Final Report

Water Quality Monitoring During Testing of Solar-Powered Circulators in Copco Reservoir, Klamath Hydroelectric Project

Prepared by

Ken Carlson (CH2M HILL)

Kaylea Foster (PacifiCorp)

Prepared for

PacifiCorp Energy

Portland, Oregon

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CH2MHILL

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Executive Summary

This report describes the results of water quality monitoring in Copco reservoir during deployment of 12 solar-powered circulators (SolarBee™ Model SB10000v12) in the upper portion of Copco reservoir from April through October 2008. The main objective of the monitoring was to assess whether the circulators act to improve water quality in the "treated" upper portion of Copco reservoir relative to other "untreated" areas, particularly in reducing blooms and accumulations of cyanobacteria (blue-green algae) such as *Microcystis aeruginosa* (MSAE) and *Aphanizomenon flos-aquae* (APFA). The concept behind the use of the circulators is to create enough mixing and agitation in surface layers of the reservoir to reduce cyanobacteria by reducing their light exposure and disrupting the generally quiescent conditions that may contribute to cyanobacteria bloom formation.

The monitoring data indicates that the solar-powered circulators did not act to improve water quality, and in particular did not act to reduce cyanobacteria blooms. The monitoring data showed that algae production and densities generally remained high throughout the reservoir during the monitoring period. For example, among all sites, the highest total phytoplankton densities (algal units per mL), total phytoplankton biovolumes (mm^3 per mL), and chlorophyll *a* concentrations (µg/L) were observed at Sites 2 and 3 within the solar-powered circulators treatment area.

The phytoplankton taxa data presents no evidence that the solar-powered circulators acted to alter the presence or dominance of APHA and MSAE during the study period. APFA was the predominant phytoplankton taxa during 2008 circulator testing, ranking first among taxa at each of the five sites in both density and biovolume. The highest values of MSAE density and highest concentrations of microcystin (a toxin produced by certain cyanobacteria, notably MSAE) were observed at Sites 2 and 3, within the solar-powered circulators treatment area.

At the outset of this study, it was reasonable to assume that the circulator units would reduce cyanobacteria levels (and other water quality conditions related to algae growth) in the upper portion of the reservoir in the vicinity of the circulators to levels below those occurring at the "untreated" sites in the lower portion of the reservoir. A complicating factor in the interpretation of the 2008 monitoring results is the likely *a priori* existence of a longitudinal gradient of water quality conditions through the reservoir. Reservoirs exhibit a marked degree of spatial heterogeneity in phytoplankton productivity and biomass due to longitudinal gradients in reservoir morphology, water residence time, nutrients, suspended solids, and light availability (Thornton et al. 1990).

The 2008 monitoring results indicate that the solar-powered circulators did not act to improve water quality, and that difference in water quality conditions between sites can be explained on the basis of reservoir zonation and spatial heterogeneity. Even if it is assumed that the solar-powered circulators provided horizontal laminar flow and vertical circulation upward throughout this mixed zone (at the depth of the circulator intake), such mixing was evidently overridden by the stronger influence of other reservoir processes, such as captured in the reservoir zonation concept.

Introduction

Purpose and Objective

This report describes the results of water quality monitoring in Copco reservoir during testing of solar-powered circulators from April through October 2008. Copco reservoir is located on the Klamath River between approximately River Mile (RM) 198 and 204 in Siskiyou County, northern California near the Oregon-California border. The reservoir is formed by impoundment at Copco No. 1 dam, which was completed in 1918, and is owned and operated by PacifiCorp as part of the Klamath Hydroelectric Project (Project).

The objectives of the testing of solar-powered circulators and associated water quality monitoring were to: (1) evaluate operational consistency and reliability in field conditions, and (2) assess water quality improvement in the "treated" reservoir area relative to other "untreated" area, particularly in reducing blooms and accumulations of cyanobacteria (blue-green algae) such as *Microcystis aeruginosa* (MSAE) and *Aphanizomenon flos-aquae* (APFA). Such testing was needed to gain better reliability and effectiveness information prior to potential scale-up to more extensive implementation of solar-powered circulators in Copco reservoir, as well as neighboring Iron Gate reservoir (located between approximately RM 190.5 and 196.5).

Twelve solar-powered circulators (SolarBee™ Model SB10000v12) were installed in the upper portion of Copco reservoir during the seven-month (April – October) deployment period in 2008. Water quality was monitored before, during, and after deployment of the circulators, and included in-situ sampling of water temperature, dissolved oxygen (DO), pH, water clarity (i.e., Secchi depth), chlorophyll-*a*, phytoplankton composition, and microcystin (a toxin that can be produced by certain cyanobacteria). Monitoring occurred at five sites in the reservoir located to assess the effectiveness and extent of the circulators' lateral mixing and circulation.

Background

During 2008, PacifiCorp continued implementation of Reservoir Management Plan (RMP) actions to improve water quality in Copco and Iron Gate reservoirs (PacifiCorp 2008). The RMP is evaluating the effectiveness and feasibility of several technologies and measures to improve water quality conditions in the reservoirs that have been impacted by significant loads of organic and nutrient matter originating from upstream of the Project. Copco and Iron Gate reservoirs are nutrient-enriched (eutrophic) due to large inflow loads of nutrient and organic matter from upstream sources, notably Upper Klamath Lake (UKL).

In general, eutrophic lakes strongly stratify and typically experience surface algae blooms during summer (Thornton et al. 1990, Holdren et al. 2001, Cooke et al. 2005). To improve these water quality conditions, PacifiCorp is assessing various technologies. One such technology is circulation, a technique intended to improve water quality by mixing the cyanobacteria (blue-green algae) out of the euphotic zone (i.e., the surface zones of reservoirs that provide sufficient light for algal growth). The concept behind the use of surface (or epilimnetic) circulation is to create enough surface mixing and agitation in surface layers of the reservoirs to reduce cyanobacteria by reducing their light exposure and disrupting the generally quiescent conditions that may contribute to bloom formation.

A popular approach used elsewhere has been solar-powered water "circulators" (e.g., SolarBee™, Pond Doctor™) that promote circulation of surface water of the reservoir at the rate of up to 10,000 gallons per minute. According to manufacturers research, these solar-powered water circulators have proven to be effective in controlling cyanobacteria blooms (including blooms of MSAE and APFA) in over 200 water bodies worldwide (including over 80 municipal raw water storage reservoirs).

In 2007, PacifiCorp conducted a pilot demonstration project of solar-powered water circulators in Copco reservoir as a part of its RMP. PacifiCorp initially retained Pond Doctor™ to install three solar-powered circulation units in Mallard Cove in Copco reservoir. These three units were installed in Mallard Cove in June 2007, but were subsequently removed in July 2007 due to inconsistent and unreliable function and operation. Rather than abort the pilot demonstration project entirely, PacifiCorp contacted SolarBee™ who had one solar-powered circulation unit available for installation in Copco reservoir. SolarBee subsequently installed the unit (SolarBee™ SB10000v12) in Beaver Cove in Copco reservoir. Because of its size and morphometry, Beaver Cove (approximately 16 acres, maximum depth about 30 ft) was considered more appropriate than Mallard Cove for a one-unit deployment.

The SolarBee™ unit operated continuously and reliably in field conditions experienced at Beaver Cove throughout the deployment period from August 4, 2007 to October 3, 2007. Field monitoring during the deployment period suggested improvement in some water quality conditions in Beaver Cove relative to other untreated areas. However, because of the limited testing that occurred in 2007, PacifiCorp decided to conduct further testing of circulators in 2008 using additional units for a more extended deployment period to gain better reliability and effectiveness information.

Methods

Installation of Circulators

Twelve solar-powered circulators (SolarBee™ Model SB10000v12) were installed in the upper portion of Copco reservoir on April 17, 2008 and were operated continuously until they were removed on October 22, 2008. Locations of the 12 circulators are shown in Figure 1, with latitude and longitude coordinates listed in Table 1.

The Model SB10000v12 operates 24 hours per day on solar-supplied power, and is designed to establish a horizontal near-laminar flow, which moves radially outward from the unit's outflow at the surface of the reservoir, and radially inward at the depth of the unit's intake. The unit intakes for the application in Copco reservoir were at a depth of 8 feet (ft). The horizontal laminar flow away from the unit at the surface, together with the horizontal laminar flow toward the unit at the depth of the intake, causes a vertical circulation upward throughout this mixed zone.

The manufacturer indicates that at full speed the impeller on the Model SB10000v12 draws 3,000 gallons per minute (gpm) of direct flow upward through the 36-inch diameter intake hose. The impeller, almost 3 feet in diameter, has a combination of both axial flow and positive displacement characteristics. It rotates at up to 100 rotations per minute (rpm) and lifts entrained water about 0.2 inches above the water surface. Due to the physical configuration of the machine, water flows 360-degrees radially-outward from the unit across the water surface.

The manufacturer indicates that the horsepower (hp) required to create the direct flow of water is 0.032 hp (24 watts). The three solar panels on the Model SB10000v12 are rated at 80 watts nominal output and about 68 watts of field-usable output. The equivalent of 1.5 solar panels, or 102 usable watts, are always exposed to the sun due to the triangular mounting configuration, so extra power is supplied to the battery during daylight hours to allow for 24-hour-per-day operation.

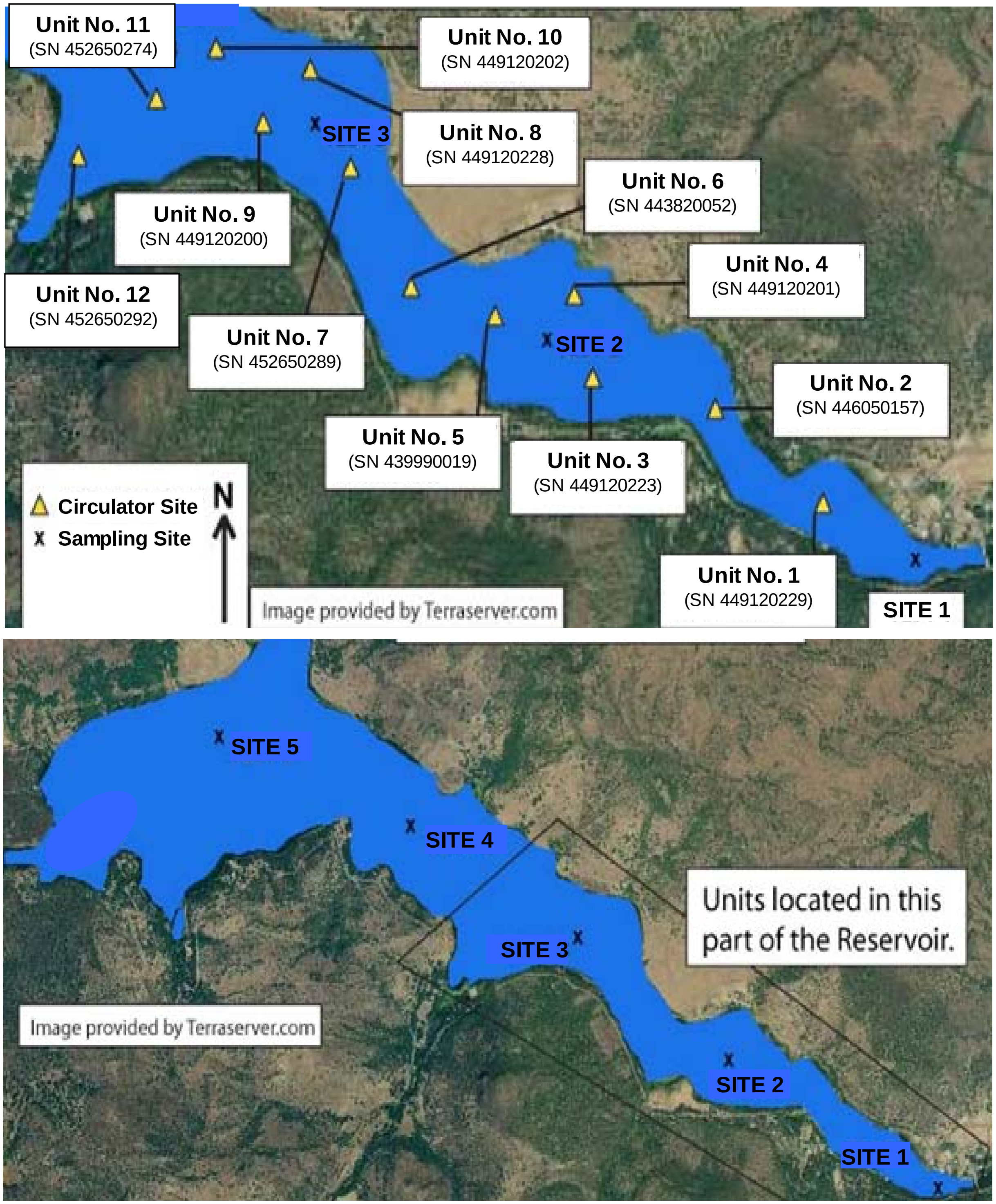

Figure 1. Locations of the 12 solar-powered circulators installed in the upper portion of Copco reservoir (bottom plot), and water quality monitoring sites (bottom plot) during 2008 circulator testing.

Table 1. Latitude and Longitude Coordinates, Intake Depth, and Total Water Depth of the 12 Solar-Powered Circulator Sites Shown in Figure 1

Unit Number	Unit Serial Number	Latitude	Longitude	Depth to Unit Intake (ft)	Total Water Depth (ft)
1	449120229	41.96537	-122.26897	8.0	15.4
2	446059157	41.96783	-122.27347	8.0	23.3
3	449120223	41.96873	-122.27877	8.0	17.0
4	449120201	41.97118	-122.27861	8.0	12.2
5	439990019	41.97027	-122.28204	8.0	23.0
6	443820052	41.97178	-122.28617	8.0	29.5
7	452650289	41.97434	-122.28908	8.0	37.8
8	449120228	41.97728	-122.29048	8.0	23.3
9	449120200	41.97583	-122.29338	8.0	13.7
10	449120202	41.97759	-122.29360	8.0	39.2
11	452650274	41.97626	-122.29606	8.0	22.5
12	452650292	41.97472	-122.29916	8.0	11.2

Monitoring Approach

A spatial approach to monitoring was used in which water quality conditions near the circulator units were compared with conditions at greater distances from the devices (i.e., “untreated” sites). Using this approach, the effectiveness of the circulators in producing an effect was evaluated by comparing conditions in “treated” areas near the circulators with measurements made farther away at “untreated” sites.

Five monitoring sites were established along the length of Copco reservoir as shown in Figure 1. Site 1 was located at the upper end of the reservoir near the inflow from the Klamath River. Sites 2 and 3 were located directly within the areas where the 12 circulators were positioned, and so were considered to represent the “treated” zone of the reservoir. Sites 4 and 5 were located in the lower portion of the reservoir outside of the treated zone, and were considered representative of the “untreated” portion of the reservoir.

Sites 1 and 2, the most upstream locations, were approximately 20 and 26 feet deep, respectively. Being near the river’s inlet at the upper end of the reservoir, Site 1 had perceptible surface water current. Sites 3, 4, and 5 were approximately 60 to 75 feet deep. Although sites were located via GPS, current or wind often caused the boat to drift from the exact locations of the monitoring sites, resulting in some variability in profile depths at individual sites during the study period.

A temporal approach to monitoring that compared water quality conditions during years before versus after the installation of circulator units would have been desirable. However, multiple years of monitoring with circulator units in operation would be needed for a valid temporal comparison. This consideration made a temporal approach infeasible for this study.

The assumption in using the spatial approach to monitoring is that the circulator units would reduce cyanobacteria levels (and improve other water quality conditions related to algae growth, like pH and water clarity) in the upper portion of the reservoir to levels below those occurring in the untreated sites. A complicating factor in the spatial approach to monitoring is the likely *a priori* existence of a longitudinal gradient of water quality conditions through the reservoir. Distinct physical, biological, and chemical gradients can develop between the reservoir inflow and its point of outflow at the dam (Thornton et al. 1990). In general, it is expected that these gradients would result in higher concentrations of soluble nutrients and lower concentrations of algae in the upper end of the reservoir with a progressive decrease in nutrients and increase in algae longitudinally down the reservoir. The potential gradient effects are discussed further in the *Results* section of this report.

Monitoring Methods

PacifiCorp conducted monitoring every two weeks from June through October 2008 at the five sites in Copco reservoir. Monitoring included in-situ sampling of water temperature, DO, pH, specific conductance, water clarity (i.e., Secchi depth), chlorophyll-*a*, phytoplankton, and microcystin.

Measurements of water temperature (°C), DO (mg/L and percent saturation), pH (units), and specific conductance (µmhos) were collected with a YSI Datasonde along vertical (depth) profiles at each of the sites. Measurements were taken at the surface (approximately 0.5 m), and then at one-meter intervals until the reservoir bed was reached, or the 23-m Datasonde cable was fully extended.

Chlorophyll-*a*, phytoplankton, and microcystin were analyzed in the laboratory from water samples collected at each site using grab and integrated techniques. The grab samples were collected at a depth of 0.5 m with a Kemmerer sampler. The Kemmerer sampler is a cylindrical sampler that can be opened at both ends, and lowered to the desired depth in the water column, where the ends can be closed by the release of a messenger. Upon retrieval, samples were drawn from the Kemmerer sampler into sample bottles for laboratory analysis.

The vertically-integrated samples were collected from the surface to a depth of 8 m (or 4 m for sites that had a maximum depth less than 8 m) with an integrated hose sampler. The hose sampler consists of clear, flexible lab-grade tubing with a weighted end that is lowered to a depth of 8 m. The hose is clamped at the surface and the weighted end is drawn to the surface, retaining within it a thin column of water from the depth range sampled. Upon retrieval, the contents of the tube were emptied into a churn splitter, which is specifically designed to composite the collected water and allow dispensing of homogenous aliquots of the sampled water into sample bottles for laboratory analysis.

Water clarity was measured with a standard 23-cm Secchi disk. The disk was lowered gradually to a depth at which the disk just lost visibility to observers at the surface. At that point, the depth (i.e., Secchi depth) was recorded to the nearest 0.1 m.

Samples for phytoplankton speciation, density, and biovolume were preserved in Lugol's solution and sent to Aquatic Analysts in White Salmon, Washington for analysis. The laboratory analysis of phytoplankton speciation and density was done on prepared microscope slides of filtered samples using phase contrast microscopy. Species were counted as algal units of cell, filament, or colony depending on the natural growth form of the species. BGA species were enumerated as individual cells. Algal forms were identified to species or otherwise to the lowest practicable taxonomic level. Biovolumes were estimated by multiplying the cell counts by the average geometric dimensions of the cells for a given phytoplankton taxa.

Samples for determination of chlorophyll-*a* and microcystin toxin were placed in a cooler on ice and shipped to CH2M HILL Applied Sciences Laboratory in Corvallis, Oregon. The chlorophyll-*a* samples were analyzed using Standard Method 10200H.3 (APHA 2008). The Method Reporting Limit[1] (MRL) was 0.02 µg/L or parts per billion (ppb). The microcystin samples were analyzed using the competitive Enzyme-Linked ImmunoSorbent Assay (ELISA) method based on the EnviroLogix QuantiPlate Kit for Microcystins. The MRL was 0.16 µg/L or parts per billion (ppb). This test method does not distinguish between the specific microcystin congeners, but detects their presence to differing degrees. That is, ELISA test results yield one value as the sum of all measurable microcystin variants or congeners.

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[1] The Method Reporting Limit (MRL) is the lowest amount of an analyte in a sample that can be quantitatively determined with stated, acceptable precision and accuracy under stated analytical conditions (i.e. the lower limit of quantitation). Therefore, analyses are calibrated to the MRL, or lower. To take into account day-to-day fluctuations in instrument sensitivity, analyst performance, and other factors, the MRL is established at three times the MDL (or greater).

Results and Discussion

Water Temperature

Water temperature was not expected to be influenced by the twelve solar-powered circulators, as circulators were designed to move water only in approximately the top 2.5 m (about 8 ft) of Copco reservoir (i.e., the approximate depth of the photic zone[2] for algae production), while the remainder of the reservoir's deeper vertical profile continues to remain thermally stratified. Water temperatures within this surface layer depth are relatively homogenous due to mixing above the thermocline caused by wind and solar radiation.

Water temperature profiles are displayed in Figures 1 and 2 as isopleth plots for the entire depth of each site. These plots were created using interpolation, so they do not display the variability in maximum depths encountered within sites. The value of these isopleth plots is that they clearly display temporal trends at each site, whereas profile scatter plots can become cumbersome when attempting to display and compare data sets over time. Temperature profile plots are provided in Appendix A.

Site 1 (Figure 2, top plot) was well-mixed and exhibited little change in temperature with depth. Temperatures were between 20°C and 21°C from early July to early August, gradually fell to 17°C during August, and then remained steady at 17°C in September.

Temperatures at Site 2 (Figure 2, bottom plot), Site 3 (Figure 3, top plot), and Site 4 (Figure 3, bottom plot) displayed trends that were comparable to Site 1, although approximately 1°C to 2°C warmer at all monitoring events. Similar temperatures were observed among these three sites. All showed evidence of weak stratification between July and August, which became isothermal with depth in mid-September.

Site 5 was thermally stratified through early September, with a pronounced thermocline at a depth of 15 to 20 m (50 to 65 ft). Surface temperatures above the thermocline were similar to previous sites during the period of stratification, but deeper waters below the thermocline were markedly cooler. Site 5 became isothermal with depth in mid-September, with water temperatures similar to the other sites.

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[2] The photic zone is the depth of the water in the reservoir that is exposed to sufficient sunlight for photosynthesis to occur. The depth of the photic zone extends from the atmosphere-water interface downwards to a depth where light intensity falls to 1 percent of that at the surface, so its thickness depends on the extent of light attenuation in the water column.

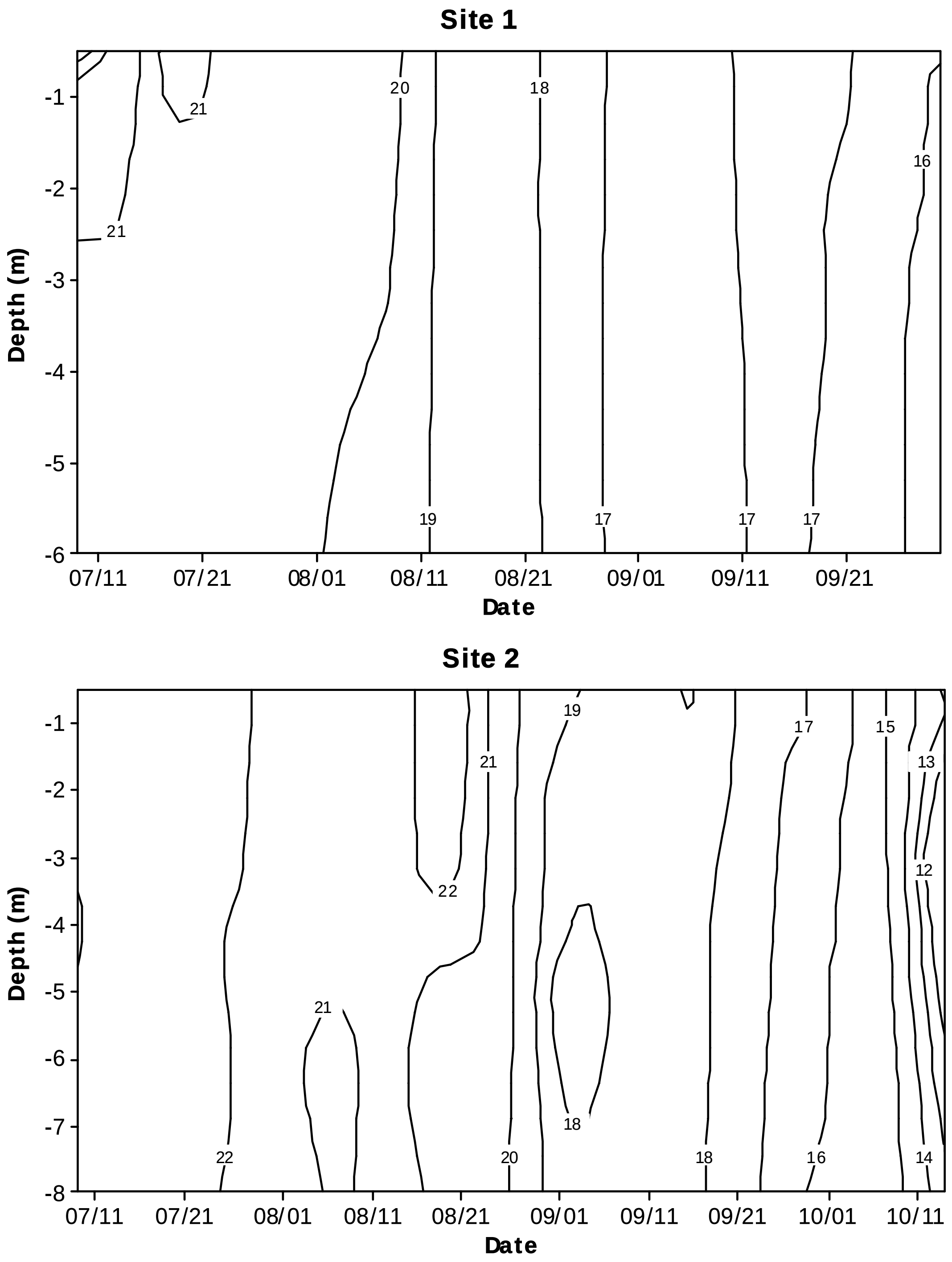

Figure 2. Isopleths of water temperature (°C) at Site 1 (top plot) and Site 2 (bottom plot) in Copco reservoir during 2008 circulator testing.

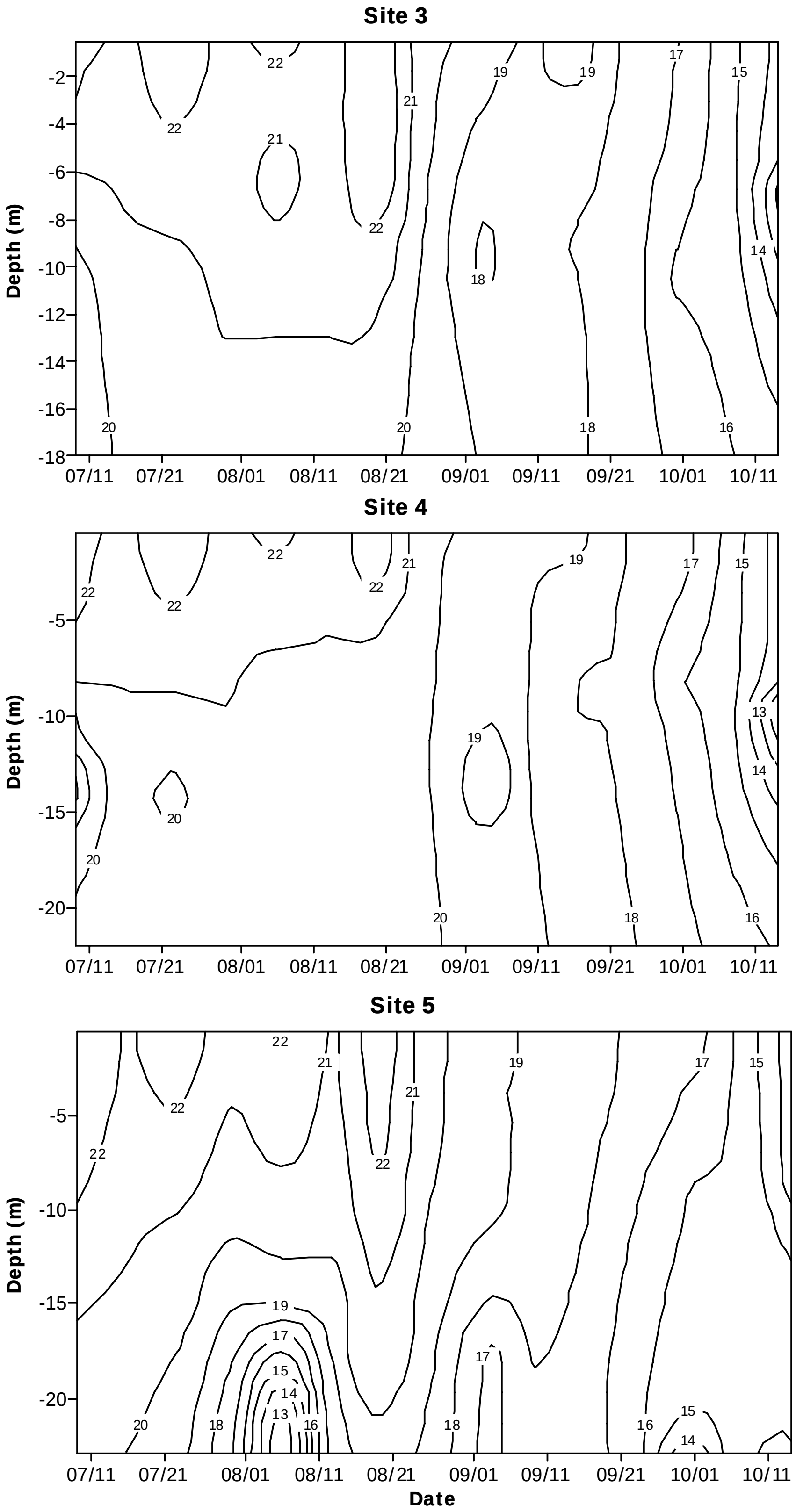

Figure 3. Isopleths of water temperature (°C) at Site 3 (top plot), Site 4 (middle plot), and Site 5 (bottom plot) in Copco reservoir during 2008 circulator testing.

Dissolved Oxygen

Dissolved oxygen measurements were made within the top 6 m (about 20 ft at each site). See Appendix B for the complete data set. Site 1, which can be viewed as an indicator of upstream conditions entering the reservoir, showed vertically-consistent dissolved oxygen concentrations of 8 to 13 mg/L throughout the summer with a peak in early September of 13 mg/L (Figure 4, top plot).

Dissolved oxygen concentrations at Sites 2, 3, 4, and 5 reflected the effects of primary production in the reservoir. Photosynthesis from algae during blooms can contribute to increased dissolved oxygen in the water column, particularly in the photic zone near the surface. Site 2 (Figure 4, bottom plot), Site 3 (Figure 5, top plot), and Site 4 (Figure 5, middle plot) displayed increases in dissolved oxygen that peaked in mid-August at 15 to 16 mg/L. Site 5 (Figure 5, bottom plot) displayed increases in dissolved oxygen that peaked in mid-August at 13 mg/L. These peak concentration represent a condition of dissolved oxygen supersaturation (greater than about 110 percent of saturation), which is evidence of high primary production at these sites. Algal blooms produce large amounts of oxygen during photosynthesis that may lead to supersaturated levels of dissolved oxygen in the water column (Thornton et al. 1990, Welch 1992, Cooke et al. 2005).

Values of dissolved oxygen (in percent saturation) are shown in Figure 6 for three examples of mid-summer sampling dates; i.e., July 22, August 20, and September 17. The values are the averages of the percent saturation in the photic zone, based on the average of measured percent saturation measurements taken at depths of 0.5, 1, 2, and 3 meters. Among the five sites, percent saturation was lowest at Site 1, which is directly influenced by river inflow. The values from July 22 and September 17 showed progressively greater dissolved oxygen percent saturation from site-to-site indicating increased algae production activity with distance downstream in the reservoir on those two sampling dates. The values from August 20 showed highest dissolved oxygen percent saturation at Sites 2, 3, and 4, indicating highest algae production activity in the middle region of the reservoir on that date. The dissolved oxygen patterns shown in these plots do not provide clear evidence that the twelve solar-powered circulators were responsible for, or contribute to, the dissolved oxygen patterns observed.

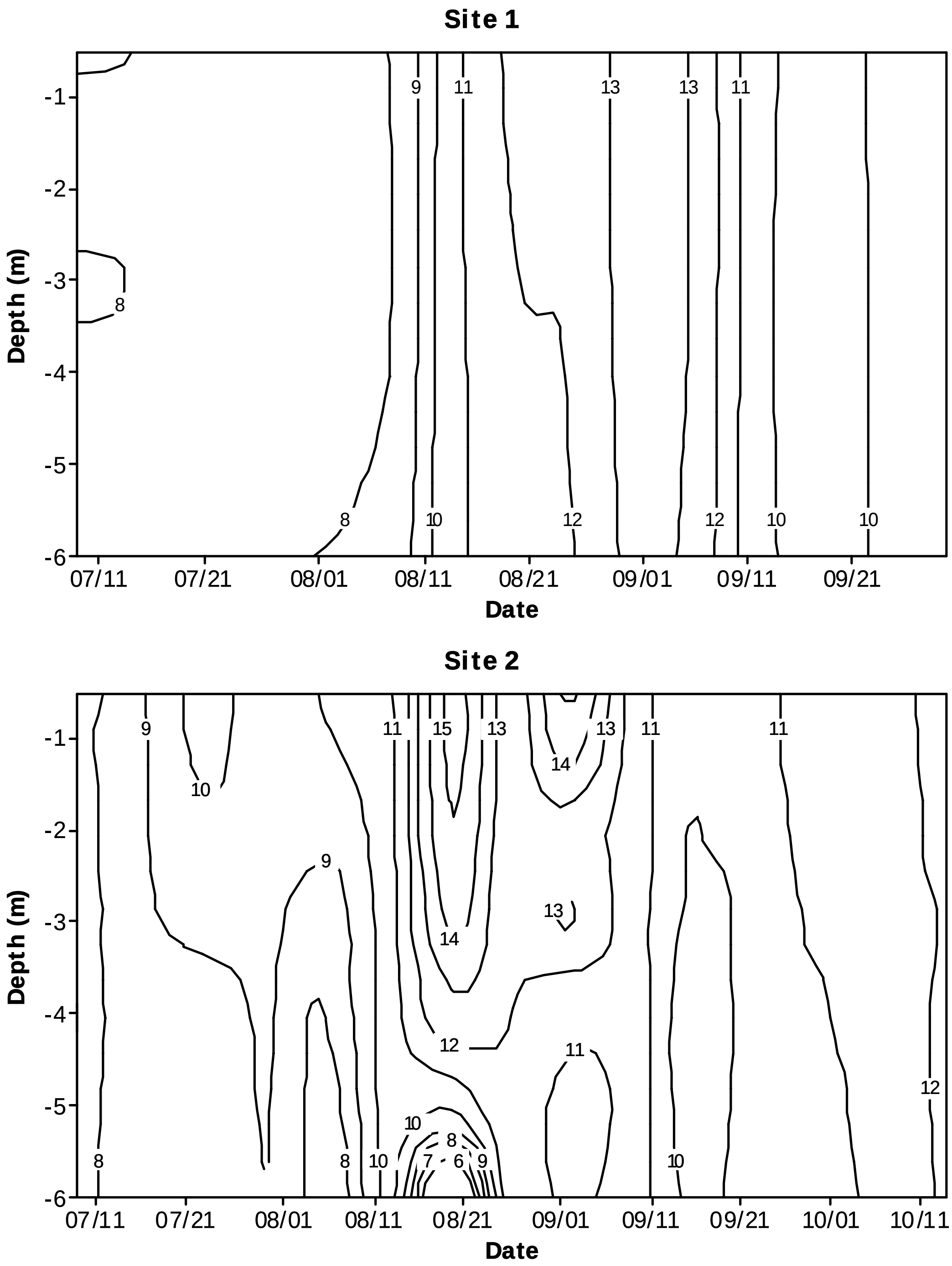

Figure 4. Isopleths of dissolved oxygen (mg/L) at Site 1 (top plot) and Site 2 (bottom plot) in Copco reservoir during 2008 circulator testing.

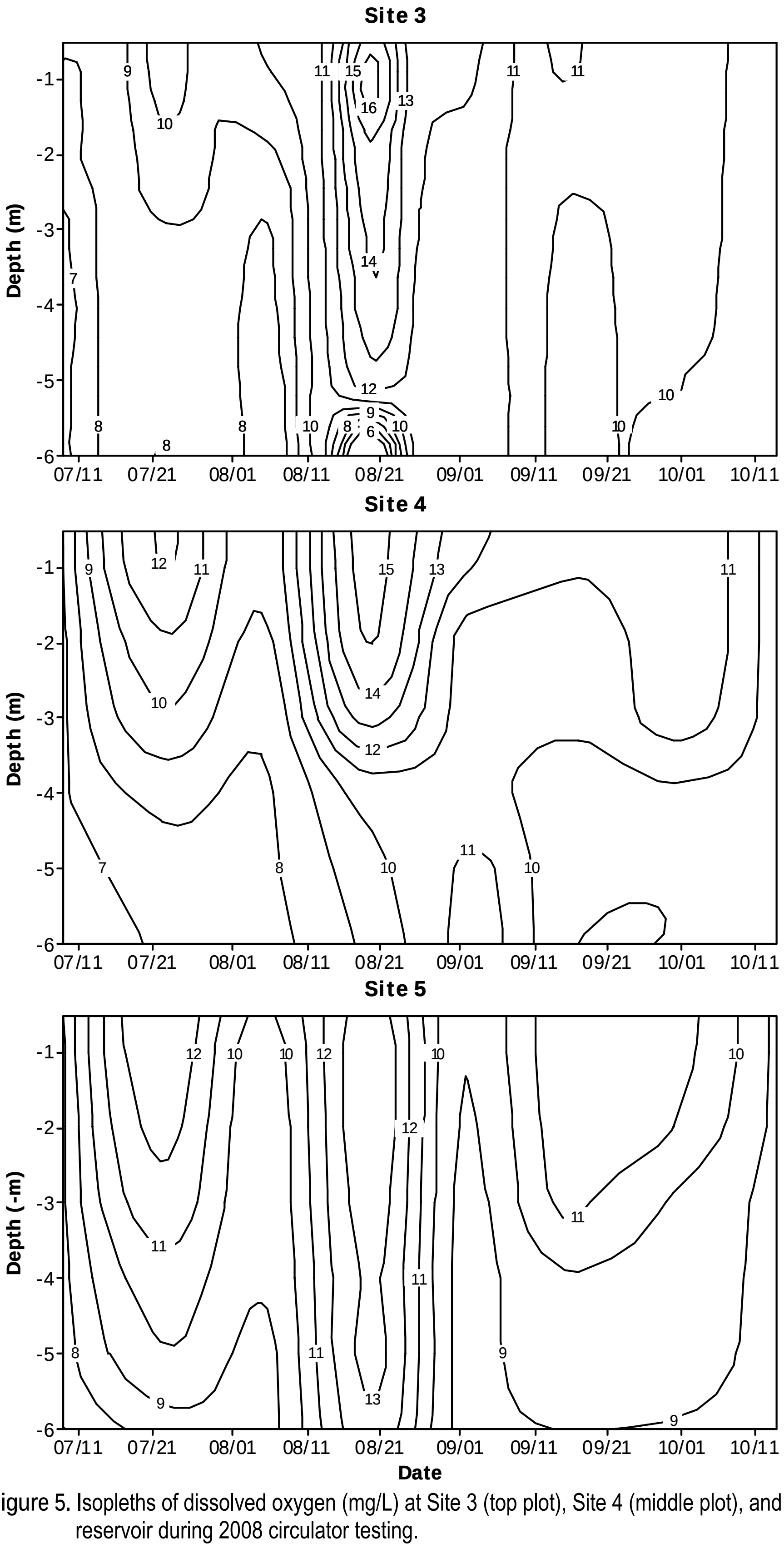

Figure 5. Isopleths of dissolved oxygen (mg/L) at Site 3 (top plot), Site 4 (middle plot), and Site 5 (bottom plot) in Copco reservoir during 2008 circulator testing.

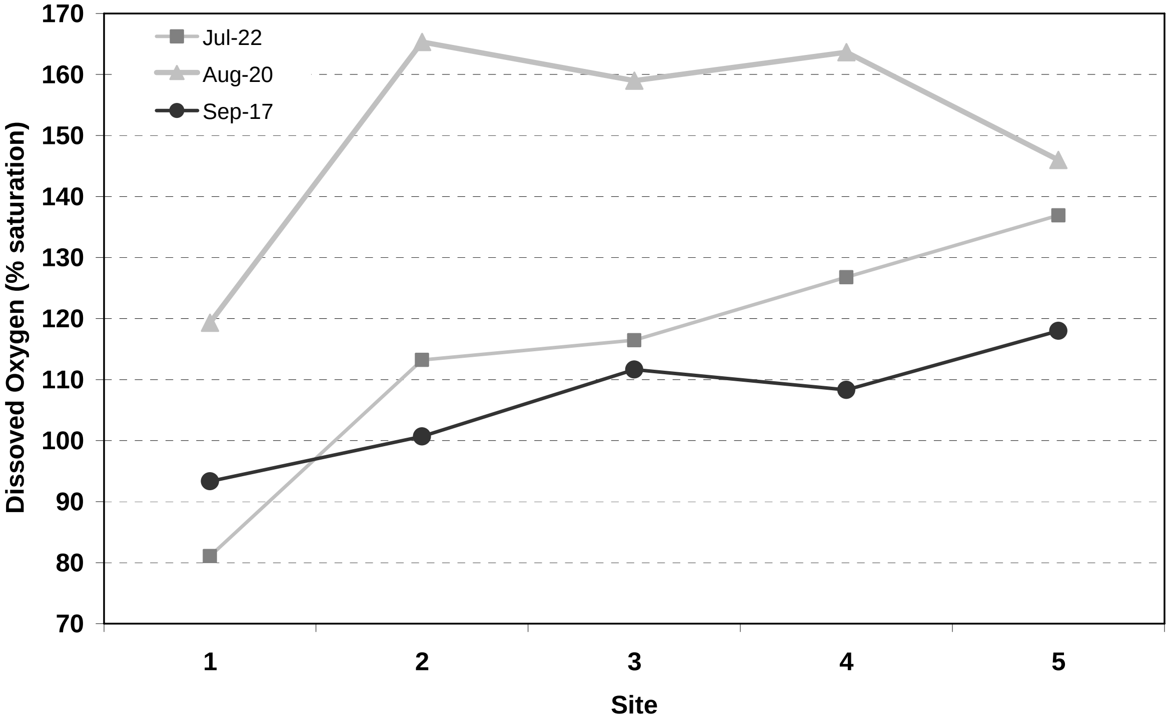

Figure 6. Values of dissolved oxygen (in percent saturation) for three example mid-summer sampling dates in 2008 (July 22, August 20, and September 17). The values are the averages of the percent saturation in the photic zone, based on the average of measured percent saturation measurements taken at depths of 0.5, 1, 2, and 3 meters.

pH

As with dissolved oxygen, pH levels can serve as an indicator of primary production in a water body. Algal blooms take up large amounts of carbon dioxide (CO_2) during photosynthesis that can lead to high pH levels in the water column, particularly in the photic zone near the surface (Thornton et al. 1990, Welch 1992, Cooke et al. 2005). This relationship dictates that pH data collected from the photic zone, where most primary production occurs, is the most relevant for determining whether the solar-powered circulators are responsible for, or contribute to, possible reductions in algae blooms. The pH data are displayed in contour plots only for the top 6 m (about 20 ft) of the monitoring sites (the entire data set is available in Appendix C). Comparisons made within this zone were assumed to characterize the photic zone and epilimnion, and were independent of any influence of thermal stratification.

Site 1 (Figure 7, top plot) was well-mixed and exhibited little change in pH with depth. Nearly all pH values obtained at Site 1 during this study remained between pH units 7 to 8 – consistently less that at Sites 2, 3, 4, and 5 – reflecting the riverine input to the reservoir.

The values of pH at Sites 2, 3, 4, and 5 reflect the effects of primary production in the reservoir. Site 2 (Figure 7, bottom plot), Site 3 (Figure 8, top plot), and Site 4 (Figure 8, middle plot) displayed increases in pH that peaked in mid-August at 8.8 to 8.9. Site 5 (Figure 8, bottom plot) displayed increases in dissolved oxygen that peaked in mid-August at 8.6 mg/L. These peak pH values observed in mid-July and mid-August provide evidence of high primary production at these sites.

The pH patterns shown in these plots do not provide clear evidence that the twelve solar-powered circulators were responsible for, or contributed to, the pH patterns observed. Overall, pH values were highest at Sites 2, 3, and 4, indicating the highest algae production activity generally occurred in the middle region of the reservoir. This middle region includes the area occupied by the twelve solar-powered circulators. Although pH values were consistently lower at Site 1, which is also in the area occupied by the circulators, the pH measurements at Site 1 likely reflected the effects of riverine input to the reservoir and the transition from a river-like (lotic) to a lake-like (lentic) environment.

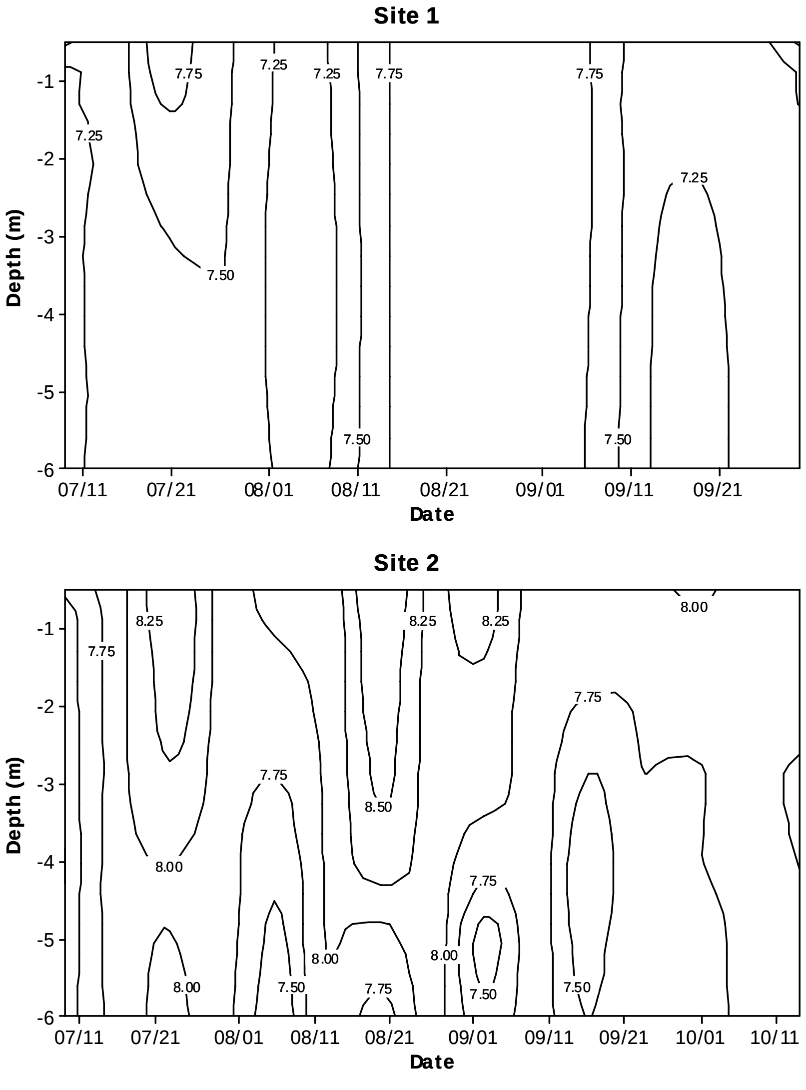

Figure 7. Isopleths of pH (units) at Site 1 (top plot) and Site 2 (bottom plot) in Copco reservoir during 2008 circulator testing.

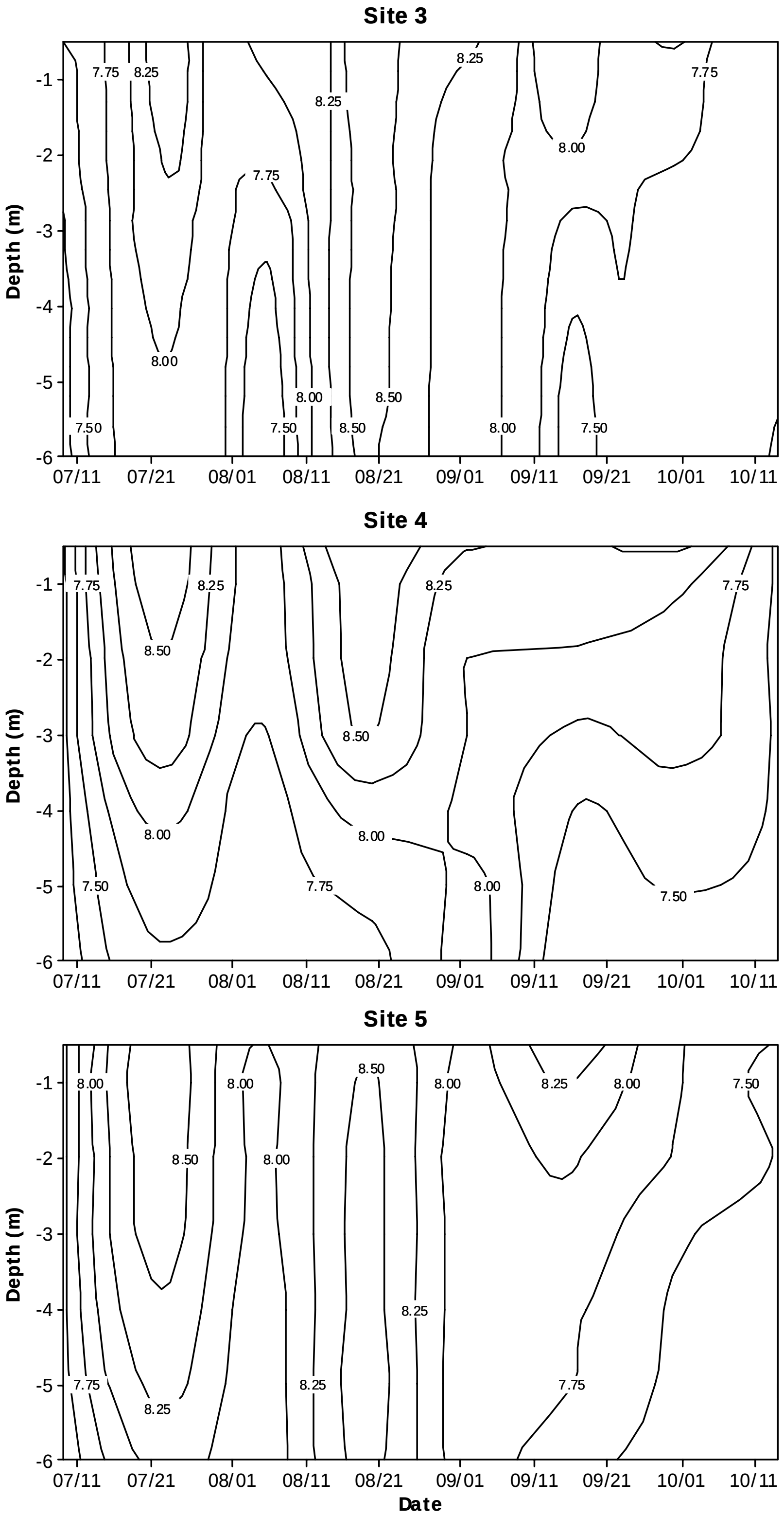

Figure 8. Isopleths of pH (units) at Site 3 (top plot), Site 4 (middle plot), and Site 5 (bottom plot) in Copco reservoir during 2008 circulator testing.

Chlorophyll-*a* and Secchi Disk Transparency

Chlorophyll *a* concentrations serve as a direct indicator of primary production and quantity of algae. Chlorophyll *a* data from the five sites and the two methods of sampling (integrated and grab) are summarized in Figure 9 and Table 2. In general, integrated samples had lower median concentrations than grab samples. The lowest chlorophyll *a* concentrations were observed at Site 1. The low and near-identical concentrations for grab and integrated samples at Site 1 point to the well-mixed, riverine conditions present at this site.

The highest chlorophyll *a* values were observed at Site 2, followed by Site 3, within the solar-powered circulators treatment area. The median chlorophyll *a* values at Sites 2 and 3 were relatively similar, but Site 2 integrated samples showed the highest 3rd quartile (14.0 µg/L) and maximum (124 µg/L) chlorophyll *a* values of all sites. The integrated samples from Site 3 showed the second-highest 3rd quartile (10.1 µg/L) and maximum (21.8 µg/L) chlorophyll *a* values of all sites.

Sites 4 and 5, located beyond the solar-powered circulators treatment area, had median chlorophyll *a* values from both integrated and grab samples that were generally similar to Sites 2 and 3. However, Sites 4 and 5 had substantially lower 3rd quartile and maximum values than Sites 2 and 3. Excluding Site 1, the integrated chlorophyll *a* samples from Site 5 had the lowest 1st quartile, median, 3rd quartile, and maximum values.

Figure 10 presents the chlorophyll *a* data from integrated sampling by sampling date. Based on these data, chlorophyll *a* appeared to peak during mid-August. During the peak, the highest chlorophyll *a* concentrations were observed at Sites 2 and 3 within the solar-powered circulators treatment area, whereas the lowest concentrations (excluding Site 1) occurred at the sites outside the treatment area (Sites 4 and 5). Thus, the chlorophyll *a* data indicate that the solar-powered circulators did not act to reduce primary production, including blue-green algae blooms, during this period.

Particularly high chlorophyll *a* values occurred in both the integrated and grab samples taken at Site 2 during the last sampling event of the study (October 14, 2008). The maximum values at Site 2 were 124 µg/L and 86 µg/L, respectively, for integrated and grab samples. These values were substantially greater than the next-highest maximum values of 21.8 µg/L and 20.0 µg/L, respectively, for integrated and grab samples taken at Site 3. The October 14, 2008 condition at Site 2 was notable in that blue-green algae concentrations (field-identified as primarily *Aphanizomenon flos-aquae*) were visually dense enough to block sight into the water column. These visual conditions (supported by the unusually high chlorophyll *a* values) at Site 2 on this date provided direct evidence that solar-powered circulators were not acting to reduce blue-green algae blooms.

Figure 11 shows Secchi depth measurements at the five sampling sites by sampling date. Results are variable, but tend to track the chlorophyll *a* data. In general, Secchi depths were least at Sites 2 and 3 within the solar-powered circulators treatment area. Secchi depths also were relatively low at Site 1, particularly on June and July sampling dates, which may indicate that particulate matter from riverine inflow contributed to turbid conditions on those dates. In general, Secchi depths tended to be greatest at Sites 4 and 5 beyond the solar-powered circulators treatment area, which reflects the relatively lower chlorophyll *a* values obtained at those sites (Figure 10 and Table 2).

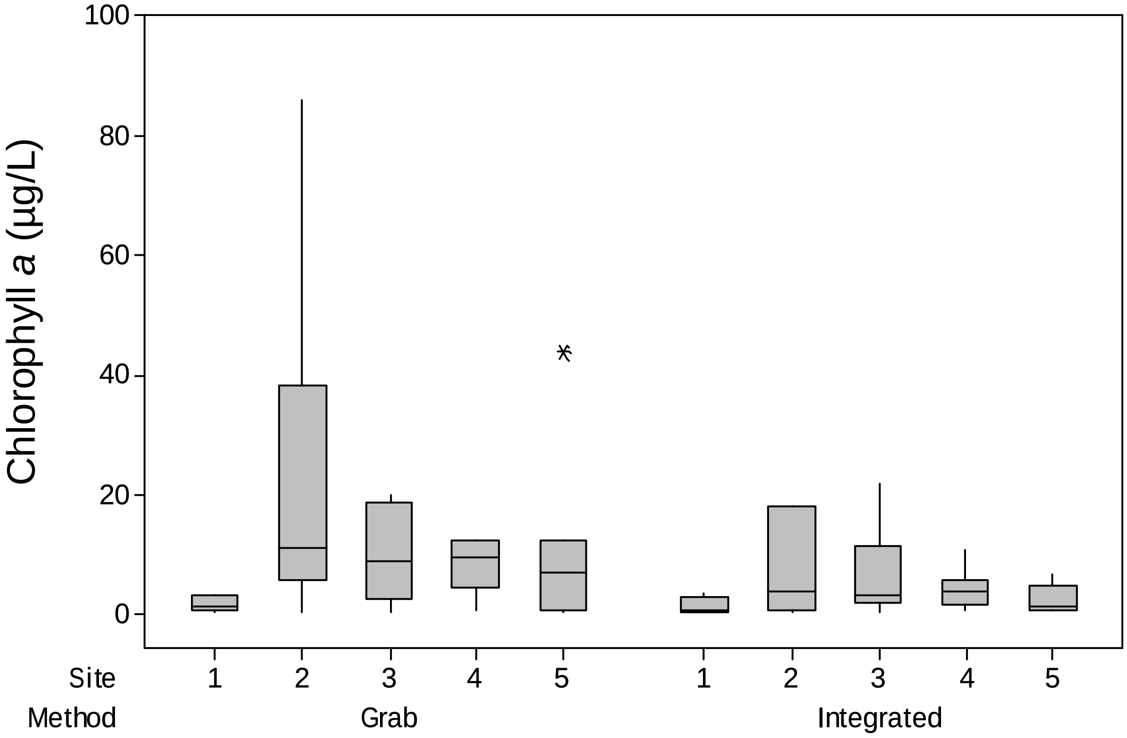

Figure 9. Box plot of chlorophyll *a* concentrations throughout study at all sites. (Note: the data at Site 2 includes a maximum values of 124 µg/L that is not shown on this plot.)

Table 2. Summary of chlorophyll *a* concentrations throughout study, all sites

Method	Metric	Site				
		1	2	3	4	5
Grab	minimum	0.40	0.44	0.30	0.67	0.20
	Q2	0.93	6.54	3.60	5.63	0.74
	median	1.20	11.00	8.90	9.50	7.18
	Q3	2.71	27.00	17.35	11.75	12.15
	maximum	3.25	86.20	20.00	12.40	43.80
Integrated	minimum	0.30	0.29	0.21	0.53	0.49
	Q2	0.40	1.70	1.95	1.87	0.98
	median	0.60	3.87	3.09	3.96	1.38
	Q3	2.04	13.98	10.13	5.55	4.49
	maximum	3.40	124.00	21.80	10.50	6.83

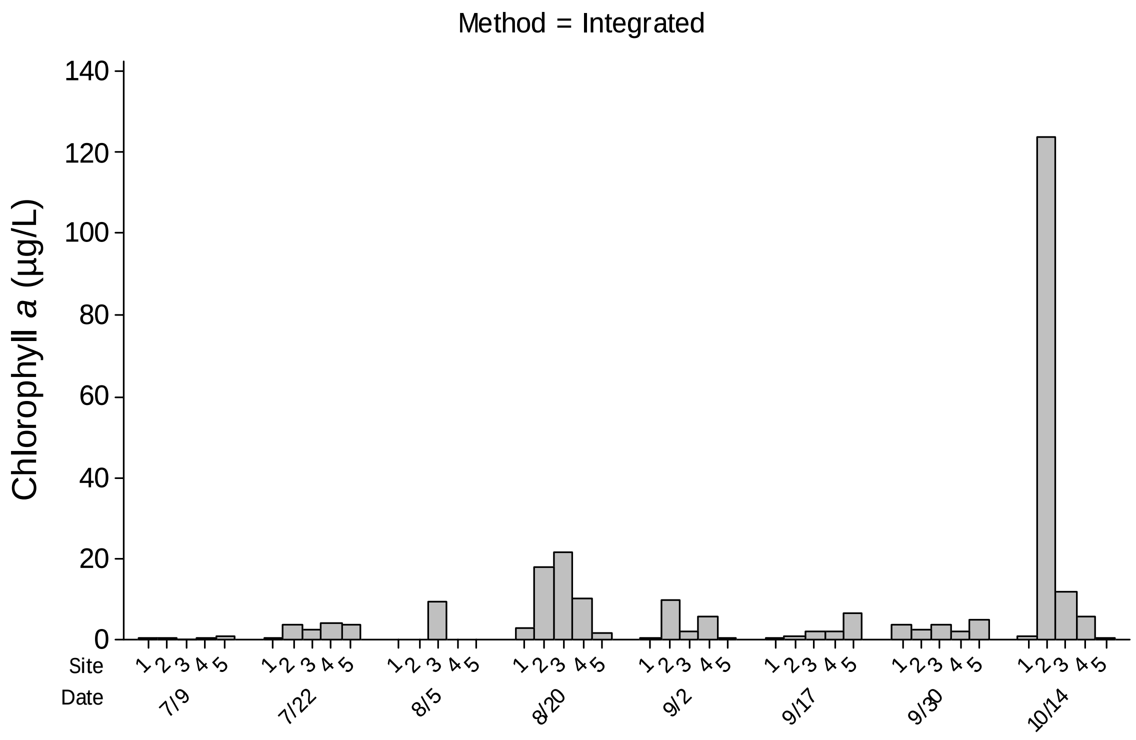

Figure 10. Chlorophyll *a* concentrations from integrated samples, all sites during 2008 monitoring season (some data not available for August 5 sampling date).

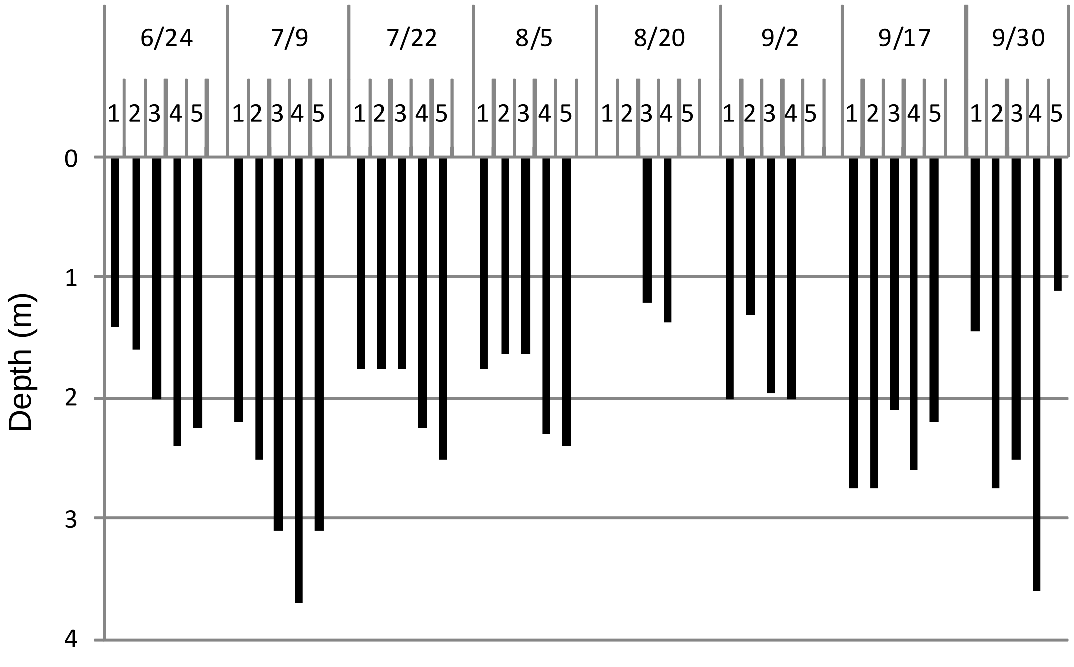

Figure 11. Chart of Secchi depth measurements throughout season (missing data correspond to conditions too windy for accurate readings).

Phytoplankton

Total Phytoplankton Density

Results of phytoplankton sample analyses show trends that are similar to those observed for chlorophyll *a* data as described above. The highest values of total phytoplankton density (algal units per mL) were observed at Site 2, followed by Site 3, within the solar-powered circulators treatment area (Figure 12). Site 2 showed the highest median and quartile values of all sites, and Site 3 showed the second-highest median and quartile values of all sites. Sites 4 and 5, located beyond the solar-powered circulators treatment area, had median and 1st quartile phytoplankton density values that were less than Sites 2 and 3. Excluding Site 1, Site 5 had the lowest minimum, 1st quartile, and median phytoplankton density values. However, Site 5 had a maximum value that was as high as observed at Site 2, and substantially higher than Sites 3 and 4.

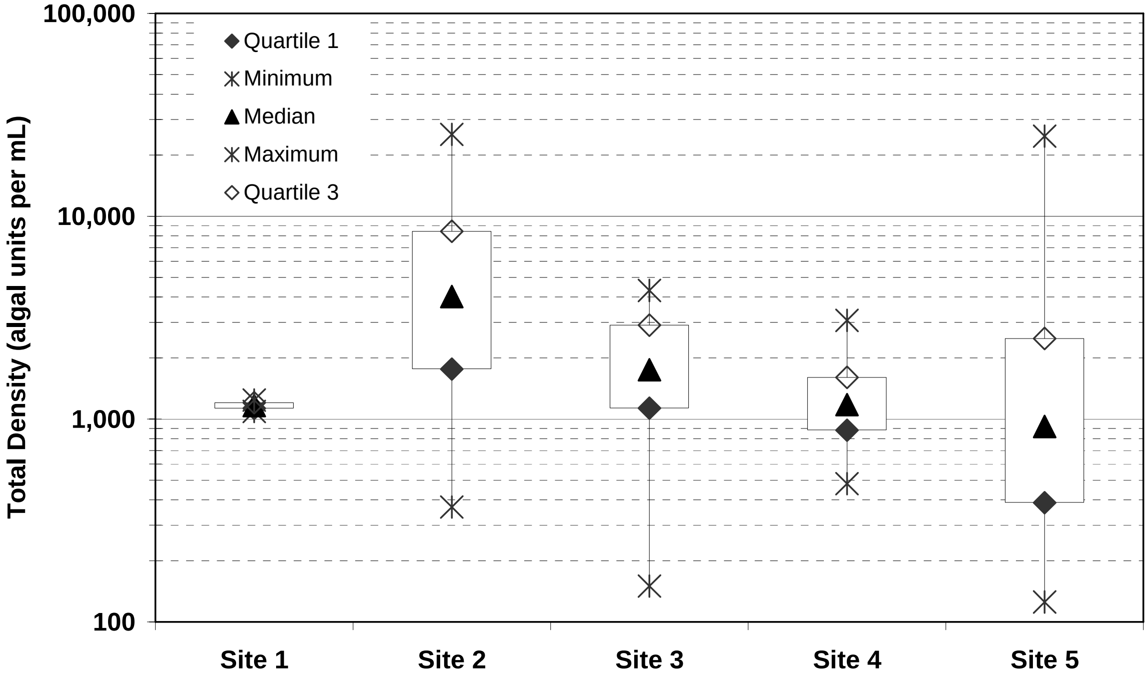

Figure 12. Total phytoplankton density (algal units per mL) in Copco reservoir during 2008 circulator testing.

Dominant Phytoplankton Taxa

Table 3 summarizes the ranking of the top four phytoplankton taxa (by density and biovolume) at the five sites in the reservoir during the 2008 study (for grab and integrated samples combined by site). The cyanobacteria (blue-green algae) species *Aphanizomenon flos-aquae* (APFA) was the predominant phytoplankton taxa in Copco reservoir during 2008 circulator testing. At all five sites, APFA ranked first by both density (algal units per mL) and biovolume (mm^3 per mL). APHA occurred in the reservoir on all sample dates from July through October 2008.

Several other taxa comprised the second, third, and fourth rankings at the five sites. The cyanobacteria species *Microcystis aeruginosa* (MSAE) ranked second by biovolume at Sites 2, 3, 4, and 5, and fourth by density at Sites 2 and 3.

As discussed in the Introduction, one of the principal objectives of the testing of solar-powered circulators was to assess potential reductions in blooms and accumulations of APHA and MSAE in the "treated" reservoir area. APHA and MSAE are common bloom-forming cyanobacteria (blue-green algae) in nutrient-enriched waterbodies, and MSAE is known to produce the toxin microcystin[3]. The phytoplankton taxa data collected in Copco reservoir during 2008 present no evidence that the solar-powered circulators acted to alter the presence or dominance of APHA and MSAE during the study period.

Table 3. Rank of top four phytoplankton taxa (by density and biovolume) at the five sites in Copco reservoir during 2008 circulator testing.

Site	Rank	Taxa	Density (units per mL)	Taxa	Biovolume (mm^3 per mL)
1	1	Aphanizomenon flos-aquae	1,295	Aphanizomenon flos-aquae	1,394,331
	2	Navicula cryptocephala veneta	1,160	Cocconeis placentula	451,262
	3	Nitzschia dissipata	1,068	Nitzschia dissipata	310,052
	4	Rhoicosphenia curvata	1,062	Rhoicosphenia curvata	133,989
2	1	Aphanizomenon flos-aquae	70,137	Aphanizomenon flos-aquae	91,915,833
	2	Chlamydomonas sp.	2,542	Microcystis aeruginosa	1,241,329
	3	Rhodomonas minuta	1,650	Chlamydomonas sp.	838,893
	4	Microcystis aeruginosa	163	Rhodomonas minuta	33,000
3	1	Aphanizomenon flos-aquae	18,381	Aphanizomenon flos-aquae	25,415,672
	2	Rhodomonas minuta	2,613	Microcystis aeruginosa	2,971,283
	3	Schroderia sp.	2,430	Cryptomonas erosa	205,575
	4	Microcystis aeruginosa	958	Schroderia sp.	109,370
4	1	Aphanizomenon flos-aquae	9,444	Aphanizomenon flos-aquae	14,123,321
	2	Schroderia sp.	2,913	Microcystis aeruginosa	659,438
	3	Rhodomonas minuta	1,475	Cryptomonas erosa	447,907
	4	Cryptomonas erosa	861	Schroderia sp.	131,074
5	1	Aphanizomenon flos-aquae	28,976	Aphanizomenon flos-aquae	37,955,600
	2	Schroderia sp.	4,376	Microcystis aeruginosa	1,026,068
	3	Rhodomonas minuta	1,740	Cryptomonas erosa	421,373
	4	Cryptomonas erosa	810	Schroderia sp.	196,932

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[3] APHA is also capable of producing microcystin, but the strain present in Upper Klamath Lake and the Klamath River is reported to be non-toxigenic (An and Carmichael 1994, Carmichael et al. 2000).

Microcystis Density

Because MSAE is capable of producing the toxin microcystin, potential for solar-powered circulators to reduce accumulations of MSAE in the "treated" reservoir area was of particular interest. Results of analyses show that the trend in the distributions of MSAE cell count data at the five study sites were similar to those observed for chlorophyll *a* and phytoplankton density data as described above. The highest values of MSAE density (algal units per mL) were observed at Sites 2 and 3, within the solar-powered circulators treatment area (Figure 13). Site 2 showed the highest 1st and 3rd quartile values, and the second-highest median value of all sites. Site 3 had a relatively low median value (compared to the other sites), but had the highest 3rd quartile and maximum values of all sites. Sites 4 and 5, located beyond the solar-powered circulators treatment area, had relatively high median values similar to Site 2 and 3, but had relatively low 3rd quartile and maximum MSAE density values.

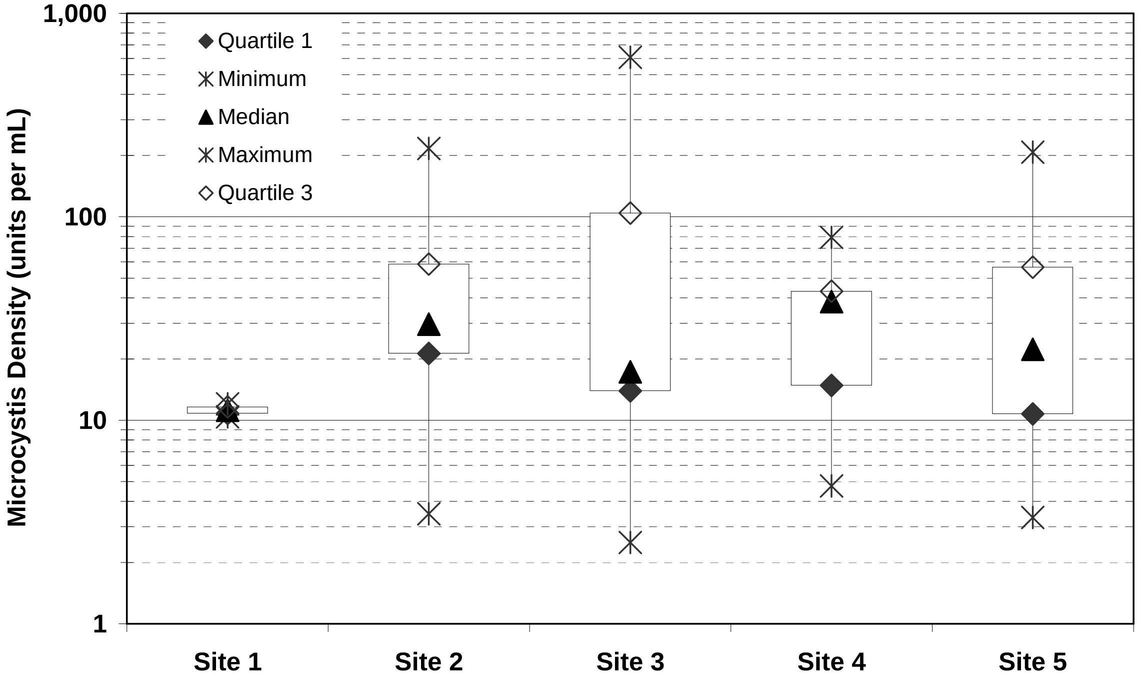

Figure 13. Density of *Microcystis aeruginosa* (MSAE; algal units per mL) in Copco reservoir during 2008 circulator testing.

Microcystin Concentrations

The distributions of microcystin values in grab and integrated samples are summarized in Figure 14 and Table 4. As expected, the distributions of microcystin concentrations generally track the distributions of MSAE density data as described above. The distributions show that microcystin concentrations were generally higher at Sites 2 and 3, with greater variation, than at Sites 4 and 5. In terms of median and 1st quartile values for integrated samples, Sites 2, 3, 4, and 5 were relatively similar. However, Sites 2 and 3 had substantially higher 3rd quartile and maximum values.

Figure 15 presents the microcystin values in integrated samples by sampling date. Based on these data, microcystin appeared to peak during mid-August. During the peak, the highest microcystin concentrations were observed at Sites 2 and 3 within the solar-powered circulators treatment area, whereas the lowest concentrations (excluding Site 1) occurred at the sites outside the treatment area (Sites 4 and 5). Thus, microcystin data present no evidence that the solar-powered circulators acted to reduce primary production, including blue-green algae blooms, during this period.

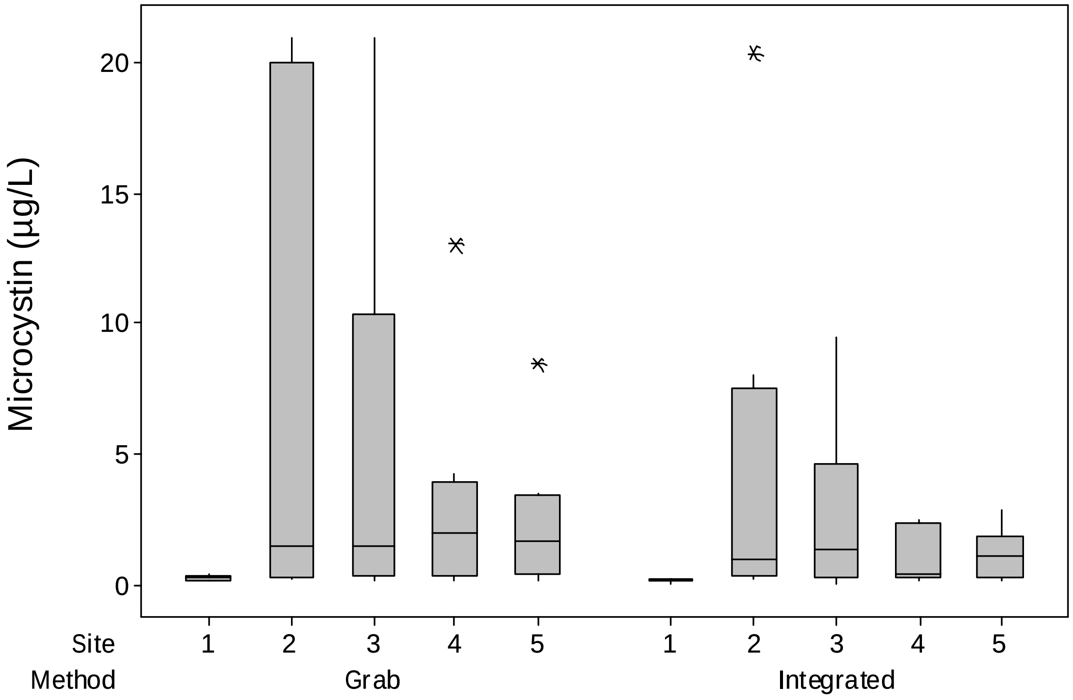

Figure 14. Box plot of microcystin concentrations throughout study at all sites.

Table 4. Summary of microcystin concentrations throughout study, all sites

Method	Metric	Site				
		1	2	3	4	5
Grab	minimum	0.09	0.16	0.07	0.05	0.10
	Q2	0.11	0.24	0.52	0.38	0.57
	median	0.22	1.37	1.42	1.97	1.62
	Q3	0.29	19.88	8.28	3.28	3.28
	maximum	0.40	21.00	21.00	13.00	8.47
Integrated	minimum	0.03	0.16	0.03	0.09	0.07
	Q2	0.07	0.44	0.28	0.27	0.23
	median	0.09	0.94	1.33	0.40	1.09
	Q3	0.13	6.59	4.28	2.27	1.44
	maximum	0.20	20.40	9.46	2.40	2.90

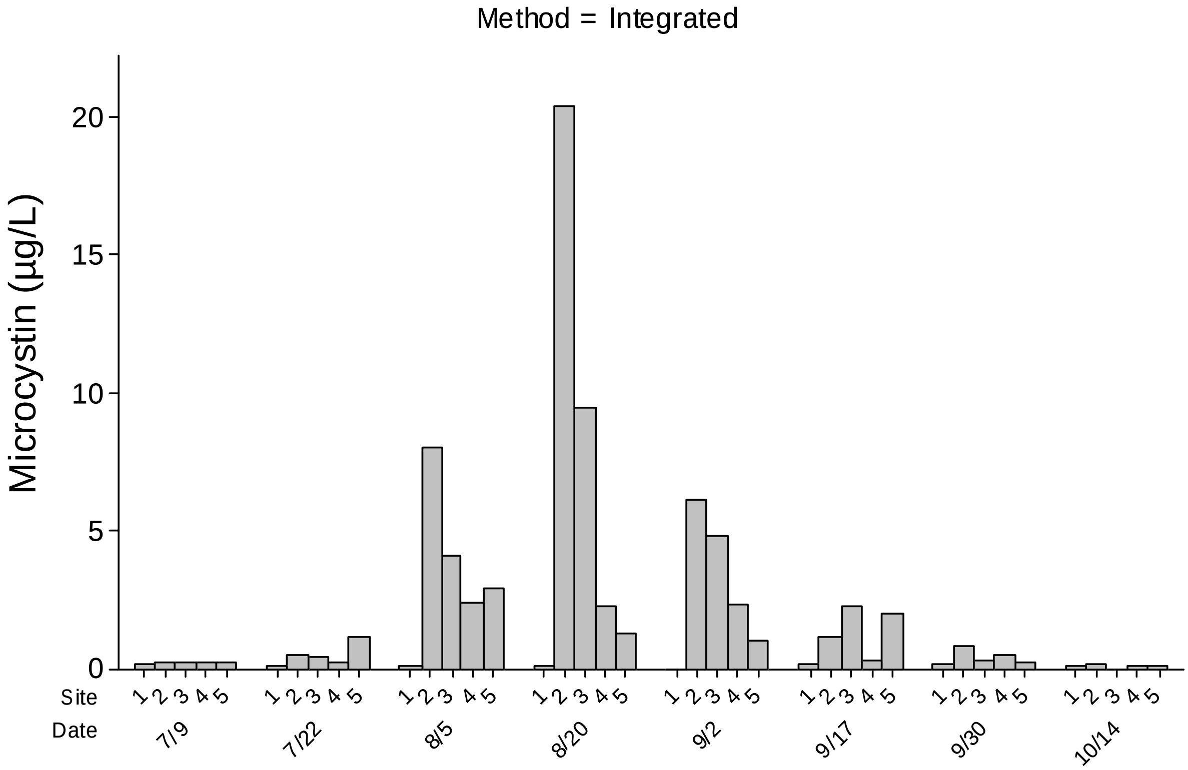

Figure 15. Microcystin concentrations from integrated samples at all sites during 2008 monitoring season.

Conclusions

The monitoring data collected from Copco reservoir during April through October 2008 indicates that the 12 solar-powered circulators did not act to improve water quality, and in particular did not act to reduce cyanobacteria blooms in the reservoir. The monitoring data showed that algae production and densities generally remained high throughout the reservoir during the monitoring period. For example, dissolved oxygen supersaturation (greater than about 110 percent of saturation) and pH values of 8 to 9 occurred at all reservoir monitoring sites, indicating high primary production at these sites.

The monitoring data further shows that algae production and densities actually were highest at Sites 2 and 3 in the upper portion of the reservoir in the vicinity of the circulators. Among all sites, the highest total phytoplankton densities (algal units per mL), total phytoplankton biovolumes (mm^3 per mL), and chlorophyll *a* concentrations (µg/L) were observed at Sites 2 and 3 within the solar-powered circulators treatment area.

The phytoplankton taxa data presents no evidence that the solar-powered circulators acted to alter the presence or dominance of APHA and MSAE during the study period. APFA was the predominant phytoplankton taxa during 2008 circulator testing, ranking first among taxa at each of the five sites in both density and biovolume. MSAE ranked second by biovolume at Sites 2, 3, 4, and 5, and fourth by density at Sites 2 and 3. The highest values of MSAE density were observed at Sites 2 and 3, within the solar-powered circulators treatment area. The monitoring data also shows that concentrations of microcystin (a toxin produced by certain cyanobacteria, notably MSAE) were generally higher at Sites 2 and 3, with greater variation, than at Sites 4 and 5 in the lower portion of the reservoir.

At the outset of this study, it was reasonable to assume that the circulator units would reduce cyanobacteria levels (and other water quality conditions related to algae growth, like pH and water clarity) in the upper portion of the reservoir in the vicinity of the circulators to levels below those occurring at the "untreated" sites in the lower portion of the reservoir. A complicating factor in the interpretation of the 2008 monitoring results is the likely *a priori* existence of a longitudinal gradient of water quality conditions through the reservoir. Reservoirs exhibit a marked degree of spatial heterogeneity in phytoplankton productivity and biomass due to longitudinal gradients in reservoir morphology, water residence time, nutrients, suspended solids, and light availability (Thornton et al. 1990). Spatial heterogeneity of surface algae conditions in Copco reservoir are clearly evident in aerial photo mosaics taken in mid-August (Figure 16, top photo) and mid-September (Figure 16, bottom photo) during the 2008 circulator monitoring study.

Typically, three zones occur longitudinally along a reservoir: the riverine, transition, and lacustrine zones (Thornton et al. 1990). The ***riverine zone*** of a reservoir occurs where the river inflow to the reservoir dominates the lake characteristics. In this region, the types of processes occurring are more like a river than a lake. Inflow turbidity often limits light penetration, and river-induced mixing usually exceeds that of the photic zone. Consequently, primary productivity by algae is often light-limited. As discussed above, the monitoring results from Site 1 demonstrated river-like water quality conditions, especially in relation to the other sites.

As can be seen in Figure 1 and Figure 16, Site 1 is located just downstream of the river inflow to the reservoir in a relatively narrow part of the reservoir.

The ***transition zone*** of a reservoir is the area in which the reservoir gradually changes from river-like (lotic) to lake-like (lentic) characteristics. This zone is characterized by higher phytoplankton productivity and biomass because both light and nutrients are available for algal photosynthesis. Thornton et al. (1990) report that the transition zone is often the most fertile region in the reservoir, and is often associated with a plunge point, if one occurs. As discussed above, the monitoring results from Sites 2 and 3 showed the highest levels of phytoplankton density, biomass, and chlorophyll *a*, and also the highest levels of MSAE and microcystin.

The plunge point in a reservoir is the location where inflow from the river can be seen to plunge beneath the reservoir water surface because the inflow density is greater than the density of the warmer water surface. The location of the plunge point occurs at the point where the momentum of the inflow (advective force) is in balance with the pressure gradient across the interface separating the river and reservoir water (buoyancy force). Thornton et al. (1990) consider the plunge point as the border between the riverine and the lacustrine zones of the reservoir. The plunge point is sometime visible because of accumulation of floating debris, indicating a stagnation point or point of convergence. A plunge point in Copco reservoir between Sites 1 and 2 is evident in aerial photo mosaics taken in mid-August (Figure 16, top photo) and mid-September (Figure 16, bottom photo).

The ***lacustrine zone*** is the deepest region of the reservoir nearest the dam (downstream from the transition zone) where strictly lake-like (lentic) processes dominate. While algal primary productivity can still be high in this zone, it is often reduced from the transition zone, because of a general decrease in the fertility of the photic zone down-reservoir as the advected nutrient supply is reduced with increasing distance from the river inflow point. The monitoring results from Sites 4 and 5 showed high levels of phytoplankton density, biomass, and chlorophyll *a*. However, the levels at Sites 4 and 5 were nonetheless generally lower than measured at Sites 2 and 3, which can be explained by the assumption that Sites 4 and 5 fall within the lacustrine zone.

The 2008 monitoring results as presented in this report indicate that the solar-powered circulators did not act to improve water quality, and that differences in water quality conditions between sites can be explained on the basis of reservoir zonation and spatial heterogeneity. Even if it is assumed that the solar-powered circulators provided horizontal laminar flow and vertical circulation upward throughout this mixed zone (at the depth of the circulator intake), such mixing was evidently overridden by the stronger influence of other reservoir processes, such as captured in the reservoir zonation concept.

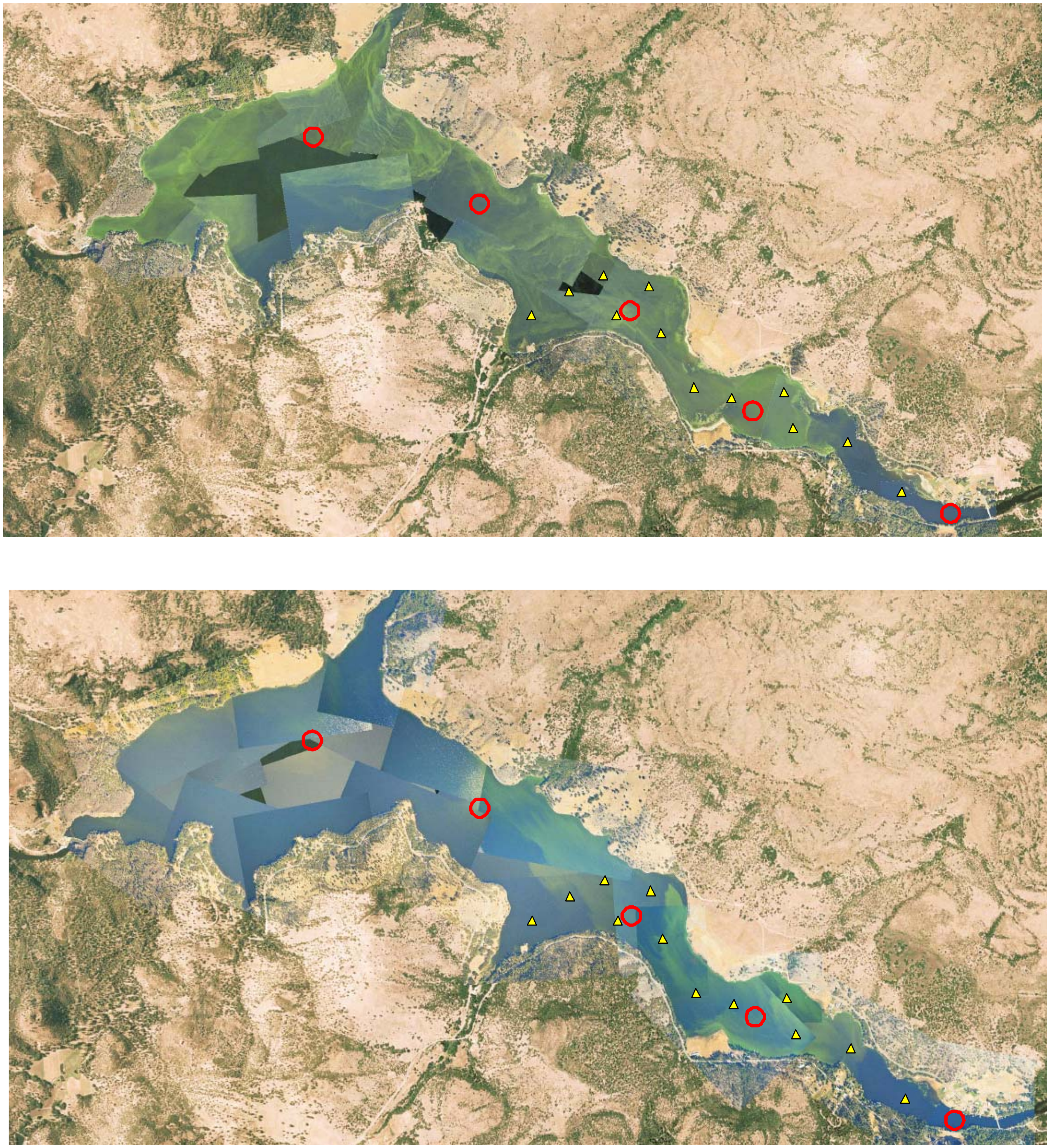

Figure 16. Aerial photo mosaics of Copco reservoir taken in mid-August (top) and mid-September (bottom) during the 2008 circulator monitoring study. The open circles indicate locations of the five monitoring sites, and the smaller triangles indicate locations of the 12 solar-powered circulators.

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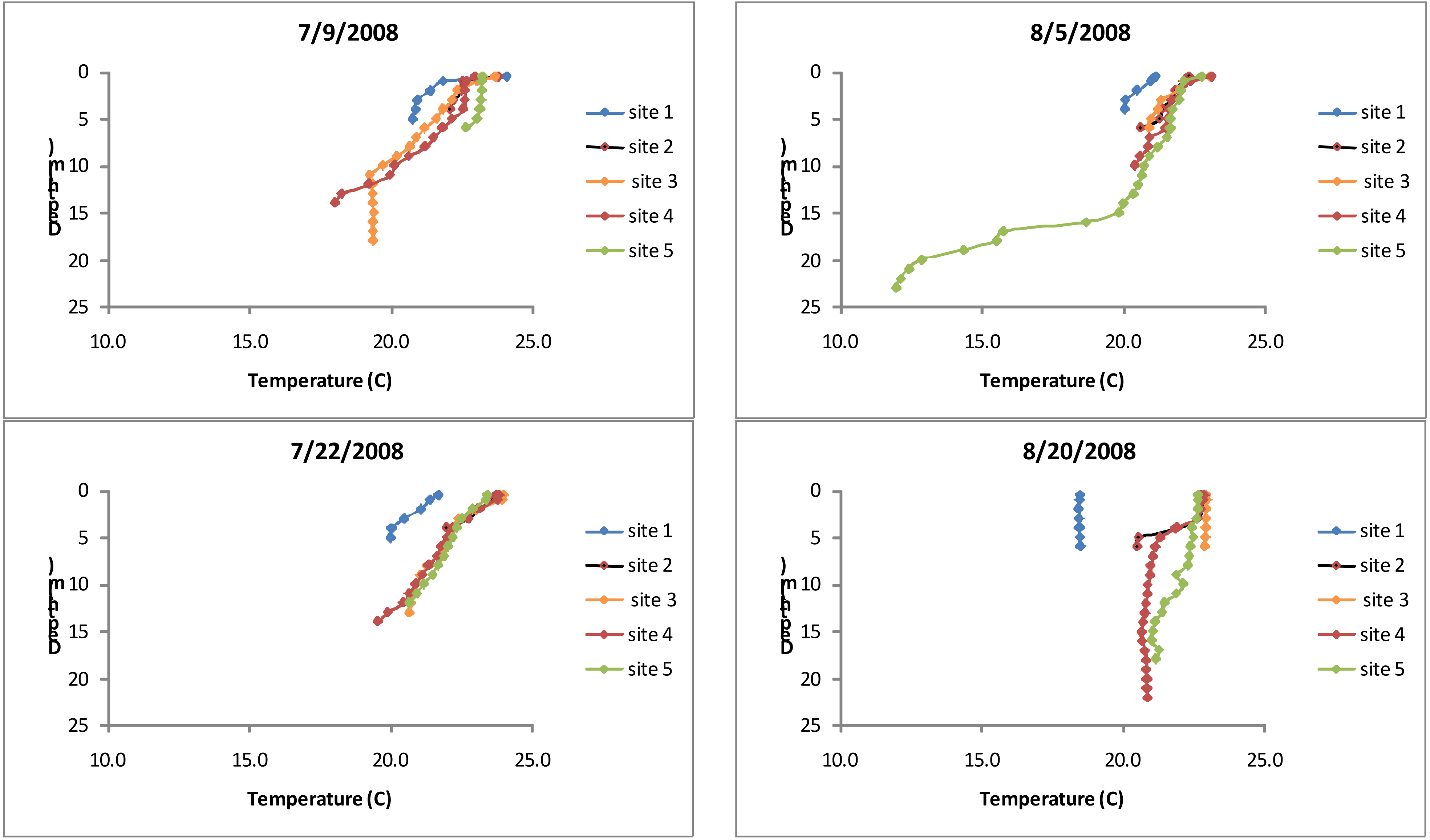
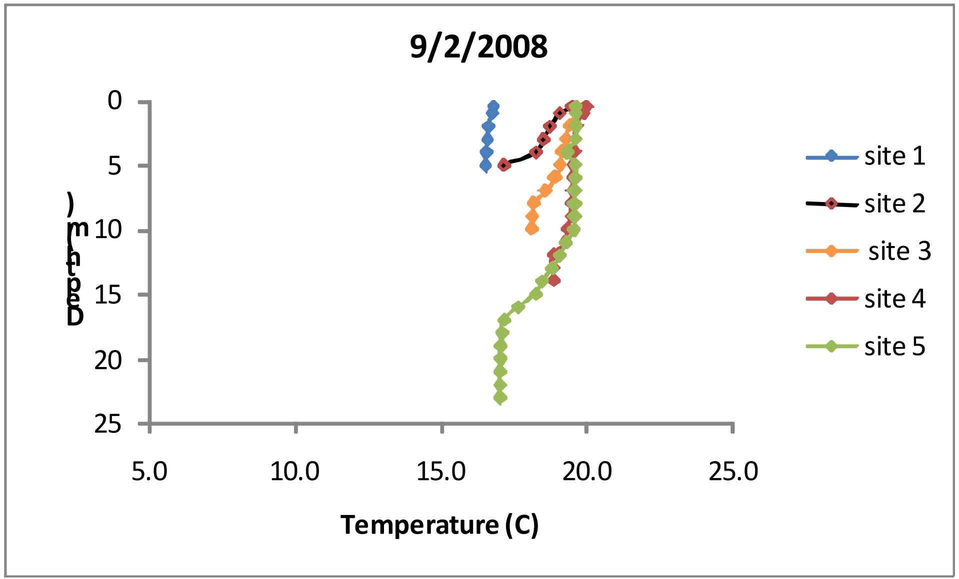
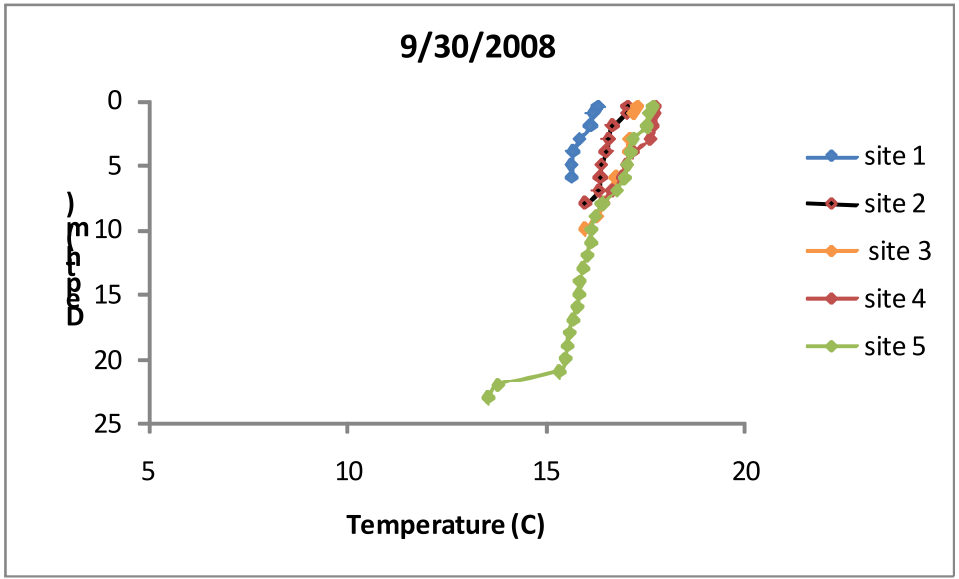
Appendix A:

Water Temperature Profile Data

Temperature Profile Plots




9/2/2008
Depth (m)
0
5
10
15
20
25
5.0
10.0
15.0
20.0
25.0
Temperature (C)
site 1
site 2
site 3
site 4
site 5


9/30/2008
Depth (m)
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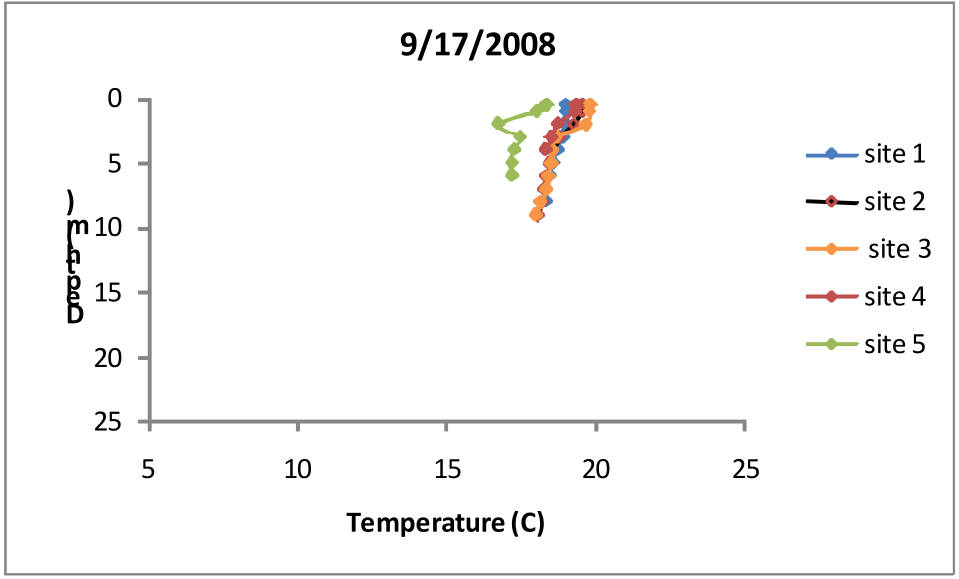
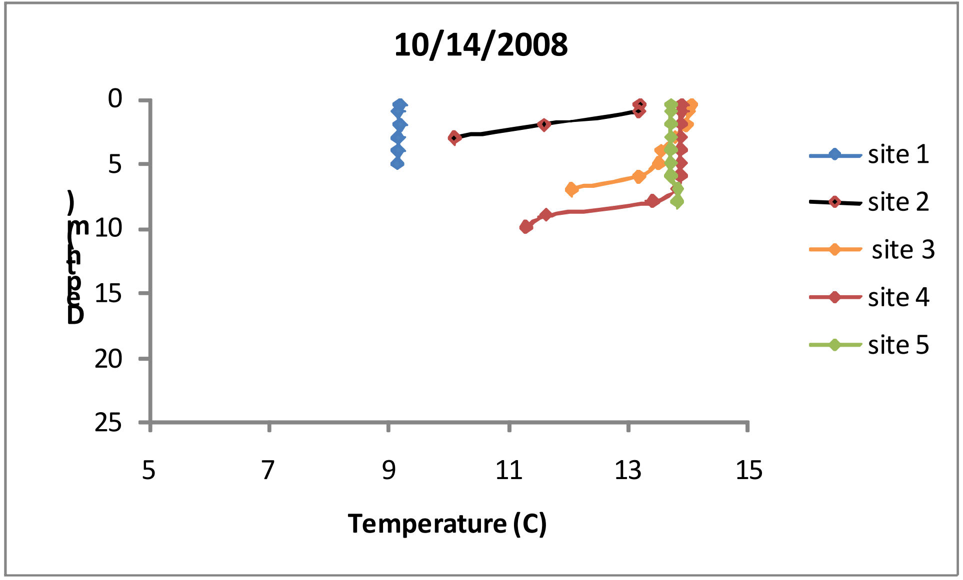
5
10
15
20
25
5
10
15
20
Temperature (C)
site 1
site 2
site 3
site 4
site 5


9/17/2008
Depth (m)
0
5
10
15
20
25
5
10
15
20
25
Temperature (C)
site 1
site 2
site 3
site 4
site 5


10/14/2008
Depth (m)
0
5
10
15
20
25
5
7
9
11
13
15
Temperature (C)
site 1
site 2
site 3
site 4
site 5

Appendix B:

Dissolved Oxygen Profile Data

Dissolved Oxygen Profile Data

Date	Depth (m)	DO (mg/L) at Site:					DO (%) at Site:				
		1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
7/9/2008	0.5	8.94	7.45	8.29	7.04	7.96	98.5	81.7	90.7	75.9	86.2
	1	7.57	7.76	7.87	6.95	7.91	79.1	83	84.9	74.4	85.6
	2	7.06	7.57	7.81	6.84	7.89	73.6	80.8	82.8	73.3	85.4
	3	8.3	7.26	6.81	6.86	7.86	85.8	76.9	72.2	73.3	84.9
	4	7.76	6.98	6.26	6.85	7.77	80.1	73.9	65.7	73.1	82.9
	5	7.55		6.63	6.37	7.55	77.6		69	67.2	81.6
	6			6.68	6	6.98			69.3	63.2	74.8
	7			6.08	5.72				71.1	59.7	
	8			5.96	5.33				60.9	55.5	
	9			2.8	4.42				28.2	45.1	
	10			2.02	3.57				19.7	36.3	
	11			0.39	3.32				3.2	33.6	
	12			0.22	3.02				2.2	30.2	
	13			0.2	1.98				2	19.2	
	14			0.19	1.69				1.9	16.6	
	15			0.18					1.8		
	16			0.17					1.7		
	17			0.16					1.7		
	18			0.15					1.5		
7/22/2008	0.5	8.34	10.84	11.15	12.09	12.97	85.9	119.1	122.6	132.5	139.7
	1	7.55	10.71	11.2	11.94	12.8	79.6	116.4	122.9	131	139.2
	2	7.5	9.63	9.52	10.82	12.26	77.7	104.2	103.9	116.8	131.9
	3	7.52	9.22	8.79	9.78	11.61	77	98.7	93.6	104.9	123.8
	4	7.61	7.85	7.94	8.33	10.54	77.2	82.1	84.2	88.3	114.5
	5	7.59		8.17	7.59	9.86	76.9		86.7	80.7	103.9
	6			7.56	7.15	8.42			79.9	78.3	89.4
	7			7.94	7.09	7.35			83.2	74.5	77.6
	8			7.82	7.1	6.4			81.6	74	67.4
	9			7.79	6.86	5.85			80.9	71.4	61.9
	10			7.97	7.27	5.01			81.7	75	51.5
	11			7.9	7.58	4.43			81.5	77.9	46.2
	12			7.94	7.63	3.12			81.7	78.1	38
	13			7.78	3.73				82.3	36.4	
	14				1.72					19.2	

Date	Depth (m)	DO (mg/L) at Site:					DO (%) at Site:				
		1	2	3	4	5	1	2	3	4	5
08/05/08	0.5	7.63	10.61	11.10	9.24	9.83	79	113	120	100	106
	1	7.60	10.06	9.87	9.23	9.44	79	107	106	98	100
	2	7.57	9.14	8.80	8.80	9.30	78	97	93	93	89
	3	7.58	8.49	7.44	8.23	9.26	77	90	79	87	98
	4	7.31	7.78	7.35	7.86	9.11	77	81	76	83	96
	5		7.40	6.93	7.74	8.75		77	72	81	92
	6		6.88	6.83	7.60	8.71		71	70	80	91
	7				6.07	8.62				63	90
	8				5.84	5.84				61	61
	9				5.94	5.14				61	54
	10				5.51	4.69				57	49
	11					4.41					46
	12					4.20					43
	13					3.62					38
	14					2.99					31
	15					2.56					26
	16					1.10					11
	17					0.28					3
	18					0.22					2
	19					0.22					2
	20					0.22					2
	21					0.21					2
	22					0.20					2
	23					0.19					2
08/20/08	0.5	12.29	15.28	14.78	15.38	13.43	121	164	159	165	144
	1	12.15	15.58	17.85	15.32	13.70	119	168	160	165	147
	2	12.08	15.30	14.64	15.01	13.68	118	164	158	161	147
	3	11.97	14.61	14.36	13.31	13.40	117	156	154	144	143
	4	11.76	13.02	14.14	10.45	13.10	115	168	153	114	139
	5	11.74	10.97	14.05	9.73	13.28	115	113	151	101	142
	6	11.62	0.51	0.55	9.29	12.65	114	6	7	98	134
	7				9.16	12.34				95	130
	8				9.06	12.20				94	129
	9				9.13	10.44				94	106
	10				9.31	10.81				93	115
	11				9.18	8.45				95	89
	12				8.24	7.91				86	82
	13				8.38	7.36				86	77
	14				8.62	6.62				89	69
	15				8.41	5.93				87	62
	16				8.06	5.62				83	58
	17				8.07	6.85				83	70
	18				8.16	6.77				84	70
	19				8.22					85	
	20				8.26					85	
	21				8.21					85	
	22				8.39					87	

Date	Depth (m)	DO (mg/L) at Site:					DO (%) at Site:				
		1	2	3	4	5	1	2	3	4	5
09/02/08	0.5	13.96	15.85	12.44	12.31	9.15	132	159	126	125	92
	1	13.82	14.39	12.18	12.04	9.05	130	143	122	122	91
	2	13.72	12.04	11.21	10.58	8.92	129	119	112	103	890
	3	13.68	13.44	11.37	10.66	8.74	129	132	114	107	88
	4	13.65	10.94	11.33	10.43	8.70	128	106	113	105	88
	5	13.63	10.07	11.56	11.14	8.69	128	96	115	112	87
	6			11.68	11.35	8.68			116	114	87
	7			11.47	11.33	8.66			113	113	87
	8			11.02	11.18	8.65			108	112	87
	9			11.01	11.02	8.63			107	110	87
	10			10.86	10.26	8.60			106	103	86
	11				8.70	7.78				90	78
	12				9.54	6.39				94	63
	13				9.15	6.52				91	64
	14				5.34	6.49				53	64
	15					7.85					77
	16					5.66					54
	17					6.55					64
	18					7.02					67
	19					0.42					4
	20					0.29					3
	21					0.27					3
	22					0.24					2
	23					0.23					2
09/17/08	0.5	9.78	10.20	11.51	11.20	11.95	96	102	116	113	119
	1	9.48	10.14	11.20	11.09	11.97	92	101	113	111	119
	2	9.56	10.08	10.58	10.13	11.69	92	99	106	101	116
	3	9.52	9.60	9.26	10.23	11.16	91	94	92	101	111
	4	9.57	8.66	9.10	9.35	9.92	92	85	90	92	98
	5	9.57		9.00	9.11	9.79	91		88	89	97
	6	9.48		8.94	9.00	9.03	91		88	88	89
	7			9.50	8.86	9.64			93	87	75
	8			9.73	8.66	0.30			95	84	3
	9			8.56	1.04				86	9	

Date	Depth (m)	DO (mg/L) at Site:					DO (%) at Site:				
		1	2	3	4	5	1	2	3	4	5
09/30/08	0.5	10.56	11.63	10.81	11.89	11.50	99	110	104	115	111
	1	10.34	11.74	10.59	11.83	11.42	96	111	99	115	110
	2	10.28	11.38		11.68	10.98	96	107		114	106
	3	10.19	11.14	20.41	11.33	9.90	94	105	195	109	95
	4	10.16	10.93	10.12	9.85	9.51	94	103	96	94	91
	5	10.10	10.68	10.02	9.16	9.37	93	100	95	86	89
	5.5	10.01					92				
	6		10.45	9.60	9.04	8.93		98	91	86	85
	7		10.14	9.71	9.39	8.07		95	92	89	76
	8		9.14	9.99	9.30	7.83		85	94	86	73
	9			10.18		8.69			95		81
	10			9.87		9.07			91		84
	11					9.46					88
	12					9.53					89
	13					9.56					89
	14					9.46					88
	15					9.25					86
	16					7.65					71
	17					7.03					65
	18					7.80					72
	19					8.08					74
	20					7.70					71
	21					2.80					33
	22					0.56					5
	23					0.51					4
10/14/08	0.5	12.95	12.68	9.82	9.32	8.65	102	112	87	82	76
	1	12.60	12.65	9.77	9.33	8.73	99	110	87	83	77
	2	12.51	12.44	9.63	9.29	8.69	99	104	86	82	77
	3	12.53	12.10	9.67	9.31	8.69	99	98	85	82	77
	4	12.56		9.76	9.30	8.71	99		85	82	77
	5	12.72		9.68	9.33	8.74	100		85	83	77
	6			9.43	9.34	8.74			82	83	77
	7			10.69	9.34	0.84			91	83	12
	7.5			7.49					67		
	8				9.79	0.21				84	2
	9				11.72					98	
	10				0.18					2	

Appendix C:

pH and Specific Conductance Profile Data

pH and Specific Conductance Profile Data

Date	Depth (m)	pH at Site:					Specific Conductance at Site:				
		1	2	3	4	5	1	2	3	4	5
7/9/2008	0.5	7.56	7.57	7.5	7.21	7.39	301	290	285	286	289
	1	7.19	7.37	7.4	7.19	7.41	300	285	285	287	290
	2	7.08	7.36	7.36	7.18	7.42	302	286	285	287	290
	3	7.16	7.31	7.23	7.19	7.45	303	286	289	287	290
	4	7.14	7.24	7.12	7.12	7.44	303	287	293	288	290
	5	7.11		7.12	7.12	7.38	304		291	292	290
	6			7.12	7.05	7.27			288	291	291
	7			7.19	7				289	293	
	8			7.07	6.95				296	296	
	9			6.84	6.86				316	305	
	10			6.78	6.8				331	316	
	11			6.72	6.77				346	324	
	12			6.7	6.76				350	343	
	13			6.73	6.72				349	364	
	14			6.73	6.71				351	367	
	15			6.73					351		
	16			6.73					353		
	17			6.75					354		
	18			6.76					356		
7/22/2008	0.5	8.3	8.57	8.54	8.67	8.64	251	273	275	275	27
	1	7.81	8.54	8.57	8.62	8.67	245	272	274	274	270
	2	7.58	8.36	8.3	8.48	8.61	244	263	263	272	267
	3	7.41	8.26	8.13	8.37	8.59	245	269	258	269	264
	4	7.34	7.79	7.96	8.07	8.46	246	251	265	267	264
	5	7.32		7.99	7.86	8.31	245		260	264	263
	6			7.86	7.72	8.08			262	266	263
	7			7.87	7.65	7.83			258	263	265
	8			7.8	7.59	7.6			251	260	267
	9			7.75	7.52	7.45			248	258	269
	10			7.77	7.55	7.33			247	253	270
	11			7.75	7.64	7.25			246	249	269
	12			7.74	7.68	7.15			245	247	270
	13			7.72	7.22				245	269	
	14				7.06					278	

Date	Depth (m)	pH at Site:					Specific Conductance at Site:				
		1	2	3	4	5	1	2	3	4	5
08/05/08	0.5	7.32	8.12	8.20	7.90	7.99	122	126	131	133	135
	1	7.22	8.05	8.02	7.90	7.94	122	126	128	131	133
	2	7.09	7.92	7.87	7.86	7.96	121	125	128	130	132
	3	7.03	7.74	7.42	7.73	7.95	121	125	126	130	132
	4	6.95	7.46	7.39	7.64	7.89	121	124	125	130	132
	5		7.41	7.26	7.67	7.88		125	125	131	132
	6		7.20	7.22	7.65	7.87		123	124	131	132
	7				7.16	7.86				129	132
	8				7.10	7.23				129	132
	9				7.03	7.03				124	132
	10				7.00	6.96				125	132
	11					6.91					132
	12					6.88					132
	13					6.80					133
	14					6.74					135
	15					6.72					135
	16					6.65					141
	17					6.58					157
	18					6.54					158
	19					6.57					155
	20					6.53					153
	21					6.49					153
	22					6.46					149
	23					6.42					150
08/20/08	0.5	7.99	8.90	8.88	8.78	8.45	162	161	161	160	161
	1	7.93	8.68	8.72	8.62	8.52	162	161	161	161	161
	2	7.94	8.63	8.59	8.59	8.55	162	161	161	161	161
	3	7.96	8.59	8.61	8.50	8.55	162	161	161	161	161
	4	7.93	8.42	8.61	8.10	8.55	162	164	161	163	161
	5	7.95	7.87	8.63	7.83	8.59	162	168	161	164	161
	6	7.94	7.52	8.52	7.70	8.55	162	169	159	164	161
	7				7.68	8.55				165	161
	8				7.65	8.52				165	161
	9				7.65	8.26				165	162
	10				7.69	8.44				165	162
	11				7.64	7.83				165	162
	12				7.52	7.63				165	164
	13				7.50	7.44				165	164
	14				7.52	7.27				165	164
	15				7.38	7.21				165	164
	16				7.04	7.15				165	164
	17				7.02	7.34				164	164
	18				7.02	7.30				163	164
	19				7.04					164	
	20				7.06					164	
	21				7.06					164	
	22				7.10					164	

Date	**Depth (m)**	**pH at Site:**					**Specific Conductance at Site:**				
		1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
09/02/08	0.5	7.92	8.44	8.37	8.26	7.96	156	156	160	161	162
	1	7.87	8.33	8.17	8.15	7.93	157	158	160	161	161
	2	7.88	8.10	8.05	8.00	7.87	156	159	161	160	162
	3	7.86	8.17	8.07	8.00	7.89	156	155	160	161	162
	4	7.89	7.82	8.07	7.95	7.88	157	153	160	161	162
	5	7.90	7.27	8.10	8.04	7.86	156	152	160	161	162
	6			8.11	8.08	7.87			160	160	162
	7			7.96	8.11	7.88			157	160	162
	8			7.83	8.11	7.85			155	161	162
	9			7.81	8.08	7.86			155	160	162
	10			7.78	7.91	7.86			155	161	162
	11				7.61	7.60				163	163
	12				7.65	7.21				160	164
	13				6.90	7.24				161	164
	14				6.79	7.21				166	164
	15					7.25					162
	16					7.07					171
	17					7.06					163
	18					7.01					168
	19					7.01					169
	20					6.91					167
	21					6.82					169
	22					6.82					169
	23					6.82					170
09/17/08	0.5	7.64	7.94	8.31	8.23	8.39	167	161	114	161	161
	1	7.55	7.92	8.28	8.22	8.23	167	162	116	161	161
	2	7.23	7.80	8.08	7.95	8.01	170	163	121	162	162
	3	7.05	7.35	7.54	7.70	7.90	171	164	129	162	162
	4	6.98	7.18	7.44	7.49	7.77	172	165	139	162	163
	5	6.97		7.34	7.41	7.74	174		142	162	163
	6	6.97		7.26	7.33	7.60	173		151	161	163
	7			7.32	7.29	7.38			156	161	164
	8			7.35	7.25	6.92			160	162	190
	9			7.21	6.78				165	214	

Date	Depth (m)	pH at Site:					Specific Conductance at Site:				
		1	2	3	4	5	1	2	3	4	5
09/30/08	0.5	7.80	8.13	8.07	8.29	7.79	217	202	189	186	186
	1	7.49	7.91	7.86	8.06	7.78	218	203	189	186	185
	2	7.38	7.78		7.89	7.74	218	205		186	185
	3	7.40	7.73	15.29	7.85	7.54	220	298	380	186	186
	4	7.41	7.74	7.62	7.62	7.48	220	290	190	186	187
	5	7.41	7.64	7.62	7.51	7.46	221	211	190	187	186
	5.5	7.34					221				
	6		7.64	7.54	7.44	7.36		211	194	189	187
	7		7.60	7.55	7.47	7.22		212	198	195	190
	8		7.14	7.60	7.44	7.17		211	202	199	195
	9			7.54		7.20			207		198
	10			7.38		7.23			210		200
	11					7.30					202
	12					7.33					203
	13					7.35					205
	14					7.33					206
	15					7.26					205
	16					7.13					202
	17					7.06					204
	18					7.09					205
	19					7.08					208
	20					7.04					208
	21					6.85					213
	22					6.55					281
	23					6.35					292
10/14/08	0.5	7.76	7.98	7.57	7.44	7.49	242	213	207	207	207
	1	7.40	7.83	7.52	7.46	7.40	242	211	207	206	207
	2	7.43	7.84	7.53	7.45	7.49	242	225	207	207	208
	3	7.44	7.69	7.54	7.46	7.45	241	243	208	208	208
	4	7.42		7.52	7.47	7.46	243		210	207	208
	5	7.43		7.54	7.46	7.50	242		209	207	207
	6			7.46	7.44	7.44			210	207	207
	7			7.48	7.47	7.09			229	207	214
	7.5			7.11					278		
	8				7.44	6.99				212	225
	9				7.60					229	
	10				7.00					238	