FINAL REPORT

2016 Evaluation of Intake Barrier Curtain in Iron Gate Reservoir to Improve Water Quality in the Klamath River

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Executive Summary

One element of improving water quality in the Klamath River downstream of Iron Gate dam involves managing cyanobacteria/blue-green algae (BGA) transported to the river from Iron Gate reservoir. Use of an intake barrier curtain is one strategy PacifiCorp is employing to limit BGA releases from Iron Gate reservoir into the Klamath River. Seasonal BGA blooms in Iron Gate reservoir typically occur near-surface waters of the photic zone where light and nutrients are available. The penstock intake for Iron Gate powerhouse has an invert elevation that is approximately 10.7 meters (m) [35 feet(ft)] below normal water surface elevation. The intake tower is open from the reservoir bottom at that depth to the surface of the reservoir. Thus, the intake tower entrains water from the full depth of the water column at the location of the intake and withdraws water from the photic zone which can result in releases of BGA to the Klamath River downstream.

The purpose of the curtain is to improve the quality of near-surface waters in the reservoir downstream of the curtain that are then released into the Klamath River downstream of Iron Gate dam. This is accomplished by utilizing the density differences associated with seasonal temperature stratification in the reservoir which provides an opportunity to use an intake barrier curtain to isolate warmer, less dense near-surface waters that contain most of the BGA, while withdrawing cooler, denser, and deeper waters from the reservoir for release to the Klamath River downstream. The near-surface waters with higher levels of BGA in the reservoir are restricted from being released to the Klamath River from Iron Gate reservoir.

The effectiveness of a curtain is dependent on the presence of stratified conditions in the reservoir that allow a curtain to isolate warmer, less dense surface waters. Hence, the 2016 assessment of curtain effectiveness began with characterizing the physical attributes of stratification, mixing, and the localized flow changes caused from deploying a barrier curtain in Iron Gate reservoir that was first installed in 2015. The dimensionless Wedderburn and Richardson numbers were used to assess the strength of stratification and the effects of wind mixing and increased local velocities associated with curtain placement (e.g., higher velocities under the curtain than would occur without the curtain).

Based on 2015 field studies, 2016 field studies were designed and conducted to assess a set of hypotheses regarding the efficacy of the curtain in reducing BGA downstream. Specifically, the 2016 field study focused on testing three hypotheses:

- The curtain isolates warm surface waters upstream of the curtain and minimizes mixing with cooler deeper waters, effectively segregating shallower and deeper waters.
- Shallow and deep water downstream of the curtain are similar to deep-water conditions upstream of the curtain because of withdrawal from beneath the curtain and mixing downstream of the curtain in the relatively shallow region immediately upstream of the intake tower.
- Conditions downstream of Iron Gate dam are similar to those downstream of the curtain, with the exception of dissolved oxygen, which increases as waters are re-aerated through the Iron Gate powerhouse.

2016 field experiment results supported these three hypotheses. Overall, the 2016 field studies indicated that the curtain is an effective water quality management tool that isolates near-surface waters in Iron Gate reservoir and reduces the entrainment in the intake and downstream release into the Klamath River of elevated BGA concentrations in the near-surface waters of the reservoir. As a secondary benefit, the curtain also functions as a simple selective withdrawal device that isolates warmer surface waters and preferentially draws deeper cooler waters for release to the Klamath River. This selective withdrawal ability can allow for some manipulation of reservoir release temperatures, which may be beneficial for managing fish disease because disease levels can be exacerbated by higher water temperatures.

Introduction

1.1 Background

The Klamath Hydroelectric Settlement Agreement (KHSA) includes Interim Measure (IM) 11 (Interim Water Quality Improvements), which is intended to address water quality improvement in the Klamath River during the interim period leading up to potential dam removal. Activity 5 of PacifiCorp's 2015 IM 11 Study Plan is "Continued Evaluation of Intake Barrier Systems for Water Quality Improvement from Iron Gate Powerhouse Releases." The purpose of Activity 5 was to evaluate the intake barrier curtain (henceforth referred to as "curtain") in Iron Gate reservoir to improve the quality of water that the Iron Gate powerhouse releases to the Klamath River.

Seasonal thermal stratification occurs in Iron Gate reservoir, commencing in spring and persisting well into the fall months (Figure 1-1). Thermal stratification occurs during spring and summer because thermal loading increases as day length and solar altitude increase, leading to warmer, less dense water overlying cooler, denser water. This unequal distribution of water temperature results in seasonal stratification that is defined by three zones of different densities:

- Epilimnion: the upper, warmest layer of a stratified lake
- Metalimnion (thermocline): the middle layer of a stratified lake that represents the transition between the warmer surface layer (epilimnion) and the colder bottom layer (hypolimnion)
- Hypolimnion: the bottom, coldest, and most dense layer of a stratified lake

During winter, lakes are often isothermal, with equal temperatures from top to bottom. Iron Gate reservoir exhibits this annual cycle of isothermal winter conditions, the onset and persistence of thermal stratification through summer, and the breakdown of stratification in the fall leading to winter isothermal conditions once again.

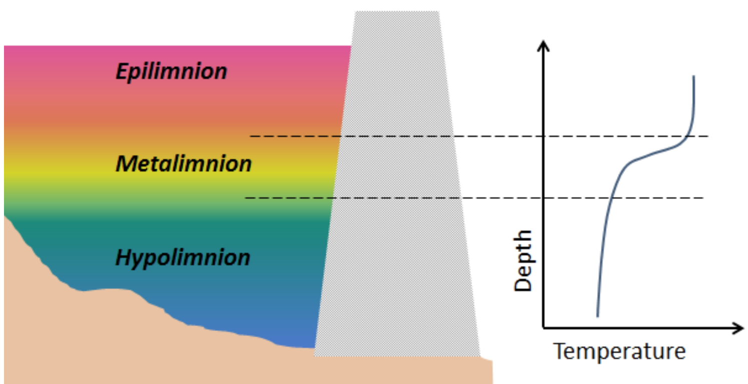

Figure 1-1. Conceptual Schematic of Reservoir Stratification Showing the Different Layers of Water Density

The temperature stratification in summer months coincides with a period of relatively high cyanobacteria abundance that results in water quality impairment in the reservoir. Blooms of cyanobacteria, commonly referred to as blue-green algae (BGA), are a water quality concern because the cyanobacteria *Microcystis aeruginosa* (simply *Microcystis* hereafter) can produces the toxin microcystin. Microcystin, a hepatotoxin (liver toxin), can lead to health advisories if microcystin levels exceed public health standards (SWRCB 2016).

Blooms of BGA in Iron Gate reservoir are usually concentrated in surface waters where favorable light conditions in the photic zone promote their growth. Previous studies at Copco and Iron Gate reservoirs have demonstrated that *Microcystis* is more prevalent in near-surface waters than at depth (Figure 1-2; Moisander 2008). The Iron Gate powerhouse intake is a vertically-oriented opening that is about 10.7 m deep and is open from the reservoir bed to the water surface. Waters over this full depth are entrained into the powerhouse intake. Thus, waters from the photic zone that may contain BGA are entrained into the powerhouse intake and released to the Klamath River.

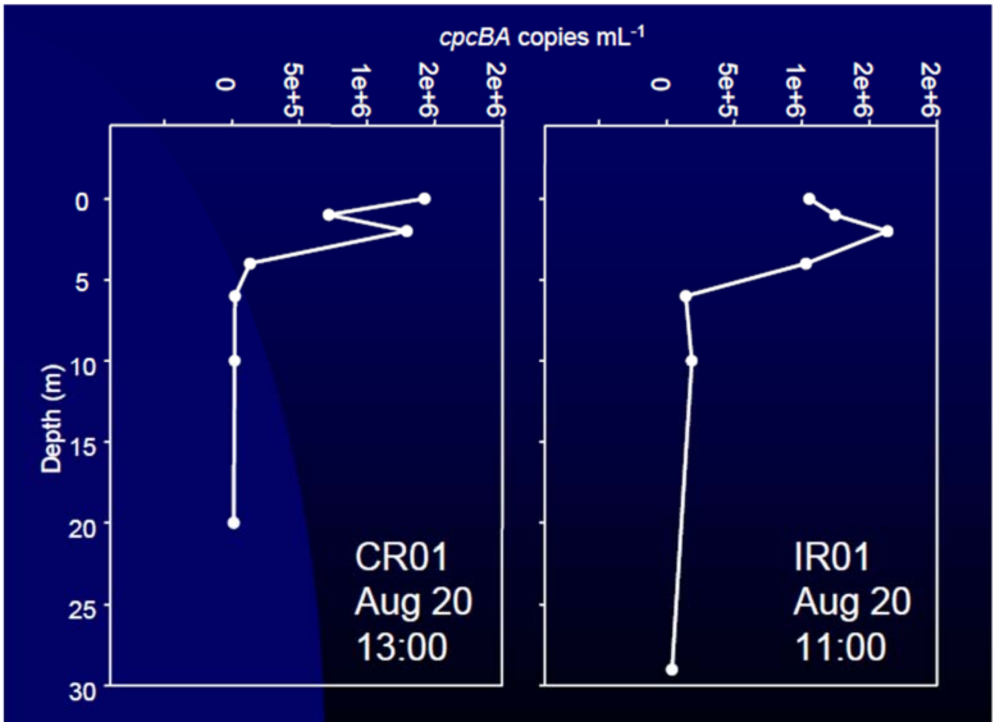

Figure 1-2. *Microcystis aeruginosa* Vertical Distribution in August 2008. (Source: Moisander 2008.)

Installation of a barrier curtain is a management strategy to improve water quality of reservoir releases by restricting entrainment into the powerhouse intake of near-surface waters from the photic zone. Density differences associated with temperature stratification provide an opportunity to use such a curtain to isolate warmer, less dense near-surface waters that contains most of the BGA, while withdrawing cooler, deeper water from the reservoir.

1.2 Previous Work

The 2016 curtain study described in this report builds on several previous studies that investigated different approaches to isolate near-surface waters of Iron Gate reservoir. In 2009, PacifiCorp installed a floating cover curtain across the entire approximate 335 m width of Iron Gate Reservoir at the log boom location, some 550 m upstream of the dam, to assess the potential efficacy of reducing algal entrainment (Deas and Miao 2010). This curtain extended to a depth of 3 m and was attached to the log boom. Velocity measurements taken with an Acoustic Doppler Current Profiler (ADCP) upstream and downstream from this curtain indicated that the curtain lacked sufficient depth and that waters, particularly under windy conditions, readily passed under the curtain. Overall, the 2009 study indicated that the curtain was of insufficient depth and its location was too distant from the intake tower to affect surface entrainment into the intake tower. However, these findings, including additional velocity measurements in the vicinity of the intake tower, led to the concept of installing a cover on the upper portion of the intake tower that could reduce the amount of surface water (with higher algal concentrations) drawn into the penstock intake.

In 2011, an intake cover was constructed and installed on the Iron Gate intake tower trash rack (see Appendix B in Watercourse 2013). Water quality conditions were characterized prior to and after the cover was deployed (i.e., lowered into place on the intake tower trash rack) by monitoring water quality parameters and taking ADCP velocity measurements. The ADCP measurements taken during the study period indicated an increase in velocity near the penstock intake depth, suggesting the withdrawal profile (or "envelope") was altered by placement of the cover. When the intake cover was lowered to the test depths, *Microcystis* cell counts were lower downstream compared to cell counts when the cover was not present.

Despite initial reductions in *Microcystis* concentrations downstream of Iron Gate dam, subsequent ADCP velocity measurements indicated that velocity profiles in the vicinity of the intake tower had not stabilized. Thus, the Intake Cover Study was repeated in 2012 (Watercourse 2013), with deployment periods of several days. Field observations identified high velocities near the bottom edge of the intake cover that developed over the course of a day or more, brought about by the reduced outlet area with the cover in place. The cover reduced the surface area of the intake by approximately 30 percent at the 3.7 m deployment depth. These increased velocities, over time, appear to have resulted in vertical mixing and entrainment of near-surface waters (and associated BGA). The 2012 study identified that a more effective barrier would require placement further away from the intake tower to prevent increased velocities. Also, a more effective barrier would need to extend deeper into the reservoir to accommodate vertical stratification and limit mixing generated by increased water velocities.

The next phase of the study, conducted in 2013 (Miao and Deas 2014), focused on performing a bathymetric survey of the reservoir in the vicinity of the dam to better understand the bottom contours and flow dynamics that occur in the reservoir around the curtain location. Data from a series of ADCP velocity transects generated comprehensive and detailed velocity profiles near the A-frame log structure at the intake tower and the log boom approximately 550 m upstream of the dam. In a separate study in 2013-14, a barrier curtain was placed in Iron Gate reservoir in Long Gulch to assess isolating the cove for seasonal algaecide application. At the end of the 2014 season (October), the curtain was redeployed near the intake tower as a proof-of-concept exercise. Lessons learned in both the installation of the curtain at Long Gulch cove and its redeployment near the dam facilitated the design of the intake barrier curtain that was deployed in 2015 and 2016.

In 2015, the existing intake barrier curtain was installed and tested (Watercourse 2016). The presence of the curtain resulted in the withdrawal of deeper waters from Iron Gate reservoir. Data from ADCP velocity measurements upstream of the curtain indicated that shallow, near-surface waters had little or no velocity, while deeper waters near the bottom of the curtain had notable velocities. Multiple transects upstream of the curtain indicated largely quiescent shallow waters and a well-defined horizontal flow zone or envelope at and below the curtain bottom. In addition to ADCP measurements, water quality samples, physical measurements, and field observations of conditions in the project area consistently identified that waters of the photic zone, where the majority of cyanobacteria occur, were largely isolated to the upstream side of the curtain. Waters that ultimately passed under the curtain were drawn from deeper, cooler depths in Iron Gate reservoir upstream of the curtain (Figure 1-3). The 2015 study indicated that the curtain was effective at isolating near-surface waters of Iron Gate reservoir upstream of the curtain (Watercourse 2016).

In summary, the design and testing of a barrier curtain to isolate reservoir surface waters and improve water quality in releases from Iron Gate dam to the Klamath River is the culmination of several years of conceptual analyses, field data collection, and physical experiments.

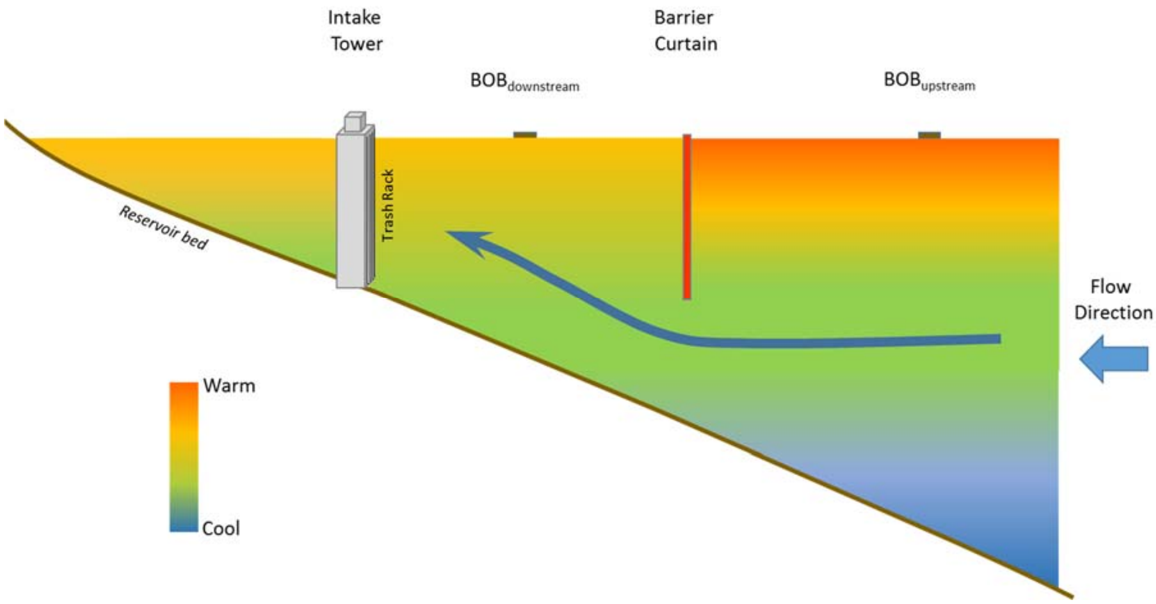

Figure 1-3. Conceptual Profile View of Thermal Conditions in Iron Gate Reservoir Showing the Location of the Basic Observation Buoys (BOBs), Curtain, and Intake Tower

2016 Study Approach

Even though the 2015 studies indicated that the curtain worked as intended, additional data collection and evaluation were desired to better evaluate effectiveness and test the hypotheses. The 2016 study plan (PacifiCorp 2016) reflected refinements in monitoring equipment, sampling frequency, and the type of sampling. The 2016 study features an approach based on testing experimental hypotheses developed from evaluating the accumulated knowledge of the system after several years of investigations.

As discussed above, the effectiveness of the curtain benefits from stratified reservoir conditions, allowing the curtain to isolate warmer, less dense surface waters upstream (those waters that contain higher concentrations of BGA) and reduce BGA concentrations released to the Klamath River downstream of the dam. Considering the physical attributes of stratification and curtain placement, the 2016 field studies were conducted during curtain deployment to test three experimental hypotheses:

- The curtain isolates upstream surface waters, segregating shallow and deep waters.
- Shallow and deep waters downstream of the curtain are similar to deep-water conditions upstream of the curtain because of withdrawal from beneath the curtain and mixing downstream of the curtain in the relatively shallow waters in the vicinity of the intake tower.
- Conditions downstream of Iron Gate dam are similar to those downstream of the curtain, with the exception of dissolved oxygen, which is increased as the water is re-aerated as it passes through the Iron Gate powerhouse.

One of the keys to overall effectiveness of the curtain is the strength of reservoir stratification. Therefore, before discussing these hypotheses in detail, the physical attributes of Iron Gate reservoir seasonal stratification and mixing are discussed. Specifically, does the reservoir stratify sufficiently to resist mixing under the curtain caused by wind or increased local velocities induced by placement of the curtain?

2.1 Stratification and Mixing Processes

Seasonal stratification and the effects of mixing associated with wind blowing across water are well-documented (Kalff 2002; Horne and Goldman 1994; Thornton et al. 1990; Fischer et al. 1979). Mixing processes of interest with respect to the curtain deployment center around the ability to reliably isolate surface waters upstream of the curtain and retain BGA in Iron Gate reservoir. Wind mixing potential was examined as part of the 2015 barrier curtain assessment. This assessment indicated that only under frequent, persistent, high winds would waters from the near-surface photic zone potentially mix to a level deeper than the bottom of the curtain. The following discussion extends the 2015 work and assesses wind as well as local water velocities at the bottom of the curtain as potential wind mixing mechanisms.

The concern is that persistent winds at sufficient velocity could mix the epilimnion to a depth where near-surface waters from upstream of the curtain could potentially be drawn under the curtain. Barrier curtain depth and local reservoir morphology play a key role in the velocity regime near the curtain. Because the curtain reduces the cross-sectional area of the reservoir, higher velocities near the curtain opening (between the bottom edge of the curtain and reservoir bed) could lead to vertical mixing (e.g., similar to the Iron Gate intake tower cover experiment completed in 2011 and 2012). Similar to mixing associated with wind, if the barrier curtain placement produces sufficiently high velocities, near-surface waters from upstream of the curtain can be drawn under the curtain. However, if reservoir stratification is adequate to resist mixing associated with surface winds or water velocities under the curtain, a curtain can be effective in segregating surface waters and affecting reservoir release water quality.

The effect of wind mixing or higher velocities brought about by the presence of the curtain on vertical mixing is assessed using the Wedderburn number, Richardson number (and associated thermocline tilt), and available field measurements.

2.1.1 Wedderburn Number

The Wedderburn number, W, is a dimensionless parameter that relates the stability of stratification (density) to mixing energy (wind velocity) (Kalff 2002; Horne and Goldman 1994; Fischer et al. 1979), and represents short-term mixing patterns in the epilimnion. Low values (W=0.01 to 1) indicate unstable conditions that translates to an isothermal or near isothermal state in the epilimnion, whereas high values (W>1) indicate higher stability in the epilimnion that represents stratification. The Wedderburn number, W, is calculated as follows:

$$W = \frac{g'h^2}{u^2 L}$$

where

- g' = reduced gravitational acceleration due to the density difference across the epilimnion [meters per second squared (m/s^2)]
- h = depth of the mixed water layer (m)
- u = characteristic shear velocity [meters per second (m/s)]
- L = fetch represented by the reservoir open water length in the direction of the wind (m)

Characteristic shear velocity, u (m/s), is calculated as U $(\rho_A/\rho_w)^{0.5}$, where U is wind speed (m/s), ρ_A is density of air [kilograms per cubic meter (kg/m^3)], and ρ_w is density of water (kg/m^3) (Fischer et al. 1979). Reduced gravitational acceleration, g', is a function of density differences between the top and bottom layers of the epilimnion. These differences were determined from thermal profiles in Iron Gate reservoir collected at the reservoir log boom as part of the KHSA monitoring program (Figure 2-1).

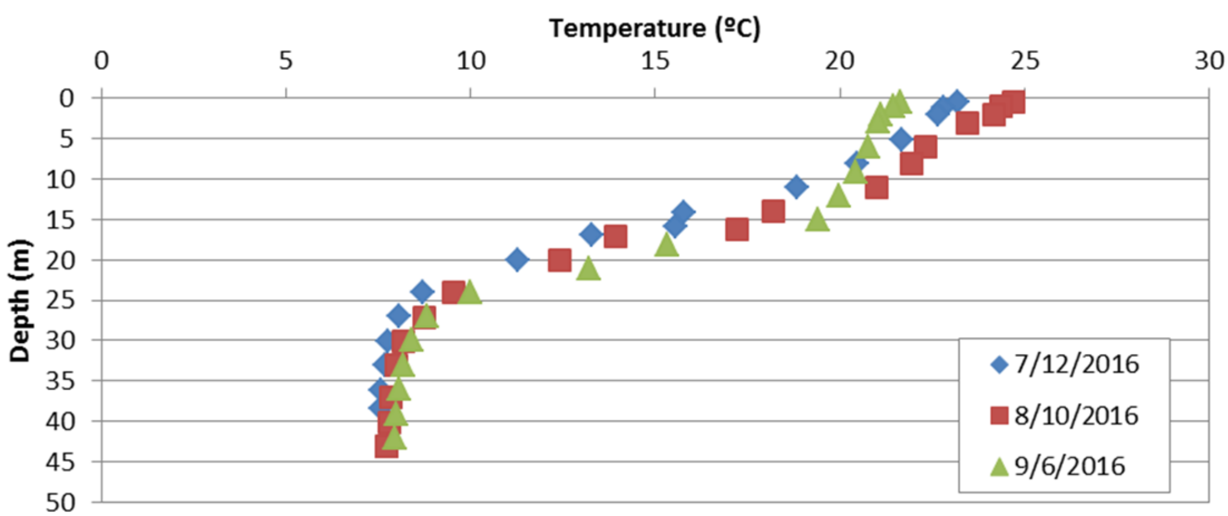

Figure 2-1. 2016 Temperature Profile Data at Iron Gate Reservoir Log Boom in Summer of 2016

2016 STUDY APPROACH

The fetch length for Iron Gate reservoir was estimated to be approximately 2,200 m, extending from near the dam upstream along the main axis of the reservoir. Three wind speeds were tested: seasonal average (representing the curtain deployment period), maximum 7-day running average for the study period, and instantaneous maximum. The seasonal average wind speed (1.7 m/s) was similar to the maximum 7-day average (2.6 m/s), while the maximum instantaneous wind speed was approximately an order of magnitude larger (15.3 m/s) (see Section 4.7).

The Wedderburn number for all three wind speeds during the 2016 curtain deployment period at Iron Gate reservoir were calculated for July through October (Table 2-1). With one exception, the range of calculated Wedderburn numbers for average and maximum wind speeds for the three identified epilimnion depths is notably greater than 1.0 in all cases (Table 2-1). These findings indicate that in summer months, when the lake is stratified, the epilimnion is typically not well mixed (i.e., is stable). Wedderburn number calculations over a range of wind speeds representing various conditions throughout the curtain deployment period indicate the following:

1. Typical wind conditions would not mix surface layers, and associated near-surface BGA, through the full depth of the epilimnion (W>1.0).
2. Vertical mixing does not extend to full depth of the epilimnion (approximately 11 to 21 m) except late in the season (October 26) under the maximum instantaneous wind speed observed), when the Wedderburn number was 0.7.

Because lake mixing processes associated with wind do not respond instantly to wind, but rather take a period of time to set up (e.g., several hours to days), instantaneous wind speed is not representative. The maximum of 7-day average wind speeds is assumed to be representative for this discussion. Wedderburn numbers for the maximum of 7-day average wind speed are all well over 1.0. Vertical profiles in Iron Gate reservoir at the log boom (Figure 2-1) of near-surface (0-15 m) water temperatures demonstrate the presence of stratified conditions in all cases. These profiles and the high Wedderburn number (much greater than 1.0) not only indicate that the epilimnion is stratified, but also that deep mixing (complete mixing to the thermocline) is not likely to occur at these wind speeds (2.6 m/s).

Because the curtain forms a barrier in the upper portion of the epilimnion, wind mixing of the epilimnion is predicted to have minimal effects on curtain performance. In other words, wind mixing will not result in systematic entrainment of epilimnion waters under the curtain and algae-concentrated water in the epilimnion layer should be largely retained in the reservoir.

Table 2-1. Summary of Range of Wedderburn Numbers for Iron Gate Reservoir during Curtain Deployment in 2016 (based on seasonal average, maximum 7-day average, and maximum instantaneous wind speed at the Iron Gate reservoir meteorological station).

Day		Wind Speed m/s	Epilimnion Depth m	Wedderburn Number -
7/12	Seasonal Average (6/14 to 11/16)	1.7	11.1	160.4
8/10			11.0	149.3
9/6			15.0	149.6
10/5			21.0	213.4
10/26			21.0	90.1
7/12	Maximum of 7-day Average (10/12 to 10/18)	2.6	11.1	68.6
8/10			11.0	63.8
9/6			15.0	63.9
10/5			21.0	91.2
10/26			21.0	38.5
7/12	Maximum (10/24 7:00 AM)	15.3	11.1	1.3
8/10			11.0	1.2
9/6			15.0	1.2
10/5			21.0	1.8
10/26			21.0	0.7

2.1.2 Richardson Number/Thermocline Tilt

Wind can also affect the thermocline depth in a lake or reservoir. Persistent wind on a lake surface imparts a shear stress to the water, resulting in lateral transport of water to the downwind end of the lake. The result is a "tilt" or displacement of the thermocline to accommodate the accumulation of warmer, less dense water in the downwind lake region (see Fischer et al. 1979 for details). Under extreme conditions of extended, high wind events, the thermocline can be displaced several meters. If the thermocline is offset sufficiently, water from the epilimnion could be entrained under the curtain, which could affect water quality downstream of the curtain. Thermocline tilt (Δh) was calculated using the following equation (Fischer et al. 1979):

$$\Delta h = \frac{L}{2R^*}$$

Where R^* is the Richardson number,

$$R^* = \frac{g''k^2}{u^2}$$

g'' = reduced gravitational acceleration caused by the density difference across the base of the thermocline which is a function of water density difference between the epilimnion and the hypolimnion (m/s^2)

k = depth of thermocline (m)

u = characteristic shear velocity, based on wind speed (m/s)

L = fetch (basin length in the direction of the wind) (m)

Note that gravitational acceleration, g'', used for calculating the Richardson number is not the same as the gravitational acceleration value, g', used for calculating the Wedderburn number. Richardson number values are relative, with larger values indicating minimal thermocline displacement and lower numbers suggesting more displacement.

The estimated thermocline tilt was calculated for the same three dates in 2016 (7/12, 8/10, and 9/6) under the same wind loadings as were used for the calculation of Wedderburn numbers (Table 2-2).

Table 2-2. Summary of Richardson Number and Thermocline Tilt for Iron Gate Reservoir during Curtain Deployment Period in 2016.

Day		Wind Speed	Thermocline Depth	Richardson Number	Thermocline Tilt
		m/s	m	-	m
7/12	Seasonal Average (6/14 to 11/16)	1.7	11.1	81,084	0.01
8/10			11.0	94,170	0.01
9/6			15.0	92,436	0.01
10/5			21.0	78,807	0.01
10/26			21.0	37,739	0.03
7/12	Maximum of 7-day Average (10/12 to 10/18)	2.6	11.1	34,665	0.03
8/10			11.0	40,259	0.03
9/6			15.0	39,518	0.03
10/5			21.0	33,691	0.03
10/26			21.0	16,134	0.07
7/12	Maximum (10/24 7:00 AM)	15.3	11.1	667	1.6
8/10			11.0	775	1.4
9/6			15.0	761	1.4
10/5			21.0	649	1.7
10/26			21.0	311	3.5

The estimated thermocline tilt under seasonal average conditions (1.7 m/s wind speed) did not exceed 0.01 m (Table 2-2). Under conditions represented by the maximum of the 7 day average wind speed (2.6 m/s), thermocline tilt was calculated to be at most 0.07 m when the thermocline was already 20 m deep. The worst-case scenario was a predicted thermocline tilt of 3.5 m, under conditions with a peak wind gust of 15.3 m/s and thermocline depth of 21 m. There are three main conclusions from this assessment:

1. Richardson number values and associated thermocline tilt for the period in question are insufficient to cause destratification of the lake because the displacement is far less than the depth of the thermocline. For destratification to occur, the thermocline tilt would have to approach the thermocline depth.
2. Sustained winds of 15.3 m/s are not likely to occur. Nonetheless, the Richardson number and the corresponding thermocline tilt calculations indicate that stratified conditions would remain throughout the summer months even under these extreme conditions.
3. Assuming the maximum of 7-day average of daily wind speed is representative, thermocline tilt is minimal.

Overall, thermocline tilt is not expected to detrimentally impact curtain performance at Iron Gate reservoir under planned operations.

2.1.3 Expected Range of Horizontal Water Velocities

Wedderburn number and Richardson number/thermocline tilt calculations are quantitative indicators of potential mixing resulting from wind events. Higher water velocities can also be created by the presence of obstructions in the water, such as a barrier curtain, that affect flow patterns. While the Wedderburn and Richardson numbers were not developed to assess barrier curtain effects, these relationships can be used as a proxy to provide insight into the range of velocities that could disrupt stratification. For example, if the calculations identify a certain velocity induced by a wind event that would disrupt the reservoir stratification, that same value can be used to estimate critical water velocity that would lead to excessive mixing (in this case due to the presence of a curtain). This approach provides a means of using wind-mixing calculations to evaluate if the presence of the curtain could bring about higher water velocities that would mix the reservoir from the bottom edge of the curtain upwards towards the surface. Instead of quantifying the energy required to mix warm water in near-surface waters downward (as with the Wedderburn number) through the epilimnion, the inverse is considered. In this case the question becomes what energy is required to mix cold, denser, deeper water upwards into warm, less dense shallower water?

Wedderburn values were calculated based on August 2016 vertical temperature profile data, which were deemed to be typical of Iron Gate reservoir on a summer day. A variety of wind speeds ranging from 1.0 to over 26 m/s were used to calculate the Wedderburn number. The corresponding maximum horizontal water velocities were also calculated (Table 2-3).

The maximum horizontal velocity is assumed to occur when the thermocline has achieved its maximum tilt, and is calculated using the following equation:

$$\text{Maximum Horizontal Water Velocity} = \frac{u^2\,T}{2h}$$

where

- u = characteristic shear velocity, based on wind speed (m/s)
- T = time for an internal wave to travel the length of the reservoir (s)
- h = depth of the mixed water layer (m)

Note that T is calculated by dividing the reservoir fetch (L) by the speed of an internal wave at density discontinuity ($\sqrt{h\,g'}$) (Fischer et al. 1979).

Table 2-3. Summary of Calculated Maximum Horizontal Water Velocity and Wedderburn Numbers

Wind Speed (m/s)	Max. Water Velocity (m/s)	Wedderburn Number	Complete Epilimnion Mixing?
1.0	0.000	1030.8	No
5.0	0.003	41.2	No
10.0	0.013	8.2	No
15.0	0.035	3.1	No
20.0	0.063	1.7	No
25.0	0.098	1.1	No
26.3	0.108	1.0	Yes

Based on these calculations, complete mixing of the epilimnion occurs when wind speeds of over about 25 m/s are sustained for 2-3 days, which would in turn generate maximum horizontal velocities of approximately 0.1 m/s in the water. These wind speeds correspond to a Wedderburn number close to 1.0, and this is the point when complete vertical mixing occurs.

Using this water velocity (0.1 m/s) as a critical value, ADCP field measurements in the vicinity of the curtain from 2015 were reviewed. None of the velocities measured with the ADCP exceeded 0.07 m/s, with the majority being notably lower. The highest velocities were found near the curtain bottom where a flow envelope developed (Figure 2-2).

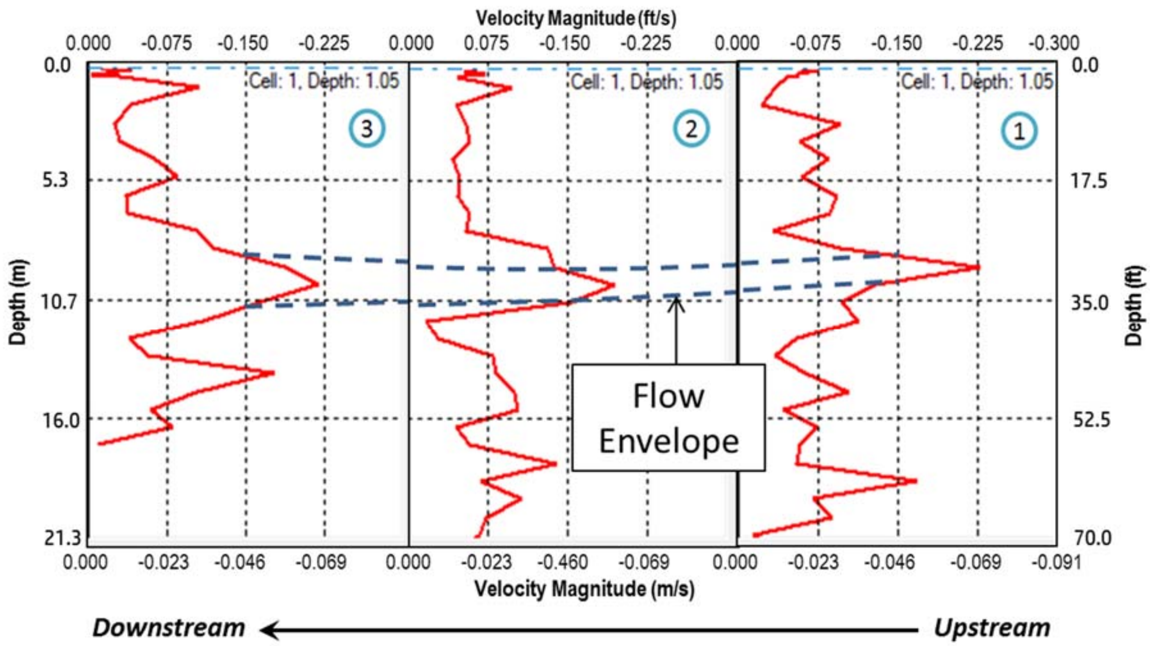

Figure 2-2. Velocity Profiles at Transect Locations 1, 2, and 3 from the Center of the Three Transects Upstream of the Curtain in 2015.

(Note: A conceptual flow envelope has been superimposed on the figures for illustrative purposes.)

Based on the 2015 ADCP results, which are representative of the common range of velocities occurring in the reservoir at the bottom edge of the curtain, the presence of the curtain would not bring about velocities higher than 0.07 m/s, which is below the threshold that would cause de-stratification.

2.1.4 Stratification and Mixing Conclusion

Prior to analyzing 2016 field data, an evaluation was conducted to determine if wind across the reservoir and water velocities under the curtain could theoretically affect the stratified conditions in Iron Gate reservoir. Theoretical calculations based on physical parameters show that stratified conditions would persist through the summer months when the curtain is installed. This indicates that the curtain can take advantage of stratified reservoir conditions to withdraw water from below the epilimnion during seasonal BGA blooms, and thus improve water quality conditions downstream of the curtain and subsequently downstream of Iron Gate dam.

2.2 Hypotheses for 2016 Field Studies

Given that Iron Gate reservoir remains stratified throughout the curtain deployment period, field studies provided a means to assess the effects of curtain deployment on water quality. Hypotheses were developed to guide this field work. To assist in developing these hypotheses and focus field investigations, specific regions in the reservoir relative to the curtain and downstream of the dam were defined (Figure 2-3):

- Shallow waters upstream of curtain in the photic zone (Location: SU)
- Deep waters upstream of the curtain well below photic zone (Location: DU)
- Shallow waters downstream of the curtain in the photic zone (Location: SD)
- Deep waters downstream of the curtain well below photic zone (Location: DD)
- Klamath River below Iron Gate dam (Location: KRBI)

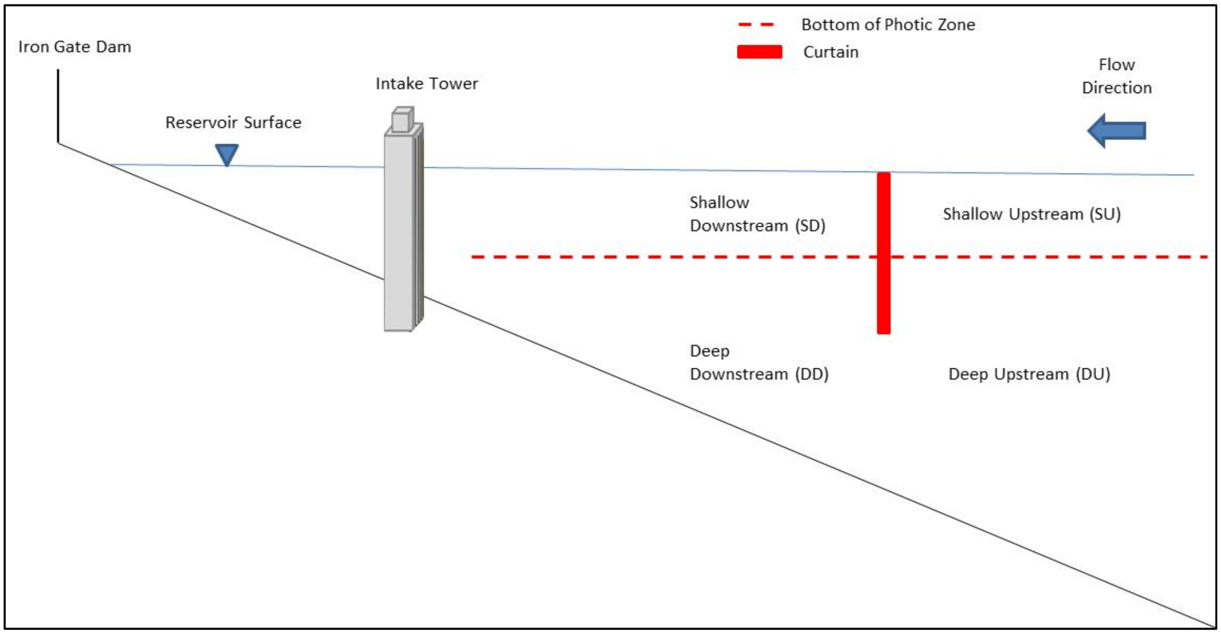

Figure 2-3. Schematic Layout of Different Depth Regions in Relation to the Curtain in Iron Gate Reservoir (Not to Scale).

These regions are referenced throughout this report. The three main hypotheses developed include:

1. The curtain isolates surface waters upstream of the curtain, segregating shallow and deep waters.
2. Shallow and deep waters downstream of the curtain are similar to deep-water conditions upstream of the curtain because of withdrawal from beneath the curtain and mixing downstream of the curtain in the relatively shallow waters in the vicinity of the intake tower.
3. Conditions downstream of Iron Gate dam are similar to those downstream of the curtain, with the exception of dissolved oxygen, which is increased as the water is re-aerated as it passes through the Iron Gate powerhouse.

If stratified conditions are in place and the curtain effective, these conditions would be observed. Each hypothesis is evaluated by analyzing data in respect to sub-hypotheses focusing on specific water quality conditions or field observations that should be observed as detailed below.

2.2.1 Hypothesis 1

The curtain isolates surface waters upstream of the curtain, segregating shallow and deep waters.

H1.1. Phycocyanin levels are higher at SU than at DU, SD, DD, or KRBI locations

H1.2. Microcystin levels are higher at SU than at DU, SD, DD, or KRBI locations

H1.3. Light extinction rates are greater at SU than SD indicating less water clarity and presumably more cyanobacteria at the SU location

H1.4. Cyanobacteria are more abundant and microcystin is present at higher concentrations in the SU zone than DU, SD, or DD

H1.5. The curtain is of sufficient depth to limit cyanobacteria from passing under the curtain during normal diel vertical movement

2.2.2 Hypothesis 2

Shallow and deep waters downstream of the curtain are similar to deep-water conditions upstream of the curtain because of withdrawal from beneath the curtain and mixing downstream of the curtain in the relatively shallow waters in the vicinity of the intake tower.

H2.1. Physical data (water temperature, dissolved oxygen, pH, phycocyanin) is comparable for DU and DD locations

H2.2. There is less stratification present downstream of the curtain at SD and DD than upstream at SU and DU

2.2.3 Hypothesis 3

Conditions downstream of Iron Gate dam are similar to those downstream of the curtain, with the exception of dissolved oxygen, which is increased as the water is re-aerated as it passes through the Iron Gate powerhouse.

H3.1. Physical data (water temperature, pH, phycocyanin) at KRBI is an integrated signal representing DU, SD, and DD, locations

H3.2. Microcystin levels are similar between DU, SD, DD, and KRBI locations

H3.3. Dissolved oxygen levels are higher at KRBI than DU or DD

To evaluate these three hypotheses, several data collection experiments and strategies were designed. The results follow this same structure and are discussed in Sections 4 and 5 below.

Methods

The 2016 field studies were designed to span the project area from upstream of the curtain (including some field data collected under the KHSA baseline sampling program at the Iron Gate reservoir log boom) to below Iron Gate dam (Figure 3-1). Outlined in this section is the curtain deployment schedule and the field data collection associated with the 2016 studies, including:

- Continuous Sampling with Data Sondes
- Thermograph Arrays
- Detailed Vertical Profiles
- Diel Autosampler Study
- Photosynthetically Available Radiation
- Heterogeneity Assessment
- Meteorological and Streamflow Data

Laboratories that conducted analysis of samples collected in the 2016 studies are briefly discussed to at the end of this section.

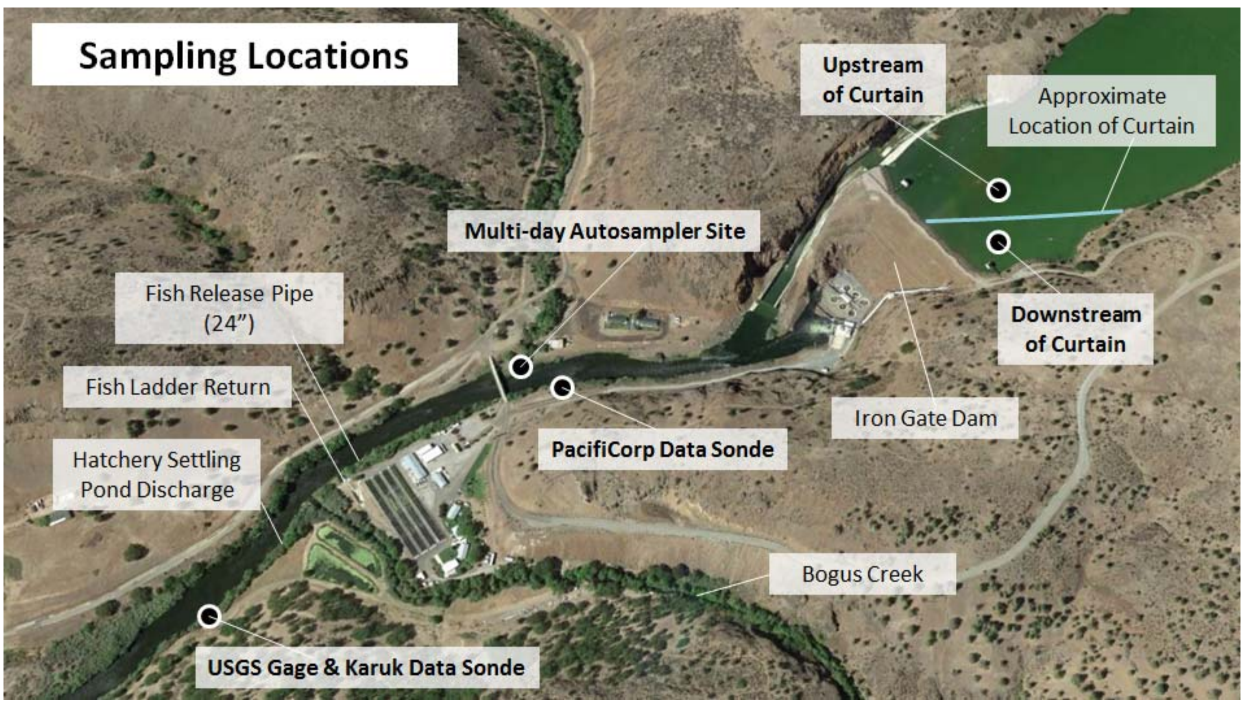

Figure 3-1. Map of Sampling Locations and Surrounding Landmarks

3.1 Curtain Deployment

The location of the curtain and Basic Observation Buoys (BOB)[1] remained the same as in 2016. The upstream and downstream BOBs remained in the same location as 2015 (Figure 3-1).

[1] The BOB is a floating platform that provided a support structure for data sondes and thermograph arrays.

Local PacifiCorp staff made adjustments to the curtain depth (lowering/raising) throughout the deployment season. Adjustments were typically done in 1.5 m increments to minimize loading stress on the curtain. The curtain was gradually lowered from late June through mid-July to its maximum depth of depth of 10.7 m. It remained at this depth until August 22 and 23 when it was raised to 7.6 and 6.1 m, respectively (Table 3-1). It remained at 6.1 m until September 29 when it was raised to 3.0 m. The curtain was fully furled on November 9.

Table 3-1. 2016 Deployment Dates and Depths in Meters (m) for the Intake Barrier Curtain in Iron Gate Reservoir.

Date	Depth (m)
June 28	4.6
June 30	7.6
July 12	9.1
July 19	10.7
August 22	7.6
August 23	6.1
September 29	3
November 9	1.5

3.2 Continuous Sampling with Data Sondes

Data sondes (YSI, EXO2™ units) collected data at three depths to characterize vertical conditions both upstream and downstream of the barrier curtain: near the surface, at the approximate extent of the photic zone, and in deeper waters (the region where water flows under the curtain). The existing data sonde in the Klamath River downstream of the dam was used to monitor conditions at that location.

In 2015, at each of the two platforms, a single data sonde was attached to a winch that moved the sonde through the water column at a regular interval. Challenges encountered with this method were most often caused by algae build-up and fouling on the winch, cable, or associated pulleys. To avoid this in 2016, three YSI EXO2 multiparameter data sondes were deployed on each side of the curtain. They were located at fixed depths (0.5 m, 5 m, and 10 m) to characterize water quality near the surface, mid-water column, and near the maximum depth of the curtain. Each sonde was equipped with probes to monitor temperature, dissolved oxygen, pH, phycocyanin,[2] chlorophyll-*a*, conductivity, and depth. Sondes were cleaned, calibrated, and accumulated data downloaded at regular intervals of every 4 to 6 weeks.

Data from the six data sondes was downloaded at each service interval, and the unit cleaned and calibrated. The first downloaded datasets formed the template to which subsequent datasets were added. Data collected during a service interval was removed from the dataset by initially reviewing the time and depth values and then immediately adjacent data. Occasionally outliers were identified in these datasets during data processing. These were instances where a single probe would spike and then return to pre-spike levels within the next two or three readings. These were flagged and removed from the dataset. Once reviewed, data from each sonde were compiled into a single file.

3.3 Thermograph Arrays

Installation of vertical strings of temperature loggers provided a continuous, detailed record of vertical water temperature profiles upstream and downstream of the curtain. This temperature data augmented data from the sondes, but at a more refined vertical spatial resolution. Detailed temperature profiles

[2] Phycocyanin is a pigment specific to cyanobacteria and the phycocyanin probe measures the fluorescence of phycocyanin in the water to provide a relative measure of cyanobacteria standing crop.

upstream and downstream of the curtain provided useful insight into thermal stratification and if a region was mixed or stratified.

A thermograph array was installed at each BOB that was comprised of 13 Onset U22-001 data loggers that recorded water temperatures every 15 minutes. The arrays remained in place until they were removed on November 16, 2016. Data loggers were attached to a weighted line at depths of: 0.1, 0.5, 1, 1.5, 2, 3, 4, 5, 6, 8, 10, 15, and 20 m. At the location downstream of the curtain, the bottom depth was approximately 15 m, so data from the 20 m unit was not used at this location.

A third thermograph array was installed on the Iron Gate log boom on June 8, 2016 and removed on December 6, 2016. Thermographs on this array were also Onset U22-001 models. They were attached to a cable at 0.5, 1, 1.5, 3, 6, 9, 12, 15, 21, 24, 27, and 30 m depths. These units recorded water temperatures at 30-minute intervals.

Once the data loggers had been removed, data was downloaded from each unit and all data from before installation and after retrieval was removed for each record. The final datasets were then combined into a single file for the upstream and downstream sides of the curtain and log boom sites. The data was then processed into daily average values by depth so that vertical profiles could be created. Weekly averages were calculated for each depth to create a series of vertical profiles throughout the summer and fall.

3.4 Detailed Vertical Profiles

Detailed vertical profiles were collected upstream and downstream of curtain within Iron Gate reservoir during selected site visits. The goal of this study element was to assess cyanobacteria and microcystin concentrations with depth. Microcystin concentrations and cyanobacteria species assemblages were compared to data from the Klamath River downstream of Iron Gate dam to determine whether the curtain effectively isolated the reservoir surface waters upstream of the curtain. Cyanobacteria assemblages were compared using genetic analysis (quantitative polymerase chain reaction, qPCR) for all samples. Genetic analysis allowed for a more rapid processing of samples and greater accuracy in identifying cyanobacteria species composition than traditional visual cell count methodology using microscopy.

During these profiles, samples were collected at both BOB locations upstream and downstream of the curtain at: 0.5, 1.5, 3, 6, 9, 12, and 15 m depths. The sampling depth of 0.5 m was selected to represent conditions in the top 1 m of water. When profiles were conducted, a corresponding water sample from the Klamath River downstream of Iron Gate dam was also collected from 0.5 m depth. Vertical profile and river samples were collected before deployment of the curtain (June 28, 2016) and after curtain deployment (August 29 and September 20, 2016).

Water samples were collected and analyzed for total and filtered microcystin (using enzyme-linked immunosorbent assay [ELISA]), total cyanobacteria, total *Microcystis* sp. (using qPCR), and chlorophyll-*a*. Total *Microcystis* indicates how many toxin-producing cells are present and not individual species because microcystin-producing genes are shared by several sub-species of *Microcystis*. These data also include estimates of total *Microcystis* and total toxic *Microcystis*. Other cyanobacteria species can be estimated by the difference between total cyanobacteria and total *Microcystis* sp.

Physical data were collected using a hand-held YSI 6600 data sonde at the time of water sample collection. Physical data collected included water temperature, dissolved oxygen, and pH. The sonde was calibrated before each sampling event. The accuracy of individual probes on the sonde that measured water temperature, dissolved oxygen, and pH data was ±0.15 degrees Celsius (°C), ±0.1 milligrams per liter (mg/L) or 1 percent whichever is greater, and ±0.2 units, respectively (based on the manufacturer specifications).

3.5 Diel Autosampler Study

Results from the 2015 diel autosampler study indicated that substantially less microcystin (an average of 68 percent less) was present in the Klamath River downstream of Iron Gate dam when compared to samples from upstream of the curtain. To confirm this result, a multiday diel autosampler study was performed from August 29 to September 1, 2016, a period when baseline and public health sampling indicated blooms of cyanobacteria were present. Autosamplers were deployed upstream of the curtain ("Upstream of Curtain" site in Figure 3-1) and downstream of Iron Gate dam ("Multiday Autosampler Site" in Figure 3-1). Both autosamplers were programmed to take coincident samples at 4-hour intervals from a depth of 0.5 m over a 72-hour period.

Water samples were analyzed for total microcystin (using ELISA), cyanobacteria species including total cyanobacteria and total *Microcystis* sp., and chlorophyll-*a*. Cyanobacteria were evaluated via qPCR by Bend Genetics. Chlorophyll-*a* samples were filtered onto 47-millimeter (mm) filter pads that were frozen and shipped to Chesapeake Bay Laboratory (CBL) for analysis.

The results from the laboratories were compiled for analysis. Statistical tests were performed on the different datasets to determine if upstream samples significantly differed from downstream samples in terms of cyanobacteria, microcystin, and chlorophyll-*a*.

3.6 Photosynthetically Available Radiation

Photosynthetically available radiation (PAR) is the amount of light available for photosynthesis which varies seasonally depending on the time of day and seasonal latitude. For this study, PAR measurements were used to calculate light extinction upstream and downstream of the curtain. A hand-held PAR sensor was used to collect detailed PAR at multiple depths at both BOB locations. Measurements were collected every 0.3 m from the surface, until the light intensity measured less than 1 percent of the reading at the surface of the reservoir. The PAR profiles were collected coincident with the vertical profiles on June 28, July 29, and September 20, 2016. Secchi depths were also measured at both locations at the same time as the PAR profiles as a semi-quantitative method for comparison with light extinction calculations.

For upstream and downstream locations, PAR data was plotted versus depth and an exponential curve fit to the data. The exponent in this relationship represented the light extinction coefficient. With the light extinction coefficient, the light extinction curve at each location was plotted and compared for upstream and downstream locations both before and after curtain deployment.

3.7 Heterogeneity Assessment

Vertical profiles were taken from the BOB locations upstream and downstream of the curtain. These two locations were assumed to be representative of the general conditions within their respective zones relative to the curtain. To confirm this, a series of physical data measurements (temperature, dissolved oxygen, pH) were taken at nearby locations upstream of the curtain at two depths (0.1 m and 1.0 m) each time vertical profile sampling was performed. For dissolved oxygen four points (H1, H2, H3 and H4) were selected at locations approximately upstream and downstream and laterally from the upstream platform (Figure 3-2). In addition, on August 29 and September 20, 2016, grab samples were collected at these selected locations and depths. These grab samples were analyzed for total and filtered microcystin (using ELISA) and cyanobacteria species: total cyanobacteria and total *Microcystis* sp. (using qPCR). The focus of this effort was to confirm that the zone upstream of the curtain was relatively homogenous and that data from the upstream BOB location was representative of overall conditions upstream of the curtain.

Data collected at the upstream BOB was similar to, and therefore representative of, data collected at other locations upstream of the curtain. On June 28, measurements of water temperature, dissolved oxygen, and pH were collected at each location. The sampling events in August and September included these parameters as well as samples for microcystin (total and filtered), total cyanobacteria, and total *Microcystis*.

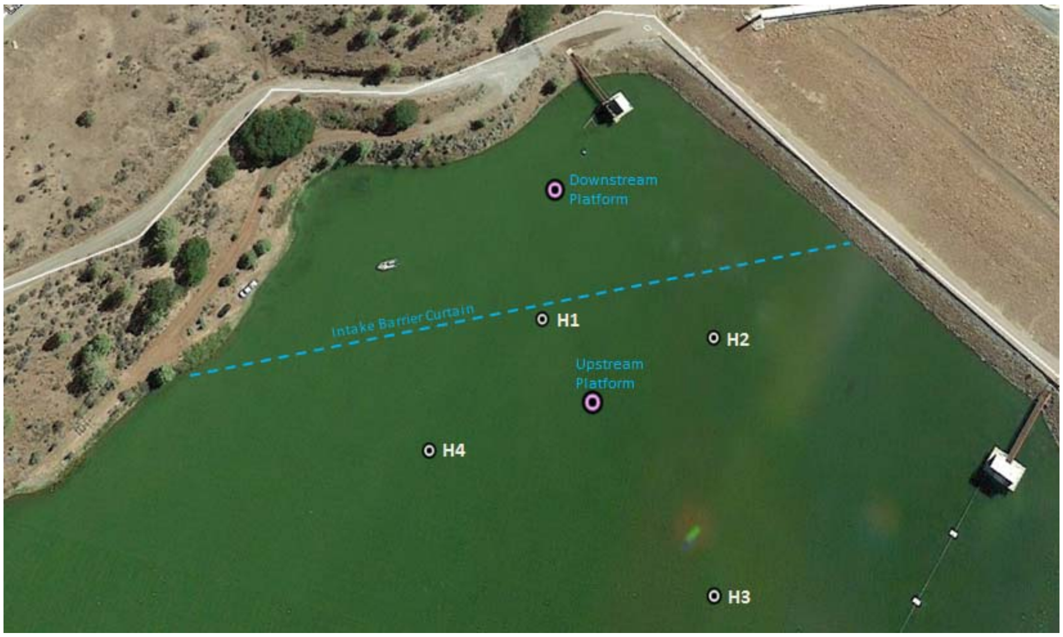

Figure 3-2. Heterogeneity Study Sampling Locations

3.8 Meteorological and Streamflow Data

Meteorological data were collected at PacifiCorp's meteorological station located at the Iron Gate dam intake tower. These include air temperature, barometric pressure, relative humidity, precipitation, solar radiation, and wind speed (peak gusts, instantaneous, and average). Reservoir stage throughout the study period was also recorded by PacifiCorp. Flow data from downstream of the Copco 2 powerhouse and downstream of Iron Gate dam were collected by PacifiCorp and U.S. Geological Survey (USGS, gage #11516530), respectively.

Review of the data from the meteorological station indicated that there were several instances where the station was off-line or where the system had automatically flagged data as being of 'bad quality'. There were also extended blocks of wind speed data reported as 999.8 or 999.9 miles per hour, denoting an invalid reading. These data were removed from the dataset before analysis.

3.9 Laboratories

Water samples collected from the different study elements described above were sent to either Bend Genetics or Chesapeake Bay Laboratory depending on the analysis desired.

3.9.1 Bend Genetics

Bend Genetics analyzed samples for total cyanobacteria and total *Microcystis* sp., using the qPCR method, which is a genetic analysis. Genetic analysis allows for rapid processing of samples and accurate identification of cyanobacteria species composition, as compared to the traditional visual cell count methodology. All qPCR results are presented in units of genes/mL and are not directly comparable to cell counts.

Bend Genetics also determined the concentration of total and filtered microcystin in grab samples using standard ELISA methods. This test followed standard U.S. Environmental Protection Agency (EPA) methodology EPA 546 and had a quantitation limit of 0.10 micrograms per liter (µg/L).

3.9.2 Chesapeake Biological Laboratory

Chesapeake Biological Laboratory conducted all analysis of chlorophyll-*a*. Water samples were filtered onto a 47 mm filter disk on the same day as sample collection, frozen, and shipped on ice to CBL for analysis. Laboratory analyses were done in accordance with EPA 445.0, SM10200H.3 with a method detection limit of 0.21 µg/L.

Results

Monitoring of curtain performance was successfully implemented from early June through early November 2016. This generated an array of data that is summarized below based on the method of collection. Analysis of this data in relation to the hypotheses is presented in Section 5.

On August 19, flows downstream of Iron Gate dam were increased to just over 2,000 cubic feet per second (cfs) for over 17 hours to support a tribal Boat Dance Ceremony downstream. These Boat Dance Flows gradually ramped down from the peak flow to about 950 cfs by August 26 (See Section 4.8). Water quality responses associated with this managed flow event are apparent in results from mid to late August.

4.1 Data Sondes

Data sondes were installed on June 15 and removed on November 16, 2016. They were serviced, cleaned, calibrated, and the data downloaded approximately every 4 to 6 weeks during the period of deployment. The downstream 10 m sonde was raised to approximately 5.4 m between October 7 and October 31 to ensure that the probe did not encounter the reservoir bottom during seasonal draw-down. All other sondes remained fixed at 0.5, 5, and 10 m throughout the installation period. Reservoir water surface elevation data during the 2016 study period can be found in Section 4.9.

4.1.1 Temperature

Water temperature at the 0.5 m depth upstream and downstream of the curtain were similar until the curtain was deployed on the June 27 and 28 (Figure 4-1). After curtain deployment, the 0.5 m downstream sonde showed substantial (approximately 4^{o}C) and rapid cooling in water temperatures while water temperatures at 0.5 m upstream of the curtain continued to increase. Water temperature at the 5 m depth upstream and downstream of the curtain were similar until the curtain was deployed. After curtain deployment, the 5 m downstream sonde showed modest (approximately 2^{o}C) and rapid cooling in water temperatures while water temperatures at 5 m upstream of the curtain continued to increase. Temperatures at the 5 m depth upstream of the curtain remained warmer than those at both the 0.5 and 5 m depth downstream of the curtain through late August, when temperatures at all depths began to converge. Water temperature data at 10 m was absent from June 28 to September 12 due to sonde failure; however, these data were available for this period from the 10 m depth on the thermograph array and are used in this analysis. Water temperatures at the 10 m depth were generally similar on both sides of the curtain throughout the entire period. There was a small decrease in water temperatures (less then 1^{o}C) when the curtain was lowered to 7.6 m, but differences were minimal after late August.

A slight warming of 0.5 and 5 m depths was observed at the downstream sondes in late August when the curtain was raised to 7.6 m and then 6.1 m (Figure 4-1). At this time, surface temperatures began to decrease notably (0.5 m). By early September, water temperatures at the 0.5 m downstream and the 5 m and 10 m upstream and downstream were within 2°C of each other.

Water temperatures in the Klamath River downstream of Iron Gate dam remained about the same as the upstream 5 m sonde until the curtain reached 7.6 m in depth (Figure 4-1). After curtain deployment, the upstream 5 m water temperatures steadily increased at a higher rate than the 5 m downstream water temperatures; the river temperature was slightly cooler than 5 m downstream of the curtain. After the curtain was deployed to 9.1 m, river temperatures remained cooler than even the 10 m sonde temperatures, until the curtain was raised to 6.1 m in late August. When the curtain was raised in August, slightly warmer (by about 1°C) water was released downstream of Iron Gate dam.

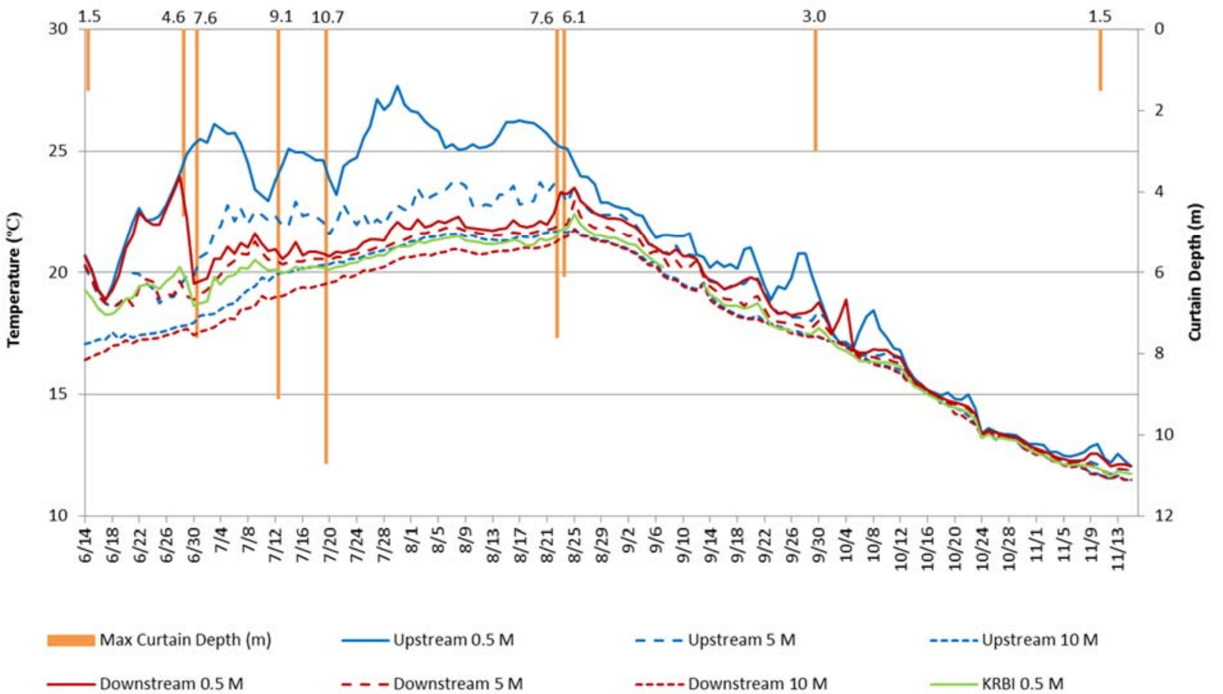

Figure 4-1. Daily Average Water Temperature (°C) and Curtain Depth (m) at Three Depths (0.5 m, 5 m, and 10 m) Upstream and Downstream of the Curtain and in the Klamath River below Iron Gate Dam (KRBI)

4.1.2 Dissolved Oxygen

Comparison of dissolved oxygen at different depths upstream and downstream of the curtain, as well as comparing these data to the Klamath River downstream, indicate the curtain depths through the summer had an effect on dissolved oxygen concentration.

Dissolved oxygen at 0.5 m depth illustrated the largest response to curtain deployment. In late June when the curtain was lowered to 7.6 m, concentrations at the 0.5 m depth diverge, with systematic differences of approximately 6 mg/L through mid-August (Figure 4-2). This separation persisted until August 19 when Boat Dance Flows were increased to just over 2,000 cfs for over 17 hours. Dissolved oxygen concentrations had been slowly declining, and PacifiCorp raised the curtain to 6.1 m on August 23 to access water with higher dissolved oxygen. Through the fall, the difference became less pronounced, though the upstream dissolved oxygen was still consistently higher until early- to mid-October (Figure 4-2 and 4-3). At 5 m depth, differences between upstream and downstream dissolved oxygen were likewise observed, but were not as pronounced as the near-surface dissolved oxygen differences. However, when the curtain was raised to 6.1 m in late-August, dissolved oxygen concentrations at this depth upstream of the curtain were higher, while downstream of the curtain concentrations remained the same. At 10 m depth, the downstream dissolved oxygen probe malfunctioned from late June to mid-September. The available data indicates that upstream and downstream dissolved oxygen levels were similar at 10 m in June. In September, at 10 m depth, the upstream dissolved oxygen was slightly higher than the downstream dissolved oxygen.

Downstream of Iron Gate dam, dissolved oxygen was not as high as the near-surface dissolved oxygen upstream of the curtain which is influenced by respiration effects, but it was for the most part higher or comparable to the dissolved oxygen levels downstream of the curtain. Dissolved oxygen concentrations in the river were typically higher than all other locations from late July to early October, except upstream of the curtain at 0.5 m, reflecting reaeration through the powerhouse (Figures 4-2 and 4-3).

RESULTS

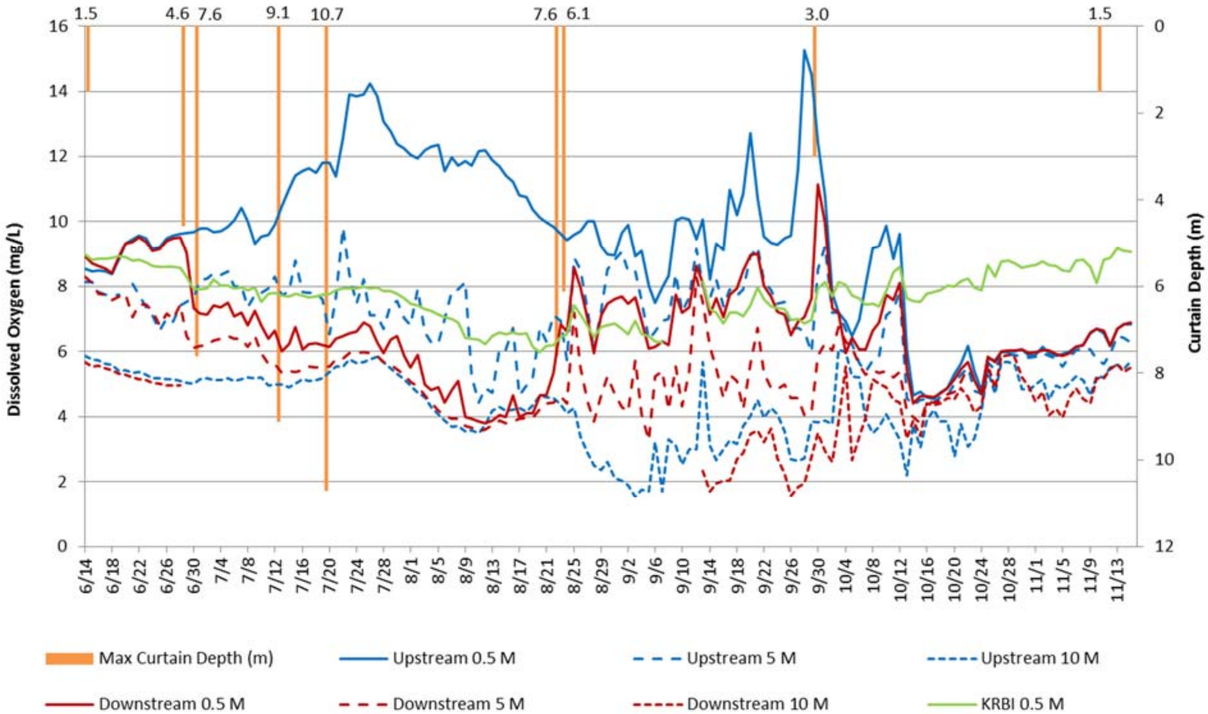

Figure 4-2. Daily Average Dissolved Oxygen (mg/L) and Curtain Depth (m) at Three Depths (0.5 m, 5 m, and 10 m) Upstream and Downstream of the Curtain and in the Klamath River below Iron Gate Dam (KRBI)

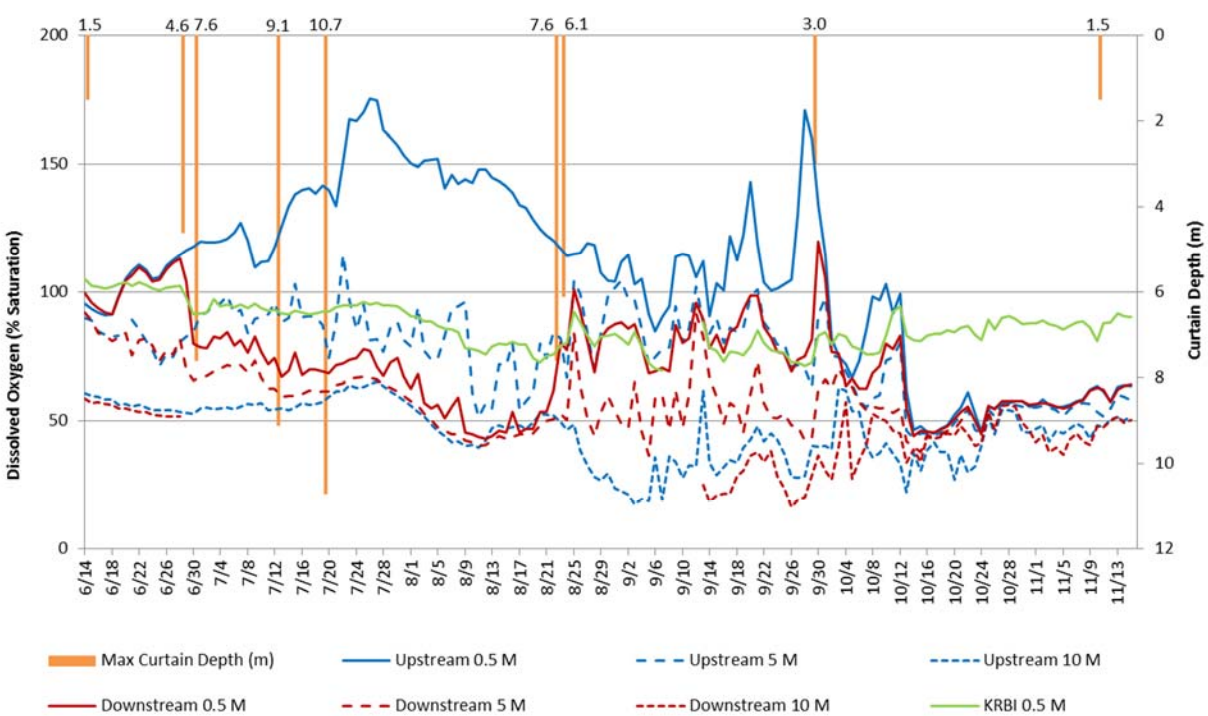

Figure 4-3. Daily Average Dissolved Oxygen Saturation (%) and Curtain Depth (m) at Three Depths (0.5 m, 5 m, and 10 m) Upstream and Downstream of the Curtain and in the Klamath River below Iron Gate Dam (KRBI)

4.1.3 pH

Curtain deployment in late June had the largest effect on pH levels at the 0.5 m and 5 m depths, and minimal effect at 10 m (Figure 4-4). Both upstream and downstream of the curtain, pH was higher closer to the surface. After curtain deployment in late June and persisting through late-August, downstream pH levels at 0.5 m depth were over 1.5 pH units lower than at the same depth upstream of the curtain. A similar deviation occurred at 5 m depth, but the decrease from upstream to downstream was less than 1.0 pH unit. Once the curtain was raised to 6.1 m in late August, the pH at 0.5 m depth downstream of the curtain increased notably. After late August, both upstream and downstream 5 m deep sites, pH increased by approximately 0.5 pH units. At 10 m depth, the downstream pH probe malfunctioned from late June to mid-September. Downstream of Iron Gate dam, pH levels tracked the reservoir pH at 5 m depth downstream of the curtain (Figure 4-4).

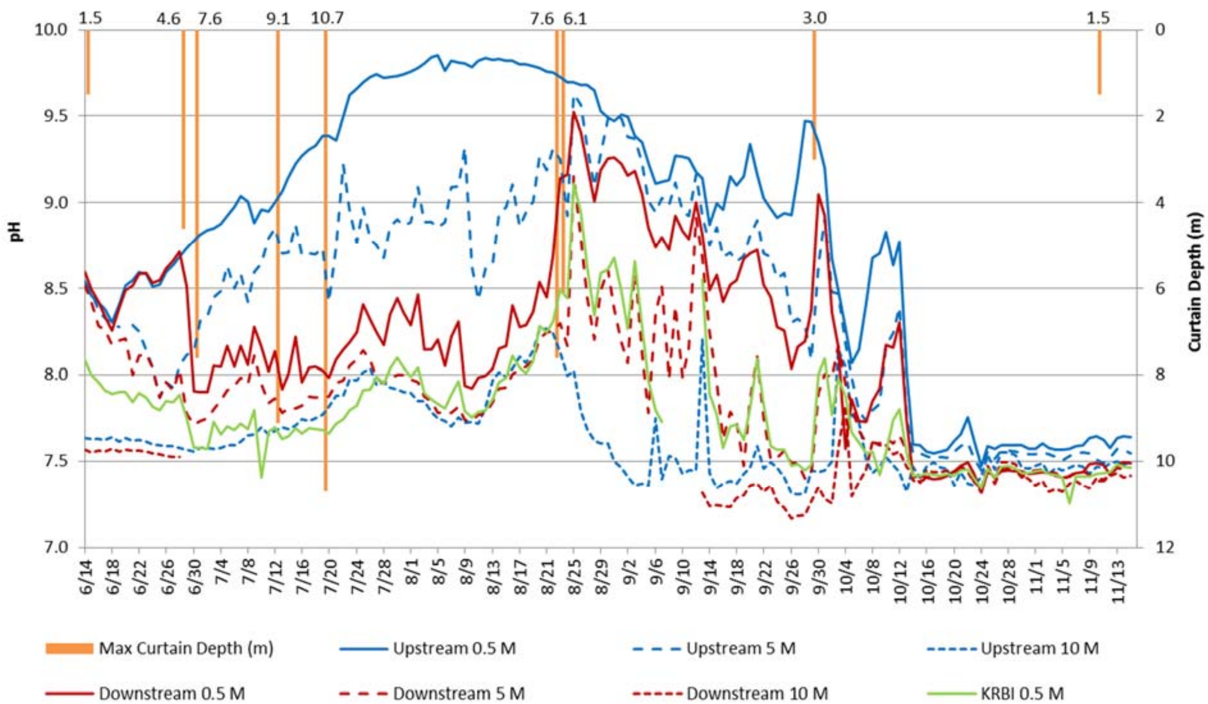

Figure 4-4. Daily Average pH and Curtain Depth (m) at Three Depths (0.5 m, 5 m, and 10 m) Upstream and Downstream of the Curtain and in the Klamath River below Iron Gate Dam (KRBI)

4.1.4 Chlorophyll-*a*

Chlorophyll-*a* levels at 0.5 m and 5 m depths downstream of the curtain were lower than the respective upstream sites (Figure 4-5). The 10 m deep sites were similar and illustrated the lowest concentration of all depths. Downstream of the curtain, there were higher levels of chlorophyll-*a* at 5 m depth at the start of the summer (June and July). In late July, the chlorophyll-*a* levels at 0.5 m depth increased rapidly to surpass concentrations at 5 m depth. There were two peaks in August, and the peaks approximately matched in timing on both sides of the curtain. In mid-September, the chlorophyll-*a* probe upstream of the curtain at 0.5 m depth indicated increasing concentrations, with the highest levels in November. While a fall-algae bloom is not uncommon, the extension of this bloom into November, with its cooler temperatures, is atypical. While bio-fouling of the chlorophyll-*a* probe on the sonde is a possible explanation for the high levels of chlorophyll-*a* in November, the increases in chlorophyll-*a* in November are consistent with concurrently collected KHSA data from the log boom (Figure 4-6). In the Klamath River downstream of Iron Gate dam, chlorophyll-*a* levels were highest in June, and remained relatively stable at a low level throughout the summer, then dropping off in early September along with the chlorophyll-*a* levels in the reservoir at all but the upstream surface location (Figure 4-5). From late July on, chlorophyll-*a* levels in the river downstream of Iron Gate were similar to the levels from 0.5 m deep downstream of the curtain but showed less variability.

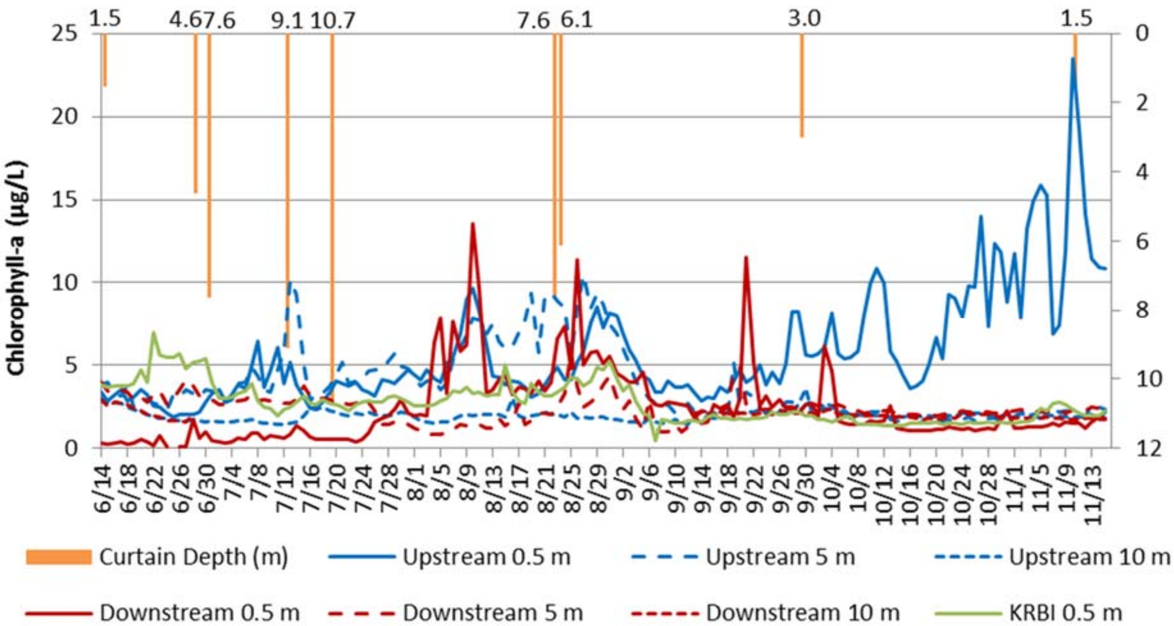

Figure 4-5. Daily Average chlorophyll-*a* at Three Depths on Upstream and Downstream Sides of the Curtain and in the Klamath River below Iron Gate dam (KRBI) and curtain depth (m)
(Note: instantaneous values that are above 60 µg/L were removed when calculating the daily average)

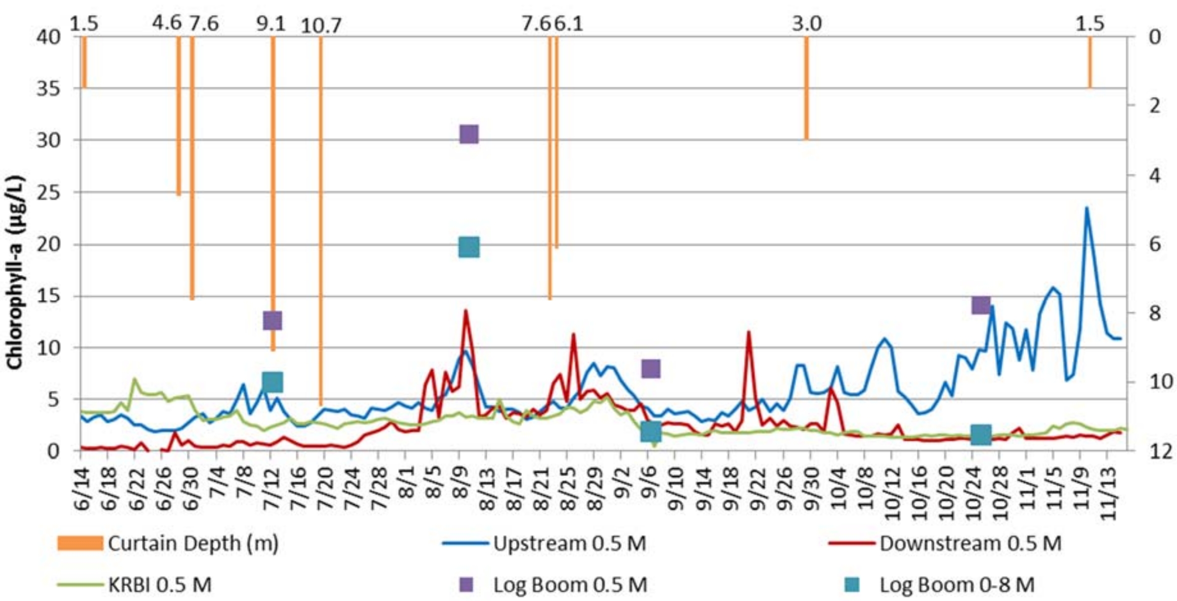

Figure 4-6. Daily Average chlorophyll-*a* and Curtain Depth (m) at 0.5 m Upstream and Downstream of the Curtain and in the Klamath River below Iron Gate Dam (KRBI) as Measured with Data Sondes and Chlorophyll-*a* Data from the KHSA Monthly Sampling Program.

4.1.5 BGA/Phycocyanin

In general, calibration issues and probe failures make the phycocyanin probe data set of limited use in 2016. The data set from both upstream and downstream of the curtain contained negative values and did not reflect BGA abundance (e.g., the October and November increase in chlorophyll-*a* just discussed was almost all *Aphanizomenon flos-aquae* but this did not manifest in the BGA data). Limitations of these data preclude its use in the analysis.

4.2 Thermographs

At the two BOBs, thermograph arrays recorded water temperatures every 15 minutes from the afternoon of May 26 to November 16, 2016. The downstream site was approximately 15 m deep, so data from 0.1 m to 15 m are used at this location. The 0.1 m thermograph on the upstream side of the curtain failed to record any data, but all other units functioned properly throughout the season. The log boom array collected data throughout installation period without any failed units.

4.2.1 Curtain Array

The curtain array included the thermograph strings at the upstream and downstream BOBs. To ensure data were consistent among the thermograph arrays and sondes, temperature data from the thermographs and data sondes at the same depth were compared and found to be consistent at 0.5, 5, and 10 m depths (Figures 4-7, 4-8, and 4-9).

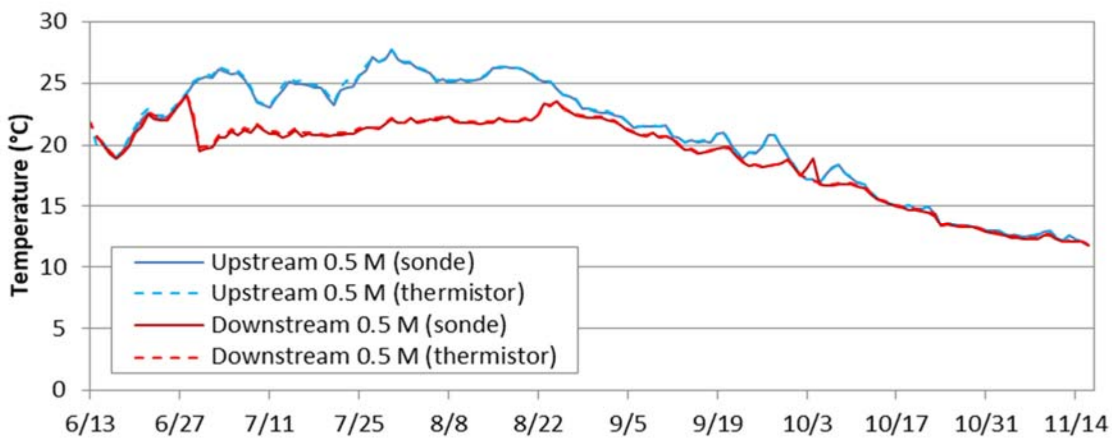

Figure 4-7. Sonde and Thermograph Array Temperature Data at 0.5 m Upstream and Downstream of the Curtain

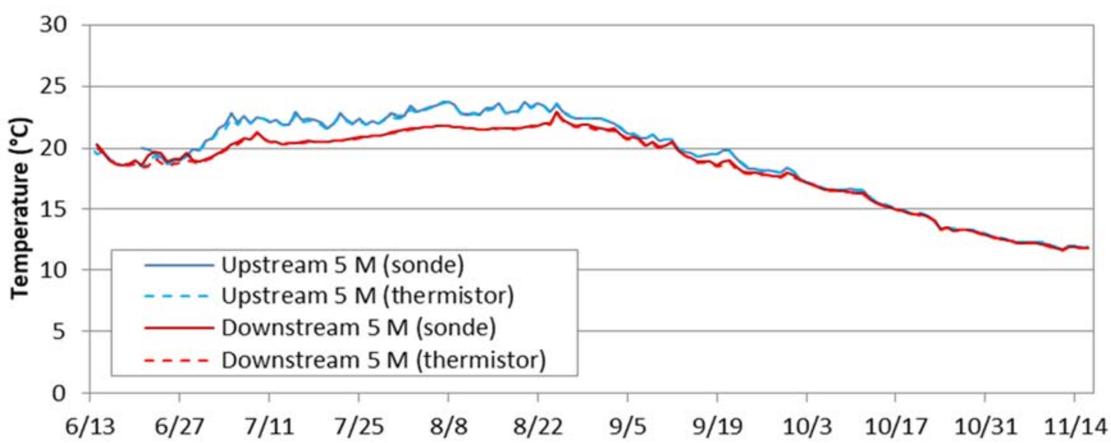

Figure 4-8. Sonde and Thermograph Array Temperature Data at 5 m Upstream and Downstream of the Curtain

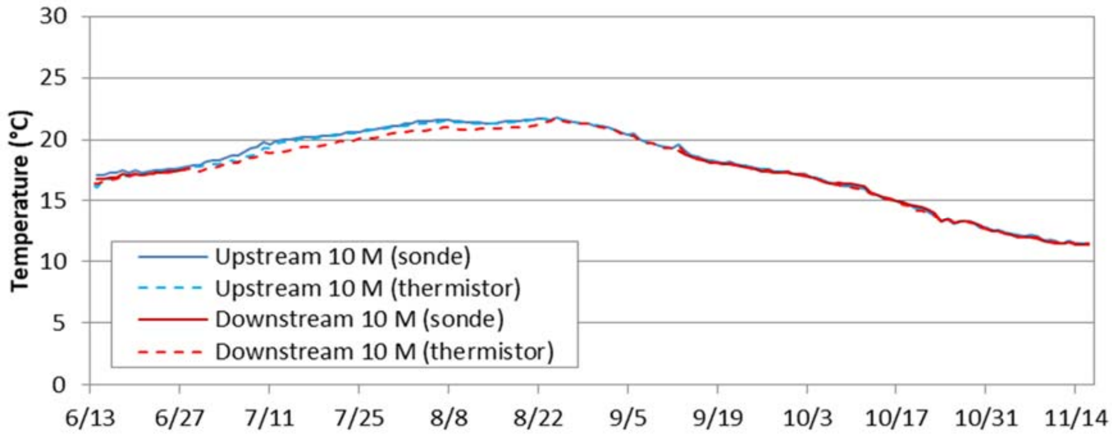

Figure 4-9. Sonde and Thermograph Array Temperature Data at 10 m Upstream and Downstream of the Curtain

Overall water temperatures at the two thermograph arrays at the curtain followed a similar seasonal pattern of rising in the early-summer months and gradually cooling off beginning in mid-August and continuing through the fall (Figures 4-7, 4-8, and 4-9). Temperatures at shallower depths reflected seasonal atmospheric conditions with higher variability and generally warmer temperatures (Figure 4-10). Deeper waters were notably cooler and displayed a more muted seasonal signal and longer response times, with maximum seasonal temperatures at the 15 m and 20 m depths lagging the shallower depths by several weeks. The top 20 m of Iron Gate reservoir were isothermal by early October (Figure 4-10). The temperature in the Klamath River below the dam (KRBI) is included for reference.

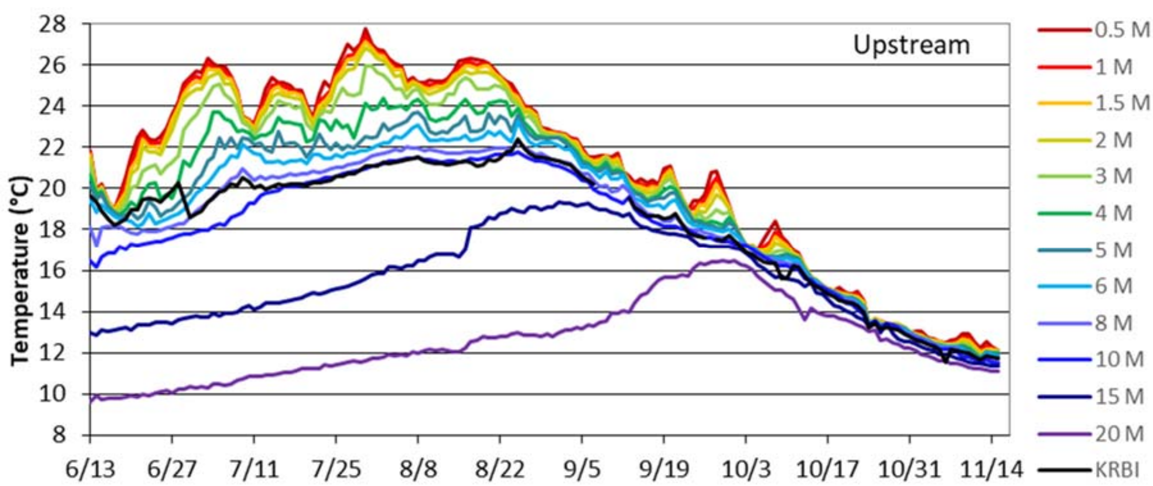

Figure 4-10. Daily Average Temperature in Iron Gate Reservoir Upstream of the Curtain at Various Depths from 6/14/2016 to 11/16/2016

Downstream of the curtain, water temperatures patterns prior to curtain deployment were similar to the upstream thermographs. Following curtain deployment to 7.6 m on June 28, there was a corresponding 4°C reduction in the near-surface water temperatures at this time. Overall, the thermograph array showed notable reduction in variability at all depths with the temperature signal generally tracking the upstream thermograph array from the 10 m depth (Figure 4-11). The temperature in the river downstream of Iron Gate dam followed a similar pattern as water temperatures in the reservoir.

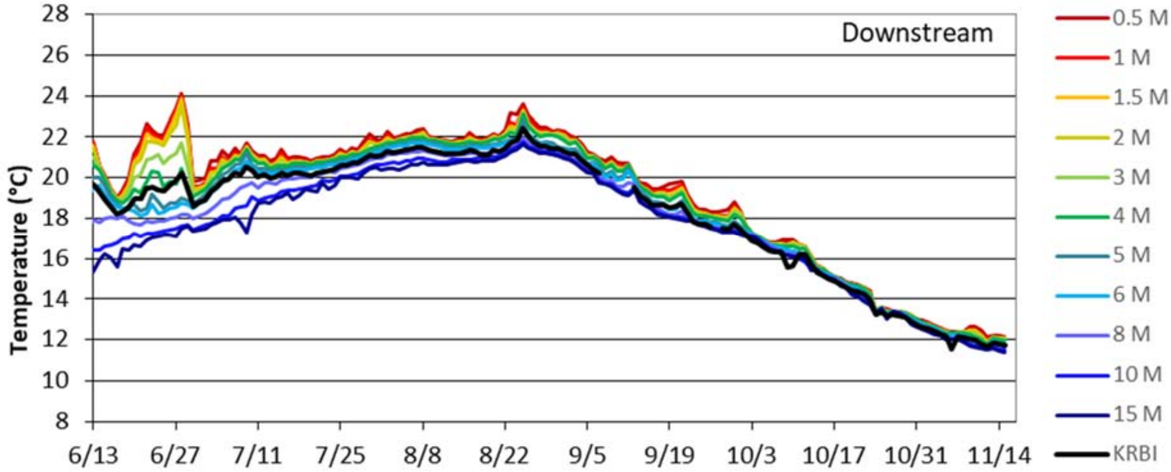

Figure 4-11. Daily Average Temperature in Iron Gate Reservoir Downstream of the Curtain at Various Depths from 6/14/2016 to 11/16/2016

Stratification was present in the June through September period, and diminished in October and November (Figure 4-12). Downstream of the curtain, notable stratification was present in June; however, following curtain deployment, the reservoir volume downstream of the curtain was weakly stratified in July and then nearly isothermal for the remainder of summer and fall (Figure 4-13).

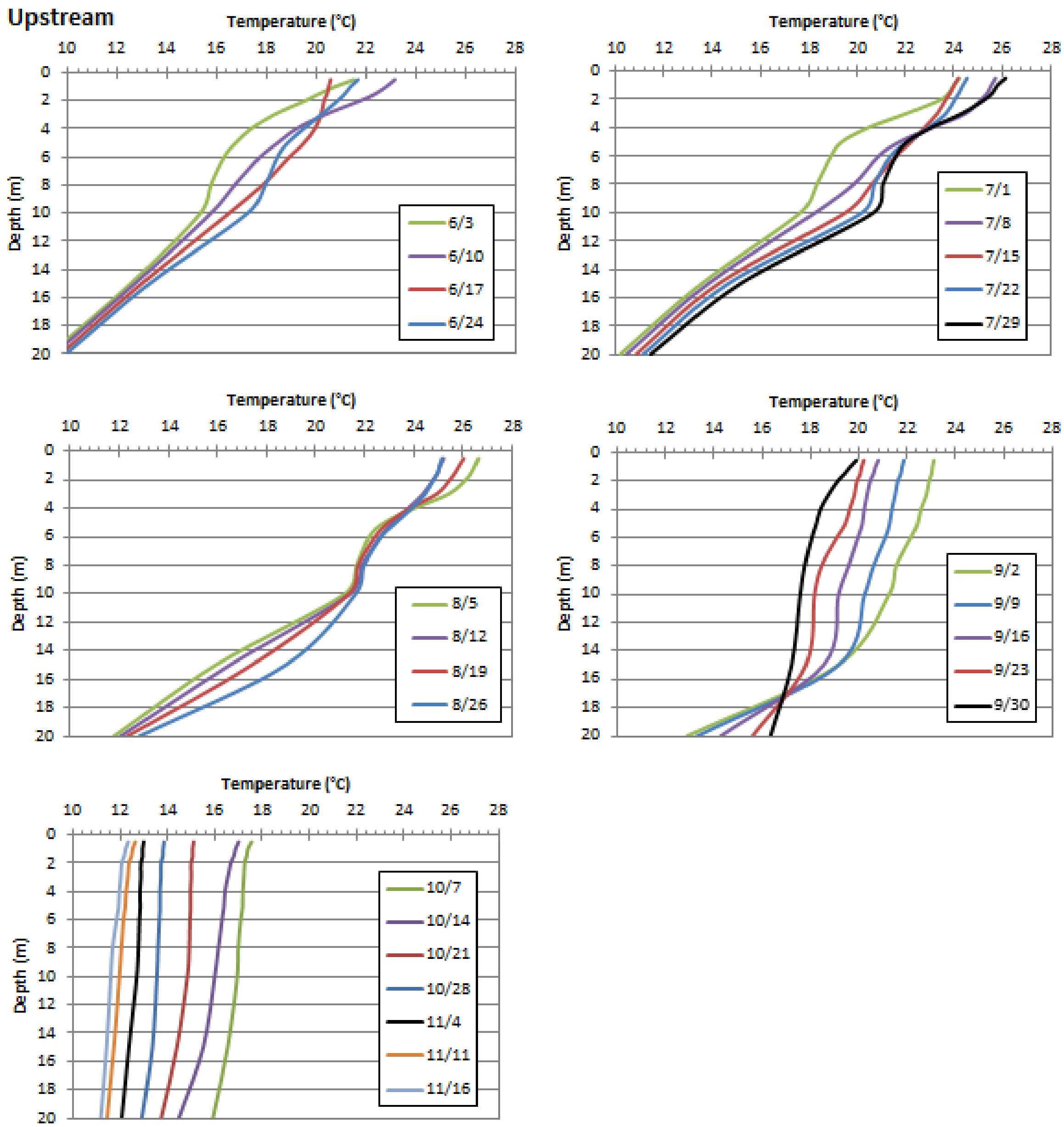

Figure 4-12. Vertical Temperature Profile Upstream of Iron Gate Reservoir Curtain on Weekly Intervals Throughout the Curtain Deployment Period

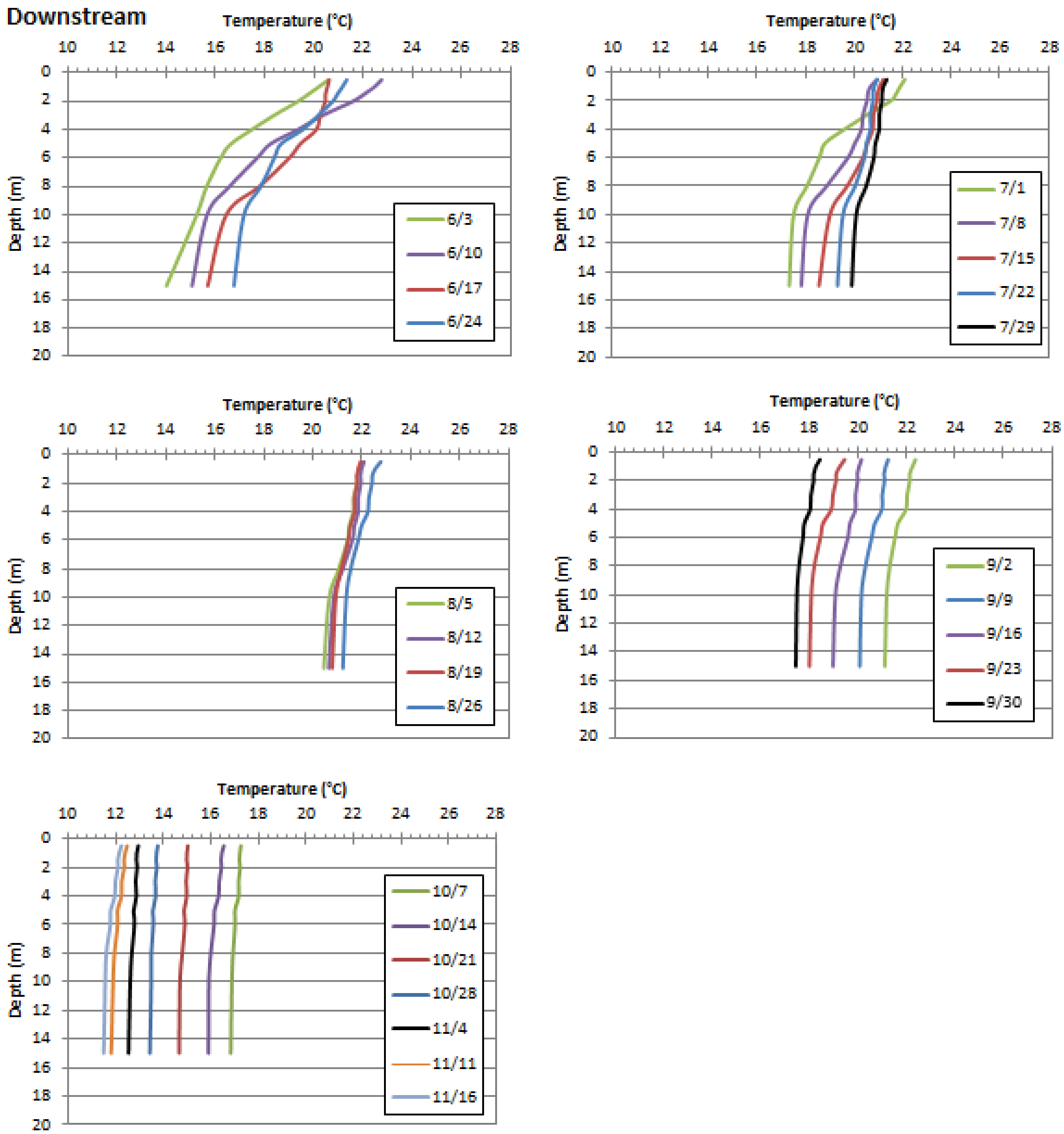

Figure 4-13. Vertical Temperature Profile Downstream of Iron Gate Reservoir Curtain on Weekly Intervals Throughout the Curtain Deployment Period

Differences in temperature between paired thermographs at fixed depths upstream and downstream of the curtain were calculated by subtracting the downstream 7-day average water temperature from the upstream 7-day average water temperature at the same depth and 7-day period. For each depth, a resulting positive difference indicates that water was warmer at that depth on the upstream side of the curtain and a negative difference indicates that water was warmer on the downstream side of the curtain at that depth. The results indicate that the 7-day average water temperatures in near-surface waters (0 to 2 m) were up to 4°C warmer upstream of the curtain than the same depths downstream of the curtain (Figure 4-14). The 7-day average water temperatures in downstream waters at 10 m were approximately the same as upstream waters at 10 m. The 7-day average water temperatures at 15 m were up to 5°C warmer downstream than upstream until late August when the difference started to decrease; likely the result of water column mixing that was occurring downstream of the curtain. These results provide additional support to the finding during this study that nearly isothermal and more fully-mixed conditions developed in reservoir waters downstream of the curtain following deployment.

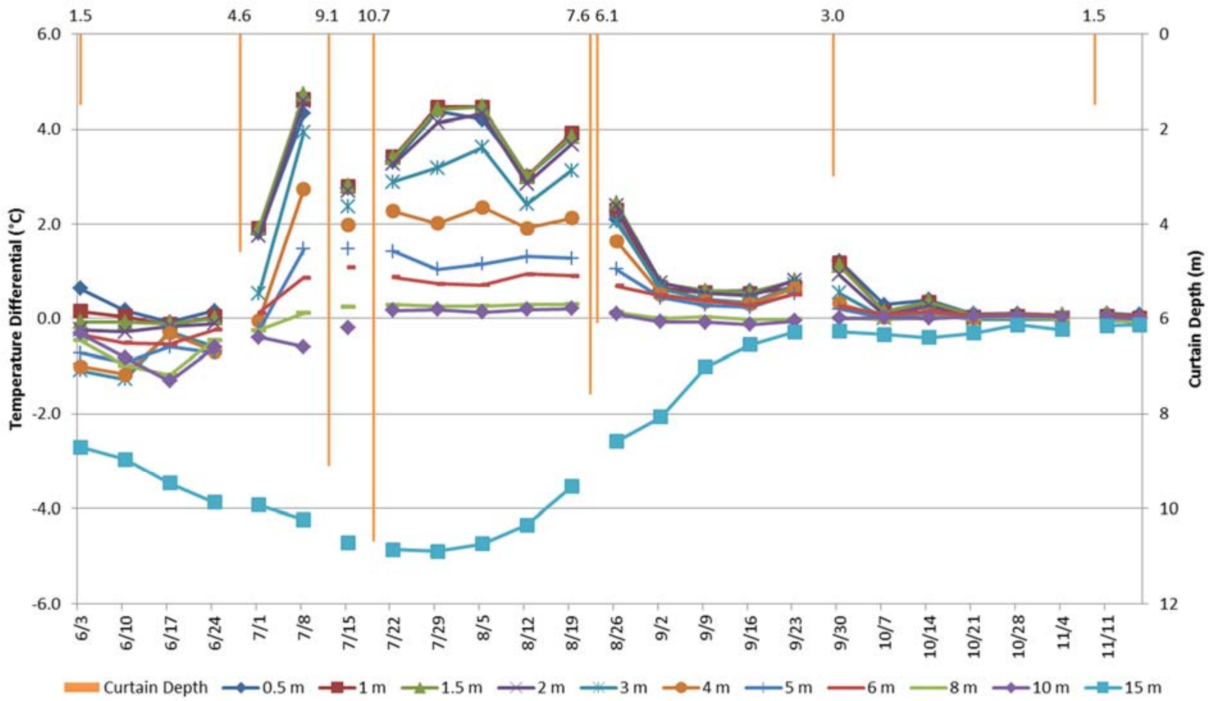

Figure 4-14. Temperature Differential between 7-day Average Water Temperatures Upstream and Downstream of Iron Gate Reservoir Curtain at Weekly Intervals Throughout the Curtain Deployment Period.

(Note: Upstream temperature minus downstream temperature; curtain depths included for reference)

4.2.2 Log Boom

Water temperatures in near-surface waters (3 m and less) at the Iron Gate log boom increased through the summer and reached maximum values in late July. Temperature of deeper waters increased more gradually through the season reaching maximum values in late August (15 m) or late September (21 and 24 m). At depths below 24 m, temperatures varied little until late October (Figure 4-15). The top 30 m of the reservoir was isothermal by early November (maximum depth is approximately 34 m). Stratification was present at the log boom in the June through September period, and diminished in October and November, similar to conditions upstream of the curtain (Figure 4-16).

A thermograph installed just downstream of the Copco 2 powerhouse collected water temperatures through the same time period. These data show that in June, water entering Iron Gate reservoir was approximately the same temperature as the 6 m water at the log boom. In August, inflow temperature tracked the 9 m temperature trace, and then gradually cooled through September and October. Iron Gate reservoir attained isothermal conditions in mid- to late-November.

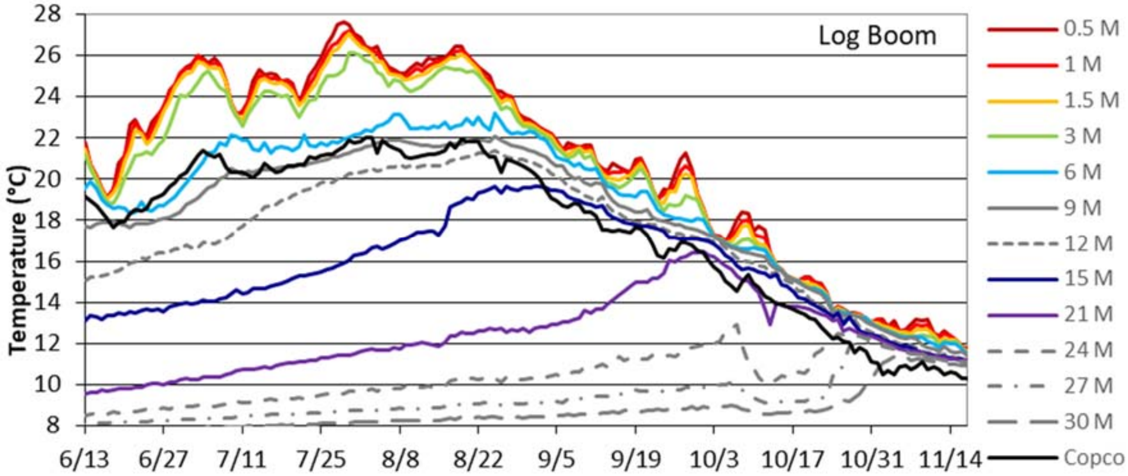

Figure 4-15. Daily Average Temperature in Iron Gate Reservoir at Log Boom at Various Depths from 6/14/2016 to 11/16/2016. Copco 2 Outflow Temperatures Included for Reference.

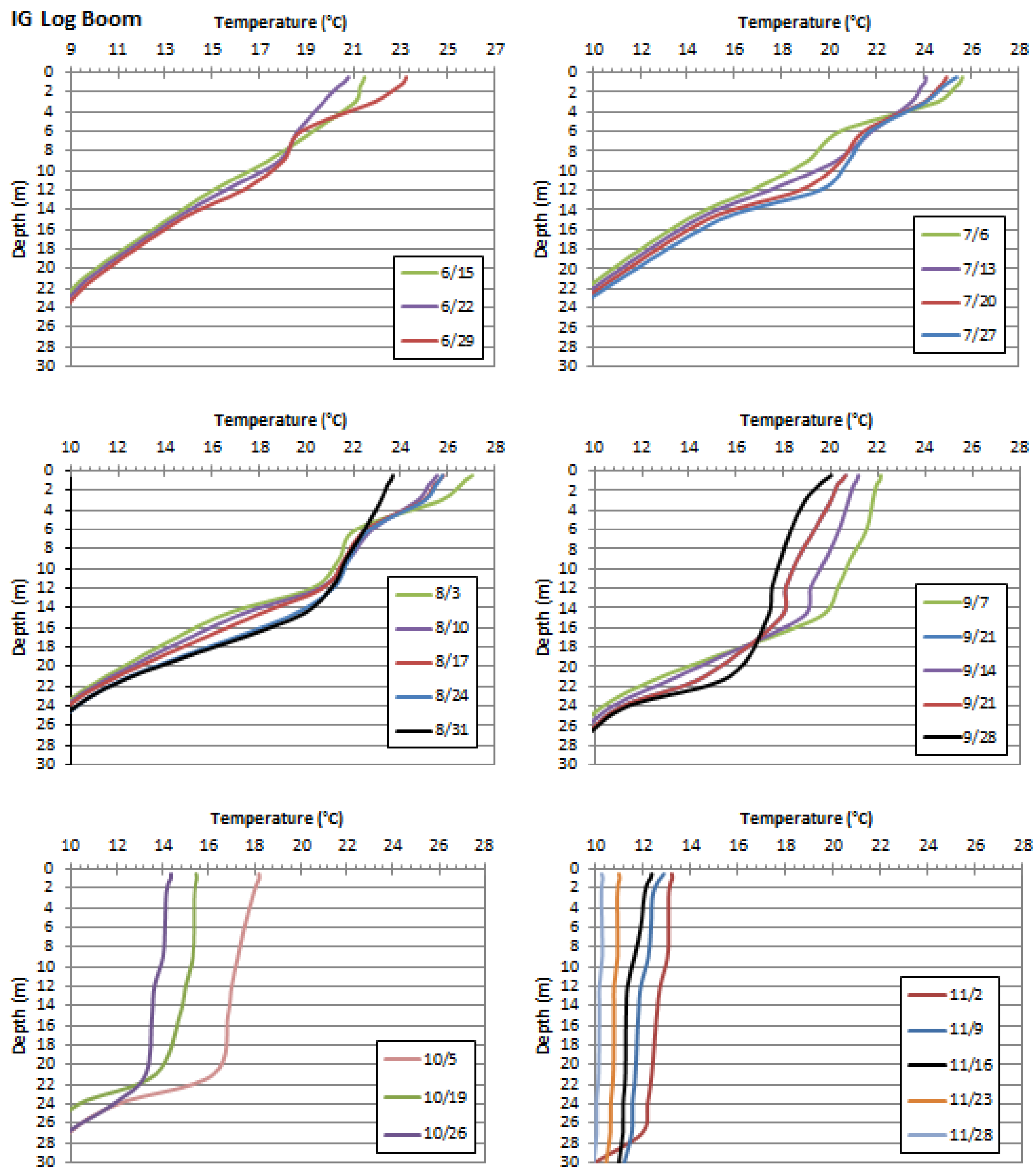

Figure 4-16. Vertical Temperature Profile at Iron Gate Reservoir Log Boom on Selected Days at Weekly Intervals Throughout the Curtain Deployment Period

4.3 Vertical Profiles

4.3.1 Microcystin.

The June 28 profile, prior to curtain deployment, identified that total and filtered microcystin concentrations were relatively low (less than 0.1 µg/L) and consistent between samples from upstream of the curtain, downstream of the curtain, and in the Klamath downstream of Iron Gate (Figures 4-17 and 4-18).

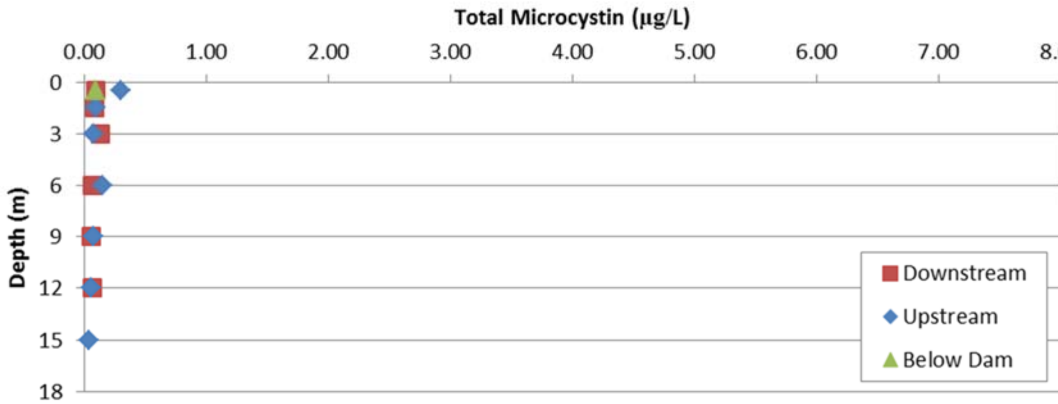

Figure 4-17. Total Microcystin Data from Samples Collected at Various Depths Upstream and Downstream of the Curtain and below Iron Gate Dam on 6/28/2016 (Quantification limit is 0.10 µg/L).

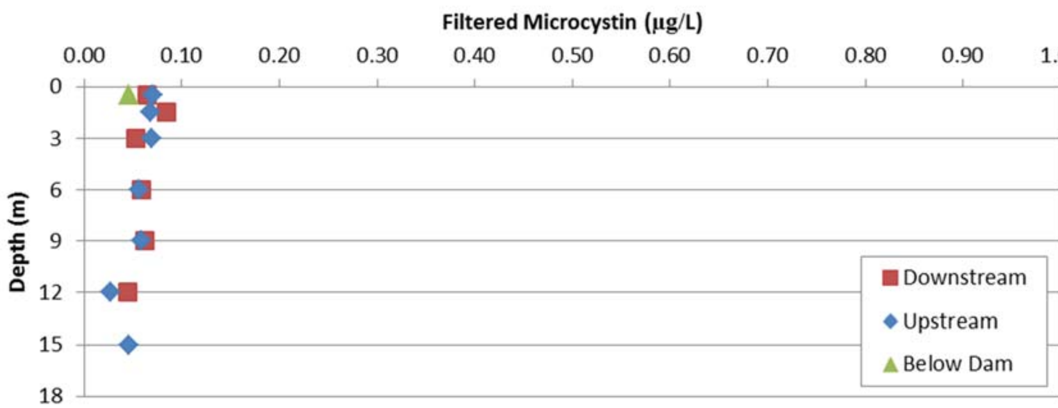

Figure 4-18. Filtered Microcystin Data from Samples Collected at Various Depths Upstream and Downstream of the Curtain and below Iron Gate Dam on 6/28/2016 (Quantification limit is 0.10 µg/L).

By August 29, the levels of total and filtered microcystin were higher than in June (Figures 4-19 and 4-20). At depths below 0.5 m, total microcystin levels were lower on the downstream side of the curtain than on the upstream side. At 0.5 m, total microcystin downstream of the curtain was higher than at the same depth upstream of the curtain or the river downstream of Iron Gate dam. For filtered microcystin, the microcystin levels downstream of the curtain were basically the same or less than those from upstream of the curtain.

By late September, the values for total and filtered microcystin in the near surface water (0.5 and 1.5 m) were much higher than those from the same depths downstream of the curtain or in the river downstream of Iron Gate dam (Figures 4-21 and 4-22). Regardless of sampling date, at depths below 6 m, the values are very similar for both upstream and downstream of the curtain.

RESULTS

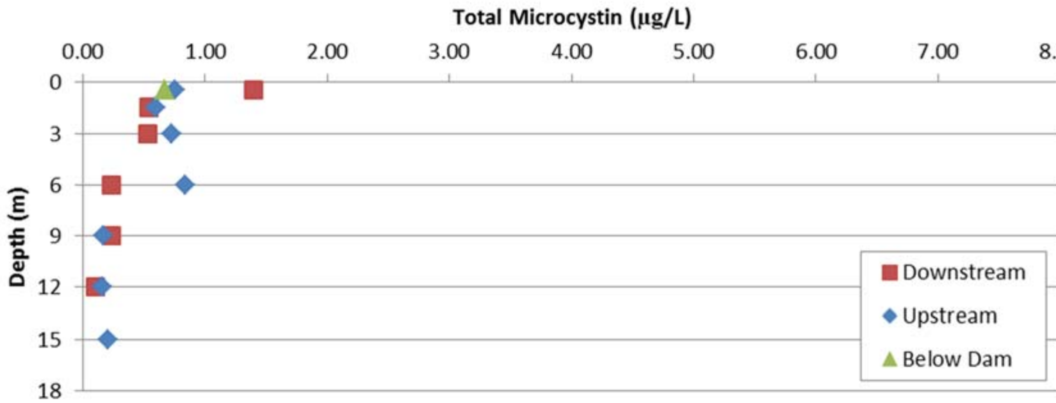

Figure 4-19. Total Microcystin Data from Samples Collected at Various Depths Upstream and Downstream of the Curtain and below Iron Gate Dam on 8/29/2016 (Quantification limit is 0.10 µg/L).

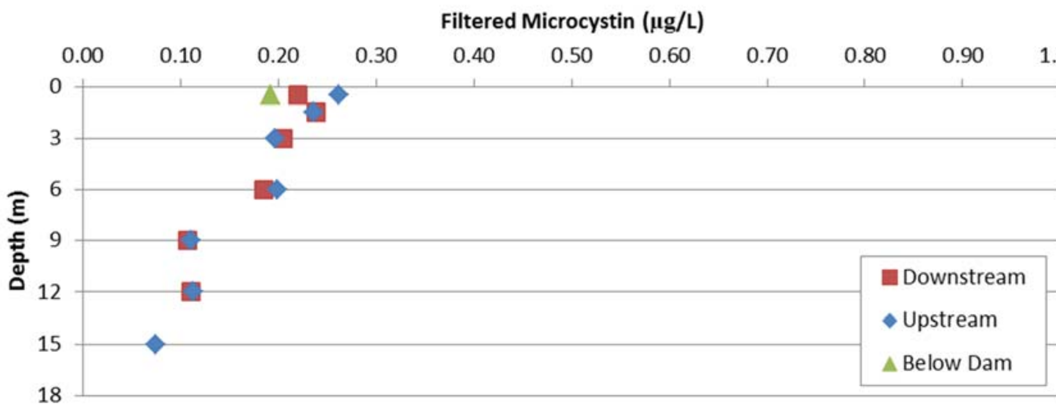

Figure 4-20. Filtered Microcystin Data from Samples Collected at Various Depths Upstream and Downstream of the Curtain and below Iron Gate Dam on 8/29/2016 (Quantification limit is 0.10 µg/L).

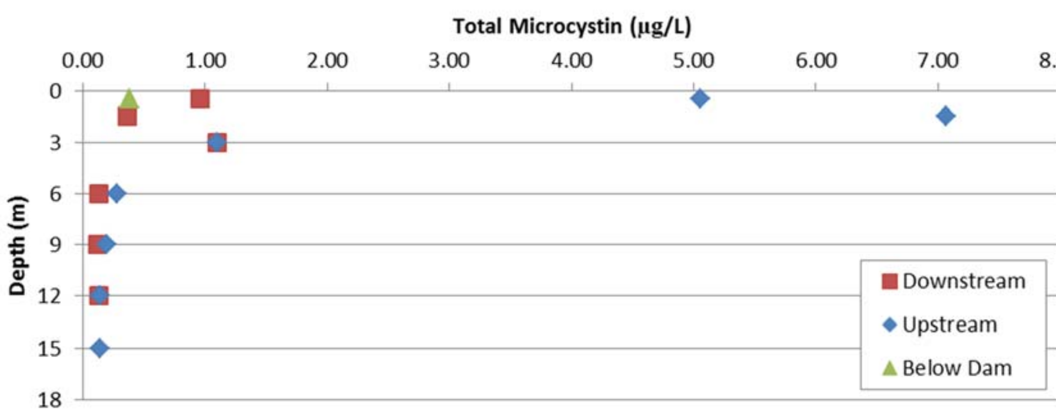

Figure 4-21. Total Microcystin Data from Samples Collected at Various Depths Upstream and Downstream of the Curtain and below Iron Gate Dam on 9/20/2016 (Quantification limit is 0.10 µg/L).

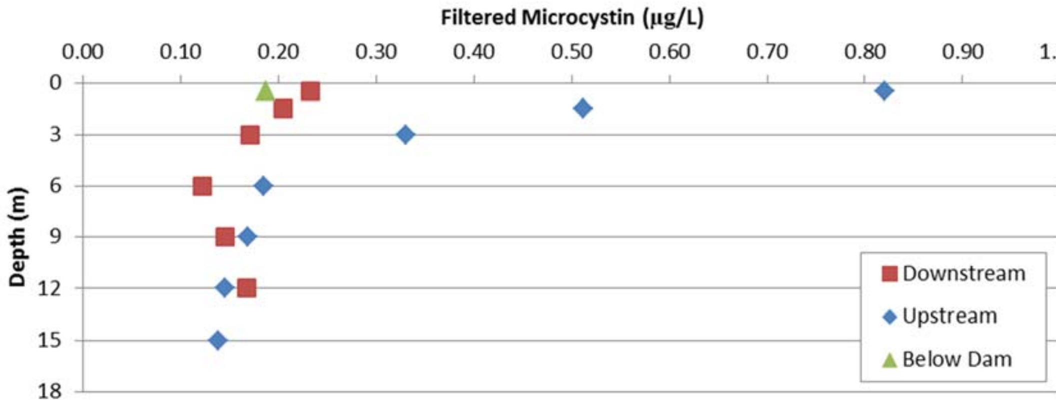

Figure 4-22. Filtered Microcystin Data from Samples Collected at Various Depths Upstream and Downstream of the Curtain and below Iron Gate Dam on 9/20/2016 (Quantification limit is 0.10 µg/L).

4.3.2 Total Cyanobacteria

Results of genetic analysis conducted via qPCR are in genes per milliliter (genes/mL), which are analogous to total cyanobacteria concentrations in cells per milliliter (cells/mL) because each individual cyanobacteria has one copy of the targeted gene. On June 28, the total cyanobacteria concentrations were more variable from 3 m to the surface, ranging from 2 million genes/mL for the 3 m sample downstream of the curtain and 1.5 million genes/mL upstream at the same depth (Figure 4-23). The total cyanobacteria concentrations in the Klamath River downstream of Iron Gate dam were similar to levels downstream of the curtain at 0.5 m deep. Total cyanobacteria concentrations were present at similar levels upstream and downstream of the curtain at depths of over 6 m.

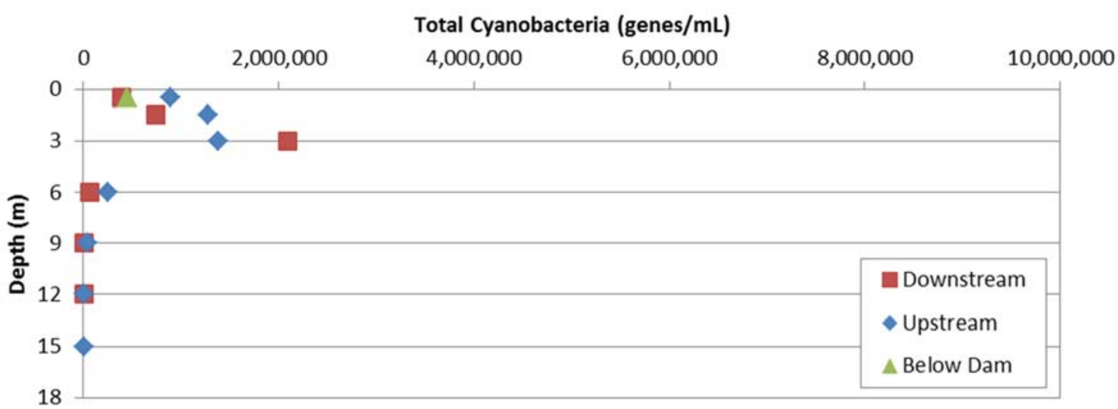

Figure 4-23. Comparison of Total Cyanobacteria Vertical Profiles Upstream and Downstream of Curtain and below Iron Gate Dam on 6/28/2016

By August 29, total cyanobacteria abundance was distinctly higher upstream of the curtain down to 6 m in depth, but similar below that (Figure 4-24). The results from the Klamath River below Iron Gate dam showed lower levels of cyanobacteria than were present in the reservoir.

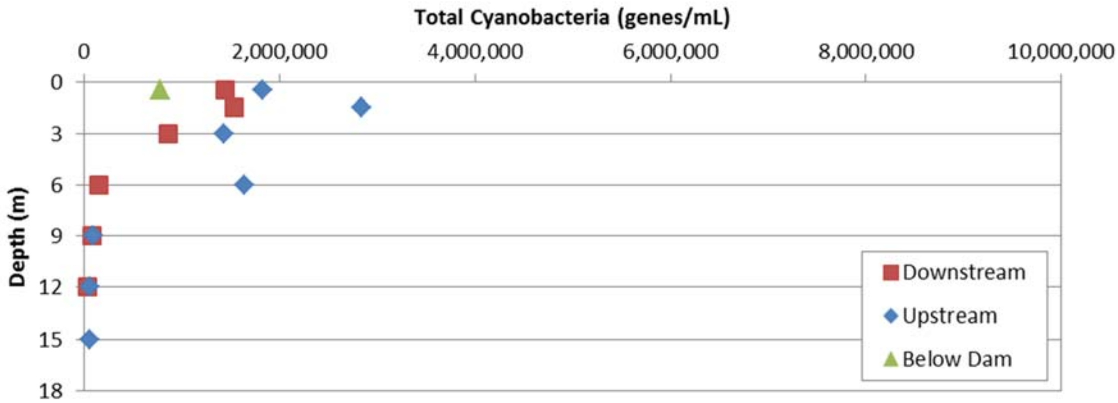

Figure 4-24. Comparison of Total Cyanobacteria Vertical Profiles Upstream and Downstream of Curtain and below Iron Gate Dam on 8/29/2016

By September 20, total cyanobacteria concentrations were over five times greater at 1.5 m than they were downstream of the curtain (Figure 4-25). Similar to August 28, total cyanobacteria abundance in the Klamath River downstream of Iron Gate dam was lower than at 0.5 m depth downstream of the curtain. Total cyanobacteria concentrations were present at similar levels upstream and downstream of the curtain at depths of over 6 m.

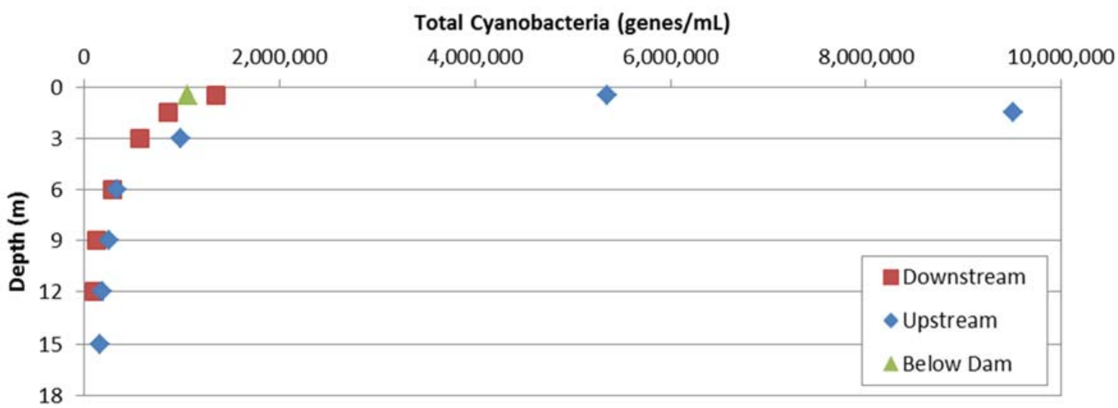

Figure 4-25. Comparison of Total Cyanobacteria Vertical Profiles Upstream and Downstream of Curtain and below Iron Gate Dam on 9/20/2016

4.3.3 Total Microcystis

As with total cyanobacteria concentrations, total *Microcystis* concentrations were assessed via qPCR and are presented in genes/mL. Total *Microcystis* concentrations on June 28 were present at relatively low abundances throughout the water column (Figure 4-26). Total *Microcystis* concentrations showed essentially the same pattern as total cyanobacteria concentrations. There was little difference in total *Microcystis* abundance between depths or sample sites on June 28.

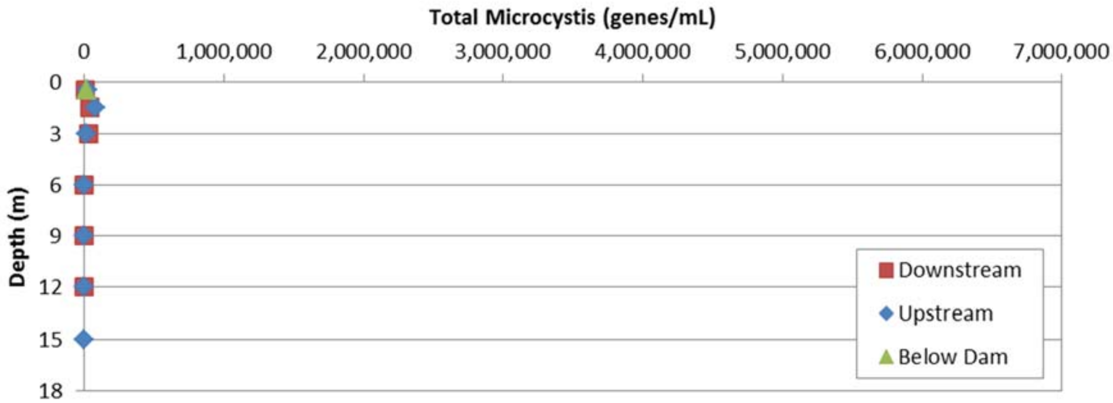

Figure 4-26. Comparison of Total *Microcystis* Vertical Profiles Upstream and Downstream of Curtain and below Iron Gate Dam on 6/28/2016

There was relatively low abundance of total *Microcystis* in late August and little difference between the upstream and downstream sides of the curtain (Figure 4-27). The total *Microcystis* data from September 20 (Figure 4-28) mirror those for total cyanobacteria. Upstream of the curtain, total *Microcystis* was about 4 to 6 times more abundant than downstream of the curtain in the upper 1.5 m of the water column.

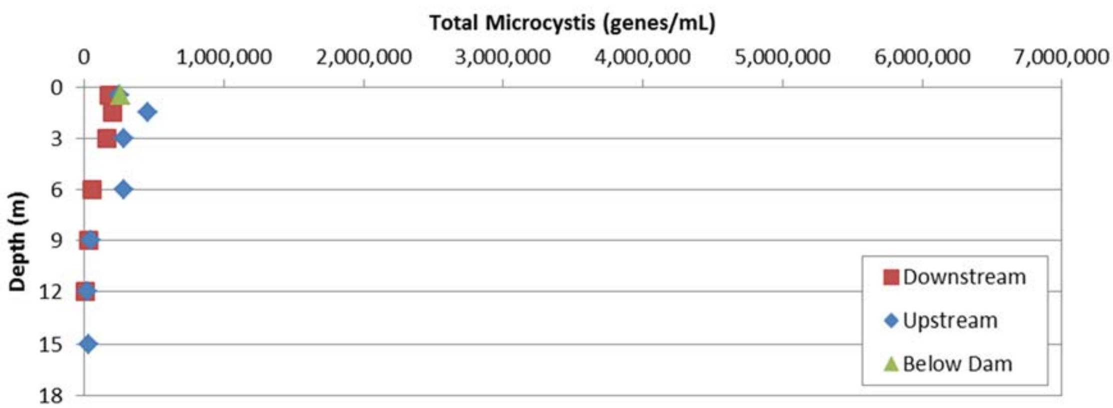

Figure 4-27. Comparison of Total *Microcystis* Vertical Profiles Upstream and Downstream of Curtain and below Iron Gate Dam on 8/29/2016

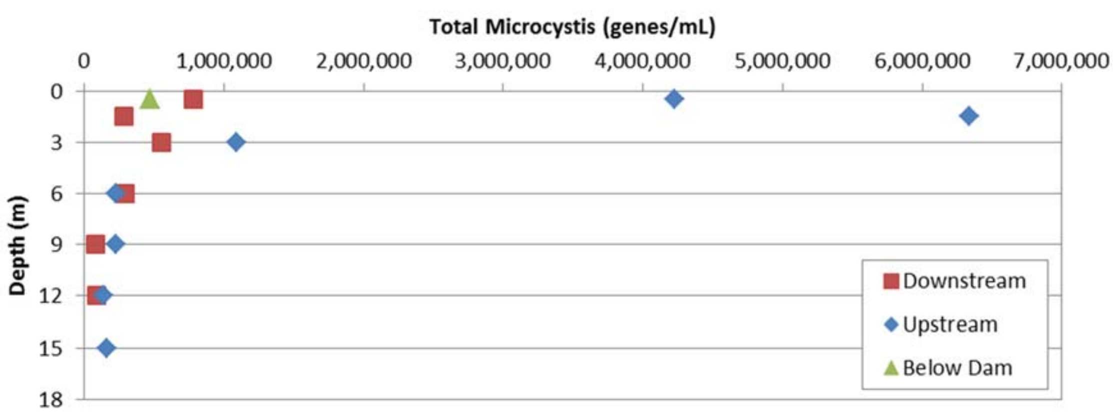

Figure 4-28. Comparison of Total *Microcystis* Vertical Profiles Upstream and Downstream of Curtain and below Iron Gate Dam on 9/20/2016

4.3.4 Chlorophyll-*a*.

On June 28, chlorophyll-*a* levels were similar upstream and downstream of the curtain and in the river downstream of Iron Gate dam (Figure 4-29). At 3 m in depth, chlorophyll-*a* values were higher downstream of the curtain than upstream. Below 6 m in depth, chlorophyll-*a* values were almost identical.

When samples were collected on August 29, chlorophyll-*a* concentrations upstream of the curtain were close to 15 µg/L from 6 m depth to the surface. Downstream of the curtain, chlorophyll-*a* values were similar from 0.5 to 1.5 m deep, then began to decline at 3 m deep and were less than 5 µg/L at 6 m depth (Figure 4-30). At the same time, chlorophyll-*a* levels in the river downstream of Iron Gate dam were about half the values of the samples taken in the reservoir downstream of the curtain.

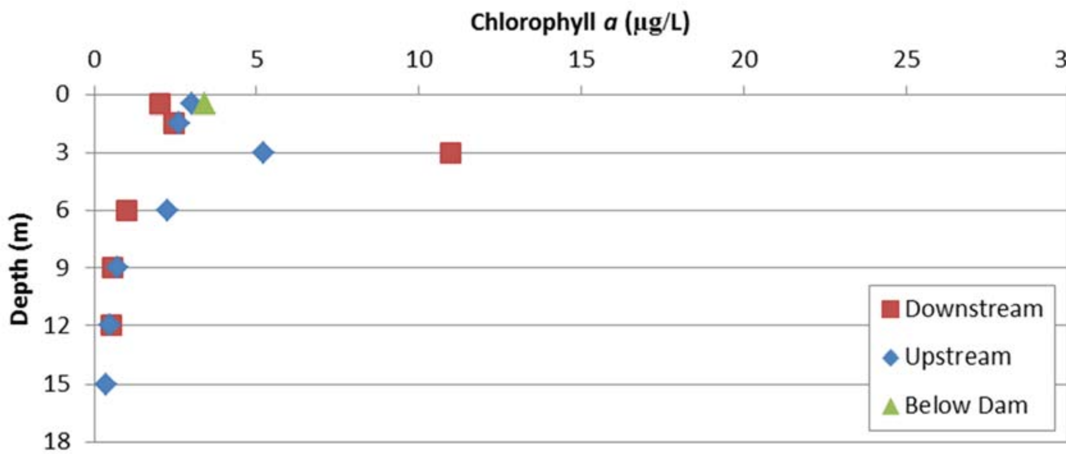

Figure 4-29. Vertical Chlorophyll-*a* Profiles Upstream and Downstream of the Curtain and below Iron Gate Dam on 6/28/2016.

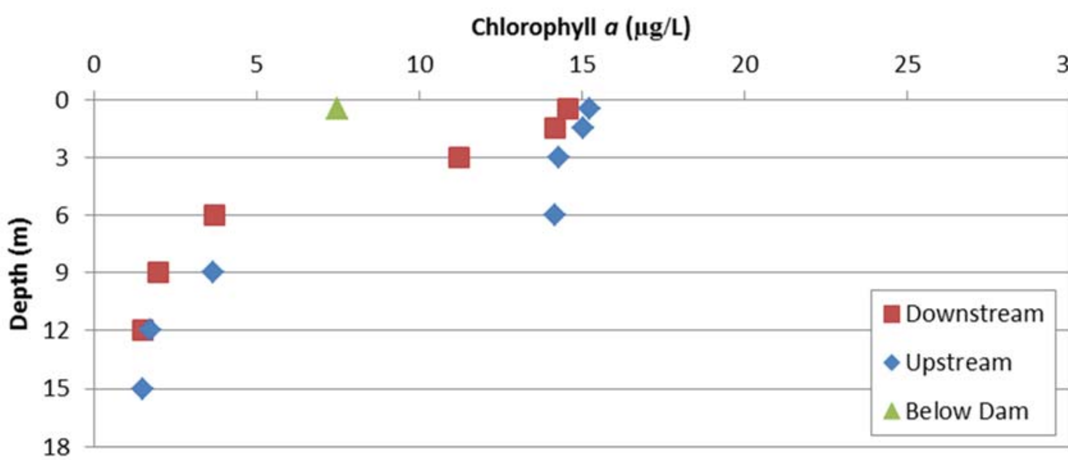

Figure 4-30. Vertical Chlorophyll-*a* Profiles Upstream and Downstream of the Curtain and below Iron Gate Dam on 8/29/2016.

On September 20, in the top 3 m, there was a pronounced difference between chlorophyll-*a* levels upstream and downstream of the curtain. Chlorophyll-*a* values were about 20-25 µg/L from the surface to 1.5 m deep upstream of the curtain, but were less than 5 µg/L at the same depths downstream of the curtain and in the river downstream of Iron Gate dam (Figure 4-31).

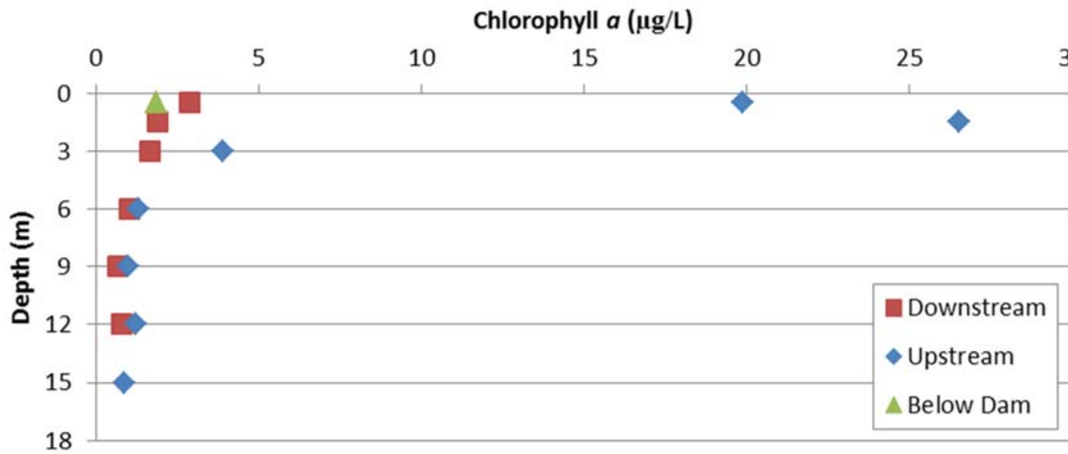

Figure 4-31. Vertical Chlorophyll-*a* Profiles Upstream and Downstream of the Curtain and Downstream of Iron Gate Dam on 9/20/2016.

4.3.5 Water Temperature

On June 28, Iron Gate reservoir was already stratified with a well-defined epilimnion. Weak, intermittent sub-daily stratification within the epilimnion occurred on this day (consistent with previously calculated Wedderburn numbers), between 3 m and 6 m depths (Figure 4-32). Conditions upstream and downstream of the curtain were almost identical. Downstream Klamath River water temperature was cooler than reservoir surface waters and warmer than reservoir deeper waters.

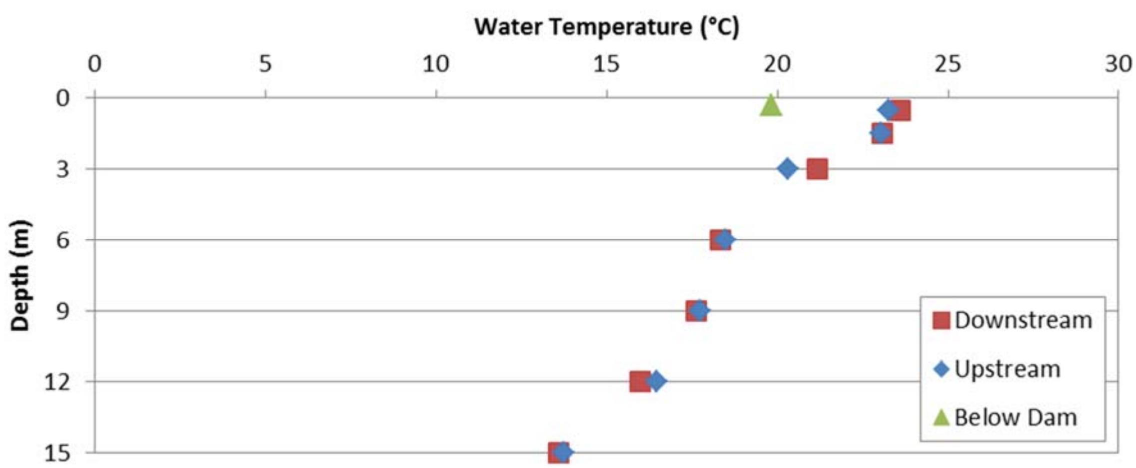

Figure 4-32. Vertical Water Temperature Profiles Upstream and Downstream of the Curtain and Downstream of Iron Gate Dam on 6/28/2016.

August and September vertical profile data indicate cooler conditions downstream of the curtain (more so in September), and that weak intermittent stratification was apparent both upstream and downstream of the curtain (Figures 4-33 and 4-34). Klamath River temperatures were notably cooler than near-surface temperatures, particularly when compared to upstream of the curtain, and warmer than deeper reservoir waters.

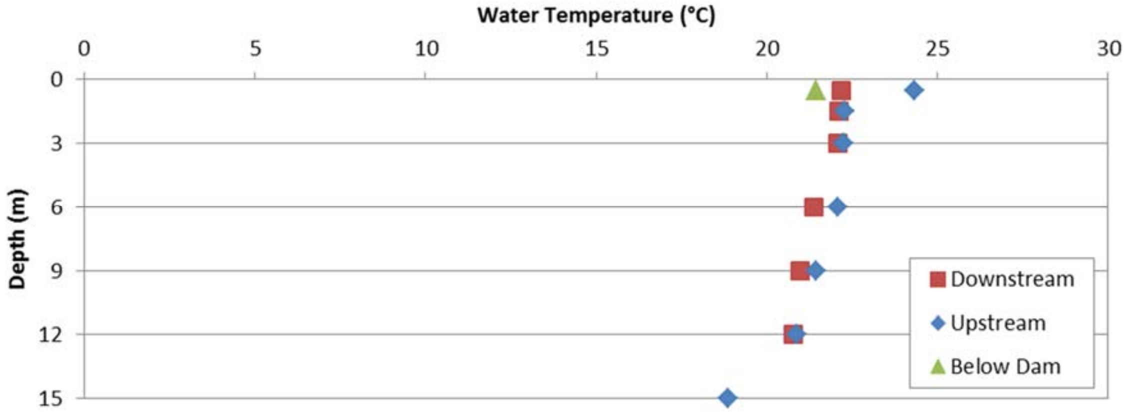

Figure 4-33. Vertical Water Temperature Profiles Upstream and Downstream of the Curtain and Downstream of Iron Gate Dam on 8/29/2016.

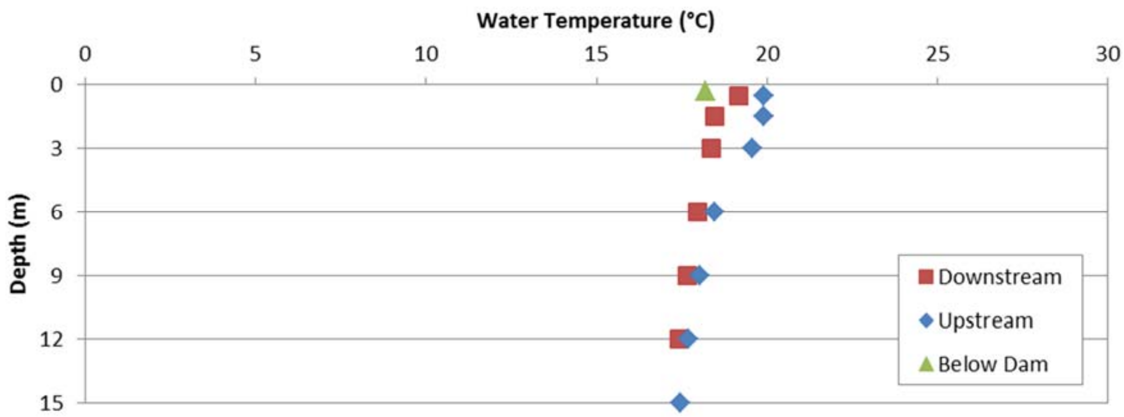

Figure 4-34. Vertical Water Temperature Profiles Upstream and Downstream of the Curtain and Downstream of Iron Gate Dam on 9/20/2016.

4.3.6 Dissolved Oxygen

Dissolved oxygen measured during the three vertical profile data collection dates reflected temperature profile patterns. Vertical stratification was apparent in the dissolved oxygen profile from June 28. On this date, dissolved oxygen levels in the near-surface increased to above 10 mg/L at 3 m, and then declined steadily from 3 m to 15 m to minimum values just over 4 mg/L (Figure 4-35). Klamath River dissolved oxygen concentrations were greater than 9 mg/L on this date.

The curtain was raised to 6.1 m on August 23 to address low levels of dissolved oxygen downstream of Iron Gate dam. As a result, dissolved oxygen levels on August 29 at the upstream side of the curtain were generally higher than those downstream of the curtain, but the differences were small and variable. Upstream of the curtain, dissolved oxygen remained well above 8 mg/L at a depth of 6 m. Dissolved oxygen values declined to a minimum of less than 2 mg/L at 12 m depth downstream of the curtain (Figure 4-36). Klamath River dissolved oxygen concentrations were almost 8 mg/L at this time.

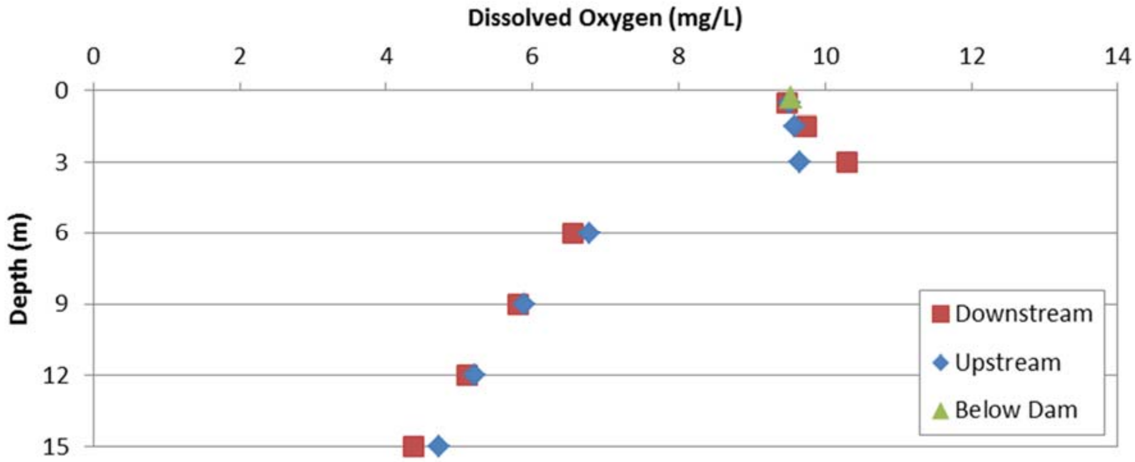

Figure 4-35. Vertical Dissolved Oxygen Profiles Upstream and Downstream of the Curtain and Downstream of Iron Gate Dam on 6/28/2016.

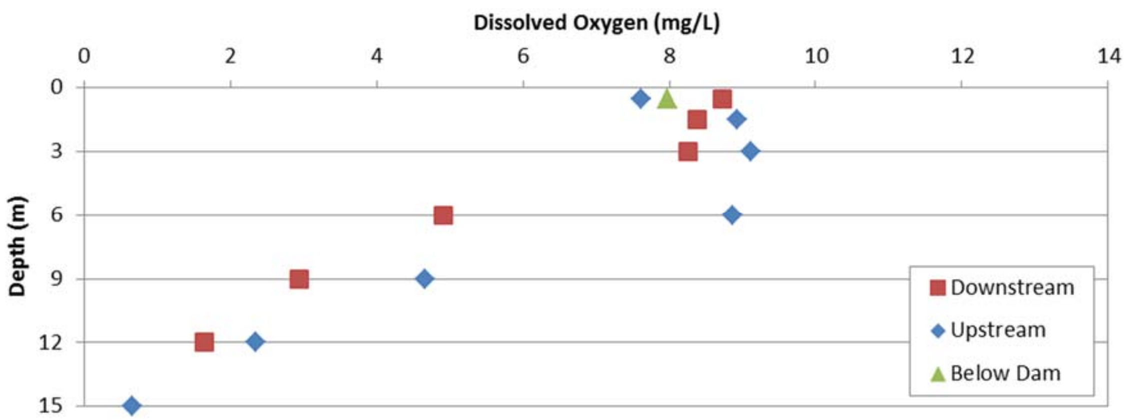

Figure 4-36. Vertical Dissolved Oxygen Profiles Upstream and Downstream of the Curtain and Downstream of Iron Gate Dam on 8/29/2016.

On September 20, near-surface dissolved oxygen levels upstream of the curtain were notably higher than those downstream of the curtain from 3 m in depth to the surface. Below 3 m deep, dissolved oxygen values declined to a minimum of less than 2 mg/L at 12 m depth downstream of the curtain (Figure 4-37). Dissolved oxygen levels in the Klamath River downstream of Iron Gate dam were higher than the 0.5 m values downstream of the curtain at well over 8 mg/L.

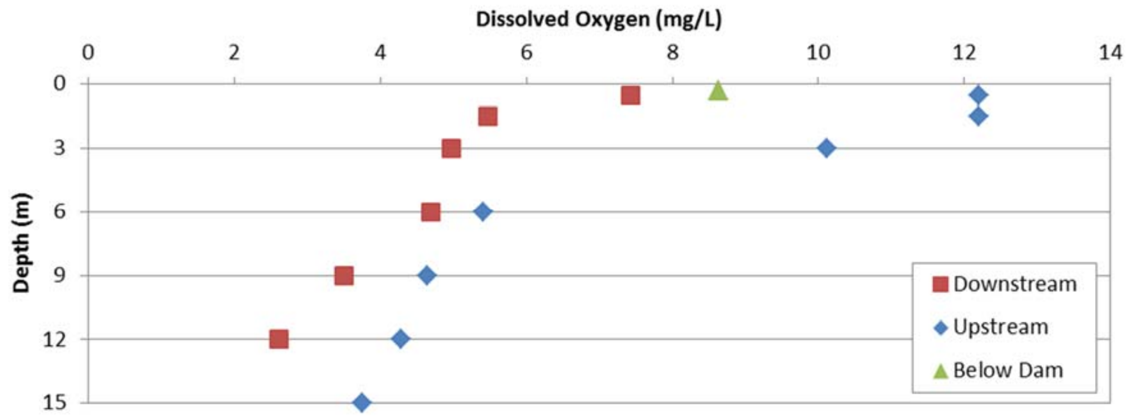

Figure 4-37. Vertical Dissolved Oxygen Profiles Upstream and Downstream of the Curtain and Downstream of Iron Gate Dam on 9/20/2016.

4.3.7 pH

Vertical profile data for pH on June 28 showed little difference between the upstream and downstream sides of the curtain (Figure 4-38). pH in the river downstream of Iron Gate was lower than 0.5 m pH values in the reservoir (at both the upstream and downstream sites).

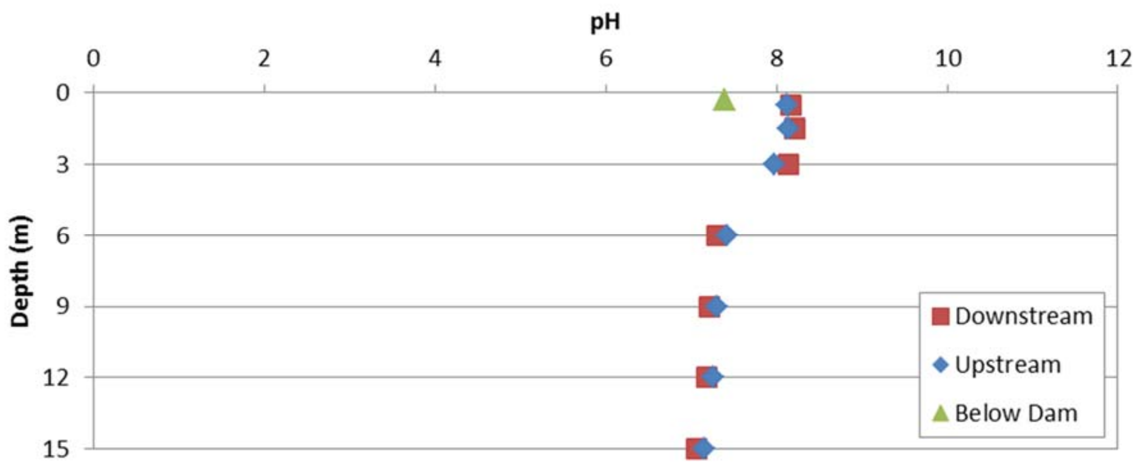

Figure 4-38. Vertical pH Profiles Upstream and Downstream of the Curtain and Downstream of Iron Gate Dam on 6/28/2016.

On August 29, pH upstream of the curtain was lower at the 0.5 m depth than downstream of the curtain, but the same or higher from 1.5 m to 6 m (Figure 4-39). pH in the river downstream of Iron Gate was lower than 0.5 m pH value in the reservoir downstream of the curtain, but higher than the 0.5 m pH value upstream of the curtain.

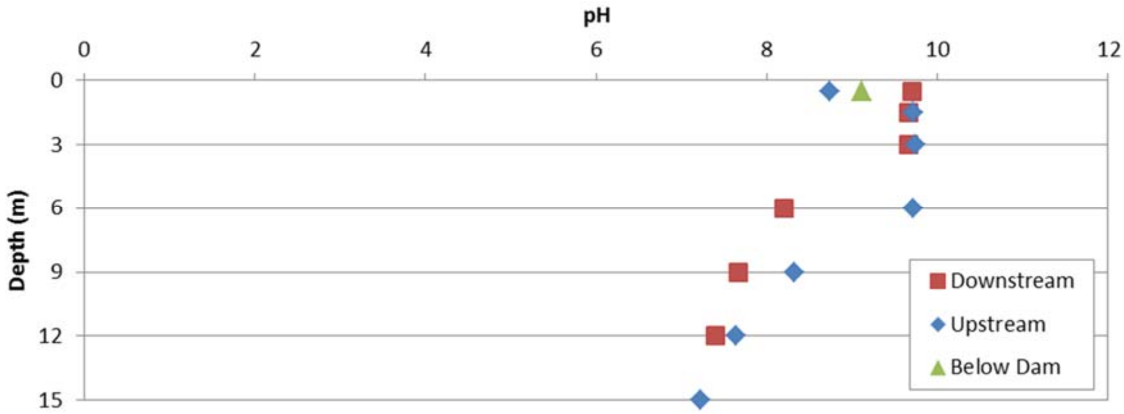

Figure 4-39. Vertical pH Profiles Upstream and Downstream of the Curtain and Downstream of Iron Gate Dam on 8/29/2016.

By September 20, pH values upstream of the curtain were higher than the same depths downstream from the 0.5 m to 3 m deep (Figure 4-40). At 6 m depth and below, pH values were approximately the same on either side of the curtain. pH in the river downstream of Iron Gate was lower than 0.5 m depth pH values in the reservoir.

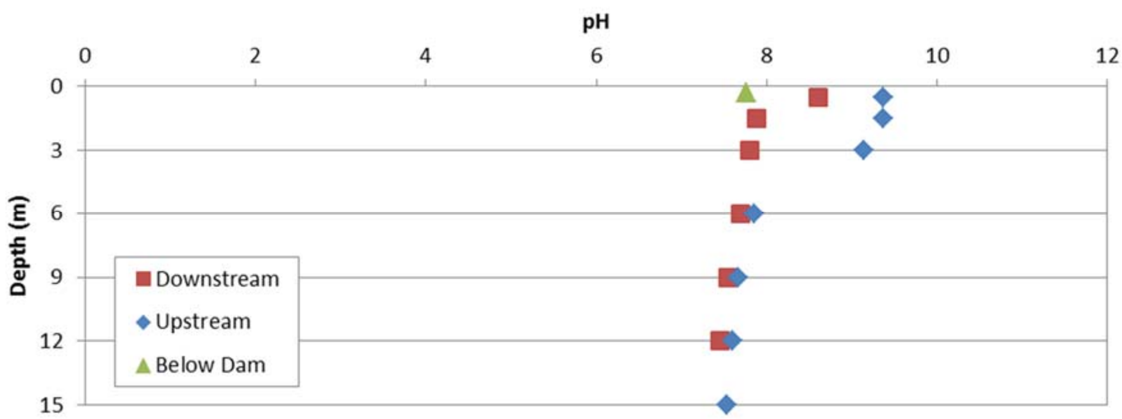

Figure 4-40. Vertical pH Profiles Upstream and Downstream of the Curtain and Downstream of Iron Gate Dam on 9/20/2016.

4.4 Autosamplers

The autosampler study was conducted as planned between August 29 and September 1, 2016. Equipment malfunction in both units reduced the number of samples collected during the deployment period. Overall, the upstream autosampler collected 15 water samples and the downstream of Iron Gate dam autosampler collected 10 samples.

4.4.1 Microcystin

Total microcystin was consistently higher at the site upstream of the curtain when compared to the river below Iron Gate dam in samples collected by autosampler during this effort (Figure 4-41). Upstream of the curtain, total microcystin concentrations ranged from just under 0.5 to 1.5 µg/L and averaged 0.80 µg/L. Downstream of Iron Gate dam, microcystin levels averaged 0.37 µg/L and were all less than 0.5 µg/L except one sample, which had a microcystin concentration of 0.62 µg/L. The mean bias and mean absolute error values for these two sets of data are the same (0.35) indicating that the mean values from these two data sets are always different. Applying a two sample t-test to the mean values indicates that the mean value for samples collected upstream of the curtain is significantly greater than the mean of samples collected downstream of Iron Gate dam (α=0.95, p<0.001).

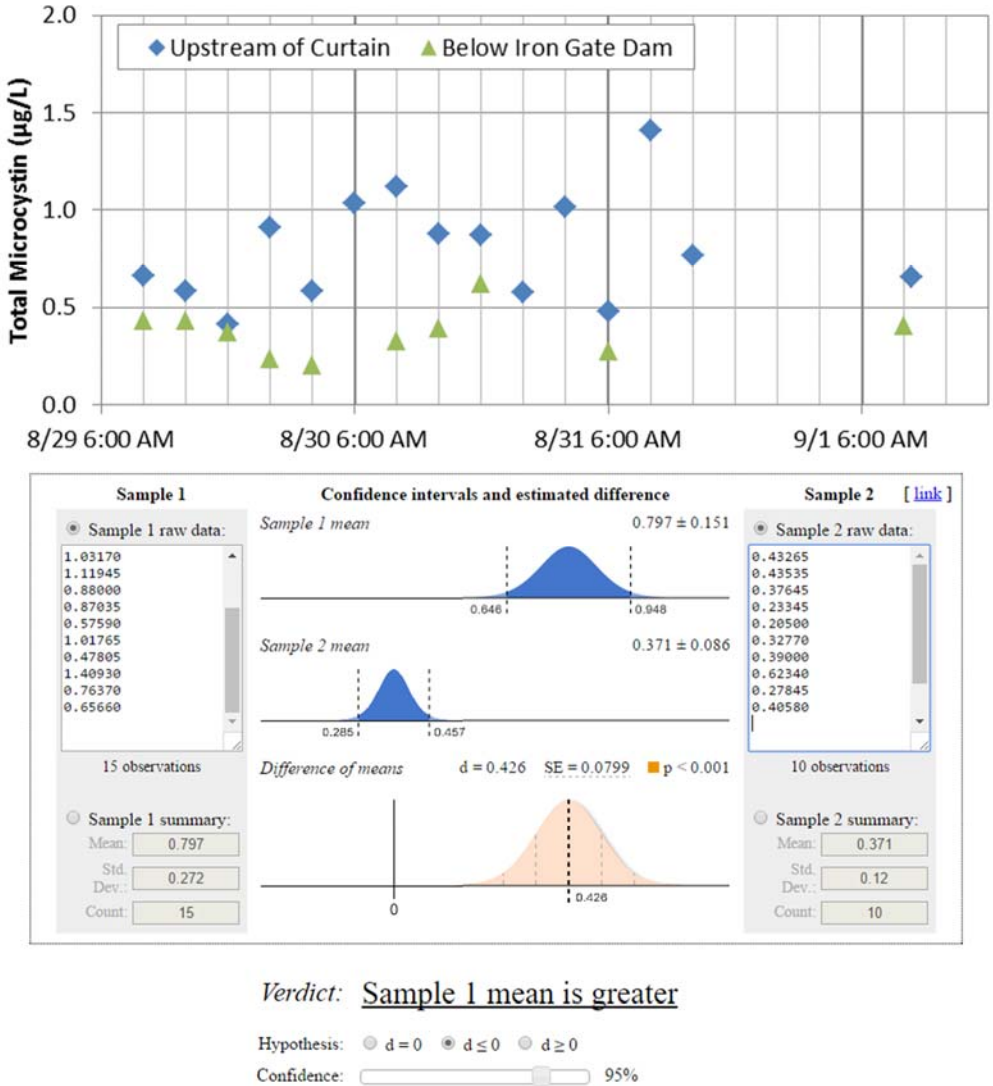

Figure 4-41. Total Microcystin Concentrations from Samples Collected over a 72-hour Sampling Period using Autosamplers Upstream of the Curtain (Sample 1) and below Iron Gate Dam (Sample 2).[3]

4.4.2 Total Cyanobacteria

Total cyanobacteria was consistently higher upstream of the curtain as compared to the river during the autosampler deployment period (Figure 4-42). Upstream of the curtain, total cyanobacteria concentrations ranged from slightly less than 600,000 to almost 5 million genes/mL and averaged about 2.6 million genes/mL. Downstream of Iron Gate dam, cyanobacteria levels averaged just over 673,000 genes/mL and were all less than 1 million genes/mL except one sample which was slightly greater than this value. Mean bias and mean absolute error for total cyanobacteria concentrations were not identical, but there was significant deviation between the mean values for these two datasets. Applying a two sample t-test to the data identified that mean value cyanobacteria samples collected upstream of

[3] T-test graphics and statistics were based on an online tool that can be found at http://www.evanmiller.org/ab-testing/t-test.html

the curtain was significantly greater than the mean of samples collected downstream of Iron Gate dam (α=0.95, p<0.001).

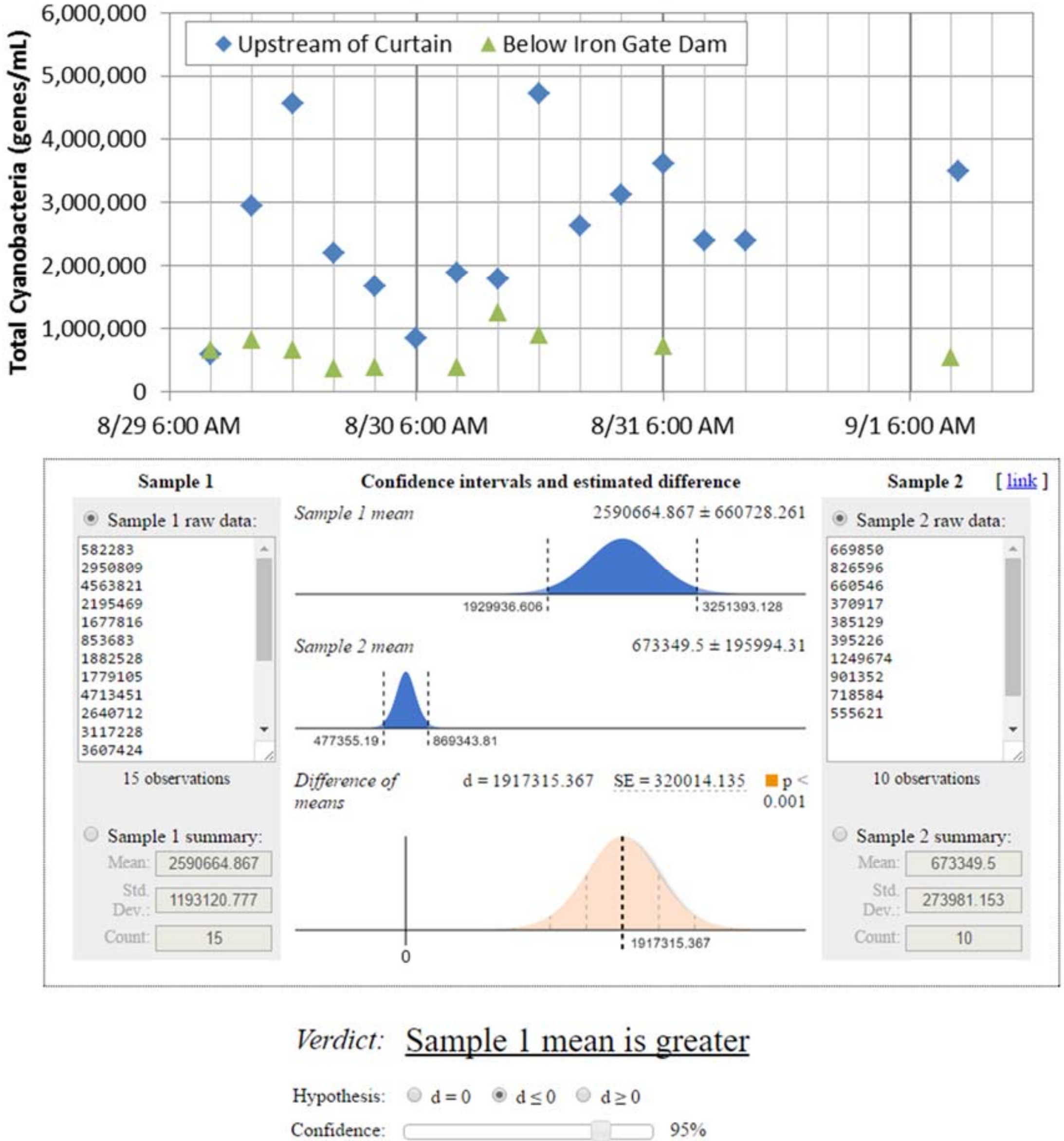

Figure 4-42. Total Cyanobacteria Concentrations from Samples Collected over a 72-hour Sampling Period using Autosamplers Upstream of the Curtain (Sample 1) and below Iron Gate Dam (Sample 2).[4]

4.4.3 Total Microcystis

Similar to the pattern observed for total cyanobacteria, total *Microcystis* levels were always higher upstream of the curtain compared to the river downstream of Iron Gate dam (Figure 4-43). Upstream of the curtain, total *Microcystis* concentrations averaged just over 719,000 genes/mL with a range of about 397,000 to over 1.1 million genes/mL. Downstream of Iron Gate dam, the average concentration of *Microcystis* was about 242,000 genes/mL and ranged from just over 108,000 to about 355,000 genes/mL. As with total cyanobacteria, the mean bias and mean absolute error were identical

[4] T-test graphics and statistics were based on an online tool that can be found at http://www.evanmiller.org/ab-testing/t-test.html

(2,264,403 genes/mL) indicating that the means of these two data sets were always different. Applying a two sample t-test indicates that the mean value for *Microcystis* samples collected upstream of the curtain was significantly greater than the mean of samples collected downstream of Iron Gate dam (α=0.95, p<0.001).

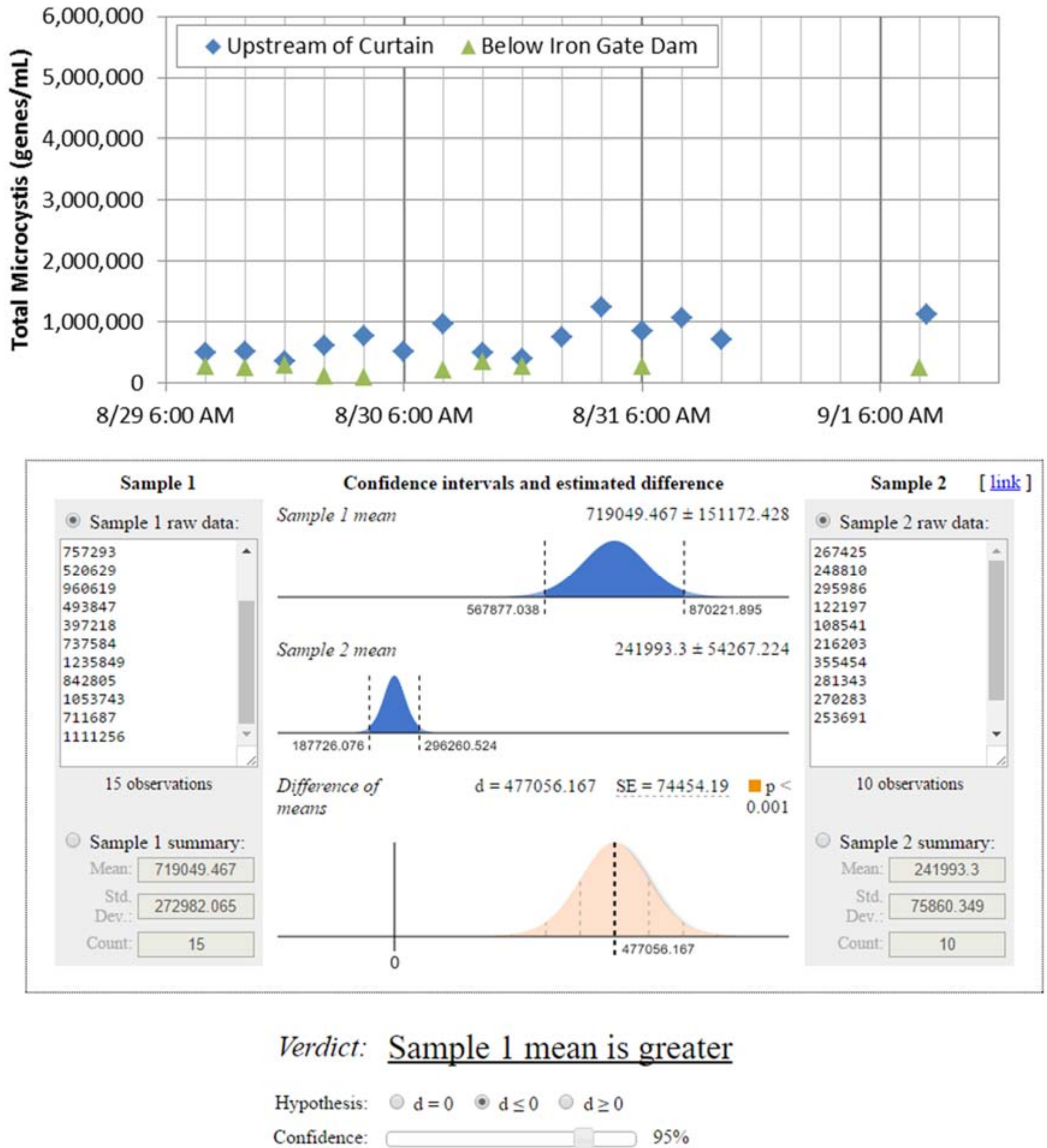

Figure 4-43. Total *Microcystis* Concentrations from Samples Collected over a 72-hour Sampling Period using Autosamplers Upstream of the Curtain (Sample 1) and below Iron Gate Dam (Sample 2).[5]

4.4.4 Chlorophyll-*a*

Just like the pattern observed in other constituents of the autosampler study, chlorophyll-*a* concentrations were always at higher levels upstream of the curtain compared to the river downstream of Iron Gate dam (Figure 4-44). Upstream of the curtain, chlorophyll-*a* concentrations averaged just

[5] T -test graphics and statistics were based on an online tool that can be found at http://www.evanmiller.org/ab-testing/t-test.html

about 14.5 µg/L with a range from 7.5 to 17.9 µg/L. Downstream of Iron Gate dam, chlorophyll-*a* concentrations averaged 6.1 µg/L and ranged from 4.5 to 8.5 µg/L. The mean bias and mean absolute error for these sample sets were identical (8.52 µg/L) indicating that the means of these two data sets were always different. Applying a two sample t-test to the mean values indicates that the mean value for chlorophyll-*a* samples collected upstream of the curtain was significantly greater than the mean of samples collected downstream of Iron Gate dam (α=0.95, p<0.001).

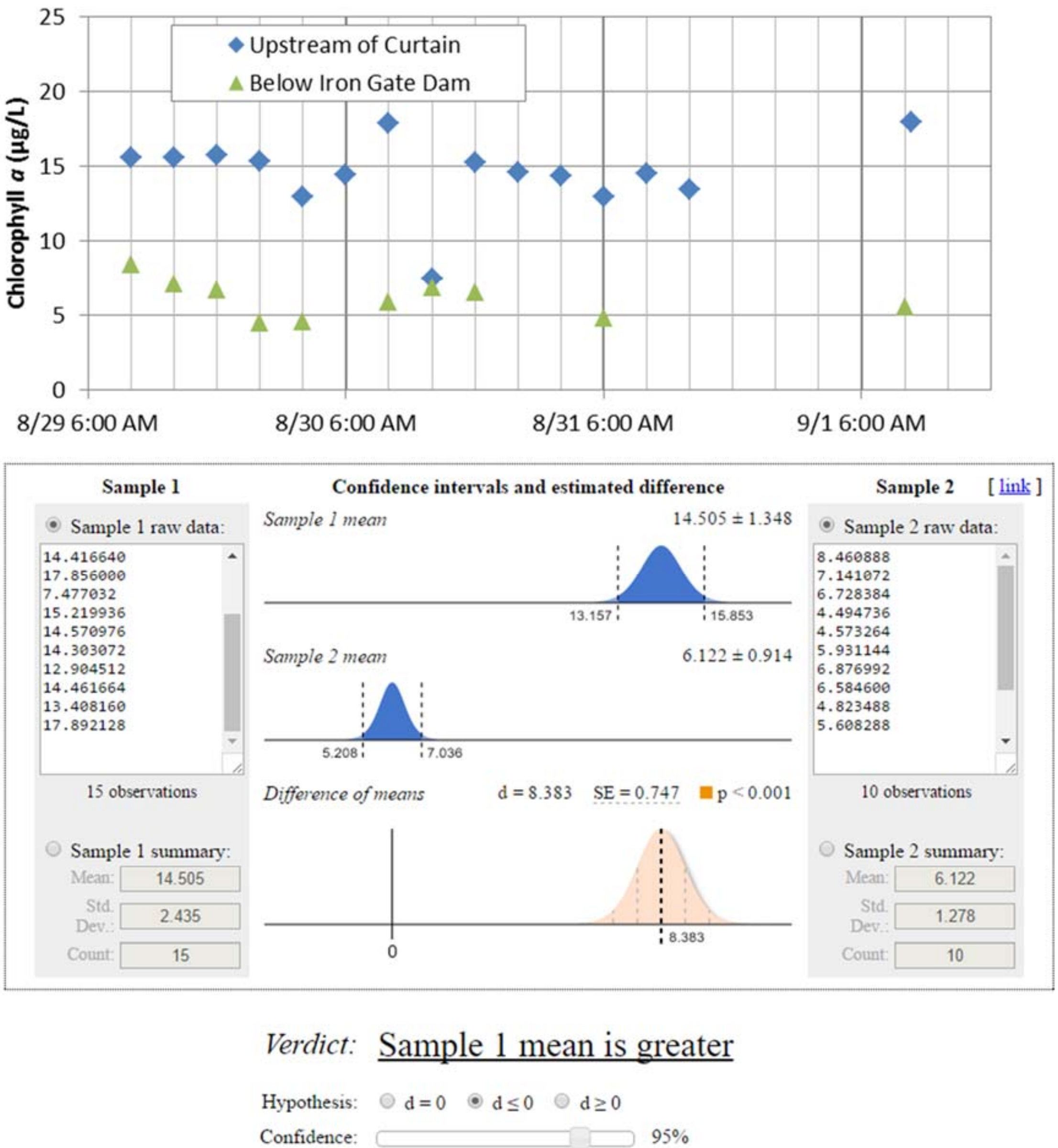

Figure 4-44. Chlorophyll-*a* Concentrations from Samples Collected over a 72-hour Sampling Period using Autosamplers Upstream of the Curtain (Sample 1) and below Iron Gate Dam (Sample 2).[6]

[6] T-test graphics and statistics were based on an online tool that can be found at http://www.evanmiller.org/ab-testing/t-test.html

4.5 Photosynthetically Available Radiation Profiles

Vertical profiles measuring PAR on June 28, August 29, and September 20, 2016 indicate that light intensity was highest near the surface and decreased with depth (Figures 4-45, 4-46, and 4-47). The pattern of PAR extinction is a function of water clarity, cloud cover, time of day, particulate and dissolved matter, and a variety of other factors. Light extinction coefficients were calculated for the three dates both upstream and downstream of the curtain. Upstream of the curtain, rates of extinction were higher (light did not penetrate as far into the water column) than downstream on June 28 (0.25 vs 0.22, respectively) and September 20 (0.34 vs 0.15, respectively). However, the data from the two profiles on August 29 were essentially identical upstream and downstream of the curtain (0.29). On September 20, PAR extended to a notably deeper depth downstream of the curtain. Secchi disk measurements for all three sampling dates were deeper downstream of the curtain than upstream.

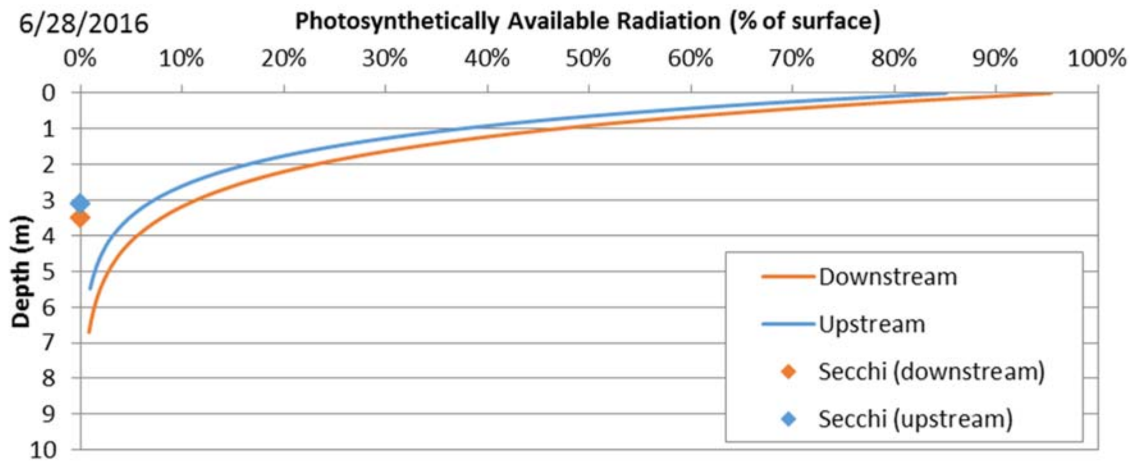

Figure 4-45. Photosynthetically Available Radiation and Secchi Disk Reading Upstream and Downstream of the Curtain on 6/28/2016.

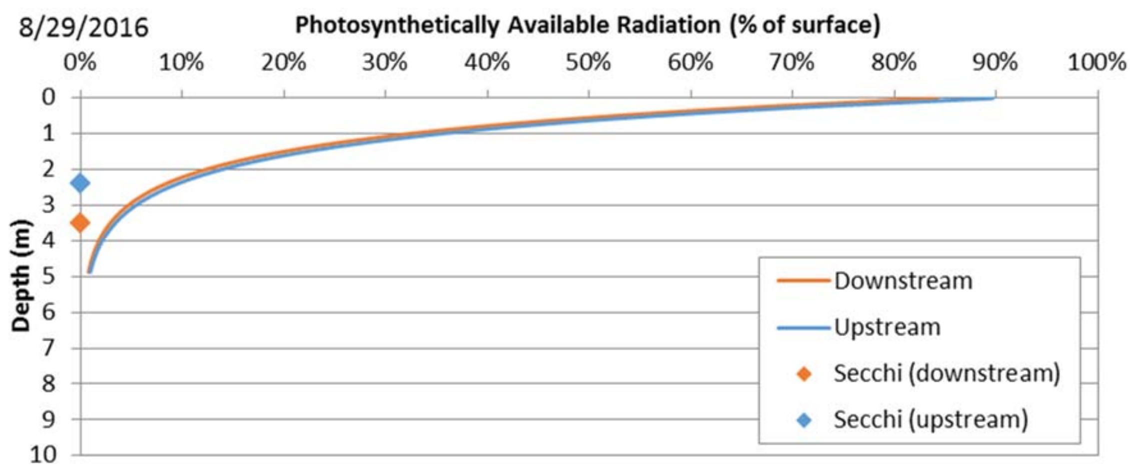

Figure 4-46. Photosynthetically Available Radiation and Secchi Disk Reading Upstream and Downstream of the Curtain on 8/29/2016.

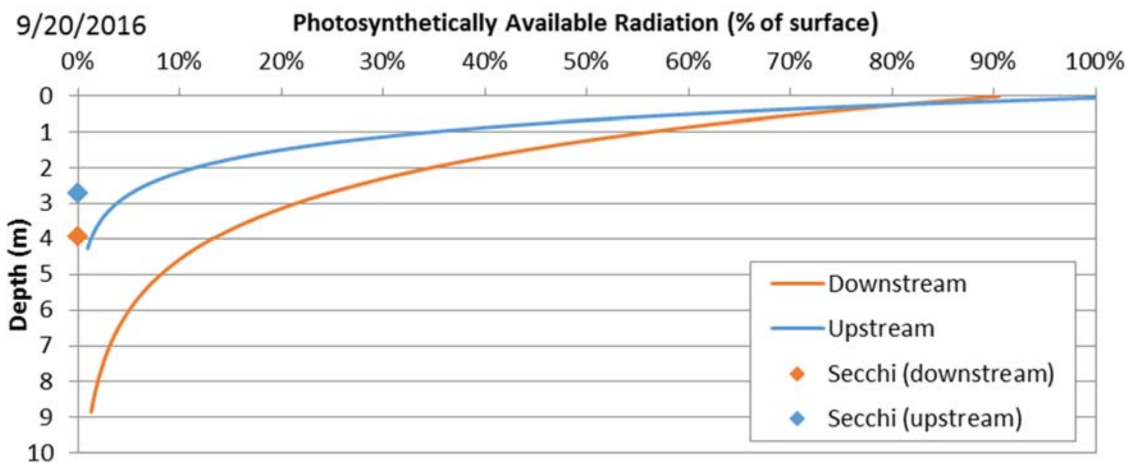

Figure 4-47. Photosynthetically Available Radiation and Secchi Disk Reading Upstream and Downstream of the Curtain on 9/20/2016.

4.6 Heterogeneity Study

Data was collected from four locations around the upstream BOB on three sampling dates from June through September 2016.

4.6.1 Physical Parameters

Compared to the platform location, water temperatures distributed around the upstream platform were generally within 0.5°C (n = 16), and the remainder within 0.9°C (n=4) over the summer sampling periods (Table 4-1).

Table 4-1. Water Temperatures (°C) Collected at the Upstream BOB and Four Heterogeneity Sampling Locations Upstream of the Curtain in 2016

		Water Temperature (°C)				
Date	Depth (m)	Upstream BOB	H1	H2	H3	H4
June 28	0.1	23.7	24.2	23.6	24.6	23.8
	1	23.1	23.7	23.4	23.2	23.4
Aug 29	0.1	22.5	22.7	22.6	22.9	22.9
	1	22.3	22.5	22.4	22.7	22.8
Sept 20	0.1	19.8	20.0	20.0	20.5	20.7
	1	19.9	20.0	19.9	19.9	20.0

Compared to the platform location, dissolved oxygen concentrations at the heterogeneity sampling sites around the upstream platform were generally within 0.5 mg/L (n=16), and the remainder within 0.7 mg/L (n=4) over the summer sampling periods (Table 4-2). Compared to the platform location, pH values at the heterogeneity sites around the upstream platform were all within 0.3 pH units (n = 20) (Table 4-3).

Table 4-2. Dissolved Oxygen (mg/L) Collected at the Upstream BOB and Four Heterogeneity Sampling Locations Upstream of the Curtain in 2016

		Dissolved Oxygen (mg/L)				
Date	**Depth (m)**	**Upstream BOB**	**H1**	**H2**	**H3**	**H4**
June 28	0.1	9.6	9.4	9.4	9.4	9.5
	1	9.6	9.4	9.4	9.4	9.5
Aug 29	0.1	8.9	9.1	8.8	9.6	8.2
	1	9.1	9.2	9.1	9.7	9.7
Sept 20	0.1	12.2	11.7	12.0	11.7	12.1
	1	12.2	11.9	11.8	12.5	12.3

Table 4-3. pH Values Collected at the Upstream BOB and Four Heterogeneity Sampling Locations Upstream of the Curtain in 2016

		pH				
Date	**Depth (m)**	**Upstream BOB**	**H1**	**H2**	**H3**	**H4**
June 28	0.1	8.1	8.3	8.3	8.3	8.3
	1	8.1	8.3	8.3	8.3	8.3
Aug 29	0.1	9.7	9.7	9.7	9.8	9.7
	1	9.7	9.8	9.8	9.8	9.8
Sept 20	0.1	9.4	9.4	9.4	9.4	9.4
	1	9.4	9.4	9.3	9.4	9.4

4.6.2 Water Quality Constituents

The heterogeneity study also examined lateral and vertical differences total and filtered microcystin, total cyanobacteria, and total *Microcystis*. Total microcystin on both the August 29 and September 20 sampling events at the upstream platform was within the range of microcystin in water samples at the four heterogeneity sites at both 0.1 m and 1 m (Figures 4-48 and 4-49).

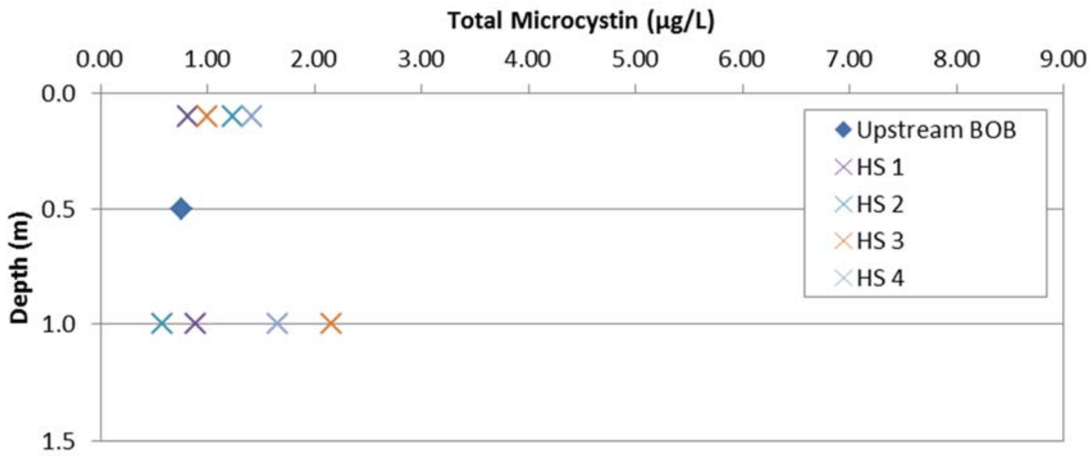

Figure 4-48. Comparison of Total Microcystin at Selected Locations Upstream of the Curtain on 8/29/2016

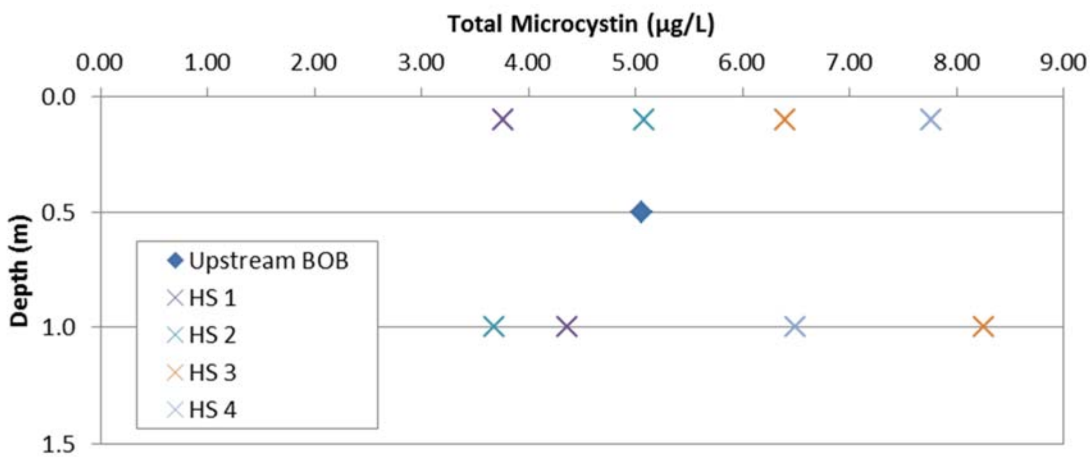

Figure 4-49. Comparison of Total Microcystin at Selected Locations Upstream of the Curtain on 9/20/2016

Filtered microcystin at the upstream platform was slightly higher (0.01 µg/L) than the range of microcystin in water samples at the four heterogeneity sites at both 0.1 m and 1 m in August, and higher (< 0.17 µg/L) in September (Figures 4-50 and 4-51).

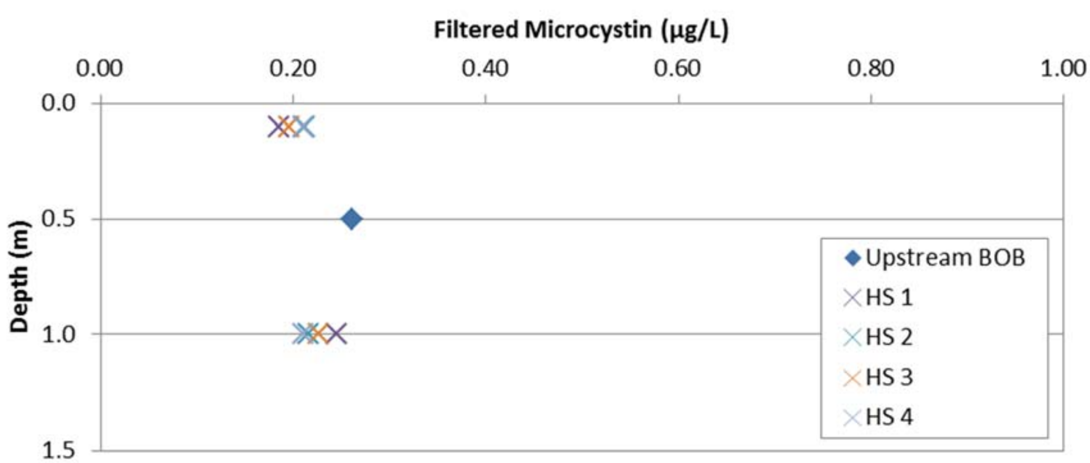

Figure 4-50. Comparison of Filtered Microcystin at Selected Locations Upstream of the Curtain on 8/29/2016

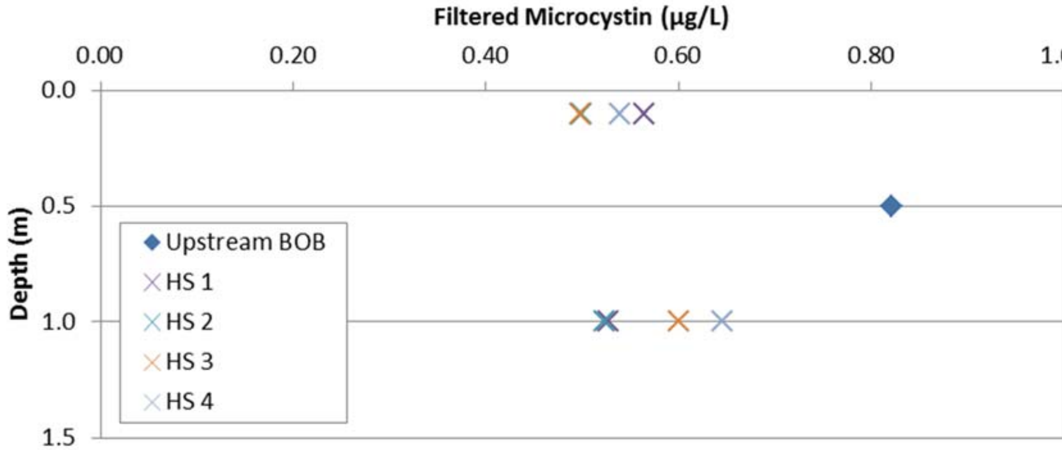

Figure 4-51. Comparison of Filtered Microcystin at Selected Locations Upstream of the Curtain on 9/20/2016

Total cyanobacteria on both the August 29 and September 20 sampling events at the upstream platform was within the range of total cyanobacteria in water samples at the four heterogeneity sites at both 0.1 m and 1 m (Figures 4-52 and 4-53).

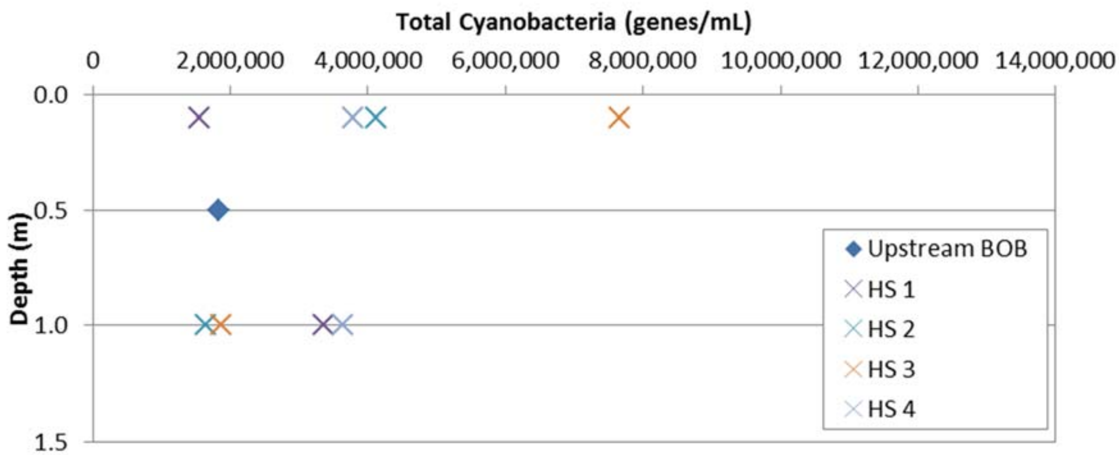

Figure 4-52. Comparison of Total Cyanobacteria at Selected Locations Upstream of the Curtain on 8/29/2016

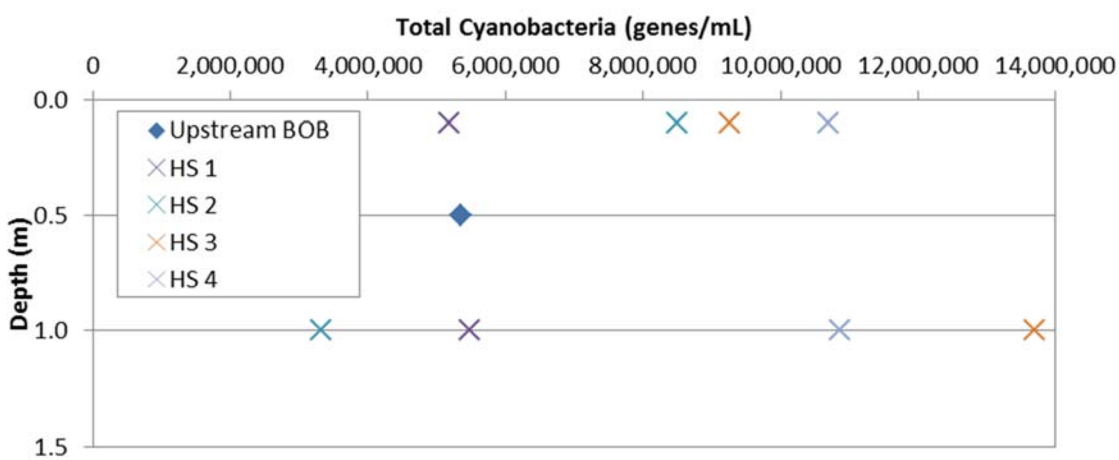

Figure 4-53. Comparison of Total Cyanobacteria at Selected Locations Upstream of the Curtain on 9/20/2016

4.6.2.1 Total *Microcystis*

Total *Microcystis* on both the August 29 and September 20 sampling events at the upstream platform was approximately within the range of total *Microcystis* in water samples at the four heterogeneity sampling sites at both 0.1 m and 1 m (Figure 4-54 and Figure 4-55). Total *Microcystis* at the BOB was slightly lower than the range at the heterogeneity sites in August (<240,000 genes/mL).

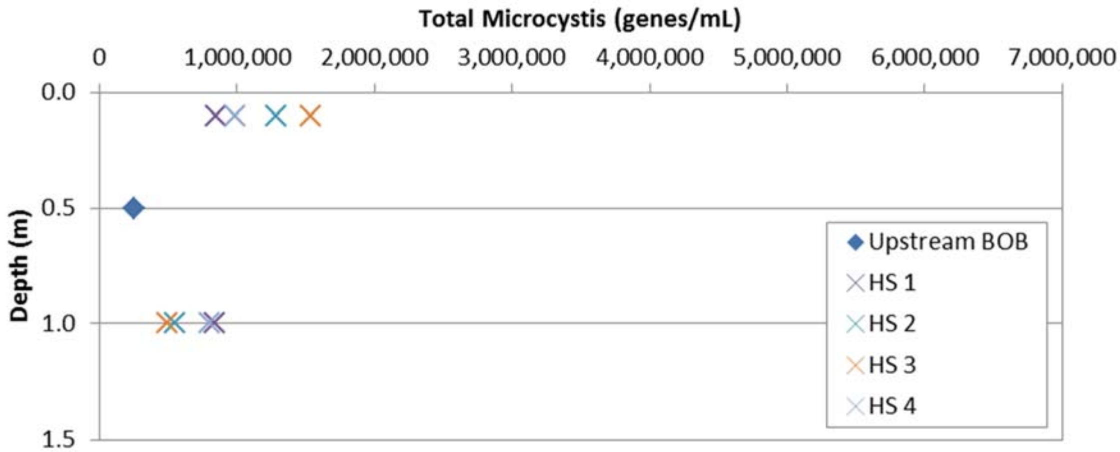

Figure 4-54. Comparison of Total *Microcystis* at Selected Locations Upstream of the Curtain on 8/29/2016

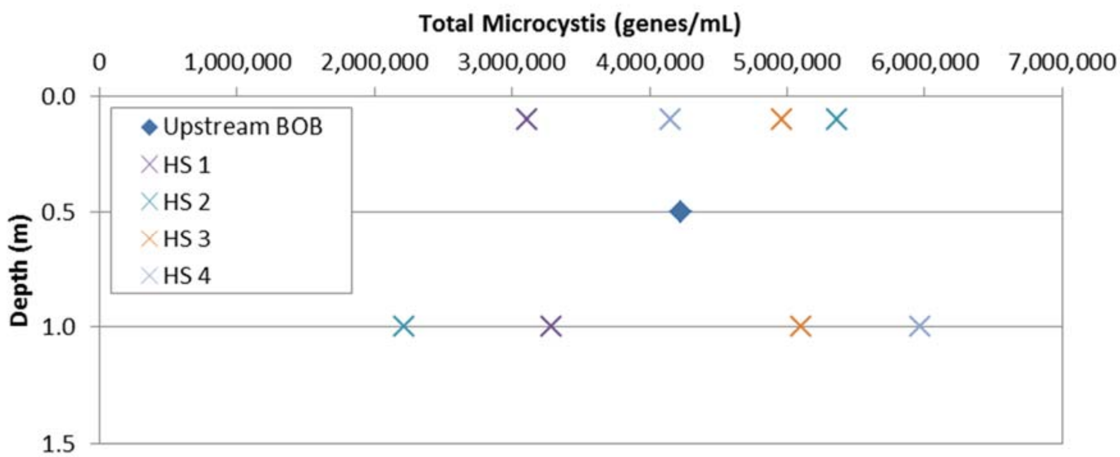

Figure 4-55. Comparison of Total *Microcystis* at Selected Locations Upstream of the Curtain on 9/20/2016

4.7 Meteorological Data

Air temperatures collected from the weather station at Iron Gate dam represent short-term (sub-daily to daily and multiple day) and long-term (monthly/seasonal) variations (Figure 4-56). Air temperatures increased gradually through June, peaking over 40°C in July and August before cooling gradually through the late summer and fall.

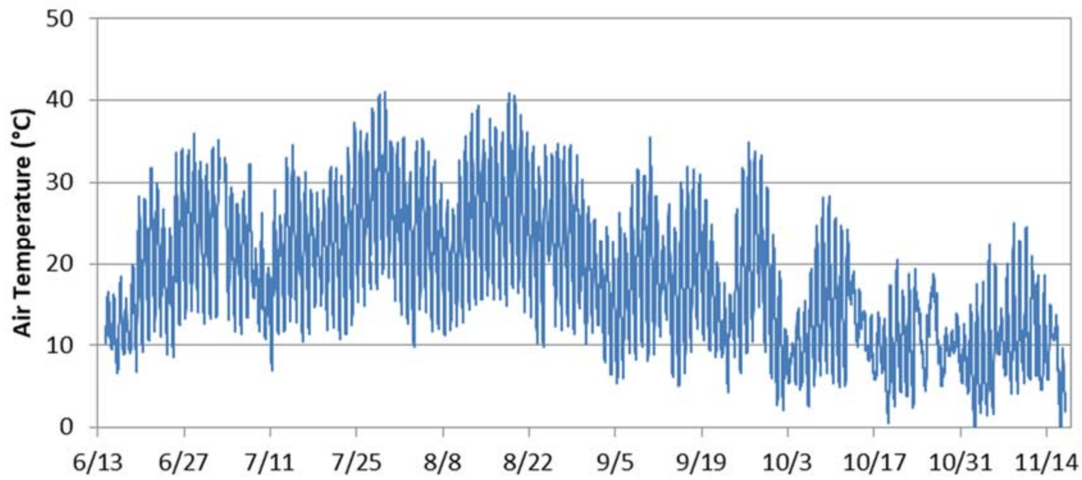

Figure 4-56. Air Temperature at Iron Gate Reservoir from 6/14/2016 to 11/16/2016

Peak wind gusts and average wind speeds during the study period represented both short term variability and broader seasonal trends (e.g., higher winds occurring later in the year) (Figures 4-57 and 4-58). Wind data was used in the calculations performed in Section 2.

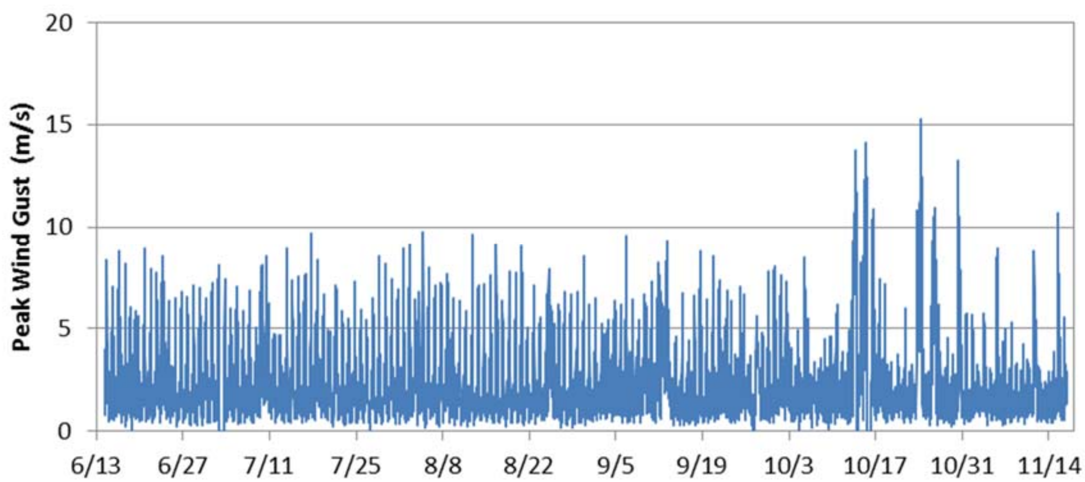

Figure 4-57. Peak Wind Gusts at Iron Gate Reservoir from 6/14/2016 to 11/16/2016

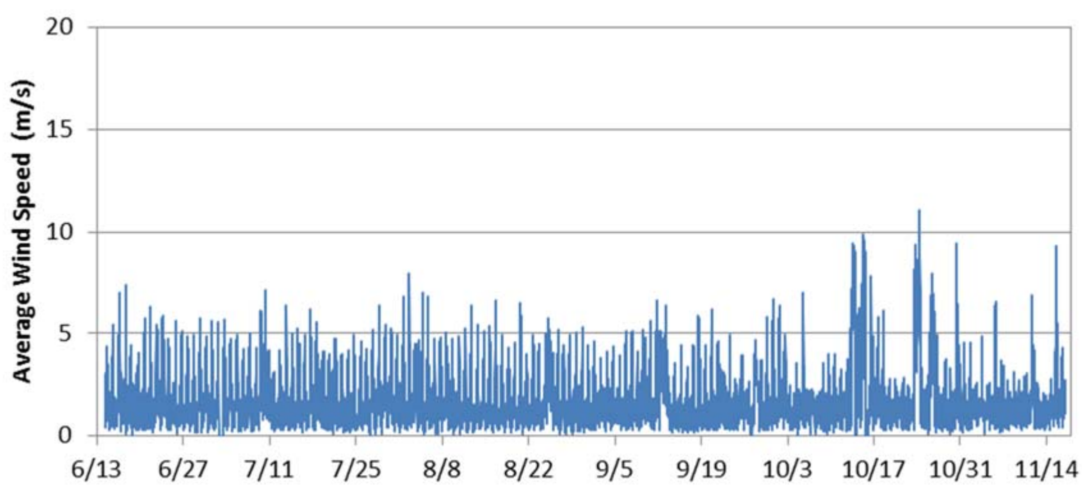

Figure 4-58. Average Wind Speed at Iron Gate Reservoir from 6/14/2016 to 11/16/2016

4.8 Boat Dance Flows

At the request of the Yurok Tribe, a pulse of water to support their Boat Dance ceremonies was released starting on August 19, 2016. Flows released from Iron Gate dam peaked at just over 2,000 cfs for about 17.5 hours before gradually declining to baseflows levels of around 950 cfs on the afternoon of August 26 (Figure 4-59).

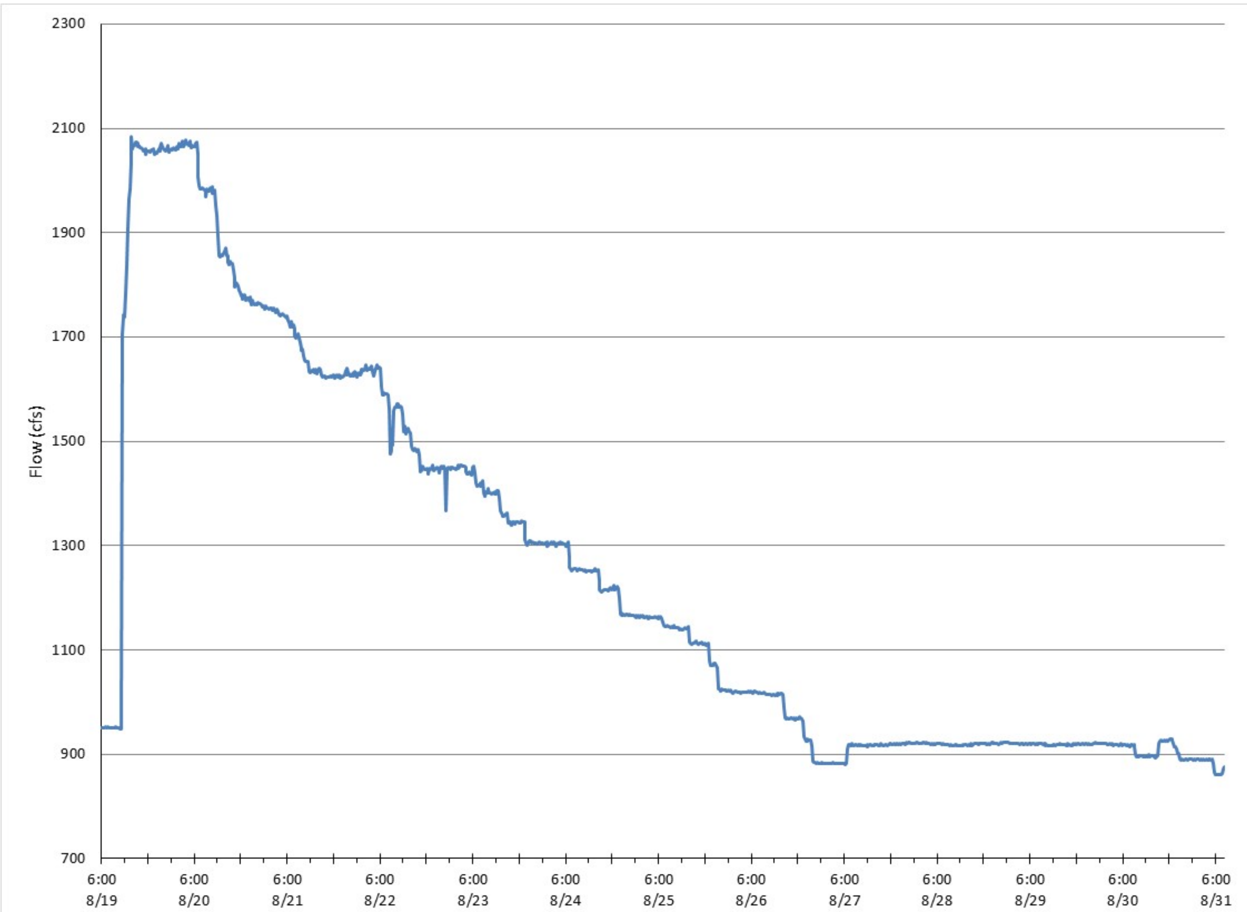

Figure 4-59. Flow in the Klamath River below Iron Gate Dam at 15-minute intervals from August 19 to 31, 2016 (USGS Gage No. 11516530)

The curtain was deployed to a depth of 10.7 m when Boat Dance flow releases started. During the peak flow release on August 19 of around 2,080 cfs (Figure 4-59), about 1,500 cfs was flowing through Iron Gate powerhouse with the balance of around 580 cfs spilled over the Iron Gate dam spillway. PacifiCorp raised the curtain to 7.6 m on August 22 and then 6.1 m on August 23. The depth of curtain was altered to increase dissolved oxygen levels downstream of Iron Gate dam and ensure compliance with conservation goals of the *Interim Operations Habitat Conservation Plan for Coho Salmon* (PacifiCorp 2012).

4.9 Reservoir Elevation

With one exception, the water surface elevation in Iron Gate reservoir was relatively stable throughout the study period (Figure 4-60). Daily fluctuations were typically less than 0.25 m. In early October,

RESULTS

PacifiCorp reduced the water surface elevation by about 3.5 m; a draw-down that lasted a few days before the reservoir gradually re-filled.

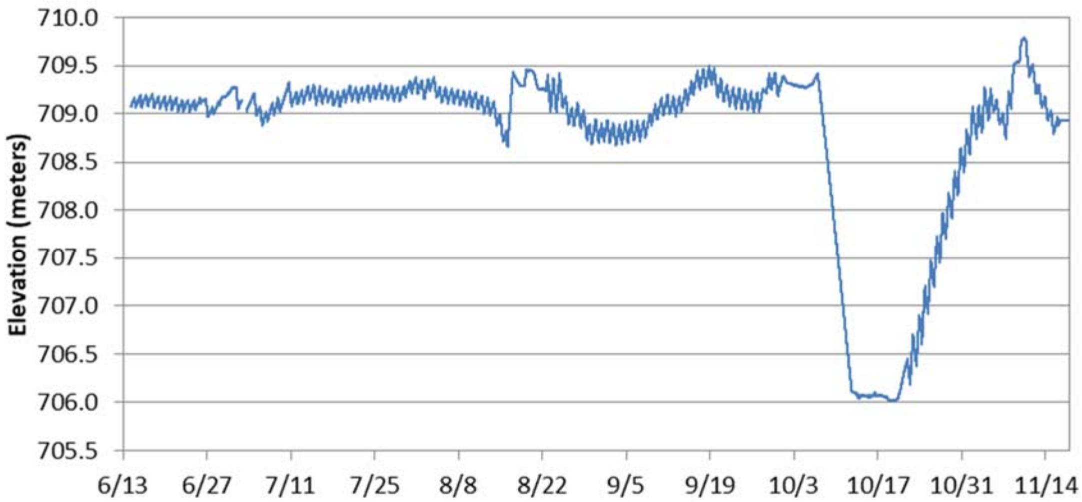

Figure 4-60. Iron Gate Reservoir Water Surface Elevation from 6/14/2017 to 11/14/2017.

Discussion

Assessment of curtain effectiveness was performed by integrating the data presented previously (Section 4) to address three principal hypotheses related to:

- segregation of shallow and deeper waters
- similarity of water downstream of the curtain and deeper water upstream
- conditions downstream of Iron Gate dam being representative of those downstream of the curtain

Field studies conducted in 2016 were designed to address these three hypotheses and their corollary sub-hypotheses. In this section, the results presented above are discussed in the context of these hypotheses.

5.1 Hypothesis 1: The curtain isolates surface waters upstream of the curtain, segregating shallow and deep waters

Under hypothesis 1, the following sub-hypotheses were evaluated:

- Phycocyanin levels are higher at SU than at DU, SD, DD, or KRBI locations
- Microcystin levels are higher at SU than at DU, SD, DD, or KRBI locations
- Light extinction rates are greater at SU than SD indicating less clarity and presumably more cyanobacteria at the SU location
- Cyanobacteria are more abundant and microcystin is present at higher concentrations in the SU zone than DU, SD, or DD
- The curtain is of sufficient depth to limit cyanobacteria from passing under the curtain during normal diel vertical movement

5.1.1 Phycocyanin levels are higher at SU than at DU, SD, DD, or KRBI

As was discussed previously, the phycocyanin probes on the data sondes proved challenging to calibrate and maintain. As a proxy, this discussion uses chlorophyll-*a* levels as a surrogate for phycocyanin. A limitation to this approach is that chlorophyll-*a* represents all phytoplankton, while phycocyanin is specific to cyanobacteria. However, assuming that chlorophyll-*a* supporting algae are found primarily in the photic zone makes this a reasonable surrogate for cyanobacteria, which dominate the Iron Gate reservoir phytoplankton community during the summer and fall.

Before late September, chlorophyll-*a* readings at the 0.5 m data sondes were slightly lower at the downstream sonde, with only short periods when downstream readings exceeded upstream values. These short periods were associated with elevated chlorophyll-*a* values that are presumed from increases in primary production (blooms) or curtain operations (Figure 4-5). There was a modest increase in chlorophyll-*a* values on August 22 and 23 when the curtain was raised from a depth of 7.6 m to 6.1 m. In late September, chlorophyll-*a* levels in shallow water on the upstream side of the curtain began to increase from 5 µg/L to over 10 µg/L, ultimately exceeding 20 µg/L in November. This increasing trend through November is consistent with chlorophyll-*a* grab samples taken at the log boom on October 25, 2016 as part of the KHSA baseline phytoplankton sampling (Figure 4-6). Bio-fouling of the sonde sensor for chlorophyll-*a* could be an explanation for the high levels of chlorophyll-*a* in November, but because chlorophyll-*a* levels were also increasing at the log boom, this seems unlikely. Based on the KHSA monthly sampling program, the dominant algal group in September and October was cyanobacteria, 89 and 66 percent, respectively (Table 5-1). However, the total algal density and cyanobacteria cell counts show that algal populations were declining towards the end of the year (Figures 5-1 and 5-2). The September 6 and October 25, 2016 KHSA baseline phytoplankton samples from the log boom indicated that *Aphanizomenon flos-aquae* was the primary cyanobacteria species present (Figure 5-2).

From September onwards, chlorophyll-*a* levels in shallow water on the downstream side of the curtain and in the river downstream of Iron Gate dam remained relatively constant and were mostly below 2.5 µg/L (Figure 4-6). The curtain during this period was 3 m deep. The curtain appeared to restrict the water with higher levels of algae from entering the powerhouse intake and being released into the river, because levels of chlorophyll-*a* from the river essentially matched those from the shallow water downstream of the curtain and were consistently lower than those in shallow waters upstream of the curtain.

Table 5-1. Total Density (in natural units) and Percentages of Phytoplankton Groups from Samples Collected at 0.5 m Depth at the Log Boom in Iron Gate Reservoir in 2016

Date, Time	Cyanobacteria		Diatom		Cryptophyte		Green	
	Natural Units	Percent	Natural Units	Percent	Natural Units	Percent	Natural Units	Percent
6/8/16, 9:20	-	0%	465	65%	195	27%	57	8%
7/12/16, 10:30	27	7%	137	34%	164	41%	76	19%
8/10/16, 10:30	3,500	75%	1,066	23%	-	0%	101	2%
9/6/16, 12:20	2,188	89%	67	3%	79	3%	123	5%
10/25/16, 9:30	641	66%	299	31%	34	4%	-	0%

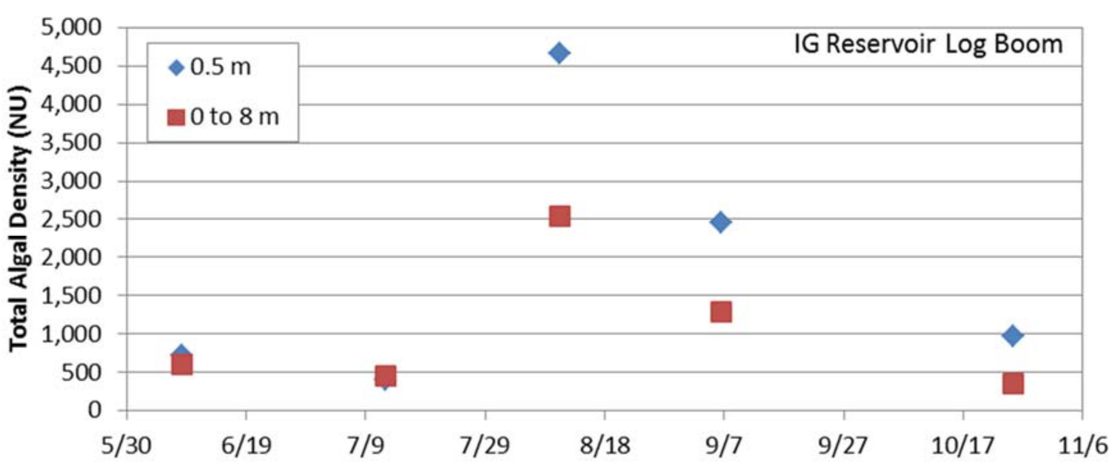

Figure 5-1. Total Algal Density in Natural Units (NU) at Surface (0.5 m) and in a Depth-integrated Sample (0 to 8 m) from the Log Boom in Iron Gate Reservoir in 2016

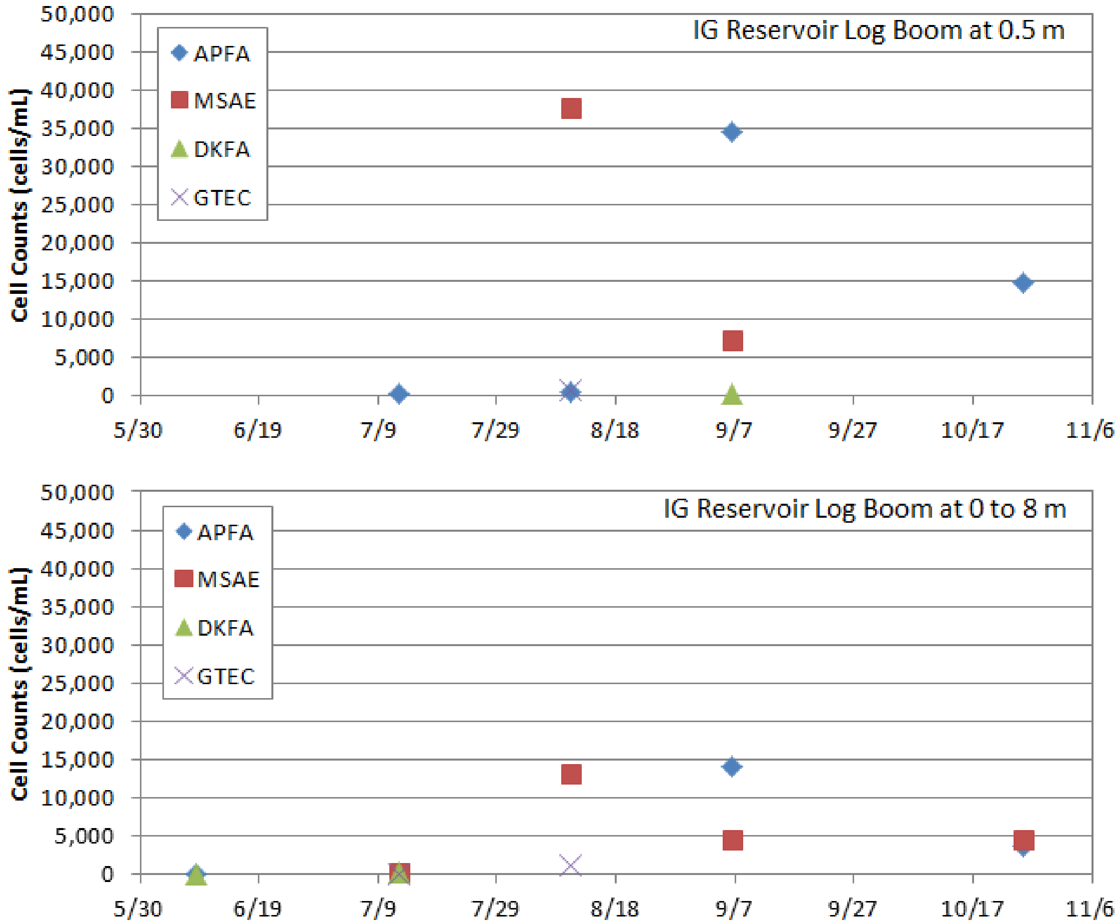

Figure 5-2. Cyanobacteria Cell Counts at Surface (0.5 m, upper panel) and in a Depth-integrated Sample (0 to 8 m, lower panel) from the Log Boom in Iron Gate Reservoir

(Note: APFA, *Aphanizomenon flos-aquae*; MSAE, *Microcystin aeruginosa*; DKFA, *Dolichospermum flos-aquae*; GTEC, *Gloeotrichia echinulata*)

5.1.2 Microcystin levels are higher at SU than at DU, SD, DD, or KRBI locations

Data from the detailed vertical profiles and the multi-day autosampler study in 2016 was used to address this hypothesis. It is worth noting that while filtered microcystin concentrations, while differing approximately by an order of magnitude lower, largely mirror unfiltered concentrations and are treated together in this discussion.

Data from detailed vertical profiles from June 28 (pre-curtain), August 29, and September 20, 2016 were evaluated. In June before the curtain was deployed, microcystin levels (total and filtered) were less than the quantitation limit (0.10 µg/L) throughout the water column on both sides of the curtain and in the river downstream of the dam (Figures 4-17 and 4-18). August profiles provide mixed results and are discussed in the following paragraph. September profiles indicate total and filtered microcystin concentrations were higher in the near-surface (depths of 3 m or less), upstream of curtain site (SU) than on the near-surface downstream of curtain site (SD) (Figures 4-21 and 4-22) and below Iron Gate dam.

High flows (up to 2,000 cfs for over 17 hours) associated with Boat Dance Flows (see Section 4.8) in late-August may have resulted in mixing of the water column upstream of the curtain which in turn affected the results of field studies. This mixing likely created similar algal distributions and microcystin concentrations both upstream and downstream of the curtain that may be atypical of summer conditions (such as those observed during curtain operations in 2015). By September, the seasonal reservoir segregation was apparent. Total cyanobacteria levels in the late August samples were relatively high (Figure 4-24) when compared to total or filtered microcystin (Figures 4-19 and 4-20) suggesting that the algae present were not *Microcystis*. Phytoplankton speciation (via microscopy) from the 0.5 m sample collected at the log boom upstream of Iron Gate on September 6 (the closest available sample date to the August 29 vertical profile) indicated that *Aphanizomenon flos-aquae* accounted for 61 percent of the sample at the same location and *Microcystis* only 27 percent.

Microcystin concentration in the Klamath River downstream of Iron Gate were lower than those in the reservoir upstream of the curtain for all samples. Further, during all vertical profile events, samples from deeper waters (9 m to 15 m) had nearly identical levels of microcystin (Figures 4-17, 4-19, and 4-21) upstream and downstream of the curtain, suggesting similar conditions at depth.

The multi-day autosampler study supplements the detailed vertical profile results at a finer time resolution. All autosampler samples were collected at 0.5 m and are representative of conditions in the top 0-1 m of waters in the reservoir upstream of the curtain and are consistent with all KHSA sampling in the river downstream of Iron Gate dam. These results indicate that there were significant differences in mean concentrations of total microcystin upstream of the curtain (SU) when compared to the river downstream of Iron Gate dam (Figure 4-41) with higher mean concentrations of microcystin upstream than downstream.

5.1.3 Light extinction rates are greater at SU than SD indicating less clarity and presumably more cyanobacteria at the SU location

In late June 2016, before the curtain was deployed, light extinction curves on the upstream and downstream side of the curtain were very similar with a slightly deeper penetration of light (about 1.5 m total depth and a slightly lower light extinction value) on the downstream side of the curtain (Figure 4-45). The second set of curves from the data collected on August 29 when the curtain was at 6.1 m deep were basically identical (Figure 4-46). High flows associated with Boat Dance Flows in late-August may have affected conditions at this time, which resulted in mixing of the water column upstream of the curtain. This in turn created similar algal distributions and light penetration profiles both upstream and downstream of the curtain that may be atypical of summer conditions. September PAR data indicate light intensity readings downstream of the curtain extending to about twice the depth of the upstream location (Figure 4-47). Throughout the summer, Secchi disk measurements were consistently higher downstream of the curtain. These data are consistent with the hypothesis that light extinction rates are greater at SU than SD, indicating less clarity and presumably more cyanobacteria at the SU location.

5.1.4 Cyanobacteria are more abundant and microcystin is present at higher concentrations in the SU zone than DU, SD, or DD

This sub-hypothesis was analyzed by using data from the detailed vertical profiles of total cyanobacteria and total *Microcystis*, as well as the cyanobacteria samples collected during the autosampler study. The results for cyanobacteria in these experiments follow the same pattern discussed above for microcystin (Section 5.1.2). Boat Dance flows and raising of the curtain appear to have influenced the distribution of total microcystin, total cyanobacteria, total *Microcystis*, and chlorophyll-*a* on August 29, 2016 when concentrations downstream of the curtain were only slightly less than those upstream of the curtain (Figures 4-19, 4-24, 4-27, and 4-30).

5.1.5 The curtain is of sufficient depth to limit cyanobacteria from passing under the curtain during normal diel vertical movement

The focus of this hypotheses is that if the curtain is placed at an appropriate depth *Microcystis* will not be entrained under the curtain. This is important for curtain effectiveness because *Microcystis* has the ability to migrate vertically up to several meters on a diel basis (see summary in Mantzouki et al. 2016). Focused investigations in Iron Gate and Copco reservoirs in 2007 and 2008 indicated that nitrogen was the nutrient limiting *Microcystis* growth during the summer months (Moisander et al. 2009). Maximum vertical movement for smaller colonies (<100 µm in radii) was predicted to be approximately 7 m in just over 12 hours while larger colonies (200-800 µm in radius) were predicted to reach over 8 m between 4-8 hours. Further, the larger colonies may cycle back and forth from depth to the near surface much faster than smaller colonies (Visser et al. 1997).

The autosampler data collected in 2016 indicates that there was diel variability in total cyanobacteria concentrations present in surface waters upstream of the curtain (Figure 4-42). This pattern is absent in *Microcystis* and chlorophyll-*a* data (Figures 4-43 and 4-44). A similar result was observed in 2015 (see Figures 34 and 35 in Watercourse 2016).

Chlorophyll-*a* can also provide insight into algae movement and fate in this discussion. The 15-minute chlorophyll-*a* levels recorded by the 5 m and 10 m sondes on the downstream side of the curtain are relatively constant from July 1-September 30. The 10 m sonde was offline for a portion of the study period; nevertheless, the data taken when both sondes are functional indicate that conditions were similar. The vertical profiles also indicate there was little algae at this depth (Section 4.3). Overall, this suggests that algae was not passing from near-surface waters under the curtain. The 5 m and 10 m sondes represent the deeper waters conveyed under the curtain and the lack of variability in chlorophyll-*a* suggests little entrainment of upstream surface waters at this depth.

5.1.6 Conclusion

Results of 2016 field investigations largely support these sub-hypotheses and show that the curtain isolates surface waters upstream of curtain and segregates shallow and deep waters of Iron Gate reservoir. Upstream of curtain, cyanobacteria and microcystin concentration were consistently higher than those downstream of the curtain. The greater depth of light penetration apparent in the PAR study (including Secchi disk) indicates that water downstream of the curtain contain less light-impeding particles. Overall, verification of these sub-hypotheses indicates that the curtain functioned as expected. However, the increase of flows associated with the Boat Dance release mixed the water columns on both sides of the curtain creating conditions that temporarily limited the effectiveness of the curtain in reducing the entrainment of algae and release of that material to the Klamath River downstream.

5.2 Hypothesis 2: Shallow and deep water downstream of the curtain will be similar to deep-water conditions upstream of the curtain because of withdrawal from beneath the curtain and mixing downstream of the curtain

Hypothesis 2 included the following sub-hypotheses:

- Physical data (water temperature, dissolved oxygen, pH) is comparable for DU and DD locations

- There is less stratification present downstream of the curtain at SD and DD than upstream at SU and DU

5.2.1 Physical data (water temperature, dissolved oxygen, pH) is comparable for DU and DD locations

Comparing the deeper upstream and downstream locations utilized data collected by the 10 m deep data sondes, as well as thermograph arrays and vertical profiles. The downstream 10 m sonde failed shortly after deployment in late June and did not record data for several weeks. However, water temperatures recorded by the thermograph array are available at this depth. Overall, water temperatures at the 10 m depth are similar on either side of the curtain. The downstream temperatures were slightly cooler, but the difference was less than 0.3°C on average. PacifiCorp raised the curtain to 7.6 m on August 22 and then 6.1 m on August 23, which resulted in an increase in both water temperature and dissolved oxygen downstream of the curtain and in the river downstream of Iron Gate dam (Figures 4-1 and 4-2).

Before the curtain was deployed in June, the 10 m deep dissolved oxygen and pH levels upstream and downstream of the curtain were similar. The downstream 10 m deep sonde failed in from June through mid-September and dissolved oxygen and pH are not available for this period. From mid-September to mid-November, the upstream and downstream 10 m deep sondes recorded similar levels of dissolved oxygen (Figures 4-2 and 4-3) and pH (Figure 4-4). Dissolved oxygen levels at all data sondes, regardless of location relative to the curtain, were declining through August (Figures 4-2 and 4-3). Dissolved oxygen concentrations were lower on the downstream side of the curtain at all three data sondes (0.5 m, 5 m, and 10 m depths) than the 5 m deep sonde on the upstream side of the curtain. With the curtain at 10.7 m on August 19, the bulk of the water entrained during the Boat Dance Flows had dissolved oxygen concentrations similar to the 10 m upstream data sonde (Figure 4-2). This altered flow regime resulted in increased entrainment under the curtain of water relatively lower in dissolved oxygen. Because of turbine venting in the Iron Gate powerhouse, dissolved oxygen concentrations in the river downstream of Iron Gate dam during this period were higher than levels in the reservoir. The upstream 10 m deep sonde recorded slightly higher dissolved oxygen concentrations than the downstream sonde through the end of September, but the difference was less than 1 mg/L (Figure 4-2).

As with dissolved oxygen, pH was similar through the mid-September to mid-November period, with modest differences and slightly higher values upstream of the curtain (Figure 4-4). Collectively, these data indicate that the water quality conditions in the deeper locations (DU and DD) on either side of the curtain were comparable.

5.2.2 There is less stratification present downstream of the curtain at SD and DD than upstream at SU and DU

Vertical profile data from the thermograph array upstream of the curtain indicate stratification was present in Iron Gate reservoir upstream of the curtain throughout most of the summer months, beginning in June and ending in September (Figures 4-10 and 4-12). In contrast, the thermograph array downstream of the curtain shows minimal difference in temperatures between readings taken near the surface and those taken at depth (Figures 4-11 and 4-13). Stratified conditions occurred downstream of the curtain in June prior to the curtain being lowered, but isothermal conditions subsequently developed downstream of the curtain after curtain deployment. Water temperatures downstream of the curtain generally mirrored the water temperature at 10 m deep upstream of the curtain. Water temperatures were cooler than shallower waters upstream of the curtain (by up to 4°C), and were warmer than deeper waters (15 m deep) upstream of the curtain by up to 5°C, indicating that waters were drawn from the 10 m depth upstream of the curtain with modest effect from either deeper or shallower waters. These observations support the hypothesis that there is less stratification present downstream of the curtain, and shallow and deeper waters are similar on the downstream side.

5.2.3 Conclusion

Results from these experiments show that while there were some minor variations in conditions throughout the water column, conditions downstream of the curtain (DD and SD) were generally similar to deep-water conditions upstream of the curtain (DU). Physical parameters at 10 m deep upstream and downstream of curtain were comparable. Furthermore, data from thermographs collected on both sides of curtain show that there was minimal stratification downstream of curtain once the curtain was deployed. These observations support the hypothesis that withdrawal from beneath the curtain creates vertically mixed conditions downstream of the curtain.

5.3 Hypothesis 3: Conditions downstream of Iron Gate dam are similar to those downstream of the curtain, with the exception of dissolved oxygen, which is increased as the water is re-aerated as it passes through the Iron Gate powerhouse

Under hypothesis 3, the following sub-hypotheses were evaluated:

- Physical data (water temperature, pH, phycocyanin) at KRBI is an integrated signal representing DU, SD, and DD, locations
- Microcystin levels are similar between DU, SD, DD, and KRBI locations
- Dissolved oxygen levels are higher at KRBI than DU or DD

As discussed under hypothesis 2 (Section 5.2), deep-water conditions upstream of the curtain (DU) are similar to conditions downstream of the curtain (SD and DD). Hence, this section discusses conditions at KRBI as an integrated signal that represents the entire water column downstream of the curtain (i.e., SD and DD); discussions pertaining to DU are not included to reduce redundancy.

5.3.1 Physical data (water temperature and pH) at KRBI is an integrated signal representing DU, SD, and DD, locations

Temperatures downstream of the curtain were previously demonstrated to reflect deep-water temperature conditions upstream of the curtain (DU) (see Section 5.2). The water temperature at 0.5 m depth downstream of the curtain was notably warmer than the other temperature traces prior to curtain deployment and remain warmer than deeper water on the downstream side of the curtain through the summer (Figure 5-3). Pertinent to this discussion is that the intake to the powerhouse is designed to withdraw water throughout the water column from the surface to approximately 10 m in depth. The Klamath River below Iron Gate dam temperature before curtain deployment closely matches the temperature at 5 m depth. After the curtain was lowered to 7.6 m, variability in temperature signals diminished downstream of the curtain and the dam. For the rest of the summer, the KRBI temperature was never more than 2.2^{o}C cooler than the 0.5 m deep temperature downstream of the curtain (Figure 5-3). Also, after curtain deployment, the difference between the KRBI temperature trace and the average of the three data sonde temperatures (0.5 m, 5 m, and 10 m deep) downstream of the curtain was always less than 1°C, with an average difference of 0.4°C. These findings indicate that water temperature conditions in the Klamath River below Iron Gate dam represent a blended or mixed volume temperature from downstream of the curtain (SD and DD).

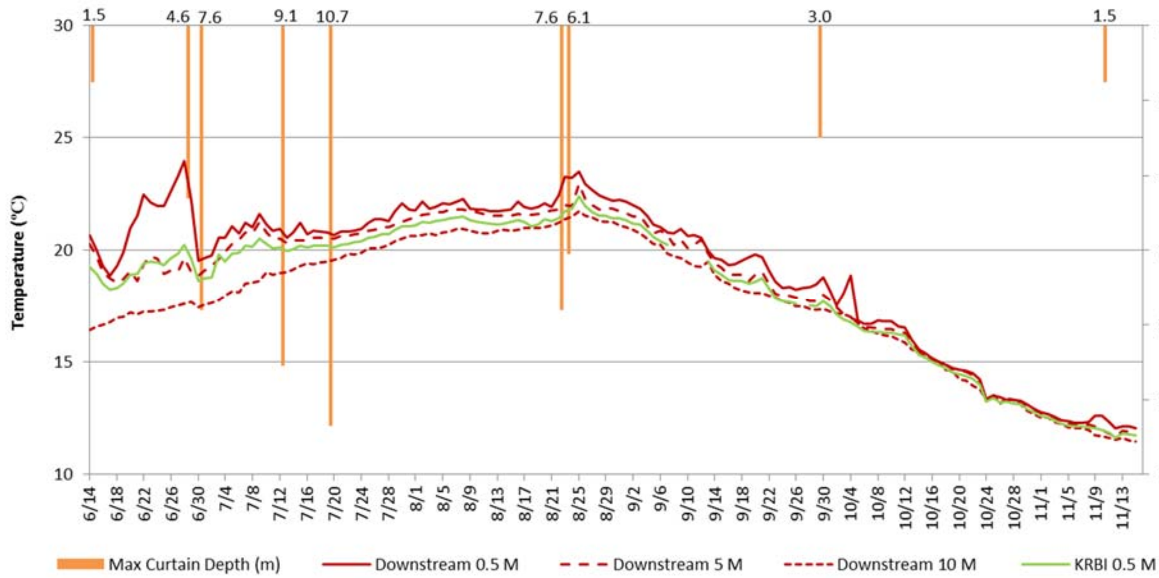

Figure 5-3. Daily Average Water Temperature (°C) in the Klamath River below Iron Gate dam (KBRI) and in Iron Gate Reservoir at 0.5 m, 5 m, and 10 m Depths Downstream of the Curtain

The pH at 0.5 m in depth downstream of curtain was higher than the pH at deeper reservoir depths and the river prior to curtain deployment (Figure 5-4). After curtain deployment through late August, the pH remained slightly higher in reservoir surface waters (0.5 m deep) than at the 5 m deep and KRBI sites. After late August, there was a larger deviation between pH at SD site and both DD and KRBI. While there were modest differences in pH values between the 5 m deep downstream sonde and KRBI though late July, from late July through the end of the study the 5 m deep and KRBI pH time series data are nearly identical (Figure 5-4).

Overall, after curtain deployment in late June, differences between the KRBI pH trace and the average of the reservoir pH traces (at depths of 0.5 m, 5 m, and 10 m downstream of curtain) were always less than 0.93, with an average difference of 0.15. These findings indicate that pH at KRBI was an integrated signal representing pH downstream of the curtain (SD and DD) (Figure 5-4). Elevated pH in near-surface waters downstream of the curtain (SD) may reflect the influence of local primary production from extensive macrophyte growth and to a lesser degree local phytoplankton production (Figure 5-5). The Klamath River is generally considered a weakly buffered system (Watercourse 2016), which typically experiences rapid increases in pH at the onset of primary production, leading to elevated pH levels in near surface water that deviate from pH levels in deeper waters.

DISCUSSION

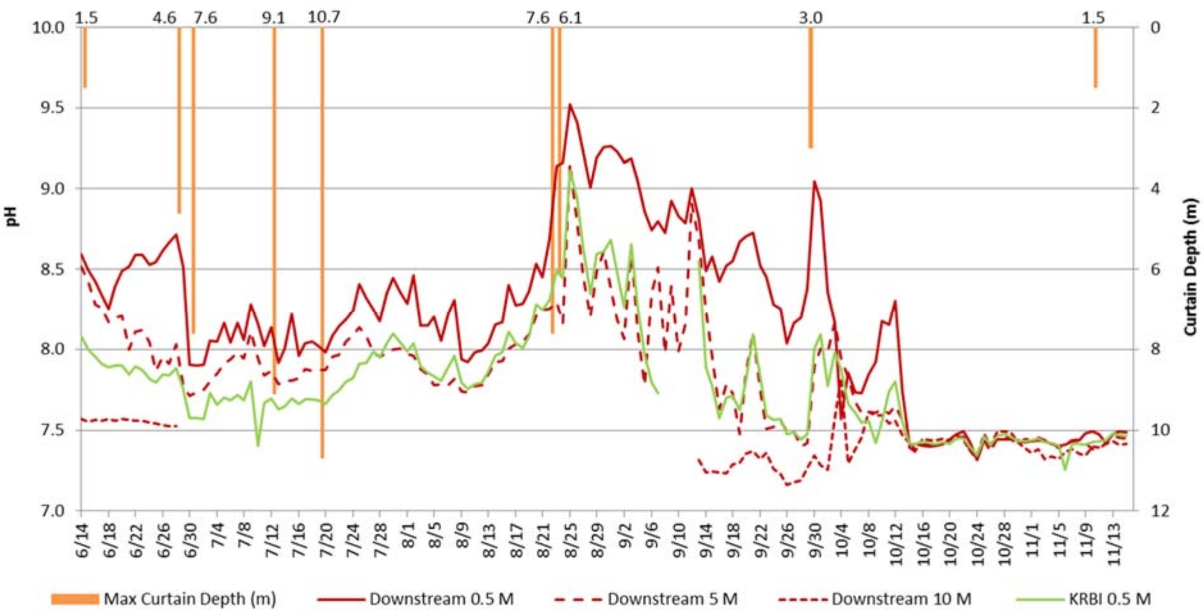

Figure 5-4. Daily Average pH in the Klamath River below Iron Gate dam (KBRI) and in Iron Gate Reservoir at 0.5 m, 5 m, and 10 m Depths Downstream of the Curtain

Figure 5-5. Photo of Iron Gate Reservoir (taken August 29, 2016) Showing Extensive Macrophyte Growth near the Shoreline.

5.3.2 Microcystin levels are similar between DU, SD, DD, and KRBI locations

Previous analysis showed that microcystin levels in near-surface waters upstream of the curtain (SU) were often appreciably higher than at KRBI (Section 5.1.2), which suggests that the curtain is effectively segregating surface waters. To further evaluate curtain effectiveness, this section discusses the similarities between reservoir conditions downstream of the curtain and conditions downstream of Iron Gate dam. The focus of this discussion is the SD and DD locations because conditions upstream of the curtain (DU) are discussed in Section 5.2.

In deeper waters, all microcystin values were low and, for the most part, consistent with one another, particularly in the filtered samples (Figure 5-6). For the filtered samples, microcystin levels downstream of Iron Gate dam were also similar to microcystin levels at SD and DD. In the Klamath River downstream of Iron Gate dam, microcystin concentrations in unfiltered June samples were similar to those from filtered samples. This is because algal populations in June were still low, resulting in low levels of extra-cellular microcystin being detected at all locations. In August and September, there were more algae in the reservoir, and microcystin levels near the water surface were not as uniform. Nevertheless, microcystin levels in the Klamath River downstream of the dam never differed by more than 1 µg/L from any of the downstream-of-curtain reservoir samples, regardless of depth.

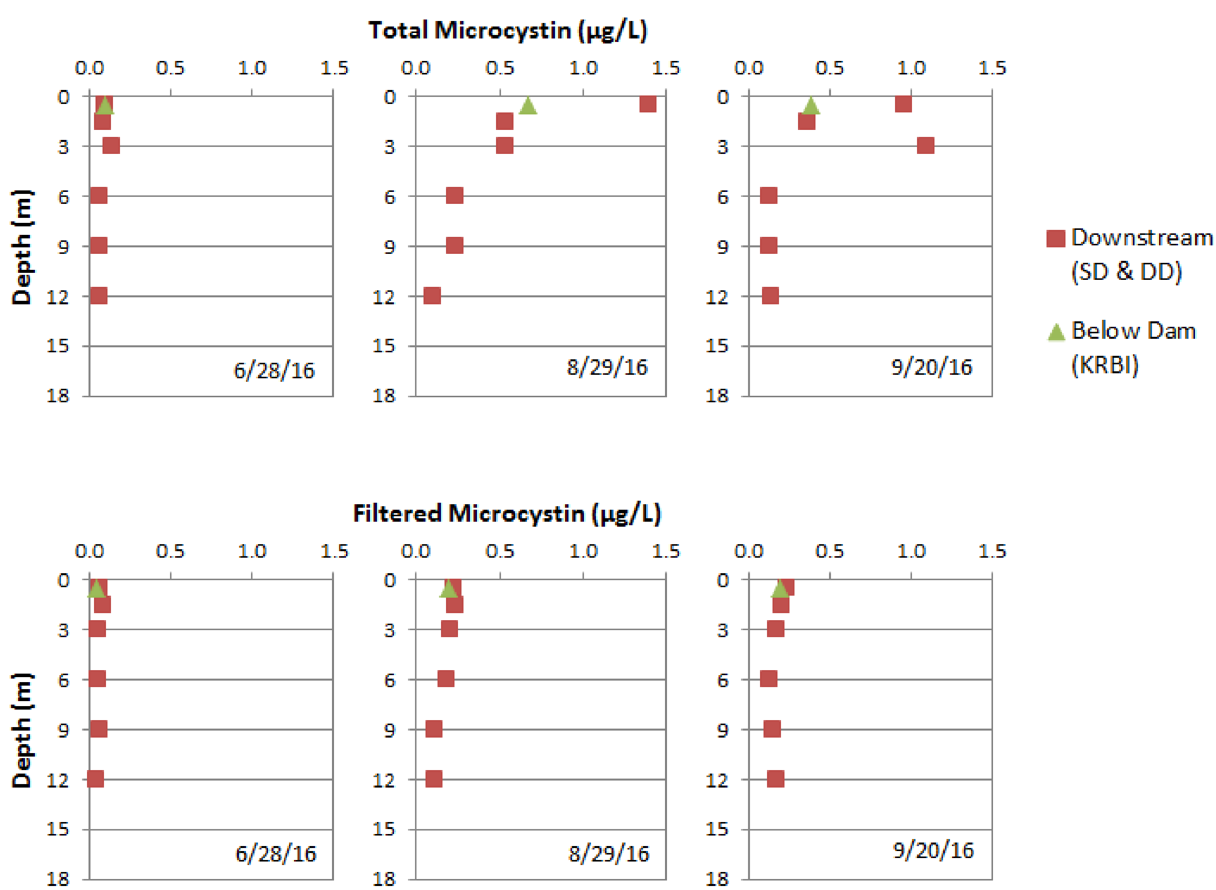

Figure 5-6. Total and Filtered Microcystin Data from Samples Collected at Deeper Depths Downstream of the Curtain and at 0.5 m below Iron Gate Dam (Quantification limit is 0.10 µg/L).

5.3.3 Dissolved Oxygen levels are higher at KRBI than DU or DD

At no point during the study period were dissolved oxygen levels downstream of the dam lower than in deeper waters upstream or downstream of the curtain (DU & DD) (Figure 5-7). In the Klamath River downstream of Iron Gate dam, the dissolved oxygen trace was also higher than dissolved oxygen levels at DU and DD by an approximately consistent amount, such that the trace for each has a similar shape. Water passing through the Iron Gate intake tower and released to the Klamath River receives re-aeration in the Iron Gate powerhouse and the short stretch of Klamath River downstream of the dam. For a stable hydrologic regime, this reaeration would be approximately constant.

As was discussed previously, the Boat Dance Flows appear to have resulted in entrainment of a relatively high volume of lower dissolved oxygen water from deeper upstream areas (Section 4.8). To increase the proportion of higher dissolved oxygen water from shallower upstream areas, adjustments were made on August 22 and 23 to raise the curtain depth from 10.7 to 6.1 m. Following this adjustment, dissolved oxygen levels at SD and in the river downstream of the dam subsequently increased. The near-surface (0.5 m deep) dissolved oxygen data trend relatively closely resembles the dissolved oxygen data trend in the Klamath River downstream of Iron Gate dam until the curtain was raised on September 29 (Figure 5-7). Dissolved oxygen near the surface was higher than dissolved oxygen in deeper waters as a result of photosynthesis, but the intake tower pulls water over a range of depths from about 10 m to the surface. The higher dissolved oxygen in the river downstream of the dam in late August 2016 is a combined result of changes in curtain operation to specifically increase dissolved oxygen levels as well as re-aeration of water moving through the Iron Gate powerhouse.

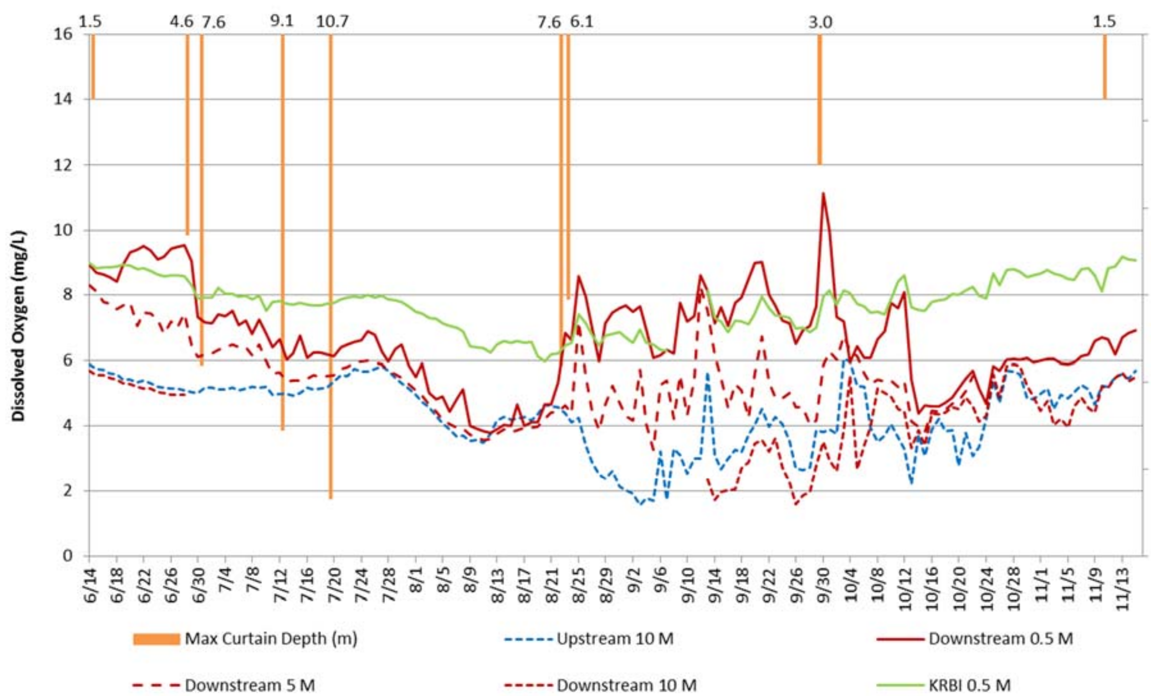

Figure 5-7. Daily Average Dissolved Oxygen (mg/L) at Depths of 5 m and 10 m in Iron Gate Reservoir and at 0.5 m in the Klamath River below Iron Gate Dam (KRBI)

5.3.4 Conclusion

The data shows that water quality conditions downstream of Iron Gate dam were similar to those downstream of the curtain. Water temperature and pH data indicate that the trace below Iron Gate dam was an integration of the entire water column downstream of the curtain, which was largely well mixed and relatively uniform for certain constituents (e.g., water temperature). Microcystin levels downstream of the dam also represented those found in shallower and deeper waters of the reservoir downstream of the curtain. Dissolved oxygen was the only water quality parameter that had a notable difference between the river and the reservoir downstream of the curtain, and this likely resulted from re-aeration as the water passed through Iron Gate powerhouse. In addition, higher levels of dissolved oxygen occurred in release waters following adjustment of the curtain depths in August to access shallower reservoir water that had higher levels of dissolved oxygen (Section 4.8).

5.4 Heterogeneity

The heterogeneity study was performed to ascertain whether samples taken at the BOB upstream of the curtain were representative of general conditions in the reservoir upstream of the curtain (Section 3.7 and 4.7). The differences between the sites are most likely to occur near the water surface where light and other environmental factors could bring about localized changes in reservoir conditions. To address this, samples were taken at depths of 0.1 m and 1 m at four sites in the vicinity of the upstream BOB. These depths were chosen because conditions in the near surface photic zone typically have the highest probability of variability caused by wind mixing, surface accumulations, and other factors. If near-surface samples display limited heterogeneity, then the conditions elsewhere would also likely have limited heterogeneity.

In general, data collected from the four sampling locations around the upstream BOB were similar to the data collected at the BOB itself (Tables 4-1, 4-2, and 4-3; Figures 4-48 to 4-55). In most cases, the data taken from the four sites fell within the range of data at the upstream platform. In no case was the data from sites around the platform an order of magnitude or more different from that at the platform. These samples and conclusions are limited to the upper 1 m of the water column.

5.5 Curtain Effects on Temperature in the Klamath River downstream of Iron Gate Dam

The presence of the curtain has been shown to affect water quality downstream of Iron Gate dam in 2015 and 2016. The effects of the curtain in 2015 and 2016 can also be compared to other years for which temperature data is available.

In 2016, curtain deployment in June produced a substantive reduction in water temperature, as compared to the other years (Figure 5-8). After the Boat Dance Flows in mid-August, the water temperature increased and briefly peaked at a level higher than all other years. A few days after the curtain was raised to 6.1 m on August 23, water temperature began to cool. In 2015, curtain deployment gradually got deeper as the summer progressed. Because of this gradual deployment, water temperature reduction in the Klamath River downstream of Iron Gate dam happened slowly over a period of a few months (Figure 5-8).

These observations suggest that any curtain deployment in June might be too early. Further, it may not be necessary to deploy the curtain to the maximum available depth. By deploying the curtain to 6.1 to 7.6 m, water quality improvements may be realized, temperature reductions may be observed, and low dissolved oxygen levels downstream of the dam (e.g., such as occurred in 2016) may be minimized. Later in the fall, the presence of the curtain in both years did not substantially affect temperature in the river because the reservoir had destratified. Studies in 2015 (Watercourse 2016) and 2016 (this report) have indicated that the curtain can result in the release of relatively cooler water into the Klamath River downstream of Iron Gate dam. It will be necessary in the future to carefully consider the deployment plan in terms of balancing the desire for cooler water, reduced BGA concentrations, and managing dissolved oxygen in the river downstream of the dam. Additionally, the potential benefit of reduced temperature releases may be a management tool that should be assessed for its utility in addressing fish disease conditions downstream of Iron Gate dam which can be exacerbated by high water temperatures.

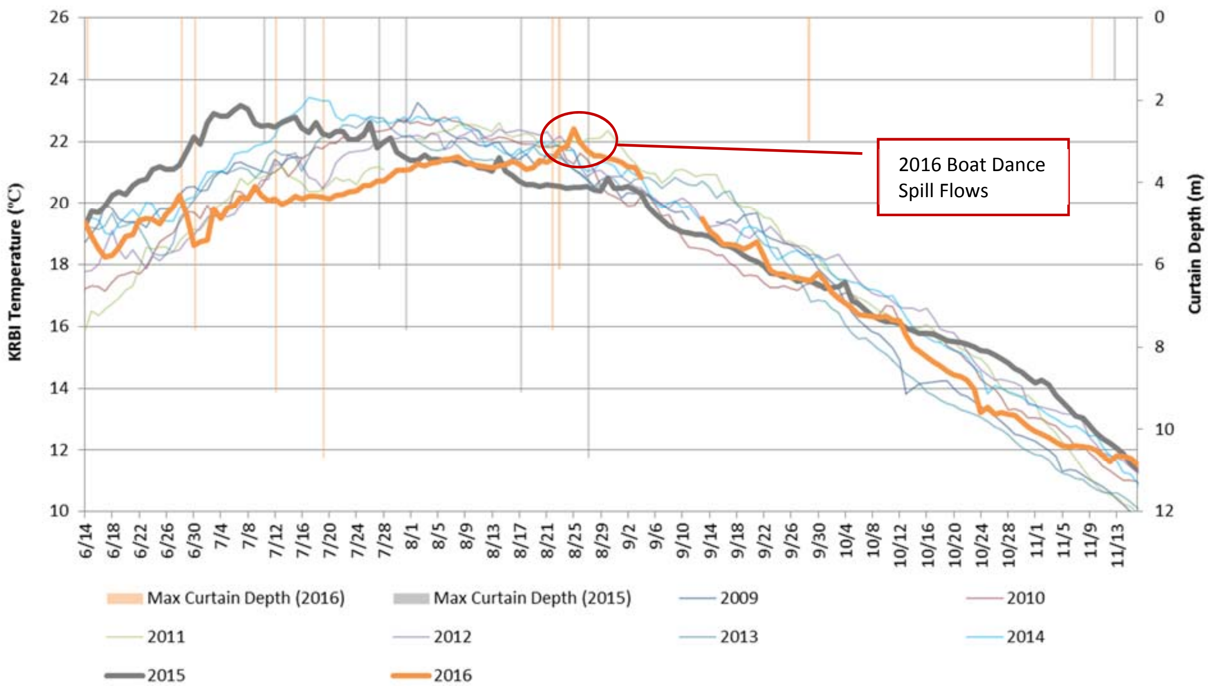

Figure 5-8. Curtain Depths in 2015 and 2016 Compared to Multiple Years of Water Temperature Data from the Klamath River below Iron Gate Dam (KRBI)

Conclusion

The effectiveness of the curtain is dependent on stratified conditions in the reservoir that allow the curtain to isolate the warmer, less dense surface waters that contain most of the BGA. The calculation of Wedderburn number, Richardson number, and maximum water velocities under the curtain indicate that stratification is sufficient in summer and fall months to resist wind mixing and mixing associated with higher water velocities under the curtain. Incidentally, increased flows create higher water velocities and can disrupt this stratification.

Having established the physical mechanisms governing stratification and considering curtain function, field studies were conducted to confirm a range of hypotheses. Three hypotheses used to develop the 2016 field studies included:

- The curtain isolates surface waters upstream of the curtain, segregating shallow and deep waters.
- Shallow and deep water downstream of the curtain are similar to deep-water conditions upstream of the curtain because of withdrawal from beneath the curtain and mixing downstream of the curtain in the relatively shallow waters in the vicinity of the intake tower.
- Conditions downstream of Iron Gate dam are similar to those downstream of the curtain, with the exception of dissolved oxygen, which is increased as the water is re-aerated as it passes through the Iron Gate powerhouse.

These three hypotheses were evaluated by using a suite of sub-hypotheses that guided development of a study plan. Implementation of that study plan resulted in data that was used to confirm the hypotheses. Some of the key observations from 2016 demonstrating curtain effectiveness include:

- Cyanobacteria and microcystin concentrations were overall higher upstream of the curtain than those downstream of the curtain.
- The greater depth of light penetration apparent in the PAR and Secchi disk data indicates that the water downstream of the curtain has lower light extinction characteristics (i.e., it is generally clearer).
- Physical parameters at deeper waters upstream and downstream of the curtain were in general comparable.
- Comparing thermograph array data shows that there was less stratification downstream of the curtain.
- Water temperature and pH data suggest that the trace downstream of Iron Gate dam is an integration of the entire, relatively uniform water column in the reservoir downstream of the curtain.
- Microcystin levels downstream of the dam closely match those found in the deeper waters of the reservoir and downstream of the curtain.
- Because of re-aeration as the water goes through the Iron Gate powerhouse, which is enhanced by turbine venting, dissolved oxygen downstream of the dam is consistently higher than the levels in the reservoir downstream of the curtain.

Overall, the 2016 field studies indicate that the curtain is an effective water quality management tool to isolate the algae-rich near-surface waters in Iron Gate reservoir and reduce the amount of algae entrained into the intake tower and subsequently transported downstream of the dam into the Klamath River. As a secondary benefit, the curtain can also isolate warmer near-surface waters and thus seasonally release relatively lower temperature water into the river below the dam. The potential benefits of the curtain in reducing water temperatures (under some conditions) should be factored into potential flow release management strategies designed to provide benefits to anadromous fish.

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APPENDIX A

Comments on August 28, 2017 Draft 2016 Intake Barrier Report and Responses

Introduction

A review draft of the *2016 Evaluation Intake Barrier Curtain in Iron Gate Reservoir to Improve Water Quality in the Klamath River* report was distributed to the Interim Measures Implementation Committee (IMIC) on August 28, 2017 for comment. The only comments received were from the Karuk Tribe (Attachment A) who submitted many excellent comments and suggestions. PacifiCorp has reviewed these in detail, adjusted the report in numerous places as a result, and provided responses below to either clarify a topic or explain why a change to the report was not made. One topic that was repeatedly brought up had to do with the relationship between conditions in Iron Gate reservoir and the Klamath River downstream without the curtain in place; there is a single response below to address this topic. The introductory material from the comments were converted into the first table below. The second table was provided by the Karuk Tribe in their comment letter. Columns have been added to these tables to document changes to the report that were made and other responses to specific comments.

Without Curtain Evaluation

Numerous comments relate to the evaluation of the relationship between algae and microcystin concentrations, water temperature, and dissolved oxygen levels between Iron Gate reservoir and the Klamath River downstream of Iron Gate dam without the curtain in place. We appreciate the work that was put into these comments and the analysis that supports them. The 2016 curtain study design was based on comments and feedback from the IMIC regarding the 2015 curtain study report. One of the over-arching concerns with the 2015 work was that it was not focused well enough to clearly demonstrate the relationship between conditions in the reservoir, curtain operations, and conditions in the river downstream. Using these concerns, the 2016 study was specifically designed to address three specific hypotheses. For each hypothesis, there are several sub-hypothesis that provide multiple lines of evidence for curtain effectiveness as different parcels of water within the reservoir and in the river downstream were compared. The 2016 study has shown that the curtain can create conditions whereby sub-surface waters are preferentially drawn toward the intake tower resulting in water characteristics of deeper reservoir depths dominating the Iron Gate outflow.

Because the 2016 study was focused on evaluating specific hypotheses, analysis of conditions from multiple years and the formation of a without-curtain condition were beyond the study's scope. In the future it may be desirable and feasible to evaluate the performance of the curtain over multiple years. This analysis could build on that provided in the comments. The 2018 Iron Gate curtain study plan could be designed to address this question, among others.

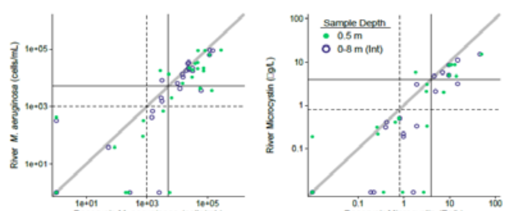
Introductory Material

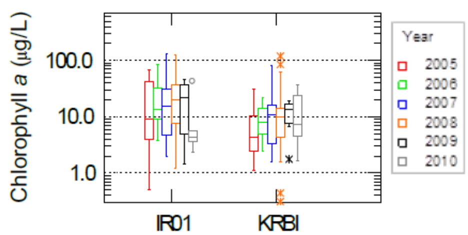
Comment	Response
The 2016 Intake Barrier analysis showed that the barrier curtain can preferentially draw sub-surface waters toward the intake tower, encourage water characteristic of lower reservoir depths to dominate the Iron Gate outflow. The theoretical basis for how curtain deployment can reduced concentrations of MSAE and microcystin toxin from the reservoir was well laid out, but because no analysis was conducted describing reduction of MSAE and microcystin without the curtain, there is no baseline	Refer to "Without Curtain Evaluation" master response at the beginning of this Response to Comments.

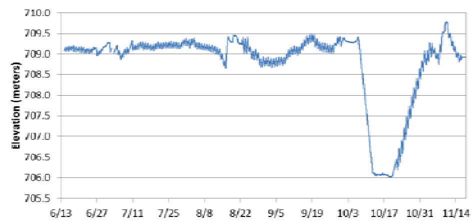
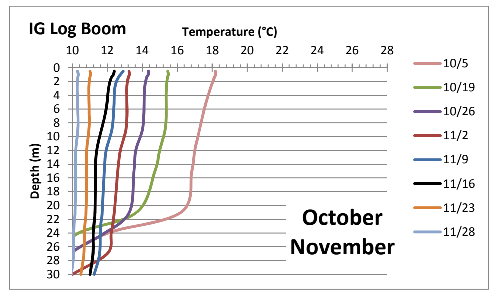
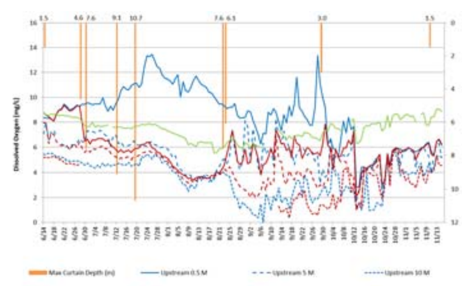
Comment	Response
for how much the curtain is expected to reduce these parameter compared to reductions observed with no curtain in place.	
Although data from some sample dates clearly show a downstream reduction in cyanobacterial cells and toxins, under other conditions, such as increased flows and lesser curtain depths, the curtain did not appear to be effective.	No change necessary.
This report provides some useful information, but is lacking context and is too focused just on the 2016 study results in isolation.	No change. The report is focused on the 2016 data because it is a review and analysis of data collected in 2016 as the 2016 study plan was implemented. In the future it may be necessary to do a multi-year synthesis report, but that effort is beyond the scope of this study and report.
To understand how the curtain affects water quality downstream of Iron Gate Dam, it is necessary to closely evaluate all relevant available information, including previous studies of the curtain deployment (i.e., the 2015 study) and previous studies evaluating reservoir dynamics when the curtain is not in place. Existing data within and below Iron Gate reservoir must be evaluated to understand how water quality parameters transfer from the reservoir to the river with and without the curtain in place. In these comments, we provide some suggestions for datasets and analyses that we recommend be considered. Previous temperature data such as the thermograph strings from 1996-1997 (Deas and Orlob 1999) and 2000 (Watercourse 2003) could be compared with temperatures downstream of Iron Gate Dam to evaluate what reservoir depths most closely match Iron Gate Dam release temperatures, and how the curtain affects that depth. Quantifying how the curtain changes the average release depth (releases are an integration of multiple depths but the knowing the center is informative) allows retrospective analysis of previous water quality data such as depth profiles to make predictions for how the curtain would affect various water quality parameters. The curtain appears to increase the average depth from which water is drawn into the intake, which has the potential to reduce DO concentrations in the river below Iron Gate Dam. There are many years of monthly vertical water quality profiles which could be used to evaluate what DO concentrations are at various depths, and how those DO concentrations change within years and between years in response to seasonal cycles of algal	Refer to "Without Curtain Evaluation" master response at the beginning of this Response to Comments.

Comment	Response
growth and decline. It may be necessary to consider previous evaluations of the effects of turbine venting on DO concentrations to determine how reservoir DO concentrations translate into vented downstream concentrations. In addition, there are many years of continuous DO measurements at PacifiCorp and Karuk Tribe datasondes downstream of Iron Gate Dam which could be used to look at the seasonal and interannual patterns to determine under what conditions DO concentrations approach problematic levels at Iron Gate Dam with and without the curtain (though there is a much shorter period of record during curtain deployment).	
It should be possible to quantify the effect of the curtain on water temperatures at Iron Gate Dam. Without such quantification, it is not possible to follow the report's suggestion to incorporate the curtain into flow management: "The potential benefits of the curtain in reducing water temperatures should be factored into potential flow release management strategies designed to provide benefits to anadromous fish" (P6-1). Once the curtain's effect of Iron Gate Dam temperatures is quantified, the next step would be to analyze how that affects water temperatures at sites further downstream. The RBM10 model (Perry et al. 2011, https://sites.google.com/site/klamathtrinityinterfacehelp/) is available to easily quantify the downstream effects of changes to Iron Gate release temperatures. Alternatively, statistical regression could also be used analyze the large quantity of existing water temperature, meteorological, and streamflow data.	No change. The 2016 report is focused on the specific study design developed for 2016. Temperature modeling in the river downstream of Iron Gate dam is well outside the scope of the 2016 study plan for the curtain. The report is simply illustrating that temperature alteration is possible using the curtain and that fact should be considered when discussing flow management strategies for the river. Obviously the specific details of how those strategies develop could require modeling of different release temperature patterns.
Discussion should include under what conditions the barrier curtain may be a viable option to mitigate poor water quality, and when it becomes unusable due to low DO levels or other physical constraints. A major concern is that when algae blooms are largest, DO levels in the lower depths may decline, forcing the curtain depth to be decreased. Therefore, when the curtain is most needed, it may not be an available mitigation tool.	No change. This report is focused on the 2016 study and an evaluation of dissolved oxygen as suggested in the comment is outside the scope of the study. Prior to 2017, dissolved oxygen levels have not been an issue of concern with curtain operation. Data collection for 2017 are ongoing and this topic will likely be discussed in detail in the future.

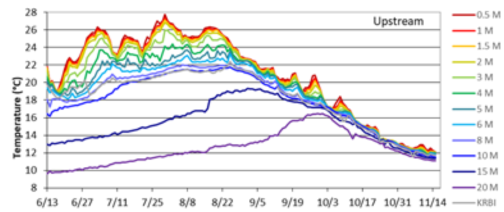
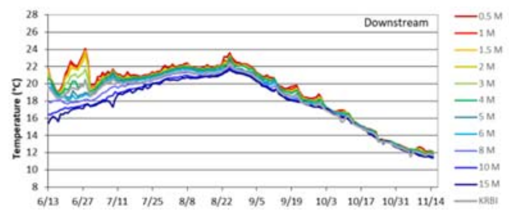
Specific Comments

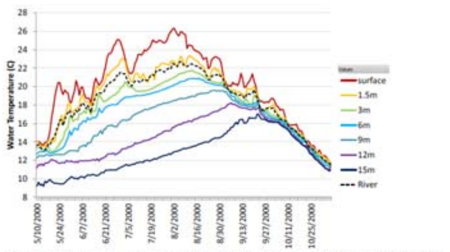
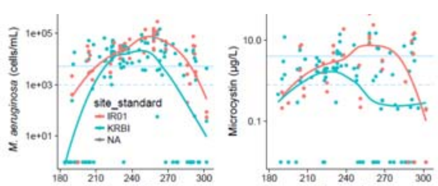
Page, ¶	**Comment**	**Response**
p. XI, pp 2	The purpose of the curtain is to improve water quality in the river below Iron Gate Dam, not the near surface waters in the reservoir as the sentence currently reads.	The entire sentence referenced in the comment refers to improving conditions in near-surface waters of Iron Gate reservoir because those waters "…are then released into the Klamath River downstream of Iron Gate dam." In this case, 'near surface waters' refers to the area in the reservoir downstream of the curtain and upstream of the intake tower. Edited text for clarity.
P2-1, bullet 3	Hypothesis 3 "Conditions downstream of Iron Gate dam are similar to those downstream of the curtain, with the exception of dissolved oxygen, which is increased as the water is re-aerated as it passes through the Iron Gate powerhouse." should consider past data comparisons between BGA conditions above and below Iron Gate Dam in the absence of the curtain. Baseline samples from 2009 through 2015 of MSAE and Microcystin from the IG log boom (0.5 m samples) and KRBI taken on the same day show a 24% reduction in microcystin and a 12% reduction in cell density from the log-boom to KRBI, with even larger declines when using the 0-8m integrated samples from the log boom.  Further documentation of this phenomenon (lower algal concentrations below Iron Gate Dam than at the reservoir surface) is provided in the following boxplot adapted from Asarian and Kann (2011) summarizes chlorophyll-*a* data from the Karuk Tribe and PacifiCorp at depths <=1 m at Iron Gate Reservoir (IR01) and KRBI for June-October 2005-2010, which	Refer to "Without Curtain Evaluation" master response at the beginning of this Response to Comments.

Page, ¶	Comment	Response
	were years when no curtain was in place. Even on the log scale which visually minimizes differences, the plots clearly shows that in 5 of the 6 years, median (horizontal line within box), 75th percentile (top of box), and maximum (upper whisker or discrete points) chlorophyll concentrations were far lower at Iron Gate Dam than in the surface of Iron Gate Reservoir:  	
P3-1	Methods should include comparison of cells and toxins transferred from IG log boom in years without and years with curtain as these data are readily available.	Refer to "Without Curtain Evaluation" master response at the beginning of this Response to Comments.
P3-2	"Sondes were cleaned, calibrated, and accumulated data downloaded at regular intervals." The specific interval should be mentioned here. According the results section, it is six weeks, which is too long an interval for the Klamath River system due to high potential for biofouling.	Specific intervals for sonde calibration and maintenance have been added to the report.
P3-3, sec 3.4	Why was no true surface grab collected in these profile samples? Large differences are common in algal densities between 0 and 0.5 m.	The sampling depth of 0.5 m was selected to represent conditions in the top 0-1 m of water.
P4-1	"The downstream 10 m sonde was raised to approximately 5.4 m between October 7 and October 31 to ensure that the probe did not encounter the reservoir bottom during seasonal drawdown." Please add a brief mention of how much reservoir elevation changed over the season, and how 2016 compared to most years? This could affect curtain dynamics. If it changed much (i.e. more than 1 meter?) then it would be useful to add a graph of reservoir	Reservoir elevation data has been added to the report. It should be noted that the curtain moves with the changes in reservoir elevation. Also, the thermograph data from the log boom indicated that the thermocline was located at about 22 m in early October. The October draw down was less than 5 m at most; there is no evidence that the thermocline was disrupted at the log boom in October.

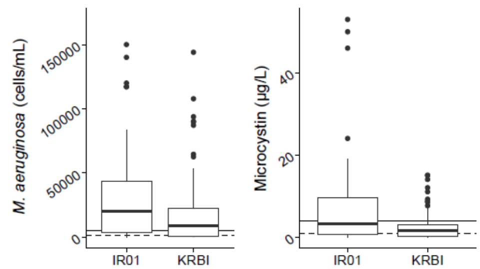
Page, ¶	Comment	Response
	elevation. It seems like reservoir elevation could potentially have a very large effect on which depths of water are drawn into the intake (more surface water when reservoir is drawn down), so this issue deserves more attention in this report and in future evaluations.	 
P4-3	Consider showing daily minimum instead of mean DO, as diel swings in DO can mask the extremes, and low DO is the parameter of concern to fish, not average.	The use of daily mean data does not appear to mask any important information contained in the minimum values (see figure below). Low levels of DO can certainly be an issue for aquatic biota, however, the absolute minimum value for a day is probably less useful from a habitat perspective because it does not persist. An evaluation of DO levels as they relate to habitat conditions for aquatic resources is beyond the scope of this study. 
P4-4	Similar comment as above for pH, but show daily max	See previous comment.

Page, ¶	Comment	Response
P4-5	The increase in the Chl. *a* probe that occurred at the end of the season shows a pattern typical of biofouling, thus conclusions made based on this pattern of increased Chl. *a* should be taken lightly and the possibility of biofouling should be discussed, especially considering the long time intervals (6 weeks) between sonde re-calibrations. The Chl. *a* grab sample taken during that time period is not very convincing, considering that earlier in the year (~8/10) log-boom chl samples with much higher concentrations resulted in sonde chl values proportionally much lower than those in October.	The text has been modified to acknowledge that biofouling could have been affecting the measurements; however, spot data from KHSA baseline sampling provided the same pattern as the sonde data. While actual concentrations are useful, patterns of change in the concentration over the period of curtain deployment are also valuable in evaluating overall curtain performance.
P4-6, sec 4.1.5	The statement, "e.g., the October and November increase in chlorophyll-*a* just discussed was almost all *Aphanizomenon flos-aquae* but this did not manifest in the BGA data" should be reconsidered; although 2016 cell counts were not publically available on the PacifiCorp web site at the time of these comments, microcystin levels through October of 2016 below Iron Gate dam of about ~2µg/L suggest that MSAE was still in the reservoir.	No change. The statement in the report is accurate based on the available data. The text does not say that microcystin was absent. Also microcystin itself wouldn't show on the BGA data, and it's possible that there's microcystin without *Microcystis*, especially near the end of the bloom season when cyanobacteria dies and cells break down releasing microcystin into the water.
P4-6 sec 4.1.5	"In general, calibration issues and probe failures make the phycocyanin probe data set of limited use in 2016." Could cleaning and calibrating the probes more often than every six weeks help mitigate this issue for future studies?	No change. More frequent sonde services are being implemented for 2017.
P4-6	What is the temperature difference between the reservoir and river without curtain deployment? Can past baseline data be used to look at river vs. reservoir temperatures in years prior to 2015 to get out what is the expected change in water temp from IG reservoir to the river? See additional comments below regarding [P4-7, P4-8].	Refer to "Without Curtain Evaluation" master response at the beginning of this Response to Comments.

Page, ¶	Comment	Response
P4-7, P4-8	Adding KRBI temperature (as an overlay, perhaps dashed black?) to Figure 4-10 and 4-11 would help show how temperature at various reservoir depths compare with river temperatures downstream, which in turn can be used to indicate how the curtain affects average release depth. As discussed in the General Comments above, the average release depth is a key metric to understand the curtain's effects. An rough eyeball comparison of the KRBI temperatures (Figure 4-1) against the above-curtain temperatures (Figure 4-10) indicates that prior to the curtain deployment in June 2016, KRBI temperatures appeared to match the 4m deep above-curtain reservoir temperature whereas after curtain deployment KRBI temperatures are closer to the 8m deep above-curtain reservoir temperature. It would be helpful for the report to do a quantitative comparison. It would also be useful to compare the multi-depth thermographs in Figures 4-10 and 4-11 to similar data from previous years, such as 1996-1997 (Deas and Orlob 1999) and 2000 (Watercourse 2003) which can be used to understand the depths from which water is typically drawn into the intake without the curtain. Including those additional years would increase the sample size, because the period in 2016 prior to the curtain deployment was too short to draw solid conclusions. A quick look at the 2000 data indicates that the river temperature appears to be intermediate between the 1.5m and 3m reservoir depths. This seems to be a shallower average release depth than the approximate 4m depth seen June 2016 prior to curtain deployment, for reasons that are not clear (perhaps reservoir water surface elevations were lower in 2000?).	Edited text to add water temperature for the river below Iron Gate dam onto these figures.   Refer to "Without Curtain Evaluation" master response at the beginning of this Response to Comments.

Page, ¶	**Comment**	**Response**
	 Figure comparing daily mean water temperatures at the Iron Gate Reservoir log boom at various depths in the Klamath River below Iron Gate Dam (hatchery bridge) in the year 2000 (data summarized from Watercourse Engineering 2003).	
P4-14	Discussion of Figure 4-19 does not mention that microcystin at the 0.5 m depth was higher downstream of the curtain than upstream.	Change made.
P4-24	The set up of the auto-samplers with comparing reservoir conditions unaffected by the curtain (i.e., upstream of the curtain) and river below the dam is good, because ultimately, we are interested in what the downstream river conditions are. This study should be repeated without the curtain in place (when it is deemed unusable due to DO issues) to see what the baseline difference between the reservoir and river are, as some decrease in toxin and cell concentrations occurs without the curtain (see figure below). Conducting more of these paired samples, with and without the curtain during variable cyanobacterial conditions will further help understand when and by how much the curtain can help reduce downstream algal transport.  Figure: *Microcystis* and microcystin plotted by day of year from baseline samples in Iron Gate Reservoir at 0.5 m (IR01, pink) and the Klamath below Iron Gate (KRBI, blue) with LOESS smoothers show that average concentrations of MSAE and microcystin are lower in the river below the dam, even without curtain deployment. Data are from 2005 through 2014, July-October.	This comment will be used to help plan study design for 2018. No changes to the 2016 report are necessary.

Page, ¶	Comment	Response
P5-1	Again, consider the possibility of biofouling before making conclusions that phytoplankton biomass was higher in November than any other time during the 2016 season. This conclusion is not likely and, as stated in the report, not consistent with the base-line phytoplankton data collected at the IG log boom. Also, a curtain depth of 3 meters is not likely sufficient at isolating the surface waters as previous graphs show water at 3 meters deep to have similar temperatures as near-surface waters, with the thermocline being much deeper than 3 m, as shown in the vertical profile plots on page 4-13. Further, 3 m is shallower than the potential depth of daily vertical migration of MSAE (7-8m), as stated in following pages of the report.	While the late-season increase in phytoplankton biomass observed in other field data (e.g., at the log boom) reduces the likelihood that biofouling was affecting this data, that possibility remains and is acknowledged in the revised text. With the curtain at 3 m in depth, isolation of the surface water relies on the weak, intermittent stratification that occurs in near-surface waters. The curtain appeared to restrict the entrainment of water higher in algae concentrations; an observation supported by the collected data.
P5-4	0.5 m is indicative of near-surface waters, but can be dramatically different than true surface samples.	The text has been edited to indicate that all autosampler samples were collected at 0.5 m and are representative of conditions in the top 0-1 m of waters in the reservoir upstream of the curtain and are consistent with all KHSA sampling in the river downstream of Iron Gate dam.
P5-4	Rather than simply stating that the boat dance flows are "atypical" of summer conditions, state how they are different (i.e., increased flow), consider how often flow increases occur and state that the curtain appears to have limited abilities to reduce downstream transport of BGA under these ceremonials releases. This is important for tribal members to understand, thus the point should be clear.	The text says that mixed conditions created by the Boat Dance flows were atypical of summer conditions, not that the Boat Dance flows were atypical. Regardless, the text was edited to provide the magnitude of Boat Dance flows and a statement was added to 5.1.6 about the effects of Boat Dance flows on curtain effectiveness.
P5-4	"These results indicate that there were significant differences in mean concentrations of total microcystin upstream of the curtain (SU) when compared to the river downstream of Iron Gate dam (Figure 4-41) with higher mean concentrations of microcystin upstream than downstream." It should also be noted that that reservoir samples were significantly different (Kruskal-Wallis p-	Refer to "Without Curtain Evaluation" master response at the beginning of this Response to Comments.

Page, ¶	Comment	Response
	value=0.005) from those at KRBI in samples taken between 2005 and 2014 without the curtain in place (see data in the figure above under comment 4-24).  	
P5-5	"The 15-minute chlorophyll-a levels recorded by the 5 m and 10 m sondes on the downstream side of the curtain are relatively constant from July 1-September 30. This suggests that algae is not passing from near-surface waters under the curtain. The 5 m and 10 m sondes represent" Figure 4-5 shows that the downstream 10m sonde was offline for most of the time period mentioned in this sentence.	Chlorophyll-*a* data from upstream and downstream 10 m sondes were reviewed. When both sondes were functioning properly, the chlorophyll-*a* values were comparable. The downstream 10 m unit was out of service for a period, but review of the overlapping data indicates that the upstream unit was representative of conditions at this depth. The vertical profiles also indicate that little algae was present at depth. The text has been revised to include these considerations.
P5-6	"In contrast, the thermograph array downstream of the curtain shows minimal difference in temperatures between readings taken near the surface and those taken at depth (Figures 4-13 and 4-14)." Also, citation should probably be Figures 4-11 and 4-13, not 4-13 and 4-14.	Change made.
P5-7 sec 5.2.3	Both sonde data and vertical profiles suggest higher algal biomass in near-surface waters both above and below the curtain, with bigger differences above the curtain. Simply concluding that conditions were similar throughout the water column at the downstream site is not accurate.	While there were some minor variations in conditions throughout the water column, the data indicates that conditions downstream of the curtain were generally similar to deep-water conditions upstream of the curtain.
P5-7	"The Klamath River below Iron Gate dam temperature before curtain deployment closely matches the temperature at 5 m depth." Is that similar or different than found in years with previous data (i.e., see	Refer to "Without Curtain Evaluation" master comment at the beginning of this Response to Comments.

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	our comments on [P4-7, P4-8] above that mention the 1996-1997 and 2000 data).	
P5-8	Include a photo or other documentation of macrophyte growth near the reservoir outlet. Due to steep sides and bottom depths that exceed the photic zone, phytoplankton would be expected to be the cause of surface increases/diel swings in pH. This point of higher surface pH contradicts the previous conclusions in section 5.2.3.	Edited text to add supporting information regarding near-shore macrophyte growth Section 5.2.3 says that water quality conditions downstream of the curtain are similar across the water column. That section is also specifically looking at the relationship between DU and SD and DD. In other words, DD is about the same as SD and of these locations should be similar to DU. While pH is somewhat higher at the surface (on both sides of the curtain), which would appear to be the contradiction mentioned in the comment, this increase relative to deeper water is also expected because of primary production. Section 5.3.2 demonstrates that the pH values at KRBI were an integrated result of water from DD and SD which is not a contradiction with the information in Section 5.2.3.
P5-9	"Previous analysis showed that microcystin levels in near-surface waters upstream of the curtain (SU) were often appreciably higher than at KRBI (Section 5.1.2), which suggests that the curtain is effectively segregating surface waters" It may be true that the curtain segregates surface waters, but observing that microcystin concentrations at KRBI are lower than those in surface waters upstream of the curtain does not directly and convincingly demonstrate that it is due entirely to the curtain, because as we noted above in our comments regarding page 4-24, such a reduction is consistently observed even without the curtain in place.	Refer to "Without Curtain Evaluation" master response at the beginning of this Response to Comments.
P5-10 sec 5.3.3	This section should include comparison of DO level to those above the curtain as well.	This specific analysis compares dissolved oxygen levels at deep upstream, deep downstream, and KRBI. Because of this, the intent of the comment is unclear.

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P5-10 sec 5.3.3	"The near-surface (0.5 m deep) dissolved oxygen data trend relatively closely resembles the dissolved oxygen data trend in the Klamath River downstream of Iron Gate dam dissolved oxygen the curtain was raised (Figure 5-6)." Sentence wording is confusing and may be missing some words. What dates is it intended to refer to?	Changes made. New sentence is as follows: "The near-surface (0.5 m deep) dissolved oxygen data trend relatively closely resembles the dissolved oxygen data trend in the Klamath River downstream of Iron Gate dam until the curtain was raised on September 29 (Figure 5-6)."
P6-1	Some conclusions of the data are over-stated. "Cyanobacteria and microcystin concentrations were consistently higher upstream of the curtain than those downstream of the curtain." Although generally near surface samples were higher for microcystin and cell densities, there are cases when downstream samples were higher during the August profile sampling, and deeper samples appeared to be similar between sampling sites. To the extent that light extinction represents algal density, it was based on only two sample dates post curtain deployment, and on one of the two sampling dates there were similar light extinction curves, indicating increased clarity below the curtain sometimes, but not always. Higher frequency sampling of fewer samples could bring more insight into how the curtain performs throughout the duration of its deployment. "Physical parameters at deeper waters upstream and downstream of the curtain were comparable." Does deeper water mean 5m or 10m? pH is not very similar upstream and downstream of the curtain (see Figure 4-4). Stating that the curtain "is an effective water quality management tool to isolate the algae-rich near-surface waters in Iron Gate reservoir and prevent them from being transported downstream of the dam into the Klamath River" is misleading.	The report has been reviewed and wording adjusted as appropriate. Curtain effectiveness should not be judged entirely by whether down-river microcystin concentrations exceeded public health screening criteria or not because local populations of microcystin-producing cyanobacteria (*Microcystis* or other species) may be present in the river downstream of Iron Gate dam even if the curtain is fully effective at eliminating *Microcystis* releases from Iron Gate reservoir. For example, recent work by Otten (2017) provided evidence for anatoxin-a being produced by a benthic species in the Klamath River somewhere downstream of Iron Gate dam. Otten, T. 2107. Application of genetic tools for improved cyanobacterial bloom monitoring in the Klamath River system: The molecular identification of anatoxin-a producers. Prepared for PacifiCorp, Portland, OR. August. 32 pp. Available online at: http://www.pacificorp.com/es/hydro/hl/kr.html

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	There can be high (albeit not as high as the surface) algal concentrations at depth, and when algae sinks (either intentionally to access nutrients, or when blooms decline) it will be entrained into the intake and the river downstream. This study demonstrated that the curtain could at times reduce algal cell and toxin transport downstream, but not prevent it. With curtain deployment in, there were still many instances of microcystin levels above the 0.8 µg/L caution level in the river below Iron Gate Dam.	
Misc. comment 1	The report sometimes uses words that are stronger than the data support. For example, in multiple places, the words “limit” and “prevent” are used to describe the curtain’s effect on BGA and associated parameters. We suggest replacing such instances with a more accurate word such as “reduce”	The report has been reviewed and wording adjusted as appropriate.

Attachment A

Karuk Tribe Comments on the Evaluation of Intake Barrier Curtain in Iron Gate Reservoir to Improve Water Quality in the Klamath River (September 15, 2017)

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MEMORANDUM REPORT

To: Pacificorp and Interim Measures Implementation Committee
From: Susan Fricke
Date: September 15, 2017
Re: Comments on the Evaluation of Intake Barrier Curtain in Iron Gate Reservoir to Improve Water Quality in the Klamath River

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(If there are questions regarding any of the content in this memorandum, please contact Susan Fricke at (530) 598-3414 or sfricke@karuk.us).

Report Summary:

The 2016 Intake Barrier analysis showed that the barrier curtain can preferentially draw sub-surface waters toward the intake tower, encourage water characteristic of lower reservoir depths to dominate the Iron Gate outflow. The theoretical basis for how curtain deployment can reduced concentrations of MSAE and microcystin toxin from the reservoir was well laid out, but because no analysis was conducted describing reduction of MSAE and microcystin without the curtain, there is no baseline for how much the curtain is expected to reduce these parameter compared to reductions observed with no curtain in place. Although data from some sample dates clearly show a downstream reduction in cyanobacterial cells and toxins, under other conditions, such as increased flows and lesser curtain depths, the curtain did not appear to be effective.

General comments:

This report provides some useful information, but is lacking context and is too focused just on the 2016 study results in isolation. To understand how the curtain affects water quality downstream of Iron Gate Dam, it is necessary to closely evaluate all relevant available information, including previous studies of the curtain deployment (i.e., the 2015 study) and previous studies evaluating reservoir dynamics when the curtain is not in place. Existing data within and below Iron Gate reservoir must be evaluated to understand how water quality parameters transfer from the reservoir to the river with and without the curtain in place. In these comments, we provide some suggestions for datasets and analyses that we recommend be considered.

Previous temperature data such as the thermograph strings from 1996-1997 (Deas and Orlob 1999) and 2000 (Watercourse 2003) could be compared with temperatures downstream of Iron Gate Dam to evaluate what reservoir depths most closely match Iron Gate Dam release temperatures, and how the curtain affects that depth. Quantifying how the curtain changes the average release depth (releases are an integration of multiple depths but the knowing the center is informative) allows retrospective analysis of previous water quality data such as depth profiles to make predictions for how the curtain would affect various water quality parameters.

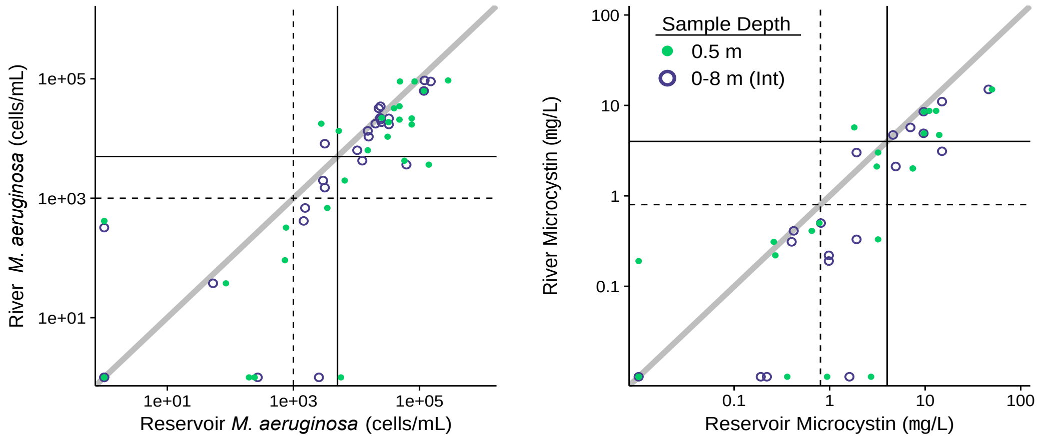
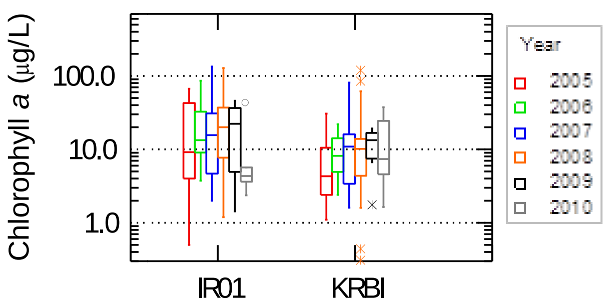
The curtain appears to increase the average depth from which water is drawn into the intake, which has the potential to reduce DO concentrations in the river below Iron Gate Dam. There are many years of monthly vertical water quality profiles which could be used to evaluate what DO concentrations are at various depths, and how those DO concentrations change within years and between years in response to seasonal cycles of algal growth and decline. It may be necessary to consider previous evaluations of the effects of turbine venting on DO concentrations to determine how reservoir DO concentrations translate into vented downstream concentrations. In addition, there are many years of continuous DO measurements at PacifiCorp and Karuk Tribe datasondes downstream of Iron Gate Dam which could be used to look at the seasonal and interannual patterns to determine under what conditions DO concentrations approach problematic levels at Iron Gate Dam with and without the curtain (though there is a much shorter period of record during curtain deployment).

It should be possible to quantify the effect of the curtain on water temperatures at Iron Gate Dam. Without such quantification, it is not possible to follow the report's suggestion to incorporate the curtain into flow management: "The potential benefits of the curtain in reducing water temperatures should be factored into potential flow release management strategies designed to provide benefits to anadromous fish" (P6-1). Once the curtain's effect of Iron Gate Dam temperatures is quantified, the next step would be to analyze how that affects water temperatures at sites further downstream. The RBM10 model (Perry et al. 2011, https://sites.google.com/site/klamathtrinityinterfacehelp/) is available to easily quantify the downstream effects of changes to Iron Gate release temperatures. Alternatively, statistical regression could also be used analyze the large quantity of existing water temperature, meteorological, and streamflow data.

Discussion should include under what conditions the barrier curtain may be a viable option to mitigate poor water quality, and when it becomes unusable due to low DO levels or other physical constraints. A major concern is that when algae blooms are largest, DO levels in the lower depths may decline, forcing the curtain depth to be decreased. Therefore, when the curtain is most needed, it may not be an available mitigation tool.

Specific comments are included in the following table:

p. XI, pp 2	The purpose of the curtain is to improve water quality in the river below Iron Gate Dam, not the near surface waters in the reservoir as the sentence currently reads.
P2-1, bullet 3	Hypothesis 3 "Conditions downstream of Iron Gate dam are similar to those downstream of the curtain, with the exception of dissolved oxygen, which is increased as the water is re-aerated as it passes through the Iron Gate powerhouse." should consider past data comparisons between BGA conditions above and below Iron Gate Dam in the absence of the curtain. Baseline samples from 2009 through 2015 of MSAE and Microcystin from the IG log boom (0.5 m samples) and KRBI taken on the same day show a 24% reduction in microcystin and a 12% reduction in cell density from the log-boom to KRBI, with even larger declines when using the 0-8m integrated samples from the log boom.

	 Further documentation of this phenomenon (lower algal concentrations below Iron Gate Dam than at the reservoir surface) is provided in the following boxplot adapted from Asarian and Kann (2011) summarizes chlorophyll-*a* data from the Karuk Tribe and PacifiCorp at depths <=1 m at Iron Gate Reservoir (IR01) and KRBI for June-October 2005-2010, which were years when no curtain was in place. Even on the log scale which visually minimizes differences, the plots clearly shows that in 5 of the 6 years, median (horizontal line within box), 75th percentile (top of box), and maximum (upper whisker or discrete points) chlorophyll concentrations were far lower at Iron Gate Dam than in the surface of Iron Gate Reservoir: 
P3-1	Methods should include comparison of cells and toxins transferred from IG log boom in years without and years with curtain as these data are readily available.
P3-2	“Sondes were cleaned, calibrated, and accumulated data downloaded at regular intervals.” The specific interval should be mentioned here. According the results section, it is six weeks, which is too long an interval for the Klamath River system due to high potential for biofouling.
P3-3, sec 3.4	Why was no true surface grab collected in these profile samples? Large differences are common in algal densities between 0 and 0.5 m.
P4-1	“The downstream 10 m sonde was raised to approximately 5.4 m between October 7 and October 31 to ensure that the probe did not encounter the reservoir bottom during seasonal drawdown.” Please add a brief mention of how much reservoir

	elevation changed over the season, and how 2016 compared to most years? This could affect curtain dynamics. If it changed much (i.e. more than 1 meter?) then it would be useful to add a graph of reservoir elevation. It seems like reservoir elevation could potentially have a very large effect on which depths of water are drawn into the intake (more surface water when reservoir is drawn down), so this issue deserves more attention in this report and in future evaluations.
P4-3	Consider showing daily minimum instead of mean DO, as diel swings in DO can mask the extremes, and low DO is the parameter of concern to fish, not average.
P4-4	Similar comment as above for pH, but show daily max
P4-5	The increase in the Chl. *a* probe that occurred at the end of the season shows a pattern typical of biofouling, thus conclusions made based on this pattern of increased Chl. *a* should be taken lightly and the possibility of biofouling should be discussed, especially considering the long time intervals (6 weeks) between sonde re-calibrations. The Chl. *a* grab sample taken during that time period is not very convincing, considering that earlier in the year (~8/10) log-boom chl samples with much higher concentrations resulted in sonde chl values proportionally much lower than those in October.
P4-6, sec 4.1.5	The statement, "e.g., the October and November increase in chlorophyll-*a* just discussed was almost all *Aphanizomenon flos-aquae* but this did not manifest in the BGA data" should be reconsidered; although 2016 cell counts were not publically available on the PacifiCorp web site at the time of these comments, microcystin levels through October of 2016 below Iron Gate dam of about ~2µg/L suggest that MSAE was still in the reservoir.
P4-6 sec 4.1.5	"In general, calibration issues and probe failures make the phycocyanin probe data set of limited use in 2016." Could cleaning and calibrating the probes more often than every six weeks help mitigate this issue for future studies?
P4-6	What is the temperature difference between the reservoir and river without curtain deployment? Can past baseline data be used to look at river vs. reservoir temperatures in years prior to 2015 to get out what is the expected change in water temp from IG reservoir to the river? See additional comments below regarding P5-12.
P4-7, P4-8	Adding KRBI temperature (as an overlay, perhaps dashed black?) to Figure 4-10 and 4-11 would help show how temperature at various reservoir depths compare with river temperatures downstream, which in turn can be used to indicate how the curtain affects average release depth. As discussed in the General Comments above, the average release depth is a key metric to understand the curtain's effects. An rough eyeball comparison of the KRBI temperatures (Figure 4-1) against the above-curtain temperatures (Figure 4-10) indicates that prior to the curtain deployment in June 2016, KRBI temperatures appeared to match the 4m deep above-curtain reservoir temperature whereas after curtain deployment KRBI temperatures are closer to the 8m deep above-curtain reservoir temperature. It would be helpful for the report to do a quantitative comparison.

<table>
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A quick look at the 2000 data indicates that the river temperature appears to be intermediate between the 1.5m and 3m reservoir depths. This seems to be a shallower average release depth than the approximate 4m depth seen June 2016 prior to curtain deployment, for reasons that are not clear (perhaps reservoir water surface elevations were lower in 2000?).

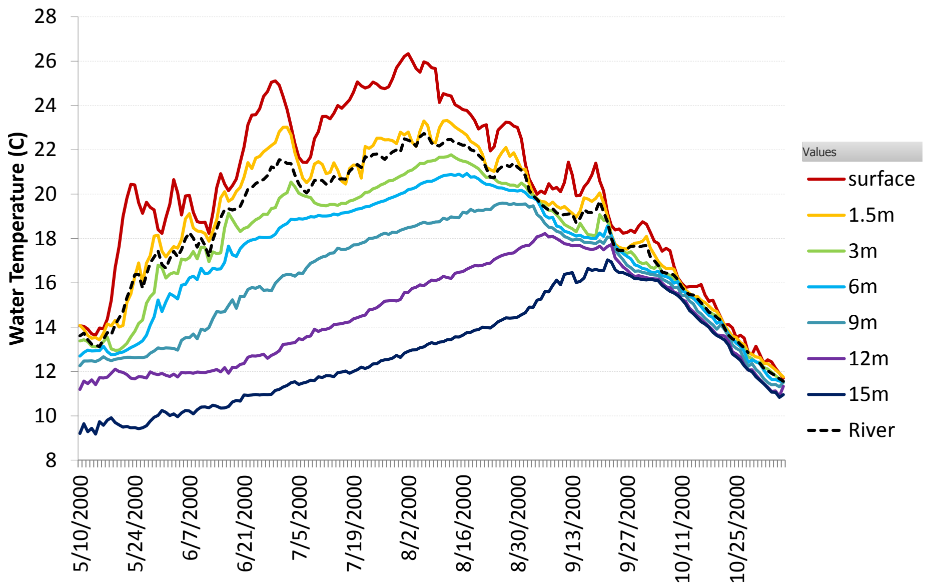

Figure comparing daily mean water temperatures at the Iron Gate Reservoir log boom at various depths in the Klamath River below Iron Gate Dam (hatchery bridge) in the year 2000 (data summarized from Watercourse Engineering 2003).</td>
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<td>P4-14</td>
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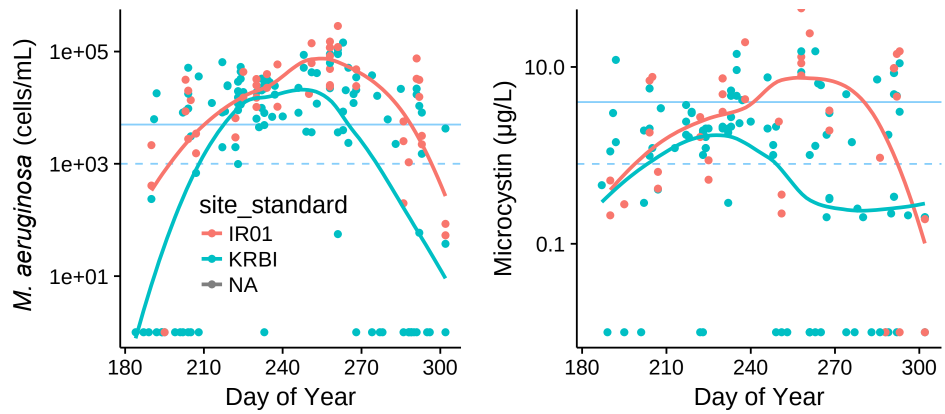
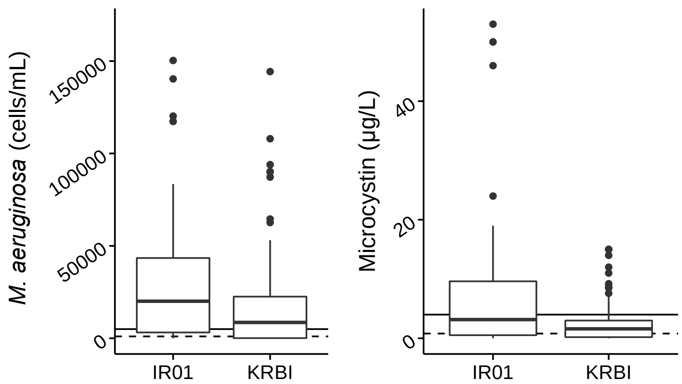
<tr>
<td>P4-24</td>
<td>The set up of the auto-samplers with comparing reservoir conditions unaffected by the curtain (i.e., upstream of the curtain) and river below the dam is good, because ultimately, we are interested in what the downstream river conditions are. This study should be repeated without the curtain in place (when it is deemed unusable due to DO issues) to see what the baseline difference between the reservoir and river are, as some decrease in toxin and cell concentrations occurs without the curtain (see figure below). Conducting more of these paired samples, with and without the curtain during variable cyanobacterial conditions will further help understand when and by how much the curtain can help reduce downstream algal transport.</td>
</tr>
</table>

	 Figure: *Microcystis* and microcystin plotted by day of year from baseline samples in Iron Gate Reservoir at 0.5 m (IR01, pink) and the Klamath below Iron Gate (KRBI, blue) with LOESS smoothers show that average concentrations of MSAE and microcystin are lower in the river below the dam, even without curtain deployment. Data are from 2005 through 2014, July-October.
P5-1	Again, consider the possibility of biofouling before making conclusions that phytoplankton biomass was higher in November than any other time during the 2016 season. This conclusion is not likely and, as stated in the report, not consistent with the base-line phytoplankton data collected at the IG log boom. Also, a curtain depth of 3 meters is not likely sufficient at isolating the surface waters as previous graphs show water at 3 meters deep to have similar temperatures as near-surface waters, with the thermocline being much deeper than 3 m, as shown in the vertical profile plots on page 4-13. Further, 3 m is shallower than the potential depth of daily vertical migration of MSAE (7-8m), as stated in following pages of the report.
P5-4	0.5 m is indicative of near-surface waters, but can be dramatically different than true surface samples
P5-4	Rather than simply stating that the boat dance flows are "atypical" of summer conditions, state how they are different (i.e., increased flow), consider how often flow increases occur and state that the curtain appears to have limited abilities to reduce downstream transport of BGA under these ceremonials releases. This is important for tribal members to understand, thus the point should be clear.
P5-4	"These results indicate that there were significant differences in mean concentrations of total microcystin upstream of the curtain (SU) when compared to the river downstream of Iron Gate dam (Figure 4-41) with higher mean concentrations of microcystin upstream than downstream." It should also be noted that that reservoir samples were significantly different (Kruskal-Wallis p-value=0.005) from those at KRBI in samples taken between 2005 and 2014 without the curtain in place (see data in the figure above under comment 4-24).



P5-5	“The 15-minute chlorophyll-a levels recorded by the 5 m and 10 m sondes on the downstream side of the curtain are relatively constant from July 1-September 30. This suggests that algae is not passing from near-surface waters under the curtain. The 5 m and 10 m sondes represent” Figure 4-5 shows that the downstream 10m sonde was offline for most of the time period mentioned in this sentence.
P5-6	“In contrast, the thermograph array downstream of the curtain shows minimal difference in temperatures between readings taken near the surface and those taken at depth (Figures 4-13 and 4-14).” Also, citation should probably be Figures 4-11 and 4-13, not 4-13 and 4-14.
P5-7 sec 5.2.3	Both sonde data and vertical profiles suggest higher algal biomass in near-surface waters both above and below the curtain, with bigger differences above the curtain. Simply concluding that conditions were similar throughout the water column at the downstream site is not accurate.
P5-7	“The Klamath River below Iron Gate dam temperature before curtain deployment closely matches the temperature at 5 m depth.” Is that similar or different than found in years with previous data (i.e., see our comments on P5-12 below that mention the 1996-1997 and 2000 data).
P5-8	Include a photo or other documentation of macrophyte growth near the reservoir outlet. Due to steep sides and bottom depths that exceed the photic zone, phytoplankton would be expected to be the cause of surface increases/diel swings in pH. This point of higher surface pH contradicts the previous conclusions in section 5.2.3.
P5-9	“Previous analysis showed that microcystin levels in near-surface waters upstream of the curtain (SU) were often appreciably higher than at KRBI (Section 5.1.2), which suggests that the curtain is effectively segregating surface waters” It may be true that the curtain segregates surface waters, but observing that microcystin concentrations at KRBI are lower than those in surface waters upstream of the curtain does not directly and convincingly demonstrate that it is due entirely to the curtain, because as we noted above in our comments regarding page 4-24, such a reduction is consistently observed even without the curtain in place.
P5-10 sec 5.3.3	This section should include comparison of DO level to those above the curtain as well.
P5-10 sec 5.3.3	“The near-surface (0.5 m deep) dissolved oxygen data trend relatively closely resembles the dissolved oxygen data trend in the Klamath River downstream of

	Iron Gate dam dissolved oxygen the curtain was raised (Figure 5-6).” Sentence wording is confusing and may be missing some words. What dates is it intended to refer to?
P6-1	Some conclusions of the data are over-stated. “Cyanobacteria and microcystin concentrations were consistently higher upstream of the curtain than those downstream of the curtain.” Although generally near surface samples were higher for microcystin and cell densities, there are cases when downstream samples were higher during the August profile sampling, and deeper samples appeared to be similar between sampling sites. To the extent that light extinction represents algal density, it was based on only two sample dates post curtain deployment, and on one of the two sampling dates there were similar light extinction curves, indicating increased clarity below the curtain <u>sometimes, but not always</u>. Higher frequency sampling of fewer samples could bring more insight into how the curtain performs throughout the duration of its deployment. “Physical parameters at deeper waters upstream and downstream of the curtain were comparable.” Does deeper water mean 5m or 10m? pH is not very similar upstream and downstream of the curtain (see Figure 4-4). Stating that the curtain “is an effective water quality management tool to isolate the algae-rich near-surface waters in Iron Gate reservoir and prevent them from being transported downstream of the dam into the Klamath River” is misleading. There can be high (albeit not as high as the surface) algal concentrations at depth, and when algae sinks (either intentionally to access nutrients, or when blooms decline) it will be entrained into the intake and the river downstream. This study demonstrated that the curtain could at times <u>reduce</u> algal cell and toxin transport downstream, but not <u>prevent</u> it. With curtain deployment in, there were still many instances of microcystin levels above the 0.8 µg/L caution level in the river below Iron Gate Dam.
Misc. comment 1	The report sometimes uses words that are stronger than the data support. For example, in multiple places, the words “limit” and “prevent” are used to describe the curtain’s effect on BGA and associated parameters. We suggest replacing such instances with a more accurate word such as “reduce”

References:

Asarian, E. and J. Kann. 2011. Phytoplankton and Nutrient Dynamics in Iron Gate and Copco Reservoirs 2005-2010. Prepared by Kier Associates and Aquatic Ecosystem Sciences for the Klamath Basin Tribal Water Quality Work Group. 60p + appendices. http://www.klamathwaterquality.com/documents/asarian_kann_2011_CopIG_res_2005_2010_rpt.pdf

Deas, M. L. and G. T. Orlob. 1999. Klamath River Modeling Project. Project #96-HP-01. Assessment of alternatives for flow and water quality control in the Klamath River below Iron Gate Dam. University of California Davis Center for Environmental and Water Resources Engineering. Report No. 99-04. 379 pp.

Perry, R.W., Risley, J.C., Brewer, S.J., Jones, E.C., and Rondorf, D.W. 2011. Simulating Daily Water Temperatures of the Klamath River under Dam Removal and Climate Change Scenarios. U.S. Geological Survey Open-File Report 2011-1243:78pp.
Watercourse Engineering, Inc. 2003. Klamath River Water Quality 2000 Monitoring Program - Project Report. Sponsored by U.S. Bureau of Reclamation Klamath Falls Area Office with support from PacifCorp. Watercourse Engineering, Inc. Napa, CA. 92p.