TWIN LAKES ENHANCEMENT

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Colville Confederated Tribes Fish and Wildlife Department

Twin Lakes Enhancement
2010

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Acknowledgements

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Funding for this project was provided by Bonneville Power Administration (BPA). We especially thank Sandra Fife or her support, cooperation and patience on this project.

Executive Summary

During the period of this report (April 1, 2010 to March 31, 2011) the Colville Tribe expanded upon the Twin Lakes Oxygenation Project that began in 2008 with the construction of a hypolimnetic oxygenation system in North Twin Lake. This system was operated briefly in 2008 and throughout the summer of 2009. Sufficient funding was obtained from BPA to operate the system in 2010, construct a South Twin oxygenation system, monitor the North Twin system and measure the effects of hypolimnetic oxygenation in North Twin (oxygenated) and compare them with South Twin that remained unoxygenated.

Oxygen monitoring was accomplished by Dr. Paul Gantzer (Gantzer Water Resources Engineering). Oxygen profiles were measured in both lakes throughout the oxygenation period (May-October) continuously by remote sensors in the deepest part of each lake and monthly is several locations in each lake. Oxygen depletion rates were measured by remote sensors in both lakes throughout the winter. These sensors will be recovered in May, 2011.

The effects of oxygenation on sediment and the water column of North Twin Lake were measured by personnel from Washington State University and compared to the unoxygenated South Twin Lake. Physical and biological parameters were measured.

Colville Tribal staff monitored fish populations with monthly hydro acoustic and gill net surveys and a creel survey throughout the fishing season.

In late summer a South Twin oxygenation system was constructed and tested by Mobley Engineering.

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Introduction

North and South Twin Lakes have been a popular recreational destination for nearly one hundred years. Apparent water quality changes and decreasing angling success resulted in the Colville Confederated Tribes commissioning a study by Juul (1986) to identify water quality problems and by Juul and Hueftle (1992) to report on the results of restoration efforts. These studies identified several sources of external nutrient loading and suggested management options for reducing nutrients. The Colville Tribes adopted these suggestions and external nutrient loading was greatly reduced.

In the late 1980s largemouth bass were illegally introduced and shortly thereafter golden shiners were also illegally introduced. Two distinct fisheries have developed at Twin Lakes. The largemouth bass fishery is managed by regulation only.

Since the 1990s anglers have complained of diminishing trout catches. In 2004 the Colville Tribes commissioned researchers from Washington State University to study Twin Lakes (Christensen and Moore, 2004) and determine the cause of the diminishing catches. At that time it was assumed that the introduction of largemouth bass and golden shiners was the principal cause of the decline. From 2004 through 2009, WSU and the Colville Tribes worked together to better understand Twin Lakes and the causes of the fishery decline. After several years of study it was determined that the primary cause of the fishery decline was not the introduction of nonnative fish species, but was internal nutrient recycling that led to summer stratification and severe trout "habitat squeeze". Epilimnion water temperatures were well above the preferred trout habitat range and the hypolimnion was anoxic creating a narrow band (<2 meters) of habitat for rainbow trout to occupy.

The consensus of opinion was that the preferred solution was hypolimnetic oxygenation. In 2008, a hypolimnetic oxygenation system was constructed in North Twin Lake. This system was operated and monitored in 2009. Funds were procured from BPA (project # 2008-111-00) to operate and monitor the system in 2010 and to build an oxygenation system in South Twin Lake. This report summarizes the operation and monitoring of the North Twin Lake oxygenation system in 2010 and the construction of the South Twin Lake oxygenation system.

Problem Statement

Water quality problems in Twin Lakes were first investigated by Juul (1986). Juul identified the sources of external nutrient loading (stream runoff, wastewater from resorts, and septic tanks) and estimated their contribution to the total nutrient load. Juul hypothesized that although external nutrient loading was significant, internal nutrient recycling contributed a greater portion of the total nutrient load, particularly in South Twin which has a longer water retention time (9.4 years vs. 2.7 years for North Twin). Juul (1986) stated that while water quality was still relatively good there was evidence that it was degrading. Juul (1986) concluded with suggestions for eliminating external loading and possible methods of controlling internal nutrient loading.

As a result of Juul's work several steps were taken to control water quality in Twin Lakes during the period between his initial report (1986) and 1992:

An effort was made to release as much water as possible through the South Twin Lake outlet in order to reduce the hydrologic retention time of that lake.

Five miles of four-wire fence were installed along the southern and western boundaries of the lakes. Two cattle guards were placed at road crossings in order to keep cattle out of the lake.

The Environmental Trust Department of the Colville Confederated Tribes prepared a watershed management plan to reduce external nutrient loading which has since been followed.

In 1989 a winter drawdown of North Twin was attempted in order to freeze out macrophytes. In 1990 a drawdown of South Twin Lake to kill macrophytes was attempted using a siphon.

In 1989 an attempt was made to remove sediment and macrophytes from the channel area between the two lakes. Approximately 22,000 cubic yards of material were removed.

Sewage and septic systems were modified in order to prevent input to the lakes.

A moratorium was placed on development in areas not already developed.

Juul and Hueftle (1992) reported on the restoration efforts and reassessed water quality conditions of both lakes and concluded that the primary nutrient load was caused by internal recycling within the lakes. External phosphorous loading was effectively reduced by the above management actions but internal recycling of nutrients continued to be problematic.

In spite of these management efforts water quality did not improve and the quality of the fishery appeared to decline. In 2003 Washington State University and the Fish and Wildlife Department of the Colville Confederated Tribes began a cooperative effort to reassess both water quality and fishery status. These studies have been reported by Shallenberger in the Hatchery Project's annual reports (2007, 2008, and 2009 annual reports). These studies concluded that because of the high internal nutrient loading, once the lakes are stratified in the summer, the hypolimnion becomes anoxic and the epilimnion water temperatures exceed the preferred range for salmonids, leaving only a narrow band of water for salmonids (figure 1).

In 2006, under the Hatchery Project (1985-038-00), the CCT Fish and Wildlife Department initiated a detailed creel study in order to assess catch rates and angling pressure (Shallenberger, 2007, 2008, 2009 and 2010). The creel study continues today as a Hatchery Project work element and although not part of the Twin Lakes Enhancement Project it will be used to help monitor the effect of oxygenation on the Twin Lakes Fishery. Four years of creel study gives a good baseline from which to measure any changes due to oxygenation.

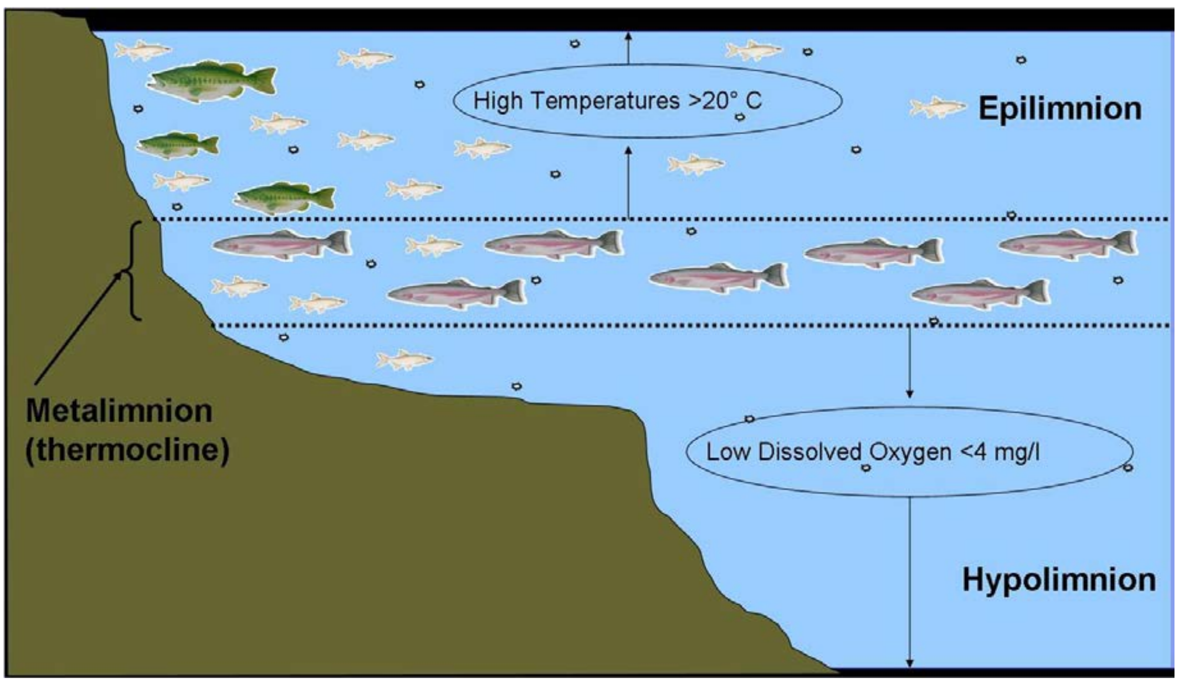

Figure 1. Twin Lakes during summer stratification

As a result of the work by Juul and later work by the CCT/WSU cooperative studies it was concluded that hypolimnetic oxygenation was needed to improve the water quality and salmonid fishery in North and South Twin Lakes. Several possible remedies were considered and are discussed in Christensen and Moore's (2008) report. Changes in stocking strategies and size of fish stocked, stocking of native redbands, further reductions in external nutrient loading, public education and hypolimnetic oxygenation have all been implemented.

Money was obtained for a two year pilot project through resident fish enhancement funds from the Columbia River Water Management Plan (CRWMP) under a Memorandum of Agreement between the State of Washington and the Colville Confederated Tribes. An oxygenation system was installed and briefly operated in North Twin Lake in 2008. This system was operated and monitored again in 2009,. This funding ended in June of 2010 and a transition to BPA funding for the project was included in the 2008 BPA Fish Accords.

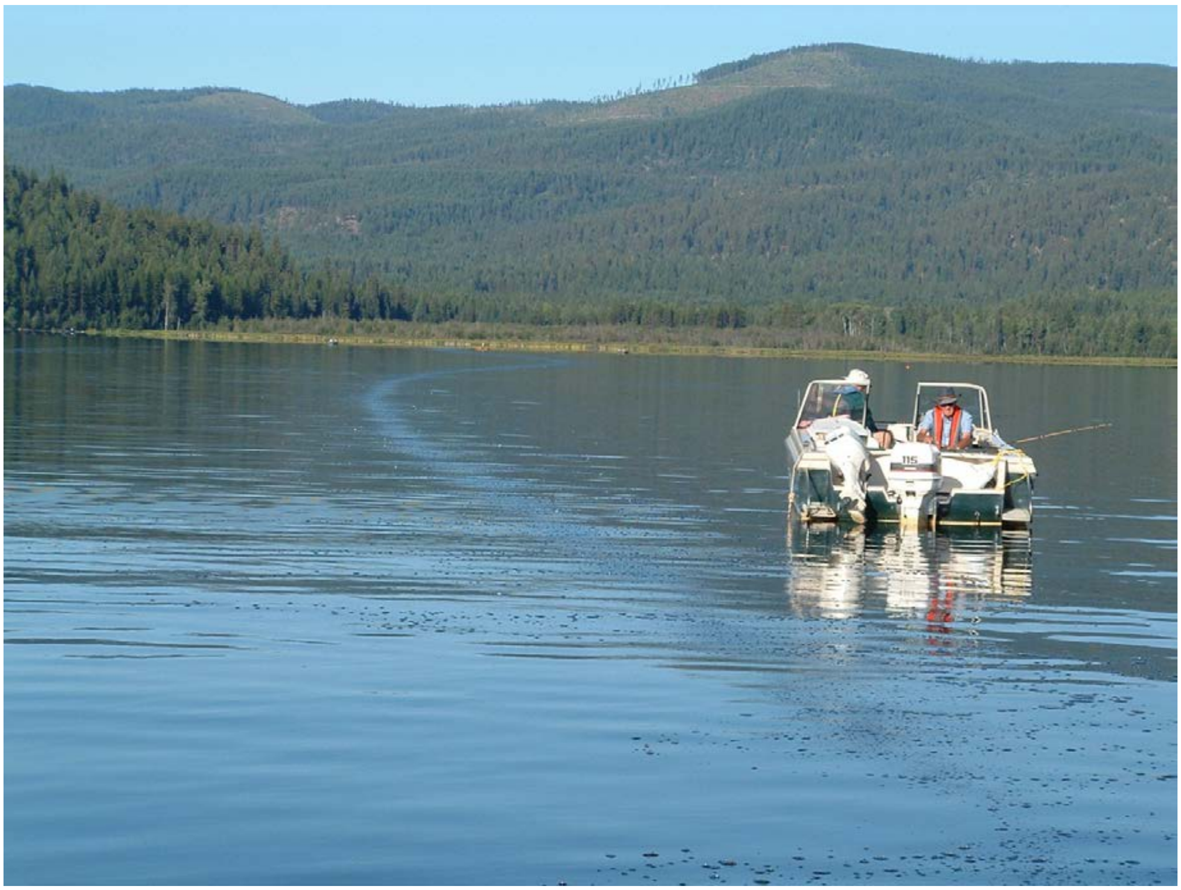

Figure 2. Angler fishing near oxygen bubble line

2010 Goals and Objectives

The oxygenation system in North Twin Lake was operated from May 12 to October 16 in 2009. Throughout that period of time various measurements and tests were made to determine the effectiveness of the system. All indications were that the system was operating as designed and fish were utilizing the hypolimnion of North Twin Lake (oxygenated) but not the hypolimnion of South Twin (unoxygenated) (Shallenberger 2010, Clegg 2010, Gantzer 2009).

In 2009 the primary goal of the oxygenation system was to enhance the fishery, reducing mortality and improving growth. While the results of the 2009 studies were encouraging they shed little light on the long term effectiveness of oxygenation on fishery.

The primary goal in 2010 was to make long term enhancement of the trout fishery at Twin Lakes by using hypolimnetic oxygenation to improve environmental and biological conditions in order to reduce summer mortality, and improve growth and catch rates, ultimately resulting in natural reproduction and reduced hatchery support.

In order to reach this goal, three sub-goals with associated objectives were developed.

Sub-goal 1. Operate the North Twin Lake oxygenation system as efficiently as possible, allowing salmonids to utilize the hypolimnion.

Objective 1. Elevate the dissolved oxygen level in the hypolimnion to a minimum of 5mg/l of dissolved oxygen, allowing salmonid utilization but does not waste oxygen.

Objective 2. Measure winter oxygen depletion rates in order to determine sediment oxygen demand (SOD).

Objective 3. Monitor and evaluate salmonid use of the hypolimnion in North Twin Lake (oxygenated) and compare it to the use of the hypolimnion of South Twin Lake (unoxygenated).

Sub-goal 2. Reduce salmonid mortality and improve growth and catch rates by improving environmental and biological conditions in North Twin Lake.

Objective 4. Measure the effects of oxygenation on benthic and pelagic invertebrates.

Objective 5. Measure the effects of oxygenation on salmonid mortality, growth and catch rates.

Objective 6. Measure the effects of oxygenation on the sediment of North Twin Lake.

Sub-goal 3. Build a South Twin Lake Oxygenation System.

Objective 7. Construct, install and test a hypolimnetic oxygenation system in South Twin Lake.

Methods

Several methods were used to reach our 2010 goals. In some cases more than one approach was used to reach a goal.

Sub-goal 1. Operate the North Twin Lake oxygenation system as efficiently as possible, allowing salmonids to utilize the hypolimnion.

Objective 1. Elevate the dissolved oxygen (DO) level in the hypolimnion to a minimum of 5mg/l of dissolved oxygen, that allowing salmonid utilization but does not wasting oxygen.

The purchase of oxygen is the major cost of operating the oxygenation system. Using insufficient oxygen does not allow dissolved oxygen levels to reach a point where fish can utilize the hypolimnion and using too much oxygen is wasteful and can even result in destratification of the lake.

In 2010, a remote monitoring station was placed in the deepest part of each lake. The South Twin station had two DO probes, one placed two feet above the bottom and the other placed 10 feet above the bottom. The North Twin station had a single DO probe positioned ten feet above the bottom. The probes were connected to general data loggers and information was transferred via radio to a station near the oxygen tank. The oxygen tank was equipted with an Alicat mass flow meter with totalizer. Data could then be continually accessed via a secure web site, thereby allowing for real time monitoring of dissolved oxygen levels in each lake. Oxygen flows could be manually adjusted in order to maintain DO at the desired level (5mg/l-7mg/l).. In addition, high resolution dissolved oxygen profiles were collected monthly with a Seabird Electronics SBE 19Plus sensor at five locations in each lake with . The sites for the dissolved oxygen profiles in North Twin were located well away from the oxygenation line. (figures 3, 4). These profiles were used to further evaluate oxygenation using a plume model.

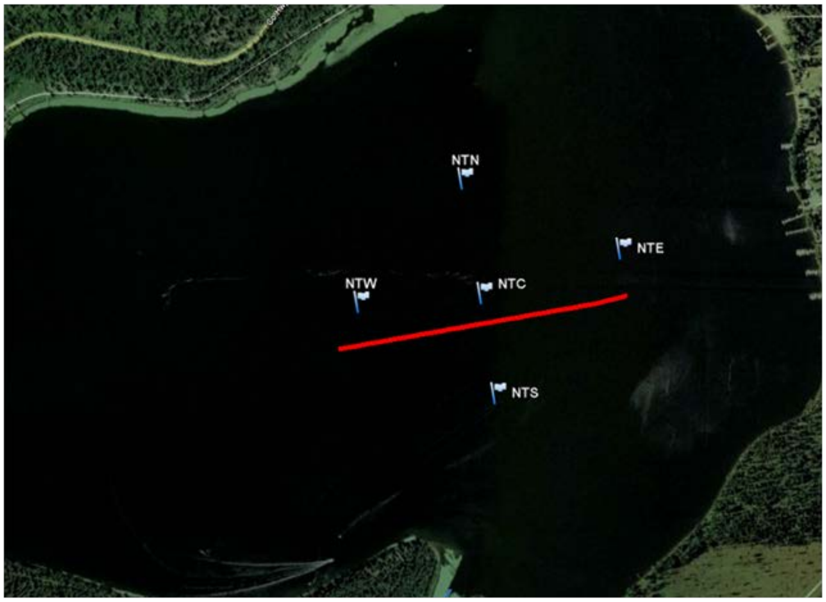

Figure 3. Gantzer North Twin monitoring sites

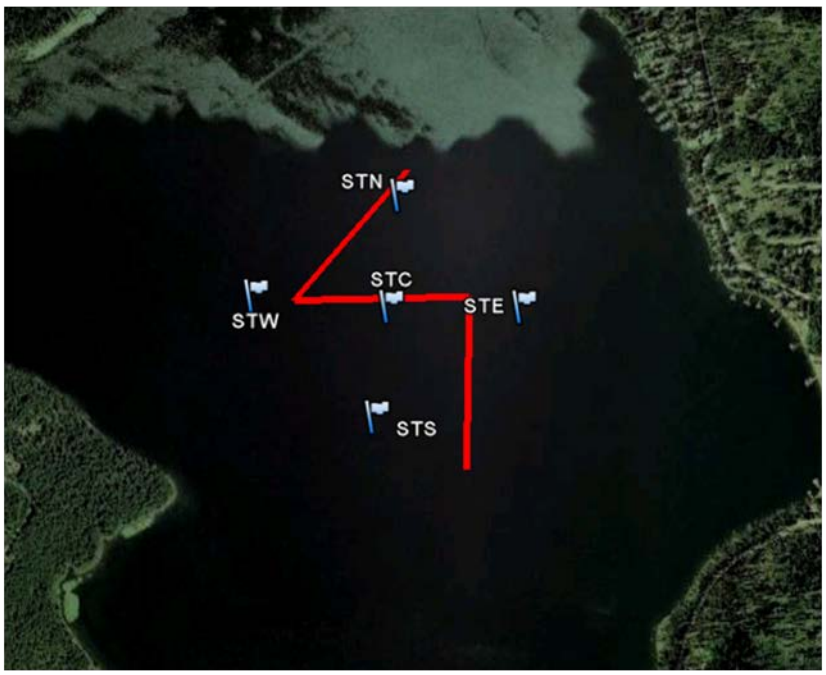

Figure 4. Gantzer South Twin monitoring sites

Objective 2. Measure winter oxygen depletion rates in order to determine sediment oxygen demand (SOD).

Under the ice dissolved oxygen monitoring was accomplished by installing dissolved oxygen and temperature sensors and a data logger within the hypolimnion of each lake prior to ice over during the winters of 2009/2010 and 2010/2011. South Twin had two DO probes, one placed two feet above the bottom and the other placed ten feet above the bottom. North Twin had a single probe positioned five feet above the bottom. Probes were connected to a general data logger and were programmed to collect data every 15 minutes. The data loggers were enclosed in a waterproof NEMA housing placed 6 feet below the surface in order to prevent ice entrapment. The sensors and data loggers were recovered in May/June, 2010 and recovered in May, 2011. Data were then downloaded in order to obtain oxygen depletion rates.

Objective 3. Monitor and evaluate salmonid use of the hypolimnion in North Twin Lake (oxygenated) and compare it to the use of the hypolimnion of South Twin Lake (unoxygenated).

In previous years acoustic tags (Christensen 2007, Biggs 2007, Clegg 2010), hydro acoustic surveys (Shallenberger, 2010) and gill nets (Shallenberger, 2010) were used to determine the use of the hypolimnion in North and South Twin Lakes. In 2010 three methodologies were used to determine vertical distribution of trout. Lanouette (2011) used archival tags to monitor fish movement. In April 2010, fifty redband rainbow trout with surgically implanted Lotek LAT 1400-64k archival pressure (depth) and temperature monitoring tags and a green Floy tag injected into the dorsal region were released into each lake. A $20 reward was offered to anglers who turned in tags.

Hydroacoustic surveys were used to monitor fish use of the hypolimnion. A BioSonics DTX hydroacoustic unit equipped with both 420 khz and 70 khz transducers was used for the surveys. Once each month East-West and North-South transects were made on each lake between previously determined way points (figures 5, 6) simultaneously recording using both transducers. Each lake had a single North-South transect. East-West transects were spaced at 500m intervals. Ping rate was set at 5 pings/second, a pulse width of 0.4 ms and boat speed of 5 kph. Analysis was done using the 70 khz transducer to avoid interference from invertebrates. A threshold level of -65 db was used. Questionable targets were magnified and examined at a threshold of -55 db and/or examined using the 420 khz transducer. Each transect was divided into five strata (1m-4m, 4m-7m, 7m-10m, 10m-13m and 13m-16m) (figure 7). Fish density (FPCM) and number of targets in each stratum were calculated in order to determine vertical distribution.

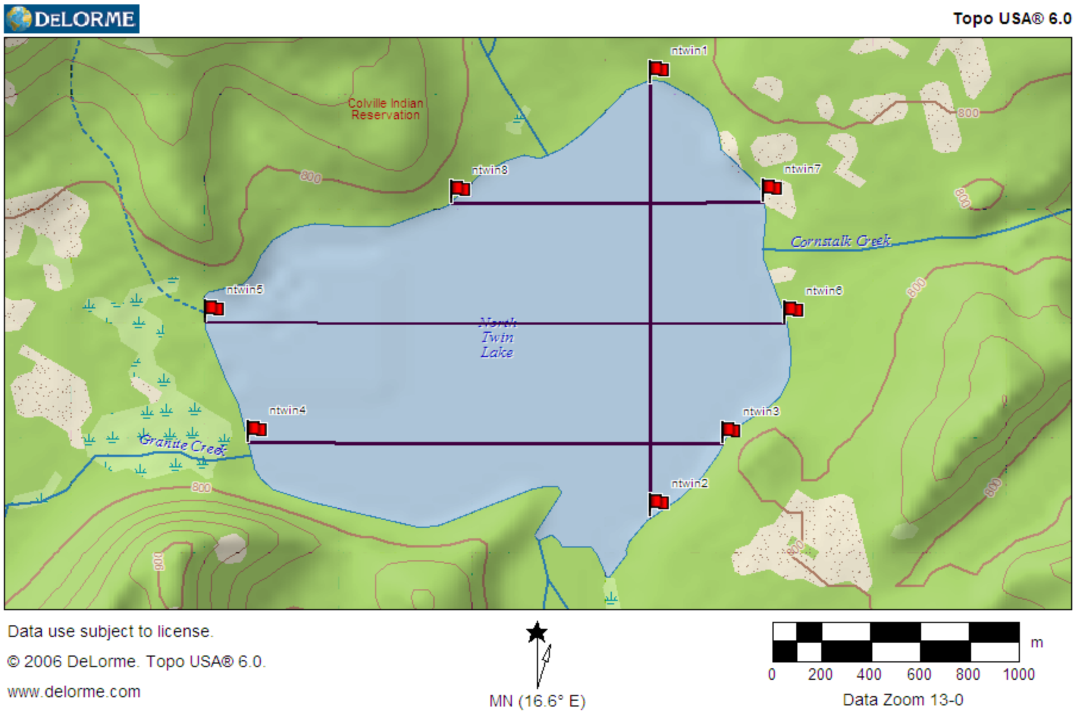

Figure 5. North Twin hydroacoustic waypoints

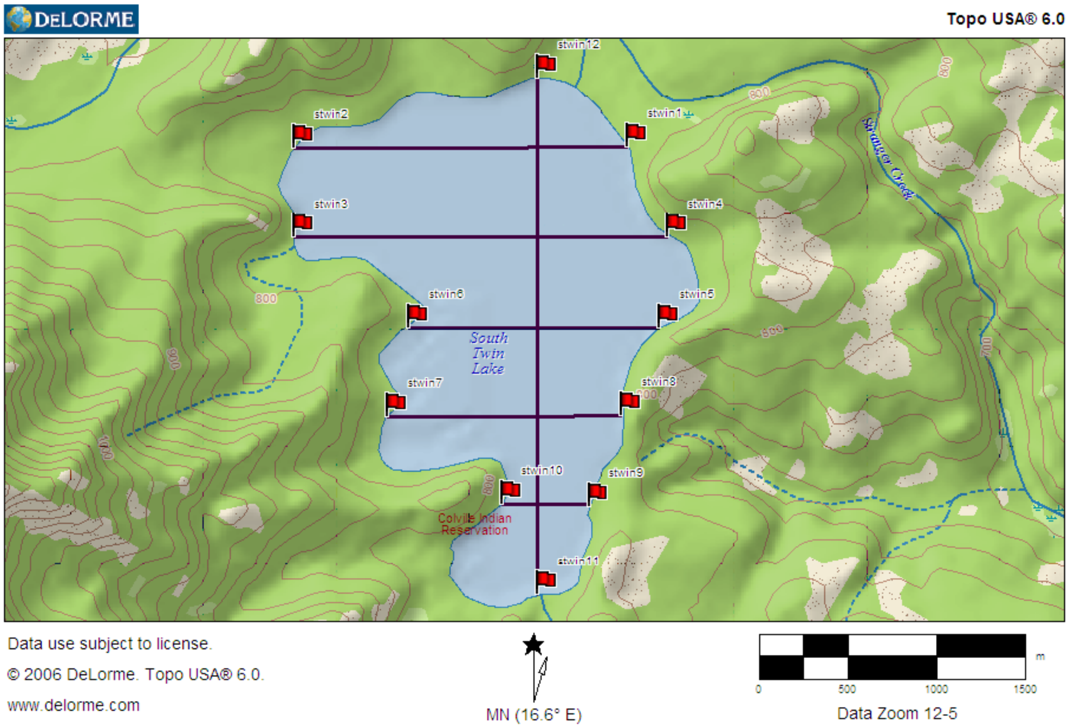

Figure 6. South Twin hydroacoustic waypoints

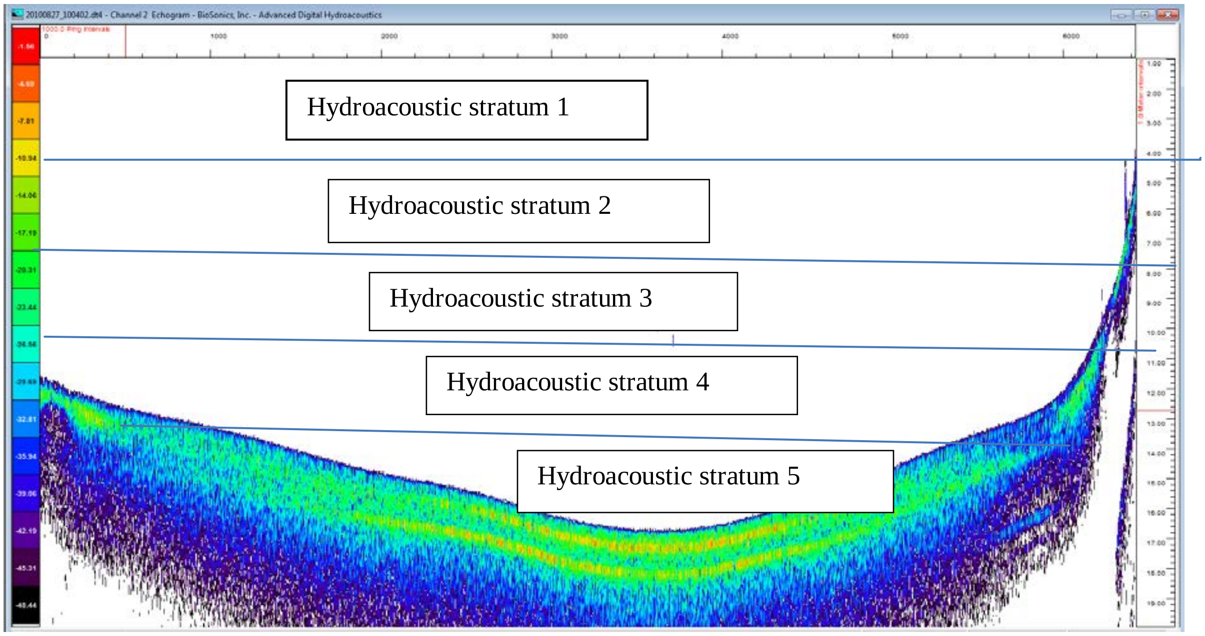

Figure 7. Hydroacoustic strata

Gill nets were also used to determine vertical distribution. All gill nets were 3m x 30m. Each month (April – October) nets with a mesh size of 1" (stretch), of 1 ½" (stretch) were set with the top line at 2m, 5m and 9m and nets with four mesh sizes (3/4', 1", 1 ½" and 2") were set with the top of the net at 2m, 5m and 9m as well as a benthic net whose lead line rested on the lake bottom were set in each lake (figure 8). Species, length, weight presence/absence of external parasites, year class (determined by clipped fins and/or tags) and type and location of nets were recorded. Comparable locations were chosen in each lake. Nets were set in the same approximate location each time. Nets were set in the afternoon and recovered in the morning for a soak time of approximately 12 hours.

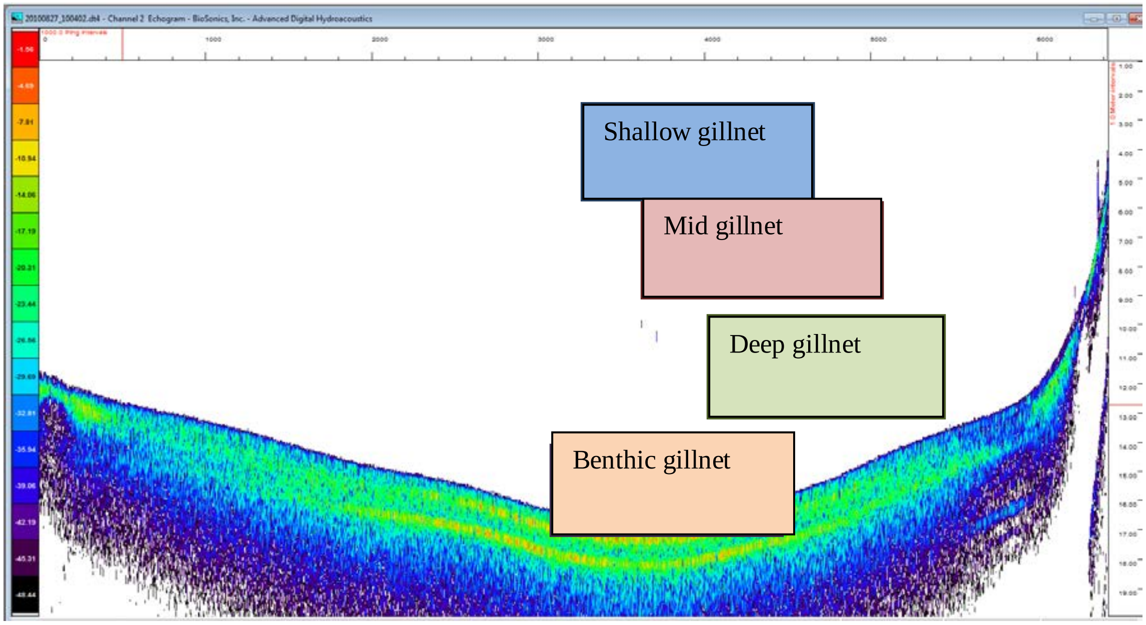

Figure 8. Gillnet depths

Sub-goal 2. Reduce salmonid mortality and improve growth and catch rates by improving environmental and biological conditions in North Twin Lake.

Objective 4. Measure the effects of oxygenation on benthic and pelagic invertebrates.

Because *Chaoborus* is found in both the sediment and the water column and is one of the most common invertebrates at Twin Lakes it was used as an indicator species (Lanouette 2011). Benthic macroinvertebrates were sampled with an Ekman bottom grabber dredge and sifted through a 500 micron wash bucket. *Chaoborus* within the water column were sampled with a 73 micron zooplankton net. There were two samples per station with two complete water column tows per 250 ml sample bottle. *Chaoborus* were then counted in an invertebrate tray using magnification and densities calculated as: Density=(#counted)/(2.05m^3 volume of two net tows) Benthic and water column densities were then compared using a paired t-test (α=0.05).

Objective 5. Measure the effects of oxygenation on salmonid mortality, growth and catch rates.

Gill netting and a roving creel survey were used to determine the effects of oxygenation on mortality, growth and catch rates.

All fish captured in the gill nets were examined for tags (elastomer or coded wire) and for finclips. These were used to determine year class and when planted. In addition all fish were weighed and measured to determine growth and relative weight. Data from each lake were averaged monthly to determine growth and any change in relative weight. Fish from the two lakes (North vs South Twin) were compared against each other and to other Reservation lakes. Mortality of each group of fish was determined by comparing the percentage of that group of the total number captured to the percentage of that group to the total number planted. The same information was gathered in 2006, 2007, 2008 and 2009 (Shallenberger, 2010).

A roving creel survey at Twin Lakes was initiated in 2006 and was continued in 2010 with only minor changes (see creel survey protocols, appendix A). Three days each week the number of anglers and their catch were monitored in both lakes. Angling pressure was determined by counting boat and shore anglers every two hours. Anglers were interviewed to determine number and species of fish captured and time spent fishing to determine catch rates. All fish observed were weighed and measured to the nearest gram or millimeter (TL) and the presence/absence of tags or other marks recorded. Angler biases was determined by comparing angler catch data versus gill net data. Catch rate (CPUE) for each species was calculated using the formula:

C.P.U.E.=(number of fish caught + number of fish released)/angler hours

Angler usage (pressure) was calculated monthly by counting both shore and boat anglers every two hours on both lakes a minimum of three days each week. Average angler use was calculated for each two hour period and then expanded to include the whole month. Weekends/holidays were calculated separately from weekdays.

Mortality was calculated by calculating the percentage of carryover fish (fish that had survived at least one summer). Gill net and angler caught fish were calculated separately to avoid angler bias.

MORTALITY = (# of fish in group/number planted) – (# of fish in group captured/total number of fish captured)

Objective 6. Measure the effects of oxygenation on the sediment of North Twin Lake.

This work was accomplished under subcontract with Washington State University (Beutel, 2011). This work was begun in 2008 and continued in 2010.

Sample Collection

Water quality profiles were collected approximately monthly in 2008 and 2009 from May through October at the center of North and South Twin Lakes. Buoys were set out in 2009 at the lakes deepest point, allowing for more consistent deep-water monitoring. Iron and manganese samples were collected every meter using tubing lowered to each depth attached to a small pump. Iron and manganese samples were preserved with nitric acid as outlined in Standard Methods (APHA, 1998). Total mercury and MeHg samples were collected every two meters with a Teflon Kemmerer into acid washed glass bottles with Teflon lined caps. We followed sampling protocol outlined in EPA methods 1630 and 1631 for trace mercury sampling (USEPA, 2001 and 2002). Unfiltered total mercury samples were preserved with bromine monochloride and unfiltered MeHg samples were preserved with trace metal grade hydrochloric acid, and both samples were stored at 4 oC until later analysis. In 2009, zooplankton samples were also collected. Tows of the complete water column were conducted using a specialized non-metallic zooplankton net with a mesh size of 250 um. Multiple tows were conducted until a significant amount of biomass was collected, and zooplankton were put in an acid washed amber bottles on ice. Within 24 hours after collection, samples were gently filtered in the lab through a course 1000 ìm Teflon screen to collect "large-body" zooplankton. Zooplankton samples were then frozen until later analysis.

Analytical Methods

Iron and manganese in water samples were analyzed using inductively coupled plasma mass spectrometry (ICP-MS) at the WSU School of Earth and Environmental Sciences Laboratory (APHA, 1998). Detection limits were on the order of 50 ìg/L for iron and 0.1 ìg/L for manganese. Duplicate analyses were performed on every tenth sample. Percent relative standard deviation on duplicates for 2008 samples averaged 1.7% for manganese and 2.3% for iron (n = 16), confirming the high precision of the analysis.

Total mercury was analyzed using a MERX-T cold vapor atomic fluorescence spectroscopy (CVAFS) mercury auto analyzer (USEPA, 2002). 2008 MeHg water samples were analyzed at Battelle Marine Science Laboratories with EPA method 1630 modular analytical technique which involves sample distillation, ethylation, purge onto TenaxTM traps, thermal desorption, gas chromatography separation, pyrolyzation, and subsequent detection via a Tekran 2500 CVAFS (USEPA, 2001). For 2009 MeHg analyses were performed at WSU on a state-of-the-art Brooks Rand MERX autoanalyzer using EPA method 1630. The detection limit for MeHg was 0.002 ng/L. Standard quality control procedures for total mercury and MeHg included duplicates (< 25% relative percent difference), matrix spikes (77-125% recovery), and method blanks.

Analyses of total mercury in zooplankton and sediment were performed at WSU on a Milestone Direct Mercury Analyzer (DMA-80) based on EPA method 7473 (USEPA, 2007). The zooplankton and sediment samples were first freeze dried. The DMA then processed the sample through a number of automated steps as follows: thermal decomposition of sample; catalytic reduction of mercury in off gas to elemental mercury; collection of elemental mercury vapor on a gold amalgamation trap; desorption of mercury from the trap; and detection of the elemental mercury via atomic absorption spectroscopy. The DMA was standardized using liquid standards made in the lab and checked using the external standard reference materials including DORM-3 (dog fish) and MESS-3 (sediments) purchased from the National Research Council of Canada.

Sub-goal 3. Build a South Twin Lake Oxygenation System

Objective 7. Construct, install and test a hypolimnetic oxygenation system in South Twin Lake.

Mobley Engineering (the same company that built the North Twin Lake oxygenation system) was contracted to design and build a similar oxygenation system for South Twin Lake. The system was designed to be controlled from the same location as the North Twin Lake oxygenation system. Construction began on September 16, 2010.

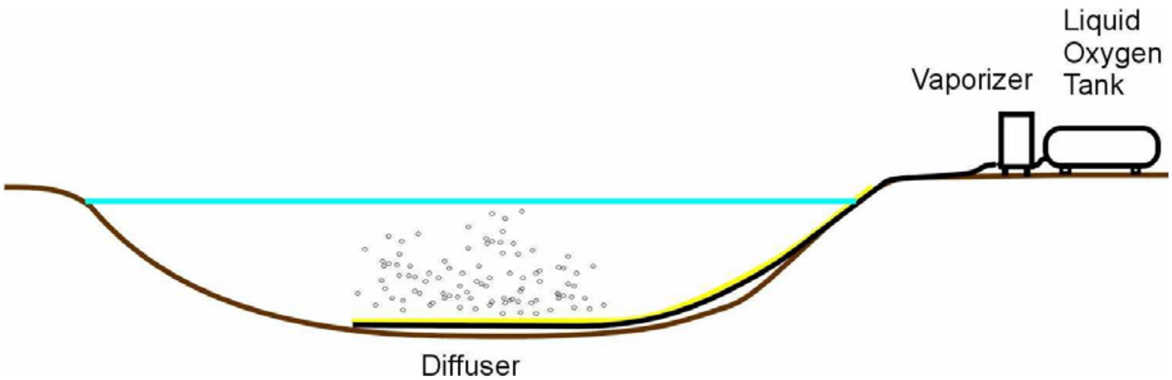

Figure 9. Diagrammatic layout of oxygenation system

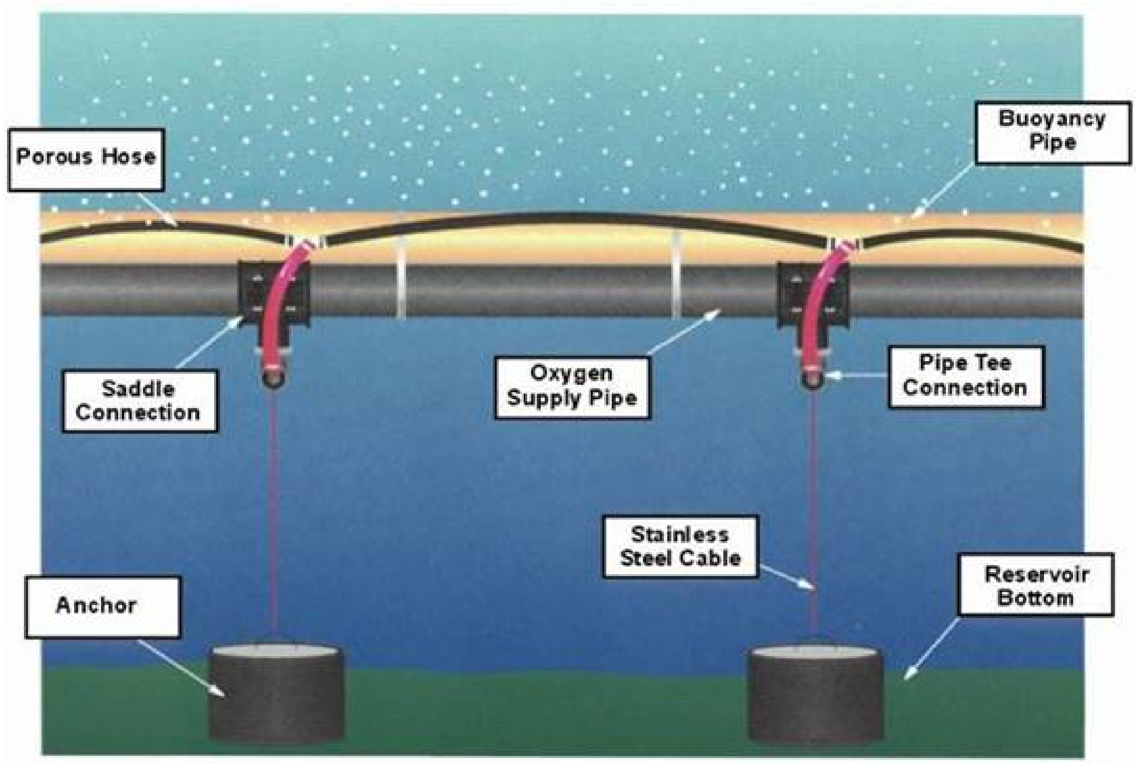

Figure 10. Details of oxygen diffuser

Results

Sub-goal 1. Operate the North Twin Lake oxygenation system as efficiently as possible, allowing salmonids to utilize the hypolimnion.

Objective 1. Elevate the dissolved oxygen level in the hypolimnion to a minimum of 5mg/l of dissolved oxygen allowing salmonid utilization but does not wasting oxygen.

The North Twin Oxygenation system was first turned on May 17, 2011 and turned off on October 15 2011. The goal was to keep dissolved oxygen levels in the hypolimnion between 5 mg/l and 7 mg/l. Dissolved oxygen levels in both North and South Twin were monitored remotely by sensors anchored in the deepest part of both lakes and by monthly dissolved oxygen profiles taken at four locations in each lake (Gantzer, 2010). Oxygen flow could then be adjusted in order to meet the desired dissolved oxygen levels.

During the 2010 oxygenation period 7,529,384 ft^3 of oxygen were added to North Twin Lake. For the most part oxygen levels were kept within the desired range, only briefly dropping below 5mg/lt near the bottom in September, which was sufficient to allow usage of the hypolimnion by salmonids. Dissolved oxygen levels in North and South Twin Lakes are depicted in figures 11-22 (Gantzer, 2010). These figures clearly show that oxygenation of the North Twin Lake hypolimnion was effective in keeping the dissolved oxygen at an acceptable level, while the hypolimnion in South Twin Lake became anoxic shortly after stratification. In the following figures oxic areas are indicated by shades of blue while anoxic areas are indicated by shades of red. Dissolved oxygen levels are indicated in mg/l. During the summer months the oxygenated hypolimnion of North Twin Lake remain oxic (blue) while the unoxygenated hypolimnin of South Twin Lake became increasingly anoxic (red).

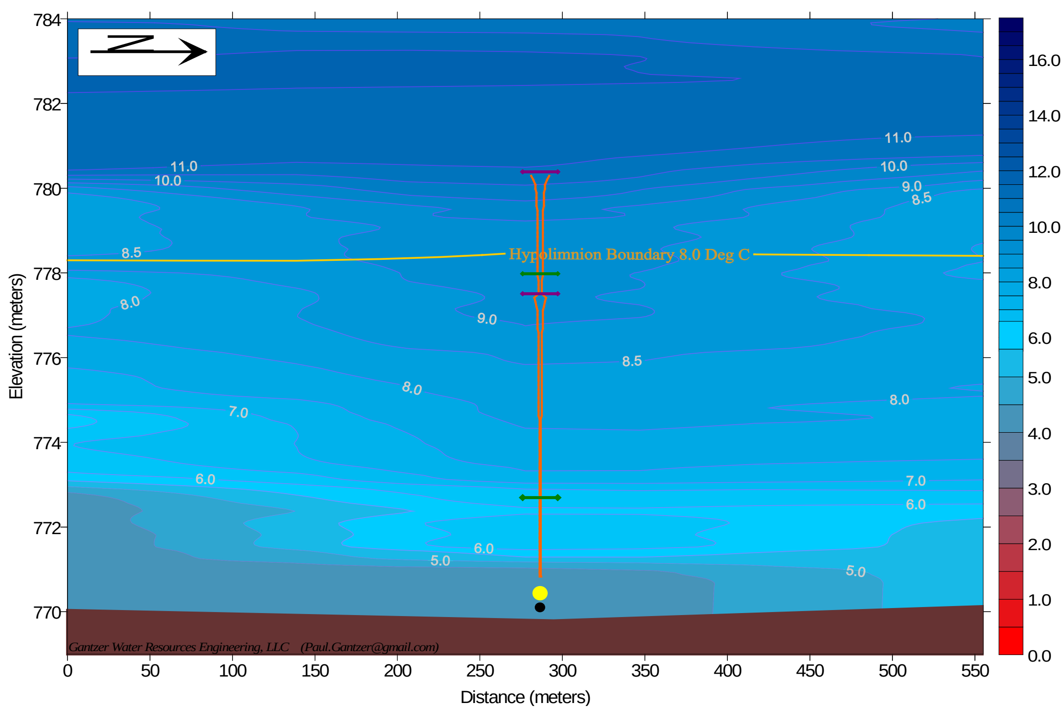

Figure 11. Oxygen levels in North Twin Lakes, May 19, 2010

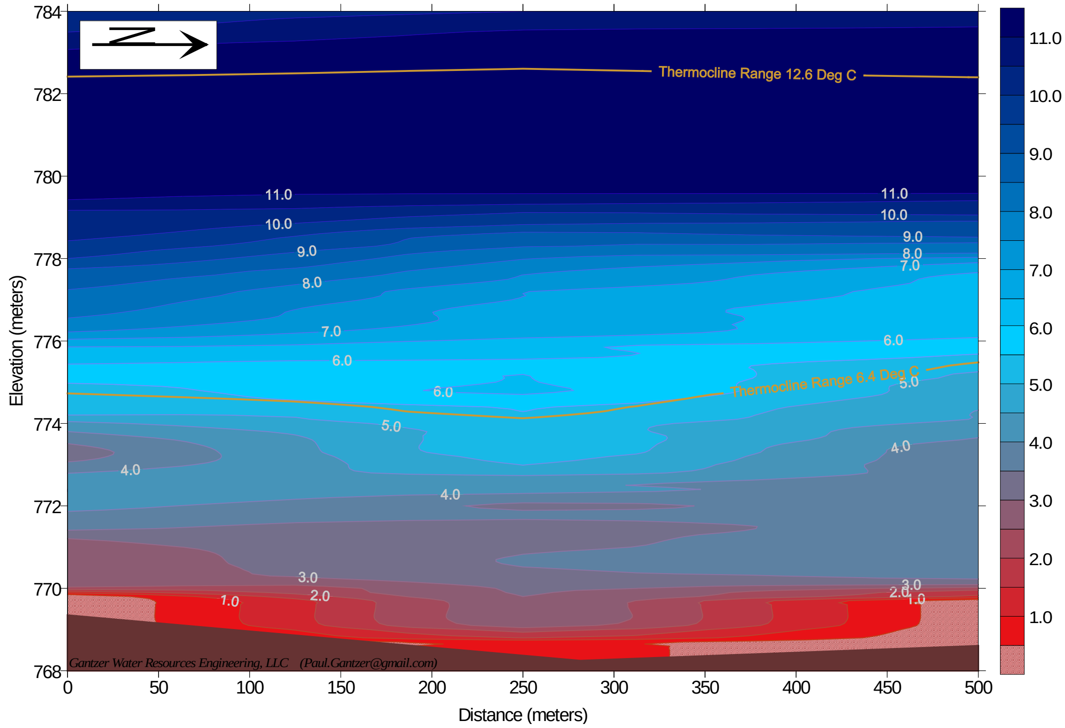

Figure 12. Oxygen levels in South Twin Lake, May 18, 2010

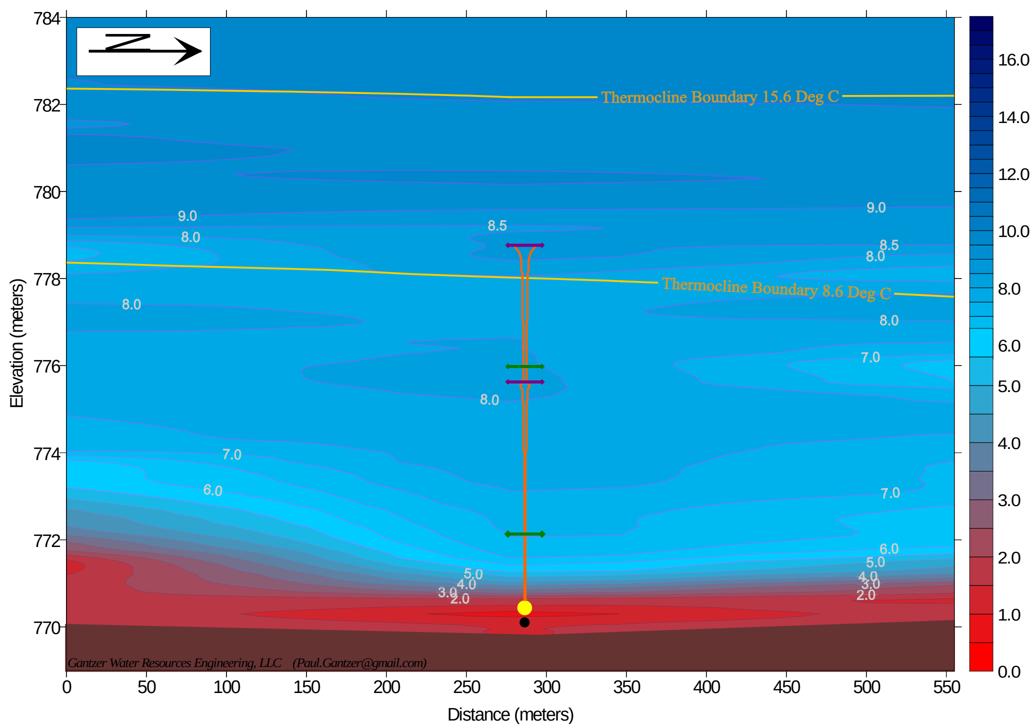

Figure 13. Oxygen levels in North Twin Lake, June 11, 2010

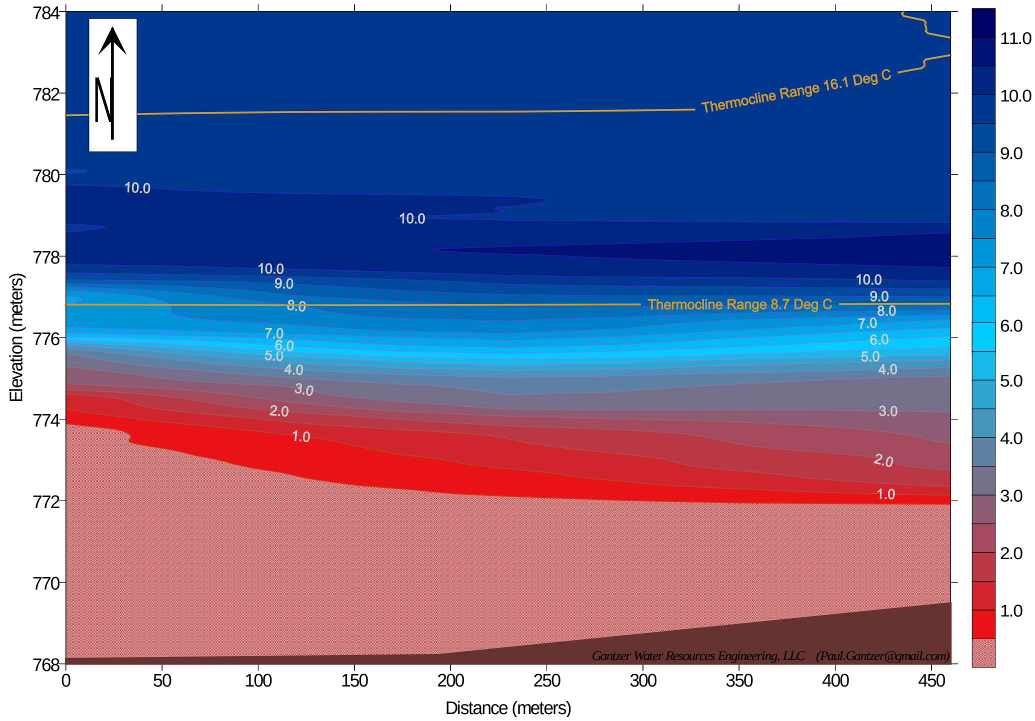

Figure 14. Oxygen Levels in South Twin Lake, June 11, 2010

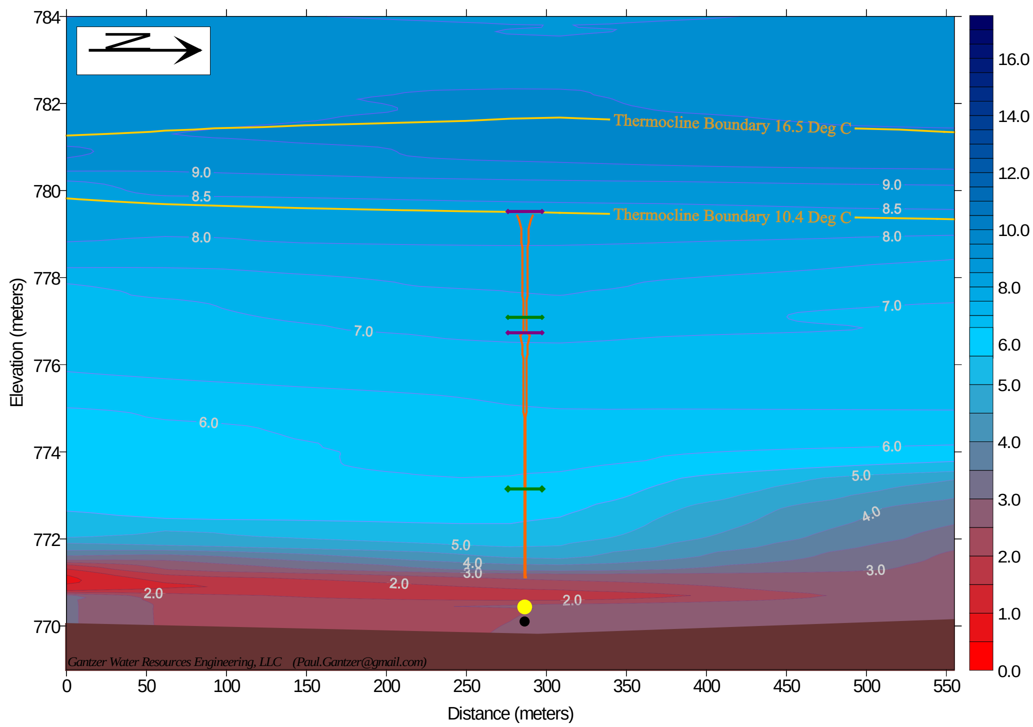

Figure 15. Oxygen Levels in North Twin Lake, July 9, 2010

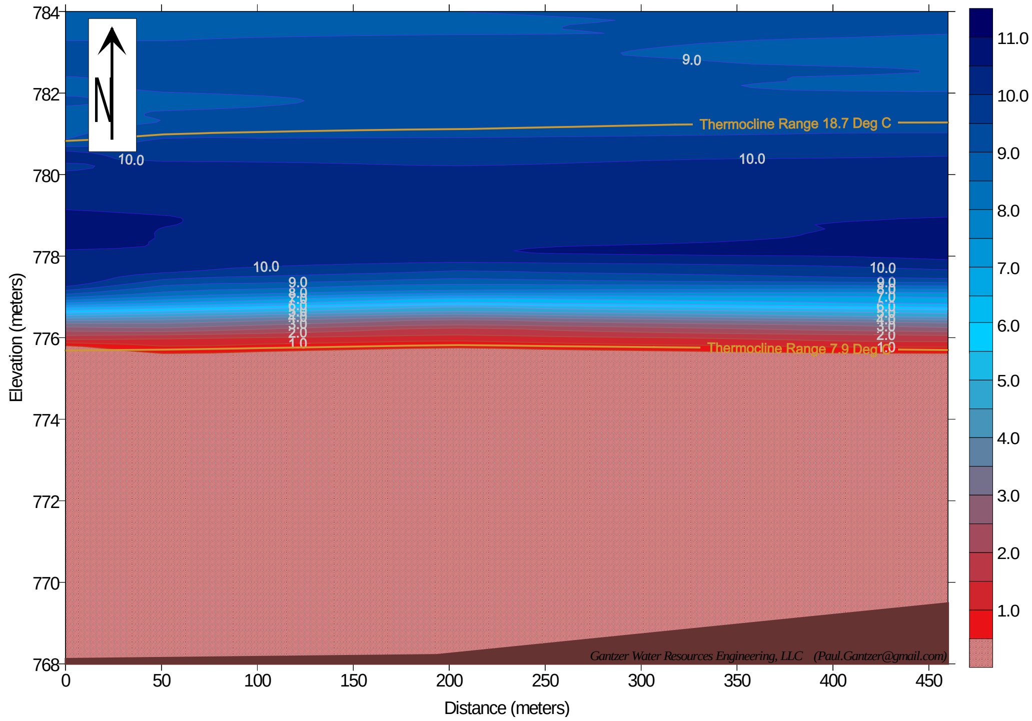

Figure 16. Oxygen Levels in South Twin Lake, July 9, 2010

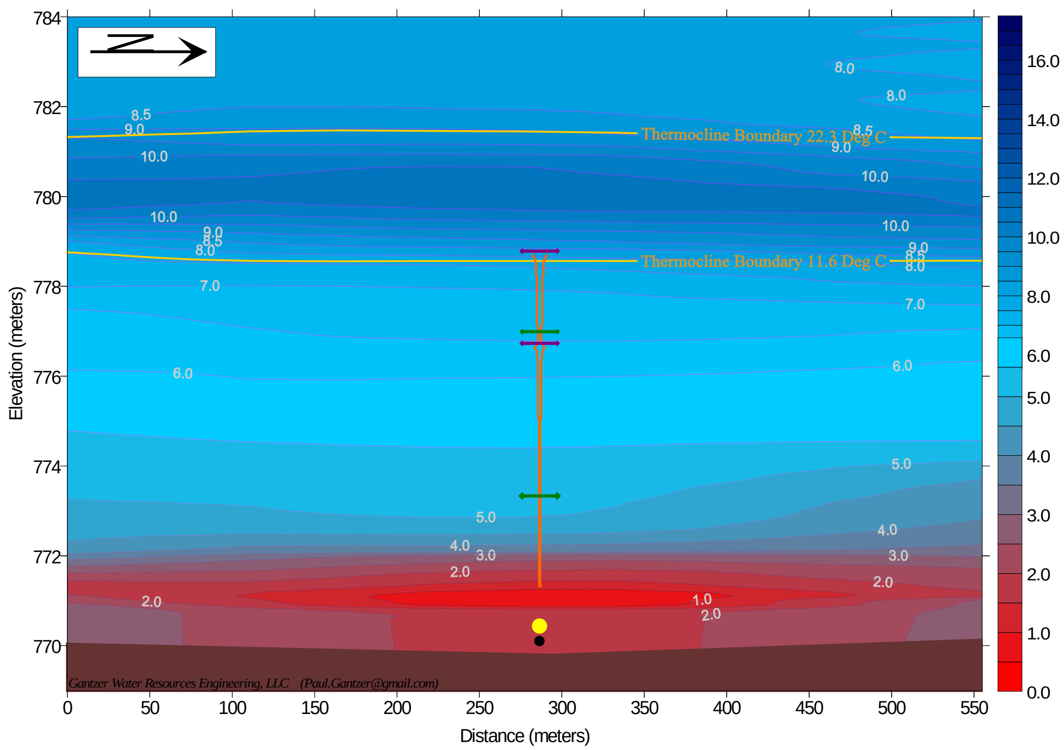

Figure 17. Oxygen Levels in North Twin Lake, August 5, 2010

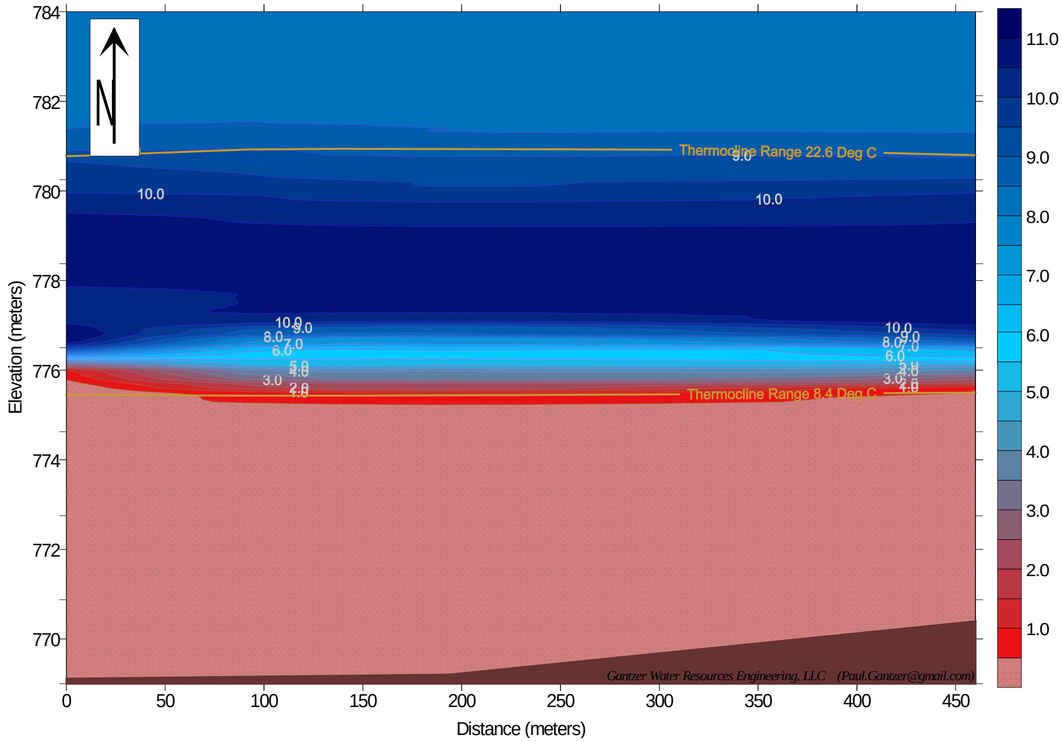

Figure 18. Oxygen Levels in South Twin Lake, August 5, 2010

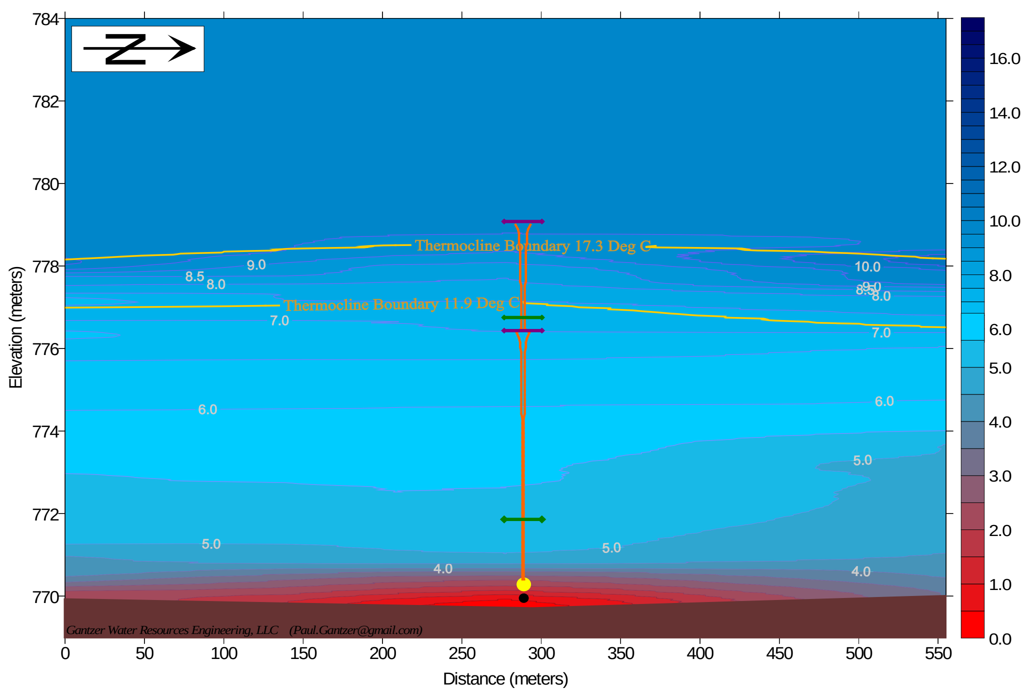

Figure 19. Oxygen Levels in North Twin Lake, September 4, 2010

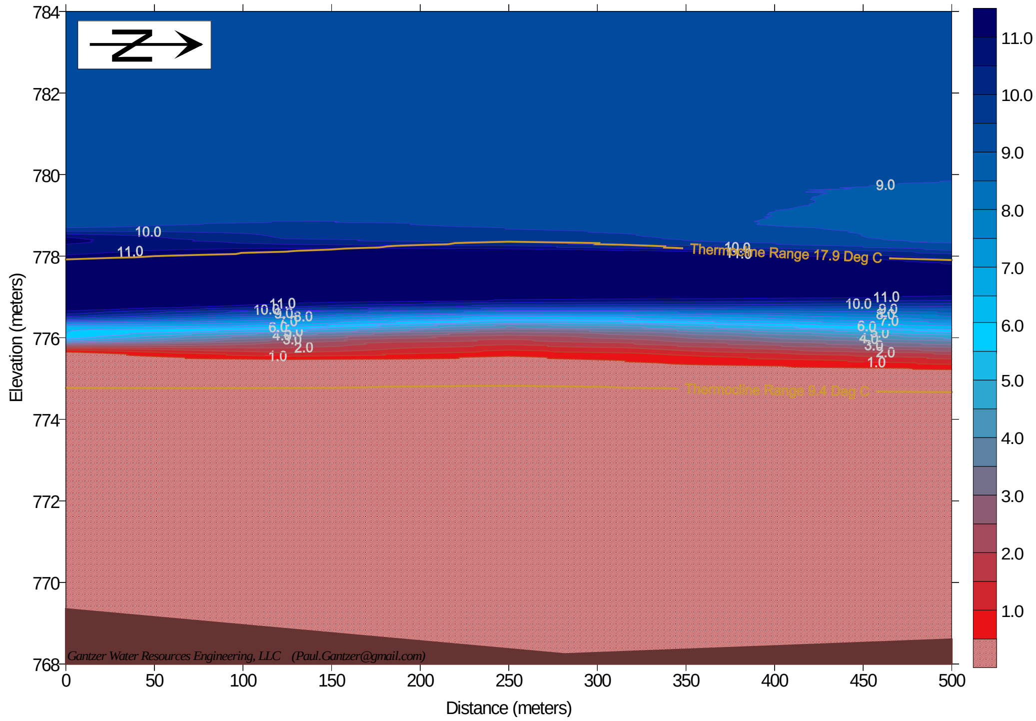

Figure 20. Oxygen Levels in South Twin Lake, September 4, 2010

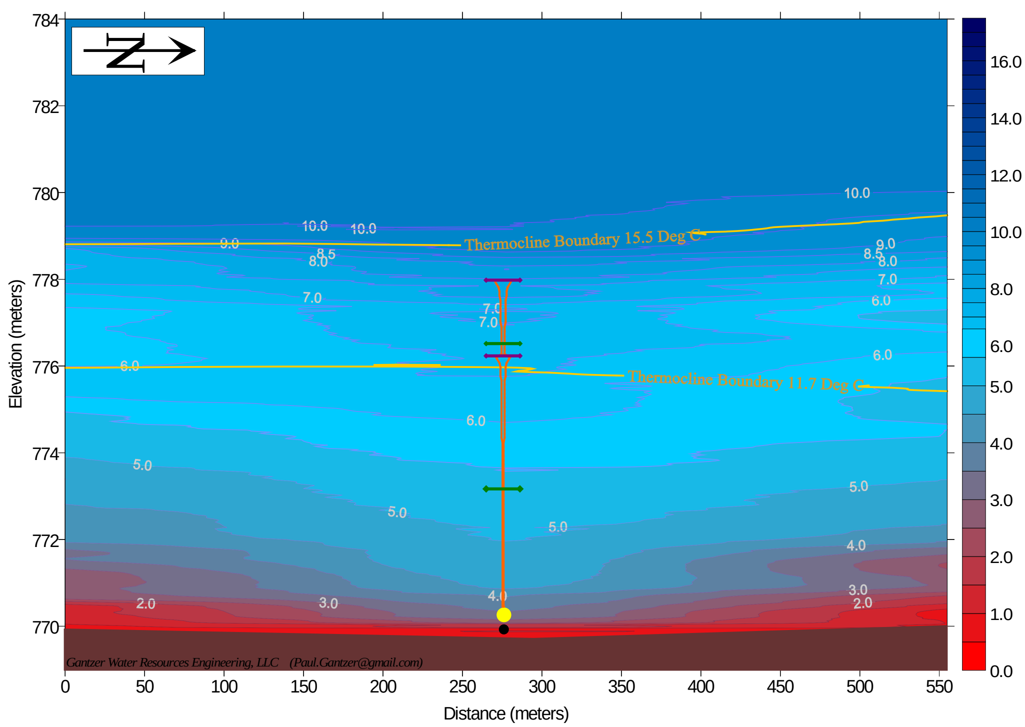

Figure 21. Oxygen Levels in North Twin Lake, October 2, 2010

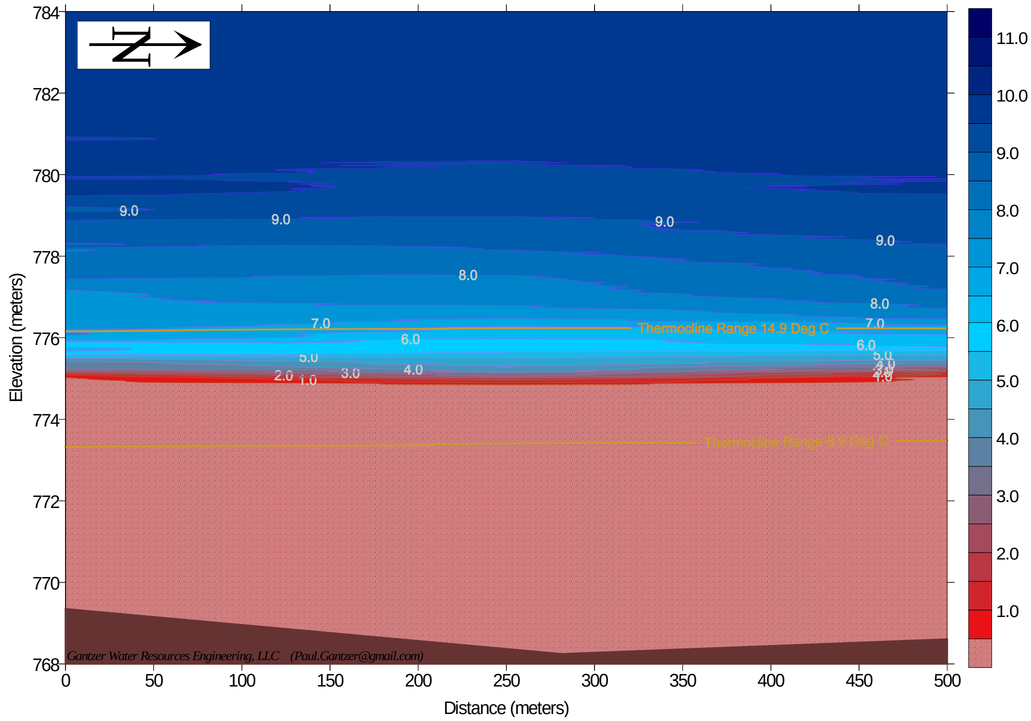

Figure 22. Oxygen Levels in South Twin Lake, October 2, 2010

Objective 2. Measure winter oxygen depletion rates in order to determine sediment oxygen demand (SOD).

Under a separate contract Gantzer (2011) placed sensors and data loggers in both lakes that measured dissolved oxygen levels throughout the winter. Sensors were placed in North and South Twin on December 2, 2009 and recovered on May 7, 2010 from North Twin and June 21, 2010 from South Twin. Data were then downloaded from the data loggers. Depletion rates can be seen in figure 23. Sensors were again placed in North and South Twin Lakes on November 22, 2010 and were recovered in May, 2011.

The data showed that in spite of the summer oxygenation, the hypolimnion on North Twin Lake became anoxic while the lake was still ice covered, although it did remain oxygenated a month longer than South Twin.

From the oxygen depletion rates it is possible to calculate the sediment oxygen demand (SOD). It is primarily the SOD that causes the hypolimnion to become anoxic once the lakes stratify in the spring and once again in the fall once the ice has formed. Once the SOD is known it is possible to calculate the approximate amount of oxygen required to maintain the desired level throughout the summer. The amount required for South Twin is at least twice as required for North Twin.

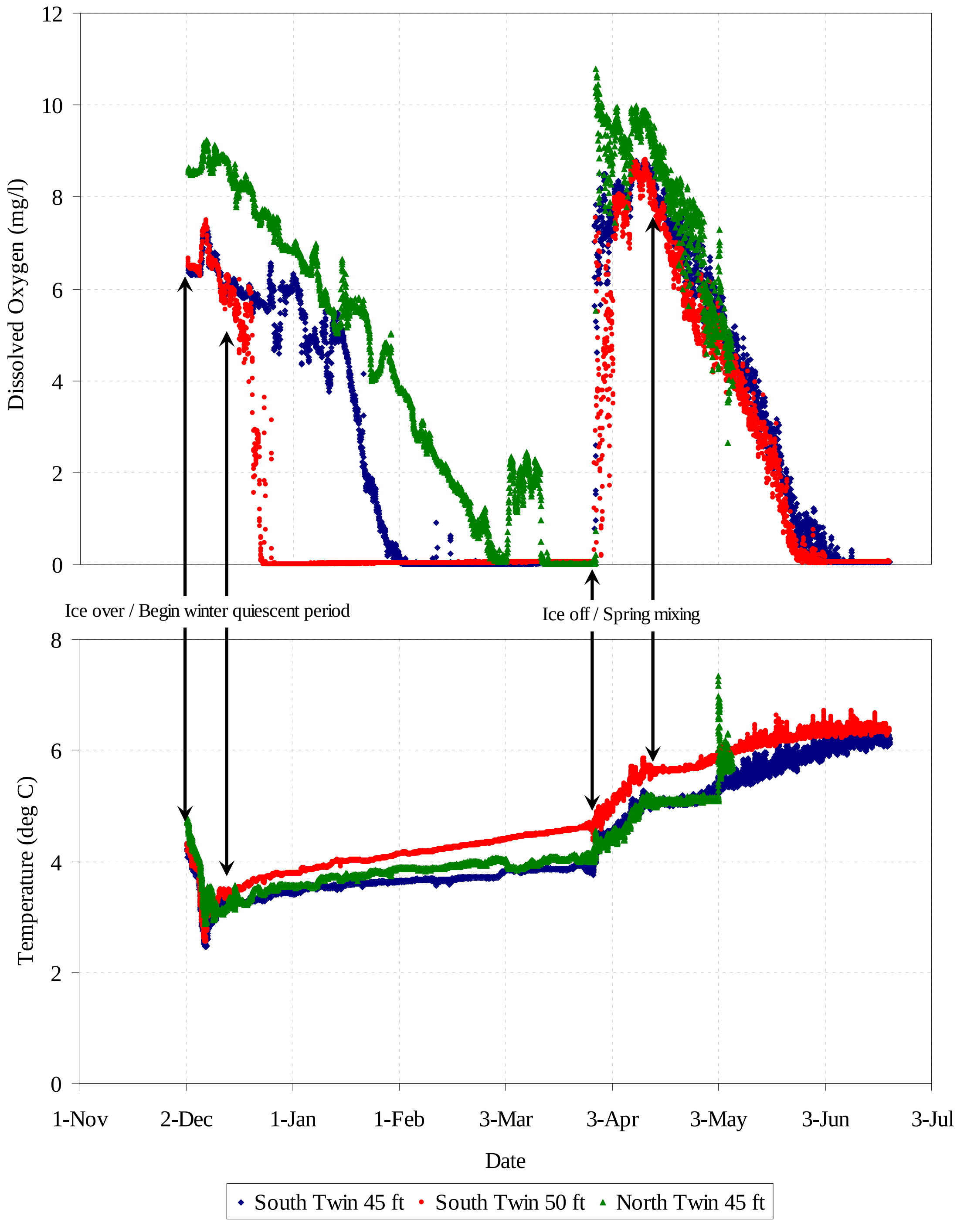

Figure 23. North and South Twin Lakes winter temperature and dissolved oxygen

Objective 3. Monitor and evaluate salmonid use of the hypolimnion in North Twin Lake (oxygenated) and compare it to the use of the hypolimnion of South Twin Lake (unoxygenated).

Several studies were conducted in order to document the use of the hypolimnion of North and South Twin Lakes. Lanouette (2011) used archival temperature/pressure tags to measure vertical movements of redband rainbow trout. Twenty fish were captured by fishermen who returned the tags for analysis. All but two of these tags were returned in May and June so little data are available to indicate vertical distribution of trout during the period of peak stratification. Even so, the data clearly showed ($p>.95$) that fish in North Twin Lake had greater vertical distribution than those in South Twin (figure 24).

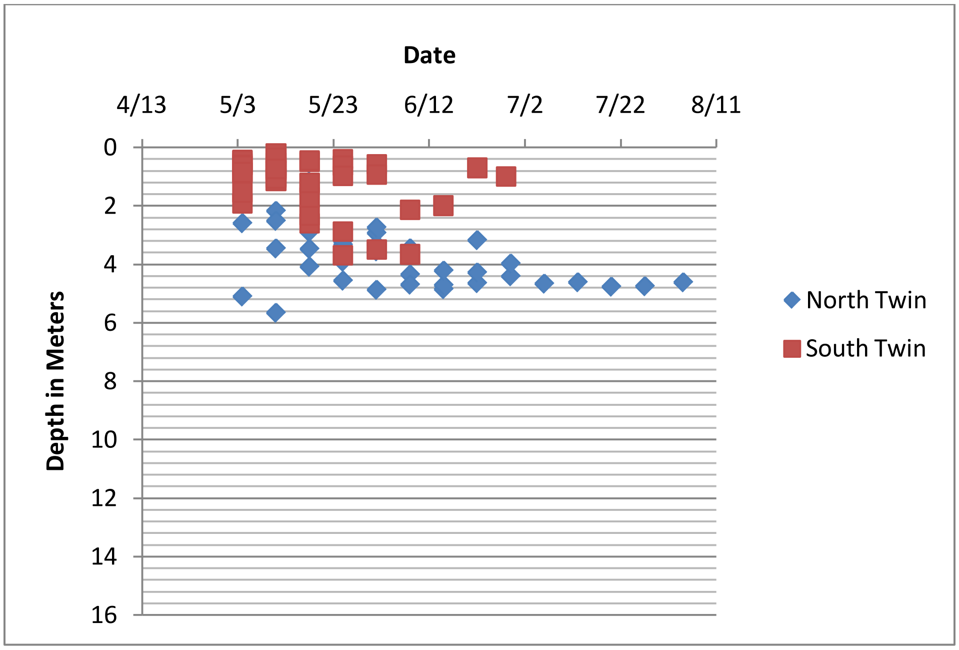

Figure 24. Mean depth of tagged fish

Tribal biologist used gill nets to measure vertical distribution. Gill nets were set each month at 2-5 meters, 5-8 meters and 9-12 meters. A benthic net whose bottom line lay on the lake bottom and whose top line lay three meters above the lake bottom was also set in each lake each month. The actual depth of this net depended on the the depth of the lake at the location of the net set. In addition, an inshore experimental gill net was set in each lake in both the spring and fall. Lanouette used these data to calculate catch per unit effort (C.P.U.E.) for the nets set at each depth and demonstrated that trout did not utilize the hypolimnion (unoxygenated) of South Twin during periods of stratification while the hypolimnion (oxygenated) of North Twin was regularly used (figure 24). Vertical distribution can also be seen in tables 1, 2. Prior to stratification all levels were utilized in both lakes, but once the lakes were stratified the hypolmnion was unused in South Twin while it was used extensively in North Twin (tables 1, 2, 3).

Table 1. South Twin Lake Gill Net CPUE

South Twin Lake Gill Net Catch Rate Net Depth in meters			
Month	2-5m	5-8m	8-11m
April	0.3	0.7	0.0
May	1.7	2.7	0.0
June	0.3	3.3	0.3
July	0.0	1.0	0.0
August	0.0	1.0	0.3
September	0.0	0.0	0.0
October	1.3	0.0	0.0

North Twin Lake Gill Net Catch Rate Net Depth in meters			
Month	2-5m	5-8m	8-11m
April	1.3	0.7	0.0
May	6.0	3.7	1.0
June	2.0	4.3	0.3
July	0.0	1.7	0.3
August	0.0	7.0	1.7
September	1.3	3.3	0.3
October	2.7	1.3	0.0

Table 2. North Twin Lake Gill Net CPUE

Table 3. Fish captured in Twin Lakes Gill Nets

Twin Lakes Gill Net Surveys, 2010 Fish Captured										
Lake	Strata	6-Apr	19-Apr	6-May	9-Jun	14-Jul	11-Aug	10-Sep	21-Oct	Total
N. Twin	inshore	37			7				60	104
	1		4	18	6	0	0	4	8	40
	2		2	11	13	5	31	10	4	76
	3		0	3	1	1	5	1	0	11
	benthic		0	0	0	0	0	1		1
S. Twin	Inshore	39			4				14	57
	1		1	5	1	0	0	0	4	11
	2		2	6	9	3	4	0	0	24
	3		0	0	1	0	0	0	0	1
	benthic		0	0	0	0	0	0	0	0

Hydroacoustic surveys were conducted monthly to measure vertical distribution of fish in North and South Twin Lakes. Echoes from invertebrate layers often appeared like fish or masked fish echoes. In 2010 both 70 khz and 420 khz transducers were used. Primary analysis was done using the 70 khz transducers and the validity of any questionable targets was determined using the 420 khz transducer. Questionable targets were magnified and their echos examined. When magnified, fish targets are normally composed of multiple echoes (figure 24) while smaller, non fish targets are normally multiple distinct single echoes (figure 25). Differences in fish distribution can be seen in both echograms (figures 26-41 as well as table 4.

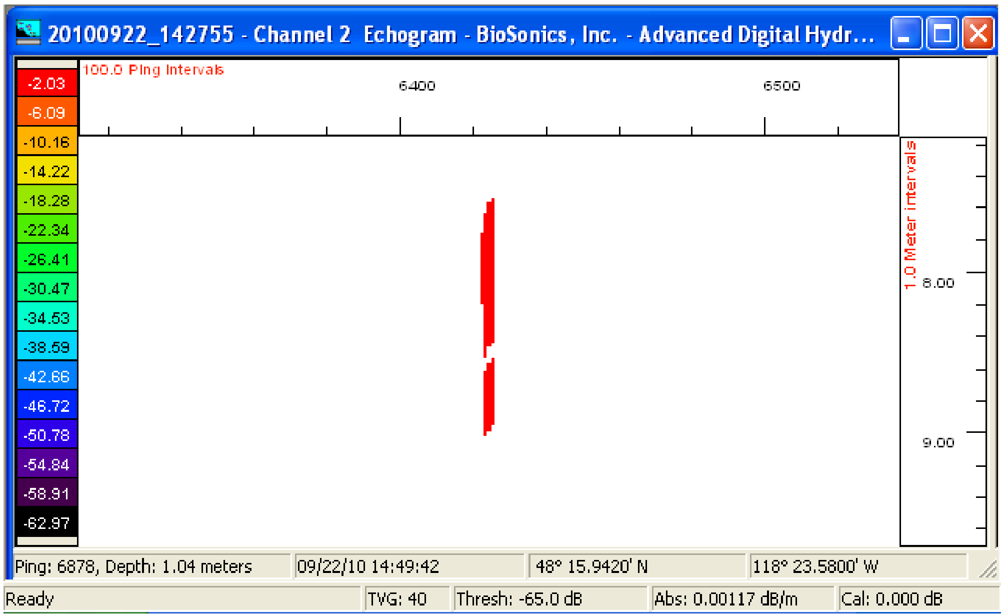

Figure 25. Magnified fish target

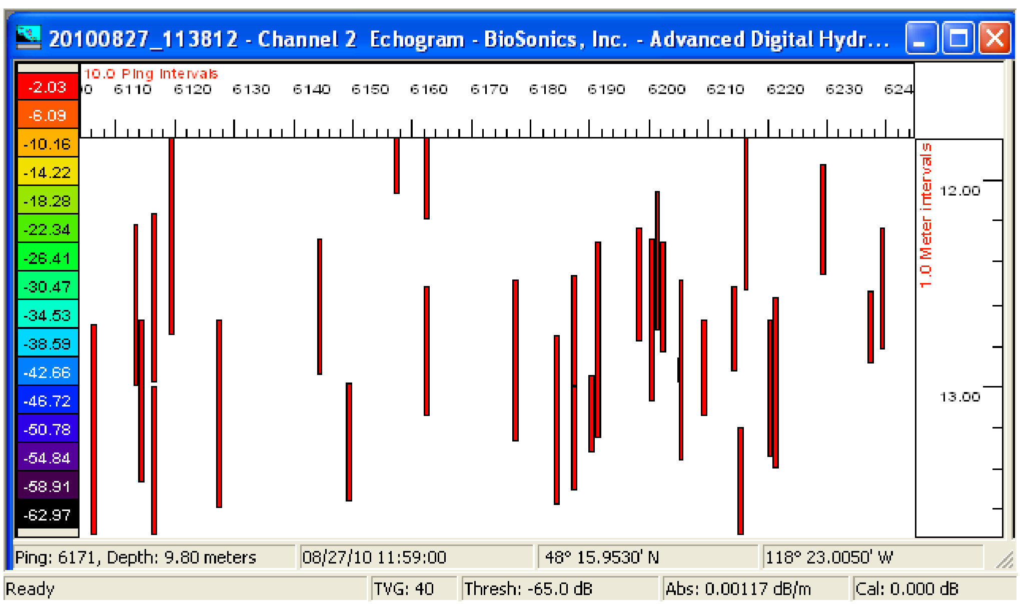

Figure 26. Magnified non fish targets

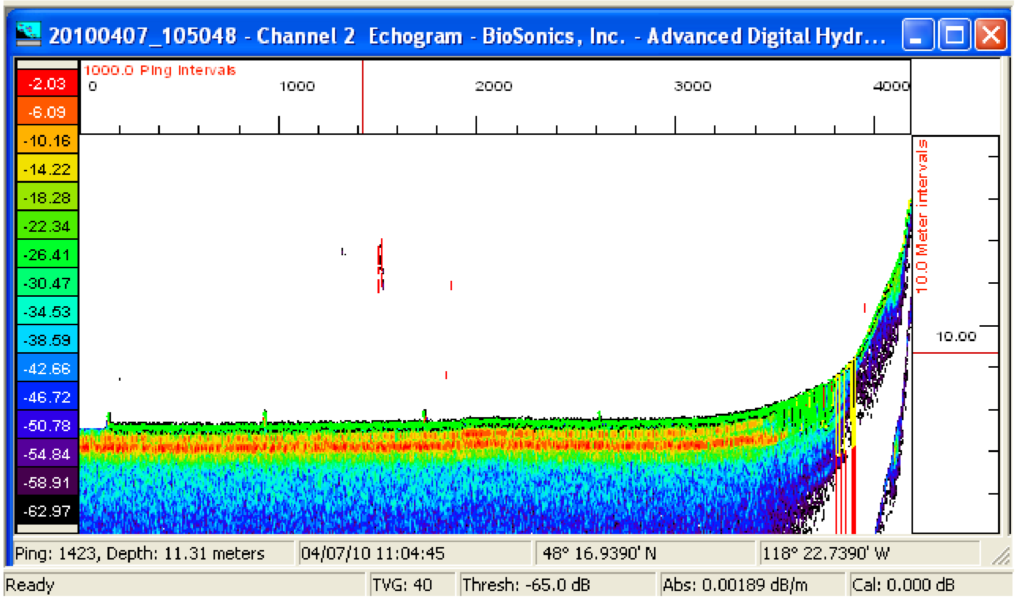

Figure 27. North Twin Lake, April 7, 2010

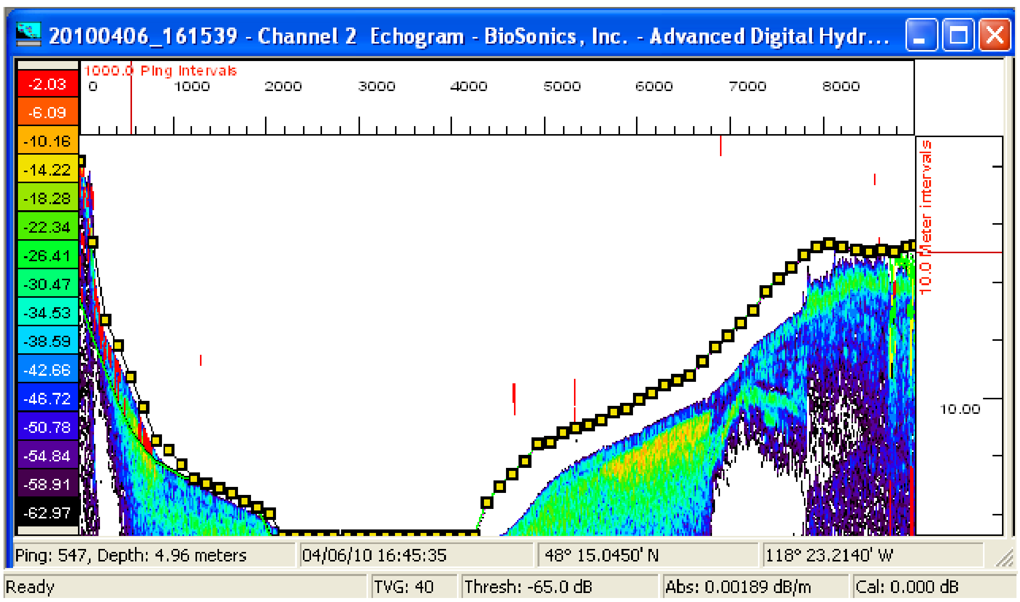

Figure 28. South Twin Lake, April 6, 2010

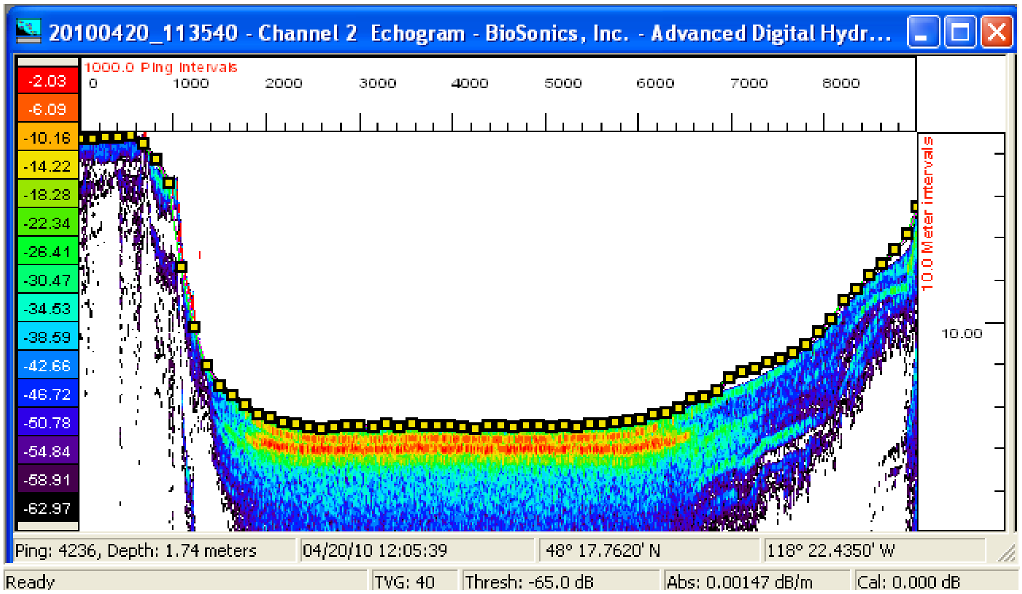

Figure 29. North Twin Lake, April 20, 2010

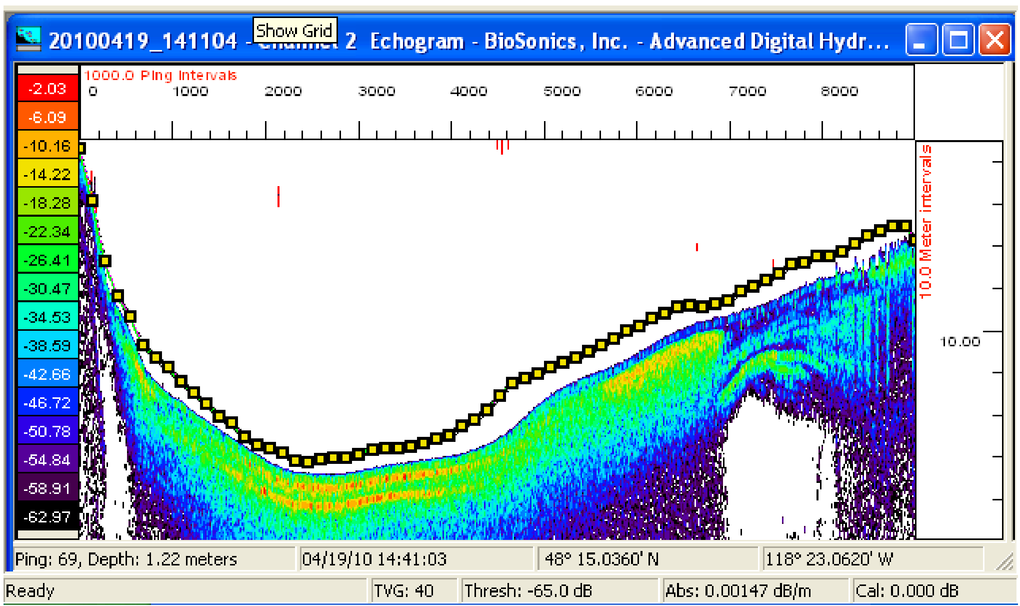

Figure 30. South Twin Lake, April 19, 2010

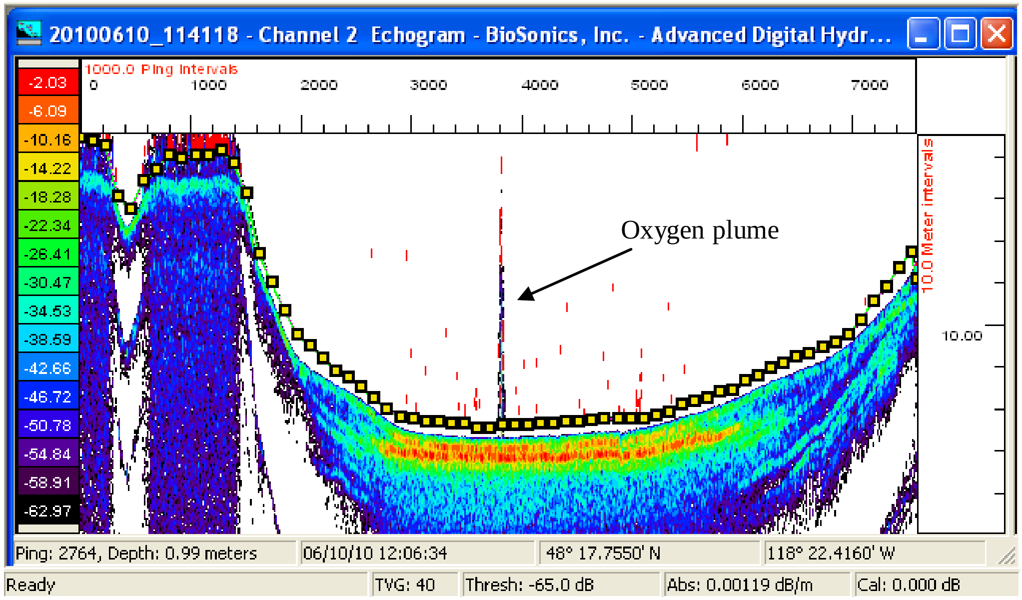

Figure 31. North Twin Lake, June 10, 2010

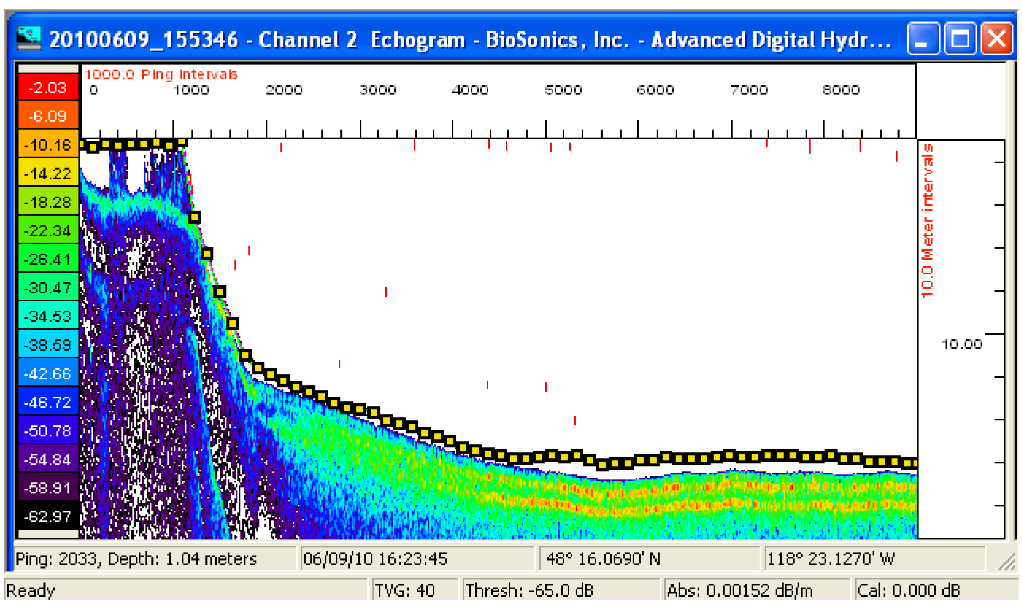

Figure 32. South Twin Lake, June 9, 2010

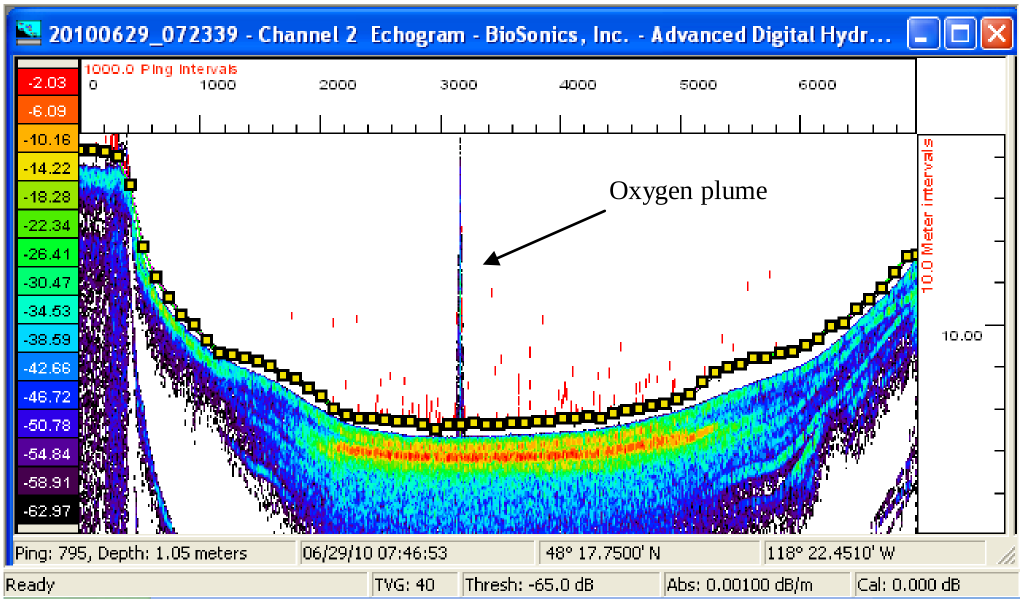

Figure 33. North Twin Lake, June 29, 2010

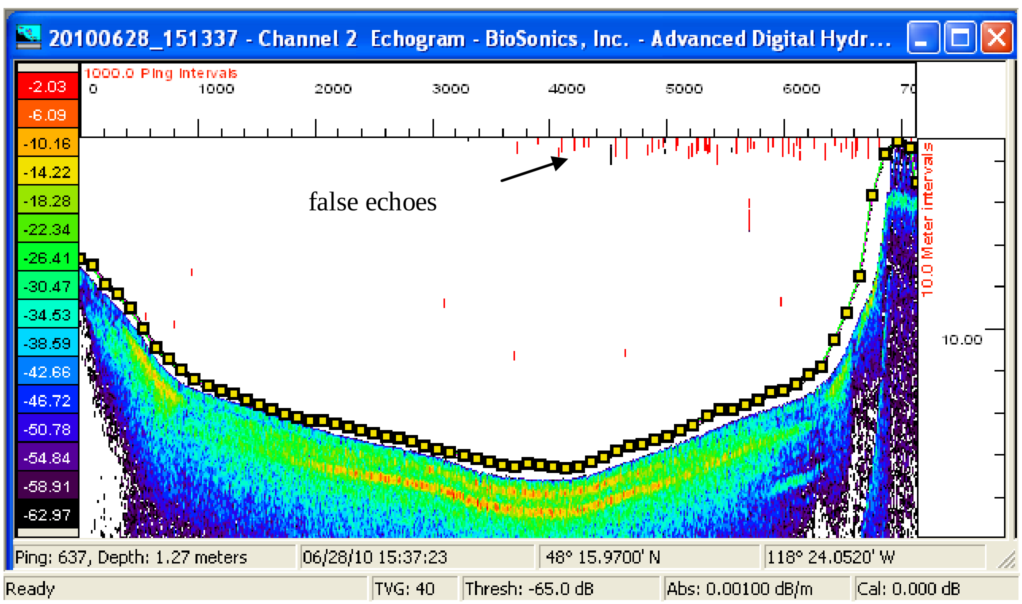

Figure 34. South Twin Lake, June 28, 2010. False targets can be seen

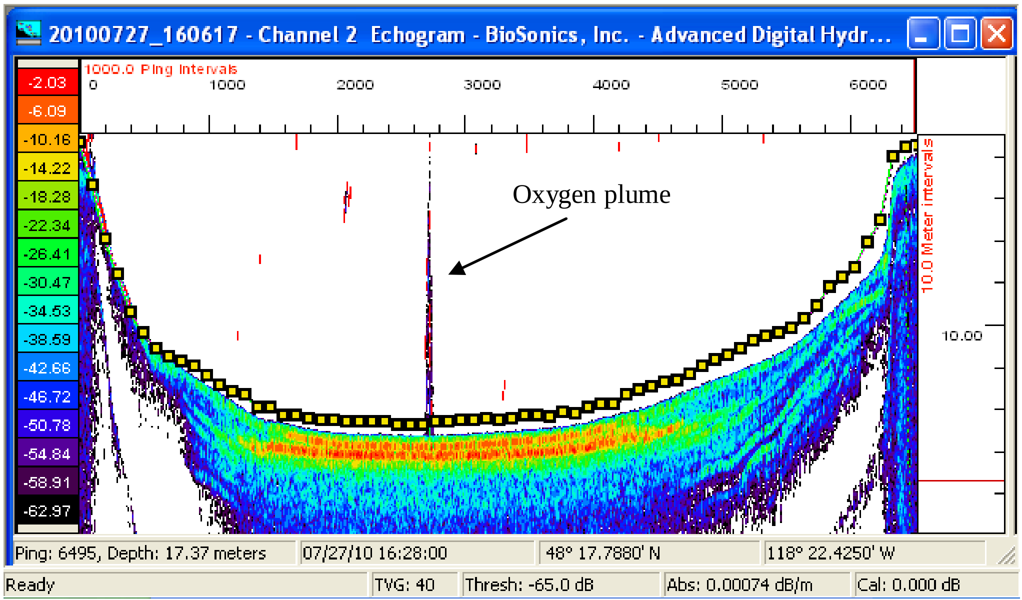

Figure 35. North Twin Lake, July 27, 2010

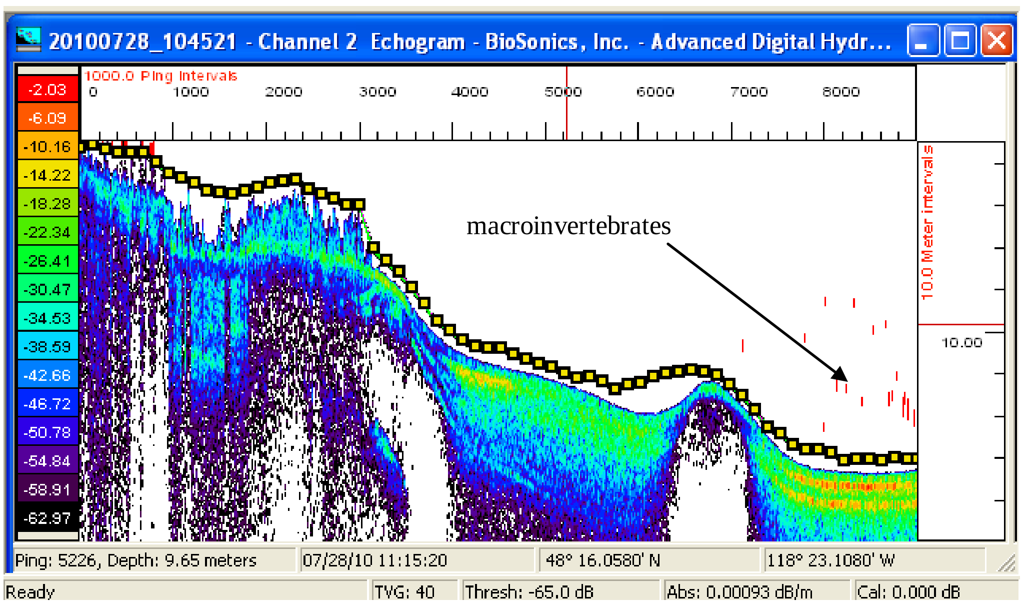

Figure 36. South Twin Lake, July 28, 2010

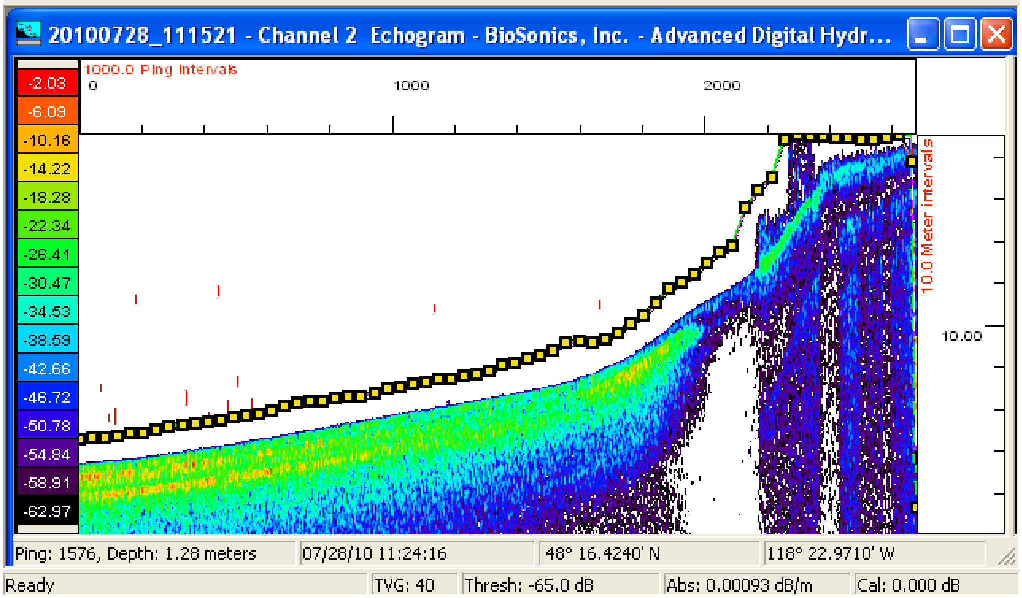

Figure 37. South Twin Lake, July 28, 2010. Continuation of figure 36

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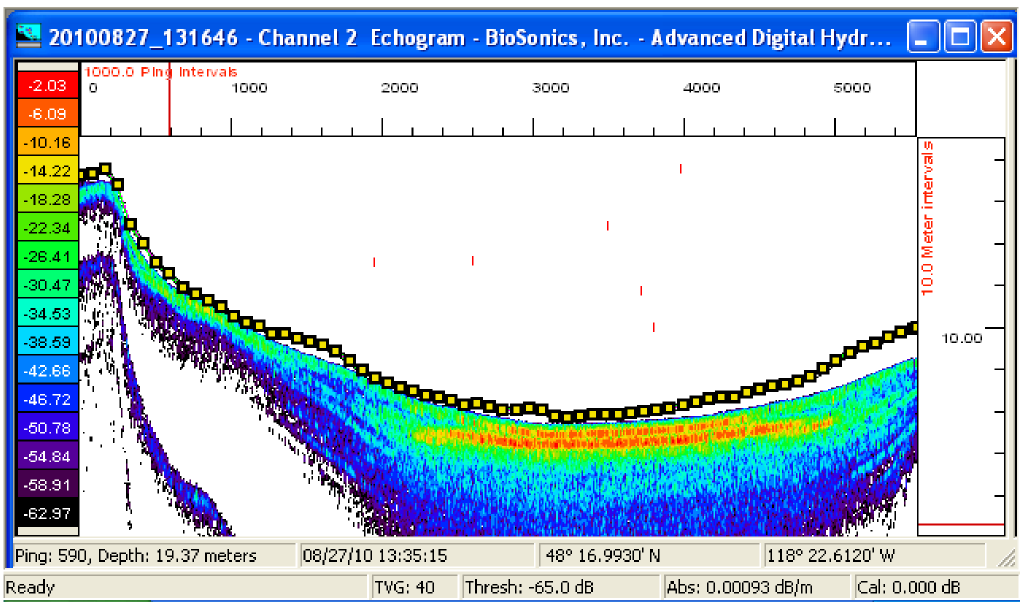

Figure 38. North Twin Lake, August 27, 2010

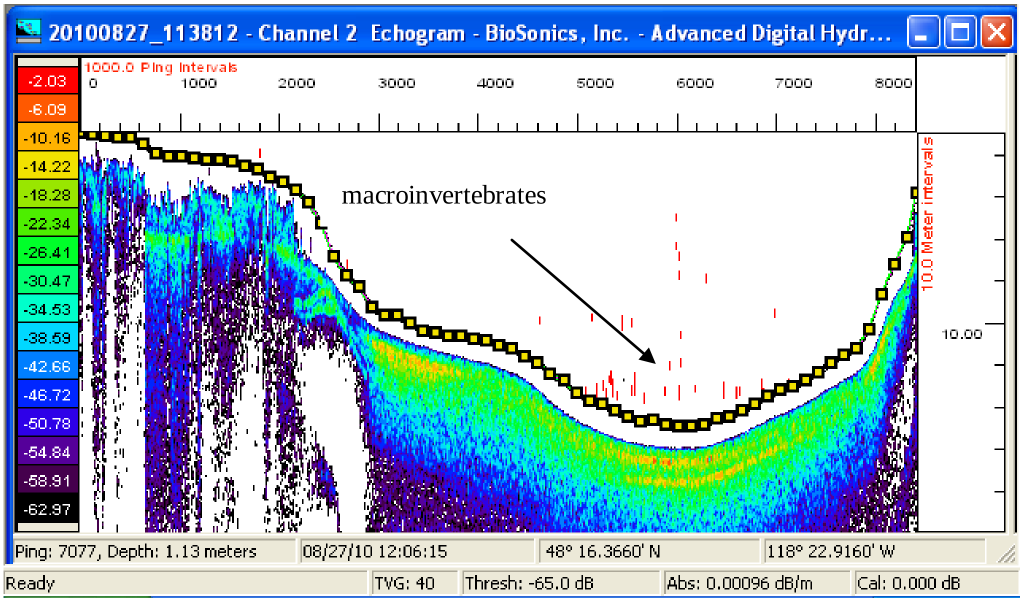

Figure 39. South Twin Lake, August 27, 2010

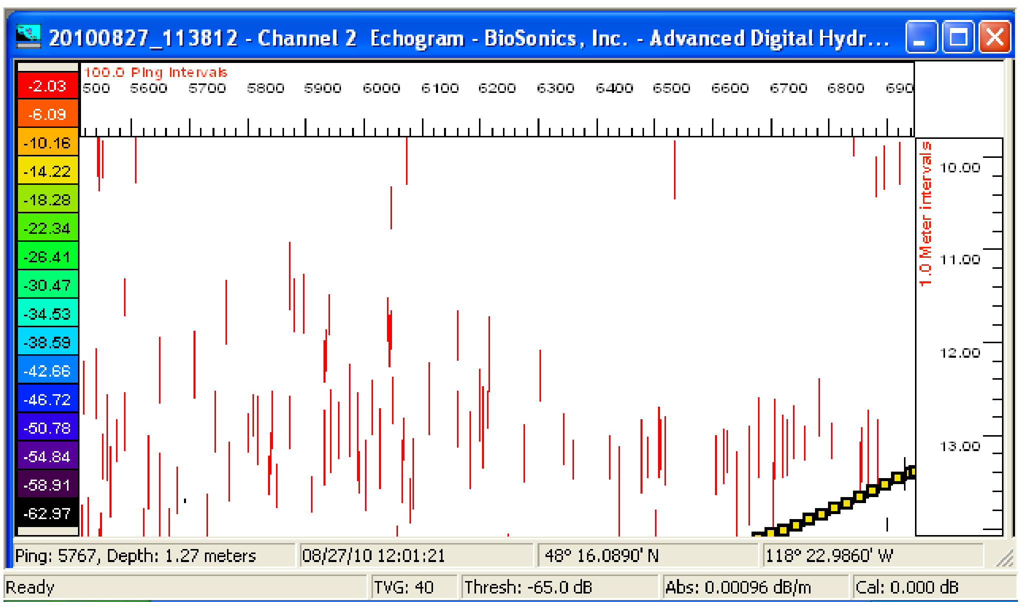

Figure 40. South Twin Lake, August 27, 2010. Macroinvertebrate targets in hypolimnion

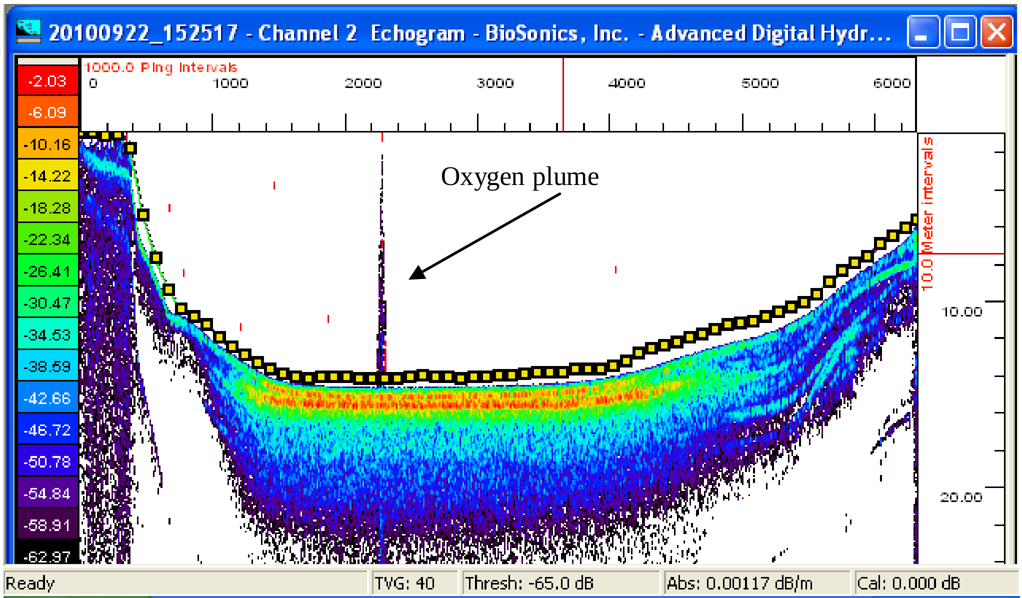

Figure 41. North Twin Lake, September 22, 2010

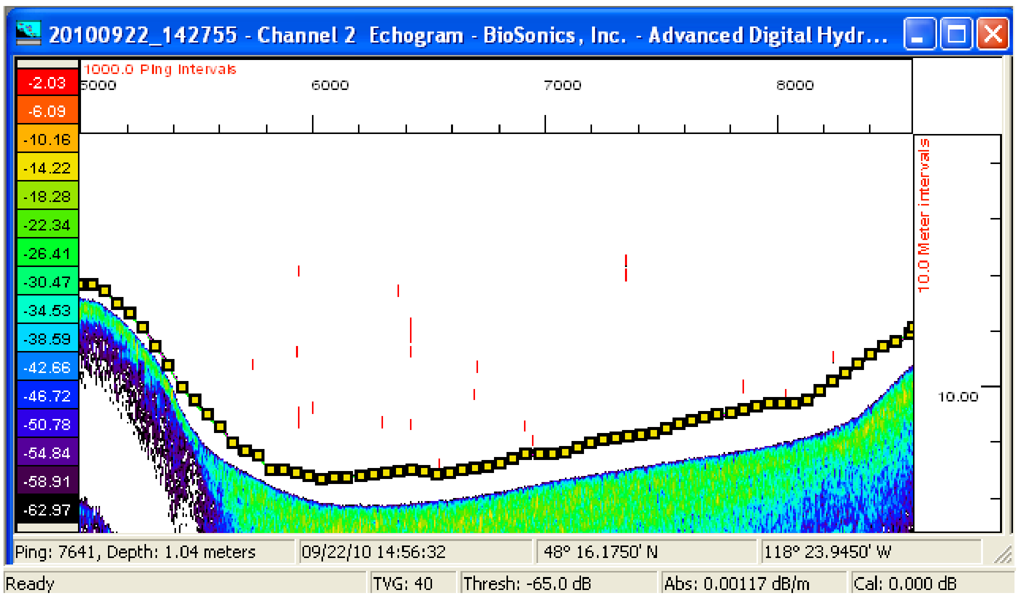

Figure 42. South Twin Lake, September 22, 2010

Table 4. Summary of hydro acoustic fish targets in North and South Twin Lakes

Twin Lakes Hydro Acoustic Surveys, 2010 Targets									
Lake	Strata	6-Apr	19-Apr	10-Jun	28-Jun	28-Jul	27-Aug	22-Sep	Total
N. Twin	1	0	15	9	5	0	0	1	31
	2	6	4	5	5	19	2	25	68
	3	14	4	2	9	7	5	7	51
	4	3	0	5	1	1	0	29	43
	5	0	0	1	6	3	6	8	29
S. Twin	1	0	21	2	1	0	0	2	27
	2	1	9	6	3	12	1	16	50
	3	1	0	1	9	4	0	19	37
	4	10	4	0	10	1	0	0	29
	5	0	0	0	0	0	0	0	5

Sub-goal 2. Reduce salmonid mortality and improve growth and catch rates by improving environmental and biological conditions in North Twin Lake.

Objective 4. Measure the effects of oxygenation on benthic and pelagic invertebrates.

Macroinvertebrates were studied by WSU scientists and reported by Lanouette (2011). *Chaoborus* was used as an indicator species because it is common in both lakes, has both a benthic and pelagic form and is a major food source for both brook and rainbow trout. Lanouette found that *Chaoborus* concentrations in the sediment of North Twin were far greater than in South Twin, but were far less in the water column. Lanouette hypothesizes that this is due to chaoborids using the sediment of North Twin as a refugia in order to escape trout predation.

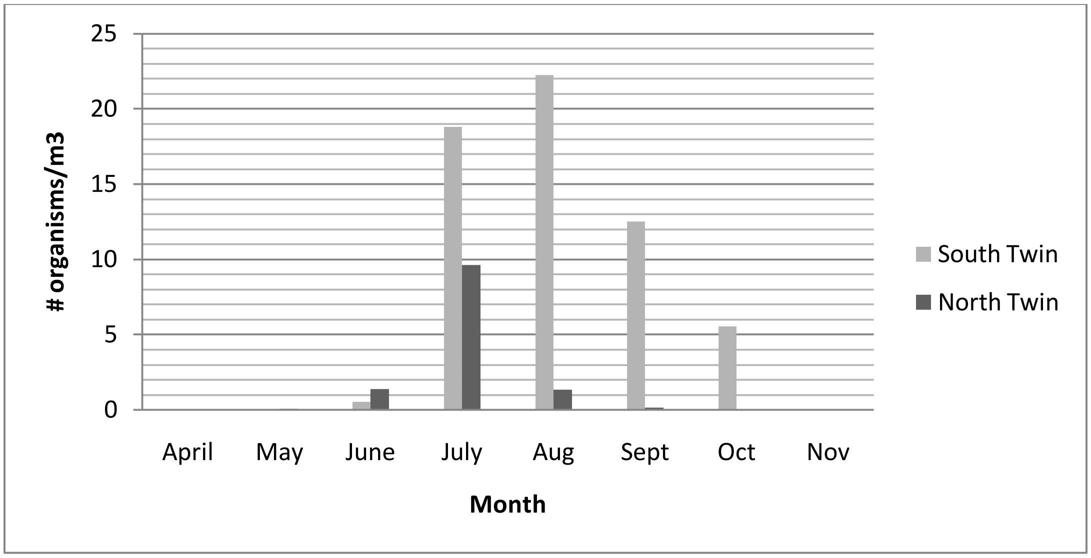

Figure 43. Monthly pelagic *Chaoborus* density

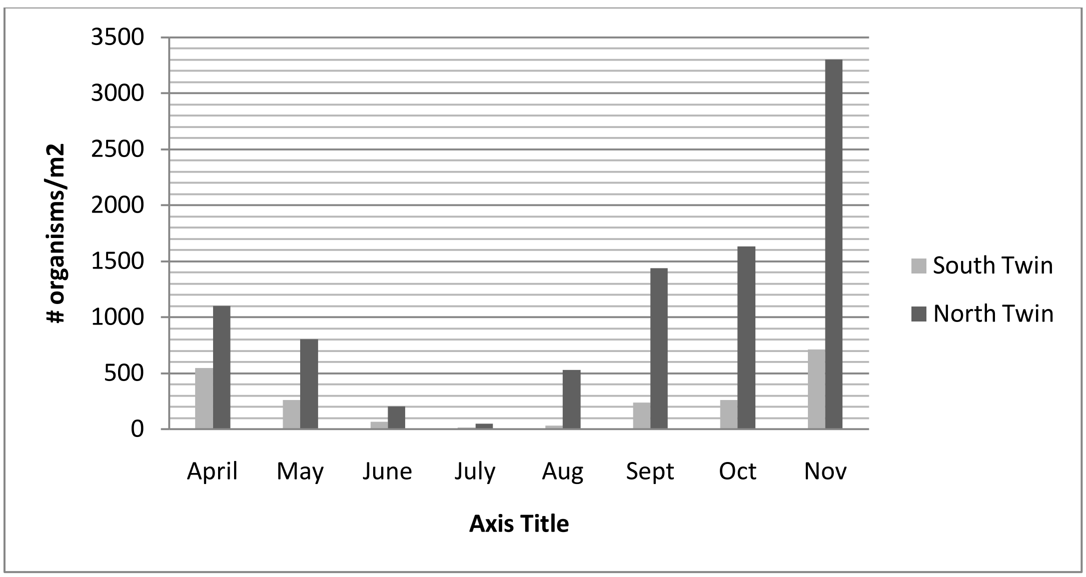

Figure 44. Monthly benthic *Chaoborus* density

Objective 5. Measure the effects of oxygenation on salmonid mortality, growth and catch rates.

These were measured by Tribal biologists using monthly gill net sets and creel survey data. These techniques have proved successful in the past (Shallenberger, 2010). Since all planted fish at Twin Lakes are marked with a combination of clips and tags it is possible to distinguish between spring and fall plants as well as year class. Since the average weight at stocking is known it is possible to determine growth rates by weighing and measuring captured fish. In 2010 we were unable to determine comparable growth rates for any group of fish. In previous years the bulk of the catch has been made up of entries from that spring and from the previous fall. Both of these groups are from the same brood year. The spring entry fish have overwintered at the hatchery and are normally larger than the fall entry fish due to high winter water temperatures at the hatchery. In 2010 most of these fish left the lakes through the Stranger Creek outlet. Both gill net and angler catches were insufficient during the summer to determine growth rates.

Annual mortality was determined by calculating the percentage of each year class in both the angler catch and the gill net catch. In previous years the percentage of carryover fish has been very low. Christenson (2005) estimated summer mortality to be in excess of 90%. 2010 was an exception, particularly in North Twin Lake (tables 5, 6 and figure 44). The majority of fish captured, both in numbers and percentage were fish of previous year classes. There were two reasons for this.

North Twin summer survival rates were better than in previous years.

A large percentage of the spring and fall plants left the lakes through the North and South Twin outlets. This was verified by gill net sets in Stranger Creek.

Because of the loss of Fall and Spring entry fish growth rates could not be determined, but because of the lack of these fish and the much higher number of carry over fish, average size of gill net captured fish increase from approximately 230 grams in 2008 and 2009 to 435 grams in 2010.

Catch rates have been measured each year since 2006. Because of the loss of the fall and spring entry fish catch rates dropped by only 1/3rd even though the lost groups of fish made up 90% of the catch in previous years (table 7).

Table 5. Rainbow trout captured in gill nets. *fall 2010 plants

Summary	Gill Net Captured Fish							
	North Twin				South Twin			
Month	Length (mm)	Weight (grams)	# new	# carryover	Length (mm)	Weight (grams)	# new	# carryover
April	300	303	21	11	239	178	20	2
May	316	389	4	16	339	466	1	3
June	350	441	1	13	397	700	2	2
July	357	435	0	3	362	470	0	2
August	341	451	1	9			0	0
September	362	571	1	1			0	0
October*	278	259	17	7	250	146	6	1
Total			45	60			29	10
Percent			42.9	57.1			74.4	25.6

Table 6. Angler caught fish, 2010, size and number of carryovers

Summary	Angler Caught Fish							
	North Twin				South Twin			
Month	Length (mm)	Weight (grams)	# new	# carryover	Length (mm)	Weight (grams)	# new	# carryover
April	328	385	2	16	349	457	0	5
May	330	414	4	43	364	530	1	25
June	353	524	2	35	337	493	7	11
July	359	510	2	35	373	578	2	6
August	372	586	1	17	377	672	1	4
September	370	546	3	15	402	733	0	3
October	360	487	0	3	none	none	0	0
Total			14	164			11	54
Percent			7.9	92.1			16.9	83.1

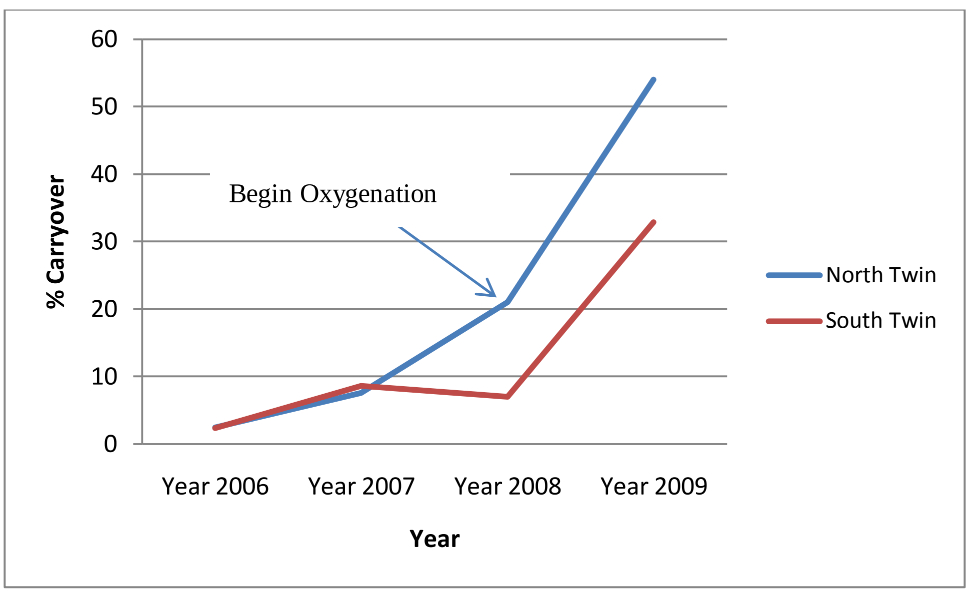

Figure 45. Percentage of carryover rainbow trout

Table 7. Summarized rainbow trout catch per unit effort from 2007-2010 by month

RAINBOW TROUT CATCH RATES (CPUE) 2007-2010								
	2007		2008		2009		2010	
Month	North Twin	South Twin	North Twin	South Twin	North Twin	South Twin	North Twin	South Twin
April	0.44	0.57	1.07	0.19	0.41	0.48	0.33	0.14
May	0.75	0.97	0.58	0.56	0.34	0.31	0.45	0.29
June	0.54	1	0.66	0.9	0.78	0.78	0.42	0.2
July	0	0.4	1.45	0.93	0.61	0.74	0.41	0.17
August	0.39	0.54	0.8	0.65	0.77	1.09	0.18	0.19
September	0.57	0.2	0.35	0.61	0.76	1.27	0.26	0.12
October	0.55	0.76	0.41	0.2	0.6	0	0.4	0
Mean	0.46	0.63	0.76	0.58	0.61	0.67	0.35	0.46

Objective 6. Measure the effects of oxygenation on the sediments of North Twin Lake.

The effects of oxygenation on the sediment of both lakes was measured by WSU scientists and reported on by Beutel et al, 2011 and Reed, 2011.

Findings

1. Iron and Manganese in Water Column. As in 2009, iron and manganese were detected in bottom waters of both North and South Twin Lakes in 2010. Levels in August/September for iron were ~500-1,000 µg/L in North Twin and ~50-300 µg/L in South Twin. Levels in August/September for manganese were ~100-200 µg/L in North Twin and ~50-300 µg/L in South Twin. As was observed in 2009, metals levels were homogenized throughout the hypolimnion in North but more localized to bottom waters in South.
2. Methylmercury in Water Column. Levels of methylmercury in 2010 peaked at ~0.2 ng/L in aerobic bottom waters of North Twin and ~0.4-0.6 ng/L in anoxic bottom waters of South Twin. Methylmercury accumulation in North Twin in 2010 was much higher than in 2009 when levels were below ~0.04 ng/L.
3. Mercury in Zooplankton. The amount of mercury in zooplankton was significantly higher in oxygenated North Twin compared to South Twin. Levels of total mercury in zooplankton averaged 143 µg/kg in North Twin and 63 µg/kg in South Twin. Levels in North Twin were also substantially higher than observed in 2009. Average values for 2009 were 95 µg/kg in North and

71 μg/kg in South. Levels of methylmercury in zooplankton in 2010 averaged 128 μg/kg in North Twin and 40 μg/kg in South Twin.

Significance

1. Iron and Manganese in Water Column. Iron and manganese were not expected to be present in the water column of North Twin Lake since oxygenation systems commonly repress metal release from sediments and subsequent accumulation in bottom waters. These results suggest that the line diffuser system in North Twin, while maintaining oxygenated conditions in the upper hypolimnion which benefits trout, is not oxygenating the sediment-water interface. This has ramifications for the cycling of nutrients in the lake as well. A presumed benefit of lake oxygenation, in addition to improving trout habitat and repressing metals accumulation, is the repression of ammonia and phosphate release from sediments, nutrients that can exacerbate eutrophication when mixed into the photic zone. If the oxygenation system is not repressing sediment release of iron and manganese, I suspect that it is also not repressing sediment release of nutrients. The same could be said for mercury - the better oxygenated the sediment-water, the more likely to have lower methylmercury levels in bottom waters.
2. Methylmercury in Water Column. Oxygenation in 2010 appears to have impeded but did not repress methylmercury accumulation in the bottom waters of North Twin Lake, as it did in 2009. This data strongly that methylmercury is controlled by oxygen levels in bottom waters, with higher levels of oxygen leading to lower levels of mercury in the water and zooplankton as was observed in 2009. This data supports the recommendation above to maintain high levels of oxygen in bottom waters to try to inhibit/minimize mercury, iron, manganese, phosphate and ammonia release from sediments.
3. Mercury in Zooplankton. The higher levels of mercury in zooplankton in North Twin, which appears to have lower levels of methylmercury in the water column compared to South Twin, is perplexing since the conventional wisdom holds that the amount of mercury in aquatic biota generally correlates with the amount of methylmercury in water. However, the higher levels of mercury in North Twin in 2010 versus 2009 can be explained by the higher levels of methylmercury in bottom waters of that lake in 2010. The bottom line is that, based on the side-by-side observation between North and South Twin Lake, oxygenation may have inadvertently enhanced mercury uptake into zooplankton in North Twin. However, without a before-and-after evaluation in North Twin, it is hard to know for sure.

Sub-goal 3. Build a South Twin Lake Oxygenation System.

Objective 7. Construct, install and test a hypolimnetic oxygenation system in South Twin Lake.

The South Twin Lakes Oxygenation System was constructed in September, 2010 by Mobley Engineering and was tested installed and tested in October. Because we did not want to interfere with the comparison of the two lakes the South Twin Oxygenation System was only operated for approximately ½ day which was sufficient to thoroughly test it.

Figure 46. Oxygenation system construction

Figure 47. Checking oxygenation system before submerging

Discussion

The primary reason for oxygenating North and South Twin Lakes is to improve conditions for trout in order to reduce summer mortality, increase growth rates and ultimately reduce or eliminate the need for hatchery supplementation. There are several steps in determining the effectiveness of hypolimnetic oxygenation.

The first, and easiest to measure step was to determine if oxygenation could raise dissolved oxygen levels in the hypolimnion to a point where trout can survive and are unstressed. In both 2009 and 2010 oxygen levels in the hypolimnion of North Twin were kept above 5mg/l while the hypolimnion in South Twin dropped below 1 mg/l. Acceptable levels of dissolved oxygen were found more than 500 meters away from the oxygen plume indicating that there is sufficient circulation within the lake to oxygenate all of the hypolimnion and therefore make all of it theoretically available for trout.

The second step in evaluation was to compare the use of the hypolimnion of North Twin (oxygenated) with the use of the hypolimnion of South Twin (unoxygenated). Gill net studies, hydro acoustic surveys and archival tags in 2009 and 2010 all showed that during periods of stratification fish in North Twin utilized the hypolimnion and fish in South Twin did not. Oxygenation is effective in raising dissolved gas levels in the hypolimnion to a point where it is utilized by salmonids. When dissolved gas levels are low, the hypolimnion is not utilized by trout.

While the first two steps in evaluation are critical, it is just as important to determine if use of the hypolimnion improves summer survival as well as improving growth and condition factor over both the short run and the long run. If these don't improve there may be little merit in continuing to oxygenate.

Mortality at Twin Lakes has been measured primarily by determining the number and percentage of each group of fish caught by anglers and caught by gill nets. If a large percentage of the catch is made up of the previous year's fish (carry over fish) then mortality has been low. Christensen (2005) determined that summer mortality (including fishing mortality) may be as high as 95%. Fishing mortality is typically < 10%, therefore non fishing mortality may be 85%. In past years, fish that have lived through the previous summer have made up < 10% of the catch. In 2010, 57% of the fish caught in gill nets in North Twin were carry over fish while only 25% of the South Twin fish were carry over fish. This was in part due to the fact that many of the newly planted fish left the lake through the outlets, but in terms of actual numbers more carry over fish were caught than have been caught in recent years. Oxygenation has certainly improved survival, but because of the large number of fish that left the lakes it is impossible to precisely evaluate the extent of improvement.

Several questions remain unanswered.

What is the effect of oxygenation on growth and condition factor?

What is the effect of oxygenation on macroinvertebrates?

What is the effect of oxygenation on the sediment?

Has two years of oxygenation reduced the SOD of North Twin Lake and therefore reduced the amount of oxygen required in future years?

1. Can higher oxygen levels in North Twin repress methylmercury accumulation in bottom waters? Oxygen levels in bottom waters were higher in 2009 versus 2010. We recommend that the oxygenation system be operated with a high oxygen input to maintain high dissolved oxygen levels in bottom waters in an attempt to more fully repress methylmercury (and iron and manganese) accumulation. In other words, we would like to see 2011 look more like 2009 (higher oxygen, lower mercury) versus 2010 (lower oxygen, higher mercury). Our 2011 monitoring efforts will help to access this question.
2. Are mercury dynamics in zooplankton translating into fish? The high levels of mercury in North Twin zooplankton relative to South Twin may lead to higher levels of mercury in trout. We will be monitoring mercury levels in fish this season to address this question.
3. Is our single sampling station representative of metals and mercury levels in the entire lake? It is possible, but unlikely in my opinion, that the unexpectedly high levels of iron and manganese are occurring where we currently sample near the bubble plume diffuser due to upwelling caused by the line diffuser. To evaluate this, we will conduct at least two synoptic sampling events to collect water quality profiles at the usual deep site (i.e., near the line diffuser), but also at two additional sites away from the line diffuser.

What mechanism is causing enhanced mercury uptake into zooplankton in North Twin Lake? This is a complex question and is somewhat beyond the scope of the original monitoring program. Our current working hypothesis is that fine iron and manganese oxide particles in the water column of North Twin Lake are absorbing mercury. These mercury-enriched particulates are then being ingested by filter-feeding zooplankton. We plan to collect monthly samples of filtered and unfiltered mercury in the water column to determine if mercury in North Twin is particulate in nature and associated with metal oxides.

The primary goal of 2011 is to answer these questions. Several steps have been taken to ensure success.

Barrier nets have been installed at the outlets of both North and South Twin Lakes to prevent entrainment.

Research by Tribal biologists will be directed towards determining growth, mortality and catch rates.

The research subcontract with WSU has been extended for an additional season.

The goals of the WSU subcontract are very specific and directed to obtaining the answers to these questions.

The ultimate goal of oxygenation is to develop self-sustaining populations of brook and redband rainbow trout and reduce the reliance on hatchery plants, allowing the hatchery to concentrate its efforts elsewhere. It will require reduced summer mortality to achieve this goal. If feed resources are not reduced and reduced mortality is achieved the average size of angler catches will be increased and reliance on hatchery plants will be reduced. Once this is shown to be the case the decision can be made to construct an oxygen generation facility and therefore reduce the reliance on outside sources of oxygen and reduce operational costs.

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Appendix

TWIN LAKES CREEL STUDY PLAN
2008

April 12-October 31

Creel Days. A minimum of four randomly selected weekend/holidays and eight randomly selected week days will be creeled each month.

Creel hours. The normal work day will be 10 hours plus ½ hour for lunch. Start and stop times will be varied so that all hours of the day are covered.

Angler usage. Both fishing boats and shore anglers will be counted on each lake every two hours throughout the day. The spacing of count times will be as regular as possible. Start and stop times will be arranged so that the maximum number of counts can be obtained each day. For example, if the creel day begins at 6:00 the daily schedule might be as follows:

N. Twin Counts	S. Twin Counts
6:00	6:15
8:00	8:15
10:00	10:15
Break 10:30-10:45	
12:00	12:15
Lunch 12:30-13:00	
14:00	14:15
16:00	16:15
Day end 16:30	

Catch Rate. Catch rates will be determined by roving creel survey. This will be done by boat between usage counts. It is realized that it may not be possible to count every boat every time. That's ok. If boats are creeled more than once each day this needs to be noted on the creel form. Only the last (and most complete) survey will be used in the analysis.

It is absolutely critical that the angler start time, creel time, number of anglers, number of fish kept of each species and number of fish released of each species be recorded.

Fish information. All fish information will be obtained are recorded using approved procedures and protocols. These are included in the Colville Tribe Resident Fish Protocol Manual. All measurement will be made using the metric system.

The observer will look for the presence or absence of fin clips, elastomer tags, coded wire tags or any other identifying makes. Presence/absence of these marks will be immediately recorded.

Information storage and dissemination. Information will be downloaded onto an appropriate computer spreadsheet and emailed to the supervising biologist on a weekly basis.