2015 LAKE BILLY CHINOOK WATER QUALITY STUDY RESULTS

Prepared for Deschutes River Alliance
by Rick Hafele - February 2016

TABLE OF CONTENTS

ACKNOWLEDGMENTS

The Deschutes River Alliance thanks Greg McMillan, Rick Hafele, and Larry Marxer for their many hours of volunteer work to collect the water quality data contained in this report. Larry Marxer deserves a special thanks for developing and writing the monitoring plan, organizing equipment, and making sure proper procedures were followed throughout this project.

In addition a special thanks to the Oregon Wildlife Foundation and Fly Fishers Club of Oregon for providing critical funding needed for this study, and the Freshwater Trust their helpful comments.

Last, thanks to all those not mentioned here who care about the Deschutes River and have contributed hours of their time to better understand the river’s changing ecology, and to all those who have provided critical financial support to better understand and protect its health. Many hundreds of people and numerous companies and foundations have made it possible to keep this work moving forward - THANK YOU.

INTRODUCTION

Lake Billy Chinook (LBC) was the focus of water quality monitoring by the Deschutes River Alliance (DRA) in 2105. Lake Billy Chinook differs from most all other reservoirs in that it has three major rivers entering its upper reaches. These rivers are the Crooked River, Deschutes River, and Metolius River. The Crooked River arm of the reservoir is six miles long and contributes 40 percent of the inflow, the Deschutes arm is 8.5 miles long and contributes 20 percent of the inflow, while the Metolius arm is 12 miles long and contributes 40 percent of the inflow (Johnson et al. 1985).

There are notable differences in land use and water quality between these rivers. For example, both the Crooked and Deschutes River watersheds include important urban and agricultural areas (crops and range land for grazing), and both rivers are used for irrigation. In contrast the Metolius River is a large spring creek that flows through forest lands with minimal human activities. These differences in land use are reflected in their water quality. A comparison of water quality in the basin is described in a watershed assessment study completed by the Oregon Department of Environmental Quality (DEQ 2011). Based on DEQ's assessment using Oregon's Water Quality Index (the OWQI incorporates eight water quality parameters into a single index score), the Crooked River and Deschutes River fall into the poor water quality category, while the Metolius River rates in the excellent water quality category.

Why does water quality of the three rivers entering LBC matter? Since the surface water withdrawal tower (SWW) at the forebay of Round Butte dam began operation in January 2010, water discharged from LBC into the lower Deschutes River has been 100% surface water for about seven months of the year. The rest of the year, when surface and bottom water are mixed, the mix usually includes more than 40% surface water (Campbell 2015). This is a major change from before 2010, when water released from LBC was 100% bottom water for the entire year. Because the Metolius River is consistently cooler than either the Crooked or Deschutes Rivers (Campbell 2015) (Figure 1), the cooler Metolius River water is denser and therefore sinks to the bottom of the reservoir, while the warmer Crooked and Deschutes water stays on the surface. Once surface water

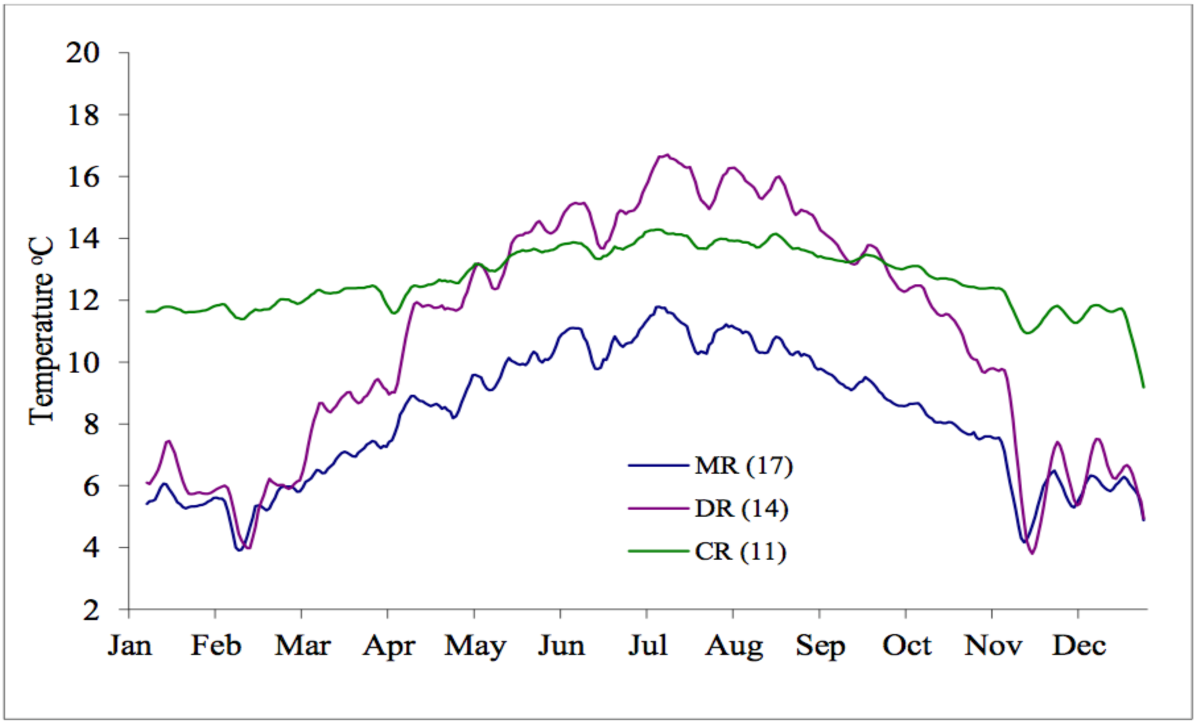

Figure 1. The 7-day average maximum inflow temperatures for the Metolius River (MR), Deschutes River (DR), and Crooked River (CR) in 2014. (From Campbell 2015).

in LBC warms in the spring, a thermocline develops about 50 feet below the surface. The thermocline further prevents mixing of surface and bottom water. What this means is that for almost the entire year for each year since 2010 the water released into the lower Deschutes River from LBC has been the water of poor quality from the Crooked and Deschutes Rivers instead of water with excellent quality from the Metolius River.

To understand just how different water quality conditions are where the three tributaries enter LBC, and differences between surface water and bottom water at the Round Butte Dam forebay, the DRA began a monthly monitoring program in LBC in May 2015. This report describes the results of the 2015 monitoring work. Portland General Electric (PGE) has also undertaken a two-year water quality study in LBC that includes samples in Lake Simtustus and lower Deschutes River. They completed the first year of sampling at the end of 2015, but the results have not been released by PGE at the time of this report.

SURVEY METHODS

Monitoring Objective:

The primary monitoring objective for 2015 was to understand the difference in water quality at the surface of LBC versus the bottom of the reservoir at the forebay of Round Butte Dam where the SWW tower collects water for discharge (Deschutes River Alliance 2015). To evaluate this DRA collected water samples for nutrient and chlorophyll-a analysis, as well as field parameters for pH, turbidity, and temperature, at three sites along the forebay of Round Butte Dam at both the surface (3-foot depth) and near the reservoir bottom (depth varied for each site). Samples were also collected in the Deschutes River approximately a half mile below the tailrace of the Reregulation Dam. Monthly monitoring began in late May and continued through November 2015. However, for the analyses included in this report, only data from June through November were used, as the results from the May sampling event did not meet the quality assurance/quality control requirements, and therefore not used. A total of 12 sampling events were completed throughout the summer and fall. A series of six samples were collected at the forebay and tailrace sites, plus one set at just the surface of the forebay sites (Table 1), and an additional set of six samples were collected for pH, turbidity, and temperature at the mouths of the three tributaries where they enter Lake Billy Chinook, and in the tributary arms of the reservoir (Table 2).

Table 1. Round Butte Dam Forebay Sample Sites: Date & Time Sampled

Date	East Site @ surface	East Site @ depth	Middle Site @ surface	Middle Site @ depth	West Site @ surface	West Site @ depth	River below Rereg Tailrace	Paremeters Measured
6/16/15	8:45	9:05	9:35	9:50	10:05	10:25	13:15	pH, turbidity, temperature, nutrients, chlorophyll-a
6/23/15	14:45		14:55		15:10			pH, turbidity, temperature
714/15	10:25	10:45	10:53	11:05	11;14	11:29	13:07	pH, turbidity, temperature, nutrients, chlorophyll-a
8/5/15	10:00	10:10	10:20	10:25	10:40	10:55	12:35	pH, turbidity, temperature
8/31/15	8:55	9:06	9:22	9:35	9:54	10:10	12:45	pH, turbidity, temperature, nutrients, chlorophyll-a
9/28/15	8:32	8:45	8:55	9:09	9:20	9:35	12:00	pH, turbidity, temperature, nutrients, chlorophyll-a
10/29/15	9:35	9:46	9:53	10:05	10:14	10:21	11:48	pH, turbidity, temperature, nutrients, chlorophyll-a

Surface = 3 feet deep
Depth: East Site = ~60'; Middle Site = ~160'; West Site = ~260'

Table 2. Lake Billy Chinook Tributary Sample Sites: Date & Time Sampled

Date	Metolius Mouth	Metolius Arm	Deschutes Mouth	Deschutes Arm	Crooked R Mouth	Crooked R Arm	Paremeters Measured
6/23/15	12:00	12:30	13:45	14:15	16:00	16:40	pH, turbidity, temperature
7/21/15	9:10		10:40		11:55		pH, turbidity, temperature, nutrients
8/10/15	8:46		10:05		11:15		pH, turbidity, temperature, nutrients
8/20/15	8:50	9:05	10:48	11:23	12:12	12:47	pH, turbidity, temperature
9/22/15	8:40		10:05		11:30		pH, turbidity, temperature, nutrients
11/4/15	9:28		10:50		12:00		pH, turbidity, temperature, nutrients

All samples taken approximately 3 feet below the surface

Sample Collection Methods:

Samples in LBC were collected from a 16-foot power boat launched at the Cove Palisades boat ramp on the Crooked River arm. Samples for nutrient analysis had to be delivered to Umpqua Research Co., an Oregon certified water analysis laboratory in Bend, by 3:00pm on the day of sampling to meet holding time requirements. To meet this requirement sample collection in the reservoir and below the reregulation dam had to be completed by 1:00pm. As a result all samples in the reservoir were collected in the morning, typically between 9:00 and 11:00am (Table 1). Figures 2 and 3 show the locations of sample sites in the three tributary arms of the reservoir and along the forebay, respectively. (See Appendix A for latitude and longitude location data for each sample site.)

Water samples were collected with a Van Dorn sampler (Figure 4). Upon reaching the sample site the Van Dorn sampler was lowered to the appropriate depth on a nylon cord. Surface samples were collected three feet deep. Bottom samples were collected a few feet above the reservoir bottom. The depth of the three sites near the forebay varied: East bank depth - 60 feet; Middle site depth - 160 feet; West bank depth - 260 feet. As shown in Figure 3, the SWW tower is located along the west bank of the reservoir with the depth of the bottom intake on the tower at approximately 260 feet.

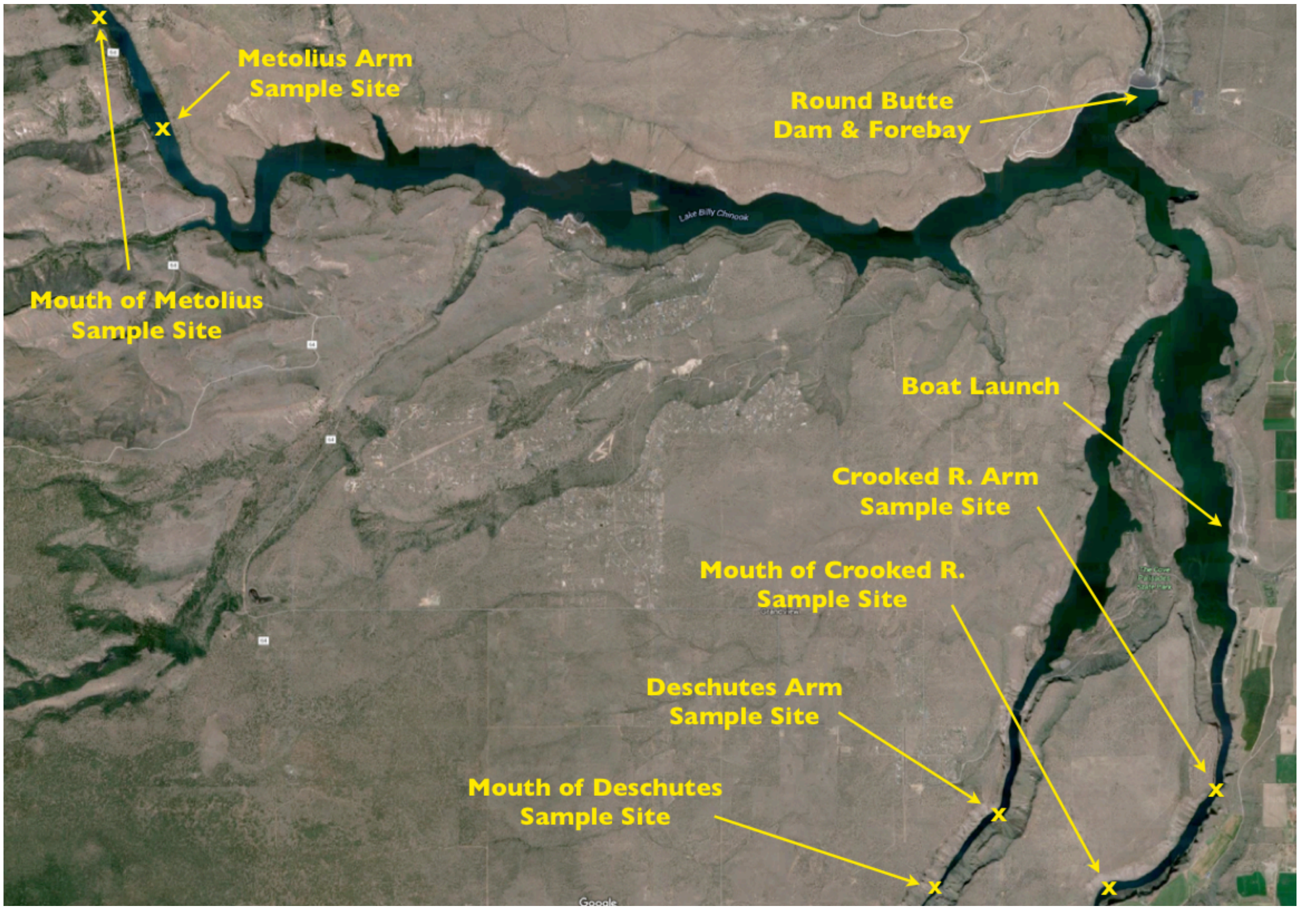

Figure 2. Lake Billy Chinook tributary arm sample site locations.

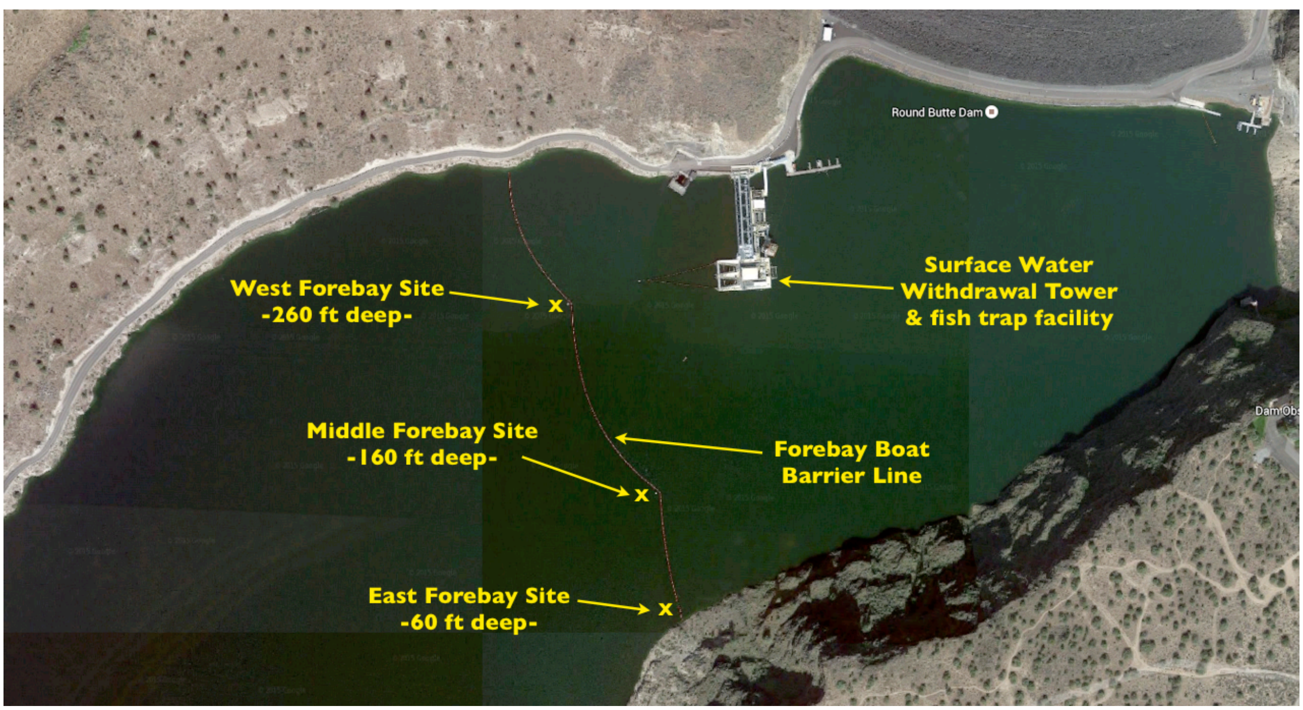

Figure 3. Forebay sample sites at Round Butte Dam.

Once the Van Dorn sampler was retrieved from the sample location, water was drawn from the sampler and placed in one of three sample bottles. These bottles were placed on ice and returned to Umpqua Research Co. by 3:00pm the same day for nutrient and chlorophyll-*a* analysis. Remaining water in the sampler was placed in a rinsed plastic beaker for pH and temperature measurements. The pH was measured with a Hana Instruments pH meter model 991001. Temperature was measured with a Thomas Scientific temperature meter model 1235C88. A final water sample was placed in a glass vial provided with the Hana Instruments turbidity meter (model 98703) and a turbidity measurement taken. After recording the time, location, and field measurements, the Van Dorn sampler was lowered to the next sample location.

Figure 4. Van Dorn Sampler

Sample Parameters:

Field parameters consisted of pH, turbidity, and temperature. The precision of field measurements and Quality Control/Assurance (QA/QC) procedures are described in the 2015 Water Quality Monitoring Plan for the Lower Deschutes River (Deschutes River Alliance 2015). Lab samples were analyzed for the following constituents along with their minimum recording levels (MRL):

- Chlorophyll-*a* (MRL = 0.0003 mg/L)
- Nitrate as N (MRL = 0.10 mg/L)
- Nitrite as N (MRL = 0.01 mg/L)
- Nitrate/Nitrite as N (MRL = 0.10 mg/L)
- Total Kjeldahl Nitrogen (MRL = 0.200 mg/L)
- Phosphate, ortho as P (MRL = 0.03 mg/L)
- Total Phosphorus (MRL = 0.050 mg/L)

Results

Temperature:

The surface water of LBC at the forebay sites was consistently warmer at the surface when compared to water near the bottom (Table 3). The difference in temperature between surface and bottom was at or close to 10 degrees celsius (C), or 18 degrees Fahrenheit (F), from mid June through mid July. By late August surface water began to cool two to three degrees C, while bottom water temperature remained several degrees cooler. The West forebay sample site (the deepest site) consistently had the coldest bottom water temperature. Of the three forebay sites, the West site is closest in depth and distance to the bottom port on the SWW tower, and best reflects the temperature of bottom water at the tower.

Table 3. Surface and bottom water temperature (degrees celsius) at Round Butte forebay sites.

	East		Middle		West		River below Rereg Tailrace
	Surface	Bottom	Surface	Bottom	Surface	Bottom	
6/16/15	18.7	10.2	18.6	9.9	19.4	10.6	17.1
6/23/15	20.9		20.9		21.4		
7/14/15	19.9	14.4	19.3	9.8	19.9	8.8	15.2
8/20/15	19.4		19.2		19.7		
8/31/15	17.0	14.9	17.2	12.2	17.4	10.0	13.8
9/28/15	14.5	13.8	14.3	11.8	14.4	10.5	14.4
10/29/15	12.2	11.9	11.9	11.9	12.4	10.9	12.2

Surface water continued to cool until late October when surface and bottom temperatures were the same at the middle forebay site (11.9 C) and close to the same at the two other forebay sites. This shows that the thermocline had disappeared, which would allow mixing of surface and bottom water to occur given that water of the same temperature has the same density. The level of mixing between surface and bottom water would depend on wind and other currents within the reservoir.

Water temperature in the lower Deschutes River below the reregulation dam was warmest in mid-June (17.1 degrees C), and gradually cooled through the summer and fall. This cooling coincided with the cooling of surface temperature in LBC. Oregon's water quality standard for maximum water temperature in the lower Deschutes River at the sample site is 16 degrees C. This standard was exceeded in mid June. Because samples were collected at the forebay and lower river sites between 9:00am and 1:00pm (Table 1) to meet sample delivery requirements to the laboratory, the results do not show the maximum surface temperatures in LBC or at the downstream river site. Maximum daily temperature typically occurs around 3:00 to 4:00pm.

Table 4 shows the surface temperature at the mouth of each LBC tributary and within the reservoir arm of each tributary. The Metolius sites were colder than the Deschutes or Crooked sites at both the mouth and within the reservoir arms. Temperatures at the Crooked and Deschutes sites were similar. This remained consistent throughout the summer and fall, and reflects the colder water temperatures of the Metolius River.

Table 4. Surface water temperature (degrees celsius) in the three tributary arms of Lake Billy Chinook.

	Metolius Mouth	Metolius Arm	Deschutes Mouth	Deschutes Arm	Crooked Mouth	Crooked Arm
6/23/15	9.7	16.8	14.9	20.6	15.1	23.9
7/21/15	8.7		14.4		14.2	
8/10/15	8.6		14.3		13.6	
8/20/15	8.1	18.6	14.7	21.6	14.6	22.5
9/22/15	7.8		11.8		13.4	
11/4/15	5.2		6.9		11.1	

pH:

The pH of water is a measure of the hydrogen ion concentration on a logarithmic scale from 0 to 14. A pH value below 7 indicates acidic water and values above 7 indicate alkaline water. The pH of pure water is commonly at or near 7. Because the pH of water affects the physiology of plants and animals in the water, it is critical that pH remain within a suitable range to protect the health of aquatic ecosystems. The Oregon State water quality standard for pH in the Deschutes basin is 6.5-8.5. Values below or above this range are considered detrimental to aquatic life. Current State standards can be found at: http://arcweb.sos.state.or.us/pages/rules/oars_300/oar_340/340_041.html

Table 5 shows the pH values recorded from surface and bottom water at the three forebay sites near the Round Butte dam and in the Deschutes River below the reregulation dam tailrace. The results show excessively high pH values (> 9.0) in surface water throughout the summer at all three forebay sites. These levels are well above State standards, and pH's above 9.5 can be lethal to salmonids when exposed for extended periods (Robertson-Bryan 2004). These high pH levels are thought to be the result of large surface blooms of blue-green algae.

Table 5. Surface and bottom water pH values at Round Butte forebay sites.

	East		Middle		West		River below Rereg Tailrace
	Surface	Bottom	Surface	Bottom	Surface	Bottom	
6/16/15	9.5	7.1	9.6	7.3	9.6	7.0	8.5
6/23/15	9.7		9.7		9.6		
7/14/15	9.4	8.1	9.4	7.9	9.6	7.9	8.2
8/20/15	9.2		9.2		9.3		
8/31/15	9.4	8.5	9.0	8.2	9.1	7.9	7.8
9/28/15	8.9	8.2	9.0	8.2	9.0	7.9	7.6
10/29/15	8.3	8.1	8.5	8.5	8.5	8.5	7.8

The pH levels of water near the bottom of the forebay reached a maximum of 8.5 on a three occasions, but ranged between 7 and 8.2 for the remaining samples. The pH levels in the river below the reregulation dam tailrace were highest on June 16th (8.5), and declined slowly through the summer and fall.

Like temperature, since samples were collected between 9:00am and 1:00pm (Table 1), the pH measurements recorded for this study are not the maximum daily values. Peak pH levels will generally occur around 3:00 to 4:00pm due to the effects of photosynthetic activity by aquatic plants and algae.

Conversely, the lowest pH levels occur just before sunrise following the night time period with no photosynthetic activity.

The pH measurements at the mouths of the three tributaries entering LBC showed the Metolius River had the lowest levels and the Crooked River the highest, however, the differences were not nearly as great as between surface and bottom water samples at the forebay (Table 6). All measurements at the mouths of the tributaries remained below the State standard. Measurements within the arms of the three tributaries, however, showed much higher pH levels, with pH measurements exceeding 9.0 at all three sites. The highest measured pH value (9.9) was in the Crooked River arm on June 23. With the exception of the June 23rd samples, which were collected from mid to late afternoon, all other samples were collected from mid to late morning (Table 2) before peak pH levels would have occurred.

Table 6. Surface pH levels in the three tributaries of Lake Billy Chinook.

	Metolius Mouth	Metolius Arm	Deschutes Mouth	Deschutes Arm	Crooked Mouth	Crooked Arm
6/23/15	7.6	9.3	8.0	9.7	7.8	9.9
7/21/15	7.6		7.7		8.1	
8/10/15	7.3		7.9		8.0	
8/20/15	7.9	9.0	7.9	8.9	7.9	8.9
9/22/15	7.0		7.2		7.5	
11/4/15	8.3		8.5		7.5	

Turbidity:

A field nephelometer (turbidity meter) was used to measure the turbidity levels of the collected water samples. The unit of measurement for turbidity is the Nephelometric Turbidity Unit (NTU). Turbidity levels vary in natural stream systems due to runoff events and parent soil type. The water quality standard for turbidity in Oregon is based on point-source impacts such that no more than a 10% increase is allowed above background levels measured at a point upstream of point-source activity. Turbidity standards in other States limit turbidity to 10 - 25 NTUs for high quality cold-water streams (EPA 1988).

Suspended sediments and phytoplankton blooms both increase turbidity levels. Turbidity readings in the LBC forebay from surface and bottom samples show noticeably higher levels in the surface water (Table 7). The higher surface turbidities were due to the phytoplankton blooms in the surface of the reservoir. Some exceptions occurred (7/14 Middle site; 8/31 & 9/28 West forebay site) where bottom samples had elevated turbidity. On these occasions the Van Dorn sampler had disturbed bottom sediments during sampling.

Table 7. Surface and bottom turbidity levels in NTUs at the Lake Billy Chinook forebay sites and Deschutes River below the Reregulation Dam.

	East		Middle		West		River Below Rereg Tailrace
	Surface	Bottom	Surface	Bottom	Surface	Bottom	
6/16/15	8.2	0.5	12.3	0.8	10.1	0.8	1.7
6/23/15	7.7		3.1		3.1		
7/14/15	9.3	0.9	7.6	18.6	9.0	0.6	1.4
8/20/15	6.7		7.3		7.6		
8/31/15	3.3	3.3	3.4	0.8	3.4	13.6	3.6
9/28/15	1.8	1.8	2.1	3.6	2.0	25.5	2.8
10/29/15	1.1	1.1	1.1	0.4	1.2	1.2	2

Turbidity levels at the mouth of each tributary were typically low (< 2 NTUs). Turbidity readings at the mouth of the Metolius River, however, were higher, ranging from just under 1 NTU to 6.20 NTUs (Table 8). This higher turbidity is normal for the Metolius River in the summer due to glacial runoff.

Table 8. Surface turbidity levels in NTUs for the three tributaries of Lake Billy Chinook.

	Metolius Mouth	Metolius Arm	Deschutes Mouth	Deschutes Arm	Crooked Mouth	Crooked Arm
6/23/15	0.80	6.42	0.80	11.10	0.40	23.20
7/21/15	2.70		1.00		0.70	
8/10/15	2.80		1.30		0.80	
8/20/15	6.20	3.60	0.90	10.40	7.90	8.90
9/22/15	3.70		1.10		1.50	
11/4/15	3.30		1.80		1.30	

Turbidity readings in the reservoir arms were much higher than the river mouths for the Deschutes and Crooked rivers, while samples from the Metolius arm and mouth of the Metolius River were similar. Large phytoplankton blooms in the Deschutes River and Crooked River arms resulted in the higher turbidity readings at those sites.

Nutrients:

Just as plants on land require sufficient nutrients for healthy growth, nutrients are also essential for the growth of aquatic plants and algae in streams and lakes. Excessive nutrients, however, can cause deleterious growth of algae and alter the species composition to less desirable species. If left unchecked the result can be large blooms of nuisance species such as cyanobacteria (also known as blue-green algae), which can produce neurotoxins toxic to animals drinking from the water, and trigger the closure of recreational water activities. Major blooms of toxin producing cyanobacteria have occurred for a few weeks during the summer in Lake Billy Chinook for a number of years including 2015, resulting in periodic health warnings against water contact recreation in LBC.

The nutrients with the greatest effect on aquatic plant growth are various forms of nitrogen and phosphorus. The forms of nitrogen and phosphorus assessed for this study included: Nitrite (NO2), Nitrate (NO3), Total Kjeldahl Nitrogen (TKN), Orthophosphate (Ortho-P), and Total Phosphorus (Total-P). Total nitrogen (Total-N) was calculated by adding NO2+NO3+TKN. Chlorophyll-*a* was also measured from the same water samples collected for nutrient analysis. Because rapidly growing algal communities deplete the available nutrients, low nutrient concentrations will occur where algal densities (indicated by chlorophyll-*a*) are high (Hynes 1970).

Some forms of nitrogen and phosphorus are more readily available to aquatic plants than others. For example, while total phosphorus (TP) is frequently reported for nutrient studies, TP includes organically bound forms of phosphorus, which are not available to plants, as well as orthophosphate, which is available and readily used by plants for growth. For nitrogen, nitrite (NO2) and nitrate (NO3) are readily used by plants. Nitrite is usually quickly converted to nitrate, so the two are typically reported together as NO2-NO3. Total Kjeldahl nitrogen (TKN) is a measure of organic nitrogen (found in living or dead organisms including algae) plus ammonia. TKN is not readily available to plants for growth, but can be high when algal biomass is high. Total nitrogen (TN) is the sum of NO2-NO3 + TKN (Wall 2013).

Tables 9, 10, and 11 show the nutrient concentrations of NO2-NO3, TKN, and Total-N, respectively, at the forebay of LBC for surface and bottom water samples, while Tables 12 and 13 show the concentration of Ortho-P and Total-P. The concentration of Chlorophyll-a at the LBC forebay sample sites is shown in Table 14.

The concentration of available nitrogen (NO2-NO3; Table 9) was very low at the surface (mostly below the minimum reporting level or MRL) and higher in the bottom samples (generally between 0.2 and 0.3 mg/L). The concentration of Ortho-P (Table 12) was also low at the surface (mostly below MRL) and higher in bottom samples. These results reflect the prolific algal growth in the surface water, which would use all the available nutrients. This is further indicated by the higher concentrations of TKN and chlorophyll-*a* in the surface samples compared to bottom samples (Tables 10 & 14, respectively).

The Oregon water quality standard for chlorophyll-a is 15 *u*g/L (0.015 mg/L) (Oregon OARs section 340-041-0019). Table 14 shows that the majority of surface samples exceeded this criteria with a maximum concentration of 99.8 *u*g/L measured at the surface of the middle forebay site on June 16th. A few bottom water samples also had high concentrations of chlorophyll-*a* (e.g. West site on August 5th). These were from samples where the Van Dorn sampler disturbed the bottom substrate, which then collected algal material that had sunk to the reservoir bottom. The few samples with higher TKN concentrations in the bottom samples also indicates that algae or other organisms (dead zooplankton for example) were collected from the bottom substrate.

Both NO2-NO3 and Ortho-P concentrations at the lower Deschutes River site below the tailrace were ten to five times higher on the June 16 sample date compared to the remaining sample dates (Tables 9 & 12, respectively). This suggests that nutrients were present in surface water of LBC in the late spring and early summer, and were discharged downstream. By September 28, both

Table 9. Surface and bottom concentration of NO2-NO3 (mg/L) at the Lake Billy Chinook forebay sites and Deschutes River below the Reregulation Dam. (Note: 0.000 = Below Minimum Recording Limit)

	East		Middle		West		River below Rereg Tailrace
	Surface	Bottom	Surface	Bottom	Surface	Bottom	
6/16/15	0.000	0.210	0.000	0.000	0.000	0.200	1.490
7/14/15	0.000	0.130	0.000	0.250	0.000	0.230	0.190
8/5/15	0.000	0.290	0.000	0.240	0.000	0.310	0.250
8/31/15	0.230	0.320	0.000	0.140	0.000	0.330	0.240
9/28/15	0.000	0.280	0.000	0.130	0.000	0.140	0.320
10/29/15	0.100	0.180	0.110	0.130	0.100	0.000	0.130

Table 10. Surface and bottom concentration of TKN (mg/L) at the Lake Billy Chinook forebay sites and Deschutes River below the Reregulation Dam.

	East		Middle		West		River below Rereg Tailrace
	Surface	Bottom	Surface	Bottom	Surface	Bottom	
6/16/15	1.130	0.813	1.310	1.320	1.110	0.528	0.720
7/14/15	0.668	0.238	0.574	0.574	0.538	0.000	0.307
8/5/15	0.695	0.304	0.732	0.939	0.732	1.580	0.308
8/31/15	0.459	0.285	0.511	3.270	0.483	0.327	0.242
9/28/15	0.436	0.412	0.440	0.695	0.431	0.299	7.120
10/29/15	0.346	0.271	0.290	0.223	0.228	0.285	0.313

Table 11. Surface and bottom concentration of Total-N (mg/L) at the Lake Billy Chinook forebay sites and Deschutes River below the Reregulation Dam.

	East		Middle		West		Rereg Tailrace
	Surface	Bottom	Surface	Bottom	Surface	Bottom	
6/16/15	1.130	1.023	1.310	1.320	1.110	0.728	2.210
7/14/15	0.668	0.368	0.574	0.824	0.538	0.230	0.497
8/5/15	0.695	0.594	0.732	1.179	0.732	1.890	0.558
8/31/15	0.689	0.605	0.511	3.410	0.483	0.657	0.482
9/28/15	0.436	0.692	0.440	0.825	0.431	0.439	7.440
10/29/15	0.446	0.451	0.400	0.353	0.328	0.285	0.443

Table 12. Surface and bottom concentration of Ortho-P (mg/L) at the Lake Billy Chinook forebay sites and Deschutes River below the Reregulation Dam. (Note: 0.000 = Below Minimum Recording Limit)

	East		Middle		West		River below Rereg Tailrace
	Surface	Bottom	Surface	Bottom	Surface	Bottom	
6/16/15	0.030	0.090	0.000	0.050	0.000	0.090	0.590
7/14/15	0.110	0.070	0.000	0.080	0.000	0.110	0.070
8/5/15	0.000	0.080	0.000	0.050	0.000	0.080	0.100
8/31/15	0.050	0.070	0.000	0.070	0.000	0.080	0.080
9/28/15	0.000	0.070	0.000	0.060	0.050	0.030	0.080
10/29/15	0.000	0.060	0.000	0.050	0.000	0.050	0.030

Table 13. Surface and bottom concentration of Total-P (mg/L) at the Lake Billy Chinook forebay sites and Deschutes River below the Reregulation Dam. (Note: 0.000 = Below Minimum Recording Limit)

	East		Middle		West		River Below Rereg Tailrace
	Surface	Bottom	Surface	Bottom	Surface	Bottom	
6/16/15	0.059	0.203	0.059	0.289	0.078	0.132	0.071
7/14/15	0.000	0.066	0.000	0.189	0.000	0.085	0.083
8/5/15	0.000	0.076	0.000	0.334	0.000	0.350	0.088
8/31/15	0.000	0.091	0.079	0.084	0.051	0.445	0.106
9/28/15	0.000	0.118	0.000	0.094	0.000	0.065	0.989
10/29/15	0.000	0.072	0.000	0.058	0.000	0.070	0.060

Table 14. Surface and bottom concentration of Chlorophyll-*a* (mg/L) at the Lake Billy Chinook forebay sites and Deschutes River below the Reregulation Dam. (Note: 0.000 = Below Minimum Recording Limit)

	East		Middle		West		River below Rereg Tailrace
	Surface	Bottom	Surface	Bottom	Surface	Bottom	
6/16/15	0.0559	0.0147	0.0998	0.0316	0.0383	0.0009	0.0079
7/14/15	0.0302	0.0020	0.0294	0.1100	0.0269	0.0000	0.0031
8/5/15	0.0282	0.0028	0.0374	0.0456	0.0374	0.1400	0.0050
8/31/15	0.0205	0.0048	0.0187	0.0020	0.0222	0.0452	0.0055
9/28/15	0.0173	0.0187	0.0120	0.0066	0.0182	0.0149	0.0333
10/29/15	0.0098	0.0067	0.0768	0.0016	0.0819	0.0019	0.0117

TKN and chlorophyll-a were much higher than on other dates (Tables 10 & 14, respectively). Late September is when large amounts of attached algae were dying and floating in the water column, which would result in higher TKN and chlorophyll-*a* concentrations in the water column.

Nutrient concentrations were also assessed at the mouths of the three tributaries entering LBC (Tables 15 - 19). Concentrations of NO2-NO3 show that the Metolius River had the lowest level (only one sample above the minimum recording limit), while the Crooked River mouth was measurably higher (0.43 to 0.55 mg/L). The sample site where the Deschutes River entered LBC showed concentrations between these two sites (Table 15). With the exception of three samples that were below the minimum detection limit, concentrations of TKN were similar between the three tributaries (Table 16). Phosphate concentrations for both ortho-P and total-P were also similar at all three tributaries (Tables 17 & 18, respectively). While there are no statewide water quality criteria for phosphorus, there is evidence that concentrations exceeding 25 *u*g/L (0.025 mg/L) can produce eutrophic conditions in lakes and streams (Anderson 2002). The water samples collected at the mouth of all three tributaries all had phosphorus levels that exceeded 25 *u*g/L (Table 18).

Table 15. NO2-NO3 concentrations (mg/L) at the mouths of the three tributaries entering Lake Billy Chinook. (Note: 0.00 = Below Minimum Recording Limit)

	Metolius Mouth	Deschutes Mouth	Crooked Mouth
7/21/15	0.00	0.28	0.43
8/10/15	0.17	0.21	0.43
9/22/15	0.00	0.24	0.45
11/4/15	0.00	0.17	0.55

Chlorophyll-a concentrations were quite low at all three sites (Table 19), indicating little suspended phytoplankton was present in the tributaries when they entered LBC. There were no seasonal changes observed for nutrients or chlorophyll-*a* at the tributary mouths over the period sampled.

Table 16. TKN concentrations (mg/L) at the mouths of the three tributaries entering Lake Billy Chinook. (Note: 0.00 = Below Minimum Recording Limit)

	Metolius Mouth	Deschutes Mouth	Crooked Mouth
7/21/15	0.000	0.234	0.252
8/10/15	0.214	0.205	0.205
9/22/15	0.280	0.280	0.304
11/4/15	0.000	0.000	0.211

Table 17. Orthophosphate concentrations (mg/L) at the mouths of the three tributaries entering Lake Billy Chinook.

	Metolius Mouth	Deschutes Mouth	Crooked Mouth
7/21/15	0.060	0.080	0.050
8/10/15	0.090	0.090	0.090
9/22/15	0.080	0.070	0.090
11/4/15	0.080	0.070	0.120

Table 18. Total phosphorus concentrations (mg/L) at the mouths of the three tributaries entering Lake Billy Chinook.

	Metolius Mouth	Deschutes Mouth	Crooked Mouth
7/21/15	0.078	0.076	0.085
8/10/15	0.073	0.076	0.083
9/22/15	0.091	0.082	0.089
11/4/15	0.077	0.077	0.079

Table 19. Chlorophyll-*a* concentrations (mg/L) at the mouths of the three tributaries entering Lake Billy Chinook. (Note: 0.00 = Below Minimum Recording Limit)

	Metolius Mouth	Deschutes Mouth	Crooked Mouth
7/21/15	0.0005	0.0008	0.0000
8/10/15	0.0000	0.0007	0.0000
9/22/15	0.0000	0.0008	0.0008
11/4/15	0.0010	0.0000	0.0004

Discussion

Water quality results from the 2015 DRA Lake Billy Chinook Water Quality Study confirm that there are important differences between surface and bottom water in Lake Billy Chinook as well as differences between the tributary streams. These differences can be summarized as follows:

1. Surface water at the LBC forebay was 7 to 11 degrees C (13 - 20 degrees F) warmer than bottom water in the forebay near the SWW tower from mid-June to late-August. All, or a large portion, of this water (depending on surface/bottom water blending) was being discharged downstream into the lower Deschutes River though the SWW during this time. The blend percentages of surface and bottom water used by PGE in 2105 had not been released at the time of this writing. As a result, it is not known when PGE began mixing surface and bottom water, and what the mixing percentages were.

2. By late September LBC surface water temperatures had cooled about 5 degrees C, but were still 3-5 degrees C warmer than bottom water. By late October surface and bottom water temperatures were similar to each other indicating that the thermocline was no longer present, and mixing of surface and bottom water could take place.

3. Surface water in LBC has sufficient nutrients to support large blooms of algae, including potentially toxic cyanobacteria or blue-green algae.

4. The large algal blooms produced extremely high pH levels in the surface water of LBC, with pH consistently above 9.0 throughout the summer and fall, with a peak measurement of 9.7 (Table 5). These values are well above the Oregon water quality standard of 8.5, and pH's above 9.5 can be lethal to fish.

5. Because water samples had to be collected in the morning to meet holding time requirements, the high pH numbers recorded in surface water were not the true daily maximum pH levels. Since photosynthesis peaks in mid-to-late afternoon, maximum pH levels are expected to occur at the same time. For example, the one surface sample that was collected in the late afternoon

(Crooked River Arm of LBC on June 23rd at 4:40pm) had a pH of 9.9, the highest recorded pH of the study.

6. Chlorophyll-*a* levels in the surface water at the forebay sites were consistently above the Oregon water quality criteria for nuisance phytoplankton growth of 0.015 mg/L (Table 14). Chlorophyll-*a* concentrations were already high in the middle of June and remained high throughout the sampling period (only two of 18 samples had chlorophyll-*a* levels below the State's criteria). Chlorophyll-*a* concentrations in the lower Deschutes River downstream of the reregulation dam tailrace were below State criteria in five of six samples (Table 14). River water column samples for chlorophyll-*a*, however, do not measure benthic algal biomass, which is the primary form of algal growth in streams and rivers (Bellinger & Sigee 2010).

7. Nutrient concentrations of available nitrogen (NO2-NO3) and phosphorus (Ortho-P) in the surface water of LBC were very low, often below the minimum recording limit (MRL) (Table 9). These low nutrient concentrations are thought to be the result of frequent large blooms of algae using all the available nutrients in the surface water.

8. Nutrient data collected at the mouth of the three tributaries entering LBC indicate that NO2-NO3 concentrations were very low (mostly below the MRL) at the mouth of the Metolius River, while the highest concentrations were at the mouth of the Crooked River (0.43-0.55 mg/L). Concentrations at the mouth of the Deschutes River ranged between 0.17 and 0.28 mg/L. These results are consistent with the findings in the DEQ Deschutes Basin Watershed Assessment study (DEQ 2011) that reported poor water quality in the Crooked and Deschutes rivers compared to excellent water quality in the Metolius River.

9. Concentrations of ortho phosphate (Ortho-P) measured at the mouth of the three tributaries entering LBC were similar to each other. This suggests that phosphate levels may be at or near natural background concentrations, while nitrogen levels in the Crooked and Deschutes rivers are elevated, likely the result of human activities upstream (fertilizer, manure runoff, urban runoff, etc.). It also suggests that controlling nitrogen inputs into the Crooked and

Deschutes watersheds will be necessary to control algal blooms in LBC, reinforcing the need for DEQ to complete the Total Maximum Daily Load (TMDL) process as the vehicle to create management plans for these pollutants.

10. Concentrations for both nitrogen and phosphorus in the lower Deschutes River at the site below the reregulation dam tailrace were consistently higher than surface water concentrations in LBC even during 100% surface water withdrawal. The reason for this is currently unknown, although it is possible that additional nutrients are entering Lake Simtustus and/or the Reregulation Dam reservoir. We have no data available to confirm this, however.

One of the implications of this study is that the poor surface water quality in LBC may be contributing to the low survival of smolts migrating through LBC as reported by PGE (Hill et al. 2014). Figures 5 & 6 show capture data for steelhead and spring Chinook juvenile migrants captured, tagged, and released

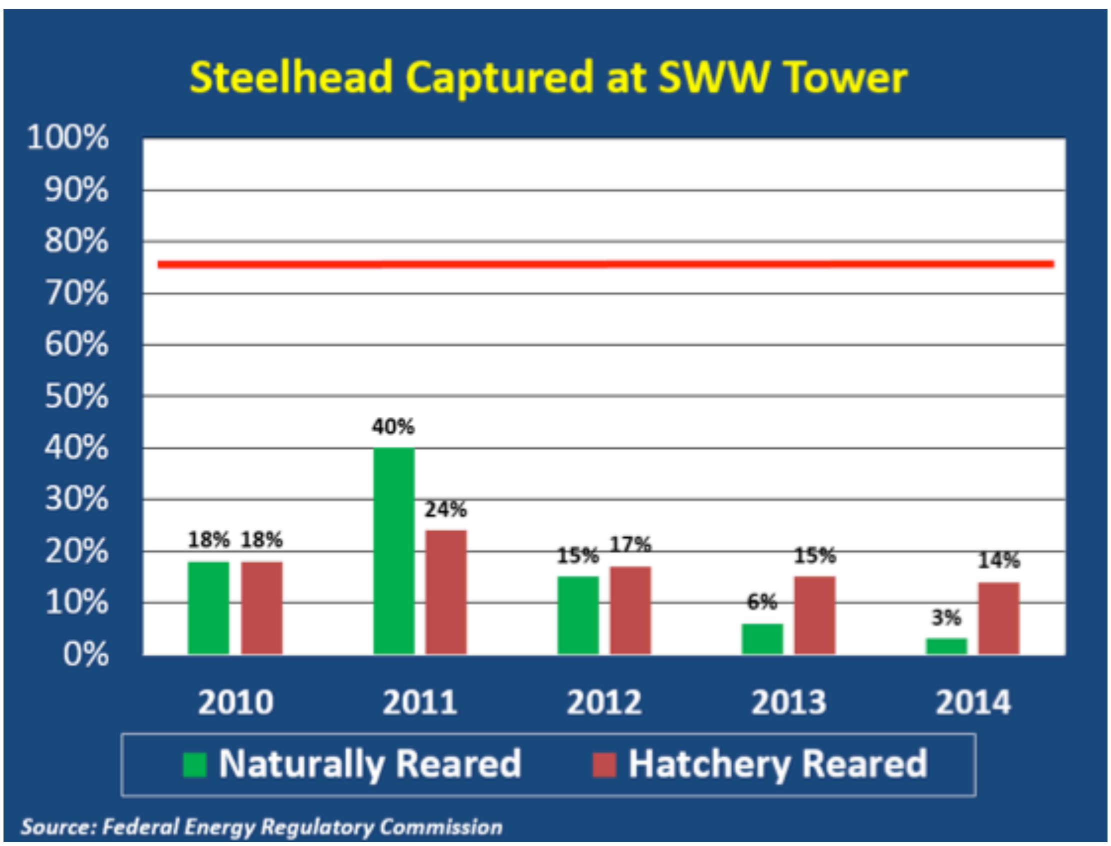

Figure 5. Steelhead survival rates of smolts traveling through Lake Billy Chinook reservoir and captured at the SWW trap facility. (From Hill et al. 2014)

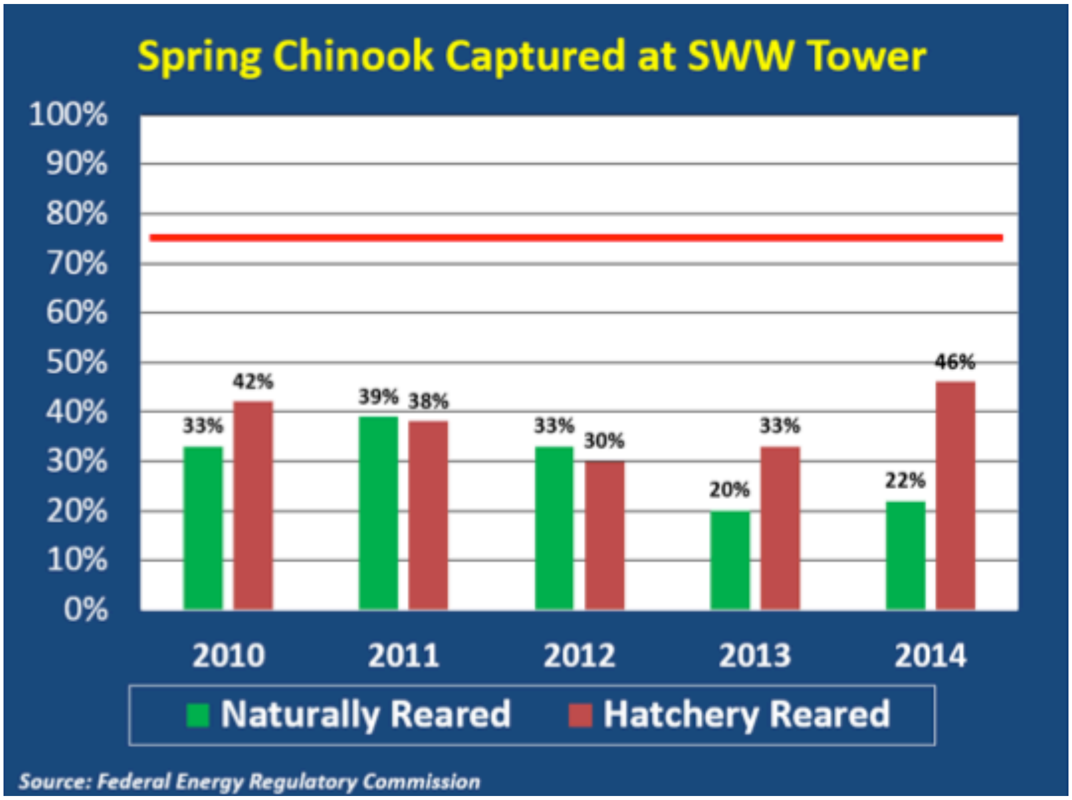

Figure 6. Spring Chinook survival rates of smolts traveling through Lake Billy Chinook reservoir and captured at the SWW trap facility. (From Hill et al. 2014)

at the mouths of the three tributaries and subsequently collected at the SWW trap after swimming through LBC. The red line in each graph represents the 75% survival objective for migrants through LBC identified in the federal operating license (FERC license, pages 146, 161). "Naturally reared" means the fish were released as fry in the upper Deschutes basin where they reared in the watershed before migrating downstream as smolts. "Hatchery reared" means the fry were raised in hatcheries where they were fin clipped and released as full term smolts in the tributaries to out-migrate.

Hatchery reared smolts survived passage through LBC better than naturally reared fish, but the survival of all steelhead and spring Chinook through the reservoir was low, and considerably below the 75% objective. For example, survival of naturally reared steelhead migrating through LBC in 2014 was extremely low, with only 3% of them being recaptured at the SWW trap (Figure 5). Hatchery reared steelhead smolts had a 14% survival rate in comparison. Spring Chinook smolts had survival rates through the reservoir of

22% and 46% in 2014 for naturally reared and hatchery reared smolts, respectively (Figure 6).

Poor surface water quality in LBC may be a key contributing factor to this low survival. For example, by mid-June surface water temperature approached 20 degree C, and pH levels were over 9.5. While conditions earlier in the spring migration period may have been less severe, surface water quality by mid-June was at or close to lethal conditions for salmonids for temperature and pH.

Data collection for this study began in late May. By mid-June prolific algal blooms were already present in the surface water of LBC, and surface water temperatures were close to their peak level. To fully understand how surface water quality in LBC impacts conditions in the reservoir and downstream in the lower Deschutes River it will be important to collect water samples from late winter through early summer. This is one of the primary objectives of DRA's water monitoring program in 2016.

References

Anderson, C. W. 2002. Ecological Effects on Streams from Forest Fertilization - Literature Review and Conceptual Framework for Future Study in Western Cascades. USGS Water-Resources Investigations Report 01-4047.

Bellinger, E. G. and D. C. Sigee. 2010. *Freshwater Algae: Identification and Use as Bioindicators*. Wiley-Blackwell, Hoboken, NJ.

Campbell, L. 2015. Pelton Round Butte Project (FERC No. 2030) 2014 Water Quality Monitoring Report. Portland General Electric.

Deschutes River Alliance. 2015. Deschutes River Alliance Water Quality Monitoring Plan for the Lower Deschutes River. Updated April 2015. http://images.wolfpk.com/deschutesriveralliance/pdf

Environmental Protection Agency (EPA). 1988. Water Quality Standards Criteria Summaries: A Compilation of State/Federal Criteria. EPA 440/5-88/013.

Hill, M. and C. Quesada. 2014. PGE Juvenile Migration Test and Verification Study Annual Reports (2010-2014). To Federal Energy Regulatory Commission.

Hynes, H. B. N. 1972. The Ecology of Running Waters. University of Toronto Press. Waterloo, Ontario.

Johnson, D. M., R. P. Petersen, D. R. Lycan, J. W. Sweet, M. E. Neuhaus, A. L. Schaedel. 1985. *Atlas of Oregon Lakes*. Oregon State University Press, Corvallis, OR.

Oregon Department of Environmental Quality. 2011. Water Quality Status and Action Plan: Deschutes Basin. Updated Sept. 6, 2011, by Bonnie Lamb, 11-WQ-043.

Robertson-Bryan, Inc. 2004. PH Requirements of Freshwater Aquatic Life: Technical Memorandum. Elk Grove, CA.

Wall, D. 2013. Nitrogen in Waters: Forms and Concerns. Minnesota Pollution Control Agency.

Appendix A

Monitoring Site Locations:

Site ID #	Site Name	Latitude	Longitude
1	Mouth of Metolius River @ LK. Billy Chinook	N44 36.731	W 121 27.563
2	Mouth of Deschutes R. @ Lk. Billy Chinook	N44 30.401	W121 18.622
3	Mouth of Crooked River @ Lk. Billy Chinook	N44 30.007	W121 17.166
4	Pelton Dam Forebay site #1 @ east bank	N44 35.95	W121 16.891
5	Pelton Dam Forebay site #2 @ Middle	N44 36.01	W121 16.899
6	Pelton Dam Forebay site #3 @ west bank	N44 36.099	W121 16.966
7	Tailrace site d/s of Re-Reg. Dam	N44 43.695	W121 14.683
8	Metolius Arm of Lake Billy Chinook	N44 36.498	W121 27.285
9	Deschutes Arm of Lake Billy Chinook	N44 31.522	W121 17.970
10	Crooked River Arm of Lake Billy Chinook	N44 31.725	W121 15.861