 and 3).

The NDEQ toxic algae monitoring network specifically analyzes for the microcystin toxin. While this is the most common toxin found in Nebraska waters, it is realized there are other toxins of concern. In addition, within the microcystin toxin, there are 71 different variants presently identified. While the ABRAXIS ELISA test analyzes the combined total of variants, some literature suggests only the LR is significant and some criteria are based solely on this. In an effort to further understand this somewhat complex group of toxins and to help determine the significance of these other components, additional analysis was performed. During 2006 through 2008, samples from 5 sites at 3 lakes were split and also analyzed for these additional fractions by the UNL Water Science Lab using liquid chromatography mass spectrometry. The results of this study are still pending.

Health Alerts and Health Advisories

A weekly routine has been established in which water samples are collected and delivered to the laboratory on Monday and Tuesday, processed using freeze-thaw methods on Wednesday, and analyzed on Thursday. Sample results are reported on Thursday, and by Friday morning, NDEQ website information is updated and if necessary, warning signs are posted at lakes.

Because of its initial unfamiliarity with cyanobacteria issues, Nebraska chose

Figure 2. Aerial photograph of the Fremont chain of lakes.

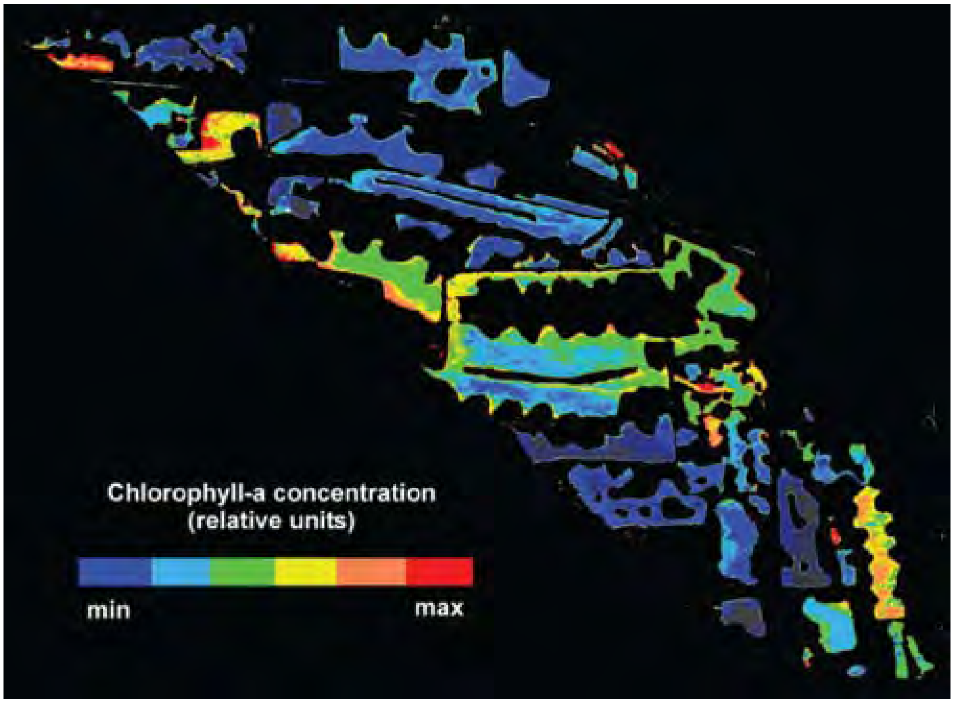

Figure3. Processed aerial image of the Fremont State Lakes in Nebraska showing spatial variation in chlorophyll within lakes and between lakes in close proximity (May 24, 2006).

to err on the side of safety by selecting a conservative approach for protecting public health, which included measuring worst-case total microcystins conditions. One of the reasons for selecting the Abraxis total microcystins ELISA kit was that it measures all microcystin variants, not just the LR variant which is used as the basis for WHO action level guidelines. Also, the freeze/thaw process prior to analysis to lyse the cyanobacteria cells simulates the exposure risk that might exist from ingesting cells and having them lyse and release toxins in the stomach. These procedures provided additional public safety factors in case grab samples failed to measure the highest total microcystins concentrations in a lake.

In 1998, WHO recommended that Microcystin LR concentrations of 20 µg/L or higher should trigger further action for recreational uses. Nebraska chose an initial action level of 15 µg/L of total microcystins for issuing health alerts in 2004, but changed it to 20 µg/L in 2005. Lakes placed on health alert status remain so until the total microcystins concentration falls below 20 µg/L for two consecutive weeks.

Methods used to notify the public of potential health hazards from cyanobacteria include; the development of a fact sheet about cyanobacteria; weekly updates of total microcystins sampling results and health alerts on the NDEQ web site; emails to interested agencies and organizations; news releases and interviews with newspapers, radio, and TV stations; and posting of warning signs at lake beaches and boat ramps.

Toxin Migration

In 2006, NDEQ conducted a study to evaluate the presence of the microcystin toxin in fish tissue and liver samples from three impoundments heavily impacted by cyanobacteria. The three impoundments consisted of one oxbow lake, one sandpit lake, and one recreational reservoir. Fish species sampled included White Crappie, Largemouth Bass, and Channel Catfish. Forty-six samples were collected for microcystin analysis using ELISA methodologies adapted by An and Carmicheal (1994) and Carmicheal and An (1999). Results of the analysis revealed eight of the 46 samples exhibited microcystin concentrations greater than the detection limit of 0.175 µg/L. All detectable concentrations, which ranged from 0.20 µg/L to 0.32 µg/L, were collected from the sandpit lake and were from four liver and four tissue samples. Detectable concentrations of the microcystin toxin were found in all species sampled. At this time there is very little guidance on what levels of the microcystin toxin are acceptable in fish tissue for safe consumption.

NDEQ initiated a toxin migration study in 2006 to investigate potential impacts to groundwater quality. Shallow wells (2-12 feet deep) were installed in sand dominated soils, along predicted groundwater flow paths at Fremont State Lake #20, located 35 miles northwest of Omaha. These wells were sampled monthly year-round from May 2006 to October 2008. The investigation indicated that the toxin will flow with lake water into groundwater at significant concentrations relative to the WHO drinking water standard of 1 µg/L. An algal bloom occurred in May of 2007 with Microcystin concentrations in the lake measured at 95.69 µg/L and a filtered concentration of 24.29 µg/L. In June of 2007, toxin concentrations were measured in groundwater at 5.49 µg/L as far as 130 feet from the lake's edge, and a 0.76 µg/L microcystin concentration was detected 250 feet from the lake's edge in July of 2007 (Figure 4).

Management and Treatment

In 2006, the NGPC coordinated an experimental algaecide treatment project on Pawnee Reservoir, located near Lincoln, NE. The treatment project was conducted to evaluate the effectiveness of early season algaecide treatments in areas of the reservoir where blue greens were starting to form. Pawnee Reservoir has had a history of severe blooms in May and officials were hopeful that the early treatment would reduce bloom magnitude and duration. The treated area encompassed approximately 25 percent of the 740 acre reservoir. While the reservoir did experience a decrease in chlorophyll and microcystin concentrations shortly after the treatment, the improvements lasted only a couple of weeks. It was determined that treating the early stages of a bloom in a larger reservoir can be difficult given the rapid expansion of blooms. While treatment of the entire reservoir would have increased effectiveness, the cost of doing so was prohibitive.

In 2007, the NDEQ, NGPC, and UNL conducted an alum treatment project on

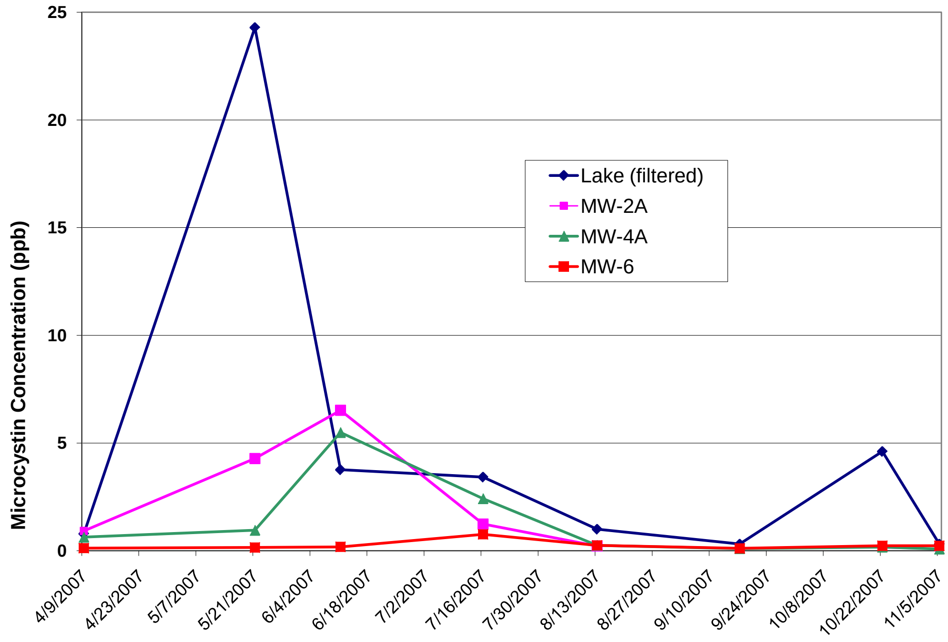

Figure 4. Total microcystin concentration measured in Fremont Lake #20 (filtered sample) and in shallow groundwater wells located 19 feet (MW-2A), 130 feet (MW-4A), and 250 feet (MW-6A) from the lake.

Fremont Lake #20. Fremont Lake #20 consists of 50 surface acres and is part of a chain of sandpit lakes collectively known as the Fremont State Lakes. Phosphorus inactivation was determined to be the best option for treatment given it's a "closed" system that lacks external nutrient loading. Prior to the project, summer epilimnetic total phosphorus and chlorophyll averaged 110 µg/L and 82 µg/L respectively. The lake system was dominated by the cyanobacteria genera *Oscillatoria* which resulted in routine beach postings due to high concentrations of microcystin toxin. From June of 2004 through September 2007, 68 of the 209 (33 percent) of the algae toxin samples collected from Fremont Lake #20 exceeded beach posting criterion of 20 µg/L. This resulted in the beach being closed for 36 weeks making this one of the most impacted public lakes in the state for blue green algae toxins. The alum project, which was conducted in October, 2007 produced immediate results. Average summer epilimnetic phosphorus was reduced from 110 µg/L to 21 µg/L, chlorophyll was reduced from 82 µg/L to 8 µg/L, and microcystin concentrations were reduced from an average of 21 µg/L to concentrations below the reporting limit of 0.15 µg/L (Figure 5). There were no beach postings in 2008 as the maximum microcystin concentration reported that year was 0.23 µg/L.

Summary

Nebraska continues to promote activities that reduce nutrient loading to lakes. While Nebraska's Surface Water Quality Standards do not allow point source discharges to lakes, nutrient loading from nonpoint sources are a concern. Nebraska's Nonpoint Source Management Progam has been successfully reducing nutrient loading in impaired watersheds through coordinated efforts between local, state, and federal agencies and watershed stakeholders. While significant progress has been made in many watersheds, the reservoirs response to these reductions will be a much longer process than in closed systems where alum can be applied. Additionally, watershed treatment addresses the external nutrient load which is only part of the picture. Many of Nebraska's reservoirs and sandpit lakes were constructed in the 1950s and 1960s and have significant internal nutrient loads. Addressing internal sources of nutrients is a difficult and costly task but a critical component in achieving measurable nutrient reductions and shifting algal communities to a more desirable or at least more tolerable state. In many cases, expectations in water quality improvement can exceed realistic outcomes, particularly if a holistic approach to nutrient management is not taken.

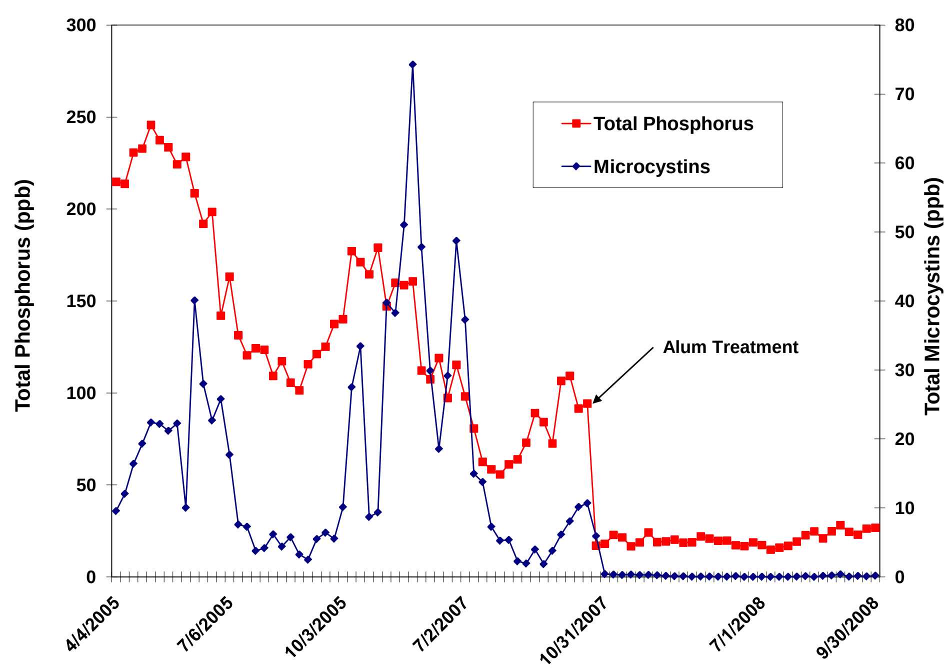

Figure 5. Pre- (2005, 2007) and post- (2008) alum treatment total phosphorus and microcystin toxin concentrations in Fremont Lake #20 near Fremont, Nebraska.

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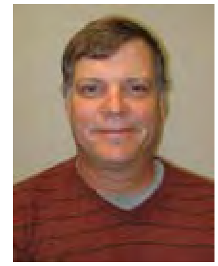

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Aeration of **Lakes and Reservoirs**

Gene Welch and Harry Gibbons

Dissolved oxygen (DO) is often the most important end-point measurement in the management of lake and reservoir water quality. Thorough sampling and accurate analysis of DO alone can usually convey more understanding of the state of a water body than any other constituent. DO can control the cycling of nutrients and other substances that affect water supplies and productivity; in addition, it is often the number one limiting factor to fish and aquatic life in eutrophic water bodies. DO standards for aquatic life have existed since the 1940s and the use of areal hypolimnetic DO deficit rate (AHOD) was the first trophic state indicator to be given numerical status (Mortimer 1941, 1942; Hutchinson 1957).

Given the significance of DO and its response to eutrophication, it's no surprise that the early emphasis in lake management was on methods to restore DO levels in affected waters. There are two principal approaches: (1) complete circulation and destratification, which oxygenates the whole water body and (2) oxygenation of the hypolimnion only or – at times – just a defined horizontal layer of the hypolimnion. Several approaches have been devised to accomplish the goal of oxygenation and each of the techniques has their advantages and disadvantages. See Cooke et al. (2005) for a full description of techniques and evaluation of results. Figure 1 illustrates the basic operational concepts.

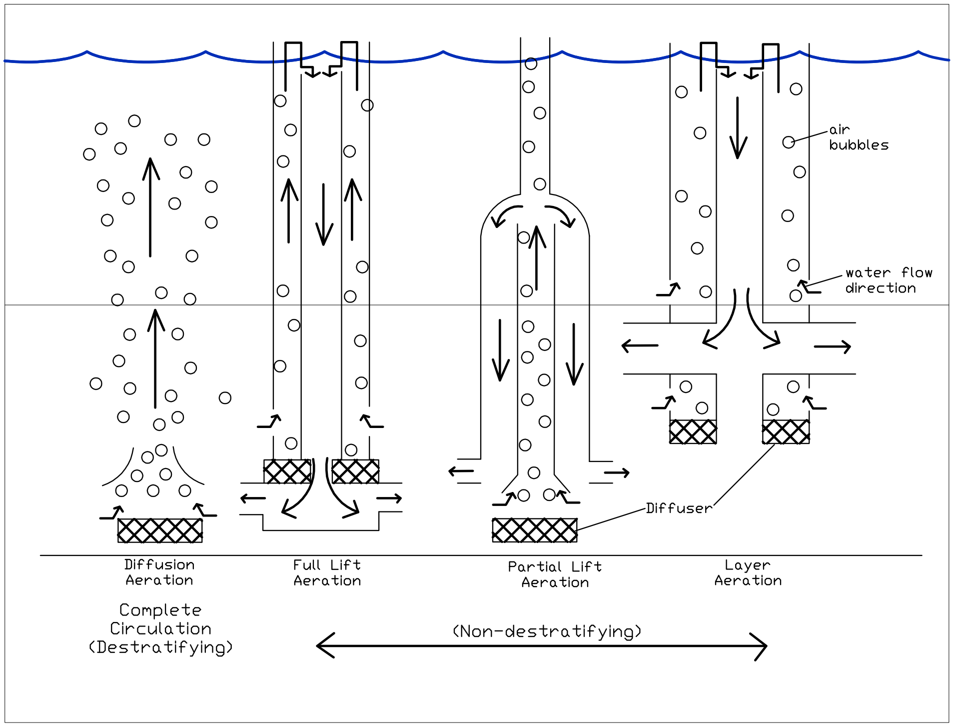

Figure 1. Aeration schematics for complete circulation and non-mixing hypolimnetic aeration.

Complete Circulation

Complete circulation has been accomplished by adding compressed air through diffuser hoses placed strategically along the lake bottom. That has been the most frequently used technique. Circulation is achieved by an unconfined rising plume of air bubbles causing the water to circulate and oxygenation occurs when the circulating water mass that is under saturated absorbs oxygen through atmospheric exchange. Circulation has also been achieved with pumps and jets. Direct mechanical mixing has also been applied. In addition to oxygenating the water column directly through the process of complete circulation and mixing, this circulation of the water column can restrict algal biomass by light limitation if mixing depth is sufficiently greater than the critical depth for net growth, even if nutrients are not limiting. Also, mixing can reduce the fraction of algal biomass that is composed of buoyant cyanobacteria (blue-green algae). However, there is a risk with circulation; if mixing is insufficient, nutrients can actually increase and algal problems can worsen. To effectively destratify a waterbody and prevent buoyant cyanobacteria blooms by air injection, the air flow rate must be at least 9.2 m^3 /km^2 per minute – the Lorenzen and Fast criterion (see Cooke et al. 2005 for a discussion of problems and experiences).

Hypolimnetic Aeration

In many instances, there is a desire to preserve the cool hypolimnetic water for its thermal habitat benefits, especially for cold water fish, as a refuge for zooplankton against predation, and for domestic water supply quality. In those cases, oxygenation of the hypolimnion can be achieved with hypolimnetic aeration (compressed air) through either full or partial airlift systems, or with pure oxygen injected at depth with a pump (deep oxygen injunction system, DOIS) – the bubbles dissolve before reaching the epilimnion, so stratification is preserved, or into water pumped through a down flow bubble contact system (DBCS). There are also pumping devices that either bring hypolimnetic water to the surface where it entrains air bubbles and the mixture is pumped back to the hypolimnion or by pumping oxygenated epilimnetic water directly to the hypolimnion.

In addition to preserving the cool water for aquatic life, oxygenation of the previously anoxic sediment – water interface will often curtail a high rate of phosphorus (P) release and internal loading – assuming enough iron is available to complex P and prevent release. In some instances, internal loading of P was not curtailed with oxygenation (see Cooke et al. 2005, for discussion). Even if sediment P release is not effectively curtailed by maintaining stratification – a goal with hypolimnetic oxygenation – the hypolimnetic P may not be available to algae in the lighted zone.

What Technique to Choose?

The magnitude of processes that determine water quality should be reasonably well understood for a water body before a technique is selected to alleviate a problem. Often the water body has not been adequately studied, users are anxious to get something done – "no more studies" – and one device/technique is selected to address several problems, or more than one is selected/installed when one would have been sufficient. For example, if the problem is too much iron in a water supply when drawn from the hypolimnion, then either hypolimnetic aeration or oxygenation will probably solve that one. But suppose there is also too much cyanobacteria producing taste and odors and surface scums? Then the source of the causative nutrient – usually P – must be known. While there may be high internal P loading from anoxic hypolimnetic sediments, thorough monitoring and two-layer, mass balance modeling may show that hypolimnetic P is unavailable to the lighted zone and the principal cause is an external P source. Or maybe there is enough internal loading from shallow oxic sediments to fuel summer cyanobacteria blooms. In these cases, hypolimnetic aeration or oxygenation would not be expected to solve both the DO and algae problems. On the other hand, if the lake is relatively shallow, anoxic sediments may be the principal source with entrainment of high-P hypolimnetic water during summer wind-caused mixing events. However, the hypolimnion may be too shallow for a hypolimnetic aeration or oxygenation system, given the risk of causing more entrainment of hypolimnetic P if the thermocline is disturbed. In that case, complete circulation may be more effective at controlling cyanobacterial blooms by neutralizing their buoyancy mechanism. However, that option would be risky, because evidence is still slim on how well mixing works to retard cyanobacterial dominance in eutrophic lakes. Given such uncertainty, sediment P inactivation may be a preferred option.

Examples of the above complications were usually the result of too little pretreatment data and understanding of the water body's dynamics (Cooke et al. 2005). Capital, installation, and annual operating costs of aeration and oxygenation systems are too great to forgo the necessary pretreatment study that could save millions of dollars. This is especially true when considering installation costs for lakes larger than ten acres that can range from about a hundred thousand dollars to well over a million dollars. Several of these systems have annual operating costs that exceed $35,000 in energy cost alone. With energy and material costs increasing at accelerating rates, this is an important ongoing and ever-increasing cost. Hence, the need for truly understanding the environmental drivers of the individual system before selecting an approach that may or may not address the real trigger mechanisms leading to decreases in beneficial uses is critical to a successful outcome.

Some basic questions to consider when evaluating the utility of aeration/circulation are:

- What is the specific objective for water quality or habitat benefit that you are trying to achieve?
  - Odor control?
  - Cyanobacterial control?
  - Nutrient control?
  - Fisheries habitat enhancement?
  - Taste and odor control?
  - Contaminant control?
- What is the level of artificial appearance that is acceptable to lake users?
  - Bubbles on the surface or surface structures?
- What is the cause or causes of environmental problems you are trying to address?
  - Is there an understanding of the external versus internal nutrient dynamics for the lake?
  - What are the sediment characteristics, both deep and shallow?
- Where are internal nutrients coming from and what are the mechanisms of release?
  - Is the lake strongly or weakly stratified?
- How is stratification related to internal nutrient loading and entrainment?
  - Is there an understanding of the mixing characteristics of the lake?
- Is there an understanding of how mixing relates to nutrient cycling?
- Will the implementation of aeration be a long-term solution or soon be overcome by other external factors?
- Can the implementing organization sustain the cost of maintenance and operation for years to come?
  - Does this organization have control over land-use activities that can change the external nutrient loading to the lake?

These and other technical questions relative to site-specific data need to be addressed if implementation success is to be achieved. Nevertheless, if applied correctly, aeration/circulation is a useful method for managing lakes and reservoirs.

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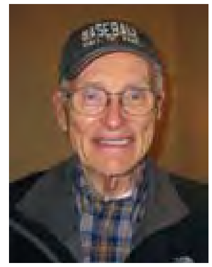

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Harry Gibbons is an environmental consultant for Tetra Tech, Inc. Throughout his career, Harry has worked in and around lake and reservoir issues and continues to maintain his love and enthusiasm for lake environments and the challenges that the human species has put upon them. Harry has been a NALMS member since its beginning and has served twice as Region 10 Director.

A Tale of Two Spiritual Lakes

Lowell Klessig

Two lakes bracket my spiritual connection with lakes.

On the small end is “Little Lake” – a spring pond less than a mile from our farm. When my boys were in grade school, we spent time there almost every week in both summer and winter. Through the full length of my professional career I had developed a conceptual framework based on “Eleven Necessary Conditions for Sustainability” at the personal, community, and societal levels (Klessig 2001). Little Lake contributed to eight of the necessary conditions for the sustainable happiness of our family:

- *Aesthetic Opportunity* – Tall white pine and mature hardwoods on three steep slopes and an inconspicuous, dark log cabin on the outlet to the Tomorrow River.
- *Cultural Opportunity* – In Wisconsin, ice fishing lore and practice is in the same league of icons as Green Bay Packer tailgating, deer hunting camp, and cheap beer.
- *Educational Opportunity* – The boys learned to count to 100 when the little perch were biting. Lessons in aquatic, terrestrial, and wetland ecology were easy to teach when the same ecosystem was visited frequently over several years. Of course, they also learned the skills of angling for a lifetime of enjoyment.
- *Emotional Security* – No other place regularly provided several hours of uninterrupted time for bonding with two sons – spontaneous (no planning required), easy (within walking distance), inexpensive (for just the price of digging up home-grown earthworms or buying wax worms in winter for two cents each).

The young Klessig boys on Little Lake.

- *Environmental Security* – The water from a tiny forested watershed and very local aquifer was clear, cold, and clean – a standard by which we judged all the other lakes we visited.
- *Individual Freedom* – Going to Little Lake was a choice we could make most days of the year; and “Can we go to Little Lake?” was the most common request I received as a father – and one that I could usually answer in the affirmative.
- *Recreational Opportunity* – “I got one!” “I got one, too!” That refrain is my most treasured memory of fatherhood and may be the most treasured memory for my boys as well. There are hundreds of reminders in family photo albums.
- *Spiritual Dimension* – It is hard to know when a six-year-old is having a spiritual experience – either at Nelsonville Lutheran Church or at Little Lake. However, I am confident that my reverence for Little Lake and comments about the its serenity and beauty inspired at least as much spiritually as the five-minute, five-star children’s sermon in front of the alter at Nelsonville Lutheran Church.

Lake Baikal is the macro end bracket of my lake experience. On a grand scale, Baikal contributes to nine of the eleven sustainability conditions for communities of reverent natives and international pilgrims:

- *Aesthetic Opportunity* – Not only of the vast lake itself, but the rugged mountains along the shores – especially the metallic days and purple evening tides of the young Barguzine Mountain on the east shore.

- *Collective Security* – Historically, the lake provided a natural back-side protection for native people. During the paranoia of WWII and the Cold War, Soviet naval vessels patrolled the lake.
- *Cultural Opportunity* – Probably no lake in the world is as central to the culture of native people around it as Baikal is to the Buryat people. They define themselves in its imagination.
- *Economic Opportunity* – The omul fishery have long been a protein source for the local consumption and barter/sale beyond. Controversial pulp and paper mills use lake water and provide jobs – mostly to ethnic Russian immigrants. Eco-tourism has potential but access, especially after the devastation of Perestroika, is difficult.
- *Educational Opportunity* – Beyond limited environmental education for K-12, the lake is a research and training center for Russian and international natural resource managers.
- *Emotional Security* – Family and community are the main pillars of this sphere of sustainability. Baikal provides a sense of community for natives, some immigrants, and a cadre of Russian environmentalists and international limnologists/lake managers.
- *Environmental Security* – The water quality of the northern stretches of the lake is pristine and sometimes used as an international standard, but water quality along the southeastern shore is threatened by paper industry effluent.
- *Recreational Opportunity* – Local people hunt waterfowl and do some sport fishing and recreational boating. If tourism develops, much of it will be recreation-based.
- *Spiritual Dimension* – From the native Buryats to Russian nationalists to world federalists, Lake Baikal is above all, a spiritual place. It is "the Sacred Sea of Siberia." For professionals involved in lake management, Baikal is Mecca – the most special lake with no easy access politically or geographically. My pilgrimage took 13 years – the longest planning horizon by far of any of my trips to over 50 countries.

These two lakes help provide the ten of the necessary conditions for sustainability. The only condition the sustainability condition that lakes do not affect is *Individual Security.*

The balance of this article explores what it means for a lake to be spiritual. How can Little Lake on a neighbor's property be more spiritual than a children's sermon in a generations-old, white clapboard church with a tall steeple on the highest hill in the village? How can the mention of Lake Baikal lift the eyes of people in every part of the planet? How can the millions of ponds, reservoirs, and lakes on the long size/splendor continuum between Little Lake and Lake Baikal provide a spiritual experience to the countless souls that see them, touch them, recreate in and on them, write about them, photograph them, and sense them in the privacy of their dens and dreams?

Spirituality is one of the most nebulous terms in our language. By definition, the root word – spirit – defies definition. Sometimes spirituality relates to elements of nature or all of nature. Sometimes it relates to the presence of physical anthropogenic things – idols, statues, altars, paintings, sculpture, mosques, synagogues, churches, cathedrals, holy water, crucifixes, Buddhas, and sweat lodges; sometimes to pageants, music, dancing; sometimes to individual soul-searching, meditation, or confrontation with the elements; sometimes to group experiences like communions, festivals, group rites of passage, speaking in tongues, and dancing.

Lakes are natural features of the landscape or become naturalized (reservoirs). My own most spiritual moment on a lake was a 24-hour long sit against a jack pine. Through a long northern latitude summer day and short moonlight night I meditated, read, and wrote from an especially beautiful vista of an unnamed lake in Ontario. For 30 years my best friend and I drove to the railroad station, took the train to an unscheduled stop, jumped off and canoed for a week (usually the best week of the year) on the lakes of Ontario. While the other forms of spirituality often include lakes as a backdrop, spirituality of lakes is experiential – a relationship to a body of water – a part of nature. Spirituality can be broken down into four generic sub-dimensions.

The author in 1990 meditating alongside an Ontario lake.

1. Humility before a Supreme Being
2. Awe
3. Acceptance of a set of moral principles
4. Breadth of sense of community

Humility

Without commenting on the existence of God or which God is the real God, I want to explain why I added "spiritual dimension" to my list of necessary conditions for sustainability. Spiritual dimension was added as a result of an "ah-ha" moment in a remote Berber village in the Atlas Mountains. I walked up the creek behind the village and observed a Muslim man kneeling on a large rock in the stream doing one of his five prayers of the day. It suddenly struck me that those prayers, whether or not ever heard or answered, provided an essential necessary element to social sustainability – humility.

Arrogance is a normal development of individuals (and nations). However, arrogant individuals do not interact in ways that sustain a community (or a family). The man on his knees on his little mat would leave that rock better able to relate to nature and to other people because he had humbled himself by praying – by saying "please" and "thank you" to his God.

Awe

Humility trims our egos. Awe is the corollary. It raises our awareness of the world beyond our control. The natural world provides many subjects for awe: lighting, thunder, fierce winds, volcanic eruptions, snow-capped mountains, and endless plains. The sunrises, whitecaps, reflections, mists, ice thunder, and sunsets of lakes inspire awe.

Baikal and a few other great lakes generate almost as intense a primordial sense of awe as oceans. Like the ocean surf, great lakes pull us back to the beginning of life in water. For those of us who don't live on the ocean or the shore of a great lake, the relationship is there – just a little more subtle. People in all cultures love water beyond their need to consume it and grow food with it. They like to touch it, immerse in it, look at it, and listen to it. The connection is deep: a subconscious awe!

Lake Baikal.

Moral Principles

The spiritual dimension demands a third relationship – the acceptance of moral principles. Whoever and whatever is worshipped (The Trinity, Science, Lake Baikal, Buddha, Holy Cows or Buffalo), there are commandments to obey.

The commandments of Judaism, Christianity, and Islam focus on the relationship of people to one God. The first three commandments of the Ten Commandments focus on the relationship of humans to God; the last seven commandments focus on the relationship of people to each other. No commandment of these monotheistic religions is focused on the relationship of people to nature. The Old Testament may even encourage sins against nature by declaring that man "has domain over the earth and creatures therein." There have been exceptions among Christian leaders – mostly notably St. Francis (White 1987). And other parts of the Bible and Koran direct humans to be good stewards of Creation.

Taoism, Buddhism, Hinduism, and pantheism (many gods) focus on the relationship of people to the natural world and have elaborate rituals for transmitting their commandments regarding how to treat nature to new generations.

Beyond Stewardship to Community

Few words have as positive a connotation as "stewardship." However, stewardship is not enough. It will not provide lakes or any other part of nature with enough love and respect. Stewardship implies a power relationship. The steward has the power – the power to take care of an object of the stewardship. The lake steward is protecting the lake for the benefit of present and future generations of humans. That is a good start, but it is a woefully inadequate paradigm because it still treats nature as a commodity to be managed for wise human use. A paradigm shift from stewardship to "interdependence and a broad sense of community" is required for families, communities, and societies to be sustainable.

Aldo Leopold (1949) is quoted so often because he said it first (in modern times) and he said it so well:

> "We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect.
>
> ". . . All ethics so far evolved rest on a single premise that the individual is a member of a community of

interdependent parts. His instincts prompt him to compete for his place in that community but his ethics prompt him to cooperate (perhaps in order that there may be a place to compete for).

"The land ethic simply enlarges the boundaries of the community to include soils, waters, plants and animals or collectively, the Land."

And that's how the tale of two lakes ends for me – a local Little Lake and a planetary Lake Baikal – two communities to which I belong in the spiritual dimension.

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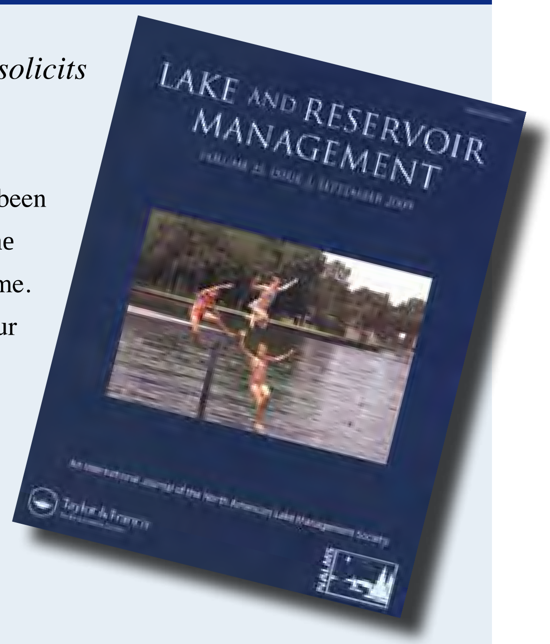
Rev. 11/09

Lake and Reservoir Management



A scientific publication of NALMS published up to four times per year solicits articles of a scientific nature, including case studies.

If you have been thinking about publishing the results of a recent study, or you have been hanging on to an old manuscript that just needs a little more polishing, *now* is the time to get those articles into *your journal*. There is room for your article in the next volume. Don't delay sending your draft article. Let the editorial staff work with you to get your article ready for publishing. You will have a great feeling of achievement, and you will be contributing to the science of managing our precious lakes and reservoirs.

Anyone who has made or plans to make presentations at any of the NALMS conferences, consider writing your talk and submitting it to the journal. It is much easier to do when it is fresh in your mind.

Send those articles or, if you have any questions at all, contact:
Ken Wagner, Editor, *Lake and Reservoir Management*
kjwagner@charter.net

If there is anyone who would like to read articles for scientific content, please contact Ken Wagner. The journal can use your help in helping the editorial staff in editing articles.

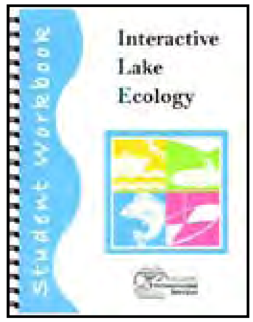
NALMS BookStore

Now Available from NALMS

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.

50¢ per copy
Bulk rates available. Contact the NALMS Office for details.

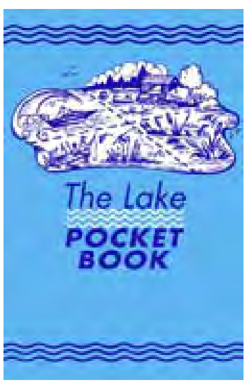


Interactive Lake Ecology

This workbook, created by the New Hampshire Dept. of Environmental Services, introduces students to elements of a lake ecosystem. It discusses basic scientific concepts of water, the water cycle, how lakes are formed, food chains & watersheds. It introduces students to problems facing lakes today such as nutrient loading, exotic species & acid rain. The workbook also looks at testing, classifying and monitoring lakes for water quality and educating your community about the problems that face lakes.

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

$6 Student Workbook
$8 Teachers’ Reference
Receive 1 free Teachers’ Reference with each order of 20 Student Workbooks



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-tounderstand style combined with its in-depth information has made *The Lake Pocket Book* an extremely popular publication among citizen lake lovers.

$11.96 NALMS Members
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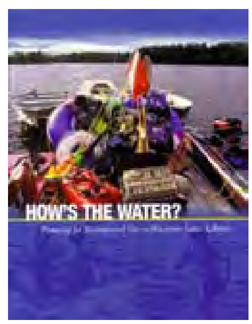

How’s the Water?

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.

$17.56 NALMS Members
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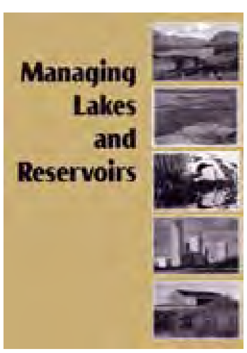

Managing Lakes and Reservoirs

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-theart information on how to manage lakes and reservoirs. Many of today’s experts in the field of lake management authored chapters in this book.

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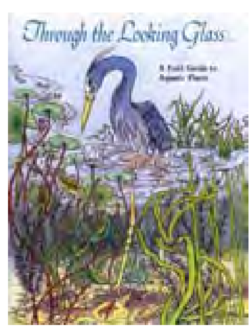

Through the Looking Glass... A Field Guide to Aquatic Plants

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.

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All publications may be ordered online.