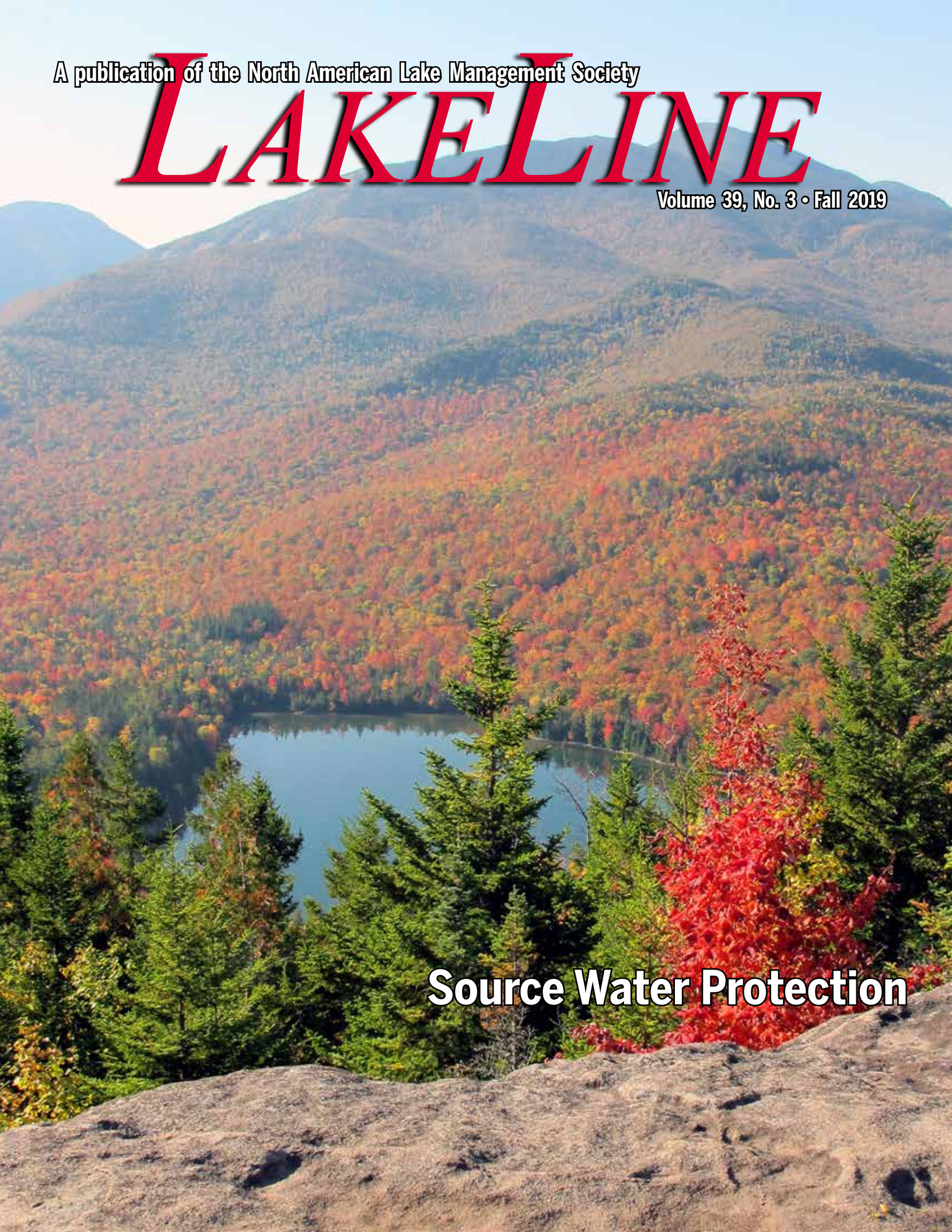
A publication of the North American Lake Management Society

LAKELINE

Volume 39, No. 3 • Fall 2019



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Heart Lake –Adirondack Mountains, New York. Photo by Bill Harman, Director, SUNY Oneonta Lake Management graduate degree programs.

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ISSN 0734-7978

P.O. Box 5443 • Madison, WI 53705
(All changes of address should go here.)

Address all editorial inquiries to:
Amy P. Smagula
29 Hazen Drive
Concord, NH 03301
Tel: 603/419-9325
LakeLine@nalms.org

Address all advertising inquiries to:
Alyssa Schulte
North American Lake Management Society
PO Box 5443 • Madison, WI 53705
aschulte@nalms.org

Payments:
PO Box 7276 • Boulder, CO 80306-7276
Tel: 608/233-2836

From Amy Smagula the Editor

As multi-use pressures increase across our landscape, it becomes even more critical to protect vital sources of freshwater to maintain quality systems. We can each likely think of our own examples of competition over a resource, and the compounded effects of overuse or mismanagement of a system. In many cases, this results in degraded water quality and impairments in the designated uses of waterbodies. Protecting those resources from impacts becomes even more critical, particularly for those waterbodies used as a drinking water supply. In this issue of *LakeLine*, we focus on source water protection (SWP) from a number of angles, to stress the importance of protecting the resource from degradation, and the programs that exist to protect these important systems.

NALMS recognizes that SWP is an important issue, and has developed both a white paper and a position statement on the subject. Additionally, NALMS is connected through its membership with a network of interest groups, including the Source Water Collaborative. In recent interactions with that group, the development of a themed issue of *LakeLine* on source water protection was born.

We start off with a lead in article from **Chi Ho Sham** with the Eastern Research Group, Inc., who provides and overview of SWP, what it is, and the regulatory framework related to source water protection.

Dan Yates, co-chair of the Source Water Collaborative and director of the Ground Water Protection Council, outlines the goals of that group, and highlights the importance of collaborations among various partners to protect source water.

Josh Weiss, Bill Becker, Jim DeWolfe, Christine Owen, Wendy Krkosek, and **Graham Gagnon** outline a decision support framework used in addressing changing water quality in reservoirs. They discuss how real time and evolving conditions in source water, like turbidity, algae and organic matter, drive change at the operational level in drinking water treatment plants, and how those plants need to be dynamic in adjusting for changing conditions real-time.

Next we hear from two water utilities on how they are actively addressing source water protection in their watersheds. **Kate Dunlap** and **Michelle Wind** discuss watershed management activities in Colorado for the City of Boulder water supply. They review specific threats they face in their watershed, and monitoring and collaborative efforts to protect their source in order to ensure quality drinking water for their customers. **Pierce Rigrod** and **John O'Neil** discuss the importance of forest management as it relates to source water protection in the Lake Massabesic watershed in New Hampshire, highlighting different examples of forest change, and resulting downstream impacts in that state and beyond.

Collaboration and buy-in are critical in this landscape level approach at source water protection, and there are some very good examples of outreach and education to encourage stewardship of source waters and their watersheds. **Matthew Rich, Becky Roark,** and **Brad Hufhines** detail some creative outreach and education activities they have found useful in educating their watershed residents about source water protection in the Beaver Lake watershed in Northwest Arkansas, building on NALMS' Lakes Appreciation Month and Secchi Dip-In events each July.

Paul Susca and Tom O'Brien highlight challenges faced in managing source water in multi-use water supply lakes. While some waterbodies are exclusively used for drinking water supply and all other uses are restricted, many are multi-use systems with competing uses and demands. They discuss regulatory frameworks implemented to protect the supply in these multi-use systems, including how some overlap in protections can be useful, and how a patchwork of different approaches can quickly become complicated and confusing. They also discuss LakeSmart, a program intended to involve the community in lake protection and stewardship activities.

Finally, **V. Reilly Hanson, Kelly Coburn, Cayelan Carey, Kevin Boyle, Michael Sorice, Nicole Ward,** and **Kathleen Weathers** provide some insights that can be useful in educating and motivating individuals about protecting lakes. In their article they look at human response to changing lakes, and evaluate those to help resource managers in making compelling motivators for protecting resources.

In our Student Corner, we welcome an article from **Sarah Coney** on her work and experience with aquatic invasive species, and the impacts that these have in our freshwater systems.

This is one of the bigger issues of LakeLine we have had in a while, but source water protection is an expansive topic, and one with many angles. We hope you find the information in this issue to be useful and informative.

Amy Smagula is a limnologist with the New Hampshire Department of Environmental Services, where she coordinates the Exotic Species Program and special studies of the state's lakes and ponds.

From Sara Peel the President

In this, my last *LakeLine* as the NALMS president, we turn our focus to the protection and enhancement of one of our most precious resources – drinking water. Source water protection is a program, usually initiated by a water utility to maintain or enhance water quality in streams, lakes, reservoirs, and groundwater that provides source water for water treatment utilities. Surface water is the source for over 220 million North Americans, and a supply of safe and abundant potable water is essential for protection of public health and maintaining the economy.

The preservation of our drinking water or source water protection involves more than management of the surface waterbody. The engagement of lake users, watershed residents, and partner groups is necessary to protect our drinking water sources. As part of this effort, NALMS developed a Source Water Protection position statement and serves on the Source Water Collaborative.

NALMS participates in the Source Water Collaborative – a 29-member organization which operates with the goal of protecting water at its source. NALMS' mission to foster the management and protection of lakes and reservoirs for today and tomorrow is in perfect alignment with the Source Water Collaborative and its goal. The Source Water Collaborative is working to develop tools and programs to assist local residents, drinking water managers and watershed groups protect their drinking water at its source.

One NALMS member, the Beaver Water District, serves as a great example of the engagement and partnerships necessary to successfully implement and manage a source water protection program. Through their partnerships with the West Fork White River Watershed Initiatives Regional Conservation Partnership Program, Beaver Watershed Alliance and other local, regional and state partners, leveraged more than $8.7 million in on-the-ground conservation efforts including agricultural best management practices, habitat restoration and streambank stabilization efforts. The Beaver Watershed Alliance hosted more than 100 events over the last year focused on connecting Beaver Water users to their local streams and Beaver Lake. And the Beaver Water District hosted their 14th Annual Secchi Day connecting local residents to Beaver Lake through educational booths while deploying more than 30 volunteers across the lake to assess water quality. Figures 1 and 2 included here highlight some of the scenes from their events, and you can read more about their efforts in their article in the following pages.

These efforts are a great example of the NALMS Source Water Protection Position Statement. It is the North American Lake Management Society's position that:

- Source water protection programs, source water management, optimized water treatment, distribution system management, and water quality monitoring are essential components to provide safe potable water.
- When lakes or reservoirs are used as source waters, water supply is the highest priority use of the water body

Figure 1. Beaver Water District hosted their 14th annual Secchi Day, including educational booths like this one.

and non-compatible uses should be minimized in the lake and along the shoreline.

- Source water protection programs should identify management strategies that will minimize nutrients, algae, turbidity, and organic loading.
- Source water protection programs should manage watersheds to prevent degradation of water quality from point and nonpoint sources of pollution, chemical spills, wildfires, storm impacts, and emerging contaminants.
- Water utilities should assess their watersheds for potential sources of contamination, impacts from upstream/nearby activities and land uses, emergencies, and extreme weather events.
- Water utilities and their customers are beneficiaries of SWP efforts and should help finance the cost of the SWP program.

Sara Peel, CLM, is the NALMS president, previously serving as the director at large, two terms as secretary, and one term as the Region 5 director. Sara received her B.S. in biology and Chemistry from Alma College and her M.S. in environmental science from Indiana University School of Public and Environmental Affairs. Sara is the lead scientist and co-owner of Arion Consultants – a regional environmental consulting firm with a focus on lake and watershed management. She is an experienced leader in water quality and watershed management.

Figure 2. West Fork White River Watershed Initiatives: restored streamback on Rock Creek using EQUIP funding. Upper photo is site prior to restoration showing eroding cut-bank; middle photo shows restored streambank with toe-wood structure and revegetated constructed soil lifts; bottom photo shows revegetated terraces planted with native trees, shrubs, and grasses and seeded with native grasses and wildflowers.

Protection of Lakes and Reservoirs as **Drinking Water Supply Sources**

Chi Ho Sham

Challenges and Solutions

What is source water protection?

Source water protection (SWP) is often referenced as the front-line barrier in the multiple barrier approach to protect drinking water (Morgan et al. 2019). Spatial variabilities associated with geography, history, ecosystem dynamic, land use, and policy make SWP a highly site-specific process that reflects the inherent diversity of natural waters and the areas from which they are derived, along with other drivers that affect source water quality.

American water utilities spend millions of dollars each year on SWP and related measurements. They understand the importance of SWP for maintaining a reliable water supply of optimal quality. They also appreciate that, by dedicating resources to SWP, they are in turn saving resources that would otherwise have to be spent on water treatment or using alternative, more expensive, and less convenient supplies.

According to the U.S. Census Bureau (2011), 70 percent of Americans are served by community water systems using surface waters as their source for raw water. These sources include rivers, streams, lakes and reservoirs. Because of the need to protect drinking water sources, water utilities are a valuable partner for local surface water management programs. Local utilities may be a direct source of funding for lake protection efforts, but more importantly, public support for protection efforts can be greatly enhanced by placing emphasis on drinking water protection. An opinion poll conducted by the Trust for Public Land in 2004 showed overwhelming support for conservation of land that protects drinking water (TPL 2004).

Drinking water sources are subject to a variety of sources of pollution. SWP programs help maintain, safeguard, and/or improve the quality of a given source water. Benefits of SWP programs include reduced water treatment costs, increased public health protection, improved environmental conditions, and other social benefits such as improved relations with stakeholders. Furthermore, SWP provides a way to respond to uncertainties presented by unknown or unregulated microbiological and chemical contaminants (i.e., preventing contamination that treatment may not remove), avoiding costs for monitoring and remediating contamination, and greater likelihood of complying with drinking water regulations.

Pollution prevention is preferable to remediating or treating contaminated source water. SWP programs provide a means toward a more sustainable and resilient future for source water. Many people are aware of the recent concerns about Poly- and Perfluoroalkyl Substances (PFAS) in source water across the U.S., which made headlines at the national and state levels in the last couple of years (see https://www.epa.gov/pfas/basic-information-pfas). The problems posed by these substances will cost billions of dollars to remediate. In other words, it is logical to prevent the introduction of any actual or potential contaminants into source water. Furthermore, certain contaminants can trigger biogeochemical activities that degrade source water and introduce serious public health risks. Contaminant sources that challenge SWP programs are wide ranging. This article will cover issues associated with stormwater runoff and agricultural practices on surface water supply sources.

Types of contaminants

Urban Stormwater

The collective impacts of rooftops, sidewalks, roadways, and other impervious surfaces on surface water bodies can be divided into two categories, those attributed to changes in hydrologic response and water quality impacts resulting from human activities. The hydrologic response of an urban area changes when drainage areas become increasingly impervious, causing stormwater runoff volumes, flows, and velocities to increase while base groundwater flows decrease. Small annual storm events that would ideally be captured by vegetation and soils of an undeveloped landscape are instead delivered quickly and efficiently through the receiving pipe network to surface water bodies. Human activities in the city, such as heavy automobile traffic and chemical uses, generate increased pollutant loads to receiving waters. During dry weather, locally generated pollutants and atmospheric deposition of pollutants from remote locations accumulate on impervious surfaces where rain and snow-melt events would mobilize them into surface water bodies.

Pollutants found in stormwater runoff from urban, industrial, and commercial land uses can have diverse adverse effects on a water supply; examples include:

- **Eutrophication** – Stormwater runoff from virtually every category of land use affected by human activities (as well as under some natural conditions) often contains elevated concentrations of nitrogen and phosphorus, which can accelerate eutrophication (excessive growth of phytoplankton and algae), leading to a host of problems including taste and odor, disinfection byproducts

formation, plant operation, and health risks

- **Elevated turbidity and sediment** – Stormwater runoff from construction sites, unvegetated open space, and unprotected areas often has high turbidity and sediment load, which can pose problems for water treatment and affect finished water turbidity, appearance, and, potentially, chemistry, depending on which pollutants are associated with sediment inflows.
- **Synthetic Organic Compounds** – This broad category of pollutants includes compounds such as pesticides, solvents, oil and gas-production related chemicals, hydraulic fluids, and others, which are often found in stormwater runoff and periodically reach water supply intakes via spills. This class of chemicals poses concerns related to public health because basic water treatment facilities are not equipped to handle them.
- **Bacteria** – Concentrations of bacteria in stormwater runoff from various sources (e.g., pet waste, bird dropping, and sewer overflow can be elevated and pose concern for public health.
- **Metals** – High concentration of metals in certain categories of stormwater discharges, such as from some industrial sites, may cause public health concerns and treatment concerns. Many metals are regulated under the Safe Drinking Water Act (SDWA) because of their potential adverse health effects.

In 1972, the Federal Water Pollution Control Act, also known as the Clean Water Act (CWA), was amended to make illegal the discharge of any pollutant as a point source to any water body in the U.S. without authorization by a National Pollutant Discharge Elimination System (NPDES) permit. Pollution control measures were first implemented in industrial wastewater operations and municipal sewerage systems; however, it became apparent that more regulations were needed to include the identification of stormwater drainage systems as a point source. In 1987, the CWA was amended to implement a two-phase approach to the reduction of stormwater discharges.

The first phase was aimed at large and medium municipal separate stormwater systems (typically systems serving populations of 100,000 or more), industrial activities, and construction activities that disturbed five acres or more of land. The Phase I part of the program was implemented on November 5, 1990. The Phase I permitting process required these larger cities to develop and implement a stormwater management program, and to address stormwater management at specific municipal facilities at which "industrial" activity took place. It also required certain industries as well as any construction project greater than five acres to obtain NPDES permit coverage through the development and implementation of stormwater pollution prevention plans that would control erosion and sedimentation as well as pollutant discharges.

On December 8, 1999, the NPDES Phase II Stormwater Rule was published in the Federal Register by EPA. The NPDES Phase II Stormwater requirements focused on small Municipal Separate Storm Sewer Systems (MS4s) (usually cities with populations of less than 100,000) and small construction activities (construction activity that disrupts one or more acres of land). The basis of this Phase II approach was to design a stormwater management program that focused on six minimum control measures that include:

- Public Education and Outreach
- Public Participation and Involvement
- Illicit Discharge Detection and Elimination
- Construction Site Runoff Control
- Post-Construction Site Runoff Control
- Pollution Prevention and Good Housekeeping at Municipal Operations

The NPDES Phase II program requires the development of best management practices (BMPs) for each of the minimum control measures and the development of an implementation schedule and measurable goals throughout the five-year permitting period. Regulated entities are required to submit progress reports annually and are subject to enforcement action as described in the CWA if they fail to implement the selected BMPs.

States are providing funds under Section 319 of the CWA for the assessment, design, and construction of stormwater BMPs, along with education and outreach of stakeholders and the public. In addition, funds from Section 604b of the CWA are available to conduct water quality assessment and watershed management planning, BMP design, and development of stormwater utilities. Furthermore, Clean Water State Revolving Fund (CWSRF) loans are available to communities for stormwater management planning, BMP design and construction, and formation of stormwater utilities. Additional state and local funding sources are available to communities to manage and control stormwater runoff.

Agriculture Practices

The advancements of food product systems have led to the increasing reliance of agrichemicals and scale of production to enhance crop yields and low prices. A variety of chemicals, ranging from phosphorus, nitrogen, and pesticides have been used intensively across the agriculture landscape.

As mentioned earlier, the increasing levels of nutrients (e.g., phosphorus and nitrogen) in surface water bodies, coupling with higher temperature and residence time, can lead to increased primary productivity (eutrophication) and natural organic matter that are precursors of disinfection byproducts in typical surface water treatment plants. When water is chlorinated to make it safer for consumption, the chlorine can react with organic material and form potentially harmful disinfection byproducts, such as trihalomethanes and haloacetic acids, which may he carcinogenic. In addition, more eutrophic waterbodies are also associated with cyanobacterial blooms like the one on Lake Eerie shown in Figure 1 (commonly referred to as harmful algal blooms) that are linked to the releases of cyanotoxins (such as microcystins and cylindrospermospsin) affecting the nervous system (neurotoxins), the liver (hepatotoxins), and the skin (dermatoxins).

Pesticide runoff from agricultural lands can enter and has the potential to contaminate surface waters. Depending on the toxicity and concentration of specific pesticides, along with the exposure of the population to these pesticides, many pesticides are regulated under SDWA. Along with the states and tribes, EPA sets

Figure 1. Harmful Algal Bloom in Lake Erie (source: NOAA; https://oceanservice.noaa.gov/news/weeklynews/july13/lake-erie-habs.html.

and implements regulations that protect our drinking water from source to tap. National Primary Drinking Water Regulations (NPDWRs) for numerous pesticides can be found at https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations to protect public health by limiting the levels of pesticides and pesticide residuals in treated drinking water. It should be noted that treatment technologies to remove pesticides to meet various regulatory standards can be expensive (e.g., the use of activated carbon and nanofiltration).

SWP and the Safe Drinking Water Act

The SDWA, authorized by Congress in 1974 and amended in 1986 and 1996, seeks to regulate public drinking water for public health protection. While the SDWA does a relatively good job addressing goals related to drinking water quality, it deals very little with the issue of water quantity and source water quality. Issues surrounding water quantity are left largely to state and regional authorities; whereas source water issues are generally addressed at the local level where decisions and actions are needed to ensure the availability of safe, reliable, and sustainable drinking water.

Section 1453 of the 1996 SDWA Amendments required states to develop and implement Source Water Assessment Programs (SWAPs). States were required to identify the sources for all public drinking water supplies, delineate the source water contributing areas, identify potential sources of contamination, determine the susceptibility of the water supplies to contamination, and disseminate the results to the public.

Although most of the source water assessments were completed (U.S. Environmental Protection Agency 2006), apart from a handful of states, SWP activities are generally not required of public drinking water supplies. In other words, SWP is voluntary in nature at the national level. Nevertheless, the information developed under SWAPs has become a useful tool to help local stakeholders develop and implement voluntary SWP programs to protect source water quality.

The 1996 SDWA Amendments recognize the direct connection between watershed protection and safe drinking water, and authorized funds to implement state drinking water programs and help states provide revolving loans to assist public water systems in improving drinking water infrastructure using the Drinking Water State Revolving Fund (DWSRF). States may use up to 10 percent of their annual DWSRF grant for SWP program, or to provide loans to acquire land or conservation easements, and an additional 10 percent of its DWSRF allotment to administer or provide technical assistance through SWP programs.

In addition, EPA's Long-Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) includes a provision whereby a water utility may qualify for a 0.5-log disinfection credit as a result of an effective SWP program (Sham and Morgan 2011).

On July 26, 2019, EPA issued a memorandum in response to an amendment to Section 1452(k) of the Safe Drinking Water Act (SDWA), which is included in the 2018 America's Water Infrastructure Act (AWIA), to expand source water protection-related eligibilities under the Drinking Water State Revolving Fund (DWSRF) program. This expansion includes the use of DWSRF's 15 percent set-aside for additional source water protection activities at the local and state levels, i.e., (1) updates to source water assessments and (2) expenditures to implement source water protection activities (under Section 1452(k)(1)(D)). The availability of these funds can be used to leverage other funding sources such as the Clean Water State Revolving Fund (CWSRF), Clean Water Act (CWA) Section 319 funding, and conservation funds from the Natural Resources Conservation Service (NRCS) as authorized under the Agriculture Improvement Act of 2018.

Finally, drinking water utilities that obtain their source water from relatively pristine surface water supplies may apply to EPA for a Filtration Avoidance Waiver which, if granted, would release them from the filtration treatment requirements of the SDWA and instead require SWP activities. New York, Boston, Syracuse (New York), Seattle, and San Francisco are examples of some of the cities that have Filtration Avoidance Waivers.

Note: The nine minimum elements in watershed-based plans under Section 319 of the Clean Water Act (U.S. Environmental Protection Agency 2013) and the six primary components of successful SWP programs (American Water Works Association 2007) can easily be cross-referenced and they cover essential the same concerns under the watershed or SWP programs.

Selected challenges and solutions associated with surface water source protection

In general, since the 1996 SDWA Amendments, SWP has been discussed and promoted in an *ad hoc* fashion by different organizations at the national, regional, state, and local levels. The site-specific nature of SWP has made these programs bottom-up exercises. A lack of awareness and recognition at the national level and the largely voluntary nature of SWP have made SWP programs a low priority or invisible to the decision makers and general public. The prospect of potentially prioritizing limited resources between treatment and protection activities, along with the sense of helplessness felt by many water utilities that do not control activities and land use in their contributing watersheds, have made SWP a complex and challenging issue. Obstacles to successful SWP typically are not technical, but rather social, political, financial, or regulatory.

In 2018, the Agriculture Improvement Act was signed into law and it directs U.S. Department of Agriculture (USDA)'s Natural Resources Conservation Service (NRCS) to allocate at least 10 percent of their conservation title funds to projects that protect drinking water sources. The allocation total over five years is $4 billion, or roughly $800 million per year. Water utilities can tap into these funds by working with their local conservation districts and NRCS. The next article in this issue includes some helpful guidance and resources to consider. Some of the NRCS programs that are included for source water protection are:

- **Regional Conservation Partnership Program (RCPP)** – including activities associated with other USDA programs such as the Environmental Quality Incentives Program, Conservation Stewardship Program, Agricultural Conservation Easement Program, Healthy Forests Reserve Program, PL 83-566 Watershed Program, and the Conservation Reserve Program. RCPP projects start with an application by an eligible partner (e.g., agricultural or silvicultural producer associations, farmer cooperatives or other groups of producers, state or local governments, American Indian tribes, municipal water treatment entities, water and irrigation districts, conservation-driven non-governmental organizations and institutions of higher education, and conservation districts). Selected partners work alongside NRCS to help agricultural producers and forest landowners implement conservation activities that address natural resource priorities on eligible lands (e.g., any agricultural or non-industrial private forest land, or associated land on which USDA determines an eligible activity would help achieve conservation benefits).
- **National Water Quality Initiative (NWQI) Source Water Protection Area Project** – focusing on addressing specific agriculturally related source water protection needs by channeling NRCS conservation program funding to agricultural producers in identified watersheds to implement practices that help to protect sources of drinking water. Due to the fact that the NWQI contains both an implementation phase and a readiness phase, utilities interested in working with NRCS on an NWQI project do not need to have every detail of a proposed project solidified prior to applying for funding. Identification of source water protection areas and source water concerns related to agriculture is sufficient to get the application processes moving. A State Conservationist can provide information on the requirements for NWQI proposals.

To effectively prioritize and spend these funds for the greatest benefit to utilities and water quality, eligible partners such as water utilities, irrigation districts, and conservation-driven watershed organizations need to be involved. NRCS decisions are made more in the state offices than in the national

office. In this decentralized model, water utilities and local partners are the key players to make things happen by:

- Developing a relationship with the NRCS state conservationist, the top official for NRCS in each state. These individuals have considerable authority in prioritizing and focusing conservation programs within their respective states. They are often the focal point of information and ideas. Conservation districts, agricultural groups and many others frequently bring concerns and ideas to them. By getting to know them – organizing a meet-and-greet with utilities, bringing specific concerns to their attention, inviting them to talk at your conference, or otherwise engaging them – you can develop important relationships that will serve your communities. A current list of NRCS state conservationists can be found at: www.nrcs.usda.gov/wps/portal/nrcs/main/national/contact/states/
- Attending and joining the State Technical Committee and applicable local workgroups. The State Technical Committee (STC) is where formal recommendations to the state conservationist are made; whereas local workgroups cover smaller areas and provide more local and specific information to the STC on specific source water protection needs at the water utility and watershed level. Involvement in the STC and/or local workgroups will raise the profile of source water protection and help to assure that local concerns are addressed
- Encouraging utilities with source water concerns to reach out to NRCS to form partnerships. There is a single pathway to implementing a project with NRCS. There are several different conservation programs (such as the NWQI and RCPP) that work differently and are built to address different types of concerns. The state conservationist is an expert in matching concerns to programs. The state conservationist may identify other potential partners such as conservation districts or local producers' associations.

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Dr. Chi Ho Sham is a vice president and the chief Scientist of Eastern Research Group, Inc. (ERG), leading the drinking water and source water protection practice. He is an active member of the American Water Works Association (AWWA) and is currently the chair of its Technical and Educational Council (TEC). He received his B.A. from the University of Regina in Canada and his M.A. and Ph.D. from the University at Buffalo in New York. Currently, he is an adjunct professor and a senior research fellow at Clark University in Worcester, Massachusetts.

Collaboration Protects Sources of Drinking Water

Dan Yates and Alan Roberson

Are you interested in accessing information and potential partners to advance your source water protection efforts? The national Source Water Collaborative can help.

Why collaborate for source water?

Water sources cross state and other jurisdictional boundaries, and water quality affects all communities, but there is no federal requirement to protect sources of drinking water. No single system connects all the agencies and professionals involved in protecting the nation's drinking water sources at the federal, state, and local levels. That's why the Source Water Collaborative (SWC) was formed – to help fill these gaps by sharing information and opportunities. In the past 14 years, the SWC has expanded to include 29 nationally prominent organizations representing drinking water utilities; conservation districts; state drinking water and groundwater protection programs; federal government agencies focused on environmental and public health, agriculture, and geological science; planners; agriculture; and other organizations committed to water quality, including the North American Lake Management Society.

We provide source water information to those positioned to act

Challenges to securing clean drinking water are becoming more complex and more interdependent across sectors and geographies. Emerging contaminants, multiple contaminant sources, land use changes and management challenges, increasing water demand, and extreme weather, are taxing capacities and driving up the cost of water treatment, underscoring our dependence on a secure water supply and the urgency of source water protection (SWP). The SWC is defined by one core principle: that by working together and combining our strengths, resources and will to action, our diverse set of member organizations can realize greater successes than by working alone.

The SWC helps promote effective working relationships with a variety of programs that affect source water quality, including the Clean Water Act and multiple conservation programs in the U.S. Department of Agriculture. Once the new Farm Bill was signed into law in December 2018, SWC members shared information at national meetings to encourage stakeholders to connect Farm Bill conservation provisions with state and local SWP opportunities; provided input to SWC member Natural Resources Conservation Service (NRCS) for source water provision implementation; and met with SWC member US Forest Service (USFS) to discuss opportunities to promote SWP through Farm Bill Title VIII, Forestry. Most recently SWC hosted a *webinar* "Working with NRCS and Agricultural Partners to Protect Drinking Water Sources."

The SWC continues to work with federal agencies to share information about programs that offer technical and financial assistance to address and implement practices on agricultural lands that benefit SWP. This type of new approach has helped communities address priority water quality issues in priority areas and with multiple benefits and partners. Two of these programs, the Resource Conservation Partnership Program and the National Water Quality Initiative are continuing under the new Farm Bill and specifically include both ground and surface water sources of drinking water.

Source Water Collaborative Members

- American Planning Association
- American Rivers
- American Water Works Association
- Association of Clean Water Administrators
- Association of Metropolitan Water Agencies
- Association of State and Territorial Health Officials
- Association of State Drinking Water Administrators
- Clean Water Action / Clean Water Fund
- Environmental Finance Center Network
- Ground Water Protection Council
- Groundwater Foundation
- National Association of Conservation Districts
- National Association of Counties
- National Environmental Services Center
- National Ground Water Association
- National Rural Water Association
- North American Lake Management Society
- River Network
- Rural Community Assistance Partnership
- Smart Growth America
- Soil and Water Conservation Society
- The Trust for Public Land
- U.S. Department of Agriculture – Farm Service Agency
- U.S. Department of Agriculture – Natural Resources Conservation Service
- U.S. Endowment for Forestry and Communities
- U.S. Environmental Protection Agency
- U.S. Forest Service (Northeastern Area)
- U.S. Geological Survey
- Water Systems Council

We help people work across organizational lines

The SWC makes it easier for members to work outside jurisdictions and

across geographical and organizational boundaries. Are you interested in getting more agricultural conservation on the ground to help protect sources of drinking water? An important natural ally is SWC member, the National Resources Conservation Service (NRCS, U.S. Department of Agriculture), which includes the State Conservationist's or District Conservationist's offices. Another key set of allies is conservation districts – important partners at the local level, who also have helpful contacts at the state level – represented by SWC member, the National Association of Conservation Districts (NACD).

As a result of extensive collaboration between members of the Source Water Collaborative, NACD and the NRCS, we developed toolkits that offer a step-by-step approach for collaboration and insightful tips based on advice we received from NRCS and NACD, and from state and regional source water coordinators based on their experience fostering effective partnerships. Here are a few tips from our conservation toolkits.

Key opportunities to connect with agricultural partners at the state level

Looking to share information about your source water concerns and to have a voice in identifying priority opportunities in your state?

- *Get to Know Your Associate State Conservationist for Programs.* They have information about how the state NRCS office sets priorities and makes funding decisions, and they can make sure you receive notification when funding opportunities become available. Ask how the state NRCS office plans to address source water protection in its ranking criteria for conservation programs. This infographic with the 2018 Farm Bill source water provisions might be helpful in making your case for source water protection projects.
- *Participate in Your State Technical Committee Meeting.* Contact your State NRCS office and ask to be on the email list to attend a State Technical Committee meeting. This public meeting is a great place to make a variety of connections with agriculture leaders in one place, to become familiar with their priorities and concerns, to share source water concerns and priorities, and to understand how the Committee develops recommendations for the NRCS State Conservationist's funding decisions. Each State Technical Committee meeting has a different dynamic. Some can be very formal so it is best to respect the process and observe more in the beginning, to develop your understanding. There may be a chance during a "round robin" part of the agenda to briefly describe your role in drinking water protection. If you have limited time, introduce priority geographic areas for protecting drinking water sources, and express your interest in working with conservation districts.
- *Conservation districts often participate in State Technical Committee meetings.* Be sure to express your interest in meeting with conservation districts, and suggest a follow-up meeting with those interested. If the next State Technical Committee meeting will not be held for a while, you may want to reach out first to schedule a meeting with the State Executive Director, or other recommended state contact listed on the NACD website.

Key opportunities to connect with agricultural partners at the local level

- *Get to Know Your Local Conservation District.* The size of the conservation district staff varies by district. Some have no staff – in that case, contact your conservation district board member. Each conservation district has an annual workplan or report, which can be a helpful resource to help you identify their priority issues and areas. Check the conservation district's website to see if the annual plan is available. If it's not on the web, contact their state office to request a copy. The conservation district may be assisting landowners in developing conservation plans with practices that can help protect drinking water sources. Sharing your source water data and maps can help inform this planning process.
- *Attend a Local Working Group Meeting.* This NRCS meeting is a good way to meet local landowners and operators (farmers, ranchers, forested land owners) and district staff, and to hear their perspective on local issues "on the ground." Recommendations for decisions about USDA-NRCS local funding distribution are developed at these meetings.

Be persistent. It is important to "keep showing up" at agriculture meetings in your state or at the county level if you're interested in a specific geographic area. If conservation district staff and NRCS staff see you showing up regularly at their meetings, it will demonstrate that you are genuinely interested in working with them. You will start to receive other invitations and be afforded opportunities to participate more.

Collaborative resources

In addition to some of the toolkits mentioned above, the SWC has developed actionable resources for creating and sustaining key partnerships.

- The How-to-Collaborate toolkit takes users step-by-step through the creation of a collaborative partnership – from the brainstorming stage to how to maintain relationships long-term, including funding options. The toolkit can be applied to any issue that is ripe for collaboration and is free to use.
- The SWC created the Learning Exchange, an information-sharing platform, features webinars that harness the power of its diverse members to provide a dynamic venue for collaboration on vital issues of water security and safety. Topics include:
  - Linking SWP to Emergency Preparedness
  - Funding for SWP
  - SWP Through Conservation Funding
  - Nutrient Reduction Successes
  - Multi-Purpose Decision Support Systems for SWP Strategies
  - Creative Partnerships
  - Forming and Sustaining Collaboratives

Do you know your local or regional source water collaborative?

The SWC has been a model for bringing diverse groups together to create solutions that work for communities. This model is being replicated across the country at the local, state and regional/ watershed level. A wide variety of collaboratives are working around the country on drinking water issues at local, state, and regional levels. The SWC's website features the work of 30+ collaboratives across the country (Figure 1). Visit today to find a collaborative near you or to feature your work.

Resources

- Visit the Source Water Collaborative website
- Sign up to receive source water updates from the SWC (scroll to bottom of home page)
- Find your conservation district via this directory
- Find your Associate State Conservationist for Programs
- Use the How-to-Collaborate Toolkit
- Use the Conservation Partners Toolkit
- Use the infographic on commonalities with State Conservationist
- Connect with a Source Water Collaborative member
- Find a SWC in your area

Contact Us

We welcome your questions, updates and information: info@sourcewatercollaborative.org

Dan Yates is the co-chair of the Source Water Collaborative and the associate executive director of the Ground Water Protection Council.

Alan Roberson is executive director of the Association of State Drinking Water Administrators (ASDWA) ASDWA's members (the state drinking water agencies) are co-regulators with the Environmental Protection Agency (EPA). He has over 27 years of experience in the development of drinking water policy and federal drinking water regulations.

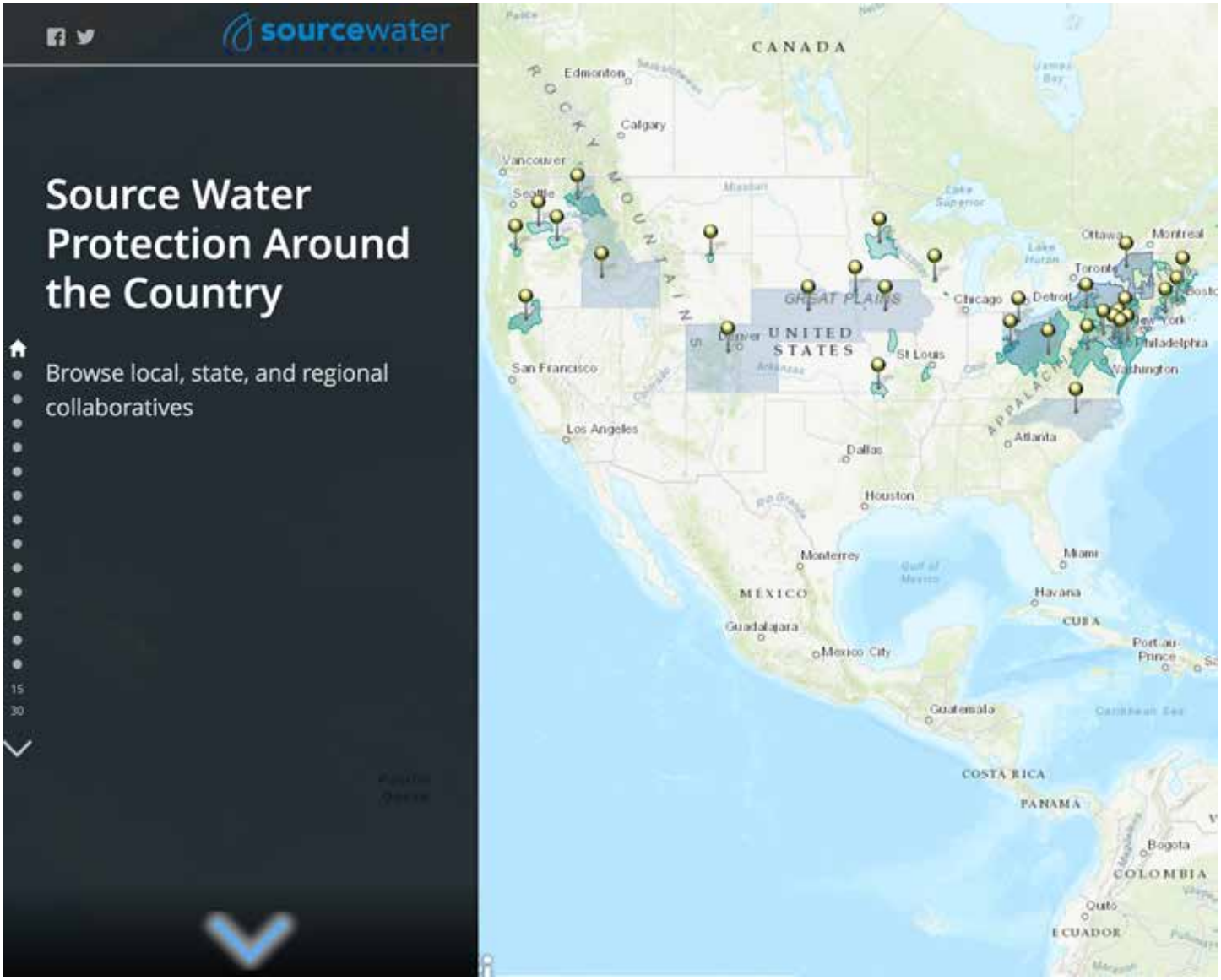

Figure 1: Collaboration map from www.sourcewatercollaborative.org.

Addressing Changing Water Quality in Water Supply Reservoirs

Josh Weiss, Bill Becker, Jim DeWolfe, Christine Owen, Wendy Krkosek, and Graham Gagnon

Using Decision Support Framework

For more than a century, surface water reservoirs have served as a critical source for public drinking water supplies. Conventional drinking water treatment processes have been employed to protect the public health from pathogenic microorganisms and other contaminants present in surface waters. In conventional treatment, the overall strategy is to chemically promote the aggregation of raw water particles and dissolved substances and remove the aggregates by physical means. Aggregation is accomplished by adding a chemical coagulant that neutralizes negative charge on the surfaces of raw water particles and converts dissolved natural organic matter (NOM) into a solid phase for subsequent removal. This is accomplished via processes known as coagulation and flocculation. The largest aggregates, known as flocs, can then be removed by clarification via sedimentation or flotation. The remaining finer particle aggregates are captured via granular media filtration. Accordingly, drinking water process selection and performance are largely driven by raw water concentrations of particles (as measured by turbidity), NOM, and other constituents (e.g., algae and cyanobacteria).

Key drivers of drinking water treatment process selection and performance

While most particles that comprise turbidity in natural waters are not a health hazard themselves, turbidity is used as an indicator or surrogate for pathogenic microorganisms and is a regulated parameter in the United States and Canada. Per the U.S. EPA's Surface Water Treatment Rule, utilities with conventional filtration plants must maintain finished water turbidity less than 1 NTU at all times and less than 0.3 NTU in 95 percent of samples each month. Elevated turbidity in raw or treated waters is often indicative of conditions under which microorganism transport is enhanced. Additionally, high particle concentrations in raw water can challenge overall treatment and result in high solids residuals production and treatment cost.

Natural organic matter is typically measured as total and dissolved organic carbon (TOC and DOC) and is comprised of precursors of disinfection by-products (DBPs). DBPs are a result of reactions of NOM with chlorine and other disinfectants and include compounds that are known or suspected carcinogens. NOM is also a source of negative particle charge that must be neutralized during the coagulation process and often drives the amount of coagulant required for treatment. In fact, for most waters, it is NOM that controls the optimum coagulant dose. NOM that remains in finished drinking water can impact corrosion processes in the water distribution system and is a source of carbon for the growth of biofilm on pipes.

Blooms of cyanobacteria are a source of taste and odor compounds in reservoirs, and in some cases can lead to the release of harmful cyanotoxins, which can be challenging to remove through conventional drinking water treatment processes. Because of their low density, cyanobacteria cells cannot be readily removed by settling processes and require a higher coagulation dose or alternative clarification process (e.g., dissolved air flotation) for effective removal. Cells are also a source of NOM and can therefore increase the production of disinfection by-products upon chlorination.

Because the design and performance of a drinking water treatment process train depends upon the raw water characteristics, particularly the concentrations of particles, NOM, and cyanobacteria, changing source water quality can present a serious challenge to drinking water treatment plant operations staff. Short term fluctuations due to extreme storm events can typically be managed, for example by optimizing coagulant dosage, adding powdered activated carbon (PAC), or making other temporary adjustments. However, more frequent occurrence of extreme events and long-term changes in source water quality can result in raw water conditions that are substantially different than those under which a treatment plant was meant to operate. Maintaining the desired level of treatment under such conditions often requires capital investments to upgrade existing treatment or add additional treatment processes.

Many utilities in northeastern North America and parts of Europe face a unique set of conditions in which successful efforts to reduce atmospheric pollution have led to the phenomenon of lake recovery, or "browning" (Anderson et al. 2017). This condition leads to increases in pH, NOM, and cyanobacterial blooms in surface water supplies. These long-term changes are problematic for treatment plants that were designed under fundamentally different water quality conditions, leading to increased treatment and residuals handling costs and reducing operational reliability and resilience. Changes in climate and the occurrence of extreme events likewise pose an acute

challenge to water utilities. The critical questions utility managers must answer now are:

- What is the new normal for source water quality and how will we know when we are there?
- When is the right time to make capital investments?

To answer these questions, utilities need data and tools to help them better understand the nature of long-term changes due to lake recovery, climate, and other drivers to help them better initiate responses across the spectrum of planning horizons, from near-term operational responses to long-term capital planning decisions. Accordingly, the Water Research Foundation is funding the development of a Decision Support Framework (DSF) to support utility response to lake recovery, climate change, and other drivers of water quality change (Water Research Foundation Project #4920: Decision Support Framework for Drinking Water Treatment Plants Experiencing Lake Recovery). The DSF will aid utilities in identifying controls at the watershed, source water, and treatment plant to ensure reliable and cost-effective maintenance of water quality objectives.

Impacts of lake recovery and climate change on source water quality

Lake recovery is a leading factor in the long-term increase in DOC concentrations in surface waters in northeastern North America and parts of Europe. Evidence from several studies has indicated that leaching of terrestrial NOM due to decreasing soil acidity is a key mechanism driving the increased DOC levels observed in these lake systems, with important implications for treatability, process efficacy, and the formation of DBPs. Increasing DOC in surface waters can reduce water clarity, which can enhance thermal stratification, potentially further reducing water quality. Increased mobilization of N and P associated with soil organic matter (SOM) can help to stimulate cyanobacteria growth. Reduced acidity as surface waters recover has been linked to changes in phytoplankton community structure, with higher pH favoring cyanobacteria, some species of which produce chemical compounds that cause taste and odor problems.

Further influencing water quality of these sources are long-term changes in climate. It has been well established that temperature, precipitation, and hydrology are important factors in the production and transport of terrestrial NOM to surface waters. NOM concentrations have been known to increase with temperature, as NOM decomposition and solubilization rates are more rapid at higher temperatures. It is also well understood that extreme rainfall can correlate with increased contamination of surface water sources from releases of microbial contaminants, nutrients, and pesticides. Increases in temperature, precipitation, and atmospheric CO_2 have been linked to increasing primary productivity and biomass, which can affect both the amount and the character of SOM. Variability in runoff timing and patterns have likewise been found to be major influences on water quality parameters. Increasing temperatures and transport of nutrients can lead to eutrophic conditions and a rise in the frequency of algal blooms.

Case study: Halifax Water, Nova Scotia, Canada

Halifax Water is a regulated drinking water, wastewater and storm water utility, with 84,000 service connections, serving the Halifax Regional Municipality on the east coast of Canada. Halifax Water operates two large-scale surface water treatment plants, and several smaller scale surface and groundwater treatment plants. Halifax Water's two major water sources, Lake Major and Pockwock Lake, receive stream flows from largely forested, protected watersheds that receive no wastewater discharges. Historically, the lakes are low pH, low turbidity and low alkalinity sources, but, recent data indicate water quality changes consistent with lake recovery and climate change. Over the last 20 years, both lakes have seen a dramatic rise in pH, color, DOC, and taste and odor events which have resulted in increased treatment chemical usage, and decreased filter run times (Anderson et al. 2017, and Figure 1).

Of particular concern is the water treatment process at the JD Kline Water Supply Plant, which treats water from Pockwock Lake and employs a direct filtration process. In direct filtration, coagulation and flocculation are followed by filtration, without a clarification step. Direct filtration is appropriate for source waters with low concentrations of particles and organic matter. Under average conditions, direct filtration is recommended for sources with less than 5 NTU turbidity and less than 3 mg/L of TOC (Valade et al. 2009). Recent observations show Pockwock Lake water nearing or exceeding those recommendations at least part of the year. Meanwhile, climate change projections indicate increasing temperature and precipitation for Nova Scotia. These trends will further exacerbate water quality conditions through changes in forest ecology, primary production, and increasing occurrence of cyanobacteria blooms.

Improving source water quality management

The complex interplay between lake recovery, climate change, land cover, nutrient dynamics, and other drivers of water quality change call into question whether conditions will simply revert to the pre-industrial baseline or whether a new equilibrium will lead to conditions heretofore unseen. Increasing lines of evidence suggest the latter. The impacts of a specific combination of factors leading to water quality changes can be difficult, if not impossible, to fully understand. For waters experiencing lake recovery and climate change, studies have highlighted several observations that have important ramifications for developing a comprehensive response strategy:

- Long-term changes in surface water DOC for systems experiencing lake recovery appear to be most strongly related to changes in atmospheric deposition chemistry rather than climate change.
- Climate change impacts on temperature and precipitation patterns have a strong influence on seasonal variability in surface water DOC and other water quality parameters.
- Both lake recovery and climate change are factors in the increase in the occurrence of blooms of cyanobacteria, resulting in increased risk for issues with T&O compounds and toxins.

These complex interactions highlight the need for a better understanding of

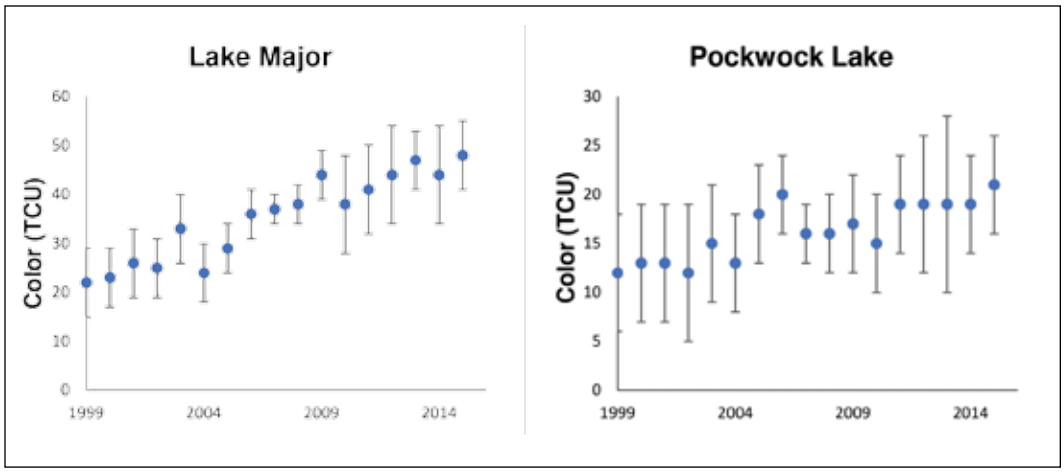

Figure 1. Example of water quality trends at Halifax Water's Lake Major and Pockwock Lake.

source water quality dynamics and better tools for identifying subtle temporal and spatial trends across a watershed. Traditional approaches to source water monitoring, which are typically limited to periodic sampling at a few key locations, and often ignore the greater watershed completely, are increasingly proving insufficient to support robust decision-making. Further, source water quality monitoring and treatment process performance monitoring are often siloed, with watershed managers and treatment plant operators making separate decisions with few opportunities for joint, holistic decision-making.

To address these challenges, the DSF under development is envisioned as a multi-platform watershed, source water, and treatment process monitoring tool with advanced data analytics and visualizations that will support holistic, data-driven decisions (Figure 2). Utilities like Halifax Water need a framework for developing a robust plan for responding to water quality changes due to lake recovery, climate change, and other critical drivers. They further require quantifiable metrics for ensuring achievement of plan objectives. The DSF will enable the development of triggers and thresholds that can be used to guide implementation of a system-wide water quality protection strategy both for the short term, operational, and longer capital planning horizons (Figure 2).

Though being developed and piloted for Halifax Water, the DSF is intended to be a widely applicable tool for managers and operators of reservoir drinking water supplies that are experiencing changes in water quality due to a variety of drivers. While the issue of lake recovery is unique to specific regions, long-term water quality changes and increasing frequency of extreme events due to climate change and other factors is universal. Utilities across North America and abroad recognize increasing uncertainty about what the future holds and the impacts that this uncertainty has on their capital planning efforts. While the DSF will be designed and tested for the specific case of lake recovery, the source-to-tap approach, analytical tools, and guidance materials will be widely applicable for the drinking water and lake management communities.

Acknowledgements

The authors acknowledge the financial support of the Water Research Foundation under Project #4920: Decision Support Framework for Drinking Water Treatment Plants Experiencing Lake Recovery.

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Valade, M.T., W.C. Becker, and J.K. Edzwald. 2009. Treatment selection guidelines for particle and NOM removal. *Journal of Water Supply: Research and Technology-Aqua*, 58(6), 424-432.

Dr. Josh Weiss is Hazen and Sawyer's director of Water Resources Innovations. He specializes in water resources planning, source water quality, modeling, hydrology, climate change, and applications of remote sensing and forecasts for water resources management. He works with water utility operations staff and managers to integrate the latest data sets and tools into their decision-making toolboxes.

Dr. Bill Becker is the Corporate Drinking Water Practice Leader for Hazen and Sawyer. He is a nationally respected water supply and treatment expert and has published and presented significantly on a wide range of drinking water topics. He is an expert in water process technology and the impacts of source water quality on treatment plant performance.

Jim DeWolfe is Hazen and Sawyer's Water Treatment Operations Leader. He works with treatment plant operations staff to implement process optimization and filter surveillance techniques to help assure consistent and confident operations. For Halifax Water, Jim has performed process audit and recommended improvements to address shortened filter run times induced by source water quality changes.

Christine Owen is the director of Water and Reuse Innovations for Hazen and Sawyer. She has 29 years of experience in the technical and policy aspects of potable water quality, research, treatment and regulatory compliance. Prior to

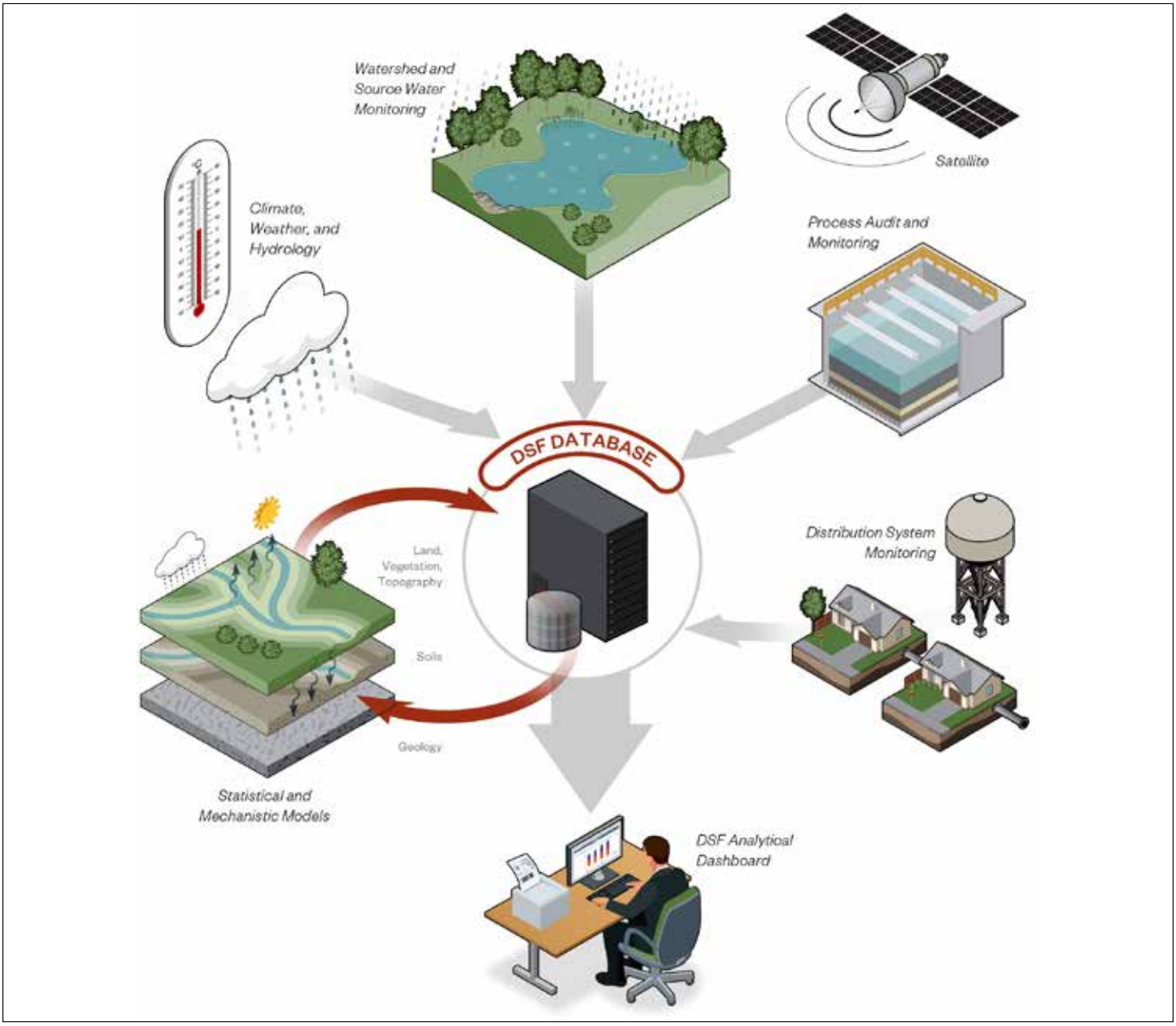


Figure 2. Illustration of the decision support framework.

joining Hazen and Sawyer, she managed the Water Quality Work Group at Tampa Bay Water, directing water quality discussions, research efforts and regulatory efforts for the agency and its member governments.

Wendy Krkosek, Ph.D., P.Eng., is the water quality manager with Halifax Water where she works with treatment, water quality and distribution operations staff to conduct water quality research, solve water quality and treatment problems, improve treatment methodologies, and develop and implement water quality plans. Wendy received her BASc in Civil (Environmental) Engineering from the University of Waterloo, followed by a Ph.D. in Civil Engineering at Dalhousie University.

Dr. Graham Gagnon is associate vice president of research and NSERC/Halifax Industrial Research Chair at Dalhousie University. Dr. Gagnon has over 25 years of experience in drinking water research and has published more than 150-peer review articles related to drinking water quality and treatment. Working with Halifax Water, Graham's team identified lake recovery processes that have been impacting water reservoirs in Halifax and Nova Scotia for the past decade or more.

Collaborate, Plan, and Prepare – A Utility's Role in Source Water Protection

Kate Dunlap and Michelle Wind

In Boulder, Colorado, the tap water comes from mountain streams and reservoirs fed predominantly by snow melt. To maintain water quality, most raw water is piped directly from the source to the water treatment plants. Boulder owns a portion of the watershed near the Continental Divide and public access has been prohibited in that area since 1920. Therefore, we can sit back, relax, and let the pure water nourish our community without a second thought, right? Not so much. Maintaining this high quality water involves water quality monitoring and evaluation, planning and preparation, and most importantly, a lot of collaboration.

The portion of the watershed owned by the city only represents 12 percent of the land area. Like other communities, water quality can be impacted by a variety of sources such as wastewater effluent; leaking septic systems; discharges from abandoned mines; lawn, road, and agricultural runoff; post-fire erosion and sediment transport; atmospheric deposition; and climate change. Boulder staff works with local, state, and federal land managers to implement projects and policies that help to provide operational flexibility and ensure a resilient, reliable, and high quality water supply for residents.

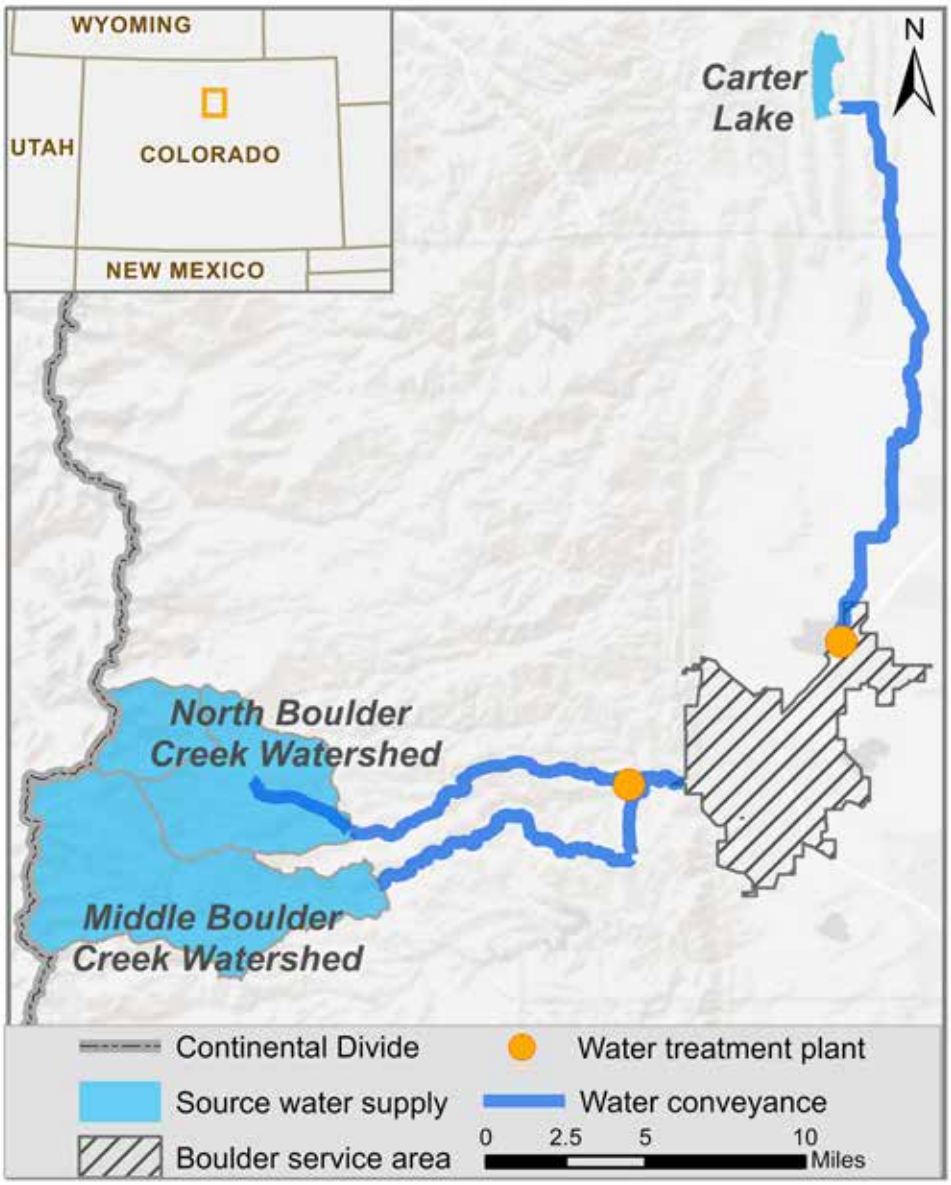


Figure 1. Boulder's source water supply watershed map.

Boulder's water supply

Boulder, Colorado, located 30 miles northwest of Denver, has a service area population of 120,000, expected to grow to 136,000 by the year 2040. Boulder's water supply comes from the following sources (one-third each): the North Boulder Creek Watershed, the Middle Boulder Creek Watershed, and Upper Colorado River diversions (Figure 1). The trans-mountain diversions are part of the Colorado-Big Thompson Project, which transfers water through a series of reservoirs, canals, and pipelines from the Upper Colorado River to eastern slope communities. Boulder's share of the diversions is delivered via Carter Lake, 20 miles north of Boulder. By 2020, the open channel delivery system from Carter Lake to Boulder's water treatment plant will be replaced with a pipeline to maintain water quality and improve resilience.

Monitoring and analyzing source water quality

Water quality monitoring is the cornerstone of Boulder's source water protection program. Water supply reservoirs and tributaries are sampled routinely for a suite of constituents including basic chemistry, nutrients, metals, organic carbon, total suspended solids, volatile organic compounds, and phytoplankton (Figure 2). Staff also monitor for more than 100 pesticides, pharmaceuticals, personal care products, hormones, and other unregulated organic chemicals on a less frequent basis through a multi-utility collaborative to reduce costs. A team of water staff evaluate and update the monitoring program annually.

Throughout the year, staff analyze water quality data to understand trends or changes, and report on key findings to Utility's staff via a Monthly Water Quality Update. The mini-newsletter is developed in PowerPoint and filled with bullet point text, figures, maps, and infographics to inform water treatment, monitor changes during spring runoff and fall reservoir stratification, and educate staff more broadly about the water supply and reservoir health (Figure 3). Data are also used to assess event-related changes (e.g., reservoir chemistry changes caused by the 2013 flood), or evaluate the effectiveness of source water protection investments (e.g., reductions in reservoir nutrient levels since investing in phosphorus removal at a small upstream wastewater treatment facility). The updates also provide a record of issues, actions, and outcomes.

Figure 2. Boulder staff collecting reservoir samples. After lab analyses, staff analyze water quality data to understand trends and changes in the source water.

Developing a source water protection work plan

Over the years, Boulder has developed a number of watershed management plans, a Source Water Master Plan, and reservoir impact assessments. To better coordinate and prioritize watershed protection efforts, Boulder embarked on a stakeholder-driven process to develop a Source Water Protection Plan (SWPP), finalized in 2017. Over the course of a year, staff and dozens of stakeholders met monthly to identify potential sources of contamination to the water supply, delineate protection zones, and prioritize specific strategies and programs to minimize or prevent water quality impacts. The SWPP identified key threats to the water supply (e.g., post-wildfire erosion and climate change), and potential sources of contamination (e.g., abandoned mine discharges, illegal hazardous waste dumping). The benefits of the SWPP process are two-fold: first, the SWPP has helped staff prioritize efforts and more efficiently allocate resources; second, and perhaps more importantly, the process was stakeholder-driven and allowed staff to further develop working relationships with local, state, and federal agencies, businesses, and landowners in the watersheds. Contact your state's environment or public health agency to learn about SWPP grant funding availability. A list of state source water contacts is maintained here: https://www.asdwa.org/sourcewatercontacts/.

Planning and preparing for wildfire

Like many communities in the West, wildfire is a key threat to Boulder's forested water supply. Specifically, erosion and sediment transport during post-fire rain events can fill reservoirs and reduce water storage capacity (a critical component of western water supply management), cause short- and long-term water quality issues, and increase water treatment costs. While forest thinning projects are a common approach to reducing or preventing severe wildfires, they take years to implement and a variety of factors make any large-scale forest thinning projects not practical in Boulder's source watersheds in the near term.

Recognizing that there could be a wildfire in the watersheds at any time, Boulder teamed up with the Colorado Forest Restoration Institute to build a pre- and post-wildfire planning tool for water supply protection. The Wildfire Erosion and Sediment Transport Tool (WESTT), simulates wildfires; predicts post-fire sediment transport under varying fuel dryness conditions and rain intensities; recommends rehabilitation plans to stabilize hillslopes and trap sediment upstream from intakes; and estimates the cost of implementing the watershed rehabilitation efforts such as wood mulch, straw mulch, and installing wattles. Staff members from U.S. Forest Service (USFS) and U.S. Geological Survey (USGS), among other partners were involved throughout WESTT development to help ensure the tool is scientifically sound and useful to all partners including any USFS Burned Area Emergency Response Team that may be activated post-fire.

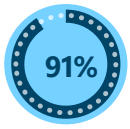
Monthly Water Quality Update

April 2018

General Updates

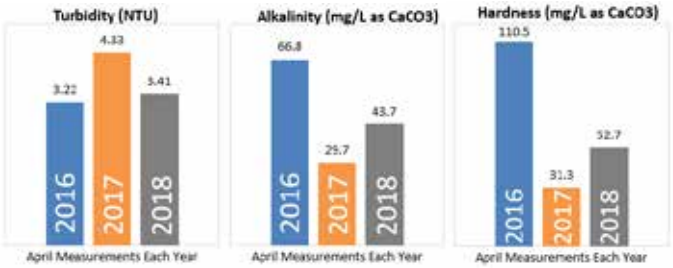
- During the week of April 30th, Betasso will run performance tests on the new basins and 63rd will shut down for ~2 weeks. 63rd is expected to come back online on May 14th and begin treating Boulder Feeder Canal (BFC).
- Northern Water has set the Colorado-Big Thompson Project quota at 80%, meaning that 80% of C-BT water will be available to allottees this year. The allocation is based on high C-BT storage levels and below average winter precipitation. Learn about the quota system here.

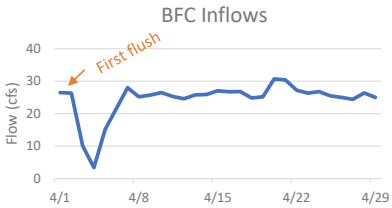
University Camp Snowpack
(% of Median)



Boulder Feeder Canal

- Boulder Feeder Canal flow has been steady in recent weeks, with a current discharge rate of 25 cfs.
- BFC basic water chemistry is shown for 2018 and the previous two years in the figures below.





3A

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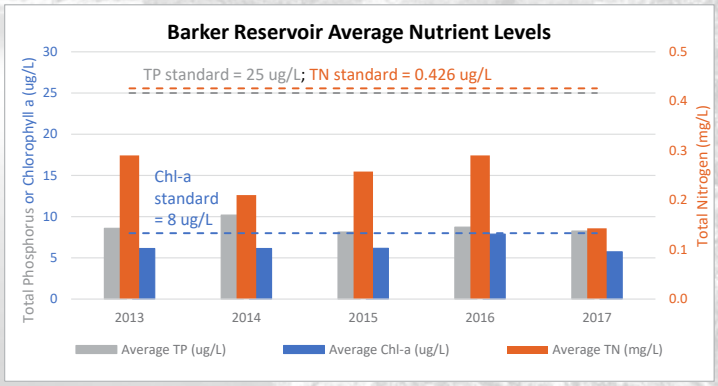
Nutrient Interim Values

- The Colorado Department of Public Health and Environment (CDPHE) performs basin-wide water quality assessments on a four-year rotational cycle. The South Platte River Basin will be assessed in 2019.
- CDPHE reviews water quality data to determine whether waterbodies are achieving their designated use (e.g., recreation, water supply) through attainment of water quality standards. 2019 will be the first year the South Platte River Basin is assessed for total phosphorus (TP) and chlorophyll-a (chl-a), which is a measure of algal growth.
  - Total nitrogen (TN) will be considered for adoption in the South Platte River Basin in 2027.
- Waterbodies will be classified as impaired or on the monitoring and evaluation list if summer average* concentrations exceed the standards more than once in five years.

How do nutrient levels stack up in Barker Reservoir?

- Barker Reservoir is in compliance with the TN, TP, and Chl-a interim values.
- While not readily visible from the summer average values shown in the figure, TN and TP have been significantly declining since the Nederland WWTF upgrades in 2013.



3B

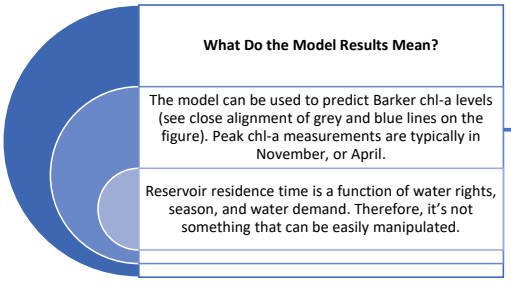
** Summer = July 1 to Sept. 30 for TP and TN or March 1 to Nov. 30 for Chl-a.*

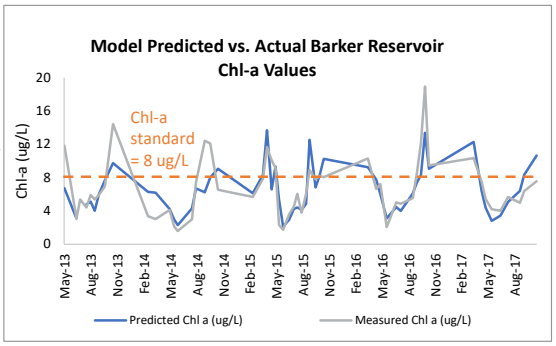
Figure 3. A-D above and on following page. Examples of information conveyed in monthly water quality updates.

So….what's driving algal growth in Barker Reservoir?

3C

Analyses suggest that Barker Reservoir chl-a (i.e., algal growth) is most strongly influenced by **reservoir residence time** and **TP concentrations** (*see methods in footnote*). Residence time is the amount of time a molecule of water stays in Barker Reservoir before being flushed out.





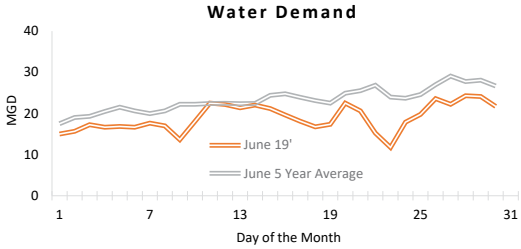
Model Results:

P value = <0.0001	Probability value – this means that there is less than a 0.01% chance that the relationship is due to chance. P values <0.05 indicate statistically significant relationships.
R^2= 0.68	R-squared value – this means that residence time and TP concentrations explain 68% of the variation in chl-a levels in the reservoir. The R^2 value assesses how well the model fits the data. Values closer to +1 or -1 (positive or negative relationship) indicate stronger models. 0.68 is a very good R^2 value.
Spearman Rho *• Res. Time = 0.63* *• TP = 0.38*	Rho – these measure the strength of the relationship to chl-a within the model (similarly to R^2, values closer to +1 or -1 indicate a stronger relationship). The higher rho value for residence time indicates that it explains more variation in chl-a than TP (i.e., it's a more important component of the model).

Methods: *Ran non-parametric spearman rank correlations between log-transformed water quality and environmental data from the 2013-2017 period (post-WWTF upgrades). Parameters included: reservoir and WWTF nitrogen (NH4+, NO3-, TKN) and phosphorus (ortho, dissolved); reservoir contents (acre-ft); air temperature; snow-water equivalent; precipitation. Then ran multiple linear regression models using the significantly correlated parameters (p<0.05) to find the best fit model that explains chl-a concentrations. Checked for autocorrelation – TP and residence time were not correlated with each other (p = 0.773). Contact Kate Dunlap if you have more questions about the methods and results.*

3

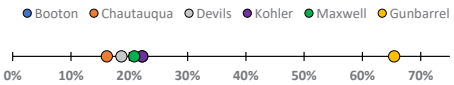
Distribution System Characteristics



Average residence time is
51 hours

a decrease from last month's 74 hours

Average % Tank Turnover

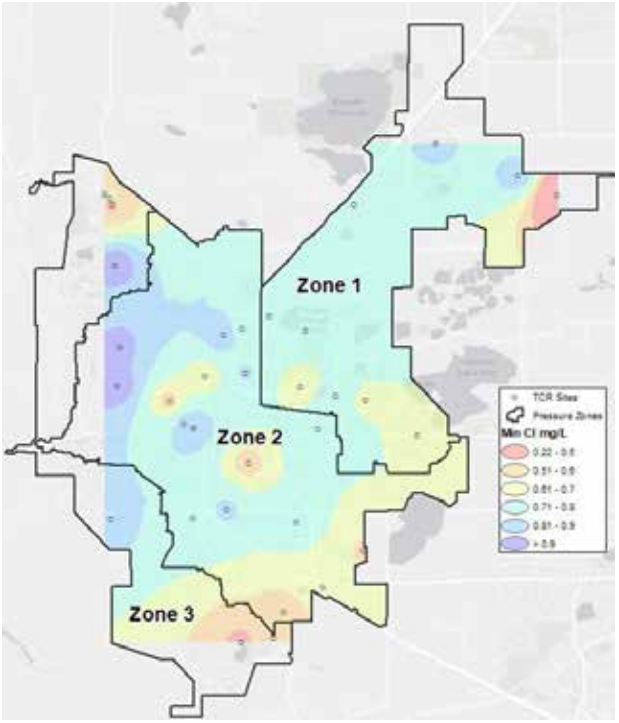


3D

*EPA recommends >20% Tank Turnover

Chlorine Residual in the Distribution System

Target Chlorine Residual Entering Distro: 1.1 mg/L.
Required Chlorine Residual in Distro: >0.2 mg/L



*Click *here* for definitions and goals related to distro characteristics

Collaborating and sharing information

Despite all of the sampling and analyses Boulder staff do internally, we could never achieve any measurable level of source water protection without collaborating with external partners, landowners, and businesses. Water quality staff take advantage of the fact that Boulder is home to more than a dozen federal labs including the Institute of Arctic and Alpine Research, National Oceanic and Atmospheric Administration, and the National Weather Service, as well as key USFS and USGS offices and the University of Colorado, Boulder. When planning projects, Boulder staff frequently consult with and involve experts from these entities. For example, to characterize potential impacts from two discharging inactive mines, Boulder consulted with scientists from USGS and the Colorado Division of Reclamation and Mining Safety to design and implement the study. Due to the partnership in this effort, Boulder received a grant to fund the sampling and lab analysis costs for this project.

Staff time and monetary resources are limited, and we can all benefit by sharing information, lessons learned, and plans that can be used by others. Recently while we were evaluating and updating the water quality monitoring program, staff asked what other Colorado utility programs look like. What are other water providers monitoring? Where do they sample and how often? To what extent do they perform statistical analyses on their water quality data and report to staff and the public on findings? What are some key threats or pollutant sources to other water supplies and how are water providers planning and adapting?

To answer these questions, Boulder staff developed an online survey in Google Forms and sent it to water providers across the state. Twenty-one providers with service area populations ranging from 4,000 to 1.4 million, responded to the survey. Staff analyzed the responses and presented the survey results at a Colorado Lake and Reservoir Management Association (CLRMA) luncheon – a NALMS affiliate. Aggregate results have also been provided to interested water providers. Learning from others has helped Boulder improve the monitoring program and embark on source water protection projects recommended by other utilities.

Conclusion

No matter where your drinking water comes from, implementing a source water protection program is paramount. From one water provider to another, here are some thoughts:

- *Monitoring = Sampling + Analysis*. What good is a database of water data if no one is looking at it? Reviewing your data can help you understand baseline conditions, identify trends, and potential pollutant sources. Seek guidance from local university professors, USGS staff, or other water providers to formulate hypotheses and conduct analyses. At a minimum, preparing a timeseries scatterplot in Excel can tell you a fair amount about your source water.
- *Try not to reinvent the wheel*. More than likely, other water providers in your area are facing similar threats to their water supplies, developing similar plans, and encountering similar issues regarding source water protection. Contact them to share information and lessons learned, and perhaps collaborate on projects to spread out the costs.
- *Planning and stakeholder involvement.* Get to know the local, state, and federal staff who own or manage the land in the source watershed. Developing these relationships in advance will facilitate working together post-natural disaster to implement projects and secure funding.

And one last thought – always serve cookies or lemon bars at your meetings. We've analyzed it, and the chances that fellow staff and stakeholders will attend your meetings and offer insightful thoughts and ideas, significantly increases (p-value <0.001).

Kate Dunlap has 15 years of experience in water resource management in the private and public sectors and an M.S. in Water Resources. To protect and preserve Boulder's source water quality, she collaborates across sectors, analyzes environmental data, and communicates results to inform special projects and policies.

Michelle Wind manages the City of Boulder Drinking Water Quality Program that provides technical support to protect, maintain, and optimize the city's drinking water quality from source to tap. Michelle is an environmental engineer with 25 years of experience in water quality and watershed management.

Lake Appreciation Month and Secchi Day on Beaver Lake, Northwest Arkansas

Matthew Rich, Becky Roark, and Brad Hufhines

Connecting source water to tap water

Northwest Arkansas (NWA) is a rapidly growing metroplex where many residents take potable water and source water quality for granted. This story plays out not only in NWA, but around the nation and many other places in the world. In relation to the value of the service, the low price of high-quality potable water that meets or exceeds all regulatory requirements expands the disconnect between source and tap. Lakes are a reflection of their watersheds. Lakes Appreciation Month and Secchi Day on Beaver Lake provide a platform to engage and inform the public about these issues. Many people do not realize where their potable water comes from, or that human activities on land affect water quality at the source. A partnership between like-minded organizations to promote educational and outreach opportunities for the public best utilizes resources and expertise.

Lake Appreciation Month

Beaver Watershed Alliance (BWA) is a nonprofit watershed organization located in NWA that is working to educate the community and protect and restore Beaver Lake and its watershed. In July of 2018, BWA celebrated another successful Lakes Appreciation Month. Beaver Lake is the drinking water source for 1 in 6 Arkansans. The Beaver Lake watershed covers over 3,087 km^2 of land (Tetra Tech 2012). As part of the BWA mission to raise awareness of watershed concerns, BWA is proud to partner with NALMS to promote Lakes Appreciation, not only for Beaver Lake, but across the state. Each year, BWA and partners submit a request to the Arkansas State Governor asking to proclaim July as Lakes Appreciation Month. July 2019 marks the eighth year to receive the statewide proclamation. Fellowing are the key points in the proclamation application:

"With over a half-million acres of reservoirs in Arkansas, summer is a great time to encourage all Arkansans to appreciate the lakes of the Natural State by participating in recreational activities such as swimming and boating, taking care of lakes, and enjoying the scenic beauty and benefits provided by them – including drinking water for much of the state. In addition to Lakes Appreciation Month being a time to appreciate lakes, it is a time to think about where communities would be without their water, and the threats facing lakes and reservoirs. These threats include sediment and nutrient loads, population growth, development, and invasive plant and animal species that put stress on waterbodies. The importance of protecting these lakes and reservoirs for future generations is critical to Arkansas' quality of life, communities, wildlife, and potential for future growth and economic development."

In July 2018, the BWA led over 17 programs, with more than 120 people participating in stewardship activities, outdoor watershed education and recreation programs, and citizen science programs within the Beaver Lake watershed. A media campaign for Lakes Appreciation Month included a customized commercial aired at gas station pump top advertising and indoor billboards at various locations around the region – the reach was estimated at 335,000 people. Beaver Watershed Alliance also connected with stakeholders through social media and digital media channels, promoting the month's activities. Television crews and newspaper reporters attended several events and broadcasted the campaign, increasing outreach efforts for Lakes Appreciation.

The BWA Lakes Appreciation Month activities included taking a group of Girl Scouts paddling 5 miles of the pristine cool waters of the White River, generated from the Beaver Lake Dam (Figure 1). These fun outings provide a great educational opportunity to talk about the White River and its tributaries and the many benefits the dam and Beaver Lake provide NWA. The group also practiced Leave No Trace principles and conducted a river cleanup along the way, removing over 60 pounds of trash. Events targeting youth from underserved communities included: "kayaking 101" around a quiet cove of Beaver Lake, snorkeling in search of underwater aquatic life, and exploring the Hobbs State Park Visitor Center. Many of the program attendees had not experienced an opportunity like that before. Beaver Watershed Alliance spent time discussing with students why the lake was important and what positive, individual actions can be taken to protect water quality. Many of the summer students remarked that they were "definitely coming back to Beaver Lake" and wanted to share it with their families and friends.

Citizen science activities included five Secchi Dip-In events, where BWA staff met volunteers at local lakes to collect Secchi measurements. Secchi data were uploaded to the Secchi Dip-In database using the Lake Observer App and will help BWA and other interested partners monitor water transparency

Figure 1. Lauren Ray, Park Ranger (Interpretation), Upper Buffalo District, Buffalo National River, assists Beaver Watershed Alliance with teaching Leave No Trace principles to NOARK Girl Scout Campers out of Huntsville, AR, before their five-mile float on the White River.

in nearby lakes. This was also a great way to inform volunteers about the annual Secchi Day on Beaver Lake hosted by Beaver Water District (BWD). By leveraging local partnerships and resources, BWA was able to provide these programs at no cost to the public, which is a great incentive to get the community engaged and thinking about watershed appreciation.

Secchi Day on Beaver Lake

Understanding the source of one's drinking water is crucial in maintaining that resource for future generations. Without public buy-in, protecting source water against cultural eutrophication would not be possible. Beaver Water District, the wholesale drinking water supplier to more than 350,000 commercial and residential customers in NWA, does not own nor maintain a distribution network. Instead, the four major cities of Bentonville, Rogers, Springdale, and Fayetteville purchase drinking water from BWD to distribute and sell to their customers though each city's independent distribution network. Because commercial and residential water bills are not paid to BWD, residents of NWA may not understand the link between source water and tap water. Results from BWD's long-range strategic plan surveys suggest that in 2006, only 36 percent of respondents correctly identified BWD as their drinking water supplier, whereas 76 percent correctly knew the answer to the same question in 2018.

In an effort to garner support from the citizens of NWA toward preserving a safe drinking water source, BWD has initiated a citizen science outreach program entitled "Secchi Day on Beaver Lake." With this citizen science program, we aim to bridge the gap between source and tap. Secchi Day is a citizen science engagement tool, always held on the third Saturday of August, that educates the public about the source of their drinking water and provides water science-based educational activities for kids and adults of all ages (Figure 2). The first Secchi Day was held in 2006 and was intended to mimic a fishing tournament-style activity where participants launched from central locations, collected water quality data and samples, and then returned for a data "weigh-in." In 2006, the inaugural Secchi Day began with $1,500 of seed money plus in-kind donations, 27 sampling teams, approximately 100 participants, and only one program partner. Fast forward to the 2017 event where funding exceeded $23,000 plus in-kind donations, 35 sampling teams, 731 participants, 13 program partners, and 21 sponsors were mobilized.

On August 18, 2018, BWD held its 13th annual Secchi Day on Beaver Lake. A total of 712 people participated,

Figure 2. Secchi Day on Beaver Lake - As part of Secchi Day on Beaver Lake, kids can experience hands-on activities that are meant to inspire thought-provoking ideas. Here, kids use a spray bottle to simulate a rain-making event on a Beaver watershed model that helps them understand how pollutants on the landscape can travel to Beaver Lake.

which included 494 attendees and 218 volunteers. Volunteers were comprised of 72 on-lake samplers, and 146 volunteers, including BWD staff, that assisted with a water quality-type science festival held at the Prairie Creek marina. In 2018, 36 on-lake volunteer teams were dispatched from one-of-four launch sites along the 80 km transect (Figure 3). Armed with a Secchi Disk, two 1-litre bottles, and GPS coordinates, volunteers were asked to measure Secchi depths at two different sites, and to collect two samples just below the surface at both sites. In order to minimize sampler error, each of the 35 lake sampling sites were sampled in duplicate by different sampling teams.

Secchi transparency values from every site across the riverine-to-lacustrine continuum were thereafter relayed to BWD personnel at Prairie Creek and displayed on a large data board known as "The Great Wall of Secchi." By having results displayed in real time, those attending the water science festival could see how the transparency of Beaver Lake changes from the riverine zone (e.g., 0.8 meters), near the White River and War Eagle Creek inflows, to the lacustrine zone (e.g., 7.5 meters) near the Beaver Lake Dam (Figure 4). Meanwhile, collected water samples were then returned to BWD staff to be analyzed at an in-house water quality laboratory. The ability to analyze water quality constituents in-house is why BWD was able to establish such a large-scale event at a reasonable price. One sample, collected in a light-resistant amber colored bottle, was used to evaluate chlorophyll-a concentrations, the second sample, collected in an opaque bottle, was used to evaluate total phosphorus, and total nitrogen. Secchi and chlorophyll-a data were then used to calculate Carlson's (1977) trophic state index values for each of the 35 sites. These data, along with total phosphorus and total nitrogen data, were later used to build spatial maps of each water quality parameter along the entire transect Beaver Lake. Secchi depth data are also uploaded to the Secchi Dip-in database.

Back at Prairie Creek marina, the home base for Secchi Day on Beaver Lake, more than 30 exhibitors from partner organizations such as NALMS, Beaver Watershed Alliance, Northwest Arkansas Land Trust, Arkansas Master Naturalists, University of Arkansas Division of Agriculture Research and Extension, USGS, and many others, held hands-on activities meant to inform about water quality and ecology of Beaver Lake and the surrounding watershed. Past activities have included viewing diatoms through a microscope, making their own take home Secchi disk, taking a kayak test drive, rain barrel building workshops, water fun fact scavenger hunts, and many more. Since 2015, Secchi Day organizers have diversified the event through outreach to the Latino and Marshallese communities of NWA. This effort is made possible by partnerships with local Spanish-speaking radio stations such as La Zeta Radio and reaching out to local Latino and Marshallese organizers such as One Community. Highlighted features of such cultural outreach have resulted in Marshallese dance troops and crafts being featured at Secchi Day on Beaver Lake. This effort, along with outreach material printed in three languages, ensures that underserved communities in NWA are included in the education effort.

The partnership between BWA and BWD is working toward the common goal of source water protection through activities such as Lakes Appreciation

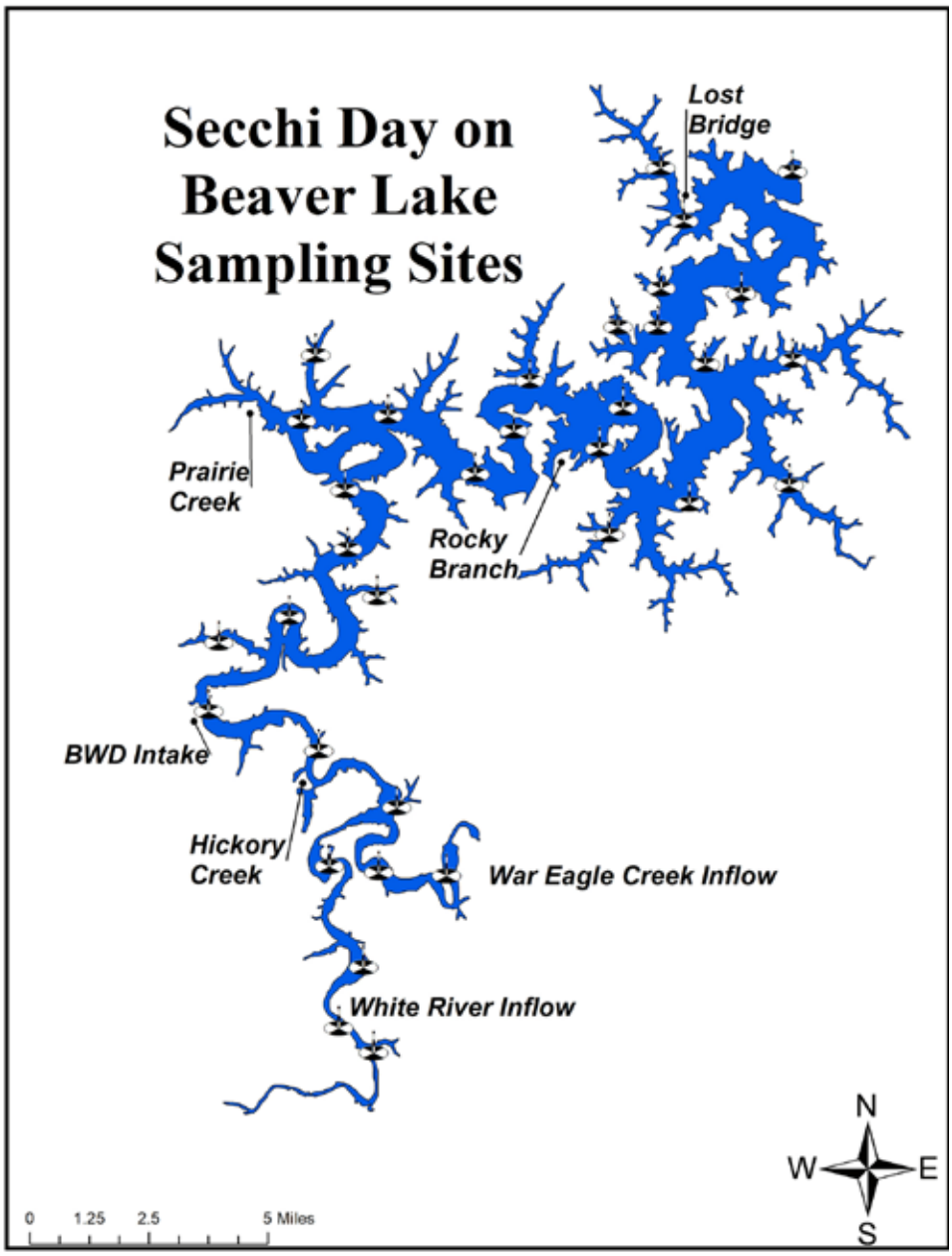


Figure 3. Map showing location of Secchi Disk readings on Beaver Lake.

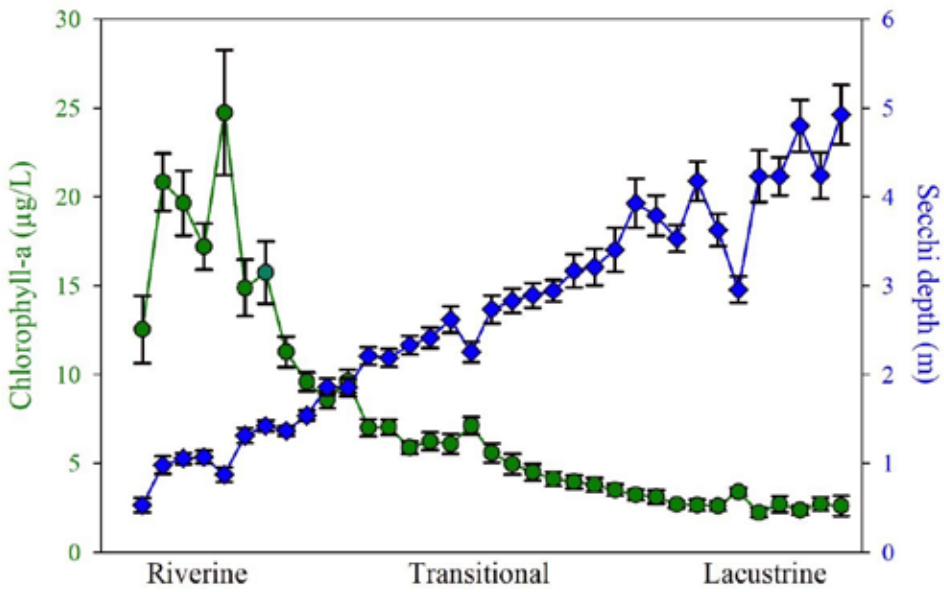


Figure 4. Changing transparency of Beaver Lake from the riverine zone (e.g., 0.8 meters), near the White River and War Eagle Creek inflows, to the lacustrine zone (e.g., 7.5 meters) near the Beaver Lake Dam.

Month, the Secchi Dip-in, and Secchi Day on Beaver Lake. Whether for flood control, hydropower generation, domestic drinking water supply, or recreation such as fishing, swimming, or boating, preserving this finite resource is imperative for the health of citizens and the growth of NWA. Together, BWA and BWD are proud to work in tandem to serve and educate the community. Beaver Watershed Alliance and Beaver Water District appreciates and thanks all partners, sponsors, and volunteers who made Lakes Appreciation Month and Secchi Day on Beaver Lake successful programs.

To learn more, check us out on Facebook or either organizations websites:

- Beaver Watershed Alliance – www.beaverwatershedalliance.org
- Beaver Water District – www.bwdh2o.org

References

Carlson, R.E. 1977. A trophic state index for lakes. *Limnol. Oceanogr.* 22: 361-368.

Tetra Tech. 2012. Beaver Lake Watershed Protection Strategy. May 2012 Revision. [Online] Available at https://www.beaverwatershedalliance.org/ (Verified 1 October 2018).

Matthew Rich, an environmental specialist with Beaver Water District, received his BS and MS degrees from the University of Arkansas. Between his time as a bachelor's and master's student, he spent time as a research associate and lab manager at the Louisiana Universities Marine Consortium (LUMCON) researching the effects of oiling to Louisiana marshes, as well as annual hypoxia in the northern Gulf of Mexico. Currently, he works on source water protection issues, along with citizen science engagement efforts like Secchi Day on Beaver Lake. He enjoys spending time in the woods and canoeing with Gus, his English Bulldog.

Becky Roark joined the Beaver Watershed Alliance in December 2016. She holds a B.S. in Landscape Architecture from the University of Arkansas. She has worked within the water quality and conservation fields since 2010, helping to develop the *Low Impact Development Manual – A Design Manual for Urban Areas*, while interning at the U of A Community Design Center, she served as an Americorps Volunteer with the University of Arkansas Office of Sustainability and has designed and installed over 75 rain gardens in both the Beaver Lake and Illinois River Watershed, helping to increase green infrastructure technologies for this region. Becky is passionate about watershed protection, education and the preservation of natural areas, serves on the Fayetteville Natural Heritage Board, enjoys kayaking and bass fishing, and spending time with her two children, Luke and Abby. Becky can be reached at becky@beaverwatershedalliance.org or by phone at 479-750-8007.

Brad Hufhines, an environmental specialist with Beaver Water District, received his BS and MS degrees from the University of Arkansas. He holds Water Treatment, Water Distribution, Wastewater Treatment, and Industrial Wastewater Treatment licenses in the state of Arkansas. Brad serves on the Arkansas HABs workgroup and the Arkansas Forestry and Drinking Water Collaborative steering committees.

UPCOMING IN *LAKELINE* –

LAKELINE WINTER 2019:
"Emerging Contaminants" is the theme of the winter issue of *LakeLine*. Articles will cover a range of contaminants, regulatory frameworks surrounding emerging contaminants, monitoring programs, and more. We will be accepting articles through December 1, 2019 for the winter issue.

LAKELINE SPRING 2020:
"Lake Browning" will be the theme of the spring *LakeLine*. The issue will include an overview of lake browning caused by increased dissolved organic carbon content in surface waters, and the chemical, biological and ecological implications of browning.

Forest Conservation and Management to Protect Sources of Drinking Water

Pierce A. Rigrod and John M. O'Neil

Forest management and conservation: A brief history

Forests play a key role in protecting water quality and stabilizing volume within lakes, reservoirs and rivers. The importance of forest cover in maintaining water quality and volume has been recognized as far back as 1700 BC in ancient Greece (Neary 2017). Trees, forest litter and soils are particularly well suited to deliver high quality water to streams and in moderating stream hydrology. This presumes forests remain intact and are well managed.

In the United States, the impetus to improve forest management was born out of the need to control wildfires in the west, serve recreational interests in the east and meet the growing need for safe drinking water in growing cities. These priorities were framed within arguments supporting the passage of Forest Reserve Act of 1891 and the Organic Administration Act of 1897. The Forest Reserve Act gave the president authority to "set apart and reserve" forested lands, leading to the creation of today's national forests.

Early research completed through the United States Department of Agriculture's (USDA) Forest Service Office of Silvics characterized how forests, forest litter and soils influence streamflow, control floods, and affect water quality. In 1910, the U.S Forest Service (USFS) conducted the first "watershed" study, comparing two similar watersheds in Colorado (Wagon Wheel Gap Project) by denuding one of the watersheds of its forest and measuring streamflow, then comparing that streamflow against the streamflow in the "control" watershed having an intact forest. Not long after, a research project completed in northern New Hampshire (at the Hubbard Brook Experimental Forest) demonstrated the degree to which forest cutting and burning reduced stormwater infiltration, lowered base flow and caused streamflow to increase more rapidly during storms. Over the following century, forest research has been crucial to improving water quality in lakes and rivers through better forest management practices.

Looking back to when the forests roared

Forest management today can be traced back to the negative experiences associated with uncontrolled forest cover removal, wildfires and soil erosion in many areas:

- Over 100 years ago the White Mountain region of New Hampshire was "stripped of trees from what was once virgin forest, streams choked with silt from eroding hillsides . . . ." (WhiteMountainHisotry.org) Uncontrolled logging led to flooding, low stream flows and blackened slopes affecting downstream mills, tourism and a variety of other interests.
- In 1907, catastrophic flooding on the Monongahela and Ohio Rivers was traced directly to the cut-over condition of the upstream watersheds in Pennsylvania and West Virginia.
- In 1910, wildfires devastated Idaho and Montana. The flood damage from large-scale removal of northern forests and wildfires eventually led to passage of the Weeks Act, referred to by some as the "single most important law in the creation of national forests in the eastern United States" (USFS, Celebrating a Century of Conservation) The Weeks Act was preceded by 20 years of forest research, advocacy and debate leading to the federal purchase of over 20 million acres in 26 states, including the White Mountain National Forest in northern New Hampshire in 1911. National forest research centers today, including Hubbard Brook in New Hampshire, continue innovative research concerning biomass/bioenergy, climate change and watershed management and restoration within national forests (USFS, R&D Priority Areas).

Forests are essential for safe drinking water

Forested lands are the source of more than half of the surface water supplies in the United States and provide drinking water to about 212 million Americans, through public and private water systems. Treating "raw" source water to comply with federal and/or state drinking water quality standards is complex and sensitive to water quality changes.

Regulatory compliance with health-based and aesthetic standards depends largely upon the quality of the water entering a public water system's water treatment plant. Approximately 90 chemical, radiological, and microbial contaminants have water quality standards regulated under state and/or federal Safe Drinking Water Acts. Maximum Contaminant Levels (MCLs) establish the maximum permissible level of contamination allowed in drinking provided by water public water systems.

A Forest Service study estimates that for each square kilometer (KM^2) of forest land converted from forest to urban cover within the Conserve Reservoir serving Mobile Alabama, TOC concentrations at the source water intake will increase the monthly median TOC concentrations between 33 percent and 49 percent.

The vast majority of Public Water Systems (PWSs) using surface water must install sophisticated treatment systems to remove total suspended solids (TSS), parasites (Giardia), microorganisms (*Escherichia coli*, or *E.coli*) and a range of inorganic and organic compounds.

Organic material in souce water can create harmful compounds when raw water is treated with a disinfectant, such as chlorine. Natural organic matter, (NOM) from decaying plant and animal matter, reacts with disinfectants, creating hundreds of disinfection byproducts (DBPs), some of which pose serious threats to human health and have regulatory limits. DBPs including Haloacetic acids (HAAs) and Trihalomethanes (THCs) are known to be carcinogenic at elevated levels. NOM increases Total Organic Carbon (TOC) that can affect taste and odor of treated drinking water and shorten the lifespan of treatment media, increasing the need for coagulants and disinfectants.

Converting forests to urban landscapes is estimated to increase annual phosphorus loading to a lake by a factor of ten (Horne 1994). Nutrient-rich conditions in lakes and reservoirs support algal growth and are associated with Harmful Cyanobacteria Blooms (HCBs), a growing concern for water suppliers. Cyanobacteria was recently identified by the Association of State Drinking Water (ASDWA, November 2018) as one of the top three concerns for state source water protection programs. *Microcystis***,** a genus of freshwater cyanobacteria, currently being considered for future regulation and listed on U.S. EPA's Contaminant Candidate List (CCL 4), can produce a class of toxins referred to as Microcystins, harmful or fatal to humans, pets and wildlife when present at high concentrations.

Without water treatment processes capable of removing cyanobacteria cells, potentially harmful toxins within the cells can enter into finished drinking water. In New Hampshire and beyond, recent cyanobacteria blooms in water supply reservoirs and lakes, that previously did not have one on record, have elevated concerns. This has created a greater focus on reducing nutrient loading from the watershed, monitoring bloom-forming conditions and improving coordination among both state and water utilities on the response to HCBs.

Retention of well managed forests reduces nutrient loading and helps to limit the need for more complex and expensive treatment. In the northeast, Lake Sebago (serving Portland, Maine) and the Catskill/Delaware reservoir system (serving New York city), both pristine sources, provide drinking water with more limited treatment. Both water systems receive Filtration Avoidance Determinations (FADs) because their surface water sources meet strict criteria for turbidity, coliform and total trihalomethane MCLs. Avoiding additional treatment saves the Portland Water District approximately $155 million dollars. U.S. EPA FADs come with conditions to implement watershed control programs that implement comparatively cost-effective land conservation investments, non-point pollution controls and forest management practices. As New York's Commissioner of the Department of Environmental Protection statement implies, high quality source water doesn't happen by accident.

> Forests cover approximately 90 percent of New York's Catskill/Delaware watershed. (New Your City Watershed Forest Management Plan, 2017)

> *"Since the City received its first filtration waiver in the early 1990s we have protected open space around our reservoirs, invested in wastewater upgrades, forged partnerships with watershed farmers, and focused considerable attention on the forests, streams and wetlands that comprise the natural infrastructure of our water supply"* (Official Website of the City of New York 2017).

While it would seem obvious, losing forest cover in water supply watersheds appears to correlate with increasing water treatment costs. (American Water Works 2016). Based on a national survey of public water systems located within forested areas, the results "imply converting 10 percent of the watershed from forest cover to developed area increases chemical treatment costs by 8.7 percent" equating to "an annual increase of over $65,000 for the typical treatment plant in this study…". For public water systems, AWWA's report adds weight to the notion that there are tangible day-to-day financial benefits from forest ecosystem services.

Forest management within Lake Massabesic's watershed

Manchester Water Works (MWW), a large public water system operated by the City of Manchester, New Hampshire, was established in 1871. Soon after, the MWW began to purchase land along the lake's shoreline, tributaries and up-gradient pond system in the watershed. Much of the property purchased during the late nineteenth century previously was being used for sheep farming, and consisted of pastureland surrounded by stone walls. MWW began to reforest grazing areas by planting tree seedlings to accelerate reforestation. This went on for decades with over one million seedlings planted between 1871 and 1935. The majority of these were Eastern White Pine (*Pinus strobus*) as seen in Figure 1. By 1935, the MWW owned nearly 6,000 acres of forested land within the 24,000-acre watershed. Not long after MWW purchased an additional 2,000 acres.

Efforts to reforest previously cleared areas and institute forest management practices have yielded a healthy and vigorous forested landscape across the watershed. Management objectives have changed over time. Initially, pine dominated forests were managed to provide maximum tree growth potential (height and girth). Forests were thinned to remove the poor quality trees in favor of the healthy crop trees to ensure the best overall forest health. Dominated by mature, well stocked, Eastern white pine timber during the second half of the last century, forested areas had very little stocking in the mid-story or understory. An overstocked ("stocking" is the degree of utilization of land by trees), mature forest is especially susceptible to major storm damage during extreme weather

> Well-managed forests are able to contribute to the protection, availability and sustainability of high quality, cost effective drinking water (*New Hampshire Forest Resource Strategies: A Component of the 2010 Forest Resources Plan*).

Figure 1. Mature white pine forest.

events, while younger forests are more resilient, something to consider in our changing climate. Today, MWW implements both an "even-aged" and "uneven-aged" forest management approach.

Even-aged forests often result from a past harvest or clearing for pasture that has re-grown, resulting in trees of approximately the same age (Figure 2). Management involves continuously removing the smaller diameter trees (less vigorous) and leaving the larger diameter trees (more vigorous) until the final harvest (clear cut). This had been a widely used forestry practice up to the early 1990s, but it has challenges arising from a closed canopy forest with a majority dominant over-story (i.e., no understory or mid-story) that can be very susceptible to wind throw and disease. These forests often lack species diversity as well as structural diversity, and harvesting often releases relatively more nutrients into the system in the short term.

To address these challenges, MWW uses an alternative approach referred to as Uneven-Aged Management. This approach is now considered a sustainable forestry approach. It involves forest harvesting operations similar to natural forest succession and disturbance(s) including harvesting trees in small areas to create openings of ¼ to 2 acres that mimic a wind/storm event and harvesting single trees to mimic natural mortality (Figure 3).

When used together Even- and Uneven-Aged Management benefit forest health and diversity, increase the number of species, and stratify age classes and vertical structure. Shade-tolerant and -intolerant species regenerating within the openings made through "group cuts/patch cuts" enhance species variety and create a young age class, while single tree harvesting enhances addition forest growth. Forest growth is accelerated due to the availability of new growing space, water and nutrients and reduction in adjacent tree competition. This approach reduces the release of nutrients into streams and to the lake. Today, 8,000 acres of high-priority water supply lands, 35 percent of the Lake Massabesic watershed, is protected by the MWW through conservation easements, yet the remaining watershed forests are highly vulnerable to development pressure.

Forest vulnerability and loss

In the northeast, much of the land cleared during the first 200 years of European settlement has reforested itself. According to the Society for the Protection of New Hampshire Forests, Maine, New Hampshire and Vermont are currently the three most heavily forested states in the country (Table 1). New Hampshire's forests cover 84 percent of the state and have largely been at this level since the 1980s. Unlike during the 19th and 20th century, forest loss in New Hampshire today is occurring through relatively small and progressive cutting to accommodate housing and commercial development, reducing the connectivity

Figure 2. Single age class forest cover.

Figure 3. Mixed age class forest cover.

Table 1. Table of Forest Loss in NH.

Year	Forest Loss Acres (NH)
2007	628,356
2011	643,769
2017	642,597

U.S. Forest Service, Durham, 2019

and quality of forests. Small and incremental forest loss attracts little public response and is a bit like the fable of a frog in a tepid pot of water that gradually comes to a boil. It didn't end well for the frog.

In 2009 the USFS published a report evaluating the risk of losing forested lands

More than 2,000 acres of forest land are cleared for development each day in the United States, and growth projections suggest that as many as 138 million acres of private forest land will be threatened by development between 2005 and 2030 (Stein and others 2005).

within water supply watersheds in the northeast and mid-west. *Water and People: Drinking water supply and forest lands in the Northeast and Midwest United States* (Barnes et al., June 2009). This study ranked watersheds across a 20-state study area according to their ability to produce clean water, the importance/reliance upon forest lands for drinking water and threat of forest conversion based primarily upon population and housing density. Out of 540 watersheds, the Merrimack River watershed in New Hampshire ranked as the fourth-most-threatened watershed.

In another *USFS report, Private Forests, Public Benefits: Forests on the Edge* (Stein et al. 2009), the Merrimack River Watershed (comprising 5,010 square miles in southern New Hampshire and Massachusetts) ranked as the most vulnerable watershed of the 15 watersheds located in the eastern U.S. in terms of the potential timber volume loss due to future increases in housing density, modeled through the year 2030. Protecting vulnerable forests contributing source water to public water systems, like Lake Massabesic and others, is going to require a more robust and coordinated effort. Locally for New Hampshire, between 2001 and 2016, US Forest Services reports 45,000 acres of forested land, an area of 70 square miles was lost within the New Hampshire portion of the Merrimack River Watershed.

Sustainable forests: The future is . . . to be determined

Sustainable forestry ensures that future generations will have forests to meet their needs and values (Penn State Extension) USFS defines sustainabilty in terms of the impacts from decisions made by natural resource managers upon the environment, society and economy, i.e., the "triple bottom line" (Elkington, 1994) Sustainable forestry balances society's demands for land and forest products with the preservation of forest health and diversity. Changes within the 2018 Farm Bill now encourage and incentivize private landowners to make sustainable forestry decisions that better protect sources of drinking water.

Strategies for Sustainable Forest Management

- Maintain a stable forest land base
- Maintain diverse forest composition
- Maintain or increase forest biodiversity
- Maintain or increase the quality and quantity of water from forest ecosystems.

Strategies for Sustainable Forest Management (USFS)

The 2018 Farm Bill dedicates $4 billion dollars over the next 10 years, increasing the financial reach of United States Department of Agriculture's (USDA) to improve forest practices within source protection areas. The law tasks USDA through Natural Resources Conservation Services to engage public water systems. Yet, land conservation within developing areas is expensive and forest management is less relevant as forests are lost to make way for other land uses.

Source water protection is largely voluntary in most states and for large geographic areas like a watershed, can be a heavy lift. Collaborative efforts among water utilities, local, state and federal partners to share expertise and resources has been an effective approach. Echoing the U.S Forest Services' *Forest-to-Faucet Partnership* (Gregory and Barten, 2008) study of population growth trends and vulnerability of drinking water supplies, protecting forests within water supply watershed will entail raising public awareness about the value of forest ecosystem services, targeting resources to support sustainable forest practices and

accelerating preservation of forested lands within the most vulnerable water supply watersheds.

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Pierce Rigrod oversees source water protection programs for New Hampshire Department of Environmental Services' Drinking Water and Groundwater Bureau. He has worked on local and state water supply protection activities for over a decade and has a background in environmental planning and community development.

John O'Neil is the current Watershed Land and Property Manager at the City of Manchester, NH, Water Works Department. He is responsible for activities on the 24,000-acre Massabesic Watershed and, with the exploration of a new intake on the Merrimack River, the 3.2 million-acre Merrimack River Watershed. John has a Bachelor of Science Forestry (BSF) from the University of New Hampshire in Durham and is a New Hampshire licensed professional forester.

Source Water Protection Challenges in **NH's Multi-Use Water Supply Lakes**

Paul Susca and Tom O'Brien

What happens when we play in the same water bodies we tap for drinking water? Are water utilities and other lake users bound to come into conflict? The potential is there, but the two have more reasons to work together than to be at odds. The source of the potential conflict is clear: a drinking water supply source that is as clean and consistent in quality as possible keeps treatment costs down, and keeps both customers and regulators happy. On the other hand, keeping a lake as clean as possible means no water-based recreation, no shoreline development – no development at all in the watershed. The challenge is to keep the lake as clean as possible for water supply while everyone enjoys the lake in other ways as well.

There's no question that recreation – especially of the body-contact variety, compromises the quality of drinking water supplies. Water quality monitoring data from Sebago Lake – the source for Portland, Maine's water system – demonstrate that fecal bacteria levels drop the further one goes from swimming beaches. And studies by the Water Research Foundation, the Trust for Public Land, and others show that both turbidity and water treatment costs increase as a watershed shifts from forest to other types of land cover. While some water utilities can achieve the ideal of an undeveloped watershed and a water supply lake or reservoir closed to all activity, in most cases water supply and other uses have to coexist. It might be because people were enjoying the lake for other uses before the water supplier came along, or the water quality and public health implications of other uses were not understood when the water supply was developed, or the water utility didn't have the money to lock up the lake and its watershed early on, or the water supplier lacks the political jurisdiction or clout to control watershed development, access, and other uses.

Examples: A patchwork of regulations in New Hampshire

Of the nearly 1,000 lakes, large ponds, and reservoirs in New Hampshire, about two dozen are used as public water supplies. Roughly half of those are used exclusively – or nearly so – as water supplies, while the others are at least partially open to recreational uses, most often boating. Swimming is allowed in only a handful of those lakes and ponds, and in almost all of those cases some part of the water body – near the water supply intake – is completely closed to recreation. To explain this patchwork of allowed and restricted uses, one only needs to recognize that the multi-use water supply lakes were tapped as water supplies at a time when the existing recreational uses were not seen as posing a likely threat to the safety of the water supply, and the compromises made since that time reflect each community's attempt to balance the desire for a safe water supply with the interests of waterfront land owners, and in some cases the larger community's interest in a recreation-based economy.

Rather than having uniform statewide restrictions on water supply lakes (and rivers), New Hampshire water suppliers or municipalities can ask the State to adopt waterbody-specific restrictions under an 1899 statute that was prompted by typhoid outbreaks during the years preceding the enactment of the law. Reading those rules today, you can see what the water quality concerns of the day were:

- "No privy, pig-pen, stable, or other building . . . in which horses, cattle, swine . . . or fowls are kept . . ."
- "No dung either human or animal, kitchen waste, swill, or garbage shall be thrown into or deposited in said lake...."
- "A person shall not deposit or allow sawdust, shavings, apple pomace, or waste from mills or factories to fall into said reservoir..."
- "No person shall bathe in said lake..."
- "A person shall not drive, ride, or race any cattle, horses, or other animals used for teaming, riding, or racing on the ice ..."

Reading the rules also makes it clear that some water systems and municipalities simply used other towns' rules as templates for their own water supplies, while others thoughtfully crafted protections to accommodate certain existing uses of their lakes and watersheds, while limiting or banning others.

Looking beyond those rules at how each lake is managed, a couple of examples help show how each situation is unique – not only in terms of each lake's natural characteristics (depth, flushing rate, etc. – regardless of whether they are natural lakes or impounded), but in terms of each lake's recreational value, history of shoreline development, and the water utility's response to water quality concerns.

Lake Massabesic, the subject of a separate article in this issue, is a sprawling, impounded lake that has long served as the sole water supply source for state's largest city, Manchester, and some adjacent areas. Massabesic is closed to all body-contact recreation, but boating and fishing are allowed except in an area surrounding the water supply intake. Manchester Water Works owns nearly all of the land with frontage on the lake as well as extensive holdings elsewhere in

Figure 1. Manchester Water Works' land holdings include the watershed of Tower Hill Pond (shown here), whose discharge is managed to recharge Lake Massabesic, the system's main reservoir.

the watershed (Figure 1). Both the lake and the Water Works lands are important recreational resources (Figure 2), particularly given their proximity to the state's largest population center, and are monitored by the only water utility "watershed patrol" force in the state.

In contrast to Lake Massabesic, which is managed primarily as a water supply, the state's largest lake, 72-square-mile Lake Winnipesaukee, is one of the state's most significant recreational resources. Its shoreline is heavily developed, and its use as the City of Laconia's sole water supply is treated as almost incidental. Only the area within about 1,000 feet of the intake, near the lake's outlet, is closed to recreation. While the lake's overall quality is very good, there has been a trend toward beach closings due to *E. coli* bacteria, increasing milfoil infestations, blooms of algae and cyanobacteria, and a decline in fish and loon populations. The increased frequency of noticeable cyanobacteria blooms in some of Winnipesaukee's coves and bays is a source of concern for Laconia's water department, as is the use of herbicides to control invasive aquatic plants in portions of the lake upstream from the intake. For its part, the City has taken the initiative to improve the management of stormwater in some of Laconia's more developed areas near the lake, takes an active role in reviewing proposals to treat invasive aquatic plants with herbicides, and works with lake associations and others in an ongoing sub-watershed approach to lake planning and management.

This joint effort, or community-based approach, between government, private groups and businesses, and citizen volunteers, is an intentional design on the part of New Hampshire to, among other things, protect and conserve its water resources. While there are state environmental statutes and municipal ordinances designed to protect water resources, state agencies such as the New Hampshire Department of Environmental Services place a high value on engaging and working with stakeholder communities, both professional and citizen volunteer, to effectuate on-the-ground protection and conservation.

At the state level there are several environmental regulatory programs designed primarily to protect water quality or water resources (e.g., Wetlands, Shoreland, Subsurface Septic, and Alteration of Terrain Permit Programs). But within the political and economic context and processes by which environmental laws are made (and strengthened or weakened as time goes by, more data becomes available, or legislative priorities shift), the result is that these state laws usually establish, from an environmental protection perspective, just minimum standards that have to be met. In addition, due to other demands on state environmental agency staff (such as emerging contaminants) enforcement of existing environmental laws affecting lakes may be limited to only the most egregious violations. This is where municipalities can and do step in, to greater and lesser extents, to adopt more restrictive lake-friendly ordinances and adopt best management practices (such as with road deicing).

In New Hampshire, municipal ordinances need to fall within existing

Figure 2. Manchester Water Works' watershed lands are an important recreational resource.

state law to the extent that state statutes enable more restrictive local ordinances.

Lake-friendly ordinances that municipalities have adopted in New Hampshire address steep slope development restrictions, increased shoreline or wetland setback distances for septic systems or other development disturbance, and restrictions on the application of road salt. In addition, restrictions can be placed on any lake in New Hampshire, either through statute or, in the case of safety-related rules (which may have environmental effects), by way of a citizen petition process administered by the New Hampshire Department of Safety (NHDOS). An example of a safety-driven rule that can have environmental consequences is the elimination of group mooring of boats near a dam or a public access boat ramp. Creating rules that prohibit such "mooring fields" may be driven primarily by safety concerns but, depending on the circumstances, may have water quality benefits as well.

Nonprofit partners – statewide and local

NH LAKES is a statewide nonprofit organization whose mission is to keep New Hampshire's lakes clean and healthy, now and in the future. This group has been an important partner in many lake and watershed related initiatives in the state. One of the ways that NH LAKES works to ensure good lake water quality is by helping its local lake association partners and other conservation groups get lake-friendly ordinances and other best management practices adopted at the municipal level. In addition, NH LAKES facilitates, with its local association partners, public participation in the process by which the NHDOS is petitioned and which, as mentioned, may set rules for each lake and which may have environmental benefits. So, we have a tiered source water protection public policy framework in New Hampshire that has both strengths and weaknesses.

One of the unintended consequences associated with this tiered framework of state laws, municipal ordinances, and lake-by-lake restrictions, is that New Hampshire now has a patchwork of standards, permit processes, and allowable uses from place to place, town to town, and lake to lake. This makes it challenging for state environmental regulators, municipal code enforcement officers, contractors and other permit applicants, lakefront property owners, and visitors to understand and comply with all the laws, ordinances, and rules. And, even when there are adequate protections provided through these public policies and practices, we know from experiences across the United States and over the decades that, when a watershed is populated with people and their associated human enterprises, a cooperative, community-based approach to source water protection may be a necessary and important complement to an environmental regulation framework.

Engaging landowners in lake protection through LakeSmart

In New Hampshire there are several programs directly or indirectly administered by government agencies or public universities which rely on the voluntary participation of private citizens and groups concerned about the long-term health of New Hampshire's 1,000 lakes. These lake water quality programs cover water quality monitoring, aquatic invasive species (prevention education, early detection, and management), and watershed assessment and pollution mitigation. One such program, directed primarily at reducing polluted runoff from private property around lakes, is LakeSmart. It is the newest program in our water quality toolbox, but one that is voluntary, non-regulatory, and which involves private property owners within and near the lake "shoreland" area (within 250-feet of shore).

At its inception in 2004, LakeSmart was a program of the Maine Department of Environmental Protection (DEP). In 2012, the Maine DEP handed over the ownership of the program to nonprofit groups, and it now functions as a program of the Maine Lakes Society, a statewide nonprofit organization. LakeSmart is a voluntary, non-regulatory program in Maine and participation is free. Maine DEP recognized the limitations of a getting private property owners to enthusiastically allow officials from a regulatory agency to come on to their private property. The agency recognized that they could increase participation in the program by transferring the program

to a private nonprofit organization. Since doing so, the program has really taken off. In 2012, the last year of DEP program ownership, ten lake communities were participating. Since being handed over to the Maine Lakes Society, the program now has over 60 participating lake groups – what we call in New Hampshire "lake communities." We talk about it in terms of community because that is who we work with and how we get it done – by engaging with communities who have a vested interest in ensuring the long-term health of our lakes.

Not unlike other major watershed programs in the U.S. today, LakeSmart is built upon concepts of community-based social marketing. Whether it is through coffee and conversation in kitchens and backyards overlooking the lake, or sessions at NH LAKES' annual Lakes Congress, highly motivated early adopters self-identify in each lake community. These folks are provided with the training, tools, and resources they need by NH LAKES to assess how lake-friendly their property is – what the potential is for their property to negatively impact water quality. With their self-assessment scores, and in many cases with follow-up on-site visits by LakeSmart Evaluators from NH LAKES or the local community, participants can then make upgrades to become more lake friendly and improve their score, ultimately scoring high enough to become LakeSmart. With that recognition comes certification and a sign (Figure 3) from the LakeSmart program. This recognition has its own social, and maybe even economic, value and is designed to inspire others to participate.

The social marketing piece here is based on the fact that the early adopters (you know, those people in your neighborhood who are always trying out new things) will pave the way, or un-pave it as the case may be. Then they can model their properties in any number of ways – again all voluntarily – with the hope and expectation that others will follow. This is not just theory but proven in practice by both social psychologists and, more importantly, by countless numbers of cooperating conservationists over the last 80-90 years with the US Department of Agriculture, County Soil and Water Conservation Districts, and the Cooperative Extension Service, and through dozens if not hundreds of other voluntary, non-regulatory conservation efforts by private property owners. LakeSmart in Maine was built on this premise and it has worked swimmingly. Now, in 2019, the program has been adapted by NH LAKES in New Hampshire and is underway with ten pilot groups participating and many more queuing up to get involved.

New Hampshire is one of many places that figured out a long time ago that private citizens can and should play a pivotal role in the conservation of our special places and shared natural resources, including our water supplies. With our land ownership model resulting in the majority of lakefront property – including the shoreland of many water supply lakes – being in private ownership, it simply makes sense for New Hampshire to augment its environmental laws, municipal ordinances, and other public policies and practices with a voluntary, non-regulatory (cooperative conservation) model to ensure the long-term health of its lakes. It also makes sense for source water protection strategies to encompass that model. In this way, on previously developed lands, we can reduce the inevitable impacts to water quality that shoreland property development might otherwise bring, and make it possible for water supply and other uses to continue to coexist.

Figure 3. Properties with LakeSmart signs carry a cachet of social responsibility.

Paul Susca supervises the Planning, Protection & Assistance section of the Drinking Water and Groundwater Bureau at the New Hampshire Department of Environmental Services. He has served in leadership and advisory capacities with national organizations focused on drinking water protection, including the Ground Water Protection Council and the AWWA Research Foundation. He currently chairs the Source Water Protection Committee of the Association of State Drinking Water Administrators.

Tom O'Brien has been the president of NH LAKES since 2011. Prior to that he was the executive director of the Network of Oregon Watershed Councils and the executive director of the Watershed Agricultural Council in the New York City water supply watersheds. This nonprofit executive experience was preceded by 20 years of public service as a natural resource manager in Massachusetts. His professional passion is helping local groups around the lakes of New Hampshire improve their capacity, impact, and sustainability.

Closing the Human-Nature Feedback Loop

V. Reilly Henson, Kelly M. Cobourn, Cayelan C. Carey, Kevin J. Boyle, Michael G. Sorice, Nicole K. Ward, and Kathleen C. Weathers

Understanding people's responses to changing lakes

Introduction

Humans are entwined in reciprocal – and often complex – relationships with lakes. When a community, agency, or individual makes a land management decision, it can impact lake water quality by affecting drinking water supplies, ecosystem health, and recreation opportunities. When negative impacts become great enough that the public begins to observe them, it can inspire individuals and communities to act to protect the lakes they love and rely upon. We think of this relationship as a feedback loop, in which people affect lakes, and lakes in turn affect people (see Figure 1).

The scientific community has made great progress in understanding the relationship between human decisions and lake water quality, but there is still much to learn about this feedback loop. A great deal of research has focused on lakes' chemical, physical, and biological responses to people's actions. Yet significantly less attention has been paid to how people respond to changes in lakes, and how their responses can influence lake water quality in the future. The way that lake ecology affects human decisionmaking represents a considerable gap in our knowledge (Troy et al. 2015).

This knowledge gap, which is captured by the brown and yellow arrows in Figure 1, represents the ways in which people respond to changes in water quality. Our team is currently conducting research to better understand this response by working to model the relationship between people and lakes. We are a team of social scientists, ecologists, and physical scientists, who collaborate by sharing our disciplinary knowledge about components of the human-lake relationship, and work to link those components together to understand the complete feedback loop.

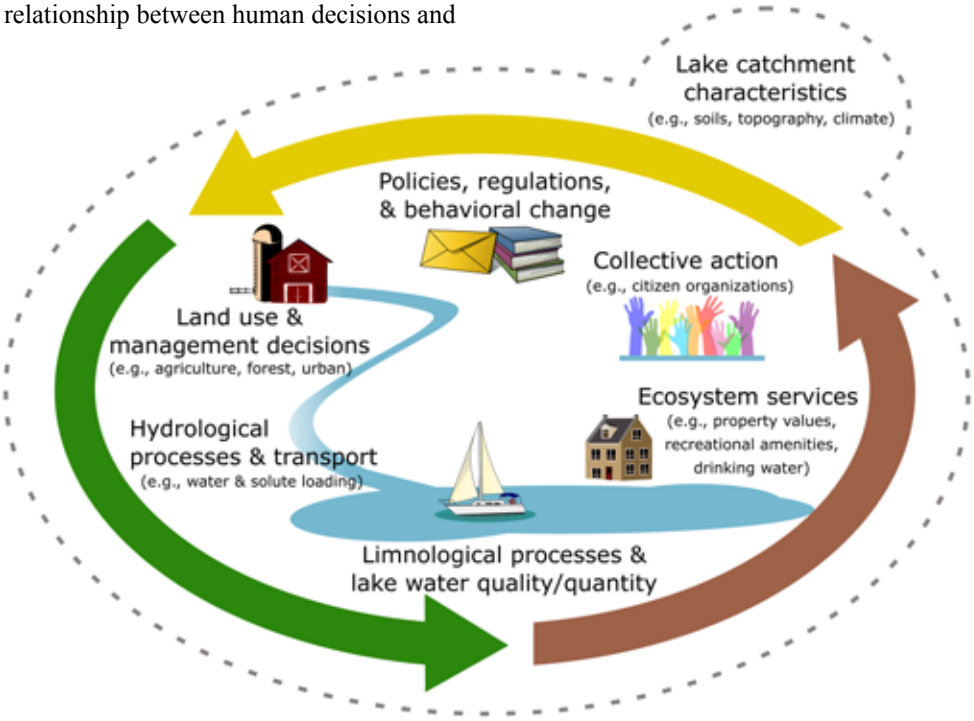

Figure 1. An illustration of how our project conceptualizes the feedback loop between lakes and people.

The importance of understanding behavior

Understanding the feedback loop between people and their environment is critical to achieving environmental, social, and economic goals over the long term (Matson et al. 2016). However, decisionmaking and policies usually address only one part of the feedback loop (a single arrow in Figure 1), which can result in unintended, often negative consequences (Matson et al. 2016). For example, if a policy requiring erosion control on personal property does not improve water quality the way that people expect, people may reject future policies under the assumption that they are ineffective.

The overarching goal of our project is to understand the full feedback loop between people and lakes, paying particular attention to the human behavioral response to changes in a lake ecosystem. This behavioral response occurs when people make decisions based on knowledge gained from past experiences, as well as predictions they make about the future. For instance, if residents observe cloudy lake water near shoreline areas with sparse vegetation after storms, they may choose to add plants or other features to reduce erosion,

either individually or by working together to implement a policy. By understanding what kinds of changes in a lake inspire behavioral response, and how those behavioral responses in turn influence lakes, our research supports lake management decisions that are more likely to achieve short and long-term goals.

Types of behavioral responses

Changes in lake water quality can affect people through a variety of mechanisms, and people respond to changes in a variety of ways (see Figure 2). These mechanisms – such as changing property values and effects on an individual's personal connection with a lake – may interact with one another, producing complex social and economic dynamics. Behavioral responses can take place at an individual or group level, or some combination of the two. An example of group behavior might be the formation of a civic organization whose mission is to protect lakes; an example of individual action would be if a resident reduced the amount of fertilizer applied to their yard in the hopes of reducing runoff into the lake.

The most pronounced behavioral changes occur in response to lake water quality degradation, which is often due to eutrophication. That could mean, for example, that the water becomes cloudier, there are longer periods of hypoxia (low oxygen) that lead to fish kills, or that algal blooms become more frequent. Identifying the mechanisms by which these changes affect people is a key step in studying the relationship between people and lakes. One such mechanism is that decreased water quality can reduce the monetary value of nearby properties. This is a phenomenon that economists study by analyzing trends in property prices. Another way people respond to degradation is to organize efforts to sustain lake water quality, which social scientists study by examining the types of action people take as a group to protect lakes, as well as their motivations for acting. Studying responses from these different disciplinary perspectives leads to a richer, more complete understanding than any one scientific discipline can provide.

Changes in property values

When water quality noticeably decreases, it can make lakefront homes less desirable, and nearby businesses may suffer if people do not visit the lake for recreation (Nichols and Crompton 2018). Property values decline due to diminished lake aesthetics, recreation quality, and other negative conditions. By using data on changes in property values alongside water quality data, it is possible to measure how strongly a decrease in water quality negatively influences property prices. Conceptually, this measures how much property owners are willing to pay to avoid a decline in water quality. This "willingness to pay" is often a helpful figure when making policy and management decisions, because it provides an economic justification for protecting lake water quality.

More complicated behavioral dynamics can also occur when a lake exhibits a pronounced shift in water quality. For instance, as water quality declines, people living near the lake who value water quality may decide to move away. The people who move in after them may tend to be more accepting of low water quality, making them less likely to actively protect the lake. This dynamic has been observed in some contexts, such as with amenities like open space, though more research is needed on its occurrence specifically around lakes.

Though scientists most often study how degradation in water quality affects people, improvements in lake water quality also affect human decisionmaking in potentially unexpected ways. For example, improvements in water quality make the lake and surrounding landscape more attractive to developers, who build housing, businesses, and other structures. As more land in the watershed is developed, the increase in impervious surface and changes in land-use practices (e.g., lawn fertilization) may create a new source of nutrient loading that degrades water quality anew. Through our research, we aim to understand and anticipate more of the unexpected responses to changes in lake water quality, including how those unexpected responses may affect the full feedback loop between people and lakes.

Changes in recreation

Just as property values tend to decrease with poorer water quality, so do tourism and recreation. When people visit from out of town to fish, boat, or sightsee, they often spend money at local businesses, including restaurants, recreational supply stores, and more. This boosts the economy of the community surrounding the lake. When decreased water quality causes these people to visit less often (perhaps choosing to visit a different lake instead), the community loses this economic benefit, providing yet another economic incentive to protect lakes (Keeler et al. 2015).

Additionally, if lower water quality reduces the number of people who visit the lake for recreation, it may contribute to a public perception that the lake is only an amenity for lakefront property owners. This will further reduce the amount of support for lake protection in the broader community, potentially reducing the degree to which land and lake managers adopt best practices for water quality.

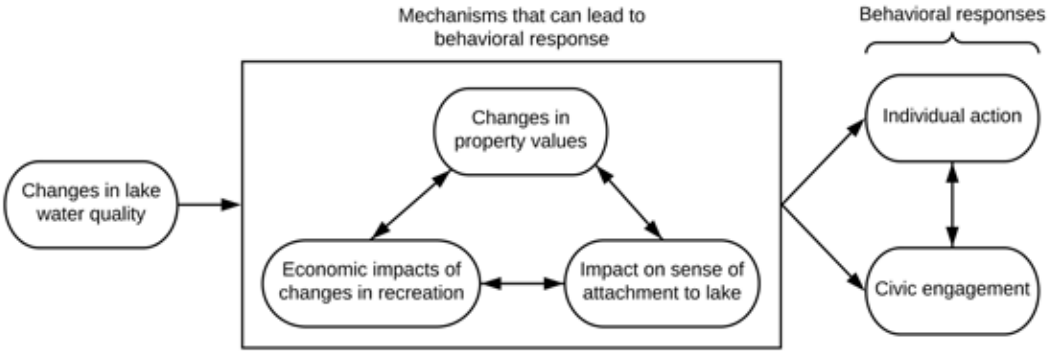

Figure 2. Examples of mechanisms by which changes in water quality can lead to behavioral responses.

Citizen engagement through lake associations

Sometimes people react to the observed change in water quality on an emotional, psychological, and even spiritual level, which occurs when people form an attachment to lakes because of the meaning the lake holds for them. For instance, a person who grew up near a lake may consider that lake to represent who they are as a person, their family heritage, or their livelihood. When people feel strongly connected to a lake in this way, it makes them more likely to take action when their lake is threatened (Stedman 2002). These bonds that people form with lakes and their communities, along with reductions in property values and diminished recreation opportunities, can motivate homeowners and people who recreate on a lake to join in civic action. Often, this action is in the form of citizen-formed lake associations.

Our project uses data on water quality, along with observations of lake associations, to examine how changes in a lake coincide with levels of civic engagement over the course of years or even decades. Lake associations can represent a variety of stakeholders, missions, and activities, often serving to educate the public, advocate for policies, and even help to bring science into community land-use planning and lake management. To understand what lake associations do, as well as how and why they do it, our project tracks their efforts over time using their newsletters, websites, and mission statements. By systematically searching for key themes and events, researchers compare changes in lake associations with changes in the lakes themselves over a given time period.

Challenges to studying behavioral responses

An interesting challenge arises when aligning ecological changes with human responses. It can take a long time for people to perceive the effects of a change in water quality, because changes are often gradual. It can take even longer for people to formulate and enact a response to these changes. This requires them to work together at multiple levels (local, state, and even national) to agree upon and implement actions. Sometimes different stakeholders' interests are not aligned with each other, or there may not be enough available scientific information, which can delay response further. To address this, our project focuses on lakes that have extensive, long-term data, meaning that a change in the lake could still be linked to a behavioral response, even many years later. This approach can provide insights for other lakes, where less information may be available, about how proactive actions to protect lakes unfold.

Conclusion

People's behavioral responses to changes in lakes can be complex, to say the least. Yet understanding these responses is critical to revealing the full dynamic relationship between humans and lakes. The better we understand coupled human-lake systems, the greater our ability to predict what management actions will work best, and when. Our project demonstrates a way to incorporate multiple disciplines to better understand human behavior, and this type of work is becoming more widespread in the scientific community. As this work progresses, we will better understand the complex human-lake relationship, which will directly inform improved lake management.

Acknowledgements

This work was supported by the National Science Foundation as part of the Dynamics of Coupled Natural and Human Systems (CNH) Program award number 1517823. The authors extend special thanks to our network of collaborators, including the Clean Lakes Alliance, the Oneida Lake Association, and the Lake Sunapee Protective Association. To keep up with the project, and to learn more, please visit http://www.cnhlakes.frec.vt.edu/.

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V. Reilly Henson works as a project manager for the research team. Her primary focus is on communicating the science, and helping to make information about the project – including its data – accessible to researchers and public audiences alike.

Kelly M. Cobourn studies natural resource economics from a variety of angles, including water quality degradation, land use, and invasive species management. She leads the development of this project's economic model of land use and management, which draws connections between environmental conditions and agricultural decisionmaking.

Cayelan C. Carey studies nutrient pathways and microbial communities in lake ecosystems. Her main focus is on how humans affect freshwater systems. In her role on this project, she uses software to model lake dynamics, including the causes and effects of eutrophication.

Kevin J. Boyle's research evaluates the best methods for economists to measure the value people place on environmental resources. He develops hedonic property value models for this project, which investigate the relationship between water quality and home prices.

Michael G. Sorice investigates how and why people engage in pro-environmental behaviors, and why humans tend to prioritize short-term benefits over long-term sustainability. As part of this project, he studies civic engagement in the form of lake associations.

Nicole K. Ward studies human-freshwater interactions. She is particularly interested in the intersection of decisionmaking, land use, and water quantity and quality. In this project, she uses a lake ecosystem model to simulate water quality outcomes of land use decisions.

Kathleen C. Weathers studies the ways in which living organisms influence biogeochemical cycling, especially across multiple landscapes and systems. She leads this project's efforts to work closely with lake associations, and to communicate its results to related organizations.

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Sarah Coney

Student Corner

Aquatic Invasive Species

From pristine mountain top lakes to gently flowing brooks, North America is home to a multitude of beautiful lakes and rivers. Many people appreciate waterbodies for their recreational uses or for their picturesque views. But what happens when our love for our waters ends up irreparably harming them? One of the biggest threats North American waterbodies face is from aquatic invasive species (AIS).

For the last three years I have been working as the assistant director of the Catskill Regional Invasive Species Partnership's (CRISP) Watershed Steward Program (WSP) to help prevent the spread of AIS in NY waterways. We have a dedicated team of stewards who seek to educate the public about the threats AIS pose, and to help them clean, drain, and treat to prevent the spread of AIS. I also work with the invasive Rusty Crayfish (*Faxionus rusticus*) as part of my thesis studying American eel (*Anguilla rostrata*) and native pearly mussels. Preventing the spread of AIS and educating the public about their dangers has been a major part of my life for the last four years and it is a topic I love to talk about.

An invasive species is any non-native species that causes environmental or economic damage or are harmful to human health. Invasive species often cost millions of dollars to control or eliminate. Invasive species tend to reproduce quickly and establish populations rapidly. AIS have no controlling herbivores or predators in the native ecosystem which allows their populations to grow out of control. These introduced species will then compete with native species within the same niche for resources, often outcompeting the native species. Invasive species can lead to declines in biodiversity, alter habitats, and can even eradicate native populations in areas where they are introduced (USDA 2019).

But how have so many of these non-native and exotic species made it to North America? AIS have been introduced through a multitude of vectors including ballast water, the aquarium trade, transient watercraft and other recreational gear. Unfortunately, more AIS are always being discovered.

The Great Lakes are a hot spot for North American introductions due to the high volume of ships moving in and out of those basins. Many larger ships use ballast water to provide stability, taking in or releasing water to adjust as the boat needs. When these ships take in water they can also take in and transport plants and animals (USDA 2019). Zebra mussels, native to the Black Sea in Eastern Europe, were brought to the Great Lakes in the 1980s through ballast (Ecochlor, n.d.). Another native to the Black Sea, the Round Goby (*Neogobius melanostomus*) was also brought into the Great Lakes through ballast water and has since become an aggressive invasive species in that system. Luckily, the threat that ballast poses to our waterbodies was recognized and the International Convention for the Control and Management of Ships' Ballast Water and Sediments was established in 2004 by the International Maritime Organization (IMO, n.d). All ships are now required to meet ship-specific ballast water and sediment standards to reduce the risk of introductions (IMO, n.d).

Posing just as much a threat, if not greater, to North American waters is the exotic pet trade. Many people delight in brightly colored foreign flowers and unique exotic pets, however, what happens when we get bored of our aquariums or they're too expensive to maintain? Unfortunately, many people simply dump their aquariums into whatever waterbody is closest. While many species will die, those that do manage to survive in this new environment thrive. Goldfish (*Carassius auratus*) are a prime example of cute pets wreaking North American native ecosystems. Goldfish and koi are in the same genus as the invasive common carp (*Cyprinus carpio*) and same family (Cyprinidae) as Silver and Bigheaded carp (*Hypophthalmichthys molitrix* and *H. nobilis*) and can be just as destructive when released. Carp are voracious herbivores or omnivores, disturbing benthic sediments as they forage and physically altering ecosystems to which they are introduced.

Asian clams (*Corbicula fluminea*), originally brought over as a food source by Asian immigrants (USDA 2019), were quickly adopted by aquarists as excellent water filterers. However, they are simultaneous hermaphrodites (having both male and female reproductive systems) and reproduce rapidly. A single mature clam can create and fertilize thousands of eggs per day. The environmental and economic impacts of Asian clams are astonishing: they out compete native bivalves, smother the benthic habitat, and cost billions of dollars for control and damage mitigation. Many states in the U.S have banned their sale but stores still sell them under various names (golden clams, filtering clams, etc.) and online.

Animals are not the only threat stemming from pet stores; invasive plants are regularly found being sold in pets stores or online. Perhaps the most well-known plant introduced through the aquarium trades is widely spread Brazilian elodea (*Egeria densa*). Sold as a good oxygenator, it became popular in aquaria and was quickly spread

throughout North America. Brazilian elodea grows fast and creates dense mats that negatively impact the ecosystem and recreation (USDA 2019). It was further spread by motor boats, becoming tangled in props and boat trailers and hitchhiking to new waterbodies.

Recreational boats and gear are another major vector for the transport of AIS. Boats offer all sorts of nooks and crannies in which invasive species can stow away. While some are obvious (plants entangled in a prop or on your trailer, zebra mussels attached to your hull, *etc.*) others are far less noticeable. Small bodied invertebrates are easy to miss but can have huge impacts on North American waters. Invasive bivalves start as small larvae, called veliger larvae, and are nearly impossible to see without a microscope. They can be found on watercraft hulls, in any pools of water, or even in gear that can hold water and they can persist for about a week in a wet environment. Spiny (*Bythotrephes longimanus*) and Fishhook (*Cercopagis pengoi*) waterfleas, both introduced to the Great Lakes from Eurasia, have rapidly spread throughout Northeastern North America due to their small size, which makes them very hard to spot. They pose a significant threat to native ecosystems by changing zooplankton community structure and competing with small native fish (USDA 2019). Waterfleas are hard to see on their own but tend to become stuck on lines dragged through the water (i.e., fishing lines, mooring lines, etc.) and accumulate, forming translucent blobs. Fishing line is the main culprit for transport of waterfleas, which can persist up to two weeks in a wet environment. Both species can reproduce sexually or by parthenogenesis (females can produce genetic clones) and do so rapidly.

Invasive plants have been spread efficiently by boats as well. Hydrilla (*Hydrilla verticillata*) was first introduced to Florida in the 1960s (possibly by aquarists) and has since spread rapidly (Gray 2014). While many thought hydrilla would be confined to warmer waters, a monoecious (having both male and female reproductive organs) biotype was introduced in the 1980s and has since spread rapidly north (Gray 2014). Hydrilla grows aggressively and can easily out compete native species, creating large mats at the surface and shading out the competition. What makes Hydrilla so threatening is its ability to spread by fragmentation. Hydrilla is a fragile plant that breaks apart with the slightest disturbance, those fragments float along the current before growing roots and eventually sinking, creating a new bed of hydrilla far down stream or on the opposite side of the lake.

So, what can you do to prevent the spread of AIS? Always remember to Clean, Drain, and Treat!

Clean

Remove any visible debris (plants, mud, etc.) and either wash or treat your watercraft and gear. Washing any mud or debris off your watercraft and gear and leaving it out to dry in five full days of sun helps to prevent any AIS from hitching a ride to (or from) your favorite lake or river. Many lakes have boat washing stations on or near their launches to help prevent the spread of AIS.

Drain

Always be sure to drain any standing water in your boat. Be sure to drain your live and bait-wells, pull your bilge plug, and drain your engine of any excess water. Canoes and kayaks are just as capable of transporting AIS as motor boats and are a bigger threat than most realize. Canoes and kayaks are easy to transport and launch and can be brought to remote locations easily. Most kayaks have a dry compartment that never seems to stay dry and offers an opportunity for small AIS to leap to new waterbodies inaccessible to motorboats.

Treat

Five full days of sun is not always an option in the summer and when that happens treating with solutions is always an option. The four most commonly used solutions are: bleach, vinegar, sodium chloride (NaCl), and potassium chloride (KCl). Bleach is effective in killing AIS (except waterflea) but leaves a nauseating smell and stains easily. Vinegar is effective but takes about 15 minutes to disinfect and has a noticeable odor. NaCl is effective in killing AIS and can be bought in large quantities cheaply, however, it quickly corrodes metal. KCl is highly effective, and while slightly more expensive than NaCl, is less corrosive to metal. Using KCl in a saturated solution (KCl + water, crystals aren't completely dissolved) to dunk gear or wipe down surfaces is a great way to prevent the spread of AIS.

Many states and providences have programs dedicated to stopping the spread of AIS. Becoming involved in your local programs can make a difference and preserve North American lakes and rivers for years to come!

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Sarah Coney is a master's student at SUNY Oneonta in NY studying the American eel (Anguilla rostrata, A.K.A best fish) and pearly mussels. She has also been involved in the Catskill Regional Invasive Species Partnership (CRISP) Watershed Steward Program (WSP) for the last three years.

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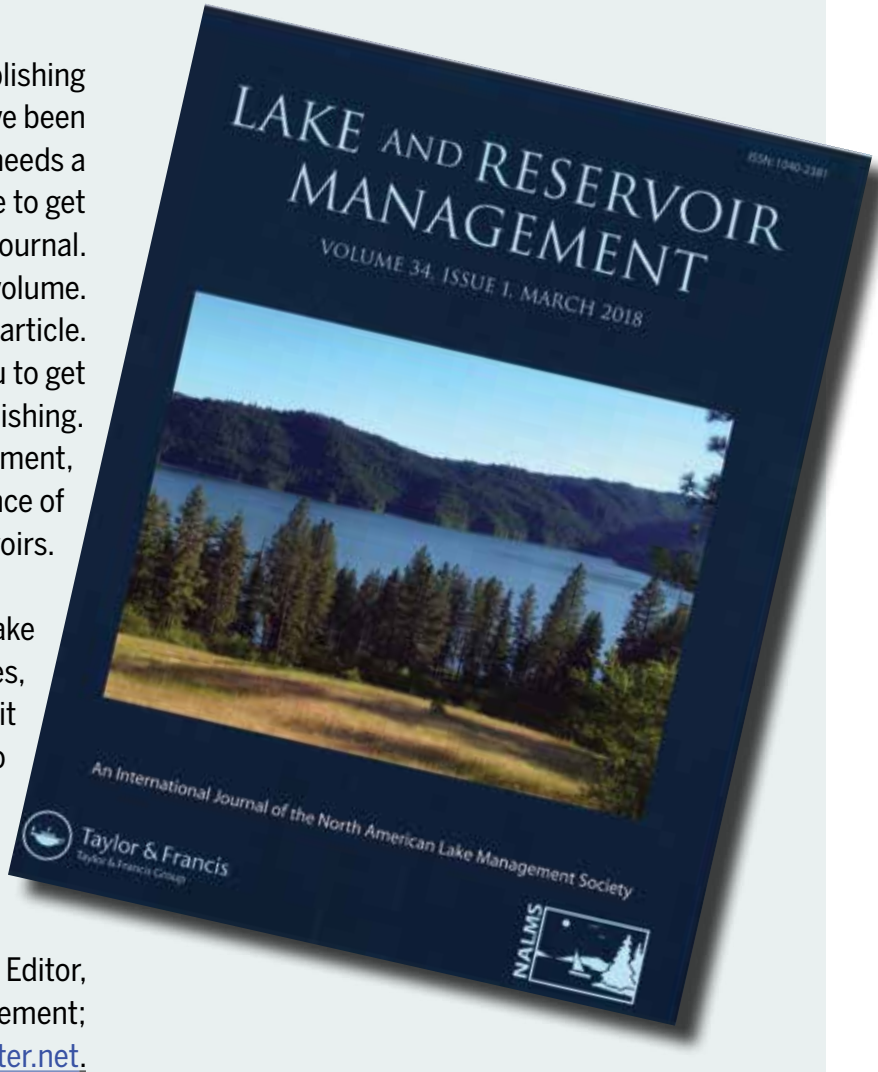

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