I love old books. One older book on my bookshelf is Bulletin No. 2 of the Indiana Bureau of Legislative Information from 1914. The title is *Drainage and Reclamation of Swamp and Overflowed Lands.* In the Preface, the Director of the Bureau points out that “this is a subject of paramount importance, involving a manifest public duty in the discharge of which… we have been guilty of unconscious criminal neglect.” What issue could have elicited such passionate verbiage? It was the presence of 80 million acres of unproductive swamp lands within the U.S. that weren’t meeting their potential as arable farmlands. The Director states that “these unprofitable, disease-breeding swamps … constitute a national liability of several billions of dollars.”

To her credit, the Director notes that “Indiana has reduced her swamp-land area by 2,500,000 acres and has added $68,000,000 to her assessable wealth.” Talk about wetland values!

Thankfully, we’ve come to our senses about the value of wetlands but there are still plenty of doubters out there. So in this issue of *LakeLine,* we will provide more evidence of the value of wetlands… for lakes and for the environment.

In our lead article, *Melanie Haveman* and *Tom Davenport* outline the many benefits of wetlands and how federal laws and policies incorporate them. The water cleansing abilities of wetlands are used in a variety of applications. We learn of two such applications here. In the first, *Ed Dunne* and his associates at the St. Johns River Water Management District describe how wetlands are being used to reduce nutrients within Lake Apopka. In the second application, *Ron Elkins* of the City of Phoenix tells us how constructed wetlands are used to treat wastewater for further human use.

Floodplain forests are important wetlands and at Lake Belle View in Wisconsin, their restoration will help improve recreational opportunities and water quality. *Steve Fix* led the project team that designed this restoration. Joni Mitchell sang, “You don’t know what you’ve got ‘till it’s gone.” This is certainly true with the loss of wetlands as *Stan Geiger,* *Kale G. Haggard,* and *Allen J. Milligan* found in their research on wetland loss and water quality changes at Klamath Lake.

While the genius of humans to create and use wetlands is well-demonstrated in this *LakeLine* issue, the mammal responsible for creating the most wetlands in North America should also receive mention. *Sharon Brown* and *Suzanne Fouty* present a brief and loving history of the beaver in North America and its role in the creation of wetland habitats.

This month’s EPA Commentary describes the first National Wetlands Condition Assessment planned for 2011.

In other *LakeLine* features, CALMS was partying at their 25th annual meeting and we have the story and pictures to prove it. Flatulence in lakes? I’d better let *Doug Larson* explain in his humorous article that further demonstrates that with lakes, it is always prudent to expect the unexpected. The 31st Annual NALMS Symposium is coming up in Spokane, WA as the Call for Papers attests. Finally, we close this issue with 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 Editor**

*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.

**Next Issue – Summer 2011**

*LakeLine*

“Lake Ecology” is the theme of the summer issue of *LakeLine* and this should be a fun one. Experts in their field will tell us all about phytoplankton, zooplankton, aquatic macroinvertebrates, fish, and aquatic birds.
I just got back from a small conference in International Falls that I have been attending for several years. The attendees share an interest in the Lake of the Woods and its watershed and have been, for many years, using solid science to understand the connections between in-lake processes and the stressors that impact them. This is possible because somehow the participants have managed to collaborate and to bring the boots of their respective agencies onto the ground in the basin to collect data that are now beginning to shed some light on the complex interactions that exist in the lake. This is a grass-roots initiative. There are no overarching authorities. This is an international effort, although the lake. This is a grass-roots initiative. There are no overarching authorities. This is an international effort, although the connections of our respective governments tend to know little about our efforts. It has a field data collection component in many cases without a “field program” – but it works beautifully. The participants have many reasons to be proud of their hard work but also of the ingenuity that has propelled this sneaky science forward. There are hundreds of examples but I can’t mention any of them or the whole thing might break down.

I realise, when I reflect on these accomplishments, that the reason why there has been so much success is that the efforts are put forth from a collection of like-minded people and not from the mandate of an agency or a collection of agencies. And it occurred to me that this collection of people, who meet each year in the middle of nowhere, has all of the elements required to fulfil the definition of a “Society.” Now you see where I am going with this. There was some talk about changing the NALMS name to something that did not contain the word “society” because it was too old and stuffy; was full of outdated connotation. I couldn’t disagree more. Fiscal pressures are everywhere today. Organisations and agencies and governments are coming apart at the financial seems – yet NALMS is quietly treading water. We can’t seem to make substantial gains with our membership – but at the same time we are far from falling apart. And I would submit to you that this is precisely because our fundamental nature is that of a vibrant society – the North American Lake Management Society.

Okay, so if this fabulous conference in International Falls is so good, then why doesn’t NALMS get involved. Aha – that’s the cool part. The International Lake of the Woods Water Quality Symposium is very well attended each year by NALMS members. We are coming out of the woodwork at this thing and to make matters better, NALMS actually sponsors the event. But we are bad with the paperwork. We always forget to get the NALMS board to ratify the sponsorship, no one has managed to get a line item for the thing into the budget, and no one can remember to hang up a banner or set up a booth with pamphlets – but it gets done, in a kind of a sneaky way – I like it. I like this whole “powered by people” thing. So keep an eye on Lake of the Woods. The research is going 100 miles an hour and nobody is complaining about the price of gas.

**Bev Clark** worked for 35 years with the Ontario Ministry of the Environment conducting whole lake experiments at the Dorset Environmental Science Center. He now works as an aquatic scientist with Hutchinson Environmental Sciences in Bracebridge, Ontario.

**NALMS Address Updates**

... we need your help!

We have an ongoing problem with outdated postal mailing and electronic (e-mail) addresses. Members can go online to correct their own information now and are encouraged to do so. Please tell your friends and colleagues who are NALMS members to check and update their records. If they are not getting LakeLine or the NALMS e-newsletter, something is wrong. If they don’t have access to fix their own contact info, they can call the office at 608-233-2836 to get changes made. This goes for postal service mail addresses as well.
Wetlands and Lake Management

Melanie Haveman and Thomas Davenport

Introduction

The natural process over thousands of years is for lakes of moderate depth to gradually fill and become wetlands. Human activities disrupt the natural life cycles for lakes and, in the process, accelerate the deterioration of lake quality and the in-filling of lake basins. Lake quality is a reflection of land use within the watershed. Land use is the most important process affecting water exchange between the land surface and the atmosphere, and this directly influences water quality.

Watershed management provides a framework for addressing water resources on a landscape scale. The landscape approach takes into account the spatial and temporal structure of the ecosystems within a watershed and allows planners to maximize opportunities to manipulate ecological patterns along a landscape gradient to improve water quality and better manage water quantity. While many watershed management efforts promote wetland restoration, the relative importance of existing wetlands within the watersheds is not widely recognized. While the first priority is to protect existing wetlands, restored, created, and enhanced wetlands can provide the same benefits as natural wetlands when properly designed, developed, and managed.

The watershed planning approach must be viewed as an opportunity to be proactive in not only protecting wetlands at the local level, but also in restoring and creating wetlands in support of water quality goals. By using a landscape approach, preservation, enhancement, creation and/or restoration of wetlands, the management practices will have a measurable effect on water quality and quantity. Watershed management planning activities in support of this approach afford the opportunity to implement site-specific, ecologically beneficial wetland (enhancement, creation, and restoration) projects on a landscape basis to address water quality and flow regime issues.

Wetlands and Their Functions

“Wetlands,” as defined in 40 CFR 232.2(r), are:

“those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.”

Creation: An activity bringing wetlands into existence at a site where a wetland did not occur before.

Wetlands are often transitional areas between upland and aquatic systems. Wetlands come in all shapes and sizes and go by many names such as marshes, swamps, sedge meadows, etc. (Figure 1). While some wetlands contain standing water for at least part of the year, many rarely or never contain standing water, or contain it for only brief periods each year. Such wetlands must have saturated soils for at least part of the year to be considered wetlands. Most wetlands receive surface water inflow at some time of the year, some are fed by both surface and groundwater, and others are supported solely by groundwater.

Wetlands are key ecosystem components. At the watershed level, an understanding of wetland ecosystems is essential for establishing water quality and quantity priorities and creating management plans. Certain wetlands provide water quality functions that benefit adjacent and downstream waters, while others provide localized benefits that cumulatively have a significant impact downstream.

Wetland functions are well documented (U.S. Fish and Wildlife Service 1984; U.S. Army Corps of Engineers 1986; Conservation Foundation 1985), and include:

• water quality improvement,
• floodwater storage,
• fish and wildlife habitat,
• aesthetics, and
• support of aquatic and terrestrial life.

Protecting these functions is essential for lake home owner associations in the implementation of their lake use and management plans.

A number of lakes’ projects supported through Federal Clean Lakes and Nonpoint Source Programs have demonstrated how wetlands provide water quality benefits by acting as filters and depositional zones for pollutants. Additionally, the ability of wetlands to temporarily store floodwater helps reduce stream discharge velocities that otherwise contribute to stream bank instability and downstream sedimentation (Figure 2).

Wetlands and Lake Management

Strategically restoring and/or creating wetlands will provide substantial water quality benefits at the watershed scale by restoring ecosystem processes. Although wetland restoration and creation are useful tools, they are only temporary fixes if environmental protection is inadequate. Wetland restoration, creation,
Figure 1. A southern cypress swamp is a forested wetland that supports a rich diversity of biota.

Figure 2. A northern Minnesota sedge meadow stores floodwaters and tempers large variations in streamflow.

and protection must be integrated on a watershed basis.

Wetlands that are waters of the U.S. must be protected and restored consistent with the Clean Water Act (33 U.S.C. §1251 et seq. [1972]). For existing wetlands, preference should be given to protecting the existing functions and ensuring that the system is self-sustaining. Planners must understand that impacts on any wetland function can eliminate or diminish wetland benefits. Watershed planning provides an opportunity to be proactive in the protection of existing wetlands. Described below are a few of available tools for protecting wetlands:

• **Section 404 permit**

  Section 404 of the Clean Water Act established a permit program regarding discharges of dredged and fill material.

• **Advance Identification (ADID)**

  ADID, advance identification of disposal areas, is a planning process used to identify wetlands and other waters that are generally suitable or unsuitable for the discharge of dredged and fill material.

• **Section 401 Water Quality Certification and Wetlands**

  States and eligible tribes have authority under Section 401 of the Clean Water Act (CWA) to protect wetlands. Under Section 401, states and tribes can review and approve, condition, or deny all federal permits or licenses that might result in a discharge to state or tribal waters, including wetlands. The major federal licenses and permits subject to Section 401 are Section 402 and 404 permits, Federal Energy Regulatory Commission (FERC) hydropower licenses, and Rivers and Harbors Act Section 9 and 10 permits.

  Creating or restoring wetlands to reduce pollutant loading to improve water quality utilizes a combination of the following techniques: (1) reestablishing the wetlands hydrology, (2) managing sediment and nutrients affecting the wetlands, and (3) reestablishing native biota. Past Clean Lakes Projects in Minnesota, Florida, Oklahoma, Michigan, and Illinois utilized the watershed scale to emphasize the importance of functional processes, and these projects demonstrated that in wetland restoration, functional processes are more important than the form (Figure 3). Section 319
Nonpoint Source Success Stories, many involving wetlands restoration, are documented at: http://water.epa.gov/pollwaste/nps/success319/.

Mitsch and Gosselink (1993) identified four landscape locations for restored/created wetlands: in-stream, riparian, upstream, and terraced wetlands. Wetlands designed as in-stream systems are constructed by adding a control structure within or by impounding a tributary of the stream. In-stream wetlands should be considered only for first or second order streams, and they may provide more water quality than flow regime benefits. Riparian wetlands are designed to capture sediment and associated pollutants to reduce pollutant loading during flood stages and surface runoff. Upstream wetlands are created to temporarily store stormwater runoff and reduce downstream discharges. Terraced wetlands are created wetlands integrated into the landscape’s steeper terrain using terraces to place wetlands on hillsides. They are used to treat runoff and decrease peak discharge.

Creation or restoration of wetlands to stimulate all functions of natural wetlands has additional challenges. For example, created wetlands often must be redesigned on landscapes according to specific engineering and management criteria. A major constraint in the creation of wetlands is providing sufficient hydrology, which often involves considerable planning, design, and engineering and construction expense. In addition, created wetlands may not contain the appropriate wetland soils and are more readily invaded by exotic or invasive plant species.

Building on the Clean Lakes Program successes, a number of nonpoint source projects have enhanced existing degraded wetlands to maximize pollutant loading. Success for any wetlands enhancement effort can be measured by how closely the repair of the damaged or degraded wetland resulted in both its structural and functional attributes attaining pre-disturbance condition. An additional design concern is how resilient a wetland is and how enhancing its functions may impact its resiliency.

Wetland zones situated along lake shorelines can contribute to improved lake water quality and a much richer diversity in aquatic biota. The Chicago Botanic Garden’s Lake Enhancement Program utilized shoreline slope re-grading and installation of over a quarter-million wetland plantings to heal over three miles of eroding lakeshore and add significantly expanded aquatic habitat (Kirschner 2005).

Lake homeowner associations can play a vital role in managing lake levels and decreasing residential flooding in their watersheds by working with land owners to use the opportunities natural and constructed wetlands provide to decrease the volume and velocity of stormwater runoff. Numerous studies and projects have shown that watershed hydrologic stability is a factor of the wetlands to watershed ratio. Results of the Illinois State Water Survey studies indicate that in order to maintain hydrologic stability, the wetland-to-watershed ratio should be at least 12 percent (TWI 1997); other studies promote a ratio of open space/wetlands to watershed of at least 18 percent. Delaney (1995) reported if a watershed was comprised of 5-10 percent wetlands, it could provide a 50 percent reduction in peak flood periods compared to watersheds without wetlands.

**Conclusions**

Environmental consequences of not properly managing the wetlands within a watershed create imbalances in flow, increases in pollutant loads, habitat destruction, and loss of biodiversity. The loss of wetland functions is manifested in the downstream lake. Based upon watershed-specific factors, state and local agencies can develop and implement watershed management plans that either prevent or minimize the cumulative impacts of inappropriate land management through a combination of management practices, wetlands, and riparian buffers. The integrated use of wetlands described above has the potential not only to remediate both water quality and quantity problems but to prevent them.
Lake watershed management plans developed for or by homeowners’ associations should address watershed and in-lake problems to support their lake use plans. It is important to note that many local lakes groups lack the capacity (funding, staff, and guidelines) necessary to fully utilize opportunities for protecting, enhancing, and creating wetlands on a watershed basis for lakes. Federal, state and local programs need to provide the capacity local lakes group lack. At a minimum, each lake watershed management plan’s wetlands component should include:

- identification of areas where wetlands need to be protected from nonpoint source pollution and conversion. This section should also include the practices and management measures that are needed to ensure adequate protection;
- identification of areas with the potential to enhance existing degraded wetlands for water quality/quantity purposes; and
- identification of areas with the potential to meet water quality/quantity goals as either restored or created wetlands.

References

U.S. Army Corps of Engineers. 1986. Wetlands and Water Quality: A regional Review of Recent Research in the United States on the Role of Freshwater and Saltwater Wetlands as Sources, Sinks and Transformers of Nitrogen, Phosphorus, and Various Heavy Metals. Waterway Experiment Station, Vicksburg, MS

Melanie Haveman is an environmental scientist in the Watersheds and Wetlands Branch at U.S. EPA Region V in Chicago.

Tom Davenport is U.S. EPA’s national expert on nonpoint source pollution and regional agricultural advisor. He works in Region V in Chicago. 

Restoration: Returning a former or degraded wetland from an altered condition with lesser acreage and functions to a close approximation of its original condition.
Lake Apopka: Reducing Excess Nutrients


Using Wetlands to Reduce Lake Apopka’s Excess Nutrients

Introduction

Wetlands, both natural and constructed, provide a range of ecosystem services. These services can include water quality improvement, recreational space, habitat, water storage, and flood control (Mitsch and Jørgensen 2004). Constructed wetlands, which are engineered ecosystems, rely on biology, chemistry, physics, hydrology, and the combinations of these processes and many others, to provide the desired service. For water quality improvement, constructed wetlands can transform and translocate nutrients, suspended materials, and contaminants due to the assemblage of soil, water, plants, detritus, and microbes (Kadlec and Knight 1996; Kadlec and Wallace 2008). Constructed wetlands use natural wetland biogeochemical processes like sedimentation, accretion, sorption, precipitation, and nutrient uptake by plants and microbes, which can be optimized to meet specific design and operation goal(s).

The St. Johns River Water Management District’s restoration program for Lake Apopka, FL includes a range of management practices that both reduce the external nutrient loading to the lake and remove nutrients already in the lake. The marsh flow-way (Figure 1), a 310-hectare constructed wetland, is one project that contributes to the removal of nutrients and suspended material already in Lake Apopka.

Typically, constructed wetlands treat incoming water in a single pass, meaning the wetland has one chance to remove incoming nutrients and/or contaminants. In addition, treatment goals often include

Figure 1. Location map of the marsh flow-way project in central Florida and its location in the Apopka watershed.
achieving a specific outflow water quality concentration. In single-pass wetlands, the goal is to maximize efficiency, which is the proportion of pollutant removed. As a recirculating wetland, the marsh flow-way operates quite differently. Rather than attempting to meet an outflow concentration, our goal is to maximize nutrient and suspended solid removal rates from incoming Lake Apopka water and recirculate the cleaner water back to the lake (Lowe et al. 1989). In physics, power is defined as the work done per unit time. As nutrient and suspended solid removal is the work of the treatment wetland, by analogy, we denote removal rate as the power of the treatment wetland. Therefore, to maximize power, the marsh flow-way is operated at high hydraulic loading rates (HLRs) relative to many constructed wetland systems within the U.S.

Our objectives for this article are to give a brief overview of system goals, description of the project, monitoring, management, and system performance for the first seven years of operation between 2003 and 2010.

Materials and Methods
Site Layout and Description
The marsh flow-way is located in the northwest corner of Lake Apopka and consists of four independent treatment cells (B1, B2, C1, and C2). The cells receive Lake Apopka water via gravity flow through a series of canals and gated culverts (Figure 2). Once in the cell, water flows west to east through the wetland. Water passes through open water areas, emergent vegetated areas and over small lateral ditches, which are perpendicular to flow. Water exits each cell over riser board structures, and all outflows are routed to a pump basin via a canal. Once in the pump basin, water is pumped back to the lake (Figure 3).

Each year, during November and/or December, aerial photographs were taken of the site and used to interpret and classify dominant vegetation communities. Based on the interpreted imagery for six years (2003-2008) 65 percent of the marsh flow-way was shallow herbaceous marsh and 18 percent was shrub swamp. The remainder (17 percent) was shallow open water.

Site Monitoring
The marsh flow-way began operation in November 2003, and we report data up until November 2010. During this time, water levels were measured daily and flows were estimated using weir flow equations.

Typically, inflow and outflow water was sampled weekly and analyzed for a range of parameters according to standard methods. A total of 20-23 parameters were analyzed, including total phosphorus (TP), total dissolved phosphorus (TDP), dissolved reactive phosphorus (PO₄-D), total suspended solids (TSS), ammonium, nitrate+nitrite, and total Kjeldahl nitrogen.

Cell maintenance includes cell drawdown, vegetation mowing, ditch cleaning, vegetation planting, installation of silt fences and wattles, and use of alum to mitigate P release during reflooding. During maintenance of C2, finger levees were constructed to reduce hydrologic short-circuits. In B cells, maintenance occurred between March 2007 and January 2008, whereas maintenance in C cells was undertaken between May 2008 and October 2009. During maintenance, various individual cells were offline.
Results and Discussion

Hydrology

Hydraulic loading rate (HLR) increased each year up until 2006. After 2006, mean HLR decreased, with recent years somewhat similar to each other (Table 1). The maintenance of wetlands cells in 2007 through 2009 contributed to the variability and low median HLR during these years. Maintenance was undertaken to mitigate the onset of reduced system performance for nitrogen (N) and P removal. Reduced effectiveness was concomitant with the occurrence of hydraulic short-circuits within cells, and there was a change from emergent vegetation to increased coverage by floating vegetation mats. We believe that these floating mats occur because of increasing water depths in cells.

During the complete period of record (POR), the mean HLR was 36 m/yr, which resulted in about 40 percent of the lake’s volume being treated per year (Figure 4). This HLR is high relative to HLRs in many other constructed wetlands in Florida and the U.S., which can range between 10-20 m/yr. The marsh flow-way was operated at a high HLR, since one of the main design and operational goals was to maximize power (Lowe et al. 1989).

One way to increase power is to increase HLR, thus treating more lake water. Previous studies report that increasing the HLR and/or nutrient loading rate contributes to increased removal rates (Reddy et al. 2009).

Another factor that makes the marsh flow-way different from other constructed wetlands is the site location. The marsh flow-way is located on land that was historically used for agricultural row crops (prior to this, it was part of the lake’s floodplain wetland); therefore, these organic soils received many years (~40-50 years) of fertilizer applications. It was found from previous on-site studies that the legacy of nutrient loads in soils contributed to a release of soluble nutrients, specifically P, from soil to overlying water (Coveney et al. 2002). We anticipated that increasing HLR, thereby reducing hydraulic residence times within the flow-way, would help mitigate P release from soil. We also applied alum residual, a water treatment by-product, to the soils at a rate of 22 wet metric tons per hectare (~47 kg Al ha⁻¹) to mitigate the release of P from the soil prior to reflooding.

Total Suspended Solids and Accretion Rates

The marsh flow-way retained large amounts of total suspended solids (TSSs) from incoming Lake Apopka water. The TSS power or removal rate varied between 3 and 20 metric tons of TSS per day (Figure 5). The primary biogeochemical process involved in removing TSS from water is sedimentation. We observed greatest power during 2007 and 2008 (Figure 5). After 2008, power decreased, as incoming TSS concentrations decreased. The HLR was also lower than preceding years, as maintenance was undertaken on C cells during 2008 and 2009.

The seven-year median areal power was 1.4 kg m²/yr, and the median removal

<table>
<thead>
<tr>
<th>Parameter</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS</td>
<td>257</td>
<td>1,396</td>
<td>926</td>
<td>1,859</td>
<td>2,104</td>
<td>2,339</td>
<td>1,035</td>
<td>1,133</td>
</tr>
<tr>
<td>TP</td>
<td>-1.9</td>
<td>0.5</td>
<td>0.4</td>
<td>1.6</td>
<td>1.6</td>
<td>1.8</td>
<td>0.4</td>
<td>0.9</td>
</tr>
<tr>
<td>TN</td>
<td>6</td>
<td>40</td>
<td>22</td>
<td>35</td>
<td>41</td>
<td>39</td>
<td>13</td>
<td>26</td>
</tr>
</tbody>
</table>

TSS = Total suspended solids; TP = Total phosphorus; TN = Total nitrogen.

*Values are yearly medians. Positive values are removal and negative values are release. Values for partial years 2003 and 2010 were annualized for comparative purposes.
efficiency for that timescale was 92 percent. Suspended solids removal is important since approximately 90 percent of the nutrients in lake water were in particulate forms (Figure 7).

We estimated that accretion rates of floculent sediment in the wetland were 2 ± 1 cm/yr for B cells and 3 ± 1 cm/yr for C cells up until maintenance was undertaken in both B and C during 2007 and 2008/2009, respectively. To estimate this, we used TSS retained by individual treatment cells up until the time of maintenance, individual treatment cell area, bulk density and percent solids of collected sediment samples prior to maintenance. In a previous pilot-scale study at Lake Apopka, it was found that floculent sediment consolidated about seven-fold during treatment cell drawdown.

**Phosphorus**

During the initial start-up period, which lasted about three to four months, the system released P (Figure 6), mostly in dissolved form. This was anticipated from previous findings and probably resulted from release of dissolved P from flooded soil, and release from decomposing terrestrial vegetation (Coveney et al. 2002). After the start-up period, TP power increased to a maximum of 17 kg/d (2008). Typically, performance was better during cooler months (October through May) relative to warmer months (June through September). During the period of record (POR), areal power ranged between 0.5 and 1.8 g of TP m²/yr (Table 1), whereas the median was 0.9 g m²/yr. Efficiency based on mass removal was 28 percent, similar to the project design goal of 30 percent.

During the POR, about 90 percent of the incoming P mass was in a particulate form, whereas PO₄-P and dissolve organic phosphorus (DOP) each accounted for about 5 percent of TP (Figure 7). The relative proportion of these fractions changed as lake water passed through the wetland. In the outflow water, which was recirculated back to Lake Apopka, particulate phosphorus (PP) was about 60 percent of the total P mass (Figure 7), while PO₄-P and DOP each made up about 2 percent.

**Nitrogen**

The yearly trend in total nitrogen (TN) power was similar to both TSS and TP. Yearly rates were variable ranging between about 11 and 350 kg/d (Figure 8). Total N power or removal rate was highest in 2007 and 2008 (Figure 8 and Table 1) and lowest in 2003 and 2009. Power was also seasonally dependent, a pattern probably caused by the effects of water temperature and dissolved oxygen content in wetland waters and underlying soils – both of which affect nitrification and denitrification rates. Nitrogen removal was best during cooler periods (October through May, ~ 35 g m²/yr), while during warmer periods (June through September) performance dropped to 19.5 g N m²/yr. For the seven years of operation, the median areal power was 28.9 g m²/yr, while efficiency was 24 percent.

**Conclusions and Management Implications**

The performance of the marsh flow-way at Lake Apopka during the first seven years of operation shows that this constructed wetland was effective in removing nutrients and suspended material from eutrophic Lake Apopka water. Relative to most other constructed wetlands, the goals, operation, and management of the marsh flow-way are different. Because the flow-way is a recirculating system, it is operated at high HLRs to maximize power, even if this causes declines in efficiency. Power grows with HLR because rate of nutrient and suspended material removal increases with HLR, while the rate of release of dissolved nutrients from soils and accumulated sediments does not.

Operating at these high HLRs may have implications for emergent vegetation management, as we observed that following high HLR years, there was a greater occurrence of floating vegetation mats and hydraulic short circuits. During the POR, we undertook maintenance once in each cell.

In a broader context, Lake Apopka water quality has improved since 1995 (1989-1994 was the baseline period used for TMDL development). Annual average TP concentrations in Lake Apopka water during marsh flow-way operating periods (2004 through 2009) averaged 43 percent lower than baseline, algal chlorophyll declined 35 percent, and Secchi transparency improved by 53 percent.

We anticipate that the marsh flow-way will continue to remove nutrients and suspended material into the future. However, it will become more difficult for the system to remove nutrients and suspended material at similar rates, as concentrations in lake water decline. The
system will require dynamic management in response to these improving conditions. This may entail operating better performing cells, while not operating and/or maintaining other cells during certain periods, increasing HLRs to increase nutrient and suspended solid loads, and adaptively managing within-cell water depth and hydropериod.

**Acknowledgements**

J. Peterson, P. Ek, E. Bailey, L. Lilja, and D. Nickerson conducted water and field sampling activities. C. Dewey, M. Henderson, and J. Shields provided engineering management. Colleagues in the Department of Operations and Land Resources were responsible for infrastructure maintenance. J. Richmond set up the hydrology database. District laboratory staff analyzed weekly water samples. E. Mace and E. Daneman maintained the water quality databases and produced manuscript graphics, respectively.

**References Cited**


---

**Figure 5.** Total suspended solids removal rate (metric tons/d) by the marsh flow-way between November 2003 and November 2010 (solid line) and the cumulative amount (metric tons) of total suspended solids retained by the marsh flow-way (dashed line).

**Figure 6.** Total phosphorus removal rate (kg/d) by the marsh flow-way between November 2003 and November 2010 (solid) and the cumulative amount (metric tons) of total phosphorus retained by the marsh flow-way (dashed line).

**Figure 7.** The relative proportions of phosphorus fractions in Lake Apopka water that flow into the marsh flow-way and treated marsh flow-way water that returns to Lake Apopka. PP = particulate phosphorus, DOP = dissolved organic phosphorus and PO_4^-D = dissolved reactive phosphorus.
Ed Dunne is a wetland scientist with the Lake Apopka Basin, St. Johns River Water Management District (SJRWMD). He joined the SJRWMD in 2007. Ed has a Ph.D from University College Dublin and undertook a postdoc position at the University of Florida.

Mike Covene is Technical Program Manager for the Ocklawaha River Basin with the SJRWMD. Mike has a Ph.D. in limnology from the University of Lund, Sweden and had a research faculty position at Michigan State University prior to joining the District in 1988. In 2009, Mike received the Edward Deevey Jr. award for his contributions to scientific understanding of Florida’s water bodies.

Erich Marzolf, Ph.D. is a limnologist with the SJRWMD. He is the technical program manager for the Middle St. Johns and Orange Creek basins in the Environmental Sciences Division. He served as an officer or board member of the Florida Lake Management Society for ten years.

Vickie Hoge is an environmental scientist with the Lake Apopka Basin, SJRWMD since 1997. She has a BS and MS from the Soil and Water Science Department at the University of Florida.

Roxanne Conrow is a senior scientist for the Lake Apopka Restoration Program. Her work focuses on restoration of former floodplain marshes on the north shore of the lake.

Robert Naleway is a graduate of the University of Central Florida with a master’s degree in environmental engineering. He is a registered professional engineer and has worked on water resource projects in Florida for nearly 20 years. He has been the Apopka Basin engineer for the SJRWMD since 2005.

Ed Lowe, Ph.D. is Director of the Division of Environmental Sciences at the SJRWMD, where he seeks science-based, practicable solutions for protection, management, and restoration of wetlands, lakes, rivers, and estuaries. In 2006, Ed received the Richard E. Coleman Aquatic Sciences Award of the Florida Lake Management Society in recognition of his efforts to understand and restore Florida’s aquatic resources.

Larry Battoe, Ph.D. is a limnologist working in water resource restoration and management. He is Assistant Division Director for Environmental Sciences at the St. Johns River Water Management District where he has worked for 24 years. He is a former director and past president of the Florida Lake Management Society. You can contact Larry at lbattoe@sjrwmd.com.

Figure 8. Total nitrogen removal rate (kg/d) by the marsh flow-way between November 2003 and November 2010 (solid line) and the cumulative amount (metric tons) of total nitrogen retained by the marsh flow-way (dashed line).
Tres Rios – Water for the Desert

Ron Elkins

Water in the desert is a scarce commodity, coveted by humans and animals alike, admired for the sights and sounds it can create, and even fought over. When quality of life in the arid Southwest is the topic of conversation, water, or the lack thereof, is often included. Desert water resources come in many forms: ground water, surface water, precipitation (that rare gem of the desert, rain), and recycled or reclaimed water. Proper terminology aside, as the population of the Southwest continues to grow, the strain of demand on this precious resource requires thoughtful conservation.

Larger cities in the Southwest use infrastructure and regulation to mitigate waste and prevent system loss. The City of Phoenix, among others, takes further steps to maximize the potential of their water resources. Wastewater is produced, then collected and treated. The treated effluent can be recycled for other uses such as for the Tres Rios Constructed Wetlands Project.

The Tres Rios Wetlands began in 1994 as a proposal for alternative water quality treatment. It was developed as a cost-effective method for advanced nitrogen removal and from there the facility is a co-mingling of discharges from the City of Phoenix and several of the surrounding cities. The site sits at the low point of the geography and is capable of handing very large flows from the populace.

The original demonstration project was built in partnership with the Bureau of Reclamation, and encompassed approximately 25 acres of land, including 15 acres of wetland cells. The areas were designated as the Cobble Site, the Hayfield Site, and the Research Site. Each site had its own characteristics, but collectively they would help develop an understanding of the natural dynamics of constructed wetlands in an arid environment.

The Cobble Site was situated in the bed of the Salt River with two parallel basins. The basins were identical with the exception of lining material. One was lined with native material and the other with soil from a local farm field. The site provided important information regarding infiltration rates and expected water quality based on liner construction. Additionally, the site served as a recreational area and provided insight into public interaction with an environmental project of this nature.

The Hayfield Site was actually a working hayfield before the project began. Located on the upper bank of the Salt River, above the ephemeral flow path, Hayfield has two parallel cells that discharge into a riparian area below. The site has become a true desert oasis. A heron rookery, beaver, and bobcats are examples of the varied wildlife it has attracted. It is not surprising that the Hayfield site has become a favorite of bird watchers and photographers. As important and unique as the fantastic collection of wildlife, the site has provided an opportunity to learn about surface water quality requirements for constructed wetlands, helped develop mosquito control programs (vector management), and has shaped budget and labor expectations for the future.

The Research Site consisted of 12 half-acre fast-flowing cells. Though problematic from the outset, the data collected were very helpful in determining minimum design standards of future wetland projects. It became apparent that size matters and constructed wetlands are not just basins containing water; wetlands encompass everything from the soil below to the treetops overhead.

Through successes and failures, the demonstration project (Figure 1) provided valuable information on the intricate nature of constructed wetlands. The original concept changed from purely one of water quality improvement to expanded goals:

1. Flood control elements for general area.
2. Ground water recharge.
3. Habitat restoration and development.
4. Public outreach and education.
5. Area-wide vector management.
6. Water reuse and availability.
7. Carbon footprint offset.

With the operational and water quality knowledge gained through the demonstration project, larger, more ambitious projects, the Tres Rios Flow Regulating Wetlands (FRW) and Tres Rios Overbank Wetlands (OBW) were constructed in partnership with the Army Corps of Engineers (Figure 2). These two larger systems are immediately west of the 91st Avenue Wastewater Treatment Plant, on the north bank of the Salt River. Using knowledge gained from the demonstration project, the new Tres Rios Wetland systems were designed and constructed to provide greatly improved performance, with considerations for water quality, localized flood management, and mosquito control taking precedence to make the project safe and useful.
Water Source

Influent for the project is supplied by discharge from one of the largest wastewater treatment facilities in the Southwest, the 91st Avenue Wastewater Treatment Plant (Figure 3). The plant has a treatment capacity up to 230 million gallons a day, with an average daily flow of 140 million gallons. The treatment plant is the starting point of the City’s reclamation effort. It provides highly treated effluent that historically had been discharged directly into the Salt River corridor, creating a perennial flow for the Salt River to its confluence with the Gila and Agua Fria rivers. Now, a portion of the daily flow provides cooling water to a power generating plant; the remainder supports the wetlands and riparian area. Water leaving the wetlands makes its way into a canal system, providing irrigation for non-food crop production. The wetlands construction was completed and steady wastewater flow was introduced in the spring of 2010.

Basin Design

The FRW incorporates two deep-water basins used for diurnal flow attenuation and three flow-regulating cells for enhanced water treatment and habitat features. The OBW system has two long parallel cells, one an emergent marsh and riparian corridor setting, and the other, a desert tree forest with grassland features. All portions of the project utilize vegetation native to the Sonoran Southwest, including Freemont cottonwood, Goodings willow, cattail, bulrush, giant and alkali sacaton grasses, mesquites, desert screwbean, and saltbush.

The two FRW deep-water basins have an approximate volume of 45 million gallons. Taking advantage of the diurnal flow patterns of the influent, water is stored in the cells and slowly discharged to the flow regulating cells using a computer control system. The discharge from these cells is monitored by pulse-Doppler flow meters as it makes its way through a set of discharge gates that provide feedback to the control system.

The three FRW flow regulating cells have a capacity of about 170 million gallons. The three cells are designed to have very tight level control functions of plus or minus one inch to help generate consistent water quality and achieve vector management requirements. Radar level sensors, pulse-Doppler flow meters, and effluent weir gate assemblies at the end of each of the three cells send information to the computer control system to maintain the tight water level tolerances.

Each of the three FRW cells has four separate islands that provide wildlife.
habitat and that can only be accessed by boat. These islands will be populated with large riparian trees to foster a soil-to-treetop complete ecosystem. Bald eagles, bobcats, and beavers have already visited the wetland and greater species diversity is anticipated.

At the end of this system, a collection channel can discharge effluent to U.S. navigable waters by direct route to the Salt River or through OBW. A function of this wetland system is to provide public interaction and wildlife habitat development. Public amenities, such as park benches and trails will be included to provide a more intimate experience. The cells are very long and narrow, allowing good public interaction and ease of facility management.

Vector Management

It became very apparent early on in the demonstration project that mosquitoes were going to be a difficult adversary. Mosquitoes are resilient and highly adaptable. Eradicating them is difficult, usually unsuccessful, and environmentally disruptive to the food chain, particularly natural predators. Accordingly, an integrated vector management plan was developed that incorporated monitoring, the assimilatory capacity of the wetland (predator-prey relations), and use of environmentally friendly vector control agents to moderate mosquito numbers.

The FRW and OBW systems are designed to produce a well-regulated number of mosquito larvae to promote food chain development, while limiting the potential of adult mosquito production.

Multiple carbon dioxide traps are used to monitor adult mosquito densities and dipping is performed to identify areas of larvae presence. Numeric triggers are being established to signal when food chain dynamics require adjustment by addition of larvicide. The biological larvicides, Bacillus thuringiensis israelensis and Bacillus sphaericus are applied in a rotational schedule to reduce the development of genetic resistance. The mosquitofish, Gambusia affinis is used as a primary predator and has been introduced to work in concert with the larvicides.

Initial Water Quality

When evaluating the benefits of constructed wetland systems in terms of ecosystem stability and water quality improvement, the rate and degree of change need to be measured against that which a regional natural source could produce. Natural systems take considerable time to establish, ecologically balance, and thrive before producing measurable water quality improvement. Constructed wetlands are no different.

One of the water quality improvements desired is nitrogen removal. Wetland systems are robust nitrogen consumers that can yield beneficial results. Although Tres Rios FRW system is in its infancy, initial nitrogen results are encouraging (Figure 4). As the system matures, more biomass will be accumulated and make more carbon available for synthesis, both of which are crucial for nitrogen sequestration.

Habitat Development

Creation and expansion of habitat is one of the most important benefits of a wetland, especially in an arid environment. The design specifications for the FRW and OBW have taken into account both successes and failures experienced in the demonstration project. Vegetation species, plant spacing, flow and depth regimes, open water zones, isolated islands, and routes for human access and maintenance were elements of the final design.

Several primary producers (macrophytic plants) and secondary consumers (fish) were introduced into the wetlands to create an accelerated communal system, based on the findings of the demonstration project. The remaining components of the food web were expected to find and colonize the site unassisted. Early evaluations indicated
that each system was functionally different, with a different level of species diversity (Figure 5).

There is a good indication of a viable and evolving micro/macro invertebrate community and food web based on less than one year of operation. Periphyton consists of 16 species and eight genera of diatoms (Gomphonema, Navicula, Cymbella, Achnanthes, Diatoma, Cyclotella, Synedra, and Nitzschia) at a total density of up to 159,000 per sq cm. Phytoplankton has included the following number of genera from each algal division: Cyanophyta (4), Chlorophyta (9), Bacillariophyta (2), Euglenophyta (10), Pyrrhophyta (1) and Cryptophyta (1). Densities were as high as $7.3 \times 10^5$ cells per ml. Zooplankton forms have included rotifers (50.1 percent), cladocerans (7.1 percent), copepods (29.3 percent), and ostracods (13.5 percent) at a maximum density of $5.1 \times 10^4$ per ml.

**Opportunities and Challenges**

The project provides a rare opportunity for documenting the development of a wetland system in the desert from its inception. Habitat development is crucial to the viability of the ecosystem, as is initial water quality data upon which relevant operational decisions are made. Internal processes need to be monitored and the personnel and equipment to do so must be made available. The current economic climate dictates that this will be a challenge for some time. With the assistance of its caretakers, the wetlands can yield impressive water quality results, perform flood mitigation, and be an ecological benefit to the area.

---

**Ron Elkins** is the Wetlands Process Control Specialist for the City of Phoenix Water Services Department. He is responsible for the daily operational process and maintenance of the Tres Rios Project. Ron can be reached at: ron.elkins@phoenix.gov.

---

*Figure 4. Preliminary nitrogen species removal efficiencies.*

*Figure 5. Flow regulating wetlands.*
Small-Scale Floodplain Forest Restoration

Steve Fix

One Facet of the Lake Belle View Restoration Project

Background

Lake Belle View was a 93-acre impoundment formed by a dam on the Sugar River at Belleville, Wisconsin (Figure 1). While the current dam was constructed in 1920, there are records of a grist mill at the site in 1847. A major renovation was done on the dam about 15 years ago.

About 172 square miles drained to Lake Belle View via the Sugar River. Its watershed was mainly agricultural, but also includes the rapidly developing southwest side of Madison and the City of Verona. The Sugar River carried heavy sediment and nutrient loadings, including an estimated 59,800 pounds of phosphorus to the lake each year. Lake eutrophication, benthic algae growth, and an overabundance of carp eliminated aquatic plant growth in the lake. The long-term sediment loading resulted in Lake Belle View silting in over the years to the point where water depths were 1 to 2 feet in much of the lake in 2008. Nutrient accumulation in the water column and in bottom sediments led to excessive algal growth in the lake causing odor and health concerns (some lake algae growth can lead to toxic conditions for humans and animals). Lake Belle View was considered a “carp factory” and a source for carp found upstream in the Sugar River and West Branch Sugar River systems.

About 30 years ago the citizens of the Village of Belleville (pop. 2,348) became concerned about the decline in water quality, fishing, and general recreational use of the lake. Several engineering studies were done for the village and alternatives considered for lake restoration. Alternatives ranged from doing nothing to large-scale lake dredging to dam removal, eliminating the lake. In March of 2009, the Village’s Lake Committee voted to proceed with a lake restoration alternative proposed by Montgomery Associates: Resource Solutions, LLC (MARS).

Lake Restoration Plan

The Lake Belle View restoration plan has the following elements:

- A reconfigured lake with construction of a berm to separate part of the lake from the Sugar River and to provide a pedestrian recreational path connecting the north side of the Village to the community park.
- Drawdown of the lake for carp eradication, bottom sediment consolidation, and construction.
- Dredging of the reconfigured lake with a maximum depth of 8-10 feet near the Belleville’s community park.
- Creation of emergent wetlands and floodplain forest through the placement and restoration of dredged material adjacent to existing islands.

The reconfigured Lake Belle View has been reduced from its pre-restoration size of 94 acres down to 40 acres. The Sugar River has been separated from most of the lake but still flows through a small impoundment and over the dam that
remains. The restored lake, cut off from the Sugar River and its pollutant load, will have aquatic ecosystem conditions more typical of natural oxbows found in the Sugar River floodplain downstream of Lake Belle View. A recent study of Sugar River oxbows cut off from the river found less turbid water and increased desirable aquatic plant growth. The study found a diversity of game fish and forage including a state endangered fish, the starhead topminnow.

The separation and dredging will have water quality benefits for both the river and the lake. Lake Belle View will benefit by not receiving sediment and nutrient inputs from the Sugar River. These benefits include better water clarity, allowing rooted aquatic plants to become established, and the re-establishment of a warm water sport fishery. The Sugar River benefits by not having Lake Belle View serve as a carp recruitment habitat. Bypassing the bulk of the lake will result in cooler summer water temperatures downstream in the river during summer low-flow conditions. Separation of the lake from the Sugar River and improvement of the fishery will reduce carp recruitment improving the Sugar River aquatic ecosystem upstream of Lake Belle View.

The project began with the drawdown of the lake in 2009 to eradicate carp, and to allow the bottom sediments to consolidate in order to construct the berm and allow heavy equipment access to dredge the bottom sediment. The berm separating the river from the lake was constructed in the fall of 2010 and dredging began after the berm was complete. The construction and initial restoration phase is expected to be complete by the end of 2011.

Floodplain Forests

Historically, floodplain forests were along the mid-size and large rivers in southern Wisconsin including the Sugar River. Floodplain forests provide habitat for diverse animal species, particularly migratory and nesting songbirds. Floodplain forests support a large number of plants and animals on the state’s endangered species or special concern lists. Agricultural and urban development has fragmented or eradicated large floodplain forest areas. Today only 8 percent of Wisconsin’s pre-settlement floodplain forest remains in moderate to high quality. The DNR believes that restoration and management of floodplain forested areas in the southern part of the state offer increased habitat opportunities for native plant and animal species.

The Sugar River floodplain forest is part of a major riparian wetlands complex that stretches along the Sugar River from Illinois to beyond Verona, Wisconsin. The pre-settlement Sugar River floodplain forest likely extended as far north as Belleville. The existing Sugar River floodplain forest extends from Illinois north to near Brodhead, Wisconsin. The forest becomes more fragmented by farms and communities between Brodhead and Belleville. The Wisconsin Department of Natural Resources has described the Sugar River floodplain forest in Rock County as having:

“large silver maples, swamp white oaks and green ash dominating the diverse tree canopy. Other tree species in the forest include shagbark hickory, hackberry, cottonwood, bitter hickory, bur oak, American elm, and basswood, with black willow common along the river.”

Floodplain Forest Restoration at Lake Belle View

The primary goal of the Lake Belle View restoration project is to restore the aquatic ecosystems of the lake and to increase the recreational and aesthetic values of the lake. An important secondary goal is to improve the aquatic ecosystem of the Sugar River upstream and downstream of the lake.

The floodplain forest restoration is geared toward providing more habitats for birds. A local amateur birdwatcher has documented prothonotary warblers at Lake Belle View (Figure 2). It is a bird “specialist” that nests in tree cavities in floodplain forests and is on the state’s special concern list. Other bird species she has seen at Lake Belle View include a nesting bald eagle, great blue herons, green herons, northern orioles, and other more common songbirds and water fowl (Figure 3).

The islands in Lake Belle View have been eroding since the dam was constructed in 1920. A comparison of the 1923 USGS New Glarus topographic map (Figure 4) with a year 2000 aerial photo of Lake Belle View (Figure 5) gives an indication of the erosion of the islands.

The islands support a floodplain forest ecosystem that is deteriorating...
due to erosion and loss of habitat. The restoration plan will expand floodplain forest habitat by using the dredge fill to expand the existing islands (Figure 6).

The restoration plan will establish a succession of habitats from open water to shallow wetland to floodplain forest. The restoration involves dredging up to eight to ten feet deep adjacent to the village park. Beyond this deeper water habitat, the dredging would get progressively shallower. Dredge spoil will be placed adjacent to the existing islands to enlarge them, creating 10.9 acres of new floodplain forest and other wetlands habitat. Creating a gradual lake bottom slope will help stabilize the islands.

The lake mitigation and restoration plan describes the habitat succession as:

- Submergent and floating-leaved aquatic beds in water with depths of approximately two to eight feet below normal pool (elevation);
- Emergent aquatic beds in water depths of approximately two feet or less below normal pool;
- Wet meadow/floodplain forest at elevations of approximately zero to two feet above normal pool;
- Wet mesic prairie/floodplain forest at elevations between approximately two to five feet above normal pool;
- Mesic prairie/forest at elevations greater than five feet above normal pool.

The created or restored wetlands will provide habitat for birds, fish, and amphibians. These vegetation zones will...
be planted with native aquatic, wetland, and floodplain plant species. Floodplain trees that are proposed for planting are silver maple, swamp white oak, green ash, hackberry, and bur oak. Wet meadow species to be planted include asters, sedges, blue-joint grass, boneset, and joe-pye weed. Mesic prairie and forest plantings will include hickories, white and red oaks, asters, big bluestem, and goldenrod. Some of the aquatic species for shallow water include yellow water-lily, white water water-lily, wild celery, bulrush, pickerelweed, and common bur reed. Dormant native seeds in the soil are expected to supplement the planted native vegetation.

A healthy floodplain forest needs regular, seasonal flood pulses to inundate the bottomland long enough for floodplain plant species to flourish and to reduce potential for invasive species to be introduced into the restored floodplain. The floodplain forest at Lake Belle View will be cut off from the Sugar River. The river-lake berm is designed so that floods greater than the 25-year flood would overflow the berm at two overflow sites creating the flood pulse. The new lake design also includes the option for water level management that could periodically raise the level of the lake a maximum of one foot to mimic natural flood pulses if needed, or draw the lake down approximately one foot to expose mud flats for shorebirds during migrations.

The lake restoration plan includes a monitoring element that the village will conduct or coordinate. The floodplain-wetland restoration monitoring will assess the wetland functional values, floodplain and wetland plant species diversity, and a health assessment of the planted trees and forest establishment every year for the first five years following the project’s completion. The tree health and forest establishment will be assessed once every five years for post-restoration years five through 20. If unforeseen or unwanted changes occur to the floodplain restoration efforts, or any other aspect of the lake restoration, action will be taken to correct the situation.

One unwanted change of great concern is the introduction and encroachment of invasive plant species. The pre-construction wetlands assessment done by Natural Resources Consulting (NCR) in 2009 noted several invasives within the project area. The ones of greatest significance were reed canary grass, creeping jennie or moneywort, common burdock, and common buckthorn. An invasive fish species, the mosquito fish, is found downstream in the Sugar River.

The removal of invasive plants from the existing floodplain islands will be done in 2011. In addition to the invasives found in 2009, other invasive species of concern include non-native honeysuckles, dames rocket, garlic mustard, purple loosestrife, and phragmites. The project’s mitigation work plan calls for additional invasive species removal in 2012. Inspecting for the presence of invasive species and their eradication or control will be an ongoing process at Lake Belle View.

The Future Vision

What will Lake Belle View look like in 2030? It will be a 40-acre lake with good water clarity dominated by groundwater rather than surface water. The restored lake, wetlands, and floodplain forest will provide habitat for diverse species while providing a range of active and passive recreational opportunities. There will be largemouth bass, panfish, and perhaps northern pike in the lake for sport fishing. The shallow water wetland on the north side of the lake will be providing good habitat for juvenile fish. Turtles and frogs will be heard and seen in the backwater areas. Bird watchers will be able to see several bird species using the lake and the island floodplain forest for nesting, feeding, or resting during migration. School children will hike along the recreational path and explore the diverse habitats and microecosystems of the floodplain and wetlands, and perhaps participate in vegetative monitoring. Lake Belle View will once again be the focal point of the community, a resource to be enjoyed by all.

References


Note: Special thanks to Jeff Hruby of Montgomery Associates for his assistance and to Jean Kringle for providing the bird photos.

Steve Fix is an environmental consultant affiliated with Agrecol Environmental Consulting. He has over 30 years experience working on environmental issues including wetland delineation and mapping, water resources planning, rural and urban nonpoint source pollution, agricultural and land conservation issues, reviewing environmental issues regarding power line siting, and preparing environmental assessments. You can reach Steve at birchhill.enviro@gmail.com.
Wetland Loss and Water Quality Changes at Upper Klamath Lake, Oregon

Oregon’s Largest Lake and Largest and Longest Reoccurring HAB

The largest freshwater lake in Oregon (Figure 1), Upper Klamath Lake (UKL) (61,543 ac; over 76,340 ac including Agency Lake), has had potentially harmful algae blooms (HABs) for over 50-60 years, and severe blooms for the past 30 years. Blooms dominated by the cyanobacterium, *Aphanizomenon flos-aquae*, typically start in May and often persist through October. One of the idiosyncrasies of the UKL condition is that the lake has been a major source of algal dietary supplements (super blue-green algae) since the early 1980s. *Aphanizomenon* and other cyanobacteria have been the primary algae ingredients in harvested quantities of over 1 million kg (dry wt.) per year (Carmichael et al. 2000).

HABs of this magnitude began to happen at UKL when over 35,000 acres of wetlands were systematically, cumulatively, and without mitigation, isolated from the lake and transformed through diking and draining for agricultural uses. That radical eco-surgery encouraged by federal policies in the late 1800s and early 1900s ended in 1971, but the consequences continue through the 25-mile length of the lake, down the 230 miles of the Klamath River to the Pacific Ocean off California.

The ability of littoral marshes to regulate or even influence lake water quality depends on a variety of factors, including the size of the marsh relative to the lake area and volume, location of the marsh in the lake or adjacent to inflowing streams, and seasonal changes in the marsh.

Wetland Loss at UKL Basin Lake Level

In the mid-1990s the U.S. Geological Survey initiated a study of drained marshland around UKL. The purpose of this study was to quantify the contribution of nutrients from drained wetlands to UKL relative to other sources of nutrients in the lake. An estimate was developed of where wetlands once were in the lake below UKL full pool. This estimate included the dates when diking and draining occurred from 1889-1971.

The study was a significant step in providing definition of the extent of Upper Klamath Lake before diking and draining began in the late 1800s (Snyder and Morace 1997). The study findings (Figure 2) made it clear where and when 35,390 acres of wetlands had been lost from the lake, resulting in a smaller and changed lake. Table 1 provides an overview of how the lake changed in area through this loss.

The littoral wetland area of the lake once comprised 51,510 acres (46.2

---

**Figure 1.** View of UKL from near Caledonia Marsh toward northwest June 25, 2007. Suspected organic products of *Aphanizomenon* bloom on wave crests in foreground.
percent) of the total lake area of 111,510 acres at maximum pool surface elevation. Following dam construction in 1921 and after the last diking and draining in 1971, the lake area at maximum pool elevation of 4143.5 ft had decreased to 76,343 acres, with littoral marsh area decreased to 16,120 acres (21.1 percent of the total lake area). In other words, the lake lost 31.5 percent of its area, and the lake volume associated with this area, through diking and draining. The in-lake wetland area was reduced by 68.7 percent. In addition, there was a reduction of littoral lake volume from 82,000 ac-ft to 28,000 ac-ft; a reduction of 65.9 percent. Figure 3 shows accumulating wetland losses 1889-1971, losses of which came to an end as national environmental legislation was enacted to prevent such loss without public scrutiny, or without mitigation.

Figure 4 is a high-altitude color infrared image acquired from a U2 aircraft in 1974 just three years after the last diking and draining project was completed in the northern part of the lake system (Agency Lake Ranch). Swirls of the cyanobacteria *Aphanizomenon* are visible in the northern end of UKL and in Agency Lake (shown in the top of the image and connected to UKL by a narrow istmus).

There is general agreement that during the first half of the 1900s UKL changed from a eutrophic to a hypereutrophic lake. This change altered the habitat of algae, zooplankton, benthos, and fish of this largest lake in Oregon. Two of the sucker species in the lake were listed as endangered in 1988 (Lost River sucker [*Deltistes luxatus*] and shortnose sucker [*Chasmistes brevirostris*]).

### Marsh Dissociation Hypothesis:
**Change of Lake Water Quality Resulted from Wetland Loss and Transformation**

Our perspective is that the elimination of over 35,000 acres of wetland from within the lake, and the transformation and loss of other UKL basin wetlands, was the primary factor changing the lake from eutrophic to hypereutrophic and altering algae populations to dominance by the cyanobacterium, *Aphanizomenon flos-aquae*. A suggestion of this relationship is shown in Figure 5, which shows the unique and persisting reproductive structure of *Aphanizomenon* (the akinete) in dated UKL sediment layers and the accumulating wetland losses.

### Pre- and Post-Loss Wetland Nutrient Retention

In the absence of basin studies addressing the function of marsh wetlands in the littoral zone under specific hydrologic conditions, we can still estimate annual nitrogen and phosphorus uptake by in-lake wetlands. Measurements of nitrogen and phosphorus annual net retention rates are readily available in wetland treatment literature. The following average to low-end estimates were selected from recent literature (Table 2).

Isolating ~35,390 ac (14,322 ha) of in-lake UKL wetlands through diking and draining, and severing their connection with UKL, would have meant a loss of nitrogen and phosphorus uptake by in-lake wetlands. Measurements of nitrogen and phosphorus annual net retention rates are readily available in wetland treatment literature. The following average to low-end estimates were selected from recent literature (Table 2).

Isolating ~35,390 ac (14,322 ha) of in-lake UKL wetlands through diking and draining, and severing their connection with UKL, would have meant a loss of nitrogen and phosphorus uptake by in-lake wetlands. Measurements of nitrogen and phosphorus annual net retention rates are readily available in wetland treatment literature. The following average to low-end estimates were selected from recent literature (Table 2).
The loss of wetland and the associated loss of nutrient uptake capacity would have resulted in increasing amounts of phosphorus and nitrogen becoming available to plants within the undiked portions of the lake, e.g., phytoplankton and particularly *Aphanizomenon*.

The seasonality of wetland uptake or retention of nitrogen and phosphorus, the plant nutrients of primary interest to wetland treatment scientists, is well documented (e.g., Kadlec and Knight 1996 and Mitsch, Horne, and Nairn 2000). The seasonal uptake of phosphorus by the extensive pre-colonial wetland plants would have desynchronized the movement of dissolved phosphorus into the lake. This seasonal requirement and uptake of phosphorus by aquatic plants would occur at approximately the same season as the need for phosphorus by the phytoplankton in the lake. Uptake of nitrogen and phosphorus in winter associated with wetland detritus also occurs (Kadlec and Knight 1996).

**Wetland Decomposition Products and Cyanobacterial Growth**

Aside from visually apparent *Aphanizomenon* blooms, one of the continuing signature characteristics of the lake has been the brownish appearance of the lake water. This coloration is very apparent in standing water of large marshes in the upper basin (Klamath Forest Marsh, for example). The quantity of wetland vegetation in the upper basin transformed marshes along with the existing in-lake marshes and seasonal pumped discharges from diked and drained wetlands is still of sufficient quantity to produce measurable dissolved organic carbon (DOC) in lake water (Table 3).

Since humic carbon or humates can comprise over 50 percent of the DOC concentrations (Perdue and Ritchie 2005), the loss of in-lake wetlands, would have resulted in lower seasonal and base lake concentrations of dissolved humic substances. These wetland vegetation decomposition products have been identified as agents that suppress the growth of Cyanobacteria (Kim and Wetzel 1993; Scully et al. 1996).

Complicating aspects of our hypothesis are the multiple possible inhibitory mechanisms related to wetland vegetation decomposition products DOM, DOC, and humates and the interactions of these with other compounds and processes. These mechanisms could be acting individually or in combinations to have produced the net end-effect of Cyanobacteria suppression.

**Testing the Marsh Dissociation Hypothesis**

It’s one thing to hypothesize that the amount of wetland loss from UKL had profound consequences for the water quality of the lake and the mechanisms

---

**Table 1.** The Area of Littoral Marsh and Limnetic Open Water of Upper Klamath Lake (including Agency Lake) Before Commencement of Diking (~1889) and After Diking, Draining and UKL Outlet (Link River) Dam.

<table>
<thead>
<tr>
<th>Condition of Lake</th>
<th>Lake Surface Elevation</th>
<th>Littoral</th>
<th>Lake Area (Ac)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Diking</td>
<td>Minimum (BR datum, ft)</td>
<td>4140.0</td>
<td>20,320 (30%)</td>
<td>47,400 (70%)</td>
</tr>
<tr>
<td>Before Diking</td>
<td>Maximum (BR datum, ft)</td>
<td>4143.0</td>
<td>51,510 (46.2%)</td>
<td>60,000 (53.8%)</td>
</tr>
<tr>
<td>After Diking and Dam</td>
<td>Minimum (BR datum, ft)</td>
<td>4136.0</td>
<td>0.0 (0.0%)</td>
<td>55,800 (100%)</td>
</tr>
<tr>
<td>After Diking and Dam</td>
<td>Maximum (BR datum, ft)</td>
<td>4143.3</td>
<td>16,120 (21.1%)</td>
<td>60,223 (78.9%)</td>
</tr>
</tbody>
</table>

---

**Figure 3.** Cumulative wetland loss from original 51,510 acres within Upper Klamath Lake 1889-1971 (Snyder and Morace 1997).
for the change in the lake seem reasonable and feasible. However, it is another thing to test the hypothesis. The relationship between sediment akinete numbers and accreting wetland loss also looks good, but just because most men wear belts doesn’t mean that pants would fall if belts weren’t worn.

We felt we needed first to determine whether we detect a suppressing effect of the brown water from Klamath Basin marshes on the growth of UKL Aphanizomenon flos-aquae. We didn’t need to identify mechanisms for the suppression but we did need to keep these in mind and select marsh water and conditions for the assays that would approach optimum conditions. We first did replicated jar assays (Figure 6) in 2005 in controlled conditions in a greenhouse at Oregon State University, then developed a limnocorral (Figure 7) to conduct in-lake assays at a protected location near Caledonia Marsh. Effects were determined by measurements of water quality (pH, DO, SpC, temp, phosphorus, and nitrogen) dry weight filtered biomass, and measurements of Aphanizomenon biovolume. The assays were the research for the MS degree of K. Haggard, Oregon State University (Haggard 2008). Figure 8 shows the results of a jar assay where dried wetland plant material was added to lake water dominated by A. flos-aquae.
Native wetland plant tissues can clearly cause mortality of *A. flos-aquae*. This finding, and others in the studies, supports our hypothesis that the loss of wetlands could contribute to the massive annual blooms of *A. flos-aquae* in UKL. Not only are wetlands nutrients sinks, but may have additional value by providing dissolved organic carbon that can suppress cyanobacteria. We hope that these results will trigger interest in an unrecognized and beneficial role that wetlands may play in protecting water resources from cyanobacterial blooms.

**Caveats and Implications**

In an attempt to compensate for these wetland losses, both the federal government and privately funded organizations have purchased former farmed and ratched wetlands areas and are reclaiming these areas as wetland (see Figure 2 for locations). The present total of this intended reclaimed wetland area is in excess of 17,500 acres. The land surfaces of these areas to be reclaimed are often at elevations six or more feet below maximum lake elevations. The total investment to acquire these former wetland areas has been $19-20 million. The cost of reclaiming and developing wetlands is additional.

Purchasing and restoring these once-wetland areas has proceeded very slowly. However, the spectacular dike-breaching explosions at four locations at the perimeter of the TNC Williamson River Preserve in fall of 2007 is significant progress in reconnecting wetlands behind dikes to the lake (see YouTube videos “Explosive Conservation: Restoring Wetlands with a Big Bang!”). The Upper Klamath Lake system cannot be restored to what it was in its pre-colonial condition, but the awareness of the importance of wetlands in this system has already produced new management strategies.

**References**


N. Stan Geiger is a professional wetland scientist with the Society of Wetland Scientists, a phycologist, and owner of Aquatic Scientific Resources, Portland, OR. He has worked in Oregon as a consulting aquatic scientist since 1974. He supervised wetland restoration at Running Y Ranch and Resort at Caledonia Marsh on UKL beginning in 1997, conducted other wetland-related investigations for public and private entities at UKL, and served on the technical advisory committee for the ODEQ 2002 TMDL for UKL. Stan can be reached at annsstang@frontier.com.

Allen J. Milligan, Ph.D., is an associate research professor in botany and plant pathology at Oregon State University. He has been working on harmful algal blooms in both lakes and oceans since 1985. He has extensive experience in photosynthetic physiology of algae. Allen can be reached at Allen.Milligan@science.oregonstate.edu.

Kale Haggard has primarily worked in the terrestrial realm of barley breeding. Many inquiries to the Oregon State University Barley Project regarding the use of barley straw for algae control led to his involvement in this research. Kale is currently a faculty research assistant for the Oregon State University Barley Project. He can be reached at haggardk@oregonstate.edu.

**We’d like to hear from you!**

**Tell us what you think of LakeLine.**

We welcome your comments about specific articles and about the magazine in general.

**What would you like to see in LakeLine?**

Send comments by letter or e-mail to editor Bill Jones (see page 7 for contact information).
Beaver Wetlands

Sharon T. Brown and Suzanne Fouty

Effects Upon Wildlife and Water

A half-mile-long beaver dam in Canada made international news recently when satellite photos clearly showed the impact of *Castor canadensis* upon the earth. The beaver is one of the few species, besides humans, that builds structures, such as the huge dam in Canada’s Wood Buffalo National Park, that are large enough to be visible from space. Today, only in highly remote locations of North America is it possible for nature’s engineers to create similarly impressive alterations of the landscape. Ecologist Jean Thie found the immense Alberta dam while scanning satellite images for signs of climate change. This is fitting because restoring beaver wetlands is one of the most effective and economical ways to minimize some potential impacts of climate change on wildlife habitat and the land’s hydrology, and thus human communities.

The path to the future requires understanding the past and how current and historic human activities have defined our present situation. Before European settlement of North America, the continent’s beaver population was between 60 to 400 million, according to estimates from historic data of trapping harvests (Naiman et al. 1988). It was the quest for “brown gold” that stimulated much of the early exploration and colonization of the New World, where beaver pelts were commonly used as currency. The first waves of fur traders and trappers emanated from the Northeast coast and the mouth of the Mississippi River. By the early 1900s, beaver populations in the continental U.S. and southern Canada were nearly eradicated. Eventually beavers from isolated, surviving colonies were used to reseed vacant habitats and trapping bans were instituted as policy makers and public land managers recognized the implications of their loss to fish and game. Yet the current beaver population of North America is probably 10 percent, or less, of the original number (Figure 1).

The estimated loss of about 90 percent of these four-footed engineers, and the vital wetlands they once maintained has profoundly affected the continent’s hydrology (Figure 2). Their systematic and widespread removal represents the first large-scale Euro-American alteration of watersheds. As beavers were removed, and their dams failed from lack of repairs or were destroyed, changes took place in how water was stored and routed from upper to lower watersheds. Channels eroded into the soft sediments once trapped behind the dams. Over time, valley bottoms shifted from landscapes dominated by ponds, multiple channels, wetlands, and wide riparian zones abundant in fish and wildlife, to landscapes defined by the simple, incised, overly wide, single-thread channels with narrow strips of riparian vegetation that we know today. In addition, widespread drainage of North American wetlands via outlet ditches lined with tiles occurred; over 50 million...
acres were drained for cropland in the U.S. Midwest alone (Hey and Phillipi 1995). Much of the drained acreage later proved unsuitable for agriculture, yet the land’s water storage, flood mitigation capacity, and complex, extensive wildlife habitat was dramatically reduced. With a few exceptions, many species of mammals, birds, amphibians, mussels, and fish have not recovered their numbers.

Human activities, past and present, have systematically stripped watersheds of those features that once helped store and slowly release water, dampen flood peaks, and sustain stream flows during droughts. Now connected, incised river systems function as sewer lines, rapidly moving water from the upper to the lower watershed with little water storage, and wetlands are a fraction of their past extent. These changes have severely compromised the ability of human and wild communities to successfully deal with climate change and increased climate variability.

The potential contribution of beavers as partners in helping to mitigate the impacts of climate change, and other environmental problems, such as the rising rate of species extinction, is considerable. Dam building by beavers (Table 1) naturally and economically restores freshwater wetlands, which have been rated as the world’s most valuable terrestrial ecosystem in terms of natural services (Costanza et al. 1997). Such services include providing water storage, climate regulation, and wildlife habitat. One species that demonstrates the restorative potential of beavers is the

<table>
<thead>
<tr>
<th>Element</th>
<th>Narrative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stream complexity</td>
<td>Dams create ponds of varying depths, add wood to the channel, and create side channels.</td>
</tr>
<tr>
<td>Riparian vegetation structure</td>
<td>Rising and more stable groundwater levels result in the expansion and diversification of the riparian woody and herbaceous vegetation on valley floors and along the stream channels.</td>
</tr>
<tr>
<td>Species diversity</td>
<td>Expanding riparian, wetland and pond habitats, and habitat edges, plus cooler stream temperatures, result in increased diversity of aquatic and riparian dependent species.</td>
</tr>
<tr>
<td>Vegetative ground cover</td>
<td>Elevated groundwater tables improve the vigor of the ground cover and shift vegetation types from drought-tolerant to more water-dependent species.</td>
</tr>
<tr>
<td>Floodplain connectivity</td>
<td>Ponds reconnect stream to their valley floor by decreasing the available channel capacity. Valley floors become active floodplains. Temporary flood storage increases, downstream flood magnitudes decrease, groundwater recharge of the valley floor sediments increases, and water tables rise.</td>
</tr>
<tr>
<td>Species migration patterns</td>
<td>Elevated water tables, increased groundwater return flows, and ponds restore perennial flow back to intermittent streams and decrease summer stream temperature. Habitat connectivity and complexity in the watersheds increase and fish passage barriers (i.e., elevated temperatures or dry channels) and fish distribution sensitivity to disturbance (i.e., fire, flooding) decrease.</td>
</tr>
<tr>
<td>Sediment transport</td>
<td>Ponds and increased riparian woody vegetation stabilize the stream banks, increase their resistance to stream erosion and trap any sediment that enters the stream. Life of downstream reservoirs increases.</td>
</tr>
<tr>
<td>Nutrient cycling</td>
<td>Increase in the diversity of plant and animal species expands mineral and carbon cycles in the area.</td>
</tr>
<tr>
<td>Water quality</td>
<td>Sediment inputs decrease. Summer stream temperatures decrease. Other improvements are related to nutrient trapping and dissolved oxygen.</td>
</tr>
<tr>
<td>Water quantity</td>
<td>Yearly water quantity stays the same but its spatial distribution (groundwater, pond, stream), timing of release and passage through the watershed change. More water is stored during the spring for later release during the summer and fall, or in following years, increasing water availability though not total quantity.</td>
</tr>
<tr>
<td>Water storage</td>
<td>Amount of water stored in a watershed increases. Ponds hold surface water behind dams, reconnect streams to their valley floor and change valley floors from terraces back to active floodplains. Water tables rise and summer base flows increase and are cooler. Total amount of water stored may increase over time to some maximum amount as valley floor sediments fill up with water and the elevated water table slows the rate of groundwater flow from the hill slopes to the streams. Groundwater stored in hill slope sediments increases.</td>
</tr>
<tr>
<td>Climate change, drought</td>
<td>Water-dependent ecosystems and species become less sensitive to droughts, wet years and climate change.</td>
</tr>
</tbody>
</table>
wood duck. Its population has rebounded from the brink of extinction with the return of just a fraction of the former beaver population.

Rapid restoration of watershed systems is critical for our survival, and the return of abundant, actively maintained and widespread beaver dams is critical to that restoration. The following examples from five different areas demonstrate the role that beavers, and beaver trapping, plays in enhancing or degrading stream and riparian stability, complexity and water storage capability. These five examples show that the influence of beavers is not limited by geography.

Example 1: Upper Mississippi and Missouri River Basins (Hey and Phillipi 1995).

The researchers estimate that beaver ponds covered 51.1 million acres in 1600 compared to 511,000 acres in 1990. This reduction in surface water and groundwater storage has resulted in a huge loss of flood control, and system stability during droughts and years with high precipitation.

Example 2: Kabetogama Peninsula, Minnesota (Naiman et al. 1988).

This study evaluated changes in stream and riparian systems between 1940 and 1986 as a result of beavers returning to the area. Table 2 shows the increase in ponds, wetlands, wet meadows, and moist meadows – indicators of increased amounts of surface and ground water stored in the system – during the expansion of beavers and beaver dams in the drainages. While the article does not talk about climatic variability, it is certain that in the 46-year-period there were dry periods and wet periods, yet during that time the amount of water stored increased.

Example 3: Elk Island National Park in east-central Alberta, Canada (Hood and Bayley 2008).

This study examined changes in the amount of open water during dry and wet years between 1948 and 2002 as a result of the presence or absence of beavers. Both 1950 and 2002 were very dry years. Beavers were absent in 1950 but present in 2002. In 1950 wetlands held 61 percent less open water (565 acres) than in 2002 when beavers were well established (1467.5 acres). The average pond size in 1950 was 9.6 acres compared to 87.7 acres in 2001 (ponds were measured in 1948, 1950, 1996, and 2001). The 2001 values represent a huge increase in the amount of water stored in the system. The beaver dam building and maintenance has made the area much less sensitive to drought as well as helped to decrease downstream flood peaks by increasing the river’s rapid access to its floodplain during high flows.

Example 4: Crane Creek, Oregon (Schaffer 1941).

Prior to 1924 beavers were present in Crane Creek and the meadows had stirrup-high native grasses that were sub-irrigated by beaver ponds. In 1924 the beavers were trapped out. In 1925 the channel began to incise and by 1935 the channel had deepened 25 feet. Instead of stirrup-high native grasses, there were clumps of new sagebrush and only sparse remnants of the original grasses, showing how fast channelization and transformation of an ecosystem could occur. In 1936 the beavers were reintroduced, and by 1938 the water table had risen and the hay meadow production had improved. 1939 was a drought year, yet water was abundant on the ranch with beaver ponds, while absent downstream on the ranch without beaver ponds.

Example 5: Price Creek, Montana (Fouty 2003).

This study showed the impact of the trapping of beavers, and their presence, upon water depths (i.e., water stored). Beavers were trapped out between 1994 and 1995, but the beaver dams inside the cattle exclosure were still largely intact and functional in 1995. In contrast, dams were absent downstream of the exclosure (Reach 1), though remnant dams had been noted during the 1994 survey of Reach 1.

Table 3 shows the average water depths and the variability in water depths (standard deviation) in the three reaches in 1995 and 1998. In 1995, the average water depths in Reaches 2 and 3 (beaver-dam controlled reaches) were twice the average depths in Reach 1 (no beaver dams). In addition, the variability in water depths in Reaches 2 and 3 was greater than in Reach 1, indicating more variable channel bed habitats with possible fisheries and macroinvertebrate benefits. By 1998, the dams in the cattle exclosure had either completely disappeared or were actively breaching. Water levels were now similar in all three reaches. Figures 3 and 4 show the visual difference between reaches with and without beaver dams.

**Coping with Climate Change**

We are entering a period of increased climatic variability. At the same time our demands for surface and groundwater are increasing, the quality and quantity of this resource is decreasing. Groundwater levels continue to drop, perennial streams go seasonally dry, wet meadows transform into sagebrush-dominated systems in the West, and large floods appear to be increasing. Too often the response has been to build more reservoirs, or build more and higher levees along rivers, further confining them. These activities may give us greater control over the short-term but little else. Reservoirs provide little habitat or groundwater storage compared to natural wetlands. Reservoirs often serve only a very few people at the expense of many species and communities. Confined rivers do not recharge water tables or develop complex habitats. Instead, they increase downstream flooding by severing the connection between the river and its floodplain – so there is nowhere to temporarily store water.

**Coexisting with Beavers**

Common reasons given for keeping beaver populations at a fraction of an area’s possible number are that their dams flood roads and properties, and they cut...
Table 3. Comparison of the Maximum Water Depths in Price Creek, MT in 1995 and 1998.*

<table>
<thead>
<tr>
<th>Stream Reach</th>
<th>Average water depth (ft)</th>
<th>Standard Deviation (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reach 1 (no beaver dam influence)</td>
<td>0.9</td>
<td>0.75</td>
</tr>
<tr>
<td>Reach 2 (beaver dam influence)</td>
<td>2.15</td>
<td>0.9</td>
</tr>
<tr>
<td>Reach 3 (beaver dam influence)</td>
<td>1.73</td>
<td>0.8</td>
</tr>
</tbody>
</table>

*By 1998 all the dams in the reaches that had been controlled by beaver dams had either totally failed or were failing.

Figure 3. Price Creek, MT (1995). This beaver dam controlled reach is just upstream of Reach 3 in Table 2.

Figure 4. Price Creek, MT (1998). This is Reach 1, downstream of Figure 3. In both 1995 and 1998, this section lacked beaver dams.

down desirable trees. But challenges can be met with a creativity that benefits the beaver, the environment, and human communities. For instance, modern water level control devices are highly effective, and can be installed for an economical and environmentally sound, lasting solution (Brown et al. 2001; www.BeaversWW.org). In addition, a variety of methods are available to protect special trees since beavers rarely engage in clear-cutting. Individual trees, or stands, can be guarded with sturdy fencing for long-term solutions.

At lakeside sites, beavers may use a dock as a roof, and/or dig into Styrofoam flotation material for a cozy den. Using galvanized wire fencing to exclude beavers from beneath docks, and/or wrap flotation blocks, provides lasting solutions. Such fencing can also be staked along the water line at earthen dikes to discourage burrowing.

Education about these good-sized, but amicable animals, and their natural methods of population control, including territorial behavior, is essential. Exaggerations about population sizes are common. Most people are unaware that one colony (family) often builds several lodges, and routinely guards a large territory from strange beavers. Like humans, their footprint can be large even when their numbers are small. Several environmental groups, including the Grand Canyon Trust, Wildlife 2000, and The Lands Council, are involved in restoring beavers to suitable habitats in the West and improving how people perceive beavers through education.

Conclusion

Competition is increasing between communities and groups for water, a limited resource. It is time to systematically and rapidly restore the stability, complexity, and water retention capability of stream and riparian ecosystems. Beavers are key to this restoration.

For beavers to successfully aid us in restoring watershed vibrancy, stability, and complexity, we must first begin to restore riparian woody vegetation (beaver food and building materials) to stream banks, where this is in short supply. In addition, we must change beaver trapping regulations to provide them, and their wetlands, with greater protection.
The return of beavers, and recognition of their contribution, will lead to rapid increases in surface and groundwater storage, improved wildlife habitat, decreased regional flood damage, improved water quality and increased water quantity within a few years. Beavers will not make sense everywhere because of the extent and location of human development. There are, however, large areas of public land with less development where beavers could be allowed greater freedom to expand. Certain private lands exist, too, where beavers would be a welcome addition. These areas would become water storage zones – complex ecosystem reservoirs that would provide huge benefits to many human and wild communities. Proactively identifying suitable sites for beavers, and the acceptable limits of beaver-driven changes, would allow communities to plan how to minimize beaver conflicts while maximizing their benefits (Figure 5).

Time is short. There are many things human and wild communities can live without. Water is not one of them.

References

Sharon T. Brown, M.A., is a biologist who is co-founder and director of the educational nonprofit Beavers: Wetlands & Wildlife (www.BeaversWW.org). Her work at BWW has included consulting on beaver/human conflicts, installing water control devices, and giving programs on coexisting with beavers for 24 years. She previously taught college biology courses full-time, and her photos and writings have appeared in national publications. She may be contacted at sbrown@BeaversWW.org.

Suzanne Fouty, Ph.D., works for the U.S. Forest Service as a hydrologist. Her research has focused on how cattle, elk, and beavers alter streams, and on long-term groundwater recharge rates in semi-arid landscapes. She has taught environmental education and has been an independent consultant. She can be reached at suzannefouty@yahoo.com.

Figure 5. This beaver dam, pond, and lodge are located along the Snake River in Grand Teton National Park, Wyoming. Such public lands could be ideal places for more beaver wetlands. Photo: © 2004 Bruce Thompson / Pangraphics
The year 2011 is a pivotal one for the National Wetland Condition Assessment, as years of planning culminate in field assessments across the country between April and September. EPA, in collaboration with committed federal, state, tribal, and academic experts from across the country, spent considerable effort over the past four years developing standard methods for collecting wetland data and assessing wetland condition for the conterminous United States. Detailed information on the NWCA technical approach can be found in the documents at www.epa.gov/wetlands/survey.

In summary, 900 wetland assessment areas were randomly selected from the FWS S&T plots using a survey design that ensures the sample is representative of wetland resources at national and regional scales (Stevens and Olsen 2004). The S&T plots were used as the base data layer because they are the most consistent and up-to-date source of mapped wetland status on a national scale. NWCA sites are distributed across seven of the Cowardin wetland classes characterized in the S&T Report to facilitate comparison of the findings from both efforts. In addition, some states invested additional resources to supplement the NWCA survey design to provide state-scale reporting of wetland quality. For example, additional NWCA sites were added in North Dakota to allow reporting of wetland quality for the Prairie Pothole region in that state.

A great deal of effort went into synthesizing and considering potential field methods and indicators of wetland condition. The selection of NWCA field

---

### The National Wetland Condition Assessment: National Data on Wetland Quality to Inform and Improve Wetlands Protection

by Michael Scozzafava, Mary E. Kentula, Elizabeth Riley, Teresa K. Magee, Gregg Serenbetz, Richard Sumner, Chris Faulkner, and Myra Price

The U.S. Environmental Protection Agency (EPA), in collaboration with states, tribes, the U.S. Fish and Wildlife Service (FWS), and other federal partners, will conduct the first-ever National Wetland Condition Assessment (NWCA) in 2011. This survey is the fifth in a series of National Aquatic Resources Surveys carried out by EPA and state partners to improve understanding of the quality of the nation’s waters. The results of the NWCA will be published in 2013 and repeat surveys will be conducted every five years, resources permitting. The NWCA is designed to build on the success of the FWS Wetland Status and Trends (S&T) Report. Just as the S&T Report characterizes wetland acreage by category across the conterminous United States, the NWCA will characterize wetland condition nationwide for many of the same wetland classes. When paired together, the two efforts will provide the public and government agencies with comparable, national information on wetland quantity and quality.

Combining wetland quantity and quality data provides a stronger basis for informing effective wetland protection strategies. The wetland quantity information produced by the FWS addresses wetland acreage gained or lost annually, where the greatest gains and losses are occurring, and what wetland types are most vulnerable to loss. The NWCA will provide detailed information on wetland quality by wetland type and area of the country, providing additional insight into the implications of the acreage gains and losses. Wetland quality or condition speaks to how wetlands differ from their “natural” state, providing an assessment of the overall ecological integrity of the resource and the relative status of wetland processes, such as the ability of a wetland to absorb nutrients (Fennessy et al. 2004). In addition, the stressors most associated with degraded wetland condition will be identified because they provide insights into the causes of declining wetland quality. For example, ditching substantially impacts wetland hydrology, altering plant community composition and habitat for many wetland-dependent organisms.

At the same time, ditches decrease the capacity of wetlands to store stormwater because they rapidly move water off-site. If ditching is a common practice in a region, the overall ability of the wetland resource to store floodwater and decrease flooding is reduced. Thus, condition assessment may provide information on the status of ecological services provided by wetlands across the landscape and potential solutions for restoring those services to better meet the needs of the environment and society (Smith et al. 1995).

---

### How Will the NWCA Assess Wetland Quality?

1. The NWCA will provide detailed information on wetland quality by wetland type and area of the country, providing additional insight into the implications of the acreage gains and losses.
2. NWCA will provide detailed information on wetland quality by wetland type and area of the country, providing additional insight into the implications of the acreage gains and losses.
3. NWCA will provide detailed information on wetland quality by wetland type and area of the country, providing additional insight into the implications of the acreage gains and losses.

---

EPA Commentary

Spring 2011 / LAKELINE 39
Vegetation will be characterized by collecting plant data in five 100-meter-squared vegetation plots systematically placed across the wetland assessment area. Vegetation is a major component of biodiversity found in wetlands and provides habitat for a myriad of organisms. The composition and abundance of plant species is both reflective of, and may influence, the hydrology, water quality, and soil characteristics of a wetland. Plants also respond to and reflect physical, chemical, or biological disturbances and stressors (Selinger-Looten et al. 1999; Rayamajhi et al. 2006). In addition, the presence and abundance of alien plant species often reflect degraded or declining quality.

Algae data will be collected from sediments (benthic samples) and the surface of vegetation stems and leaves (epiphytic samples). Algae respond rapidly to ecological change in wetlands and have been used by some researchers as indicators of wetland condition because of their rapid reproduction rates, short life cycles, and broad distribution (McCormick and Cairns 1994). More notably, because nutrients such as nitrogen and phosphorus are limiting factors to most types of algae, they respond quickly to excess nutrients. In addition, diatom species can provide insights into past hydrology, such as recent flooding, standing water, or droughts (Lane and Brown 2007; US EPA 2002; McCormick and Cairns 1994).

Soils data will be collected in four soil pits and will include an on-site description of the soil profile and collection of three types of soil samples (chemistry, bulk density, and stable isotope) for laboratory analysis. Soils cycle nutrients, store pollutants, mediate groundwater, and provide habitat for microorganisms, invertebrates, and other more complex organisms (Richardson and Vepraskas 2001). Biogeochemical processes and ecosystem services that rely on hydric soils or soils with hydric indicators directly influence wetland condition. Soil structure and chemistry can also indicate water quality and hydrology (Hargreaves et al. 2003; Mitsch and Gosselink 2007).

Hydrologic data will include an assessment of hydrologic sources and connectivity, indirect evidence of hydroperiod, estimates of hydrologic fluctuations, and documentation of hydrology alterations or stressors. Wetland hydrology is the primary driver of wetland formation and persistence. Hydrology impacts soil geochemical dynamics, plant productivity, nutrient cycling, and accretion and erosion of organic and inorganic materials in wetlands (Mitch and Gosselink 2007; Tiner 1999).

When standing water is present at a wetland assessment area, water chemistry samples will be taken and analyzed for general surface water conditions, various chemical analytes, and evidence of disturbance. Total nitrogen and phosphorus reflect the trophic state of the wetland, providing crucial information on possible eutrophication (Keddy 1983). Anthropogenic disturbances such as hydrologic modifications and land use changes are known to alter water quality variables (Lane and Brown 2007).

The NWCA will also verify the utility across regions and wetland classes of the newly developed USA Rapid Assessment Method (USA RAM). Rapid assessment methods are becoming increasingly useful tools for evaluating the ecological integrity of wetlands and the risk posed by stressors affecting the broader environment (Fennessey et al. 2007). The primary purpose of USA RAM is to effectively assess wetland condition in a substantially shorter time frame than required for more detailed sampling. It unites information gained from field observations of wetland ecology, buffers, and stressors. Once verified, USA RAM will provide states and tribes with a wetland assessment framework that can be adapted to meet their own monitoring needs.

The NWCA will use a reference-based approach to assess wetland quality nationally and regionally. This involves comparing survey data to assessments of high quality wetlands of similar type and geographic region. The data will be combined and summarized in a variety of ways, with a particular focus on the development of Multi-Metric Indices.

NWCA ORISE Fellow Elizabeth Riley trains participants at the National Water Quality Monitoring Council Meeting on how to set up the NWCA Assessment Area.
NRCS Soil Scientist Phil King demonstrates the NWCA soil sampling protocol.

(MMI). An MMI summarizes various wetland attributes or metrics into one score or index (Karr and Chu 1999). This index is then used to rank the condition of the resource in broad categories. Stressor data will be reported based on how commonly stressors were observed and how severely they impact NWCA sample sites. The final results will not reflect the condition of individual sample sites, but instead will be aggregated to describe condition of wetlands by type across the nation and in regions where a statistically significant number of sites were sampled.

How Will the NWCA Data Be Used?  
The 2011 NWCA will provide the baseline for wetland quality in the coterminous United States. Subsequent iterations will be used to track trends in quality by wetland class and region of the country, resources permitting. When paired with the S&T Report information, we will for the first time be able to measure progress toward the national goal to increase the quantity and quality of the nation’s wetlands. The S&T Report is an integrated assessment of the net effect of all actions affecting wetlands acreage across the nation. Similarly, the NWCA will be an integrated gauge of wetland condition nationwide, summarizing the cumulative effects of federal, state, tribal, and local government and private-party actions that either degrade wetlands or protect and restore their ecological condition.

Combining the FWS and EPA data on wetland quantity and quality can potentially be used to inform broad-scale environmental goals and priority-setting. For example, the combined data might reveal that estuarine marshes in a region of the country have declining acreage, poor quality, and are often impacted by excess nutrients and buffer fragmentation. This information sets the stage for federal, state, or tribal agencies to consider a number of potential actions to counter these trends. They could pursue collaborative partnerships with conservation and water protection programs and stakeholders to leverage resources designated for shoreline restoration or nutrient reduction strategies. Wetland permit data could be examined to determine if certain wetland types are disproportionately impacted and whether mitigation practices are reaching ecological performance standards. In addition, agencies could consider how grant funds are allocated and provide greater incentives for restoration and protection activities in estuarine marshes.

As another example, NWCA data may indicate that wetland quality is consistently high in certain regions of the country. The data could be used by agencies to highlight the success of their management framework and encourage continued stewardship into the future. It may lead to consideration of focusing on other wetland types or aquatic resources that may need more attention. Key lessons could be shared with other regions of the country where wetlands were found to be more degraded. Data from high-quality wetlands in this region could also be used to establish ecologically meaningful performance standards for restoration and compensatory mitigation projects.

When complete, the 2011 NWCA will represent a significant advancement in the science of wetland monitoring and assessment. The planning process has already succeeded in forging strong partnerships among federal agencies, state agencies, tribes, and nongovernmental organizations around the shared goal of improved national data describing wetland quality to support policy and management decisions. In many ways, the NWCA is pushing the limits of our conceptual and technical knowledge by producing a condition assessment at the national scale in one field season. While subsequent national wetland condition surveys will no doubt benefit from the lessons learned during this precedential effort, the 2011 survey will mark a significant leap in our understanding of wetlands science and assessment at the national scale.

Acknowledgements  
The development of a logistically feasible and scientifically sound technical approach for the NWCA is due to the contributions of many federal, state, tribal, and private organizations. The FWS provided extensive technical support for the survey design and production of site maps. The U.S. Department of Agriculture Natural Resources Conservation Service provided significant technical support for the development of soils field and laboratory protocols. The National Oceanic and Atmospheric Administration and the National Park Service reviewed the field protocols and provided examples of high-quality wetland reference sites. The U.S. Geological Survey Kansas Water Science Center provided significant technical support for the development of field and lab protocols for algal toxins. EPA scientists from EPA’s Office of Research and Development and regional offices provided invaluable technical feedback on all components of the NWCA technical approach. The Association of State Wetlands Managers supported the planning process by keeping their membership engaged and aware of the NWCA. Finally, our committed state and tribal partners provided tireless effort in reviewing protocols, attending planning workshops, challenging our thinking,
and committing to the goal of improved national data describing wetland quality.

References


Participants in the NWCA Technical Review Panel lay out measuring tapes for an NWCA vegetation sampling plot.

Michael Scozzafava is an environmental protection specialist at the U.S. Environmental Protection Agency headquarters in Washington, D.C. He is the national coordinator for EPA’s Wetland Monitoring and Assessment Program and the National Wetland Condition Assessment. E-mail: scozzafava.michael@epa.gov.

Mary E. Kentula is a wetland ecologist for the U.S. EPA’s Western Ecology Division in Corvallis, Oregon. Her extensive research focuses on ecological restoration and monitoring and assessment of wetlands at regional and watershed scales. E-mail: kentula.mary@epa.gov.

Elizabeth Riley is an ORISE Fellow with the wetlands division at the U.S. EPA’s headquarters in Washington, D.C. She specializes in wetlands monitoring and assessment with a particular focus on vegetation monitoring methods. E-mail: riley.elizabeth@epa.gov.

Teresa K. Magee is a plant ecologist for the U.S. EPA’s Western Ecology Division in Corvallis, Oregon. Her current research focuses on developing a vegetation-based index of alien invasion for wetlands. E-mail: magee.teresa@epa.gov.

Gregg Serenbetz is an environmental protection specialist at the U.S. EPA’s headquarters in Washington, D.C. He co-leads the National Wetland Condition Assessment with a particular focus on GIS analysis, aerial photo interpretation, and site reconnaissance. E-mail: serenbetz.gregg@epa.gov.

Richard Sumner works at the U.S. EPA’s National Health and Environmental Effects Research Laboratory in Corvallis, Oregon. He is the regional liaison to EPA’s National Wetlands Program. E-mail: sumner.richard@epa.gov.

Chris Faulkner is an ecologist in the wetlands division at the U.S. EPA’s headquarters in Washington, D.C. He is research coordinator for the Office of Wetlands, Oceans and Watersheds. E-mail: faulkner.chris@epa.gov.

Myra Price works in the wetlands division at the U.S. EPA’s headquarters in Washington, D.C. She is the national coordinator for EPA’s Wetland Program Development Grants Program. E-mail: price.myra@epa.gov.
CALMS Annual Meeting

The California Lake Management Society (CALMS) held its 25th annual meeting in Palm Springs, California October 7-8, 2010. The approximately 60 people in attendance were greeted with fantastic weather with temperatures in the mid-80s, clear skies, and no wind. To celebrate the 25-year milestone of CALMS, all of the registration packets contained a commemorative Secchi Disk with a distinctive anniversary logo.

As has been the tradition at these meetings, the first day was dedicated to technical presentations, followed by a short business meeting, and ending with dinner. Dinner this year was hosted by a local landmark restaurant, Las Casuelas, and was thoroughly enjoyed by all as was the Palm Springs Street Fair, a monthly event that happened to coincide with the CALMS meeting.

The presentations for the morning sessions covered a wide variety of topics including an overview of how Southern California gets its water. The vast majority of water for this area is imported from hundreds of miles away from several sources and a number of the talks discussed the challenges presented by changing conditions affecting these sources. These challenges include, but are not limited to, increased demand due to growing populations in the West, invasive species, a reduction in the amount of water available due to climate conditions, and the increased amount of water dedicated to environmental mitigation measures. On the demand front, it was noted that the City of Los Angeles uses the same amount of water as it did 25 years ago despite experiencing an increase in population of a million people during that time. Other presentations focused on work being done to enlarge a couple of California reservoirs, reservoir manipulations for the control of quagga mussels, early warning strategies for taste and odor episodes, and the reduction in photochemical production of disinfectant by-products through the use of shade balls.

Typically, a significant portion of the meeting focuses on a nearby water body and this year was no exception as the afternoon was spent discussing the current conditions of and plans for Salton Sea. Created “by accident” in 1904-1905, the Salton Sea has become an important stopping place for migratory waterfowl on the Pacific Flyway and is the largest lake in California. The Journal of Lake and Reservoir Management had an entire edition devoted to Salton Sea in 2008, so you know there is always a lot to talk about. Salinity in the Salton Sea continues to increase putting pressure on fish stocks. This trend is expected to accelerate as water is diverted from agriculture to urban...
uses since a significant source of water for Salton Sea is agricultural runoff.

A brief business meeting took place following the presentations where it was decided that CALMS would again offer two $1,000 scholarships to students studying lake management related topics. Also, several new officers were elected. Congratulations to new Northern Director Alex Horne, new Southern Director Bill Taylor, and President-elect Imad Hannoun.

Friday found the majority of attendees on a bus for a tour of Coachella Valley. Stops included an engineered water ski lake where a couple of CALMS members had a hand in the design and are involved the maintenance thereof, a portion of the Salton Sea including the recently refurbished Yacht Club building, and a stop for date shakes, a local specialty.

The 2011 CALMS meeting will be in Northern California in early October. The CALMS website, california-lakes.org, will have details as they become available.

Submitted by: Douglas Ball.
On February 8, 1973, shortly after I had poured my third cup of morning coffee, the phone on my desk at the Oregon Department of Environmental Quality (ODEQ) in Portland began ringing. It was my supervisor, Glen Carter, telling me to get down to Tahkenitch Lake on the central Oregon Coast as quickly as possible. The operator of the lake’s resort, Ed Nores, had called the Douglas County Sheriff’s office the day before to report that water was “boiling up” from the bottom of the lake.

Later, in an interview with a reporter from The Oregonian, Portland’s newspaper, Mr. Nores described what he had witnessed: “It was really boiling up. It was like a geyser-like plume of water coming from underneath, under pressure, with smoke boiling out of it. It smelled like carbide, or sulfuric gas, and it put a slick of 20 feet across for miles along the lake” (The Oregonian, February 9, 1973). When the sheriff’s people arrived to investigate, they took one look at the smoking, oily turbulence and immediately declared that the entire lake, all 1,674 acres, was “off limits” to boaters.

As a field biologist for ODEQ, I was often dispatched on troubleshooting trips to investigate reports of water pollution. Glen issued a terse, but straightforward set of instructions to me: “Grab some water samples from the boiling area and bring ’em back to the lab for analyses.”

With a battered aluminum rowboat in tow, I sped down Interstate 5, finally arriving at Tahkenitch Lake near Reedsport in the early afternoon.

The lake appeared surprisingly calm – no sign of boiling water and fiery plumes of smoke. Despite the lake’s apparent tranquility, a team of eager scientific experts were present, along with professional divers and a small army of ordinary curiosity-seekers.

Speculation about the source of the boiling water abounded among experts and non-experts alike.

Speculation about the source of the boiling water abounded among experts and non-experts alike. Some geologists believed that the phenomenon was caused by “marsh gas,” presumably meaning methane generated prodigiously by bacteria in the lake’s organically rich sediments.

Local folks advanced their own theories: “It’s a geyser,” said one old geezer, suggesting geothermal activity beneath the lake. “Could be oil,” said another onlooker. Little if any credibility was given to the theory that a Japanese midget submarine had somehow ventured from the ocean into the lake, via Tahkenitch Creek, during World War II, got trapped and now had finally ruptured, releasing gas.

Alert to the possibility of renewed activity, I cautiously steered my boat into the former “boiling” zone and hurriedly collected samples. Nothing seemed unusual except for the mysterious small, black, cinder-like particles scattered across the lake surface. Later that day, divers searching the lake bottom discovered a rusted barrel that was leaking blackish particles. Someone guessed that the barrel had been in the lake for 20 to 30 years.

Analyses indicated that the particles consisted of impure calcium carbide. This chemical reacts spontaneously with water, vigorously forming acetylene gas. With this information, investigators offered the following plausible explanation: A barrel of calcium carbide had probably fallen off a work train as it passed over one of the three railroad trestles that cross the lake. The rusting barrel had eventually breached, releasing large volumes of acetylene gas that erupted at the lake’s surface.

Years later, the authors of Atlas of Oregon Lakes (Oregon State University Press, 1985) noted on page 129 in their description of Tahkenitch Lake that a proposal to rename it Lake Flatulence “was rejected by the Oregon Board of Geographical Names.”
**Biological Invasions**

**Conservation Genetics**

**Critical Reviews in Environmental Science and Technology**


**Ecosystems**


**Hydrobiologia**


**Journal of Plankton Research**

**Restoration Ecology**


**Water Resources Management**


**Wetlands Ecology and Management**