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# LakeLine

Volume 29, No. 1 • Spring 2009

## Shoreline Management

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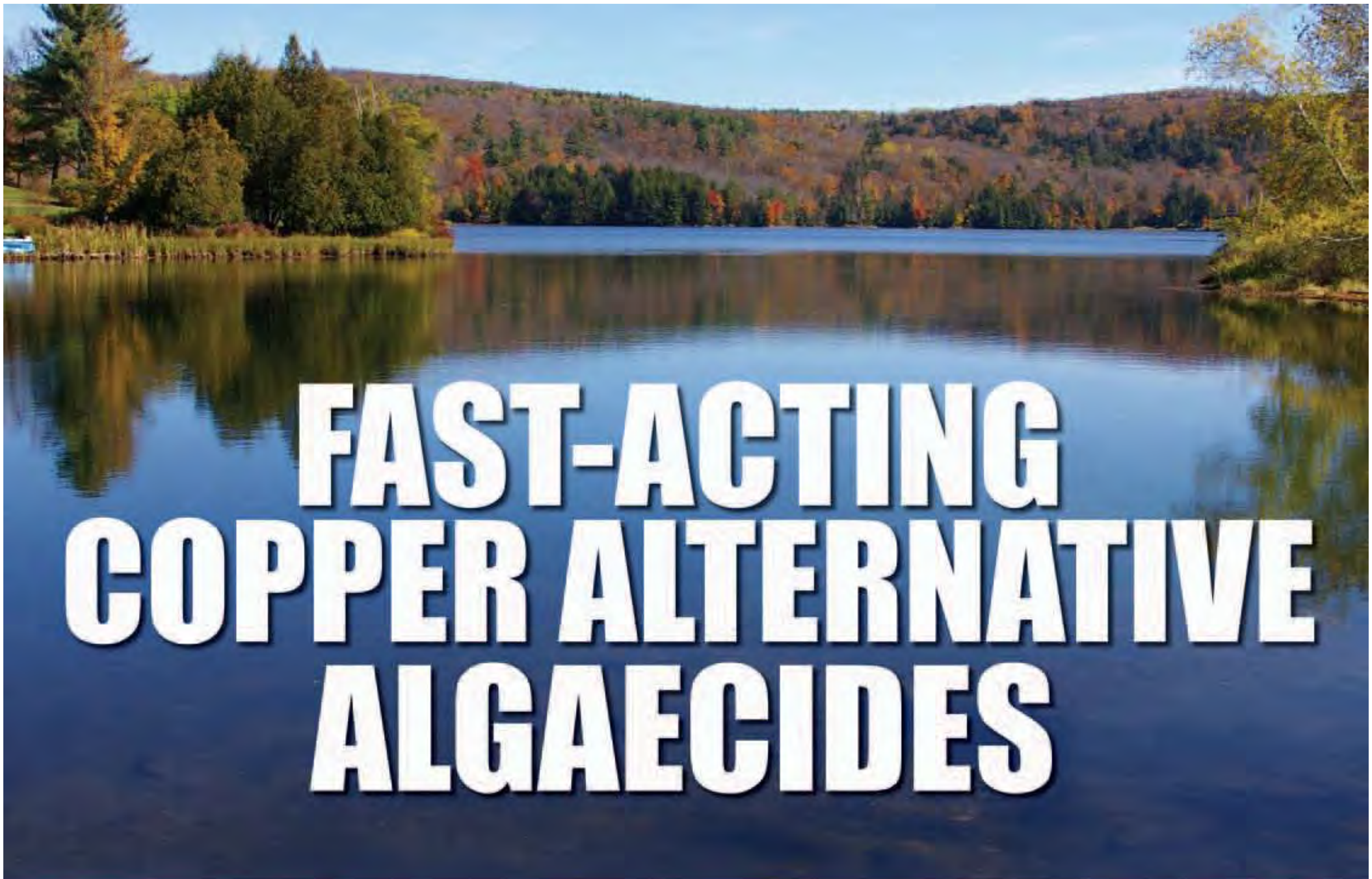


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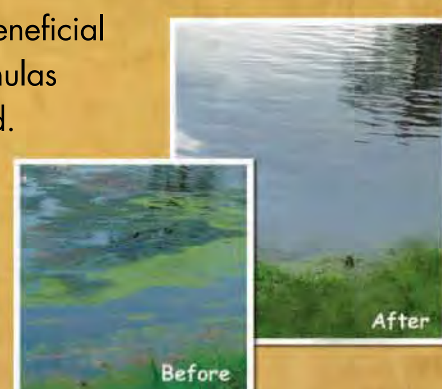


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# Call for Papers

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### General Abstract Information

**Abstracts are due by May 15, 2009** and must contain the following information in the format specified below. **Only submissions via the NALMS web site will be accepted. Due to the large number of abstracts anticipated for this conference, abstracts received after May 15 may not be considered.**

**Submittal:** Submit abstract via NALMS' online abstract submission system by visiting www.nalms.org.

**Title:** Should accurately summarize the subject of the proposed presentation.

**Authors:** Provide names and affiliations of all authors including address, phone and fax numbers & email address.

**Text:** Abstract should state the purpose, significant results and main conclusions of work. Abstracts must not exceed 250 words. **Abstracts in excess of 250 words may be truncated.** Abstracts selected for either oral or poster presentations will be published in the Final Program.

**Format:** Indicate the type of presentation you prefer (Oral, Poster or Both).

**Students:** If primary author is a student, please indicate so when entering author information.

### General Presentation Information

PowerPoint created files will be required for all oral presentations. Laptop computers and LCD projectors will be provided. Overhead and slide projectors will not be available.

The use of embedded video and audio files is discouraged.

Oral presentations will be allotted 30 minutes, including time for questions.

The Program Committee will give preference to requests for oral presentations that describe completed or well-advanced studies which present actual lab or field data. Presentations which describe future projects or which do not contain actual data are discouraged.

NALMS does not endorse specific products or services. Therefore, papers presented by individuals representing corporations or projects conducted by corporations should avoid the use of trade or brand names and refer to the products or services by a generic descriptor.

The 2009 symposium will feature enhanced visibility for poster sessions and abstract submissions are encouraged. All posters will be displayed throughout the entire symposium and will be featured in the exhibit hall area. Posters may be up to 4'x8' (Landscape format).

Students presenting oral papers or posters as primary authors will be considered for monetary awards.

**Presenters of accepted abstracts must register for the symposium.** The NALMS Office must receive registration and payment **no later than August 28, 2009** in order to be included in the symposium program.

### Ensuring Our Lakes' Future

The New England Chapter of the North American Lake Management Society (NEC-NALMS) invites you to "come home" to the birthplace of NALMS -New England. Located in the heart of New England, Hartford is a stellar place to view spectacular fall foliage, experience history, and exchange research results, ideas, and information with lake managers, regulators, researchers, educators, students, lake leaders and watershed stewards from around the country and the world.

The 2009 NALMS Symposium will provide ample opportunities for both lake management professionals and lake and watershed stewards. The theme of this year's conference draws upon Hartford's reputation as the insurance capitol of the world, so what better venue to talk about how to successfully manage threats to the viability of our lakes? Workshops, concurrent sessions, and educational programming will provide us with the latest information on lake management issues so that we can ensure the future of our lake resources for generations to come.

Hartford is conveniently located on major interstate highways, just two hours from New York or Boston. Bradley International airport is just minutes away from downtown. The symposium will be held at the Connecticut Convention Center on the banks of the Connecticut River and directly across from the new 144,000 square foot Science Center. Hartford and the region offer many attractions to make this an exciting meeting for NALMS. The city has numerous cultural features within walking distant from the Convention Center including the Wadsworth Athenaeum, Bushnell Center for Performing Arts, the Old State House, and the Mark Twain House and Museum. Regional attractions include Foxwoods and Mohegan Sun Casinos, Mystic Seaport, and the Berkshire Mountains. Whether your preference is hiking, theater, or even touring some of Southern New England's lakes, the Hartford area will have something to offer for everyone. For more information on Hartford, please visit www.enjoyhartford.com/links.

The Hartford Marriott and Hilton will provide accommodations for Symposium. Both hotels were selected by NALMS for their luxurious amenities and convenient location to the conference center (the Marriott is attached to the convention center and is the anchor hotel for the conference), as well as their excellent room rates. Each hotel offers the latest technology and stunning views of the Hartford skyline.

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### Contact Information

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### Important Deadlines

**May 15, 2009**
Abstracts due.

**August 28, 2009**
Registration and payment from presenters of accepted abstracts due.

**October 2, 2009**
Last day conference hotel rate available.

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LAKELINE

# Contents

Volume 29, No. 1 / Spring 2009



*On the cover:*
Lake Winnisquam in Tilton, New Hampshire, is one of the larger lakes in New Hampshire, and one where shoreline development, shoreland clearing, and competing uses are at the forefront of issues. Photo by Amy Smagula.

## Advertisers Index



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# From the Editor

## Bill Jones

As I sit here thinking of how to begin this column, my thoughts keep turning to the bounty that Barb and I have been blessed with this week – our first two grandchildren! No twins, no special planning; both of our children just delivered around the same time. This clearly is a pleasant distraction, but I can't help wondering what kind of world these two little ones will grow up in. Many of us have pleasant memories from our youth of fun-filled, care-free visits to lakes or reservoirs. Back then (I'm dating myself here!), we weren't so worried about overcrowding, aquatic nuisance species, harmful algal blooms, and loss of shoreline ecological values – certainly on our minds today.

Will we, as a nation, recognize as Aldo Leopold did so many years ago that humans are a part *of* Nature, not apart *from* Nature? We are changing the Earth in unprecedented ways and at unprecedented rates. Will the hope of the new Obama Administration yield new environmental protections while the world wrestles with a global financial crisis? Will young Wes and Lily have clean lakes to appreciate and play in?

This issue of *LakeLine* offers some hope. As long as people keep researching new and better ways to protect the lakes we love . . . there is hope. We recognize how engineering and biological research are essential to discover new ways to solve shoreline management problems. But social research, as we featured in the fall 2008 issue, may be even more important if we are to change how people view and use lakes and other natural resources.

*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.

We begin this issue by reviewing why littoral zones are so valuable and seeing evidence of how development reduces those values in an article by **Kellie Merrell**, **Eric Howe**, and **Susan Warren**. Next, **Tessa Francis** describes results from her recently completed thesis that demonstrates how shoreland development reduces the abundance of terrestrial insects, an important source of food for fish. How do we reclaim damaged, hardened shorelands? **Larry Butler** describes how the Reston Association has used low-impact development techniques and education/outreach to change shoreland homeowners' behaviors. Wisconsin has embarked on a bold cooperative plan to restore shoreland buffers called the "Wisconsin Lakeshore Restoration Project." Authors **Patrick Goggin**, **Michael Meyer**, and **Daniel Haskell** discuss these efforts. Restored shoreland buffers require plants. **Patrick Goggin** serves double-duty by identifying workhorse species for successful shoreland restorations in the Upper Midwest. Policy must keep up with science and, often, policy can help direct science. **Jeremy Price** describes several policies that Indiana has implemented to encourage better shoreland management. **Mark Hoyer** finishes off our theme articles by showing how a new technology can be used to help assess littoral vegetation.

Our "Featured Lake" this month is North Dakota's Devils Lake. I've heard of this lake previously, but I'm embarrassed to say that I knew very little about this most interesting lake. **Doug Larson's** article tells a fascinating story of how this lake has been manipulated by climate and people over time. It is a story about the forces of nature.

Also in this spring issue, we hear from newly elected NALMS President **Harry Gibbons** in his first *LakeLine* column. NALMS Affiliates in Indiana, New York, and Oregon share news from their organizations. Our resident lake educator, **Alicia Carlson**, encourages kids to get outside and enjoy lakes. Her advice is reminiscent of my youthful explorations of the natural world. Our own lake name etymologist, **Marty Kelly**, sheds light on some of the "V" lakes, and rounding out this issue is the Literature Search.

Enjoy!

**William (Bill) Jones**, CLM, is *LakeLine*'s editor and a former NALMS president. He can be reached at Indiana University's School of Public and Environmental Affairs, Room 347,1315 E. Tenth Street, Bloomington, IN 47405-1701; (812) 855-4556; e-mail:joneswi@indiana.edu.

# From the President

Harry Gibbons

## Springtime and Lakes

It is spring, and after a long winter I look forward to the annual renewal of life, especially in lakes. Given that all

life is dependent upon water and there is 20 times more water in lakes than in rivers worldwide, wouldn't it be assumed that lakes and reservoirs should demand significant attention? To the contrary, I would argue that, in fact, lakes and reservoirs are barely on the radar for resource and regulatory managers and policymakers. For sure, lakes and reservoirs are social centers of attention when it comes to recreation. Many of us have fond memories from our childhoods that are associated with our experience in and around lakes and reservoirs. In many locations throughout North America, a recognized sign of success is having a home on a lake or reservoir. So how can I make that earlier assertion that our society does not pay enough attention to our lake and reservoir resources?

For now, let's look at just one subject relative to lake and reservoir resource management, shoreline management, which happens to be the theme of this *LakeLine*. Human activities in the shoreland zone have both direct and indirect effects on shoreline ecological functions. Understanding and documenting these ecological consequences is essential if we are to implement the low-impact approach to shoreline management.

Combining the subject of shoreline management with springtime and the annual renewal of life, we, as humans, often introduce new plants to our yards and gardens, as part of our landscape management plans. Do we pay attention to how that landscaping may have an effect downstream, or – if we are one of the lucky ones to have yards adjacent to shorelines – how our landscaping impacts that shoreline environment? Also, what about the plants we introduce? How many of us know the true ecological impacts of introduced non-native species? Are there recognized controls and monitoring to limit the adverse impact to lakes and reservoirs from our landscaping activities throughout North America? I think not.

What happens when money becomes an issue with shoreline management? Many human activities have direct and indirect impacts on lake and reservoir water quality and on aquatic life within those waterbodies. When there are monetary concerns relative to a management decision, we must consider and understand the true environmental and social cost of an action. For example, direct and near-shore access by livestock could cause physical impact to shorelines and nutrient loading to the waterbody. Here the environmental cost associated with providing buffer/fencing and water supply for the livestock should be considered relative to production revenue. The environmental cost of such actions is often not considered.

Similar impacts need to be considered relative to parks and shoreline access, but this is about far more than just money; it is almost a fundamental right issue. Nevertheless, there are ways to meet the demands of human access and lake and reservoir management.

There are far more shoreline management issues than I have space to write about here. My real point is that NALMS is the only society dedicated solely to the management of lakes and reservoirs and, as such, can and will help resolve these issues by providing information and forums to exchange information. This information exchange will lead to better understanding and the formation of partnerships that will learn to deal with shoreline management issues in a fair and sustainable way. Thank you for reading *LakeLine* and being part of the NALMS family. Together we can make progress toward a more sustainable future for North America's lakes and reservoirs.

**Harry Gibbons** graduated from Gonzaga in 1973 in biology and went on to earn his MSEE and Ph.D. in limnology from Washington State University. After four years as a post-doctorate research associate in lake and reservoir management at WSU, he began his career as 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 a Region 10 Director.

# Examining Shorelines, **Littorally**

Kellie Merrell, Eric A. Howe, and Susan Warren

## The Effects of Unbuffered Lakeshore Development on Littoral Habitat, or – More Accurately – Littoral Biotope

### Why Study Lake Shorelines?

The littoral zone is an important part of the lacustrine ecosystem as it forms a transition zone between the terrestrial and aquatic environment. However, despite the increasing frequency in which the importance of the littoral zone appears in the published literature, there are few management programs that have incorporated the littoral zone into their routine monitoring operations. The littoral zone functions as a nursery ground for a variety of species and as primary habitat for aquatic plants. It serves as a critical interface between the aquatic and terrestrial environment for the transport of nutrients, sediment, woody substrate, organic matter, and species that utilize both lake and land.

Since the mid-1980s there has been substantial shoreline redevelopment on lakes. The transformation of lakeshores from their natural forested and wetland cover to newly developed lawn and sandy beaches, and the conversion of summer cottages to residential homes is a stressor to littoral zones in lakes. In the early 1990s, the U.S. Environmental Protection Agency and U.S. Fish and Wildlife Service concluded from a study of 345 northeast lakes that the stress from shoreline alteration was a more widespread problem than eutrophication and acidification (Whittier et al. 2002).

In Vermont, removal of the vegetated lakeshore buffer is not prohibited by state law, and approximately nine percent of the towns have shoreland vegetation protection in their zoning laws. The University of Vermont's Spatial Analysis Laboratory mapped shorelines within 25 feet of the waters' edge for 74 lakes in the Northern Forest of Vermont. The results indicated that, as of 2003, lakeshore development had impacted the vegetated buffer on up to 74 percent of a lake's shoreline (Capen et al. 2008). From 2005-2008, the Vermont Department of Environmental Conservation (VT DEC) conducted a study to measure what, if any, effects unbuffered development has on littoral aquatic habitat.

### What Do We Mean by "Littoral Biotope"?

The littoral zone is the area of a lake where light penetrates to the bottom, usually in the near-shore shallow water environment. "Habitat" is a commonly used term in ecological studies, but its definition varies with different disciplines of ecology and natural resource management. *Autecologists* (species ecologists) define habitat as species-specific, yet that is not the habitat we are addressing. *Biotope* can be defined as the sum of the physical, chemical, and biological components present in an area providing a living space for a distinct, recurring community of species (Tillin et al. 2008). Literally translated, biotope means "the area where life lives." Hence, to avoid confusion, we will use "biotope," a term used as a synonym for habitat by the "father of modern limnology" (Hutchinson 1957) in this article.

### What We Surveyed in Vermont Lakes and Ponds

In this study, we used the reference approach as defined by Tillin et al. (2008) to assess how the littoral biotope is altered by development that removes the natural shoreline vegetation. This approach assumes that littoral biotopes subjected to little or no anthropogenic shoreline alterations represent the best physical, chemical, and biological "natural" condition in the littoral zone. These sites were considered high quality and are referred to as "reference sites." The quality of the littoral habitat adjacent to unbuffered developed lakeshore sites was then measured as the degree to which conditions within it departed from the "natural" or reference state. These treatment sites are referred to as "unbuffered developed sites."

Our study contains results from surveys conducted on 40 lakes across Vermont. We surveyed lakes comprising three trophic classes: oligotrophic, mesotrophic, and dystrophic. We divided these classes further by lake surface area into small lakes (<200 acres) and large lakes (>200 acres). We avoided artificial lakes and lakes with significant drawdowns because we felt that the natural biotope conditions were compromised in these lakes and would not meet our criteria for reference condition. We visually selected unbuffered developed sites for each lake, and corresponding undeveloped reference condition sites with similar exposure, slope, and sediments. We surveyed a total of eight sites on each small lake and a total of 12 sites on each large lake. We attempted to pair every developed site with a reference site, but lakes with little to no development had more reference sites and lakes with little undeveloped shore had more unbuffered developed sites. In total, we sampled 234 reference sites and 151 unbuffered developed sites. At each site we placed a 10-m floating transect line at the 0.5-m depth contour and ran it parallel to the shore.

The transect was then divided into two 1-m wide by 5-m long plots. Snorkelers estimated the percent cover of a number of physical and biological parameters within each plot (Figure 1). Transects were also laid at 1-m and 2-m depths to capture the full diversity of aquatic plants within the near-shore littoral zone. Results presented here focus on the 0.5-m transect results (the transect nearest shore) and therefore most directly influenced by adjacent terrestrial conditions.

Let's define the littoral biotope in the context of what we examined in this study. We observed the biotope as the shallow nearshore area of a lake and took measurements of the physical, chemical, and biological components in that area. There are many important chemical properties that control what life exists there. For this study, we focused on nutrient enrichment (trophic condition) and alkalinity as important chemical defining features. We identified and selected dystrophic, high alkalinity oligotrophic, and high alkalinity mesotrophic lakes for use in this study. VT DEC has been collecting this water quality information since 1977, which enabled us to focus on lakes with these specific water chemistries.

There are many important physical properties that control what life exists in the littoral zone. The size and shape of the lake can influence the intensity with which the littoral zone experiences wind-driven wave activity; hence, we separated lakes into large (>200 acres) and small (<200 acres) classes. In the field, we estimated the percent cover of trees along the shore parallel to the littoral transects at each site. We also measured shading of the littoral zone at 1 m from shore using a densiometer. Our densiometer measured shading as a range from 0 to 17, with 17 representing 100 percent shaded. We counted the number of pieces of large (>10 cm diameter) woody structure in the littoral zone of the site from the waters' edge out to the 2-m depth transect. In each transect plot we recorded percent cover of fine (<4 cm diameter) and medium (4-10 cm diameter) littoral woody structure, deciduous leaf litter, sediment type (sand/gravel, silt, cobble, rock/bedrock, muck, woody detritus, floc), and sediment embeddedness.

Finally, there are the biological components of the littoral biotope.

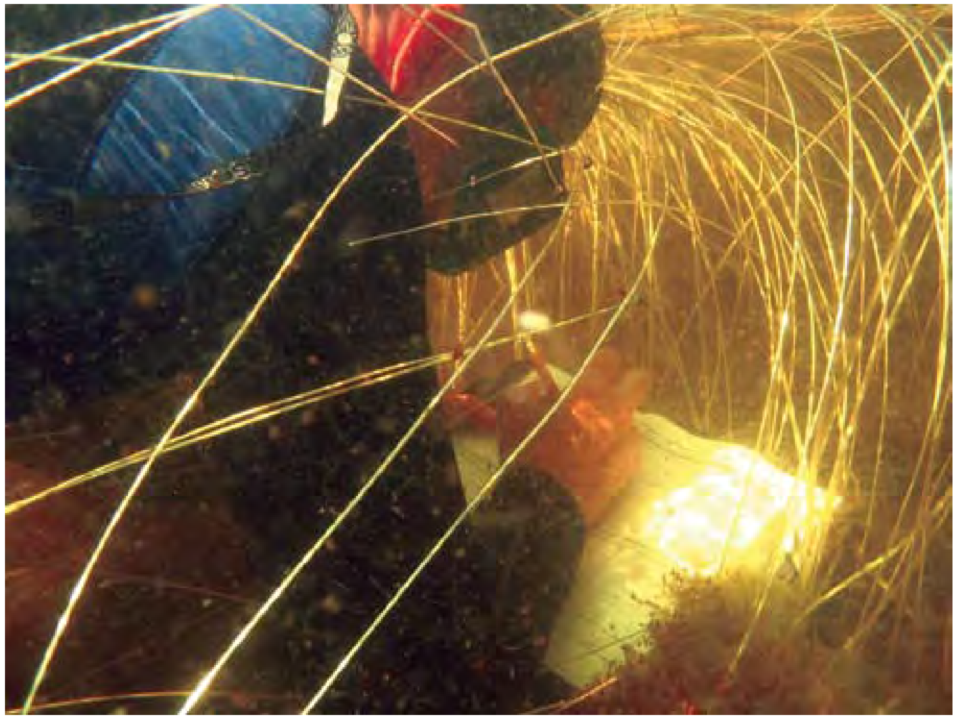

*Figure 1. Snorkeler recording aquatic plant data.*

"Aufwuchs" is the term that describes the community of small plants and animals that form biofilms on rocks, woody substrate, and aquatic plants (Figure 2). Aufwuchs is an important food base for fish and macroinvertebrates. We measured the percent cover of aufwuchs on solid surfaces (i.e., sediments and woody substrate), in each plot. Dragonfly and damselfly (odonates) larvae are another important biological component of the littoral biotope, as they feed on aufwuchs, and become prey for fish and other vertebrates. Odonate *exuviae* are the skins left behind by these insects when they crawl out of a lake in their larval form and transform into their adult winged terrestrial form (Figure 3).

*Figure 2. Aufwuchs living on piece of large woody structure.*

*Figure 3. Larval odonate exuviae (skin) left behind after adult damselfly emerged.*

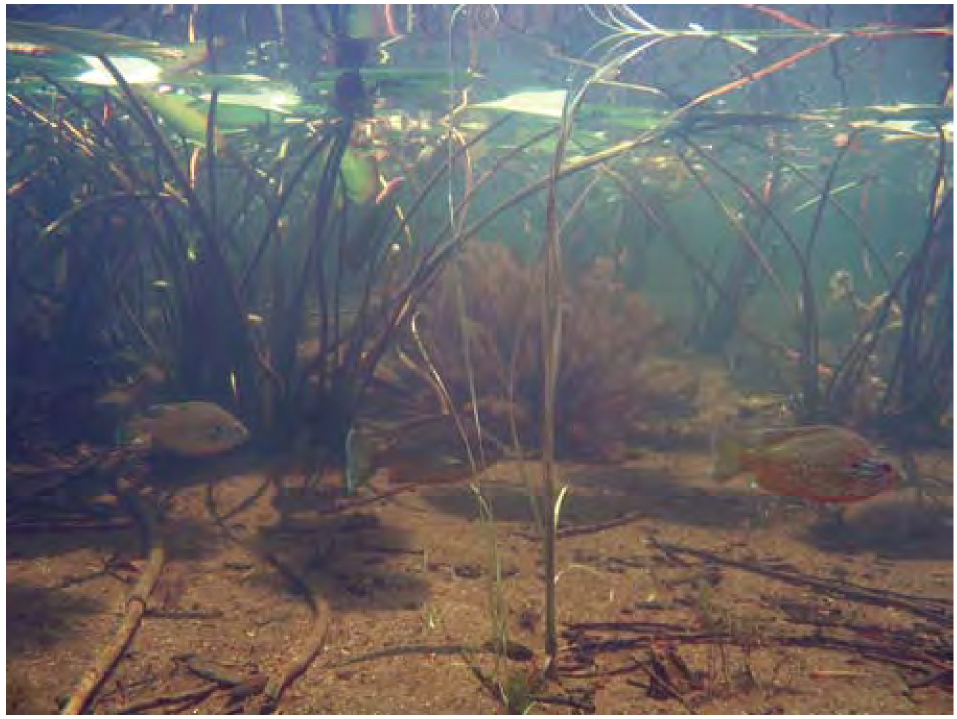

*Figure 4. Aquatic plants providing physical structure and food supply for other aquatic biota.*

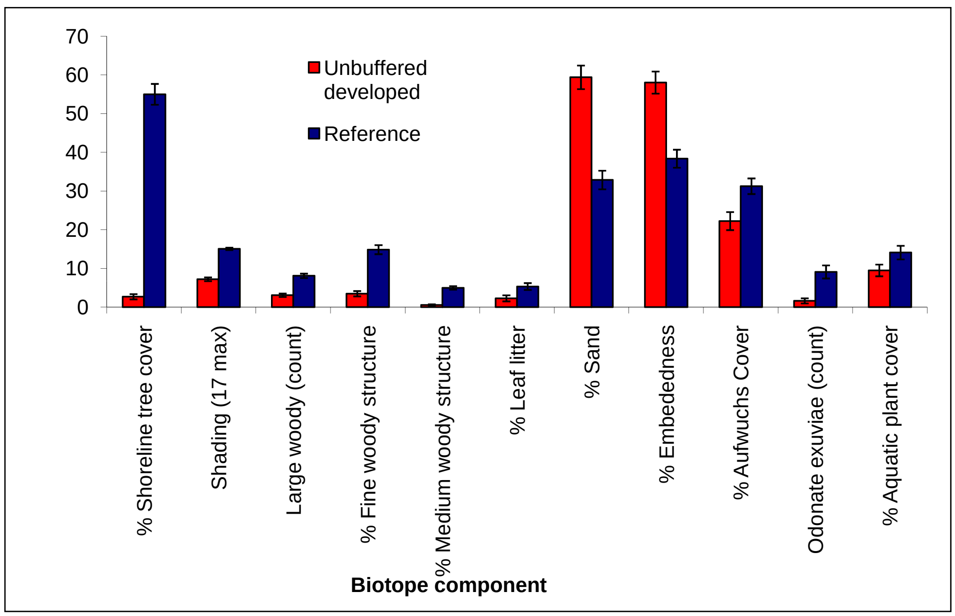


*Figure 5. Mean values (±1 SE) for shading at 1 m depth (0-17), count of large woody structure and odonate exuviae, and mean percent cover of shoreline trees, fine and medium woody structure, leaf litter, sand, embeddedness, and aufwuchs.*

These insects have habitat requirements for both the aquatic littoral zone and the terrestrial shoreline. We collected all exuviae from along the 10-m shoreline transect and 2-m inland at each site. The final biological component of the littoral habitat we measured was the percent cover of aquatic plants (macrophytes) in each transect plot. Aquatic macrophytes are important in defining biological components of the littoral zone. They influence both the chemistry (through nutrient uptake, oxygen production during the day, and respiration during the night) and also function as physical structural components within the littoral biotope (Figure 4).

## Is There an Observed Biotope Change at Unbuffered, Developed Sites?

We accounted for a total of 13 defining littoral biotope components in this study (Table 1). Three were predetermined by our selection of lake classes using lake size, trophic state, and alkalinity range. The remaining ten components were measured at each site. With the exception of aquatic plant cover, means of these measured biotope components at unbuffered developed sites were significantly different from their respective mean reference condition biotope components (Table 2, Figure 5).

The differences in all of the biotope components between the reference sites and unbuffered developed sites were substantial. We used relative percent differences to express these observed differences because we thought it more aptly conveyed the change as experienced by the biological community that had evolved to inhabit the reference condition (Figure 6). We calculated the relative percentage difference between the mean values of reference vs. unbuffered developed conditions for each of the ten measured biotope components. Figure 6 illustrates the percent deviation from the reference biotope. There was 182 percent less shoreline tree cover at unbuffered developed sites. This factor explains the majority of the observed differences for all of the other parameters evaluated

**Table 1.** Components of the Littoral Biotope Examined in This Study, Ranges for the Component Values, and Method of Data Collection.

| Biotope Component | Range of Measurement | Data Collection Method |
|---|---|---|
| *Chemical* | | |
| Trophic state | Dystrophic, oligotrophic, mesotrophic | VTDEC lake monitoring database |
| Alkalinity | >12.5 ug $CaCO_3$/liter for meso- & oligotrophic | VTDEC lake monitoring database |
| *Physical* | | |
| Shoreline tree cover | 0-100% cover | Estimated along 10 m of shore transect |
| Shading | 0-17, where 17 =100% shaded | Collected 1 m from shore |
| Large woody structure | Count | Counted all pieces >10 cm diameter from shore to 2 m depth |
| Medium woody structure | 0-100% cover | Estimated in 0.5 m depth transect plots |
| Fine woody structure | 0-100% cover | Estimated in 0.5 m depth transect plots |
| Leaf litter | 0-100% cover | Estimated in 0.5 m depth transect plots |
| Sediment type | % cover for sand/gravel, silt, cobble, rock/bedrock, muck-organic, woody detritus, floc | Estimated in 0.5 m depth transect plots |
| Embeddedness | 0-100% embedded | Estimated in 0.5 m depth transect plots |
| *Biological* | | |
| Aufwuchs | 0-100% cover | Estimated in 0.5 m depth transect plots |
| Aquatic plants | 0-100% cover | Estimated in 0.5 m depth transect plots |
| Odonates | Count | Collected all exuviae along shore |

**Table 2.** Biotope Component Mean, Standard Error, Number of Sites, and Statistical Significance (< 0.05) Across All 40 Study Lakes for All Unbuffered Developed and Reference Sites.

| | Unbuffered Developed | | | Reference | | | | |
|---|---|---|---|---|---|---|---|---|
| **Biotope Variable** | **N** | **Mean** | **SE** | **N** | **Mean** | **SE** | **F-stat** | **P-value** |
| Shoreline % tree cover | 150 | 2.7 | 0.68 | 234 | 55.0 | 2.70 | 12.29 | <0.0001 |
| Shading 1 m | 151 | 7.2 | 0.49 | 229 | 15.1 | 0.31 | 354.61 | <0.0001 |
| Large woody count | 151 | 3.1 | 0.44 | 231 | 8.1 | 0.56 | 49.42 | <0.0001 |
| % Fine woody cover | 151 | 3.5 | 0.69 | 234 | 14.9 | 1.17 | 70.07 | <0.0001 |
| % Medium woody cover | 151 | 0.6 | 0.17 | 234 | 5.0 | 0.45 | 84.18 | <0.0001 |
| % Leaf litter | 151 | 2.3 | 0.78 | 234 | 5.3 | 0.88 | 6.75 | 0.0097 |
| % Sand | 151 | 59.4 | 3.05 | 234 | 32.9 | 2.40 | 46.71 | <0.0001 |
| % Embeddedness | 151 | 58.0 | 2.86 | 234 | 38.4 | 2.34 | 28.43 | <0.0001 |
| % Aufwuchs cover | 151 | 22.2 | 2.32 | 234 | 31.2 | 2.02 | 8.53 | 0.0037 |
| Odonate exuviae count | 151 | 1.6 | 0.66 | 234 | 9.1 | 1.68 | 17.10 | <0.0001 |
| % Aquatic plant cover | 151 | 9.5 | 1.52 | 234 | 14.1 | 1.76 | 1.44 | 0.1474 |

in this study. With respect to the other physical components, there was 71 percent less shading in the littoral zone off the unbuffered developed sites. Less shading of the water means warmer water temperatures and more exposure to predation from visual avian and terrestrial predators.

There was also 90 percent less large woody structure in the littoral zone at unbuffered developed sites, providing less cover for fish. This reduction also means there is less vertical substrate available for amphibians and fish to attach their eggs to so they will remain well oxygenated above the lake bottom. Less large woody structure also means fewer basking sites for turtles that are safe from terrestrial predators (basking helps reptiles regulate their body temperature and save energy for reproduction). There was 124 percent less fine woody structure off unbuffered developed sites. This substrate is important to macroinvertebrates; it serves

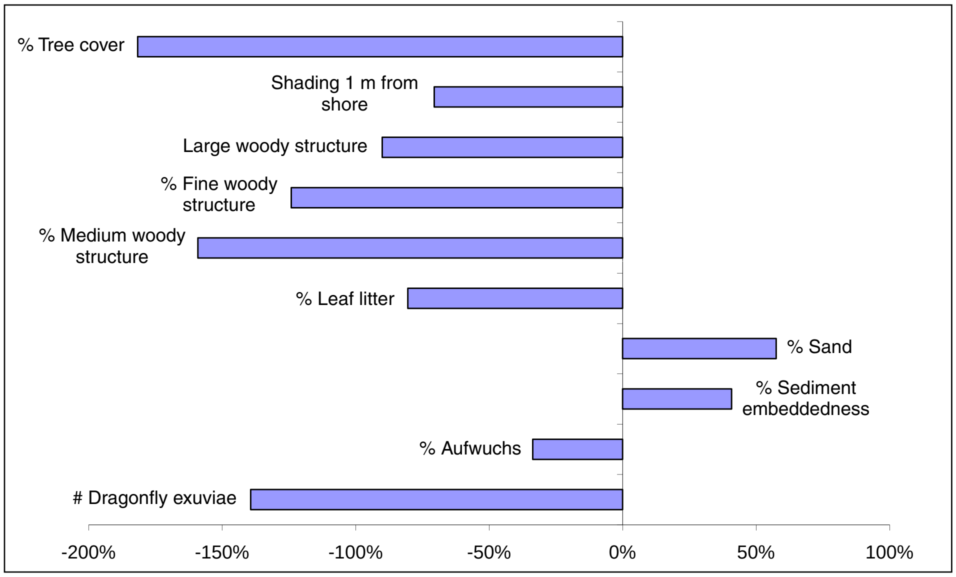


*Figure 6. Relative percent difference of unbuffered developed sites from reference sites for ten biotope parameters*

as cover from predation, material from which caddisflies make their casings, and substrate for microorganisms that form the foundation of the food chain. Of the three woody structure size classes, medium-sized branches and sticks were the most reduced off unbuffered developed sites. These unbuffered developed sites had 159 percent less woody structure than reference sites, representing a reduction in the cover and ecological functions of the medium woody structure class. There was 80 percent less deciduous leaf litter in the shallow littoral zone of unbuffered developed sites, further reducing the available substrate for macroinvertebrates and microorganisms. The sediment structure was altered off of unbuffered developed sites as well, with the addition of 57 percent more sand and 41 percent more sediment embeddedness of rocks and woody material.

The differences in the biological components measured were also striking. There was, on average, a 34 percent reduction in aufwuchs at the unbuffered developed sites compared to the reference sites, meaning less food is available for fish, snails, and macroinvertebrates. There were 139 percent fewer odonate exuviae skins at unbuffered developed sites. This represents an additional reduction in prey for fish and a reduction in the number of emerging dragonflies and damselflies into the terrestrial ecosystem.

Aquatic macrophyte abundances were also changed by unbuffered development, but physical and chemical components helped determine what that change would look like. In small oligotrophic and mesotrophic lakes, unbuffered developed sites had greater aquatic plant cover than reference sites, whereas in large mesotrophic, large oligotrophic, and dystrophic lakes, unbuffered developed sites had less aquatic plant cover. Aquatic plant cover was the only biotope component with a response to unbuffered development that varied with the predefined trophic and lake size classes (Figure 7).

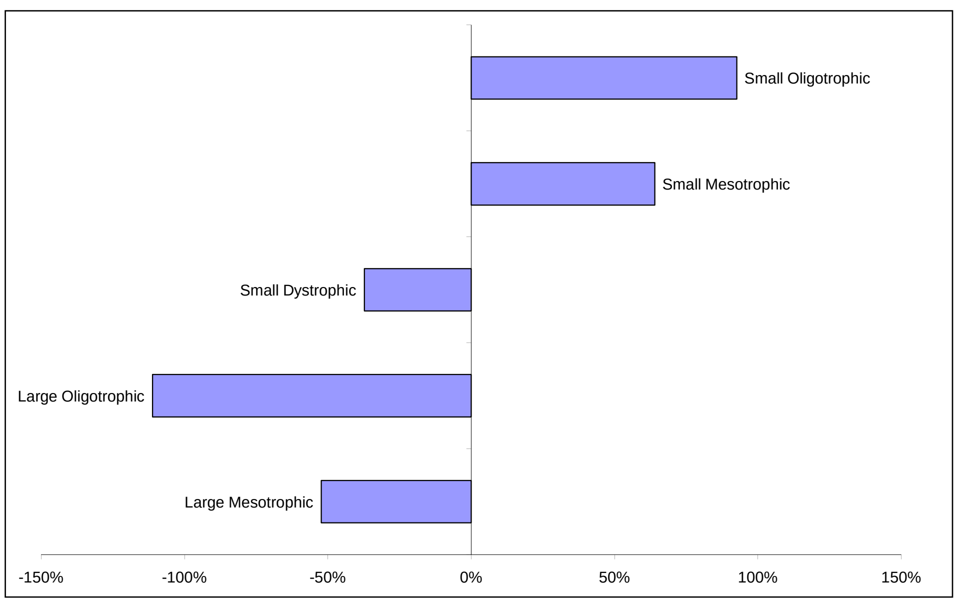


*Figure 7. Relative percent difference in mean aquatic plant cover for dystrophic lakes and small and large oligo- and meso- trophic lakes at unbuffered developed sites from reference sites at 0.5-m depth.*

In summary, conversion of treed shorelines to lawn may seem harmless to humans, but the chemical, physical, and biological components of the littoral biotope are radically changed by this activity. The natural community of aquatic and terrestrial organisms that has evolved to grow, reproduce, and survive there will change or disappear as the biotope undergoes the physical, chemical, and biological transformation to something with substantially diminished habitat quality. Minimizing the extent of shoreline conversion from forested land to lawns within the buffer zone and maximizing the extent of naturally buffered shores will help ensure that the natural community of lacustrine species endures.

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# Urbanization vs. **Natural Habitat**

Tessa B. Francis

## Shoreline Urbanization Reduces Terrestrial Insect Subsidies to Fish in North American Lakes

Across North America, the shorelines of lakes have been developed by humans for residential and other uses. Shoreline development is associated with many alterations to lake habitats and ecosystems, including eutrophication, loss of coarse wood, removal of emergent vegetation, and reductions in fish growth. An important driver of many of these responses by lakes is the tight association between the lake and the surrounding terrestrial habitat, as forest habitats provide key inputs of terrestrial energy and material that are transferred across the forest-lake boundary.

"Forests and fish" is a phrase that is commonly heard in the Pacific Northwest, where native salmon populations are declining and research has shown that streamside vegetation has important benefits for salmon and salmon habitat. Less appreciated is that forests also serve critical functions for lake ecosystems. For example, delivery of coarse wood from riparian forests provides critical habitat structure for fish that is essentially a permanent feature of shallow water habitats, as dead wood is stable in lakes for centuries. Inputs of dissolved organic matter and particulate organic matter, such as leaves and finer pieces of terrestrial vegetation, may also provide key energetic support to aquatic organisms. In addition, riparian vegetation provides habitat for terrestrial insects, and these insects can be important prey items for fish. This dynamic is well known in stream ecosystems, but we are only just beginning to understand the importance of terrestrial insects as prey for fish in lakes.

Residential development of lakes affects shoreline habitat in many ways. One of the most apparent changes to lakeshore habitats that accompanies development is deforestation: Native trees and shrubs are replaced by houses, lawns, and ornamental trees and other vegetation (Figure 1). In Pacific Northwest lakes, highly urbanized lakes have very little vegetation within ten meters of shore (Figure 2), a pattern that exists in other regions of North America, as well (Marburg et al. 2006; Christensen et al. 1996). This loss of riparian forest likely has several consequences for lake food webs, including reducing inputs of coarse wood to shallow waters, or of finer particulate organic material such as leaves. What is unknown is how lakeshore

*Figure 1. Typical urban (left, Shady Lake) and undeveloped (right, Gwendoline Lake) lakeshores in the Pacific Northwest.*

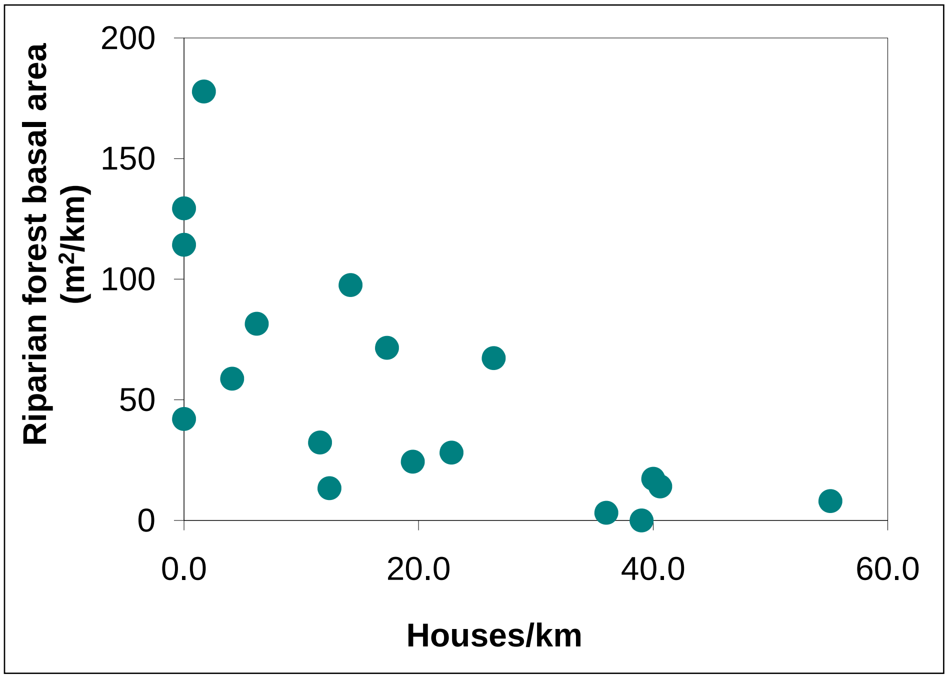


*Figure 2. Forest density within ten meters of shore on 20 Pacific Northwest lakes. Each symbol represents a mean for a single lake. Basal area is a measure of tree size, and represents the amount of wood on the landscape.*

development and riparian deforestation, impacts the delivery of terrestrial insects to lake surface waters, and what the consequences of these changes are for lake fish that may rely on terrestrial insect prey.

## Inputs of Terrestrial Insects

In contrast to the extensive research on the role of terrestrial insects as prey for fish in streams, very little is known about the inputs of terrestrial insects to lakes, or their importance as prey for fish. Terrestrial prey can represent a substantial portion of the diets of some fish in lakes. However, the limited research on this subject indicates that the importance of terrestrial prey in fish diets is variable among different fish taxa, and very little is known about what controls the fluxes of terrestrial insects to lakes.

In stream ecosystems, inputs of terrestrial insects are strongly associated with riparian vegetation. Fluxes of terrestrial invertebrates to streams are greater in areas with higher densities of riparian vegetation that serves as invertebrate habitat. Because of the many shared characteristics of stream and lake shorelines, terrestrial insect fluxes may be similarly associated with riparian vegetation on lakes.

We collected rainbow trout (*Oncorhynchus mykiss*) and cutthroat trout (*O. clarkia*) from four Pacific Northwest lakes, two undeveloped lakes with fully vegetated shorelines, and two urban lakes with little shoreline vegetation, to determine the influence of riparian vegetation on the prevalence of terrestrial insects in fish diets. We collected fish monthly for one year, via angling and gill netting, and sampled fish diets using gastric lavage, identifying all prey items to habitat of origin, i.e., terrestrial, benthic (lake bottom), or pelagic (open water). Terrestrial insects represented up to 100 percent of fish diets in the undeveloped lakes (Figure 3). These invertebrate taxa include spiders, beetles, aphids, wasps, and ants. In contrast, terrestrial insects were extremely scarce in the diets of fish in urban lakes, indicating that inputs of terrestrial insects are reduced by riparian deforestation.

This pattern of declining terrestrial insects in fish diets with increasing shoreline development is general across North American lakes and across several fish taxa. A broad survey that includes a single-visit sampling survey of 28 Pacific Northwest lakes and a literature survey of 24 North American lakes shows dramatic declines in the amount of terrestrial insects in fish diets of trout (*Oncorhynchus* spp.), bass (*Micropterus* spp.) and yellow perch (*Perca flavescens*; Figure 4) as shoreline development intensity increases. These data show clear associations among shoreline development, riparian vegetation, and the prevalence of terrestrial insects in fish diets, and indicate that building houses around lakes can alter fish food webs.

## Energetic Consequences of Shoreline Development

Terrestrial insects clearly can represent a very substantial portion of fish diets in lakes with intact riparian habitats. An additional issue relates to the contribution of terrestrial prey to energy that can be devoted to the biological demands of fish. To satisfy their energetic demands for growth and reproduction, fish can consume prey from terrestrial, pelagic, or benthic habitats. Prey taxa from different habitats have different energetic densities, and are therefore of variable value to fish as prey.

In general, terrestrial prey are more energetically valuable to fish. The terrestrial prey consumed annually by fish in two undeveloped Pacific Northwest lakes were on average 30 percent more energetically valuable than the benthic prey consumed, and 75 percent more valuable than the pelagic prey consumed (Table 1). Terrestrial prey were worth on average 9,500 joules (2.27 calories) per wet gram of mass, as compared to 7,150 joules for benthic prey and 5,400 for pelagic prey.

When the prey energy information is combined with the proportions in which each prey taxa was consumed by fish in the four lakes, we see that fish in the undeveloped lakes consumed two to three times more energy per day than fish in the urban lakes (Table 1), in no small part owing to the consumption of the more energetically valuable terrestrial prey, which represented up to 30 percent of the energy consumed by fish in the undeveloped lakes. Thus, in the two undeveloped lakes, terrestrial prey, which represented 14-16 percent of total diet mass on an annual basis, represented a much greater proportion of the energy consumed by fish that can be dedicated to growth and reproduction. Furthermore, in lakes where terrestrial prey comprise

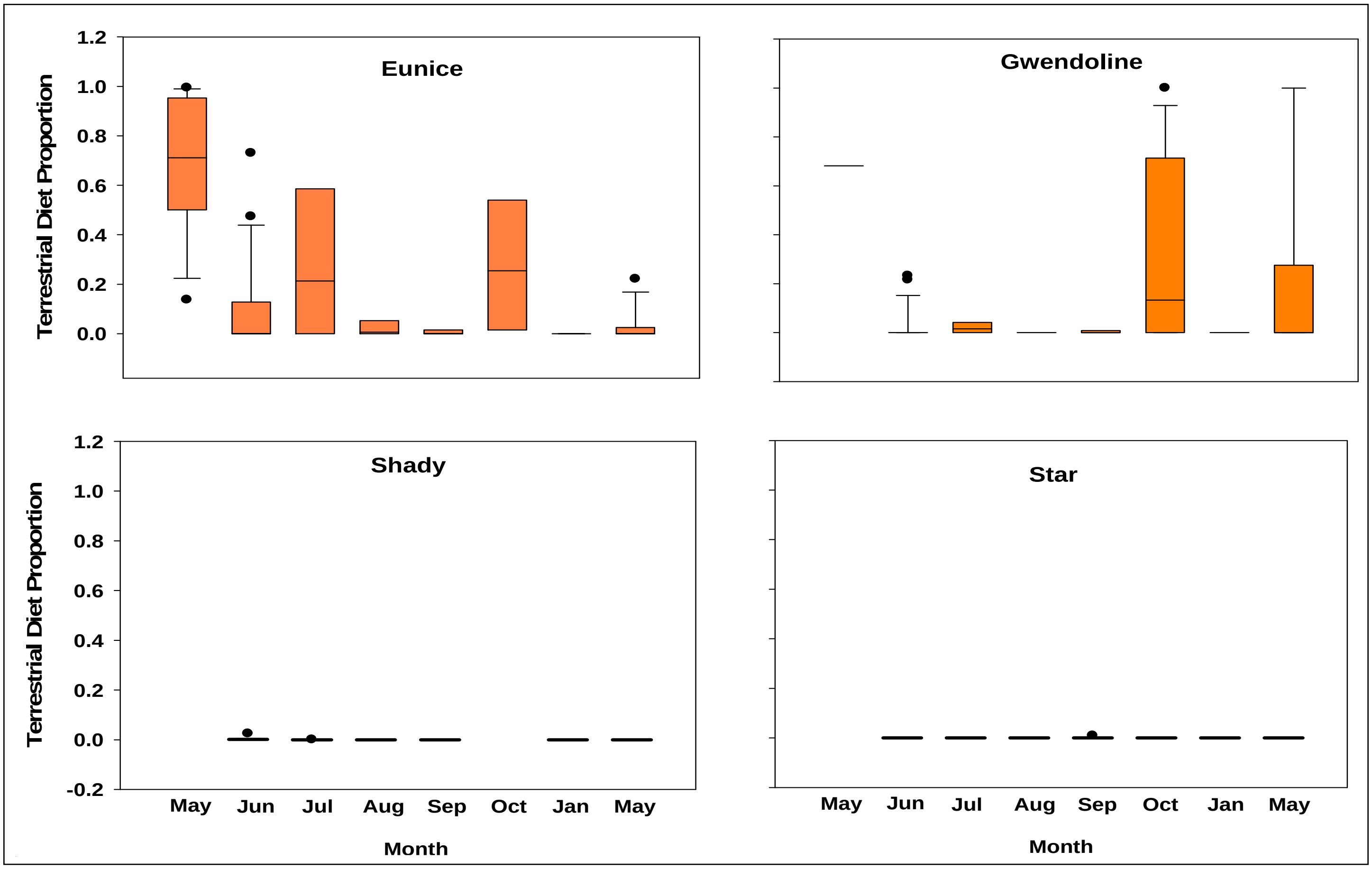


*Figure 3. The proportion of fish diets represented by terrestrial insects in four Pacific Northwest lakes. Eunice and Gwendoline lakes are 0 percent developed; Shady and Star lakes have 95 percent of their shorelines developed.*

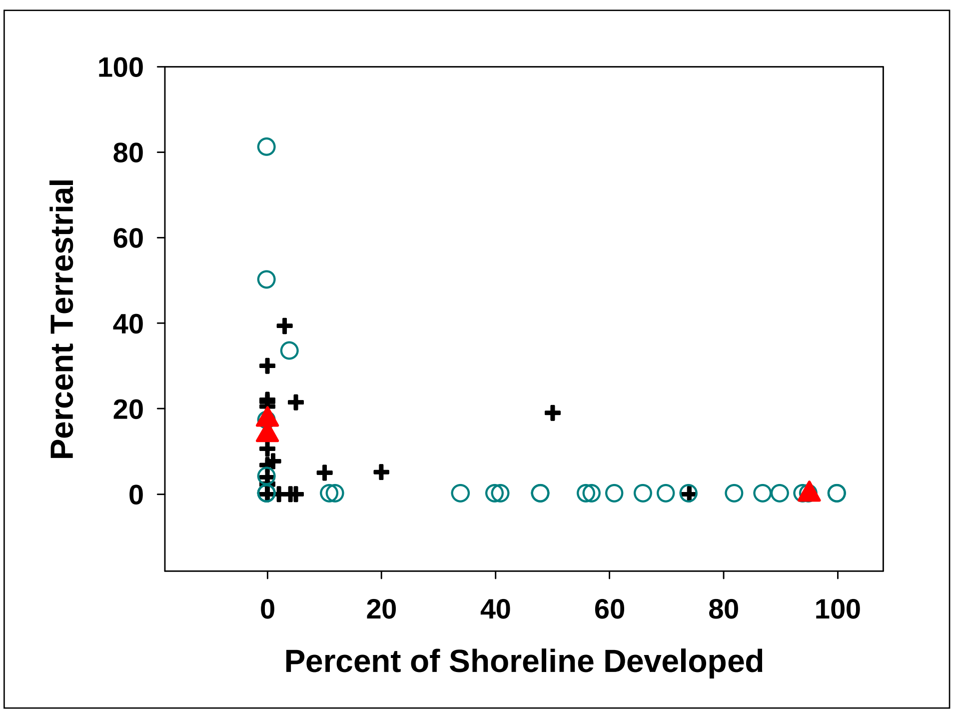


*Figure 4. The proportion of fish diets represented by terrestrial insects in 52 North American lakes along a shoreline development gradient: four lakes sampled regularly for one year (▲); 28 Pacific Northwest lakes sampled once (○); and 24 lakes from a literature review (+).*

an even greater proportion of total diet mass (see Figure 4), terrestrial prey may be of even greater value, indicating that lakes with intact riparian habitats are more likely able to support healthy fish populations than lakes that have been deforested by shoreline urbanization.

## Conclusions

The proportion of people living in urban areas around the world, including in North America, is projected to increase over the next 40 years (United Nations 2007). Because humans preferentially settle near freshwaters, this means that development pressures on lakes will continue to increase, and shorelines will continue to be altered in ways discussed in this and other articles in this issue of *LakeLine*. It is therefore imperative that we understand the effects of shoreline development on lake habitats, food webs, and ecosystem functions. We know that residential development of shorelines reduces riparian vegetation, and we now have some evidence that this has

**Table 1.** Energy Densities by Prey Habitat Type and by Lake.

| *Habitat* | *Prey Energy Density ($J\ g^{-1}$ wet mass)* | *Lake* | *Diet Energetic Value ($J\ g^{-1}$ wet mass)* | *Daily Energy Ration ($J\ g^{-1}$)* |
|---|---|---|---|---|
| Benthic | 7154 | Eunice | 7626 | 146.7 |
| Pelagic | 5409 | Gwendoline | 8761 | 127.1 |
| Terrestrial | 9561 | Shady | 3529 | 43.7 |
| | | Star | 3447 | 66.8 |

Eunice and Gwendoline lakes are undeveloped; Shady and Star lakes have shorelines that are 95 percent developed. Prey energy densities are mean joules per gram wet mass of all prey items from each habitat type found in fish diets in four Pacific Northwest lakes. Diet energetic values are means across all fish of the product of each prey's energy density and the proportional occurrence of that prey item in the diet (by wet mass), summed across all prey items in the diet. Daily energy ration is a daily measure of energetic intake based on consumption rates and prey energy densities.

effects on fish living in lakes, as well. One important step that can be taken to preserve the functions of lake food webs, therefore, is to retain riparian vegetation along shorelines. This can be done by individuals as well as by lake associations and government agencies. In this way, we can all be taking responsibility to ensure our lakes can continue to sustain healthy fish populations.

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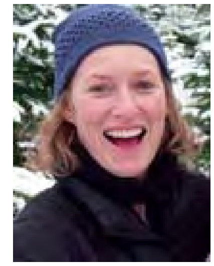


**Tessa Francis** is a recent Ph.D. graduate of the University of Washington's Zoology program. Her research interests center on aquatic-terrestrial coupling, including lakeshore dynamics, food web interactions and energy subsidies between riparian and aquatic ecosystems. Her dissertation focused on the impacts of shoreline urbanization on lake ecosystems, including riparian deforestation, loss of coarse wood from littoral habitats, reduced terrestrial invertebrates in urban lake fish diets, changes in lake sediment characteristics and processing, and shifts in littoral invertebrate communities. She was also an IGERT fellow in the UW's Urban Ecology program, where she researched how local governments use "best available science" in developing policy to protect critical habitats. You may reach Tessa at: tessa@u.washington.edu.

# Reston, VA: Softening the Hard Line

Larry Butler and Nicki Foremsky

## Taking a Soft Approach to a Hard Line: The Shoreline Management Experience in Reston, VA

### Introduction

Lake and reservoir management has evolved over the past two decades to be more watershed-focused, recognizing that the health and management of the water resource ultimately is tied to what happens upstream. However, a similar evolution has occurred on the shorelines of these same water bodies. Low impact development (LID) techniques, coupled with policy and ordinance changes affecting the use and protection of shorelines has helped improve water quality and shoreline habitat on many lakes and reservoirs.

Common, older approaches to stabilizing and managing shorelines for erosion prevention and recreational access relied on more traditional engineering solutions using bulkheads, rock groins, and rip-rap. The use of less-hardened solutions, utilizing plants or bio-engineered approaches, is becoming more common and more successful in meeting multiple lake management objectives.

The planned community of Reston, VA (pop. 60,000) has four community-owned lakes and two ponds ranging in size from three to 45 acres. Reston Association (RA), the homeowners association for the community, began active lake management in the early 1980s, mostly treating symptoms versus causes. In the late 1990s, RA began a more aggressive approach to treat causes of water quality degradation, which included watershed and shoreline management.

Over 90 percent of the property abutting the lakes is privately owned by individuals or townhouse and condominium cluster associations; however, the actual shoreline – where water meets land – is not always clear due to property line locations and shoreline erosion. Many lake front owners (individuals or associations) have enjoyed and maintained bulkheads built with pressure-treated lumber using chromated copper arsenate or CCA. As many of these structures are now more than 30 years old and in poor condition, many lot owners are seeking approval for replacements. The approval process now enables RA staff to engage these owners in discussions regarding alternatives that are friendlier to the lake environs.

This article will cover the RA experience in developing and implementing new shoreline protection practices. Specifically, it will discuss the practices employed, the outreach required, the regulatory aspects of the program, and experiences learned from specific projects.

### The Hard Line

Reston's lakes were constructed from the early 1960s through the late 1970s. For many years the developer owned and operated the lakes with little involvement from RA. On many lakefront lots, builders constructed bulkheads to create a "clean edge" look, which appealed to many buyers wanting undisturbed views to the water and ease of access to their boats (Figure 1). After the lots were sold, the developer deeded the lakes to RA for long-term stewardship. These bulkheads were constructed of CCA lumber and often constructed in haste to get homes sold. Over time, many structures became structurally unsound, collapsed, or simply began rotting away.

Often, the bulkheads are associated with localized erosion on adjoining lots, resulting from the wave energy running laterally to the next available unprotected shoreline. These bulkheads provide no habitat for either the shore land or littoral zone. Because bulkheads are considered structural elements by the community's architectural covenants, an application must be made for anything other than an exact replacement. With more recent innovations such as coir fiber logs coming into use, the range of possible alternatives – and less costly ones, at that – is helping make bulkheads less desirable. A change in the Design Review Board (DRB – community architectural committee) procedures also brought RA's environmental resource staff into the review process, providing the opportunity (and notice) to engage owners in considering alternatives.

More recently, findings reported by the United States Geological Survey and covered on some local news outlets aided RA's interest in decreasing the use of bulkheads. The report indicated high levels of arsenic in sediments in Reston's oldest lake, Lake Anne, and indicated that among likely sources were bulkheads and docks (Rice, Conko, and Hornberger 2002).

There is some difficulty in convincing an owner who has become accustomed to mowing grass to the back of a bulkhead, or mooring one's boat anywhere along his or her lakefront that alternatives exist that benefit the lake. RA has written articles and guidelines to help educate owners about the benefits of other shoreline stabilization techniques, and staff has met – and continues to meet – with many owners at their properties to discuss solutions.

*Figure 1. A typical manicured lawn to bulkhead lakefront. These are slowly disappearing.*

## The Soft Approach

Because there is nothing like a demonstration project to show lakefront owners what a new practice looks like, and how one might be installed, RA undertook several shoreline stabilization projects on its own shoreline properties. These ranged from simple shoreline vegetation plantings and coir log installations, to more complex combination projects of coir logs and rip-rap (Figure 2).

The multiple objectives of such installations are to improve water quality by reducing nutrient suspension along the shoreline, filtering overland runoff, and improving aquatic habitat. An ancillary benefit in some locations is discouraging Canada geese grazing by incorporating a wide natural shoreline vegetative complex at least ten feet in width along the entirety of the shoreline.

Some of the frequently mentioned concerns expressed by those reluctant to convert to a softer shoreline stabilization approach are the unkempt look, reduced lake view or recreational access, and wildlife. Overcoming an owner's desire for a clean edge at the lake is the most difficult of these to address, and only through education – and perhaps a little convincing – does this happen. Reduced views and access can be accommodated in the design and plant choice, as well as in some compromises affodring safe access to boats moored at the shoreline. Wildlife concerns generally stem from a fear of snakes, most notably the Northern Water Snake (*Nerodia sipedon sipedon*), which is often confused with the Northern Copperhead (*Agkistrodon contortrix mokasen*). Again, education plays a key role here in helping residents understand the facts and ecology of these shoreline practices.

In terms of a hierarchy of the available approaches, RA staff have a strong preference for vegetated shorelines and buffers, using coir logs if necessary depending upon the specific site conditions. The next approach is to use a combination of rip-rap and vegetation, often where wave fetch is greatest, or where the slope of the land entering the lake makes a vegetated shoreline less likely to gain a foothold. Rip-rap alone has been used in some instances, however, many believe it has an industrial or stark aesthetic. The spaces between the rocks do provide some habitat value, but no nutrient uptake (Figure 3).

In some cases where recreation access is important for fishing or boating, RA has developed compromise solutions. Recognizing the need for safe entry and exit for boating, which many owners desire, RA has permitted the limited use of short sections of bulkhead for this purpose (Figure 4). Often, the remaining shoreline of the property is stabilized using vegetation, rip-rap, or a combination thereof.

As more owners approach RA to replace old bulkheads or stabilize eroding shorelines, the complexities of property lines and shorelines that are not

*Figure 2. A re-established vegetated shoreline (l) and a newly installed and planted coir log (r).*

Figure 3. A stable rip-rap shoreline.

Figure 4. A recent compromise solution where "mini-docks" provide access over and adjacent to a shoreline re-vegetation project using coir logs.

concurrent often become an issue. In some cases the shoreline may be entirely on the lot owner's property, with their lakeside lot line under water. In other cases, there might be a strip of land between their property line and the lake. In extreme cases, an individual may have both situations on their lot, with little interest in spending funds to stabilize the shoreline on or off their property adjacent to the lake shoreline. In these situations, RA picks up the cost to stabilize its property, in concert with the owner doing so for that portion of shoreline on their property. RA can also purchase the materials for both applications at wholesale costs, thus saving the homeowner money.

These small incentives are important to further the softening of the lake shorelines and improving lake conditions. RA will not pay to put bulkheads on any shoreline behind a lot owner's or cluster association's property, even when RA owns the actual shoreline. Nor does RA permit owners to install new bulkhead on shorelines RA owns, even if the owner is willing to pay.

The combination of outreach, education, and policy guidance in the community's covenants has gone a long way toward reducing the amount of hardened shoreline on Reston's lakes (Figure 5). RA staff put together a simple matrix to help explain the shoreline stabilization options available (Table 1) and it has been a useful tool in our efforts. The greening of America, from the use of recycled and organic products to the


Figure 5. Examples of education materials. Effective outreach and education is critical to success.

**Table 1.** Matrix to Help Explain Shoreline Stabilization Options and Costs.

**COMPARISON MATRIX FOR SHORELINE STABILIZATION METHODS**

| | BULKHEADS | RIP-RAP | VEGETATION | COIR LOGS w/ VEGETATION |
|---|---|---|---|---|
| **ADVANTAGES** | Reasonable longevity depending on construction quality<br><br>Ease of recreational access<br><br>Architecturally pleasing | Indefinite longevity<br><br>Excellent energy dissipater<br><br>Some use for wildlife<br><br>Can be planted<br><br>Various sizes, colors available<br><br>Inexpensive<br><br>Little maintenance required | Longevity/warm seasons only<br><br>Dissipates energy<br><br>Amenity for wildlife, fish<br><br>Choice of flowering plants<br><br>Inexpensive<br><br>Aesthetically pleasing<br><br>DRB approval not needed | Reasonable longevity, longer than vegetation alone<br><br>Dissipates energy better than vegetation alone<br><br>Amenity for wildlife, fish<br><br>Choice of plants<br><br>Enhances colonization of native plants<br><br>Relatively inexpensive<br><br>Aesthetically pleasing<br><br>DRB approval not needed |
| **DISADVANTAGES** | Life expectancy 15-20 years<br><br>Does not dissipate wave energy well<br><br>Professional installation required<br><br>Expensive<br><br>Does not provide a benefit to wildlife, fish<br><br>Chemical leaching<br><br>Require maintenance<br><br>Does not deter waterfowl<br><br>Need DRB approval | Design must accommodate an area for recreational access<br><br>Some consider aesthetically displeasing<br><br>Can catch floating debris<br><br>Expensive<br><br>Access to site<br><br>Need DRB Approval | May hinder some access<br><br>May harbor wildlife<br><br>Can collect floating debris<br><br>Some species can overpopulate<br><br>Need fencing first two growing seasons | May hinder some access<br><br>May harbor wildlife<br><br>Can collect floating debris<br><br>Some species can overpopulate<br><br>Need fencing first two growing seasons |
| **COSTS** | By contractor:<br>$50-90/linear ft. not including backfill (for vertical sheeting wall) | By contractor:<br>$40-80/linear ft. depending on grading & access<br><br>By resident:<br>$20-30/linear ft. dependent on rock type | $12-18/linear ft.<br><br>Depends on number, size, and types of plants | $18-25/linear ft.<br><br>Depends on number, size, and types of plants |

Notes:
1. Some advantages and disadvantages listed for each type of measure are simply perceptions of different individuals – i.e., one resident may like the attractiveness of vegetation to wildlife, another may consider it a nuisance.
2. Costs are approximate and would vary based on exact materials chosen, access to the work area, and specific design considerations such as slope or depth to lake bottom.

introduction of sustainable development practices, has also contributed to a more receptive public when approached about more lake-friendly techniques.

Perhaps the best outreach is showing tentative owners the results of earlier shoreline projects. The vast majorities of the owners who have converted to softer shorelines are very pleased with the results and are happy to share their experiences with neighbors or the occasional boater passing by. RA staff monitors its shoreline projects on a regular basis to make sure the plants (and rocks, if applicable) are stable and in good condition. While no specific biological surveys are conducted to determine the wildlife use of vegetated shorelines, casual observation indicates the frequent presence of fish fry, turtles, dragonflies, and wading birds such as herons (family: Ardeidae).

Shoreline management goals that fit into the larger context of lake management and improvement can be successful with proper outreach and education. With good information about lake water quality trends, it is easier to get support for changing attitudes and practices on shorelines. This is particularly true if water quality is declining! The experience in Reston has shown that gradual changes, which can then be viewed and evaluated by other lake users and property owners, can be made and supported by many.

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**Nicki Foremsky** is Reston Association's Watershed Manager. Nicki monitors and manages the Association's lakes, ponds, and streams and explores ways to help protect and improve Reston's water resources. Prior to joining Reston Association she worked on water quality outreach and education for Penn State University Extension in Westmoreland County, PA.


# 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 ≥ 2.5 cm and ≤ 10 cm in diameter and ≤ 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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# Showcasing **"Workhorse Species"**

Patrick Goggin

## And They're Off... Workhorse Species Gallop Toward Successful Shoreland Restorations

Naturalist skills can come in handy when you're thinking about shoreland restoration. If you observe an intact, natural shoreline, you begin to see which plants stand out as protectors of the soil and suppliers of food and habitat for wildlife. For example, you might notice alder (*Alnus incana*) and sweet gale (*Myrica gale*) along a lake shoreline, bouncing up and down like a shock absorber, softening the wave action and the energy coming into it. Or perhaps you watch water during a rainstorm flow around thickets and clumps of grasses and sedges, where it is intercepted by thousands of leaf blades, and the water's power becomes minimized and braided, and it has a chance to infiltrate.

People around the country doing shoreland restorations over the last 10-15 years put these naturalist's abilities to work by realizing that a core group of plant species can help make for successful plantings. Often practitioners call them the "workhorse species." We have come to realize that this group of plants has characteristics that make them desirable for reestablishing shoreland buffer form, function, and beauty. Workhorse species should be abundant across a wide range of ecological settings. These plants help protect shoreland areas from erosive forces and add to the structure at a site as trees, shrubs, and ground layer vegetation.

Typically, these plants have traits we admire for shoreland habitats, such as penetrating, deep roots, or they are prolific seeders that pioneer into disturbed ground before weeds and invasive species arrive. Many also have rhizomatous, fibrous, and/or clump-forming root systems, so they spread out effectively along the shore holding soil in place to minimize erosion. Practitioners give these plant species a gold star for reestablishing our shoreland buffers because they offer other functions besides deep roots. Most have wildlife habitat benefits of one sort or another, too. They provide nesting material, food, and cover. Further, these species are more tolerant of variability in site conditions for moisture, water depth, soil type, and light. They can also be propagated efficiently and in a cost-effective manner by nurseries specializing in native plant material production.

Experiment with trying to identify a suite of plants in your region that can act as workhorse species for shoreland restorations. Choose plants that hold the soil well, spread effectively through rhizomes or seed, and have ways of supporting and assisting wildlife in their survival. Consider species that tolerate a variety of site conditions and are relatively resistant to overgrazing from muskrats,

*Butternut Lake, Forest County, Wisconsin, USA, natural shoreline.*

*Drift example.*

Helenium autumnale.

*Native alder and other shrub shock absorbers.*

waterfowl, or other critters. By having this building block as part of any project, you will improve the chances of your shoreland reestablishment work being successful now and well into the future.

Think about using your workhorse species in larger patches. Using irregular shaped drifts of these plants running parallel to the shore will improve the aesthetics of your project. A good plan should include workhorse species laid out in these types of shoreline planting beds. Landowners can conceptually recognize more easily this kind of design versus an ecologically driven method of laying out the plant material in some type of matrix. This patch technique makes it easier for lakeshore property owners to accept the idea of enhancement work. Visually and aesthetically, people can identify more with the workhorse species used in this manner.

You can always add showy and more niche-type plant species elsewhere in the planting through small accent areas. Overall, try to pick a diversity of plants to minimize impacts from pests, disease, or prolonged periods of high water or drought. Choose a rich color palette, bloom time assortment, and striking shape of plants that can provide the site with interesting foliage, flowers, and structure year-round.

Silphium perfoliatum.


Peltandra virginica.

Pontederia cordata.

**Table 1.** A List from the Author of Potential Great Lake States Workhorse Species to Consider for Shoreland Restorations*.

| Native plant type | *Common name* | *Scientific name* | *Traits* | *Height* | *Flower color* |
|---|---|---|---|---|---|
| *Wet feet / aquatic species* | | | | | |
| **Shrubs & small trees** | Elderberry | *Sambucus canadensis* | Plants are browsed and fruit eaten by assorted critters | 5’-8’ | White |
| | Highbush-cranberry | *Viburnum opulus* | Easy to grow; adaptable to a variety of soil and acidity | 3’-15’ | White |
| | Labrador-tea | *Ledum groenlandicum* | Northern lakes in transitional areas | 1.5’-3’ | White |
| | Leather-leaf | *Chamaedaphne calyculata* | Northern lakes in transitional areas | 1’-3’ | White |
| | Meadowsweet Steeplebush | *Spiraea alba; S. tomentosa* | Found on sandy-peaty shores and dried lake-beds | 3’-6’ | White/pink |
| | Mountain holly | *Ilex mucronata* | Plant male and female stock | To 10’ | Yellowish |
| | Red-osier dogwood | *Cornus sericea* | Bright red stems year-round; tolerates some inundation | 6’-12’ | White |
| | Sandbar willow; Pussy willow | *Salix exigua; S. discolor* | Cover and food for many wildlife species; fast grower; colonizer | 6’-20’ | Yellow |
| | Speckled alder | *Alnus incana* | Cover and food for many wildlife species; tolerant | To 30’ | Catkins |
| | Sweet gale | *Myrica gale* | Propagated by bare root; northern distribution | To 7’ | Bluish |
| **Grasses, sedges & rushes** | Blue-joint grass | *Calamagrostis canadensis* | Readily colonize disturbed areas; rhizomes form dense sod | 2’-4’ | Tan |
| | Bulrushes | *Scirpus atrovirens; S. cyperinus; S. fluviatilis; Schoenoplectus acutus; S. validus* | Soil stabilizers; wildlife food; nesting material | 3’-5’ | Brown |
| | Great bur-reed | *Sparganium eurycarpum* | Creeping rootstock | 1 ’-3.5’ | Green |
| | Needle spike-rush | *Eleocharis acicularis* | Fine spreading rhizomes; often volunteers | 2’-6” | Greenish |
| | Rattlesnake grass | *Glyceria canadensis* | Semi-aquatic grass; spreads by rhizomes; significant to wildlife | 2’-3’ | Green |
| | Sedges | *Carex aquatilis; C. comosa; C. crinita; C. lacustris; C. limosa* | Plants often colonial, form clumps, and/or with fibrous roots or rhizomes long-creeping | 1’-5’ | Yellow to brown |
| | Prairie-cord grass | *Spartina pectinata* | A good performer; withstands tough situations | 4’-7’ | Tan |
| | Virginia wild rye | *Elymus virginicus* | Moderate moisture to moist; in sandy, loamy soil | 4’-5’ | Tan |
| **Wildflowers** | Arrow-arum; Tuckahoe | *Peltandra virginica* | Emerges annually from bulbs with thick fibrous roots | To 2’ | Green |
| | Blue-flag iris; north, blue-flag | *Iris virginica; I. versicolor* | Easily established and increased by nurseries | 2’-3’ | Blue |
| | Blue vervain | *Verbena hastata* | Prolific seeder; easy to establish | 2’-3’ | Blue |
| | Boneset | *Eupatorium perfoliatum* | Species of shorelines and recently exposed wet soil | 2’-4’ | White |
| | Common rush | *Juncus effusus* | Forms dense clumps; good performer in moist soils | 1’-2’ | Brown |
| | Golden Alexander | *Zizia aurea* | Good performer with year-round interest; mesic to moist soil | 1’-3’ | Yellow |
| | Great St. John’s wort | *Hypericum pyramidatum* | Prolific seed producer; striking foliage and flower; shrub-like | 3’-5’ | Yellow |
| | Joe-pye weed | *Eupatorium maculatum* | Widespread in northern North America from ocean to ocean | 2’-7’ | Pink |
| | Marsh milkweed | *Asclepias incarnata* | Prefers sandy, loamy soil; host plant for monarch butterfly | To 5’ | Pink |
| | New England aster | *Aster novae-angliae* | Moderate moisture to moist; in sandy, loamy soil | 1’-7’ | Purple |
| | Pickerelweed | *Pontederia cordata* | Covers sediments with a tough vegetative mat; colonizer; plant in 12+ inches of water as tuber can freeze | 1’-3.5’ | Violet |

| | | | | | |
|---|---|---|---|---|---|
| | Sneezeweed | *Helenium autumnale* | Prolific seeder; moist to wet; in sandy, loamy soil | 3'-4' | Yellow |
| | Swamp aster | *Aster puniceus* | On peaty, mucky, or sandy soils; eastern US | 1'-7' | Purple |
| | Swamp loosestrife | *Decodon verticillatus* | Mat forming woody perennial; eastern US; likes shallows | 1'-9' | Pink |
| | Sweet flag | *Acorus americanus* | Likes water less than 20" deep; in wet, silty soil | To 6' | Green |
| *Dry feet species* | | | | | |
| **Shrubs & small trees** | Chokecherry | *Prunus virginiana* | Everywhere but wet ground; grow in thickets by runners | 10'-25' | White |
| | Black chokeberry | *Aronia melanocarpa* | Plants are browsed and fruit eaten by assorted critters | 3'-6' | White |
| | Hazelnuts | *Corylus americana; C. cornuta* | Tolerate dry to wet soils; attractive foliage and fall color; fast growers; significant wildlife value | 6'-8' / to 16' | Catkins |
| | Juneberry; serviceberry | *Amelanchier arborea; A. laevis; A. sanguinea* | Eastern US; clump forming; dry to moist sites; significant wildlife value | 10'-30' / to 15' | White |
| | Nannyberry | *Viburnum lentago* | Adapts to a wide range of sites; fibrous roots, multi-stemmed | To 15' | Green |
| | Pin cherry | *Prunus pensylvanica* | Routinely available; adapted to assorted soil conditions | 5'-25' | White |
| | Snowberry | *Symphoricarpos albus* | Important browse; good for shelter; tolerates different soils | To 18' | White |
| | Sweet fern | *Comptonia peregrina* | Does especially well in open, sterile, sandy soils; mat-forming | 1'-3' | Catkins |
| | Wild plum; American plum | *Prunus americana* | Produces runners and spreads to form a hedge | To 15' | White |
| **Grasses, sedges & rushes** | Big bluestem | *Andropogon gerardii* | Used by assorted wildlife for food & cover; sandy, loamy soil | 5'-8' | Purple |
| | Fringed brome | *Bromus ciliata* | Widely adapted species; tolerates some shade | 2'-3' | Green |
| | Indian grass | *Sorghastrum nutans* | Sandy, loamy soil; excellent for wildlife habitat and food | 5'-7' | Brown |
| | Prairie drop seed | *Sporobolus heterolepsis* | Dry to moderate moisture; sandy, loamy soil; clump former | 2'-4' | Green |
| | Sedges | *Carex bicknellii; C. stricta; C. stipata; C. vulpinoidea* | Plants often colonial, form clumps, and/or with fibrous roots or rhizomes long-creeping; dry to moderate moisture | 1'-3' | Yellow to green |
| | Switch grass | *Panicum virgatum* | Dry to moderate moisture; sod forming; quality habitat | 3'-6' | Purple |
| **Wildflowers** | Bergamot | *Monarda fistulosa* | Prolific seeder; dry to moist soils; showy flower | 3'-4' | Pink |
| | Big-leaved aster | *Aster macrophyllus* | Spreads quickly; common ground cover in northern forests | 0.5-1.5' | Blue |
| | Cup plant | *Silphium perfoliatum* | Aggressive, tall plant; birds love it; cupped leaves hold water | 6'-9' | Yellow |
| | Fireweed | *Epilobium angustifolium* | Forms clumps and stands, hummingbirds dig it | 3'-4' | Pink |
| | Grass-leaved goldenrod | *Euthamia graminifolia* | Rhizomes forming patches; tidy goldenrod | 1'-4' | Yellow |
| | Grey goldenrod | *Solidago nemoralis* | Good for dry sites; in rocky, sandy soil | 1'-2' | Yellow |
| | Yellow coneflower | *Ratibida pinnata* | Prolific seeder; easy to establish; in sandy, loamy, limy soil | 2'-4' | Yellow |

* Larger trees should be chosen according to specific site conditions and ecological region.

**Web links of interest:**
Native Plant Network http://nativeplants.for.uidaho.edu/network/general.asp.
USDA Natural Resources Conservation Service PLANTS database: http://plants.usda.gov/index.html.

# Better Lakes for **Tomorrow**

Jeremy Price

## An Overview of Shoreline Management Efforts in Indiana

Looking back, I find many of my fondest childhood memories were tightly connected to water. Whether it was catching bluegill from the front seat of my dad's 14-foot fishing boat or jumping from the end of a pier to cool off on a sweltering August day, the call of the lake was undeniable. It's a call that many feel – and for good reason. In an age when the stresses of life come at us from every direction, time at the lake offers the solace we need to get through another week.

This call has prompted many to take up full-time residence along the shorelines of our lakes. The small cabins and cottages of yesteryear have dwindled in number, giving way to larger homes and condominiums. More and more people are heeding the call to the water's edge; but, at what cost?

Whether we like it or not, we cannot inhabit riparian areas without having some impact on the quality and functionality of the ecosystem that draws us there in the first place. Construction of roads and homes and conversion of natural areas to residential lawns is merely the beginning. Inevitably, our well-intentioned desire to enhance the view from the back porch or improve the recreational utility of lakefront property results in alterations to the shoreline and nearshore areas of the lake. Often the impacts become much larger than we would anticipate.

The shallow water area of lakes, or littoral zone, is typically the most biologically productive and diverse in terms of plant species and structural habitat complexity. These factors combine to provide a wide array of habitat niches which are filled by a variety of aquatic organisms that all play a vital role in the health of aquatic ecosystems (Figure 1). A common and seemingly harmless practice such as the removal of native vegetation and woody debris results in fragmentation and simplification of nearshore habitat. Generally, when implemented on a small scale, this type of activity has negligible impacts on lake resources as a whole. However, as residential development increases along the margins and more of these practices are employed by an ever-growing number of riparian owners, the cumulative effects of incremental losses result in degradation of resources including natural scenic beauty, floral and faunal communities, and water quality. This example clearly shows that management of human activities affecting this important resource must be conducted judiciously in order to preserve its quality for generations yet to come.

### Regulation of Lake Construction

In Indiana, major steps toward protecting lakes were taken in the first half of the twentieth century. Most notably, the state's authority to regulate lake construction activities on Public Freshwater Lakes was established by the state legislature in 1947 with the passing of the Lakes Preservation Act (Indiana Code 14-26-2). Deeply rooted

*Figure 1. A pair of sandhill cranes explore the littoral zone of Kuhn Lake in Kosciusko County.* Photo: Bob Peterson.

in the Public Trust Doctrine, the Lakes Preservation Act established publicly held rights and charged the state with holding public freshwater lakes in trust for its citizens. Under this law, a process was also established for permitting of numerous types of projects including excavation, placement of fill, and placement or modification of structures within the waters of the lake.

As any permitting process should be, this is far more than just a regulatory hurdle for property owners to overcome. Under this process, the Indiana Department of Natural Resources (IDNR) conducts a comprehensive review of proposed projects to ensure that unreasonable detrimental impacts do not result and that the public trust is upheld. Typically, up to five divisions of the IDNR are solicited for comments regarding permit applications on issues such as public safety, recreational impacts, and biological concerns. Applications that are likely to cause unreasonable harm face denial unless changed to reduce the impact. If impacts from the project are deemed reasonable, a permit is issued and the project may proceed as planned.

One of the most common impacts riparian owners impose upon lakes is shoreline alteration. Seawalls of every type have long been used to protect shorelines, from the smallest inland lakes to the most battered coastal shores. On the inland lakes of Indiana, typical seawall applications request one of three general types: bulkhead, glacial stone, or bioengineered seawalls. Each, when properly designed, can be very effective in controlling the erosional forces imposed by wave action. Each method has strengths and weaknesses that must be weighed when determining which to use on a particular shoreline.

When people hear the word "seawall," most picture bulkheads. These are hard-armor structures that create a vertical or near-vertical ledge at the interface of land and water (Figure 2). Bulkheads are most often comprised of concrete or steel, although other materials such as vinyl are sometimes used. These walls are very effective at halting erosion and retaining soil landward of the structure. Due to their strength and toughness, they are best used in locations where erosion threatens infrastructure or where severe erosion occurs due to high wave energy. However, there are also a number of drawbacks associated with their use. Reflectance of wave energy may exacerbate erosion problems on adjacent shorelines and result in scour of the lakebed immediately lakeward of the wall. Where bulkheads are widespread, a "bathtub effect" may occur, thus creating irregular, choppy wave patterns that inhibit boating and other recreation. On the biological side, the vertical face of bulkhead seawalls creates an insurmountable barrier that prevents the ingress and egress of animal species, such as frogs and turtles, requiring both aquatic and terrestrial habitats to complete their life cycle.

While bulkheads are sometimes necessary to achieve shoreline stability, the far more lake-friendly options of glacial stone and bioengineered seawalls are adequate to suit the needs of most shorelines of smaller inland lakes. In glacial stone seawall construction, geotextile is laid along the shoreline and covered with layers of 8-inch to 12-inch rounded field stone. The stone gradually slopes to the lakebed (Figure 3) creating a profile similar to a natural shoreline. In this design, the stone provides structural armoring, while the geotextile prevents erosion from occurring

*Figure 2. Bulkhead seawalls reflect wave energy and create barriers for many aquatic animals.*

*Figure 3. Glacial stone seawalls provide shoreline armoring while causing less damage to habitat and natural aesthetics.*

through the interstitial spaces between the rocks. Bioengineering is a technique that combines structural, biological, and ecological concepts to construct living structures (plant communities) for erosion control. More specifically, native plants are used in conjunction with coconut fiber logs, turf reinforcement mats, or other structural materials to create a "living wall" that controls erosion while still appearing and functioning much like a natural shoreline (Figure 4).

## Shoreline Classification

Prior to the late 1990s, DNR biologists were faced with the difficult task of assessing the impacts of proposed projects without clear and specific guidelines regarding what were reasonable impacts to the resource. With the status of shorelines being quite variable from lake to lake across Indiana's natural lakes region and different staff reviewing projects in different districts, it became apparent that more formal guidance was necessary. Work soon began to develop a system for deciding what types of alterations would be permissible for a given site. The system must strike a balance between the ecological sensitivity of an area and the amount of impact deemed "reasonable" in each case. It must also be unambiguous, to ensure that applications are reviewed consistently across the region. With these needs in mind, a method of classifying shorelines was developed and formally adopted into Indiana's administrative code for lake construction (312 IAC 11) in 1999. Under this system, biologists have specific and measureable criteria regarding wetland vegetation (emergent and rooted, floating-leaf plant species) and prior shoreline disturbance that allow a classification to be assigned to any shoreline. Initially, three classifications were described: *significant wetland*, *area of special concern*, or *developed area*. An additional category, *natural shoreline*, was added in 2005 to protect stretches of unaltered shorelines that lacked wetland vegetation.

*Figure 4. Bioengineered seawalls effectively control erosion while still providing a natural appearance and wildlife habitat.*

*Significant wetland* is considered the most sensitive of the shoreline classifications. Under the legal definition, significant wetlands are transitional areas between terrestrial and deepwater habitats that also contain one or more of a number of characteristics including: at least 2,500 sq. ft. of wetland vegetation, adjacent wetlands designated by a federal or state government agency, or plant or animal species that are rare, threatened, or endangered in the state of Indiana. Significant wetlands are often areas that remain largely unperturbed by development. However, they sometimes occur in areas where development has taken place historically but were allowed to recover.

*Natural shorelines* are an equally sensitive and precious resource. According to Indiana's administrative rules, a natural shoreline is considered a continuous stretch of unaltered shoreline where there is at least 250 ft. between lawful permanent structures (i.e., seawalls). Years of unchecked development have left many Indiana lakes nearly devoid of natural shorelines.

Because significant wetlands and natural shorelines are considered to be the most sensitive classifications, they are also the most restricted concerning allowable options for shoreline stabilization. Only bioengineered materials are approvable for use in these areas. This restriction is intended to preserve the quality of habitat and the natural scenic beauty of these areas.

*Area of special concern (AOSC)* is an intermediate shoreline classification. While more developed and typically less sensitive than aforementioned classifications, AOSCs provide some of the functionality of shorelines from the lesser impacted classifications despite having been fragmented or altered in some way. Legally, AOSCs are described as having at least one of the following characteristics: more than 625 sq. ft. of emergent or floating leaf wetland vegetation, a unique habitat identified by the Indiana Division of Nature Preserves, or an altered shoreline where bulkhead seawalls are at least 250 ft. apart. Due to the limited alterations found in the vicinity of shorelines with this classification, natural scenic beauty and habitat are still important considerations. On the other hand, AOSCs are not pristine areas, either. Therefore, the impacts deemed reasonable along shorelines of this type include construction of both bioengineering and glacial stone seawalls.

*Developed areas* are the most highly impacted lakeshore environments. Shorelines of this class are either nearly or completely devoid of wetland vegetation and lie between and in close proximity to bulkhead seawalls. Due to the highly impacted nature of these areas and the low likelihood of natural shoreline recovery, they are deemed least sensitive and offer the most latitude in seawall design. This is the only shoreline classification in Indiana where bulkhead seawalls are permissible. However, installation of softer armoring techniques such as glacial stone seawalls is encouraged where feasible.

Nearly ten years after first being implemented, Indiana's shoreline classification system has proved to be quite successful. Biologists now have a tool to aid them in making consistent permit recommendations. Property owners and consultants have more managed expectations of what type of alterations are permissible prior to submitting applications. Most importantly, the rules hold the line on shoreline development, thus preventing further losses of habitat in our lakes.

Sometimes in our greatest successes we also discover hidden weaknesses. One such inadequacy in the Lakes Preservation Act was discovered following the implementation of the shoreline classification system. Following denial of his application for a bulkhead seawall in a significant wetland, a riparian owner installed a concrete retaining wall two feet landward of the legal shoreline. Because IDNR had no jurisdiction there, no violation had occurred. As time passed, the existing natural shoreline eroded and eventually disappeared altogether, leaving the retaining wall at the water's edge. News of this loophole quickly spread and several contractors began to install retaining walls, sometimes just inches landward of the legal shoreline (Figure 5). In 2006, at the recommendation of the Lakes Management Work Group, a law was enacted giving IDNR jurisdiction below the legal lake level within ten feet of the legal shoreline (Figure 6). This effectively closed the loophole and ended the installation of retaining walls as a means to obtaining a bulkhead seawall.

*Figure 5. An example of a retaining wall installation.*

## Striving for Improvement

While rules and regulations play an important role in resource management, the long-term health of our lakes is equally dependent on the decisions riparian owners make in managing their shorelines. The current construction rules have essentially placed a ceiling on the number of bulkhead seawalls that that can be constructed across the Indiana's natural lake region, but in managing a natural resource, the status quo should never be considered "good enough." As the steward of these public resources, IDNR has sought various ways of improving conditions in our lakes.

One approach involved adopting a new rule that allows a lawfully placed bulkhead seawall to be "refaced" with glacial stone without acquiring a permit from the department. Because the new face of the seawall has characteristics of a more natural shoreline, it benefits the lake. In addition to being far less expensive than replacing an existing seawall, the glacial stone reface rule offers a simplified process as well. Thus, the rule facilitates a more lake-friendly choice by riparian owners. Overall, the idea has been well-received and appears to be growing in popularity. One local lake organization, the Lake Maxinkuckee Environmental Council, has even spearheaded its own effort to encourage its use. Their program collects field stone from area farmers and then distributes it to participants for only the cost of hauling and labor. While just over two years old, the fledgling effort has already resulted in more than

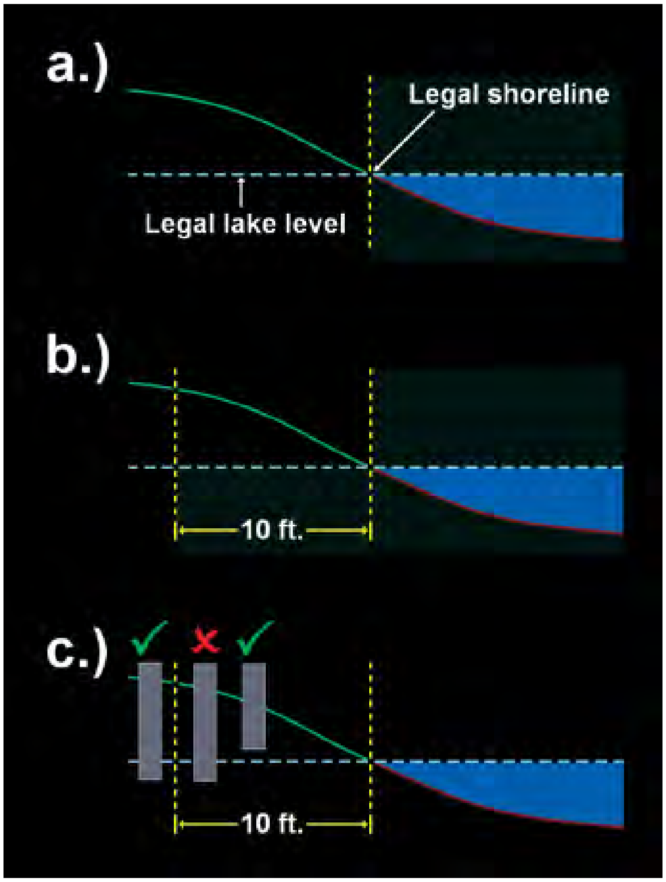


*Figure 6. DNR shoreline jurisdiction (in green cross-hatch) (a) before and (b) after the retaining wall loophole was closed. Examples of one retaining wall that would require a permit and two that would not (c).*

approximately 20 glacial stone refaces covering around a quarter-mile of the Lake Maxinkuckee shoreline.

IDNR has also escalated outreach efforts across the natural lakes region. Biologists frequently appear at meetings to educate lake associations or other stakeholder groups about sound lake management practices. The newest initiative by the IDNR's Lake and River Enhancement Program promotes "lakescaping." Lakescaping is a concept originally developed by Minnesota DNR that encourages use of vegetative buffers to enhance riparian habitat. In addition to providing benefits to the lake, these buffers offer an aesthetically pleasing alternative to traditional landscape design. These are just two examples on ongoing efforts to improve lake habitat by engaging riparian owners at the local level. The key for success in both cases is establishing partnerships with stakeholder groups and equipping them to be the torchbearers for the programs that will benefit the resources they hold dear.

### Better Lakes for Tomorrow

In *A Sand County Almanac*, Aldo Leopold writes, "All conservation of wildness is self-defeating, for to cherish we must see and fondle, and when enough have seen and fondled, there is no wilderness left to cherish." The truth in this statement is troubling, because it reminds us that while we take great pleasure in our lake resources, we also cannot help but to alter their natural character. However, with the increasing environmental awareness of today's society, we're continually learning new ways to reduce our impacts on natural systems. Through innovative thinking and diligent regulatory and educational efforts, we can find the balance between enjoying our lakes today and preserving them for tomorrow.

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# **Calculations** for Successful Planning

Mark. V. Hoyer

## Measuring Bathymetry and Aquatic Plant Abundance for Planning Shoreline Management

### Introduction

Bathymetry is the underwater equivalent to topography. The name comes from the Greek β∝θυς (depth) and μετρον (measure). Therefore, bathymetry is the study of underwater depth in a third dimension. A bathymetric map or chart generally shows floor relief or terrain as contour lines called "isobaths" (Figure 1). A bathymetric map is needed to define the morphology and all major morphometric parameters of a lake that include but are not limited to:

- Surface area – Total area that the surface of the water covers, generally measured with a planimeter and more recently with digitizing software in computers.
- Volume – The volume of a lake is the integral of the area of each stratum at successive depths from the surface to the point of maximum depth.
- Maximum depth – The greatest depth of a lake.
- Mean depth – Generally defined as the volume divided by the surface area.

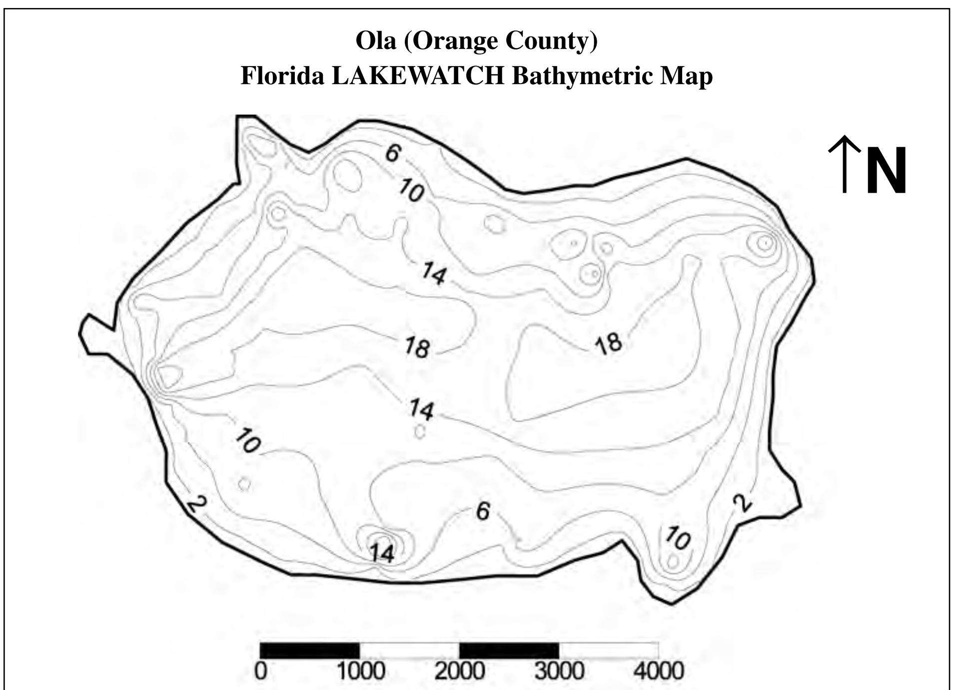


*Figure 1. Florida LAKEWATCH created this map using global positioning equipment (GPS) and a depth sounder. Data were collected on October 10, 2006. Scale and map contours are in feet and were generated using Kriging technique in Surfer, a software package (Golden, CO). The center of the lake is located at Latitude 28°45'16" and Longitude 81°38'56". On this date, the lake surface area was calculated at 461 acres.*

The morphology of a lake basin has important effects on nearly all physical, chemical, and biological functions of a lake. Detailed morphology is also essential for safe navigation on lakes. Additionally, anglers are extremely interested in good bathymetric maps to help locate deep holes and structures that hold fish, hopefully, increasing angling success. Therefore, it is almost essential to create a bathymetric map for work and/or recreation that uses a lake.

Historically, the creation of a bathymetric map was difficult and extremely time-consuming. Equipment that was need included, but was not limited to: transits, planeing tables, sounding lines, boats, calibrated survey chains, compasses, and sextants. In fact, Paul Welch, in his 1948 book entitled *Limnological Methods,* spends over 20 percent of the whole book on how to create a bathymetric map. However, with today's new Global Positioning System (GPS) and electronic depth sounders, the task of creating a bathymetric map is much simpler. Without going into too much detail, GPS units can give a location by using signals from satellites and a receiver that computes the actual location based on the angles and the timing of the signals sent from the satellites to the ground receivers. The accuracy of these positions are even increased from the first GPS systems with the development of WAAS (Wide Area Augmentation Service). WAAS is a system set in place to improve errors caused by atmospheric disturbances, timing and satellite orbit errors generally yielding sub-five-meter accuracy.

Florida LAKEWATCH, a volunteer monitoring program founded in 1986 and currently monitoring over 800 locations (Canfield et al. 2002) has constructed bathymetric maps on almost 300 lakes (http://lakewatch.ifas.ufl.edu). LAKEWATCH also uses this GPS technology to get a good estimate of aquatic plant abundance measured as percent of the lakes area covered with aquatic plants (PAC) and percent volume infested with aquatic plants (PVI, which is a closer estimate of biomass). This technique of estimating aquatic plant abundance follows the pioneering work of Maceina and Shireman (1980). Knowing shoreline morphology and aquatic plants abundances around shoreline areas has been beneficial to many lake associations when developing shoreline management plans. In this paper I will briefly describe the simple and inexpensive methods LAKEWATCH uses to create bathymetric maps and measure the abundance of aquatic plants.

## Bathymetric Maps

There are two main types of data that are required to create a bathymetric map. The first is a good outline of the lake's land water interface in latitude and longitude points. One of the easiest places to get outline data is from aerial photographs that have a reference latitude and longitude that can be used to digitize the whole outline of the individual lake. A good source for this type of information is an individual county's property appraiser's Website. If the county has a sufficient budget, it generally have an excellent collection of aerial photos on its Websites. Figure 2 shows a good aerial photograph from the Orange County, Florida, property appraiser's site where LAKEWATCH was able to create the lake outline for Lake Ola with a digitizing tool offered on the Website. This digitizing tool allowed for the export of each latitude and longitude describing the shoreline to an Excel spreadsheet for future map development.

If an aerial photograph is not available and the lake is small, a hand-held GPS unit can be used to capture the shoreline by simply walking the water land interface. For larger lakes or lakes with a large littoral zone or difficult to walk shorelines, more expensive equipment is needed. LAKEWATCH uses a Trimble Pro XR that combines a GPS with a data logger. The Pro XR allows the user to set a horizontal offset so you can use a boat to circumnavigate the lake, keeping the same distance from shoreline. The data logger compensates the actual shoreline latitude and longitude based on the inputted offset distance. This way, an actual shoreline can be measured quite accurately.

The second type of data needed to create a bathymetric map is latitude (x), longitude (y), and depth (z) data in a grid covering the entire lake. The resolution of the map depends on the density of transects used in the grid, which is generally determined by the amount of time and money available for the job. It is only recently that companies have been building depth finders and GPS receivers into the same unit, so originally LAKEWATCH had to connect a depth sounder with a GPS data logger (Trimble Pro XR) using a standard communication language called NMEA 0183 (National Marine Electronics Association). This allowed simultaneous capture of x, y, and z data that can be used in multiple types of software to create bathymetric maps.

Several company have developed affordable depth sounders that have integrated GPS technology and data logging capabilities making it much easier to capture x, y, and z data for the construction of bathymetric maps.

There are several companies that make depth sounders that incorporate GPS technology, however, LAKEWATCH currently uses a Lowrance LCX-28C HD for creating bathymetric maps. The advantages of this unit include the ability to capture and save, to a removable memory card, the entire screen pictures of the depth transects as a boat runs a grid over a given lake. This facilitates moving data from the depth sounder to a computer for processing. Lowrance also supplies free software called Sonar Viewer (http://lowrance.com/Downloads/SLV/sonar_viewer.asp) that allows the user to export captured data into an Excel spreadsheet. Many different types of software can use these x, y, and z data to create a bathymetric map. LAKEWATCH uses a relatively inexpensive program called Surfer, which creates excellent bathymetric maps like the one of Lake Ola displayed in Figure 1. However, if you wish to geo-reference a map created with data collected using Lowrance equipment, you will have to convert the data to a standard geological position format (i.e., UTM, Lat/Long, etc.), because the positional information is in the Lowrance Mercator Meter format, which is used in all Lowrance units. This conversion is made easy with a small program supplied by Lowrance.

## Aquatic Macrophyte Abundance

LAKEWATCH also uses the Lowrance LCX-28 to measure the percent area covered (PAC) and the percent volume infested (PVI) with aquatic plants. These measurements are extremely important to aquatic plant managers, both for controlling plant problems and increasing habitat for aquatic organisms in areas that have lost aquatic vegetation. To estimate these two parameters you can use the same data that are collected for the construction of bathymetric maps, allowing a lake manager to essentially kill two birds with one stone.

Once all of the depth sounding and GPS data are saved on a removable disk and moved to a computer, each individual transect can be viewed using Sonar Viewer. In Sonar Viewer you can adjust the sensitivity and contrast of the image, just like on the depth-sounding unit, so you can distinguish the lake bottom from aquatic vegetation. For this measurement, ground truthing in the field is essential to make sure that the color you are seeing is actually vegetation and not something else like flocculent sediment. For example, Figure 3 shows one transect from Lake Ola, Orange County, Florida where the bottom is recorded in yellow and the submersed aquatic vegetation shows red. Additionally, there is a tool in Sonar Viewer that allows you to measure the distance from the water surface to the lake bottom and the water surface to the top of the submersed vegetation. Sonar viewer gives each individual sonar reading (called a ping) a observation number. To estimate PAC and PVI, all observation numbers can be randomizing and a sub-sample selected to measure plant presence and absence and plant height in the water column. The size of the sub-sample can vary but generally increases with the size of the lake and is often dependent on the time available for measuring individual observations.

LAKEWATCH generally measures 100 randomly selected observations,

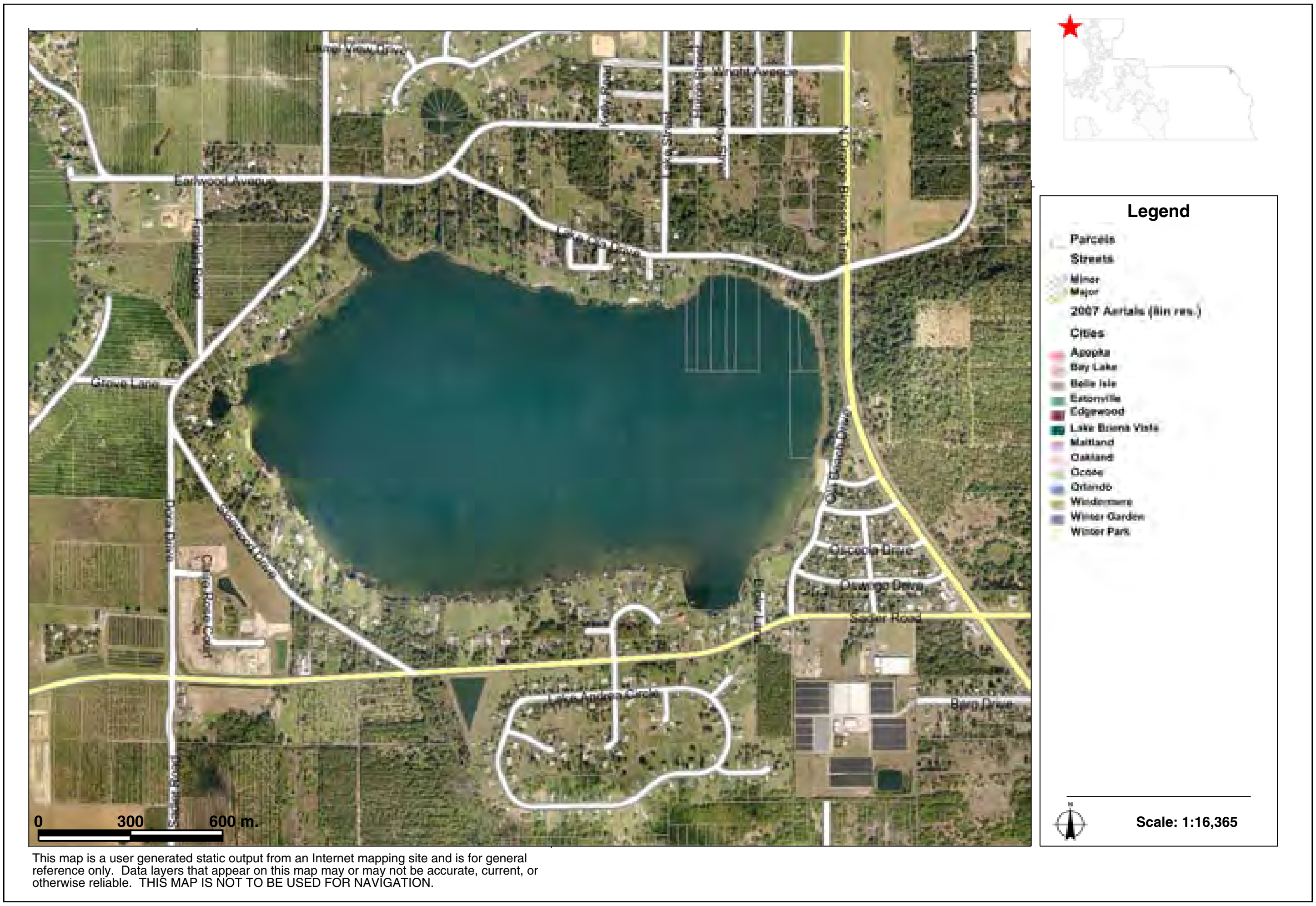


*Figure 2. Aerial photograph of Lake Ola (446 acres) captured from the Orange County, Florida Property Appraisers Web page.*

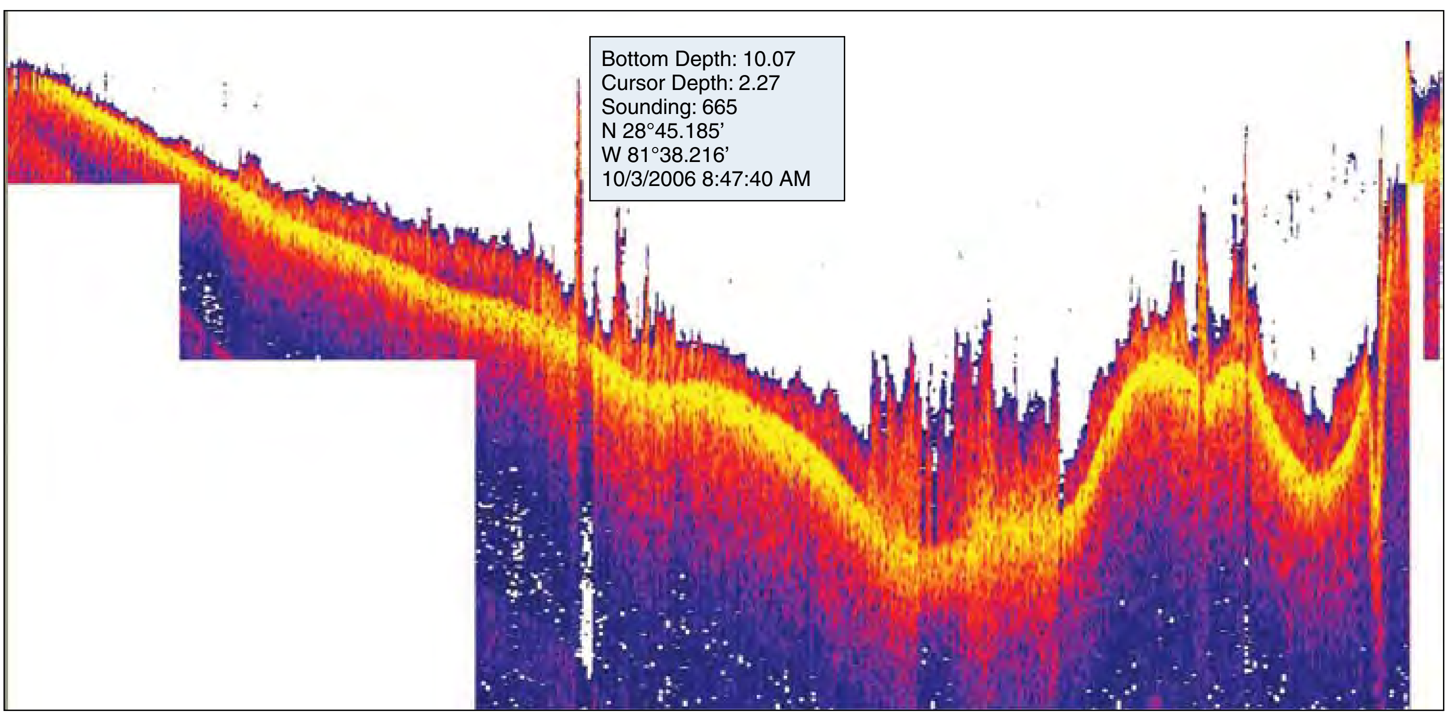


*Figure 3. Depth sounding transect of Lake Ola taken October 10, 2006 using a Lowrance LCX-28CHD. The picture is captured from a computer as the transect is viewed with a program called Sonar Viewer. The hard bottom of the lake is shown in yellow while the submersed aquatic plants show in red above the yellow.*

which takes approximately three hours to accomplish. To calculate PAC, you take the number of observations with submersed plants present and divide by the total number of observations. For Lake Ola, there were 60 observations with aquatic plants present, divided by the 100 observations, giving Lake Ola a PAC of 60 percent. To calculate PVI, you take the sum of all plant heights and divide by the sum of all lake depths. For Lake Ola ,the total plant height was 255 ft and the total lake depth at these observations was 850, yielding a PVI of 30 percent.

## Conclusions

The current price of depth sounders with GPS and data logging capabilities is approximately $1,200, making it a relatively inexpensive way to create bathymetric maps and measure aquatic plant abundance. There is a learning curve that accompanies all of this new technology, especially for those of us who conducted their Master's research using punch cards. Carefully studying the owner's manuals and/or Websites are usually sufficient to help get you started creating bathymetric maps and measuring aquatic plants. Most companies also have technical assistance through e-mail or telephone. As technology increases so does our ability to measure and, hopefully, manage lake and reservoir systems.

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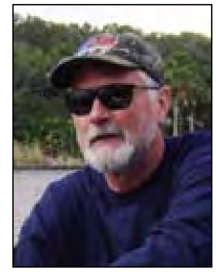


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*Featured Lake*

# Devils Lake, ND

Douglas W. Larson

## A Rising Prairie Sea

In October 2004, I chartered a small plane in Jamestown, North Dakota, to obtain aerial photos of Devils Lake, the largest natural lake in North Dakota and the place where I began my career in limnology 40 years earlier. Back then, in 1964, Devils Lake covered about 30 square miles, had a maximum depth of 10 feet, and held around 145,000 acre-feet of water (Figure 1).

Devils Lake is located 75 air miles directly north of Jamestown. To my amazement, the lake began to appear on the far horizon shortly after we had departed Jamestown Airport and had reached an altitude of about 10,000 feet. My amazement grew as the lake came into full view, its vastness evident by the fact that it now covered more than 200 square miles (Figure 2). As we circled the lake, I searched for the site of our limnological field lab, presumably submerged under 30 or more feet of water. Indeed, the rather unimposing lake that I had worked on during the 1960s had become a rising "prairie sea."

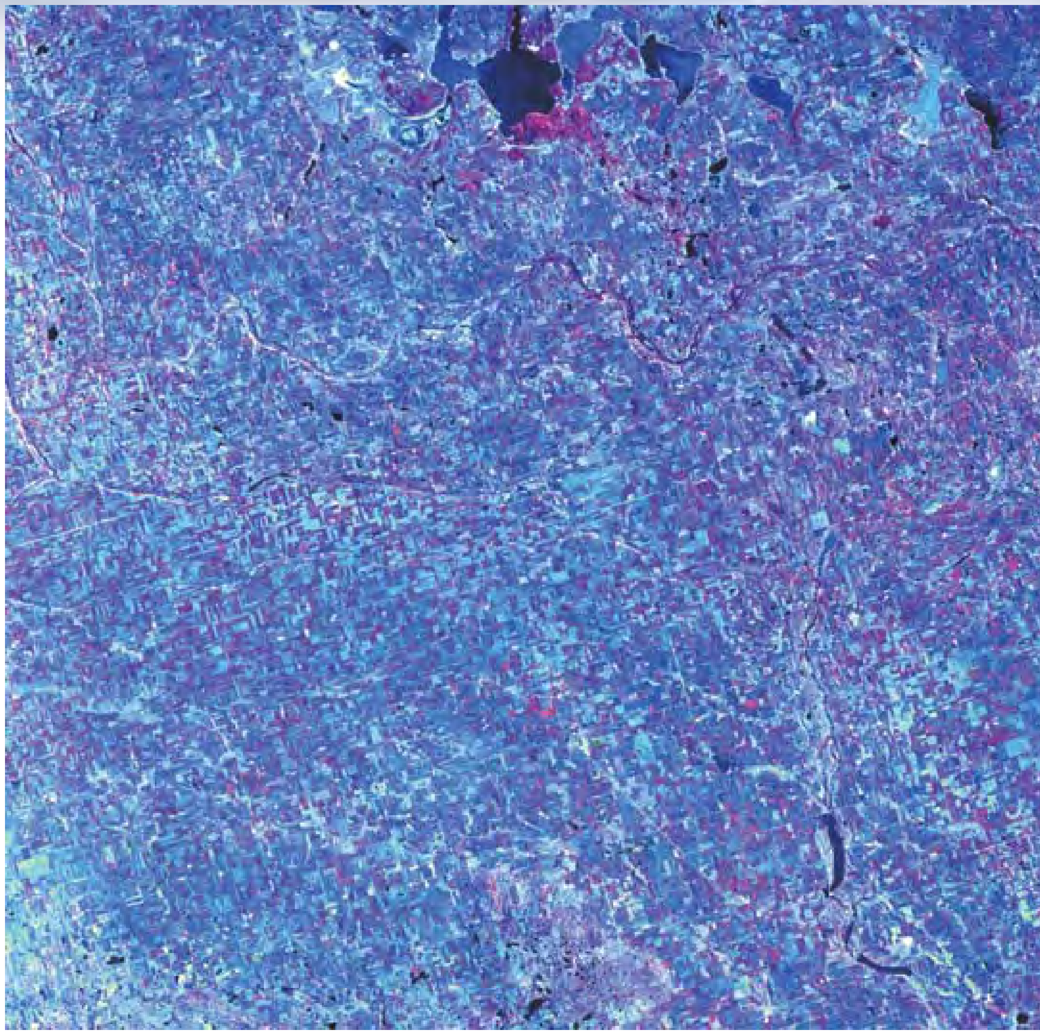

*Figure 1. Landsat color infrared satellite image of Devils Lake, North Dakota, June 1973. The largest and darkest blue body of water is Devils Lake Main Bay. Creel Bay, about three miles long, is the finger-like projection extending directly north from Main Bay. Sixmile Bay branches off along the west side of Main Bay before bending north for several miles. East and West Stump Lakes appear in the far right-hand side of the photo.* Source: EROS, U.S. Geological Survey, Sioux Falls, SD.

### Lake Origin and Lake Rise and Fall . . . and Rise Again

The Devils Lake Basin is a closed basin (endorheic) covering about 3,900 square miles in northeastern North Dakota (Figure 3). The basin was carved from earth and rock by a continental glacier that covered much of North America during the Pleistocene Epoch. As the glacier advanced, excavated materials were deposited along its leading edge, creating a series of prominent ridges or terminal moraines marking the glacier's farthest movement. Roughly 10,000 years ago, as the glacier retreated, its meltwaters gradually filled a portion of the basin, producing a vast proglacial lake dammed by morainal deposits.

Over time, in response to drier and warmer climates, the lake receded periodically, leaving behind abandoned beaches, or strand lines. Based on the location of the highest *remaining* strand line, geologists estimated that the lake originally covered about 435 square miles and reached a surface elevation of about

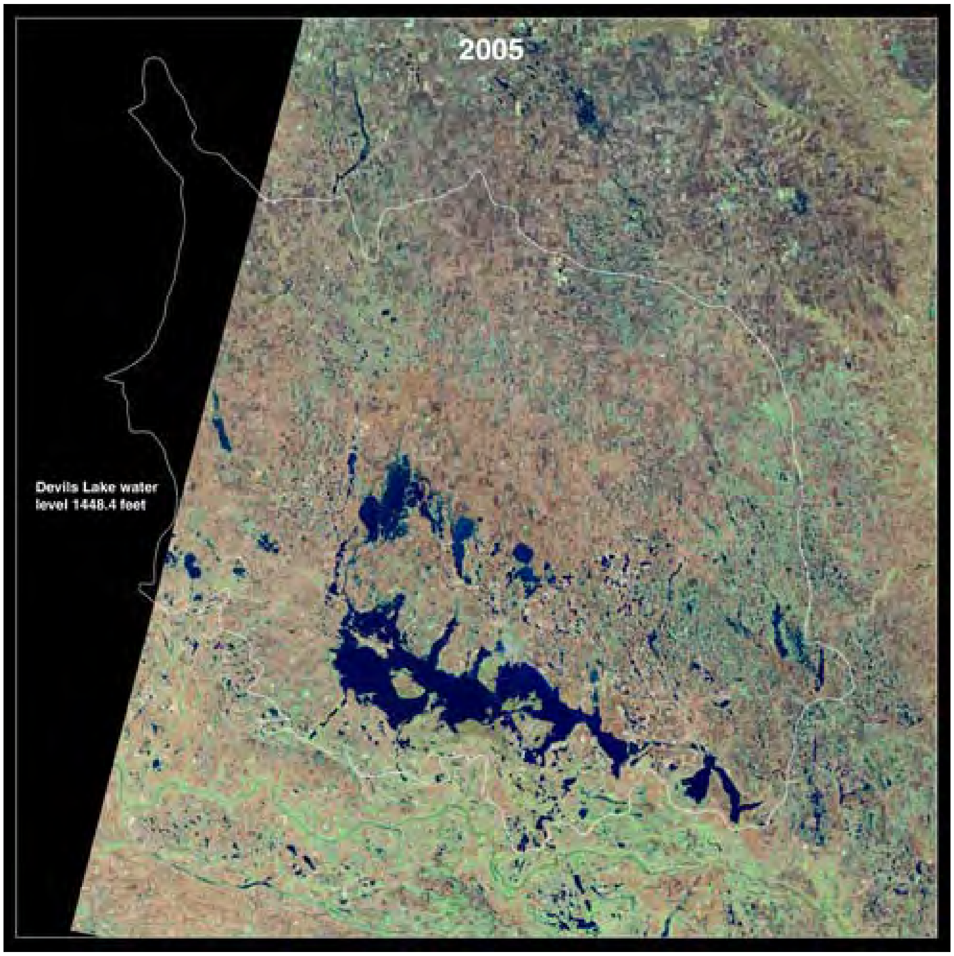


*Figure 2. Landsat natural color satellite image of Devils Lake, North Dakota, April 2005.* Source: North Dakota Water Science Center, U.S. Geological Survey, Bismarck.

1,459 feet above mean sea level (amsl). At this elevation, lake volume would have been roughly 5.3 million acre-feet.

Native Americans called this ancient lake "Minnewaukan," meaning Spirit Water. European settlers renamed the lake Devils Lake in deference to an Indian legend about the drowning of a large party of Sioux warriors whose canoes had capsized in the lake's treacherous storm-tossed waters. Today, what was once Lake Minnewaukan has since been reduced to several remnant lakes – including Devils Lake – scattered across the south-central portion of the basin (Figure 3).

Following the lake's origin, water levels fluctuated roughly 20 to 40 feet *every few hundred years* in response to climate variations. Sediment analyses indicated that the lake may have been completely dry 6,500 years ago (Callender 1968). In 1867, when lake surface elevation was first measured, the lake stood at elevation 1,438 feet amsl, covered about 130 square miles, and contained about 1.5 million acre-feet of water. By 1940, after several years of extreme drought, the lake had diminished even further, dropping to a record-low elevation of 1,401 feet amsl and covering only 10 square miles (Wiche and Pusc 1994).

Since 1940, the lake has exhibited a dramatic resurgence – particularly over the past 15 years – largely in response to a substantially wetter climate (Figure 4). By 2006, the lake had risen nearly 50 feet, reaching its modern-day maximum elevation of 1,449.2 feet amsl on May 9. By then, the lake covered about 240 square miles and contained about 3.3 million acre-feet of water.

The rising lake has flooded a major portion of the Devils Lake region. The town of Minnewaukan (population 318), located eight miles west of the lake in 1992, is now partly under water (Figure 5). Rising lake waters also threaten the city of Devils Lake, a community of about 7,200 inhabitants located on the lake's north shore (Figure 6). The flooding has perhaps given credence to another Indian legend, claiming that the lake once overflowed and flooded the entire world.

## Lake Hydrology and Climate

Devils Lake consists of three principal basins: West Bay, Main Bay, and East Bay. Several smaller bays (Sixmile, Creel, Fort Totten, Mission, and Black Tiger ) indent the shoreline of the combined basins (refer back to Figure 3). In 1964, West Bay was largely dry. Main Bay stood at elevation 1,411 feet amsl and covered about 20 square miles. East Bay, at roughly the same elevation, covered about 11 square miles and was separated from Main Bay by the Rock Island State Military Reservation (reference: 1950 USGS 15' quadrangle maps titled "Camp Grafton, N.Dak." and "Grahams Island, N.Dak."). Pope (1909) estimated that flow from Main Bay into East Bay would have ended when lake surface elevation had fallen to 1,418 feet amsl.

The three basins have since merged along with Pelican Lake to the west and several smaller lakes to the east, including East Devils Lake, Swan Lake, West Stump Lake, and East Stump Lake (refer to Figures 2 and 3). Overflow water from Devils Lake began reaching the Stump Lakes in 1999; the surface elevation of Devils Lake then stood somewhere between 1,446 and 1,447 feet amsl. If Devils Lake were to rise another 12 feet, to elevation 1,459 feet amsl, lake water would begin to flow out of the basin into the Sheyenne River. The Sheyenne River Valley meanders along an east-west line located about 10 miles south of Devils Lake. The river originates about 30 miles west of the lake and flows in a southeasterly direction before joining the Red River of the North near Fargo, North Dakota (refer to Figure 3).

Devils Lake receives nearly all of its surface water runoff from a chain of remnant lakes located a few miles north. These lakes drain into Devils Lake via (1) an intermittent stream flowing out of Lake Irvine through Big Coulee and (2) a manmade drainage canal called Channel A, which connects Dry Lake with Devils Lake's Sixmile Bay (refer back to Figure 3). Surface runoff also enters from adjacent upland terrain, but this is

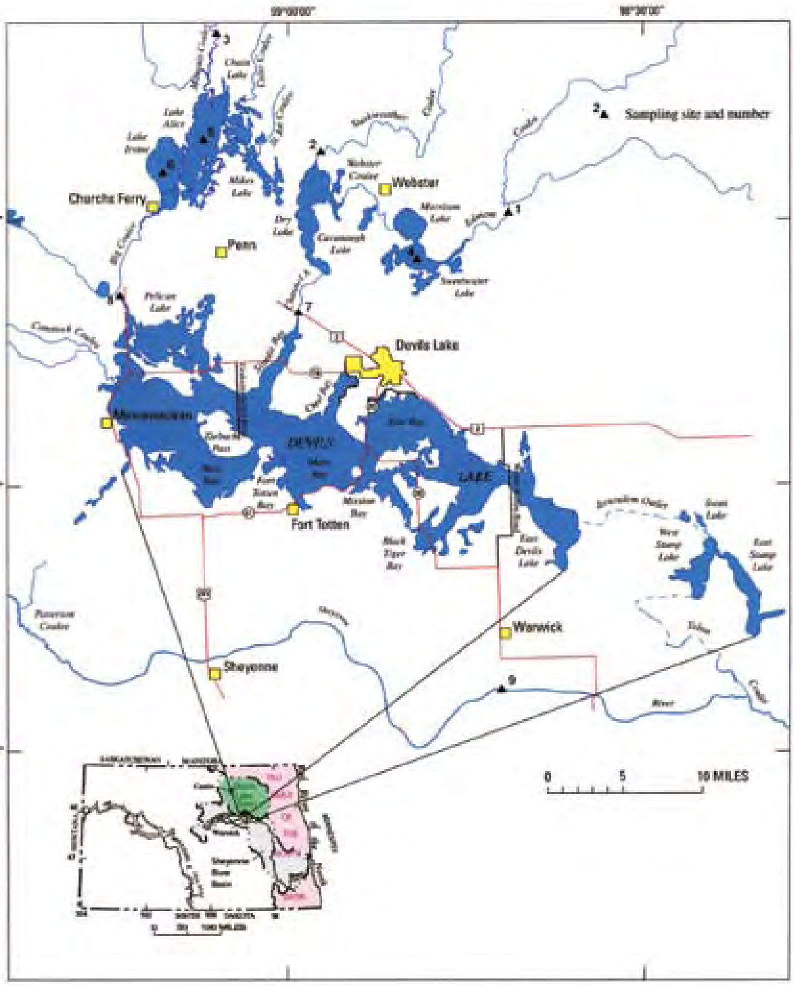


*Figure 3. Map of North Dakota and the remnant lakes of ancient Lake Minnewaukan.* From Wiche et al. 2000.

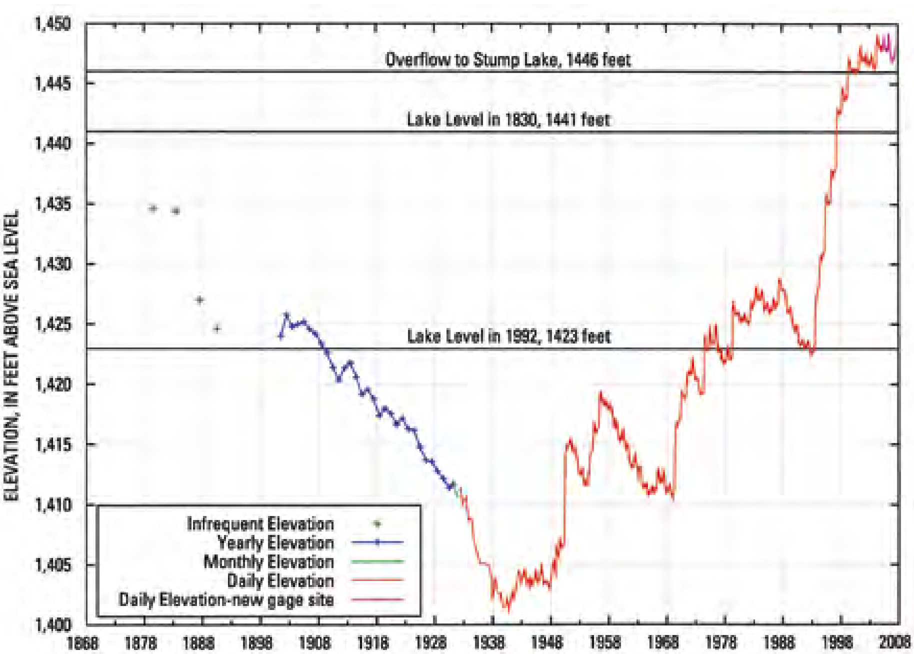


*Figure 4. Surface elevations, Devils Lake, North Dakota, 1879-2008.* Source: North Dakota Water Science Center, U.S. Geological Survey, Bismarck.

a comparatively small source. Overall, surface-water inflow is highly variable from year to year, as indicated by inflow records for years 1986 through 1988 (Table 1).

Devils Lake also receives appreciable amounts of water from direct precipitation, which likewise varies considerably from year to year (Table 1). Precipitation contributed roughly 63 percent of the lake's total inflow in 1986, 31 percent in 1987, and 72 percent in 1988 (Table 1). Moreover, with an increase in lake-surface area, the volume of water received via direct precipitation increases proportionally. Although groundwater volume varies little from year to year, this source contributes only a small percentage of total inflow, averaging 2.4 percent between 1986 and 1988 (Table 1).

Over a longer period of record, total annual inflows ranged from near-zero during the drought-stricken 1930s to nearly 400,000 acre-feet in 1993. Inflows, which had averaged 65,500 acre-feet annually between 1950 and 1993, increased to 317,000 acre-feet annually between 1993 and 2000. Years 1993 through 1995 contributed 24 percent of all inflow to Devils Lake during the period 1950 to 1995 (U.S. Geological Survey 1997).

Lacking a natural surface outlet below elevation 1,459 feet amsl, Devils Lake loses water largely to evaporation. Evaporation removed 86 percent of total inflow in 1986 and 73 percent in 1987. In 1988, the evaporation amount exceeded the total inflow by more than 200 percent, resulting in a net lake-water loss of more than 100,000 acre-feet (Table 1). Some water is lost through groundwater seepage, but the amount is comparatively small. Additionally, to stabilize and hopefully lower lake levels, an emergency outlet channel was constructed and first opened in August 2005. Since then, the outlet has removed about 340 acre-feet of water, representing about one-hundredth of one percent of the lake's total volume. (More information about the outlet follows.)

The climate of the Devils Lake region is typical of the Northern Great Plains. Annual temperatures average between 36° and 42° F, with July temperatures averaging 69° F and January temperatures

*Figure 5. Aerial view of the town of Minnewaukan.* Photo by the author, October 9, 2004.

*Figure 6. Aerial view of the city of Devils Lake.* Photo by the author, October 9, 2004.

averaging 6° F (U.S. Department of Commerce 2002). Bingham and de Percin (1955) reported that the highest and lowest temperatures on record were (and may still be) 112° and minus 46° F, respectively. Precipitation, including 30 inches of snowfall on average, averages 18.9 inches per year, roughly half of which falls during May, June, and July (U.S. Department of Commerce 2002). In an environmental assessment of the Devils Lake region as a possible winter-warfare testing site for the U.S. Army, Bingham and de Percin (1955) described the area as one featuring "severe winters," with climatic conditions resembling those "in Kazan and Chkalovo in the upper Volga River, in Barnaul in south central Siberia, and in Harbin in central Manchuria."

## Endorheic Lake Chemistry

By 1940, Devils Lake had nearly evaporated from the face of the earth. Lake volume then was approximately 37,000 acre-feet, or less than one percent of the volume of Lake Minnewaukan. Anderson (1969) reported that Devils Lake was less than one meter deep, and that most of Creel Bay was dry.

As the lake evaporated, it became increasingly saline. In November 1948, Swenson and Colby (1955) obtained a salinity reading of 25,000 parts per million (ppm as total dissolved solids), the highest recorded value for Devils Lake. By then, in response to improved moisture conditions, lake volume had increased to about 51,000 acre-feet, raising the surface elevation to about 1,406 feet amsl. Since TDS measurements were discontinued between 1923 and 1948, the salinity of Devils Lake during its record-low elevation of 1,401 feet in 1940 is unknown, although it is likely that the lake had become extremely brackish, with TDS values easily exceeding 25,000 ppm. TDS measurements prior to 1923 (n=9) ranged from 8,471 ppm in 1899, when TDS was first measured, to 15,889 ppm in 1920 (Swenson and Colby 1955).

The extraordinary increase in lake volume over the past 15 years has greatly diluted Devils Lake water, although salinity varies considerably throughout the recombined lake system. An upward-trending salinity gradient extends from Pelican Lake at the west end of the Devils Lake complex to Stump Lake at the east end. In 1949, when the lakes were separate bodies of water, Swenson and Colby (1955) reported TDS concentrations of roughly 2,300 ppm in Devils Lake's Sixmile Bay, 13,000 ppm in the lake's Main Bay, 41,000 ppm in East Devils Lake, and up to 106,000 ppm in East Stump Lake. Fifty years later, in 1999, TDS concentrations ranged from less than 400 ppm in Pelican Lake to slightly more than 6,000 ppm in East Devils Lake (Elstad 2002). Overflow waters from Devils Lake had a dilution effect on the Stump lakes, greatly reducing their salinities. By September 2007, when Devils Lake and the two Stump lakes had completely merged, the TDS concentration in East Stump Lake stood at 4,000 ppm (Website data, U.S. Geological Survey), roughly 27 times lower than the TDS concentration in 1949.

Sulfate is the predominant ion in Devils Lake, comprising nearly 60 percent of the TDS load in 1967 (Table 2). Sodium is second, representing 20-25 percent of the total ionic load. The

**Table 1.** Water Budget, Devils Lake, North Dakota, 1986-1988.[1]

| | *1986* | *1987* | *1988* |
|---|---|---|---|
| **Water Gain (Acre-Feet)** | | | |
| Surface Water | 58,100 | 174,000 | 19,700 |
| Direct Precipitation | 102,100 | 77,900 | 59,400 |
| Groundwater | 3,000 | 3,000 | 3,000 |
| Total | 163,200 | 254,900 | 82,100 |
| **Water Loss (Acre-Feet)** | | | |
| Evaporation | 139,700 | 185,800 | 183,700 |
| **Water Stored (Acre-Feet)*** | +23,500 | +69,100 | -101,600 |

*Plus value indicates lake-volume increase; minus value indicates lake-volume decrease.

*Source*: Wiche and Pusc (1994).

**Table 2.** Water Chemistry, Devils Lake, North Dakota, 1919-2001.

| | *1919*[1] | *1949*[4] | *1967*[5] | *2001*[6] |
|---|---|---|---|---|
| Lake Elevation (feet above msl) | 1,416 | 1,406 | 1,413 | 1,448 |
| Total Dissolved Solids, mg/liter | 13,462 | 14,600 | 11,500 | 1,650 |
| Specific Conductance, µmhos/cm | NA[2] | 15,800 | NA | 2,400 |
| Bicarbonate, mg/liter | 458 | 764 | 700 | NA |
| Carbonate, mg/liter | 305 | 66 | 125 | NA |
| Calcium, Dissolved, mg/liter | 70 | 70 | 62 | 67 |
| Magnesium, Dissolved, mg/liter | 844 | 662 | 485 | 82 |
| Sodium, Dissolved, mg/liter | 2,548 | 3,440 | 2,800 | 265 |
| Potassium, Dissolved, mg/liter | 204 | 295 | 268 | 38 |
| Silica ($SiO_2$), Dissolved, mg/liter | NA | 10 | 5 | 9-50[7] |
| Chloride, Dissolved, mg/liter | 1,310[3] | 1,610 | 1,200 | 125 |
| Sulfate, Dissolved, mg/liter | 7,187 | 7,490 | 6,800 | 710 |
| Iron, Dissolved, µg/liter | NA | 160 | 3,300 | <1 |

[1] *Source*: Young (1924).
[2] Not Available.
[3] Reported as "chlorine."
[4] *Source*: Swenson and Colby (1955); mean of 20 samples collected June 18.
[5] *Source*: Anderson (1969); data from samples collected in June; values derived from time-series plots.
[6] *Source*: U.S. Geological Survey; values derived from time-series plots.
[7] Range of values between 1990 and 1992.

percentile composition of major ionic components remained fairly constant between 1911 and 1948 (Swenson and Colby 1955), and again between 1948 and 1967; this indicated that evaporation and not other factors (e.g., geothermal saltwater intrusions) accounted for the lake's increased mineralization (Anderson 1969). The calcium percentage has increased, inexplicably, since 1967, while percentages for sulfate, chloride, and sodium have decreased (Table 2).

## Disappearance of a Commercial Fishery

European settlement of the Devils Lake region began in earnest following the establishment of a U.S. military outpost called Fort Totten on the south shores of Devils Lake in 1867. Settlers soon discovered that the lake offered a variety of water-resource benefits. Beginning in 1883, a side-wheel steamer christened the *Minnie H.* (Figure 7) plied the waters of Devils Lake carrying cargo and passengers between lakeside towns and other settlements. As the lake continued to recede, however, steamboat travel became increasingly risky as shoals and other underwater hazards developed in an ever-shrinking lake. By 1907, the lake had shoaled from its 1883 maximum depth of 35 feet to a depth of 25 feet in 1907. The *Minnie H.* was finally retired in 1909, replaced by railroads and other faster, more efficient, and, perhaps, safer forms of transportation.

According to early settlers, "swarms" of northern pike inhabited Devils Lake. The abundance of these fish, identified as *Esox lucius* (Young 1924), led to the development of a commercial fishery. During the 1880s, tens of thousands of pike were harvested annually and shipped by railroad to Minneapolis, Chicago, and other large Midwestern cities. The once-prodigious fishery finally disappeared by 1905, its demise attributed to one or more possible factors including overfishing, loss of spawning grounds by agricultural land-use, disease, parasites, suffocation during prolonged lake ice cover (winter kill), and intolerance to high salinity (Young 1924). Among these, high salinity was thought to be the chief contributing factor to the lake's declining fishery (Young 1923, 1924). Salinities in Devils Lake's Main Bay increased from 9,448 ppm in 1907 (Pope 1909) to 14,452 ppm in 1918 (Nerhus 1920). Salinities of 18,000 ppm will kill northern pike, although salinities down to 7,000 ppm can "reduce or prevent spawning." (Scott and Crossman 1973). By 1924, only the salt-tolerant brook stickleback (*Culaea inconstans*) could be found in Devils Lake (Young 1924). Although this species can tolerate salinities up to 17,500 ppm, it becomes increasingly inactive as salinities approach 25,000 ppm (Scott and Crossman 1973).


*Figure 7. Steamboat* Minnie H. *at boat landing for Chautauqua, Devils Lake, North Dakota, date unknown.* Source: State Historical Society of North Dakota, Bismarck.

## The North Dakota Biological Station

Despite the disappearance of fish and other aquatic life in Devils Lake, Pope (1909) and other scientists believed that the lake's once-thriving and well-balanced ecosystem could be reclaimed. Although they admitted that pike and other game fish would probably continue to perish in the lake's increasingly saline waters, they argued that the lake's "alkaline salts" were "not necessarily prohibitive to the acclimatization of certain species of fish." (Swenson and Colby 1955). To prove their point, they began conducting experimental fish introductions in 1908, stocking the lake with chiefly yellow perch (*Perca flavescens*), but even these fish failed to survive (Young 1924).

In 1909, while efforts continued to restore the fishery and study the unusual brackish-water ecology of North Dakota's largest natural lake, the North Dakota Legislature authorized the construction of the North Dakota Biological Station at Devils Lake. The facility – a spacious, two-story structure (Figure 8) – was located along the east shore of Creel Bay. Several prominent scientists from across the United States spent time at the station conducting research or observing field and lab procedures. These scientists included Chauncey Juday – a "founding father" of limnology in North America – and C.H. Edmondson of the University of Oregon, who studied the lake's protozoans. E.A. Birge, another "founding father" from the University of Wisconsin, identified crustaceans and provided advice on limnological methods and apparatus. In 1923, the station was closed after the North Dakota Legislature failed to appropriate operating funds. The North Dakota Game and Fish Department used the station as a research laboratory until 1931 when it was turned over to the Devils Lake Park Board. The Park Board then passed the station on to the Devils Lake Jaycees, a civic organization, who used the building as a clubhouse until it was finally abandoned during the 1950s.

## The Life of Devils Lake: 1924

Following the station's closure, R.T. Young, a biology professor at the University of North Dakota and the station's director, published a book (Young 1924) titled *The Life of Devils Lake, North Dakota* [*author's note: I have an original copy*]. Young's book, a milestone treatise on the limnology of Devils Lake, covered station research between 1909 and 1923. Young generally described the lake's biota as a relatively sparse flora and fauna consisting of many species well-adapted to brackish waters. In addition to sticklebacks being the only fish in Devils Lake, Young reported that the lake contained no reptiles and only two amphibians: *Rana pipiens,* the pickerel frog, and *Ambystoma tigrinum*, the tiger salamander. Bishop (1962) referred to Devils Lake as the type locality for *Ambystoma tigrinum diaboli* Dunn, also called the Devil's Lake tiger salamander.

*Figure 8. Researchers with equipment at the North Dakota Biological Station, circa 1914. In March 1995, as rising lake waters threatened to engulf the building, the upper half of the structure was lifted off the lower rock walls and moved to higher ground on the lake's south shore. Purchased by a private party, the building was restored and converted to a family residence.* Photo taken by J.V. Harrison of Devils Lake, North Dakota.

Among invertebrates, protozoans were most diverse (106 species), followed by rotifers (31 species), nematodes, or roundworms (9 genera, one species), cladocerans (11 species), copepods (9 species), and hydracarina, or water mites (4 or 5 species). Other invertebrates included a planarian, or flatworm (*Gyratrix hermaphroditus*), a gastrotrich (*Chaetonotus maximus*), an ostracod, or seed shrimp (*Cypris pellucida*), and an amphipod, or scud (*Hyalella azteca*). Among rotifers, two species (*Brachionus satanicus*, *Pedalia fennica*) occurred periodically in "great numbers." Rotifers *Brachionus satanicus*, *B. spatiosus*, and *B. pterodinoides* were described by Young as new species. Cladocerans occurred "infrequently," while copepods were extremely abundant; Young observed that a large area of the lake was once "literally colored red" by "great masses" of the copepod *Diaptomus* sp.

Although aquatic insects had been collected between 1909 and 1923, insect identifications and life-history research had not yet been completed when Young published his book. He reported that knowledge about Devils Lake insects in 1924 was "only a beginning." Generally, insect species in Devils Lake were relatively few, but most of those were highly prolific. Chironomids, or midge flies (*Chironomus* sp., *Protenthes* sp.) greatly predominated the insect fauna, their summertime abundance described as "evening swarms that fill the air." Other dipterans included soldier flies, horseflies, deer flies, and flower flies ("rat-tailed maggots"). Among beetles, six genera and two species had been identified. Dragonflies and damselflies consisted of "several species," none of which were listed. Water boatmen (Corixidae) and back swimmers (Notonectidae) were second to midges in abundance. Among caddis flies, *Limnephilus rhombicus* was the most common.

Invertebrates *not* found included porifera (sponges), coelenterates (hydroids, jellyfish), nemerteans (proboscis worms), annelids (aquatic earthworms, leeches), or bryozoans (moss animalcules). Among insects, stoneflies (Plecoptera), mayflies (Ephemeroptera), spongilla flies (Neuroptera), and aquatic caterpillars (Lepidoptera) were also absent. The lake was devoid of living mollusks (snails, clams, mussels), although the shoreline was littered with "large numbers" of snail and mussel shells, described by Young as "remains of a former fresh-water fauna."

Lake algae were dominated by blue-greens (41 species) and diatoms (80 species). Chlorophyta (grass-green) species numbered 35. Three blue-greens (*Coelosphaerium kuetzingianum*, *Nodularia spumigena*, *Lyngbya contorta*) were the most common algal species. Among the diatoms, 46 species were described as freshwater types, four species as brackish types, and four species as "marine" or seawater types. The remaining species were euryhaline, able to tolerate a wide range of salinities. Two new diatoms were discovered and named *Navicula minnewaukonensis* and *Chaetoceros elmorei*. A filamentous alga, *Cladophora* sp., formed "extensive masses" throughout the littoral zone. Widgeon grass (*Ruppia maritima*) was described as the lake's "only flowering plant of importance." In 1916, however, due to an influx of "an abundant supply of fresh water," sedges (*Cyperus* sp.) and rushes grew profusely across a wide expanse of rehydrated old lake bottom.

## The Garrison Diversion Project

In December 1944, Congress passed the Flood Control Act of 1944, which included the Pick-Sloan Plan to divert water from the Missouri River to irrigate drought-stricken farmlands in eastern North Dakota. Passage of Pick-Sloan authorized the U.S. Army Corps of Engineers to construct Garrison Dam on the Missouri River and the U.S. Bureau of Reclamation to develop a system of irrigation canals and intermittent water-storage reservoirs (Figure 9). The plan, renamed the Garrison Diversion Project, called for diverting a portion of water through a permanent feeder canal into Devils Lake to "deepen, flush and desalinate the lake for recreation." Diversion would raise surface elevation to 1,425 feet amsl (Figure 10) and increase surface area to about 80 square miles. Desalination – resulting in a reduction in the lake's TDS concentration from about 25,000 ppm to about 900 ppm – would require 10 to 12 years to achieve, assuming that 180,000 acre-feet of water having a TDS concentration of 800 ppm was diverted to Devils Lake annually (Swenson and Colby 1955).

Considerable opposition to the Garrison Diversion Project eventually developed, particularly from environmental organizations and the Canadian government. In 1973, Canada sent a diplomatic note to the U.S. State Department requesting an "immediate stop" to Garrison construction, claiming that the project would violate the 1909 Boundary Waters Treaty by polluting the waters of the Souris and Red rivers which flow into Canada. Although partly built at a cost of more than $1 billion, the project – derided as the "last of the Dust Bowl relics" – was finally shelved in the late 1980s due to funding and environmental constraints. Nature has since more than compensated for the project's grand design for Devils Lake.

## Reopening of the Biological Station and Resumption of Limnological Research

While Garrison Diversion was being planned during the early 1960s, the University of North Dakota received substantial funding from the Office of Water Resources Research, U.S. Department of the Interior, to determine how and to what extent diversion of Missouri River water would possibly affect the limnology of Devils Lake. A second objective was to determine the limnological impacts of untreated sewage, which the City of Devils Lake had discharged into the lake between 1924 and 1958. Staff and graduate students representing the departments of biology, geology, and microbiology formed an interdisciplinary team to study the lake. The biological station, dilapidated after years of neglect, was restored and outfitted with living quarters and laboratory facilities to accommodate field scientists. Research got underway in 1964 and continued until the early 1970s when funding ended and the biological station was again closed.

Limnological surveys indicated that the lake's biota had changed little between 1924 and 1964. In addition to the brook stickleback, the only other fish species present was the fathead minnow (*Pimephales promelus*), also capable of tolerating salinities exceeding 10,000 ppm. Northern pike (*Esox lucius*) had

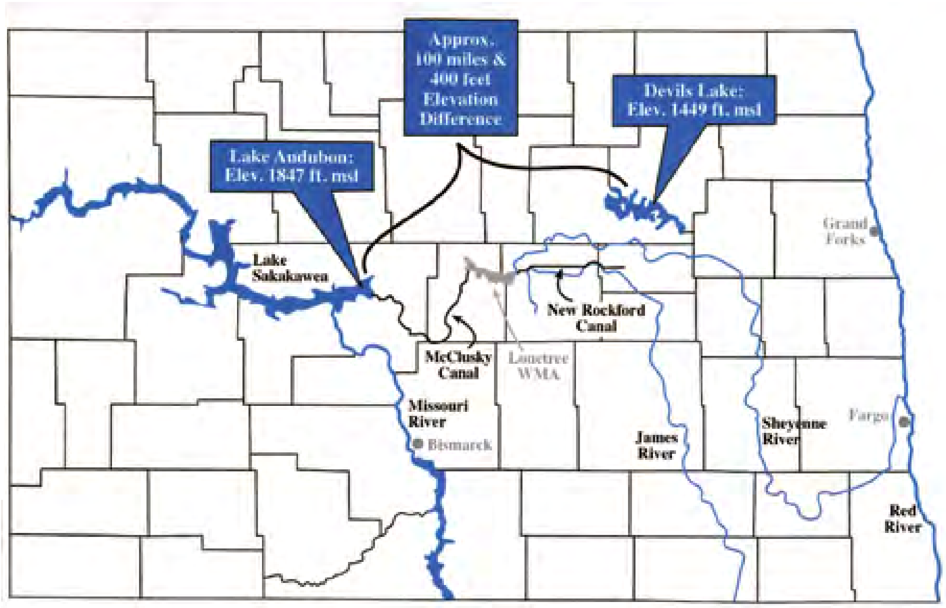


*Figure 9. Map of the Garrison Diversion Project, North Dakota. Garrison Dam impounds Lake Sakakawea. S*ource: North Dakota State Water Commission, Bismarck.

*Figure 10. Post marker showing surface elevations of Devils Lake between 1870 and 1910. Elevation 1,425 feet amsl represents lake level under the Garrison Diversion Project. Elevation of Devils Lake (in background) when photo was taken (July 1966) was about 1,413 feet amsl.* Photo by the author.

been stocked in the lake by the North Dakota Game and Fish Department beginning in 1956 (1.3 million fingerlings introduced between 1956 and 1969), but this species could not be sustained until the late 1960s (Hiltner 2003), possibly due to high salinity during ice-cover (Scott and Crossman 1973).

The lake's amphibian assemblage remained at two species, the pickerel frog and the tiger salamander. Salamander larvae were mostly neotenic and relatively large, ranging in total length from 7.6 to 15.2 inches (mean=10.1 inches, n=517). Larvae were also extremely abundant: In October 1964, nearly 6,000 individuals were trapped in a single hoop-net apparatus set for 72 hours in Creel Bay (Larson 1968). The prevalence of neotenic larvae was attributed, hypothetically, to the lack of density-dependent factors such as predation and interspecific competition (Larson 1968). During the late 1960s, however, as highly predaceous northern pike became reestablished in the lake, salamander larvae probably became major sources of prey.

Invertebrate studies focused on crustaceans and insects. Among zooplankton, copepods greatly outnumbered cladocerans, with copepods dominated by *Diaptomus sicilis* and cladocerans by *Moina macrocopa*. Rotifers were comprised of "several" species, two of which (*Brachionus satanicus*, *Pedalia fennica*) were most common (Anderson 1969). Amphipods included *Hyalella azteca* and *Gammarus pseudolimnaeus*. Chironomids completely dominated the macrobenthic fauna; nine chironomid species comprised over 98 percent of the macrobenthic organisms in the sublittoral zone, and over 90 percent in the littoral zone. Among chironomids, *Tanypus nubifer* was most abundant (95 percent of total organisms), followed by *Chironomus decorus* (4 percent). The maximum density of *T. nubifer* (25,324 individuals/meter$^2$) attested to the prodigious production capacity of chironomids in Devils Lake, particularly in Creel Bay where 34 years of untreated sewage disposal greatly enriched sediments with organic matter and nutrients (Knauss 1970).

Despite high production by chironomids, phytoplankton primary production (ppn) in Devils Lake was indicative of a mesotrophic system. Mean annual productivity over a three-year period (1966-1968) ranged from 420 to 800 mg C/meter$^2$/day (Anderson 1969), roughly within the mesotrophic range (210-729 mg C/meter$^2$/day) cited by Wetzel (1983, pages 398-399). But Anderson (1969) also reported a maximum ppn rate of 5,140 mg C/meter$^2$/day, which, according to Wetzel's classification, would have easily qualified Devils Lake as eutrophic.

Heavy growths of filamentous algae, *Cladophora glomerata* and *Enteromorpha prolifera*, clogged near-shore waters in Creel Bay (Figure 11). Dense clusters of *Ruppia maritima* (widgeon grass) and *Potamogeton pectinatus* (sago pondweed) occurred intermittently along the lake's entire beaches (Knauss 1970).

*Figure 11. Dr. David Anderson, University of North Dakota, displays mass of filamentous algae in Creel Bay near the biological station.* Photo by the author, August 15, 1968.

In winter, extremely low air temperatures (typically -20° F and lower) produced surface ice layers that were 3 to 4 feet thick. Freezing caused lake-water salts to concentrate, resulting in TDS concentrations ranging between 16,000 and 18,000 ppm. When ice-free, the lake was considerably less saline; summertime TDS concentrations were usually around 12,000 ppm (Anderson 1969).

## The Life of Devils Lake: 2004

By 2004, Devils Lake was about 35 feet deeper, more than five times larger in area, and nearly 10 times less saline than it had been in 1924. Elstad (2002) described the lake as "hypereutrophic" because of substantial nutrient enrichment causing "prolific" blue-green algal blooms. Between 1995 and 2001, sample concentrations for total phosphorus ranged between 180 and 950 micrograms/liter (parts per billion), with the highest value falling well within the range cited by Wetzel (1983, page 293) for hypereutrophic lakes. Sample concentrations for chlorophyll-*a* (10-30 micrograms/liter) were more typical of eutrophic lakes (3-78 micrograms/liter on Wetzel's scale).

Agricultural runoff (fertilizers, animal wastes) was and still is a major source of nutrient loading, particularly during spring snowmelt; approximately 88 percent of the Devils Lake watershed is used for agricultural (Hiltner 2003). Other nutrient sources include wastewater from sewage stabilization ponds and nutrients released from agricultural lands inundated by rising lake waters.

Devils Lake is currently the "number two" fishery in North Dakota (Hiltner 2003), second only to giant Lake Sakakawea behind Garrison Dam on the Missouri River. The lake is known locally as "the perch capital of the world." Since 1956, the North Dakota Game and Fish Department has stocked the lake with nearly 65 million fish, mostly fingerlings. Roughly 68 percent of these fish were wall-eyed pike, followed by yellow perch (18 percent), and northern pike (14 percent). Other species introduced included muskellunge (228,000), striped bass (13,000), black crappie (4,500), and about 600 white bass (Hiltner 2003).

## Flood Control

As it expanded, Devils Lake inundated thousands of acres of valuable agricultural land, dozens of farmsteads, three state parks, miles of paved highways and roads (Figure 12), railroad tracks (Figure 13) and an estimated half-million trees (Figure 14). As many as 400 rural families were forced to move their homes away from steadily advancing lake waters. Several farmsteads were left stranded on an island created by the rising water. Residents in the town of Minnewaukan, who once viewed the lake from a considerable distance, now found themselves at the water's edge (refer back to Figure 5).

To protect the city of Devils Lake from the encroaching lake, the Army Corps of Engineers designed and constructed a $50-million dike during the 1990s that stretches for about seven miles along the southern and western edges of the city (Figure 15; also refer back to Figure 6). The dike, consisting of gravel and clay overlaid by boulders (Figure 16), was built to an elevation of 1,457 feet amsl. The Corps of Engineers certified that the dike would provide flood protection to a lake level of 1,450 feet amsl. But as the lake continued to rise, reaching elevation 1,449.2 feet amsl in May 2006, the Corps raised the dike's crest another three feet, to elevation 1,460 feet amsl, at a cost of about $8 million. If the lake were to rise above elevation 1,454 feet amsl – the current level of protection – the dike would need to be raised further. Relief would finally come at elevation 1,459 feet amsl when the lake would begin draining naturally into the Sheyenne River, an event that has occurred only three times over the past roughly 4,000 years.

Plans were also made to slow or halt the lake's continued rise by drawing it down. In 2001, the North Dakota Legislature authorized the construction of an emergency outlet through which water would be pumped from Devils Lake into the Sheyenne River. Given the cost of the outlet project ($185 million based on estimates by the Corps of Engineers), North Dakota officials decided that the State of North Dakota should build the outlet, albeit a considerably downsized, and thus cheaper, version than the one recommended by the Corps.

Like the Garrison Diversion Project earlier, the Devils Lake outlet plan was controversial. Proponents of the project estimated that the outlet, under a "wet scenario," would remove about 170,000 acre-feet of water over a ten-year period, resulting in a total drawdown of about 17 inches. Other estimates were more optimistic, claiming that the drawdown could be as much as four inches per year. Outlet opponents disagreed, arguing

*Figure 12. Aerial view of Devils Lake's West Bay. The town of Minnewaukan appears in the upper left-hand corner of the photo. U.S. Highway 281 proceeds north out of Minnewaukan and crosses the west end of the lake before intersecting with State Highway 19 and continuing north. U.S. Highway 281 was kept open by raising the roadbed and riprapping its shoulders. The highway was later relocated farther west, away from the lake.* Photo by the author, October 9, 2004.

*Figure 13. Tracks of the former Northern Pacific Railway lie partly submerged along the north shore of Devils Lake.* Photo by the author, October 6, 2004

that the lake would continue to rise if inflows like those measured between 1993 and 2000 (averaging 317,000 acre-feet annually) recurred.

Opponents also argued that lake waters discharged through the outlet could introduce potentially harmful biota (microorganisms, invasive species) and pollutants (agricultural pesticides, herbicides, organic wastes) downstream into the Sheyenne River. Contaminants would eventually reach Canada, via the Red River of the North, which empties into Manitoba's Lake Winnipeg.

Fearing environmental damage to their waters, the Canadian government, the State of Minnesota, and nine other states that border the Great Lakes stood opposed to the outlet. In July 2003, then U.S. Secretary of State Colin Powell wrote a letter to various federal agencies discussing "unresolved environmental concerns" involving the 1909 Boundary Waters Treaty between the U.S. and Canada (*Grand Forks Herald*, August 26, 2007). Despite intensive lobbying by the Canadian Government and others, along with two legal challenges, the Bush Administration and the U.S. Congress refused to block the project. A non-binding agreement was finally reached between the Canadian government and the U.S. to build the project, although Canada required that the outlet be equipped with a filter to prevent harmful biota and pollutants from entering the Sheyenne River. Although Canada agreed to pay $25 million for a sophisticated sand filter, the State of North Dakota installed a simple rock filter costing $50,000. The effectiveness of the filter would later be questioned.

Construction of the outlet was completed during the summer of 2005 at a cost of nearly $30 million. Yearly operational costs were estimated at $800,000. Since the outlet was not a federal project, an environmental impact statement was not required. When possible, water is pumped at the rate of 100 cubic feet per second through a 14-mile-long outlet channel that empties into the Sheyenne River. The channel's intake is located near the town of Minnewaukan (refer back to Figure 3).

The outlet began operating in August 2005. Outlet pumps operated for 11 days in August 2005, discharging about 38 acre-feet of water before the project was shut down for the remainder of the year. In 2006, the outlet was shut down for the entire year because sulfate concentrations in discharge waters (600-800 ppm) violated North Dakota's pollution discharge permit for sulfate set at 450 ppm. In 2007, the outlet was operated for about a month, discharging about 300 acre-feet of water.

## Concluding Remarks

Young (1924) predicted that Devils Lake would "probably disappear during the next forty or fifty years," assuming that climatic conditions of the 1920s would continue. But the lake was nearly gone after only 16 years and would have

*Figure 14. Aerial view of State Highway 57 (SH57), which extends from upper right-hand corner of photo to an island in the lower left-hand corner. SH57 separates Main Bay (left side) from East Bay (right side). Spirit Lake Casino and Resort, complete with boat marina and wastewater stabilization ponds, occupies the island. Portions of the island's forest are partly submerged offshore. State Highway 20 extends from lower right-hand corner of photo to junction with SH57. Sixmile Bay is visible at top of photo. Creel Bay extends north from Main Bay.* Photo by the author, October 9, 2004.

*Figure 15. Aerial view of the City of Devils Lake and the protective dike.* Photo by the author, October 9, 2004.

disappeared completely had it not been for a slow but steady improvement in North Dakota's moisture conditions beginning in 1941. In 1974, 50 years after Young's dire prediction, Devils Lake had instead risen about seven feet – to elevation 1,423 feet amsl – and covered about 71 square miles, nearly twice the area it had covered in 1924. Few would have predicted what the lake has become over the past 30 years, a rising prairie sea that has flooded not the entire world – but a sizeable portion of northeastern North Dakota.

*Figure 16. Protective dike, ground level.* Photo by the author, October 6, 2004.


## Acknowledgments

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**Douglas W. Larson** is an independent scientist and writer in Portland, Oregon. He worked on Devils Lake as a limnologist between 1964 and 1967, studying salamander neoteny and chironomid production and emergence relative to the lake's nitrogen budget.



Next Issue – Summer 2009

***LakeLine***

The theme of the summer 2009 issue of *LakeLine* is "Cyanobacteria Toxins."

The next issue of *LakeLine* will explore innovative state programs that address this public health threat. We'll also consider the role that NALMS can play in promoting cyanotoxin science and policy.

# *Affiliate* News

## Indana Lakes Conference 2009 Builds Partnerships with Fisheries Professionals

The 2009 Indiana Lakes Management Conference opened with a new twist – a joint meeting of the minds between the Indiana Lakes Management Society and the Indiana Chapter of the American Fisheries Society. This joint effort was the first endeavor to build camaraderie between the groups' members, allowing both societies to gain valuable information and share insight into Indiana's many lake management issues. The aquatic resources conference was held January 29-31 at the Sheraton City Centre in downtown Indianapolis and not even record snowfall in Indianapolis could keep attendees away.

The program opened with a plenary session focused on the National Fish Habitat Action Plan (NFHAP). Five presentations detailed the complexity of the NFHAP, including an overview of the planning process in light of the importance of habitat and fisheries conservation; a review of the two phases in which Indiana is participating – the Midwest Glacial Lakes Partnership and the Ohio River Basin Fish Habitat Partnership; and a discussion and review of the variety of fish habitats available throughout the United States and, thus, the variety of data required to assess these habitats. Thursday's program concluded with separate business meetings for each society and an exhibitor reception.

During ILMS' business meeting, out-going President Ron Bedwell described ILMS' efforts during the past year including numerous workshops, the joint conference, and the launching of ILMS' marina outreach program. The gavel was passed to new officers, with Ed Spanopoulos elected as the new president and Sara Peel elected as the new vice president. With their previous positions open, Eileen Boekestein was appointed secretary, while Carrie Pintar was appointed as the new treasurer. Congratulations to elected board members: Angela Sturdevant, Nate Long, Heather Buck, Laura Esman, Jed Pearson, and Ed Sprague!

Concurrent sessions occurred throughout Friday with a total of 40 presenters covering a variety of fisheries and water quality related topics. The fisheries technical session focused on fish species diversity, naturalization, and hybridization within both lake and stream communities. Additionally, the impacts of glaciation, low oxygen concentrations, and hydrologic alternations on fish communities throughout Indiana were also discussed.

Concurrent with these topics were presentations focused on resources available for individual lake and watershed management, watershed and shoreline management practices, and lessons learned from the 2008 flooding events. Morning presentations by Katie Hodgdon from the Natural Resources Education Center, Bob McCormick from Planning with POWER, Eileen Boekestein with Kosciusko County Lakes and Streams, and Lyn Crighton from the Tippecanoe Watershed Foundation provided attendees with practical information that they could use with their lake and watershed. This session included information on raising money, the importance of planning, the availability of information and resources, and a look at the future of invasive species.

The afternoon sessions covered on-the-ground implementation efforts like Indiana Wildlife Federations' Backyard Certification Program, conservation practices with which the NRCS can assist individuals and groups, shoreline protection efforts from the DNR, and looks at two specific on-going efforts to reduce shoreline impacts to Clear Lake in Steuben County and Prairie Creek Reservoir near Muncie.

The final two sessions of the day included a look at water quality monitoring and assessment tools and a review of aquatic plant management efforts throughout the state.

Hands-on learning through workshops was the focus of Saturday's program. In total, four workshops occurred on Saturday morning: two focused on shoreline plant and fish identification and two focused on water quality management and goal setting. All four workshops provided attendees with detailed information usable with their association or management efforts.

In total, 187 individuals attended this three-day conference. Their attendance could not have occurred without the generous support of our 21 exhibitors and 14 conference sponsors. We look forward to inviting all of you to our 2010 conference where we will be back to our normal scheduling, as the conference will occur in northern Indiana in late March. More details will be posted soon to www.indianalakes.org.

*Submitted by: Sara Peel*

## NYSFOLA Publishes 2nd Edition of *Diet for a Small Lake*

The New York State Federation of Lake Associations, Inc. (NYSFOLA) is proud to announce the spring 2009 publication of the long-awaited *Diet for a Small Lake: The Expanded Guide to New York State Lake and Watershed*

*Management*. This is an expanded and updated version of the 1990 publication prepared in cooperation with the NYS Department of Environmental Conservation. The new volume was also a joint effort and will be published by The Forager Press, LLC of Cleveland, NY.

The book will make its debut at NYSFOLA's 26th annual conference May 1-3, 2009 entitled "Invasive Species in New York State 1609-2009: Celebrating the Hudson-Champlain Quadricentennial."
*Submitted by: Nancy Mueller*

## Oregon Lakes Association

During the past year, Oregon has experienced an unusual pattern of cyanobacteria blooms in some of its lakes and reservoirs. Typically, local authorities at less than a dozen of the more prominent lakes will notify the State Department of Human Services of a visible scum at beaches or lake surfaces within their jurisdiction. These observations can occur as early as May or as late as September, depending largely on specific lake features such as trophic state or water temperatures. A standard format advisory cautioning against water contact is issued for these occurrences and the warning remains in place until two weeks after the scum dissipates. The advisories have become routine at locations well suited for cyanobacteria blooms, but can also be posted for lakes without this history. The onset of cold weather in November brings cyanobacteria season to an end.

Official awareness of cyanobacteria health risks took shape in Oregon during the 1990s and led to a series of well-attended public meetings between 2004 and 2006. These sessions formulated a state-wide approach to threshold levels, news releases, and educational materials. The protocol has proved effective in raising the public recognition that any water with a cyanobacteria scum presents a contact risk, whether an official warning is in place or not. The repetitious reminders that appear in all parts of the state reinforce the message that cyanobacteria are an on-going concern.

On May 15th of last year, the first of the 2008 advisories was posted at a flood control reservoir that is familiar with the process. Others followed as normal, but by the end of November there were still three advisories in effect. An irrigation reservoir in the Columbia River sage lands of eastern Oregon did not clear up until December 23rd. A flood control reservoir on the upper Rogue River in southwest Oregon was posted in mid-September and remained under the advisory until January 27, 2009. The advisory posted at a shallow sand dune lake on the mid-Oregon coast went up at the end of October and lasted until January 29, 2009. Finding cyanobacteria in these three lakes during the summer is not unusual, but for it to persist into winter is something new. There are no ready answers for why the blooms would last so long in these markedly different lakes. The question is under consideration at the three locations. The likelihood of finding the probable cause for the unseasonal blooms depends on the understanding of the cycling that the three lakes undergo. It is a good example of why it is good policy to do systematic lake monitoring. Changes are best discovered when there is familiarity of normal ranges.
*Submitted by: Roger Edwards, OLA President*

# Dr. K's Glossary

## Lakes – The V's

**Vaca Pond and Laguna de Las Vaca** – are both located in New Mexico. I really have no idea if these waterbodies are named after Cabeza de Vaca, but his story is one of the most interesting of the early explorers of North America, and it is possible that he even visited parts of New Mexico, so I'm going with it anyway. Unlike most of the early explorers, Cabeza wasn't the captain of his ship. He actually took command of his expedition (if you want to call it that) after the captain died. Actually, Cabeza de Vaca means "Head of a Cow." (How this surname came to be is an interesting story in itself, but I'll refrain in the interest of space – although, I did have a flashback to the "Godfather" and the Cabeza de Caballo.) I suppose Vaca Pond and Laguna de Las Vaca may actually be just a more refined way of saying "cow pond," but I'll proceed with the story of Alvar Nunez Cabeza de Vaca. Alvar was born in 1490, and after a military career of some distinction was appointed second in command in the Narvaez expedition of 1527. Pamfilo de Narvaez, governor of Cuba, sailed from Mexico on June 17, 1537 with a fleet of five ships and 600 men. He arrived on the coast of Florida (near Tampa Bay) in April 1538 with 300 men after losing many to desertions and storms. De Vaca's diary of the expedition included the first account of an Atlantic hurricane, one of the storms that devastated his crew members. This was before we were aware of the connection between increasing water temperatures in the North Atlantic and hurricane activity in the Gulf of Mexico and before most insurance companies in Florida decided not to renew homeowner policies. After landing near Laguna de Tampa, Narvaez led his remaining force toward the interior in search of gold and other treasures only to encounter the Apalachee Indians who convinced him, in a rather forceful manner, to re-evaluate his goals and consider other options. Since his ships were now anti-buoyant, Narvaez had his men constructed four rafts with the intent of returning to Mexico. Most of the men, along with Narvaez, drowned during a storm. The 80 survivors, now led by de Vaca, began an overland journey of 6,000 miles to Mexico. Unfortunately, only four men, including de Vaca, survived the trip. His real-life story and exploits from 1527 to 1537 rival those of Ulysses.

**Lake Valhalla** – can be found in Washington State. Valhalla is, in Norse mythology, the "Hall of the Slain" and is presided over by the god Odin. Apparently, Odin only got to draft half of the heroes that died on the battle fields, the rest go to Folkvang (the goddess Freya's hall). Odin Hall (i.e., Valhalla) has 540 doors, and when the battle of Ragnarok takes place, 800 warriors will march shoulder to shoulder out of each door (that's 432,000 warriors). I found more references to Valhalla than Folkvang, so I don't know what Freya's warriors are doing when Odin's are fighting in Ragnarok. If I've got my facts straight (and I'm not promising anything here), Odin is the head god; he is also known as Alfadir or Allfather, since he is the father of most of the gods. The stories of the Norse gods are just as convoluted and intriguing as the Roman and Greek gods, and it's not surprising that Lake Valhalla is located in the Labyrinth Mountains.

**Van Winkle Lake** – There are Van Winkle lakes in Michigan and New Mexico, and while they may not be directly named for Rip Van Winkle, there is certain to be a common genealogical connection somewhere. For whatever reason, the story of Rip Van Winkle begins with the following lines:

*By Woden, God of Saxons,*
*From whence comes Wensday, that is*
*Wodensday,*
*Truth is a thing that ever I will keep*
*Unto thylke day in which I creep into*
*My sepulchre—*

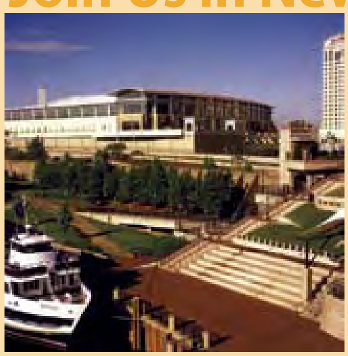
As I said, I don't know why Washington Irving (aka Diedrich Knickerbocker) began his short story with these dark lines, but I now know that he is referring to Odin, a Norse god, and would never have guessed there would be a connection between Lakes Valhalla and Van Winkle. But this is an important bit of trivia that you can work into your oral defense or a casual conversation, and if you cite this little verse in the process, you're certain to establish your reputation as a really strange person. In any case, I believe I first read the story of Rip Van Winkle in a grade school literature text at least 50+ years ago, and it established in me a certain respect and mystique for the Catskill Mountains. I only wish there were a lake there named after old Rip Van Winkle in upstate New York, but as we've noted previously, there are a couple of Knickerbocker lakes in the area, so I guess that's good enough.

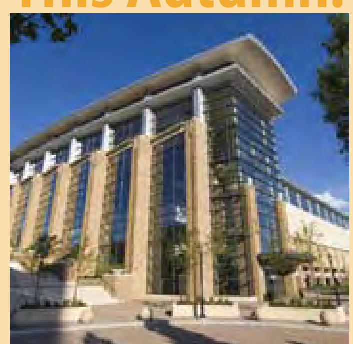
**Lake Valentine** – There are a few Valentine lakes and ponds scattered around. I thought sure that this would be an easy lake name to trace, expecting to find all kinds of information about Saint Valentine, the patron saint of love, young people, and happy marriages, but the story of Saint Valentine is a little obscure. In any case, it appears that at least one St. Valentine really existed, because archaeologists have unearthed an ancient church dedicated to him, and in 496 AD, Pope Gelasius marked February 14th as a celebration in honor of his martyrdom, which resulted from his refusal to give up his Christian faith. Pope Gelasius apparently designated February 14th as Valentine's Day to upstage a similar pagan holiday celebrated on the 15th. In any case, Valentine's Day is very important to the florist, greeting card and candy industries, and at one time in the United States there was as much postage mailed on February 14th as there was on April the 15th.

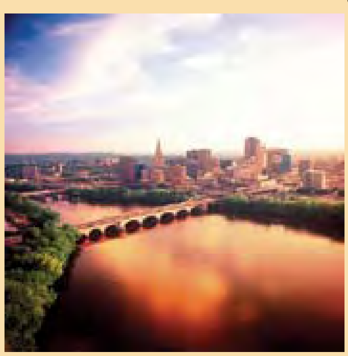
**Viking Lake** – I found two Viking Lakes and both were located in Michigan. I guess I was expecting to find at least one in Minnesota, possibly near Lake Wobegon. Don't ask me how I got here, but in researching Vikings and Lake Wobegon, I somehow got to lutefish (there's a real Norse theme to this edition of the glossary). My apologies to all of you of Nordic heritage, but who came up with this one? Apparently, lutefish is something of a traditional dish in Norway, Finland, and Sweden, and literally means "lye fish" and is made from dried and/or salted whitefish or cod marinated in soda lye. According to Garrison Keillor, "Lutefisk is cod that has been dried in a lye solution. It looks like the desiccated cadavers of squirrels run over by trucks, but after it is soaked and reconstituted and the lye is washed out and it's cooked, it looks more fish-related, though with lutefisk, the window of success is small. It can be tasty, but the statistics aren't on your side. It is the hereditary delicacy of Swedes and Norwegians who serve it around the holidays, in memory of their ancestors, who ate it because they were poor. Most lutefisk is not edible by normal people. It is reminiscent of the afterbirth of a dog or the world's largest chunk of phlegm." I think I would rather eat kimchi, the Korean national dish. The documentary I saw on public TV showed acres of clay pots almost totally buried in the ground with their contents of fermenting cabbage and raw fish left to stew in the sun for weeks or months. Anyway, back to the Vikings, the term is used most often to denote a Norse explorer, warrior, merchant, or pirate who traveled in their longships raiding and colonizing wide areas of Europe in the 8th to early 11th centuries, a period of Norse expansion known as the Viking Age. Their explorations and colonization lead them as far east as Constantinople and as far west as Greenland and Newfoundland, and even as far southwest as present-day Pennsylvania. Much of what we know about Vikings has been learned from runestones, a sort of Nordic hieroglyphic or pictograph. Recently, a runestone was found near Pittsburg, detailing how the Vikings would be defeated by the Steelers who would ultimately establish themselves as the champions of the NFL at the Viduderlig Bolle in Tampa in the early 21st century.

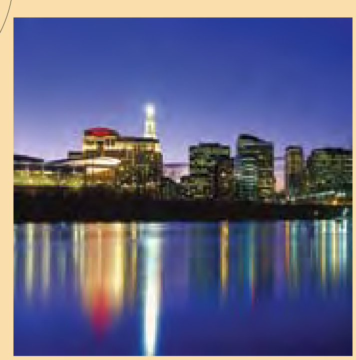
**Marty Kelly** is manager of the Ecologic Evaluation Section of the S.W. Florida Water Management District in Brooksville, FL. His e-mail is: marty.kelly@swfwmd.state.fl.us.











# Hey Kids!

**Get outside this spring to enjoy your local lakes and ponds!**

Read below for some ideas.

Spring is a great time to be outdoors. Plants are emerging from the ground. Leaves are coming out on trees. Animals are becoming more active. There is a lot to see! Why not take this opportunity to get outside and enjoy nature?

Your explorations can be very simple. Take a walk with your family and friends to a local wetland, pond, or lake. Watch for birds looking for food near the water's edge. Bend down to look into the water. What do you see?

Spend 10 minutes in silence, watching and listening to the water. When the 10 minutes are up, share your observations with your family and friends.

Your explorations can also be more detailed. Some supplies you can bring along on your journey might include: a net for collecting small animals, a small pan to look at collections, bags for collecting flowers and leaves, a digital camera, and a journal or sketch pad (don't forget a pencil!).

**Some tips for collecting organisms:**

- **Be careful**! Don't pick up any dangerous or poisonous plants or animals.
- Only collect plant parts if there are many plants of that type, and only collect ONE.
- Return all animals to where you found them.
- Treat plants and animals with respect – don't squeeze them or touch them too roughly.

You can write and draw about what you saw using the journal and sketch pad. Or, pictures can be taken of animals you saw (or signs of animals), different plants that live in the water, and your family and friends enjoying nature.

Here are some ideas for when your return home:

- Press any plant parts to preserve them. You can begin a collection of local plants to enjoy later.
- Identify plants and animals that you saw using local field guides. Write these names on your sketches or in your journal.
- Make a collage or photo album using the pictures you took with your digital camera.
- Start planning your next trip to a nearby water body!

It's amazing what you can find when you take just a few minutes to look around!

# Literature Search

Bill Jones

### *Canadian Journal of Fisheries and Aquatic Sciences*

Bristow, C.E., A. Morin, R.H. Hesslein and C.L. Podemski. 2008. Phosphorus budget and productivity of an experimental lake during the initial three years of cage aquaculture. *Can J Fisheries Aquat Sci* 65(11):2485-2495.

### *Fisheries*

Phelps, Q.E. and N.C. Wahl. 2008. Connecting with the community through active pond management. *Fisheries* 33(9): 464-467.

### *Freshwater Biology*

Ellis, S. and H.J. Macisaac. 2009. Salinity tolerance of Great Lakes invaders. *Freshwater Biol* 54(1): 77-89.

Schilling, E.G., C.S. Loftin and A.D. Huryn. 2009. Macroinvertebrates as indicators of fish absence in naturally fishless lakes. *Freshwater Biol* 54(1): 181-202.

Vanderploeg, H.A., T.H. Johengen and J.R. Liebig. 2009. Feedback between zebra mussel selective feeding and algal composition affects mussel condition: Did the regime changer pay a price for its success? *Freshwater Biol* 54(1):47-63.

### *Hydrological Processes*

BoixFayos, C., J. deVente, M. MartinexMena, G.G. Barbera and V. Castillo. 2008. The impact of land use change and check-dams on catchment sediment yield. *Hydrol Process* 22(25): 4922-4935.

### *Journal-American Water Resources Association*

Chen, C.W., J.W. Herr and R.A. Goldstein. 2008. Model calculations of Total Maximum Daily Loads of mercury for drainage lakes. *J Am Water Resour Assoc* 44(5):1295-1307.

Maret, T.R., D.E. MacCoy and D.M. Carlisle. 2008. Long-term water quality and biological responses to multiple best management practices in Rock Creek, Idaho. *J Am Water Resour Assoc* 44(5): 1248-1269.

### *Journal of Great Lakes Research*

Marcogliese, D.J. 2008. First report of the Asian fish tapeworm in the Great Lakes. *J Great Lakes Res* 34(3):566-569.

### *Journal of Soil and Water Conservation*

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Starzec, K., L. French, N. Nelson and D. Devlin. 2008. Conservation and citizen participation in the Cheney Lake watershed. *J Soil Water Conserv* 63(6): 204A-207A.

### *Limnology and Oceanography*

Carini, S.A. and S.B. Joye. 2008. Nitrification in Mono Lake, California: Activity and community composition during contrasting hydrological regimes. *Limnol Oceanogr* 53(6):2546-2557.

Jager, C.G., S. Diehl and G.M. Schmidt. 2008. Influence of water-column depth and mixing on phytoplankton biomass, community, composition, and nutrients. *Limnol Oceanogr* 53(6):2361-2373.

LopezUrrutia, A. 2008. The metabolic theory of ecology and algal bloom formation. *Limnol Oceanogr* 53(5):2046-2047.

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# Pond Design, Management and Maintenance

***May 1, 2009***

This one-day class will help you properly design, maintain and manage your pond to minimize water quality problems while maximizing aesthetics and function. Starting with design, learn how to build a pond, including recommended water depths, volume and flushing relationships, shoreline shape, integration of aquascaping benches, and optimal design of outlet structures.

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- Maximize the quality of fish habitat
- Review applicable environmental permitting issues

***This course is approved for 0.7 CEUs towards the NALMS Certified Lake Manager/ Certified Lakes Professional program.***

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