Technical Report

2014 Localized Treatment of Long Gulch Cove in Iron Gate Reservoir Using Hydrogen Peroxide Based Algaecide

Prepared for

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April 2015

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1.0 INTRODUCTION

On February 18, 2010, the United States, the States of California and Oregon, PacifiCorp, regional 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 (i.e., J.C. Boyle, Copco 1, Copco 2, and Iron Gate dams) will advance restoration of the salmonid fisheries of the Klamath Basin and is in the public interest (which includes effects on local communities and tribes).

The KHSA includes provisions for 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.

Watercourse Engineering, Inc. (Watercourse), under contract to PacifiCorp, conducted a series of bench studies (in 2008, 2009, and 2011) to assess the potential use of algaecide as part of an overall algae management strategy in Copco and Iron Gate reservoirs on the Klamath River (Deas *et al*. 2009; Deas *et al*. 2012). The use of algaecide to treat the entire reservoir or even a large portion of the reservoir is not being considered at this time. Algaecide application would be considered as a potential management tool in isolated areas of the reservoirs; for example, where algae accumulations might otherwise impact recreational access or use.

These bench studies consisted of laboratory-based testing of two types of algaecide on collected samples of site-specific reservoir water to assess the effectiveness of algaecide application at different dosing conditions. The two tested algaecides included a copper-based algaecide, Algimycin PWF, and a hydrogen peroxide-based algaecide, GreenClean PRO. However, only the hydrogen peroxide-based algaecide is being assessed because it is effective at low concentrations where no toxic effects are expected, breaks down rapidly in the environment to oxygen and water, and is not expected to cause adverse effects to humans or the environment when label directions are followed (EPA 2014). Hydrogen peroxide is non-persistent, has no mutation resistance, there is no bioaccumulation or sediment accumulation, and has no water use restrictions in treated waters (Biosafe 2011). GreenClean Liquid is EPA approved as a biopesticide[1] and is NSF/ANSI 60 certified for drinking water. This type of algaecide has been effective in controlling blue-green algae blooms and reducing microcystin concentrations (Matthijs *et al*. 2011). Further information on these tested algaecides is provided below in Section 2.2.

The bench studies indicated that algaecide could be effective in improving water quality by reducing algal concentrations and associated microcystin levels (microcystin is a toxin that can be produced by blue-green algae species). However, these lab-based bench tests

[1] Biopesticied definition can be found at http://www.epa.gov/oppbppd1/biopesticides/whatarebiopesticides.htm.

were performed under controlled conditions that are not fully representative of in-situ conditions in the natural setting. As such, in September 2012, a limited pilot application of hydrogen peroxide-based algaecide (GreenClean Liquid) was conducted in Copco Cove in Copco reservoir in order to evaluate the algaecide's effectiveness under the natural conditions of the reservoir (e.g., wind factors, advective influences, etc.).

The results of the 2012 pilot application study indicated that GreenClean Liquid is effective in reducing blue-green algae in the reservoir environment and reducing microcystin concentrations (Watercourse 2013). Response patterns of total nitrogen (TN) and total phosphorus (TP) concentrations mirrored the response of chlorophyll *a*, *Aphanizomenon flos-aquae*, and *Pseudoanabaena sp.* indicating that a large component of total nutrients were in their organic form at the time of treatment. Reductions in these constituents indicated that the application of the hydrogen peroxide-based algaecide was effective in reducing the overall levels of algal cells. In addition, algaecide treatment led to modest increases in nitrate-plus-nitrite (NO3+NO2) and phosphate (PO4) concentrations. These increases were assumed to be a consequence of reduction in algal uptake and release of inorganic nutrients from algal cell death and lysis.

Based on the recommendations from the 2012 pilot study, the study was repeated in 2013 in an isolated portion of Long Gulch Cove in Iron Gate reservoir. The results of the 2013 pilot application study indicated that GreenClean Liquid is effective in reducing blue-green algae in a confined reservoir environment and may potentially reduce microcystin concentrations. Reductions in chlorophyll *a* and algal species constituents indicated that the application of the hydrogen peroxide-based algaecide was effective in killing algal cells and reducing their overall levels. Algaecide treatment led to modest increases in NO3+NO2 and PO4 concentrations immediately after treatment. These increases were assumed to be a consequence of reduction in algal uptake and release of inorganic nutrients from algal cell death and lysis. GreenClean Liquid application was also shown to have the potential to reduce microcystin levels within the treated area of the reservoir through several possible mechanisms.

Based on the 2013 findings, as well as previous algaecide experiments, recommendations for future work included:

- Begin application earlier in the year within the isolated area to assess algal management into the summer season.
- Focus evaluation efforts on the effectiveness of algaecide in reducing algal cells by observing the response of chlorophyll *a* and cyanobacteria species to the algaecide application.
- Maintain an application frequency on a weekly or bi-weekly basis

In response to these recommendations, the 2014 study was implemented. This study was completed in Long Gulch Cove in Iron Gate reservoir. A divider curtain, placed in the cove, isolated the treatment area (of approximately 7.5 acres) from the main reservoir

area. All treatments in 2014 employed GreenClean Liquid, and associated monitoring was carried out.

This report is organized into several sections. Section 1 provides an introduction. Section 2 includes background information of conditions in the Klamath Basin, the use of algaecide treatment as a possible management strategy, and previous algaecide studies. Section 3 describes methodology, including the study location, algaecide application procedures, and sampling procedures. Section 4 describes study results, followed by a discussion in Section 5. Section 6 summarizes conclusions and provides several recommendations for future consideration. Section 7 includes references, and there is an appendix that includes additional data in tabular and graphical form.

2.0 BACKGROUND

Detailed background information regarding algae production effects in the Klamath River, various algaecides, and the potential effects of algaecide are presented in Watercourse (2013). A brief summary is included herein.

2.1 Algae Production Effects in the Klamath River

Algae are a key component of aquatic systems, playing a vital role in food webs and producing oxygen through photosynthesis. However, excessive and/or persistent phytoplankton blooms can impair water quality. Algae can cause taste and odor problems in drinking water and can produce toxins that can affect wildlife, livestock, or humans via contact or ingestion. Algae can also present filter clogging challenges in water treatment and irrigation facilities and lower the aesthetic appeal and recreational use of surface waters. In addition, when toxins are involved, reservoirs and other surface waters may be posted with public health warnings, as has been the case with Copco and Iron Gate reservoirs and portions of the Klamath River.

The Klamath River is nutrient-enriched due to large loads of nutrients and organic matter introduced to the river from hypereutrophic Upper Klamath Lake and other upstream sources. These nutrients help to cause seasonal algae blooms in the reservoirs along the Klamath River, including Iron Gate reservoir where this experiment was completed. Extensive seasonal algae blooms have been known to directly affect key water quality constituents in lakes and reservoirs, including dissolved oxygen (DO), pH, and nutrients, among others (Horne and Goldman 1994). The algal community in Iron Gate reservoir consists of diatoms, golden-brown algae, green algae, dinoflagellates, cryptomonads, microflagellates, and cyanobacteria (blue-green algae, BGA). Inter-annual variations are typical; as is the timing of the onset and decline of algae blooms (see Raymond 2008; 2009; 2010).

Cyanobacteria are of particular concern in reservoir management because they can produce undesirable toxins, including the hepatotoxin microcystin, which can, at a sufficient dose, affect the liver of animals, including humans. Cyanobacteria that can produce microcystin are *Microcystis aeruginosa*, *Anabaena flos-aquae*, *Planktothrix*

(*Oscillatoria*), *Nostoc*, *Hapalosiphon*, *Anabaenopsis, and Pseudoanabaena* (World Health Organization (WHO) 1999; Oudra *et al*. 2002).

Characteristics of cyanobacteria that make their management challenging include the ability of these species to tolerate elevated water temperatures, reproduce at high rates, regulate their buoyancy, and, for certain species, the ability to fix atmospheric nitrogen dissolved in the water. These characteristics can combine to create intensive bloom conditions for cyanobacteria populations. Heterogeneous (or "patchy") distributions, accumulation of shoreline mats, wind driven accumulations, variability in toxin production, and other factors contribute to the management challenge.

2.2 Algaecides

Algaecides are a common technique for management and control of overabundant algae in ponds, lakes, and reservoirs. Algaecides kill algae either by direct toxicity or through metabolic interference. Algaecide treatment can provide rapid removal of algae from the water column, sometimes resulting in dramatic short-term reductions in algal standing crop and improvements in water clarity. Algaecides are typically applied several times throughout periods of algae growth to prevent or reduce algal blooms. Application frequency is a function of the lake or reservoir management objective and the type of algaecide used (Cooke *et al*. 2005).

For this study, a peroxide-based algaecide was applied. Hydrogen peroxide is non-persistent and there is no bioaccumulation or sediment accumulation of the product because it degrades into water and oxygen (Ding *et al*. 2012; Environmental Protection Agency (EPA) 2012). Because hydrogen peroxide exists naturally in lacustrine environments where it is generated photochemically from organic products in the presence of sunlight (Cooper and Zika 1983; Scully *et al*. 1995; 1996), it is environmentally benign (Antoniou *et al*. 2005; Qian *et al*. 2012). Hydrogen peroxide can selective remove toxic or nuisance cyanobacteria in surface waters and Drábková *et al.* (2007) suggest that because "cyanobacteria are prokaryotic, and lacking organelles for photosynthesis appear to be more sensitive to hydrogen peroxide than other species of phytoplankton, such as green algae or diatoms".

Hydrogen peroxide acts as an oxidizing agent that inhibits algal growth by altering algal physiological and biochemical processes (Samuilov *et al*. 2004; Qian *et al*. 2010; 2012), specifically, algal mortality, chlorophyll content, cellular soluble protein, microcystin synthesis, carbon assimilation, and photosynthetic activity (Drábková *et al*. 2007; Ding *et al*. 2012; Qian *et al*. 2012). Finally, hydrogen peroxide can also destroy toxins that are released upon the lysis of cyanobacterial cells (Svrcek and Smith 2004).

Local studies of algaecide have occurred over several years, commencing with bench-top studies prior to pilot in-reservoir applications. In 2008 and 2009 bench-top studies were conducted with water samples taken from Copco reservoir to investigate the effects of higher dosages and re-application of GreenClean PRO on the algae species present. The performance of the liquid version of GreenClean PRO, GreenClean Liquid, was similarly tested in 2011. Findings from these studies can be found in Deas *et al*. (2012). In 2012, a

field test occurred in a 4.7 acre area of Copco reservoir at Copco Cove (Watercourse 2013). In 2013, two algaecide treatments using GreenClean Liquid were performed in the late-summer and fall behind the barrier curtain at Long Gulch in Iron Gate reservoir (Watercourse 2014). The reservoir treatments using GreenClean Liquid in 2012 and 2013 were completed by Clean Lakes, Inc.

GreenClean Liquid, like GreenClean PRO, is produced by BioSafe Systems, LLC, and is a hydrogen peroxide-based alternative to copper-based algaecide and algaecides with other toxic chemicals as their active ingredient. In California and Oregon, there are no usage restrictions associated with the use of GreenClean Liquid, which contains sodium carbonate peroxyhydrate (SCP) as its active ingredient. SCP is a stabilized form of hydrogen peroxide that is paired with peroxyacetic acid (PAA). PAA is a compound made up of hydrogen peroxide and acetic acid. This compound is an activated form of hydrogen peroxide and acts as a more stable and powerful oxidizer (Larose *et al*. 2008). The combination of hydrogen peroxide and PAA causes an oxidation reaction that breaks down or damages algae cell walls (Knox 2009). The reaction works quickly (seconds to minutes), reducing the likelihood of mutational resistance. In water, SCP rapidly dissociates into hydrogen peroxide and sodium carbonate. Sodium carbonate is subsequently neutralized to sodium bicarbonate. Hydrogen peroxide is normally short-lived and does not persist in the environment – the half-life for this process is approximately eight hours (USDA 2014). As the reaction takes place, hydrogen peroxide and PAA break down into natural compounds: water, oxygen and elements of organic acids (Larose *et al*. 2008; EPA 2012). Like hydrogen peroxide, PAA does not persist in the environment (Knox 2009). Further, the concentration of PAA in GreenClean Liquid is extremely low (on the order of 0.0000033-0.000083 molar for the manufacturer's listed range of application rates) (V. Choppakatla, *pers. comm*.).

2.3 Consideration of Potential Hydrogen Peroxide-Based Algaecide Effects

The use of hydrogen peroxide algaecides above their recommended dosages may impact aquatic species; however, EPA (2002) identifies that when SCP "is applied in accordance with directions on the label, no harm is expected to birds, other terrestrial animals, freshwater fish, or freshwater invertebrates", and several algaecides are designed for use in the treatment of fish ponds and other water bodies that contain fish (BioSafe 2012, USDA 2014). Oxygen depletion in the water column may follow algaecide application due to the decomposition of dead algae. Nutrient concentrations can increase or decrease following algaecide applications. Also, because cyanotoxins are stored intracellularly, algaecide treatments could lead to releases of intercellular toxin to surrounding waters (Kenefick *et al*. 1993; Jones and Orr 1994; Touchette *et al*. 2005). This can be a concern in drinking water supply conditions in which physical treatment methods (e.g., settling, filtration) are the primary treatment mechanism, since these methods may not be expected to be effective at removing dissolved constituents. However, the release of intracellular microcystis does not impact public health notifications applicable to Klamath project reservoirs since public health criteria are assessed using total toxin concentrations – including both intracellular and dissolved toxins.

More recent studies specific to the application of hydrogen peroxide examine toxin release associated with cell lysing and the fate of microcystin. Fan *et al*. (2013) presents information on cell lysing and damage, identifying that hydrogen peroxide application damages only a portion of the cells and many remain intact. Research by Barrington *et al*. (2013) and Matthijs *et al*. (2011) has also indicated that hydrogen peroxide application to cyanobacteria blooms can rapidly reduce both cyanobacteria (as indicated by chlorophyll *a*) and microcystin concentrations in water bodies while promoting more favorable phytoplankton assemblages. These studies are consistent with the idea that hydrogen peroxide, a strong oxidant, is able to oxidize microcystin during or immediately following cell lysis. Barrington *et al*. (2013) reported that while cell lysing occurred with hydrogen peroxide application, total microcystin was reduced for up to three weeks following treatment. Further, dissolved microcystin continued to decrease to non-detectable levels a few days after treatment. Because hydrogen peroxide oxidizes out the system quickly (e.g., hours), these declines in microcystin concentrations may be due to ultraviolet light (UV) radiation, bacterial activity or other environmental factors. Reductions are increased where UV is present (Qiao *et al*. 2005; Matthijs *et al*. 2011; Bandala *et al*. 2004; Cornish *et al*. 2000). The persistence of hydrogen peroxide in aquatic environments is short, which may limit the effectiveness of hydrogen peroxide at degrading microcystin from recently lysed cells (Fan *et al*. 2013, Qiao *et al.* 2005). Other research (Lawton *et al*. 1999; Liu *et al*. 2002; Rodrıguez *et al*. 2007; 2008) has demonstrated that the products of the oxidation of forms of microcystin (-LR and –RR congeners) are non-toxic, and thus no longer present a danger for public health. Though hydrogen peroxide treatment may lead to cell lysing, this in itself does not increase total microcystin.

Other concerns expressed with algaecide treatment has been that nutrients will be released as a result of cell lysis and contribute to additional algal growth. Nutrient release upon cell lysis and cell death will occur with any algaecide or pesticide application. Additionally, algal growth in Klamath River reservoirs is not nutrient-limited such that additional bioavailable nutrients would exacerbate seasonal algal conditions. Further, cell lysis will result in some algal biomass sinking to the reservoir bottom, where nutrients within the biomass will not be available in the photic zone for uptake as algal biomass. Regardless, in the worst case, released nutrients would only be able to form the same amount of cyanobacteria that was eliminated through treatment.

3.0 METHODOLOGY

This section describes the study location, algaecide application procedure, and the sampling approach associated with the in-situ pilot application of GreenClean Liquid, which utilizes SCP as its active ingredient, conducted in Long Gulch Cove of Iron Gate reservoir in June and July of 2014.

The 2014 study in Long Gulch used application and sampling plans similar to the 2013 and 2012 study. There were four total treatments that occurred in 2014 (June 24, July 1, July 15, and July 29), compared to two treatments in 2013 (September 11 and October 2).

Per the recommendations from the 2013 Long Gulch Cove study, sampling within Long Gulch Cove focused on the chlorophyll *a* and cyanobacteria densities, microcystin, and other constituents as required by the General Permit (water temperature, dissolved oxygen, pH, electrical conductance, and turbidity). Secchi depth was also collected within the treatment area as well as outside the treatment area, and public health sampling was collected from shore both inside and outside the curtain in 2014.

3.1 Study Location

Long Gulch Cove (Figure 1) in Iron Gate reservoir was selected as the study location based on its size, accessibility, and the amount of algae observed. Conducting the study in Long Gulch Cove utilized the natural shape of the cove to limit water movement and potential exposure to wind. Additionally, a divider curtain was deployed in the cove to isolate the treatment area (of approximately 6.5 acres) from the main body of the reservoir. The curtain, consisting of Type 2 DOT, yellow vinyl-coated polyester, was assembled in place in sixteen 50 foot sections with a total length of 800 feet (Figure 2). Each of the sixteen sections was fabricated to extend from surface to a maximum depth of approximately 35 feet. The curtain was deployed using surface floats and anchors to maintain position.

Figure 1. Aerial view of Iron Gate reservoir that includes the location of Long Gulch Cove (Google Earth).

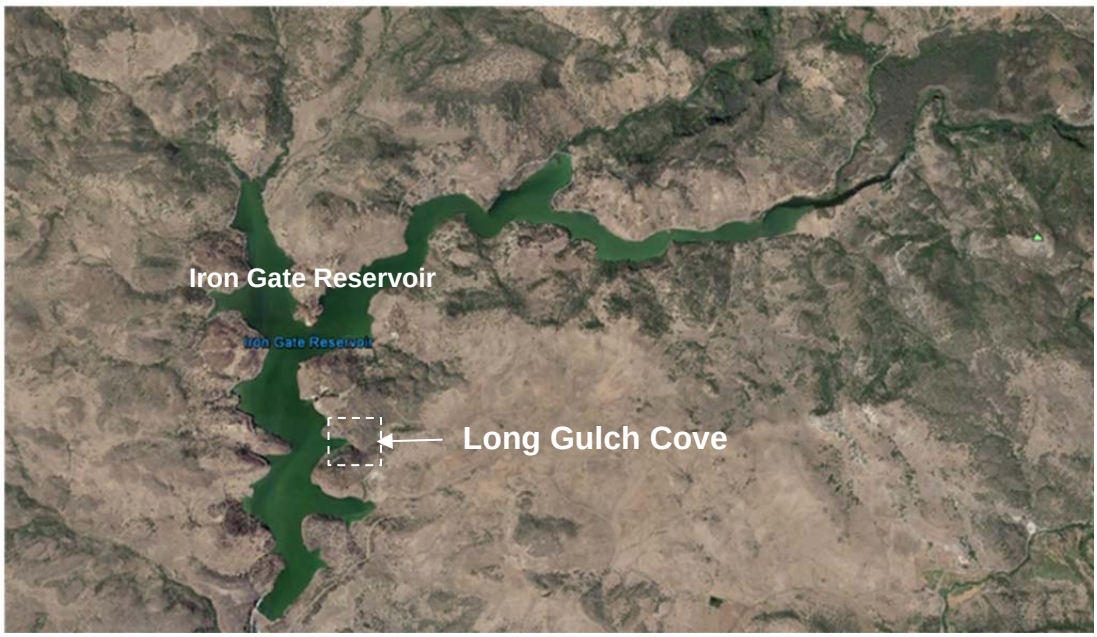


Figure 2. Curtain installed to isolate a portion of Long Gulch Cove.

3.2 Algaecide Application Procedures

The algaecide used for the study was GreenClean Liquid (EPA Registration No. 70299-2), which is manufactured by BioSafe Systems, LLC (BioSafe). The algaecide application was performed by Clean Lakes, Inc. (CLI) on June 24, July 1, July 15, and July 29, 2014. The application of algaecide was conducted in compliance with:

- California Department of Pesticide Regulation (DPR).
- State Water Resources Control Board (SWRCB) Water Quality Order No. 2013-0002-DWQ, which is the Statewide General National Pollutant Discharge Elimination System Permit for the Discharge of Aquatic Pesticides for Aquatic Weed Control in Waters of the United States (General Permit No. CAG990005).

GreenClean Liquid, contained in 275-gallon totes, was delivered to the Pacific Power facility in Yreka, California on the mornings of June 24, July 1, July 15, and July 29, 2014. CLI staff delivered the totes to the Long Gulch Cove boat ramp. At the boat ramp, CLI staff transferred GreenClean Liquid from the delivery totes to the treatment vessel using a closed system algaecide transfer procedure. On the morning of each application date the information board located at Long Gulch Cove was posted with a notice informing the public that algaecide application was taking place.

Algaecide application at Long Gulch Cove occurred from 11:42 am to 12:32 pm on June 24, from 9:30 am to 10:25 am on July 1, from 9:20 am to 11:10 am on July 15, and from 9:20 to 10:45 on July 29 (Table 1). CLI utilized a LittLine® Littoral Zone Treatment vessel for algaecide application. The isolated area of Long Gulch Cove covered approximately 6.5 acres of water surface area.

For each treatment, the top 13 feet (4.0 meters) of the water column was treated, corresponding to the approximate photic zone. The upper 6 feet (1.8 meters) of the water column were treated at an active ingredient concentration of 3.0 ppm, leading to a treatment volume of 39 acre-feet. A total of 139 gallons of GreenClean Liquid was applied in the upper 6 feet, which amounts to 3.6 gallons per acre-feet. This dosage corresponds to the specimen label application rate for medium density (filamentous) algae conditions (BioSafe 2012). The water column from 6 to 13 feet (1.8 to 3.9 meters) below the surface was treated at an active ingredient concentration of 2.0 ppm, leading to a treatment volume of 24.5 acre-feet. A total of 59 gallons of GreenClean Liquid was applied at this deeper depth, which amounts to 2.4 gallons per acre-feet. This deeper treatment dosage corresponds to the algaecide label application rate for low density (filamentous) algae conditions (BioSafe 2012). After algaecide application, empty algaecide drums were triple rinsed into the application vessel's pesticide tanks. Rinsed drums were then transported by CLI to their disposal facility in Martinez, CA for removal per DPR regulations.

Table 1. Treatment dates, depths, areas, volumes, and concentrations for 2014 treatments.

Date	Treatment Time	Treatment Depth (ft)	Treatment Area (acre-ft)	Treatment Volume (gal)	Treatment Concentration (ppm)
06/24/2014	11:42 - 12:32	0 – 6	63.5	198	3.0
		6 – 13			2.0
07/01/2014	9:30 - 10:25	0 – 6	63.5	198	3.0
		6 – 13			2.0
07/15/2014	9:20 - 11:10	0 – 6	63.5	198	3.0
		6 – 13			2.0
07/29/2014	9:20 - 10:45	0 – 6	63.5	198	3.0
		6 – 13			2.0

3.3 Sampling Approach

Grab samples and physical measurements were collected at three treatment locations located within the treated area (Figure 3). The sampling locations were identified using a Garmin Oregon® 450 Geographic Positioning System (GPS) prior to pre-treatment sampling. The coordinates were recorded in the GPS and later used to position the boat when samples were taken. A summary of the sampling location coordinates are included in Appendix A. At each location, all constituents were collected near the surface at 0.3 feet (0.1 meter), with the exception of chlorophyll *a* which was also collected at 3 feet (0.9 meter) below the surface. Grab samples were collected at 0.3 feet (0.1 meter) by following the Public Health sampling procedures (SWRCB 2010). The Van-Dorn Sampler was used to collect the chlorophyll *a* samples at 3 feet (0.9 meter) depth.

In addition to grab samples, measurements of water temperature, dissolved oxygen (DO), pH, electrical conductance, turbidity, and Secchi depth were measured. To measure these

water quality constituents, CLI used the Horiba Model U-10 probe. E&S Environmental Chemistry, Inc. (E&S) used the In-situ troll 9500 (#45654), and PacifiCorp used the Yellow Springs Incorporated (YSI) EXO sonde with a four-parameter sensor (#599102-01). Each sonde was calibrated prior to measurements on the day of use. Water quality probe resolution and accuracy for each constituent and sampling entity is found in Appendix A.

CLI and E&S collected grab samples at Long Gulch Cove based on the PacifiCorp's QAPP and SOP on June 24. CLI collected the grab samples using the same sampling procedures on July 1, July 15, and July 29. Watercourse and E&S collected samples for the one-week post on July 8. E&S collected samples for the one-week post on July 23. Finally, PacifiCorp and E&S collected samples for the one-week post on the last sampling day, August 4.

Microcystin and algae samples were shipped to Watercourse, located in Davis, CA. From there the microcystin samples were cataloged, frozen, and shipped overnight to Tamarack Environmental Laboratories, LLC in Sault Sainte Marie, Michigan. All samples were stored, transported, or shipped on ice or refrigerated. Algae species samples were sent to Aquatic Analyst (P.I. Jim Sweet) in Friday Harbor, Washington. Laboratory information associated with each constituent is included in Table 2.

Figure 3. Sampling locations for in-situ algaecide study in 2014 (denoted 'T'). 'N Curtain' and 'S Curtain' denotes the approximate northern and southern anchor point for the curtain. The dashed line represents the approximate location of the curtain in Long Gulch Cove.

Table 2. Laboratory methods, method detection limits (MDL), and reporting limits (RL), as applicable for each constituent. Physical water quality parameters also presented.

Constituent	Units	Method	Preservative	MDL	RL	Laboratory
Chlorophyll *a*	µg/l	EPA[a] 445.0	None	1 ppb	1 ppb	Biogeochemistry Laboratory, U.C. Davis
Microcystin	mg/l	ELISA[b]	None	0.16	n/a	Tamarack Environmental Laboratory
Species	cell count, biovolume	Direct count[c]	Lugols	n/a	n/a	Aquatic Analysts

[a] Environmental Protection Agency.
[b] USEPA Region 9 SOP 1305 (Envirologix ELISA method).
[c] Standard Methods, 1992, 10200.F.2.c.

4.0 RESULTS

The response of algae to algaecide treatments in the 2014 Long Gulch pilot study was assessed qualitatively through visual observations, and quantitatively through water quality samples. Results from the four test applications in Long Gulch Cove are summarized below and the discussion of these results is presented in Section 5. All data are included in Appendix A.

4.1 Visual Observations

Visual observation of the site were created to qualitatively document the water conditions at the three sampling locations for pre, post, and one week sampling events. These observations included monitoring area, appearance of waterway, weather conditions, presence/absence of floating or suspended matter, water discoloration, bottom deposits, aquatic life, visible films or coating, objectionable growths, and potential nuisance conditions. The tabulated notes for pre-, post and one week post-treatment conditions for the June 24, 2014 treatment are shown in Table 3. Tabulated information for all treatments is included in Appendix B. The observations are required under the General Permit, and provide a qualitative description of field conditions for comparison through time. For example, in July, multiple large wildfires generated clouds of smoke.

Table 3. Visual observations for treatment #1, Pre-, Post, and One Week Post-treatment, June 24 2014.

Visual Observation	T1-Pre	T1-Post	T1-One Week
1. Monitoring area description (pond, lake, open waterway, channel, etc.)	LAKE	LAKE	LAKE
2. Appearance of waterway (sheen, color, clarity, etc.)	LIGHT GREEN	GREEN	LIGHT GREEN
3. Weather conditions (fog, rain, wind, etc.)	WARM, SUNNY, 5% CLOUDS	SUNNY, WINDY	COOL, CLEAR, NO WIND
4. Floating or suspended matter (presence/absence)	AQUATIC WEEDS	PRESENCE	PRESENCE
5. Discoloration (high, medium, low)	LOW	MEDIUM	LOW
6. Bottom deposits (fine, coarse, organic)	FINE, ORGANIC	ORGANIC	ORGANIC
7. Aquatic life (presence/absence)	NONE	PRESENCE (SMALL FISH)	PRESENCE - FISH
8. Visible films, sheens, or coatings (presence/absence)	NONE	ABSENCE	ABSENCE
9. Fungi, slimes, or objectionable growths (presence/absence)	FILAMENTOUS ALGAE ALONG SHORELINE	ABSENCE	PRESENCE
10. Potential nuisance conditions (high, medium, low)	LOW	LOW	LOW

4.2 Water Quality

Water quality consisted of grab samples of chlorophyll *a*, algae species, and microcystin. Additionally, water samples for public health monitoring are collected in accordance with the *Standard Operating Procedures, Environmental Sampling of Cyanobacteria for cell enumeration, identification and toxin analysis* (Cyanobacteria SOP, KBGAWG 2009). This SOP, developed for the Klamath River by the Klamath BGA Workgroup, is posted on the KBMP website (www.kbmp.net). Spot measurements of physical parameters and Secchi disk depths were also collected.

4.2.1 Algae: Chlorophyll *a*, Algae Species, and Microcystin

Algae response to the treatment was assessed using chlorophyll *a*, enumeration of cyanobacteria (BGA) species, and microcystin concentrations collected via grab samples.

4.2.1.1 Chlorophyll a

Chlorophyll *a* concentrations ranged from a minimum of 2.11 ppb to a maximum of 102.08 ppb throughout the experiment. Generally, concentrations increased through the duration of the study period. For treatment #1 (June 24) the chlorophyll *a* concentrations ranged from 2.33 to 5.53 ppb at the two depths: 0.3 feet (0.1 meter) and 3 feet (0.9 meters) below the surface for pre-event conditions. Generally, chlorophyll *a* concentrations decreased during the post-event sampling, with concentrations for the one-week post event sampling showing notable decrease from pre-event sampling (range: -40 percent to 33 percent; average: -14 percent). Chlorophyll *a* concentrations for treatment #2 (July 1) ranged from 2.15 to 3.33 ppb pre-event. Chlorophyll *a* concentrations did not change notably in the post-event sampling; however, concentrations increased in the one-week post-event sampling at all sites, with increases ranging from 42 to 158 percent (average: 103 percent) over the pre-event conditions. For treatment #3 (July 15) the chlorophyll *a* concentrations ranged from 5.36 to 8.58 ppb. At all sites the chlorophyll *a* concentration increased 128 to 287 percent (average: 212 percent) from the pre-event to the one-week post event. The chlorophyll *a* for treatment #4 (July 29) concentrations had increased an average of 39 percent over the July 23 values (one week post-treatment for treatment #3 to pre-event of treatment #4). On July 29, the pre-event chlorophyll *a* concentrations ranged from 17.93 to 44.10 ppb (Figure 4, Table 4). At all sites the chlorophyll *a* concentration decreased from between 8 and 64 percent (average: 37 percent decrease) from the post-event to the one-week post event. At Site T1, post-event chlorophyll *a* concentrations increased from the pre-treatment to post treatment from 34.62 to 102.08 ppb, most likely due to sampling heterogeneity and incorporation of a locally high concentration of algae.

Figure 4. Chlorophyll *a* concentrations at sampling locations T1, T2, and T3 for the treatment events on June 24, July 1, July 15, July 29, 2014 at two depths: 0.3 feet (0.1 meter) and 3 feet (0.9 meters) below the surface.

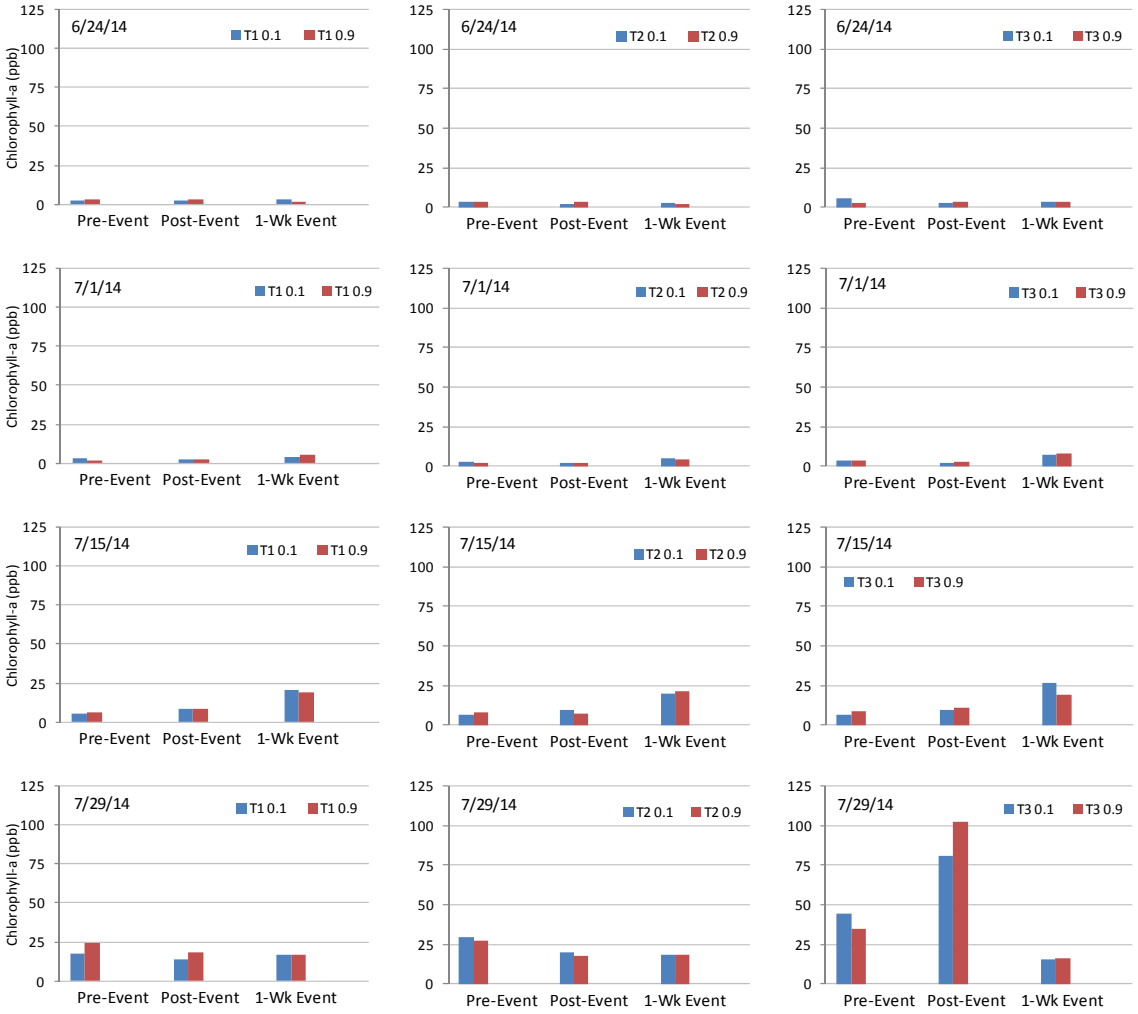


Table 4. Chlorophyll *a* concentration at sampling locations T1, T2, and T3 for the treatment events on June 24, July 1, July 15, July 29, 2014 at two depths: 0.3 feet (0.1 meter) and 3 feet (0.9 meters) below the surface.

			Chlorophyll *a* (ppb)		
Date	Location	Depth (ft)	Pre-Event	Post-Event	One-Week
6/24/2014	T1	0.3 (0.1 m)	2.33	2.55	3.10[a]
	T1	3 (0.9 m)	3.50	2.95	2.15[a]
	T2	0.3 (0.1 m)	3.42	2.11	3.04[a]
	T2	3 (0.9 m)	3.26	3.29	2.34[a]
	T3	0.3 (0.1 m)	5.53	2.96	3.33[a]
	T3	3 (0.9 m)	3.18	3.35	3.29[a]
7/1/2014	T1	0.3 (0.1 m)	3.10	2.90	4.39[b]
	T1	3 (0.9 m)	2.15	2.58	5.55[b]
	T2	0.3 (0.1 m)	3.04	1.97	5.33[b]
	T2	3 (0.9 m)	2.34	2.44	4.29[b]
	T3	0.3 (0.1 m)	3.33	2.50	7.36[b]
	T3	3 (0.9 m)	3.29	2.69	7.83[b]
7/15/2014	T1	0.3 (0.1 m)	5.36	8.53	20.49[c]
	T1	3 (0.9 m)	6.49	8.52	19.17[c]
	T2	0.3 (0.1 m)	6.44	9.32	19.80[c]
	T2	3 (0.9 m)	7.88	7.68	21.30[c]
	T3	0.3 (0.1 m)	6.97	9.46	26.96[c]
	T3	3 (0.9 m)	8.58	10.77	19.52[c]
7/29/2014	T1	0.3 (0.1 m)	17.93	13.83	16.57[d]
	T1	3 (0.9 m)	24.37	18.27	16.90[d]
	T2	0.3 (0.1 m)	29.52	19.67	18.26[d]
	T2	3 (0.9 m)	27.53	18.07	18.66[d]
	T3	0.3 (0.1 m)	44.10	80.77	15.80[d]
	T3	3 (0.9 m)	34.62	102.08	16.57[d]

Note: Laboratory analysis was performed by Chesapeake Biological Laboratory. Method Detection Limit is 0.18 parts per billion (ppb).
[a] collected on 7/1/14
[b] collected on 7/8/14
[c] collected on 7/23/14
[d] collected on 8/4/14

4.2.1.2 Algae Species

Six types of algae species groups were identified in water samples taken from Long Gulch Cove: cyanobacteria (blue-green algae), chrysophyte (golden brown algae), cryptophyte, diatom, dinoflagellate, and green algae. Only cyanobacteria data are presented and algae species enumeration was limited due to concern for toxin production.

Algae species densities for *Microcystis aeruginosa* (MSAE), *Aphanizomenon flos-aquae* (AFA), *Anabaena flos-aquae* (ANAB), and *Gloeotrichia echinulata* (GLOE) were analyzed. Other ANAB species were detected (e.g., planctonica, circinalis), but are not presented in this section due to low cell counts. Algae density is presented in cells per milliliter (cells/mL). Outlined below is a general discussion of these BGA species present though the study period. The results for BGA are presented in Figure 5 and results for MSAE are presented Table 5; the results for the other BGA are presented in Appendix A.

While several BGA species were present during the study, not all were consistently present. Herein, the focus is on MSAE, AFA, ANAB, and GLOE, the most consistently present species. MSAE cell counts were used to identify conditions throughout the study period. MSAE was not detected in the treatment #1 (June 24) and treatment #2 (July 1) samples. For treatment #3 (July 15) the pre-treatment cell counts for MSAE ranged from 3,999 to 11,284 cells/mL. Cell counts increased during the post-event sampling, with one-week post event sampling cell counts ranging from 15,198 to 36,964 cells/mL, representing an increase ranging from 280 to 379 percent (average: 296 percent increase). By July 29, cell counts had increased an average of 40 percent over the July 23 values (one-week post treatment for treatment #3) – consistent with the 39 percentage increase identified in the chlorophyll *a* data. For treatment #4 (July 29) the MSAE cell counts ranged from 29,982 to 50,154 cells per mL, and one-week post-event samples ranged from 3,522 to 18,434 cells/mL, representing a decrease ranging from -31 to -88 percent (average: 61 percent decrease).

AFA was detected in one sample on June 24; the sample result was 518 cells/mL. AFA was not detected in any samples on July 1. Cell counts ranged from 64 to 1,754 cells/mL for treatment #3 (July 15); 397 to 4,349 cells/mL for treatment #4 (July 29). Cell counts decreased during the sampling one-week following treatment with cell counts ranging from 52 to 1,121 cells/mL, representing a decrease – of 10 to 84 percent (average: 52 percent decrease). ANAB was detected in one sample on June 24 with a result of 1,361 cells/mL. ANAB ranged from 43 to 2,983 cells/mL for treatment #2 (July 1); and 29 to 256 cells/mL for treatment #4 (July 15). ANAB was not detected during treatment #4 (July 29) or in the subsequent one-week post samples collected on July 23 and August 4. GLOE was detected on July 8 during the one-week post treatment for treatment #2. GLOE densities ranged from 125 to 16,833 cells/mL on July 15 and from 79 to 58,252 cells/mL on July 29. Similar to AFA, GLOE increased from the pre-event to the post event on July 29 and decreased on August 4. GLOE densities ranged from 79 to 58,252 cells/mL during the study period. All data for AFA, ANAB, and GLOE are included in Appendix A.

Figure 5. Blue-green algae (BGA) densities at sampling locations T1, T2, and T3 for the treatment events on June 24, July 1, July 15, July 29, 2014. Red line represents the 40,000 cell/mL CA public health posting guideline for *Microcystis aeruginosa* (SWRCB 2010).

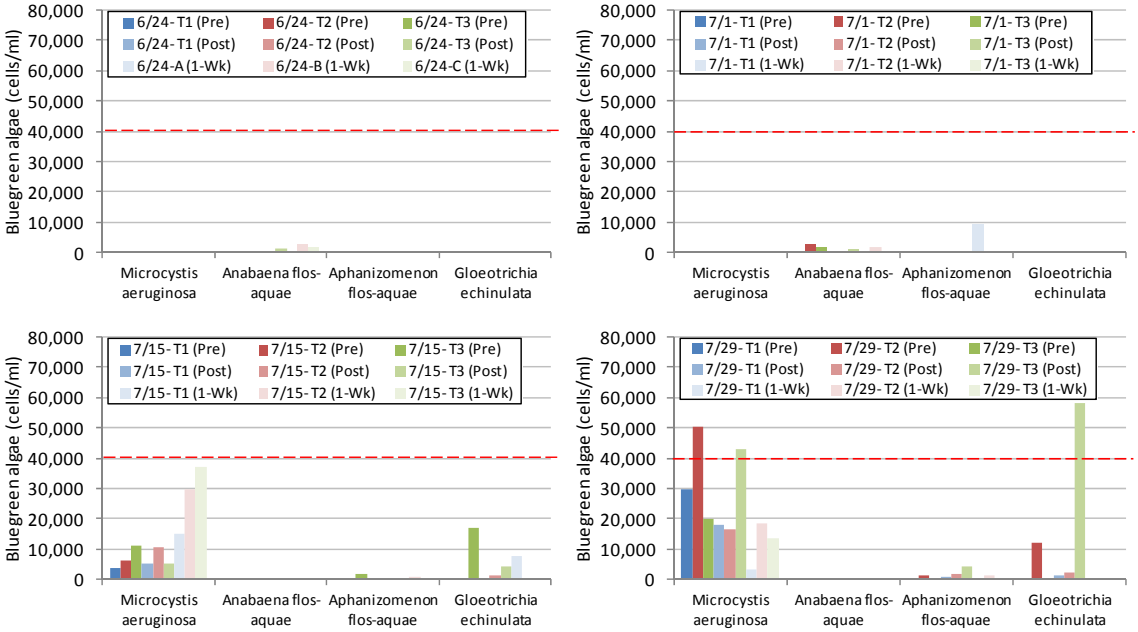


Table 5. *Microcystis aeruginosa* density (cells/mL) at sampling locations T1, T2, and T3 for the treatment events on June 24, July 1, July 15, July 29, 2014.

			Microcystis aeruginosa (cell count)		
Date	**Location**	**Depth (ft)**	**Pre-Event**	**Post-Event**	**One-Week Post**
6/24/2014	T1	0.3	-	-	-[a]
	T2	0.3	-	-	-[a]
	T3	0.3	-	-	-[a]
7/1/2014	T1	0.3	-	-	-[b]
	T2	0.3	-	-	333[b]
	T3	0.3	-	-	334[b]
7/15/2014	T1	0.3	3,999	5,485	15,198[c]
	T2	0.3	6,237	10,599	29,892[c]
	T3	0.3	11,284	5,108	36,964[c]
7/29/2014	T1	0.3	29,982	18,143	3,522[d]
	T2	0.3	50,154	16,619	18,434[d]
	T3	0.3	19,794	42,796	13,662[d]

[a] collected on 7/1/14
[b] collected on 7/8/14
[c] collected on 7/23/14
[d] collected on 8/4/14

4.2.1.3 Microcystin

Microcystin concentrations ranged from a minimum of 0.16 µg/L to a maximum of 2.90 µg/L throughout the study period. Generally, concentrations increased through the study period. Microcystin data are presented in Figure 6 and Table 6.

For treatment #1 (June 24), pre-event microcystin concentrations ranged from 0.16 to 0.31 µg/L. Concentrations generally decreased during the pre-event sampling with the one-week post event sampling ranging from 0.16 to 0.21 µg/L, with changes from a 13 percent increase to a 48 percent decrease (average: 19 percent decrease).

The pre-event microcystin concentrations for treatment #2 (July 1) ranged from 0.16 to 0.21 µg/L. Concentrations generally increased from the pre-event sampling to the one-week post event sampling with a range from 0.16 µg/L to 0.24 µg/L, representing changes from a 5 percent decrease to a 33 percent increase (average: 10 percent increase). There was a two week period between treatment #2 and #3, and during the second week (July 8 to July 15) concentrations increased between 83 to 150 percent (average: 126 percent). There was a two week period between treatment #2 and #3, and during the second week (July 8 to July 15) concentrations increased between 83 to 200 percent (average: 144 percent).

For treatment #3 (July 15) pre-event microcystin concentrations ranged from 0.39 to 5.0 µg/L. Concentrations increased during the pre-event to the one-week post event sampling, which ranged from 2.4 to 2.9 µg/L, representing an increase ranging from 380 to 644 percent (average: 501 percent increase). There was a two week period between treatment #3 and #4, and during the second week (July 22 to July 29) concentrations decreased between 9 to 35 percent (average: 26 percent).

Treatment #4 (July 29) was the final application and pre-event microcystin concentrations ranged from 0.23 to 1.02 µg/L. Concentrations decreased from the pre-event to the one-week post event sampling, ranging from 0.56 to 0.73 µg/L, representing a decrease ranging from 65 to 91 percent (average: 75 percent decrease).

Figure 6. Microcystin concentrations (µg/L) at sampling locations T1, T2, and T3 for the treatment events on June 24, July 1, July 15, July 29, 2014.

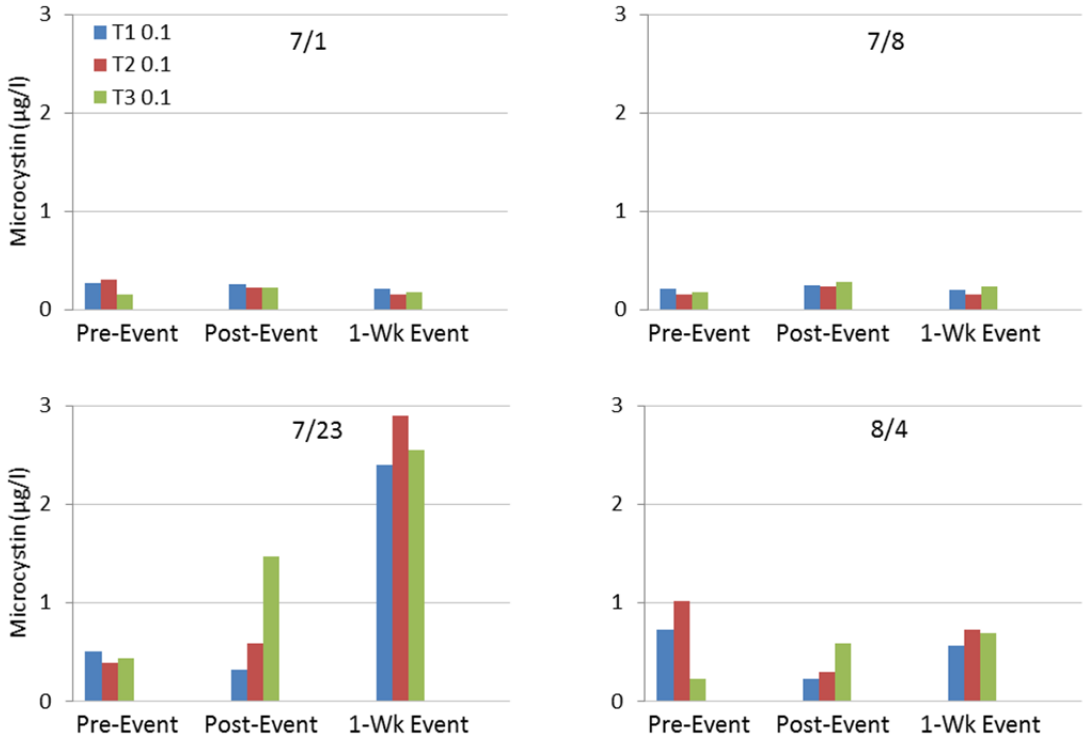


Table 6. Microcystin concentrations (µg/L) at sampling locations T1, T2, and T3 for the treatment events on June 24, July 1, July 15, July 29, 2014.

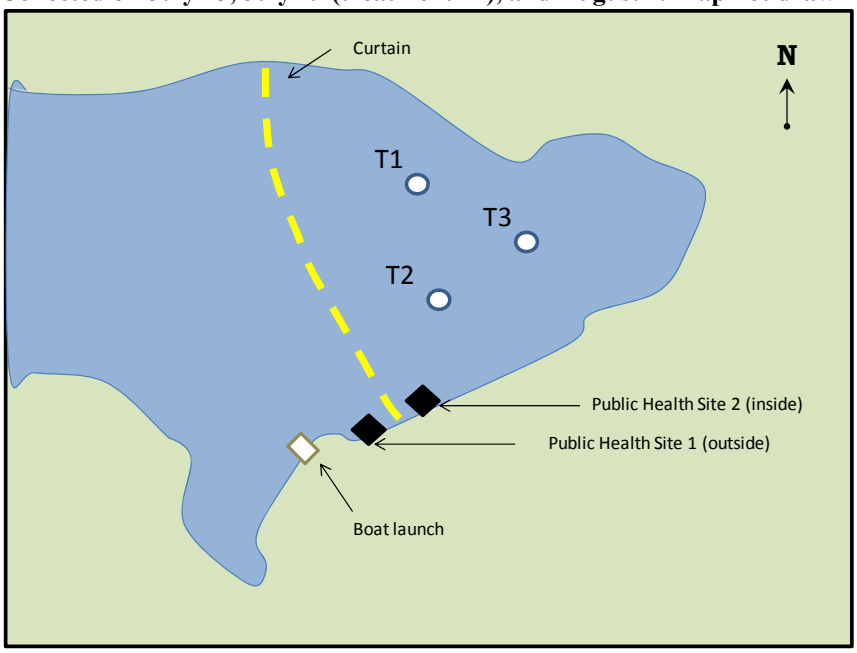
Date	Location	Depth (ft)	Microcystin (µg/l)		
			Pre-Event	Post-Event	One-Week
6/24/2014	T1	0.3	0.27	0.26	0.21[a]
	T2	0.3	0.31	0.23	0.16[a]
	T3	0.3	0.16	0.22	0.18[a]
7/1/2014	T1	0.3	0.21	0.25	0.20[b]
	T2	0.3	0.16	0.24	0.16[b]
	T3	0.3	0.18	0.28	0.24[b]
7/15/2014	T1	0.3	0.50	0.32	2.40[c]
	T2	0.3	0.39	0.58	2.90[c]
	T3	0.3	0.44	1.47	2.55[c]
7/29/2014	T1	0.3	0.72	0.23	0.56[d]
	T2	0.3	1.02	0.29	0.73[d]
	T3	0.3	0.23	0.59	0.69[d]

[a] collected on 7/1/14
[b] collected on 7/8/14
[c] collected on 7/23/14
[d] collected on 8/4/14
[†] Method detection limit (MDL) for microcystin is 0.16 µg/l. Samples were sent to Tamarack Environmental, Inc. in Michigan.

4.2.2 Public Health Samples

Shoreline areas inside and outside the curtain were sampled consistent with the public health protocols on July 23, July 29, and August 4 and processed for algae species and microcystin (Figure 7). The three dates represent one week post-event sample (treatment #3), pre-event and one week post-event sample (treatment #4), respectively. These shoreline samples were collected to provide information on the reservoir conditions near the shoreline inside and outside of the treated area. Results for algae species and microcystin are discussed below.

Figure 7. Map of the public health sampling locations (inside and outside curtain near the shore). Collected on July 23, July 29 (treatment #4), and August 4. Map not drawn to scale.



4.2.2.1 Public Health: Algae Species

The algae species most prevalent were MSAE and GLOE, with MSAE being the only species identified as present in all samples. MSAE densities ranged from 29,400 to 236,775 cells/mL and GLOE densities ranged from 226 to 83,014 cells/mL. AFA densities ranged from 631 to 11,213 cells/mL and ANAB densities ranged from 452 to 1,495 cells/mL (Table 7). MSAE cell counts were higher inside the curtain on July 23, July 29 and lower on August 4. GLOE densities were highly variable inside and outside the curtain, and AFA and ANAB cell counts were variable and/or not detected.

MSAE cell counts outside the curtain remained approximately stable from July 29 to August 4 (82,146 to 84,733 cells/mL), while inside the curtain, there was an 88 percent reduction (236,214 to 29,400 cells/mL). AFA cell counts outside the curtain reduced from 40 percent (1,060 to 631cells/mL), while AFA inside the curtain, there was a 93 percent reduction (11,213 to 780 cells/mL). There was no ANAB detected outside the curtain, while inside the curtain there was 70 percent reduction (1,495 to 452 cells/mL). GLOE cell counts increased 892 percent (636 to 6,308 cells/mL) outside the curtain,

while inside the curtain there was 99 percent reduction (35,818 to 226 cells/mL). MSAE public health cell counts for MSAE were notably higher than at the treatment sampling water sites, ranging from 29,400 to 236,214 cells/mL for public health sample sites and 3,522 to 50,154 cells/mL for the treatment sites.

Table 7. Blue-green algae species densities (cells/mL) for the public health sampling approach collected inside and outside the curtain on July 23, July 29, and August 4. MSAE = *Microcystis aeruginosa*; AFA = *Aphanizomenon flos-aquae*; ANAB = *Anabaena flos-aquae*; GLOE = *Gloeotrichia echinulata*

Date	Time	Location	Algae Species (cells/mL)			
			MSAE	AFA	ANAB	GLOE
7/23/2014	12:15	Outside Curtain	135,868	44,116	-	15,891
7/23/2014	12:20	Inside Curtain	216,480	-	-	-
7/29/2014	8:03	Outside Curtain	82,146	1,060	-	636
7/29/2014	9:06	Inside Curtain	236,214	11,213	1,495	35,818
8/4/2014	8:00	Outside Curtain	84,733	631	-	6,308
8/4/2014	8:56	Inside Curtain	29,400	780	452	226

4.2.2.2 Public Health: Microcystin

Microcystin concentrations outside the curtain were higher than inside the curtain for two of three samples. Prior to treatment #4 (July 29), the concentration was higher inside the curtain than outside the curtain. On August 4, the concentration was higher outside the curtain than inside the curtain; the concentration increased from 0.55 to 2.42 µg/L (340 percent increase) outside the curtain, and increased from 1.17 to 1.60 µg/L (37 percent increase) inside the curtain (Table 8). Overall, concentrations were greater along the shoreline than at the open water sites, ranging from 1.17 to 4.54 µg/L at shoreline sites and 0.23 to 2.90 µg/L for the open water sites.

Table 8. Microcystin concentration (µg/L) for the public health samples collected inside and outside the curtain on July 23, July 29, and August 4. (2014)

Date	Time	Location	Microcystin (µg/L)
7/23/2014	12:15	Outside curtain	11.90
7/23/2014	12:20	Inside curtain	4.54
7/29/2014	8:03	Outside curtain	0.55
7/29/2014	9:06	Inside curtain	1.17
8/4/2014	8:00	Outside curtain	2.42
8/4/2014	8:56	Inside curtain	1.60

4.2.2.3 Secchi Disk

Secchi disk depth measurements were taken at each sampling location as a proxy for water clarity. Recorded Secchi disk depths on June 24 were 3.6 feet (1.1 meters) at all location. On July 1, the Secchi disk measurements ranged from 12.5 to 13.8 feet (3.8 to 4.2 meters) and 11.8 to 13.1 feet (3.6 to 4.0 meters) on July 15. Secchi disk depths on July 29 ranged from 7.6 to 9.5 feet (2.3 to 2.9 meters). Secchi depth increased from the

pre-event to the one-week post for treatment #1 (June 24). Secchi depth decreased from the pre-event to the one week post-event for subsequent treatments.

Table 9. Secchi disk measurements for the sampling locations for the treatment events. Note: July 8, July 23, and August 4 represent the one week post-treatment days.

		Secchi Depth (ft)		
Date	**Location**	**Pre-Treatment**	**Post- Treatment**	**One-Week Treatment**
6/24/2014	T1	3.6 (1.1 m)	3.6 (1.1 m)	12.5 (3.8 m)[a]
	T2	3.6 (1.1 m)	3.6 (1.1 m)	13.1 (4.0 m)[a]
	T3	3.6 (1.1 m)	3.6 (1.1 m)	13.8 (4.2 m)[a]
7/1/2014	T1	12.5 (3.8 m)	13.1 (4.0 m)	10.8 (3.3 m)[b]
	T2	13.1 (4.0 m)	12.8 (3.9 m)	10.8 (3.3 m)[b]
	T3	13.8 (4.2 m)	13.8 (4.2 m)	9.8 (3.0 m)[b]
7/15/2014	T1	12.5 (3.8 m)	12.8 (3.9 m)	5.9 (1.8 m)[c]
	T2	12.1 (3.7 m)	12.5 (3.8 m)	4.9 (1.5 m)[c]
	T3	11.8 (3.6 m)	11.8 (3.6 m)	3.3 (1.0 m)[c]
7/29/2014	T1	9.5 (2.9 m)	7.6 (2.3 m)	5.9 (1.8 m)[d]
	T2	8.2 (2.5 m)	7.9 (2.4 m)	5.6 (1.7 m)[d]
	T3	8.9 (2.7 m)	7.6 (2.3 m)	5.9 (1.8 m)[d]

[a] collected on 7/1/14
[b] collected on 7/8/14
[c] collected on 7/23/14
[d] collected on 8/4/14

4.2.3 Physical Data: Water Temperature, Dissolved Oxygen, pH, Electrical Conductance, and Turbidity

Physical data were collected to record general background conditions present during the treatment experiment. Results are briefly described herein and data are included in Appendix A.

Water temperatures ranged from 21.7 to 23.5°C in late June and 24.9 to 25.0°C in early August. Water temperature increased throughout the experiment. Dissolved oxygen concentrations ranged from 8.1 to 9.4 mg/L in late June and 12.9 to 14.3 mg/L in early August. DO concentrations increased throughout the experiment. As with temperature and DO, pH increased through the pilot project period, ranging from 7.6 to 9.0 in late June to 9.9 at all sites in early August. Electrical conductance and turbidity both decreased through the study. Electrical conductance ranged from 298 to 318 µS/cm in late June and from 157 to 158 µS/cm in early August. Turbidity ranged from 9 to 10 NTU in late June and 3 to 4 NTU in early August.

5.0 DISCUSSION

In 2014, the objective of the study was to build on the findings presented in the 2013 algaecide treatment in Long Gulch Cove. Specifically, the goals were to continue the treatment of an isolated cove, assess the efficacy of multi-depth treatments, and target early season conditions with multiple treatments to manage blue-green algae conditions. In 2014, four algaecide treatments occurred from June 24 to July 29. The study focused primarily on chlorophyll *a* concentrations, blue-green algae speciation, and microcystin

concentration. The study is a continuation of work that dates back to the series of bench-top tests (Deas *et al*. 2012), the 2012 pilot application study in Copco Cove (Deas *et al*. 2013), and an initial test in 2013 in Iron Gate reservoir (Watercourse 2014).

During the 2014 algaecide application study, the same technical objectives were studied in an isolated in-situ reservoir setting. This section includes a brief review on the study events and sampling location and findings on algal growth (i.e. chlorophyll *a*, algal species, microcystin, public health samples) and water quality physical parameters (i.e., water temperature, dissolved oxygen, pH, electrical conductance, and turbidity).

5.1 Study Events and Sampling Locations

For the 2014 study, CLI applied GreenClean Liquid in Long Gulch Cove at two depths, a strategy identified in the 2013 study. CLI treated the first five feet below the surface using 3.0 ppm of hydrogen peroxide algaecide and six to thirteen feet using 2.0 ppm of algaecide to target the photic zone. Four treatments in total were conducted in 2014, on June 24, July 1, July 15, and July 29. While meteorological conditions were typical of summer period weather in the project area, exceptions included the Oregon Gulch wildfire in the Copco reservoir region during July and August. Smoke generated from that wildfire, as well as others in the area, may have impacted algae growth rates as a result of reduced available sunlight.

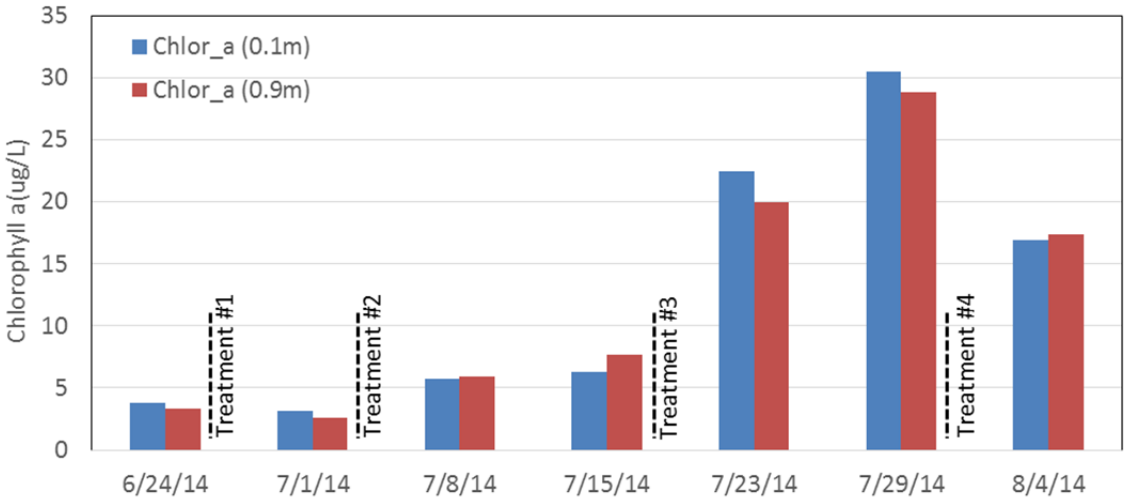
5.2 Water Quality Samples

Chlorophyll *a*, algae species, and microcystin conditions in the project area and response to algaecide application during the study are presented in this section.

5.2.1 Chlorophyll a

Chlorophyll *a* concentrations varied throughout the experiment and generally showed an increase above initial concentrations (Figure 8). Initially low concentrations in the treatment area were consistent with visual observations, where algae were qualitatively assessed as being largely absent. This conditions extended through the second treatment, and conditions were not appreciably different prior to and after treatment #1 or treatment #2. Efficacy of treatments was difficult to assess at these low algae concentrations. Concentrations increased notably a week after treatment #3. The subsequent treatment occurred two weeks later on July 29. During this time chlorophyll *a* concentrations increased markedly and remained elevated until treatment #4, suggesting that the two week gap between treatments was likely too long during this period of the summer. The highest chlorophyll *a* concentrations occurred during this two-week period from July 15 to July 29. Concentrations generally decreased after treatment #4, suggesting the algaecide had effects on lowering chlorophyll *a* concentrations. Other factors that may have contributed to the decrease in concentration could be smoke from the Oregon Gulch fire, natural algae bloom dynamics, seasonal conditions, and other factors (e.g., cyanophage). Conditions were similar at both depths where chlorophyll *a* was sampled (Figure 8).

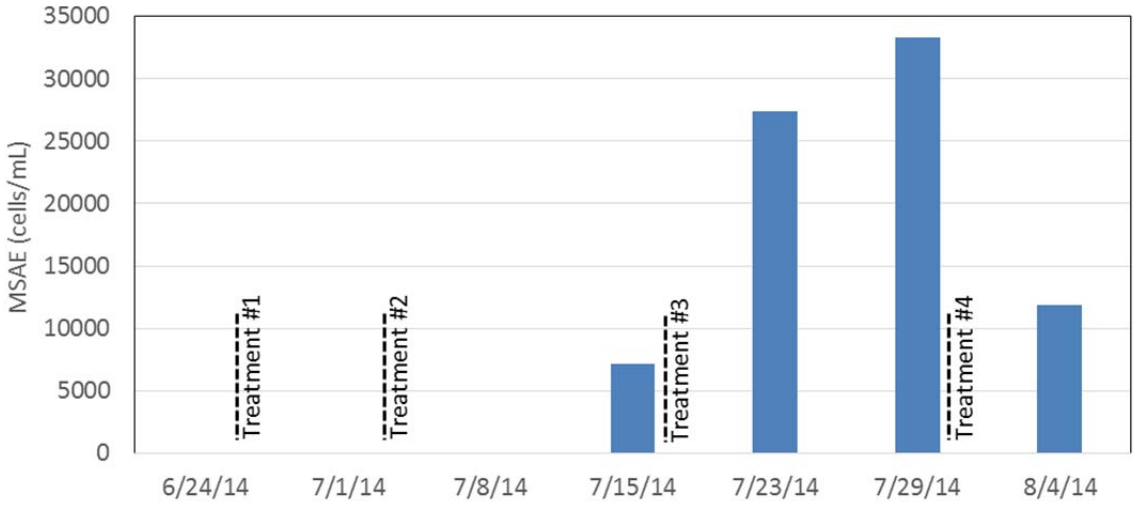
Figure 8. Average chlorophyll *a* of three sampling locations for the pre-event and one week post-event samples (for 0.1 meter and 0.9 meter below the surface) showing the treatment dates. 2014.



5.2.2 Algae Species

BGA species observed during the study include: MSAE, AFA, ANAB, and GLOE. The focus of this discussion will be on the most prevalent and persistent species, MSAE (Figure 9). Similar to chlorophyll *a*, the change to MSAE due to the application of algaecide could not be readily assessed during the first two treatments because of low initial concentrations: a condition confirmed by visual observations. MSAE cell counts increased notably one week after the third treatment (average increase of 296 percent), suggesting the bloom markedly increased during this period. The highest cell count occurred during the two week period from July 15 to July 29. MSAE cell counts decreased (average: 66 percent) a week after treatment #4, suggesting the algaecide had an effect on reducing MSAE cell counts. Additional factors identified above for chlorophyll *a* at the end of the treatment experiment may have contributed to the reduced MSAE following treatment #4.

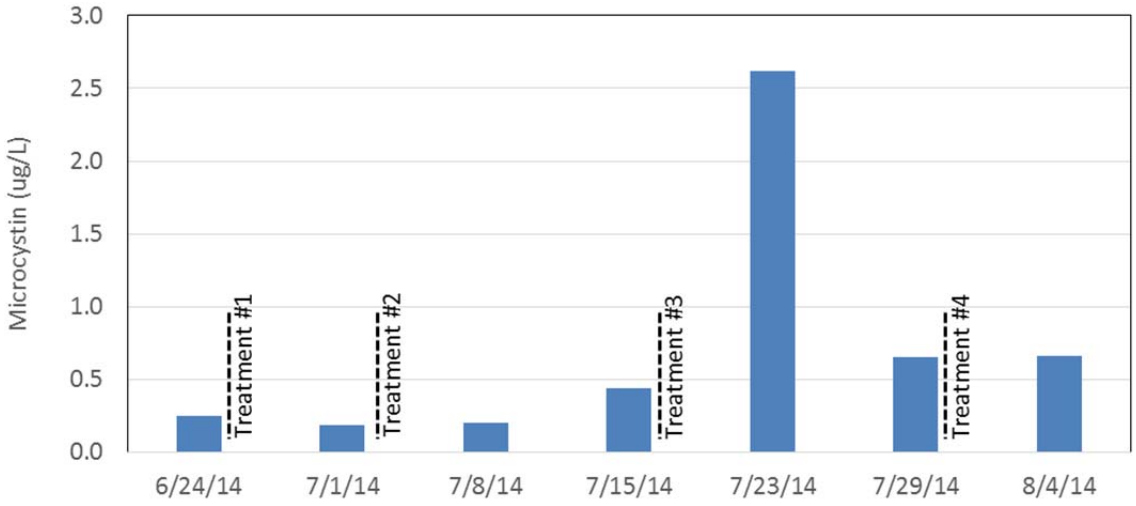
Figure 9. Average MSAE cell count of three sampling locations for the pre-event and one week post-event samples. 2014



5.2.3 Microcystin

Microcystin concentrations followed similar patterns as chlorophyll *a* and MSAE, with low initial concentrations, increasing later in the treatment period, before decreasing again. No notable changes occurred for the first two treatments. On July 23, microcystin increased several-fold, from well under 0.5 µg/L to about 2.5 µg/L. Then, after July 23, microcystin concentrations decreased to levels below 1.0 µg/L and remained at similar low concentrations through August 4. Microcystin concentration did not change from treatment #4, even though chlorophyll *a* and MSAE were lower on August 4. Other factors that may have contributed to the decrease in concentration could be natural algae bloom dynamics, meteorological conditions, as well as aforementioned conditions that may have affected chlorophyll *a* and species counts.

Figure 10. Average microcystin concentration of three sampling locations for the pre-event and one week post-event samples. 2014



5.3 Public Health Monitoring

The public health monitoring program under KHSA Interim Measure 15 includes sampling at public access points to assess algal conditions in the reservoirs as compared to established public health guidelines (see PacifiCorp 2015). Public health samples do not represent average conditions, but usually near-surface, shoreline accumulations. To assess how algaecide treatment may have affected conditions at Long Gulch Cove, similar public health sampling was conducted both inside and outside the curtain. To compare conditions in Long Gulch Cove with other reservoir areas during the treatment period, data from the long-term Camp Creek and John Williams Campground (Table 11) public health sampling locations were examined (June 24, July 9, and July 22).

Comparisons of the data suggest that there were differing conditions inside and outside the curtain, with the area outside the curtain being exposed to, and potentially reflecting, the larger reservoir conditions (Watercourse 2014). Inside the Long Gulch curtain, concentrations were higher initially, then decreased by an order of magnitude in early August, while outside the curtain concentrations decreased earlier (July 29) and then remained relatively constant. No clear relationship between concentrations inside and outside the curtain was observed.

The data from Camp Creek and John Williams Campground indicate increasing algal concentrations from late June to late July. However, these two sites also experienced heterogeneity in that cell counts increased by a factor of five at Camp Creek from July 9 to July 22 (25,387 to 125,839 cell/mL), while cell counts increased by four orders of magnitude at John Williams Campground (5,891 to 35,633,333 mg/L). In comparison, the results obtained from samples collected within Long Gulch Cove pursuant to the algaecide application study showed relatively stable cell counts that did not exhibit large variability. Additionally, cell counts were relatively stable or decreasing in the Long Gulch samples as compared to the increasing concentrations observed at Camp Creek and John Williams sampling sites.

While drawing conclusions from these small sample sets is challenging, the data illustrate a wide range of conditions occurring not only at Long Gulch Cove, but at other public health sampling locations in Iron Gate reservoir.

Table 10. MSAE (cells/mL) and microcystin (µg/L) cell counts at Long Gulch Cove.

Date	Long Gulch Inside (cells/mL) | (µg/L)	Long Gulch Outside (cells/mL) | (µg/L)
7/23/2014	216,480 | 4.54	135,868 | 11.90
7/29/2014	236,214 | 1.17	82,146 | 0.55
8/4/2014	29,400 | 1.60	84,733 | 2.42

Table 11. MSAE (cells/mL) and microcystin (µg/L) cell counts at Camp Creek and John William Campground (two public health sampling sites). Sampling dates: June 24, July 9, and July 22, 2014.

Date	Camp Creek (cells/mL) | (µg/L)	John Williams Campground (cells/mL) | (µg/L)
6/24/2014	6,085 | 0.30	0 | 0.16
7/9/2014	25,387 | 2.4	5,891 | 0.63
7/22/2014	125,839 | 6.3	35,633,333 | 1,400

5.3.1 Algae Species and MSAE

Analysis focused on the most prevalent algal species, MSAE. MSAE cell counts were notably higher near the shoreline than at the treatment sample locations (e.g., T1, T2, and T3). Shoreline concentrations of BGA are often higher than at open water sites as wind and wave action accumulate the algae in shallow, near-shore areas. MSAE cell counts inside the barrier curtain (along with AFA, ANAB, and GLOE) decreased notably after treatment #4, similar to findings at the open water sites. Generally, the cell counts outside the curtain were lower, but more variable due to lake conditions, while the cell counts were higher inside the curtain, which acted as a 'closed' system. The area outside of the curtain was subject to open lake processes, most notably wind conditions. Conditions inside the curtain were representative of a smaller volume and surface area, and local meteorological conditions. Previous experiments (Watercourse 2014) identified that comparison between open water sites and sites inside the barrier curtain were not necessarily illustrative given the differences between those locations. Further, local morphology of the shoreline area, as well as the barrier position may affect conditions in the sampling vicinity, making direct comparisons challenging.

5.3.2 Microcystin

Microcystin concentrations were higher outside the curtain in two of the three comparisons. Concentrations inside the curtain were higher on July 29 (treatment #4). Shoreline samples had higher concentrations than the open water samples inside the curtain. Microcystin concentrations were higher on July 23 both inside and outside the curtain than at later dates. As a whole, field data were variable, and specific conclusions were difficult to draw due to this variability related to algal dynamics.

5.4 Physical Water Quality Parameters

A discussion of water temperature, dissolved oxygen, pH, electrical conductance, and turbidity results are presented in this section. Review of the pre-event, post-event, and one week post-event data for these parameters did not identify any notable pre-event to post-event changes associated with treatment. Rather, these parameters reflected overall seasonal heating and conditions associated with algal standing crop and associated water quality response, including elevated DO and pH during periods of increased primary production. DO increases were consistent with lake systems where primary production produces super-saturation conditions during day time periods. pH increases through the summer study period were consistent with typical values in the river and reservoirs as a result of relatively low alkalinity and thus the weakly buffered nature of the Klamath

River that is susceptible to photosynthesis driven changes in pH (NCRWQCB 2010). Electrical conductance and turbidity decreased throughout the experiment, similar to findings from previous years.

5.5 Secchi Depth

Secchi depth was generally the same at open water sites for each discrete sampling: pre-event, post-event, and one-week post-event. However, during the experiment, recorded Secchi depths increased notably into mid-July. Subsequently, Secchi depths decreased in late-July and early-August, consistent with observations of greater algae standing crop as indicated by higher chlorophyll *a* values during this period. Secchi depth is a semi-quantitative measure of light extinction in relation to turbidity. Such measurements do not identify how attenuation occurs. Thus, relating Secchi depth to algae standing crop, while insightful, may not provide a direct measure of algal health in the quantitative manner that chlorophyll *a* would.

5.6 Summary

Treatment responses for chlorophyll *a*, algae species, and microcystin were generally consistent. Water quality samples did not change appreciably over the first two treatments due to low initial algal concentrations. Between the third and fourth treatment, a BGA bloom appeared resulting in higher algal concentrations. While algal concentrations did increase after treatment #3 (based on the one-week sample results), the treatment may have affected the growth period of BGA, resulting in lower peak concentrations than what would have been observed had algaecide not been applied. Treatment #4 appeared to reduce algal growth as indicated by chlorophyll *a* and algae species; however, microcystin concentrations had dropped prior to treatment #4. Overall, the first two treatments may have kept concentrations low, but would have been more effective later in the experimental period when more algae were present. Further, another treatment between the second and third, and between the third and the fourth treatments may have kept control the bloom.

6.0 CONCLUSION AND RECOMMENDATIONS

The 2014 study of the application of hydrogen peroxide based algaecide in Long Gulch Cove in Iron Gate reservoir was designed based on information developed from previous studies conducted in 2008, 2009, 2011, and 2012 (Deas *et al*. 2009; 2013).

The 2014 test application Long Gulch Cove addressed several objectives:

- Begin application earlier in the year within the isolated area to assess algal management into the summer season.
- Focus evaluation efforts on the effectiveness of algaecide in reducing algal cells by observing the response of chlorophyll *a* and cyanobacteria species to the algaecide application.
- Maintain an application frequency on a weekly or bi-weekly basis.

Overall, the experiment addressed the objectives described in the 2014 study and provided additional insight on the application of this algaecide to an isolated region of the reservoir. Application of algaecide started before algal blooms, with focused efforts on collecting algal samples. Reductions in chlorophyll *a* and algae species were generally consistent with the previous year's findings. Algae concentrations remained relatively stable prior to mid-July, with a notable increase occurring from July 15 to July 29. Additional treatments during July, or a higher concentration of applied algaecide, would have provided a better assessment in the ability of the algaecide to inhibit algae growth during the peak algal growth periods, but would have required better real-time information on algae concentrations.

Based on the 2014 findings, as well as previous algaecide experiments, recommendations for future work include:

- Continue to perform treatments to inhibit algae growth before the peak of the growth season.
- During the treatment period, it would be beneficial to monitor algae conditions on a daily basis via a water quality monitoring probe in the treatment area to provide information to the applicator regarding when treatments should occur and the appropriate treatment concentration. Changes in the frequency of application may be needed in response to changing conditions.
- Because algaecide treatment concentrations may need to be adjusted during the treatment period based on observed algal bloom conditions, provisions should be made for having sufficient product quantities available on site or in the local area to support varying treatment dosage recommendations.
- To better assess how effective algaecide application was in controlling and/or reducing algal blooms, representative control samples would be helpful. In 2013, control sites were selected outside the isolated area, but pre-treatment samples indicated that the initial water conditions were markedly different inside and outside of the barrier-isolated cove area. Future studies would benefit by including control sites that are located within an isolated area, similar to the treatment area. This would require the isolated area to be divided to create two similar sized isolated areas; one that is treated and one that is not. The control sites could be located in the non-treated area within the isolated area.

Application of algaecide to isolated portions of a reservoir is one possible component of an overall algal management strategy for Copco and Iron Gate reservoirs. Along with its potential effectiveness in reducing or controlling nuisance algae blooms, the costs associated with algaecide application would have to be considered.

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Personal Communications

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Judy Westrick, PhD, Tamarack Environmental Laboratories, LLC. September 24, 2012; December 17, 2012; January 10, 2013; August 31, 2014.

Tom McNabb, Clean Lakes, Inc. September 1, 2012; January 28, 2013; September 22, 2014.

APPENDIX A

Summary Tables of Sampling Locations and Data

This appendix contains summary tables for sampling location coordinates, sampling times, dissolved oxygen (DO) measurements, DO saturation, water temperature, turbidity, Secchi disk readings, reservoir depth, and field data measurements.

A.1 Sampling Location Coordinates

Each sampling location was identified using a Garmin Oregon® 450 Geographic Positioning System (GPS) prior to pre-treatment sampling (Table A-1). The coordinates were recorded in the GPS and later used to position the boat when subsequent samples were collected. This procedure ensured that the location of the pre-event, event, and one-week sampling would consistent.

Table A-1. Approximate coordinates of three sampling locations.

Sampling Location	Coordinates	
T1	41°56'40.25"N	122°25'27.77"W
T2	41°56'37.68"N	122°25'27.59"W
T3	41°56'39.14"N	122°25'25.61"W

A.2 Water Quality Sonde: Water Temperature, Dissolved Oxygen, pH, Specific Conductance, Turbidity

Clean Lakes, Inc. (CLI) collected physical parameter sonde measurements during the treatment events. PacifiCorp and E&S Environmental Chemistry, Inc. (E&S) collected measurements during the one-week post events. A summary of the sondes used for the experiment are presented in Table A-2, Table A-3, and Table A-4.

Clean Lakes, Inc. used the Horiba Model U-10 sonde to collect water temperature measurements. The temperature sensor has an operational range of 0°C to 50°C in water. The results have an accuracy of ±0.3°C.

PacifiCorp used the Yellow Springs Incorporated (YSI) EXO sonde with a four-parameter sensor (#599102-01) which includes phycocyanin (#6131). The temperature sensor has an operational range of -5°C to 50°C in water. The results have an accuracy of ±0.01°C.

E&S used the In-Situ, Inc., Troll 9500 Professional (#45654) water quality probe. The temperature sensor has an operational range of -5°C to 75°C in water. The results have an accuracy of ±0.2°C.

A.3 Dissolved Oxygen (DO)

Clean Lakes, Inc. used the Horiba Model U-10 sonde to collect dissolved oxygen measurements. The DO sensor has an operation range of 0 to 19.9 mg/l in water. The results have an accuracy of ±1 percent of reading or ±0.1 mg/L, whichever is greater.

PacifiCorp used the Yellow Springs Incorporated (YSI) EXO sonde. The DO sensor has an operation range of 0 to 20 mg/l in water. The results have an accuracy of ±1 percent of reading or ±0.1 mg/L, whichever is greater.

E&S used the In-Situ, Inc., Troll 9500 Professional (#45654) water quality probe. The DO sensor has an operation range of 0 to 20 mg/l in water. The results have an accuracy of ±2 percent of reading or ±0.2 mg/L, whichever is greater.

A.4 pH

Clean Lakes, Inc. used the Horiba Model U-10 sonde to collect pH. The pH sensor has an operational range of 0 to 14 units in water. The results have an accuracy of ±0.1 pH unit.

PacifiCorp used the Yellow Springs Incorporated (YSI) EXO sonde. The pH sensor has an operational range of 0 to 14 units in water. The results have an accuracy of ±0.1 pH units.

E&S used the In-Situ, Inc., Troll 9500 Professional (#45654) water quality probe. The pH sensor has an operational range of 0 to 12 pH units in water. The pH sensor has an accuracy of ±0.1 pH units.

A.5 Electrical Conductance

Clean Lakes, Inc. used the Horiba Model U-10 sonde to collect EC. The EC sensor has an operational range of 0 to 100,000 µS/cm in water. The results have an accuracy of ±1% µS/cm.

PacifiCorp used the Yellow Springs Incorporated (YSI) EXO sonde. The EC sensor has an operational range of 0 to 200,000 µS/cm in water. The results have an accuracy of ±1% µS/cm.

E&S used the In-Situ, Inc., Troll 9500 Professional (#45654) water quality probe. The EC sensor has an operational range of 5 to 20,000 µS/cm in water. The EC sensor has an accuracy of ±2 µS or ±0.5% of reading, whichever is greater.

A.6 Turbidity

Clean Lakes, Inc. used the Horiba Model U-10 sonde to collect turbidity. The turbidity sensor has an operational range of 0 to 800 NTU in water. The results have an accuracy of ±3% NTU.

PacifiCorp used the Yellow Springs Incorporated (YSI) EXO sonde. The turbidity sensor has an operational range of 0 to 4,000 NTU in water. The results have an accuracy of ±5% NTU.

E&S used the In-Situ, Inc., Troll 9500 Professional (#45654) water quality probe. The turbidity sensor has an operational range of 0 to 2,000 NTU in water. The results have an accuracy of ±5% NTU.

Table A-2. Water quality parameters for the Horiba Model U-10 water quality sonde (CLI).

Parameters	Units	Resolution	Accuracy
Water Temperature	^{o}C	0 – 50	±0.3
Dissolved Oxygen	mg/L	0 – 19.9	±1 percent or ±0.1
pH	log [H^+]	0 -14	±0.1
Electrical conductance	µS/cm	0 -100,000	±1 percent
Turbidity	NTU[a]	0 - 800	±3 percent

[a] Nephelometric Turbidity Units

Table A-3. Water quality parameters for the YSI EXO water quality sonde (PacifiCorp).

Parameters	Units	Resolution	Accuracy
Water Temperature	^{o}C	-5 – 50	±0.3
Dissolved Oxygen	mg/L	0 – 20	±1 percent or ±0.1
pH	log [H^+]	0 -14	±0.1
Electrical conductance	µS/cm	0 -200,000	±1 percent
Turbidity	NTU[a]	0 – 4,000	±5 percent

[a] Nephelometric Turbidity Units

Table A-4. Water quality parameters for the Troll 9500 Professional water quality sonde (E&S).

Parameters	Units	Resolution	Accuracy
Water Temperature	^{o}C	-5 – 75	±0.2
Dissolved Oxygen	mg/L	0 – 20	±2 percent or ±0.2
pH	log [H^+]	0 -12	±0.1
Electrical conductance	µS/cm	5 -200,000	±2 percent
Turbidity	NTU[a]	0 – 2,000	±5 percent

[a] Nephelometric Turbidity Units

A.7 Depths (Secchi Disk)

Secchi depths were taken at every sampling location for all four treatments.

Table A-5. Secchi disk measurements for the three locations for the treatment events. Note: July 8, July 23, and August 4 represent the one week post-treatment days.

		Secchi Depth (ft)		
Date	**Location**	**Pre-Treatment**	**Post- Treatment**	**One-Week Treatment**
6/24/2014	T1	3.6 (1.1 m)	3.6 (1.1 m)	12.5 (3.8 m)[a]
	T2	3.6 (1.1 m)	3.6 (1.1 m)	13.1 (4.0 m)[a]
	T3	3.6 (1.1 m)	3.6 (1.1 m)	13.8 (4.2 m)[a]
7/1/2014	T1	12.5 (3.8 m)	13.1 (4.0 m)	10.8 (3.3 m)[b]
	T2	13.1 (4.0 m)	12.8 (3.9 m)	10.8 (3.3 m)[b]
	T3	13.8 (4.2 m)	13.8 (4.2 m)	9.8 (3.0 m)[b]
7/15/2014	T1	12.5 (3.8 m)	12.8 (3.9 m)	5.9 (1.8 m)[c]
	T2	12.1 (3.7 m)	12.5 (3.8 m)	4.9 (1.5 m)[c]
	T3	11.8 (3.6 m)	11.8 (3.6 m)	3.3 (1.0 m)[c]
7/29/2014	T1	9.5 (2.9 m)	7.6 (2.3 m)	5.9 (1.8 m)[d]
	T2	8.2 (2.5 m)	7.9 (2.4 m)	5.6 (1.7 m)[d]
	T3	8.9 (2.7 m)	7.6 (2.3 m)	5.9 (1.8 m)[d]

[a] collected on 7/1/14
[b] collected on 7/8/14
[c] collected on 7/23/14
[d] collected on 8/4/14

A.8 Water Quality Sonde Summary Tables

Table A-6. Summary of the physical sonde measurements for June 24.

6/24/2014		Site (0.1 meter)			Site (0.9 meter)		
Constituents	Site	Pre-Treatment	Post-Treatment	One-Week	Pre-Treatment	Post-Treatment	One-Week
Time	T1	9:34	12:59	8:20	9:38	13:00	8:10
	T2	10:05	13:15	10:30	10:02	13:18	10:35
	T3	10:25	13:25	8:38	10:22	13:27	8:42
Tw (degC)	T1	21.9	23.2	23.0	21.7	23.0	23.0
	T2	22.2	23.1	23.8	22.0	23.3	23.4
	T3	22.5	23.5	23.2	22.3	23.4	23.4
DO (%)	T1	108.8	122.7	102.3	112.1	118.7	106.7
	T2	111.5	114.3	106.1	109.8	114.0	103.6
	T3	104.4	122.1	116.7	107.5	116.0	114.2
DO (mg/l)	T1	8.8	9.7	8.1	9.1	9.4	8.5
	T2	9.0	9.0	8.3	8.9	9.0	8.1
	T3	8.4	9.6	9.2	8.6	9.1	9.0
pH	T1	8.7	8.1	8.4	8.4	8.3	8.0
	T2	7.9	8.3	8.6	7.6	8.5	8.7
	T3	8.7	8.8	8.1	8.5	9.0	7.9
EC (µs/cm)	T1	310	302	317	319	300	323
	T2	303	305	311	305	300	326
	T3	298	300	328	300	298	314
Turbidity (NTU)	T1	10	10	15	10	10	18
	T2	10	10	9	10	10	9
	T3	9	9	22	9	10	19

Table A-7. Summary of the physical sonde measurements for July 1.

7/1/2014		Site (0.1 meter)			Site (0.9 meter)		
Constituents	Site	Pre-Treatment	Post-Treatment	One-Week	Pre-Treatment	Post-Treatment	One-Week
Time	T1	8:10	10:30	16:34	8:20	10:35	16:39
	T2	8:38	11:04	16:49	8:42	11:10	16:55
	T3	8:55	11:30	17:02	8:59	11:40	17:04
Tw (degC)	T1	23.0	23.8	26.7	23.0	23.4	26.7
	T2	23.2	24.1	27.2	23.4	23.8	26.6
	T3	23.8	24.4	27.3	24.1	24.1	27.2
DO (%)	T1	102.3	106.1	130.6	106.7	103.6	131.9
	T2	116.7	118.7	142.9	114.2	8.0	134.8
	T3	104.0	121.3	164.6	107.7	118.8	204.7
DO (mg/l)	T1	8.1	8.3	9.5	8.5	8.1	9.6
	T2	9.2	9.2	10.5	9.0	8.9	9.9
	T3	8.1	9.4	11.9	8.4	9.2	14.8
pH	T1	8.4	8.6	9.1	8.0	8.7	9.0
	T2	8.1	8.3	9.1	7.9	8.4	9.1
	T3	8.3	8.7	9.2	8.8	8.8	9.5
EC (µs/cm)	T1	317	311	160	323	326	160
	T2	328	301	160	314	309	160
	T3	291	301	161	295	297	161
Turbidity (NTU)	T1	15	9	2	18	9	3
	T2	22	17	3	19	15	3
	T3	17	11	3	19	9	2

Table A-8. Summary of the physical sonde measurements for July 15. Turbidity sonde malfunctioned; no turbidity data was measured on July 15.

7/15/2014		Site (0.1 meter)			Site (0.9 meter)		
Constituents	Site	Pre-Treatment	Post-Treatment	One-Week	Pre-Treatment	Post-Treatment	One-Week
Time	T1	8:30	11:29	11:18	8:28	11:32	11:23
	T2	8:48	11:48	11:45	8:51	11:50	11:48
	T3	9:04	12:03	11:32	9:07	12:05	11:38
Tw (degC)	T1	28.5	29.1	25.2	28.5	28.9	25.1
	T2	28.4	29.5	25.4	28.3	28.8	25.3
	T3	28.5	29.5	25.4	28.3	29.0	25.6
DO (%)	T1	144.3	154.4	150.9	149.8	159.0	147.1
	T2	148.0	155.0	150.4	147.8	157.9	150.5
	T3	148.8	156.9	140.6	151.1	119.0	144.5
DO (mg/l)	T1	10.3	10.9	11.4	10.7	11.3	11.1
	T2	10.6	10.9	11.3	10.6	11.3	11.4
	T3	10.7	11.0	10.6	10.9	11.4	11.0
pH	T1	9.6	8.7	8.8	9.5	8.3	8.8
	T2	9.3	8.7	8.8	9.1	8.5	8.8
	T3	9.4	8.9	8.7	9.1	8.5	8.7
EC (µs/cm)	T1	224	205	152	216	205	152
	T2	210	204	151	208	203	151
	T3	208	204	153	207	203	153
Turbidity (NTU)	T1	-	-	-	-	-	-
	T2	-	-	-	-	-	-
	T3	-	-	-	-	-	-

Table A-9. Summary of the physical sonde measurements for July 29.

7/29/2014		Site (0.1 meter)			Site (0.9 meter)		
Constituents	Site	Pre-Treatment	Post-Treatment	One-Week	Pre-Treatment	Post-Treatment	One-Week
Time	T1	8:22	11:17	8:20	8:25	11:19	8:23
	T2	8:36	11:48	8:40	8:41	11:52	8:42
	T3	8:55	11:57	8:51	8:59	12:00	8:53
Tw (degC)	T1	25.2	26.3	25.0	25.2	25.3	25.0
	T2	25.3	26.1	25.0	24.8	25.5	25.0
	T3	25.3	27.0	24.9	25.2	25.2	25.0
DO (%)	T1	170.5	161.2	156.0	169.1	166.6	158.2
	T2	169.9	165.1	170.9	177.6	163.9	173.3
	T3	175.7	162.5	160.7	169.2	177.8	156.8
DO (mg/l)	T1	13.0	12.0	12.9	12.9	12.6	13.1
	T2	12.9	12.3	14.1	13.6	12.4	14.3
	T3	13.3	12.0	13.3	12.9	13.5	13.0
pH	T1	9.1	9.0	9.9	8.9	8.7	9.9
	T2	8.8	8.9	9.9	8.7	8.7	9.9
	T3	8.7	9.0	9.9	8.6	8.9	9.9
EC (µs/cm)	T1	226	230	158	225	222	158
	T2	225	224	157	225	219	158
	T3	224	221	157	223	221	157
Turbidity (NTU)	T1	9	5	3	8	4	4
	T2	7	4	4	6	4	4
	T3	6	4	4	6	4	3

A.9 Chlorophyll *a*

Table A-10. Chlorophyll *a* concentration (ppb) for the four treatment events. June 24, July 1, July 15, July 29.

			Chlorophyll *a* (ppb)		
Date	Location	Depth (m)	Pre-Event	Post-Event	One-Week
6/24/2014	T1	0.1	2.33	2.55	3.10
	T1	0.9	3.50	2.95	2.15
	T2	0.1	3.42	2.11	3.04
	T2	0.9	3.26	3.29	2.34
	T3	0.1	5.53	2.96	3.33
	T3	0.9	3.18	3.35	3.29
7/1/2014	T1	0.1	3.10	2.90	4.39
	T1	0.9	2.15	2.58	5.55
	T2	0.1	3.04	1.97	5.33
	T2	0.9	2.34	2.44	4.29
	T3	0.1	3.33	2.50	7.36
	T3	0.9	3.29	2.69	7.83
7/15/2014	T1	0.1	5.36	8.53	20.49
	T1	0.9	6.49	8.52	19.17
	T2	0.1	6.44	9.32	19.80
	T2	0.9	7.88	7.68	21.30
	T3	0.1	6.97	9.46	26.96
	T3	0.9	8.58	10.77	19.52
7/29/2014	T1	0.1	17.93	13.83	16.57
	T1	0.9	24.37	18.27	16.9
	T2	0.1	29.52	19.67	18.26
	T2	0.9	27.53	18.07	18.66
	T3	0.1	44.10	80.77	15.80
	T3	0.9	34.62	102.08	16.57

Note: Laboratory analysis was performed by Chesapeake Biological Laboratory. Method Detection Limit is 0.18 parts per billion (ppb).

[a] collected on 7/1/14

[b] collected on 7/8/14

[c] collected on 7/23/14

[d] collected on 8/4/14

A.10 Blue-green Algae

Table A-11. *Microcystis aeruginosa* algae density (cells/mL) for the each sampling locations, June 24, July 1, July 15, July 29.

			Microcystis aeruginosa (cell count)		
Date	**Location**	**Depth (m)**	**Pre-Event**	**Post-Event**	**One-Week**
6/24/2014	T1	0.1	-	-	-
	T2	0.1	-	-	-
	T3	0.1	-	-	-
7/1/2014	T1	0.1	-	-	-
	T2	0.1	-	-	333
	T3	0.1	-	-	334
7/15/2014	T1	0.1	3,999	5,485	15,198
	T2	0.1	6,237	10,599	29,892
	T3	0.1	11,284	5,108	36,964
7/29/2014	T1	0.1	29,982	18,143	3,522
	T2	0.1	50,154	16,619	18,434
	T3	0.1	19,794	42,796	13,662

Table A-12. *Aphanizomenon flos-aquae* algae density (cells/mL) for the each sampling locations, June 24, July 1, July 15, July 29.

			Aphanizomenon flos-aquae (cell count)		
Date	**Location**	**Depth (m)**	**Pre-Event**	**Post-Event**	**One-Week**
6/24/2014	T1	0.1	-	-	-
	T2	0.1	-	-	-
	T3	0.1	-	518	-
7/1/2014	T1	0.1	-	-	9,253
	T2	0.1	-	-	41
	T3	0.1	-	-	-
7/15/2014	T1	0.1	86	-	-
	T2	0.1	-	64	801
	T3	0.1	1,754	-	295
7/29/2014	T1	0.1	397	773	154
	T2	0.1	1,244	2,077	1,121
	T3	0.1	334	4,349	52

Table A-13. *Anabaena flos-aquae* algae density (cells/mL) for the each sampling locations, June 24, July 1, July 15, July 29.

			Anabaena flos-aquae (cell count)		
Date	**Location**	**Depth (m)**	**Pre-Event**	**Post-Event**	**One-Week**
6/24/2014	T1	0.1	-	-	127
	T2	0.1	-	-	2,983
	T3	0.1	-	1,361	1,737
7/1/2014	T1	0.1	127	210	-
	T2	0.1	2,983	43	1,728
	T3	0.1	1,737	721	-
7/15/2014	T1	0.1	29	-	-
	T2	0.1	-	52	-
	T3	0.1	-	256	-
7/29/2014	T1	0.1	-	-	-
	T2	0.1	-	-	-
	T3	0.1	-	-	-

Table A-14. *Gloeotrichia echinulata* algae density (cells/mL) for the each sampling locations, June 24, July 1, July 15, July 29.

			Gloeotrichia echinulata (cell count)		
Date	**Location**	**Depth (m)**	**Pre-Event**	**Post-Event**	**One-Week**
6/24/2014	T1	0.1	-	-	-
	T2	0.1	-	-	-
	T3	0.1	-	-	-
7/1/2014	T1	0.1	-	-	-
	T2	0.1	-	-	321
	T3	0.1	-	-	84
7/15/2014	T1	0.1	-	609	7,618
	T2	0.1	125	1,353	490
	T3	0.1	16,833	4,100	147
7/29/2014	T1	0.1	79	1,533	154
	T2	0.1	12,053	2,214	208
	T3	0.1	334	58,252	52

A.11 Microcystin

Table A-15. Microcystin concentration (µg/l) for the four treatment events (June 24, July 1, July 15, July 29). (2014)

Date	Location	Depth (m)	Microcystin (µg/l)		
			Pre-Event	Post-Event	One-Week
6/24/2014	T1	0.1	0.27	0.26	0.21
	T2	0.1	0.31	0.23	0.16
	T3	0.1	0.16	0.22	0.18
7/1/2014	T1	0.1	0.21	0.25	0.20
	T2	0.1	0.16	0.24	0.16
	T3	0.1	0.18	0.28	0.24
7/15/2014	T1	0.1	0.50	0.32	2.40
	T2	0.1	0.39	0.58	2.90
	T3	0.1	0.44	1.47	2.55
7/29/2014	T1	0.1	0.72	0.23	0.56
	T2	0.1	1.02	0.29	0.73
	T3	0.1	0.23	0.59	0.69

[a] collected on 7/1/14

[b] collected on 7/8/14

[c] collected on 7/23/14

[d] collected on 8/4/14

[†] Method detection limit (MDL) for microcystin is 0.16 µg/l. Samples were sent to Tamarack Environmental, Inc. in Michigan.

APPENDIX B

Visual Observation Tables

This appendix contains visual observation tables. These observations included monitoring area, appearance of waterway, weather conditions, presence/absence of floating or suspended matter, water discoloration, bottom deposits, aquatic life, visible films or coating, objectionable growths, and potential nuisance conditions.

B.1 Visual Observation Table

Table B-1. Visual observation includes assessment at the three locations for Pre, Post, and One Week Post-treatment. Treatment #1 (June 24) and July 1 (One Week Post-treatment).

Visual Observation	T1-Pre	T1-Post	T1-One Week	T2-Pre	T2-Post	T2-One Week	T3-Pre	T3-Post	T3-One Week
1. Monitoring area description (pond, lake, open waterway, channel, etc.)	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE
2. Appearance of waterway (sheen, color, clarity, etc.)	LIGHT GREEN	GREEN	LIGHT GREEN	LIGHT GREEN, POOR CLARITY	GREEN	LIGHT GREEN	LIGHT GREEN	GREEN	LIGHT GREEN
3. Weather conditions (fog, rain, wind, etc.)	WARM, SUNNY, 5% CLOUDS	SUNNY, WINDY	COOL, CLEAR, NO WIND	WARM, SUNNY, 5% CLOUDS	SUNNY, WINDY	COOL, CLEAR, NO WIND	SUNNY, WARM	SUNNY, WINDY	HOT, CLEAR, NO WIND
4. Floating or suspended matter (presence/absence)	AQUATIC WEEDS	PRESENCE	PRESENCE	AQUATIC WEEDS	PRESENCE	PRESENCE	AQUATIC WEEDS	PRESENCE	PRESENCE
5. Discoloration (high, medium, low)	LOW	MEDIUM	LOW	LOW	MEDIUM	LOW	LOW	MEDIUM	MEDIUM
6. Bottom deposits (fine, coarse, organic)	FINE, ORGANIC	ORGANIC	ORGANIC	FINE, ORGANIC	ORGANIC	ORGANIC	FINE, ORGANIC	ORGANIC	ORGANIC
7. Aquatic life (presence/absence)	NONE	PRESENCE (SMALL FISH)	PRESENCE - FISH	NONE SEEN	PRESENCE	ABSENCE	SMALL FRY	PRESENCE	PRESENCE
8. Visible films, sheens, or coatings (presence/absence)	NONE	ABSENCE	ABSENCE	NONE	ABSENCE	ABSENCE	NONE	ABSENCE	ABSENCE
9. Fungi, slimes, or objectionable growths (presence/absence)	FILAMENTOUS ALGAE ALONG SHORELINE	ABSENCE	PRESENCE	FILAMENTOUS ALGAE	ABSENCE	ABSENCE	FILAMENTOUS ALGAE ALONG SHORELINE	ABSENCE	ABSENCE
10. Potential nuisance conditions (high, medium, low)	LOW	LOW	LOW	LOW - WEEDS	LOW	LOW	LOW	LOW	LOW

Table B-2. Visual observation includes assessment at the three locations for Pre, Post, and One Week Post-treatment. Treatment #2 (July 1) and July 8 (One Week Post-treatment).Note: APFA = *Aphanizomenon flos-aquae*

Visual Observation	T1-Pre	T1-Post	T1-One Week		T2-Pre	T2-Post	T2-One Week		T3-Pre	T3-Post	T3-One Week
1. Monitoring area description (pond, lake, open waterway, channel, etc.)	LAKE	LAKE	LAKE		LAKE	LAKE	LAKE		LAKE	LAKE	LAKE
2. Appearance of waterway (sheen, color, clarity, etc.)	LIGHT GREEN	LIGHT GREEN	DARK GREEN		LIGHT GREEN	LIGHT GREEN	DARK GREEN		LIGHT GREEN	LIGHT GREEN	DARK GREEN
3. Weather conditions (fog, rain, wind, etc.)	COOL, CLEAR, NO WIND	WARM, CLEAR, NO WIND	90% CLOUDS, HUMID, WARM, SOME RAIN		COOL, CLEAR, NO WIND	WARM, CLEAR, NO WIND	90% CLOUDS, HUMID, WARM, WINDY		CLEAR, COOL, LIGHT WIND	HOT, CLEAR, NO WIND	90% CLOUDS, HUMID, WARM, WINDY
4. Floating or suspended matter (presence/absence)	PRESENCE	PRESENCE	ABSENCE		PRESENCE	PRESENCE	AQUATIC WEEDS		ABSENCE	PRESENCE	AQUATIC WEEDS
5. Discoloration (high, medium, low)	LOW	LOW	LOW		LOW	LOW	LOW		LOW	MEDIUM	LOW
6. Bottom deposits (fine, coarse, organic)	ORGANIC	ORGANIC	FINE		ORGANIC	ORGANIC	FINE		ORGANIC	ORGANIC	FINE
7. Aquatic life (presence/absence)	PRESENCE - FISH	PRESENCE	SOME MACROPHYTE		ABSENCE	ABSENCE	LOTS OF MACROPHYTES		ABSENCE	PRESENCE	LOTS OF MACROPHYTES
8. Visible films, sheens, or coatings (presence/absence)	ABSENCE	ABSENCE	ABSENCE		ABSENCE	ABSENCE	ABSENCE		ABSENCE	ABSENCE	ABSENCE
9. Fungi, slimes, or objectionable growths (presence/absence)	PRESENCE	ABSENCE	APFA AND MICROCYSTIS		ABSENCE	ABSENCE	APFA AND MICROCYSTIS		ABSENCE	ABSENCE	APFA AND MICROCYSTIS
10. Potential nuisance conditions (high, medium, low)	LOW	LOW	LOW		LOW	LOW	LOW		LOW	LOW	LOW

Table B-3. Visual observation includes assessment at the three locations for Pre, Post, and One Week Post-treatment. Treatment #3 (July 15) and July 23 (One Week Post-treatment).

Visual Observation	T1-Pre	T1-Post	T1-One Week	T2-Pre	T2-Post	T2-One Week	T3-Pre	T3-Post	T3-One Week
1. Monitoring area description (pond, lake, open waterway, channel, etc.)	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE
2. Appearance of waterway (sheen, color, clarity, etc.)	MED GREEN	MED GREEN	LIGHT RIFFLE, GREEN	MED GREEN	MED GREEN	LIGHT RIFFLE, GREEN	MED GREEN	MED GREEN	LIGHT RIFFLE, GREEN
3. Weather conditions (fog, rain, wind, etc.)	WARM, CLEAR, NO WIND	HOT, CLEAR, LITTLE WIND	LIGHT WIND, 90% BLUE SKY	WARM, CLEAR, NO WIND	HOT, CLEAR, LITTLE WIND	LIGHT WIND, 90% BLUE SKY	WARM, CLEAR, NO WIND	HOT, CLEAR, LIGHT WIND	LIGHT WIND, 90% BLUE SKY
4. Floating or suspended matter (presence/absence)	ABSENCE	ABSENCE	SUSPENDED MATTER	ABSENCE	ABSENCE	SUSPENDED MATTER	PRESENCE - FEW AQUATIC WEEDS	PRESENCE - FEW AQUATIC WEEDS	SUSPENDED MATTER
5. Discoloration (high, medium, low)	LOW	LOW	MED	LOW	LOW	MED GREEN	LOW	LOW	MED GREEN
6. Bottom deposits (fine, coarse, organic)	ORGANIC	ORGANIC	NOT VISIBLE	ORGANIC	ORGANIC	NOT VISIBLE	ORGANIC	ORGANIC	NOT VISIBLE
7. Aquatic life (presence/absence)	ABSENCE	ABSENCE	MACROPHYTES , NONE W/IN 10M OF BOAT	ABSENCE	ABSENCE	NO MACROPHYTES , NONE W/IN 10M OF BOAT	PRESENCE-SMALL FISH	PRESENCE-SMALL &MED SIZE FISH	FEW MACROPHYTES , NONE W/IN 10M OF BOAT
8. Visible films, sheens, or coatings (presence/absence)	ABSENCE	ABSENCE	P - SCUM IN MACROPHYTES AT SHORELINE	ABSENCE	ABSENCE	ABSENCE	ABSENCE	ABSENCE	ABSENCE
9. Fungi, slimes, or objectionable growths (presence/absence)	ABSENCE	ABSENCE	ABSENCE	ABSENCE	ABSENCE	ABSENCE	ABSENCE	ABSENCE	ABSENCE
10. Potential nuisance conditions (high, medium, low)	LOW	LOW	MEDIUM	LOW	LOW	MEDIUM	LOW	LOW	MEDIUM

Table B-4. Visual observation includes assessment at the three locations for Pre, Post, and One Week Post-treatment. Treatment #4 (July 29) and August 4 (One Week Post-treatment).

Visual Observation	T1-Pre	T1-Post	T1-One Week		T2-Pre	T2-Post	T2-One Week		T3-Pre	T3-Post	T3-One Week
1. Monitoring area description (pond, lake, open waterway, channel, etc.)	LAKE	LAKE	LAKE		LAKE	LAKE	LAKE		LAKE	LAKE	LAKE
2. Appearance of waterway (sheen, color, clarity, etc.)	GREEN-BLOOM OUTSIDE + INSIDE	GREEN-BLOOM OUTSIDE + INSIDE	OUTSIDE CURTAIN		GREEN-BLOOM OUTSIDE + INSIDE (GLOBULES)	GREEN-BLOOM OUTSIDE + INSIDE	VISUALLY NOT AS MUCH ALGAE-LESS STRATIFIED		GREEN-BLOOM OUTSIDE + INSIDE	GREEN-BLOOM OUTSIDE + INSIDE	OUTSIDE CURTAIN
3. Weather conditions (fog, rain, wind, etc.)	SUNNY INSIDE CURTAIN	SUNNY INSIDE CURTAIN	VERY SMOKY AND DARK (DUE TO FIRES)		SUNNY INSIDE CURTAIN	SUNNY INSIDE CURTAIN	VERY SMOKY AND DARK (DUE TO FIRES)		SUNNY	SUNNY INSIDE CURTAIN	VERY SMOKY AND DARK (DUE TO FIRES)
4. Floating or suspended matter (presence/absence)	PRESENCE MORE GLOBULES	PRESENCE FEWER GLOBULES	-		PRESENCE MORE GLOBULES	PRESENCE FEWER GLOBULES	-		PRESENCE MORE GLOBULES	A- NO GLOBULES	-
5. Discoloration (high, medium, low)	HIGH-GREEN	HIGH-GREEN	HIGH		HIGH-GREEN	HIGH-GREEN	HIGH		HIGH-GREEN	HIGH-GREEN	HIGH
6. Bottom deposits (fine, coarse, organic)			-				-				-
7. Aquatic life (presence/absence)	P-SMALL FISH	P-SMALL FISH	PRESENCE		P-SMALL FISH	P-SMALL FISH	PRESENCE		P-SMALL FISH	P-SMALL FISH	PRESENCE
8. Visible films, sheens, or coatings (presence/absence)	ABSENCE	ABSENCE	ABSENCE		ABSENCE	ABSENCE	ABSENCE		ABSENCE	ABSENCE	ABSENCE
9. Fungi, slimes, or objectionable growths (presence/absence)	P-MACROPHYTES	P-MACROPHYTES	P-MACROPHYTES		P-MACROPHYTES	P-MACROPHYTES	P-MACROPHYTES		P-MACROPHYTES (MORE PRESENT)	P-MACROPHYTES (MORE PRESENT)	P-MACROPHYTES
10. Potential nuisance conditions (high, medium, low)	MED-HIGH	HIGH	HIGH		HIGH	HIGH	HIGH		MED-HIGH	HIGH	HIGH

APPENDIX C

PacifiCorp Vertical Profiler Device (BOB)

PacifiCorp designed, built, and deployed a vertical profiler device called "BOB" from April 22 to August 5, 2014 in Long Gulch Cove. BOB is a device which automatically raises and lowers the attached sonde over a fixed range (intervals of 0.5 to 1 meter). The attached sonde was the Yellow Springs Incorporated (YSI) EXO sonde with a four-parameter sensor (#599102-01).

BOB was maintained near the surface in spring and early summer and deployed over a range of 0 to 3 meters below the surface in July. Sonde data for the BOB is displayed in the figures below. Physical water quality parameters include: chlorophyll-a (µg/L), Blue-green algae (µg/L), water temperature (°C), pH, specific conductance (µS/cm), and dissolved oxygen concentration (mg/L).

Figure C-1. Chlorophyll-a concentration (µg/L) from April 22 to August 5. YSI EXO sonde was deployed at Long Gulch Cove. Green line represents the depth (m) of the sonde below the surface (see secondary access). Red line represents algaecide treatment dates.

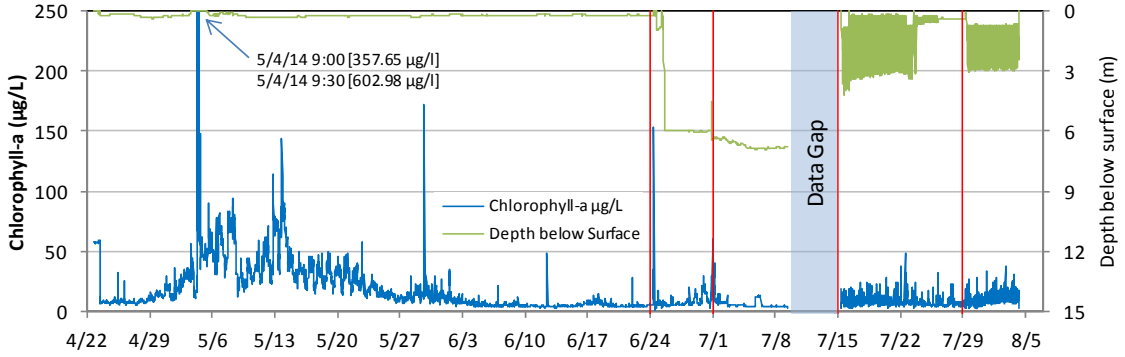

Figure C-2. Blue-green algae concentration (µg/L) from April 22 to August 5. YSI EXO sonde was deployed at Long Gulch Cove. Green line represents the depth (m) of the sonde below the surface (see secondary access). Red line represents algaecide treatment dates.

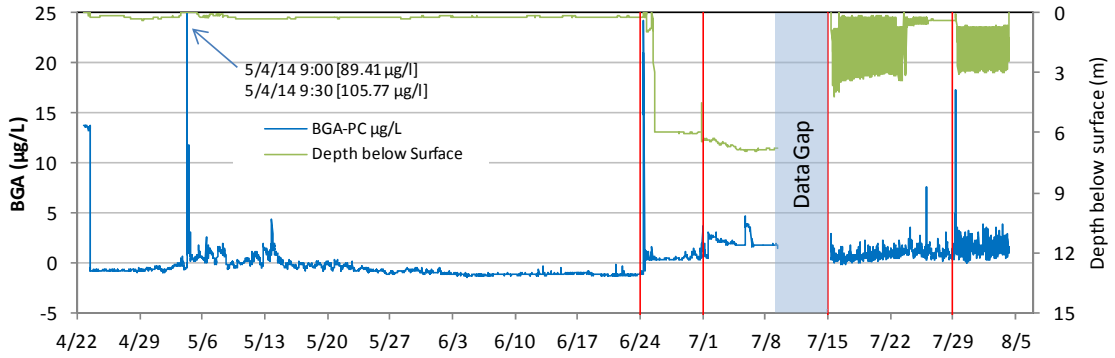

Figure C-3. Water temperature (°C) from April 22 to August 5. YSI EXO sonde was deployed at Long Gulch Cove. Green line represents the depth (m) of the sonde below the surface (see secondary access). Red line represents algaecide treatment dates.

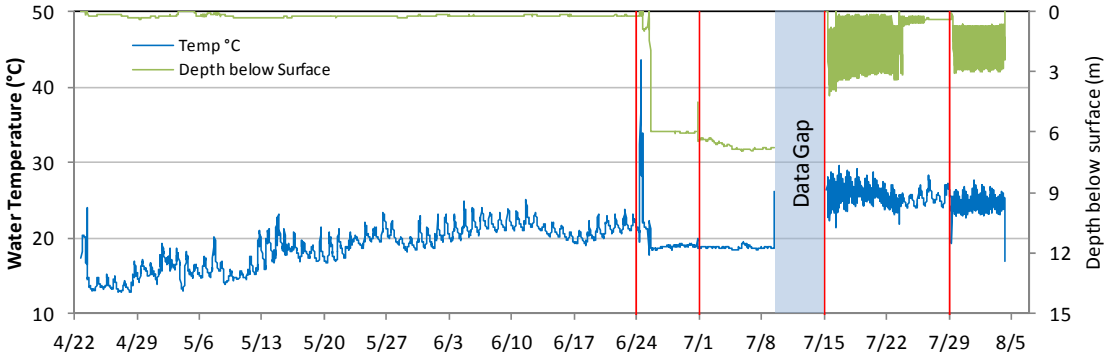

Figure C-4. The pH from April 22 to August 5. YSI EXO sonde was deployed at Long Gulch Cove. Green line represents the depth (m) of the sonde below the surface (see secondary access). Red line represents algaecide treatment dates.

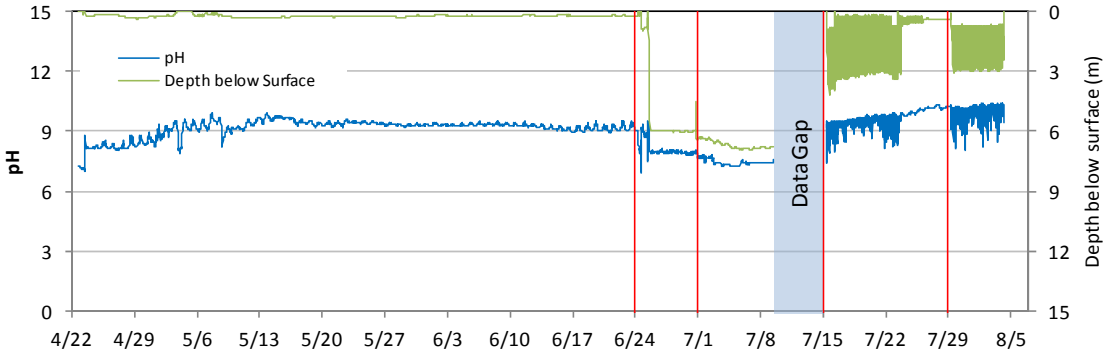

Figure C-5. Specific conductance (µS/cm) from April 22 to August 5. YSI EXO sonde was deployed at Long Gulch Cove. Green line represents the depth (m) of the sonde below the surface (see secondary access). Red line represents algaecide treatment dates.

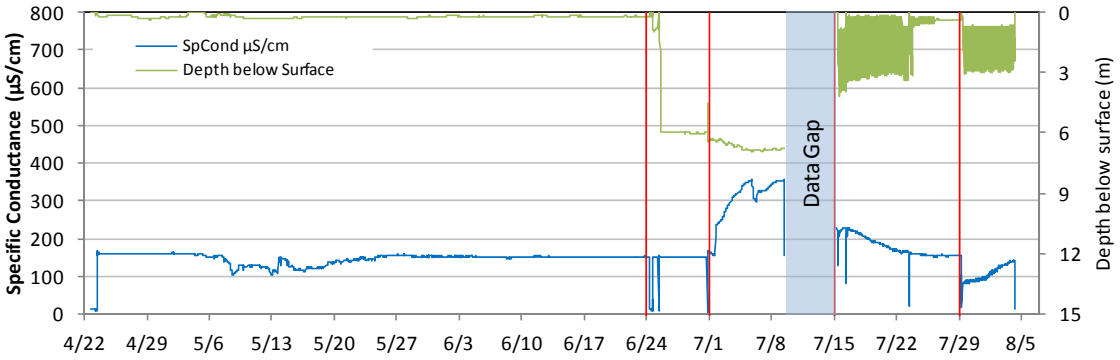

Figure C-6. Dissolved Oxygen (mg/L) from April 22 to August 5. YSI EXO2 sonde was deployed at Long Gulch Cove. Green line represents the depth (m) of the sonde below the surface (see secondary access). Red line represents algaecide treatment dates.