

# Ease the Squeeze in Twin Lakes, WA

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## The Colville Confederated Tribes Work to Enhance a Trout Fishery and Improve Water Quality in Reservation Lakes

### Twin Lakes, Washington

The Confederated Tribes of the Colville Indian Reservation include nearly 10,000 descendants from 12 aboriginal tribes in northeastern Washington State ([www.colvilletribes.com](http://www.colvilletribes.com)). The tribes include the Colville, the Nespelem, the San Poil, the Lake, the Palus, the Wenatchee, the Chelan, the Entiat, the Methow, the southern Okanogan, the Moses Columbia, and the Nez Perce of Chief Joseph's Band. Prior to the influx of Europeans in the 1850s, the aboriginal tribal members were nomadic, following their sources of food. Their aboriginal territories were grouped primarily around waterways including the Columbia, San Poil, Okanogan, Snake, and Wallowa Rivers. The Reservation was established in 1872, and today encompasses over 1.4 million acres (2,100 square miles), rich in timber, wildlife, fish, and water resources. The tribe has an intense cultural connection to their water and land; wild game and fish are important sources of food for many tribal members.

Of the many natural resources on the Colville Reservation, North and South Twin Lakes near Inchelium, Washington, are especially prized for recreational and fishing opportunities. These lakes are the only reservation waters open to non-tribal members, and are economically important to the region. The dimictic, mesotrophic lakes are similar in size with a mean depth around 10 m, a maximum depth around 15 m, and a surface area around 400 ha (Figure 1). As with many lakes throughout the country, the Twin Lakes fish communities have been dramatically altered due to human activity. The lakes

once supported populations of native inland redband trout (*Onchorhynchus mykiss gairdneri*) (Figure 2). Once widely distributed throughout the Columbia Basin east of the Cascades, redband trout have been substantially reduced from historical levels prior to European settlement. This reduction has multiple and complex causes: the effects of dams, water quality deterioration, altered flow regimens, habitat degradation and loss, and competition with introduced species. In addition, hatchery stocking programs that historically used coastal rainbows (*O. mykiss irideus*) have led to displacement and hybridization, so that pure populations of redbands are now rare. In Twin Lakes, the fish community is now dominated by non-native species including Eastern brook trout (*Salvelinus fontinalis*), largemouth bass (*Micropterus salmoides*), and the non-game golden shiners (*Notemigonus crysoleucas*). While the lakes have remained a popular fishing destination, the public perception is that both

brook and rainbow trout populations have declined as bass and shiners have increased; these perceptions are supported by available data (Christensen and Moore 2007). Tribal management goals are to support brook trout, but to increase emphasis on stocking of native redbands.

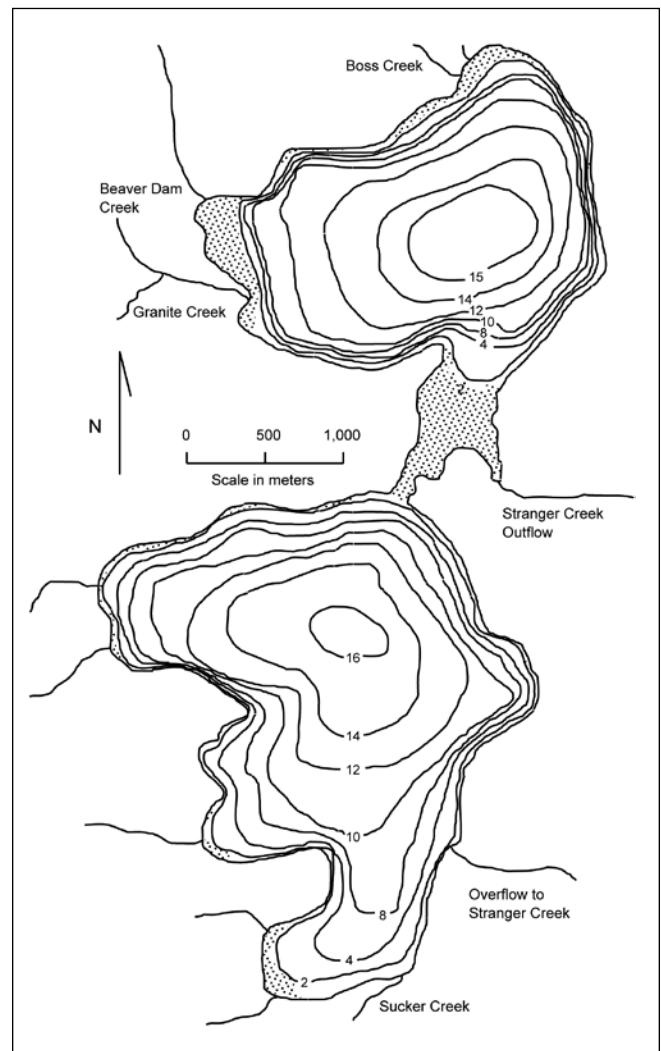


Figure 1. Bathymetric map of Twin Lakes, Washington. Contour depths are in meters. Hypolimnetic oxygenation was implemented in North Twin Lake (top) in summer 2009. Oxygenation will commence in South Twin Lake (bottom) starting in summer 2011.



Figure 2. The native inland redband trout (*Onchorhynchus mykiss gairdneri*) at left and the non-native largemouth bass (*Micropterus salmoides*) at right from Twin Lakes, Washington. Photos compliments of the Colville Indian Tribe's Department of Fish and Wildlife.

The temperature-dissolved oxygen squeeze has other consequences for fish besides loss of suitable habitat. Zooplankton at Twin Lakes display pronounced diurnal migration patterns, allowing them to avoid the sight-feeding trout by remaining in the hypolimnion during daylight hours. Acoustic fish tracking of tagged trout showed that they roamed much further

Public perceptions also tended to attribute declines in trout populations to the very visible increase in golden shiners, which tend to school in large numbers along littoral areas. To test that conventional wisdom, the Tribe's Department of Fish and Wildlife initiated a series of studies, led by Dr. Barry Moore at Washington State University's Department of Natural Resource Sciences, to investigate the impact of shiners on trout, as well as potential control options. Dr. Moore's research group initiated a series of detailed food web studies using stomach content analysis, stable isotope signatures, active fish tracking, hydroacoustics, and net- and electrofishing-captures (Christensen and Moore 2008, 2009, 2010). These studies demonstrated little interaction between the primarily littoral shiners and pelagic trout. They also found that while larger bass (> 300 mm) feed on brook trout, these bass likely prey heavily on golden shiners, keeping their populations in check.

These conclusions led researchers to look elsewhere for an explanation for trout declines. Water quality monitoring pointed to another factor likely limiting the trout fishery: a classic temperature-dissolved oxygen "squeeze." In both lakes, stable thermal stratification typically begins by late April or early May and persists through the summer into September or October. With thermal stratification and increasing water temperatures, hypolimnetic oxygen demand results in rapid development of anoxia at the sediment-water interface. Anoxia continues to ascend in the water column, so that by late July, the entire

hypolimnion is devoid of oxygen. These conditions lead to greatly reduced summer habitat availability, which has tremendous consequences for cold-water fish species. The summer epilimnion is too warm, and cold-water refuge afforded by the hypolimnion becomes inaccessible due to lack of oxygen, forcing trout to live within a 2 to 3 m deep stratum at the metalimnion (Figure 3).

during daylight hours in Twin Lakes at relatively high swim speeds. This is likely due to the large distances necessary to feed in the zooplankton-sparse daytime metalimnion. Indeed, stocked rainbow and brook trout condition factors decline throughout the summer, indicating poor feeding success, in spite of very abundant large-bodied zooplankton communities in the daytime hypolimnia of both lakes.

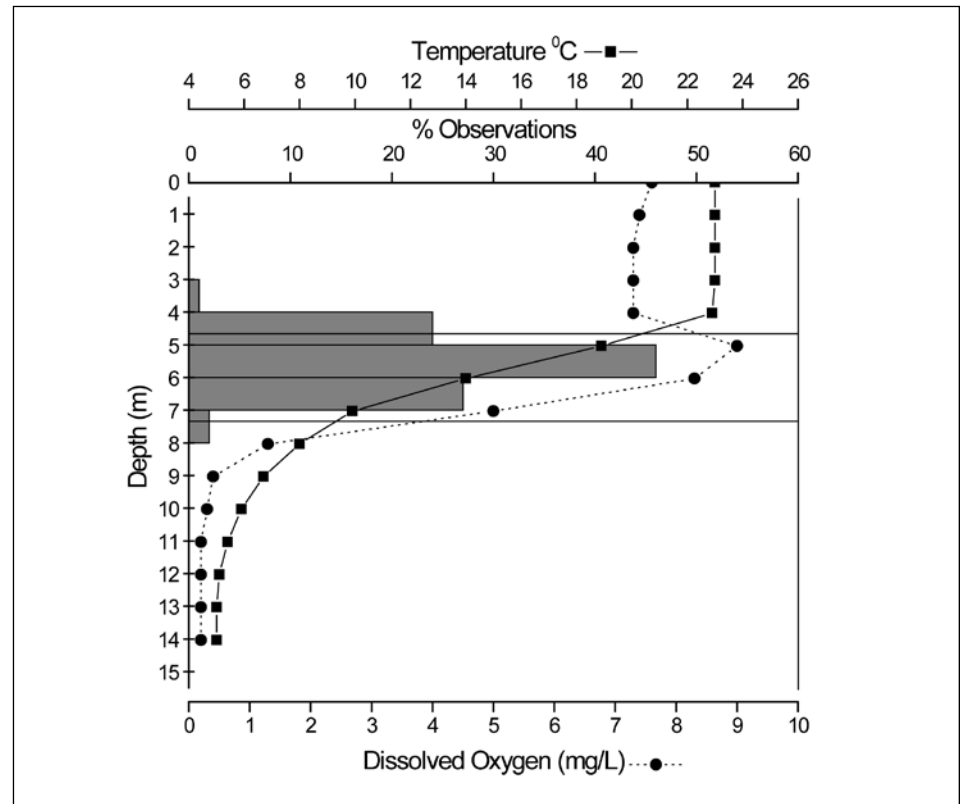


Figure 3. Trout distribution in North Twin Lake in August 2007. Grey bars represent % observations of trout within the water column using hydroacoustics. Horizontal lines define optimal trout habitat with water less than 20 °C and oxygen greater than 4 mg/L. Note that trout are squeezed into a 3-m-thick slab of water. Modified from Biggs (2007).

In addition, rainbow trout caught in Twin Lakes often display infestations of parasitic copepods, probably exacerbated by stress and overcrowding. Estimates suggest that total mortality of stocked trout in recent years could exceed 90 percent, and may approach 100 percent. Overall, the data pointed to highly stressed trout populations with poor survival and reproduction.

With the relationship between temperature-dissolved oxygen squeeze and health of the Twin Lakes trout fishery clearly established, the question turned to options for addressing the problem. If dissolved oxygen is the problem, one seemingly obvious solution is to add more oxygen. At this point, Dr. Beutel's engineering research group joined the project, and in collaboration with the Tribe, the research team developed, implemented, and is now monitoring the ecosystem-level effects of hypolimnetic oxygenation in Twin Lakes.

### Hypolimnetic Oxygenation

Hypolimnetic oxygenation is the use of engineered systems to enhance dissolved oxygen levels in bottom waters of lakes and reservoirs using pure oxygen gas without disrupting stratification (Beutel and Horne 1999). The technology has been installed in a number of lakes and reservoirs to improve water quality and enhance fish habitat. In the fall of 2008, a hypolimnetic oxygenation system was installed in North Twin Lake to improve summertime trout habitat. Historical oxygen profiles were used to estimate a peak hypolimnetic oxygen uptake rate of 0.1 mg/L·d. This is a typical uptake rate for a mesotrophic lake or reservoir, and with its relatively thin hypolimnion, much of the oxygen demand in North Twin Lake is at the sediment-water interface versus the hypolimnetic water column (Beutel 2003). Multiplying the uptake rate by the hypolimnetic volume, and also by an inducement factor to account for an increase in oxygen demand after system startup, yielded a design hypolimnetic oxygenation demand of around 3 metric tons per day. The oxygenation system consisted of a 6,000-gallon temporary on-shore liquid oxygen storage tank and evaporator (Figure 4) connected to 2,500 feet of submerged line diffuser located at the bottom of the



Figure 4. Liquid oxygen storage tank and evaporator on the shore of North Twin Lake. The storage tank can hold 6,000 gallons and the system can deliver 4,300 kg/day of gaseous oxygen to the lake.

lake. The ultimate system capacity, which accounted for diffuser-induced oxygen demand, recovery from unanticipated shutdown, diffuse oxygen transfer efficiency, and an additional safety factor, was 80 standard cubic feet per minute or 4.3 metric tons per day. The system was designed and installed by Mobley Engineering, Inc.

The line diffuser is a simple design that spreads fine bubbles over a large area (Mobley and Brock 1995). The system uses long lines of flexible porous hose connected to a high density polyethylene supply pipe that distributes the gas along the length of the diffuser (Figure 5). Flow control orifices control the oxygen flow to independent lengths of porous hose to maintain a continuous flow of fine pure oxygen bubbles along the full length of the diffuser. A second buoyancy pipe can support the entire weight of the diffuser system when filled with air, thereby bringing the entire system to the surface for maintenance as needed. Concrete anchors are attached to the diffuser piping with stainless steel cable and saddle connections. The line diffuser has proven to be an economical diffuser design that transfers oxygen efficiently, minimizes temperature destratification, and minimizes sediment disruption.

An alternative oxygenation system considered for the lake was a submerged contact chamber system similar to the one used in Newman Lake, Washington (Moore, Christensen and Richter 2009). The chamber system differs from the line diffuser system in a number of fundamental ways. A major disadvantage of the chamber system is the need for electricity and a submerged pump to force water through the oxygenation chamber. At remote Twin Lakes, this was a deciding factor in favor of the line diffuser. But, the line diffuser system tends to have lower oxygen transfer efficiencies, particularly in relatively shallow but stratified systems like Twin Lakes. Transfer efficiency is around 80 percent for the line diffuser in North Twin Lake compared to typical values of 95 percent for the submerged contact chamber. This difference in oxygen transfer efficiency can add up to significant cost when evaluated over the lifetime of a project. Another difference between the two systems is that the line diffuser discharges oxygen bubbles that dissolve as they move vertically up the water column. In contrast, in the submerged chamber system contact between oxygen bubbles and lake water takes place inside a chamber, and highly oxygenated water is discharge horizontally into the hypolimnion.

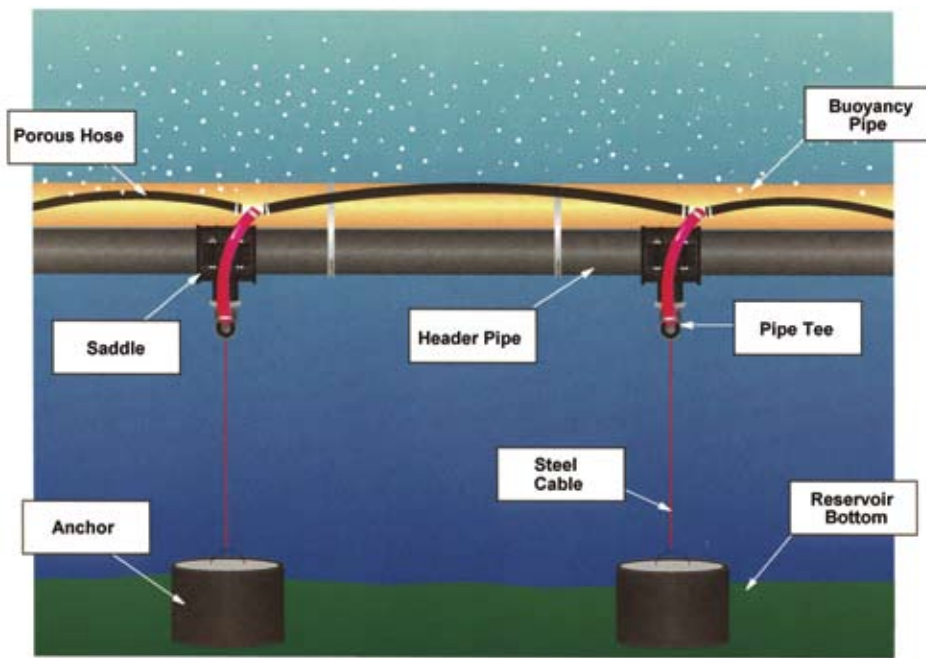


Figure 5. Schematic of submerged line diffuser installed in North Twin Lake. Compliments of Mark Mobley, Mobley Engineering, Inc., Norris, TN.

### Habitat and Water Quality Improvements

Hypolimnetic oxygenation in 2009 had a major impact on bottom dissolved oxygen levels in North Twin Lake (Figure 6). The co-location of the Twin Lakes, along multi-year data, allowed for both a before-and-after evaluation of oxygenation, as well as a side-by-side evaluation, with South Twin Lake as an anoxic reference site. Dissolved oxygen levels in the bottom waters of North Twin Lake were maintained above 5 mg/L, except for water in contact with profundal sediments. In South Twin Lake, the entire hypolimnion was anoxic from around May until destratification in late October. Mass of oxygen in the hypolimnion of North Twin Lake ranged around 100-200 metric tons, and closely tracked system delivery rates, which were experimentally turned up in early August and turned down in late August (Figure 7). In contrast, oxygen mass in the bottom of South Twin Lake was minimal and what little oxygen was available was mostly in the upper water of the hypolimnion. Estimates show that the volume of suitable trout habitat (> 5 mg/L dissolved oxygen and < 20 °C) in North Twin Lake in late summer expanded from 3 million m<sup>3</sup> in 2008 to 18.2 million m<sup>3</sup> in 2009. Based on ultrasonic telemetry of tagged trout and gill netting, the

vertical distribution of trout also shifted downwards in 2009 (Clegg 2010). In anoxic South Twin Lake, summertime gillnetting found only 2 percent of trout below the thermocline. In contrast, in oxygenated North Twin Lake, 35 percent of trout were captured below the thermocline.

Oxygenation also impacted the internal cycling of metals and nutrients. Dissolved manganese, iron, and phosphate typically accumulate in the bottom of lakes under anaerobic condition. If the released phosphate diffuses or gets entrained into surface waters, it can stimulate phytoplankton growth and exacerbate eutrophication. Metals accumulation is the result of anaerobic microbial processes in which bacteria use metal oxides in the sediments as terminal electron acceptors, reducing the solid metal oxides to reduced manganese and iron. Any phosphate bound to the metal oxides is also mobilized. The soluble compounds build up in sediment pore water and then diffuse into overlying waters. Manganese tends to undergo microbial reduction first, followed by iron, which is reduced at a slightly lower redox potential.

Monitoring results in 2009 show that oxygenation delayed the onset of metals accumulation by a few months, but did not fully repress metals accumulation

(Figure 8). Oxygenation also appeared to homogenize the metals throughout the hypolimnetic water column. In the anoxic reference, South Twin Lake, metals accumulation was well underway by June, and by September bottom waters contained around 300 µg/L of manganese and 3,000 µg/L of iron. There was a distinct spatial pattern of metals accumulation in the lake with manganese accumulating up to the thermocline and iron accumulating only in the bottom 3 m. Concentrations of manganese and iron increased towards the sediment-water interface, indicative of the reduced sediments being the source of the compounds. In oxygenated North Twin Lake, minor accumulation of metals occurred through August. Significant accumulation was observed in September, particularly near the sediment-water interface. This accumulation corresponded with experimental operations of the oxygenation system in which the oxygen delivery rate to the lake was decreased in August, resulting in lower levels of dissolved oxygen in the hypolimnion for the rest of stratified season. Manganese and iron were also more distributed throughout the water column, possibly as a result of enhanced mixing from operation of the line diffuser. Preliminary mass balance calculations indicate that summertime internal phosphorus release in North Twin Lake was roughly half that before oxygenation was implemented.

The observation that metals and nutrients still accumulated in bottom waters of North Twin Lake during oxygenation correlate with the observation that dissolved oxygen was low at sediment-water interface. In future years the oxygenation system will be operated at a higher and/or more consistent oxygen delivery rate. As oxygen demand decreases in the system in future years, we anticipate that the oxygenation system, while installed to enhance summertime trout habitat, will also have a greater impact on enhancing water quality as well.

### Mercury Cycling in Twin Lakes

Another unique component of our study at Twin Lakes was a focus on the effects of hypolimnetic oxygenation on mercury cycling. Mercury in freshwater aquatic food webs has become a

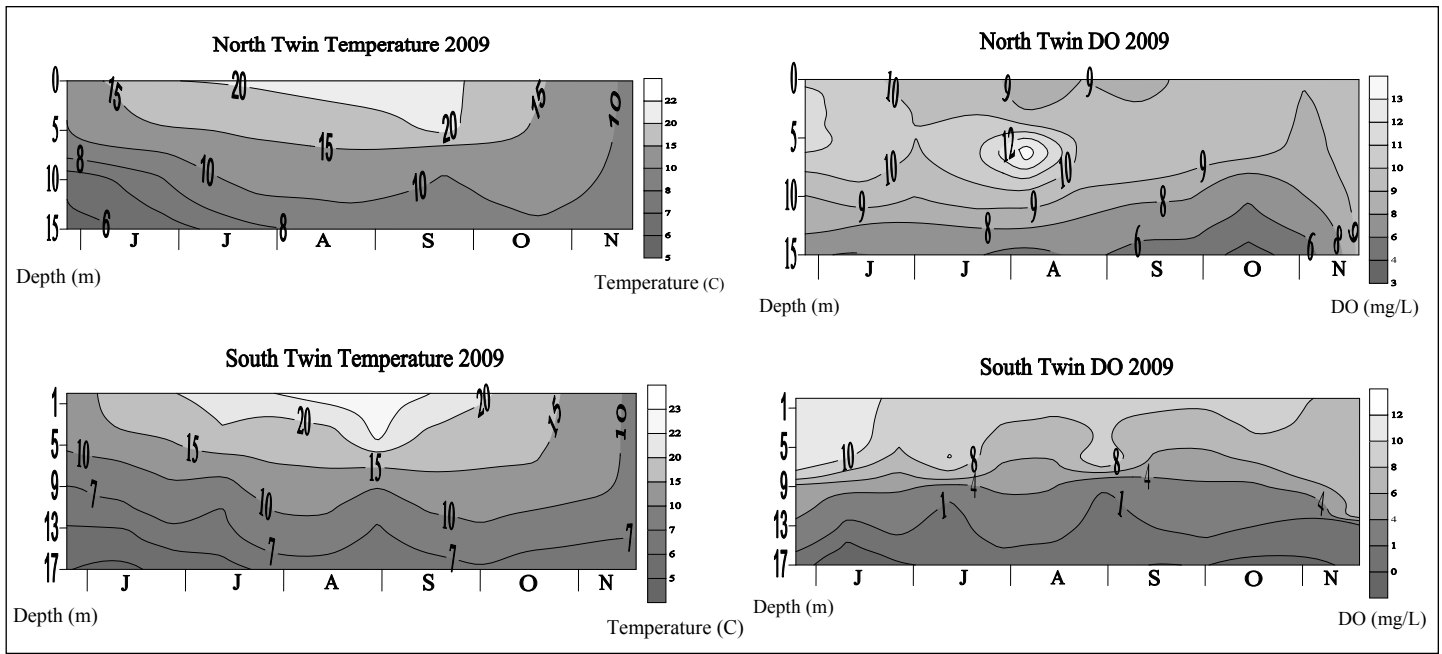


Figure 6. 2009 growing season temperature and dissolved oxygen isopleths in North Twin Lake (top) and South Twin Lake (bottom). Patterns of thermal stratification were similar in both lakes. Oxygenation in North Twin enhanced dissolved oxygen (DO) levels in bottom waters compared to South Twin Lake.

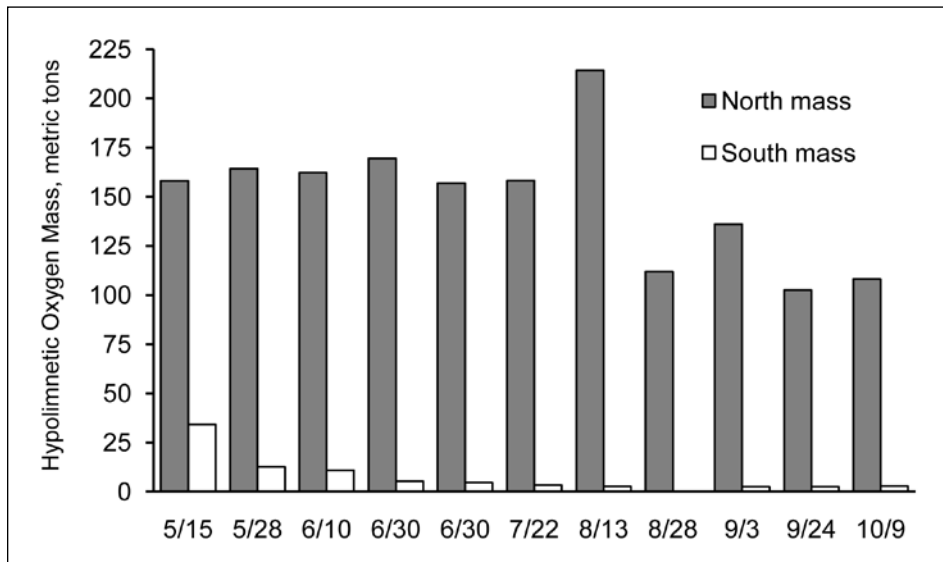


Figure 7. Hypolimnetic oxygen in oxygenated North Twin Lake and non-oxygenated South Twin Lake for 2009, expressed as total hypolimnetic mass (grey and white bars, respectively) in metric tons (1,000 kg).

worldwide health concern. Primarily as a result of fossil fuel combustion, the element is dispersed in the atmosphere and deposited widely across landscapes in the form of ionic mercury. Deposited ionic mercury can be transformed to toxic methylmercury ( $\text{CH}_3\text{Hg}^+$ ) by anaerobic bacteria, including sulfate-reducing bacteria, in aquatic waters and sediments such as anoxic hypolimnia. Once produced, methylmercury is taken

up by algae and other microscopic biota, and then biomagnified up the aquatic food web with levels increasing in successive trophic levels. Bioaccumulation can lead to high levels of mercury in fish, even in pristine ecosystems. In humans and wildlife that eat contaminated fish, methylmercury is a potent neurotoxin that impairs reproduction and fetal development. Nearly one-third of U.S. lakes have fish consumption advisories

in place due to elevated mercury in fish tissue. For example, Washington has a fish consumption advisory for all lakes and rivers in the entire state.

A handful of studies have linked hypolimnetic accumulation of methylmercury with uptake into the aquatic food chain. Some researchers have also observed that methylmercury levels drop in lake and pond bottom water when nitrate is added. Nitrate like oxygen can repress the activity of sulfate-reducing bacteria responsible for mercury methylation, and also repress the production of sulfide that tends to mobilize mercury in aquatic environments. Another important observation relates to the environmental factors that control mercury levels in aquatic biota. Of the numerous factors that have been evaluated, methylmercury levels in water have been found to be an important predictor of mercury levels in fish. Based on the dynamics of the biogeochemical cycling of mercury in the profundal zone of lakes, it is reasonable to conclude that the avoidance of anaerobic conditions in the bottom waters of lakes should result in a decrease in the amount of methylmercury in lake water and a related drop in the amount of methylmercury in the pelagic food chain. Yet-to-be-published data from 2009 showed that oxygenation repressed

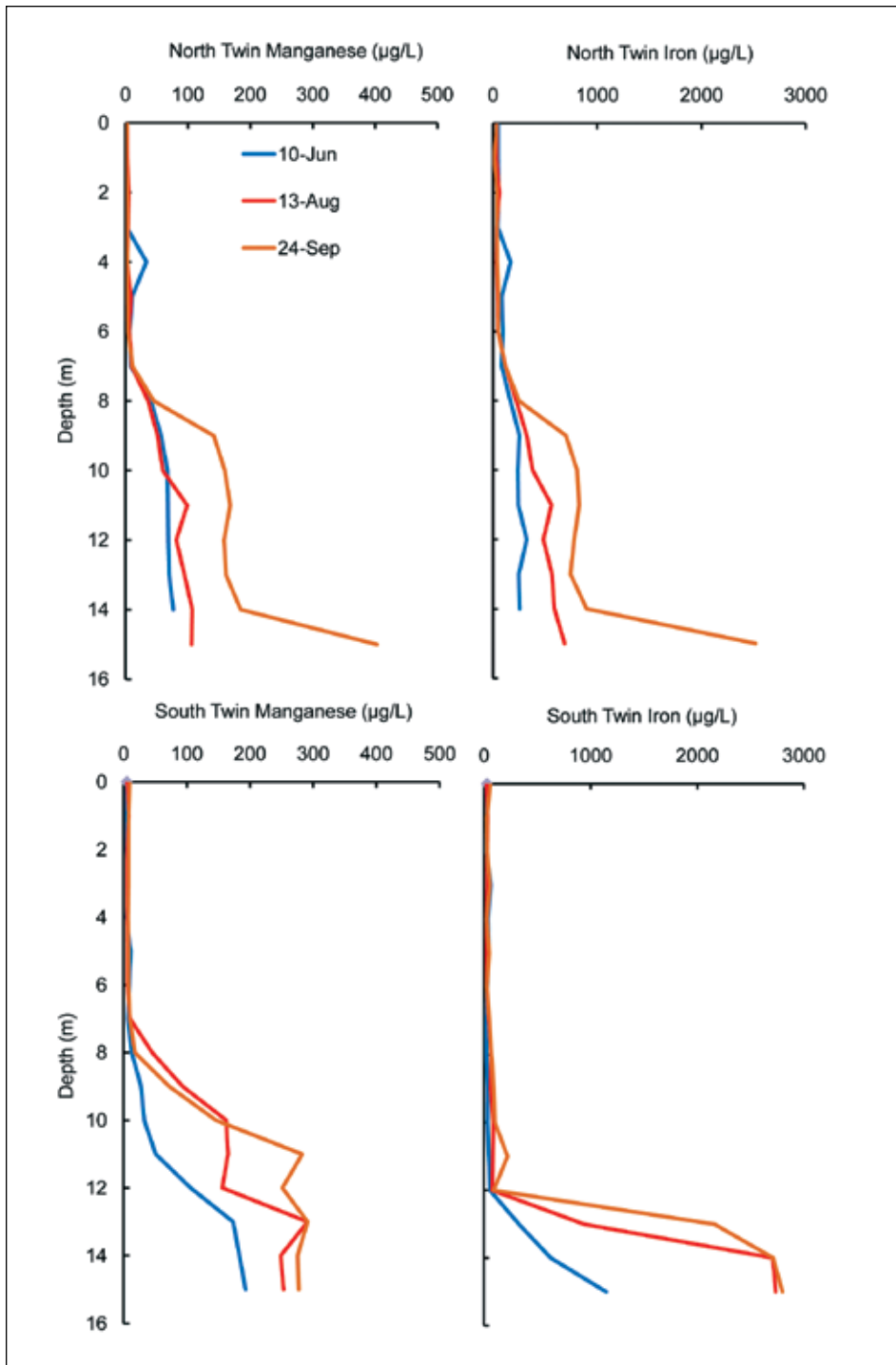


Figure 8. 2009 total manganese (left) and total iron (right) in oxygenated North Twin Lake (top) and non-oxygenated South Twin Lake (bottom). Oxygenation delayed the release metals but did not fully inhibit it.

methylmercury accumulation in the bottom of North Twin Lake (Figure 9). Peak levels of methylmercury in North Twin before oxygenation in 2008 were around 0.4 ng/L; levels after oxygenation were > 0.04 ng/L. Similar levels of methylmercury enrichment (~0.4 ng/L) were observed in non-oxygenated South

Twin Lake in 2008 and 2009. While additional study is needed, especially linking changes in water column mercury levels with effects in aquatic food web, this exciting result suggests that lake oxygenation, in addition to improving cold-water fish habitat and repressing internal cycling of metals and nutrient,

could also lower levels of mercury in aquatic biota.

## Conclusion

The Colville Indian Tribe has been extremely proactive in improving trout habitat in Reservation lakes. In North Twin Lake, hypolimnetic oxygenation has been successfully used to enhance summertime cold-water habitat for trout, relieving them of the “squeeze” between warm surface waters and anoxic bottom waters. A similar oxygenation system will be installed in South Twin Lake for operation in 2011. Ongoing studies at Twin Lakes related to oxygenation and fisheries, zooplankton, water quality, and mercury cycling will shed new light on this promising technology.

You will have a chance to visit Twin Lakes and talk to tribal managers about lake oxygenation at the upcoming 2012 NALMS annual conference in Spokane, Washington. As part of the conference we are planning a number of field trips to regional lakes, including Twin Lakes, the focus of this article. We will also host a fieldtrip to Newman Lake, the site of the first ever submerged contact chamber oxygenation system or “Speece Cone.” Lake managers in the Pacific Northwest are extremely excited about hosting the upcoming conference and look forward to sharing our beautiful lakes with the NALMS family!

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Figure 9. Dr. Marc Beutel and doctoral student Stephen Dent collect water samples for analysis of trace levels of total mercury and methylmercury. A number of strategies were used to minimize the potential for contamination, including the use of a Teflon water sampler; bottles that undergo a rigorous cleaning protocol, and the use of the clean hands-dirty hands technique in which the bottle holder touches nothing but clean bottles.

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National Science Foundation CAREER Grant that integrates research on mercury cycling in Twin Lakes with aquatic science outreach to youth from the Colville Confederated Tribes.

**Barry Moore** is an associate professor in the Department of Natural Resource Sciences at Washington State University in Pullman, Washington. He has over 30 years of experience in lake and reservoir management. He was a driving force behind one of the first-ever installations of a submerged contact chamber using pure oxygen gas to enhance dissolved oxygen content of bottom waters in Newman Lake near Spokane, Washington.



**Paul Ganzer** is president of Ganzer Water Recourses Engineering, LCC, a full-service lake and reservoir monitoring consulting company headquartered in Seattle, Washington. He is an expert in lake oxygenation and remote continuous monitoring of water quality. He has worked on a wide range of lake oxygenation projects throughout the United States, including the 100 ton per day system implemented by the U.S. Army Corps of Engineers in Richard B. Russell Reservoir, Georgia.



**Ed Shallenberger** is the Senior Resident Fisheries Biologist with the Colville Confederated Tribe's Department of Fish and Wildlife. He is responsible for the lakes and streams on the Colville Reservation. He is also responsible for Tribe's hatchery and stocking program. Ed has worked in a range of capacities with fisheries management since the 1970s. 🐟

