Final Technical Report

2012 Assessment of an Intake Cover for Water Quality Control at Iron Gate Reservoir

Prepared for

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1.0 INTRODUCTION

On February 18, 2010, the United States, the states of California and Oregon, PacifiCorp, Native American tribes, and a number of other stakeholder groups signed the Klamath Hydroelectric Settlement Agreement (KHSA). The KHSA lays out the process for additional studies, environmental review, and a determination by the Secretary of the Interior regarding whether removal of four dams owned by PacifiCorp on the Klamath River will advance restoration of the salmonid fisheries of the Klamath Basin and is in the public interest (which includes local communities and tribes).

The KHSA includes provisions for the interim operation of the dams and mitigation activities prior to potential removal of the hydroelectric facilities. One such provision—titled Interim Measure 11: Interim Water Quality Improvements—emphasizes water quality improvement projects in the Klamath Basin during the interim period.

As a means of improving water quality downstream of Iron Gate Reservoir, located in Northern California near the Oregon border, PacifiCorp implemented a multi-year study (Cover Study) to assess the efficacy of an intake cover to potentially reduce cyanobacteria entrainment into the existing Iron Gate Reservoir intake. An intake cover could provide a straightforward means of controlling the depth at which intake waters are withdrawn from the reservoir at or near the surface; thus, providing a method for potentially reducing the amount of algae entrained into the Iron Gate intake and discharged from the powerhouse. Specifically, for this Cover Study, the focus of control is on reducing the cyanobacteria (i.e., *Microcystis aeruginosa*) and potential associated algal toxin (i.e., microcystin) concentrations downstream of the reservoir. To assess the potential for a cover that could easily be fitted to the existing intake to accomplish this, an understanding of the relationship between in-reservoir velocities, the intake cover, and diel movements of algae in the reservoir had to be developed.

The first phase of the Cover Study established baseline velocity conditions near the log boom and intake tower and informed the second phase of the study (Section 3.1). The second phase of the study tested the deployment of an intake cover and assessed the effects of that deployment on velocity profiles and downstream water quality conditions (Section 3.2). The third phase of the study determined the effects of the intake tower cover over longer periods of deployment (i.e., days) and assessed if clear and consistent diel movement of algae occurs in the reservoir to provide information on the depth of movement of algae to inform further refinement of concepts related to algae exclusion from the reservoir intake.

This report presents the findings of the third phase of the Cover Study. Section 2 provides background information on the Iron Gate intake tower. Section 3 summarizes the previous first and second phases of the Cover Study. Section 4 describes the study approach and methods for the third phase of the Cover Study. Section 5 presents and discusses third phase study results, followed in section 6 by conclusions and recommendations from the third phase.

2.0 BACKGROUND

Iron Gate Dam, completed in 1962, impounds Iron Gate Reservoir, which has a storage capacity of 53,000 acre-feet at normal full pool (PacifiCorp 2004). The outlet works consist principally of an intake tower for the Iron Gate Powerhouse, two fish hatchery intakes, a weir spillway with a leaf gate (Table 1~~Table 1~~, Figure 1~~Figure 1~~), and low-level outlet tunnel from the original construction. The low-level outlet is not used during normal operations. The intake tower is screened with a trash rack that extends from above the water surface to the bottom of the structure, which is approximately the invert of the penstock intake to the powerhouse. In addition, there is a small debris boom structure (termed herein "A-frame debris boom", or simply "A-frame") attached to the upstream face of the intake tower to prevent larger floating debris from impinging on the trash rack. Water depth near the intake tower is approximately 35 ft (10 m) at normal reservoir operating elevation (2,328 ft msl), but varies with powerhouse operations.

Table 1. Iron Gate Dam Outlet Facilities Information (PacifiCorp 2002)
Metric units are also presented in parenthesis.

Outlet	Diameter/Width/Length (ft)	Invert (ft msl)	Capacity (cfs)
Iron Gate Powerhouse Intake Tower	12 (3.7 m) Diameter	2,293 (698.9 m)	1,850 (52.4 cms)
Upper Fish Hatchery Intake	2 (0.6 m) Diameter	2,309 (703.8 m)	50 (1.4 cms)
Lower Fish Hatchery Intake	2 (0.6 m) Diameter	2,253 (717.2 m)	50 (1.4 cms)
Leaf Gate[a]	10 (3.1 m) Width	2,322 (707.7 m)	460[b] (13.0 cms)
Spillway (Weir)	724 (220.7 m) Length	2,328 (709.6)	71,000[c] (2010.5 cms)

[a] Source: PacifiCorp.

[b] At 2,328.5 feet (at the water surface elevation).

[c] At 2,342.0 feet (at the water surface elevation).

Figure 1. Iron Gate Reservoir Intake Tower, Trash Rack, and A-frame Debris Boom

3.0 PREVIOUS STUDY PHASES

The first and second phases of the Cover Study were completed in 2009 and 2011, respectively. These studies established the foundation on which the objectives and methods of third phase could be developed. The details describing the methods and results are documented in Deas and Miao (2010) and Appendix A. A general overview of these previous studies is included here to provide background for the objectives and methods of the third phase of study conducted in 2012 as discussed below in Section 4.

3.1 2009 Study

The main purpose of the 2009 study was to assess the feasibility of using an Acoustic Doppler Current Profiler (ADCP) for monitoring water column velocities to determine the depth profile (or "envelope") from where reservoir water was being entrained into the penstock intake (Deas and Miao, 2010). ADCP measurements also were identified as a means to characterize flow conditions prior to and during cover deployment by providing insight into the velocity and direction of water entering the penstock intake immediately upstream of the intake tower.

Velocity measurements were taken with the ADCP along the log boom and near the intake tower. Velocity measurements indicated that the velocity profile was not uniform throughout the water column. Despite the asymmetrical water velocity distribution (faster velocities were observed at deeper depths, near the elevation of the penstock intake), the velocity profiles indicated that water was being entrained from all elevations extending The velocity profiles helped to support the hypothesis that installation of a cover could potentially reduce cyanobacteria concentrations downstream of Iron Gate Dam by:

- Reducing the amount of surface water (that presumably has higher algal concentrations) withdrawn into the penstock intake; and

- Increasing velocities near the penstock inlet at the bottom of the intake tower and thus increasing contributions from deeper waters (that presumably has lower algal concentrations).

Based on these results, the second phase of the Cover Study was conducted in 2011.

3.2 2011 Study

In 2011, an intake cover was constructed and installed on the Iron Gate intake tower trash rack. The cover consisted of two, 17 feet by 6 feet (5.2 m by 1.8 m), steel-frames was attached to a hoist in front of the intake tower. The hoist allowed the cover to be lowered to different depths (Figure 2~~Figure 2~~). 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 physical water quality measurements (i.e., water temperature, dissolved oxygen, and pH); nutrient, algae, and chlorophyll *a* grab samples; and ADCP velocity measurements.

Figure 2. One of Two Steel Frames Shown Prior to Installation (a) and After Installation onto the Intake Tower (b)

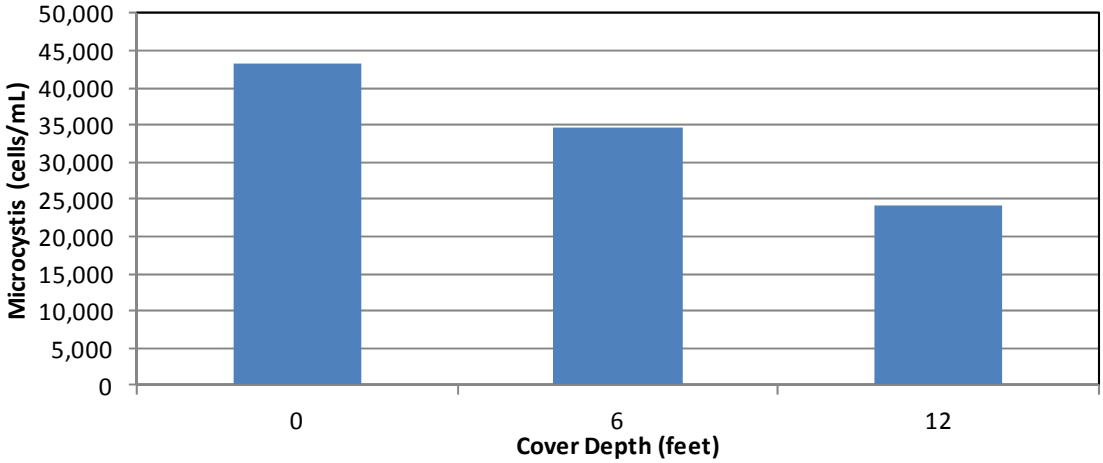
(a) (b)

The intake cover was placed over the near-surface portion of the intake tower trash rack to two test deployment depths–6 ft and 12 ft[1] below the surface–for periods (at each depth) of approximately 45 minutes. During the two test deployment periods, ADCP measurements were taken and indicated an increase in velocity near the penstock intake, suggesting the withdrawal profile (or "envelope") was altered due to the placement of the cover. When the intake cover was lowered to the test depths, *Microcystis aeruginosa*

[1] The intake trash rack is slightly inclined (one foot horizontal per six feet vertical). Thus the 6 ft and 12 ft cover deployment depths actually correspond to 5.9 ft and 11.8 ft of vertical depth. For simplicity, this report will use 6 ft and 12 ft to denote cover deployment depth.

(MSAE) cell counts were 19 percent and 44 percent lower downstream during the 6 ft and 12 ft test deployments, respectively, compared to cell counts when the cover was not present (Figure 3~~Figure 3~~). These results suggested the cover could be an effective means of reducing entrainment of MSAE into downstream releases. Physical water quality parameters, such as dissolved oxygen, temperature, pH, and nutrient concentrations, did not change during the two test cover deployments compared to when the cover was not present.

Figure 3. *Microcystis aeruginosa* (MSAE) Concentrations (cells/mL) Associated with Cover Depth
August 31, 2011



Despite the reduction in MSAE concentrations, the ADCP velocity data indicated that velocity profiles in the vicinity of the intake tower had not stabilized during the two test deployment periods, suggesting the test periods were not sufficiently long for the velocity field in the region of the cover and intake to stabilize (i.e., the test periods were each less than an hour). As a result, it was recommended that additional studies (third phase) should assess the effects of longer-term deployment of the cover.

The 2011 Iron Gate Cover Study provided insight on the complex hydrodynamics near the intake tower. Based on these findings, recommendations for future studies included:

- Extend the study period to span two weeks and deploy the cover for longer periods of time (i.e., multiple sequential days) to test the effects of the cover when stable hydraulic conditions are attained as determined from consistent velocity readings over a range of days.

- Conduct a vertical migration study of cyanobacteria within the vicinity of the intake structure by deploying a phycocyanin probe in the reservoir for a full day or over several days (including overnight).

Additional results from the 2011 study are included in Appendix B.

4.0 2012 STUDY APPROACH AND METHODS

Based on the findings and recommendations of the 2011 study (as described above), the design of the 2012 intake cover study included: (1) increased test deployment periods (multi-day continuous deployment); (2) increased horizontal spatial sampling locations upstream in the reservoir and downstream in the river; (3) additional vertical grab samples in-reservoir at three depths; and (4) continuous sonde measurements upstream of the intake in the reservoir and downstream in the river (Figure 4~~Figure 4~~).[2] The methods employed for the 2012 study are described in the following subsections below, including the study duration, ADCP velocity measurement and water sample collection and analysis.

Concurrent with the 2012 Cover Study, a study was conducted to assess the vertical distribution and potential diel movement of cyanobacteria, and is presented below.

Figure 4. Iron Gate Reservoir and Downstream Klamath River Area; Inset: In-reservoir Monitoring Location and A-frame
Google Earth.

[2] Study design is reported in English units, but note that field measurements were often taken in metric. The gradations on the cover were measured in feet, whereas sampling depths were measured in meters. As a result, all metric units for sampling depths and design are reported in feet.

4.1 Study Duration

The 2012 Iron Gate Cover Study spanned the period from August 20, 2012 to August 30, 2012. Prior to the deployment of the cover, one full day of pre-deployment monitoring occurred. Mid-day and afternoon samples were collected on August 20 and a morning sample was collected on August 21. Subsequently, three separate cover deployment events were conducted to a depth of approximately 12 ft (Table 2~~Table 2~~). These included a 31-hour deployment on August 22-23 and about a 72-hour deployment during August 27-30. The 7-hour cover deployment on August 21 was used to test equipment and sampling methods. As such the data collected on August 21 are not included in the analysis and discussion.

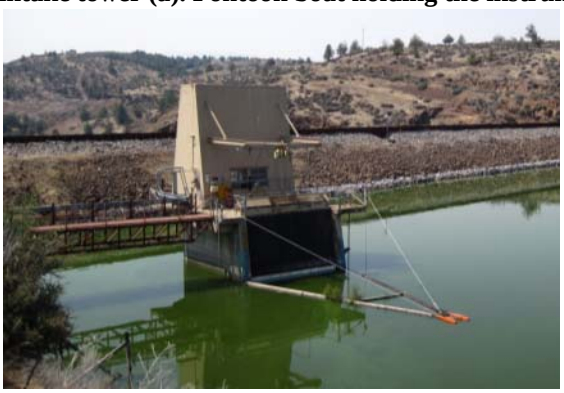
Table 2. Dates and Times of Cover Movement and Duration of Cover Deployment in 2012

Date/Time of Cover Movement		Duration (Hours)
Lowered	**Raised**	
August 21 at 08:00	August 21 at 15:00	7:00
August 22 at 07:45	August 23 at 14:45	31:00
August 27 at 14:00	August 30 at 14:20	72:20

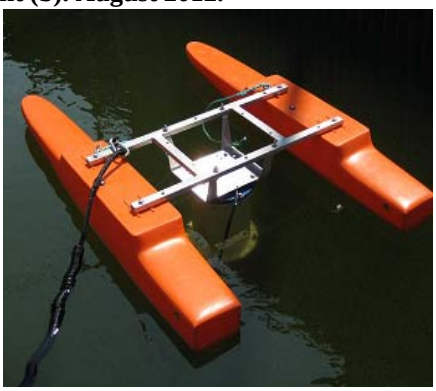
4.2 ADCP Velocity Measurements

A 600-Hertz ADCP (Workhouse Sentinel by Teledyne) was used to measure water column velocities in Iron Gate Reservoir near the intake tower. The measurements were taken at the tip of a metal A-Frame that lies on the water surface perpendicular to the intake tower opening (Figure 5; also noted as “A-Frame” in Figure 4~~Figure 4~~). The ADCP instrument was deployed on a small pontoon boat (Figure 5) and connected directly to a laptop to record and view data.

Figure 5. ADCP velocity measurement location at the tip of the A-Frame, about 36 ft upstream of the intake tower (a). Pontoon boat holding the instrument (b). August 2012.



(a)



(b)

4.3 Grab Samples (Nutrient, Algae, and Chlorophyll *a*)

Grab samples were collected during the study period in Iron Gate Reservoir and downstream of Iron Gate Dam. The samples were analyzed for total nitrogen (TN), nitrate plus nitrite ((NO_3+NO_2)-N), ammonia (NH_4-N), total phosphorus (TP), orthophosphate (PO_4-P), dissolved organic carbon (DOC), chlorophyll *a*, and pheophytin. Samples were analyzed for cyanobacteria, including dominant species, notably MSAE and *Aphanizomenon flos-aquae* (APFA). Laboratory methods and associated information are described included in Table 3~~Table 3~~.

Table 3. Laboratory Methods, Method Detection Limits (MDL), and Reporting Limits (RL), as Applicable

Constituent	Units	Method	Preservative	MDL[a]	RL[a]	Laboratory
TN	mg/l	NEMI[b] I-4650-03	None	0.01	0.02	Biogeochemistry Laboratory, U.C. Davis
NO3+NO2	mg/l	Nitrate via V(III) reduction[c]	None	0.005	0.01	Biogeochemistry Laboratory, U.C. Davis
NO2	mg/l	Nitrate via V(III) reduction	None	0.002	0.01	Biogeochemistry Laboratory, U.C. Davis
NH4	mg/l	SM[d] 4500-NH3 F	None	0.005	0.01	Biogeochemistry Laboratory, U.C. Davis
TP	mg/l	NEMI I-4650-03	None	0.01	0.01	Biogeochemistry Laboratory, U.C. Davis
OPO4	mg/l	SM 4500-P E	None	0.001	0.005	Biogeochemistry Laboratory, U.C. Davis
DOC	mg/l	EPA[e] 415.3	None	0.1	0.1	Biogeochemistry Laboratory, U.C. Davis
Chlorophyll *a*	µg/l	EPA 445.0	None	1 ppb	1 ppb	Biogeochemistry Laboratory, U.C. Davis
Microcystin	mg/l	ELISA[f]	None	0.16	n/a	CH2MHill Environmental Laboratory, Corvallis

Table 3. Laboratory Methods, Method Detection Limits (MDL), and Reporting Limits (RL), as Applicable

Constituent	Units	Method	Preservative	MDL[a]	RL[a]	Laboratory

[a] Units are in mg/l unless otherwise specified.

[b] National Environmental Methods Index

[c] This method was developed by UC Davis Department of Land, Air and Water Resources (Doane and Horwath, 2003)

[d] Standard Methods

[e] Environmental Protection Agency

[f] USEPA Region 9 SOP 1305 (Envirologix ELISA method)

4.3.1 Downstream Sampling

Grab samples were collected from the Klamath River downstream of Iron Gate dam (at the "Downstream Monitoring" location shown on Figure 4). Grab samples were generally collected three times a day[3] (in the morning, afternoon and early evening) using a churn sample splitter. The grab samples were collected at the same downstream monitoring location where the sonde to measure physical water quality parameters was deployed (as described in section 4.4 below).

4.3.2 In-Reservoir Sampling

Grab samples were collected once per day in the afternoon (approximately at noon each day after the cover was deployed). The grab samples occurred at three depths in the reservoir (surface, 10-ft depth, and 30-ft depth below the surface) using a 5-L Van Dorn sampler before being transferred into a churn sample splitter for processing. The samples were collected approximately 33 ft (10 m) upstream of the A-frame (noted as "In-Reservoir Monitoring" location in Figure 4~~Figure 4~~) to characterize conditions entering the powerhouse.

4.4 Sonde Measurements

YSI Professional Plus (YSI ProPlus) sondes were used to measure physical water quality parameters during the two-week study at downstream and in-reservoir locations (as described below). Parameters included water temperature, dissolved oxygen, and pH.

4.4.1 Downstream Measurements

One YSI ProPlus sonde was deployed downstream of Iron Gate Reservoir on river right approximately 600 feet upstream of the Hatchery Bridge (noted as the "Downstream Monitoring" location in Figure 4~~Figure 4~~). The instrument was deployed throughout the study period. The instrument recorded in five-minute intervals. PacifiCorp also had a

[3] With the exception of August 20 and August 21, when two samples were collected on August 20 and four samples were collected on August 21.

sonde deployed on river left at approximately the same distance upstream of the Hatchery Bridge recording hourly (noted as the "PacifiCorp Sonde" location in Figure 4~~Figure 4~~).

4.4.2 In-Reservoir Measurements

Another YSI ProPlus sonde was used for vertical spot measurements taken in-reservoir at two locations in the reservoir. At the log boom, which is located about 2,000 ft upstream of the dam (noted as the "Log Boom" location in Figure 4~~Figure 4~~) measurements were taken approximately every 3 ft from the surface to about 66 ft below the water surface. Vertical measurements were also taken approximately 33 ft upstream of the A-Frame (noted as the "In-Reservoir Monitoring" location in Figure 4~~Figure 4~~, inset). Measurements were taken approximately every 3 ft from the surface to approximately 40 ft below the water surface.

5.0 RESULTS AND DISCUSSION

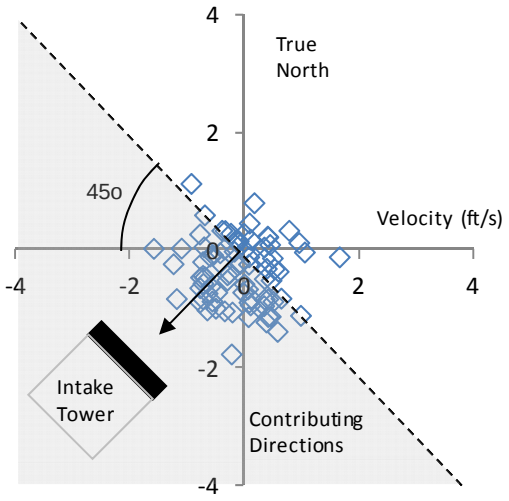
The 2012 Iron Gate Reservoir Cover Study results are presented and discussed in the following subsections below, including on velocity profiles in the reservoir, algae species, water quality (grab samples), and physical water quality (sonde measurements).

5.1 Velocity Profiles

Velocity data (obtained at the tip of the A-Frame as shown in Figure 5) were collected using the ADCP in a continuous profile for the water column from approximately 3 ft below the surface to about 30 ft below the surface (the top of penstock intake was approximately 23 ft below the water surface). ADCP velocity measurements were unavailable for approximately the top 3 ft of the water column due to interferences from the close proximity of the instrument to the initial depth layer at the surface (common to ADCP applications). Velocities below approximately 30 ft could not be determined from the ADCP due to interference with the outlet tower, as well as the bed of the reservoir. As such, velocity profiles estimated based on previous measurements if velocity in the reservoir (Deas, 2010) and theoretical velocity distributions (Granger, 1995; White, 1994) were used to estimate surface velocities in the vicinity of the penstock intake and below approximately 30 ft.

To assist in analyzing the continuous profile data from the ADCP, the data were averaged by 3.3 ft interval (approximately 1.0 m) (e.g., 0 to 3.3 ft, 3.3 ft to 6.6 ft, etc.). The ADCP measures velocities in all directions (360°) along the measured vertical profile. Near the A-Frame, water particles may move in any direction (laterally and vertically) at any particular time due to small-scale hydrodynamics. The majority of the velocities measured at the A-Frame monitoring location were towards the intake tower (Figure 6~~Figure 6~~). Only measured velocities into the penstock intake were averaged for this analysis.

Figure 6. The ADCP Measured Velocity, Along with the Direction (Angle) from True North
The velocities (ft/s) with a direction within the grey area are assumed to contribute to intake inflows. The approximate location of the penstock intake, relative to true north, is also indicated.



ADCP measurements indicated that the velocity profiles were relatively stable during both pre-deployment measurements on August 22 and August 27 (Figure 7~~Figure 7~~, green lines). Pre-deployment velocities ranged from 0.77 feet per second (ft/s) to 0.91 ft/s on August 22 and ranged from 0.66 ft/s to 0.94 ft/s on August 27. In general, the highest velocities were observed near the penstock intake depth. Averages of these pre-deployment velocities (from 3 ft to 30 ft) were 0.85 ft/s and 0.75 ft/s for August 22 and August 27, respectively.

During August 22-23, the cover was deployed for approximately 31 hours. A-Frame velocities were measured approximately two hours after the cover was fully deployed (on August 22) and again approximately 24 hours later (on August 23). Almost immediately after the cover was deployed, the water column velocity profiles were affected (Figure 7~~Figure 7~~(a)). Two hours after deployment, water column velocities ranged from 0.66 ft/s to 1.13 ft/s, with an average of 0.80 ft/s. Decreased velocities were observed throughout the water column, except near the penstock intake location where velocities increased. In the short-term (e.g., 2 hours up to approximately 24 hours), near-surface velocities were notably lower with the cover in place.

Twenty-four hours after the cover was deployed, water column velocities were generally less than pre-deployment velocities. Velocities ranged from 0.60 ft/s to 1.03 ft/s, with an average of 0.78 ft/s. Variability is evident in the velocities for all time periods and is most likely due to local hydrodynamic variability in the vicinity of the intake tower.

During August 27-30, the cover was only deployed once and remained in place for approximately 72 hours. Velocity measurements were taken 24, 45, and 72 hours after deployment (Figure 7~~Figure 7~~(b)). The range and average of the measured water column velocities for these three measurements were:

- 24 hours: 0.62 ft/s to 0.83 ft/s (average of 0.71 ft/s),

- 45 hours: 0.66 ft/s to 0.82 ft/s (average of 0.72 ft/s), and
- 72 hours: 0.60 ft/s to 1.16 ft/s (average of 0.80 ft/s).

In general, the water column velocities during these three deployment measurements were similar to the August 27 pre-deployment conditions. Seventy-two hours after deployment, velocity measurements were available at approximately 31 ft (8.5 m) below the surface, which is deeper than any other profile[4], but were consistent with the theoretical profiles. Conditions shown in Figure 7~~Figure 7~~(b), where the velocity regime under post-cover is similar to pre-cover, suggest that after approximately 24 hours the flow regime around the covered intake area approaches a "new" equilibrium with the cover in place. Before cover deployment, water can enter the intake from a vertical profile extending from the reservoir surface to the reservoir bed (Figure 8~~Figure 8~~(a)). Immediately after the cover is deployed, the vertical extent of the intake withdrawal zone is notably reduced (Figure 8~~Figure 8~~(b), t=0+). This reduction in the withdrawal zone leads to isolation of near-surface waters (i.e., near-surface waters are outside the withdrawal zone and therefore not entrained by the intake). However, field data suggest that after approximately 24 hours the withdrawal zone begins to expand as the flow regime around the covered intake approaches a new equilibrium (Figure 8~~Figure 8~~(b), t>24). This observation was supported by vertical velocity ADCP readings. When the cover was fully deployed for a relatively short period (e.g., 1 to up to 24 hours), the downward vertical velocities were reduced, indicating that the cover isolated a large proportion of surface water within the cover depth. When the cover was deployed for longer periods (e.g., 24 hours, 45 hours, and 72 hours), downward velocities developed that were slightly larger and occurred more consistently at a shallower depth.

[4] On occasion the ADCP picks up a deeper signal due to local orientation, signal interference, or other factors. In this one instance, the ADCP picked up a reading at just over 30 feet, but generally signals were returned for depths to approximately 30 feet.

Figure 7. Velocity Profiles for Week 1 – August 20-23 (a) and Week 2 – August 27-30 (b) Cover Deployments

Secondary y-axis scale represents the water surface elevation. Grey rectangle represents the approximate elevation of the penstock intake. Near-bed velocities are estimated based on theoretical velocity profiles (Granger, 1995; White, 1994).

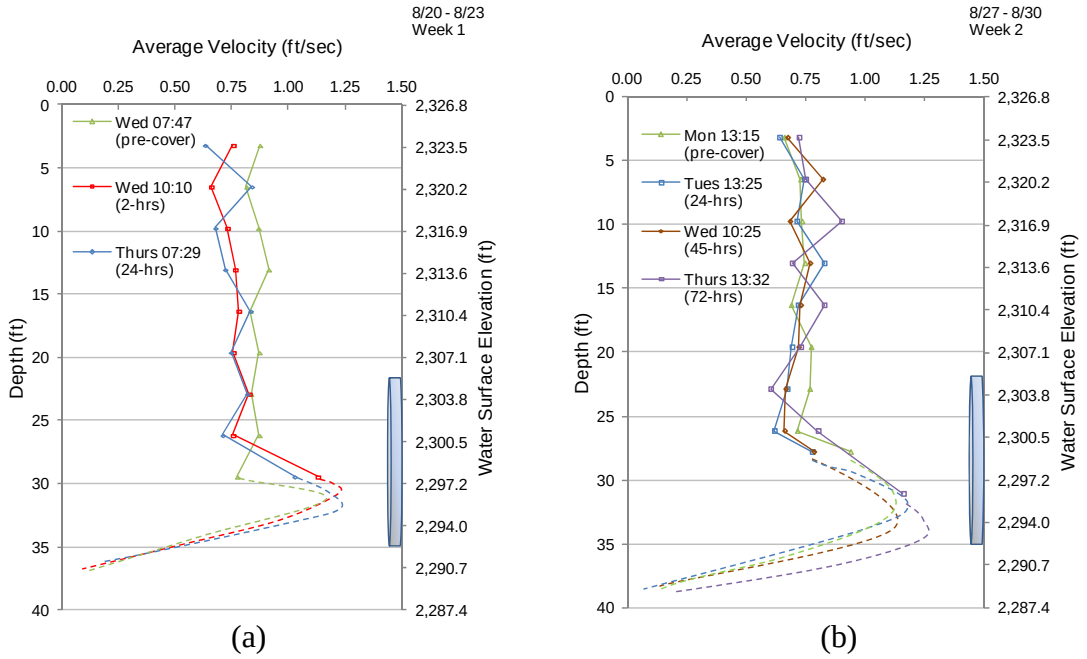
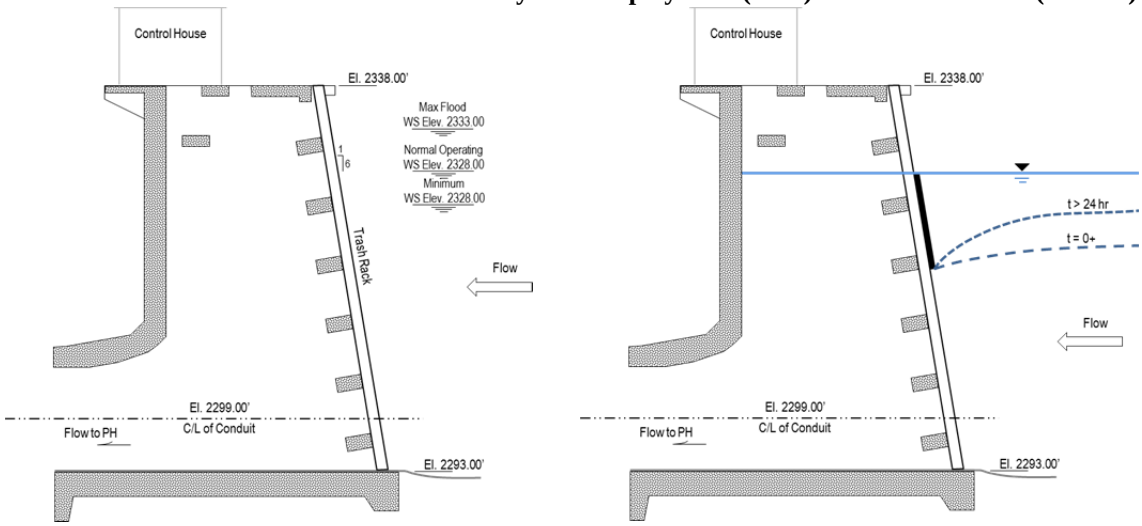


Figure 8. Profile View of the Iron Gate Intake Tower (a) Showing the Trash Rack, Elevation of the PH Penstock Invert and Centerline, and Range of Operating Elevations and (b) Depiction of Intake Zone with Cover in Place for the Period Shortly after Deployment (t=0+) and after 24 hours (t>24 hr)



5.2 Algae Species and Chlorophyll *a*

The 2012 study was intended to confirm the 2011 findings of reduced MSAE concentrations below Iron Gate Dam during cover deployment, and to assess the effect of

longer deployments than conducted in 2011. As such, the 2012 results would help to determine how the period of cover deployment might affect reductions in downstream MSAE concentrations.

In 2011, downstream MSAE concentrations decreased with increasing cover depth (Figure 3~~Figure 3~~) for short duration deployments. However, downstream APFA concentrations did not respond in a similar fashion. This potential discrepancy may have been due in part to the larger size of APFA colonies compared to MSAE colonies. The rates of sinking and floating (buoyancy) for such algae are typically based on the Stokes equation (Reynolds, 2006), which identifies that larger particles have the ability to sink or float faster than smaller particles. While MSAE colonies could reasonably be approximated as spherical, APFA colonies consist of cells that are more cylindrical or barrel-shaped, which certainly deviate from the spherical shape assumption for Stokes law. Yet, the overall volume of APFA colonies is also markedly larger than MSAE colonies, leading to higher settling or floating rates in APFA. APFA colonies could be occupying a greater range of depths in Iron Gate Reservoir, due to their larger size. As such, the intake cover, which only occupies approximately the top 12 ft of the water column at the intake tower, likely has a smaller effect on APFA compared to MSAE. The size discrepancy between APFA and MSAE may also explain the modest reduction chlorophyll *a* in the 2011 data. While MSAE concentrations were reduced up to approximately 40 percent for the 12 ft cover deployment, chlorophyll *a* concentrations were reduced approximately 8 percent. A large fraction of the biovolume of APFA (often an order of magnitude larger than MSAE), coupled with other algae present (e.g., diatoms, cryptophytes, greens) could explain the smaller reduction in chlorophyll *a* concentrations.

In 2012, MSAE concentrations were reduced (as denoted by arrows in Figure 9) in samples taken shortly after the deployment of the intake cover on both August 22 and August 27 (see Table 2). However, in both deployments, a rebound or subsequent increase in MSAE was observed in later samples taken during the deployment period. For example, after a decrease in the initial post-deployment sample, subsequent increases were observed in samples taken after approximately 24 hours of cover deployment on August 23 and after approximately 19 hours of cover deployment on August 28. MSAE concentrations then varied throughout the rest of the deployment periods. By comparison, APFA concentrations were also reduced following the deployment of the intake cover on August 22, but did not appear to be reduced after the August 27 deployment (Figure 9). As in 2011, the chlorophyll *a* concentrations in 2012 samples exhibited the same variability as algal species and only generally followed overall total algae concentrations (Figure 10).

These results indicate that the intake cover had a notable effect on downstream MSAE concentrations following deployment, but that the effect may dissipate over time as a new hydraulic condition develops in which vertical velocities near the intake entrain a larger proportion of surface water over time.

PacifiCorp's sonde downstream of Iron Gate Dam (see Figure 4) includes a phycocyanin probe that serves as an approximate measure of cyanobacteria concentrations. A review

of the phycocyanin probe data during the 2012 Cover Study yielded valuable information regarding the variability in algae concentrations that likely occurred in the flows released from Iron Gate Dam during the deployment periods. The phycocyanin probe observations from August 18 to August 31, 2012 are shown in Figure 11~~Figure 11~~. However, the phycocyanin data are not directly comparable to cyanobacteria concentrations, and in particular MSAE. Thus, the phycocyanin data are assumed as surrogate values only of cyanobacteria cell counts. The phycocyanin data have not been calibrated to observed data, so the phycocyanin levels are not directly comparable to cell counts identified in grab samples. In addition, the phycocyanin probe was not calibrated to a specific blue-green algal species (e.g., wavelength and bandwidth associated with specific pigment fluorescence), but rather was based on a factory default setting for general blue-green algal species assemblages.

Three observations of the data shown in Figure 11~~Figure 11~~ include:

- The phycocyanin data exhibits background "noise" as exhibited by hourly variations on the order of 2,000-3,000 cell counts.

- Short-term (sub-daily) variability in the phycocyanin data on the order of 5,000 to 10,000 or more cell counts over several hours.

- Long-term (multi-day) variability in the phycocyanin data where trends are apparent, such as the August 27 to 29 period when cell counts increased from near zero to over 25,000.

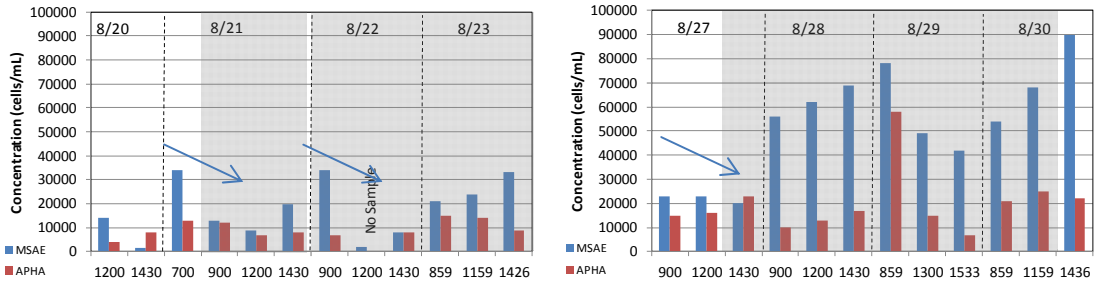
Superimposing the period of cover deployment on the phycocyanin trace illustrates that during week 1 (August 21-23) downstream phycocyanin concentrations were generally lower during cover deployment than when there was no cover in place. The generally lower phycocyanin concentration is consistent with the reduced MSAE concentrations observed in samples taken following cover deployment (as discussed above and shown in Figure 9). However, the considerable variability in the phycocyanin data adds uncertainty as to whether this generally lower phycocyanin trend was an effect of the intake cover, natural variability, or other phenomena.

During the August 27-30 period, phycocyanin was steadily increasing just prior to cover deployment, appeared to stay steady for many hours following cover deployment, and then steadily increased again for about the next 24 hours before varying appreciably throughout the rest of the cover deployment period. This phycocyanin trend also appears generally consistent with the trend in MSAE concentrations for the August 27-30 period. During this period, MSAE was observed to decrease initially and then subsequently increase again after approximately 19 hours of cover deployment (as discussed above and shown in Figure 9). However, once again, the variability in the phycocyanin data and the lack of an upstream phycocyanin indicator uncertainty as to whether the observed phycocyanin trend is due to the effect of the intake cover.

The complexity of in-reservoir conditions, including bloom dynamics, meteorological conditions (e.g., wind mixing, convective cooling, etc.), or other factors, lead to inherent

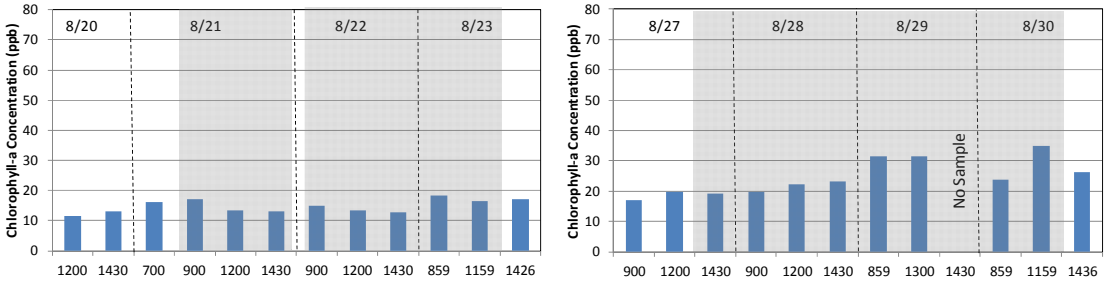
variability in algae concentrations within the reservoir and in releases to the Klamath River. Another factor that could affect results is the vertical distribution of cyanobacteria. While not explicitly addressed at the barrier location, a separate vertical distribution study was undertaken and is discussed in the following section. The data on the vertical distribution of chlorophyll-a and phycocyanin (from this study and the automated vertical profiler deployed by EPA in Iron Gate reservoir in 2011) indicate that the obvious trend in the data is simply that chlorophyll-a and phycocyanin concentrations generally decrease with depth. Highest concentrations generally occur from the surface to 3-m depth, then decline in concentrations from 3-m to 7-m depths to appreciably lower, relatively consistent concentrations from 7-m to 11-m depths. Therefore, the intent of the cover to impede entrainment of the top few meters of depth was appropriately targeted to where the bulk of the reservoir's cyanobacteria (including Microcystis) typically reside. Finally, further data collection upstream of the intake cover would allow for a better assessment of the effects of deployment.

Figure 9. *Microcystis aeruginosa* (MSAE) and *Aphanizomenon flow-aquae* (APFA) Concentrations (cells/mL) for (a) Week 1 (August 20 to 23) and (b) Week 2 (August 27 to 30) Downstream
Grey areas denote samples collected when the cover was fully deployed. (Note that no sample was collected on August 22 at 1200.)



(a) (b)

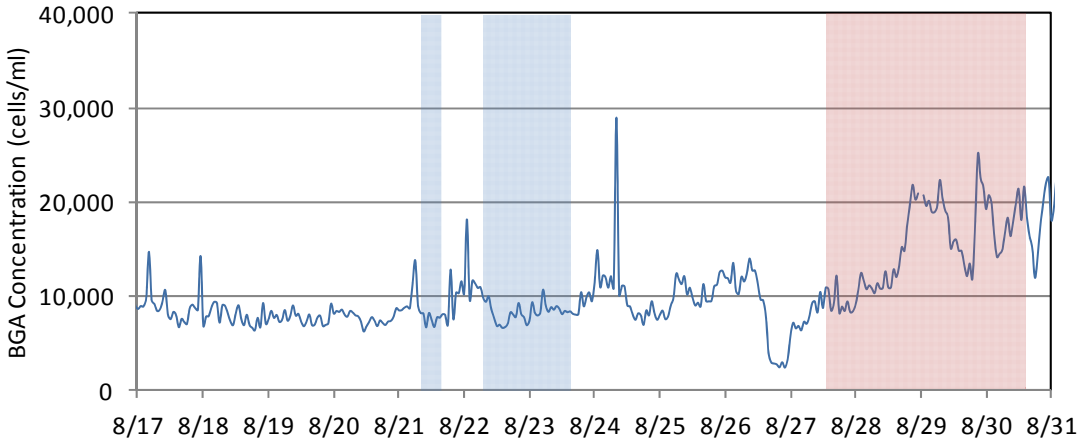
Figure 10. Downstream Chlorophyll *a* Concentrations for (a) Week 1 (August 20 to 23) and (b) Week 2 (August 27 to 30)
Units are in parts per billion (ppb). Grey area corresponds to samples collected while the cover was fully deployed. (Note that no sample was collected on August 29 at 1430.)



(a) (b)

Figure 11. Downstream Phycocyanin Probe Concentrations for Week 1 (8/20-8/23) and Week 2 (8/27-8/30)

Blue and red boxes denote week 1 and week 2 cover deployment periods, respectively.



5.3 Vertical Distribution of Cyanobacteria

The vertical migration data collection was designed to determine if cyanobacteria moved or were distributed vertically in the water column in a discernible manner that may inform the design objectives for a cover on the existing intake (see Appendix C). Spatial and temporal heterogeneity in the vertical (as well as lateral) distribution of algal populations in lakes and reservoirs is widely reported in the literature (Wetzel, 2001; Horne and Goldman, 1994 Reynolds *et al*., 1987). In general, cyanobacteria appear to move or distribute themselves vertically in the water column in response to temperature, to satisfy nutrient requirements (Brookes and Ganf, 2001), attain desirable light conditions (Visser *et al.*, 1997) and other factors. Moisander (2009) found that MSAE exhibited vertical variability over a diel period in Iron Gate Reservoir. Previous studies have shown that cyanobacteria colonies, colonies of MSAE in particular, respond to changes in light and nutrient conditions by adjusting their buoyancy to alter their position in the water column (Okada and Aiba, 1983; Reynolds *et al*., 1987; Wallace *et al*., 2000). Buoyancy regulation in response to environmental conditions has also been observed in APFA colonies (Rabouille *et al*., 2005; Chu *et al*., 2007). To a lesser extent, vertical distribution of *Psuedoanabaena Sp.* (PSAB) in the water column has also been observed (Gervais *et al*., 2003).

Vertical migration data was collected over an approximately 2-day period in Iron Gate Reservoir at 5 depths (from 0.2m to 10 m based on data provided by Andy Lincoff (pers. comm.)), and indicates a dynamic vertical distribution of cyanobacteria. A principal factor in this dynamic distribution likely is advection of algae into and from the study site. For example, such advection is indicated by the observation of average chlorophyll *a* concentrations at 0600 and 1800 on August 28 of 12.6 ppb and 34.2 ppb, respectively. This nearly threefold increase is most likely due to advection into the sampling area due to large- or small-scale reservoir circulation, thermal loading and density driven currents, wind loading on the reservoir surface, or other factors. Further, the study location –

adjacent to the reservoir spillway in the shallow northwest corner of the reservoir when spill was occurring from the leaf gate – may further contribute to advection effects.

The results of vertical migration data include the following observations:

- Cyanobacteria (MSAE, APFA, and PSAB) were observed to be vertically segregated at or near the surface in the vicinity of the intake. This is an important finding since an intake cover would be infeasible if vertical segregation was not observed.

- Spatial and temporal trends in APFA and PSAB in Iron Gate Reservoir were consistent with phycocyanin and chlorophyll *a* results.

- Most primary production during the 2012 study occurred in water depths of less than 10 m. This was consistent with data provided by Lincoff (pers. comm.). Considerably more algal biomass and generally lower inorganic nutrients were observed in near-surface waters.

- The algae counts, phycocyanin, and chlorophyll *a* data all illustrate a notable upward trend in biomass starting approximately mid-day on August 28. Interestingly, this increase is also present in the phyocyanin probe maintained by PacifiCorp at the long term sampling location (Figure 11~~Figure 11~~). These observations are consistent with larger scale in-reservoir processes discussed above.

5.4 Water Quality

Six water quality constituents and three physical parameters were collected in-reservoir and downstream of Iron Gate Dam during the 2012 Cover Study. Water quality constituents included total nitrogen (TN), nitrate-nitrite ((NO_3+NO_2)-N), ammonia (NH_4-N), total phosphorous (TP), orthophosphate (PO_4-P), and dissolved organic carbon (DOC). Physical parameters included water temperature, dissolved oxygen, and pH. Overall, no clear trends in downstream nutrient concentrations were identified in 2012 (consistent with 2011). Further, water temperature, dissolved oxygen, and pH exhibited no clear deviation from longer-term trends related to the cover. All data are included in Appendix A.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The 2012 Cover Study added considerably to the information obtained in 2009 and 2011 on the effectiveness of placing a cover over the upper portion of the Iron Gate intake tower to reduce entrainment of buoyancy-regulating cyanobacteria and the feasibility of this approach as a means to reduce algae entrained into the Iron Gate intake. The 2009 study identified the general velocity distribution in the vicinity of the intake tower. In 2011, a prototype cover was constructed by PacifiCorp and installed on the intake tower. The relatively short deployments in 2011 (less than one hour each) explored the impacts of placing a cover at different depths over the intake tower to quantify the effects of isolating near surface waters where buoyant cyanobacteria most frequently occur. Initial results from the 2011 study suggested that placement of a cover to approximately 12 ft of

depth decreased MSAE concentrations in downstream reaches by approximately 40 percent. In 2012, the intake cover was again installed on the Iron Gate intake tower over a two-weeks period to test effectiveness over longer for deployment duration periods (i.e., 7 , 24, 45, and 72 hour periods) and results were less conclusive over this longer-term deployment.

The 2012 Cover Study was conducted against a backdrop of complex hydrodynamics in the vicinity of the intake cover and substantial variability in cyanobacteria conditions in the reservoir. As such, a multiple lines of evidence approach was used to assess the effects of cover deployment using data from velocity measurements in the reservoir in the vicinity of the intake tower, information on cyanobacteria species (particularly MSAE) in the reservoir and downstream of Iron Gate Dam, and phycocyanin data from the PacifiCorp sonde downstream of Iron Gate Dam, and vertical migration patterns of cyanobacteria in the reservoir.

The velocity, algae species, and phycocyanin data collected during the 2012 Cover Study suggest that cover deployment to its full depth of approximately 12 ft results in short-term changes in local in-reservoir velocities and reductions in downstream cyanobacteria concentrations. These changes occurred over a period of about 24 hours, and then appeared to diminish thereafter. However, the data also indicated that conditions in the reservoir, particularly the concentrations and distribution of algae, are variable spatially and temporally. As a result of such variability, the effects of cover deployment over longer periods during the study were not distinctive or persistent.

Nonetheless, the observed short-term reductions in downstream algae concentrations as a result of cover deployment point to the possible use of a cover such as the one used in the study as a water quality management tool. Potential options include designing a cover that is longer and extends deeper into the reservoir, that the cover could be deployed in a more dynamic fashion over shorter periods (e.g., 12 – 24 hours), or other configurations that affect inflows to the intake tower.

The observed vertical segregation of cyanobacteria at or near the surface in the vicinity of the Iron Gate intake was also an important finding given that this is the layer of reservoir water whose entrainment an intake cover would be intended to substantially reduce. This indicates that the use of a cover or barrier system to reduce downstream algae concentrations is feasible but may require intake and/or intake cover design modifications that were beyond the scope of this limited study using an inexpensive barrier.

Based on the 2012 study results, the following steps are recommended to improve the efficacy of an intake cover to reduce cyanobacteria entrainment.

- A bathymetric survey in the vicinity of the intake tower is recommended to improve the interpretation of data collected to date and to inform potential future work to better understand local velocities and hydraulics near the intake that would be useful in the design of an intake cover or barrier system. In both 2011 and 2012 it was hypothesized that local bed geometry at the intake tower limits the spatial range of ADCP sampling. A bathymetric survey would determine the bed configuration in the

vicinity of the intake tower and other local features in the area of the intake to test this hypothesis.

- Other cover deployment tests with additional downstream sample collection should be considered to more fully assess the effects of the cover on downstream water quality throughout the daily cycle. Samples were collected only during the daylight hours, and for longer cover deployments (up and beyond 24 hours), diel sampling would provide additional insight into the effects of cover deployment. Autosamplers could readily be deployed to collect these data on predetermined frequencies (e.g., hourly, 3 hour samples, or some other frequency). Likewise, a phycocyanin probe could be deployed along with continuous sonde measurements and in-reservoir sampling.

- A weather station should be installed at or near Iron Gate Dam to characterize meteorological (i.e., cloud cover, wind speed, air temperature) conditions. Site-specific meteorological data would enhance the understanding of factors affecting reservoir hydrodynamic and thermal conditions. These reservoir conditions likely play a pivotal role (with or without a cover) in algae distribution and variability in the reservoir, and on algal entrainment in the intake and subsequent releases to the Klamath River.

- A cover that extends deeper into the reservoir (i.e., deeper than 12 ft) should be considered for future test deployments since study results indicated that cover depth may significantly affect the ability of a cover to restrict the entrainment of surface water. A deeper cover may more effectively isolate surface water or may do so for a longer period of time. The assessment of a cover that extends deeper in the reservoir would require additional design thought regarding loading on the intake tower trash rack (i.e. loading of the cover itself and loading due to hydraulic pressure on the cover).

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Personal Communications

Andy Lincoff, July 27, 2012 (email communication with vertical sonde profile data)

Appendix A
2012 Study Data

APPENDIX A

2012 Study Data

This appendix contains supporting data and information compiled for the Iron Gate Cover Study in 2012.

A.1 Water Quality (Nutrients and Chlorophyll a)

The U.C. Davis laboratory follows quality assurance/quality control included in the State Water Resources Control Board's Surface Water Ambient Monitoring Program (SWAMP) compatible standard laboratory procedures including replicates, spikes, reference materials, setting of control limits, criteria for rejection, and data validation methods (Puckett, 2002).

A.1.1 Nutrients (UC Davis Laboratory)

A subsample was filtered through a pre-rinsed 0.45- micrometer (µm) polycarbonate membrane (Millipore) filter for quantification of orthophosphate (PO_4-P), nitrate plus nitrite ((NO_3+NO_2)-N), ammonium (NH_4-N), and dissolved organic carbon (DOC). PO_4-P was determined using the ammonium molybdate spectrophotometric method with a Limit of Detection (LOD) of approximately 0.005 mg LP^{-1} (Clesceri *et al.*, 1998). The vanadium chloride (VCL_3) method was used to spectroscopically determine (NO_3+NO_2)-N and NO_2-N; however, the VCL_3 was not added for determination of NO_2-N (LOD is 0.01 mg/L) (Doane and Horwath, 2003). NH_4-N was determined spectroscopically with the Berthelot reaction, using a salicylate analog of indophenol blue (LOD is approximately 0.010 mg/L) (Forster, 1995). Analyses for PO_4-P, NO_3+NO_2-N, NO_2-N, and NH_4-N were completed within 48-hours of sample collection.

DOC was measured using a Phoenix 8000, a Dohrmann UV enhanced-persulfate total organic carbon (TOC) analyzer (EPA Standard Methods 5310C; LOD is approximately 0.1 mg/L). TN and TP were measured on a non-filter sample following oxidization with 1% persulfate and subsequent quantification of nitrate and phosphate, respectively (Yu *et al.*, 1994; Standard Methods 4500-N C; Clesceri *et al.*, 1998).

Nutrient concentrations for the sampling site downstream of Iron Gate Dam near the Hatchery Bridge are shown in Figure 7-1~~Figure 7-1~~ and Figure 1-2~~Figure 1-2~~. Nutrient concentrations for the sampling location in Iron Gate reservoir near the intake tower are shown in

Figure 1-3

~~Figure 1-3~~ and Figure 1-4~~Figure 1-4~~.

Figure 7-1. Nutrient data for the downstream location near Hatchery Bridge for week 1 (August 20 to 23). Shaded areas indicated that the cover was deployed.

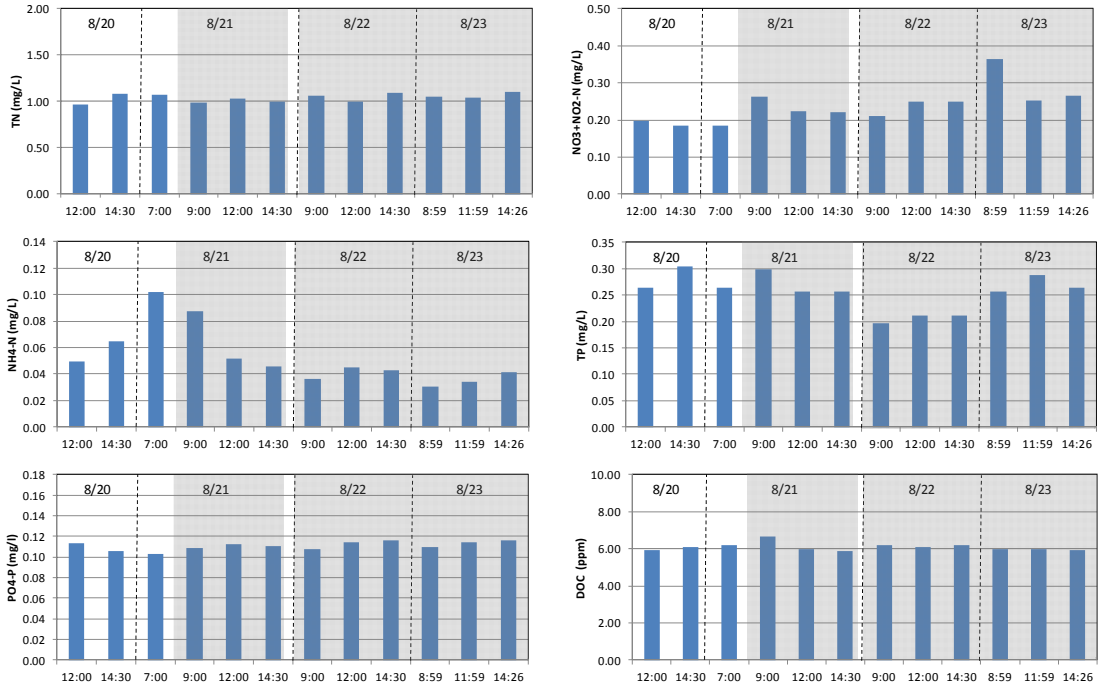


Figure 1-2. Nutrient data for the downstream location near Hatchery Bridge for week 2 (August 27 to 30). Shaded areas indicated that the cover was deployed.

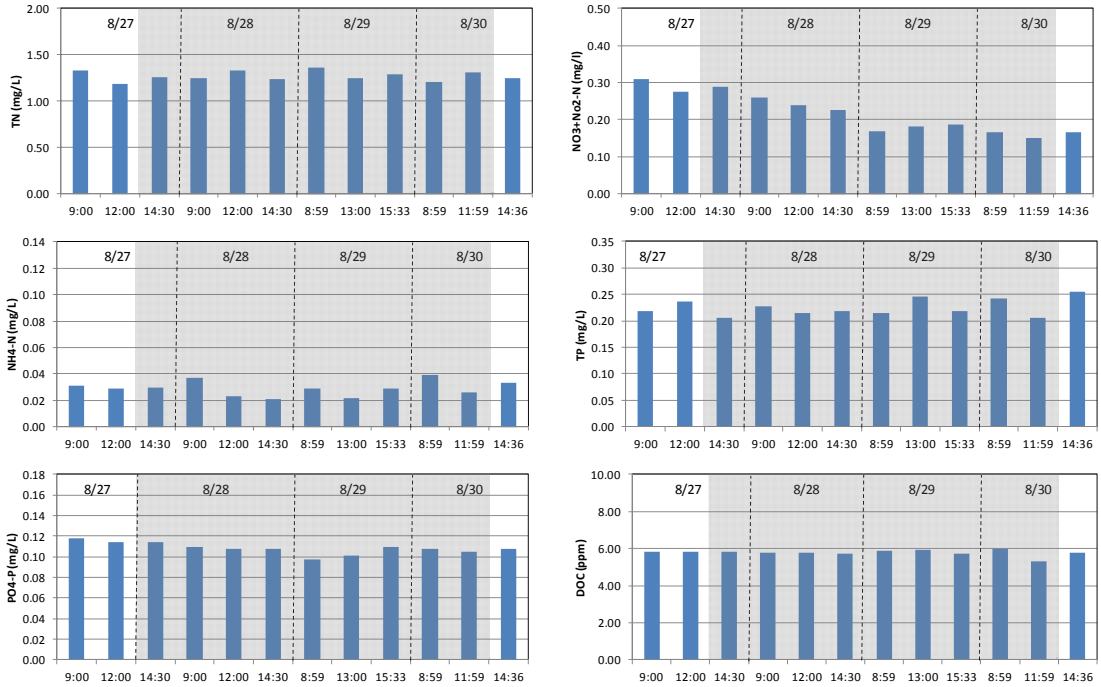


Figure 1-3. Nutrient data for in-reservoir location for week 1 (August 20 to 23). Grab samples collected at three depths: 0.5 ft (blue), 10 ft (red), and 30 ft (green) for each day. Grey denotes samples collected when cover was deployed.

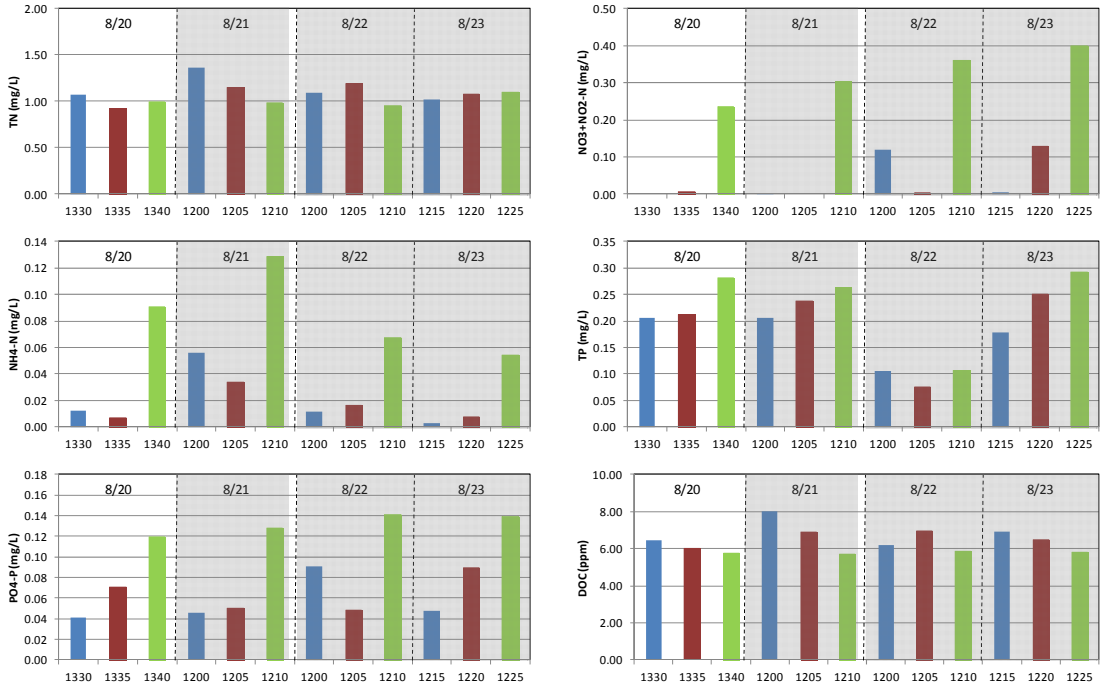
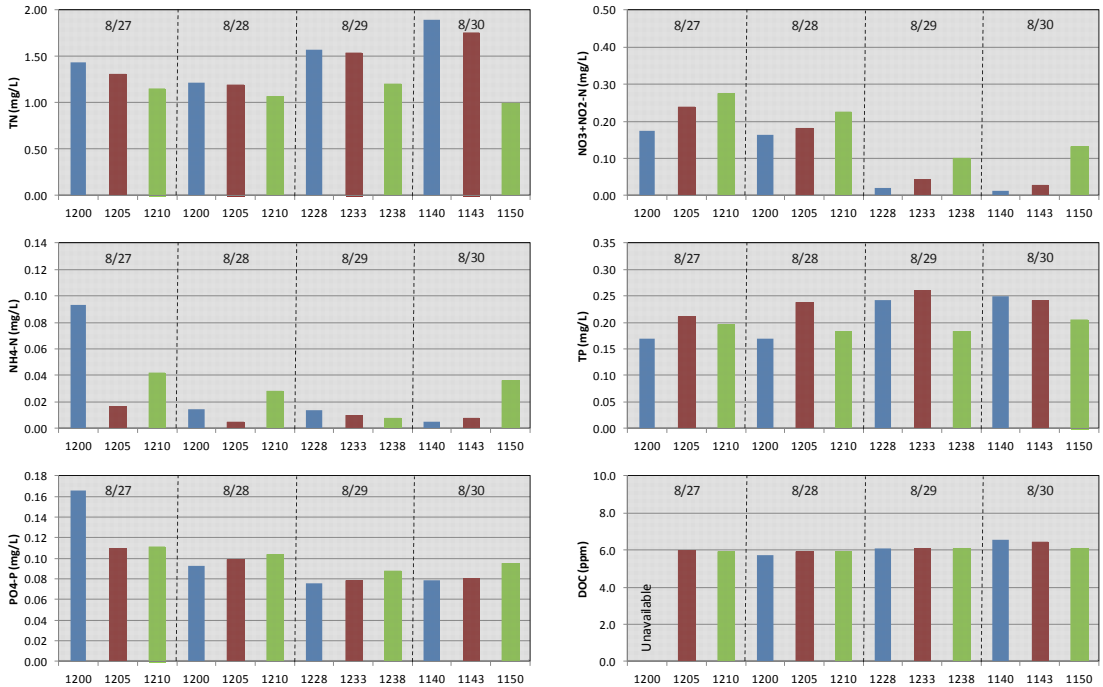


Figure 1-4. Nutrient data for in-reservoir location for week 2 (August 27 to 30). Grab samples collected at three depths: 0.5 ft (blue), 10 ft (red), and 30 ft (green) for each day. Grey denotes samples collected when cover was deployed.



A.1.2 Chlorophyll *a*

Samples were returned from the field on ice in the evening and processing began the next morning. Algal pigments were determined using SM10200-H (Clesceri *et al.*, 1998) as modified by Sartory and Grobbelaar (1984). Samples were filtered using a Whatman 0.45 micron GF/F glass fiber filter within 12 hours of delivery and the filters were frozen prior to extraction. Samples were analyzed by fluorometric determination with the limit of detection dependent on the volume of water filtered (200 to 1000 mL); generally about 0.5 µg/L.

Figure 1-5. Chlorophyll *a* data for the downstream location near Hatchery Bridge for week 1 (August 20 to 23) and week 2 (August 27 to 30). Units are in parts per billion (ppb). Grey denotes samples collected when cover was deployed.

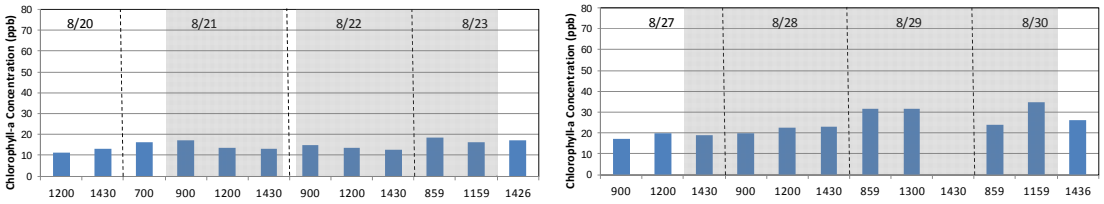
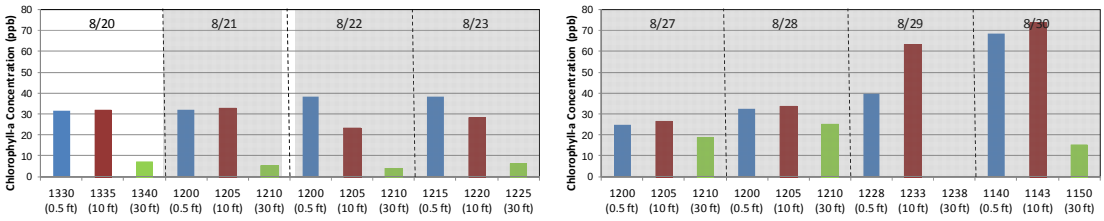


Figure 1-6. Chlorophyll *a* data in-reservoir for week 1 (August 20 to 23) and week 2 (August 27 to 30). Grab samples collected at three depths: 0.5 ft (blue), 10 ft (red), and 30 ft (green) for each day. Grey denotes samples collected when cover was deployed.



A.1.3 Algae Species

Aquatic Analysts processed all algae species counts and biovolume quantification. Permanent microscope slides were prepared from each sample by filtering an appropriate aliquot of the sample through a 0.45- µm membrane filter. A section of the membrane filter is cut out and placed on a glass slide with immersion oil added to make the filter transparent, followed by placing a cover slip on top, with nail polish applied to the periphery for permanency.

The most accurate method of algal enumeration is to count each individual cell versus a colony or filament (Wetzel and Likens, 1991). However, this is impractical and often impossible. Most cyanobacteria form colonies or filaments of numerous cells. Enumerating cyanobacteria as colonies or filaments provides little information regarding algal density since they are variable in size (Chorus and Bartram, 1999). Although some methods recommend breaking up the colonies and counting individual cells, this would make identification difficult since most cyanobacteria are identified in their colonial or filament form.

Algae concentrations in (algal cells per mL) in samples collected downstream of Iron Gate Dam near the Hatchery Bridge are shown in Figure 1-7~~Figure 1-7~~. Algae concentrations in samples from the Iron Gate reservoir near the intake tower are shown in Figure 1-8~~Figure 1-8~~. Cyanobacteria concentrations estimated using a phycocyanin probe at PacifiCorp's continuous monitoring station near the Hatchery Bridge are shown in Figure 1-9~~Figure 1-9~~.

Figure 1-7. *Microcystis aeruginosa* (MSAE) and *Aphanizomenon flos-aquae* (APFA) data for the downstream location near Hatchery Bridge for week 1 (August 20 to 23). Shaded areas indicated that the cover was deployed.

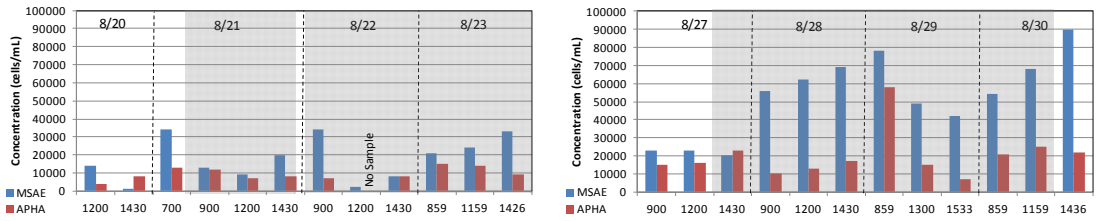


Figure 1-8. *Microcystis aeruginosa* (MSAE) and *Aphanizomenon flos-aquae* (APFA) data for in-reservoir location for week 2 (August 27 to 30). Grab samples collected at three depths: 0.5 ft, 10 ft, and 30 ft for each day. Grey denotes samples collected when cover was deployed.

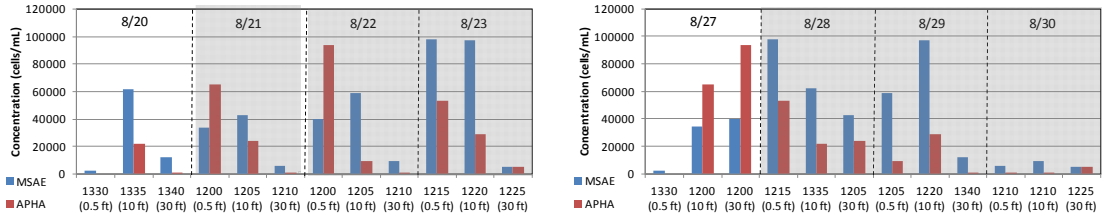
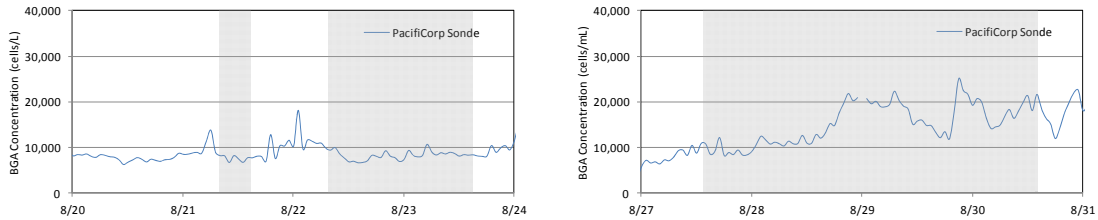


Figure 1-9. Cyanobacteria concentration at the PacifiCorp continuous monitoring site upstream of the Hatchery Bridge for week 1 (August 20 to 23). Shaded areas indicated that the cover was deployed.



A.2 Water Quality (Water Temperature, pH, Dissolved Oxygen)

Physical water quality parameters were monitored in Iron Gate reservoir and downstream of Iron Gate Dam. Water temperature, dissolved oxygen and pH were continuously monitored at the downstream site using a YSI Professional Plus sonde. The values measured by the sonde at the downstream site are shown in Figure 1-10~~Figure 1-10~~.

Within the reservoir, physical water quality parameters were measured using a YSI Professional Plus sonde throughout the water column. Measurements were made approximately 30 ft upstream of the A-Frame from the surface to approximately 40 ft below the surface. A second set of vertical profiles were also taken at the log boom from

the surface to approximately 66 ft below the surface. Measurements were taken approximately every 3.3 ft. The values measured by the sonde in the reservoir are shown in Figure A-11 through Figure A-16.

Figure 1-10. Water temperature (deg C), dissolved oxygen (mg/l), and pH at the downstream location for week 1 (August 20 to August 23) and week 2 (August 27 to 30). YSI sondes are maintained by Watercourse and the PacifiCorp sonde is maintained by PacifiCorp at their continuous monitoring station. Both downstream monitoring locations are upstream of the Hatchery Bridge.

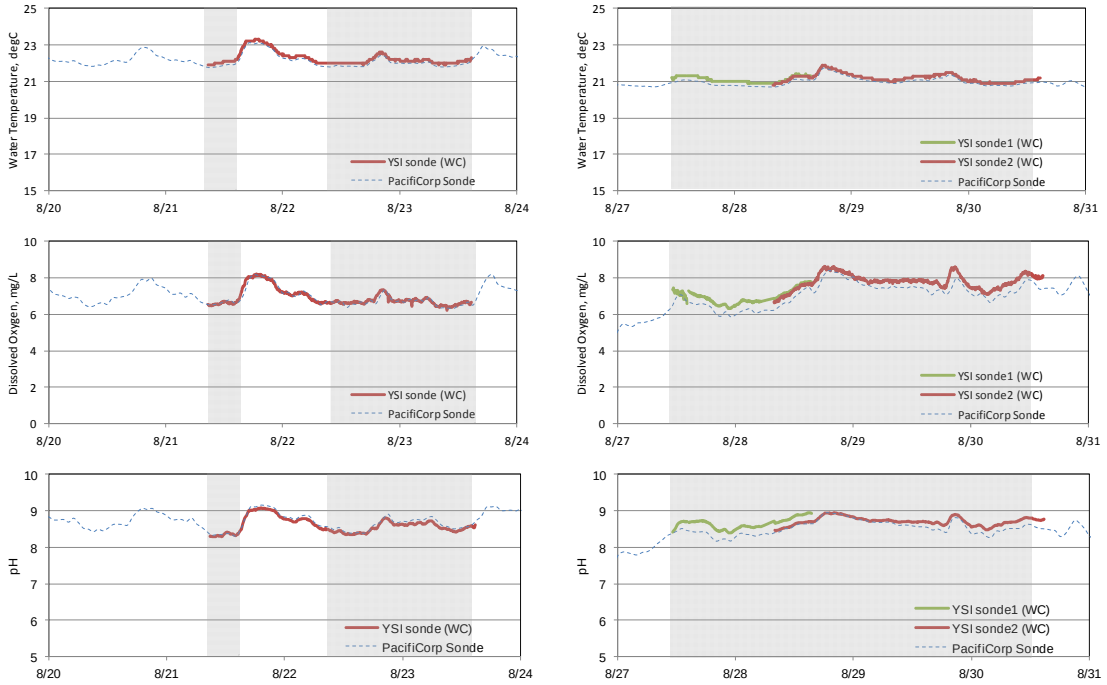
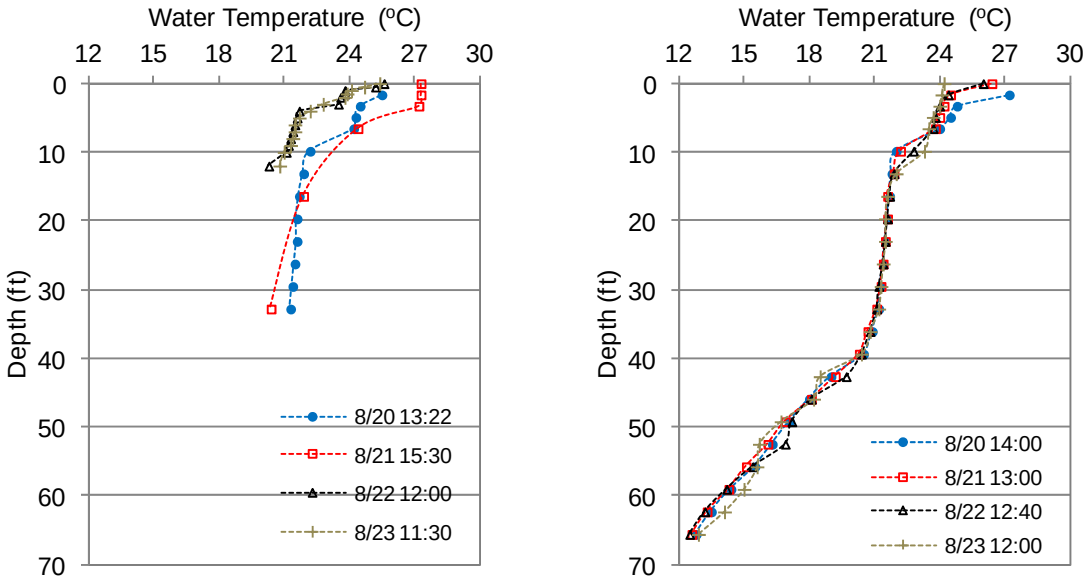
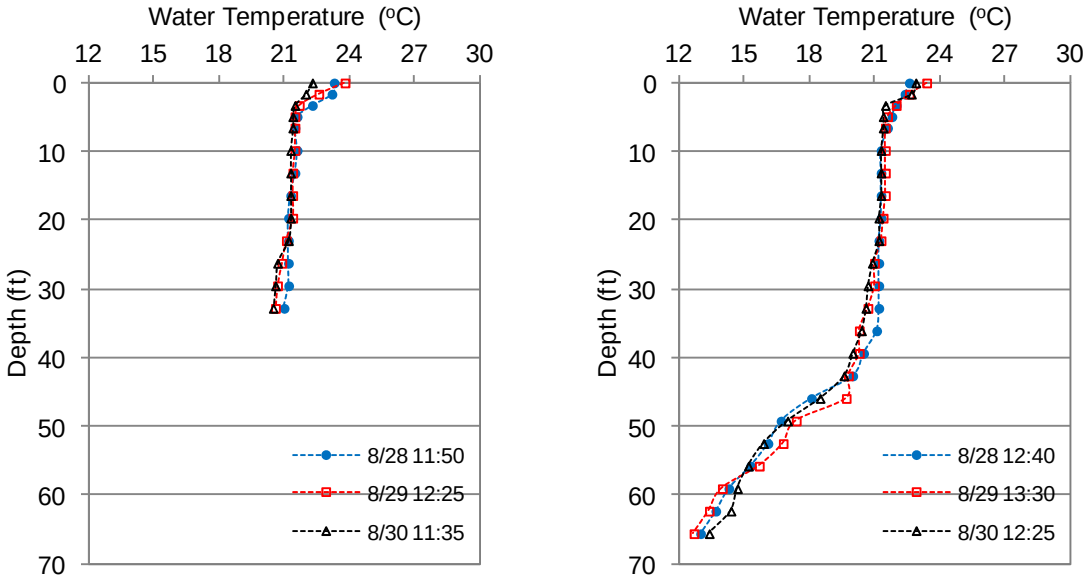


Figure 1-11. Water temperature profile for near the A-frame (a) and at the log boom (b) for week 1 (August 20 to 23).



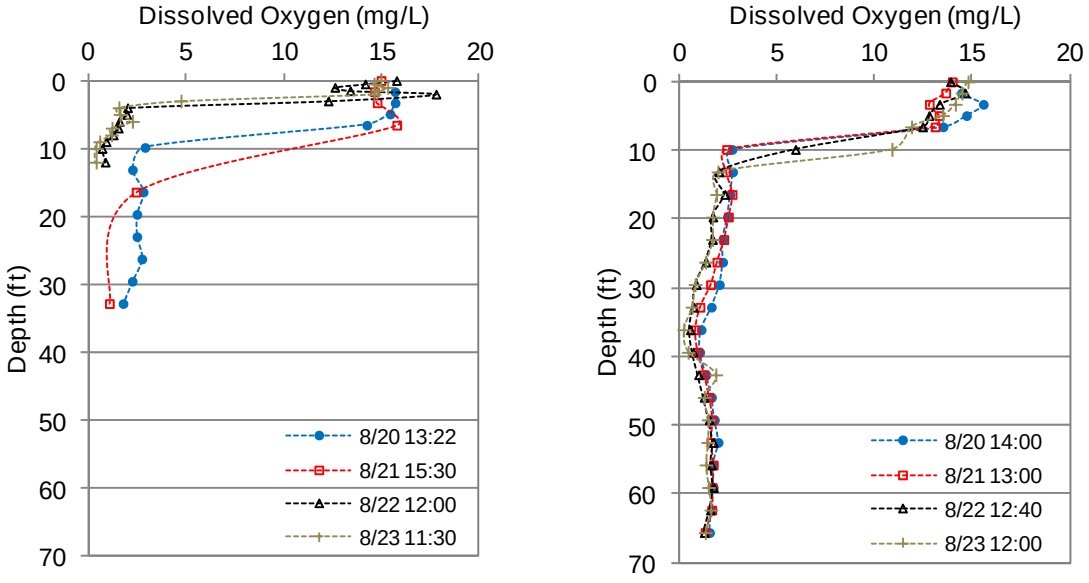
(a) (b)

Figure 1-12. Water temperature profile for near the A-frame (a) and at the log boom (b) for week 2 (August 28 to 30).



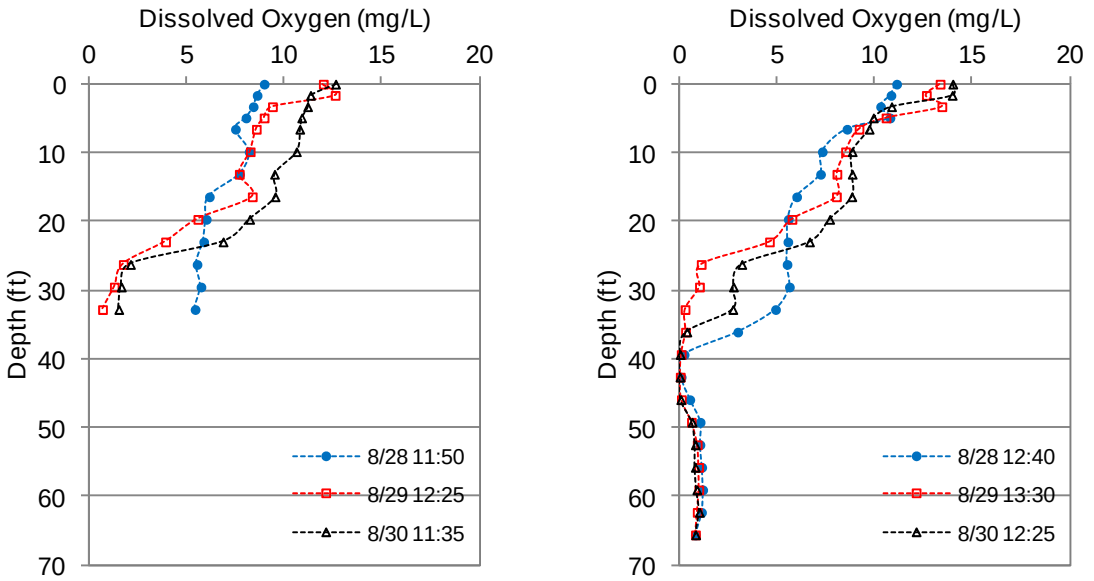
(a) (b)

Figure 1-13. Dissolved oxygen profiles for near the A-frame (a) and at the log boom (b) for week 1 (August 20 to 23)



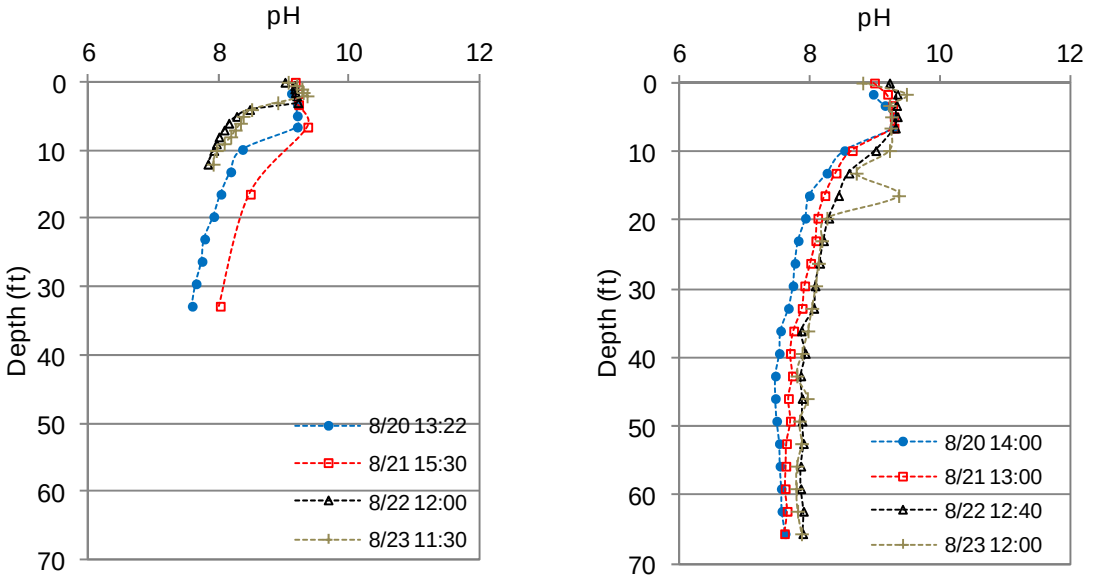
(a) (b)

Figure 1-14. Dissolved oxygen profiles for near the A-frame (a) and at the log boom (b) for week 2 (August 28 to 30).



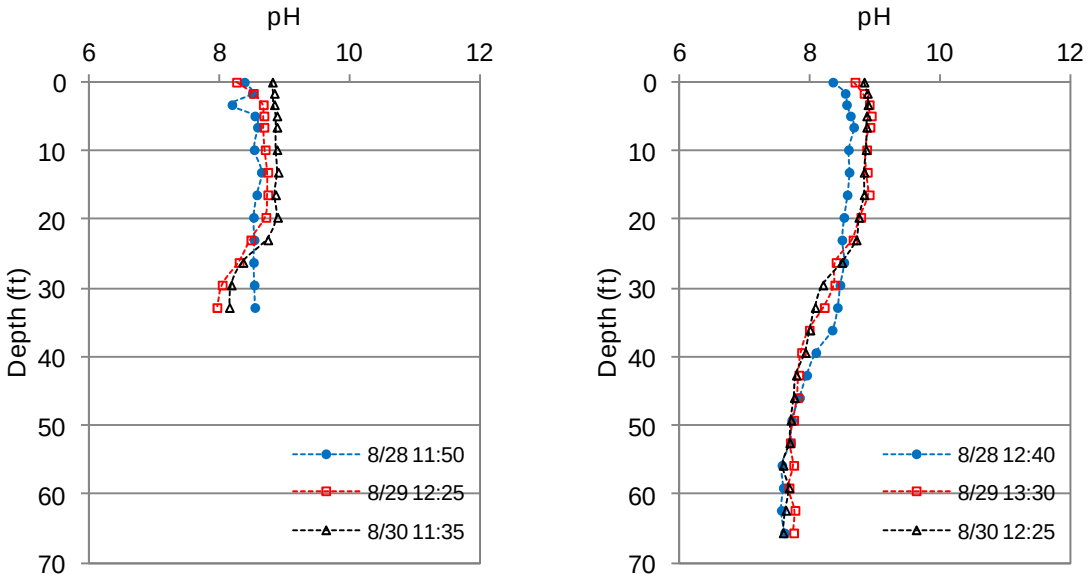
(a) (b)

Figure 1-15. pH profiles for near the A-frame (a) and at the log boom (b) for week 1 (August 20 to 23).



(a) (b)

Figure 1-16. pH profiles for near the A-frame (a) and at the log boom (b) for week 2 (August 28 to 30).



(a) (b)

Appendix B
Prior 2011 Study Data and Results

APPENDIX B

Prior 2011 Study Data and Results

This appendix contains supporting data, information, and results for the prior Iron Gate Cover Study in 2011.

B.1 Approach

In August 2011, PacifiCorp installed a cover on the Iron Gate Reservoir intake tower to explore its effectiveness as a water quality control method. The purpose of the intake cover was to alter the depth in the reservoir from which water was withdrawn, potentially isolating or restricting the near-surface water to reduce cyanobacteria (cyanobacteria) entrainment in the downstream reaches. The two main tasks of the study included: (1) velocity profile measurements near the intake tower at the A-frame, and (2) algae and nutrient grab sampling upstream and downstream of Iron Gate Dam. Other tasks included vertical water quality measurements within the reservoir and additional ADCP readings away from the tower.

PacifiCorp personnel installed the intake cover on the intake tower trash rack using a chain and pulley system. The cover consisted of two steel-frames, 17 feet wide and 6 feet deep, each weighing several hundred pounds. One foot height gradations were painted onto the covers to aid in determination of deployment depths.

On August 29 (Monday), PacifiCorp operators (operators) lowered the cover via a central metal hoist and two mechanical pulleys placed on both ends of the cover. As a precaution against decreased downstream dissolved oxygen concentration, PacifiCorp implemented mitigation methods, such as turbine venting, to increase aeration. The cover was lowered in one-foot intervals with thirty minute ‘rest’ periods, which allowed operators to check powerhouse flows and monitor various conditions (i.e., differential pressure on cover, flow and turbine activity, water quality conditions, etc). Dissolved oxygen concentrations were monitored regularly in the Iron Gate powerhouse control room and by a water quality sonde a quarter-mile downstream of the reservoir. Ultimately the cover was lowered to a depth of three feet with no signs of dissolved oxygen impairments. The cover was not deployed overnight.

On August 31 (Wednesday), the cover was lowered directly to 6 feet below the surface. Using the same procedure employed on August 29 (e.g., one foot intervals with a rest period), the cover was lowered to 8 feet, 10 feet, and 12 feet with minimal effects on dissolved oxygen concentrations. The intake cover was raised to the surface at the end of the day.

B.2 Results

In 2011, monitoring occurred on August 29 and 31. On August 29, water quality profiles were taken at four locations (A through D) and at the A-Frame (Figure 7-1~~Figure 7-1~~). On August 31, water quality profiles and grab samples were collected at Site I and II, approximately 25 ft and 50 ft upstream of A-Frame, respectively (Figure 1-2~~Figure 1-2~~).

Grab samples were also collected downstream. Velocity profiles were collected at the A-Frame (Figure 1-2~~Figure 1-2~~).

Figure 7-1. Water quality profile locations: A-frame and Location A, B, C, and D.

Figure 1-2. Velocity measurement locations: A-frame and Site I and II.

B.2.1 Velocity

Surface velocity measurements were taken at approximately 1 ft, 2 ft, and 3 ft below the water surface. At the A-frame, velocity measurements prior to cover deployment ranged from 0.52 to 0.59 ft/s (average of 0.56 ft/s). When the intake cover is lowered to 6 ft and 12 ft below the surface, velocities ranged from 0.16 ft/s to 0.26 ft/s (Table 1-1~~Table 1-1~~).

Table 1-1. Surface velocity measurements at A-frame using Marsh-McBirney FloMate. Velocity is presented in centimeters per second. August 31, 2011.

		Velocity (ft/s)			
Intake Cover Depth (ft)	**Time**	**1 ft (below surface)**	**2 ft (below surface)**	**3 ft (below surface)**	**Average**
0 (pre)	08:30	0.59	0.52	0.56	0.56
6	10:15	0.23	0.26	0.23	0.24
12	12:40	0.16	0.16	0.23	0.19

The ADCP was used to measure flow velocities at the A-frame. Over thirty velocity profiles were measured at locations near the intake tower. The approximate surface elevation of the invert of the penstock intake pipe is 2,293 ft (698.9 m). Velocity data was reviewed and averaged over two minutes (120 data points) for each depth (increments of 3.2 ft (1.0 m)). Velocity data is presented for four scenarios: pre-cover (before the cover was lowered), cover lowered to 6 ft (1.8 m) below water surface, cover lowered to 12 ft (3.6 m) below water surface, and post-cover (after the cover was raised to surface) (Table 1-2~~Table 1-2~~).

Table 1-2. ADCP velocity measurements for the four ADCP scenarios: (1) pre-cover, (2) cover at 6 ft depth, (3) cover at 12 ft depth, and (4) post-cover. Flow direction is in degrees from true north (the inlet down is approximately 135 degrees from true north). Measurements are in ft/s. August 31, 2011.

	Pre-cover		Cover at 6 ft		Cover at 12 ft		Post-cover	
Depth (ft)	**Velocity * (ft/s)**	**Direction (degree)**	**Velocity* (ft/s)**	**Direction (degree)**	**Velocity * (ft/s)**	**Direction (degree)**	**Velocity * (ft/s)**	**Direction (degree)**
4.8	0.73	218.5	0.73	208.6	0.71	204.3	0.64	217.0
8.1	0.64	195.7	0.77	215.5	0.74	220.9	0.78	216.5
11.4	0.69	216.1	0.68	215.8	0.72	201.1	0.70	216.1
14.7	0.69	202.7	0.66	207.8	0.74	218.5	0.75	208.5
17.9	0.71	219.0	0.73	216.0	0.76	203.5	0.71	210.0
21.2	0.72	213.9	0.77	211.1	0.69	213.5	0.74	210.8
24.5	0.69	201.2	0.69	193.5	0.75	198.4	0.72	208.1
27.8	0.86	198.1	0.80	203.0	0.78	202.0	0.75	211.1

*Velocity measurements are averaged for each vertical “bin”.

B.2.1.1 Discussion

The velocity distribution prior to deployment of the cover is non-uniform with depth. The velocity profile is fairly uniform for first 25 feet below surface, similar to findings from 2009 (Deas, 2010). Higher velocities are observed in the vicinity of the penstock intake. This is primarily due to the penstock intake drawing a larger fraction of the water from deeper depths than at shallower depth. While measurements near the bed of the reservoir were not obtained (due to local bed morphology and possibly debris near the bottom of the trash rack), the presumption is that velocities approach zero near the reservoir bottom.

In the near-surface areas, Marsh-McBirney data were used to estimate reductions in velocity with 6 ft and 12 ft cover deployments (Table 1-1~~Table 1-1~~). The average velocity at the surface before the cover was lowered was 0.56 ft/s. When the cover was lowered to 6 ft and to 12 ft, the average velocity was approximately 0.24 and 0.19 ft/s, respectively ft/s. Overall, when the cover was deployed, the near-surface velocities (top 3 feet) were reduced by 58 and 65 percent, respectively, from the velocities measured pre-deployment. The observed reductions suggest the cover impeded near-surface flow, and most likely reduced the near-surface waters entrainment into the intake tower.

From the ADCP results, higher velocities were observed near the penstock intake (invert approximately 33 ft below surface) when the cover was lowered than when the cover was not lowered. When the cover is lowered 6 ft and 12 ft below the surface, the velocities in the top six feet of water are reduced compared to pre-cover conditions. This finding suggests that during cover deployment less near-surface water is entering the intake tower. Velocities at 6 ft to 12 ft depth are typically higher when the cover is lowered than in pre-cover conditions. This increase in velocity may be due to the increased velocities passing the bottom edge of the cover during deployment.

Results suggest that although the velocity field is complex, the placement of a cover over part of the intake tower decreases the velocity of near-surface waters. Furthermore, the reduction of near-surface flows has implications for the flow field at greater depths. Because the total flow into the intake remained constant, the velocities below the cover increased as the cover was lowered, indicating that more deep water (and, consequently, less surface water) was withdrawn upon deployment of the intake tower cover. Given the relative size of the cover and the flow into the intake tower, there is a possibility that the velocity near the intake tower did not reach an equilibrium condition during the relatively short duration deployments.

B.2.2 Water Quality: Grab Samples

Grab samples included algae (phytoplankton) species and nutrients taken from in-reservoir (Site I and II) and downstream locations. In-reservoir locations were sampled to identify general water quality characteristics in the reservoir and are not necessarily representative of waters entering the intake tower.

B.2.2.1 Algae (Phytoplankton) and Chlorophyll *a*

Algae grab samples were collected in-reservoir and at the downstream location. At the in-reservoir sites, Site I and II, about 25 ft and 50 ft upstream of the tip of the A-Frame, respectively, samples were collected at the surface and about 10 ft below the surface (Table 1-3~~Table 1-3~~). Algae grab samples collected at the downstream location were taken at the surface (Table 1-4~~Table 1-4~~ and Table 1-8~~Table 1-8~~).

Table 1-3. *Microcystis* (MSAE) and *Aphanizomenon* (APFA) cell counts and Chlorophyll *a* (Chlor-*a*) concentration in Iron Gate Reservoir at Site I and II. August 31, 2011.

Site	Time	Cover Depth (ft)	Sample Depth (ft)	Chlor-*a* (mg/L)	MSAE (cells/mL)	APFA (cells/mL)
Site I	8:57	0	0.5	29.63	37,583	25,861
Site II	14:25	0	0.5	16.13	38,636	22,923
Site I	8:59	0	10	25.93	82,028	2,522
Site II	14:30	0	10	24.69	44,295	16,395
Site I	10:25	6	0.5	27.78	43,600	26,529
Site II	10:55	6	0.5	24.69	45,935	13,085
Site I	10:30	6	10	26.55	70,503	14,264
Site II	10:58	6	10	21.61	n/a*	n/a*
Site I	12:53	12	0.5	34.57	42,964	38,770
Site II	13:17	12	0.5	29.63	45,062	41,060
Site I	12:57	12	10	17.90	44,233	105
Site II	13:20	12	10	21.61	n/a*	n/a*

* Samples were not collected as per the study plan due to distance from the intake tower.

Table 1-4. *Microcystis* (MSAE) and *Aphanizomenon* (APFA) cell counts and Chlorophyll *a* (Chlor-*a*) concentration downstream of Iron Gate Reservoir. August 31, 2011.

Time	Cover Depth (ft)	Sample Depth (ft)	Chlor-*a* (mg/L)	MSAE (cells/mL)	APFA (cells/mL)
9:24	0	0.5	15.43	43,336	6,213
10:56	6	0.5	14.82	34,550	8,284
13:14	12	0.5	14.20	24,068	5,421

Table 1-5. *Microcystis* (MSAE) and *Aphanizomenon* (APFA) cell counts and Chlorophyll *a* (Chlor-*a*) concentration downstream of Iron Gate Reservoir. August 31, 2011.

Time	Cover Depth (ft)	Sample Depth (ft)	Chlor-*a* (mg/L)	MSAE (cells/mL)	APFA (cells/mL)
9:24	0	0.5	15.43	43,336	6,213
10:56	6	0.5	14.82	34,550	8,284
13:14	12	0.5	14.20	24,068	5,421

Determining the concentration of the cyanobacteria species present at the upstream and downstream locations provided insight into the water quality entering and exiting the penstock intake. The cyanobacteria, *Microcystis aeruginosa* and *Aphanizomenon flos-aquae* were the dominant algae species in all water samples regardless of sampling location, time of day, or cover depth. Both species of freshwater cyanobacteria are typically dominant in Iron Gate Reservoir during the late summers (Raymond, 2010). Both *Aphanizomenon* and *Microcystis* can control their buoyancy in the water column and move to depths which allow them to have an advantage over competing species. Water samples were collected upstream in Iron Gate Reservoir (at Site I) prior to and after the cover was deployed. Results indicate the *Microcystis* and *Aphanizomenon* cell counts vary over the course of a day. The change in cell counts upstream may be due to temporal variability, spatial variability (vertical or lateral location in water column), vertical movement of these species in the water column, meteorological conditions, thermal stratification, other algal populations present, sampling location, and other factors.

Blue-green species were the dominant species at the downstream location. The downstream *Microcystis* cell count was 43,336 cells per milliliter (cells/ml) before the cover was lowered and decreased by 20 percent (to 34,550 cells/ml) and 44 percent (to 24,068 cells/ml) when the cover was lowered to 6 ft and 12 ft below the surface, respectively. The downstream *Aphanizomenon* cell count was 6,213 cells/ml before the cover was lowered. Cell count increased by 33 percent (8,284 cells/ml) when the cover was lowered 6 ft below the surface and decreased by 13 percent (5,421 cells/ml) when the cover was lowered 12 ft below the surface. The results suggest the cover reduced *Microcystis* more than *Aphanizomenon* concentrations at the downstream location for short duration deployments. While MSAE cell counts diminished by up to 44 percent downstream, chlorophyll *a* measurements only showed modest decreases. Thus the vertical distribution of the cyanobacteria in the water column may be an important consideration for future studies.

B.2.2.2 Nutrients

Total nitrogen (TN), ammonia (NH4), nitrate plus nitrite (NO3+NO2), total phosphorus (TP), orthophosphate (PO4), dissolved organic carbon (DOC), and chlorophyll *a* (Chlor-A) samples were collected at Site I, Site II, and at the downstream location near Hatchery Bridge. The results are presented below (Table 1-6~~Table 1-6~~ and Table 1-7~~Table 1-7~~, respectively).

Table 1-6. Nutrient concentrations (mg/L) in samples collected at Site I and Site II. All nutrient samples were collected at the surface of the reservoir: August 31, 2011.

Location	Time	Cover Depth (ft)	TN	NH4	NO3+NO2	TP	PO4	DOC
Site I	8:57	0	1.03	0.01	0.00	0.18	0.034	5.40
Site II	14:25	0	0.78	0.02	0.00	0.12	0.026	5.30
Site I	10:25	6	1.02	0.01	0.00	0.14	0.028	5.60
Site II	10:55	6	0.88	0.01	0.00	0.12	0.031	5.50
Site I	12:53	12	1.00	0.01	0.00	0.17	0.026	5.50
Site II	13:17	12	1.03	0.01	0.00	0.14	0.024	5.50

Table 1-7. Nutrient concentrations (mg/L) in samples collected downstream of Iron Gate Reservoir: August 31, 2011.

Location	Time	Cover Depth (ft)	TN	NH4	NO3+NO2	TP	PO4	DOC
Downstream	9:24	0	0.89	0.02	0.14	0.18	0.081	5.20
Downstream	10:56	6	0.81	0.02	0.15	0.16	0.080	5.30
Downstream	13:14	12	0.85	0.02	0.17	0.17	0.085	5.10

Results of the nutrient analysis for the downstream location under the pre- and post-cover deployment scenarios showed not marked changes.

B.2.3 Water Quality: Physical Parameters

Physical water quality parameters were also monitored in the reservoir to determine if there were any far-field (distant from the outlet tower) effects. The profiles for temperature, dissolved oxygen, and pH were taken at the A-Frame and in-reservoir locations (A through D) on August 29 and at the A-Frame and in-reservoir sites (I and II) on August 31. Physical water quality parameters were also measured at the downstream site on August 29 and August 31. Overall, physical measurements in the reservoir yielded little evidence that cover operations had upstream effects (Figure 1-3~~Figure 1-3~~ through Figure 1-6~~Figure 1-6~~). Further, it appears that larger-scale reservoir processes were dominant, e.g., seasonal and short term stratification, diel variations in primary production, local and near-term meteorological conditions (wind, solar radiation, air temperature, etc.)). Likewise, downstream conditions did not exhibit any clear response from the cover placement; rather the downstream signal appeared to be reflecting the

longer-term reservoir outflow conditions (Figure 1-7~~Figure 1-7~~ through Figure 1-9~~Figure 1-9~~).

Figure 1-3. Profiles at the A-frame and upstream locations *A* through *D*. August 29, 2011.

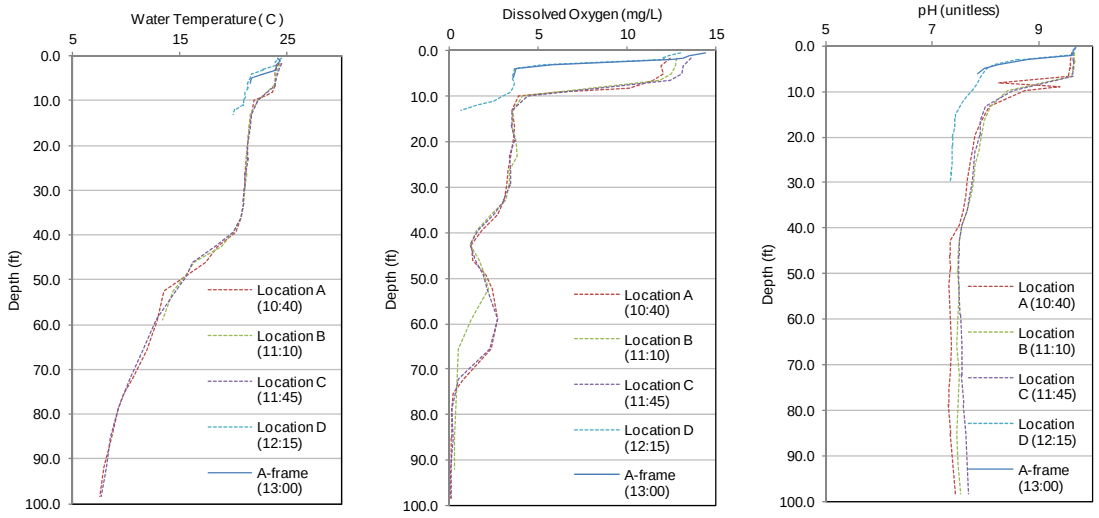


Figure 1-4. Profiles at the A-frame and upstream sites I and II prior to cover deployment (cover depth is zero). August 31, 2011.

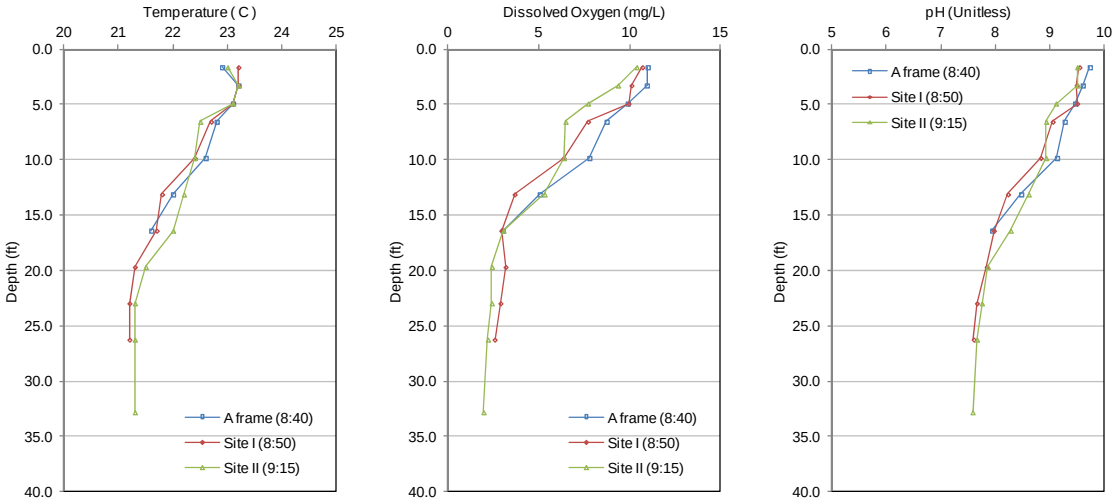


Figure 1-5. Profiles at the A-frame and upstream sites I and II when the cover was deployed 6 ft (1.8 m). August 31, 2011.

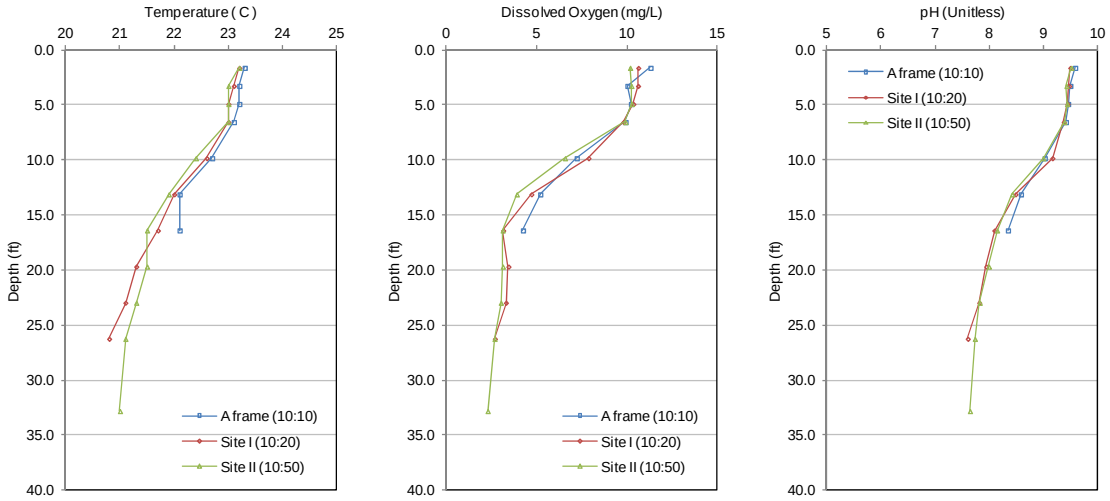


Figure 1-6. Profiles at the A-frame and upstream sites I and II when the cover was deployed 12 ft (3.6 m). August 31, 2011.

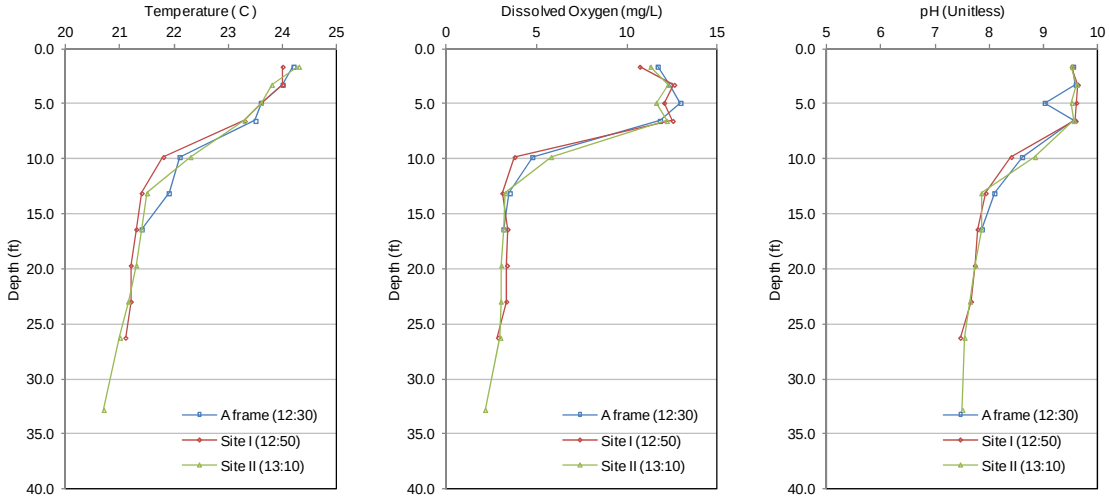


Figure 1-7. Downstream water temperatures for August 29, 2011 (top) and August 31, 2011 (bottom).

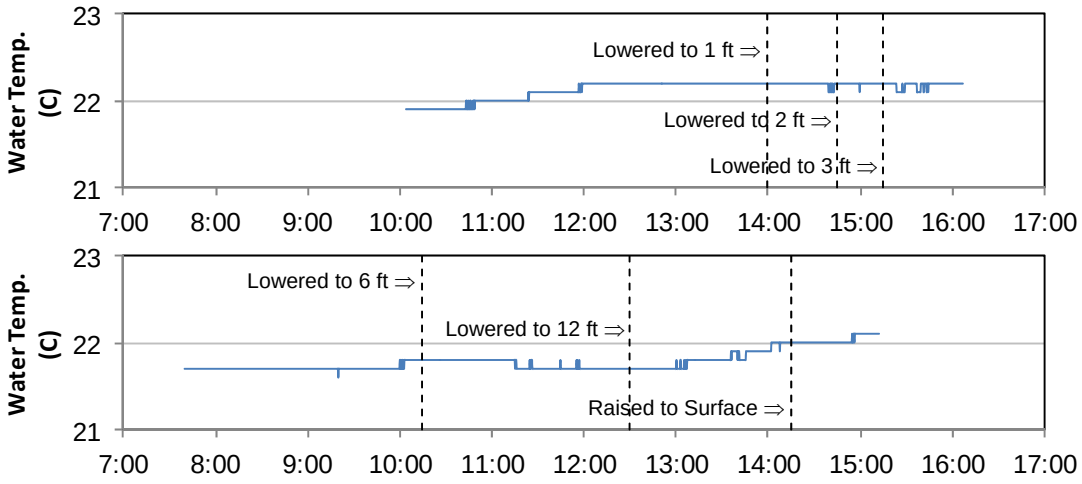
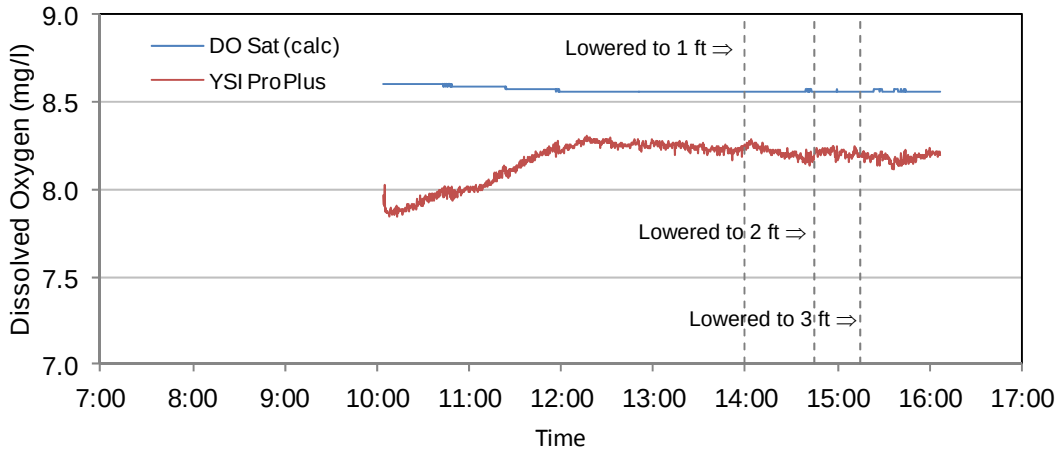


Figure 1-8. Downstream dissolved oxygen (DO) concentrations for August 29, 2011 (top) and August 31, 2011 (bottom) at the downstream location. Blue line is the calculated DO saturation based on altitude and water temperature. Red line is measurements taken using the YSI Professional Plus data presented as green dotted line.



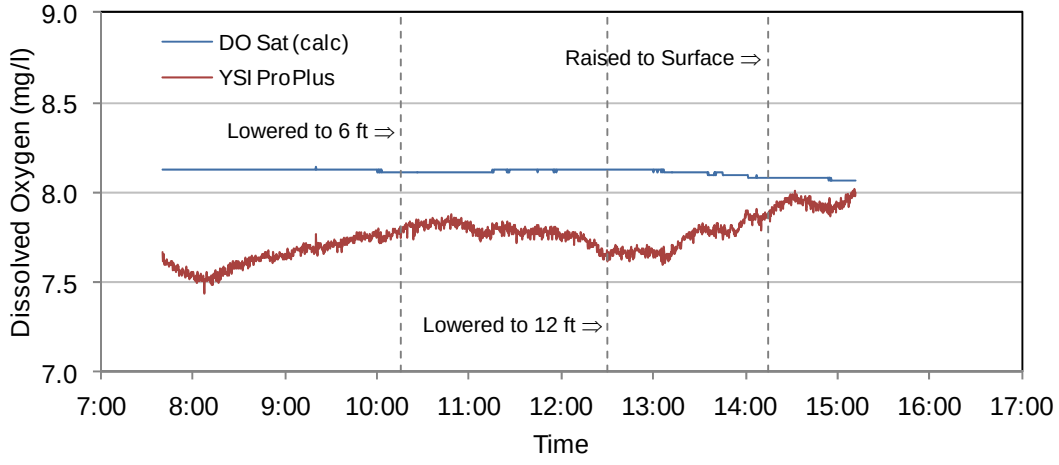
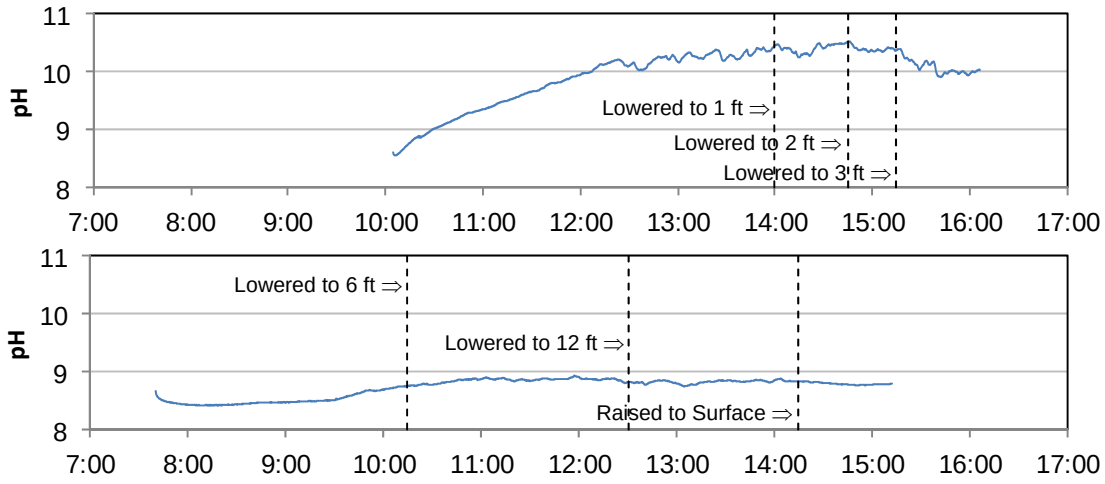


Figure 1-9. Downstream pH for August 29, 2011 (top) and August 31, 2011 (bottom).



B.3 Recommendations

The Iron Gate intake cover study provided insight on the complex hydrodynamics near the intake tower. Based on these findings, recommendations for future studies include:

- Increase the number of velocity measurements at the A-frame and measure velocity profiles in the surrounding areas to quantify and minimize interference from the reservoir bed and/or intake tower.

- Extend the study period to span two weeks and deploy the cover for longer periods of time (i.e., multiple sequential days). Longer deployment may allow the reservoir to reach hydraulic equilibrium for consistent velocity readings over a range of days. A longer study period can also provide a buffer in case there are anomalous events (e.g., large algal bloom, wind or rain event, etc).

- Conduct a vertical migration study of cyanobacteria by deploying a phycocyanin probe in-reservoir for a full day or over several days (including overnight).

- Conduct a basic bathymetry study near the intake tower to characterize the reservoir bed and understand the impacts of bank geometry on flow.

B.4 Conclusions

In August 2011, PacifiCorp installed a steel cover on the Iron Gate Dam intake tower, to explore its effectiveness as a water quality control method. The purpose of the intake tower cover was to alter the depth at which water was withdrawn from the reservoir. It was hypothesized that limiting the entrainment of near-surface waters would result in reduced cyanobacteria downstream. There were two main tasks to the study: (1) measure the velocity profile near the front of the intake tower at the A-frame and (2) analyze algae and nutrient grab samples collected upstream and downstream of Iron Gate Dam.

When the intake cover was lowered to 6 ft and 12 ft below the surface, ADCP measurements indicated an increase in velocity near the penstock intake, suggesting the selective withdrawal range is altered due to the presence of the cover. Variable velocity data in the near-surface region suggested hydraulic flow equilibrium had not been achieved prior to the conclusion of the study period. When the intake cover was lowered 12 ft below the surface, *Microcystis aeruginosa* cell counts were 44 percent lower downstream compared to cell counts when the cover was not present. This finding suggests the cover can be an effective means of reducing entrainment of *Microcystis aeruginosa*. While the installation and deployment of the intake tower cover reduced the entrainment of cyanobacteria species, downstream effects on nutrient concentrations or physical constituents (water temperature, dissolved oxygen, or pH) were not observed.

B.5 Algae Laboratory Data

Table 1-8. Algae species results (August 29, 2011 and August 31, 2011). The summation of the density and biovolume for each sample is presented (in bold).

Sampling Location	Sample Date	Time	Species Name	Count per taxa	Density	Biovolume	Group
Site I	8/29/2011	12:46	*Microcystis aeruginosa*	56	378	30,247	blue-green
(0.5 ft)	8/29/2011		*Aphanizomenon flos-aquae*	210	1,418	1,875,768	blue-green
	8/29/2011		*Nitzschia palea*	1	7	1,215	diatom
	8/29/2011		*Ankistrodesmus falcatus*	3	20	506	green
					1,823	**1,907,737**	
Site I	8/29/2011	15:19	*Microcystis aeruginosa*	145	3,159	252,734	blue-green
(0.5 ft)	8/29/2011		*Aphanizomenon flos-aquae*	105	2,288	2,738,354	blue-green
	8/29/2011		*Cryptomonas erosa*	1	22	11,329	cryptophyte
	8/29/2011		*Rhodomonas minuta*	1	22	436	cryptophyte
	8/29/2011		*Nitzschia palea*	5	109	19,609	diatom
	8/29/2011		*Stephanodiscus hantzschii*	1	22	2,614	diatom
	8/29/2011		*Cocconeis placentula*	1	22	10,022	diatom
	8/29/2011		*Ankistrodesmus falcatus*	3	65	1,634	green
	8/29/2011		*Chlamydomonas sp.*	1	22	7,081	green
					5,730	**3,043,814**	
Site I	8/31/2011	8:57	*Microcystis aeruginosa*	210	3,758	300,667	blue-green
(0.5 ft)	8/31/2011		*Aphanizomenon flos-aquae*	85	1,521	1,629,238	blue-green
	8/31/2011		*Rhodomonas minuta*	2	36	716	cryptophyte
	8/31/2011		*Cryptomonas erosa*	2	36	18,613	cryptophyte
	8/31/2011		*Nitzschia palea*	13	233	41,879	diatom
	8/31/2011		*Nitzschia frustulum*	2	36	4,295	diatom
	8/31/2011		*Cyclotella pseudostelligera*	2	36	2,327	diatom
	8/31/2011		*Fragilaria construens*	1	18	8,018	diatom
	8/31/2011		*Ankistrodesmus falcatus*	2	36	895	green

Table 1-8. Algae species results (August 29, 2011 and August 31, 2011). The summation of the density and biovolume for each sample is presented (in bold).

Sampling Location	Sample Date	Time	Species Name	Count per taxa	Density	Biovolume	Group
					5,709	**2,006,646**	
Site I	8/31/2011	8:59	*Microcystis aeruginosa*	542	6,836	656,220	blue-green
(10 ft)	8/31/2011		*Aphanizomenon flos-aquae*	10	126	158,909	blue-green
	8/31/2011		*Cryptomonas erosa*	11	139	72,140	cryptophyte
	8/31/2011		*Nitzschia palea*	24	303	54,483	diatom
	8/31/2011		*Cocconeis placentula*	4	50	23,206	diatom
	8/31/2011		*Nitzschia capitellata*	1	13	4,540	diatom
	8/31/2011		*Melosira granulata*	1	13	6,937	diatom
	8/31/2011		*Gomphonema subclavatum*	1	13	7,567	diatom
	8/31/2011		*Stephanodiscus hantzschii*	1	13	1,513	diatom
	8/31/2011		*Synedra ulna*	1	13	25,098	diatom
	8/31/2011		*Schroderia sp.*	3	38	1,703	green
					7,555	**1,012,316**	
Site II	8/31/2011	14:25	*Microcystis aeruginosa*	223	2,972	309,090	blue-green
(0.5 ft)	8/31/2011		*Aphanizomenon flos-aquae*	86	1,146	1,444,160	blue-green
	8/31/2011		*Anabaena sp.*	1	13	18,125	blue-green
	8/31/2011		*Cryptomonas erosa*	4	53	27,721	cryptophyte
	8/31/2011		*Rhodomonas minuta*	1	13	267	cryptophyte
	8/31/2011		*Nitzschia palea*	5	67	11,995	diatom
	8/31/2011		*Cocconeis placentula*	1	13	6,131	diatom
	8/31/2011		*Chlamydomonas sp.*	3	40	12,994	green
	8/31/2011		*Schroderia sp.*	3	40	1,799	green
					4,358	**1,832,281**	
Site II	8/31/2011	14:30	*Microcystis aeruginosa*	231	4,429	354,357	blue-green
(10 ft)	8/31/2011		*Aphanizomenon flos-aquae*	45	863	1,032,871	blue-green
	8/31/2011		*Cryptomonas erosa*	12	230	119,653	cryptophyte
	8/31/2011		*Rhodomonas minuta*	3	58	1,151	cryptophyte
	8/31/2011		*Nitzschia palea*	15	288	51,773	diatom
	8/31/2011		*Cocconeis placentula*	2	38	17,641	diatom
	8/31/2011		*Nitzschia amphibia*	2	38	3,682	diatom
	8/31/2011		*Ankistrodesmus falcatus*	1	19	479	green
	8/31/2011		*Schroderia sp.*	1	19	863	green
					5,983	**1,582,469**	
Downstream	8/31/2011	9:24	*Microcystis aeruginosa*	339	4,334	346,687	blue-green
(0.5 ft)	8/31/2011		*Aphanizomenon flos-aquae*	27	345	391,404	blue-green

Table 1-8. Algae species results (August 29, 2011 and August 31, 2011). The summation of the density and biovolume for each sample is presented (in bold).

Sampling Location	Sample Date	Time	Species Name	Count per taxa	Density	Biovolume	Group
	8/31/2011		*Cryptomonas erosa*	2	26	13,295	cryptophyte
	8/31/2011		*Nitzschia palea*	15	192	34,515	diatom
	8/31/2011		*Cocconeis placentula*	4	51	23,522	diatom
	8/31/2011		*Fragilaria construens venter*	1	13	614	diatom
	8/31/2011		*Cyclotella pseudostelligera*	1	13	831	diatom
	8/31/2011		*Nitzschia linearis*	1	13	38,964	diatom
	8/31/2011		*Chlamydomonas sp.*	1	13	4,155	green
	8/31/2011		*Ankistrodesmus falcatus*	1	13	320	green
	8/31/2011		*Schroderia sp.*	1	13	575	green
					5,024	**854,880**	
Site I	8/31/2011	10:25	*Microcystis aeruginosa*	251	3,964	348,799	blue-green
(0.5 ft)	8/31/2011		*Aphanizomenon flos-aquae*	80	1,263	1,671,353	blue-green
	8/31/2011		*Cryptomonas erosa*	3	47	24,634	cryptophyte
	8/31/2011		*Rhodomonas minuta*	1	16	316	cryptophyte
	8/31/2011		*Nitzschia palea*	11	174	31,267	diatom
	8/31/2011		*Pinnularia sp.*	1	16	6,317	diatom
	8/31/2011		*Navicula decussis*	1	16	3,032	diatom
	8/31/2011		*Schroderia sp.*	1	16	711	green
					5,511	**2,086,428**	
Site I	8/31/2011	10:30	*Microcystis aeruginosa*	519	7,050	564,022	blue-green
(10 ft)	8/31/2011		*Aphanizomenon flos-aquae*	50	679	898,604	blue-green
	8/31/2011		*Cryptomonas erosa*	3	41	21,192	cryptophyte
	8/31/2011		*Rhodomonas minuta*	1	14	272	cryptophyte
	8/31/2011		*Nitzschia palea*	15	204	36,678	diatom
	8/31/2011		*Nitzschia frustulum*	2	27	3,260	diatom
	8/31/2011		*Gomphonema angustatum*	1	14	2,445	diatom
	8/31/2011		*Ceratium hirundinella*	1	14	133,127	dinoflagellate
	8/31/2011		*Ankistrodesmus falcatus*	1	14	340	green
					8,056	**1,659,938**	
Site II	8/31/2011	10:55	*Microcystis aeruginosa*	300	4,176	367,481	blue-green
(0.5 ft)	8/31/2011		*Aphanizomenon flos-aquae*	47	654	824,328	blue-green
	8/31/2011		*Gloeotrichia echinulata*	1	14	18,931	blue-green
	8/31/2011		*Cryptomonas erosa*	5	70	36,191	cryptophyte
	8/31/2011		*Nitzschia palea*	12	167	30,067	diatom
	8/31/2011		*Nitzschia amphibia*	1	14	1,336	diatom

Table 1-8. Algae species results (August 29, 2011 and August 31, 2011). The summation of the density and biovolume for each sample is presented (in bold).

Sampling Location	Sample Date	Time	Species Name	Count per taxa	Density	Biovolume	Group
	8/31/2011		*Epithemia turgida*	1	14	118,318	diatom
	8/31/2011		*Ankistrodesmus falcatus*	2	28	696	green
					5,136	**1,397,348**	
Downstream	8/31/2011	10:56	*Microcystis aeruginosa*	231	2,658	276,399	blue-green
(0.5 ft)	8/31/2011		*Aphanizomenon flos-aquae*	40	460	521,871	blue-green
	8/31/2011		*Cryptomonas erosa*	5	58	29,913	cryptophyte
	8/31/2011		*Rhodomonas minuta*	1	12	230	cryptophyte
	8/31/2011		*Nitzschia palea*	12	138	24,851	diatom
	8/31/2011		*Rhoicosphenia curvata*	2	23	2,692	diatom
	8/31/2011		*Asterionella formosa*	2	23	5,062	diatom
	8/31/2011		*Stephanodiscus hantzschii*	1	12	1,381	diatom
	8/31/2011		*Nitzschia frustulum*	1	12	1,381	diatom
	8/31/2011		*Fragilaria capucina mesolepta*	1	12	2,934	diatom
	8/31/2011		*Nitzschia paleacea*	1	12	1,128	diatom
	8/31/2011		*Nitzschia amphibia*	1	12	1,104	diatom
	8/31/2011		*Cocconeis placentula*	1	12	5,292	diatom
	8/31/2011		*Epithemia sorex*	1	12	13,116	diatom
	8/31/2011		*Gomphonema angustatum*	1	12	2,071	diatom
	8/31/2011		*Schroderia sp.*	5	58	2,589	green
					3,521	**892,014**	
Site I	8/31/2011	12:53	*Microcystis aeruginosa*	181	3,580	343,709	blue-green
(0.5 ft)	8/31/2011		*Aphanizomenon flos-aquae*	98	1,939	2,442,521	blue-green
	8/31/2011		*Cryptomonas erosa*	7	138	72,002	cryptophyte
	8/31/2011		*Rhodomonas minuta*	5	99	1,978	cryptophyte
	8/31/2011		*Nitzschia palea*	9	178	32,045	diatom
	8/31/2011		*Cyclotella pseudostelligera*	1	20	1,286	diatom
					5,954	**2,893,541**	
Site I	8/31/2011	12:57	*Microcystis aeruginosa*	306	4,021	353,862	blue-green
(10 ft)	8/31/2011		*Aphanizomenon flos-aquae*	1	13	6,623	blue-green
	8/31/2011		*Rhodomonas minuta*	2	26	526	cryptophyte
	8/31/2011		*Cryptomonas erosa*	1	13	6,833	cryptophyte
	8/31/2011		*Nitzschia palea*	22	289	52,038	diatom
	8/31/2011		*Cocconeis placentula*	4	53	24,179	diatom
	8/31/2011		*Asterionella formosa*	1	13	2,891	diatom

Table 1-8. Algae species results (August 29, 2011 and August 31, 2011). The summation of the density and biovolume for each sample is presented (in bold).

Sampling Location	Sample Date	Time	Species Name	Count per taxa	Density	Biovolume	Group
	8/31/2011		*Stephanodiscus astraea minutula*	1	13	4,599	diatom
	8/31/2011		*Nitzschia frustulum*	1	13	1,577	diatom
	8/31/2011		*Navicula cryptocephala veneta*	1	13	1,248	diatom
	8/31/2011		*Nitzschia amphibia*	1	13	1,262	diatom
	8/31/2011		*Schroderia sp.*	5	66	2,957	green
					4,547	**458,596**	
Site II	8/31/2011	13:17	*Microcystis aeruginosa*	218	4,097	360,499	blue-green
(0.5 ft)	8/31/2011		*Aphanizomenon flos-aquae*	95	1,785	2,586,767	blue-green
	8/31/2011		*Rhodomonas minuta*	3	56	1,128	cryptophyte
	8/31/2011		*Cryptomonas erosa*	3	56	29,315	cryptophyte
	8/31/2011		*Nitzschia palea*	11	207	37,208	diatom
	8/31/2011		*Nitzschia capitellata*	1	19	6,765	diatom
	8/31/2011		*Cocconeis placentula*	1	19	8,644	diatom
	8/31/2011		*Asterionella formosa*	1	19	4,134	diatom
	8/31/2011		*Gomphonema subclavatum*	1	19	11,275	diatom
	8/31/2011		*Cyclotella pseudostelligera*	1	19	1,221	diatom
	8/31/2011		*Chlamydomonas sp.*	1	19	6,107	green
	8/31/2011		*Ankistrodesmus falcatus*	1	19	470	green
					6,333	**3,053,533**	
Downstream	8/31/2011	13:14	*Microcystis aeruginosa*	111	1,337	192,542	blue-green
(0.5 ft)	8/31/2011		*Aphanizomenon flos-aquae*	30	361	341,502	blue-green
	8/31/2011		*Cryptomonas erosa*	3	36	18,792	cryptophyte
	8/31/2011		*Rhodomonas minuta*	1	12	241	cryptophyte
	8/31/2011		*Nitzschia palea*	18	217	39,029	diatom
	8/31/2011		*Cocconeis placentula*	5	60	27,706	diatom
	8/31/2011		*Nitzschia frustulum*	2	24	2,891	diatom
	8/31/2011		*Stephanodiscus hantzschii*	1	12	1,446	diatom
	8/31/2011		*Gomphonema subclavatum*	1	12	7,228	diatom
	8/31/2011		*Gomphonema angustatum*	1	12	2,168	diatom
	8/31/2011		*Schroderia sp.*	2	24	1,084	green
	8/31/2011		*Scenedesmus quadricauda*	1	12	3,132	green
					2,120	**637,760**	

Appendix C
Study of Vertical Migration of Blue Green Algae in Iron Gate Reservoir, August 2012

APPENDIX C

Study of Vertical Migration of Blue Green Algae in Iron Gate Reservoir, August 2012

C.1 Introduction

PacifiCorp is exploring managing reservoir outflows in the vicinity of the powerhouse intake tower at Iron Gate Dam to reduce entrainment of cyanobacteria that would be released downstream to the Klamath River. As part of the Iron Gate Cover Study, a concurrent study was conducted to assess the vertical distribution in cyanobacteria species and water quality parameters over an approximately 48 hour period in August 2012.

The rationale for the study was based on the known ability of *Microcystis aeruginosa* (MSAE) to undergo vertical migration (Reynolds *et al*, 1987; Rabouille *et al*., 2005; Chu *et al*., 2007) over relatively short time periods (e.g., hours). Changes in the vertical distribution of MSAE over time due to such migration could therefore be an important factor in determining the appropriate placement and operation of the Iron Gate intake cover.

C.2 Methodology

Cyanobacteria and water quality samples were collected at three-hour intervals at five depths over the course of two days (August 27-29, 2012) to determine the vertical distribution of cyanobacteria in the water column in the vicinity of the intake tower in Iron Gate Reservoir. The study approach also assumes that comparison of samples results between the sampling intervals can be used to infer vertical movement or migration of cyanobacteria in the water column. Outlined herein are the project location, equipment used, and the experiment set-up.

C.2.1 Project Location

Samples were collected in the lower end of Iron Gate Reservoir near the Iron Gate dam spillway (Coordinates: 41°56’8.91”N, 122°26’8.74”W). The spillway is located on the northwest shoreline of the reservoir, and the sampling site was located adjacent to the buoys near the spillway. Reservoir depth at the sampling site was approximately 65.6 feet (Figure C-1).

Figure C-1. Aerial photo showing the location of vertical migration experiment (as indicated by the yellow star) within Iron Gate Reservoir. (Aerial photo courtesy of Google Earth.)

C.2.2 Equipment

Samples were collected using Teledyne ISCO portable autosamplers (Model Number: 6712). Each autosampler consists of a removable top cover, the center section, and the base section. The removable top cover protects the control box that is mounted on the center section. The center section includes the control box, liquid detector, pump, and distribution system. The base section holds the sample bottles.

Figure C-2. Photo of Teledyne ISC0 6712 portable autosampler. (Photo courtesy of Teledyne Technologies Incorporated, 2012)

The autosamplers can be programmed to automatically collect specific volumes of samples at specific time intervals. The autosamplers use a peristaltic pump for sample collection, which compensates for pumping head and triggers automatic suction line rinsing following sampling to prevent cross contamination. Each sampling cycle includes

an air pre-sample purge and post-sample purge to clear the suction line both before and after sampling. Pump speed is approximately 250 RPM. The pumping rate of 3,500 ml per minute is generated when using 3/8-inch internal diameter suction line at 3 feet of head. The line transport velocity, using the same suction line and head, is 2.9 feet per second. The pump tubing is made of silastic medical-grade silicon rubber.

The 24-bottle configuration was chosen for all the autosamplers used in this experiment. In this configuration, each autosampler module contains 24 1000-ml polypropylene sample bottles that are filled as the samples are drawn.

C.2.3 Experiment Set-Up

Five autosamplers, each drawing samples from a different depth, were deployed on an anchored boat at the sampling site location (Figure C-3). The five sample depths were 0.65 ft, 3.5 ft, 8.2 ft, 18 ft, and 33 ft (0.2 m, 1.0 m, 2.5 m, 5.5 m, and 10 m, respectively) and were selected based on previous, long-term vertical profiling of phycocyanin in the reservoir (A. Lincoff, pers comm). Weights were attached to the suction lines to counter buoyant forces and to keep the lines vertical in the water column. Samples were taken at 3-hour intervals over the two-day study period. The first set of samples was collected on August 27 at 18:00 and the second set of samples was collected on August 29 at 15:00.

Figure C-3. Boat deployment of autosamplers adjacent to the Iron Gate Reservoir spill way

C.2.4 Sampling Procedure

For each time and depth, two 1-Liter sample bottles were filled by the autosampler. These water samples were used to fill pre-labeled bottles for subsequent laboratory analyses of blue green algae species, chlorophyll *a*, and nutrients. Phycocyanin measurements were conducted by inserting a phycocyanin probe into the sample bottles (after other samples had been taken from the bottle) and waiting one minute for the sample to stabilize. In addition, water temperature sensors were also attached at each depth. These sampling and measurement results will be presented in the next section.

C.2.5 Laboratory Analyses

The samples collected by the autosamplers were analyzed for blue green algae species, phycocyanin, and chlorophyll *a* in all samples (i.e., at 3-hour intervals). Nutrient analyses were conducted on every other sample (i.e., at 6-hour intervals) for total nitrogen (TN), nitrite plus nitrate (NO2+NO3), ammonia (NH4), total phosphorus (TP), orthophosphate (PO4), dissolved organic carbon (DOC), and chlorophyll a (Table C-1).

Table C-1. Laboratory Methods, Method Detection Limits (MDL), and Reporting Limits (RL), as Applicable

Constituent	Units	Method	Preservative	MDL[a]	RL[a]	Laboratory
TN	mg/l	NEMI[b] I-4650-03	None	0.01	0.02	Biogeochemistry Laboratory, U.C. Davis
NO3+NO2	mg/l	Nitrate via V(III) reduction[c]	None	0.005	0.01	Biogeochemistry Laboratory, U.C. Davis
NO2	mg/l	Nitrate via V(III) reduction	None	0.002	0.01	Biogeochemistry Laboratory, U.C. Davis
NH4	mg/l	SM[d] 4500-NH3 F	None	0.005	0.01	Biogeochemistry Laboratory, U.C. Davis
TP	mg/l	NEMI I-4650-03	None	0.01	0.01	Biogeochemistry Laboratory, U.C. Davis
OPO4	mg/l	SM 4500-P E	None	0.001	0.005	Biogeochemistry Laboratory, U.C. Davis
DOC	mg/l	EPA[e] 415.3	None	0.1	0.1	Biogeochemistry Laboratory, U.C. Davis
Chlorophyll *a*	µg/l	EPA 445.0	None	1ppb	1 ppb	Biogeochemistry Laboratory, U.C. Davis

[a] Units are in mg/l unless otherwise specified.

[b] National Environmental Methods Index

[c] This method was developed by UC Davis Department of Land, Air and Water Resources (Doane and Horwath, 2003)

[d] Standard Methods

[e] Environmental Protection Agency

C.3 Results

C.3.1 Blue Green Algae Species

Aphanizomenon flos-aquae (APFA), *Microcystis aeruginoa* (MSAE), and *Pseudoanabaena sp.* (PSAB) were the principal species present (Table C-2 to Table C-4, respectively). APFA and PSAB showed a consistent abundant presence through time and depth, while MSAE was occasionally abundant but otherwise inconsistently present at the study site. The abundance of each of these species was consistently lower at 10 m than at shallower depths (Figure C-4 through Figure C-6).

Table C-2. *Aphanizomenon flos-aquae* cell density (cells/ml) at 0.2, 1.0, 2.5, 5.5, and 10.0 meters: 8/27/2012 18:00 to 8/29/2012 15:00

	Depth (m)				
Time	**0.2**	**1.0**	**2.5**	**5.5**	**10.0**
8/27 1800	13,468	7,869	6,413	7,978	4,002
8/27 2100	3,231	6,023	2,708	5,586	193
8/28 0000	32,636	6,397	7,189	17,244	480
8/28 0300	6,777	5,586	6,941	16,193	549
8/28 0600	5,867	5,798	3,591	3,846	3,302
8/28 0900	NS	14,987	5,589	8,022	6,715
8/28 1200	NS	16,186	19,674	7,673	5,634
8/28 1500	15,952	5,902	6,084	7,502	2,068
8/28 1800	15,999	40,880	14,741	18,203	4,407
8/28 2100	29,926	16,412	14,897	20,473	4,070
8/29 0000	25,639	21,163	19,123	17,807	167
8/29 0300	NS	12,908	10,740	13,961	362
8/29 0600	25,976	21,140	14,439	6,935	735
8/29 0900	17,706	22,445	10,708	4,853	920
8/29 1200	21,548	13,783	19,618	6,211	417
8/29 1500	14,551	19,015	10,404	696	NS

NS – no sample

Figure C-4. *Aphanizomenon flos-aquae* cell density (cells/ml) at 0.2, 1.0, 2.5, 5.5, and 10.0 meters: 8/27/2012 18:00 to 8/29/2012 15:00

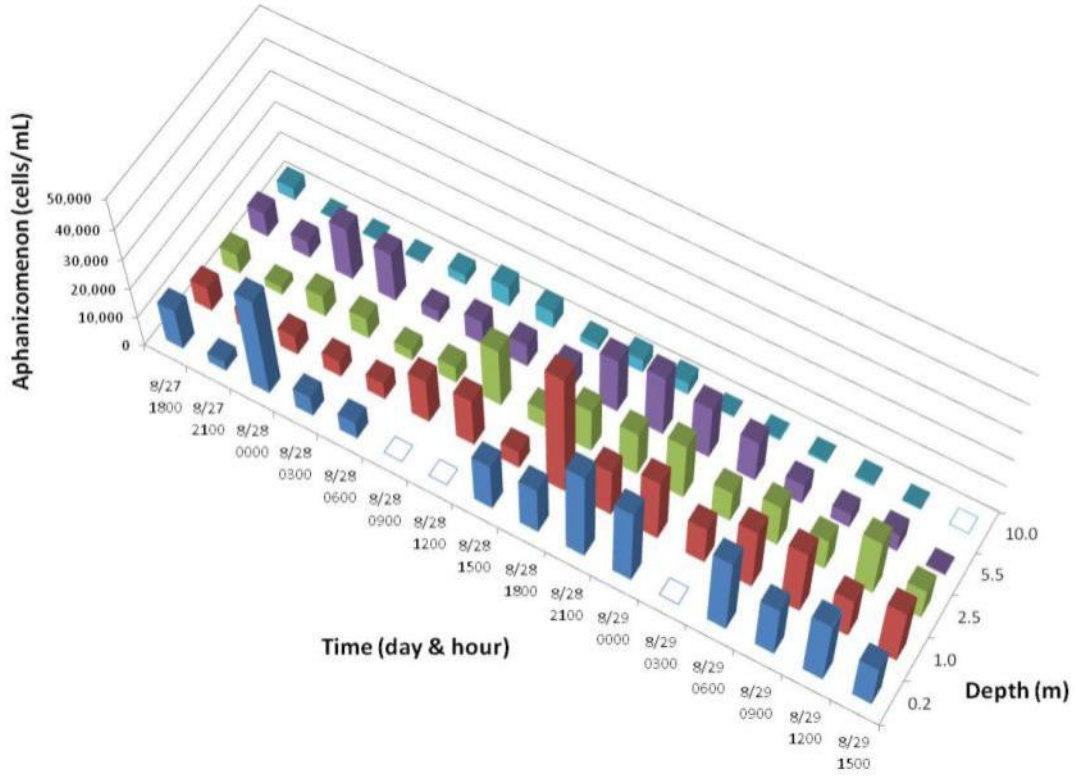


Table C-3. *Microcystis aeruginosa* cell density (cells/ml) at 0.2, 1.0, 2.5, 5.5, and 10.0 meters: 8/27/2012 18:00 to 8/29/2012 15:00

	Depth (m)				
Time	**0.2**	**1.0**	**2.5**	**5.5**	**10.0**
8/27 1800	6,467	5,306	7,271	19,400	3,632
8/27 2100	10,994	5,147	345	2,247	2,038
8/28 0000	5,943	5,215	ND	18,302	ND
8/28 0300	15,312	5,222	3,365	110,093	688
8/28 0600	5,762	7,608	4,069	28,377	ND
8/28 0900	NS	3,765	4,291	616	ND
8/28 1200	NS	21,969	647	7,213	ND
8/28 1500	48,414	1,035	ND	119,747	5,288
8/28 1800	ND	71,135	ND	159,083	71,458
8/28 2100	225,476	ND	46,983	59,279	259,506
8/29 0000	172,309	73,444	91,234	4,503	20,030
8/29 0300	NS	ND	ND	329,598	ND
8/29 0600	15,089	388,870	ND	33,596	1,176
8/29 0900	5,405	271,606	ND	ND	3,708
8/29 1200	ND	ND	124,633	464,316	ND
8/29 1500	12,934	ND	81,148	ND	NS

Figure C-5. *Microcystis aeruginosa* cell density (cells/ml) at 0.2, 1.0, 2.5, 5.5, and 10.0 meters: 8/27/2012 18:00 to 8/29/2012 15:00

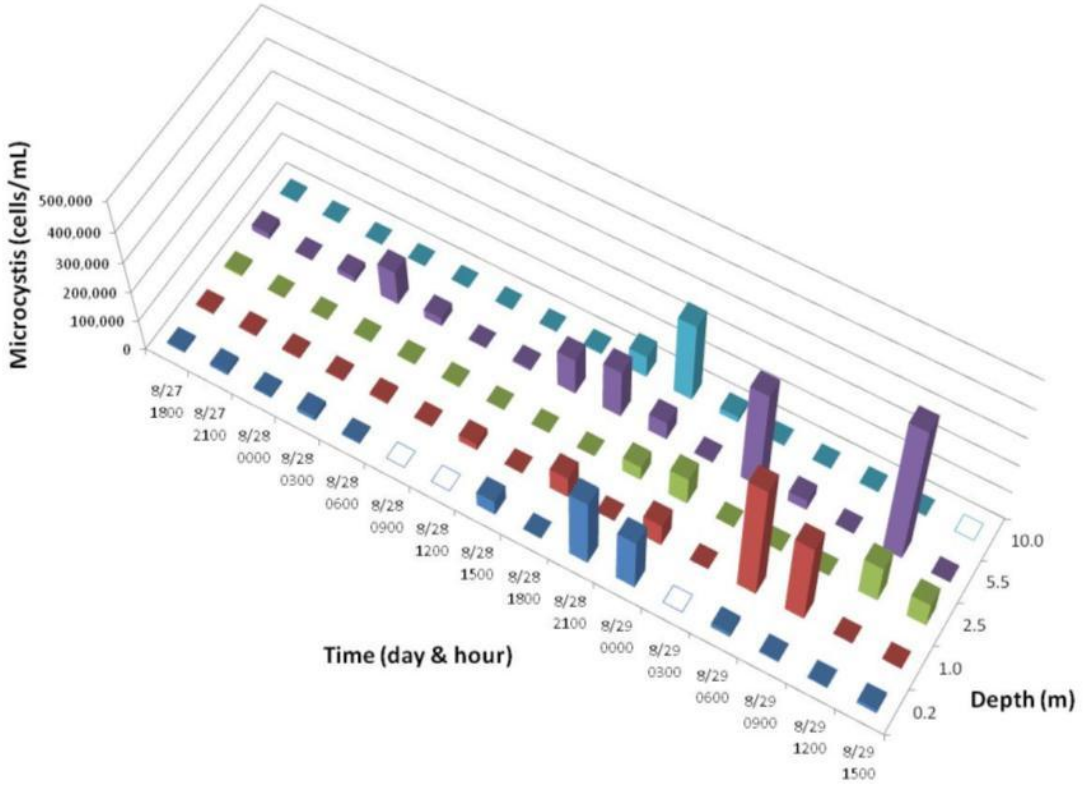
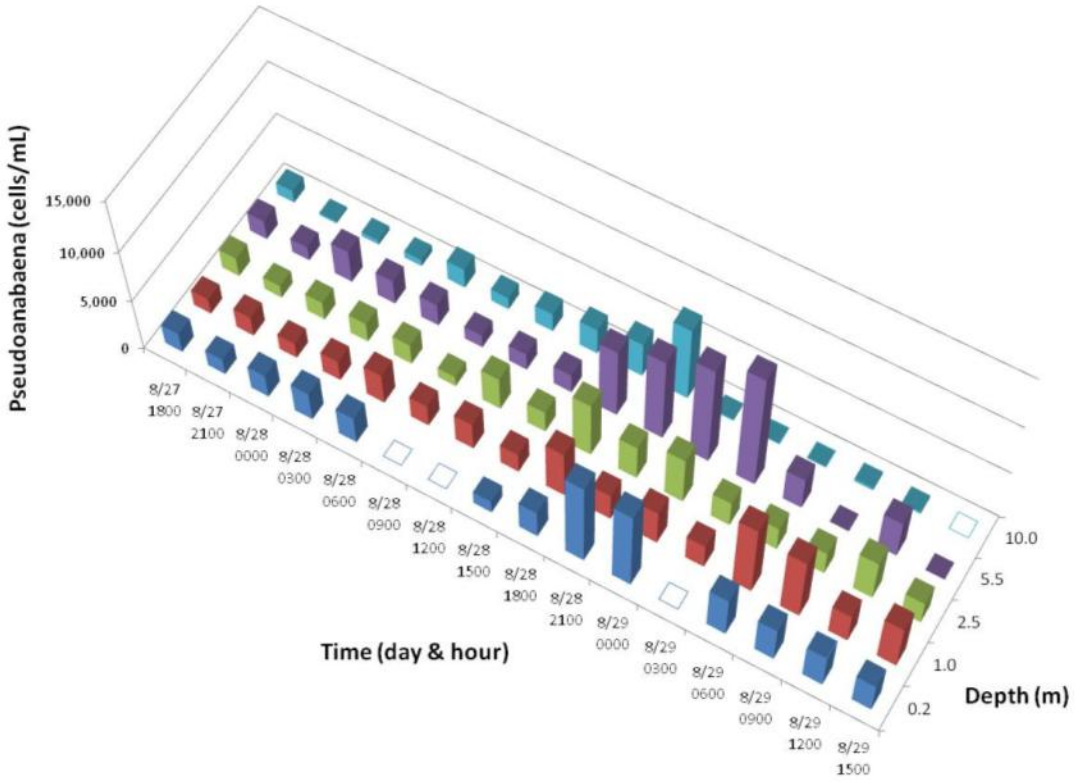


Table C-4. *Pseudoanabaena Sp.* cell density (cells/ml) at 0.2, 1.0, 2.5, 5.5, and 10.0 meters: 8/27/2012 18:00 to 8/29/2012 15:00

	Depth (m)				
Time	**0.2**	**1.0**	**2.5**	**5.5**	**10.0**
8/27 1800	1,919	1,529	1,844	1,841	1,170
8/27 2100	1,575	1,904	1,229	1,361	229
8/28 0000	2,252	1,522	1,767	3,134	434
8/28 0300	2,794	2,004	1,889	2,347	641
8/28 0600	2,633	2,948	1,977	2,174	1,887
8/28 0900	NS	2,123	984	1,281	1,193
8/28 1200	NS	2,658	3,214	1,661	1,805
8/28 1500	1,234	1,912	2,095	1,816	2,505
8/28 1800	2,683	4,565	5,393	6,752	3,345
8/28 2100	8,192	2,626	3,382	8,179	7,248
8/29 0000	7,802	3,383	4,603	9,748	191
8/29 0300	NS	2,365	2,486	11,370	ND
8/29 0600	3,956	7,030	2,334	3,169	ND
8/29 0900	3,423	6,212	2,303	117	297
8/29 1200	3,195	2,894	3,998	3,697	244
8/29 1500	2,890	4,387	2,236	53	NS

Figure C-6. *Pseudoanabaena Sp.* cell density (cells/ml) at 0.2, 1.0, 2.5, 5.5, and 10.0 meters: 8/27/2012 18:00 to 8/29/2012 15:00



C.3.2 Phycocyanin

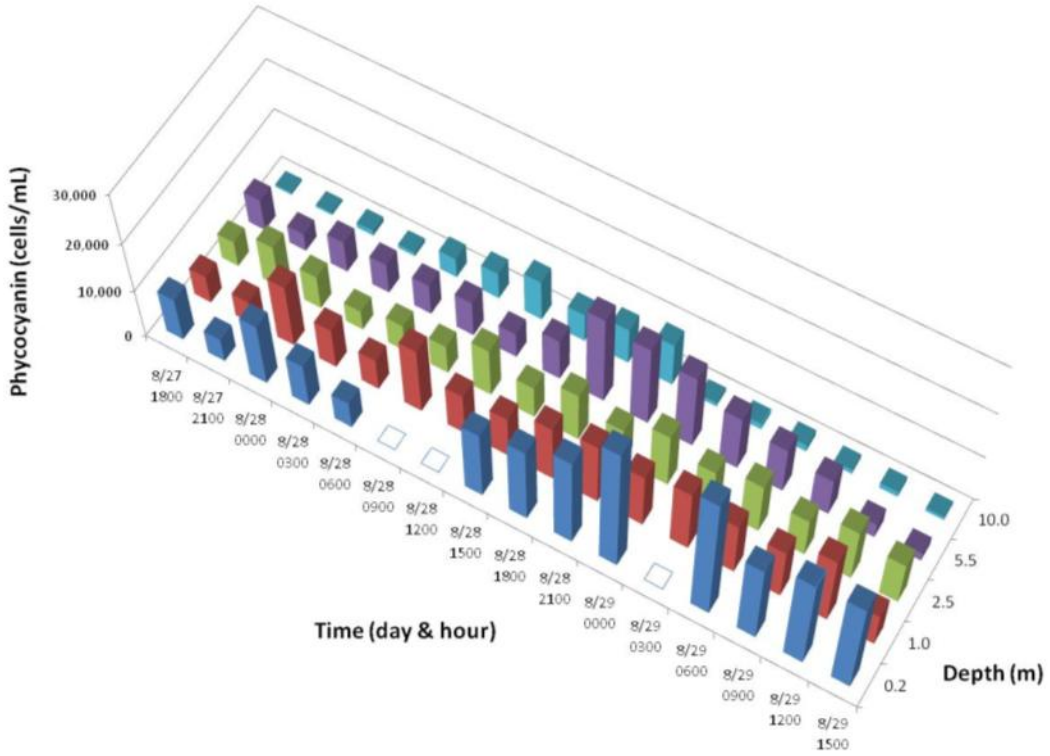
Phycocyanin results show a similar trend in distribution as observed form APFA and PSAB, including consistently lower concentrations at 10 m than at shallower depths (Table C-5, Figure C-7).

Table C-5. Phycocyanin probe measurements (cells/ml) at 0.2, 1.0, 2.5, 5.5, and 10.0 meters: 8/27/2012 18:00 to 8/29/2012 15:00

	Depth (m)				
Time	**0.2**	**1.0**	**2.5**	**5.5**	**10.0**
8/27 1800	8,800	5,616	5,200	6,400	440
8/27 2100	4,800	4,810	8,600	3,600	440
8/28 0000	12,600	12,713	6,800	6,300	1,000
8/28 0300	8,800	8,210	4,000	6,100	800
8/28 0600	5,500	6,429	5,600	6,200	4,000
8/28 0900	NS	13,482	5,900	7,200	5,400
8/28 1200	NS	8,512	9,900	5,100	8,200
8/28 1500	14,000	8,500	6,600	8,400	5,800
8/28 1800	15,500	11,500	10,000	18,000	7,300
8/28 2100	18,600	12,700	7,300	16,500	8,800
8/29 0000	26,000	11,200	11,100	15,200	840
8/29 0300	NS	12,800	8,300	11,300	1,000
8/29 0600	26,000	10,900	10,500	9,500	1,340
8/29 0900	16,500	10,500	8,000	7,800	940

8/29 1200	19,000	14,300	11,000	3,000	1,100
8/29 1500	19,500	7,000	9,000	1,750	650

Figure C-7. Phycocyanin probe measurements (cells/ml) at 0.2, 1.0, 2.5, 5.5, and 10.0 meters: 8/27/2012 18:00 to 8/29/2012 15:00



C.3.3 Chlorophyll *a*

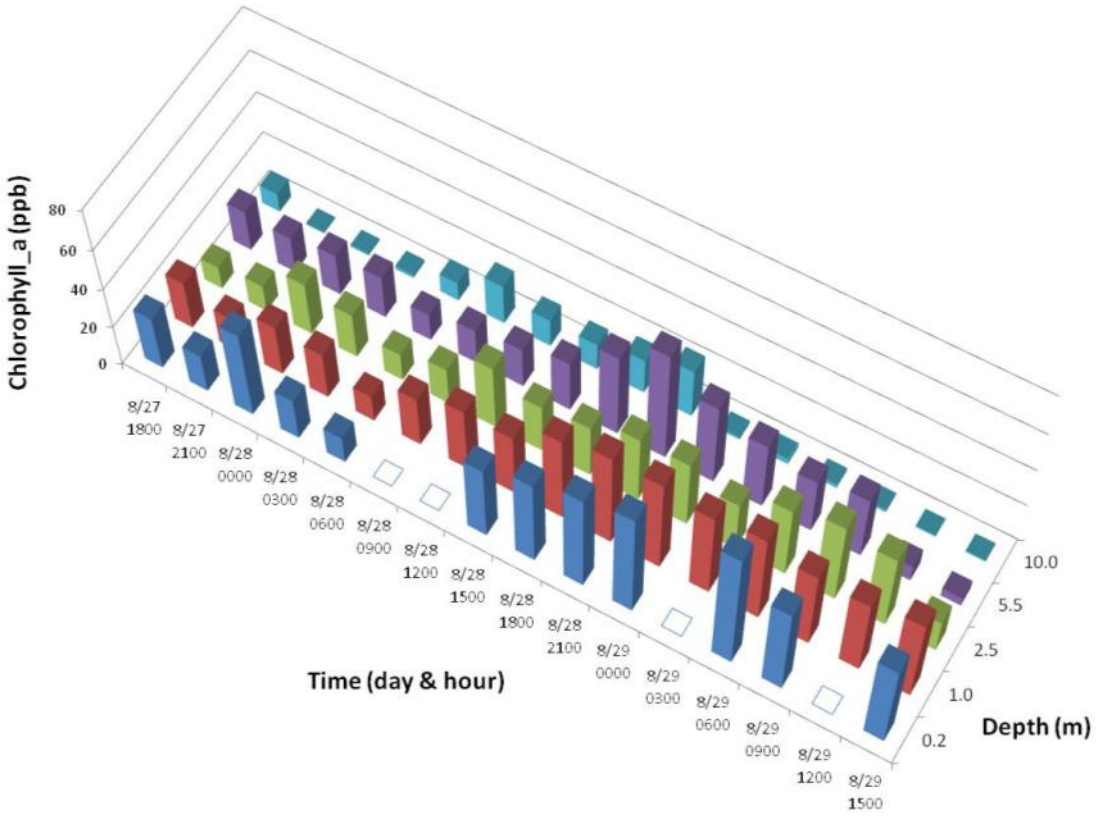
Samples analyzed for chlorophyll *a*, like the phycocyanin data, reflect a similar distribution to APFA and PSAB distribution in space and time, with lower concentrations at the 10 m than at shallower depths (Table C-6, Figure C-8).

Table C-6. Chlorophyll *a* measurements (ppb) at 0.2, 1.0, 2.5, 5.5, and 10.0 meters: 8/27/2012 18:00 to 8/29/2012 15:00

	Depth (m)				
Time	**0.2**	**1.0**	**2.5**	**5.5**	**10.0**
8/27 1800	26.3	23.7	11.2	19.8	9.2
8/27 2100	19.1	17.1	13.2	17.8	0.8
8/28 0000	42.8	25.0	26.3	20.4	1.0
8/28 0300	20.7	23.0	22.4	21.1	1.6
8/28 0600	13.5	13.2	13.8	13.5	9.2
8/28 0900	NS	25.0	18.4	17.4	19.8
8/28 1200	NS	31.6	32.3	19.8	13.8
8/28 1500	36.9	30.9	24.4	25.2	13.2
8/28 1800	42.8	42.8	26.3	41.5	17.4
8/28 2100	48.7	47.4	33.6	55.3	24.4
8/29 0000	52.7	46.7	33.6	40.8	1.5
8/29 0300	NS	42.8	25.0	33.6	2.3
8/29 0600	60.6	45.4	36.2	27.7	1.9

8/29 0900	44.8	39.5	41.5	31.6	1.6
8/29 1200	NS	38.2	38.2	8.0	0.9
8/29 1500	43.5	42.1	16.5	4.4	0.8

Figure C-8. Chlorophyll *a* measurements (ppb) at 0.2, 1.0, 2.5, 5.5, and 10.0 meters: 8/27/2012 18:00 to 8/29/2012 15:00



C.3.4 Nutrients

The results of the analysis of nutrients in the samples are shown in Table C-7 to Table C-12, respectively; and Figure C-9 to Figure C-14, respectively, for TN, NO2+NO3, NH4, TP, PO4, and DOC. In general, TN, TP, DOC showed only modest differences among sample times and depths, while inorganic forms experienced higher concentrations at the deepest depth (10 m). Inorganic nitrogen ((NO2+NO3)-N, NH4-N) data suggest that shallower waters (0.2 m to 5.5 m) had notably lower values than total forms. Similarly inorganic phosphorus (PO4-P) data indicated lower values in shallower waters, but concentrations were high (i.e., 0.078 mg/l or greater) relative to algae growth needs, suggesting there is no phosphorus limitation on algae growth.

Table C-7. Total Nitrogen (TN) analyses results (mg/l) at 0.2, 1.0, 2.5, 5.5, and 10.0 meters: 8/27/2012 18:00 to 8/29/2012 15:00

	Depth (m)				
Time	**0.2**	**1.0**	**2.5**	**5.5**	**10.0**
8/27 1800	1.201	1.200	1.191	1.386	1.162
8/27 2100	1.303	1.168	1.213	1.243	1.313
8/28 0000	-	-	-	-	-
8/28 0300	1.215	1.112	1.291	1.216	1.680
8/28 0600	-	-	-	-	-
8/28 0900	NS	1.168	1.285	1.200	1.244
8/28 1200	-	-	-	-	-
8/28 1500	1.305	1.246	1.249	1.216	1.167
8/28 1800	-	-	-	-	-
8/28 2100	2.004	1.305	1.158	1.572	1.352
8/29 0000	-	-	-	-	-
8/29 0300	NS	1.437	1.088	1.155	0.986
8/29 0600	-	-	-	-	-
8/29 0900	1.472	1.318	1.313	1.080	1.121
8/29 1200	-	-	-	-	-
8/29 1500	1.394	1.650	1.062	0.997	1.158

Figure C-9. Total Nitrogen (TN) analyses results (mg/l) at 0.2, 1.0, 2.5, 5.5, and 10.0 meters: 8/27/2012 18:00 to 8/29/2012 15:00

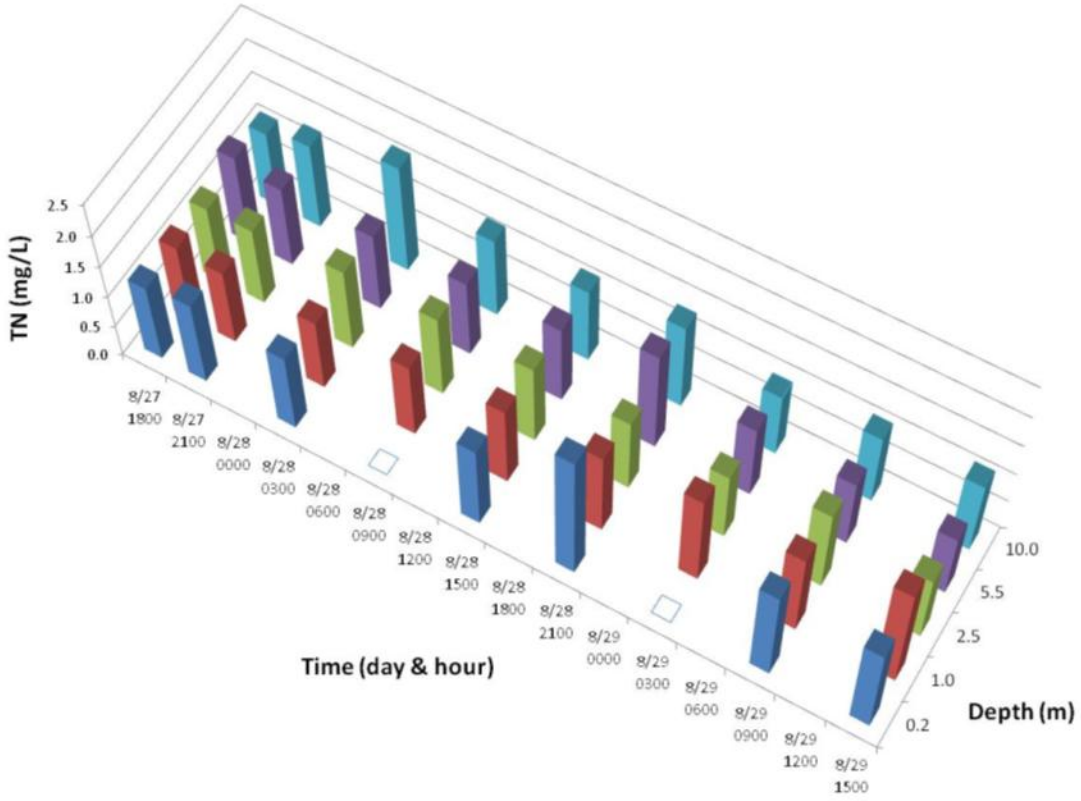


Table C-8. Nitrate and Nitrite (NO3+NO2)-N analyses results (mg/l) at 0.2, 1.0, 2.5, 5.5, and 10.0 meters: 8/27/2012 18:00 to 8/29/2012 15:00

	Depth (m)				
Time	**0.2**	**1.0**	**2.5**	**5.5**	**10.0**
8/27 1800	0.265	0.269	0.289	0.273	0.369
8/27 2100	0.279	0.269	0.256	0.270	0.413
8/28 0000	-	-	-	-	-
8/28 0300	0.235	0.228	0.198	0.228	0.426
8/28 0600	-	-	-	-	-
8/28 0900	NS	0.233	0.191	0.238	0.247
8/28 1200	-	-	-	-	-
8/28 1500	0.153	0.200	0.211	0.217	0.249
8/28 1800	-	-	-	-	-
8/28 2100	0.102	0.082	0.092	0.068	0.182
8/29 0000	-	-	-	-	-
8/29 0300	NS	0.068	0.094	0.102	0.366
8/29 0600	-	-	-	-	-
8/29 0900	0.080	0.089	0.108	0.117	0.380
8/29 1200	-	-	-	-	-
8/29 1500	0.056	0.051	0.116	0.263	0.408

Figure C-10. Nitrate and Nitrite (NO3+NO2)-N analyses results (mg/l) at 0.2, 1.0, 2.5, 5.5, and 10.0 meters: 8/27/2012 18:00 to 8/29/2012 15:00

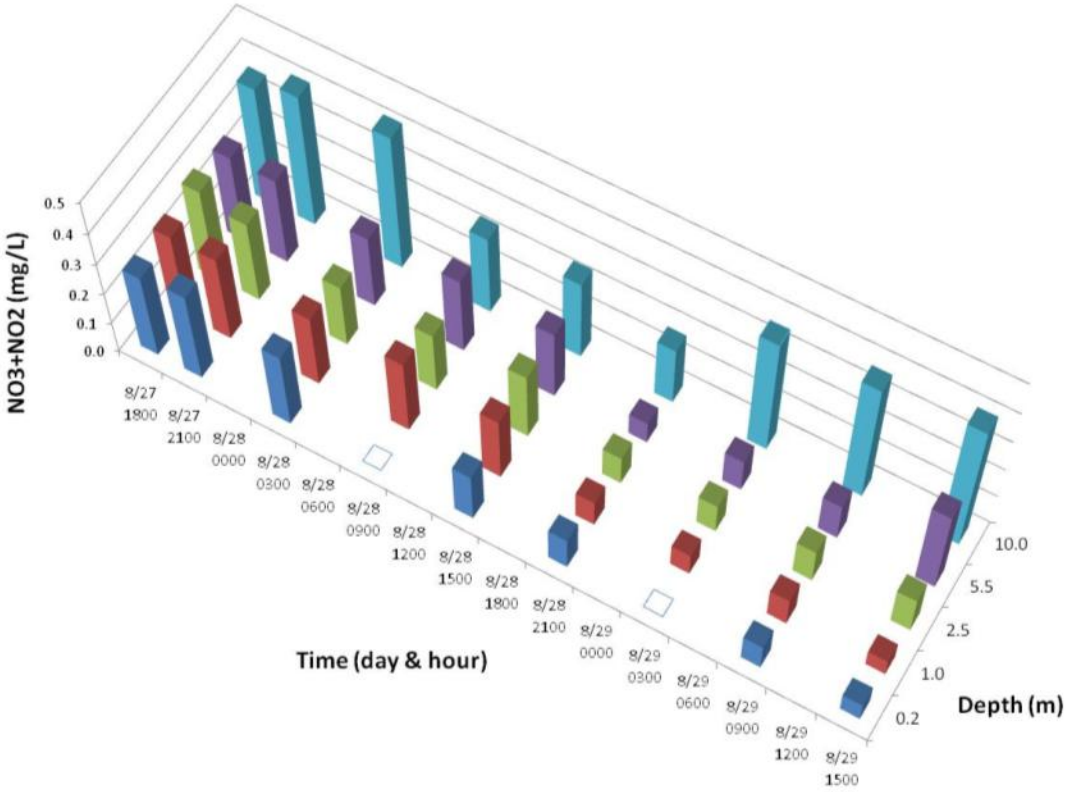


Table C-9. Ammonia (NH4-N) analyses results (mg/l) at 0.2, 1.0, 2.5, 5.5, and 10.0 meters: 8/27/2012 18:00 to 8/29/2012 15:00

	Depth (m)				
Time	**0.2**	**1.0**	**2.5**	**5.5**	**10.0**
8/27 1800	0.040	0.030	0.023	0.016	0.013
8/27 2100	0.061	0.035	0.006	0.023	0.078
8/28 0000	-	-	-	-	-
8/28 0300	0.061	0.030	0.009	0.027	0.109
8/28 0600	-	-	-	-	-
8/28 0900	NS	0.021	0.018	0.048	0.028
8/28 1200	-	-	-	-	-
8/28 1500	0.017	0.018	0.032	0.014	0.051
8/28 1800	-	-	-	-	-
8/28 2100	0.011	0.010	0.011	0.006	0.006
8/29 0000	-	-	-	-	-
8/29 0300	NS	0.008	0.011	0.012	0.075
8/29 0600	-	-	-	-	-
8/29 0900	0.003	0.088	0.018	0.016	0.103
8/29 1200	-	-	-	-	-
8/29 1500	0.008	0.004	0.013	0.057	0.102

Figure C-11. Ammonia (NH4-N) analyses results (mg/l) at 0.2, 1.0, 2.5, 5.5, and 10.0 meters: 8/27/2012 18:00 to 8/29/2012 15:00

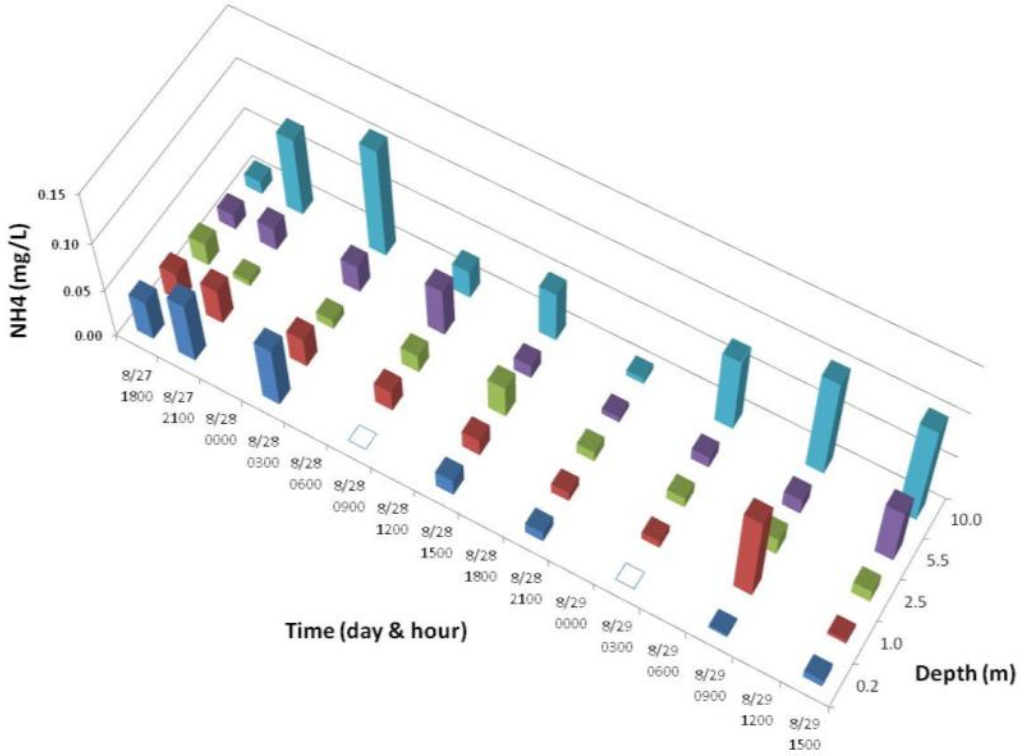


Table C-10. Total Phosphorus (TP) analyses results (mg/l) at 0.2, 1.0, 2.5, 5.5, and 10.0 meters: 8/27/2012 18:00 to 8/29/2012 15:00

	Depth (m)				
Time	**0.2**	**1.0**	**2.5**	**5.5**	**10.0**
8/27 1800	0.187	0.237	0.191	0.246	0.264
8/27 2100	0.250	0.191	0.191	0.210	0.330
8/28 0000	-	-	-	-	-
8/28 0300	0.191	0.182	0.250	0.178	0.268
8/28 0600	-	-	-	-	-
8/28 0900	NS	0.223	0.205	0.228	0.187
8/28 1200	-	-	-	-	-
8/28 1500	0.191	0.210	0.241	0.191	0.178
8/28 1800	-	-	-	-	-
8/28 2100	0.268	0.201	0.182	0.219	0.223
8/29 0000	-	-	-	-	-
8/29 0300	NS	0.228	0.178	0.187	0.205
8/29 0600	-	-	-	-	-
8/29 0900	0.237	0.196	0.246	0.178	0.223
8/29 1200	-	-	-	-	-
8/29 1500	0.201	0.259	0.214	0.187	0.201

Figure C-12. Total Phosphorus (TP) analyses results (mg/l) at 0.2, 1.0, 2.5, 5.5, and 10.0 meters: 8/27/2012 18:00 to 8/29/2012 15:00

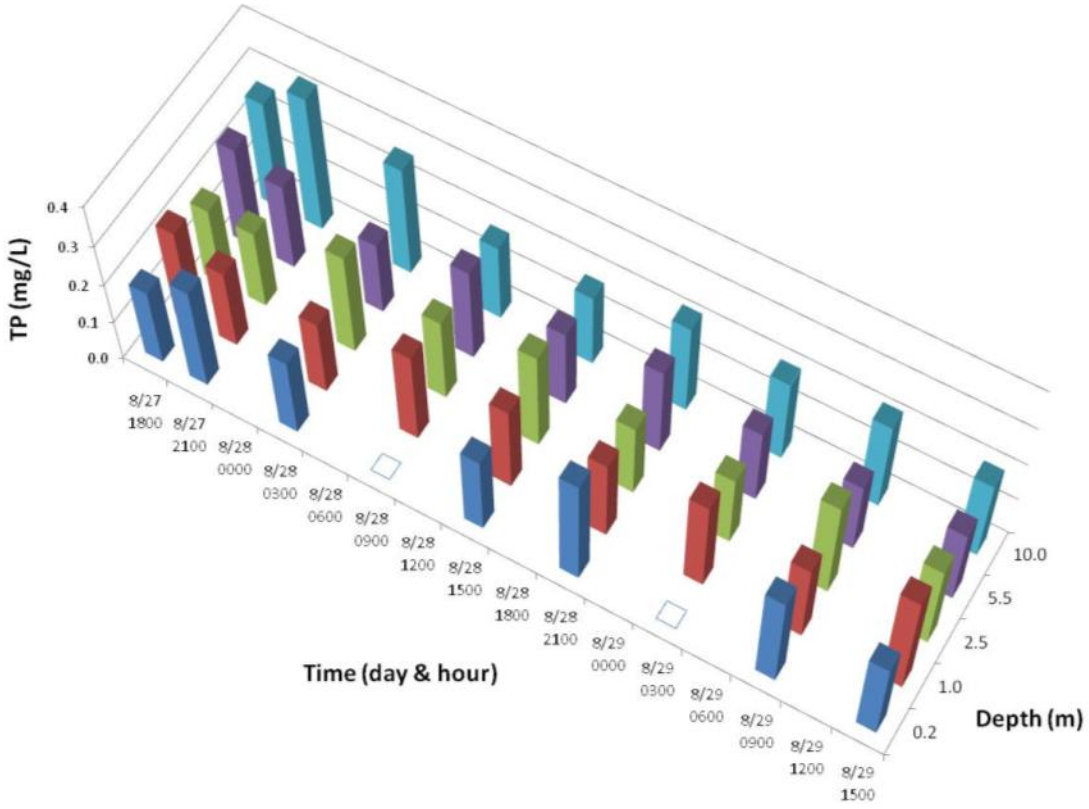


Table C-11. Orthophosphate (PO4-P) analyses results (mg/l) at 0.2, 1.0, 2.5, 5.5, and 10.0 meters: 8/27/2012 18:00 to 8/29/2012 15:00

	Depth (m)				
Time	**0.2**	**1.0**	**2.5**	**5.5**	**10.0**
8/27 1800	0.109	0.108	0.109	0.108	0.137
8/27 2100	0.109	0.109	0.102	0.108	0.239
8/28 0000	-	-	-	-	-
8/28 0300	0.103	0.103	0.103	0.102	0.163
8/28 0600	-	-	-	-	-
8/28 0900	NS	0.103	0.103	0.109	0.108
8/28 1200	-	-	-	-	-
8/28 1500	0.094	0.095	0.097	0.100	0.108
8/28 1800	-	-	-	-	-
8/28 2100	0.114	0.080	0.083	0.078	0.095
8/29 0000	-	-	-	-	-
8/29 0300	NS	0.083	0.088	0.086	0.152
8/29 0600	-	-	-	-	-
8/29 0900	0.088	0.088	0.086	0.088	0.155
8/29 1200	-	-	-	-	-
8/29 1500	0.080	0.080	0.091	0.114	0.152

Figure C-13. Orthophosphate (PO4-P) analyses results (mg/l) at 0.2, 1.0, 2.5, 5.5, and 10.0 meters: 8/27/2012 18:00 to 8/29/2012 15:00

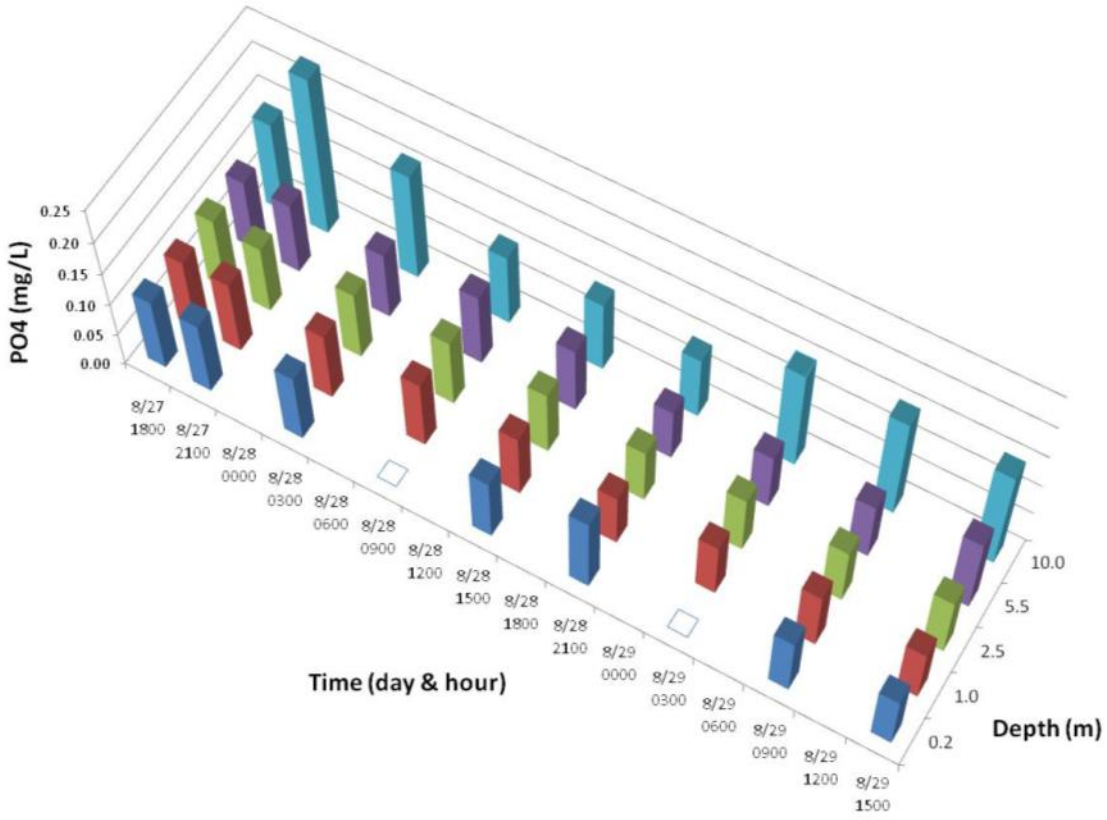
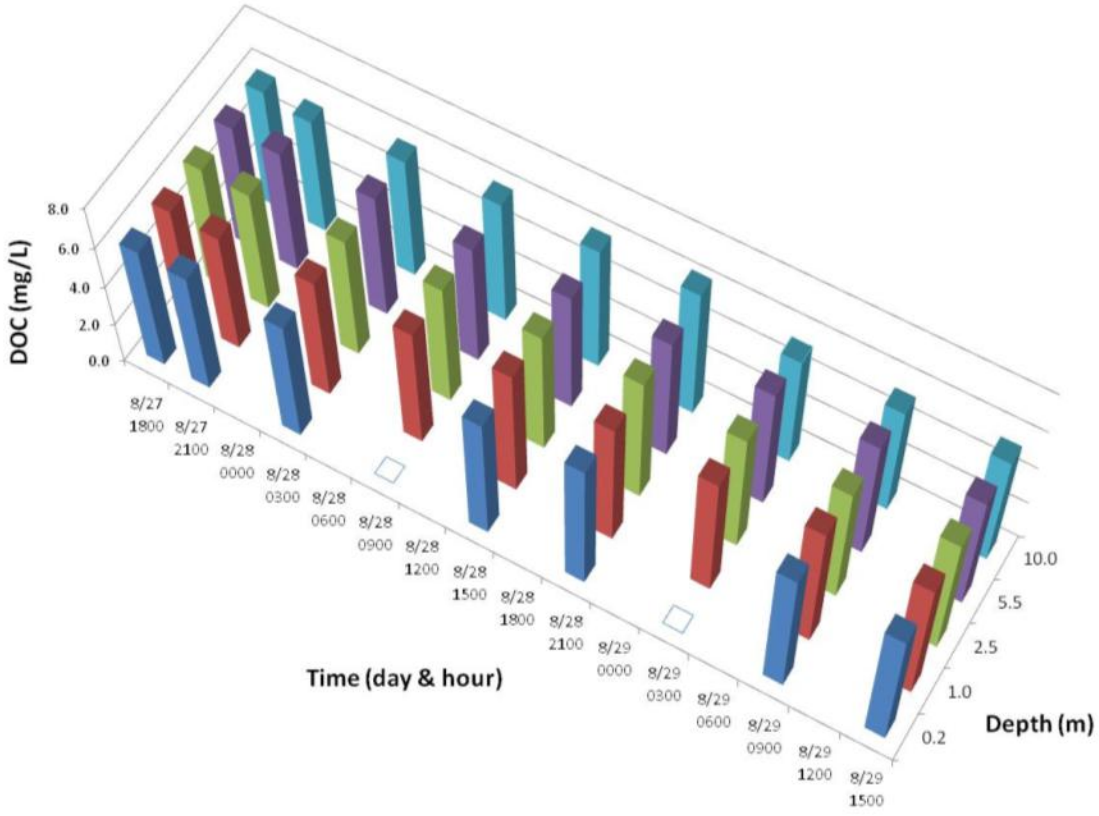


Table C-12. Dissolved Organic Carbon (DOC) analyses results (mg/l) at 0.2, 1.0, 2.5, 5.5, and 10.0 meters: 8/27/2012 18:00 to 8/29/2012 15:00

	Depth (m)				
Time	**0.2**	**1.0**	**2.5**	**5.5**	**10.0**
8/27 1800	5.977	5.946	6.001	6.066	5.898
8/27 2100	5.844	5.797	5.893	5.935	5.544
8/28 0000	-	-	-	-	-
8/28 0300	5.870	5.960	5.937	6.032	5.854
8/28 0600	-	-	-	-	-
8/28 0900	NS	5.865	5.969	5.867	6.044
8/28 1200	-	-	-	-	-
8/28 1500	6.058	6.295	6.045	5.870	6.091
8/28 1800	-	-	-	-	-
8/28 2100	6.387	6.181	6.265	6.055	6.381
8/29 0000	-	-	-	-	-
8/29 0300	NS	6.064	5.989	6.044	5.443
8/29 0600	-	-	-	-	-
8/29 0900	6.311	6.282	5.905	5.995	5.425
8/29 1200	-	-	-	-	-
8/29 1500	6.011	6.165	6.061	5.818	5.535

Figure C-14. Dissolved Organic Carbon (DOC) analyses results (mg/l) at 0.2, 1.0, 2.5, 5.5, and 10.0 meters: 8/27/2012 18:00 to 8/29/2012 15:00



C.4 Discussion

The results presented above indicate that cyanobacteria are distributed vertically in the water column in a manner that may be important in determining the appropriate placement and operation of the Iron Gate intake cover. The consistently higher concentrations at the shallower, near-surface sample depths suggest that vertical segregation of algae at or near the surface of the water column is occurring.

The observed vertical segregation of cyanobacteria at or near the surface is not surprising, but is an important finding to verify that the algae mostly occur in the near-surface layer of Iron Gate Reservoir. This is the layer of reservoir water whose entrainment the intake cover is intended to substantially reduce. Previous studies have shown that cyanobacteria colonies, in particular colonies of MSAE, respond to changes in light and nutrient conditions by adjusting their buoyancy to alter their position in the water column (Okada and Aiba, 1983; Reynolds *et al*., 1987; Wallace *et al*., 2000). Buoyancy regulation in response to environmental conditions has also been observed in APFA colonies (Rabouille *et al*., 2005; Chu *et al*., 2007). To a lesser extent, vertical distribution of PSAB in the water column has also been indirectly studied (Gervais *et al*., 2003). In general, cyanobacteria have a competitive advantage (due to abilities like buoyancy regulation) to move or distribute themselves vertically in the water column, notably at or near the water surface, in response to temperature, to satisfy nutrient requirements (Brookes and Ganf, 2001), and attain desirable light conditions (Visser *et al.*, 1997). Moisander (2009) found

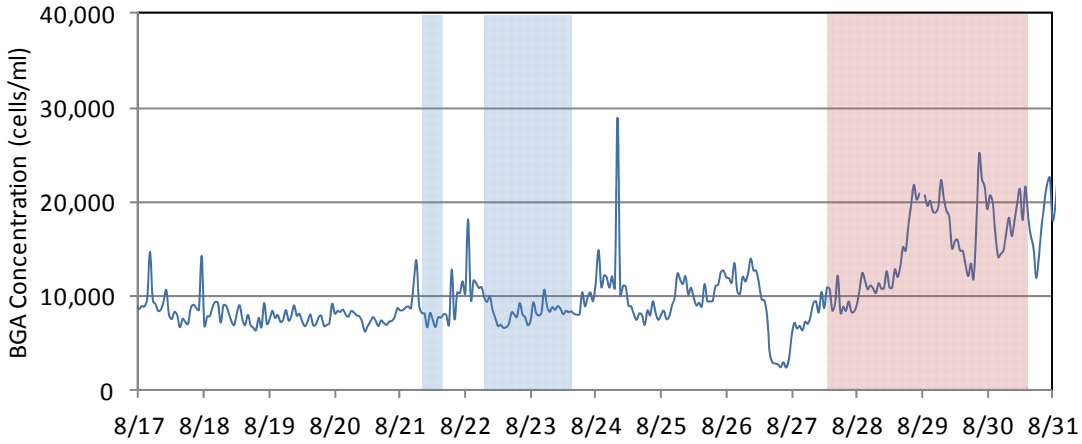
that MSAE exhibited vertical movement over a diel period in Iron Gate Reservoir that appeared to be a response to such conditions.

Changes in total algal mass at the sampling site (beyond what could be attributed to algal growth alone) suggests that there is also lateral exchange (i.e., wash-in) of algae to the sampling site from elsewhere in the reservoir. Lateral spatial variability is consistent with the highly heterogeneous nature of cyanobacteria (Reynolds *et al*., 1987; Moisander *et al*., 2009), and indicates a dynamic environment. Spatial and temporal heterogeneity of algal populations in lakes and reservoirs is widely reported in the literature, and which can result from a wide variety of factors (Wetzel, 2001; Horne and Goldman, 1994 Reynolds *et al*., 1987). One of the principal factors that likely explains spatial variability such as observed in this study is advection into and from the study site. Comparing data at distinct times for any one of the collected constituents illustrates this process. For example, average chlorophyll *a* concentration at 0600 and 1800 on August 28 is 12.6 ppb and 34.2 ppb, respectively. This nearly threefold increase is most likely due to advection into the sampling area due to large- or small-scale reservoir circulation due to the effects of reservoir inflows and operations, thermal loading and density driven currents, wind loading on the reservoir surface, or other factors. Further, the study location—adjacent to the reservoir spillway in the shallow northwest corner of the reservoir—may also contribute to advection processes.

The results of this study include the following observations from the data collected:

- The observed vertical segregation of cyanobacteria at or near the surface is an important finding to verify that the algae mostly occur in the near-surface layer of Iron Gate Reservoir. This is the layer of reservoir water whose entrainment the intake cover is intended to substantially reduce.
- Spatial and temporal trends in APFA and PSAB in Iron Gate Reservoir were consistent with phycocyanin and chlorophyll *a* results.
- Most primary production during the 2012 study was in water depths of less than 10 m. This was consistent with data provided by Lincoff (pers. comm.). Considerably more algal biomass and generally lower inorganic nutrients were observed in near-surface waters.
- The algae counts, phycocyanin, and chlorophyll *a* data all illustrate a notable upward trend in biomass starting approximately mid-day on August 28. Interestingly, this increase is also present in the phyocyanin probe maintained by PacifiCorp at the long term sampling locations (Figure C-16). These observations are consistent with larger scale in-reservoir processes discussed above.

Figure C-16. Downstream phycocyanin probe concentrations for week 1 (8/20-8/23) and week 2 (8/27-8/30). Blue and red boxes denote week 1 and week 2 cover deployment periods, respectively.



C.5 Conclusions and Recommendations

Experiment results illustrate the dynamic nature of algal biomass vertical distribution within the water column. These observations are consistent with previous studies that have described the vertical migration and buoyancy regulation capabilities of cyanobacteria in response to light and nutrient conditions. Nevertheless, the factors affecting the dynamics of algal vertical migration in Iron Gate Reservoir are difficult to determine based on a two-day experiment.

The principal recommendation from this experiment is to consider a vertical migration study extended over a longer duration. As described above, meteorological and thermal conditions (e.g., stratification) are important factors that affect the vertical distribution of algae in the water column. An extended period of study would give a more comprehensive picture of shorter- and longer-term variations in reservoir algal dynamics, particularly in the vicinity of the intake. Prior to such a study, review of location and vertical sampling depths should be considered

C.6 References

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Personal Communications

Andy Lincoff, July 27, 2012 (email communication with vertical sonde profile data)