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Development of a Novel Photobiological System to Improve Water Recovery in Brackish Groundwater Desalination

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14. ABSTRACT

A series of bench- and pilot-scale experiments were carried out to investigate the feasibility of a novel photobiological treatment process using a brackish water diatom (*Pseudostaurosira trainorii* PEWL001) to treat silica-rich brackish groundwater and brackish groundwater reverse osmosis (RO) concentrate to enable additional desalination and freshwater recovery using a standard secondary RO process. The bench- and pilot-scale experiments confirmed that the RO concentrate produced at the BGNDRF, as well as silica-added Well 2 water could be treated by the photobiological treatment process using this brackish water diatom. A majority (60% to 95%) of reactive silica, as well as calcium carbonate (>60%), could be removed by the photobiological process. The pilot-scale RO experiment revealed that the photobiologically-treated brackish water could be readily filterable with an ordinary 10-micrometer (μm) cartridge filter to yield clear filtrate for brackish groundwater desalination. A standard brackish water RO unit could be used to desalinate the photobiologically-treated water at a permeate recovery up to 70%, which could be translated as 92.5% overall recovery including the primary RO process.

15. SUBJECT TERMS
Bacillariophyta, Brackish Groundwater, Desalination, Diatoms, Photobiological Treatment, Reverse Osmosis

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Acronyms and Abbreviations

AMW	approximate molecular weight
BGNDRF	Brackish Groundwater National Desalination Research Facility
COD	chemical oxygen demand
DOC	dissolved organic carbon
DOM	dissolved organic matter
EEM	excitation emission matrix
EPA	Environmental Protection Agency
HDPE	high-density polyethylene
HRT	hydraulic retention time
LED	light emitting diode
NOM	natural organic matter
PACE	Pacific Advanced Civil Engineering, Inc.
PAR	photosynthetically active radiation
PBR	photobioreactor
Reclamation	Bureau of Reclamation
R&D	research and development
RO	reverse osmosis
ROC	reverse osmosis concentrate
SEC-OCD	size exclusion chromatography coupled with organic carbon detection
TDS	total dissolved solids
TEP	transparent exopolymer particles
TOC	total organic carbon
UV	ultraviolet

Measurements

°C	degrees Celsius
cm	centimeter
Da	dalton
GPD	gallons per day
gpm	gallons per minute
K	Kelvin
L	liter
L/min	liters per minute
mg/L	milligrams per liter
mg/L/day	milligrams per liter per day
mL	milliliter
mm	millimeter
MΩ.cm	mega ohms centimeters.
nm	nanometer
rpm	revolutions per minute
µg/L	micrograms per liter
$\mu E/m^2 \cdot s$	microeinsteins per second and square meter
µm	micrometer
µS/cm	microsiemens per centimeter
W	watt

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Executive Summary

Brine (concentrate) management is a critical issue in reverse osmosis (RO)-based water reuse and desalination projects, which are becoming more and more common in the southwestern United States due to the ongoing drought in the area. According to the American Membrane Technology Association (https://www.amtaorg.com/), there are also more than 770 municipal brackish water RO plants in the United States. Brine minimization is a major challenge especially for inland desalination projects where brine discharge to the ocean is not an option. Many RO plants are considering adding an additional stage of RO process to recover additional 5% to 15% of reusable water, although serious scaling due to the presence of inorganic scalants, including silica/silicates, phosphate, and hardness metals, is a major obstacle (Greenlee et al. 2009 and Koo et al. 2001).

To help solve this problem, the research and development (R&D) group at Pacific Advanced Civil Engineering Inc., (PACE) has invented a novel photobiological process using selectively cultured diatoms to efficiently remove these inorganic scalants, in particular silica/silicate and phosphate, from silica-rich alternative water resources such as RO concentrate and agricultural drainage water (Ikehata et al. 2017a and b). In this treatment process, water to be treated is inoculated with algal biomass with or without pretreatment in a photobioreactor that consists of a light source, a shallow reactor with or without inert support for biomass attachment, and any post-treatment, such as filtration and disinfection. Different light sources, including incandescent, fluorescent, and light-emitting diode (LED) light bulbs, as well as natural sunlight, may be used. This proposed approach will help reduce the environmental impacts of water reuse and brackish water desalination by harnessing the natural power of microalgae that has been known for decades (Lewin 1954) but largely overlooked in water and wastewater treatment. Although the treatability of several RO concentrate samples from full-scale RO-based desalination facilities has been confirmed in our preliminary work (Ikehata et al. 2017b), a more detailed study is needed to investigate the feasibility of the proposed approach for the treatment and desalination of brackish groundwater.

The primary objective of this project was to demonstrate the feasibility of our proposed photobiological treatment technology combined with a secondary RO system to achieve silica and calcium removal from silica- and calcium-rich brackish groundwater RO concentrate followed by high (>90% overall) water recovery under realistic environmental conditions that were typical in an inland desalination project using one of the brackish groundwater sources at the Bureau of Reclamation's (Reclamation) Brackish Groundwater National Desalination Research Facility (BGNDRF) in Alamogordo, New Mexico.

In this project, we first conducted a series of bench-scale experiments to evaluate different treatment conditions, including nutrient types and concentrations, vitamins and minerals, mixing, carbon dioxide, and light sources, to optimize the

photobiological process using the RO concentrate samples provided by the BGNDRF. Subsequently, we designed, constructed, and operated a 1,500-gallon (5,700 liter [L]) pilot-scale photobiological reactor at BGNDRF (Figure ES-1) to continuously treat a simulated brackish groundwater RO concentrate stream at a flow rate of up to two gallons per minute (gpm) or 7.6 liters per minute (L/min). After settling and clarification, the photobiologically-treated water was desalinated by a 1 gpm (3.8 L/min) pilot-scale RO skid at different recovery rates.

Figure ES-1.—1,500-Gallon (5,700-L) Pilot-scale Photobioreactor at the BGNDRF.

Our bench-scale experiment confirmed that the concentrate samples from an RO skid treating Well 1 water at the BGNDRF, as well as silica-added Well 2 water, could be treated by the photobiological treatment process using a brackish water diatom *Pseudostaurosira trainorii* PEWL001. Nutrient requirements for the diatom for nearly complete (>85%) removal of reactive silica was determined to be 2 to 4 milligrams per liter (mg/L) of PO_4^{3-} of orthophosphate and 12 mg/L of nitrate-N, while ammonia was toxic to the diatom at the concentrations tested in this study. Adding carbon dioxide did not show significant impact on the reactive silica removal. Since the carbon dioxide addition suppressed the calcium carbonate removal by lowering the pH, it was concluded that there was no need to add carbon dioxide in this photobiological treatment. Unlike previous studies with RO concentrate from advanced water purification facilities, direct sunlight was found to be undesirable in the case of brackish groundwater treatment due to the high transparency of the groundwater.

Because the photobiological treatment process produces some organic matter via algal photosynthesis, which may become a concern in the subsequent RO process, natural organic matter (NOM) in the photobiologically-treated water was investigated in this project. Our analysis confirmed that photobiological treatment

of Well 1 RO concentrate generated 2.7 to 4.6 mg/L of dissolved organic carbon (DOC). The majority of the generated DOC could be characterized as relatively low-molecular weight (1,400 < MW < 100,000 daltons [Da]) and more protein-like than recalcitrant DOC. Although some DOC may be generated during the photobiological treatment process, it may not significantly affect the subsequent RO process.

The pilot-scale photobioreactor operated from August 10, 2017 until November 17, 2017 at the BGNDRF. In this pilot experiment, silica-added Well 2 water was used in lieu of Well 1 RO concentrate. In this report, the operational data after September 22, 2017 is shown and discussed. The reactive silica removal in the pilot-scale photobioreactor was modest (up to 20%) when the hydraulic retention time (HRT) was short (12.3 hours). The reactive silica removal improved by reducing the influent flow rate and increasing the HRT. More than 60% of reactive silica was removed in the photobioreactor with an HRT of 125 hours (Figure ES-2).

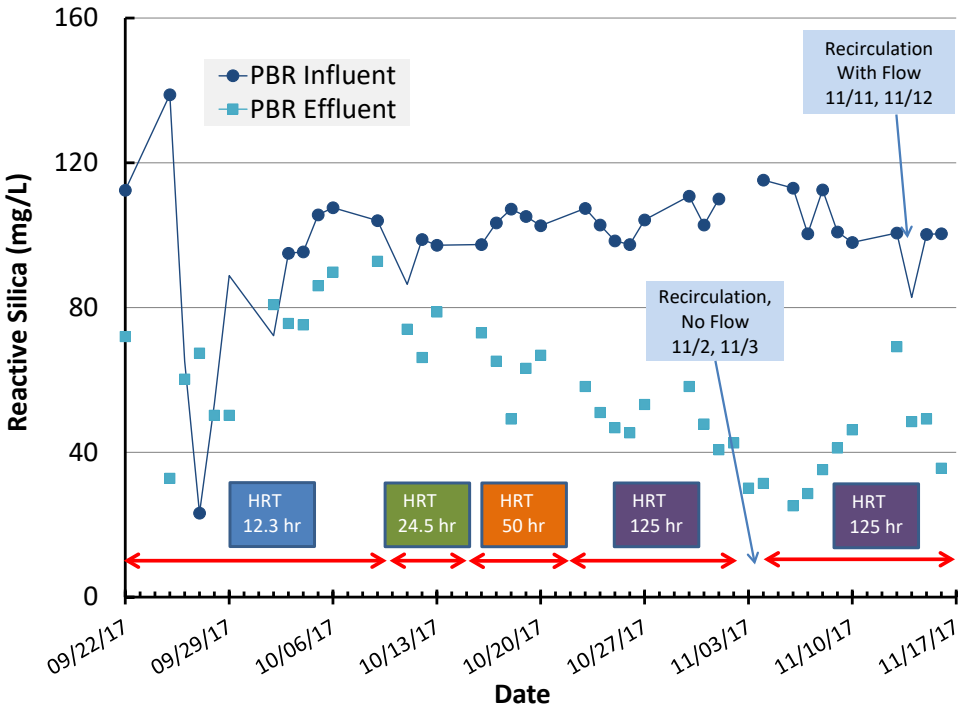

Figure ES-2.—Reactive Silica Removal in the 1,500-Gallon (5,700-L) Pilot-scale Photobioreactor at the BGNDRF.

The reactive silica removal in the pilot-scale photobioreactor is comparable to the result of bench-scale experiments using sunlight as a light source (Table ES-1). However, reactive silica removal was much lower than the more efficient small (50-mL) tube experiments where a majority (>60%) of reactive silica could be removed within 24 hours (Table ES-1). There are a number of possible reasons, including:

- Contamination by green algae, native diatoms, and other eukaryotic microorganisms
- Light intensity/quality
- Water temperature
- Reactor hydraulics and mass transfer

Additional research is needed to investigate and optimize the reactive silica removal in the continuous flow photobioreactor.

Table ES-1.—Summary of Reactive Silica Removal Rates

Treatment Conditions	Reactor Size	Maximum Reactive Silica Removal Rate
Indoors (LED, Static)	50 mL	74 mg/L/day
Indoors (LED, Static)	3.8 L	27 mg/L/day
Indoors (LED, Aerated)	3.8 L	32 mg/L/day
Outdoors (Direct Sunlight, Static)	3.8 L	10 mg/L/day
Outdoors (Indirect Sunlight, Static)	50 mL	15 mg/L/day
Outdoors (Indirect Sunlight, Continuous Flow)	5,700 L	13 mg/L/day

The pilot-scale RO experiment revealed that the photobiologically-treated Well 2 water could be readily filterable with an ordinary 10-micrometer (μm) cartridge filter to yield clear filtrate for brackish groundwater desalination. Also, a standard brackish water RO unit could be used to desalinate the photobiologically-treated Well 2 water at a permeate recovery up to 70%. Assuming that the silica-added Well 2 water properly represents the concentrate from an RO system desalinating Well 1 water at 75% permeate recovery, this result can be translated as a 92.5% overall permeate recovery. Additional research is recommended to investigate the long-term feasibility of using this process scheme (photobiological treatment followed by secondary RO) at existing brackish water desalination facilities and to explore potential issues such as the risk of biological and/or organic fouling.

1. Introduction

1.1. Project Background

Brine (concentrate) management is a critical issue in reverse osmosis (RO)-based water reuse and desalination projects, which are becoming more and more common in the southwestern United States due to the ongoing drought in the area. For example, currently 10 RO-based advanced water purification plants for indirect/direct potable reuse are in the United States with at least seven more being planned. According to the American Membrane Technology Association (https://www.amtaorg.com/), more than 770 municipal brackish water RO plants are in the United States (Figure 1). According to the National Groundwater Association (https://www.ngwa.org/),Texas has an estimated 2.7 billion acre-feet of brackish groundwater, and 75% of groundwater is too saline for most uses in New Mexico. Brine minimization is a major challenge, especially for inland desalination projects where brine discharge to the ocean is not an option. Many RO plants are considering adding an additional stage of RO process to recover additional 5% to 15% of reusable water, although serious scaling due to the presence of inorganic scalants, including silica/silicates, phosphate, and hardness metals, is a major obstacle (Greenlee et al. 2009 and Koo et al. 2001).

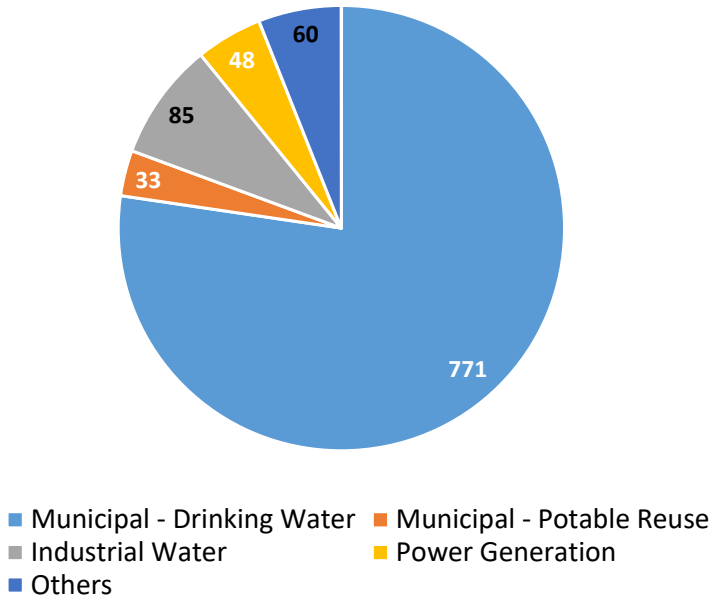

Figure 1.—RO Facilities in the United States (as of March 2017).

To help solve this problem, the research and development (R&D) group at Pacific Advanced Civil Engineering, Inc. (PACE) has invented a novel photobiological process using selectively cultured diatoms to efficiently remove these inorganic scalants, in particular silica/silicate and phosphate, from silica-rich alternative

water resources such as RO concentrate and agricultural drainage water (Ikehata et al. 2017a and b). Several strains of naturally occurring brackish water diatoms have been isolated from silica-rich agricultural drainage water in the central valley of California. In this treatment process, water to be treated is inoculated with algal biomass with or without pre-treatment in a photobioreactor that consists of a light source, a shallow reactor with/without inert support for biomass attachment, and any post-treatment such as filtration and disinfection. Different light sources, including incandescent, fluorescent, and light-emitting diode (LED) light bulbs, as well as direct sunlight, may be used.

This proposed approach will help reduce the environmental impacts of water reuse and brackish water desalination by harnessing the natural power of microalgae that has been known for decades (Lewin 1954) but largely overlooked in water and wastewater treatment. Our technology has been successfully tested with several silica-rich water samples, including RO concentrate from existing advanced water reclamation facilities, such as the Orange County Water District's Groundwater Replenishment System and Water Replenishment District of Southern California's Leo J. Vander Lans Advanced Water Treatment Facility, as well as agricultural drainage water from the central valley in California and RO concentrate from an brackish groundwater RO facility in Dateland, Arizona (Ikehata et al. 2017a and b). Our results showed rapid removal of silica and phosphate, as well as other scalants including calcium, bicarbonate, iron, and manganese by applying our technology. After the photobiological treatment and subsequent solid-liquid separation with or without disinfection, another RO can be used to obtain additional fresh water (Figure 2).

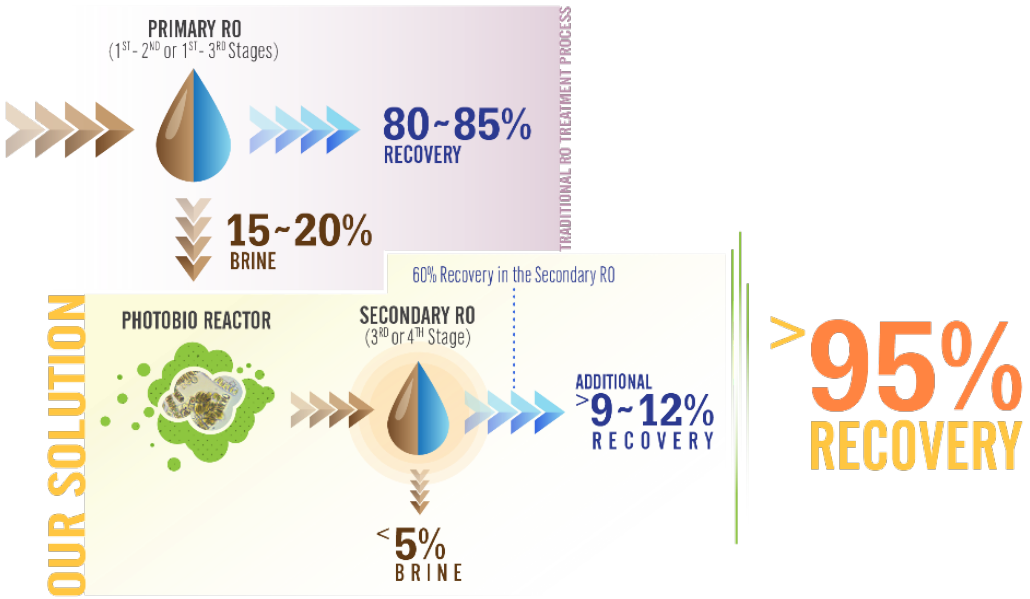

Figure 2.—The Photobiological Technology Improves Purified Water Recovery in RO-based Advanced Water Purification and Brackish Water Desalination Facilities.

The significance of this innovative photobiological water treatment technology is three-fold:

1. **Multiple benefits:**
    - Remove multiple inorganic scalants, including silica, phosphate, calcium, iron, and manganese
    - Reduce environmental impacts due to RO concentrate discharge
        - Reduce the volume of RO concentrate
        - Remove excess nutrients from RO concentrate
        - Remove trace organics and inorganics
    - Recover more fresh water (permeate) for beneficial use
    - Produce potentially useful algal biomass

2. **Low energy requirements:**
    - May use sunlight as an energy source

3. **Strong interest and support from the water industry:**
    - Inland water utilities need new methods to reduce RO concentrate volume
    - Coastal water utilities also seek new methods to recover more permeate and reduce RO concentrate volume
    - Interviews with experts and decision makers at 40+ utilities in California, Arizona, Texas, Florida, and New Mexico revealed strong interest and support from many of them (e.g., Orange County Water District, West Basin Municipal Water District, Pure Water San Diego, Eastern Municipal Water District, El Paso Water, City of Rio Rancho, and Scottsdale Water Campus).

The multiple benefits discussed above specifically meet with one of five focus research areas at the BGNDRF, that of "developing innovative methods for reducing the volume of concentrate that is removed from desalinated water" (https://www.usbr.gov/research/bgndrf/about.html), as well as Reclamation's mission "to manage, develop, and protect water and water resources in an environmentally and economically sound manner in the interest of the American public."

In a concurrent research that was funded by the National Science Foundation, Small Business Innovation Program (Phase I, Award #: 1648498, PI: Keisuke Ikehata), RO concentrate samples from 12 different full-scale advanced water purification and brackish groundwater desalination facilities were successfully treated by the photobiological treatment process in our bench-scale experiments (Zhao et al. 2017). Additionally, we studied combining the photobiological treatment and secondary RO treatment to recover additional permeate from RO concentrate samples from one full-scale advanced water purification facility in Orange County, California in detail in both bench- and pilot-scale

photobioreactors and RO apparatuses (Ikehata 2018). The latter study demonstrated more than 95% overall recovery by combining the primary RO (existing facility) and secondary RO (experimental facility) which reduced the final concentrate volume by 66%.

1.2. Project Needs and Objectives

1.2.1. Needs

As noted above, brine disposal is a major challenge for the brackish groundwater desalination facilities. The treatability of several RO concentrate samples from brackish groundwater desalination facilities has been confirmed in our preliminary work (Ikehata et al. 2017b), as well as in the bench-scale study (Zhao et al. 2017). However, brackish groundwater has different characteristics from recycled water RO concentrate from advanced water purification facilities, such as little to no color and turbidity as well as the lack of dissolved constituents, including nutrients, bulk and trace organics, and heavy metals and minerals. Therefore, a more detailed study was needed to investigate the feasibility of the proposed approach for the treatment and desalination of brackish groundwater.

1.2.2. Objectives

This project's primary objective was to demonstrate the feasibility of our proposed photobiological treatment technology combined with a secondary RO system to achieve silica and calcium removal from silica- and calcium-rich brackish groundwater RO concentrate followed by high (>90% overall) water recovery under realistic environmental conditions. Learning about the impacts of different water quality parameters and environmental factors, including water temperature, light, and contamination, in both bench-scale and pilot-scale photobiological treatment systems was also an important objective.

1.3. Project Overview

1.3.1. Overall Approach and Concepts

Using the RO concentrate samples provided by the BGNDRF, we conducted a series of bench-scale experiments to evaluate different treatment conditions, including nutrient types and concentrations, vitamins and minerals, mixing, carbon dioxide, and light sources and optimize the photobiological process. Subsequently, we designed, constructed, and operated a 1,500-gallon (5,700-L) pilot-scale photobiological reactor at the BGNDRF to continuously treat a simulated brackish groundwater RO concentrate stream at a flow rate of up to two gallons per min (gpm) or 7.6 L/min (Figure 3). After settling and clarification, the photobiologically-treated water was desalinated by a 1 gpm (3.8 L/min) pilot-scale RO skid at different recovery rates.

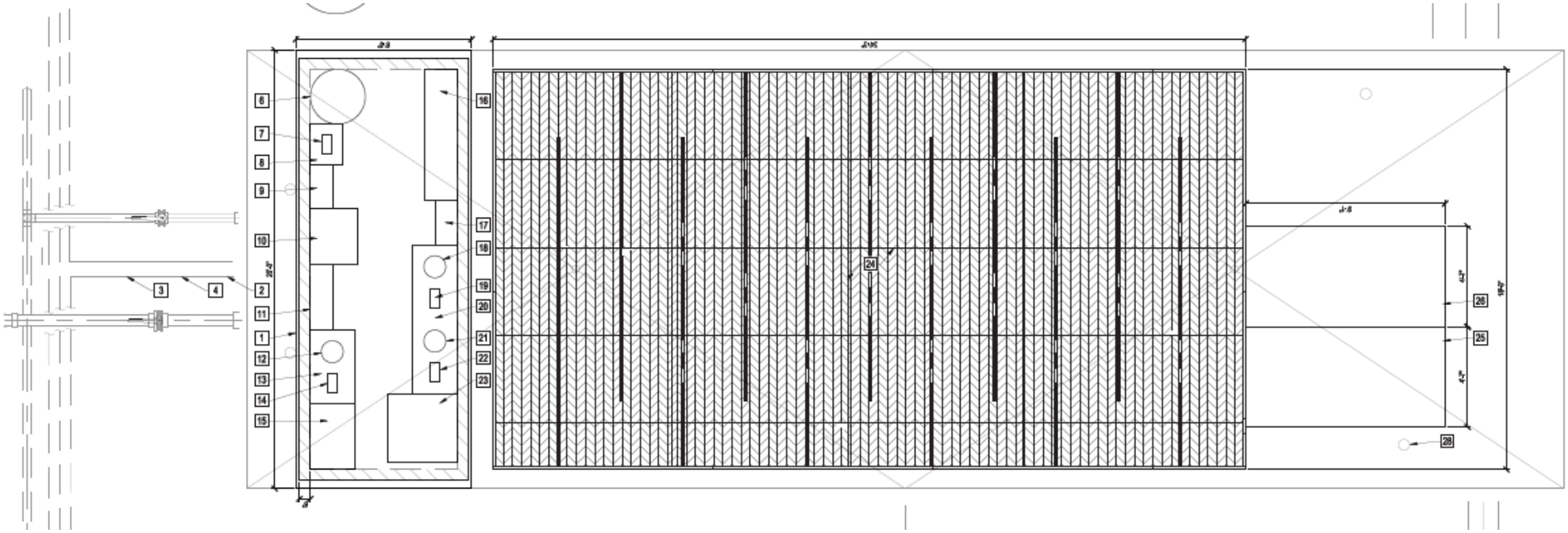

Figure 3.—1,500-gallon (5,700-L) Pilot-scale photobioreactor site plan at the BGNDRF Outdoor Test Pad 7.

The pilot-scale photobioreactor has a serpentine configuration with eight baffles in a rectangular shape box structure constructed with plywood boards and 2-inch x 10-inch wood planks coated with waterproof liquid rubber-based paint. The entire reactor was covered with white corrugated plastic panels.

During the pilot-scale experiment, we first used a separate RO skid to pre-concentrate the water from Well 1 to obtain a continuous supply of silica-rich RO concentrate to be fed into the photobioreactor. However, because of the technical difficulties, it was later decided to use Well 2 water with chemical modifications to simulate the silica-rich RO concentrate in the pilot-scale photobiological treatment.

1.3.2. Overall Method and Project Schedule

The project schedule is presented in Table 1. All the bench-scale experiments were performed by the R&D group of PACE at our in-house laboratory in Fountain Valley, California. RO concentrate samples for the bench-scale experiments and biomass development for the pilot-scale experiment were prepared using an RO skid at the BGNDRF and shipped to our laboratory with assistance of Mr. Steven Holland and Mr. Roberto Granados.

Table 1.—Summary of Project Schedule

Task #	Task Description	Started	Completed
Task 01	Pilot System Design	February 2017	July 2017
Task 02	Pilot System Construction	July 11, 2017	August 3, 2017
Task 03	Pilot System Transportation	July 10, 2017	July 11, 2017
Task 04	Bench-scale Experiments and Biomass preparation	January 2017	July 2017
Task 05	Pilot System Startup and Initial Operation	August 7, 2017	August 21, 2017
Task 06	Pilot System Reconfiguration	August 22, 2017	September 21, 2017
Task 07-1	Pilot-scale Experiment – Photobioreactor	September 22, 2017	November 8, 2017
Task 07-2	Pilot Experiment – Photobioreactor and Secondary RO	November 9, 2017	November 17, 2017
Task 08	Decommission and Site Wrap up	February 11, 2018	February 17, 2018

The entire pilot setup, including pre-treatment system (a primary RO or chemical feed system), a photobioreactor, treated water storage tanks, assorted pumps and piping, flow, pH, and total dissolved solids (TDS) sensors and monitors, a cartridge filter system, and a secondary RO, was designed and constructed by a design and fabrication team of PACE. Most of the construction work was done at the BGNDRF with assistance of the facility staff.

The pilot-scale experiment was performed from Monday, August 7, 2017 until November 16, 2017 by the R&D group of PACE at the BGNDRF with assistance of the facility staff. A detailed pilot activity log can be found in Appendix 1.

A majority of the sample analyses, including general chemistry and microbiology, were performed by the R&D group of PACE in our in-house laboratory and/or the analytical laboratory at BGNDRF. Aliquots of samples were submitted to appropriate laboratories for specialized analysis, such as trace metals and total organic carbon (TestAmerica, Irvine, California), algal genomic sequencing (RTL Genomics, Lubbock, Texas), and natural/dissolved organic matter (Snyder Lab, University of Arizona, Tucson, Arizona). See Section 2 for more details in methodologies.

2. Technical Approach and Methods

2.1. Project Facility/Physical Apparatus

2.1.1. Source Water

In this project, we used two groundwater sources Wells 1 and 2 at the BGNDRF (Figure 4) with pre-concentration and chemical addition, respectively. The raw well water was stored in one of the BGNDRF's raw water storage tanks and delivered to the Outdoor Test Pad #7 during the pilot study. Because of the high temperature (around 40 degrees Celsius [°C]) of the groundwater from Well 1, the raw water from this well was cooled by a cooling tower as shown in Figure 4 before being sent to the storage tank.

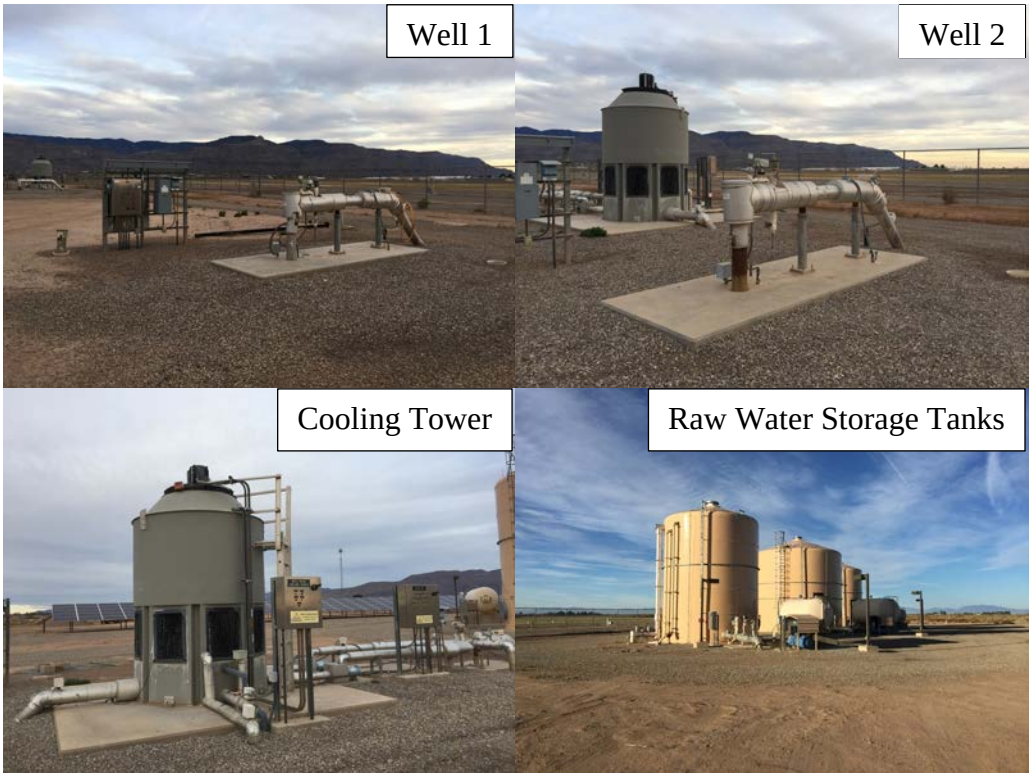

Figure 4.—Source Water Wells (Wells 1 and 2), Cooling Tower, and Raw Water Storage Tanks.

For the bench-scale experiments, Well 1 water was pre-concentrated by four times which represents permeate recovery of 75% using one of Reclamation's High Productivity Membrane Evaluation Systems (Figure 5) at the BGNDRF. No antiscalant was used in this pre-concentration step. Table 2 shows the typical water quality of the raw Well 1 water and RO concentrate.

Figure 5.—RO Skid Used for the Pre-concentration of Well 1 Water.

Table 2.—Summary of Water Quality Data

Parameter	Units	Well 1 Raw	Well 1 ROC	Well 2	Well 2 with Silica
pH	mg/L	7.8	8.2	7.7	7.5
Conductivity	µS/cm	1,540	6,390	6,410	6,130
TDS	mg/L	1,090	4,620	4,540	4,380
Total hardness	mg/L as $CaCO_3$	220	1,070	2,600	2,600
Alkalinity	mg/L as $CaCO_3$	164	468	230	150
Color	PtCo U	0	0	0	3
COD	mg/L	0.7	3.9	3.2	Not tested
Sodium	mg/L	163	790	404	Not tested
Potassium	mg/L	4	14	2	Not tested
Calcium	mg/L	60	340	530	510
Magnesium	mg/L	20	68	310	320
Iron	mg/L	0.01	0.02	0.01	0.01
Manganese	mg/L	0.03	0.07	0.10	0.11
Chloride	mg/L	55	220	590	Not tested
Sulfate	mg/L	480	2,700	2,600	2,600
Nitrate-N	mg/L	0.01	0.41	7.1	7.1
Reactive silica	mg/L	25	85	11	90
Orthophosphate	mg/L	0.1	0.1	0.2	0.1

COD = chemical oxygen demand, ROC = reverse osmosis concentrate, $CaCO_3$ = calcium carbonate, µS/cm = microSiemens per centimeter

During the pilot-scale experiment, we first used a rental RO skid (GE E4-8800) to concentrate Well 1 water and generate RO concentrate to be fed into a pilot-scale photobioreactor. However, the RO skid was not able to deliver a concentrate flow continuously (24/7, unattended) and consistently at the desired flow rate (2 gpm or 7.8 L/min). In addition, there was a major risk of interruptions during unattended operations due to a number of factors, such as power failure and lack of feed pressure, which could cause inconsistent feed water quality and flow rate in the photobioreactor.

Therefore, alternative approach was sought to generate brackish water similar to the Well 1 RO concentrate. After several laboratory and field attempts, the acidification using sulfuric acid followed by sodium metasilicate injection into Well 2 water appeared to be the most feasible and consistent method, which yielded silica-rich brackish groundwater very similar to the Well 1 RO concentrate used in the bench-scale experiments (Table 2).

The silica-added Well 2 water had lower pH and alkalinity than the Well 1 RO concentrate, due to the sulfuric acid addition, which was necessary to counteract the basicity of sodium metasilicate solution (pH about 11) and to prevent silica and calcium precipitation. On the other hand, hardness was more than 140% higher in the silica-added Well 2 water due to the high calcium and magnesium contents in Well 2 water. Therefore, it should be noted that sodium sulfate ($CaSO_4$, gypsum) was the primary calcium salt that could precipitate in the high-recovery RO process of the silica added Well 2 water, while the gypsum scaling could have been a lesser concern if Well 1 RO concentrate had been used.

2.1.2. Set Up

2.1.2.1. Bench-scale Experimental Setup

All of the bench-scale experiments were performed in our in-house laboratory at the company headquarters in Fountain Valley, California. Outdoor experiments were performed on the roof of the two-story building (33°42’32”N 117°55’40”W). The photobiological treatment was carried out in two types of experimental reactors, namely 50-milliliter (mL) clear polypropylene centrifuge tubes with screw caps and white high-density polyethylene (HDPE) cylindrical containers (diameter: 230 millimeters (mm), water depth: 100 mm) with clear plastic film covers. The working volume of these reactors were 45 mL and 3.8 L, respectively. As a light source, 9-watt (W) light emitting diode (LED) bulbs (EcoSmart, Home Depot, Atlanta, Georgia; light temperature: 5,000 Kelvin (K), 800 lumens [lm] each) were used for the indoor experiments, while natural sunlight was used for the outdoor experiments. Figure 6 shows the typical indoor and outdoor experimental setups.

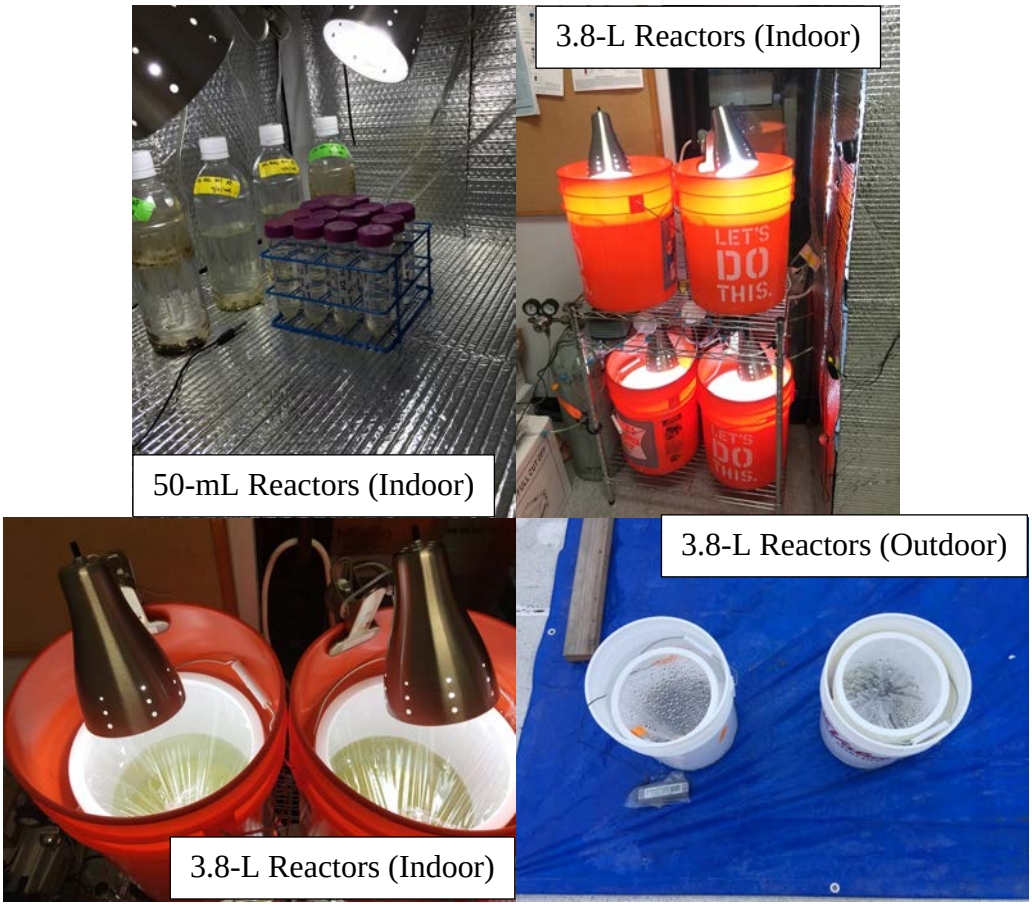

Figure 6.—Bench-scale experimental setups.

2.1.2.2. Pilot-scale Photobioreactor and RO Setup

Figure 7 shows the simplified process schematic of the pilot-scale photobioreactor and RO system that was built on the Test Pad 7 at the BGNDRF. The chemical injection systems for sulfuric acid, sodium metasilicate, and f/2 algal food part B, as well as the cartridge filter skid, antiscalant injection, and the 2-gpm (3.8 L/min) RO skid were housed in a 10-foot x 10-foot x 16-foot container.

The 1,500-gallon (5,700-L) pilot-scale photobioreactor was constructed with 8-foot x -foot plywood boards and 2-inch x 10-inch x 10-foot wood planks (made of Douglas fir) coated with white waterproof liquid rubber-based paint (Flex Seal) as shown in Figure 8. The entire reactor was covered with corrugated polycarbonate panels (6 mm thick, Opal (white), 20% light transmission, Greenhouse Megastore, http://www.greenhousemegastore.com/). The dimensions of the reactor were 18 feet, 3 inches wide, 34 feet, 3 inches long and 1 foot, 8 inches high, including the platform built underneath the reactor. The water depth was about 4 inches in the photobioreactor.

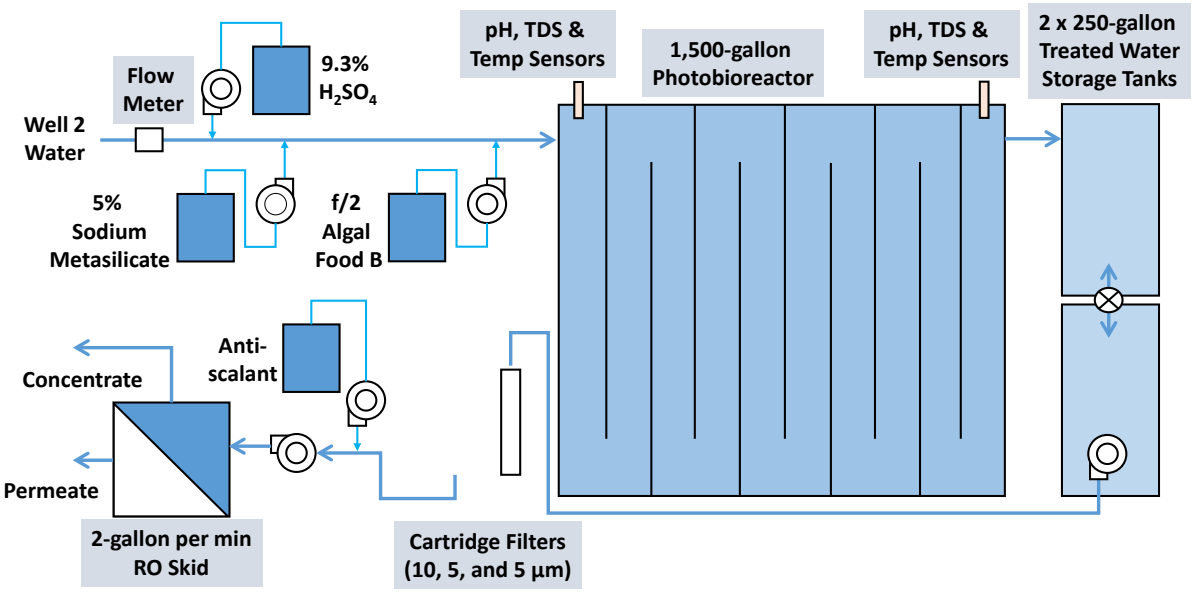

Figure 7.—Simplified process flow schematics of the pilot-scale photobioreactor-RO experimental setup.

Figure 8.—1,500-gallon photobioreactor (left: uncovered, right: covered) and two 250-gallon water storage tanks (right, blue-yellow tanks).

The following equipment was used:

- For chemical injection:
  - Two Model 45MHP2 pumps (Stenner Pump Company, Jacksonville, Florida) for sulfuric acid and nutrients
  - One Model A151-822SI pump (LMI, Houston, Texas) for sodium metasilicate solution
  - One MIKRO DLTA 2508 pump (ProMinent, Pittsburgh, Pennsylvania) for antiscalant

- One 5-MSP Series submersible pump (Little Giant, Oklahoma City, Oklahoma) was used to pump the photobiologically-treated water in the Treated Water Storage Tanks to the cartridge filters and RO skid

- One Model DB5.5 pump (Finish Thompson, Inc., Erie, Pennsylvania) was used as a booster pump for the RO skid

- One CF-8/1 and one CF-12/1 flow switches (Harwil Corporation, Oxnard, California) were used to control the chemical feed pumps for the photobioreactor feed and those for the RO feed, respectively

- Paddle wheel flow meters (S-Series, SPX/SPT, SeaMetrics, Kent, Washington) were used to monitor the flow rates of the photobioreactor feed, RO feed, and RO permeate

- Three cartridge filters (pore sizes: 10, 5, and 5 µm, dimensions: 4.5-inch diameter x 9-$^{7}/_{8}$-inch length, GE Aquatrex Depth Filters, Boston, Massachusetts) were used in-series as a pre-filtration of stored photobiologically-treated water

- A pilot-scale RO skid (Lifestream Water Systems, Huntington Beach, California) with five 2.5-inch brackish water RO elements (4 x CSM RE2540-FE and 1 x CSM RE2540-TE, diameter: 61 mm, length: 1,016 mm, TCK Membrane America, Anaheim, California) was used in the RO experiment

Figure 9 shows the chemical injection systems, pre-filter skid, and RO skid.

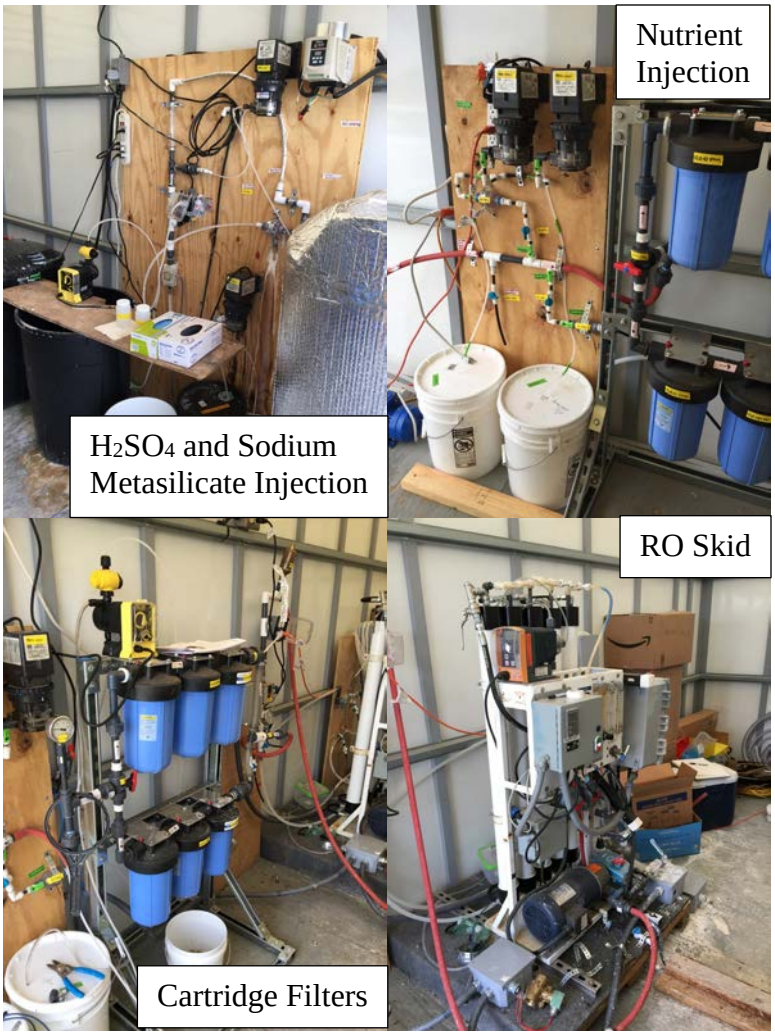

Figure 9.—Chemical injection systems, cartridge filter skid, and 2-gpm ro skid.

The following chemicals were used in the pilot-scale experiment:

- 93% sulfuric acid
- Sodium metasilicate (Na_2SiO_3) anhydrous (Baron Chemicals, El Paso, Texas)
- Household bleach (sodium hypochlorite, HDX, Home Depot)
- 10% ammonia solution (Rooto Corporation, Howell, Michigan)
- Pretreat+0100 antiscalant (King Lee Technologies, San Diego, California)
- F/2 Algae Food Part B (6% nitrogen, 2% phosphorous, pH about 3, Fritz Aquatics, Mesquite, Texas)

2.2. Methodology

2.2.1. Diatom

The diatom *Pseudostaurosira trainorii* PEWL001 used in this project was previously isolated from the agricultural drainage water from the central valley in California as described in Ikehata et al. (2017a). Briefly, the diatom *P. trainorii* PEWL001 exhibited slightly elliptical valves with the characteristic striae on the valve face and on the valve mantle. This strain was found to form long-chain colonies under the favorable growth conditions while the diameter of the valves was 4-µm and the thickness of the frustules was 3-µm approximately (Ikehata et al. 2017a).

The working culture of *P. trainorii* PEWL001 used for the bench-scale experiments was prepared by incubating the seed culture in filter sterilized (Acrodisc Syringe Filter 0.8/0.2-µm, VWR International, Radnor, PA, Catalog # 23139) Well 1 RO concentrate spiked with appropriate amounts of nitrogen and phosphorus. Once a desired amount of biomass was established in the working culture, the biomass was harvested and cleaned using 1% solution of the reagent grade sodium chloride (Sigma Aldrich, St. Louis, Missouri) and rinsed using filter sterilized Well 1 RO concentrate. The cleaning and rinsing of the biomass was done by the three cycles of vortex mixing for 30-seconds (GeneMate VWR, Radnor, Pennsylvania, Catalog # 89039) followed by centrifugation for 5-minutes at 4,000 revolutions per minute (rpm) using a Clinical50 Centrifuge (VWR International, Radnor, Pennsylvania). Finally, the cleaned and rinsed biomass was re-suspended in 5-mL of the filter sterilized brackish groundwater RO concentrate and used for the inoculation. The initial biomass density of the working culture was determined gravimetrically and light microscopy was used to confirm the viability of *P. trainorii* PEWL001 cells at the beginning of the incubation. All the diatom biomass culture preparation for the bench-scale experiments was done in our laboratory in Fountain Valley, California.

A large amount of *P. trainorii* PEWL001 biomass was prepared for the pilot-scale experiment by a series of culturing in 50-mL tubes followed by in 3.8-L reactors in a similar manner to the bench-scale experiments as described above. The Well 1 RO concentrate was filtered through 1.5-µm glass fiber filters (HACH, Loveland, Colorado) instead of 0.8/0.2-µm filters in the pilot-scale experiment.

2.2.2. Bench-scale Experiments

A series of semi-batch experiments were conducted to investigate the physical, chemical and environmental conditions that affect the reactive silica uptake by the diatom *P. trainorii* PEWL001. The experimental set-ups and conditions are summarized in Appendix 1. Briefly, the semi-batch experiments were conducted on two scales, in 50-mL tube reactors and in 3.8-L white containers, as described in Section 2.1.2.1.

The incubation of the reactors was done either indoors under LED light bulbs or outdoors under direct sunlight. Filtered Well 1 RO concentrate (see Section 2.1.1) was used as a culture medium. Either 0.8/0.2-µm sterile syringe filters or 1.5- µm glass fiber filters were used.

Three types of nutrient solutions were added aseptically, including sodium phosphate monobasic (NaH_2PO_4), sodium nitrate ($NaNO_3$), and ammonium sulfate [$(NH_4)_2SO_4$], to yield desired concentrations of phosphorus and nitrogen in the medium.

The reactive silica uptake by the diatom was also tested in the three conditions as static, aeration mixing and carbon dioxide addition. In the 50-mL reactor experiments, the reactive silica concentration was measured daily by taking 2-mL of sample without disturbing the biomass, while the concentrations of orthophosphate, nitrate-N, ammonia-N, calcium and the weight of biomass were measured only at the end of the experiments. In the 3.8-L reactor experiments, 30-mL of the sample was used to measure all of these parameters daily. In the semi-batch mode, the completion of the cycle was characterized by the residual reactive silica concentration less than 5 mg/L.

At the completion of each cycle, the medium was replenished without disturbing the biomass.

2.2.3. Pilot-scale Experiments

2.2.3.1. Photobiological Treatment

The pilot-scale photobioreactor started up on August 7, 2017 as shown in Table 1. The actual experiment started on August 10, 2017 by inoculating the photobioreactor filled with pre-concentrated Well 1 water with cultured *P. trainorii* PEWL001 biomass. The water was flowing continuously though the photobioreactor as shown in Figure 10. A mixture of nutrients (F/2 Algal Food Part B) was injected at the photobioreactor influent. Sample locations/ports are also shown in Figure 10. Water samples were collected at selected sample locations daily and were analyzed for pH, conductivity, reactive silica, orthophosphate, nitrate, phycocyanin, and *in vivo* chlorophyll. In addition, visual and microscopic observation of algal biomass was performed daily. Appendices 2 and 3 show the detailed activities during the pilot-scale experiments, including the RO experiments, at the BGNDRF.

As described in Section 2.1.1, an RO skid (primary RO) was used to pre-concentrate Well 1 water for the pilot-scale experiment. However, the performance of the primary RO started declining on August 16, 2017 and the desired pre-concentration (x 4) of Well 1 water became unfeasible on August 22nd, 2017. After discussion with BGNDRF staff and Mr. Saied Delagah, Reclamation's Grants Officer Technical Representative, it was decided to use Well 2 water, which has a very similar water quality characteristics to Well 2 RO

concentrate (Table 2), except for lower reactive silica concentration (11 mg/L) and higher calcium concentration (530 mg/L).

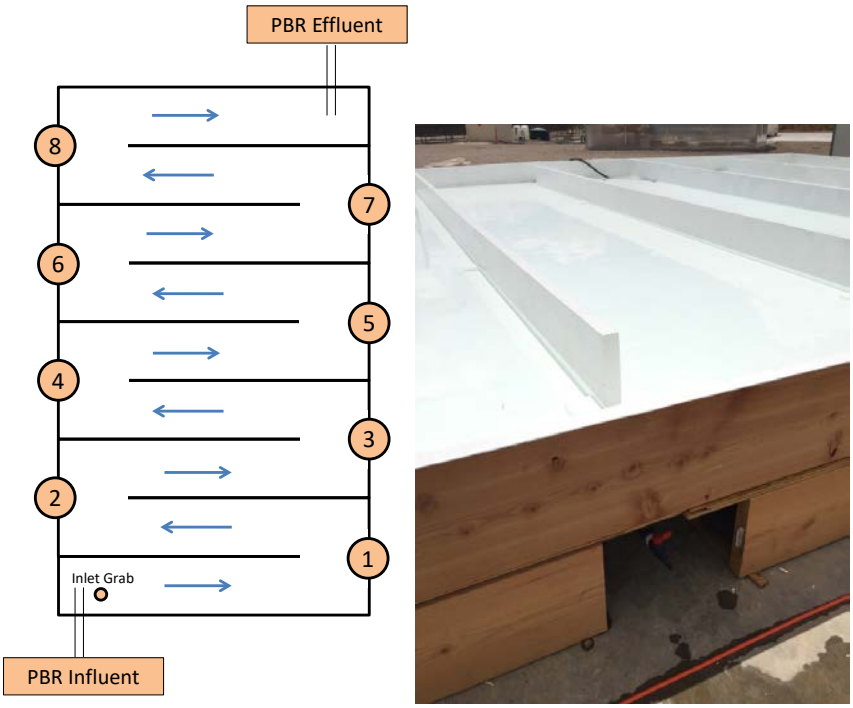

Figure 10.—Flow direction in the pilot-scale photobioreactor (PBR), sample locations (orange circles and rectangles), and one of the sample ports.

To adjust the water quality of Well 2 water to simulate the Well 1 RO concentrate, silica addition was investigated in the BGNDRF laboratory with different methods, as shown in Table 3. Finally, the fourth method (sulfuric acid addition followed by sodium metasilicate addition) was found to be useful. While configuring the online injections of sulfuric acid and sodium metasilicate into Well 2 water, the influent to the photobioreactor was seized from September 8, 2017 to September 21, 2017. The sulfuric acid and sodium metasilicate injections became fully adjusted and operational on September 22, 2017 as shown in Table 1. See Appendices 2 and 3 for more details about this attempt.

2.2.3.2. RO Treatment

The pilot-scale RO treatment of photobiologically-treated Well 2 water was performed from November 9, 2017 until November 17, 2017 (Table 1). The water in one of the treated water storage tanks (Figure 7) was used as feed water for the RO skid and the tank was isolated from another one by closing the valve between two tanks. During the experiment, ammonia and sodium hypochlorite solutions were added directly to the storage tank to yield about 2 mg/L of monochloramine as a biocide. Four different permeate recovery rates were attempted: 30%, 50%, 60%, and 70%.

Table 3.—Summary of Silica Addition Methods

Chemical 1	Chemical 2	Results	Worked?
Sodium orthosilicate (Na_4SiO_4)	None	Sodium orthosilicate is not very soluble in water and required a base (NaOH) to prepare a concentrated solution.	No
Sodium metasilicate (Na_2SiO_3)	None	Sodium metasilicate solution is basic (pH about 11) and its addition caused calcium carbonate/hydroxide precipitation. Silica also co-precipitated as well.	No
Sodium metasilicate	Sulfuric acid (H_2SO_4)	Addition of sulfuric acid after sodium metasilicate addition helped to dissolve some of the precipitate (calcium).	No
Sulfuric acid	Sodium metasilicate	Adjusting the Well 2 water pH <4 by sulfuric acid then add sodium metasilicate solution to elevate reactive silica concentration to >90 mg/L. No precipitate formed.	Yes

2.3. Analysis

2.3.1. Laboratory Analytical Methods

A HACH DR-2800/DR-2700 spectrophotometer and a HACH 2100N turbidimeter were used for colorimetric and turbidity analyses, respectively.

A HACH ISENa38101 sodium ion selective electrode combined with an HQ40d portable meter was used for sodium analysis.

Appropriate HACH methods were used for general chemical parameters, including: reactive silica, orthophosphate, ammonia-N, nitrate-N, chloride, sulfate, hardness, alkalinity, iron, manganese, color, and chemical oxygen demand (COD), as described in Ikehata et al. (2017a).

Analyses for total organic carbon (TOC; Standard Method 5310C) and heavy metals (Environmental Protection Agency [EPA] Method 6010B) were performed by TestAmerica, Inc. (Irvine, California).

The photosynthetically active radiation (PAR) was measured by an International Light Technologies ILT 1400 portable radiometer with an attenuated PAR sensor (Peabody, Massachusetts).

A turner Design AquaFluor® handheld fluorimeter (Model #: 8000-010, San Jose, California) was used for phycocyanin and *in vivo* chlorophyll measurements.

A compound microscope (AM Scope T400B-30W, Irvine, California) and an inverted microscope (AM Scope, IN200TA) were used for microscopic analysis of diatoms.

Aliquots of biomass samples were submitted to RTL Genomics (Lubbock, Texas) for the MiSeq microbial diversity analysis for algae.

2.3.2. Natural Organic Matter (NOM) Analysis

The samples (untreated and treated) were filtered through 0.2/0.8-µm sterile syringe filters. The dissolved organic carbon (DOC) analysis was carried at the University of Arizona. Absorbance and fluorescence spectra were acquired using a Horiba Aqualog spectrophotometer at Orange County Water District (Fountain Valley, CA) and at the University of Arizona. The sample was placed in a 1-centimeter (cm) path length quartz cuvette and integration time of 0.25 s was used. The absorption spectra were collected between 240 nanometers (nm) to 600 nm range with an increment of 3 nm. Simultaneously, the sample was excited with wavelengths 240 nm to 450 nm, and emission spectra were acquired from 300 nm to 600 nm. Excitation emission matrix (EEM) was corrected for inner filter effect (Ohno 2002), Rayleigh scattering (Stedmon and Bro 2008) and normalized with Raman area of 18.3- Mega Ohms centimeters (MΩ.cm) ultrapure water. Spectral slope ratios (Helms et al. 2008) and fluorescence intensities (Coble 1996) were computed from the corrected EEMs. Approximate molecular weights (AMW) were computed from size exclusion chromatography coupled with organic carbon detection (SEC-OCD) spectra.

Transparent exopolymer particles (TEP) in the photobiologically-treated water were analyzed using the Alcian Blue dye method (Passow and Alldredge 1995) with some modifications. In brief, 100-mL of samples was filtered through a 0.4-µm polycarbonate filter and 4-mL of Alcian Blue (50 mg/L, pH 2.5) was added to the filter. After rinsing the excess dye, the filter paper was soaked in 6-mL of 80% sulfuric acid for two hours at room temperature. Absorbance of sulfuric acid solution at 787 nm was recorded using HACH DR 2800 spectrophotometer. Six concentrations of xanthan gum (0, 0.5, 1, 2, 3.5 and 5 mg/L) were used to prepare the calibration curve.

2.3.3. Field Analytical Methods

At BGNDRF, a limited number of water quality analyses were performed on site in a similar manner as in our laboratory in Fountain Valley, CA. A HACH DR-2700 spectrophotometer and a LaMotte 2020we portable turbidity meter were used for colorimetric and turbidity analyses, respectively. In addition, two Omega CDH-SD1 conductivity, TDS, salt meters with a data loggers and two HACH PHC20103 IntelliCAL pH probes combined with two HACH HQ40d handheld meter were used to continuously monitor conductivity/TDS/salinity and pH/temperature, respectively, at the locations indicated in Figure 7. Meteorological data in the Alamogordo area were obtained from The Weather Channel (https://weather.com).

3. Results and Discussion

3.1. Bench-scale Experiments

In the bench-scale experiments, the optimum photobiological treatment conditions were explored in smaller, laboratory-scale reactors. The parameters explored included nutrient types and doses, mixing, carbon dioxide (CO_2) addition, and light sources and intensity. In addition, the NOM generation during the photobiological treatment was investigated. In this section, the experimental results of these bench-scale experiments are summarized. More detailed experimental data are shown in Appendix 4.

3.1.1. Impact of Nutrients

Figure 11 shows the impacts of different types and doses of nutrients on the reactive silica removal from Well 1 RO concentrate by brackish water diatom *P. trainorii* PEWL001. The numbers after them indicate their concentrations in mg/L.

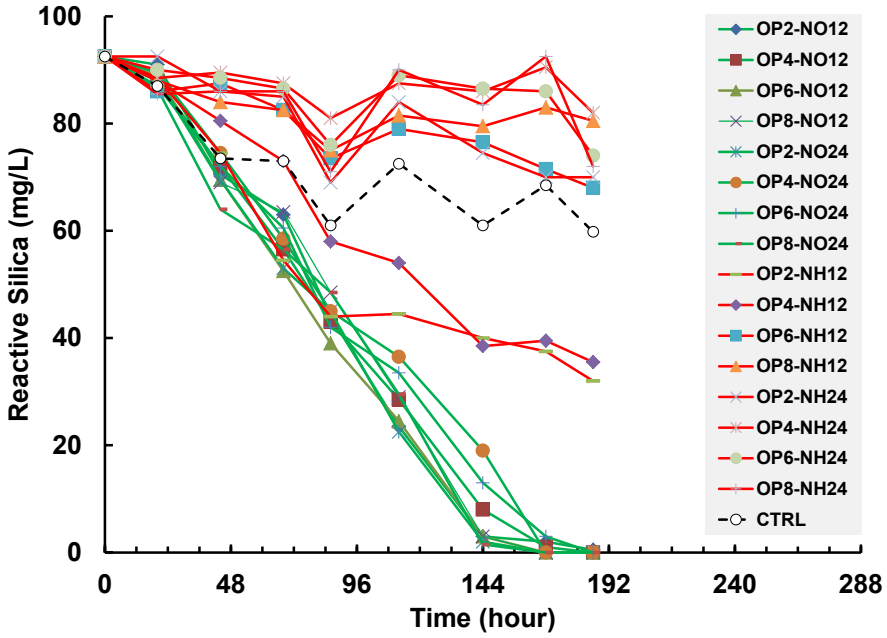

Figure 11.—Removal of reactive silica with *P. trainorii* PEWL001 with different types and doses of nutrients (50-mL indoor tube reactors). OP, NO, and NH stand for orthophosphate, nitrate-N, and ammonia-N, respectively

The result clearly indicated that the nutrient addition was necessary to complete (>90%) the reactive silica removal as only modest removal (about 30%) occurred in the reactor that did not receive nutrient (the active control reactor [Active

CTRL]). Also, ammonia inhibited the growth of the diatom and reactive silica uptake at the concentrations tested (12 and 24 mg/L), while nitrate concentrations did not have any negative impact. Based on the result, it is clear that 2 mg/L of orthophosphate (as PO_4^{3-}) and 12 mg/L of nitrate-N would be sufficient to achieve >90% of reactive silica removal from Well 1 RO concentrate.

Figure 12 shows the impact of trace metals and vitamins addition to the photobiological treatment. These compounds were added to the same levels to the recommended values (Guillard's f/2 medium) or two times of the recommended values. Sufficient concentrations of nutrients (4 mg/L of orthophosphate and 12 mg/L of nitrate-N) were also added in all the reactors. As can be seen from the result, no marked improvement in the rate of reactive silica removal was observed in any of the trace metals and/or vitamins fortified RO concentrate as compared with the control (Active CTRL). Therefore, no trace metals or vitamins were added in the subsequent bench- and pilot-scale experiments.

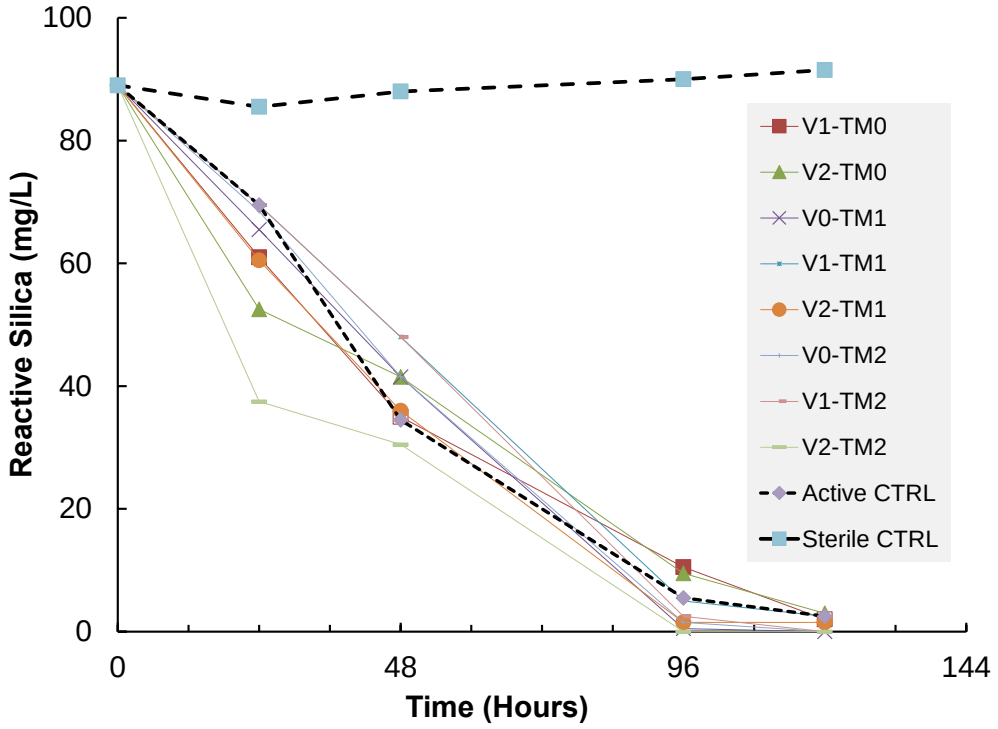

Figure 12.—Impact of trace metals and vitamins on the removal of reactive silica with *P. trainorii* PEWL001 (50-mL indoor tube reactors).

3.1.2. Semi-batch Treatment

The ability of *P. trainorii* PEWL001 in reactive silica removal was further explored in a series of semi-batch experiments where only Well 1 RO concentrate was replenished when a semi-batch cycle was completed while diatom biomass was kept in the reactor. Figure 13 shows the result of this semi-batch experiment.

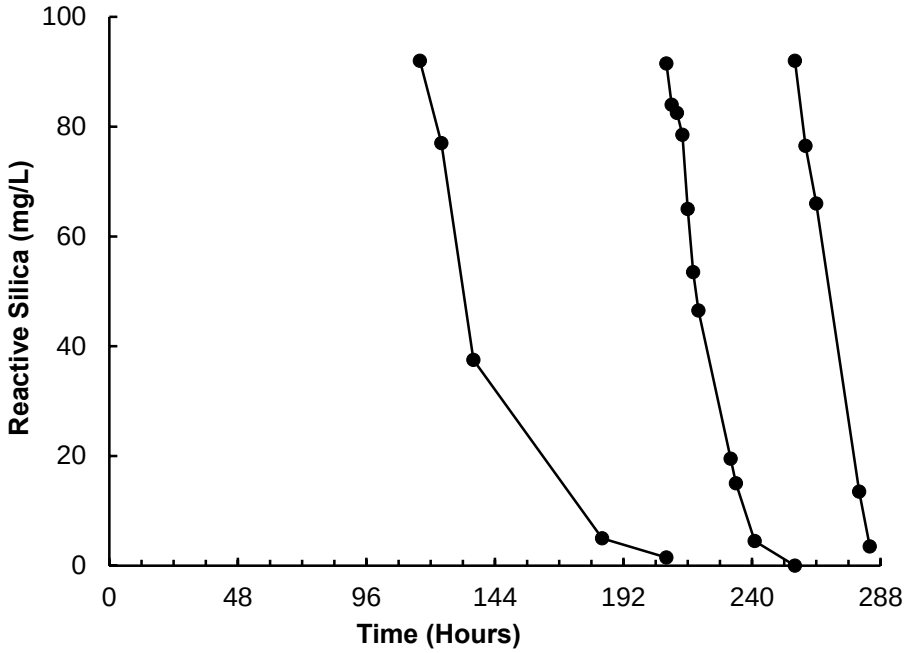

Figure 13.—Semi-batch photobiological treatment result (50-mL indoor tube reactors).

The result of this semi-batch experiment revealed that the photobiological treatment could be performed for at least 12 days with the same starting diatom biomass. The rate of reactive silica uptake increased from Cycles 1 to 2 (26 and 68 mg/L/day, respectively), decreased in Cycle 3 (36 mg/L/day), then increased again in Cycles 4 and 5 (69 and 74 mg/L/day, respectively). The decreased reactive silica removal rate in Cycle 3 was likely due to the disturbance of biomass in the tube reactor.

3.1.3. Impact of Aeration and Carbon Dioxide Addition

The impact of aeration (1.3 L/hr) and carbon dioxide (2% CO_2) added to aeration at 1.3 L/hr) on the photobiological removal of reactive silica and calcium was investigated in 3.8-L reactors. The result shown in Figure 14a revealed that the reactive silica uptake rate in 3.8-L reactors was 20% more than in the static reactor, while carbon dioxide addition did not have a significant impact on the reactive silica removal. It was speculated that the gentle mixing by aeration enhanced the mass diffusion of dissolved constituents for their better uptake/removal by the diatoms. It is known that carbon dioxide (1 to 5%) addition to algal cultures can enhance the photosynthesis and biomass yield, as free carbon dioxide in the medium is used for photosynthesis by the cells rather bicarbonate (Azov 1982 and Moroney and Tolbert 1985). However, silica uptake, which is related to the cell division and new cell construction, is independent of photosynthesis (Martin-Jezequel et al. 2000). This is most likely the reason why the reactive silica removal was not affected by the carbon dioxide addition.

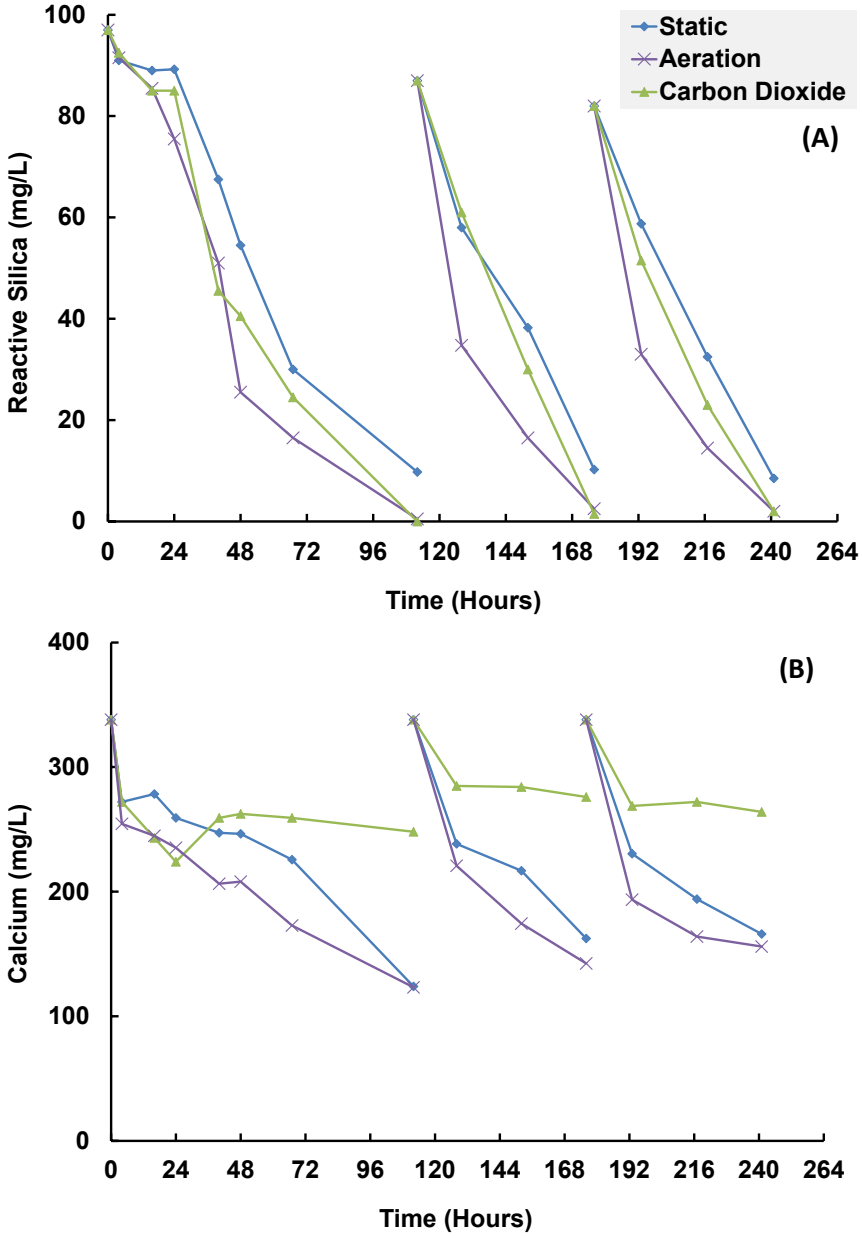

Figure 14.—Impact of aeration and carbon dioxide addition to: (a) reactive silica and (b) calcium removal (3.8-l indoor reactors).

In fact, the calcium removal was inhibited/reduced by the carbon dioxide addition (Figure 14b). While up to 67% of calcium was removed in the static/aerated reactors, the calcium removal was much lower (up to 27%) in the carbon dioxide-added reactors. Since the mechanism of calcium removal is presumed to be the calcium carbonate precipitation at higher pH (about 9) (Ikehata et al. 2017a), adding carbon dioxide reduced the pH of the water (about 6.8) and inhibited the calcium removal in the photobiological treatment. Therefore, it appears that there is no benefit from adding carbon dioxide in the photobiological treatment of Well 1 RO concentrate.

3.1.4. Impact of Light Sources and Intensity

An important feature of the photobiological process is that the sunlight can be used as a light and energy source. Therefore, additional experiments were performed to investigate the impact of light sources. The result showed that the photobiological reactive silica removal was slower under sunlight than under LED light (Figure 15). The nutrient uptake and calcium removal also followed the same trend as the reactive silica removal (see Appendix 4). Several factors might have impacted the reactive silica removal rate in the reactors using sunlight as a light source, such as limited daylight, temperature fluctuation, ultraviolet (UV) radiation, and airborne contaminations. The water temperature fluctuated between 17 °C and 32 °C in the outdoor reactors due to the diurnal patterns, while it was relatively stable (25 ± 2 °C) in the reactors indoors with a LED bulb. Also, it is known that the direct exposure to UV radiation has also shown to diminish the growth rate of some marine diatoms (Cullen and Lesser 1991 and Nilawati et al. 1997).

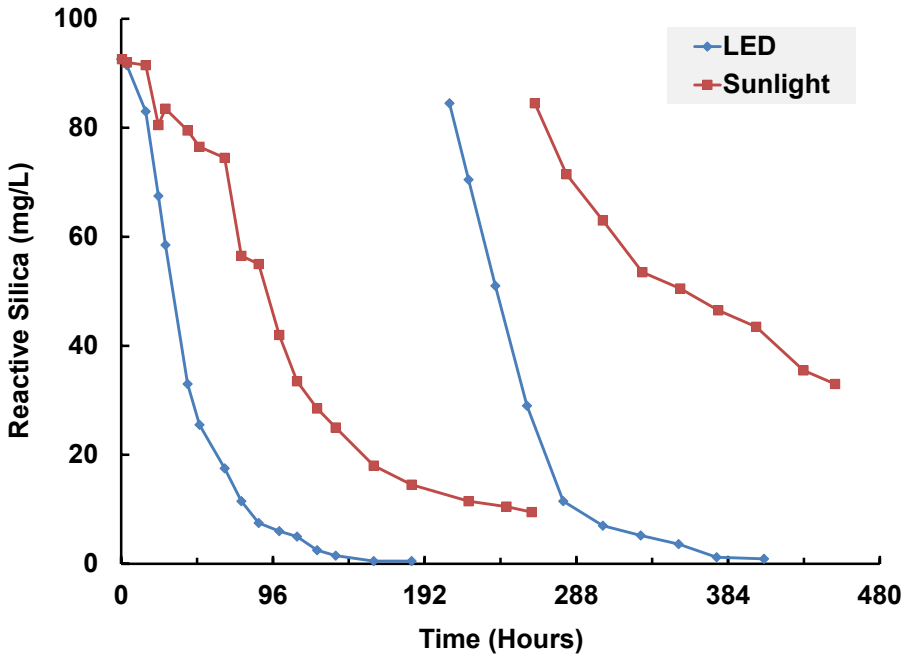

Figure 15.—Photobiological reactive silica removal with LED and sunlight as light sources (3.8-L indoor and outdoor reactors).

The slower reactive silica removal in the photobiological treatment with sunlight as a light source is contradictory to the results of another project where RO concentrate from an advanced water purification facility was treated by the same brackish water diatom where the reactive silica removal rates were comparable with LED and sunlight (Zhao et al. 2017 and Ikehata 2018). The reactive silica removal did not slow down during the nights in that case, which indicated that the daylight was not the limiting factor. The RO concentrate from the advanced water purification facility is highly colored (>200 PtCo unit) due to the organic matter

originated from the sewage. UV radiation was likely blocked by the colored organic matter in the RO concentrate from the advanced water purification facility. However, the Well 1 RO concentrate used in this study was not colored (about 0 PtCo unit), and it was speculated that the diatom was likely affected by the bleaching effect of UV radiation.

To investigate the impact of UV radiation, another experiment was performed. Figure 16 shows that the reactive silica removal was faster in the reactors where solid cover was placed to block direct sunlight (LUX = 30,900 lux, PAR = 31 Microeinsteins per second and square meter [µE/m^2·s]) than those placed under direct sunlight (LUX = 134,000 lux, PAR = 173 µE/m^2·s).

Based on this result, it was decided to use white, opaque plastic panels to block a majority of direct sunlight (20 % light transmission) to cover the pilot-scale photobioreactor to be built at the BGNDRF.

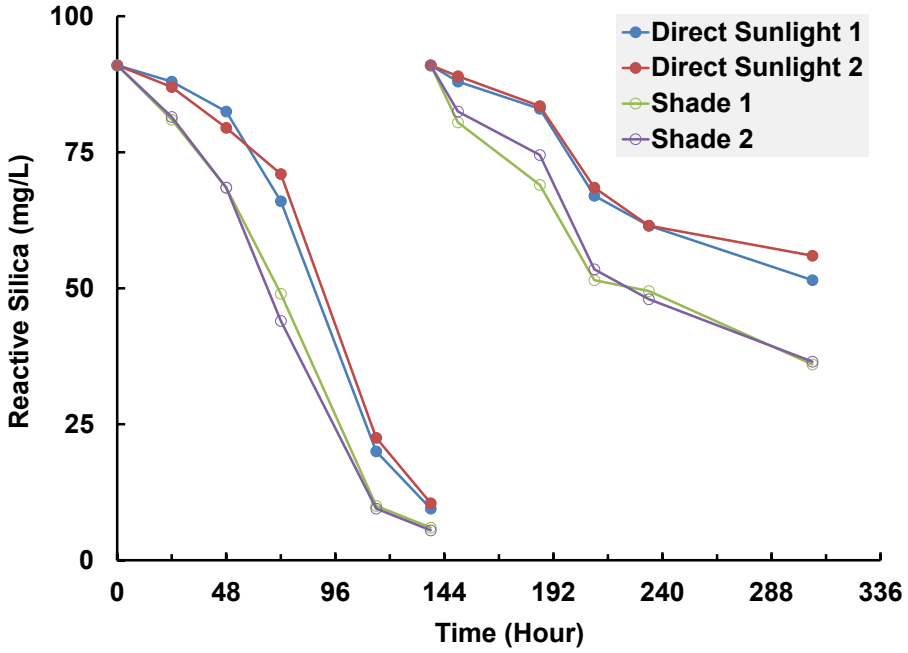

Figure 16.—Photobiological reactive silica removal with LED and sunlight as light sources (50-mL outdoor tube reactors).

3.1.5. NOM Analysis

The Well 1 RO concentrate used in this study contained <0.1 mg/L of DOC with more humic-like fluorescence intensity than protein-like fluorescence (Figure 17 and Figure 18). Upon photobiological treatment of RO concentrate in a 2-gallon reactor, the average DOC concentrations in three cycles were found to increase to 2.67 mg/L in the static condition, to 3.6 mg/L in the aerating reactor and to 4.3 mg/L in the reactor with carbon dioxide addition (Figure 17). The overall ultraviolet absorbance intensities were decreased after the photobiological treatment. The intensities of protein-like fluorescence (tryptophan-like peak T) increased by 87-fold in static, 192-fold in aerating and 586-fold in carbon dioxide mixing reactors (Figure 18). However, the humic-like fluorescence intensities did not change considerably. The increase in DOC and protein-like fluorescence post-treatment suggests the generation of allochthonous DOM by the diatom.

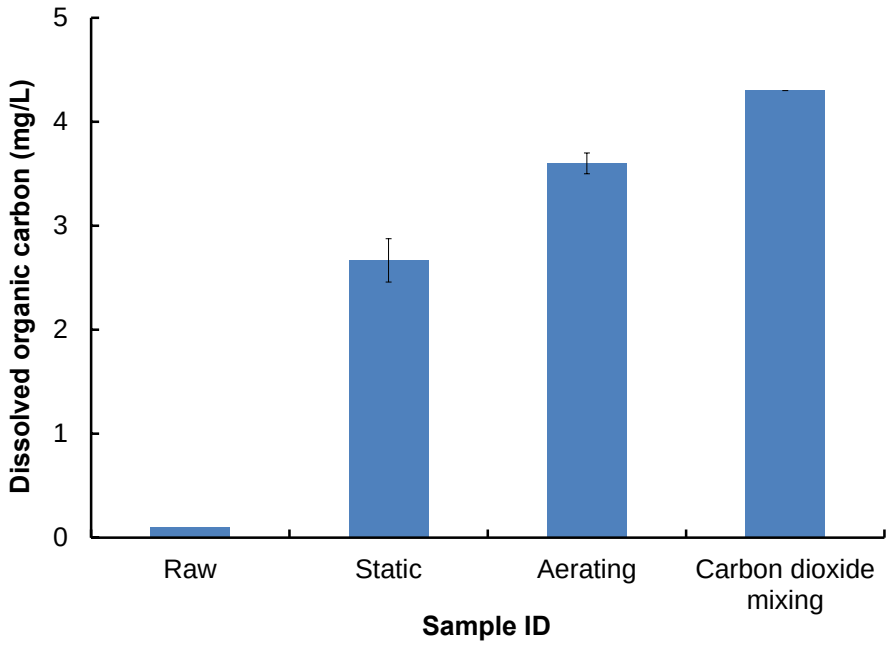

Figure 17.—Increase in DOC Concentration in Well 1 RO Concentrate by Photobiological Treatment (3.8-L Indoor Reactors).

The SEC-OCD analyses of the photobiologically treated Well 1 RO concentrate revealed that the dissolved organic matter (DOM) in the raw brackish groundwater RO concentrate was mostly low molecular weight (< 1,400 Da) (Figure 19). It was observed that during the photobiological treatment under LED or sunlight, the proportion of molecules with molecular weights ranging between 1,400 and 100,000 Da was increased by a small but evident increase of 4%. This implies that the molecular weight of DOM molecules generated by the diatom during the photobiological treatment ranged between 1,400 and 100,000 Da. Additional NOM/DOM analysis results are presented in Appendices 5 and 6.

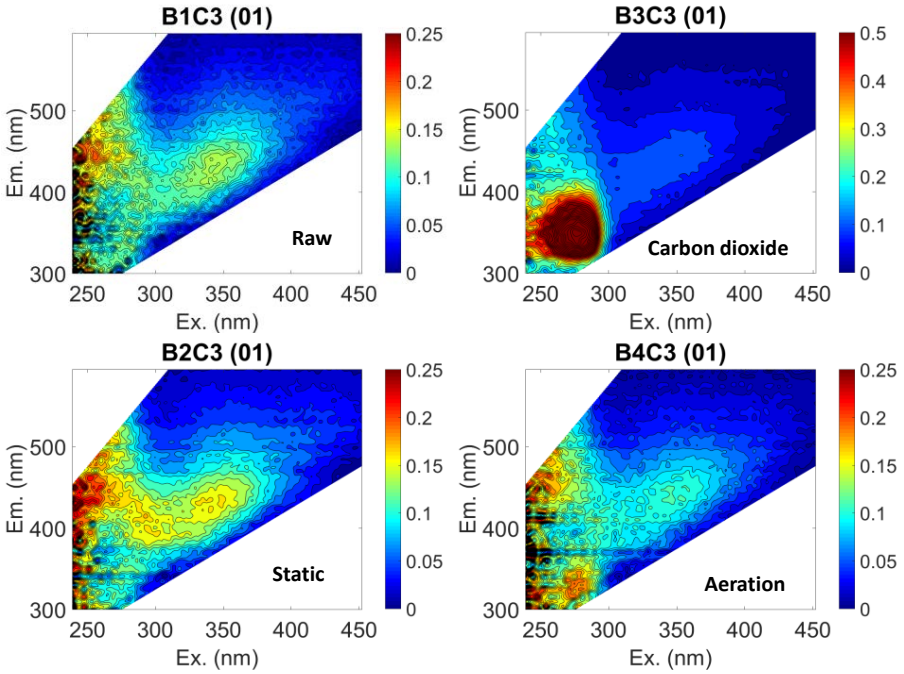

Figure 18.—Fluorescence excitation emission matrix plots showing generation of fluorescent DOM during photobiological treatment of Well 1 RO concentrate (3.8-L indoor reactors).

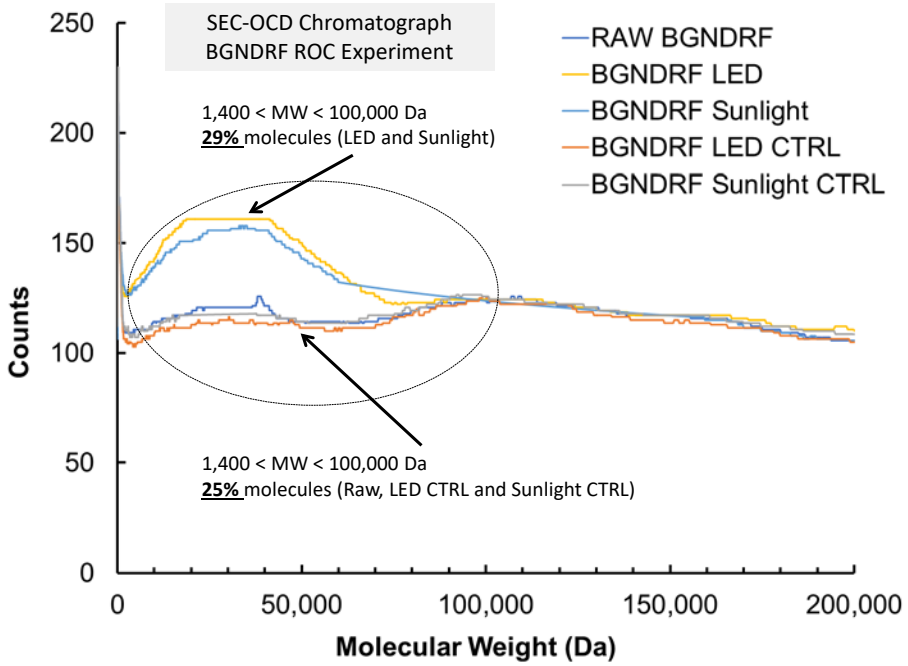

Figure 19.—Distribution of molecular weights of DOM in Well 1 RO concentrate before and after the photobiological treatment (50-mL indoor and outdoor tube reactors).

3.2. Pilot-scale Experiments

3.2.1. Pilot Photobioreactor Operation Overview

As described in Section 2, the pilot photobioreactor became operational on August 10, 2017. However, due to technical difficulties, the operation was halted and restarted with modified Well 2 water on September 22, 2017. In this report, the operational data after this date will be shown and discussed. Note that the treatability of silica-added Well 2 water by the photobiological treatment was confirmed by a bench-scale experiment (see Appendix 3).

A complete pilot data set is shown in Appendix 7, including summaries of the meteorological data, including ambient temperature (average, maximum, and minimum); precipitation; and length of day/visible light in Alamogordo, New Mexico during the pilot study. Briefly, the average ambient temperature in the area ranged from 9 to 28 °C, while the highest and lowest ambient temperatures were 35 and 1 °C, respectively. There were six storm events (>0.1 inches of precipitation) with an average of 0.3 inches (7.6 mm) of precipitations. The lengths of day were 14.3 and 10.4 hours on August 14 and November 17, 2017, respectively. The majority (67 days) of the days were clear, while there were 32 days with thunderstorms/rain, 3 days with scattered clouds, and 1 day with fog.

Figure 20 shows the pilot photobioreactor operational data, in terms of flow rate of reactor influent (modified Well 2 water), chemical feed rates, influent pH and reactive silica concentration. The average influent reactive silica concentration was 98 ± 19 mg/L, whereas the average influent pH was 7.2 ± 0.6.

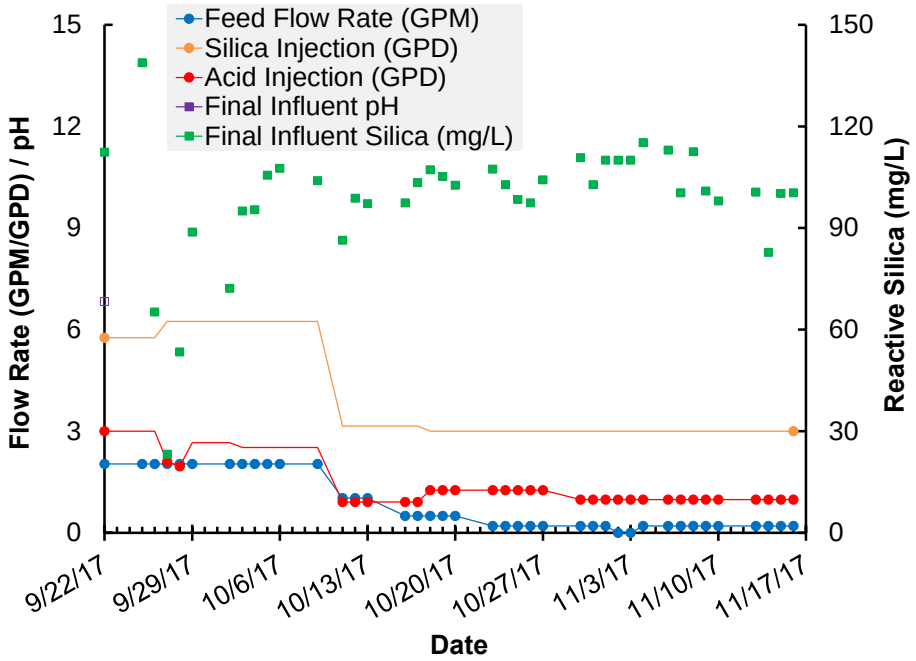

Figure 20.—Influent flow rate, influent pH, silica (sodium metasilicate) and sulfuric acid dosing rates, and reactive silica concentration. GPD is gallons per day.

Figure 21 shows the conductivity of photobioreactor influent and effluent, whereas the influent and effluent pH and temperature are shown in Figure 22. Effluent conductivity was always slightly higher (on average 10%), indicating a minor evaporation loss and water concentration within the photobioreactor.

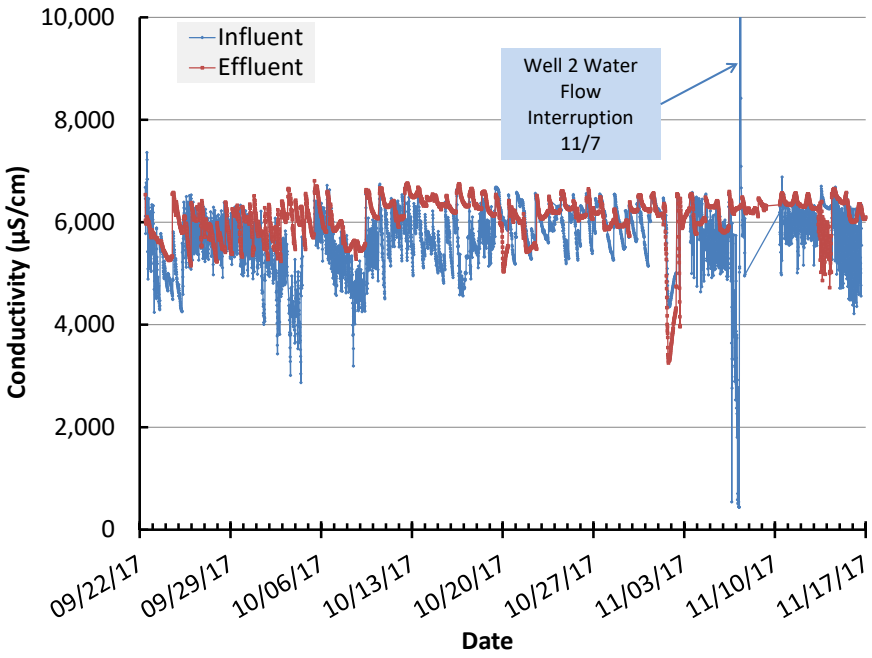

Figure 21.—Conductivity of pilot photobioreactor influent and effluent.

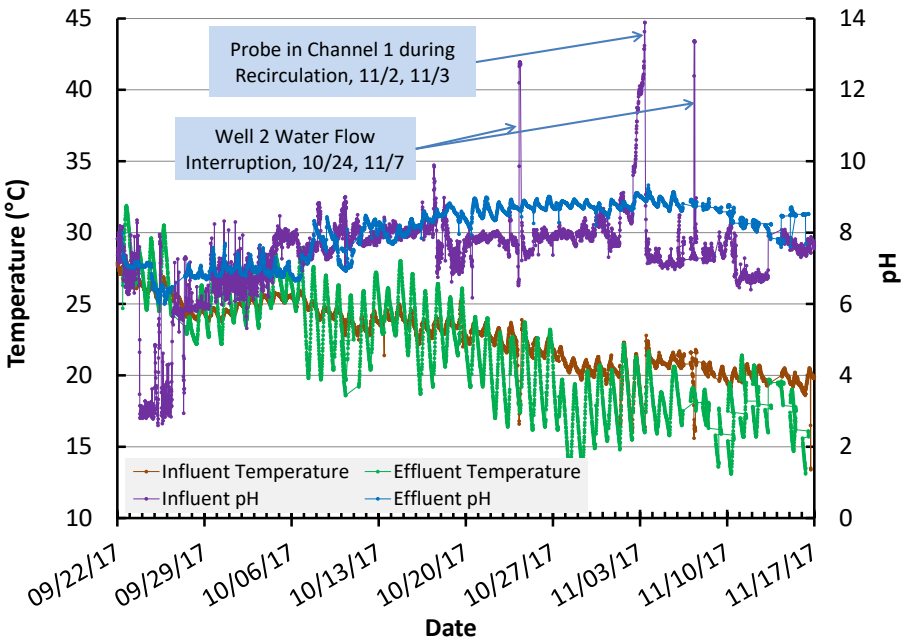

Figure 22.—pH and temperature of photobioreactor influent and effluent.

Both influent and effluent temperatures showed a decreasing trend, while influent and effluent pH values were relatively stable. The effluent temperature exhibited a stronger diurnal pattern than the influent temperature. The effluent pH was typically 1 to 2 units higher than the influent pH—showing an active photosynthesis in the photobioreactor.

3.2.2. Reactive Silica Removal and Nutrient Uptake

Figure 23 shows the reactive silica concentrations in different parts of photobioreactors, while Figure 24 and Figure 25 show orthophosphate and nitrate-N uptake at the same sample locations. See Figure 10 for the sample locations. After 10 days of lag period, reactive silica removal in the photobioreactor became evident in the first week of October 2017. The removal occurred evenly throughout the reactor. However, the extent of reactive silica removal was modest (up to 20%) during this period.

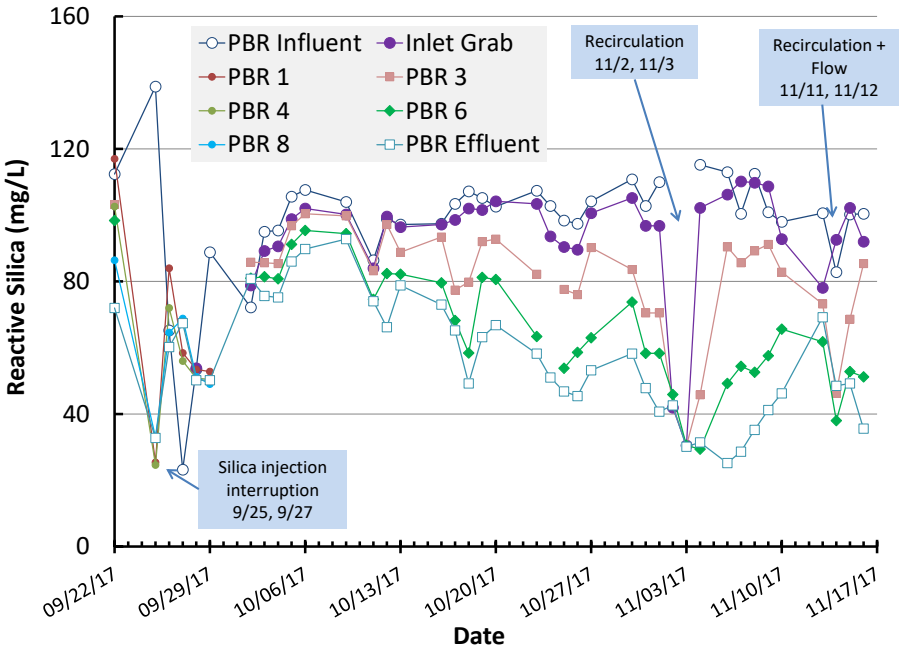

Figure 23.—Reactive silica removal in the pilot-scale photobioreactor.

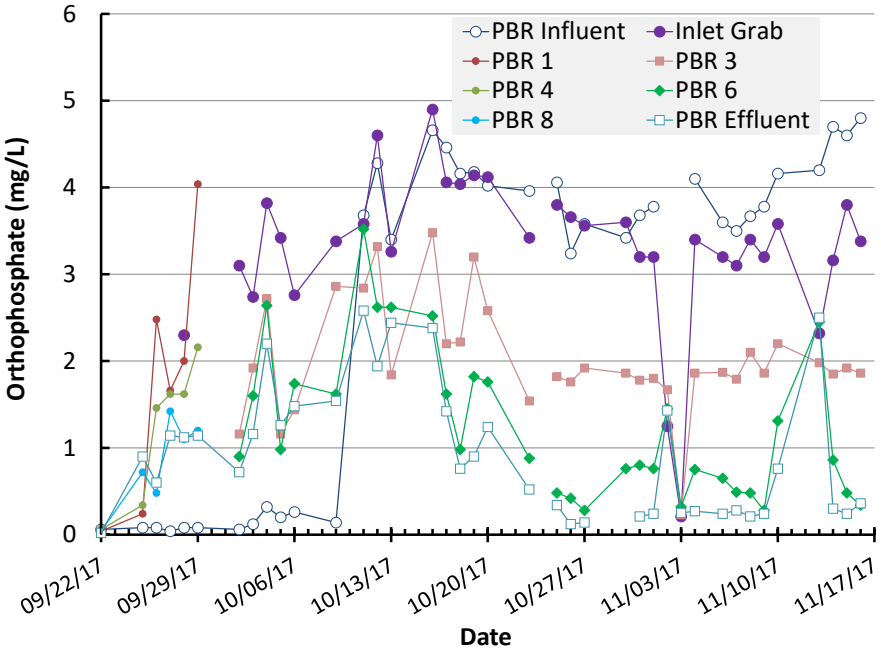

Figure 24.—Orthophosphate uptake in the pilot-scale photobioreactor.

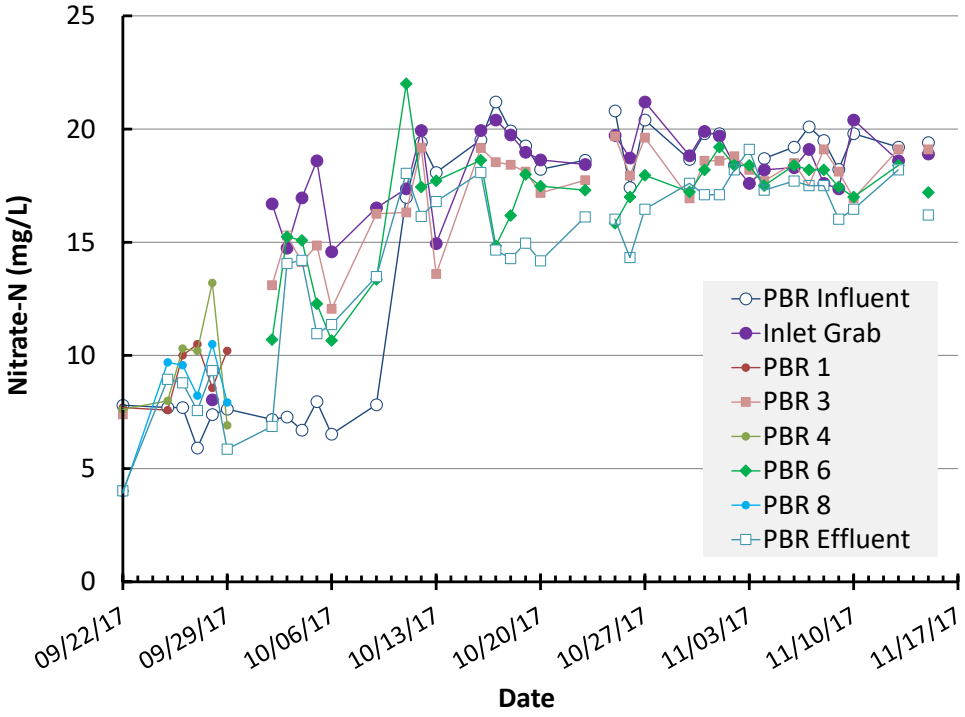

Figure 25.—Nitrate-N uptake in the pilot-scale photobioreactor.

Table 4.—Relationship of Photobioreactor Feed Flow Rate, HRT, and Reactive Silica Removal

Dates	Flow Rate (gpm)	HRT (Hours)	Reactive Silica Removal
Sept. 22, 2017-Oct. 10, 2017	2.03	12.3	Up to 21%
Oct. 11, 2017-Oct. 15, 2017	1.02	24.5	14% to 33%
Oct. 16, 2017-Oct. 22, 2017	0.5	50	25% to 54%
Oct. 23, 2017-Nov. 1, 2017	0.2	125	46% to 63%
Nov. 2, 2017-Nov. 3, 2017	0 (Reactor Recirculation)	Not applicable	Not applicable
Nov. 4, 2017-Nov. 16, 2017	0.2	125	Up to 78% (immediately after the recirculation), 31% to 65% (after 5 days)

The reactive silica removal improved by reducing the influent flow rate (Figure 20) and increasing the hydraulic retention time (HRT) of the photobioreactor (Figure 23) (Table 4). At a flow rate of 0.2 gpm (0.76 L/min), which corresponds to an HRT of 125 hours, up to 63% of reactive silica was removed. On November 2, 2017 and November 3, 2017, the influent to the photobioreactor was intentionally stopped and a submersible pump was used to mix and recirculate the water in the reactor. Then, the influent flow was resumed on November 4, 2017. The reactive silica removal improved immediately after the recirculation, likely because the extra HRT (+ 48 hours) gained during the recirculation. However, the reactive silica removal became deteriorated after 5 days, which is the HRT at the flow rate of 0.2 gpm, and returned to 50% to 60% removal.

A majority of orthophosphate was taken up during the photobiological treatment (Figure 24), while nitrate-N was present in excess in the water and was not consumed completely (Figure 25). Some of the nitrate-N (about 7 mg/L) was originated from Well 2 water as shown in Table 2. The system was phosphorus limited. Boosting orthophosphate dosing rate was considered. However, it was avoided because of the risk of having more interfering/competing algal species in the photobioreactor (see Section 3.2.3).

3.2.3. Algae Biomass Development and Management

The development of algal biomass was monitored during the pilot experiment as shown in Appendix 3. The first two sections of photobioreactor was initially inoculated with *P. trainorii* PEWL001. This diatom slowly migrated into the latter sections and covered the bottom of the photobioreactor. However, a major bloom of green algae occurred in many parts of the photobioreactor during the system start up (in mid-August; Figure 26). The green algae bloom could be

controlled by reducing/stopping the nutrient dosing and increasing/maintaining the reactive silica concentration. Using recirculating UV reactor (UVC-9, Tetra Pond, Blacksburg, Virginia) was attempted to clean suspended green algae, although no visible improvement was noticed. Manual harvesting of green algae was also done periodically using a vacuum cleaner. Additional *P. trainorii* PEWL001 inoculation was performed on September 29, 2017. The appearance of the algal biomass improved as shown in Figure 27. The greenish-brown color indicates the presence of diatoms, although the presence of some green algae was also noticed by visual and microscopic analysis.

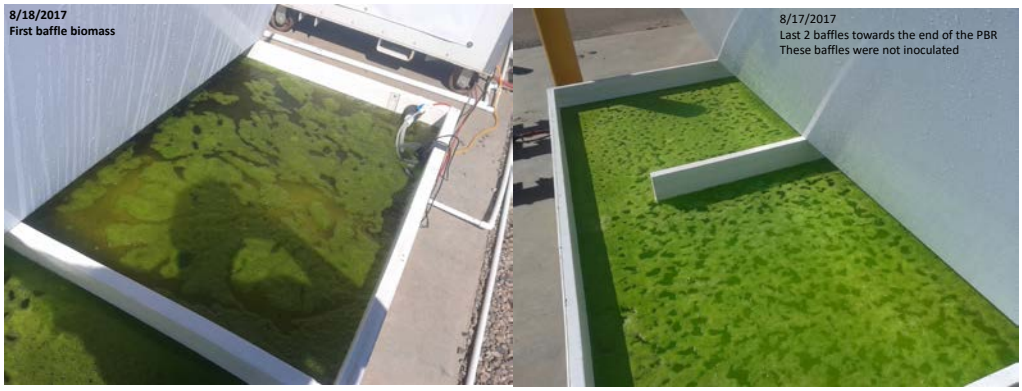

Figure 26.—Green algae bloom in the pilot-scale photobioreactor (left: near inlet, right: last two sections).

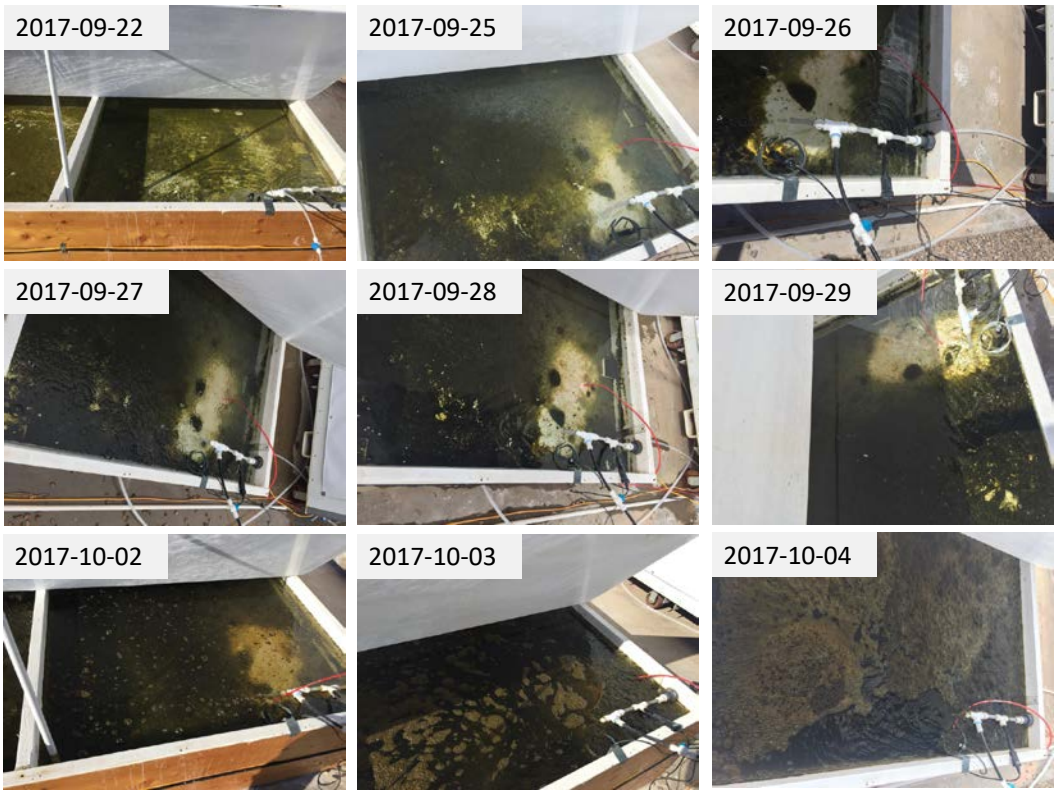

Figure 27.—Less green algae in the photobioreactor after the nutrient regulations.

The relative abundance of algae in the photobioreactor was investigated by *in vivo* chlorophyll and phycocyanin analyses (Figure 28 and Figure 29). The concentrations of those plant pigments in the reactor was relatively stable. Based on the *in vivo* chlorophyll data, more algae (including diatoms) were present in the first section (Inlet Grab), followed by the effluent (PBR 6) and PBR3. The recirculation helped distribute the algae, although the *in vivo* chlorophyll levels went back immediately after the recirculation was seized. Based on the phycocyanin analysis (Figure 29), no major bloom of cyanobacteria (blue-green algae) was observed.

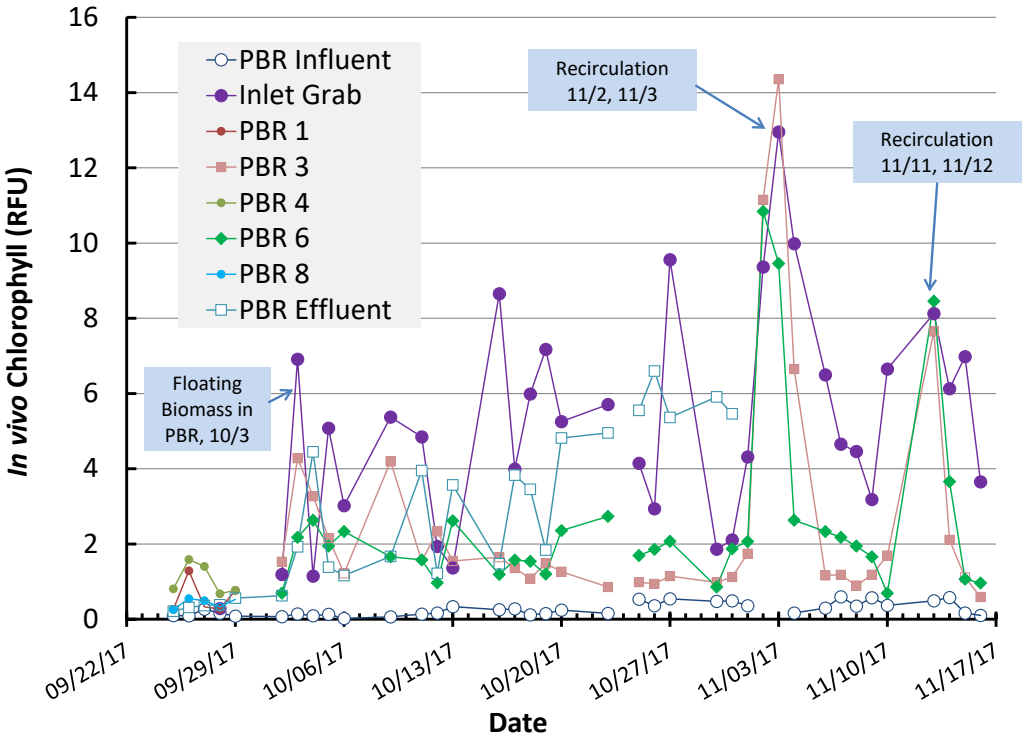

Figure 28.—*In vivo* chlorophyll in the pilot-scale photobioreactor.

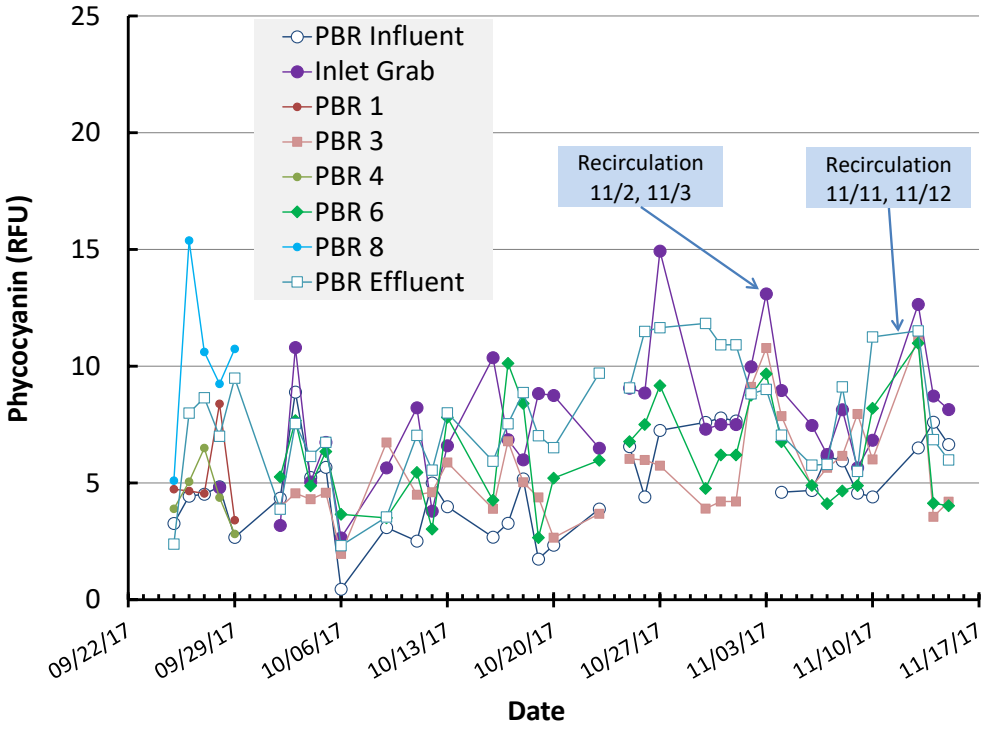

Figure 29.—Phycocyanin in the pilot-scale photobioreactor.

Figure 30 shows the diatoms commonly found in the bottom and surface the photobioreactor. The filamentous species in the bottom biomass is *P. trainorii* PEWL001, which was originally inoculated to the bioreactor. It is apparent that the diatom species floating at the surface were not *P. trainorii* PEWL001, but other native diatom species likely introduced by wind and insects.

The native diatoms identified by the eukaryotic microbial diversity analysis (sequencing analysis) included: *Nitzschia palea* and *Navicula* sp. It should be noted that the identifications of many diatom species were still unknown because of the limited availability of published sequence data. The presence of *P. trainorii* (identified as *Nanofrustulum* cf. *shiloi*) in the bottom (more abundant) and surface (less abundant) biomass was also confirmed by the sequencing analysis. *P. trainorii* was also much less abundant in the later sections of the photobioreactor. A number of marine protozoa and choanoflagellates were also found, including: *Cyclidium glaucoma*, *Vorticella fusca*, *Sterkiella* sp., *Lagenoeca* sp., and *Salpingoeca napiformis*, as well as some fungi. See Appendix 8 for more details.

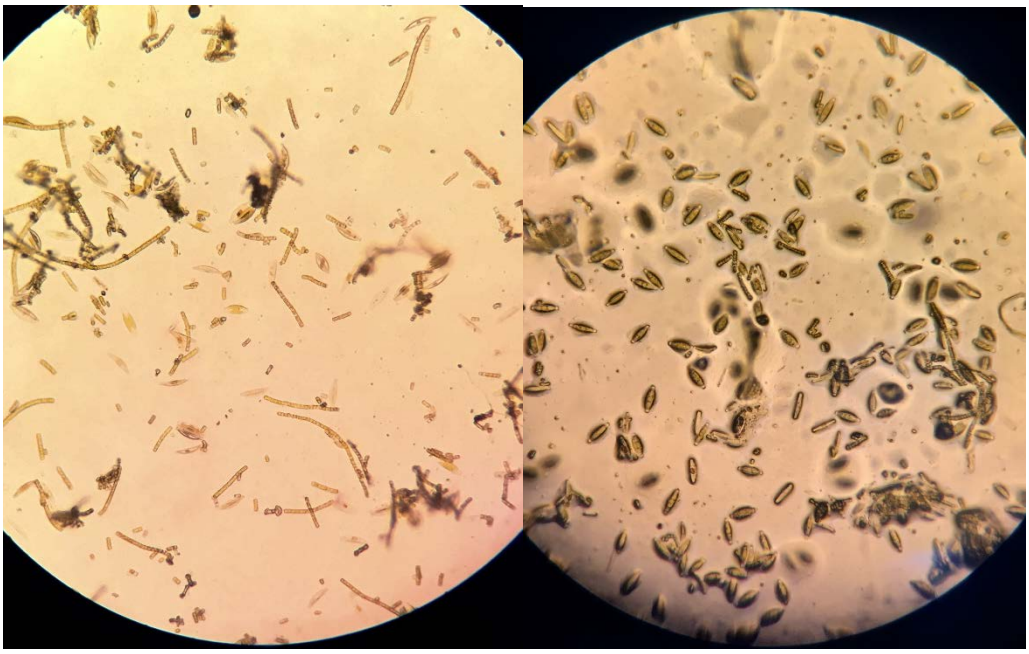

Figure 30.—Light microscope images of diatoms found in the bottom (left) and surface (right) of the pilot-scale photobioreactor (first section).

3.2.4. Discussion on Reactive Silica Removal in the Pilot-scale Photobioreactor

Overall, the reactive silica removal achieved in this pilot-scale photobiological treatment was comparable (up to 60% removal in 125 hours) to what we saw in the bench-scale experiments using sunlight as a light source (Figure 16; about 90% removal in 132 hours in 3.8-L reactors). However, the performance in the pilot-scale reactor was much less efficient than the small-scale semi-batch reactors' performance (Figure 13) where a majority (>60%) of reactive silica could be removed within 24 hours. There are a number of possible reasons, including:

- Contamination by green algae and other eukaryotic microorganisms
- Contamination by other native diatoms
    - Another laboratory experiment performed in our laboratory also revealed that the contamination of pure diatom cultures with other diatom species, green algae, and/or protozoa seriously slowed down the reactive silica uptake.
    - By modifying water quality (e.g., reactive silica concentration, nutrient ratio and doses), it is possible to encourage/discourage the growth of particular types of algae. However, it is impossible to eliminate undesirable organisms completely. In a large-scale field

treatment, contamination is inevitable. A better control strategy is needed.
    - Also, more research is needed to investigate the impact of different types of contamination on reactive silica removal by diatoms.

- Light intensity/quality
    - The photosynthesis could be improved by adjusting the intensity and/or wavelength of visible light.

- Decreasing temperature
    - As the ambient temperature started reaching zero during the night, the water temperature was showing a steady decreasing trend (Figure 22). Diatoms are less active at lower temperature.

- Reactor hydraulics and mass transfer
    - Short-circuiting might have occurred in the photobioreactor.
    - A gentle mixing may be helpful to improve the mass transfer. However, excessive mixing should be avoided because it damages the diatom cells and slows the silica uptake (Cycle 3 [Hours 120 - 206]) in Figure 13).

3.2.5. Pilot-scale RO Treatment

3.2.5.1. Pre-filtration and Particulate Organics Analysis

The filterability of photobiologically-treated Well 2 water was investigated during the RO experiment using a series of cartridge filters. The treated water collected in the storage tanks was actually very clear and did not contain a significant amount of algal cells because these cells tended to settle at the bottom of the covered storage tanks. After the cartridge filtration, the filtered water appeared very clear (Figure 31) and ready for RO treatment. After about 10 days of use, the cartridge filters were removed from the housing and inspected for possible fouling by the algal biomass. However, filters were relatively clean as shown in Figure 31. A majority of algal biomass was filtered by the first 10 µm cartridge filter.

Figure 31.—Appearance of filtered photobiologically-treated Well 2 water.

Figure 32.—Appearance of cartridge filters after use (pore sizes: 10, 10, and 5 µm).

To investigate the possible generation of organic particles by the photobiological treatment, we conducted a TEP analysis. About 17 mg/L of TEPs were detected in the first channel of the reactor while 6 mg/L were detected in the last channel. In general, these findings are consistent with previous studies that reported the generation of DOM by diatoms (Passow 2002). However, the generated DOM appeared to be more protein-like rather than recalcitrant and within the molecular weight range of 1,400 to 100,000 Da, which may be removed easily by filtration using membranes with appropriate molecular weight cut off. Therefore, this preliminary study indicates that although some DOM may be generated during photobiological treatment process, it may not significantly affect the secondary RO of the effluent from photobiological treatment.

3.2.5.2. Pilot-scale RO Results

The pilot-scale RO experiment confirmed that the photobiologically-treated Well 2 water could be desalinated using a standard brackish water RO unit at a permeate recovery up to 70% (Figure 33). More RO operation and water quality data are presented in Appendices 7 and 9.

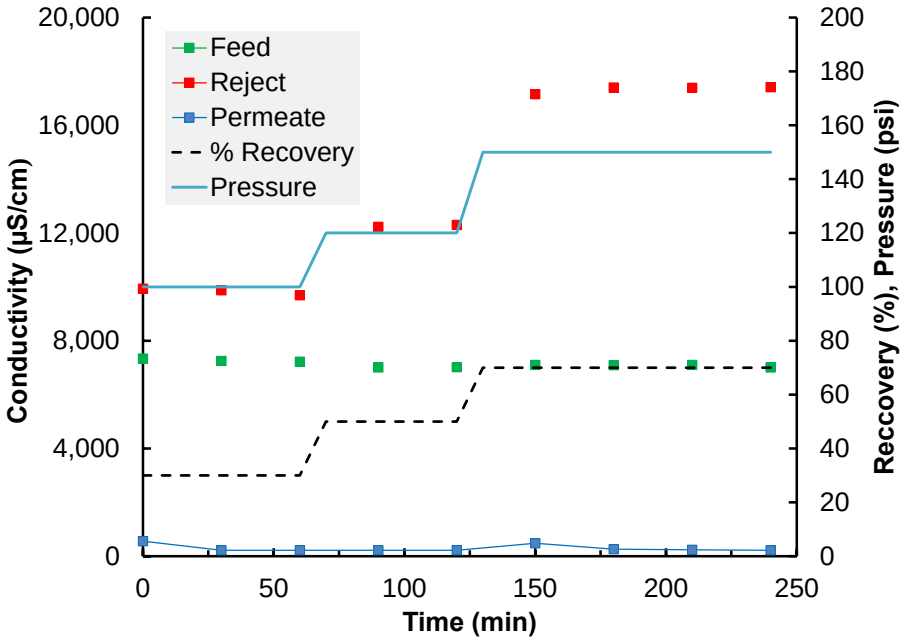

Figure 33.—An example of pilot RO operational data.

Assuming that the silica-added Well 2 water properly represents the concentrate from an RO system desalinating Well 1 water at 75% permeate recovery, this result can be translated as Equation 1:

$$75\% + 25\% \times 70\% = 92.5\% \text{ overall permeate recovery} \qquad [1]$$

With this result, one of the project objectives—to achieve more than 90% permeate recovery using the combination of the photobiological treatment and secondary RO process—could be met. Due to the time limitation, long-term impacts of dissolved and particulate constituents originated from the photobiological treatment on the RO process could not be investigated. Additional research, preferably on a smaller scale, is required and recommended to continue the development of this photobiological treatment technology.

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4. Conclusions and Next Steps

4.1. Conclusions

In this project, a series of bench- and pilot-scale experiments were carried out to investigate the feasibility of the novel photobiological treatment process to treat silica-rich brackish groundwater and brackish groundwater RO concentrate to enable additional desalination and freshwater recovery using a standard secondary RO process. This was the very first attempt to perform a pilot study on this novel, green technology for RO concentrate treatment and management in a realistic inland desalination project setting at the BGNDRF in Alamogordo, New Mexico.

Our bench-scale experiment confirmed that the concentrate from an RO skid desalinating Well 1 water at the BGNDRF, as well as silica-added Well 2 water, could be treated by the photobiological treatment process using a brackish water diatom *P. trainorii* PEWL001. Nutrient requirements for nearly complete (>85%) removal of reactive silica was determined to be 2about 4 mg/L as PO_4^{3-} of orthophosphate and 12 mg/L of nitrate-N, while ammonia was toxic to the diatom at the concentrations tested in this study. Adding trace minerals and vitamins was found to be unnecessary. Whereas gentle mixing by aeration could enhance the reactive silica removal, adding carbon dioxide did not show significant impact on the reactive silica removal. Because the carbon dioxide addition suppressed the calcium carbonate removal by lowering pH, it was concluded that there was no need to add carbon dioxide in this photobiological treatment. Disturbance of algal biomass also slowed down the reactive silica uptake in the semi-batch treatment experiment. Unlike previous studies with RO concentrate from advanced water purification facilities, direct sunlight was found to be undesirable for brackish groundwater treatment because of the high transparency of the groundwater. Based on the bench-scale experiment, it was decided to use white, opaque plastic panels to block a majority of direct sunlight (6 mm thick, 20% light transmission) to cover the pilot-scale photobioreactor to be built and tested at the BGNDRF.

Since the photobiological treatment process produced some organic matter via algal photosynthesis, which may become a concern in the subsequent RO processes, natural organic matter in the photobiologically-treated water was investigated in this project. Our analysis confirmed that the photobiological treatment of Well 1 RO concentrate generated 2.7 to 4.6 mg/L of DOC. The majority of the generated DOC could be characterized as relatively low-molecular weight (1,400 < MW < 100,000 Da) and more protein-like than recalcitrant DOC. Although some DOC may be generated during the photobiological treatment process, it may not significantly affect the subsequent RO process.

In the pilot-scale experiment, a 1,500-gallon (5,700-L) pilot-scale photobioreactor was constructed with 8-foot x 8-foot plywood boards and 2-inch x 10-inch x 10-foot wood planks coated with white waterproof liquid rubber-based paint on the Test Pad 7 at the BGNDRF. The pilot-scale photobioreactor was operated from August 10, 2017 until November 17, 2017. In this pilot experiment, silica-added Well 2 water was used in lieu of Well 1 RO concentrate, starting on September 22, 2017. Figure 34 shows the simplified reactive silica removal data during this experiment.

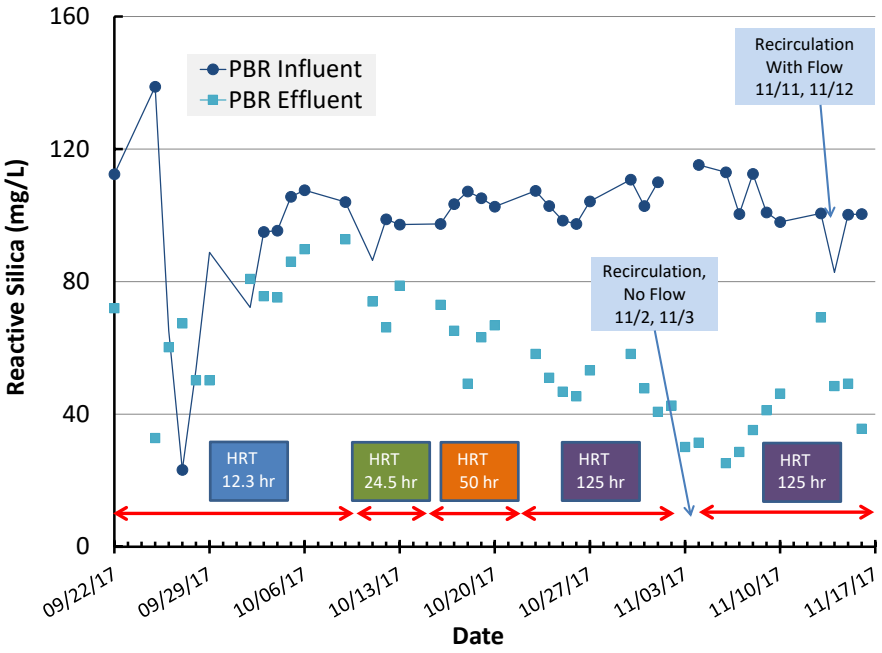

Figure 34.—Simplified silica removal data.

The reactive silica removal in the pilot-scale photobioreactor was modest (up to 20%) when the HRT was short (12.3 hours). The reactive silica removal improved by reducing the influent flow rate and increasing the HRT as shown in Table 4. More than 60% of reactive silica was removed in the photobioreactor with an HRT of 125 hours. This is comparable to the result of bench-scale experiments using sunlight as a light source (Table 5). However, this removal was much lower than the more efficient small (50-mL) tube experiments where a majority (>60%) of reactive silica could be removed within 24 hours. There are a number of possible reasons, including:

- Contamination by green algae, native diatoms, and other eukaryotic microorganisms
- Light intensity/quality
- Water temperature
- Reactor hydraulics and mass transfer

Additional research is needed to investigate and optimize the reactive silica removal in the continuous flow photobioreactor.

Table 5.—Summary of Reactive Silica Removal Rates

Treatment Conditions	Reactor Size	Maximum Reactive Silica Removal Rate
Indoors (LED, Static)	50 mL	74 mg/L/day
Indoors (LED, Static)	3.8 L	27 mg/L/day
Indoors (LED, Aerated)	3.8 L	32 mg/L/day
Outdoors (Direct Sunlight, Static)	3.8 L	10 mg/L/day
Outdoors (Indirect Sunlight, Static)	50 mL	15 mg/L/day
Outdoors (Indirect Sunlight, Continuous Flow)	5,700 L	13 mg/L/day

mg/L/day = milligrams per liter per day

The pilot-scale RO experiment revealed that the photobiologically-treated Well 2 water could be readily filterable with an ordinary 10-µm cartridge filter to yield clear filtrate for brackish groundwater desalination. Also, a standard brackish water RO unit could be used to desalinate the photobiologically-treated Well 2 water at a permeate recovery up to 70%. Assuming that the silica-added Well 2 water properly represents the concentrate from an RO system desalinating Well 1 water at 75% permeate recovery, this result can be translated as 92.5% overall permeate recovery. Additional research is recommended to investigate the long-term feasibility of this process scheme (photobiological treatment followed by secondary RO), such as risk of biological and/or organic fouling, at existing brackish water desalination facilities.

4.2. Recommended Next Steps

More bench-scale and smaller pilot-scale photobiological treatment studies are recommended to investigate the following key issues:

- Impact of contamination by green algae and other diatoms
- Contamination control strategies
- Feasibility of using mixed culture diatoms instead of a pure culture
- Optimization of light intensity and wavelength
- Optimization of reactor hydraulics to improve mass transfer without disturbing diatom cells
- Potential commercial value of generated and harvested algal biomass
- Harvesting mechanisms for algal biomass

It is desirable to perform the smaller pilot-scale studies at existing brackish groundwater desalination facilities and/or advanced water purification facilities to treat real-life RO concentrate. The pilot-scale photobiological treatment studies

should be accompanied by a continuous flow secondary RO unit to obtain a long-term RO performance data. To develop a practical RO concentrate treatment process, the HRT needs to be shortened to less than 12 hours in a continuous flow, small pilot system.

Once all the technical questions and challenges are answered and solved, a larger-scale (5about 10 gpm), continuous flow pilot study should be planned and conducted at an existing brackish groundwater desalination facility and/or advanced water purification facility to investigate the feasibility of scaling up the system without slowing down the treatment process in a larger reactor. More detailed cost analysis should be done during the larger-scale pilot study.

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RECLAMATION

Managing Water in the West

Pitch to Pilot Program

Development of a Novel Photobiological System to Improve Water Recovery in Brackish Groundwater Desalination Appendices

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

March 2018

APPENDIX 1

Table A1. Summary of experimental designs for the photobiological treatment of brackish groundwater RO concentrate

Objective	Experimental Setup	Conditions
Requirement of nutrients (nitrogen and phosphorous) by diatom	• Sixteen combinations tested • Orthophosphate[1] doses tested: 2, 4, 6 and 8 mg/L as PO_4 • Nitrate-N[2] doses tested: 12 and 24 mg/L • Ammonia-N[3] doses tested: 12 and 24 mg/L	• 50-mL clear polypropylene centrifuge tubes[5] • Working volume of 45-mL • Incubated inside a reflective cabin • LED bulb (40 W, 470 lumens, 5,000 K) • Light intensities - LUX: 1,500 lux - Photosynthetically Active Radiation (PAR): 1.7 $\mu E/m^2/s$ • Temperature: 25 ± 2°C
Requirement of trace metals and vitamins by diatom	• Nine combination tested • Three levels of trace metals (0, 1X and 2X of recommended dose in f/2 medium) • Three levels of vitamins (0, 1X and 2X of recommended dose in f/2 medium) • Orthophosphate[1] dose: 4 mg/L as PO_4 in each culture tube • Nitrate-N[2] dose: 12 mg/L in each culture tube	
Long-term reactive silica uptake by diatom in semi-batch mode	• Silica uptake tested in five consecutive treatment cycles • Orthophosphate[1] dose: 4 mg/L as PO_4 • Nitrate-N[2] dose: 12 mg/L • Trace metals and vitamins[4]: none	
Effect of aeration and carbon dioxide addition on the reactive silica uptake by diatom	• Two static reactors: no mixing or aeration • One aerated reactor: sterile filtered[8] air at 1.3 L/hr[9] • One CO_2 added reactor: sterile filtered[8] 2% CO_2 at 1.3 L/hr[9] • Tested for three consecutive treatment cycles • Orthophosphate[1] dose: 4 mg/L as PO_4 in each reactor • Nitrate-N[2] dose: 12 mg/L in each reactor • Trace metals and vitamins[4]: none	• 2-gallon high density polyethylene pails[7] • Working volume of 1-gallon • LED bulb[6] (40 W, 470 lumens, 5,000 K) • Light intensities - LUX: 4,065 lux - PAR: 4.32 $\mu E/m^2/s$ • Temperature: 25 ± 2°C
Effect of light source (sunlight and LED) on the reactive silica uptake by diatom	• Two conditions tested, under LED light and under sunlight, for two consecutive treatment cycles • Orthophosphate[1] dose: 4 mg/L as PO_4 in each reactor • Nitrate-N[2] dose: 12 mg/L in each reactor • Trace metals and vitamins[4]: none	• 2-gallon high density polyethylene pails[7] • Working volume of 1-gallon • Outdoor light intensities (also see Figure S8) - LUX: 1,34,188 lux - PAR: 173 $\mu E/m^2/s$ • Ambient temperature: 17°C to 37°C
Reactive silica uptake by diatom under direct sunlight and under the shade	• Two conditions tested, under direct sunlight and outdoor but under the shade, for two consecutive treatment cycles • Orthophosphate[1] dose: 4 mg/L as PO_4 in each culture tube • Nitrate-N[2] dose: 12 mg/L in each culture tube • Trace metals and vitamins[4]: none	• 50-mL clear polypropylene centrifuge tubes[5] • Working volume of 45-mL • Light intensities under direct sunlight - LUX: 1,34,188 lux - PAR: 173 $\mu E/m^2/s$ • Light intensities under shade (also see Figure S9) - LUX: 30,863 lux - PAR: 31 $\mu E/m^2/s$ • Ambient temperature: 17°C to 37°C

[1]Reagent grade sodium phosphate monobasic monohydrate, [2]sodium nitrate and [3]ammonium sulfate (Sigma Aldrich, St. Louis, MO, USA); [4] F/2 (Guillard, 1975) medium (Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, USA, catalog #MKF250L); [5]50-mL clear polypropylene centrifuge tube (VWR International, Radnor, PA, USA); [6]EcoSmart LED Bulb (Home Depot, Atlanta, GA, USA); [7]2-gallon HDPE Pails (United Solutions, Leominster, MA, USA) cleaned with dilute bleach and rinsed with the medium; [8]Sterilized air filter 0.2-µm (Cole-Parmer, Vernon Hills, IL, USA); [9]Aquarium air pump Whisper40 (Tetra, Blacksburg, VA, USA); Light intensity measurements using Digital Luxmeter (Dr. Meter, Union City, CA, USA, Catalog # LX1010B) and Handheld Radiometer ILT1400 (International Light Technologies, Peabody, MA, USA).

APPENDIX 2

B054 Pilot Activity Log Last updated on 2018-03-09 by HK

Monday 7th August, 2017

Time	Activity	Personnel
7:15 AM	Check In	KI, TM, HK, SS
8:00 AM	Check In	SHG
8:30 AM	PBR filled with tap water	SS, TM
9:30 AM	Added bleach to the PBR to disinfect. • Target chlorine dose = 20 ppm • PBR water volume ~3,000 gallons (at 8" depth) • Bleach concentration = 7.86% ~ 78.6 g/L • Bleach requirement = 20 mg/L x 3,000 gallons x 3.78 L/gallons / 78.6 g/L / 1,000 mg/g = 2.8 L = 3 quarts (0.75 gallons) • Actual added dose = 1 gallon, at 4-5 different locations for even distribution • PBR internal recirculation using sump pump	SS, TM
11:00 AM	Tested for free chlorine • Expected concentration : 3 to 10 ppm • Observed concentration : 0.02 ppm	HK, SHG
11:30 AM	Added another 1-gallon of bleach	SS, TM
11:45 AM	Left for NMSU, meeting with Dr. Khandan	KI, HK, SHG
11:45 AM	Check out	SHG
12:30 PM	Added another 1-gallon of bleach	SS, TM
2:00 PM	Started draining PBR with sump pump	SS, TM
4:00 PM	Stopped sump pump and opened sample ports for draining the PBR	SS, TM
5:00 PM	Check out	SS, TM

Tuesday 8th August, 2017

Time	Activity	Personnel
7:30 AM	Check In	KI, TM, HK, SS
8:00 AM	Check In	SHG
8:30 AM	pH probe calibrated, sample bottles preparation	HK, SHG
9:00 AM	Ran primary RO for 20 min • Pre-filter pressure = 90 psi • Post-filter pressure = 90 psi • Primary pressure = 250 psi • Final pressure = 210 psi	SS, TM, HK, SH
9:50 AM	Started monitoring primary RO • Pressure, flow rate, pH, conductivity, TDS, temperature and silica monitored	HK, SHG
11:30 AM	Recovery stabilized at ~ 70%. Samples were collected every 30 min in 250-mL bottles	HK, SHG
12:00 pm	Check out	SHG
1:30 PM	Primary RO stopped due to low inlet pressure (other groups were drawing water which caused low inlet pressure). • After Alarm Reset button was pressed, RO operation resumed	KI, SS, TM, HK
3:30 PM	Primary RO performance data collected for 4 hours at 30 min interval	HK
4:00 PM	Check out	KI, SS, TM, HK

Wednesday 9th August, 2017

Time	Activity	Personnel
7:30 AM	Check In	KI, TM, HK, SS
7:30 AM	Primary RO was running overnight without problem and PBR was filled completely. Overflow weir opening was small so water level in PBR was higher than designed (4”).	
7:45 AM	Samples collected and tested for pH, temperature, conductivity, TDS and silica. • Primary ROC entering the PBR (SP-1) • ROC leaving the PBR (SP-4) Both samples had very similar chemistry	HK
8:00 AM	Check in	SHG
8:30 AM	Labeled sampling ports (SP-1 through SP-13) covering primary RO, PBR and secondary RO as per legend in sampling plan. Used different color labeling tapes.	HK, SHG
9:30 AM	Tested the nutrient medium for actual orthophosphate and nitrate concentrations. 10-mL of stock solution from the bucket was transferred in 15-mL centrifuge tube. Two other tubes with 1:100 and 1:10,000 dilutions were prepared. • Orthophosphate = 20.6 g/L, tested using DR2700 • Nitrate-N = 72.1 g/L, tested using DR6000 Concentrations are found to be correct for our design calculations. Nutrient pump flow rate required is 0.58 gpd.	HK, SHG
10:00 AM	Discussed and reviewed sampling plan, analysis with SHG. Discussed handheld fluorometer operation, calibration and data recording. Discussed light intensity measurements.	HK, SHG
11:30 AM	Four points near four corners of PBR were selected for light intensity measurement (labeling tape is pasted). Ambient Lux, PAR and UV intensities were measured above the PBR. A side panel was lifted and light sensors were held slightly above the water level and measured the intensities under cover.	HK, SHG
12:00 PM	Lunch break	KI, TM, HK, SS, SHG
12:30 PM	Check out	SHG
12:45 PM	Restarted the primary RO system with booster pump. VFD was set to 59 Hz • Pre-filter pressure = 60 psi • Post-filter pressure = 60 psi • Primary pressure = 290 psi • Final pressure = 280 psi	KI, TM, HK, SS, SHG

	• Permeate flow = 4.5 gpm • Concentrate flow = 2.1 gpm	
1:00 PM	Check out	SHG
1:00 PM	Calibrated and installed continuous monitoring pH probes. Currently set to record pH every 1 min. Two probes are installed: 1. Near SP-1, this measures pH of feed to PBR 2. Near overflow weir towards the end of PBR, this measures ROC leaving PBR pH meters are kept in a dark tupperware box.	HK, SS
1:30 PM	Assembled and set up microscope	HK
2:30 PM	Check out	KI, SS
2:30 PM	Wired flow switches, added 2 junction boxes, wired control panel. TM working on the program.	HK, TM
4:00 PM	Installed two conductivity probes / meters 1. Near SP-1, sample place as pH meter, this measures conductivity of feed to PBR 2. In 2nd blue tank (post-PBR sump well) The conductivity meters are kept in the same tupperware boxes as pH meters. Batteries (AA size) need to be purchased for one of the conductivity meters.	HK
5:00 PM	Check out	HK, TM

Thursday 10th August, 2017

Time	Activity	Personnel
6:30 AM	Check in	TM, HK
7:30 AM	Home depot shopping for buckets, aluminum film, LED lamp	HK, SS
8:00 AM	Check in	SHG
8:15 AM	Check in	HK, SS
8:30 AM	Water level in PBR high, primary RO running fine	SS, TM, SHG, HK
8:45 AM	Installed second conductivity meter	HK
9:00 AM	Nutrients pump configuration • Variable flow chemical pump stopped working • Tried other Mec-o-Matic pump, worked but fixed flow of 22 gpd and we needed 0.6 gpd • Used one of the Stenner pumps at 10% speed to obtain 0.6 gpd flow • Flow was measured actually using beaker and confirmed 0.6 gpd	TM, SHG, HK
10:00 AM	Checklist for Shanka for primary RO and PBR operation, switches, pumps on/off	TM, SS, SHG, HK
10:00 AM	Installed depth measurement scale in the PBR, prepared small indoor LED incubator box	SS
10:30 AM	Biomass preparation • Supernatant in 2 x 1-gallon seed culture bottles was decanted and fresh ROC was added to it • Biomass in tube was cleaned and combined • 45-mL of biomass suspension sample (exactly what is used for inoculating the PBR) was collected and stored separately. This will be brought back to PACE • Biomass observed under microscope to ensure they are in healthy conditions. Took pictures using phone camera. • 16 x 45-mL tubes were prepared for growing back-up cultures and kept in LED box inside office • Nutrient dose of 4.9 mg/L orthophosphate and 14 mg/L nitrate-N was added to all tubes using Fritz F/2 medium (same solution that is being added to PBR)	HK, SS
12:15 PM	Check out	SHG
12:15 PM	Nutrient pump configuration was completed and nutrient flow started in the PBR	HK, TM

	• The pump tubes caught air in them, so would take long time to start pumping nutrient solution. Tubes were disconnected and using syringe, nutrient solution was filled in the tubes to expedite the pump operation. • Samples from first baffle and from primary ROC port were collected and tested for background orthophosphate and nutrient concentrations, found none.	
1:15 PM	Samples were collected and tested for orthophosphate • Grab sample near nutrient addition place (SP-4-L) = 1.4 mg/L • Sample from sampling port SP-4-R = 1.3 mg/L (this is towards the other end of first baffle)	HK
2:15 PM	Lunch	HK, TM, SS
2:55 PM	Inoculation • Total 2-L of biomass suspension was used for inoculation • Biomass was added using 500-mL beaker • Distributed evenly from side panels of first and second baffle	HK, TM, SS, Bobby
3:30 PM	Preparing for secondary RO test, but bug in the program, TM speaking to Patrick to solve it. (Solenoid valve does not open). Need to upload new program tomorrow morning.	HK, TM, SS
4:00 PM	Rain started, some water accumulated over the panels	-
4:30 PM	Check out	HK, TM, SS

Friday 11th August, 2017

Time	Activity	Personnel
6:30 AM	Check in	TM, HK, SS
7:30 AM	Valve change on RO	TM, SS
8:00 AM	Nutrients bucket – pump set up change to simplify tubing	HK, SHG
9:30 AM	Inventory for lab supplies and material left at BGNDRF	HK, SHG
10:30 AM	Secondary RO go-through and wrap up	SS, TM, SHG, HK
11:30 AM	Phone call for discussion before leaving	HK, TM, SS, SHG, KI
12:30 PM	Check out	HK, TM, SS, SHG

Monday 14th August, 2017

Time	Activity	Personnel
8.55 AM	Check In	SHG
9:00 AM	Primary RO System Performance • Pre-filter pressure = 55 psi • Post-filter pressure = 54 psi • Primary pressure = 290 psi • Final pressure = 285 psi **Remark:** Increase the booster pump VFD to 56.0 Hz to increase filter pressures.	SHG
9:10 AM	Wiped out the rain water collected on top of the PBR cover.	SHG
9.30 AM	PBR checkup and sampling PBR depth – 5 in **Remarks:** Biomass growth on first 1/3 of the PBR.	SHG
9. 45AM	Data Logger Check up **Remarks**- Rainwater has flooded the data logger boxes and data loggers got disturbed 1. Conductivity meter 2 (SP -7) display is not working and SD card got damaged. 2. Conductivity meter 1 (SP-4) data hasn't recorded.	SHG
10.30 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
11.15 AM	Laboratory sample analysis: • Direct measurements • Laboratory testing	SHG
12.25 PM	Primary RO system Performance Check • Pre-filter pressure = 66 psi • Post-filter pressure = 65 psi • Primary pressure = 295 psi • Final pressure = 290 psi **Remark:** Booster pump VFD Lowered to 53.6 Hz to increase filter pressures closer to 60 psi	SHG
12.25 PM	Antiscalant pump stopped	SHG, HK, SS

	- Switched of the pump and Informed HK and SS - Restart Pump again at 12.32 PM and started working.	
12.45 PM	Laboratory sample analysis	SHG
1.15 PM	Checking of Antiscalant Pump for working	SHG
1.20 PM	Check out	SHG

Tuesday 15th August, 2017

Time	Activity	Personnel
9.00 AM	Check In	SHG
9:05 AM	Primary RO System Performance • Pre-filter pressure = 60 psi • Post-filter pressure = 59 psi • Primary pressure = 295 psi • Final pressure = 290 psi **Remark:** Antiscalant pump out let came off. Fixed by Steve Holland (BGNDRF) at 8.30 am and secured with wire ties.	SHG
9:15 AM	Wiped out the rain water collected on top of the PBR cover.	SHG
9.30 AM	PBR checkup and sampling PBR depth – 5 in **Remarks:** Increased biomass growth on first 1/3 of the PBR with higher density in first baffle	SHG
9.40 AM	Data Logger download, pH probe calibration, battery replacement and starting of loggers.	SHG
10.00 AM	Data logger storage box modification to minimize rain water penetration	SHG
10.15 AM	Laboratory sample analysis: • Direct measurements • Laboratory testing	SHG
12.05 PM	Primary RO system Performance • Pre-filter pressure = 56 psi • Post-filter pressure = 54 psi • Primary pressure = 295 psi • Final pressure = 290 psi **Remark:** Booster pump VFD increased to 54.0 Hz to increase filter pressures closer to 60 psi	SHG
12.20 PM	Check out	SHG

Wednesday 16th August, 2017

Time	Activity	Personnel
9.03 AM	Check In	SHG
9:12 AM	Primary RO System Performance • Pre-filter pressure = 60 psi • Post-filter pressure = 58 psi • Primary pressure = 295 psi • Final pressure = 290 psi **Remark:** Flow rates got lower from 4.0 gpm to 3.5 gpm.	SHG
9.25 AM	PBR checkup and sampling PBR depth – 5 in **Remarks:** Floating biomass growth in last baffle	SHG
9.45 AM	Data Download, pH probe calibration, battery replacement and starting of loggers **Remarks**- • Conductivity meter 2 (SP -7) display is not working and SD card got damaged.	SHG
10.15 AM	Laboratory sample analysis: • Direct measurements • Laboratory testing	SHG
11.50 PM	Primary RO system Performance Check • Pre-filter pressure = 56 psi • Post-filter pressure = 54 psi • Primary pressure = 295 psi • Final pressure = 290 psi **Remark:** Booster pump VFD increased to 55.0 Hz to increase filter pressures closer to 60 psi	SHG
12.10 PM	Sending photographs of the RO Panel to Thomas	SHG
12.18 PM	Check out	SHG

Thursday 17th August, 2017

Time	Activity	Personnel
8.55 AM	Check In	SHG
9:08 AM	Primary RO System Performance • Pre-filter pressure = 62 psi • Post-filter pressure = 60 psi • Primary pressure = 300 psi • Final pressure = 295 psi **Remark:** Flow rates got lower from 3.5 gpm to 2.75 gpm.	SHG
9.15 AM	PBR checkup and sampling PBR depth – 5 in **Remarks:** Contamination of the PBR with green floating algae Wasp Flying around the PBR cover (informed Mr. Dan Lucero)	SHG
9.35 AM	Data Download, pH probe calibration, battery replacement and starting of loggers **Remarks**- • Conductivity meter 2 (SP -7) display is not working and SD card got damaged.	SHG
10.05 AM	Laboratory sample analysis: • Direct measurements • Laboratory testing	SHG
10.30 AM	RO system check up with Bobby from BGNDRF	SHG
11.02 AM	RO system report and updates (Via Phone)	SHG, HK, TM
11.10 AM	Laboratory sample analysis: • Laboratory testing	SHG
12.05 PM	Primary RO system Performance Check • Pre-filter pressure = 58 psi • Post-filter pressure = 56 psi • Primary pressure = 295 psi	SHG

	• Final pressure = 290 psi	
12.20 PM	Check out	SHG

Friday 18th August, 2017

Time	Activity	Personnel
9.05 AM	Check In	SHG
9:10 AM	Primary RO System Performance • Pre-filter pressure = 60 psi • Post-filter pressure = 58 psi • Primary pressure = 300 psi • Final pressure = 295 psi **Remark:** Lower the concentrate to 2.25 gpm to make the recovery 50% recovery.	SHG
9.20 AM	PBR checkup and sampling PBR depth – 6.25 in **Remarks:** Contamination of the PBR with green floating algae	SHG
9.40 AM	Change the nutrient f/2 medium to Sodium orthosilicate. (Silica concentration – 272.0 mg/L)	SHG
10.00 AM	Antiscalant pump flow rate increased to 20% as for the instructions	SHG, HK, TM
10.05 AM	Data Download, pH probe calibration, battery replacement and starting of loggers **Remarks**- • Conductivity meter 2 (SP -7) data logger button is not working.	SHG
10.36 AM	Laboratory sample analysis: • Direct measurements • Laboratory testing	SHG
11.50 AM	Light intensity measurements (LUX measurements)	SHG
12.15 PM	Primary RO system Performance Check • Pre-filter pressure = 60 psi • Post-filter pressure = 58 psi • Primary pressure = 300 psi • Final pressure = 295 psi	SHG

12.30 PM	Check out	SHG

Monday 21st August, 2017

Time	Activity	Personnel
9.00 AM	Check In	SHG
9:05 AM	Primary RO System Performance • Pre-filter pressure = 62 psi • Post-filter pressure = 60 psi • Primary pressure = 270 psi • Final pressure = 240 psi **Remark:** Permeate flow rate is <1 gpm and concentrate 4.0 gpm. Adjust the concentrate flow to 2.25 gpm by adjusting concentrate flush valve.	SHG
9:15 AM	Wiped out the rain water collected on top of the PBR cover.	SHG
9.25 AM	PBR checkup and sampling PBR depth – Overflowing **Remarks:** Divert concentrate flow (PBR inflow) to drain Pump out water from secondary containment tank (Tank 01) for faster drainage.	SHG
09.50 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
10.20 AM	Laboratory sample analysis: • Direct measurements • Laboratory testing	SHG
12.10 PM	Primary RO system Performance Check • Pre-filter pressure = 58 psi • Post-filter pressure = 56 psi • Primary pressure = 265 psi • Final pressure = 235 psi	SHG
12.30 PM	Check out	SHG

Tuesday 22nd August, 2017

Time	Activity	Personnel
8.50 AM	Home depot order pickup and search for data cable for charging PAR and UV meter	SHG
9.25 AM	Check In	SHG
9:30 AM	Primary RO System Performance • System switched off due to PBR overflowing **Remark:** According to Mr. Steve Holland (BGNDRF), the concentrate flowrate was 7.0 gpm when the system is switched off	SHG
9.32 AM	PBR checkup and sampling PBR depth – Overflowing **Remarks:** PBR leakage from SP – 6R (several places) and SP-4L (dripping) Overflow and leakage has contaminated the surrounding soil	SHG
9.40 AM	Created a berm with sand with the help of BGNDRF staff (Steve and Bobby)	SHG
10.10 AM	PBR pumped out to reduce the water level and fixed two major leaks closer to SP-6R.	SHG
11.15 AM	Data Logger download, pH probe calibration, battery replacement and starting of loggers.	SHG
11.45 PM	PBR pumping out and secondary containment pumping and trying to fix the minor leaks	SHG
12.30 PM	Check out	SHG

Wednesday 23rd August, 2017

Time	Activity	Personnel
8.55 AM	Check In	SHG
9:10 AM	Sodium Ortho-silicate dosage preparation and switching the nutrient dosage with Sodium Ortho-Silicate. **Remarks:** • Dosage - 17g for 5 gallon of water (As for Calculations by HK) • Pump flow rate – 10 % from 3 gpd	SHG
9.20 AM	PBR checkup and sampling PBR depth – 3.8 in PBR Inflow rate – 2.0 – 2.6 gpm (well 2 direct injection) **Remarks:** • Minor leaks closer to sampling port SP – 6R	SHG
9.40 AM	Data Download, pH probe calibration, battery replacement and starting of loggers **Remarks**- • Conductivity meter 2 (SP -7) is not working.	SHG
10.05 AM	Laboratory sample analysis: • Direct measurements • Laboratory testing	SHG
11.30 PM	Laboratory backup culture media exchange (Nutrient addition and well 2 water addition)	SHG
11.50 PM	Re-measuring of Reactive silica content for a grab sample closer to inlet (As for request of HK) Remarks: • Measured concentration – 32.2 mg/L	SHG
12.25 PM	Check out	SHG

Thursday 24th August, 2017

Time	Activity	Personnel
8.45 AM	Check In	SHG
9:00 AM	System Performance Check PBR Inflow rate – 1.8 – 2.4 gpm (well 2 direct injection)	SHG
9.05 AM	Meeting with KI, HK, SS, TM and AL (Via Phone)	SHG
9.15 AM	Wiped out the rain water collected on top of the PBR cover.	SHG
9.40 AM	PBR checkup and sampling PBR depth – 4.5 in **Remarks:** • Minor leaks closer to sampling port SP – 6R	SHG
9.50 AM	Data Download, pH probe calibration, battery replacement and starting of loggers **Remarks**- • Conductivity meter 2 (SP -7) is not working.	SHG
10.15 AM	Laboratory sample analysis: • Direct measurements • Laboratory testing	SHG
11.40 AM	Preparation of new Sodium Ortho-silicate solution and addition to the dosage reservoir **Remarks:** • Dosage – 360 g for 5 gallon of water (As for Calculations by HK) • Pump flow rate – 50 % from 3 gpd	SHG
12.15 PM	Check out	SHG

Friday 25th August, 2017

Time	Activity	Personnel
8.55 AM	Check In	SHG
9:00 AM	Photographing the RO system as for the Thomas request.	SHG
9.15 AM	System Performance Check PBR Inflow rate – 2.1 – 2.6 gpm (well 2 direct injection)	SHG
9.25 AM	PBR checkup and sampling PBR depth – 4.25 in **Remarks:** Contamination of the PBR with green floating algae (1st Baffle)	SHG
9.45 AM	Laboratory sample analysis: • Direct measurements • Laboratory testing	SHG
11.25 AM	Data Download, pH probe calibration, battery replacement and starting of loggers **Remarks**- • Conductivity meter 2 (SP -7) data logger button is not working.	SHG
12.20 PM	Check out	SHG

Monday 28th August, 2017

Time	Activity	Personnel
8.45 AM	Check In	SHG
8:55 AM	Sodium Ortho-silicate dosage preparation as the reservoir is almost empty (Precipitate at the bottom of the tank) **Remarks:** • Dosage - 300g for 5 gallon of water • Pump flow rate – 50 % from 3 gpd	SHG
9.38 AM	PBR checkup and sampling PBR depth – 3.8 in PBR Inflow rate – 1.9 – 2.6 gpm (well 2 direct injection) **Remarks:** • White color precipitate in the first baffle closer to inlet (Probably sodium Ortho-silicate) • Minor leaks closer to sampling port SP – 6R. • Biomass concentration is relatively high in first three baffles.	SHG
9.55 AM	Laboratory sample analysis: • Direct measurements • Laboratory testing **Remarks:** Checked the dissolved reactive silica level in the reservoir tank with filtered (0.2 micron) supernatant: Reactive silica - 1490 mg/L	SHG
11.40 AM	Data Download, pH probe calibration, battery replacement and starting of loggers **Remarks**- • Conductivity meter 2 (SP -7) is not working.	SHG
12.25 PM	Check out	SHG

Tuesday 29nd August, 2017

Time	Activity	Personnel
8.50 AM	Check In	SHG
9.05 AM	PBR checkup and sampling PBR depth – 3.8 in PBR Inflow rate – 1.4 – 2.8 gpm (well 2 direct injection) **Remarks:** • Minor leaks closer to sampling port SP – 6R and SP – 7R • Wasp flying around the PBR.	SHG
10.05 AM	Laboratory sample analysis: • Direct measurements • Laboratory testing	SHG
11.35 AM	Data Download, pH probe calibration, battery replacement and starting of loggers **Remarks**- • Conductivity meter 2 (SP -7) is not working.	SHG
12.05 PM	Laboratory backup culture media exchange **Remarks:** • adding well 2 water and nutrient dosage	
12.25 PM	Check out	SHG

Wednesday 30th August, 2017

Time	Activity	Personnel
8.50 AM	Check In	SHG
9.00 AM	PBR checkup PBR depth – 3.8 in PBR Inflow rate – 1.9 – 2.8 gpm (well 2 direct injection) **Remarks:** • Lower green algae concentration in baffle 01 • Minor leaks closer to sampling port SP – 6R and SP – 7R	SHG
09.50 AM	Laboratory sample analysis: • Direct measurements • Laboratory testing	SHG
11.30 AM	Data Download, pH probe calibration, battery replacement and starting of loggers **Remarks-** • Conductivity meter 2 (SP -7) is not working.	SHG
12.15 PM	Check out	SHG

Thursday 31st August, 2017

Time	Activity	Personnel
7:00 AM	Check in	SS
7:30 AM	Removed 440V electrical panel and removed GE RO skid. Placed RO unit on the crate that it came in with Shanka's assistance. Replaced the needle valve with the original valve that came with the system.	SS
9.05 AM	Check In	SHG
9:10 AM	• Helping SS to dismantle primary RO system and loading it to the pallet. • Going over PBR covering and leaks	SS, SHG
9.45 AM	PBR checkup and sampling PBR depth – 4.5 in PBR Inflow rate – 1.9– 2.8 gpm (well 2 direct injection) **Remarks:** • Minor leaks closer to sampling port SP – 6R and SP – 7R	SHG
10.15 AM	Laboratory sample analysis: • Direct measurements • Laboratory testing	SHG
11.45 AM	Data Download, pH probe calibration, battery replacement and starting of loggers **Remarks**- • Conductivity meter 2 (SP -7) has setup.	SHG
12.15 PM	Check out	SHG
1PM	Cleaned out GE RO skid and removed all filters. Plumbed new well 2 feed water system with pre-injection sample port. Silica injection "T". Added a post-injection sample port. Added rotary and vertical tube flow meters.	SS

	Added influent PBR sample port. Set up PLC manifold onto the wall of the container. Performed an initial cleanup of the container from the morning's demolition and setup for tomorrow's activities.	
6:00 PM	Check out	SS

Friday 1st September, 2017

Time	Activity	Personnel
7:00 AM	Check In.	SS
7:30AM	Connected PLC brain to laptop computer for calibration. Called Thomas to set up the calibration. Calibration was not able to take place due to scheduling conflicts and Patrick was unavailable. We had agreed to leave the laptop connected so that calibration would be able to take place the following week (after Labor Day).	SS
9:00AM	Went to Home Depot to procure items needed for PBR upgrades (cover panel support. Trash can for silica injection).	SS
11:00AM	Returned from Home Depot and purchases. Helped Shanka with conductivity meter issues.	SS SHG
12:00PM	Installed trash can for silica injection. Filled half-way with tap water. Primed the pump and confirmed system was working. FedEx arrived but was unable to pick-up the RO unit as it was not crated properly.	SS
1:00PM	Setup the UV system from sample port 5L to drain back into channel 3L. Cleaned the remaining mess left over and prepped for leaving BGNDRF the next day.	SS
6:00PM	Checkout	SS

Saturday 2nd September, 2017

Time	Activity	Personnel
7:00AM	Checkin. Began preparing for crating the RO unit.	SS
1:00PM	Took evaporation pond samples per Harshad's request. One gallon from each pond.	SS
4:00PM	Completed the crate and had a final cleanup.	SS

Monday 04th September, 2017

Time	Activity	Personnel
	Labor Day Holiday	

Tuesday 05th September, 2017

Time	Activity	Personnel
9.05 AM	Check In	SHG
9.10 AM	Sodium Ortho silicate dosage Preparation	SHG
9.20 AM	PBR checkup and sampling PBR depth – 6.0 in PBR Inflow rate – 2.59 gpm (read from inline flow meter) -well 2 direct injection **Remarks:** • Minor leaks closer to sampling port SP – 6R and SP – 7R • Secondary containment tank (tank 01) water level was high. – Used submerged pump to pump out	SHG
9.50 AM	Printing out bill of landing for the RO skid shipping and attached to the shipment	SHG
10.05 AM	Laboratory sample analysis: • Direct measurements • Laboratory testing	SHG
11.40 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
12.20 PM	Check out	SHG

Wednesday 06th September, 2017

Time	Activity	Personnel
9.10 AM	Check In	SHG
9.15 AM	PBR checkup PBR depth – 5.8 in PBR Inflow rate – 2.45 – 2.59 gpm (well 2 direct injection) **Remarks:** • Minor leaks closer to sampling port SP – 6R and SP – 7R	SHG
9.30 AM	Sodium Meta-silicate dosage preparation (Anhydrous 99%) **Remarks:** • Received 5 bags (10 lb each) – Total 50 lb • Dosage – 20lb for 25 gallon of water (Not dissolving as expected) • Pump flow rate – 80 % from 3 gpd	SHG
10.25 AM	Laboratory sample analysis: • Direct measurements • Laboratory testing	SHG
11.50 AM	Data Download, pH probe calibration, battery replacement and starting of loggers **Remarks**- • Conductivity meter 2 (SP -7) is not working.	SHG
12.25 PM	Check out	SHG

Thursday 07th September, 2017

Time	Activity	Personnel
8.05 AM	Check In	SHG
8.15 AM	PBR checkup and sampling PBR depth – 5.5 in PBR Inflow rate – 2.32 – 2.45 gpm (well 2 direct injection) **Remarks:** • Minor leaks closer to sampling port SP – 6R and SP – 7R	SHG
08.40 AM	Laboratory sample analysis: • Direct measurements • Laboratory testing	SHG
10.15 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
10.50 AM	Added additional 10 lb for the Sodium meta silicate tank to increase the silica dosage to the PBR **Remarks:** • Used drill with a impeller for rigorous mixing	
11.10 PM	Check out	SHG

Monday 11th September, 2017

Time	Activity	Personnel
8.05 AM	Check In	SHG, HK
12:00 PM	Existing silica solution mixing	SHG, HK
12:30 PM	Check out	SHG

12:30 PM	Cleaning of baffle one, to remove white precipitate	HK
5:30 PM	Check out	HK

Tuesday 12th September, 2017

Time	Activity	Personnel
8.05 AM	Check In	SHG, HK
12:00 PM	Pump recirculation for mixing of existing silica precipitate (suspension)	SHG, HK
12:30 PM	Lab experiments to figure out the solubility of silica in permeate, tap water and well 2 water.	HK, SHG
4:00 PM	Exhibition set up (poster) and attend BGNDRF event	HK, SHG
7:30 PM	Check out	HK, SHG

Wednesday 13th September, 2017

Time	Activity	Personnel
8:00 AM	Check In	SHG, HK
12:00 PM	Check out	SHG
9:00 AM 8:30 PM	BGNDRF Event and dinner	HK, KI, SHG
1:00 AM (14th Sept)	Drop off KI to El Paso	HK, KI

Thursday 14th September, 2017

Time	Activity	Personnel
9:00 AM	Check In	SHG, HK

12:00 PM	Received sulfuric acid tanks. Pump setup (Thanks Thomas for facetiming)	HK, SHG, TM
1:00 PM	Test run of acid injection • Each adjustment takes about 2 hour time to observe the pH change at sampling port at inlet of PBR	HK
6:00 PM	pH dropped below 4 so had to flush off the feed line by turning off the acid injection pump	HK
6:30 PM	Check out	HK

Friday 15th September, 2017

Time	Activity	Personnel
6:30 AM	Left for El Paso, for El Paso Water 10th Anniversary event and tour to desalination plant	HK
9:00 AM	Check in	SHG
12:00 PM	Existing silica suspension mixing with recirculation. Preparation of fresh metasilicate solution in 5-gallon bucket using permeate.	SHG
12:30 PM	Check out	SHG
6:00 PM	Check out (Back to Alamogordo)	HK

Monday 18th September, 2017

Time	Activity	Personnel
8:30 AM	Check in	HK
9:00 AM	Check in	SHG
12:00 PM	Lab experiment to check different approaches of silica and acid injection, aim is to obtain - ~ 100 mg/L reactive silica - No precipitation To determine flow rate of acid and silica injection - Add silica stock to well 2 water and attempt to dissolve the precipitate by adding sulfuric acid - Then drop the pH of well 2 water first by adding sulfuric acid and then add silica stock, and confirm that nothing precipitates and final pH is near neutral or slightly alkaline	HK, SHG
2:00 PM	Above experiment continued	HK
2:00 PM	As per experiment in lab,	HK

	- 200-mL of Well 2 water (pH = 7.5, silica = 25 mg/L) - Add 0.2-mL of 1:10 diluted 93% sulfuric acid (pH = 5.98) - Add 0.2-mL of silica stock (existing, 52,000 mg/L) - Final pH is 6.73 and final silica concentration is 79 mg/L According to this, acid injection is required at 0.015 GPH rate.	
2:00 PM	Simultaneously, acid injection started at pump speed 30% and stroke length 5%. This should give pump output of 0.015 GPH (1GPH x 0.3 x 0.05 = 0.015 GPH), where 1GPH is maximum output. At this time, the feed was bypassed and was transferred to drain with tap water flow. Silica injection line re-plumbed including a check valve (Thanks Thomas for facetiming). Pump auto-primed using supernatant in trash can that has 52 g/L silica concentration. Pump set at maximum speed (3 gpd). Silica injection started in feed line. A pH probe was set-up at PBR inlet using a temporary flow-cell using existing tubing and was monitored using HQD meter. After silica injection started the pH increased up to 9.87. At this point speed of acid injection pump was increased (since no decrease in pH observed within 2 hours after initial setting of 0.015 GPH). The new pump setting calculated output was 0.3 GPH.	HK,TM
4:30 PM	After new setting for acid injection pump, within 30 minutes, pH at PBR inlet (after silica injection) was 7.22. A sample was collected and tested for silica. Reactive silica was 85 mg/L at pH of 7.22. This is the condition we'd like to have continuously.	HK
5:30 PM	However, pH dropped gradually to 3.97. The pump setting was changed back to initial and the feed line was flushed. - When the feed water is at acidic pH, injection of silica does not cause in precipitate, and final concentration ~80 mg/L was obtained. - Difficult to fine-adjust the pH since it takes ~2 hour to reflect the change in pump setting.	HK
5:45 PM	Check out	HK

Tuesday 19th September, 2017

Time	Activity	Personnel
8:30 AM	Check In	HK
9.05 AM	Check In	SHG
9.10 AM	Activity Log Updates and reporting	SHG
09.45 AM	• Acid addition system configuration • Cleaning the secondary containment for Acid reservoir tank • Acid dilution ratio calculation • 3 gallon diluted acid stock solution preparation (10 fold diluted sulfuric acid)	HK, SHG

11.50 AM	Data Download on conductivity meters, battery replacement and logger setup	SHG
12:10 PM	Start dosing acid with the diluted stock from in line from Acid room and change of pH recording at PBR inlet	SHG, HK
12.35 PM	Check out	SHG
1:30 PM	Finalized that acid injection will be done from stock tank near the PBR. Started plumbing required for that.	HK
2:30 PM	Moved secondary containment tank for acid near PBR. Plumbing partially completed for acid injection.	HK
5:30 PM	Check out	HK

Wednesday 20th September, 2017

Time	Activity	Personnel
8:00 AM	Check In	HK
10:00 AM	Purchasing items relates to new plumbing system for acid injection and silica addition from "Home Depot / Lowes"	HK
8.55 AM	Check In	SHG
9.05 AM	System checkup	SHG
9.25 AM	Lab Culture media exchange with nutrients and new well 2 water	SHG
10.20 AM	• New plumbing configuration setup for well 2 feed, acid injection and silica injection • Acid injection pump setup • Silica injection system setup	HK, SHG
1:20 PM	Check out	SHG
2:30 PM	Completed plumbing: - Well 2 water → Paddle wheel flowmeter connected to PLC → Flow switch to turn ON/OFF acid and silica pumps → Acid injection → Rotameter → Elbows for mixing → silica injection → Final water to PBR - Tested each component separately - Tested simultaneous silica (3 gpd of 52 g/L solution) and acid (1.6 gpd of 1:10 sulfuric acid) injection, pH between 7.5 – 8 - Paddle wheel reading 0.9 gpm higher than rotameter and BGNDRF flow meter	HK
6:00 PM	Check out	HK

Thursday 21st September, 2017

Time	Activity	Personnel
8:30 AM	Check In	HK
10.05 AM	Check In	SHG
10.10 AM	System configuration check and checking for operation on dosage pumps	HK, SHG
10.30 AM	Starting acid dosage with diluted 3-gallon stock solution from test pad and monitoring the pH shift **Remarks:** • 90% speed level: pH ranges 6.09 – 6.15 • 100% speed level: pH range 5.20 – 5.27	HK, SHG
10.45 AM	Reactive silica level measurements **Remarks:** • PBR inflow Reactive silica concentration (after acid injection, before silica injection): 24.4 mg/L	SHG
11.00 AM	100 gallon acid stock solution preparation with the assistance from BGNDRF staff (Bobby and Skyler) and relocate at the secondary containment at test pad.	SHG, HK
11.25 AM	Starting inline silica injection – with stock solution concentration – 52.1 g/L **Remarks:** • 3 GPD feed level: pH ranges 6.33 – 6.37 • 3.6 GPD feed level: pH ranges 7.03-7.13 • Reactive silica concentration (with the 3.6 GPD) – 60.2 mg/L	SHG, HK
12.15 PM	Purchasing new stock tank for silica stock solution and parts for sampling port setup and nutrient pump setup from “Home Depot”.	SHG, HK

1.15 PM	Configure plumbing modifications needed	SHG, HK
1.35 PM	Check out	SHG
2:00 PM	Set up new silica stock tank, started simultaneous silica and acid injection	HK
5:30 PM	Check out	HK

Friday 22nd September, 2017

Time	Activity	Personnel
8:30 AM	Check in	HK
8:45 AM	Reactive silica concentration in final feed water was 120 mg/L	HK
9:05 AM	Check in	SHG
9.10 AM	System checkup and plumbing nutrient dosage pump setup. Started 2 mg/L orthophosphate injection (pump speed 10%)	SHG, HK
9.15 AM	Calibration of flow meter setup	HK, TM
9.45 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
10:00 AM	Remotely monitoring camera setup and configuration	HK
10.44 AM	PBR sampling for analysis and sending for PACE laboratory in fountain valley. **Remarks:** 1. 200 ml samples from System inlet (well 2), PBR feed, PBR sampling ports and PBR outlet – 11 samples 2. 50 ml filtered samples (0.2 micron) for Pace lab from System inlet (well 2), PBR feed, PBR sampling ports and PBR outlet – 11 samples 3. 1 gallon samples from System inlet (well 2) and PBR feed after acid and silica injection – 2 samples	SHG
11.45 AM	Neutralization of the disposal sample at Acid room	SHG
12.15 PM	Sampling procedure reevaluation	HK, SHG
12:45 PM	Check out	HK,SHG

Monday 25th September, 2017

Time	Activity	Personnel
9:00 AM	Check in	SHG
9.05 AM	System checkout 1. Feed flow rate – 2.68-2.77 gpm 2. Acid pump working (speed 100%) 3. Silica injection Pump working – (speed - 60%, stroke – 40%) 4. PBR water level – 7 in **Remarks:** • PBR overflowing from the overflow port • Silica injection line is above the silica stock level	SHG
9.15 AM	1. Reduce the flow rate to nearly 2 gpm (1.94-2.03 gpm) 2. Reset the silica injection system and adjust the pumps to make the pH closer to pH 7.	SHG
9.35 AM	Sampling for laboratory analysis	SHG
9.45 AM	Laboratory sample analysis: (Daily samples) • Direct measurements • Laboratory testing	SHG
11.15 AM	Laboratory sample analysis: (Preserved samples from 09/22/2017 from PBR) • Direct measurements • Laboratory testing	SHG

12.05 PM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
12:35 PM	Checking the Reactive silica level on the new stock solution and transfer the new stock solution to the feed reservoir tank	SHG
12:45 PM	Check out	SHG

Tuesday 26th September, 2017

Time	Activity	Personnel
9:15 AM	Check in	SHG
9.20 AM	System checkout 1. Feed flow rate – 1.20 – 1.29 gpm (pH dropped to 3.32) 2. Acid pump working (speed 100%) 3. Silica injection Pump working – (speed - 60%, stroke – 40%) 4. PBR water level – 6.5 in **Remarks:** • Main regulator pressure – 42 psi • Increased the flow rate back to 1.85 -1.96 gpm with flow control valve	SHG
9.45 AM	Download PLC data files for reporting **Remarks:** • PLC storage pen drive is corrupted and data couldn't be downloaded. • Used a new pen drive for data download and only partial data on 09/25/2017 is downloaded.	SHG
10.00 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
10.30 AM	Sampling for laboratory analysis	SHG
10.45 AM	Laboratory sample analysis: (Daily samples) • Direct measurements • Laboratory testing	SHG

11.45 AM	Rebooting the PLC setup with new pen drive storage with Patrick and Harshad	HK, PF, SHG
12:20 PM	New stock solution preparation in recirculation tank **Remarks:** • 10 lb. of sodium meta-silicate in 15 gallons of RO permeate.	SHG
12:45 PM	Check out	SHG

Wednesday 27th September, 2017

Time	Activity	Personnel
9:05 AM	Check in	SHG
9.10 AM	System checkout 1. PBR water level – 7 in **Remarks:** • PBR overflowing through overflow outlet • Silica recirculation tank got leaked and lost all new stock solution • Temporally suspended the acid injection and silica injection	SHG
9.30 AM	Download PLC data files and reporting	SHG
10.15 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
10.45 AM	New stock solution preparation in feed storage tank recirculation **Remarks:** • Around 4 lb. of sodium meta-silicate in 20 gallons of RO permeate.	SHG
11.00 AM	Sampling for laboratory analysis	SHG
11.15 AM	Laboratory sample analysis: (Daily samples) • Direct measurements • Laboratory testing	SHG
11.35 AM	Stopped recirculation of silica stock solution	SHG
12.20 PM	Restart the acid injection and silica injection	SHG

	Remarks: • Silica stock solution pH – 12.11 • Acid pump speed – 75% • Silica injection pump (Speed – 65%, stroke – 40%) • Inflow pH – 6.7 -7.2	
12.40 PM	Check out	SHG

Thursday 28th September, 2017

Time	Activity	Personnel
9.10 AM	Check In	SHG
9.10 AM	System checkout 1. PBR water level – 7 in **Remarks:** • As pH is 5.85, Acid injection pump speed reduced to 70%.	SHG
9.25 AM	Download PLC data files and reporting	SHG
9.40 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
10.05 AM	Sampling for laboratory analysis	SHG
10.20 AM	Laboratory sample analysis: (Daily samples) • Direct measurements • Laboratory testing	SHG
11.20 AM	Laboratory sample analysis: (Preserved samples from 09/22/2017 from PBR) • Direct measurements • Laboratory testing	SHG
12.10 PM	New recirculation tank setup and new stock solution preparation in recirculation tank **Remarks:** • 15 lb. of sodium meta-silicate in 20 gallons of RO permeate.	SHG
12.50 PM	Check out	SHG

Friday 29th September, 2017

Time	Activity	Personnel
9.10 AM	Check In	SHG
9.10 AM	System checkout 1. PBR water level – 6 in **Remarks:** • Stop recirculation tank for precipitation of silicate particles.	SHG
9.20 AM	Download PLC data files and reporting	SHG
9.35 AM	Discussion of the inoculation procedure of laboratory biomass in PBR	HK, SHG
10.00 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
10.45 AM	Transferred new stock solution to the silica feeding tank **Remarks:** • After addition of new stock solution pH of the stock solution raised to 12.37 and pH of the inflow raised to 8.03 -8.16. • Acid pump speed increased up to 95% to reduce the inlet pH closer to pH 6.89-.7.12.	SHG
10.50 AM	Sampling for laboratory analysis	SHG
11.05 AM	Laboratory sample analysis: (Daily samples) • Direct measurements • Laboratory testing	SHG
12.05 PM	Preparation of biomass for inoculation and inoculate biomass to the PBR **Remarks:**	SHG

	• Combine the settled biomass from 12 tubes in a clean plastic beaker • Make the volume of the suspension to 250-mL by adding our modified PBR influent • Then using a 10-mL pipette, transfer 30-mL of this suspension in a 50-mL centrifuge tube and save it in the fridge. • Total of 18 locations considering both sides of the reactor. • Add 20-mL suspension to each side of first two baffles (i.e. 80-mL) • Add 10-mL each to each side of remaining baffles (i.e. 140-mL)	
12.40 PM	New stock solution preparation in recirculation tank **Remarks:** • 15 lb. of sodium meta-silicate in 20 gallons of RO permeate.	SHG
13.00 PM	Check out	SHG

Monday 02nd October, 2017

Time	Activity	Personnel
7.50 AM	Check in	SHG
8.00 AM	System checkout 5. Feed flow rate – 2.03 - 2.12 gpm 6. Acid pump working (speed 95%) 7. Silica injection Pump working – (speed - 65%, stroke – 40%) 8. Nutrient feed pump working – (speed – 10%) 9. PBR water level – 7 in **Remarks:** 10. PBR overflowing from the overflow port 11. Silica stock solution was low level 12. Add 3 gallons of permeate to cope up the time duration taken to settle floating particles in stock solution at recirculation tank.	SHG
8.25 AM	Replace the nutrient f/2 medium feed bucket with new feed solution (New Bucket)	SHG
8.40 AM	Download PLC data files and reporting	SHG
8.55 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
9.25 AM	Transferred the silica stock solution (from recirculation tank) to the feed tank	SHG
9.35 AM	Sampling based on new sampling plan **Remarks:** • Well 2 water (SP-01) once a week	SHG

	• Change sampling ports of the PBR to PBR 3 and PBR 6	
9.45 AM	Laboratory sample analysis • Direct measurements • Laboratory testing	SHG
11.10 AM	Check out	SHG

Tuesday 03rd October, 2017

Time	Activity	Personnel
9:10 AM	Check in	SHG
9.15 AM	System checkout 5. Feed flow rate – 2.03 – 2.12 gpm 6. PBR water level – 7 in **Remarks:** • Floating biomass in first three baffles • Water overflowing with overflow outlet	SHG
9.25 AM	Download PLC data files for reporting	SHG
9.35 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
10.15 AM	Inflow pH adjustment (Reduce pH pump to 90%) • New pH level – 7.23-7.38	SHG
10.20 AM	Sampling for laboratory analysis	SHG
10.35 AM	Laboratory sample analysis: (Daily samples) • Direct measurements • Laboratory testing	SHG
11.45 AM	New stock solution preparation in recirculation tank **Remarks:** • 15 lb. of sodium meta-silicate in 20 gallons of RO permeate.	SHG
12:15 PM	Check out	SHG

Wednesday 04th October, 2017

Time	Activity	Personnel
12.00 noon	Check in	SHG
12.05 AM	System checkout 2. PBR flow rate – 2.03 – 2.12 gpm 3. PBR water level – 7 in **Remarks:** • PBR overflowing through overflow outlet	SHG
12.15 AM	Switch off recirculation for settling	SHG
12.20 PM	Download PLC data files and reporting	SHG
12.35 PM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
1.05 PM	Sampling for laboratory analysis	SHG
1.15 PM	Transferred the silica stock solution (from recirculation tank) to the feed tank	SHG
1.20 PM	Laboratory sample analysis: (Daily samples) • Direct measurements • Laboratory testing	SHG
2.50 PM	Measuring new inlet reactive silica level **Remarks:** • New reactive silica concentration – 108.6 mg/L	SHG
3.10 PM	Check out	SHG

Thursday 05th October, 2017

Time	Activity	Personnel
9.10 AM	Check In	SHG
9.15 AM	System checkout • PBR flow rate – 2.03 – 2.12 gpm • PBR water level – 7 in **Remarks:** • Heavily raining • PBR overflowing through overflow outlet	SHG
9.35 AM	Download PLC data files and reporting	SHG
9.50 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
10.35 AM	Acid wash and cleaning of the Conductivity meter probes	SHG
10.50 AM	Sampling for laboratory analysis	SHG
11.10 AM	Laboratory sample analysis: (Daily samples) • Direct measurements • Laboratory testing	SHG
12.15 PM	Cleaning of the PBR outlet to remove clogging and reduce the PBR water level	SHG
12.20 PM	New recirculation tank setup and new stock solution preparation in recirculation tank **Remarks:** • 20 lb. of sodium meta-silicate in 30 gallons of RO permeate.	SHG
12.50 PM	Check out	SHG

Friday 06th October, 2017

Time	Activity	Personnel
8.50 AM	Check In	SHG
8.55 AM	System checkout • PBR flow rate – 2.03 – 2.12 gpm • PBR water level – 7 in **Remarks:** • Lot of floating biomass in the PBR • PBR overflowing through overflow outlet	SHG
9.05 AM	Stop silica recirculation system for settling	SHG
9.10 AM	Download PLC data files and reporting	SHG
9.20 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
10.10 AM	Repairing of damaged PBR covering panel	SHG
10.30 AM	Modification of the system to lower the PBR water level **Remarks:** Disconnect the PBR outlet from secondary containment and directed to drain	SHG, HK, TM
11.10 AM	Sampling for laboratory analysis	SHG
11.20 AM	Transferred the silica stock solution (from recirculation tank) to the feed tank	SHG
11.25 AM	Laboratory sample analysis: (Daily samples) • Direct measurements • Laboratory testing	SHG

12.30 PM	Arrangements for check in on Monday 10/9 with Dan due to federal holiday	SHG
12.35 PM	Check out	SHG

Monday 09th October, 2017

Time	Activity	Personnel
9.00 AM	Check in	SHG
9.05 AM	System checkout 13. Feed flow rate – 2.03 - 2.12 gpm 14. Acid pump working (speed 90%) 15. Silica injection Pump working – (speed - 65%, stroke – 40%) 16. Nutrient feed pump working – (speed – 10%) 17. PBR water level – 5.25 in **Remarks:** • Higher biomass concentration in first three channels.	SHG
9.20 AM	Download PLC data files and reporting	SHG
9.40 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
10.40 AM	Sampling for laboratory analysis	SHG
10.50 AM	Transferred the silica stock solution (from recirculation tank) to the feed tank	SHG
10.55 AM	Sending photographs of weir setup to HK	SHG
11.05 AM	Laboratory sample analysis • Direct measurements • Laboratory testing	SHG
12.20 PM	New stock solution preparation in recirculation tank	SHG

	Remarks: • 15 lb. of sodium meta-silicate in 20 gallons of RO permeate.	
12.50 PM	Check out	SHG

Tuesday 10th October, 2017

Time	Activity	Personnel
8.55 AM	Check in	SHG
9.00 AM	System checkout 7. Feed flow rate – 2.03 – 2.12 gpm 8. PBR water level – 5.25 in **Remarks:** • Higher concentration of floating biomass in first three Channels	SHG
9.15 AM	Download PLC data files for reporting	SHG
9.25 AM	Discussion on flow modification with KI and HK **Remarks:** • Main target is to reduce flow rate to 0.5 gpm • As flow switch is switching off at 0.8 gpm, the idea is to reduce the flow rate to 1 gpm with required silica addition and split the flow in half to attain 0.5 gpm	KI, HK, SHG
9.35 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
10.05 AM	Sampling for laboratory analysis	SHG
10.15 AM	Flow modification as for the discussion 1. Feed flow rate – 1.02 gpm 2. Acid pump working (speed 30%) 3. Silica injection Pump working – (speed - 50%, stroke – 25%)	SHG

	4. Nutrient feed pump working – (speed – 5%) **Remarks:** • Modified nutrient injection for inline injection • Attained pH level – 7.52 – 7.76	
11.00 AM	Cleaning flow meter 01 for in line connection to split the modified flow rate **Remarks:** • Did not work even after cleaning and reassembly.	SHG
11.45 AM	Modification of PBR inlet for flow splitting setup	SHG
12.30 PM	Data logger reset for data recording	SHG
12.40 PM	Transferred the silica stock solution (from recirculation tank) to the feed tank	SHG
12:50 PM	Check out	SHG

Wednesday 11th October, 2017

Time	Activity	Personnel
8.05 AM	Check in	SHG
8.10 AM	System checkout 4. PBR flow rate – 1.02 – 1.11 gpm 5. PBR water level – 4.75 in **Remarks:** • PBR water level dropped due to flow reduction	SHG
8.20 AM	Download PLC data files and reporting	SHG
8.35 PM	Data Download, pH probe calibration, battery replacement and starting of loggers **Remarks:** • pH probe USB connection had issue on connection • Report for ordering new replacement cable	SHG
9.35 AM	Sampling for laboratory analysis	SHG
9.50 AM	Laboratory sample analysis: (Daily samples) • Direct measurements • Laboratory testing	SHG
11.05 AM	Modification on silica injection level based on laboratory test results **Remarks:** • Flow rate had increased to 1.29-1.38 gpm and it was reduced back to 1.11 gpm	SHG

	• Increased silica injection pump speed 52.5% • Adjust the acid pump speed to 32.5%	
11.35 AM	Check out	SHG

Thursday 12th October, 2017

Time	Activity	Personnel
9.10 AM	Check In	SHG
9.15 AM	System checkout • PBR flow rate – 0.83 gpm • PBR water level – 4.75 in **Remarks:** • Increased PBR flow rate 0.92 – 1.02 gpm • All pump were working without affect from the flow switch due to fluctuation in flow	SHG
9.25 AM	Download PLC data files and reporting	SHG
9.35 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
10.20 AM	Sampling for laboratory analysis	SHG
10.30 AM	Biomass sampling for Microscopic analysis **Remarks:** • Sampling locations : Channels 1, 3, 6 and 9 from the right hand side of the PBR	SHG
11.40 AM	Laboratory sample analysis: (Daily samples) • Direct measurements • Laboratory testing	SHG
12.50 PM	Check out	SHG

Friday 13th October, 2017

Time	Activity	Personnel
9.05 AM	Check In	SHG
9.10 AM	System checkout • PBR flow rate – 0.92 – 1.02 gpm • PBR water level – 4.75 in **Remarks:** • Lot of floating biomass in the PBR	SHG
9.20 AM	Download PLC data files and reporting	SHG
9.35 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
10.35 AM	Sampling for laboratory analysis	SHG
10.50 AM	Laboratory sample analysis: (Daily samples) • Direct measurements • Laboratory testing	SHG
12.00 noon	Lab culture medium exchange	SHG
12.20 PM	Biomass re-inoculation on channel 4-9 with biomass from channel 1 -3	SHG
12.55 PM	Check out	SHG

Monday 16th October, 2017

Time	Activity	Personnel
9.05 AM	Check in	SHG
9.10 AM	System checkout 18. Feed flow rate – 0.92 – 1.02 gpm 19. Acid pump working (speed 32.5%) 20. Silica injection Pump working – (speed – 52.5%, stroke – 25%) 21. Nutrient feed pump working – (speed – 5%) 22. PBR water level – 4.75 in **Remarks:** • Higher biomass concentration in first three channels.	SHG
9.20 AM	Download PLC data files and reporting	SHG
9.30 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
10.35 AM	Sampling for laboratory analysis	SHG
10.45 AM	Inlet modification to split the inflow and feed the PBR with 0.5 gpm	SHG
11.25 AM	Laboratory sample analysis • Direct measurements • Laboratory testing	SHG

12.25 PM	New stock solution preparation in recirculation tank **Remarks:** • 15 lb. of sodium meta-silicate in 20 gallons of RO permeate.	SHG
12.50 PM	Check out	SHG

Tuesday 17th October, 2017

Time	Activity	Personnel
8.55 AM	Check in	SHG
9.00 AM	System checkout 9. Feed flow rate – 0.92 – 1.02 gpm 10. PBR split flow rate – 0.5 gpm 11. PBR water level – 4.75 in	SHG
9.10 AM	Stop silica recirculation system for precipitation	SHG
9.15 AM	Download PLC data files for reporting	SHG
9.25 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
10.20 AM	Sampling for laboratory analysis	SHG
10.25 AM	Biomass transplant on channel 4-9 with biomass from channel 1 -3	SHG
10.45 AM	Laboratory sample analysis: (Daily samples) • Direct measurements • Laboratory testing	SHG
11.55 PM	Transferred the silica stock solution (from recirculation tank) to the feed tank **Remarks:** • New silica stock addition increased the pH to 9.5	SHG

	• Adjust Silica injection pump (speed – 50%, stroke – 25%) • Adjust acid injection pump (speed – 45%)	
12:15 PM	Check out	SHG

Wednesday 18th October, 2017

Time	Activity	Personnel
8.10 AM	Check in	SHG
8.15 AM	System checkout 6. PBR flow rate – 0.92 – 1.02 gpm 7. PBR split flow rate – 0.5 gpm 8. PBR water level – 4.75 in	SHG
8.25 AM	Download PLC data files and reporting	SHG
8.35 PM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
9.25 AM	Sampling for laboratory analysis	SHG
9.35 AM	Laboratory sample analysis: (Daily samples) • Direct measurements • Laboratory testing	SHG
10.45 AM	Aeration pump setup at channel 2 and 3 separation baffle (left hand side of the PBR)	SHG
11.10 AM	Check out	SHG

Thursday 19th October, 2017

Time	Activity	Personnel
9.10 AM	Check In	SHG
9.15 AM	System checkout 1. PBR flow rate – 0.92 – 1.02 gpm 2. PBR split flow rate – 0.4 gpm 3. PBR water level – 4.75 in	SHG
9.25 AM	Download PLC data files and reporting	SHG
9.35 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
10.25 AM	Modification on the inlet flow split setup with a flow cell for pH probe	SHG
10.35 AM	Sampling for laboratory analysis	SHG
10.45 AM	Laboratory sample analysis: (Daily samples) • Direct measurements • Laboratory testing	SHG
12.05 PM	Replacing the nutrient stock solution with new stock bucket (Asked HK to order new)	SHG
12.15 PM	New stock solution preparation in recirculation tank **Remarks:** • 15 lb. of sodium meta-silicate in 20 gallons of RO permeate.	SHG

12.45 PM	Check out	SHG

Friday 20th October, 2017

Time	Activity	Personnel
9.15 AM	Check In	SHG
9.20 AM	System checkout • PBR flow rate – 0.92 – 1.02 gpm • PBR split flow rate – 0.5 gpm • PBR water level – 4.6 in	SHG
9.30 AM	Download PLC data files and reporting	SHG
9.40 AM	Stop silica recirculation system for precipitation	SHG
9.45 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
10.45 AM	Sampling for laboratory analysis	SHG
10.55 AM	Biomass transplant on channel 7-9 with biomass from channel 1 -3	
11.20 AM	Laboratory sample analysis: (Daily samples) • Direct measurements • Laboratory testing	SHG
12.25 PM	Aeration pump setup at channel 1 and 2 separation baffle (Right hand side of the PBR)	SHG
12.40 PM	Transferred the silica stock solution (from recirculation tank) to the feed tank **Remarks:**	SHG

	• Adjust acid injection pump (speed – 35%) • Attained pH level – 7.72 -7.84	
12.55 PM	Check out	SHG

Monday 23rd October, 2017

Time	Activity	Personnel
12.05 PM	Check in	SHG
12.10 AM	System checkout 23. Feed flow rate – 0.83 – 0.92 gpm 24. PBR split flow rate – 0.65 gpm 25. Acid pump working (speed 35%) 26. Silica injection Pump working – (speed – 50%, stroke – 25%) 27. Nutrient feed pump working – (speed – 5%) 28. PBR water level – 4.6 in **Remarks:** • Overall flow to the PBR was less than 0.5 gpm.	SHG
12.15 PM	Download PLC data files and reporting	SHG
12.30 PM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
1.25 PM	Sampling for laboratory analysis	SHG
1.35 AM	Laboratory sample analysis • Direct measurements	SHG

	• Laboratory testing	
2.45 PM	Adjust overall PBR in flow rate to 0.2 gpm 1. Feed flow rate – 1.02 gpm 2. PBR split flow rate – 0.8 gpm	SHG
2.55 PM	Manually remove green algae biomass for PBR	SHG
3.30 PM	Site Demonstration to Dr. Pei Xu from New Mexico State University and Dr. Matthew Ringer from National Renewable Energy Laboratory (NREL)	SHG
4.00 PM	Check out	SHG

Tuesday 24th October, 2017

Time	Activity	Personnel
9.15 AM	Check in	SHG
9.20 AM	System checkout 12. PBR water level – 4.75 in Remarks: • PBR flow has stopped due to clogging developed from precipitation. • Issue was caused due to flow interruption from the feed flow interruptions.	SHG
9.45 AM	Download PLC data files for reporting	SHG
10.00 AM	Data logger download	SHG
10.20 AM	Cleaning the clogging to startup the feed flow and informed BGNDRF staff on the flow interruption	SHG
11.15 AM	pH probe calibration, battery replacement and starting of loggers	SHG
11.30 AM	Sampling for laboratory analysis	SHG
11.40 AM	System feed flow restart 1. Feed flow rate – 1.02 – 1.11 gpm 2. PBR split flow rate – 0.8 gpm 3. Acid pump working (speed 35%)	SHG

	4. Silica injection Pump working – (speed – 50%, stroke – 25%) 5. Nutrient feed pump working – (speed – 5%)	
12.00 noon	Laboratory sample analysis: (Daily samples) • Direct measurements • Laboratory testing	SHG
12:40 PM	Check out	SHG

Wednesday 25th October, 2017

Time	Activity	Personnel
9.20 AM	Check in	SHG
9.25 AM	System checkout 9. PBR flow rate – 0.92 – 1.02 gpm 10. PBR split flow rate – 0.8 gpm 11. PBR water level – 4.6 in	SHG
9.35 AM	Download PLC data files and reporting	SHG
9.45 PM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
10.40 AM	Sampling for laboratory analysis	SHG
10.50 AM	Laboratory sample analysis: (Daily samples) • Direct measurements • Laboratory testing	SHG
12.05 PM	Cleaning the UV clarifier system clogging.	SHG
12.15 PM	Media exchange on lab cultures	SHG
12.30 PM	Check out	SHG

Thursday 26th October, 2017

Time	Activity	Personnel
9.40 AM	Check In	SHG
9.45 AM	System checkout 4. PBR flow rate – 1.02 – 1.11 gpm 5. PBR split flow rate – 0.8 gpm 6. PBR water level – 4.6 in	SHG
9.55 AM	Download PLC data files and reporting	SHG
10.10 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
10.45 AM	Sampling for laboratory analysis	SHG
10.55 AM	Laboratory sample analysis: (Daily samples) • Direct measurements • Laboratory testing	SHG
11.55 AM	New stock solution preparation in recirculation tank **Remarks:** • 15 lb. of sodium meta-silicate in 20 gallons of RO permeate.	SHG
12.30 PM	Check out	SHG

Friday 27th October, 2017

Time	Activity	Personnel
9.20 AM	Check In	SHG
9.25 AM	System checkout • PBR flow rate – 1.02 – 1.11 gpm • PBR split flow rate – 0.8 gpm • PBR water level – 4.6 in **Remarks:** • One of the PBR covering panels (left hand side middle panel) was missing due to high wind.	SHG
9.35 AM	Stop silica recirculation	SHG
9.38 AM	Check the site to find the missing panel around the site with the assistance from BGNDRF staff	SHG
10.15 AM	Download PLC data files and reporting	SHG
10.30 AM	Fixed the covering panel while pumping out the water from secondary containment tanks for refill	SHG
11.00 AM	Data Download, pH probe calibration, battery replacement and starting of loggers	SHG
11.35 AM	Sampling for laboratory analysis	SHG
11.45 AM	Laboratory sample analysis: (Daily samples) • Direct measurements • Laboratory testing	SHG

12.50 PM	Transferred the silica stock solution (from recirculation tank) to the feed tank Pumped out the existing water from two secondary tanks and connected the PBR effluent to secondary tank to fill with treated water.	SHG
12.55 PM	Check out	SHG

Monday 30th October, 2017

Time	Activity	Personnel
9.20 AM	Check In	SHG
9.25 AM	System checkout • PBR flow rate – 0.92 – 1.02 gpm • PBR split flow rate – 0.8 gpm • PBR water level – 4.6 in • Acid pump – 35% • Nutrient pump – 5% • Silica pump – speed 50%, stroke length 25%	SHG
9:30 AM	PLC data download and reporting	SHG
9:40 AM	Data logger download and reporting	SHG
10:00 AM	Meeting with KI, HK and SS	SHG
10:10 AM	Data logger battery change, reset and calibration	SHG
10:45 AM	Sampling for laboratory analyses	SHG
10:55 AM	Laboratory analyses	SHG
12:40 PM	Check out	SHG

Tuesday 31st October, 2017

Time	Activity	Personnel
8:00 AM	Check in	HK
8:15 AM	Testing silica and orthophosphate in PBR. Collected floating and settled biomass for microscopic examination	HK
9:20 AM	Check in	SHG
9:25 AM	System check up Water level – 4.6 inches PBR flow rate – 0.92 – 1.02 gpm PBR split flow rate – 0.85 gpm Adjusted the split flow rate to 0.8 gpm	SHG, HK
9:30 AM	Biomass microscopic observation	HK
9:35 AM	PLC data download	SHG
9:45 AM	Data logger download, calibration, battery change and reset	SHG
10:50 AM	Sampling for laboratory analyses	SHG
11:00 AM	Transfer new silica stock solution and adjust acid injection	SHG, HK
11:15 AM	Lab analyses	SHG, HK
12:30 PM	Check out	SHG

2:00 PM	Green biomass was vacuumed out	HK
5:00 PM	Check out	HK

Wednesday 1st November 2017

Time	Activity	Personnel
8:00 AM	Check in	HK
8:15 AM	Check in	SHG
8:30 AM	Green algae vacuum cleaning	HK, SHG
9:00 AM	Set-up for PBR recirculation using sump pump	HK, SHG
9:20 AM	Modified PBR influent stopped. PBR recirculation started (20 gpm)	HK, SHG
10:00 AM	Biomass sampling for microscopic analyses from each channel (1-9) floating and settled biomass for microscopic examination prior to sample collection for genetic analysis.	HK, SHG
11:00 AM	Check out	SHG
2:00 PM	Microscopic observation for biomass	HK
3:00 PM	Sump pump interruption troubleshoot	HK
4:30 PM	Changed the sump pump	HK
5:00 PM	PBR recirculation resumed	HK
5:30 PM	Check out	HK

Wednesday 1st November 2017

Time	Activity	Personnel
8:00 AM	Check in	HK
8:15 AM	Check in	SHG
8:30 AM	Green algae vacuum cleaning	HK, SHG
9:00 AM	Set-up for PBR recirculation using sump pump	HK, SHG
9:20 AM	Modified PBR influent stopped. PBR recirculation started (20 gpm)	HK, SHG
10:00 AM	Biomass sampling for microscopic analyses from each channel (1-9) floating and settled biomass for microscopic examination prior to sample collection for genetic analysis.	HK, SHG
11:00 AM	Check out	SHG
2:00 PM	Microscopic observation for biomass	HK
3:00 PM	Sump pump interruption troubleshoot	HK
4:30 PM	Changed the sump pump	HK
5:00 PM	PBR recirculation resumed	HK
5:30 PM	Check out	HK

Thursday 2nd November 2017

Time	Activity	Personnel
7:45 AM	Check in	SS
8:00 AM	Check in	HK
9:25 AM	Check in	SHG
9:35 AM	Data logger download, battery change, calibration and reset	SHG
10:00 AM	Collected PBR samples and tested PBR samples for silica, orthophosphate	HK
11:00 AM	Setting up extra pump for recirculation	HK, SHG
12:50 PM	Check out	SHG
2:00 PM	Re-plumbing for filter skids connected to the sump pump from holding tank 2	SS, HK
4:00 PM	Testing of PBR samples	HK
5:00 PM	Check out	HK, SS

Friday 3rd November 2017

Time	Activity	Personnel
8:00 AM	Check in	SS, HK
9:20 AM	Check in	SHG
9:30 AM	Collect and test PBR samples for silica, orthophosphate	HK
9:35 AM	Data logger download, battery replacement, calibration and reset	SHG
10:30 AM	Prepare for starting PBR influent	HK
10:45 AM	Cleaning the PBR panels	SHG
11:15 AM	Recirculation stopped. PBR influent started (silica = 108 mg/L, pH 7.5) Acid pump – 40% Silica pump – speed 50%, stroke length 25% Nutrient pump – 5%	HK, SHG, SS
11:45 AM	Preparation of new silica stock solution Transfer metasilicate powder (25 lb) from Acid Room to container in 5-gallon bucket Add it to the mixing tank (trash can) with 20-gallons of permeate Started the pump for mixing	SHG, HK

12:40 PM	Check out	SHG
1:45 PM	Holding tank 2 was isolated. Disconnected from HT 1 and drain. The treated water with ~ 30 mg/L was stored in isolated holding tank 2.	HK
2:30 PM	Set up the cartridge filter flow, plumbing for returning the filtrate to holding tank 2 One hour filter test (10, 5 and 1 micron). Samples taken every 15 min and tested for color, phycocyanin, in vivo chlorophyll and absorbance at 750nm.	HK, SS
3:45 PM	Test PBR samples for other parameters	HK
5:00 PM	Check out	HK, SS

Saturday 4th November 2017

Time	Activity	Personnel
8:00 AM	Check in	SS, HK
8:15 AM	PLC data download	HK
9:00 AM	Data logger data download, calibration and reset	HK
9:30 AM	PBR samples collected and tested for silica, orthophosphate	HK
11:30 AM	Change of pipe between HT1 and HT 2, increased the height of HT2 drain outlet	HK, SS
1:30 PM	New pump set up for ammonia injection. Re-plumbing for bleach, ammonia and antiscalant injection	HK, SS
2:30 PM	Plumbing for RO	HK, SS
4:00 PM	Tested PBR samples for remaining parameters	HK
5:00 PM	Check out	HK, SS

Monday 6th November 2017

Time	Activity	Personnel
8:00 AM	Check in	HK
8:30 AM	Samples collected from PBR and tested for silica and orthophosphate	HK
9:25 AM	Check in	SHG
9:35 AM	Data logger download, battery change, calibration and reset	SHG, HK
11:00 AM	Biomass collection for genetic analysis	HK, SHG
11:35 AM	Exchange of media in laboratory biomass tubes	SHG
12:00 PM	Went to Fedex for shipping the biomass samples	HK, SHG
12:25 PM	Check out	SHK
2:30 PM	Laboratory experiments to determine appropriate concentration of stock solution for bleach and ammonia	HK
4:30 PM	Tested remaining parameters in PBR samples	HK
5:30 PM	Check out	HK

Tuesday 7th November 2017

Time	Activity	Personnel
8:00 AM	Check in	HK, SHG
8:30 AM	Well 2 water flow cut off (7:40 AM) due to hydro-tank low pressure Caused precipitation in the PBR influent line (after silica injection) Disconnected the line, cleaned with acid and reconnected.	HK, SHG
11:30 AM	Lunch with Shanka	HK, SHG
3:00 PM	Acid tank needed refill. ~ 5-gallons of acid (1:10) from the acid tank was transferred into a 5-gallon bucket to keep the system running. The acid tank was then moved inside the warehouse and started filling ~ 85-gallons RO permeate The tank with permeate was then moved near the Acid Room. Concentrated sulfuric acid was pumped into the acid tank using a manual pump The acid tank was moved back near the container. The suction line of acid injection pump was reset into the acid tank. Re-adjusted the silica and acid injection flow rates to have ~ 100 mg/L silica and 7.5 pH.	HK

	Thanks to Bobby and Skyler.	
4:30 PM	Tested the PBR samples	HK
5:30 PM	Check out	HK

Wednesday 8th November 2017

Time	Activity	Personnel
8:00 AM	Check in	HK
8:15 AM	Collected PBR samples and tested for silica, orthophosphate	HK
9:30 AM	Download PLC data	HK
11:30 AM	Download data logger, change batteries, calibration and reset	HK
1:30 PM	Started bleach and ammonia injection while the holding tank 2 water is recirculated through cartridge filters Aim is to achieve 2 ppm chlorine residual with 0 ppm free chlorine.	HK
4:30 PM	Tested in lab, To 1-L of holding tank 2 water, increasing concentrations of bleach were added 400-µL of ammonia (10%) required per 1-L of water to be treated 120- µL of bleach (8.25%) required per 1-L of water to be treated	HK
5:00 PM	Check out	HK

Thursday 9th November 2017

Time	Activity	Personnel
8:00 AM	Check in	HK
8:15 AM	Collected PBR samples and tested for silica, orthophosphate	HK
9:30 AM	Download data logger data, change batteries, calibration and reset. Download PLC data	HK
10:30 AM	Tested silica, calcium, alkalinity, total and free chlorine in holding tank 2 water	HK
12:00 PM	Started the recirculation through filter skid, added ammonia, then bleach to have 2 ppm total chlorine residual and 0 ppm free chlorine.	HK
1:00 PM	Re-checked chlorine residual. Modified the plumbing (added a T) to return ROC / ROP flow into the holding tank 2. Sample bottles arranged for RO sample collection.	HK
2:00 PM	RO begins @ 30% recovery RO Feed, ROC and ROP samples collected every 15 min. High pressure, Q_R, Q_P and Q_C recorded. Samples tested for pH, conductivity, TDS, salinity, temperature, silica and calcium.	HK
4:30 PM	Last sample collected at 150 min and then RO was turned OFF.	HK

5:30 PM	Check out	HK

Friday 10th November 2017

Time	Activity	Personnel
8:00 AM	Check in	HK
8:15 AM	Collected PBR samples and tested for silica, orthophosphate	HK
9:30 AM	Download data logger data, change batteries, calibration and reset. Download PLC data	HK
11:00 AM	Checked chlorine residual in holding tank 2. Added ammonia and bleach to adjust chlorine residual to 2 ppm and 0 ppm free chlorine. Silica, calcium, alkalinity checked in holding tank 2. Recirculation through cartridge filters ON.	HK
12:00 PM	RO begins @ 30% recovery RO Feed, ROC and ROP samples collected every 15 min. High pressure, Q_R, Q_P and Q_C recorded. Samples tested for pH, conductivity, TDS, salinity and temperature.	HK
4:00 PM	Recirculation (20 gpm) from 9th channel to 1st channel + 0.2 gpm PBR influent flow was set up.	HK
5:30 PM	Check out	HK

Monday 13th November 2017

Time	Activity	Personnel
7:30 AM	Check in	HK
8:00 AM	Check in	KI
8:30 AM	Silica tested in PBR samples and in holding tank 2. Downloaded the PLC and data logger data, calibration and reset.	HK
9:00 AM	RO begins @ 30% recovery No samples collected for first 5 hours.	HK, KI
2:30 PM	Recovery increased to 50% Samples collected every 30 min and tested.	HK, KI
4:00 PM	RO turned OFF	HK, KI
5:00 PM	Check out	HK, KI

Tuesday 14th November 2017

Time	Activity	Personnel
8:00 AM	Check in	HK, KI
9:30 AM	PLC and data logger data download. Probe calibration and reset. PBR samples tested for silica. Holding tank 2 tested for silica, calcium, alkalinity, total and free chlorine, monochloramine and sulfate.	HK
10:20 AM	RO begins @ 50% recovery. Samples collected every 30 min. All tested for pH, conductivity, TDS, salinity, turbidity, phycocyanin and in-vivo chlorophyll. Pressure and three flows were recorded every 10 min. Silica, alkalinity, calcium and sulfate was measured intermediately for mass balance. 0 – 83 min @ 50% recovery 83 – 335 min @ 60% recovery 335- 390 min @ 70% recovery.	HK, KI
3:00 PM	Test America samples collected for heavy metals, total silica, boron and TOC analyses.	HK, KI

	Raw Well-2 water, modified PBR influent, PBR effluent, RO feed, ROC and RO permeate. Another set of samples in plastic bottles was also collected.	
4:00 PM	RO turned off	HK, KI
5:00 PM	Check out	HK, KI

Wednesday 15th November 2017

Time	Activity	Personnel
8:00 AM	Check in	HK
8:15 AM	Collected PBR samples and tested for silica, orthophosphate	HK
9:30 AM	Download data logger data, change batteries, calibration and reset. Download PLC data	HK
10:30 AM	Since the pH of water in holding tank 2 was higher (> 9.5), sulfuric acid (1:10) was to be added to HT2 to lower the pH to 7.5. Lab test performed (titration) and appropriate amount of acid was added to HT2 and recirculated using sump pump for mixing. pH monitored using effluent data logger probe temporarily. Ammonia and bleach was added to have 2 ppm chloramine residual prior to adjusting the pH with acid. Note that adding ammonia (ammonium hydroxide) increases the pH dramatically.	HK
1:00 PM	RO begins @ 30% recovery. Samples collected every 30 min. At T = 60 min, recovery was increased to 50 %	HK

	At T = 120 min, recovery was increased to 70%	
5:00 PM	RO turned OFF. Prepared for CIP. Two 150-gallons tank being filled with permeate.	HK
5:30 PM	Check out	HK

Thursday 16th November 2017

Time	Activity	Personnel
8:00 AM	Check in	HK, KI
8:45 AM	Ammonia, bleach and acid added to the holding tank 2, to adjust the chlorine residual and pH	HK, KI
9:00 AM	RO begins @ 50% recovery. Samples collected every 30 min. At T = 60 min, recovery increased to 60% At T = 160 min, recovery increased to 70%	HK,KI
11:00 AM	PBR samples tested for silica, orthophosphate, phycocyanin, in-vivo chlorophyll	HK
3:00 PM	Test America samples collected for heavy metals, total silica, boron and TOC analyses. Raw Well-2 water, modified PBR influent, PBR effluent, RO feed, ROC and RO permeate. Another set of samples in plastic bottles was also collected.	HK, KI
3:15 PM	RO turned OFF	HK, KI

3:30 PM	About 13 lb of citric acid was added to 80-gallons of permeate in 150-gallon tank connected to the RO feed.	HK, KI
4:06 PM	CIP started. The prepared ~2% citric acid solution as circulated through RO membranes.	HK, KI
4:36 PM	CIP was stopped. And RO was rinsed with permeate water and the waste was collected in citric acid tank. Conductivity was monitored during rinse. Rinse stopped when the conductivity of return water was less than 100 µS/cm.	HK, KI
5:30 PM	Check out	HK, KI

Friday 17th November 2017

Time	Activity	Personnel
8:00 AM	Check in	HK, KI
8:00 AM	RO begins with PBR influent water @ 30% recovery. Samples collected every 30 min. At T = 60 min, recovery was increased to 60%. Mass balance was checked with calcium, silica, sulfate and alkalinity intermediately.	HK, KI
10:00 AM	PBR samples collected, data logger data downloaded.	HK
11:00 AM	RO turned off.	HK, KI
11:30 AM	Started packing for return	HK,KI
2:30 PM	Check out	HK, KI

Monday 12th February 2018 – Friday 16th February 2018

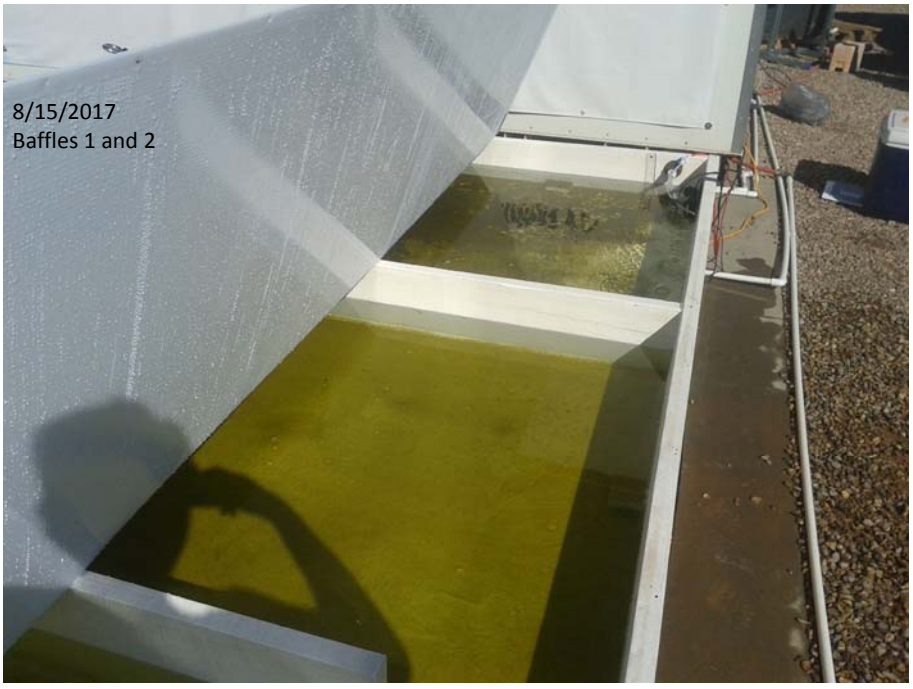
Time	Activity	Personnel
8:00 AM	Check in	SS
-	Demolition of pilot PBR	SS
5:00 PM	Check out	SS

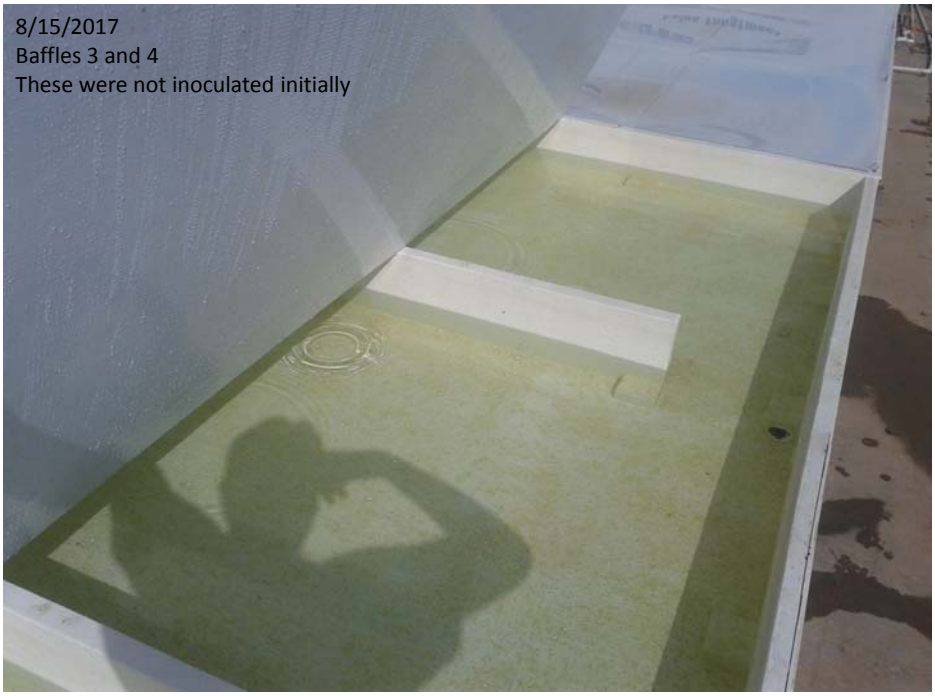
APPENDIX 3

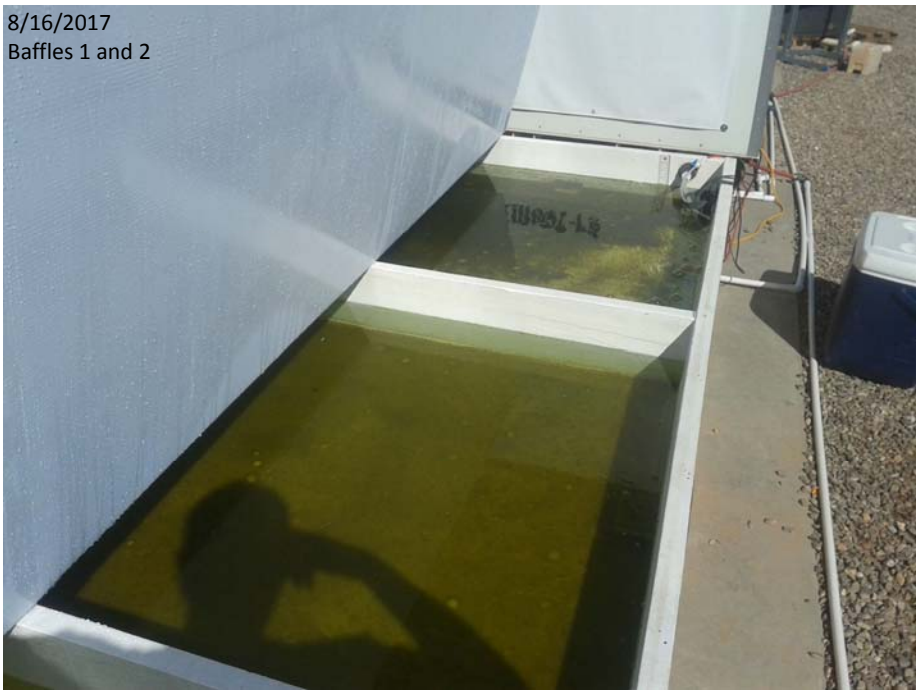
B054 Activities Slides

2017-10-31


8/14/2017
Baffles 1 and 2

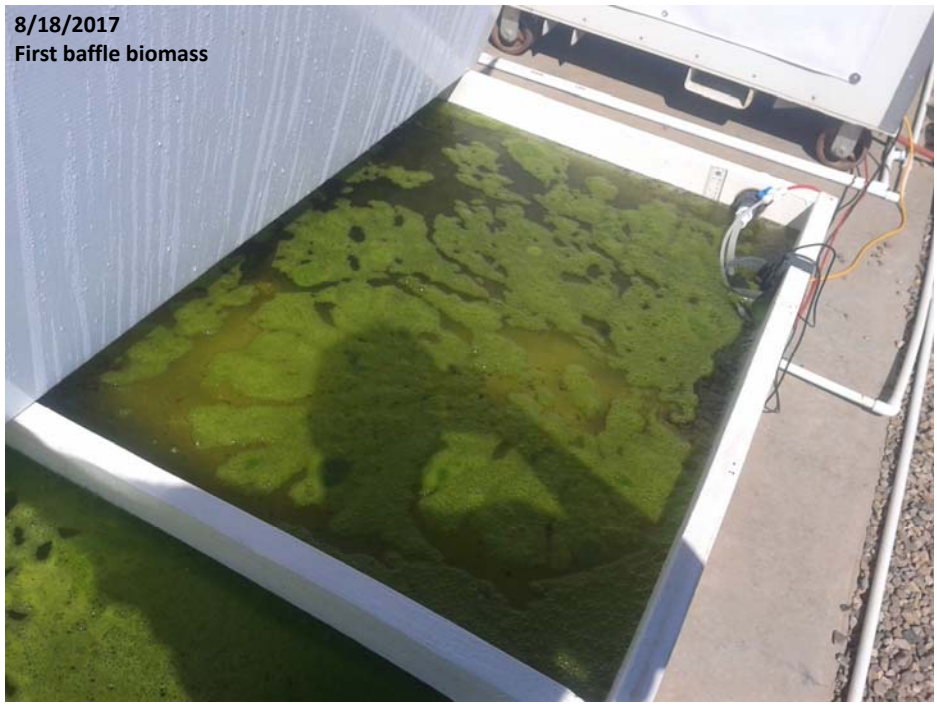

8/15/2017
Baffles 1 and 2


8/15/2017
Baffles 3 and 4
These were not inoculated initially

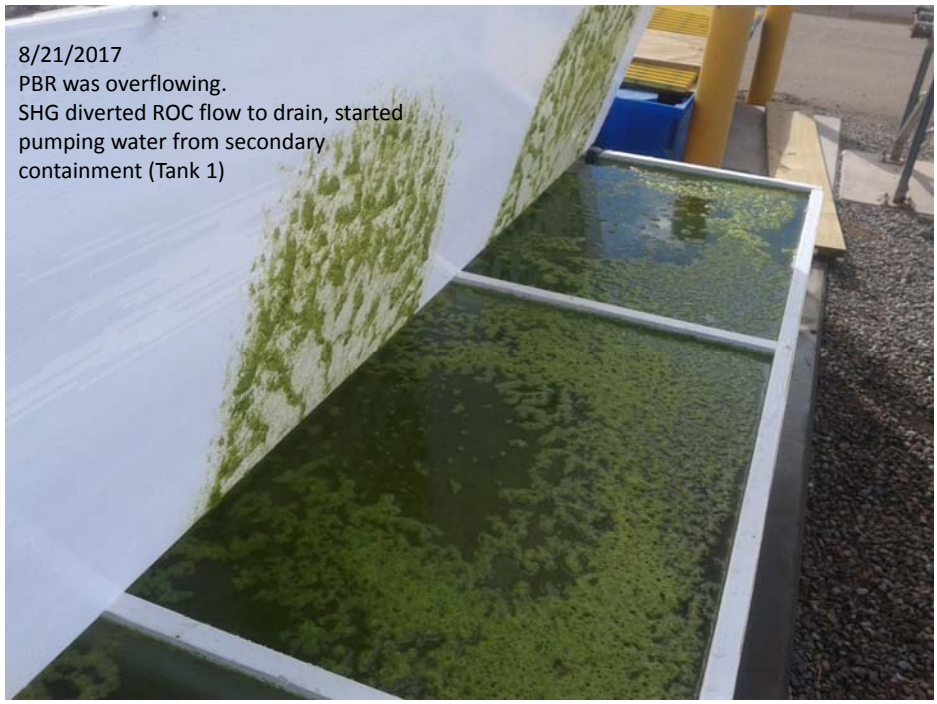

8/16/2017
Baffles 1 and 2


8/17/2017
Baffles 1 and 2


8/17/2017
Last 2 baffles towards the end of the PBR
These baffles were not inoculated


8/18/2017
First baffle biomass


8/21/2017
Rainfall on 8/20, water collected on panels

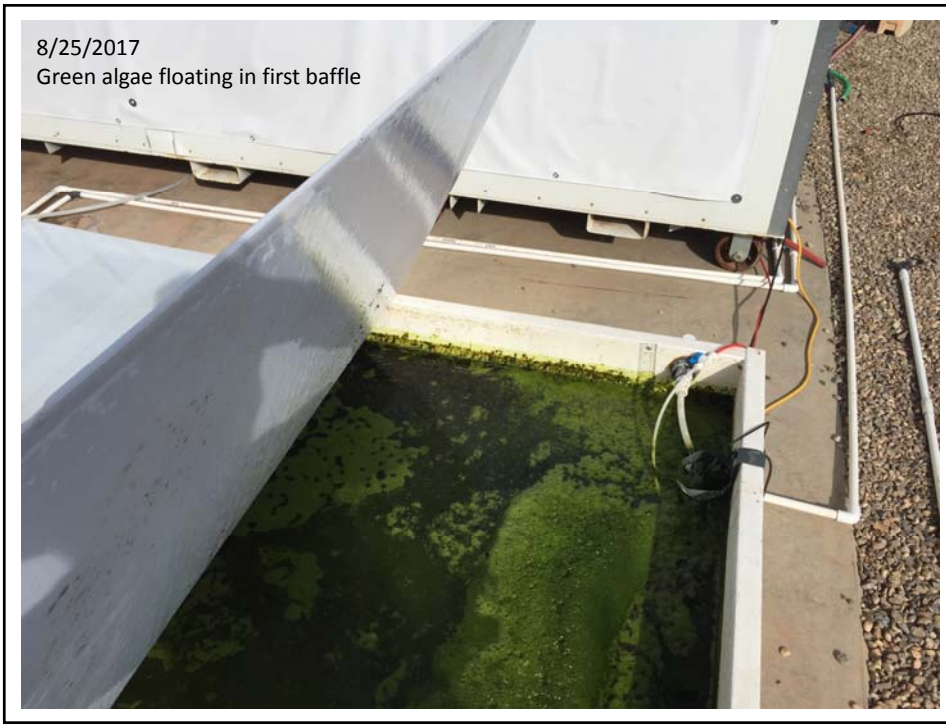

8/21/2017
PBR was overflowing.
SHG diverted ROC flow to drain, started pumping water from secondary containment (Tank 1)


8/22/2017
Earthen barrier was made to avoid overflow water contaminating the soil

8/22/2017
Leakage observed near sampling ports on both sides of PBR

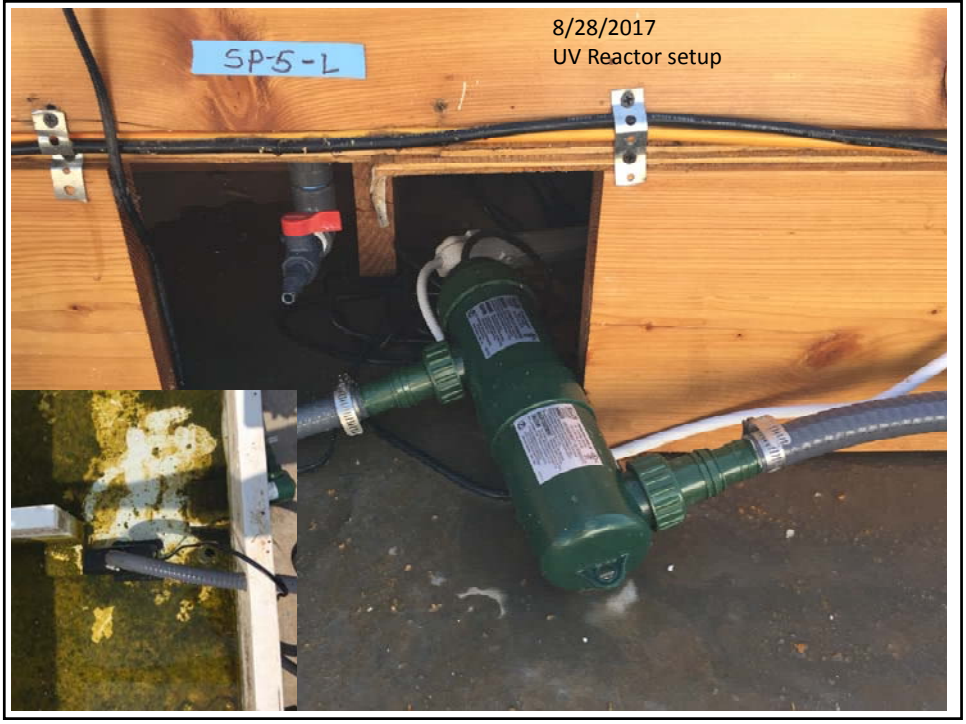
8/23/2017
Biomass in first baffle. Orthosilicate injection started today

8/24/2017
Orthosilicate injection setup



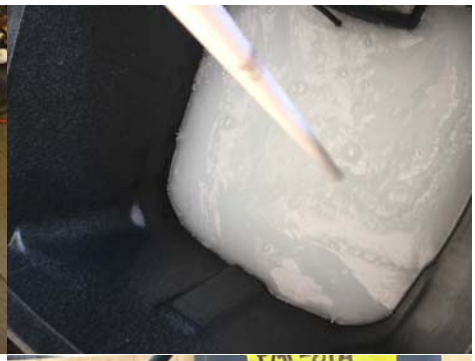
8/25/2017
Green algae floating in first baffle

8/28/2017
Overflow management

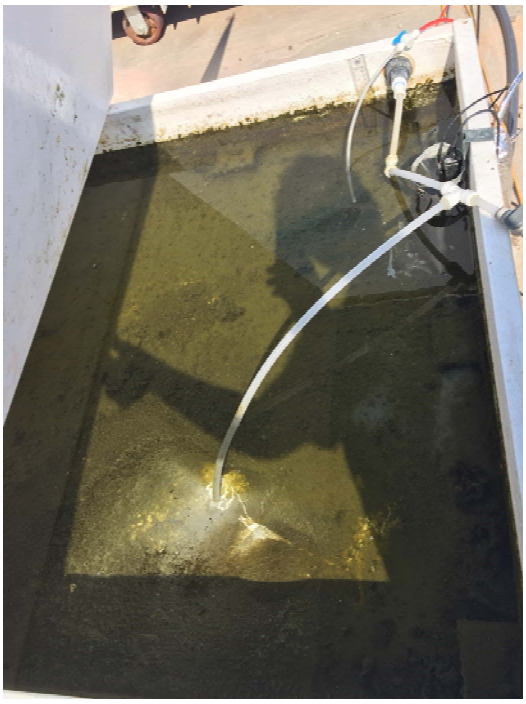


8/28/2017
UV Reactor setup

8/29/2017
Feed water was switched to Well 2 Water. Silica needed to be added.
A tank and pump was set up for silica injection. Flow measurement for PBR feed and sampling port was installed.



9/5/2017
Sodium metasilicate arrived at BGNDRF 5 x 10 lb bags. Two bags added and tried to dissolved manually. Pumped at 80% speed (2.2 gpd).



9/8/2017
A white precipitate appeared in the first baffle of the PBR.

9/11/2017

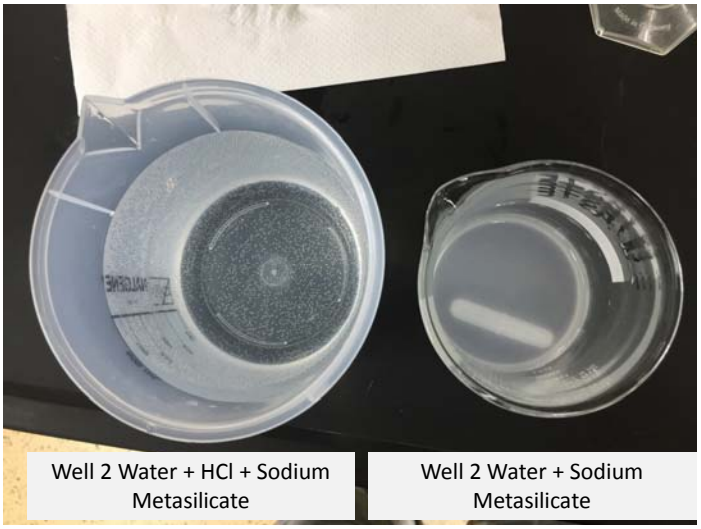
White precipitate covered the first baffle of PBR completely.

In later analyses, it appeared that the precipitate was combined “Ca-Si” and precipitation occurred as very basic pH silica stock solution (pH > 10) was added to the Well 2 water that has very high calcium.

9/11/2017
PBR Clean up

1st baffle was isolated from others.

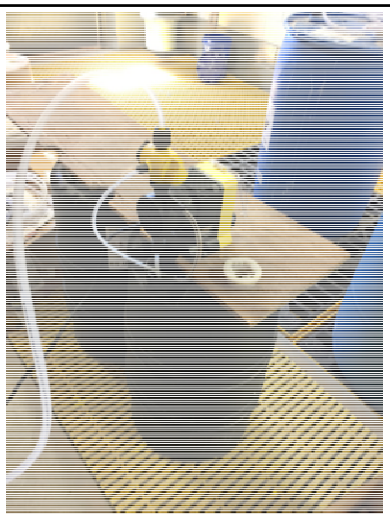
Precipitate in 1st baffle was pumped out multiple times with additional well 2 water.

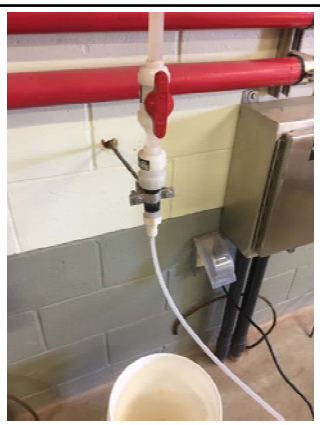


Well 2 Water + HCl + Sodium Metasilicate

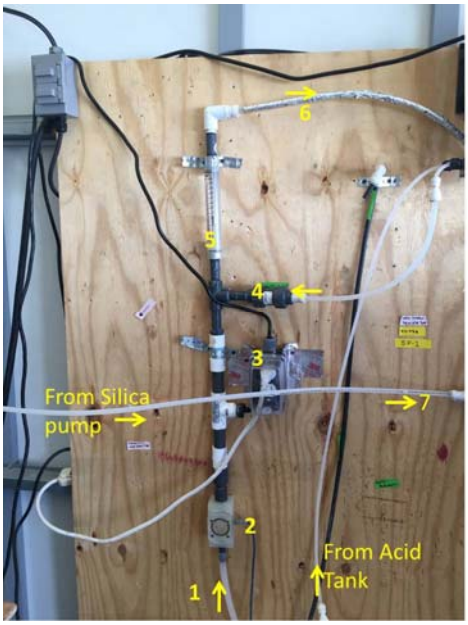
Well 2 Water + Sodium Metasilicate

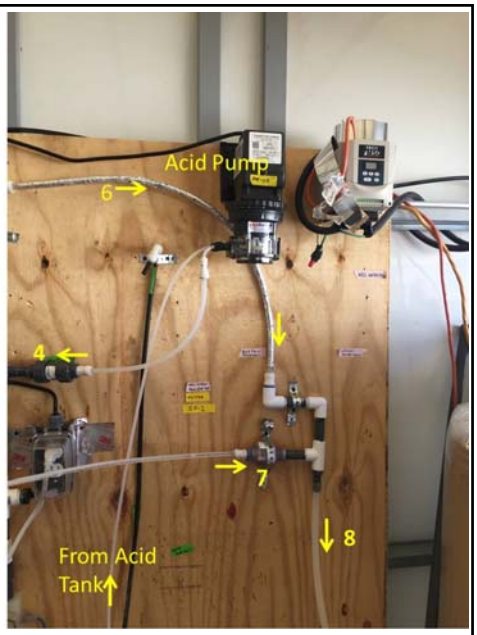
9/12/2017
It was determined experimentally that acid addition prior to silica stock solution addition to well 2 water is required in order to avoid precipitation and achieve desired reactive silica concentration.





9/14/2017
93% Sulfuric Acid in Acid Injection Room. However, it was observed that it takes ~3 hours to reflect the change in pH due to longer distance of PBR from the Acid Room.

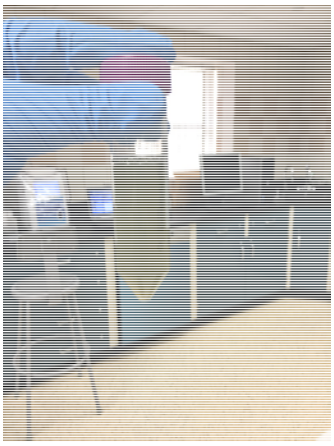


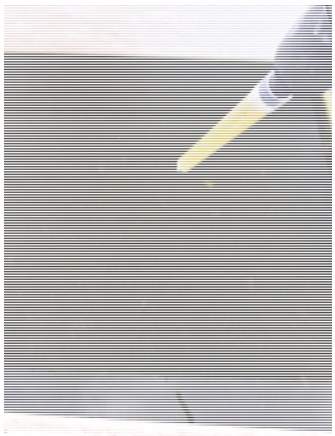


9/20/2017
Plumbing was changed to inject the acid near PBR.

9/21/2017
A 100-gallon tank with 1:10 sulfuric acid on secondary containment near PBR

9/27/2017
A hydro tank near the storage tank pressurizes the water with compressed air. Pressure range was initially set as 40 to 55 psi. This wide range caused flow fluctuations. So upon PACE's request, BGNDRF staff changed this range to 50 to 55 psi. This helped in reducing the flow fluctuations.

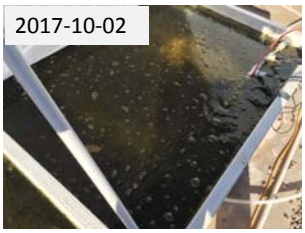


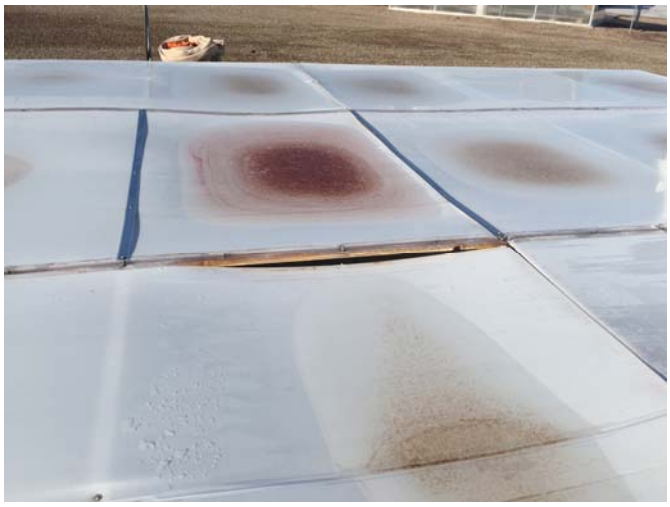


9/29/2017
Additional PEWL 001 biomass was added throughout the PBR. 20-mL of suspension in first two baffles and 10-mL of suspension in rest of the baffles. Weight of the biomass is being determined.

Biomass Visuals in Baffle 1
9/22 to 10/04

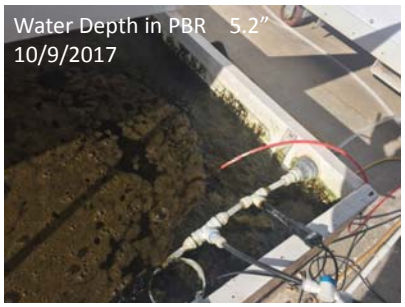
Biomass Visuals in Baffle 3-4
9/22 to 10/04

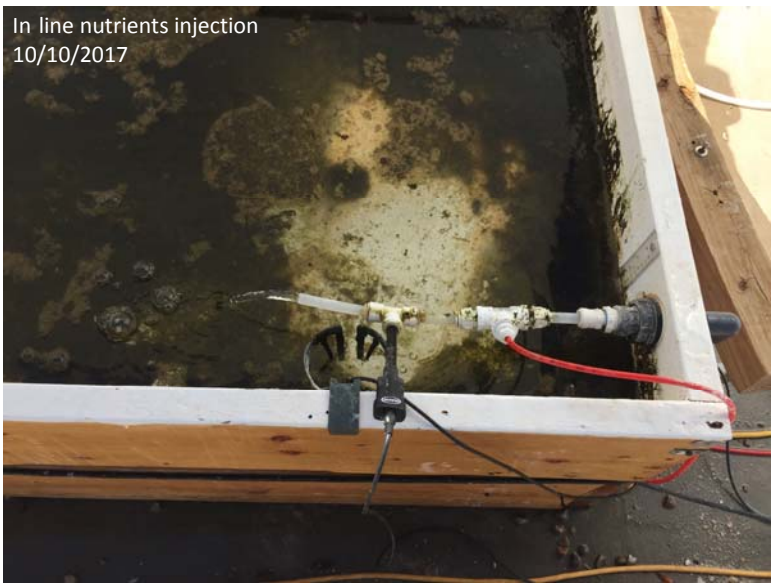


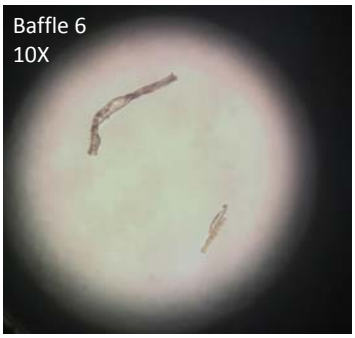


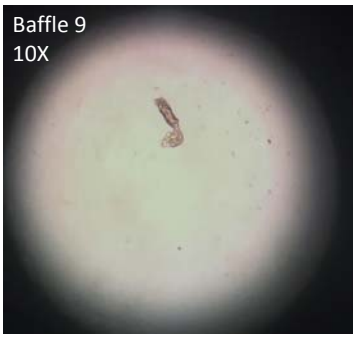
10/6/2017
PBR panel damaged by wind. Shanka fixed it with additional screws.

10/6/2017
PBR was disconnected from secondary containment. Effluent is being drained.

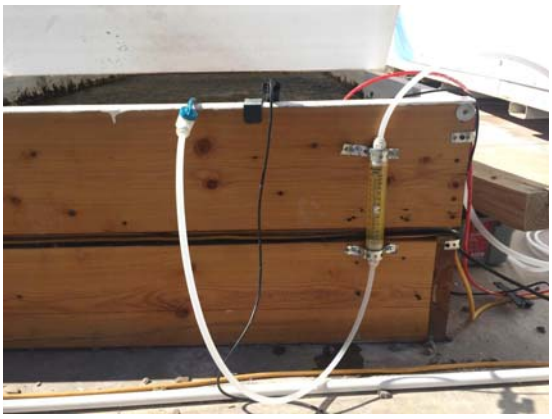


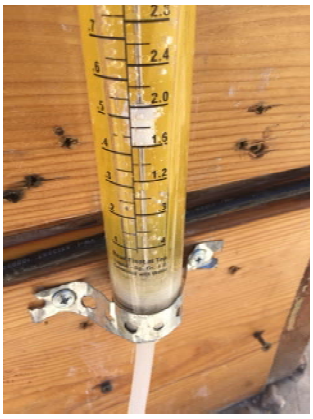






Microscopic images of biomass in the PBR
2017-10-12

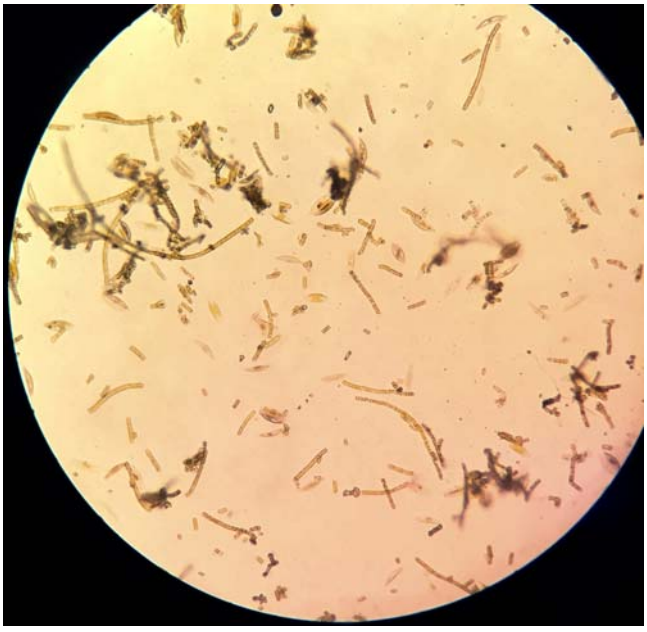




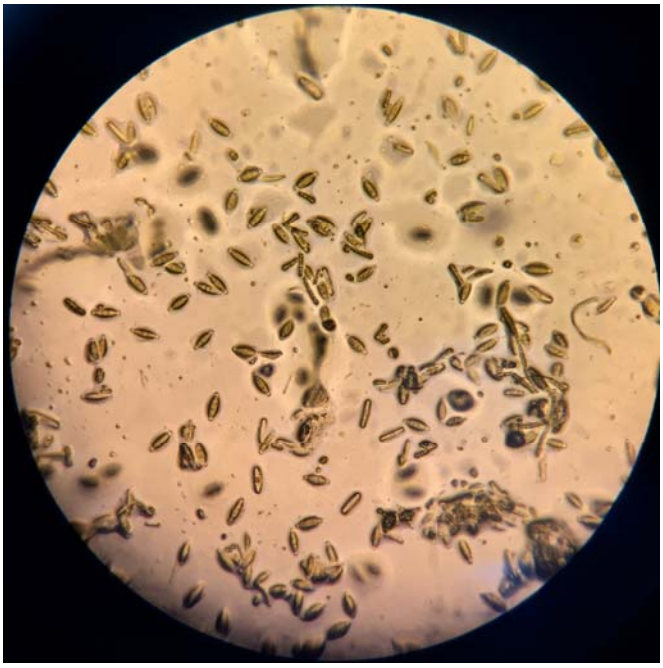
PBR influent flow is adjusted to 0.5 gpm. A rotameter is installed on waste line (drain) to control the flow entering the PBR.
2017-10-16

Biomass in Channel 1 – mostly dark brown color diatoms

Biomass in Channels 3 and 4 – green algae



Biomass sample taken from the bottom layer in Channel 1 shows mixture of diatoms including PEWL 001 and others.



Biomass sample taken from the floating layer in Channel 1 shows predominantly the diatoms other than PEWL001 (ID needed)

The green floating biomass from Channels 3 – 9 was removed using a vacuum cleaner.

Floating biomass in channels 1 and 2 was not removed as it didn't have major green contamination.

Green biomass at bottom in Channel 4. After floating biomass was removed

Demolition of pilot photobioreactor 2018-02-13

APPENDIX 4

B054 Task 04.2
Laboratory Experiments

9/28/2017

1

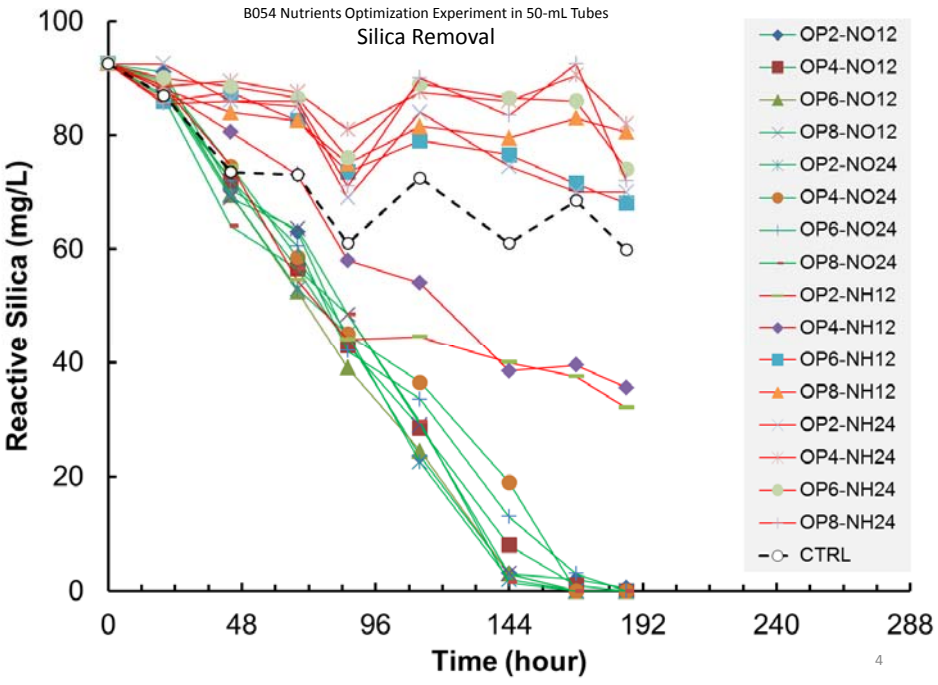
Visit to BGNDRF (January 2017)

- Samples collected
  - Raw Groundwater (4 Wells)
  - Well-1 RO Concentrate
  - Evaporation Ponds (3)
- Other Information
  - Test Bed (dimensions, electrical and plumbing details)
  - Laboratory facility, equipment

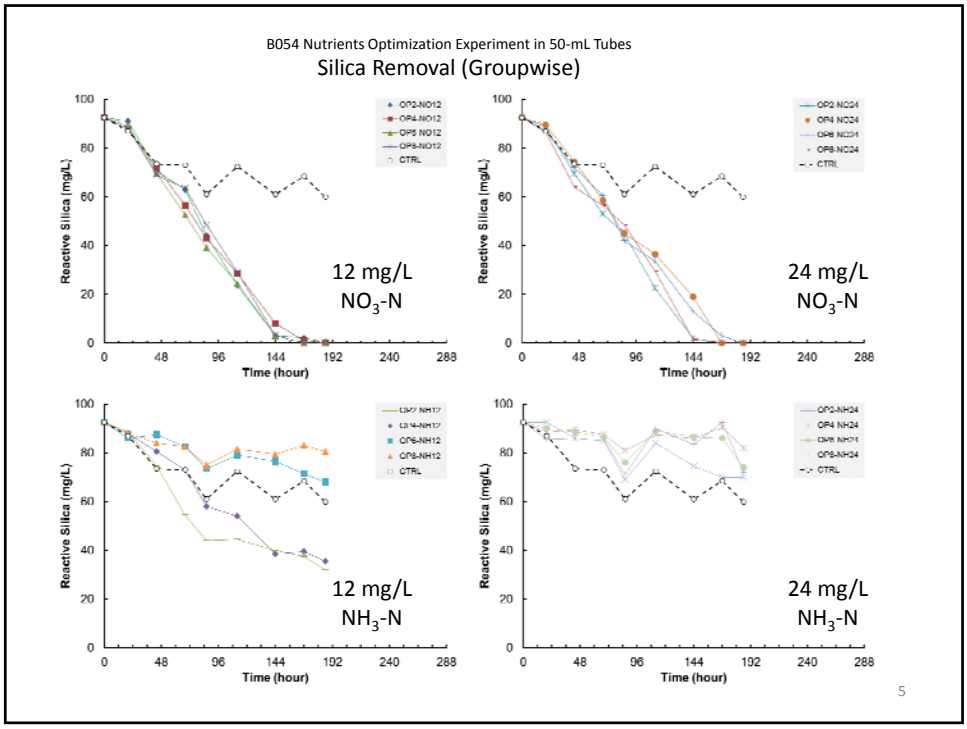
Type	Parameter	Well 1	Well 2	Well 1 ROC
Scalants	Reactive Silica (mg/L)	25	30	92
	Calcium (mg/L)	115	1,380	845
Nutrients	Nitrate-N (mg/L)	0	7	0
	Orthophosphate (mg/L)	0	0	0
General	pH	8	7	8
	TDS (mg/L)	1,090	4,540	4,620
	Salinity (mg/L)	760	3,190	3,250
	Total Hardness (mg/L as $CaCO_3$)	145	2,795	1,070
	Conductivity (µS/cm)	1,538	6,410	6,390

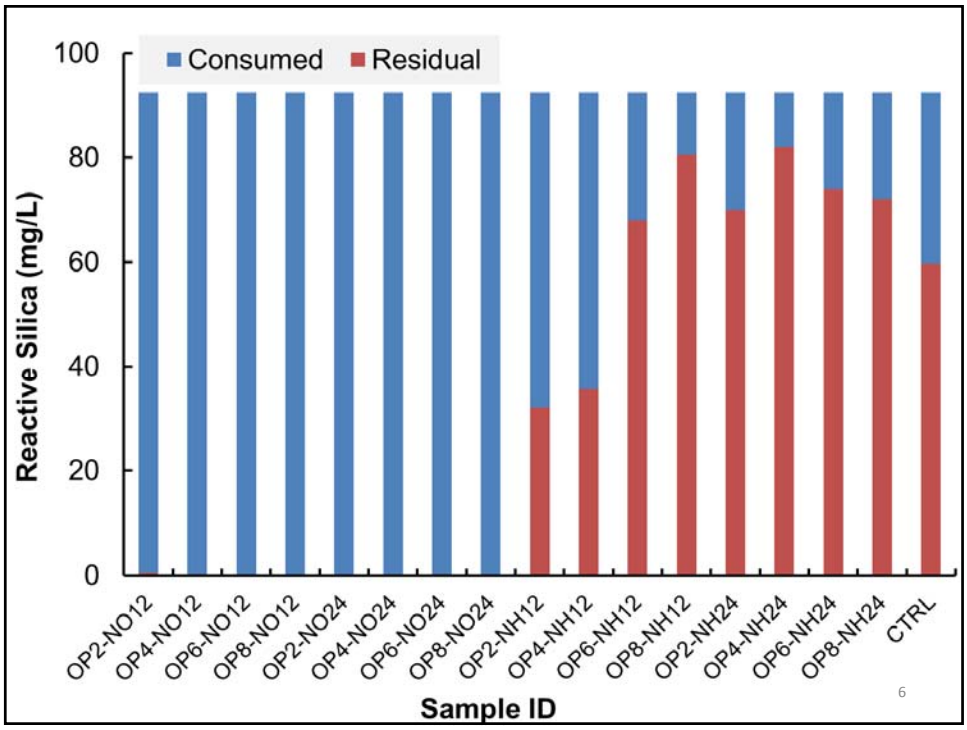
B054 Task 04.2
Nutrients Optimization Experiment in 50-mL Tubes

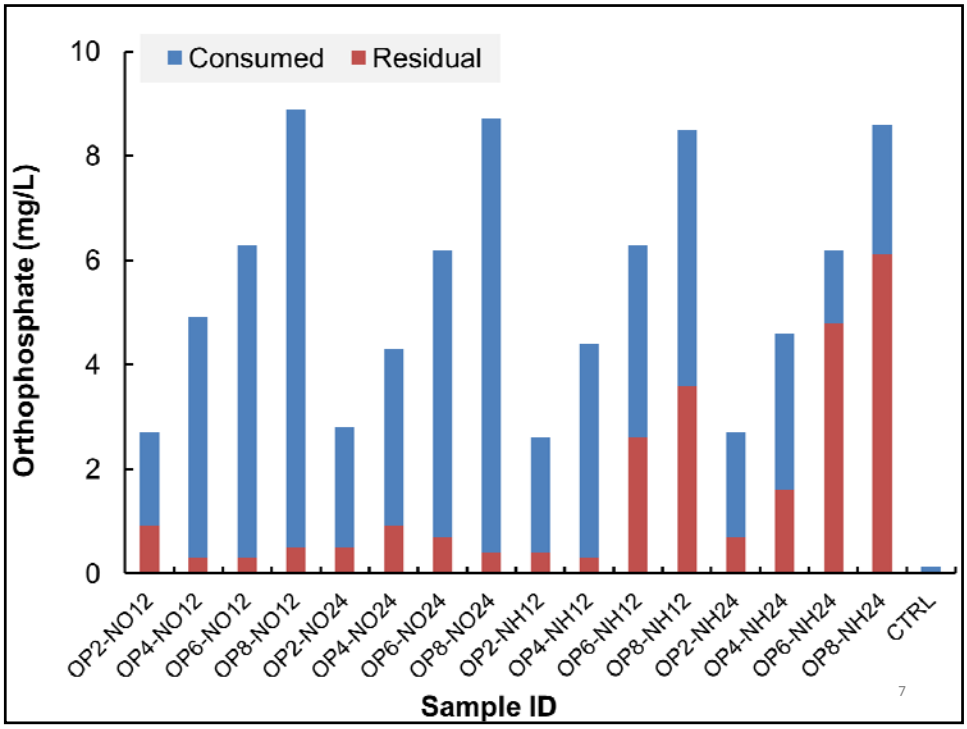
3

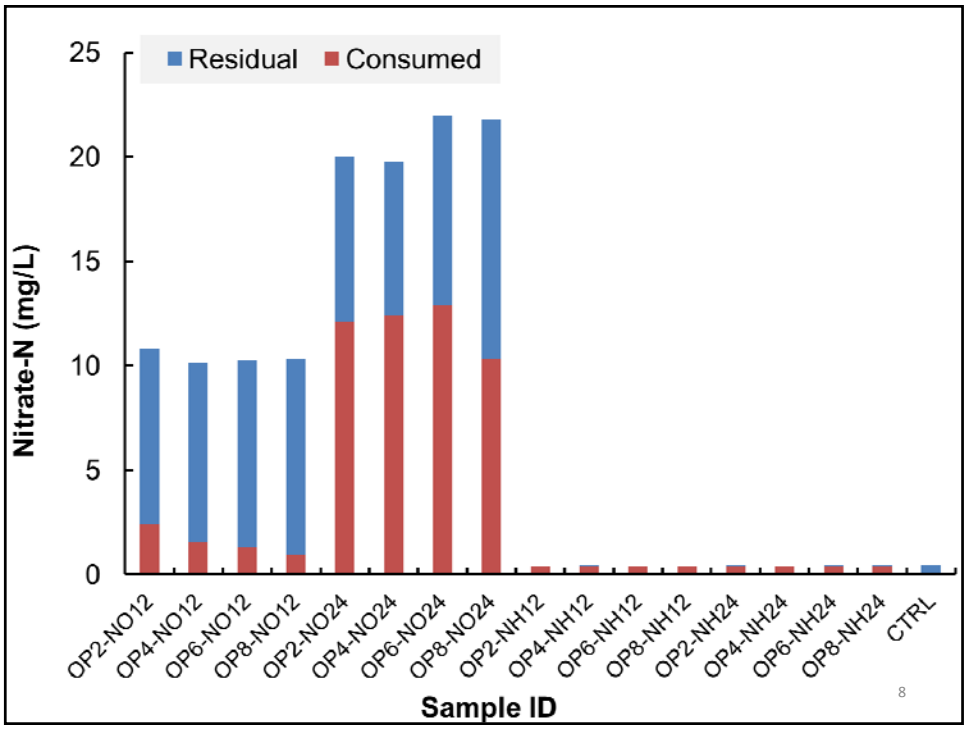


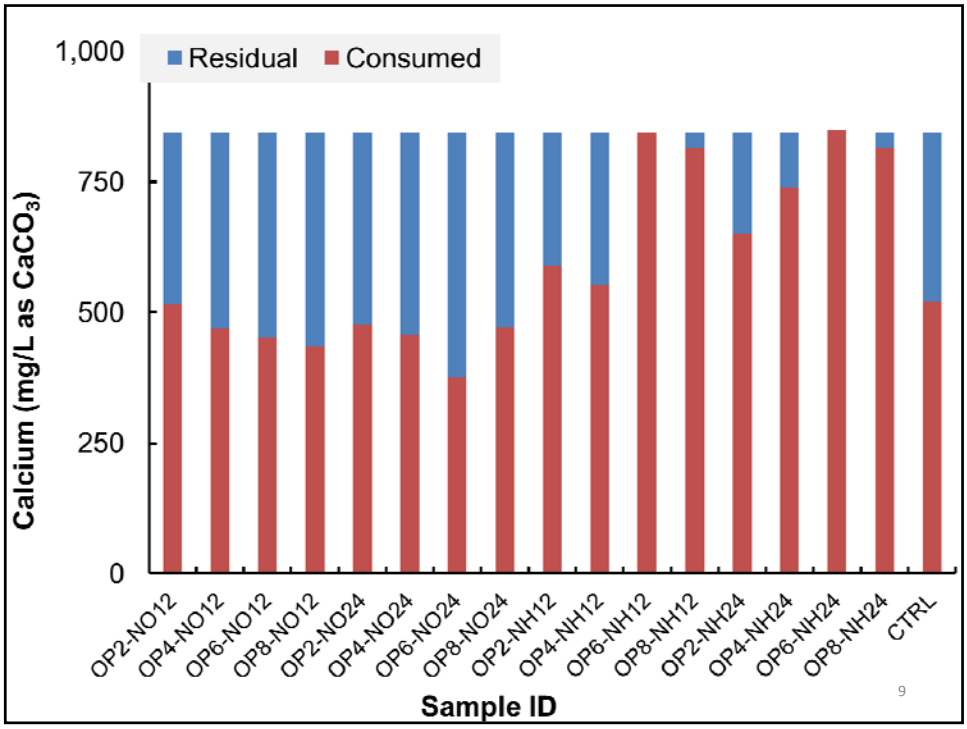
4

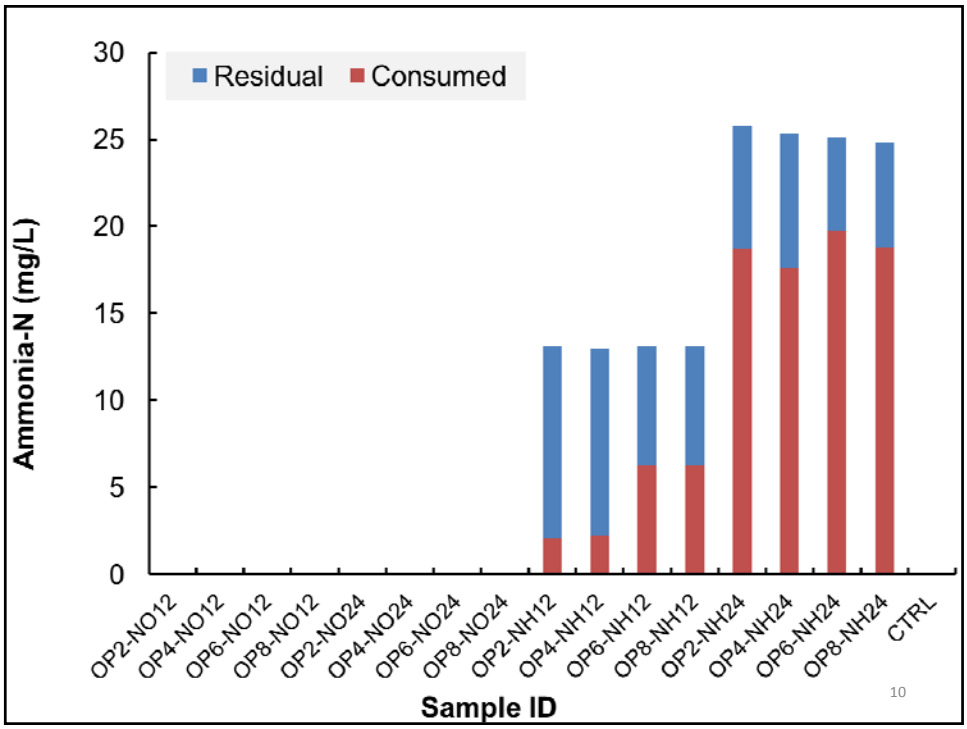

B054 Nutrients Optimization Experiment in 50-mL Tubes
Silica Removal (Groupwise)
Reactive Silica (mg/L)
Time (hour)
12 mg/L
NO3-N
24 mg/L
NO3-N
12 mg/L
NH3-N
24 mg/L
NH3-N
CTRL
5

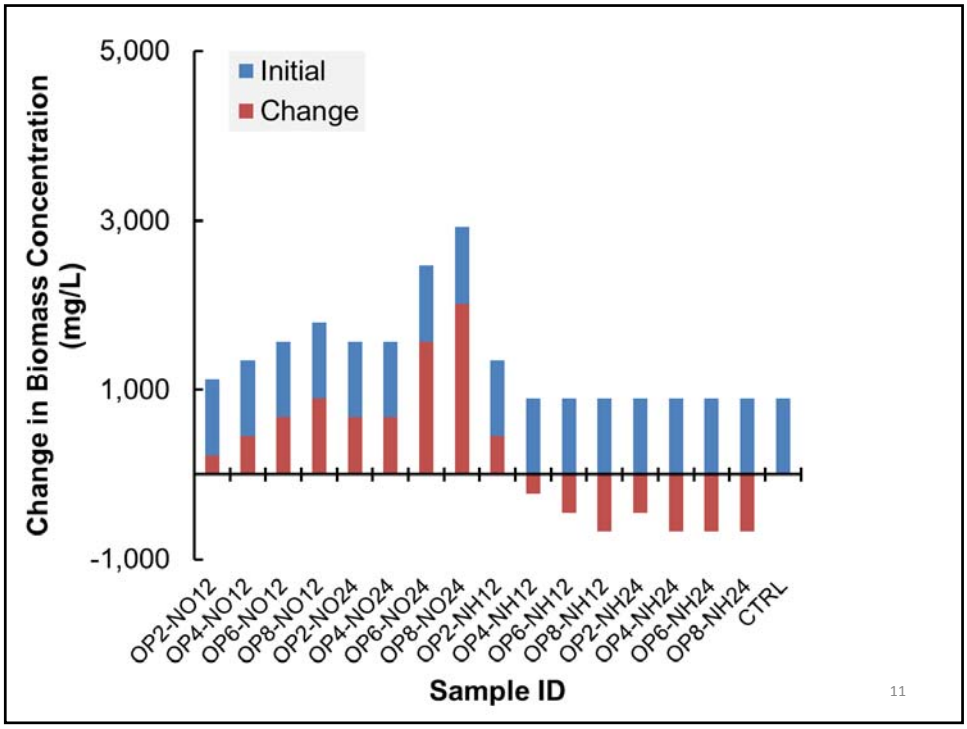

Consumed
Residual
Reactive Silica (mg/L)
Sample ID
OP2-NO12
OP4-NO12
OP6-NO12
OP8-NO12
OP2-NO24
OP4-NO24
OP6-NO24
OP8-NO24
OP2-NH12
OP4-NH12
OP6-NH12
OP8-NH12
OP2-NH24
OP4-NH24
OP6-NH24
OP8-NH24
CTRL
6


Consumed
Residual
Orthophosphate (mg/L)
0
2
4
6
8
10
OP2-NO12
OP4-NO12
OP6-NO12
OP8-NO12
OP2-NO24
OP4-NO24
OP6-NO24
OP8-NO24
OP2-NH12
OP4-NH12
OP6-NH12
OP8-NH12
OP2-NH24
OP4-NH24
OP6-NH24
OP8-NH24
CTRL
Sample ID
7


Residual
Consumed
Nitrate-N (mg/L)
0
5
10
15
20
25
OP2-NO12
OP4-NO12
OP6-NO12
OP8-NO12
OP2-NO24
OP4-NO24
OP6-NO24
OP8-NO24
OP2-NH12
OP4-NH12
OP6-NH12
OP8-NH12
OP2-NH24
OP4-NH24
OP6-NH24
OP8-NH24
CTRL
Sample ID
8


1,000
750
500
250
0
Residual
Consumed
Calcium (mg/L as CaCO3)
OP2-NO12
OP4-NO12
OP6-NO12
OP8-NO12
OP2-NO24
OP4-NO24
OP6-NO24
OP8-NO24
OP2-NH12
OP4-NH12
OP6-NH12
OP8-NH12
OP2-NH24
OP4-NH24
OP6-NH24
OP8-NH24
CTRL
Sample ID
9

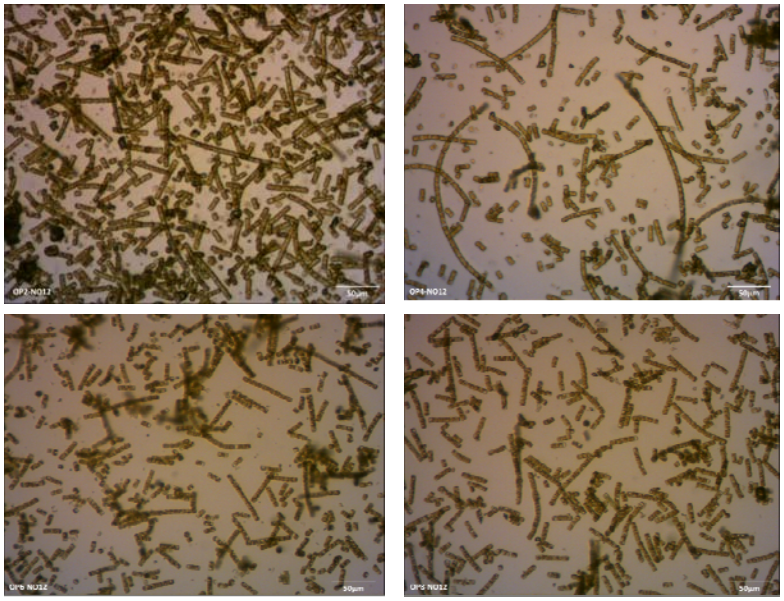

30
25
20
15
10
5
0
Residual
Consumed
Ammonia-N (mg/L)
OP2-NO12
OP4-NO12
OP6-NO12
OP8-NO12
OP2-NO24
OP4-NO24
OP6-NO24
OP8-NO24
OP2-NH12
OP4-NH12
OP6-NH12
OP8-NH12
OP2-NH24
OP4-NH24
OP6-NH24
OP8-NH24
CTRL
Sample ID
10



11

B054 Nutrients Optimization Experiment in 50-mL Tubes

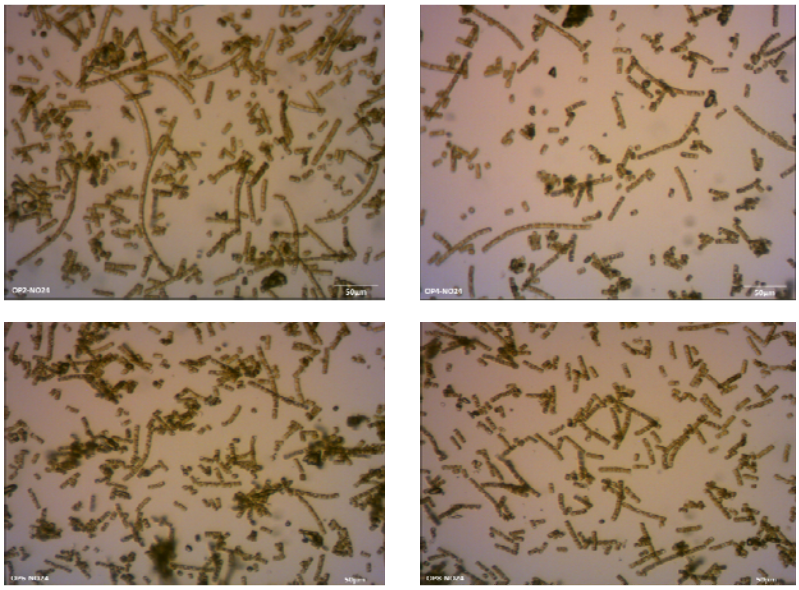
Microscopic Inspection (12 mg/L NO_3-N Tubes)



12

B054 Nutrients Optimization Experiment in 50-mL Tubes

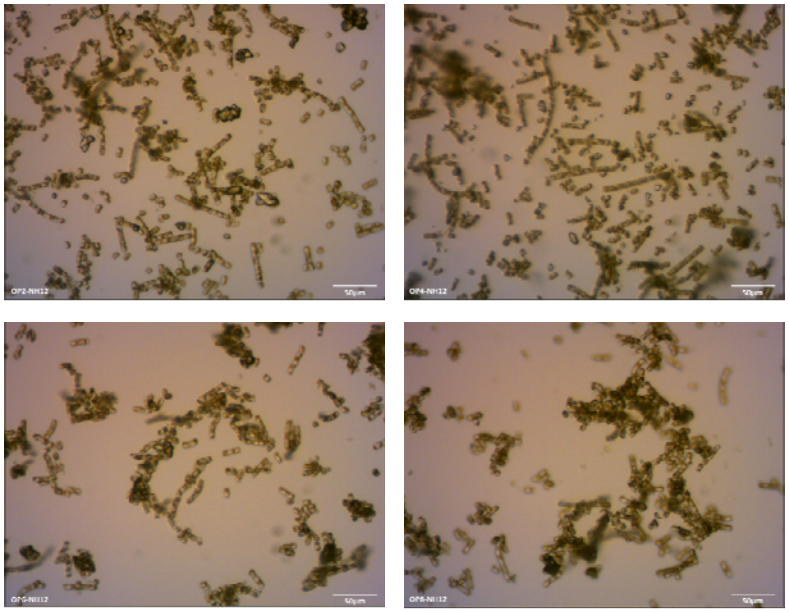
Microscopic Inspection (24 mg/L NO_3-N Tubes)



13

B054 Nutrients Optimization Experiment in 50-mL Tubes

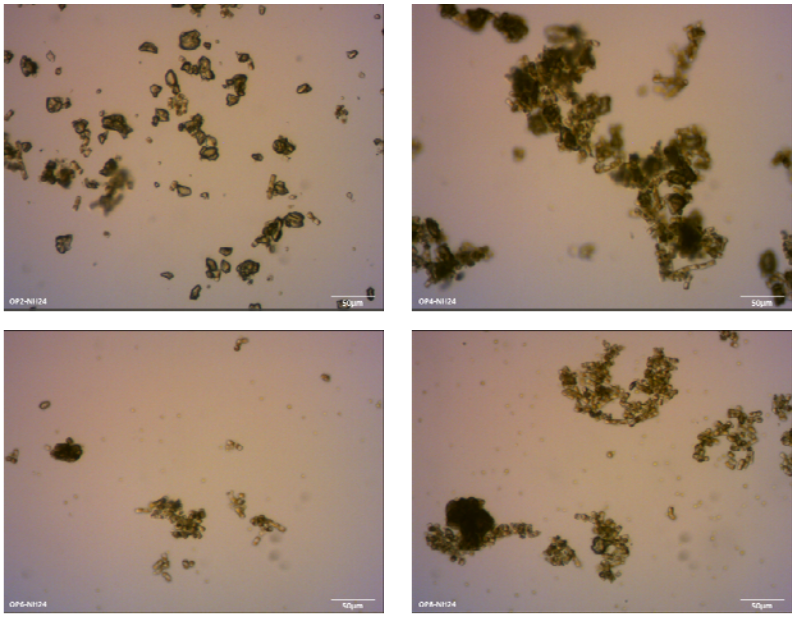
Microscopic Inspection (12 mg/L NH_3-N Tubes)



14

B054 Nutrients Optimization Experiment in 50-mL Tubes

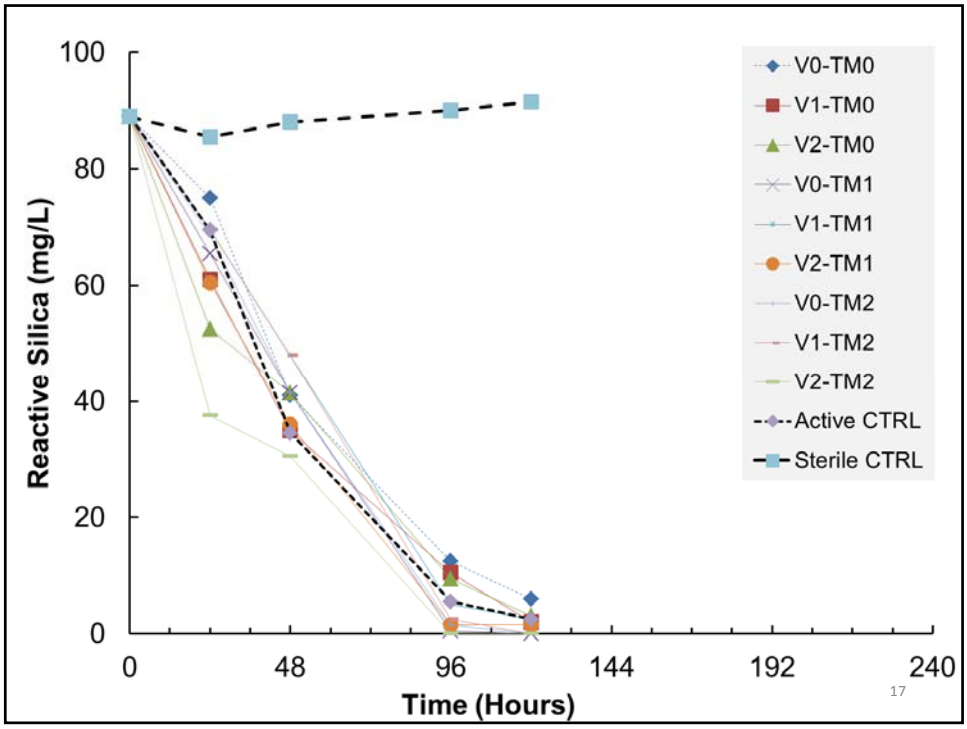
Microscopic Inspection (24 mg/L NH_3-N Tubes)

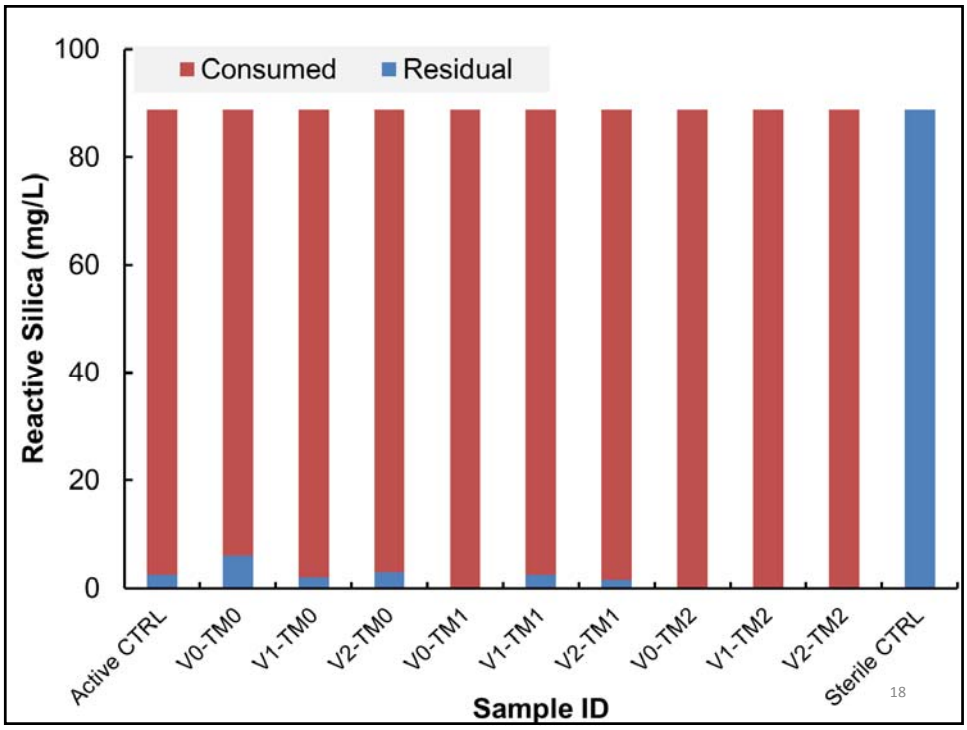


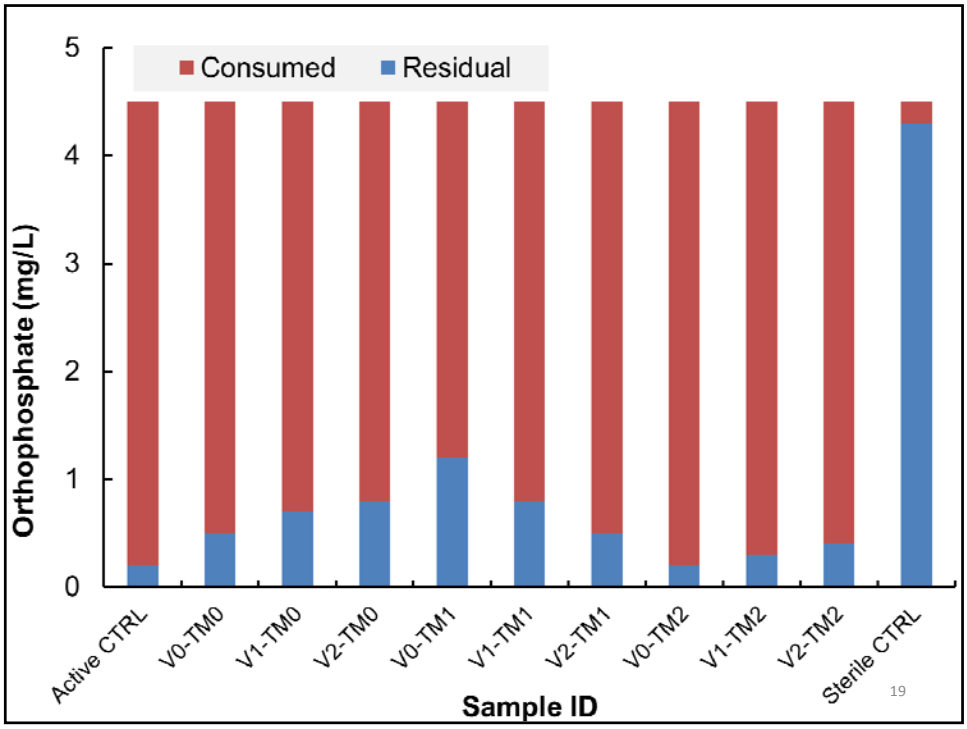
15

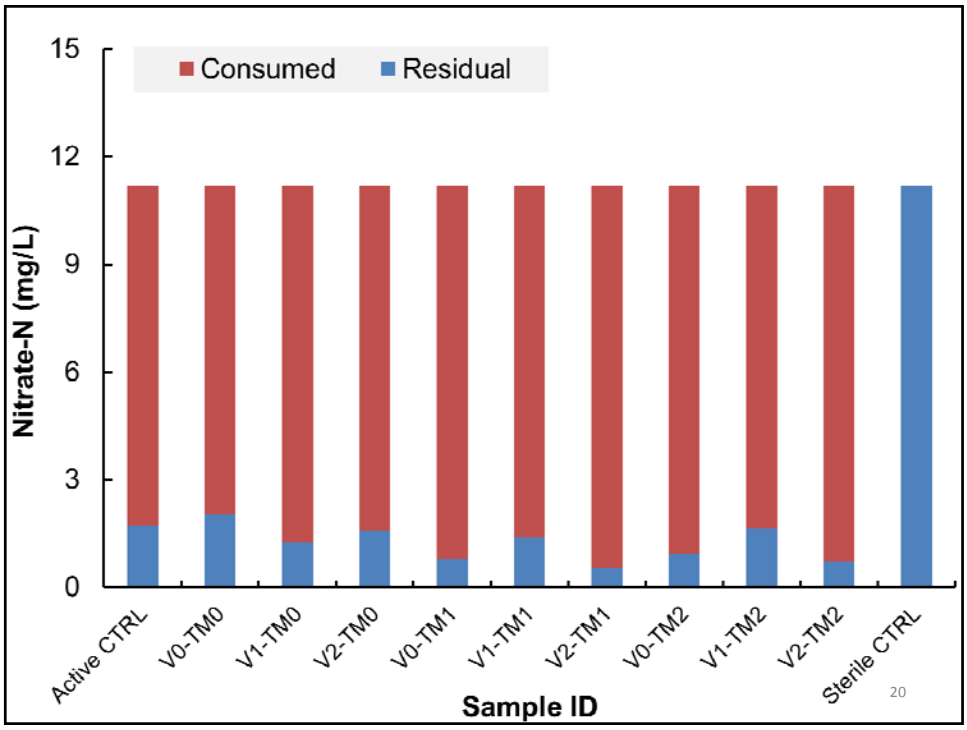
B054 Task 04.2
Trace Metals and Vitamins
Requirement Experiment

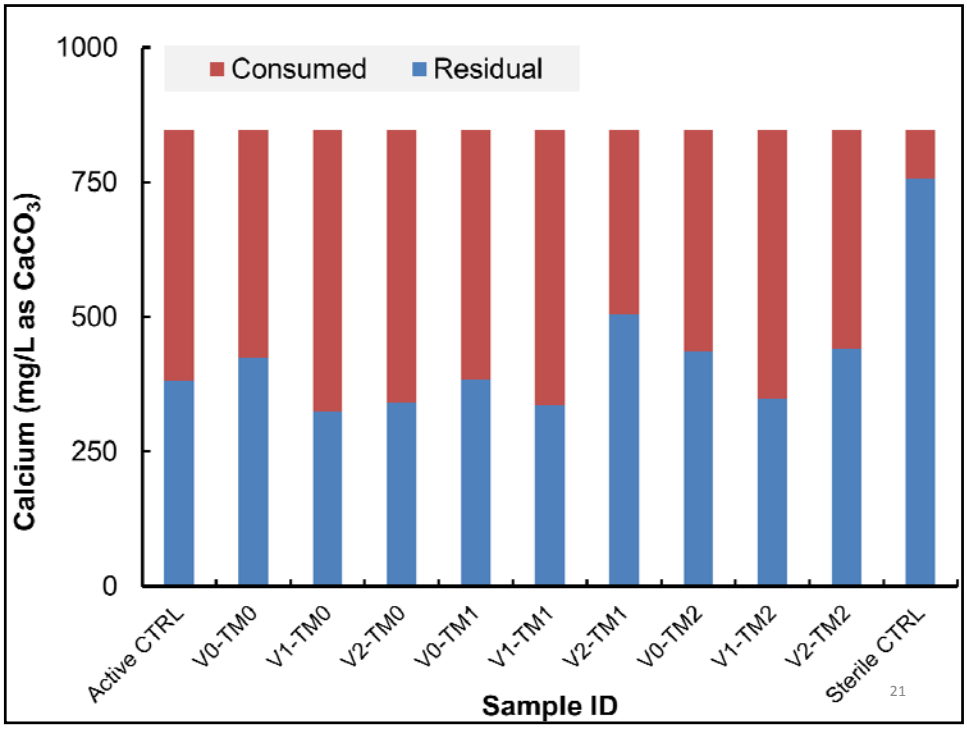
16


Reactive Silica (mg/L)
100
80
60
40
20
0
0
48
96
144
192
240
Time (Hours)
V0-TM0
V1-TM0
V2-TM0
V0-TM1
V1-TM1
V2-TM1
V0-TM2
V1-TM2
V2-TM2
Active CTRL
Sterile CTRL
17


Consumed
Residual
Reactive Silica (mg/L)
100
80
60
40
20
0
Active CTRL
V0-TM0
V1-TM0
V2-TM0
V0-TM1
V1-TM1
V2-TM1
V0-TM2
V1-TM2
V2-TM2
Sterile CTRL
Sample ID
18

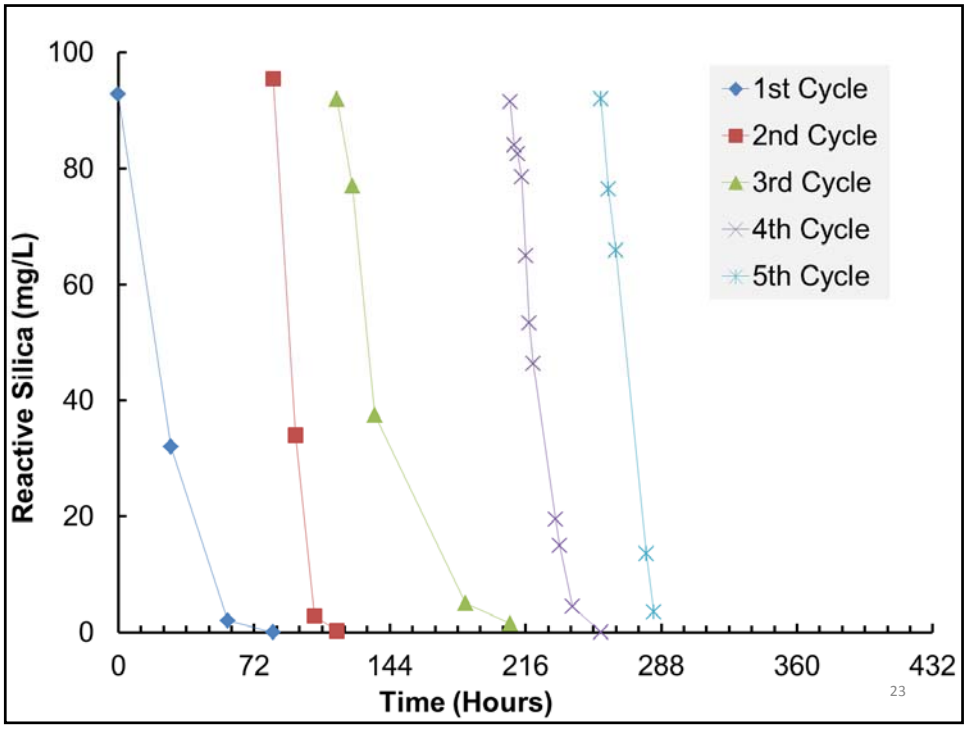

Consumed
Residual
Orthophosphate (mg/L)
0
1
2
3
4
5
Active CTRL
V0-TM0
V1-TM0
V2-TM0
V0-TM1
V1-TM1
V2-TM1
V0-TM2
V1-TM2
V2-TM2
Sterile CTRL
Sample ID
19

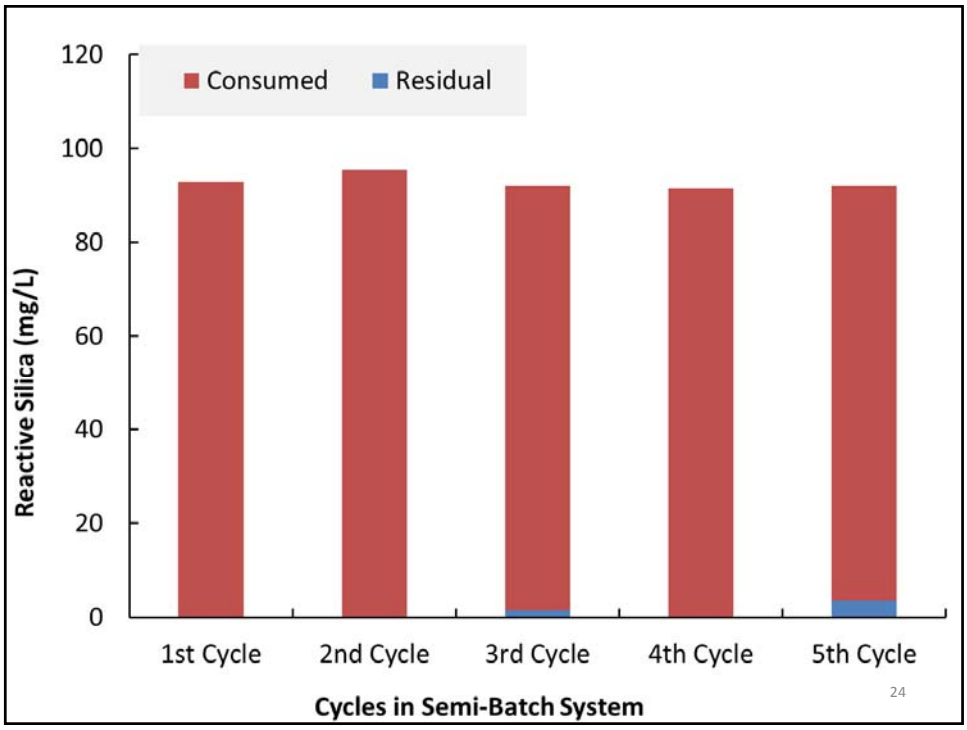

Consumed
Residual
Nitrate-N (mg/L)
0
3
6
9
12
15
Active CTRL
V0-TM0
V1-TM0
V2-TM0
V0-TM1
V1-TM1
V2-TM1
V0-TM2
V1-TM2
V2-TM2
Sterile CTRL
Sample ID
20

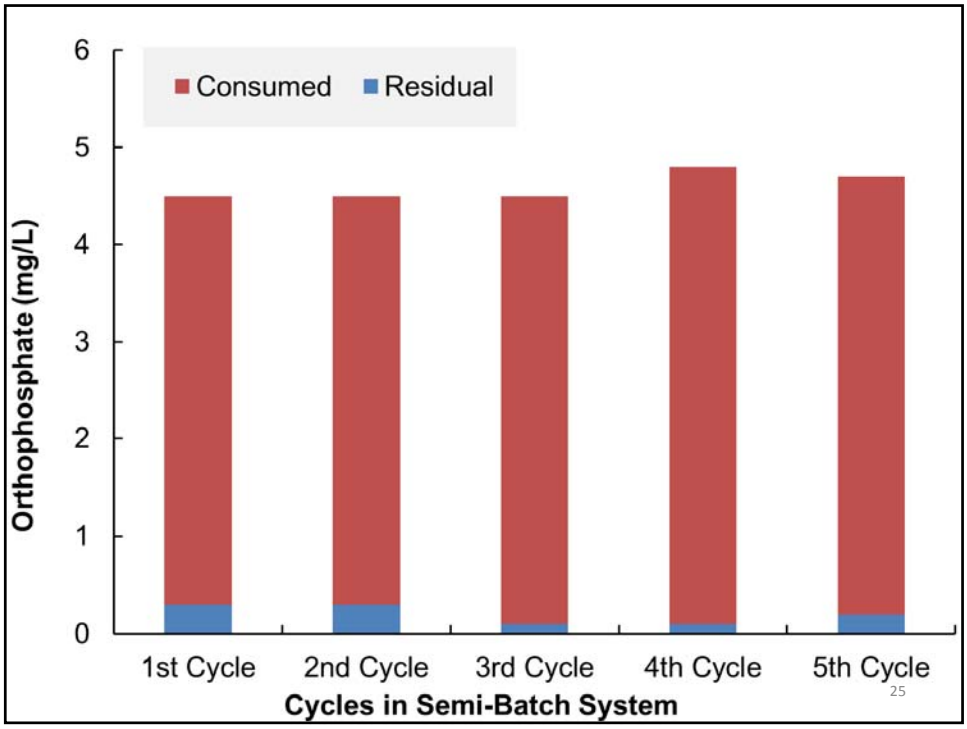


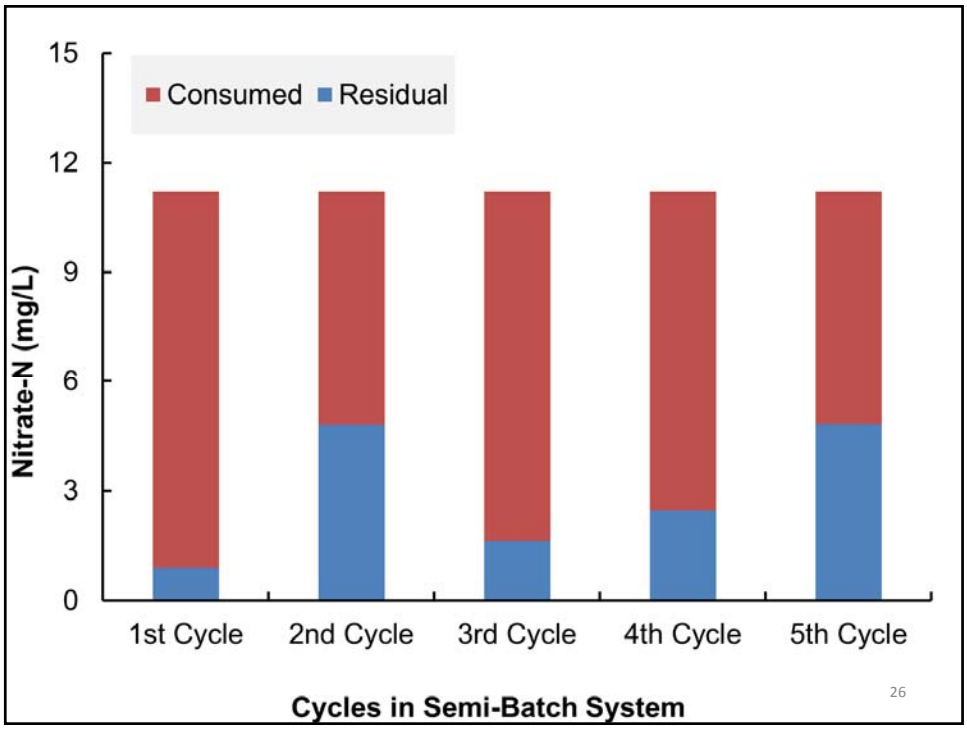
B054 Task 04.2
Long Term Semi Batch Experiment

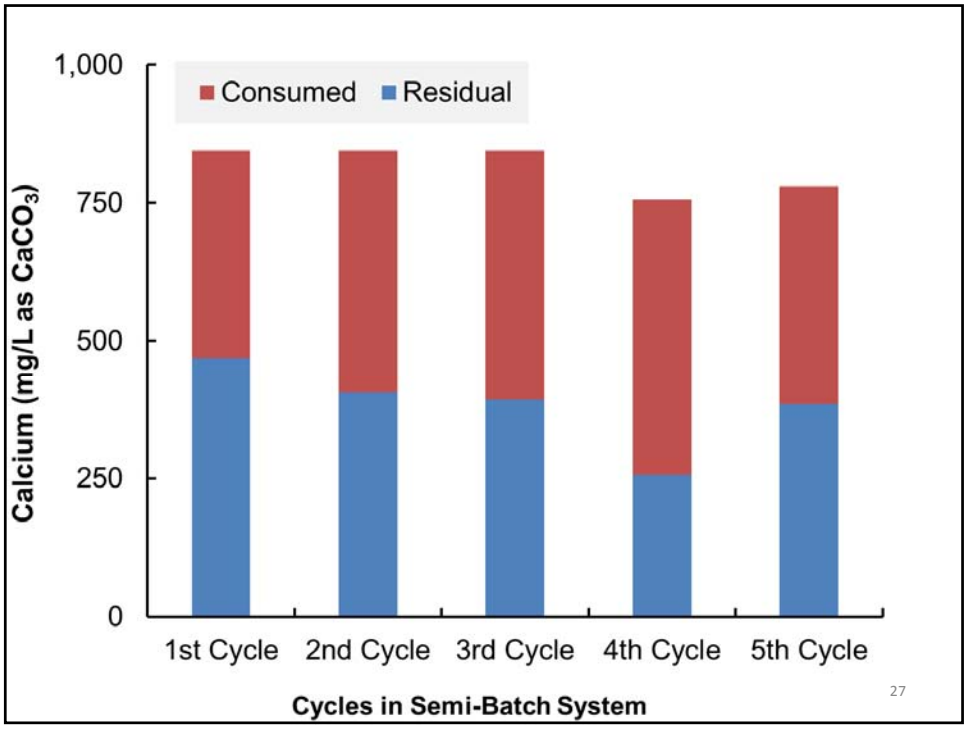
22

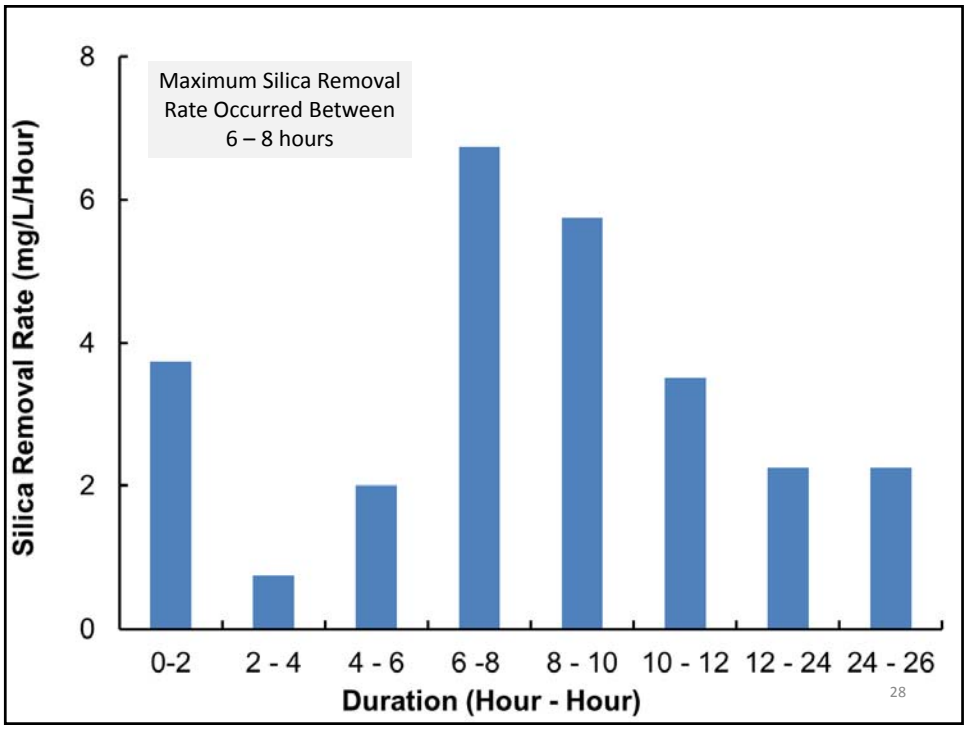

100
80
60
40
20
0
Reactive Silica (mg/L)
0
72
144
216
288
360
432
Time (Hours)
1st Cycle
2nd Cycle
3rd Cycle
4th Cycle
5th Cycle
23

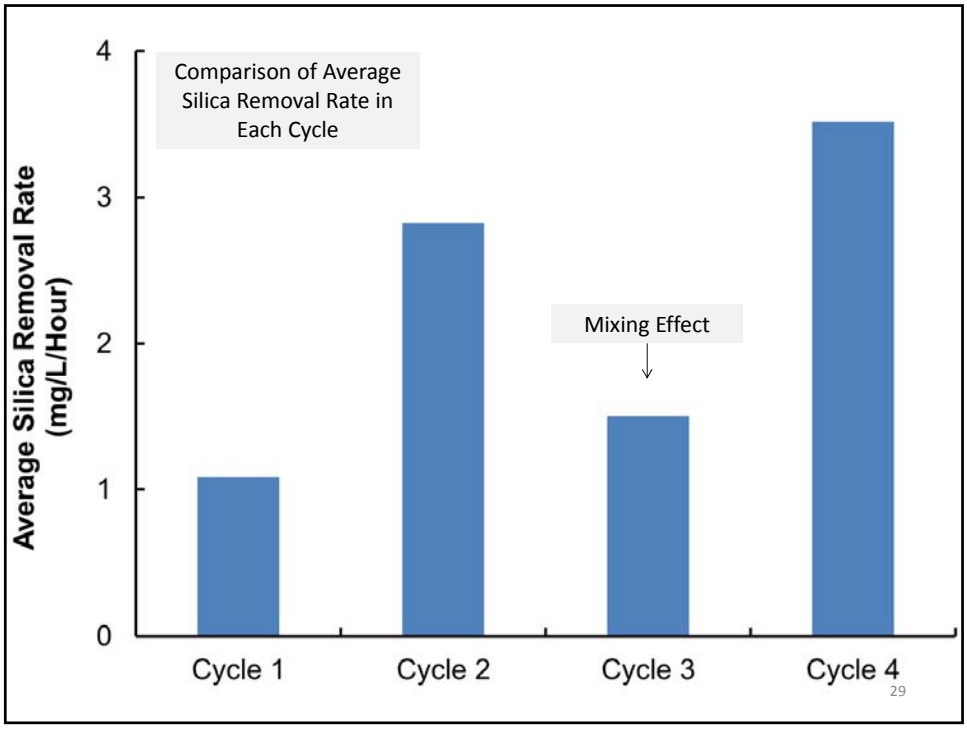

120
100
80
60
40
20
0
Reactive Silica (mg/L)
Consumed
Residual
1st Cycle
2nd Cycle
3rd Cycle
4th Cycle
5th Cycle
Cycles in Semi-Batch System
24


Consumed
Residual
Orthophosphate (mg/L)
0
1
2
3
4
5
6
1st Cycle
2nd Cycle
3rd Cycle
4th Cycle
5th Cycle
Cycles in Semi-Batch System
25


Consumed
Residual
Nitrate-N (mg/L)
0
3
6
9
12
15
1st Cycle
2nd Cycle
3rd Cycle
4th Cycle
5th Cycle
Cycles in Semi-Batch System
26

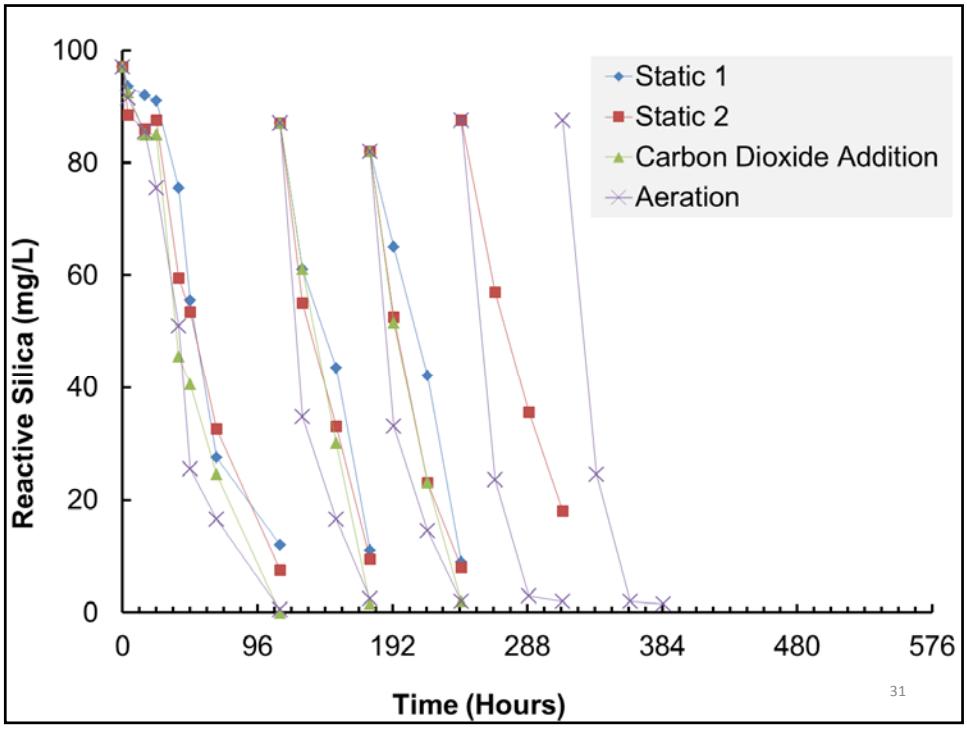

1,000
750
500
250
0
Consumed
Residual
Calcium (mg/L as CaCO3)
1st Cycle
2nd Cycle
3rd Cycle
4th Cycle
5th Cycle
Cycles in Semi-Batch System
27

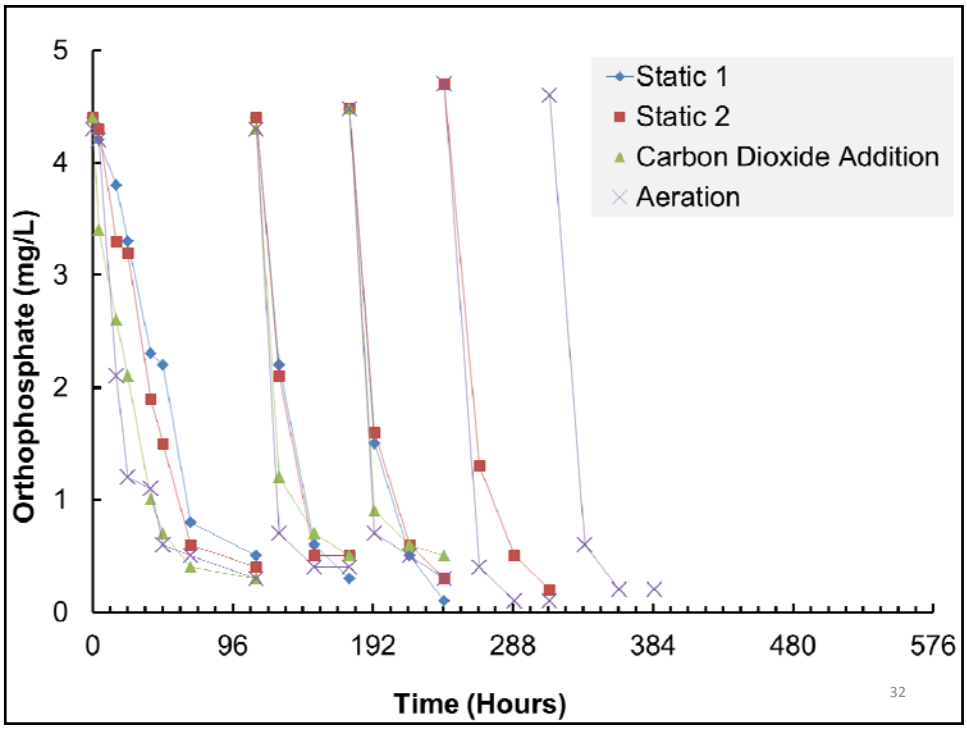

Maximum Silica Removal Rate Occurred Between 6 – 8 hours
8
6
4
2
0
Silica Removal Rate (mg/L/Hour)
0-2
2 - 4
4 - 6
6 -8
8 - 10
10 - 12
12 - 24
24 - 26
Duration (Hour - Hour)
28

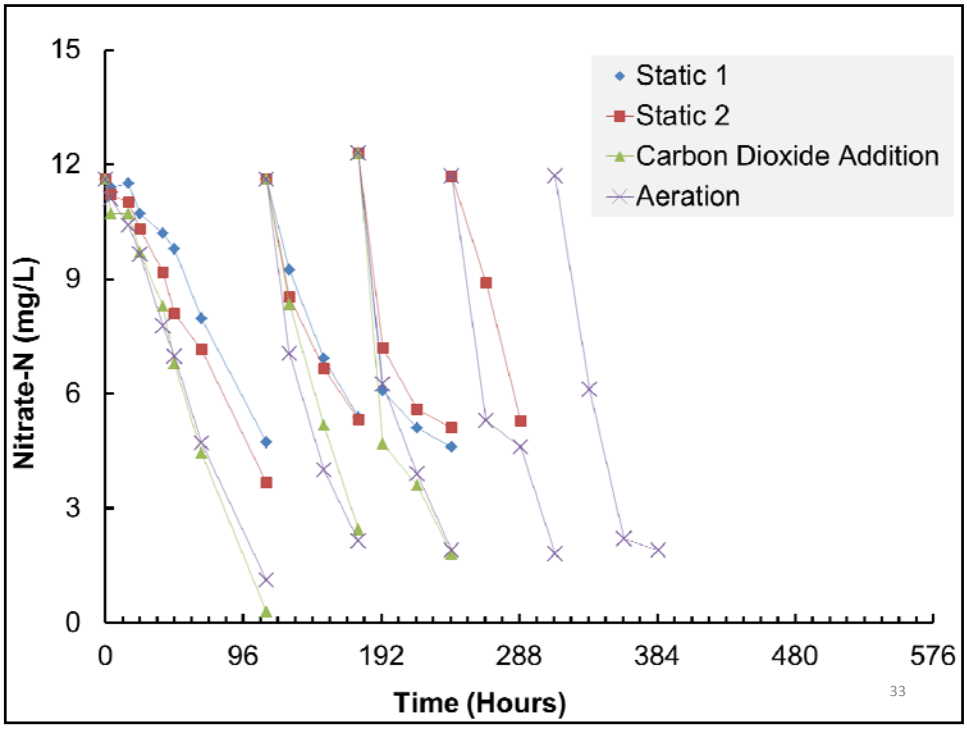


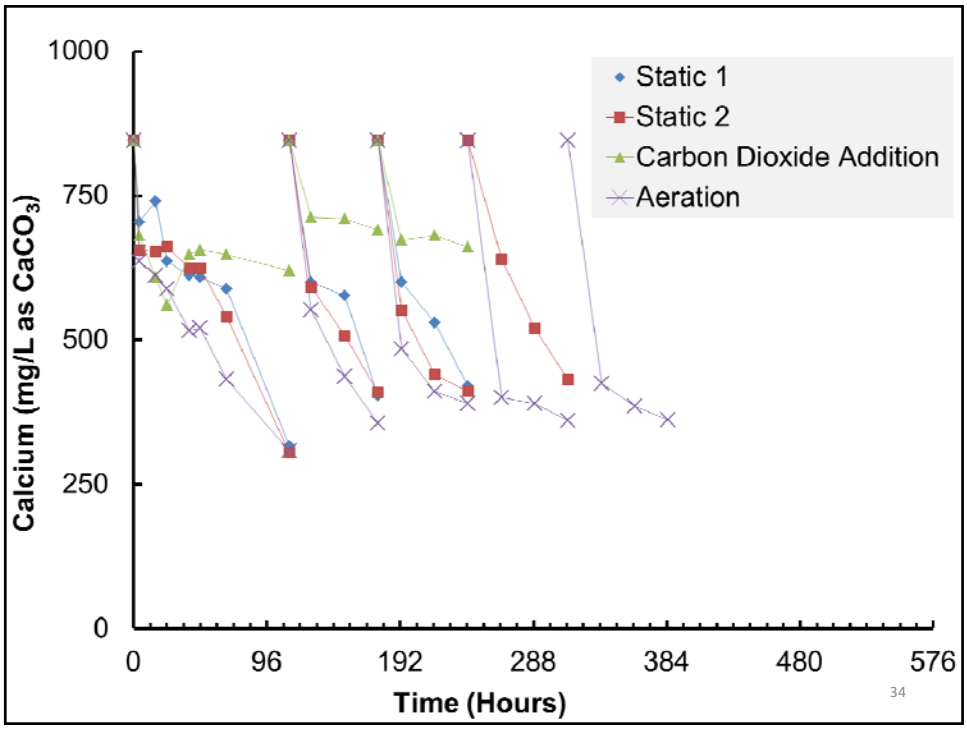
B054 Task 04.2
1-gallon LED Bucket Experiment

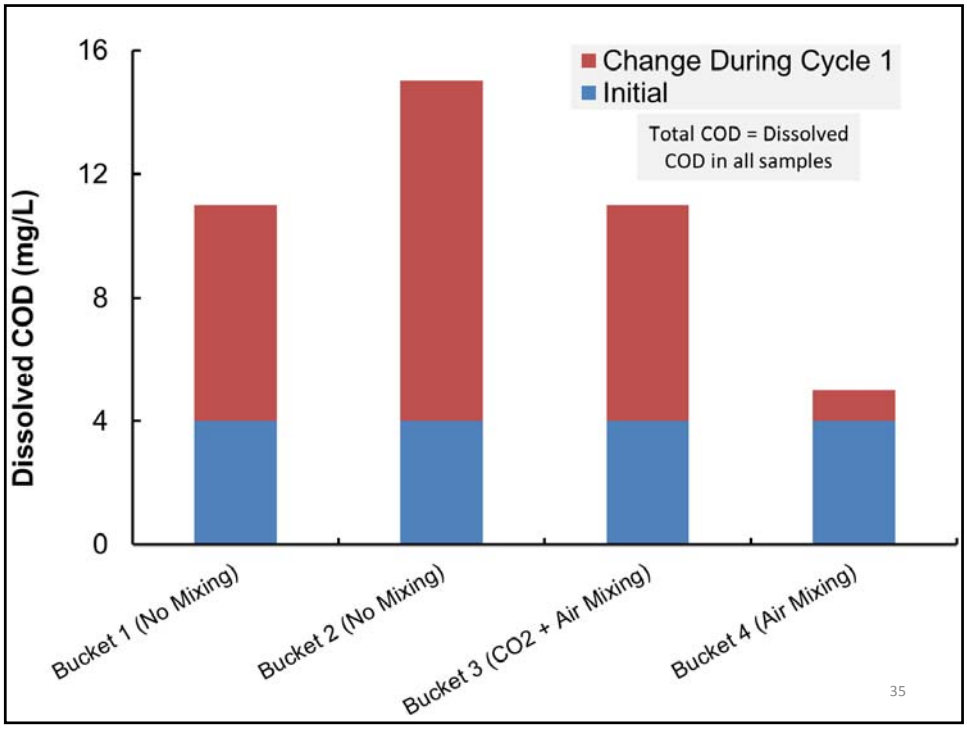
30


Reactive Silica (mg/L)
100
80
60
40
20
0
0
96
192
288
384
480
576
Time (Hours)
Static 1
Static 2
Carbon Dioxide Addition
Aeration
31


Orthophosphate (mg/L)
5
4
3
2
1
0
0
96
192
288
384
480
576
Time (Hours)
Static 1
Static 2
Carbon Dioxide Addition
Aeration
32


15
12
9
6
3
0
Nitrate-N (mg/L)
0
96
192
288
384
480
576
Time (Hours)
Static 1
Static 2
Carbon Dioxide Addition
Aeration
33


1000
750
500
250
0
Calcium (mg/L as CaCO3)
0
96
192
288
384
480
576
Time (Hours)
Static 1
Static 2
Carbon Dioxide Addition
Aeration
34



B054 Task 04.2
Sunlight Vs. LED
1-gallon Bucket Experiment

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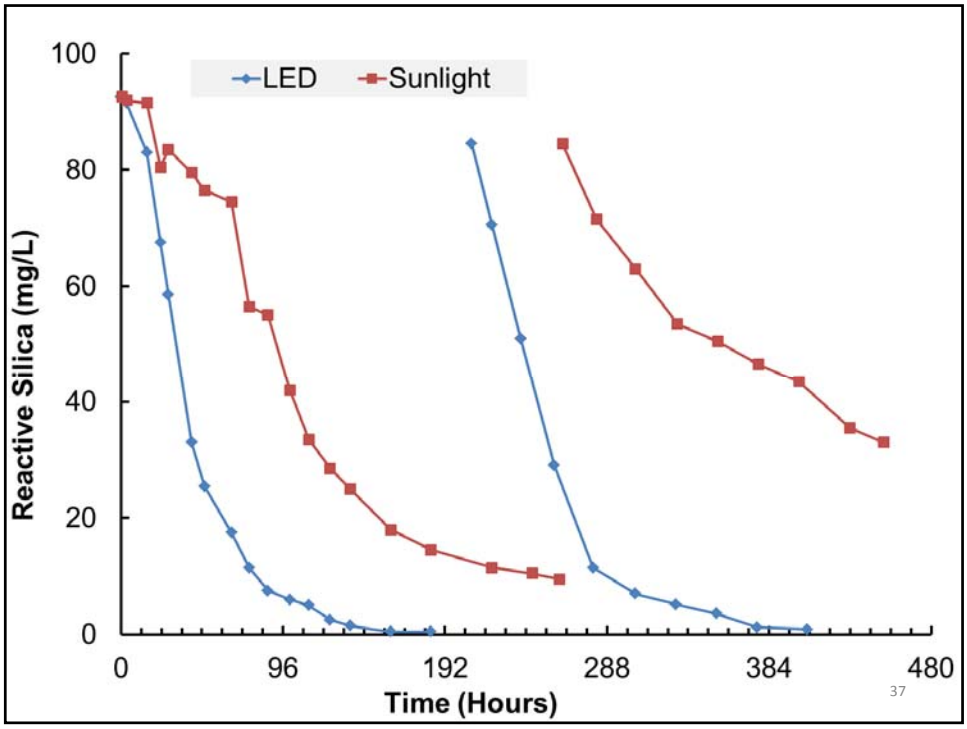
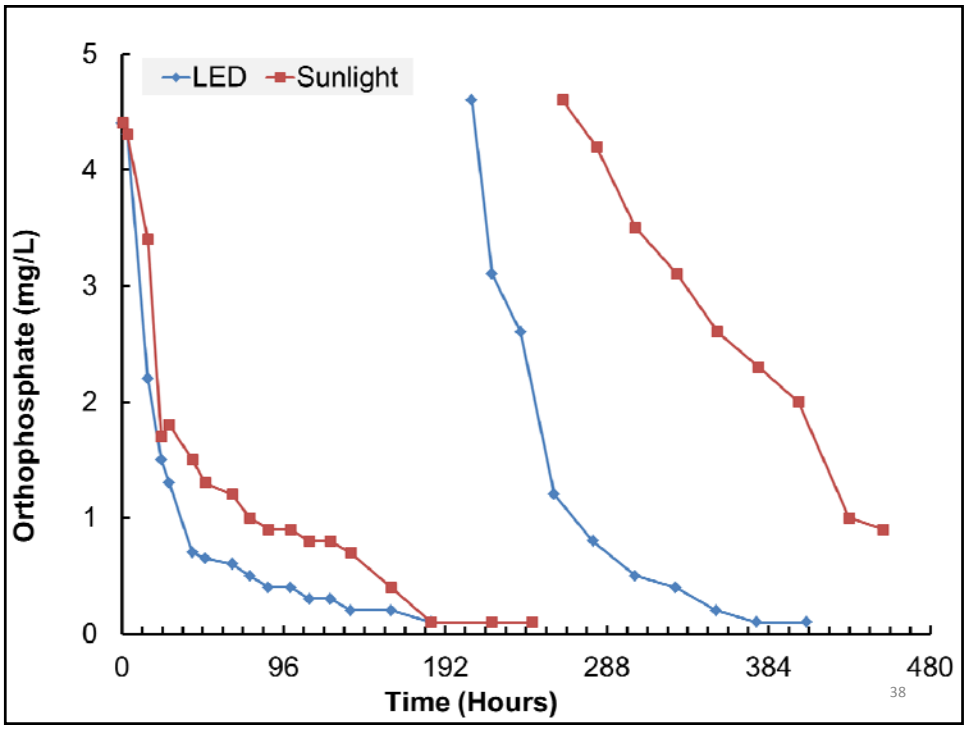
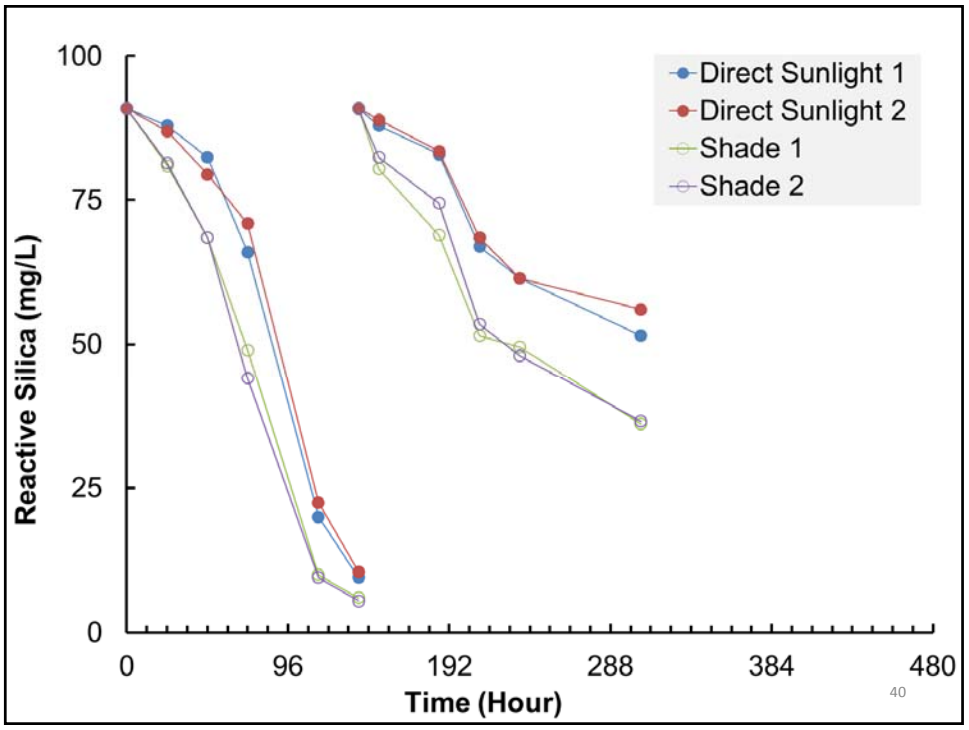

LED
Sunlight
Reactive Silica (mg/L)
100
80
60
40
20
0
0
96
192
288
384
480
Time (Hours)
37

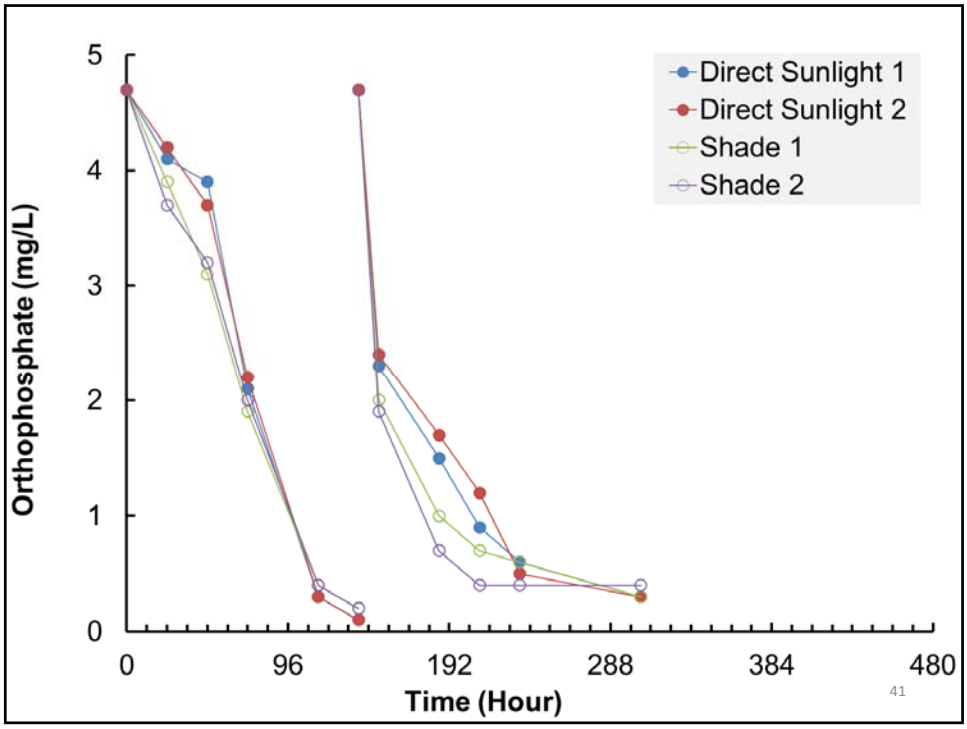

LED
Sunlight
Orthophosphate (mg/L)
5
4
3
2
1
0
0
96
192
288
384
480
Time (Hours)
38

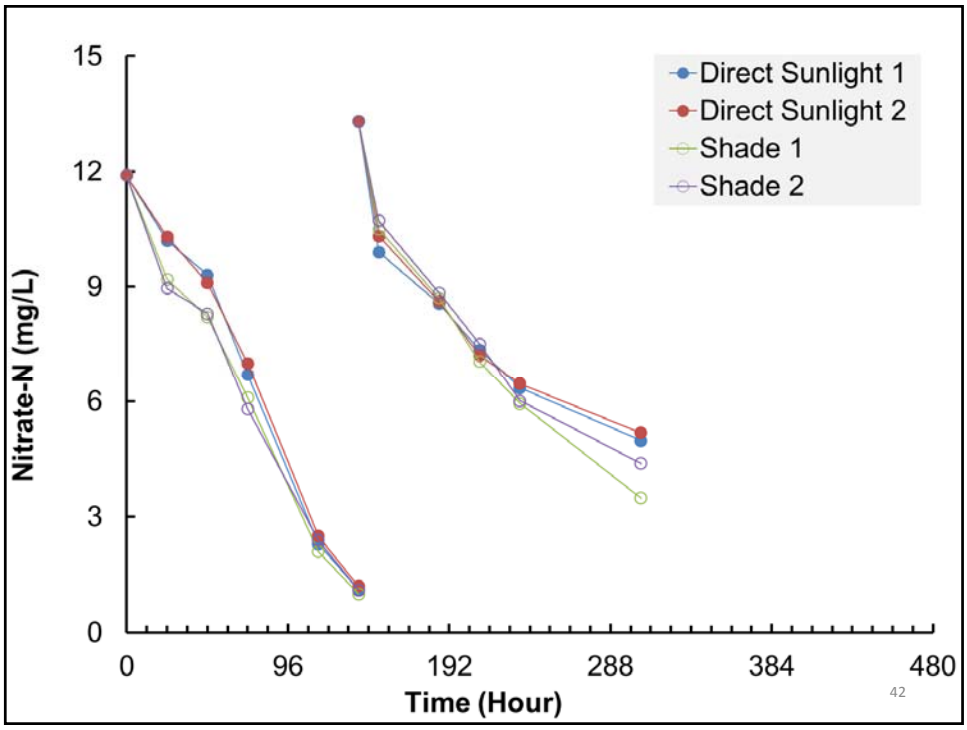
B054 Task 04.2
Direct Sunlight Vs. Shade Experiment

39



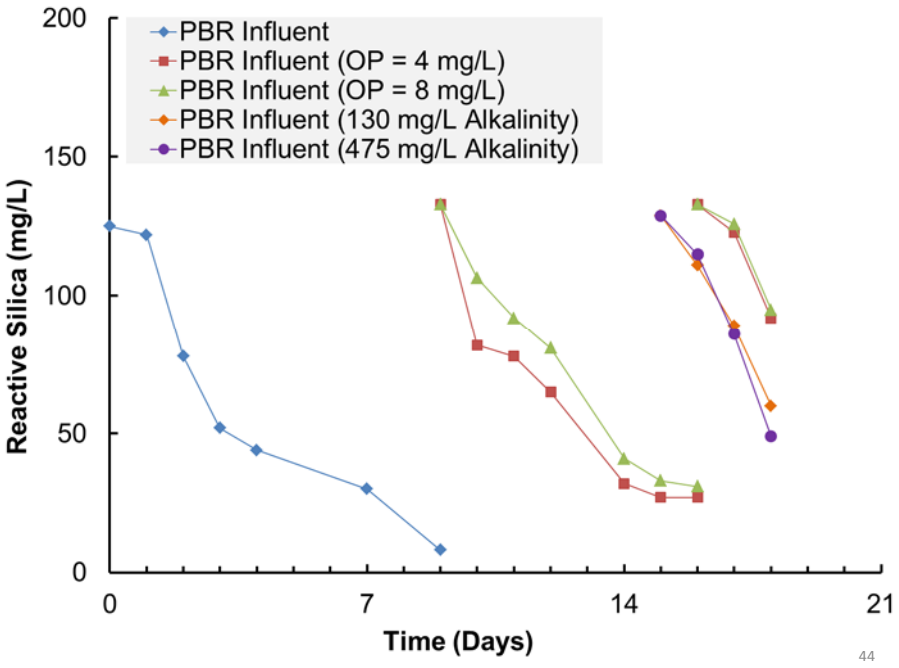
40


Direct Sunlight 1
Direct Sunlight 2
Shade 1
Shade 2
Orthophosphate (mg/L)
0
1
2
3
4
5
0
96
192
288
384
480
Time (Hour)
41


Direct Sunlight 1
Direct Sunlight 2
Shade 1
Shade 2
Nitrate-N (mg/L)
0
3
6
9
12
15
0
96
192
288
384
480
Time (Hour)
42

B054 Task 04.2
Silica Removal in
Modified Well 2 Water

43



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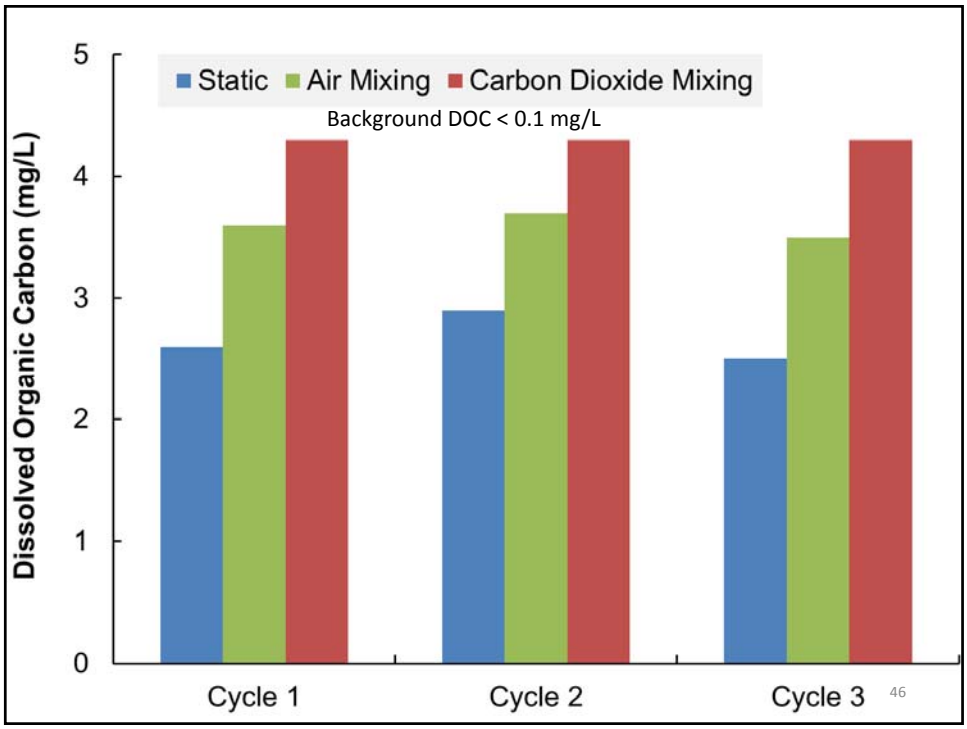
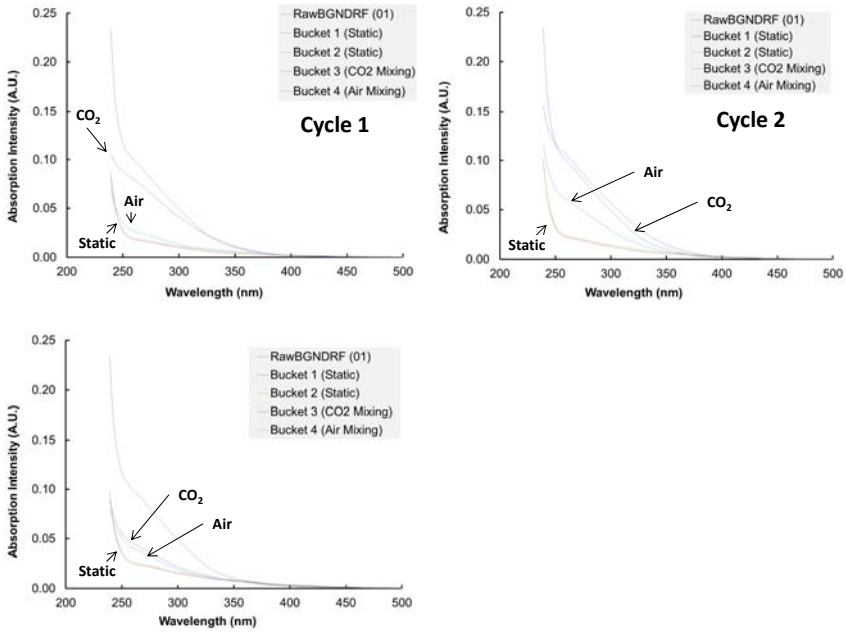
APPENDIX 5

B054 Task 04.2
DOM Characterization in
1-gallon LED Bucket Experiment

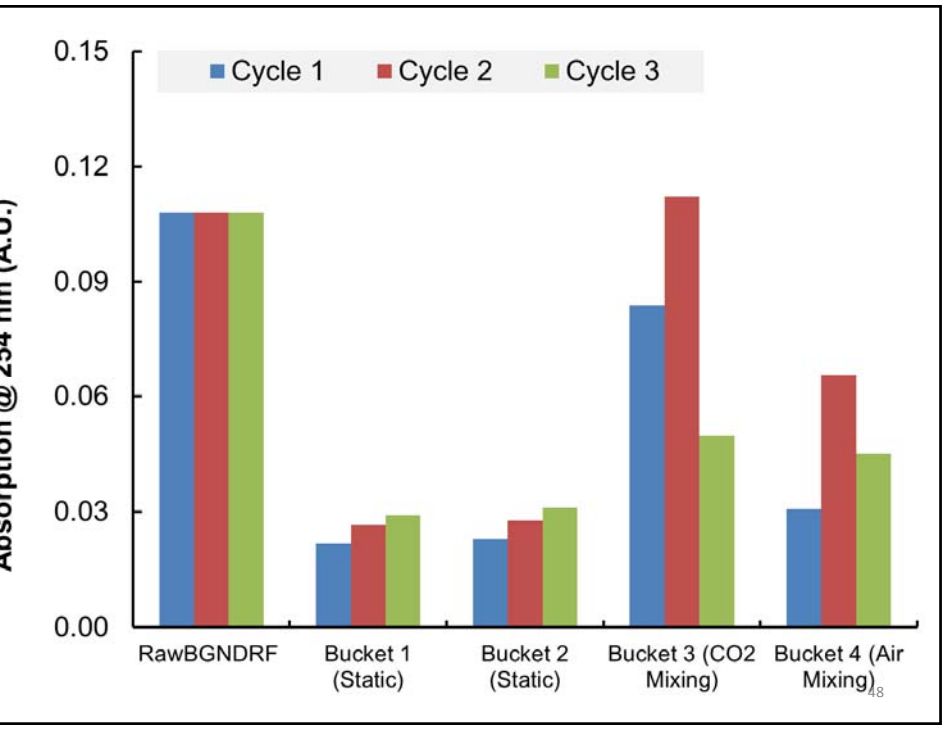
45



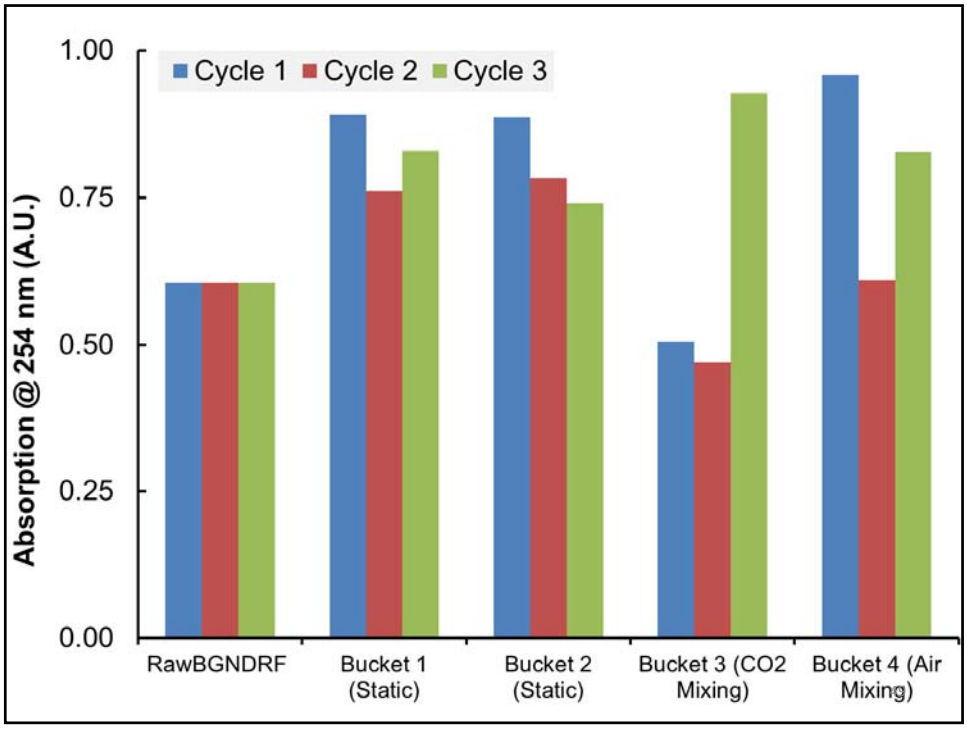
46

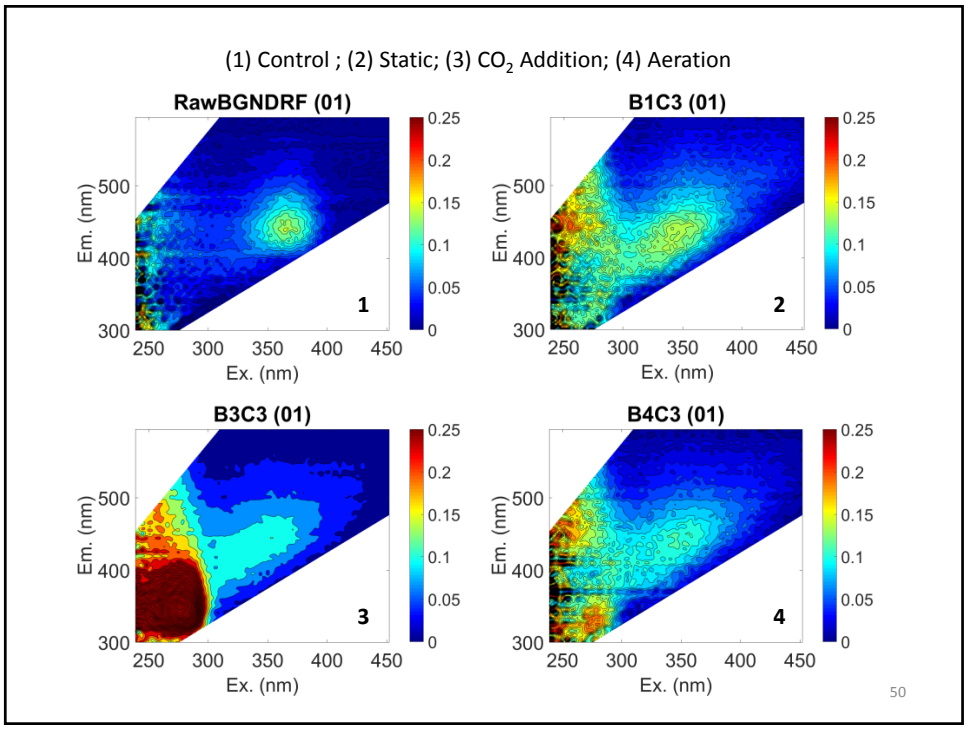

RawBGNDRF (01)
Bucket 1 (Static)
Bucket 2 (Static)
Bucket 3 (CO2 Mixing)
Bucket 4 (Air Mixing)
Cycle 1
Cycle 2
CO2
Air
Static
Absorption Intensity (A.U.)
Wavelength (nm)

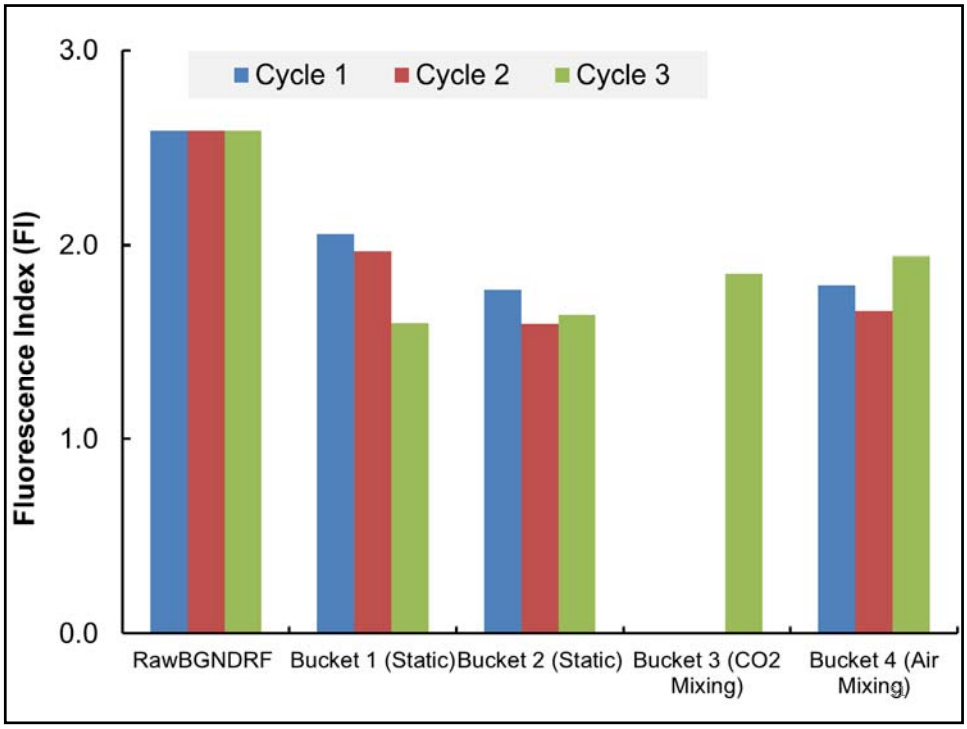
47

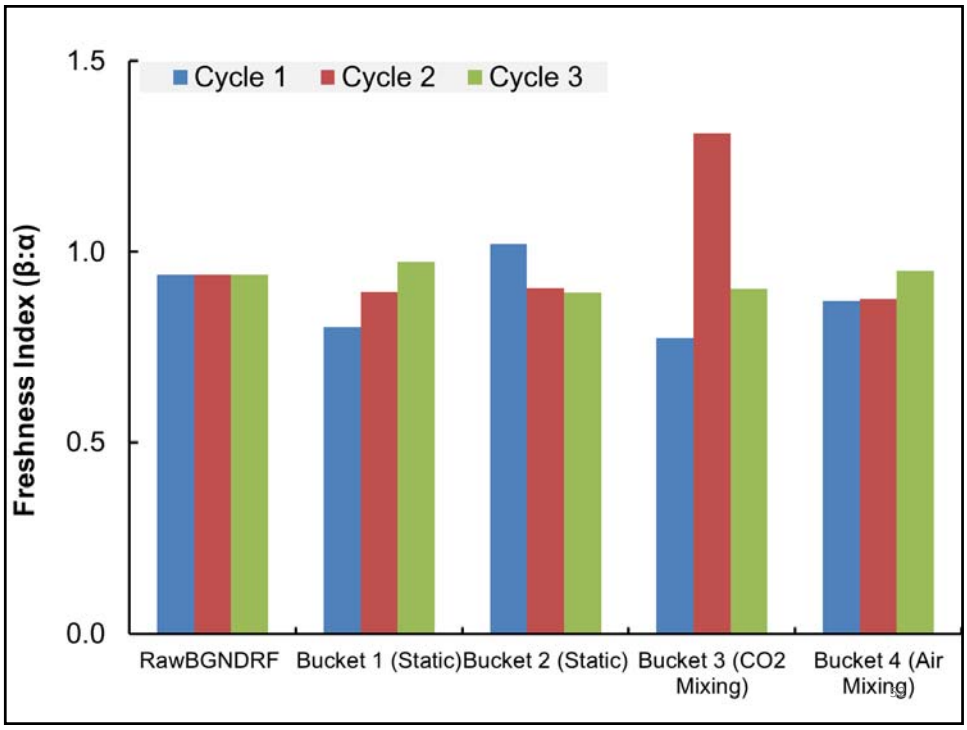

Cycle 1
Cycle 2
Cycle 3
Absorption @ 254 nm (A.U.)
RawBGNDRF
Bucket 1 (Static)
Bucket 2 (Static)
Bucket 3 (CO2 Mixing)
Bucket 4 (Air Mixing)

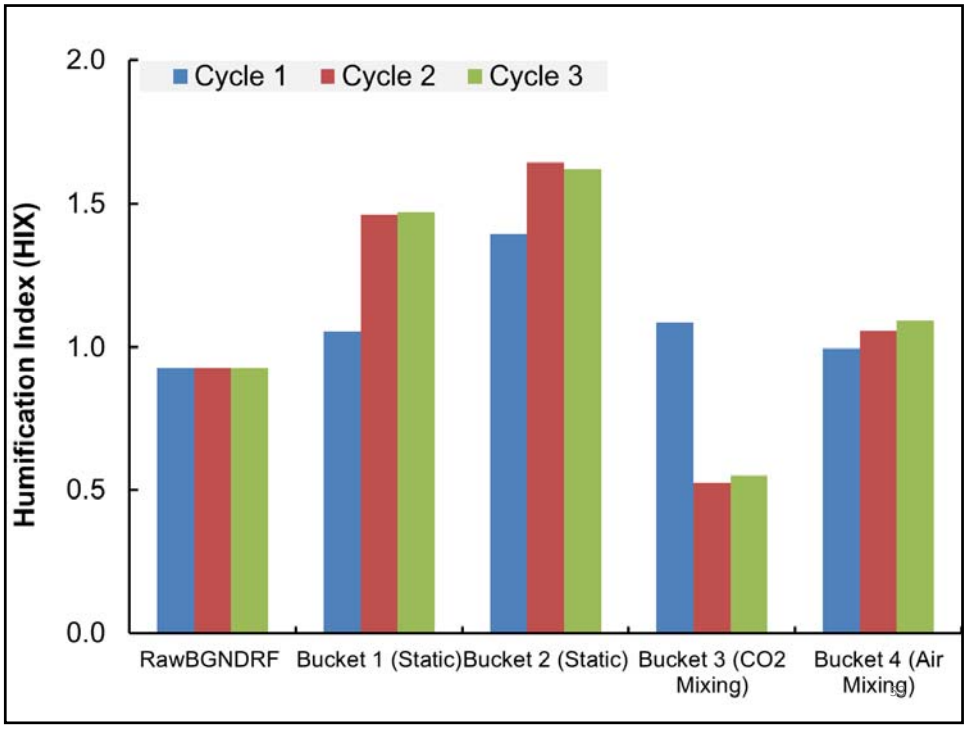
48

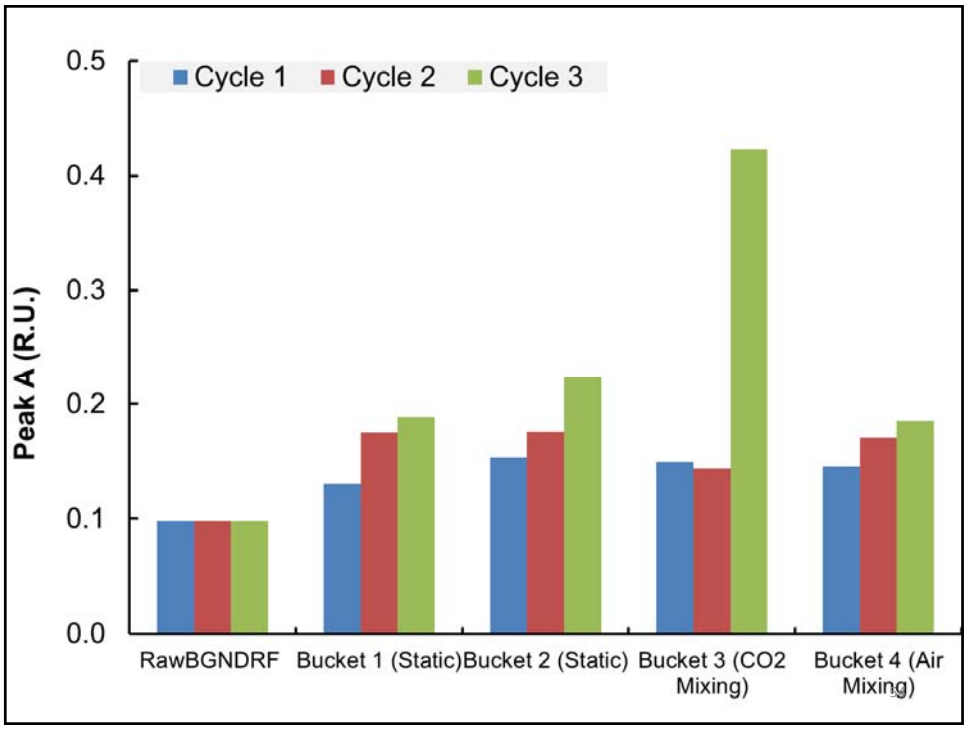

Cycle 1
Cycle 2
Cycle 3
Absorption @ 254 nm (A.U.)
1.00
0.75
0.50
0.25
0.00
RawBGNDRF
Bucket 1 (Static)
Bucket 2 (Static)
Bucket 3 (CO2 Mixing)
Bucket 4 (Air Mixing)

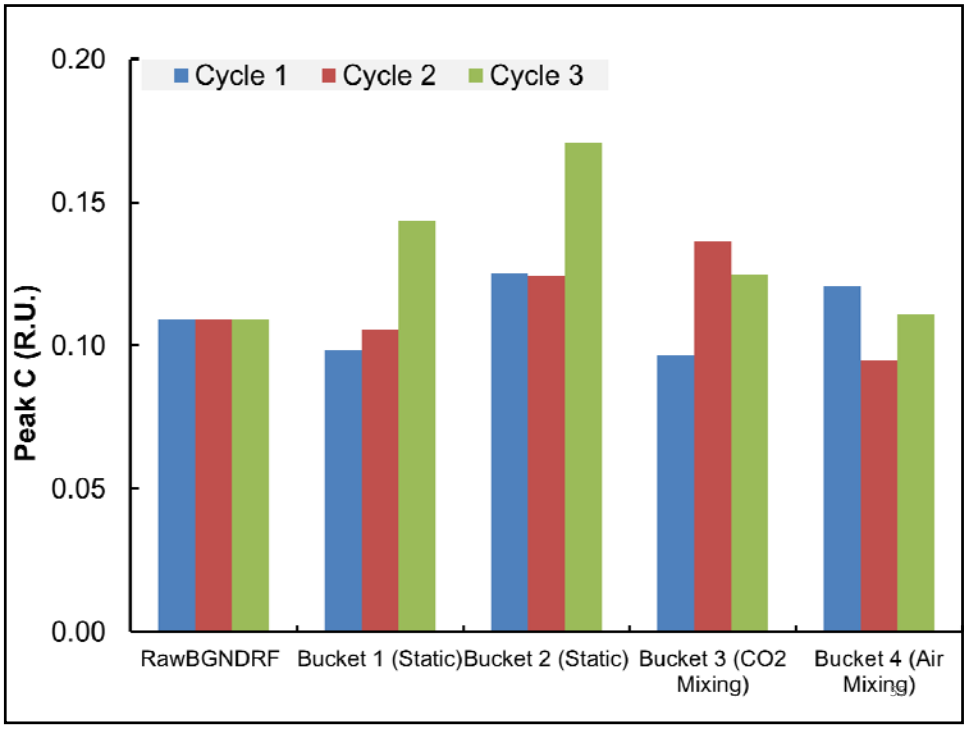

(1) Control ; (2) Static; (3) CO2 Addition; (4) Aeration
RawBGNDRF (01)
B1C3 (01)
B3C3 (01)
B4C3 (01)
Em. (nm)
Ex. (nm)
1
2
3
4
50

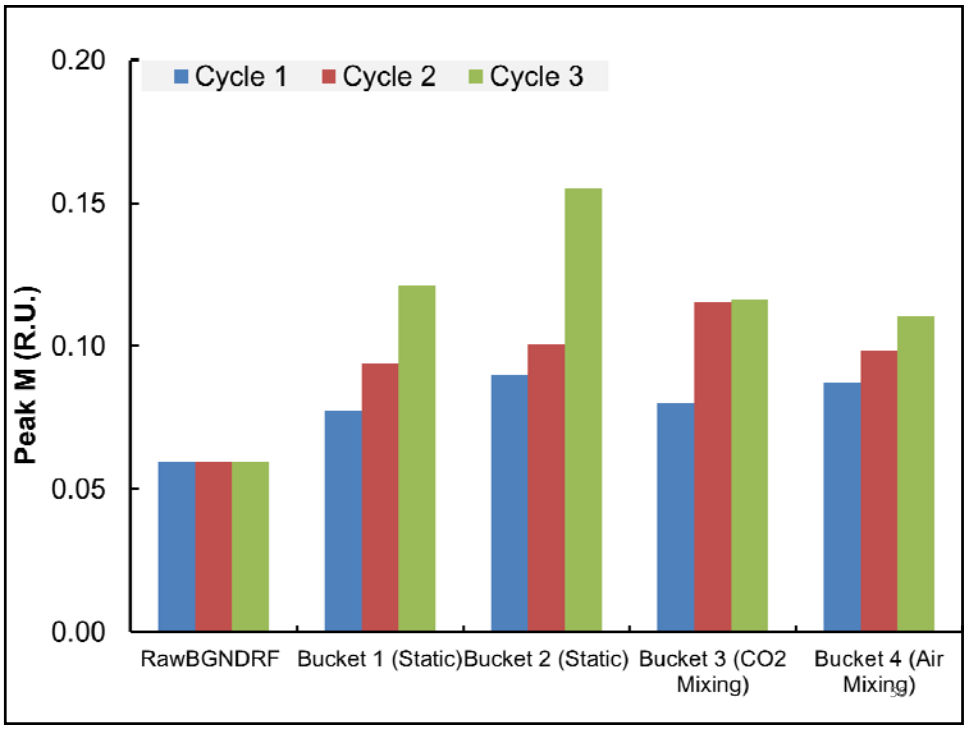

3.0
2.0
1.0
0.0
Fluorescence Index (FI)
Cycle 1
Cycle 2
Cycle 3
RawBGNDRF
Bucket 1 (Static)
Bucket 2 (Static)
Bucket 3 (CO2 Mixing)
Bucket 4 (Air Mixing)

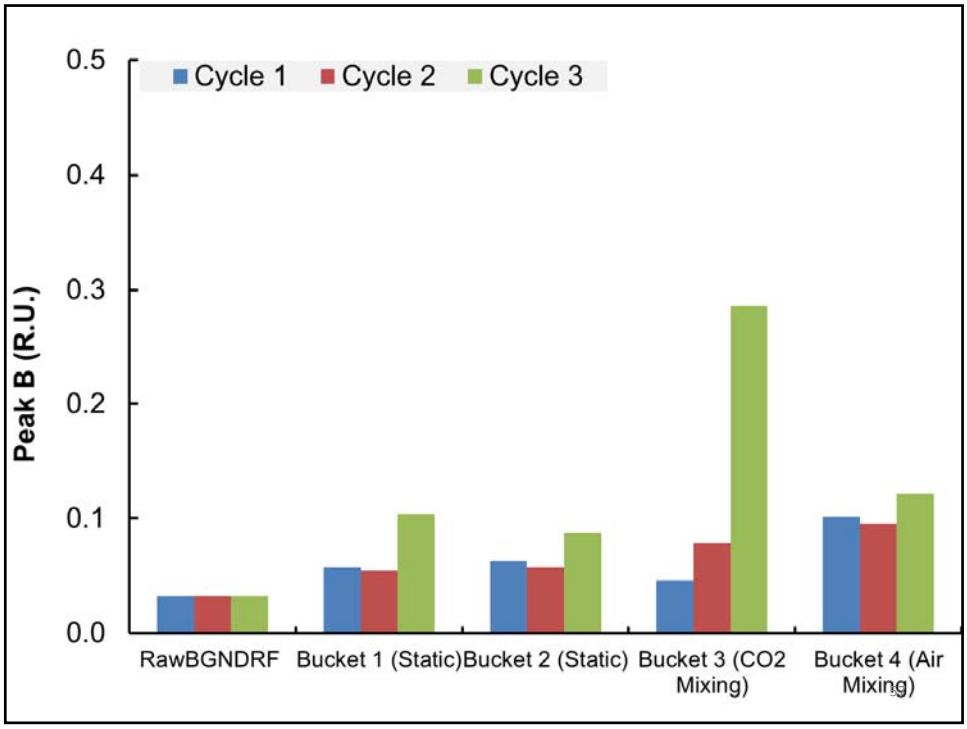

1.5
1.0
0.5
0.0
Freshness Index (β:α)
Cycle 1
Cycle 2
Cycle 3
RawBGNDRF
Bucket 1 (Static)
Bucket 2 (Static)
Bucket 3 (CO2 Mixing)
Bucket 4 (Air Mixing)

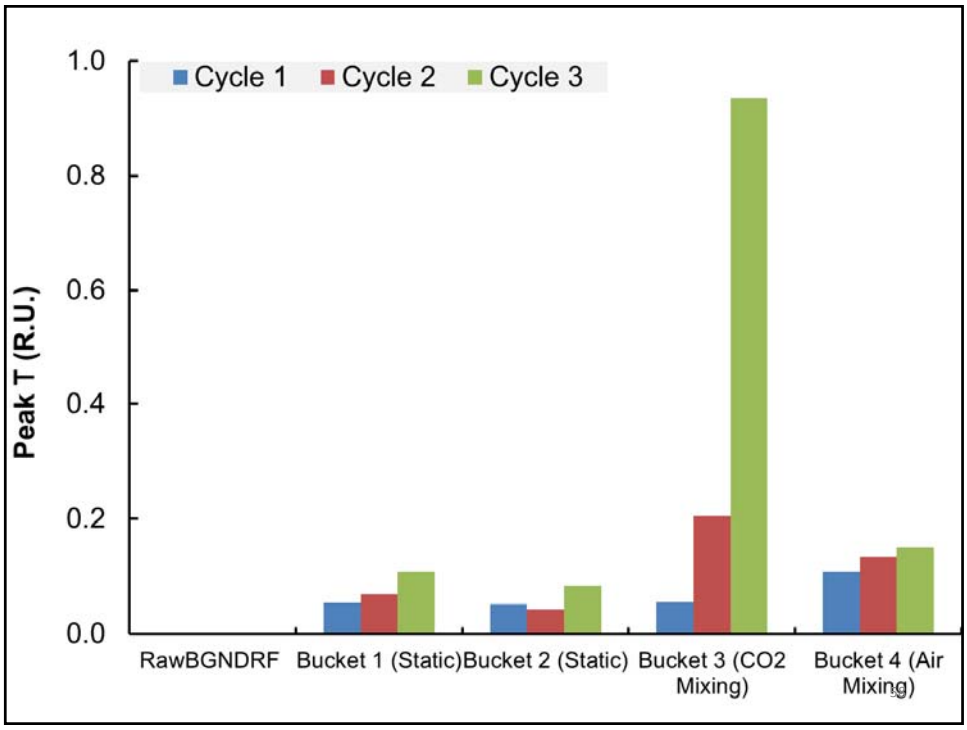

Humification Index (HIX)
2.0
1.5
1.0
0.5
0.0
Cycle 1
Cycle 2
Cycle 3
RawBGNDRF
Bucket 1 (Static)
Bucket 2 (Static)
Bucket 3 (CO2 Mixing)
Bucket 4 (Air Mixing)

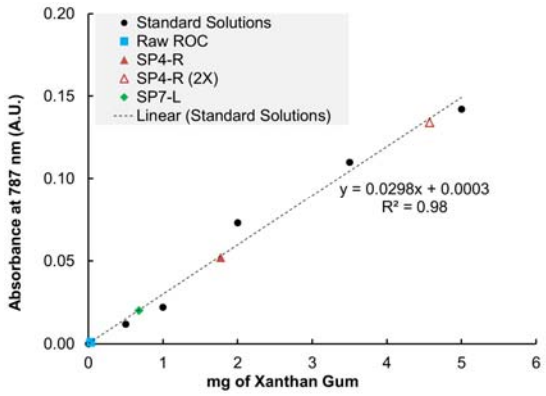

Peak A (R.U.)
0.5
0.4
0.3
0.2
0.1
0.0
Cycle 1
Cycle 2
Cycle 3
RawBGNDRF
Bucket 1 (Static)
Bucket 2 (Static)
Bucket 3 (CO2 Mixing)
Bucket 4 (Air Mixing)


Cycle 1
Cycle 2
Cycle 3
Peak C (R.U.)
0.20
0.15
0.10
0.05
0.00
RawBGNDRF
Bucket 1 (Static)
Bucket 2 (Static)
Bucket 3 (CO2 Mixing)
Bucket 4 (Air Mixing)


Cycle 1
Cycle 2
Cycle 3
Peak M (R.U.)
0.20
0.15
0.10
0.05
0.00
RawBGNDRF
Bucket 1 (Static)
Bucket 2 (Static)
Bucket 3 (CO2 Mixing)
Bucket 4 (Air Mixing)


Cycle 1
Cycle 2
Cycle 3
Peak B (R.U.)
0.5
0.4
0.3
0.2
0.1
0.0
RawBGNDRF
Bucket 1 (Static)
Bucket 2 (Static)
Bucket 3 (CO2 Mixing)
Bucket 4 (Air Mixing)


Cycle 1
Cycle 2
Cycle 3
Peak T (R.U.)
1.0
0.8
0.6
0.4
0.2
0.0
RawBGNDRF
Bucket 1 (Static)
Bucket 2 (Static)
Bucket 3 (CO2 Mixing)
Bucket 4 (Air Mixing)



TEP Analysis

Sample ID	mg equivalent of XG	Sample Volume (mL)	TEP Concentration (µg/L)	Corrected TEP Concentration (µg/L)
PBR Influent (ROC)	0.03	100	341	0
PBR 1	1.78	100	17,747	17,406
PBR 8	0.68	100	6,826	6,485
PBR 1 (2X)	4.57	200	22,867	22,526

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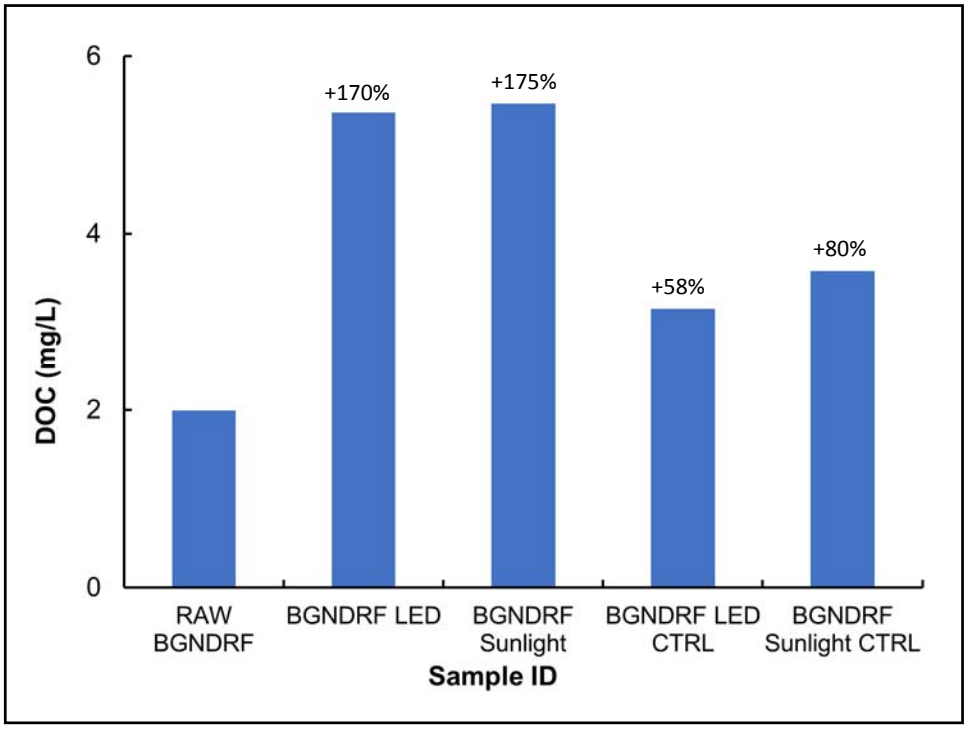
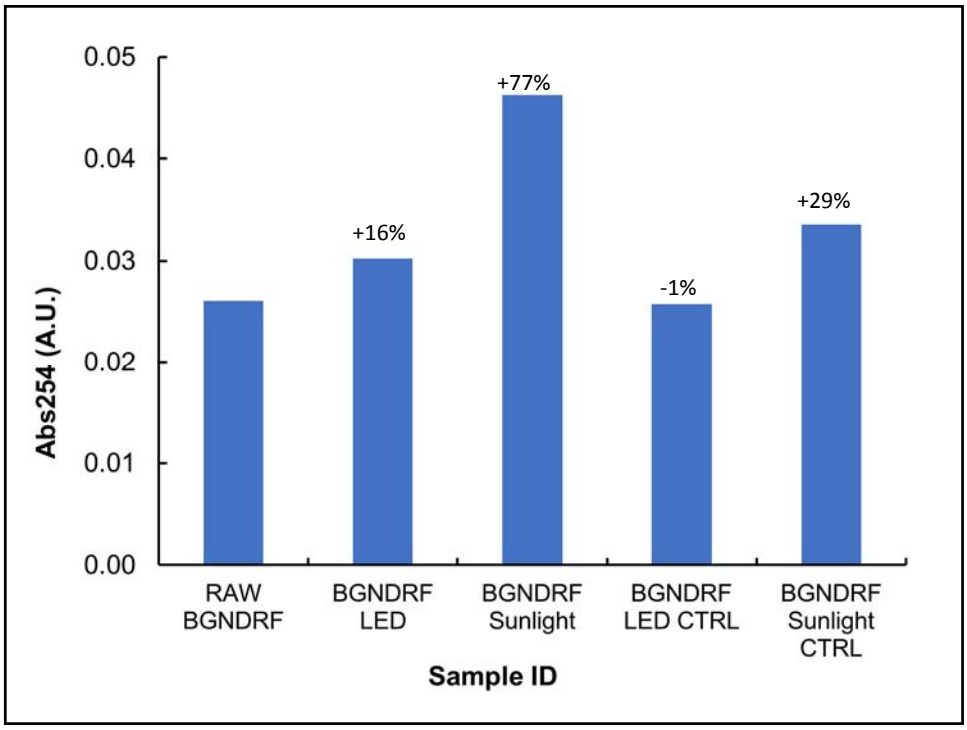
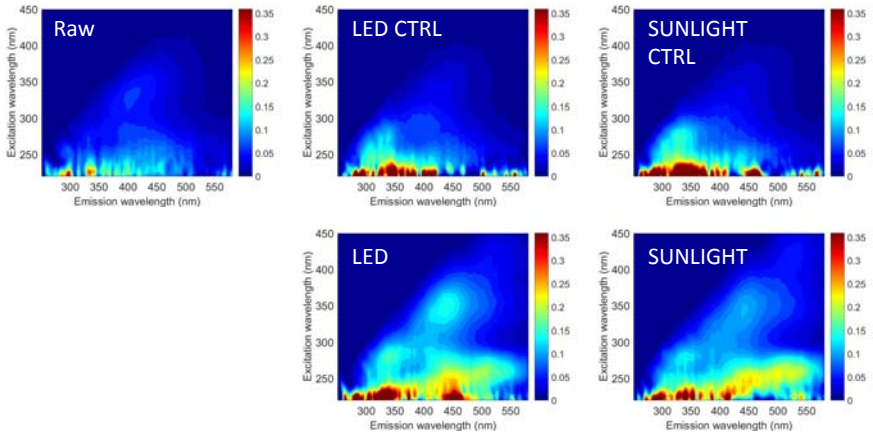
B054 DOM Characterization Experiment
BGNDRF ROC (Analysis at University of Arizona)

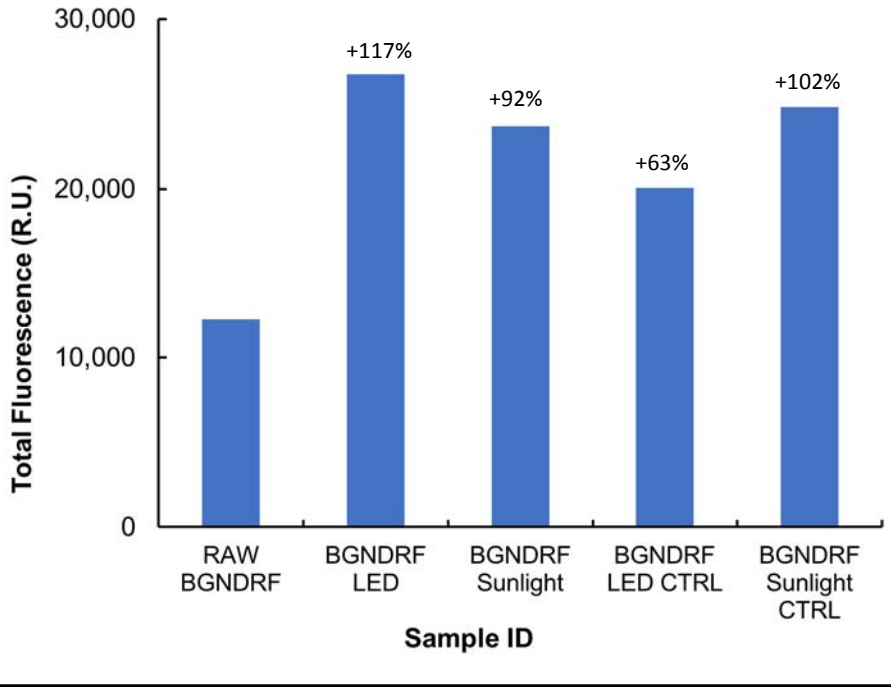
2017-12-01

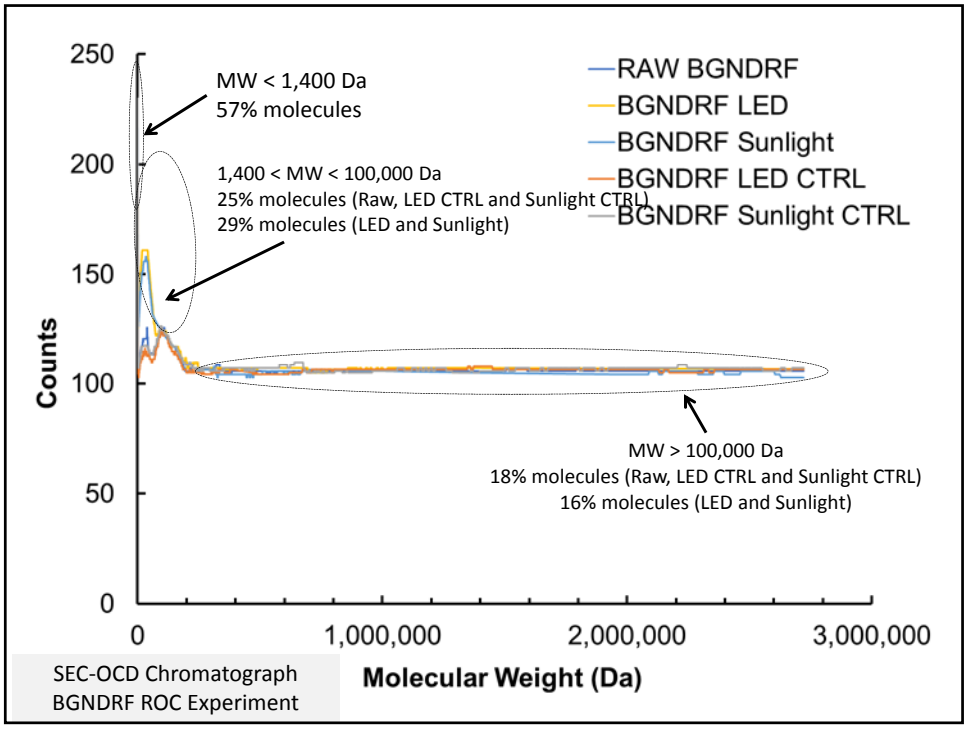

6
4
2
0
DOC (mg/L)
+170%
+175%
+58%
+80%
RAW BGNDRF
BGNDRF LED
BGNDRF Sunlight
BGNDRF LED CTRL
BGNDRF Sunlight CTRL
Sample ID

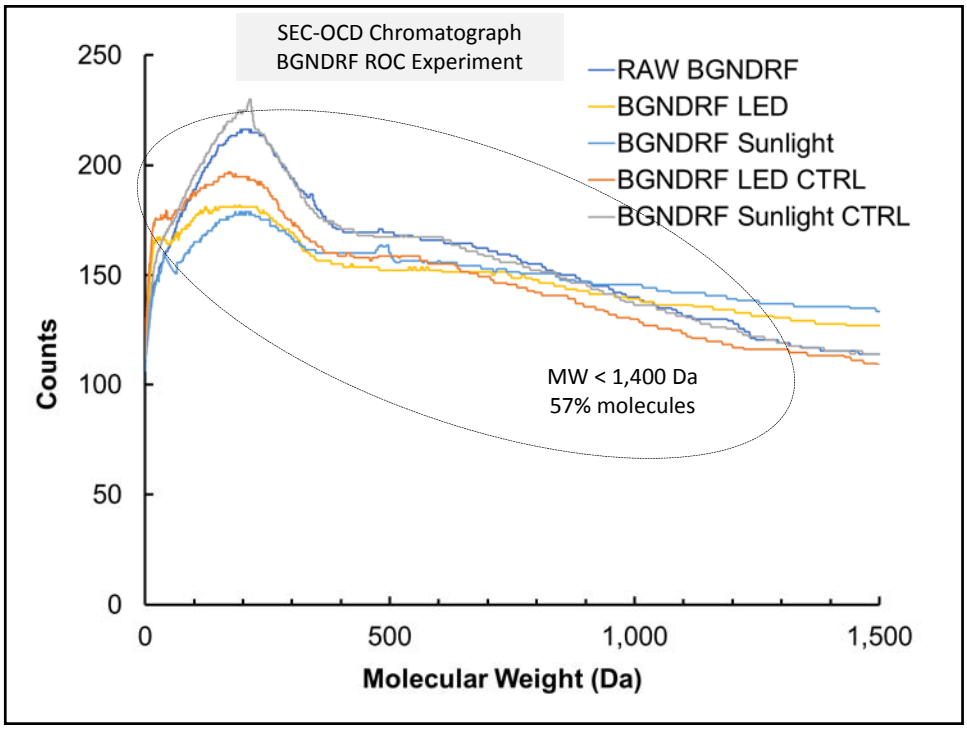

0.05
0.04
0.03
0.02
0.01
0.00
Abs254 (A.U.)
+77%
+16%
-1%
+29%
RAW BGNDRF
BGNDRF LED
BGNDRF Sunlight
BGNDRF LED CTRL
BGNDRF Sunlight CTRL
Sample ID

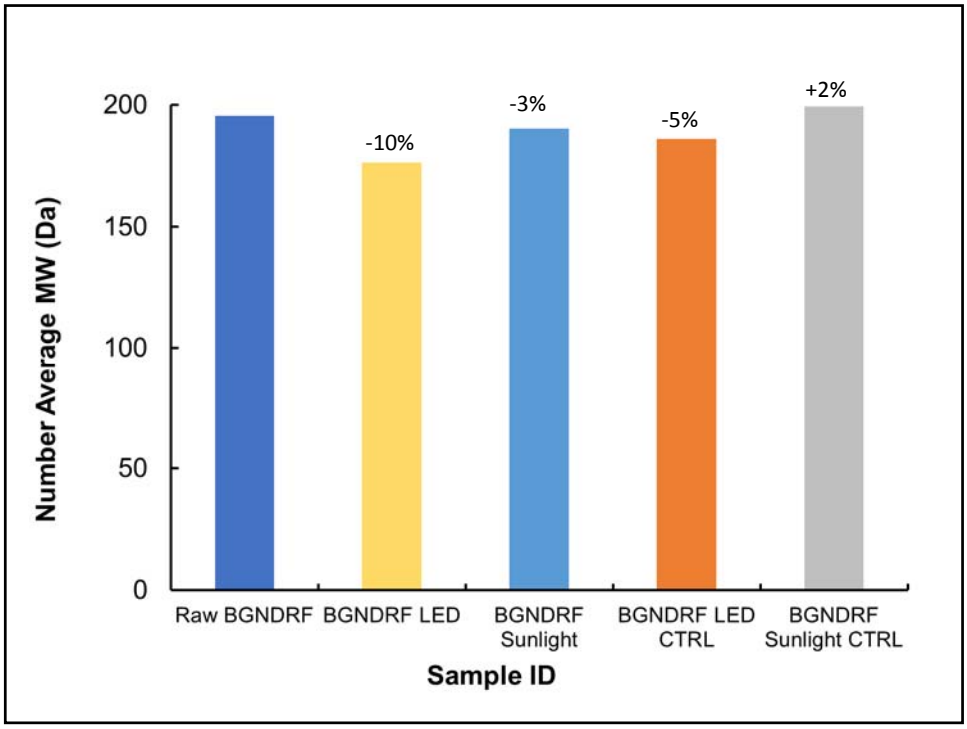
3D-EEM Fluorescence Spectroscopy
BGNDRF ROC Experiment

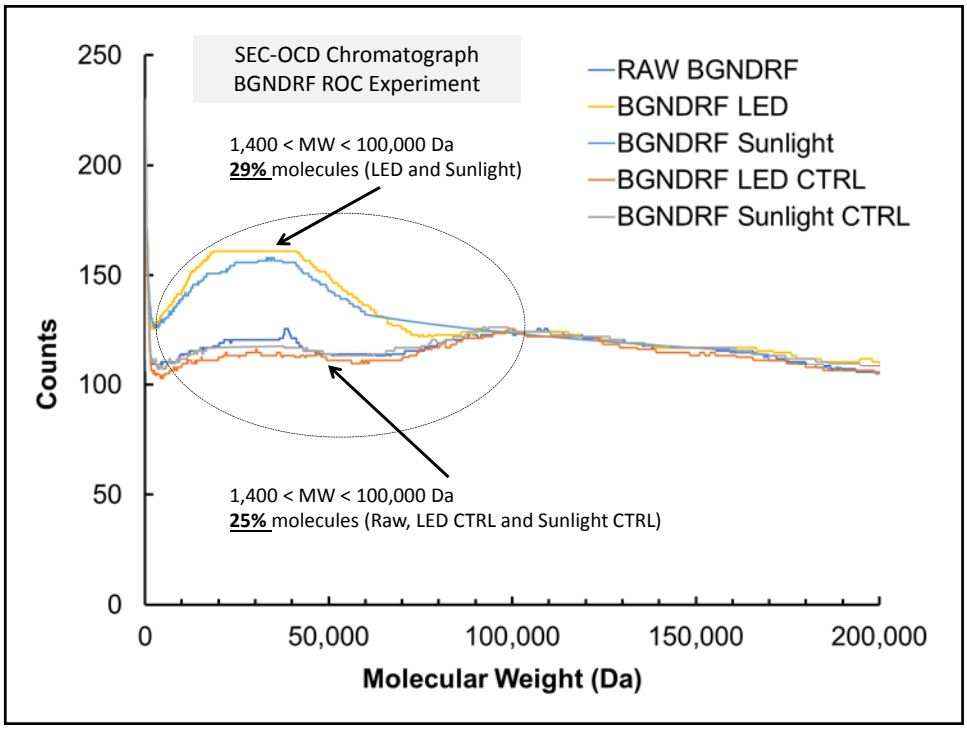


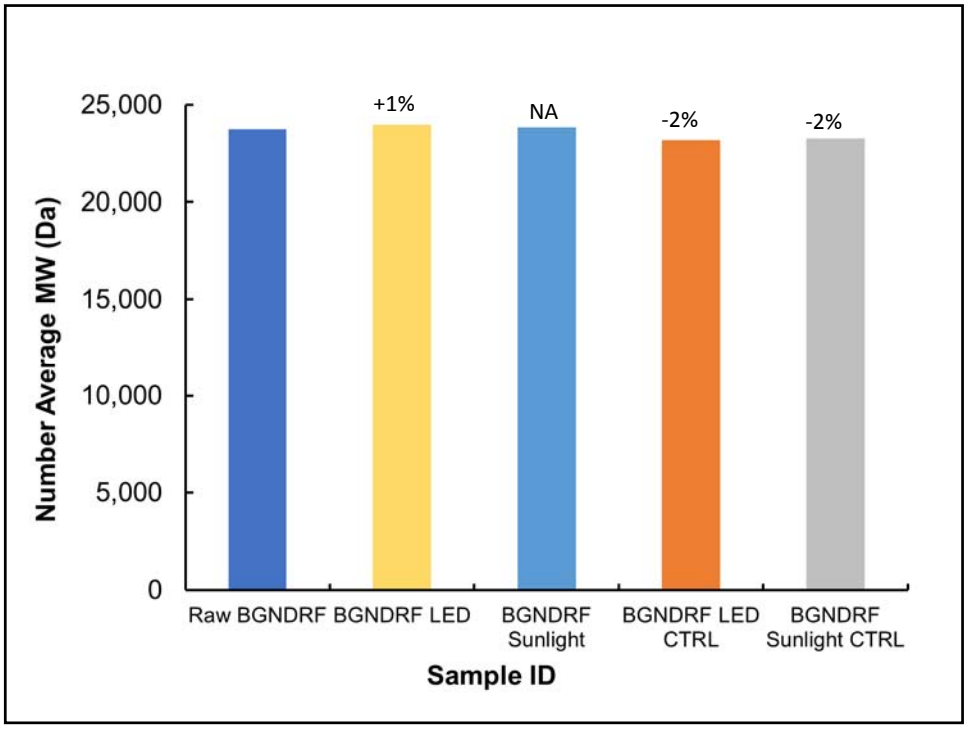


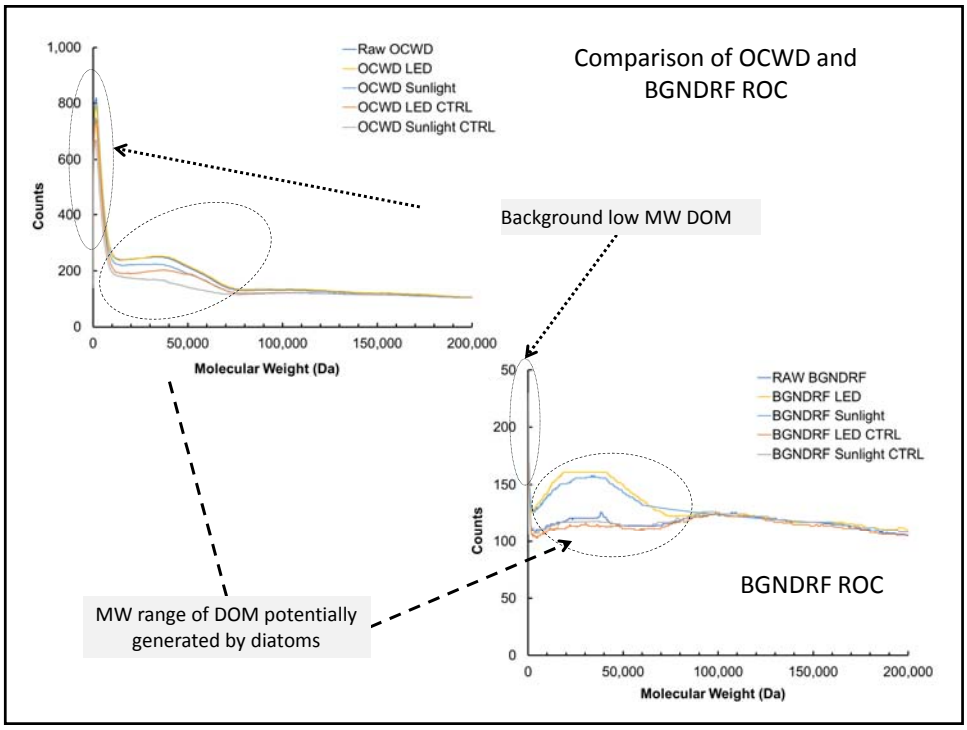

250
200
150
100
50
0
Counts
0
1,000,000
2,000,000
3,000,000
Molecular Weight (Da)
MW < 1,400 Da
57% molecules
1,400 < MW < 100,000 Da
25% molecules (Raw, LED CTRL and Sunlight CTRL)
29% molecules (LED and Sunlight)
MW > 100,000 Da
18% molecules (Raw, LED CTRL and Sunlight CTRL)
16% molecules (LED and Sunlight)
RAW BGNDRF
BGNDRF LED
BGNDRF Sunlight
BGNDRF LED CTRL
BGNDRF Sunlight CTRL
SEC-OCD Chromatograph
BGNDRF ROC Experiment


SEC-OCD Chromatograph
BGNDRF ROC Experiment
250
200
150
100
50
0
Counts
0
500
1,000
1,500
Molecular Weight (Da)
MW < 1,400 Da
57% molecules
RAW BGNDRF
BGNDRF LED
BGNDRF Sunlight
BGNDRF LED CTRL
BGNDRF Sunlight CTRL


Number Average MW (Da)
200
150
100
50
0
-10%
-3%
-5%
+2%
Raw BGNDRF
BGNDRF LED
BGNDRF Sunlight
BGNDRF LED CTRL
BGNDRF Sunlight CTRL
Sample ID


SEC-OCD Chromatograph
BGNDRF ROC Experiment
RAW BGNDRF
BGNDRF LED
BGNDRF Sunlight
BGNDRF LED CTRL
BGNDRF Sunlight CTRL
1,400 < MW < 100,000 Da
29% molecules (LED and Sunlight)
1,400 < MW < 100,000 Da
25% molecules (Raw, LED CTRL and Sunlight CTRL)
Counts
250
200
150
100
50
0
0
50,000
100,000
150,000
200,000
Molecular Weight (Da)


25,000
20,000
15,000
10,000
5,000
0
Number Average MW (Da)
+1%
NA
-2%
-2%
Raw BGNDRF
BGNDRF LED
BGNDRF Sunlight
BGNDRF LED CTRL
BGNDRF Sunlight CTRL
Sample ID


Comparison of OCWD and BGNDRF ROC
Raw OCWD
OCWD LED
OCWD Sunlight
OCWD LED CTRL
OCWD Sunlight CTRL
Counts
Molecular Weight (Da)
Background low MW DOM
RAW BGNDRF
BGNDRF LED
BGNDRF Sunlight
BGNDRF LED CTRL
BGNDRF Sunlight CTRL
BGNDRF ROC
MW range of DOM potentially generated by diatoms

APPENDIX 6

Analysis of Dissolved Organic Matter in Photobiologically Treated Brackish Groundwater Reverse Osmosis Concentrate

Introduction

Fouling of RO membranes by biopolymers, allochthonous and autochthonous organic matter has been reported widely (*Amy and Cho, 1999; Lee et al., 2006; Tang et al., 2007; Li et al., 2007; Ang and Elimelech, 2007*). The photobiological process (*Ikehata et al., 2017a, 2017b*) was developed as a pre-treatment of RO concentrate prior to additional stage of RO to improve water recovery, where the brackish water diatoms were used to remove scalants from the RO concentrate. Several species of diatoms (e.g. *Chaetoceros affinis, Thalassisira mendiolana, Detonula confervacae and Niztschia angularis*) have been reported to generate allocthonous organic matter in the form of aromatic compounds or polysaccharide containing transparent exopolymer particles (TEPs) during their growth (*Passow and Alldredge, 1995; Hong et al., 1997; Passow, 2002*). In this study, a brackish groundwater RO concentrate was treated using a brackish groundwater diatom *Pseudostaurosira trainorii*. The dissolved allocthonous organic matter generated during the photobiological process was analyzed by measuring dissolved organic carbon (DOC) concentrations, absorbance and fluorescence spectroscopic properties and using size exclusion chromatography coupled with organic carbon detection (SEC-OCD), whereas TEPs were quantified in the bulk sample.

Methods

The samples (untreated and treated) were filtered through 0.2/0.8-µm sterile syringe filters. The DOC analysis was carried at Test America Inc. (Irvine, CA) and at University of Arizona. Absorbance and fluorescence spectra were acquired using a Horiba Aqualog spectrophotometer at Orange County Water District (Fountain Valley, CA) and at University of Arizona. The sample was placed in a 1-cm path length quartz cuvette and integration time of 0.25 s was used. The absorption spectra were collected between 240 nm to 600 nm range with an increment of 3 nm. Simultaneously the sample was excited with wavelengths 240 nm to 450 nm and emission spectra were acquired from 300 nm to 600 nm. Excitation emission matrix (EEM) was corrected for inner filter effect (*Ohno, 2002*), Rayleigh scattering (*Stedmon and Bro, 2008*) and normalized with Raman area of 18.3-MΩ.cm ultrapure water. Spectral slope ratios (*Helms et al., 2008*) and fluorescence intensities (*Coble, 1996*) were computed from the corrected EEMs. Approximate molecular weights (AMW) were computed from SEC-OCD spectra. Analysis of TEPs was done using Alcian Blue dye method (*Passow and Alldredge, 1995*) with some modifications. In brief, 100-mL of samples was filtered through a 0.4-µm polycarbonate filter and 4-mL of Alcian Blue (50 mg/L, pH 2.5) was added to the filter. After rinsing the excess dye, the filter paper was soaked in 6-mL of 80% sulfuric acid for 2 hours at room temperature. Absorbance of sulfuric acid solution at 787 nm was recorded using HACH DR 2800 spectrophotometer. Six concentrations of Xanthan Gum (0, 0.5, 1, 2, 3.5 and 5 mg/L) were used to prepare the calibration curve.

Experimental setup

Two 2-gallon white pail reactors with thin food-wrap cover containing 1-gallon of 1.5-µm filtered brackish groundwater RO concentrate were inoculated with *P. trainorii* PEWL001 and incubated under LED at static condition, with aeration and with carbon dioxide mixing conditions. Reactive silica (HACH#8185), orthophosphate (HACH#8048) and nitrate (TNT835) were monitored regularly and removal of >75% reactive silica was considered as end of the treatment cycle. Three such cycles were performed in each experiment and samples were collected at the end of each cycle for analysis of DOM. In another experiment, two 50-mL centrifuge tubes (VWR International, LLC Radnor, PA, USA) containing P. *trainorii* and brackish groundwater RO concentrate were inoculated under LED and sunlight respectively. After two cycles of silica removal (> 75% removal), the treated RO concentrate was filtered through 0.2/0.8-µm sterile syringe filters and analyzed for DOC, absorbance and fluorescence properties and molecular weight distribution. The samples for TEP analysis were collected from pilot-scale photobioreactor at Alamogordo, NM on 8/17/2017. The raw RO concentrate sample, two samples from the first and the last channels of the photobioreactor were tested by filtering 100-mL of each through 0.4-µm polycarbonate filter paper.

Results

The brackish groundwater RO concentrate used in this study contained < 0.1 mg/L of DOC with more humic-like fluorescence intensity than protein-like fluorescence (Table 1). Upon photobiological treatment of RO concentrate in 2-gallon reactor, the average DOC concentrations in three cycles were found to increase to 2.67 mg/L in static condition, to 3.6 mg/L in aerating reactor and to 4.3 mg/L in the reactor with carbon dioxide addition (Figure 1). The overall ultraviolet absorbance intensities were decreased after the photobiological treatment. The intensities of protein-like fluorescence (tryptophan like peak T) increased by 87-fold in static, 192-fold in aerating and 586-fold in carbon dioxide mixing reactors (Table 1, Figure 2). However the humic-like fluorescence intensities did not change considerably. The increase in DOC and protein-like fluorescence post-treatment suggests the generation of allochthonous DOM by diatom. In the other experiment where 50-mL tube reactors were incubated under LED and sunlight, up to 170% and 175% increase in DOC concentrations was observed (Table 1, Figure 3). This suggested that in 50-mL reactors, type of light source did not affect much on the generation of DOC during the treatment. The overall fluorescence intensity (Table 1, Figure 4) also increased by 117% and 92% under LED and sunlight respectively, suggesting the generation of chromophoric DOM including both humic- and protein-like fluorescence. The SEC-OCD analyses of these samples revealed (Figure 5) that the DOM in the raw brackish groundwater RO concentrate was mostly low molecular weight (< 1,400 Da). It was observed that during the photobiological treatment under LED or sunlight, the proportion of molecules with molecular weights ranging between 1,400 and 100,000 Da was increased by a small but evident increase of 4%. This implies that the molecular weight of DOM molecules generated by the diatom during the photobiological treatment ranged between 1,400 and 100,000 Da. The analysis of TEPs in the samples collected from the pilot photobioreactor (Figure 6 and 7) revealed that about 17 mg/L of TEPs were generated in the first channel of the reactor while 6 mg/L in the last channel (Table 2). In general these findings are consistent with previous studies that reported the generation of

DOM by diatoms (*Passow, 2002*). However, the generated DOM appears to be more protein-like rather than recalcitrant and within molecular weight range of 1,400 to 100,000 Da, which may be removed easily by filtration using membranes with appropriate molecular weight cut off. Therefore, this preliminary study indicates that although some DOM may be generated during photobiological treatment process, it may not significantly affect the secondary RO of the effluent from photobiological treatment.

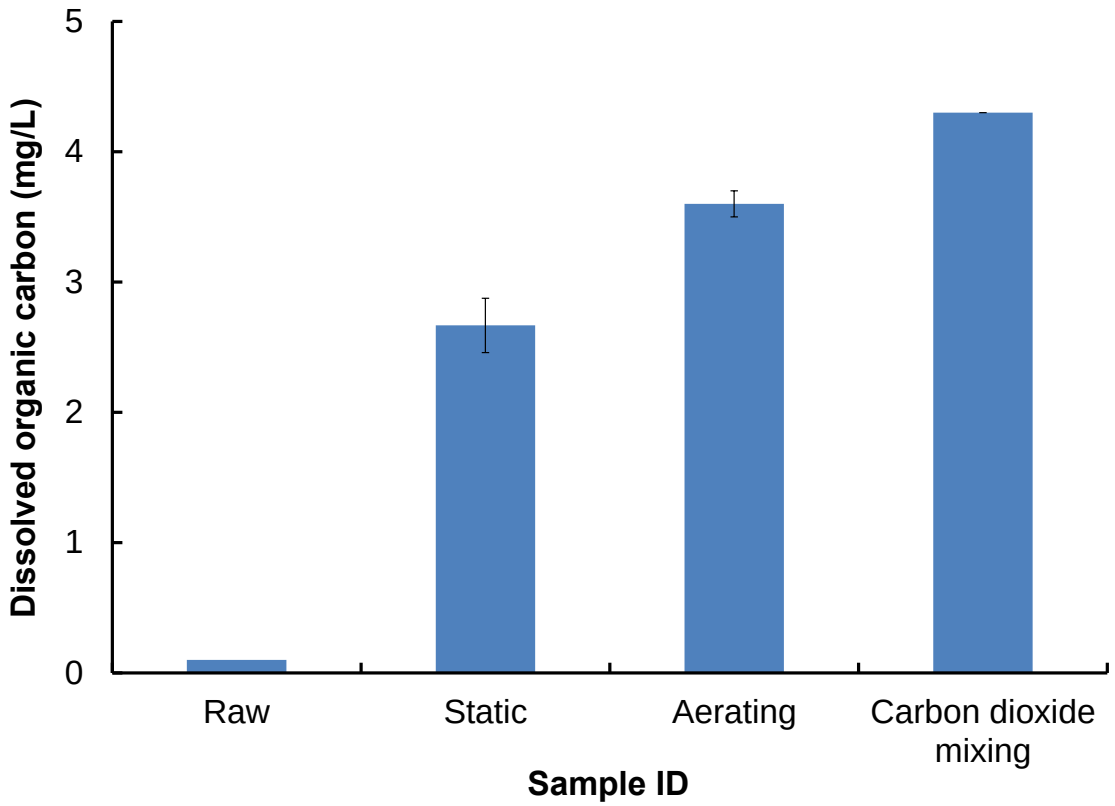


Figure 1 Increase in DOC concentrations in brackish groundwater RO concentrate treated in 2-gallon reactor under LED and different mixing conditions.

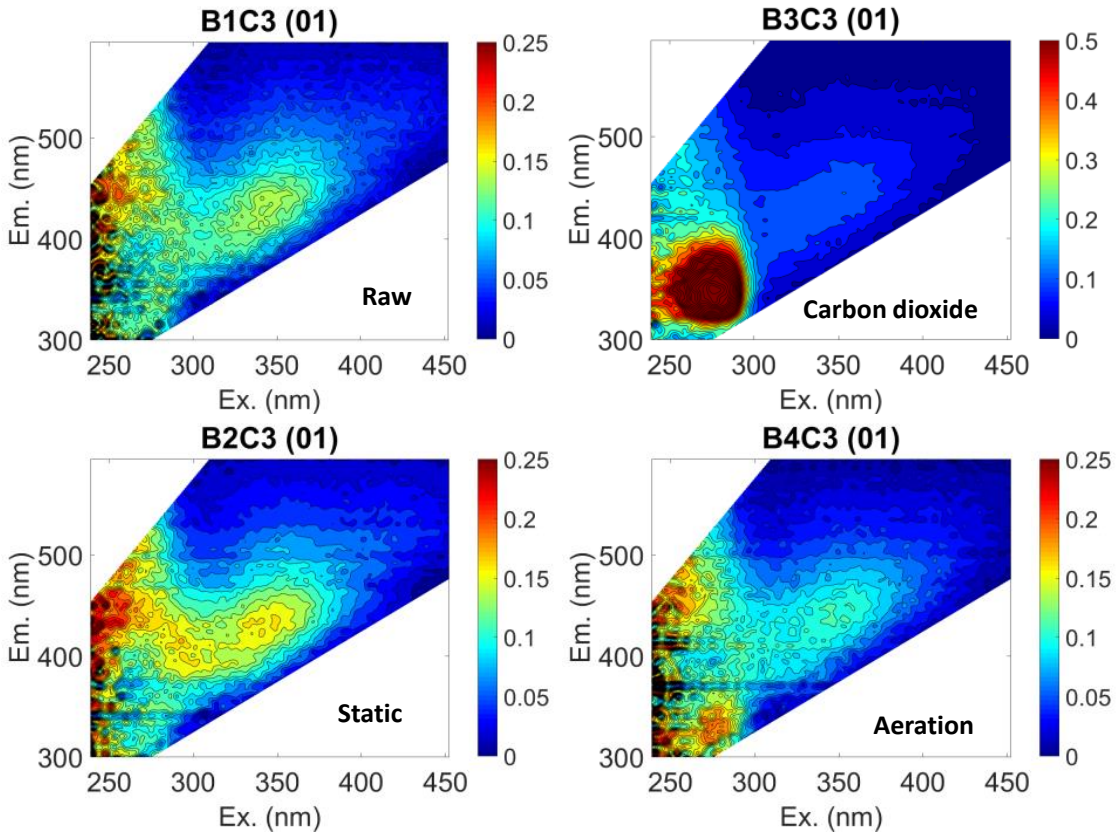


Figure 2 Fluorescence excitation-emission matrix plots showing generation of fluorescent DOM during photobiological treatment in brackish groundwater RO concentrate

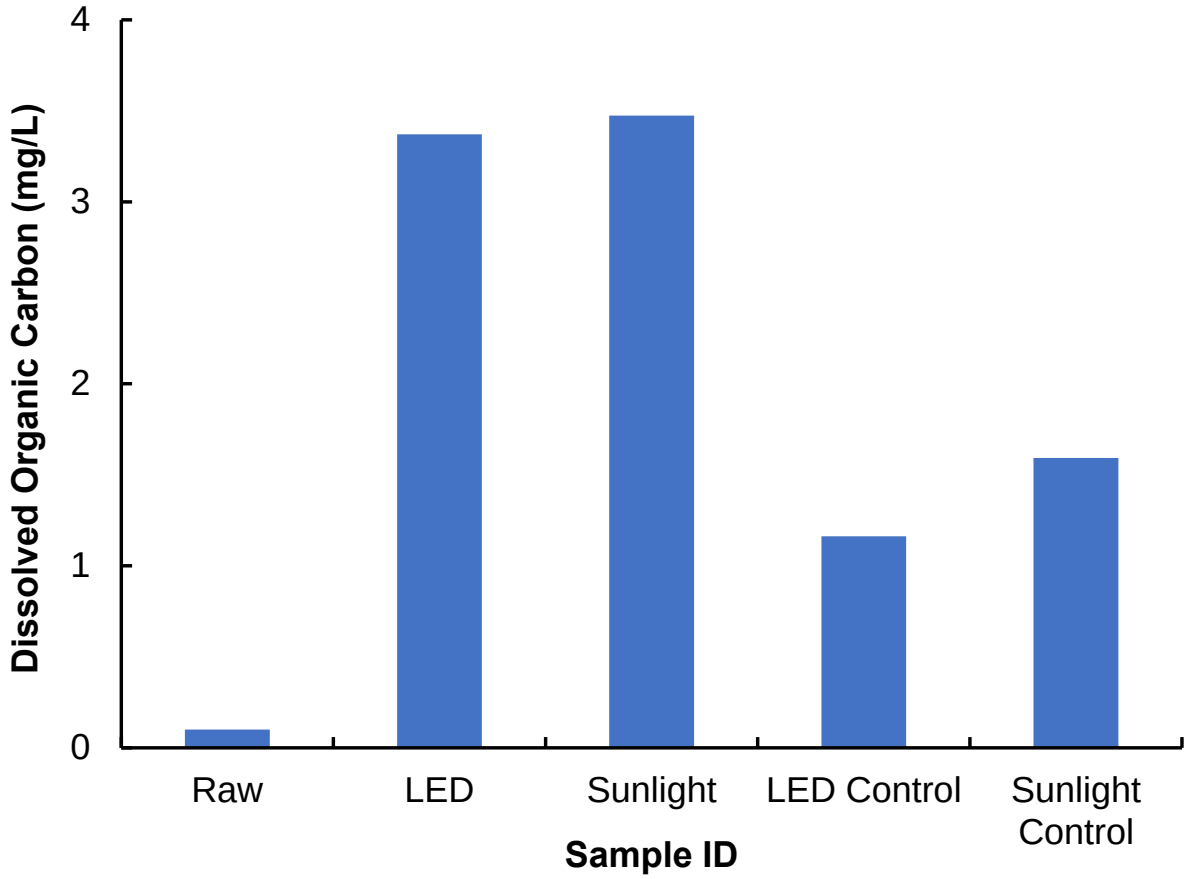


Figure 3 Increase in DOC concentrations in brackish groundwater RO concentrate treated in 50-mL reactors under LED and under sunlight

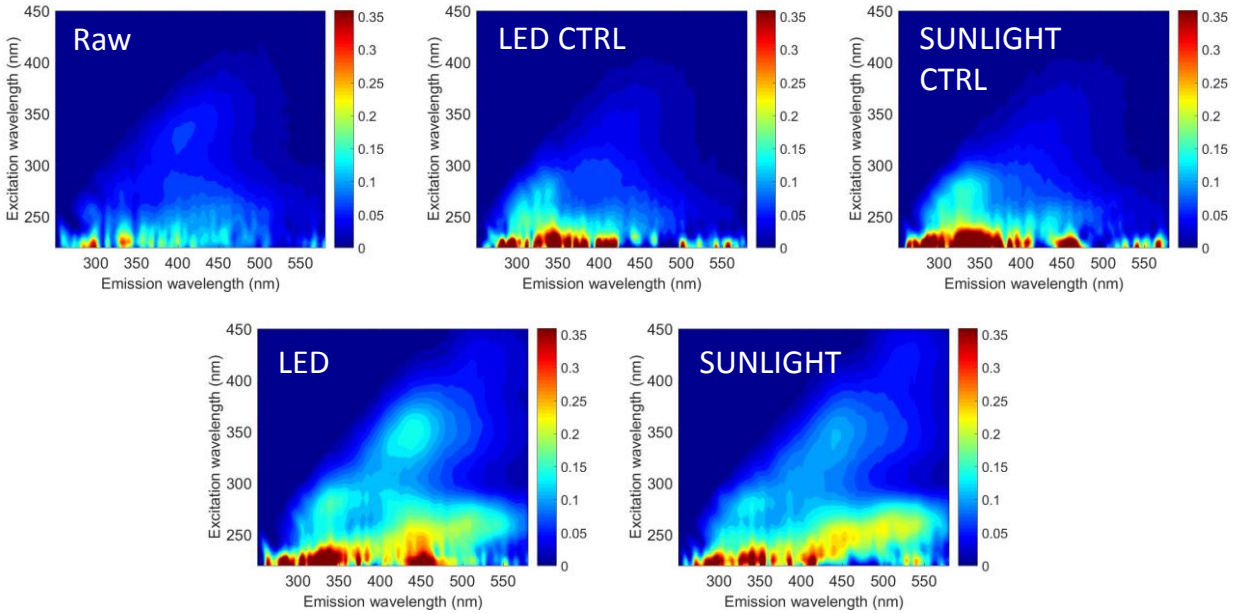


Figure 4 Fluorescence excitation-emission matrix plots showing generation of fluorescent DOM in brackish groundwater RO concentrated treated under LED and under sunlight

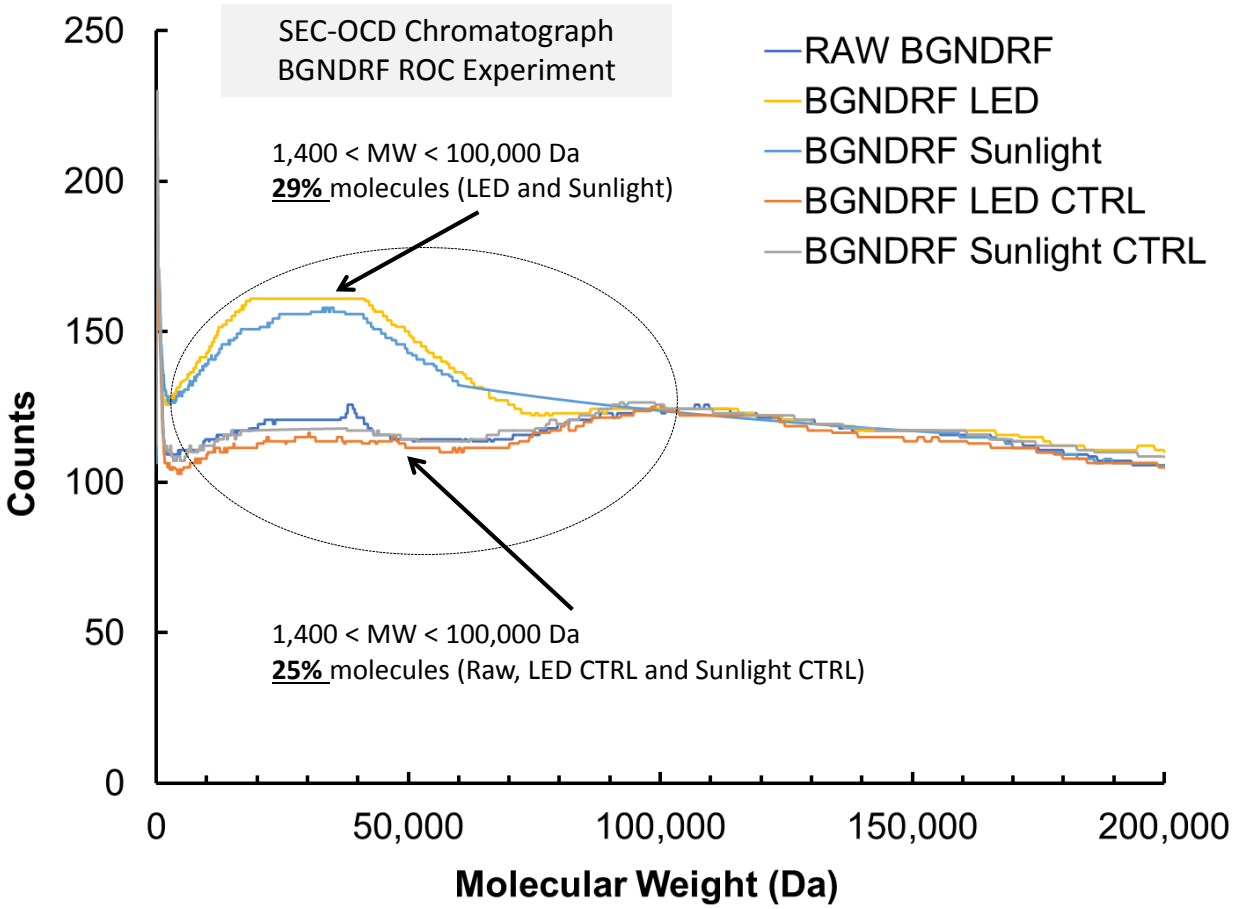


Figure 5 Distribution of molecular weights of DOM in brackish groundwater RO concentrate before and after photobiological treatment using size exclusion chromatography coupled with organic carbon detection.

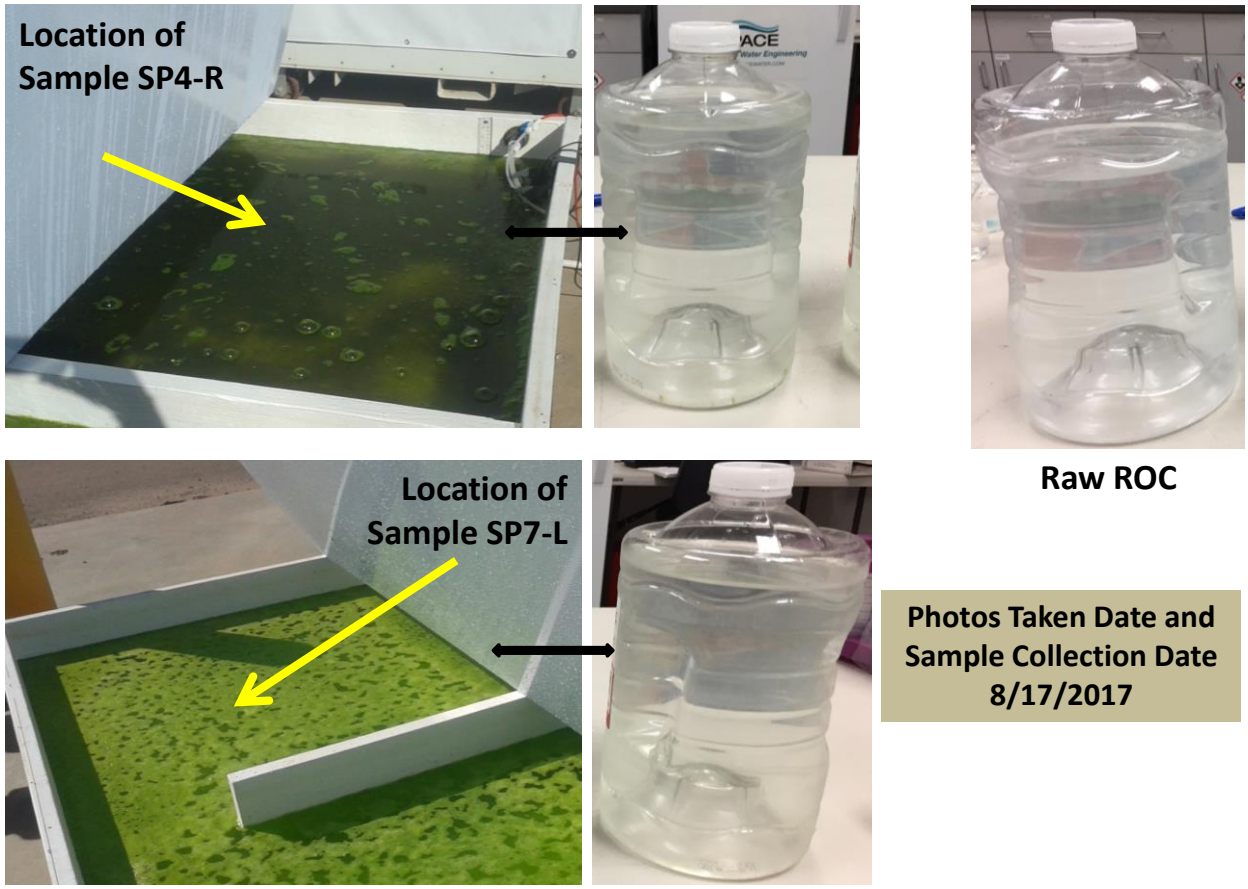


Figure 6 Location of samples collected for TEP analysis from pilot photobioreactor

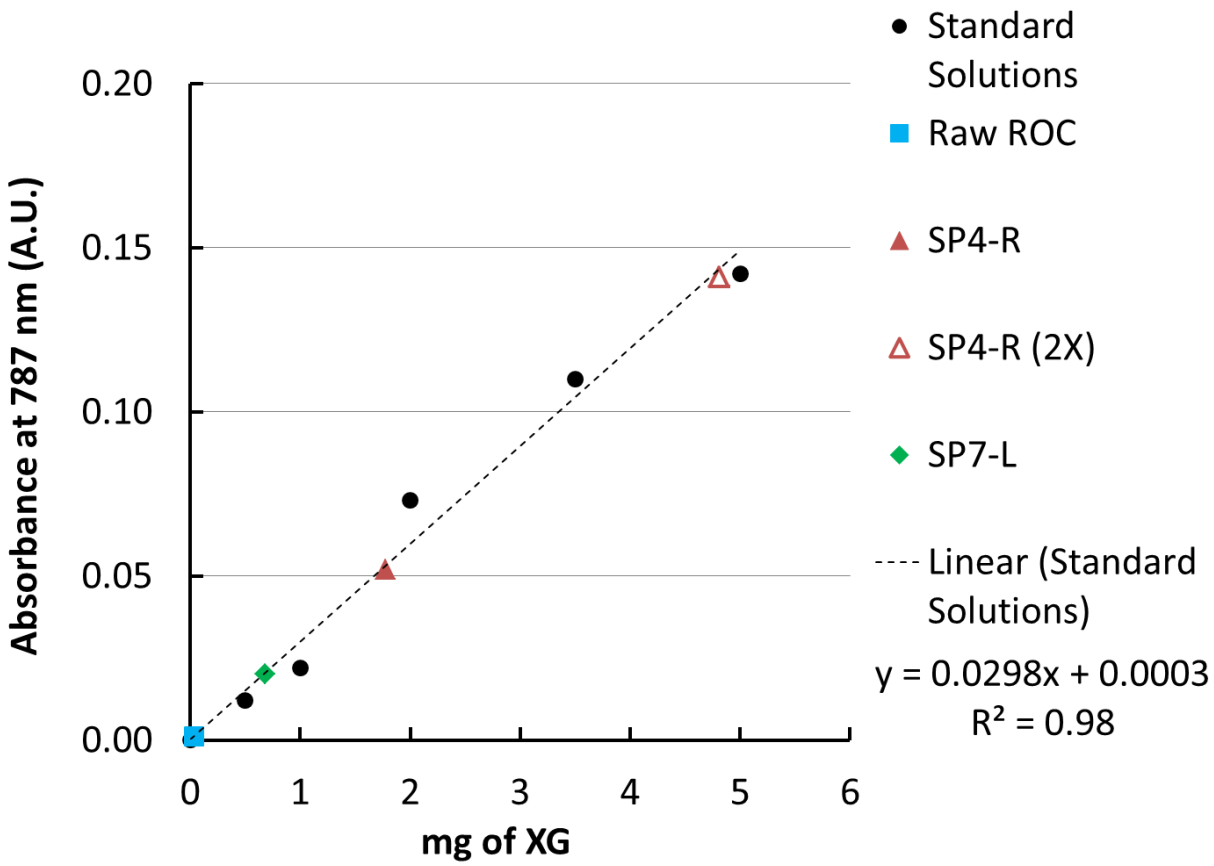


Figure 7 Calibration curve showing concentrations of Xanthan Gum standards and results of samples tested on the calibration line.

Table 1 Characteristics of dissolved organic matter generated during photobiological treatment

Parameter	Raw	2-gallon Reactor LED Experiment			50-mL Reactor Experiment			
		Static	Aerating	Carbon dioxide	LED	Sunlight	LED Control	Sunlight Control
DOC (mg/L)	0.1	2.67	3.6	4.3	3.37	3.47	1.16	1.59
Abs_{254} (a.u.)	0.03	0.03	0.05	0.08	0.03	0.05	0.03	0.03
Total Fluorescence Intensity ($R.U.nm^2$)	12,304	-	-		26,749	23,677	20,057	24,805
Tryptophan-like fluorescence (R.U.)	0	0.06	0.13	0.40	-	-	-	-
Humic-like fluorescence (R.U.)	0.10	0.12	0.10	0.10	-	-	-	-

Table 2 Concentration of TEPs in the samples collected from pilot photobioreactor

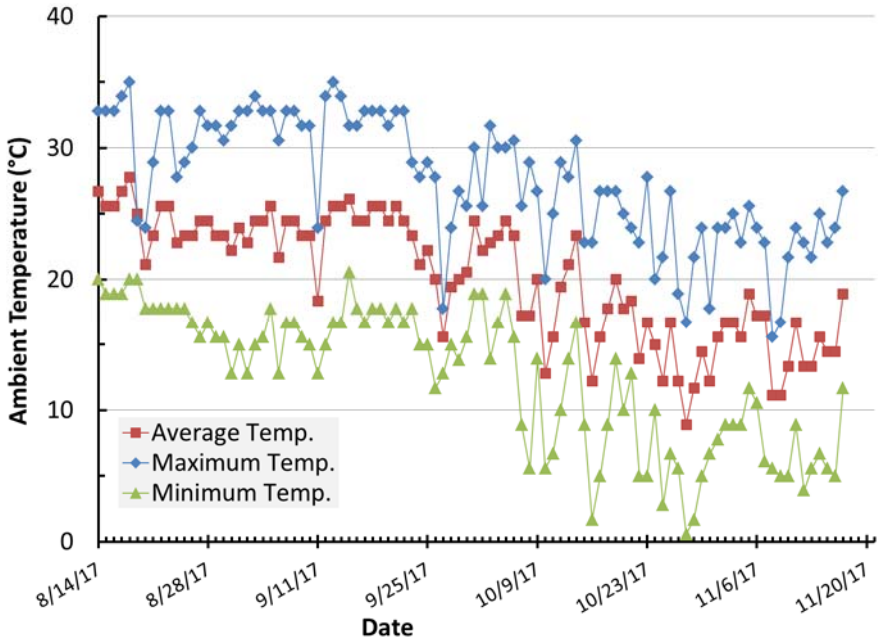
Sample ID	TEP (μg/L)
Untreated RO concentrate	0
Pilot photobioreactor 1st channel	17,406
Pilot photobioreactor last channel	6,485

APPENDIX 7

B054 Pilot PBR Operational and Water Quality Data

2017-11-22

1



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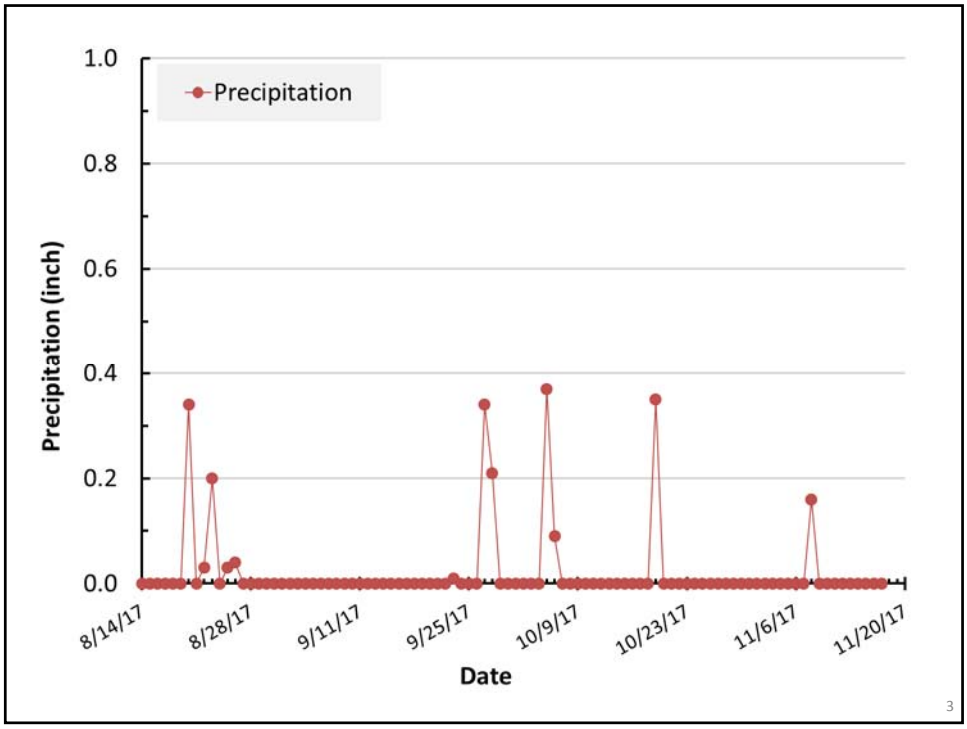
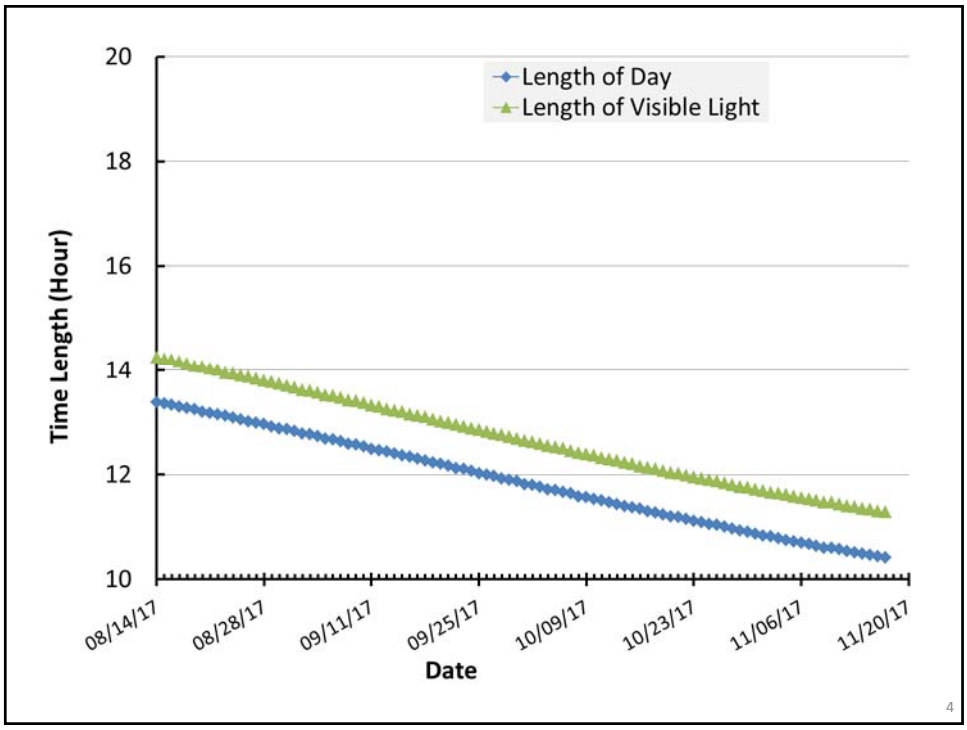
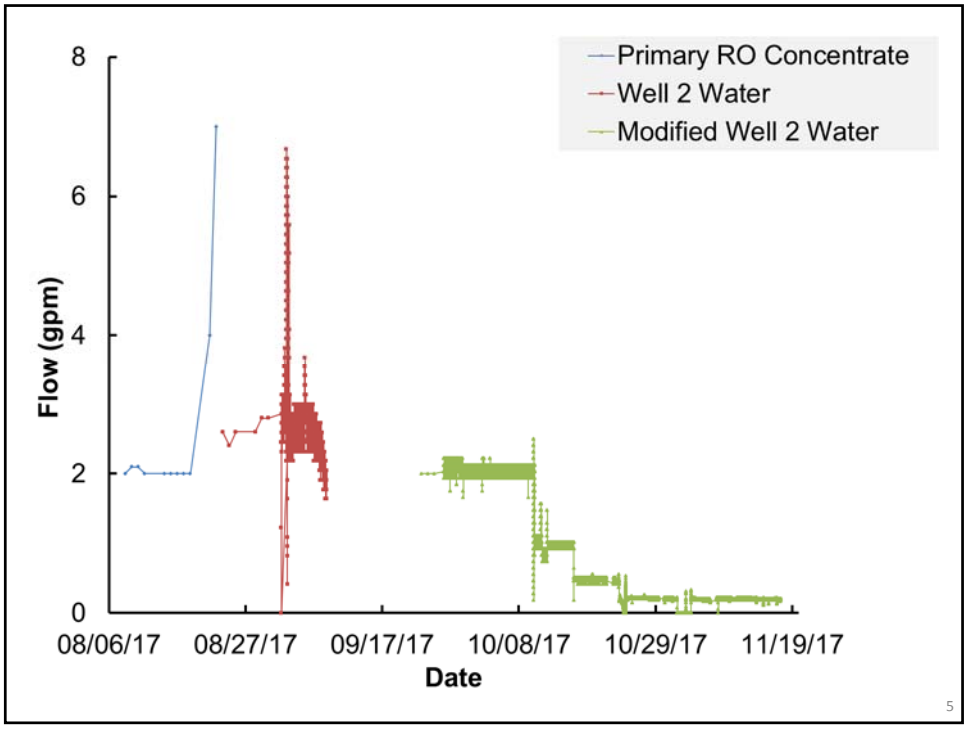
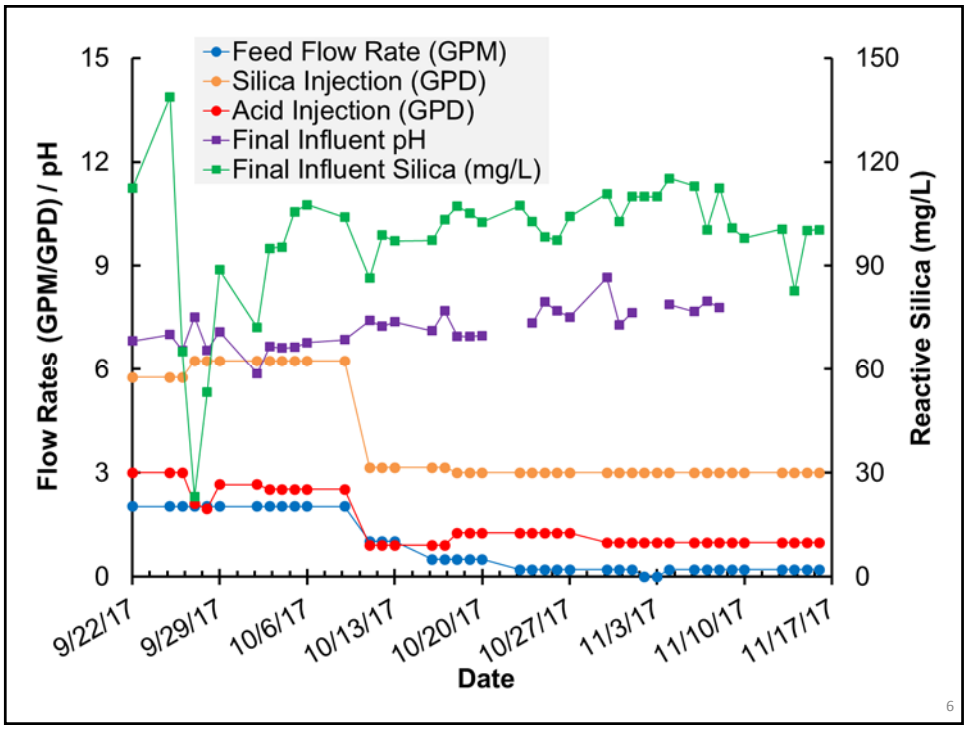
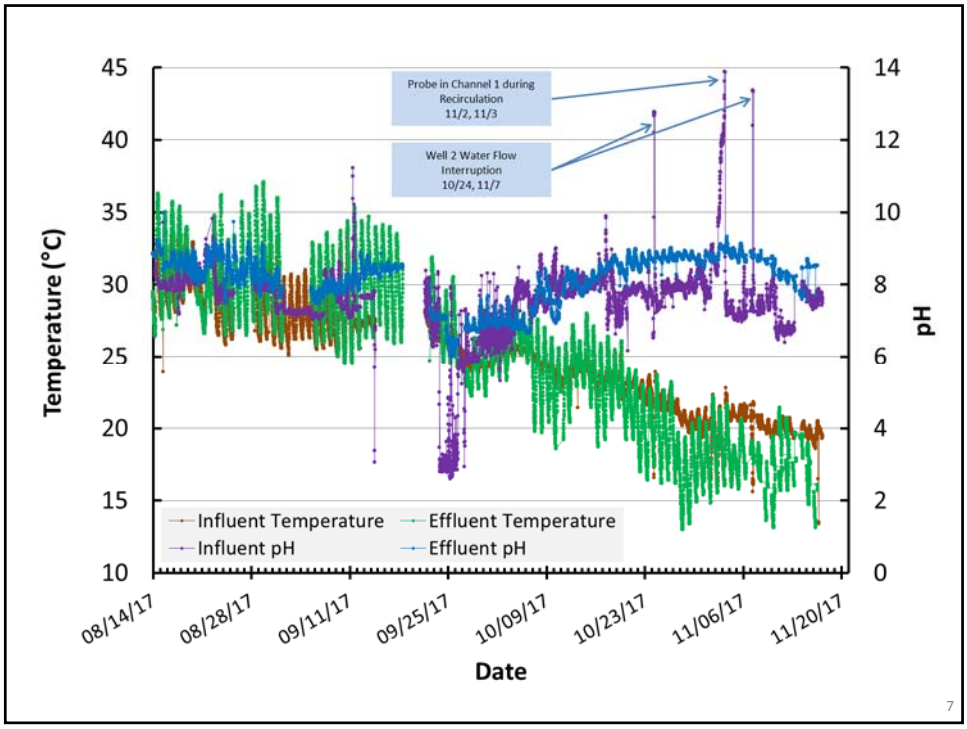
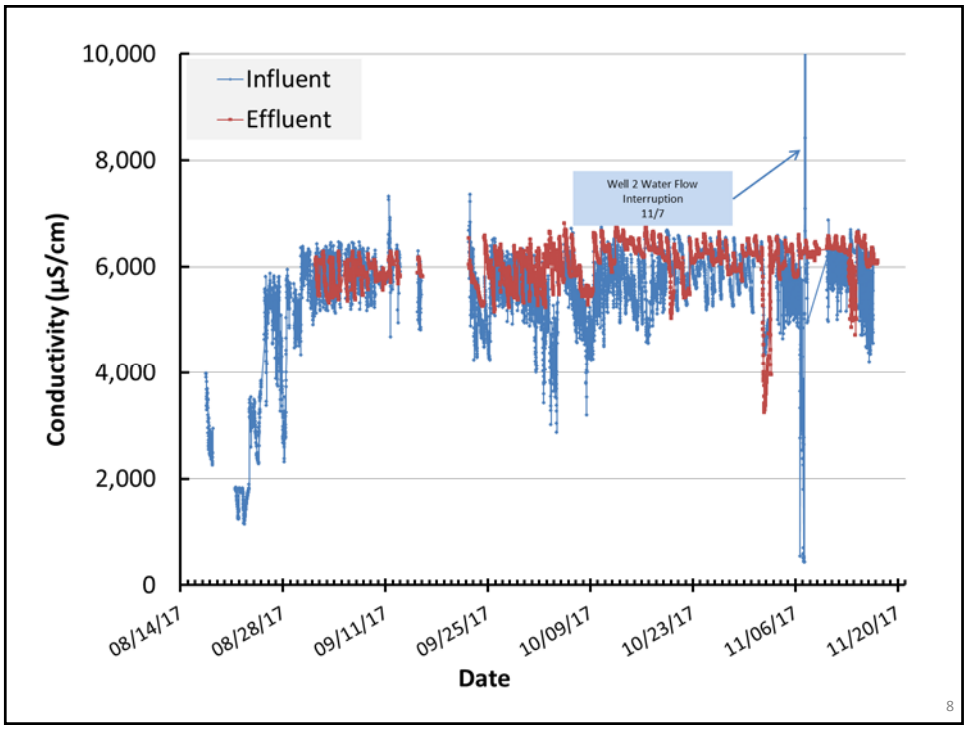

Precipitation
1.0
0.8
0.6
0.4
0.2
0.0
Precipitation (inch)
8/14/17
8/28/17
9/11/17
9/25/17
10/9/17
10/23/17
11/6/17
11/20/17
Date
3

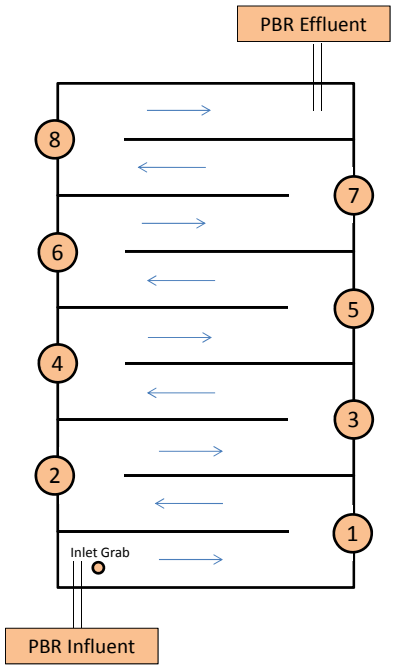

Length of Day
Length of Visible Light
20
18
16
14
12
10
Time Length (Hour)
08/14/17
08/28/17
09/11/17
09/25/17
10/09/17
10/23/17
11/06/17
11/20/17
Date
4


Primary RO Concentrate
Well 2 Water
Modified Well 2 Water
Flow (gpm)
0
2
4
6
8
08/06/17
08/27/17
09/17/17
10/08/17
10/29/17
11/19/17
Date
5


Feed Flow Rate (GPM)
Silica Injection (GPD)
Acid Injection (GPD)
Final Influent pH
Final Influent Silica (mg/L)
Flow Rates (GPM/GPD) / pH
Reactive Silica (mg/L)
0
3
6
9
12
15
0
30
60
90
120
150
9/22/17
9/29/17
10/6/17
10/13/17
10/20/17
10/27/17
11/3/17
11/10/17
11/17/17
Date
6


Probe in Channel 1 during Recirculation 11/2, 11/3
Well 2 Water Flow Interruption 10/24, 11/7
Temperature (°C)
pH
Influent Temperature
Effluent Temperature
Influent pH
Effluent pH
08/14/17
08/28/17
09/11/17
09/25/17
10/09/17
10/23/17
11/06/17
11/20/17
Date
7

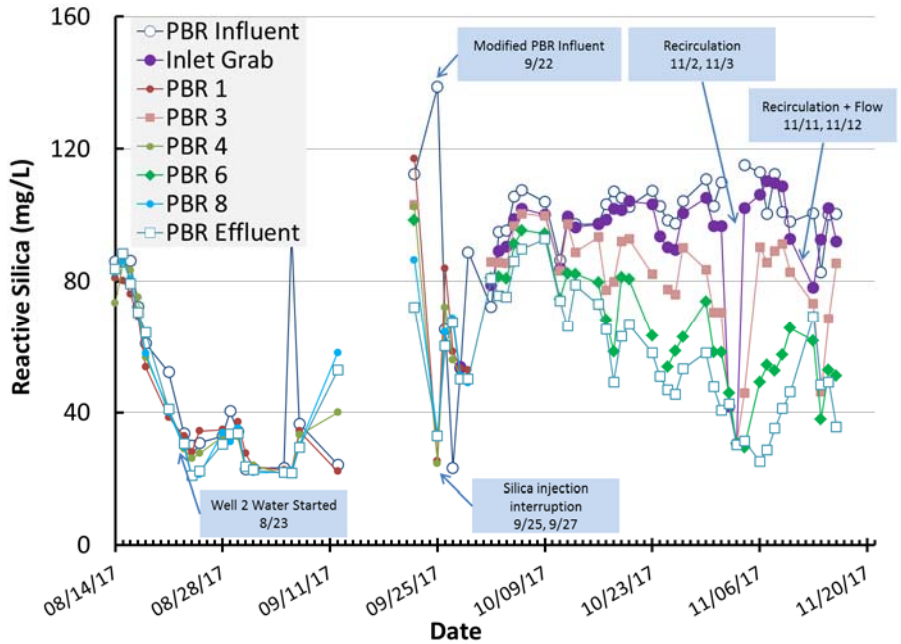

Influent
Effluent
Well 2 Water Flow Interruption 11/7
Conductivity (µS/cm)
08/14/17
08/28/17
09/11/17
09/25/17
10/09/17
10/23/17
11/06/17
11/20/17
Date
8



Location of Sampling Ports on PBR

- Currently samples are collected from,
  - ✓ PBR Influent
  - ✓ PBR 1
  - ✓ PBR 4
  - ✓ PBR 8
  - ✓ PBR Effluent
- Sampling locations to be modified based on data trend and as needed.

9



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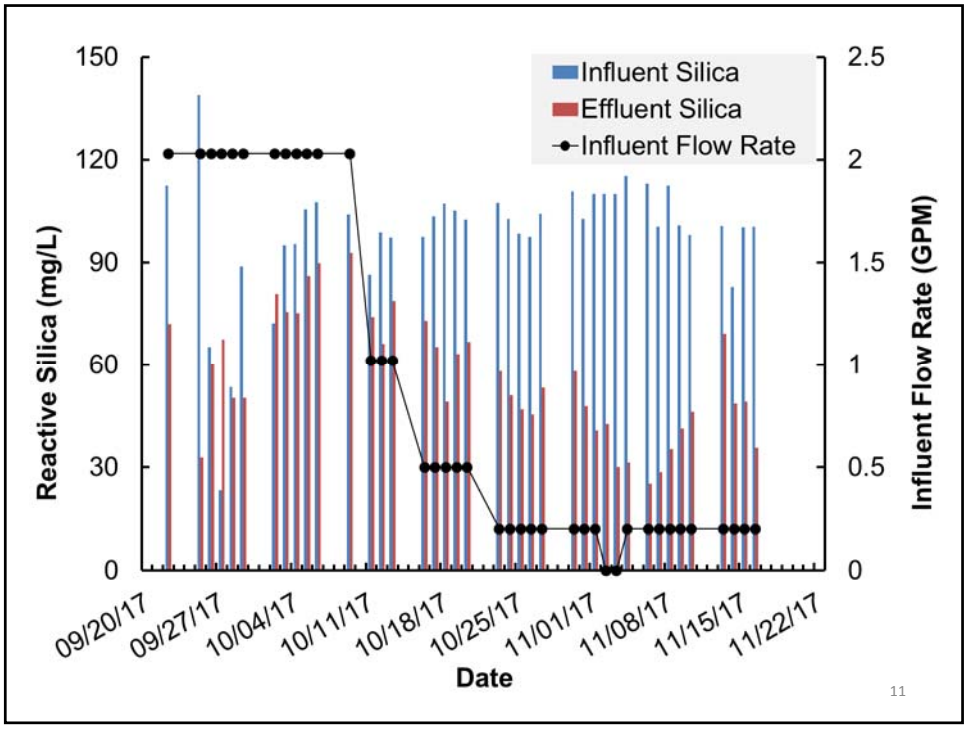
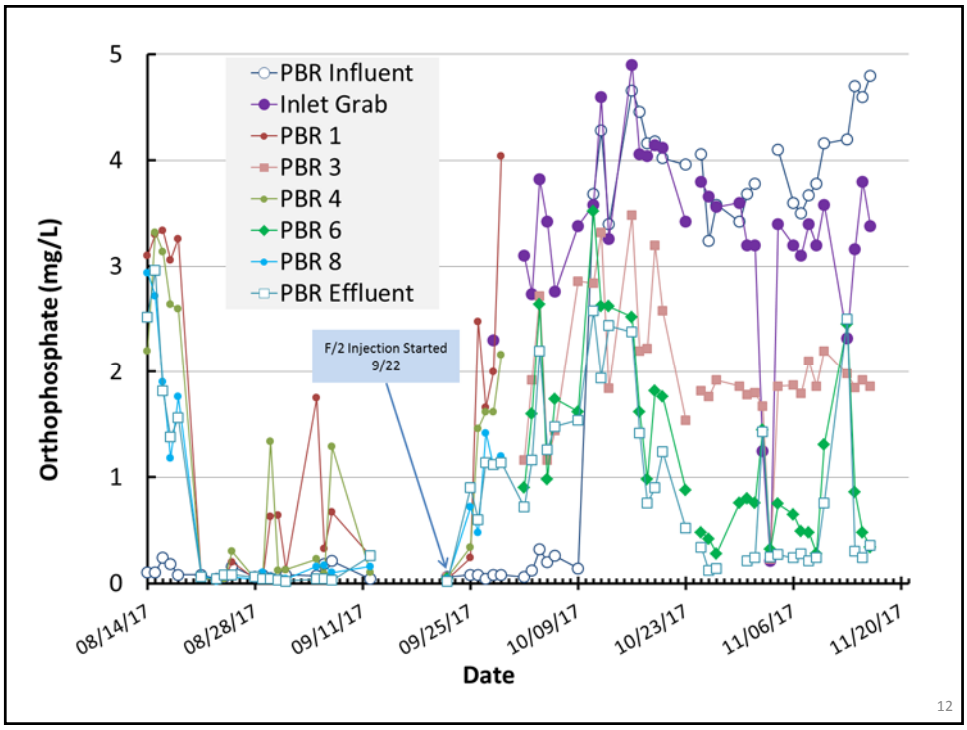
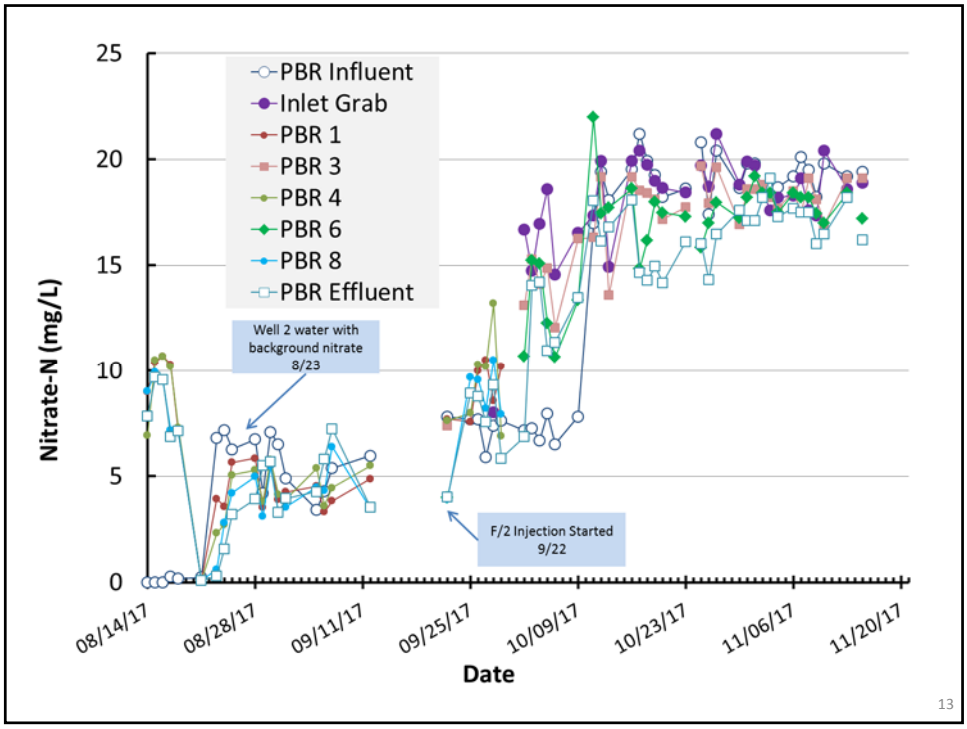
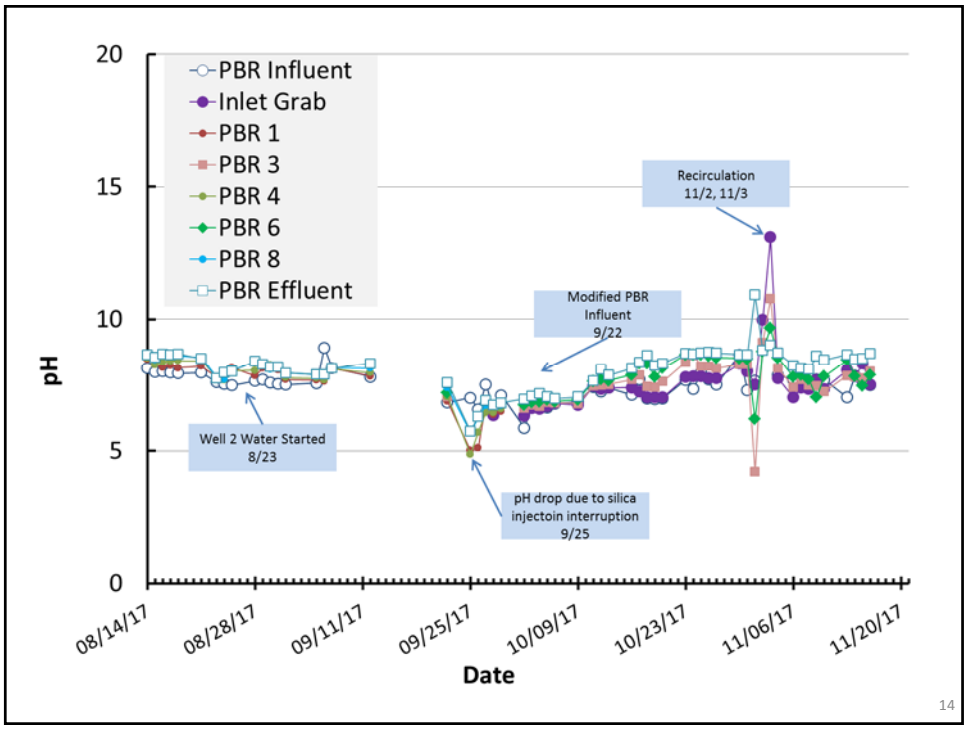
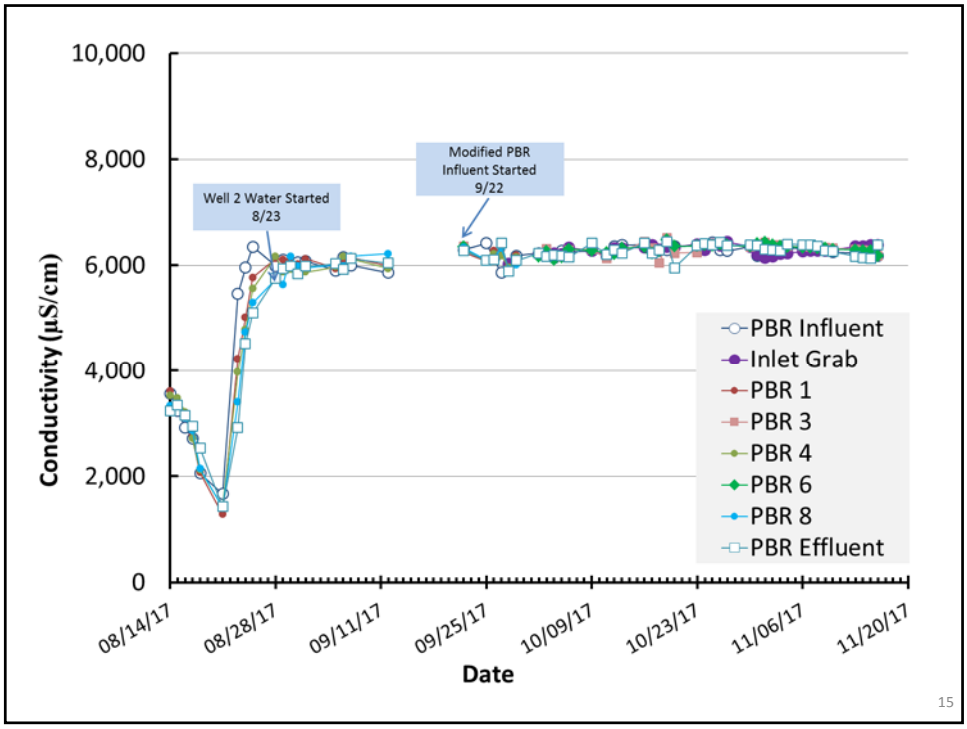
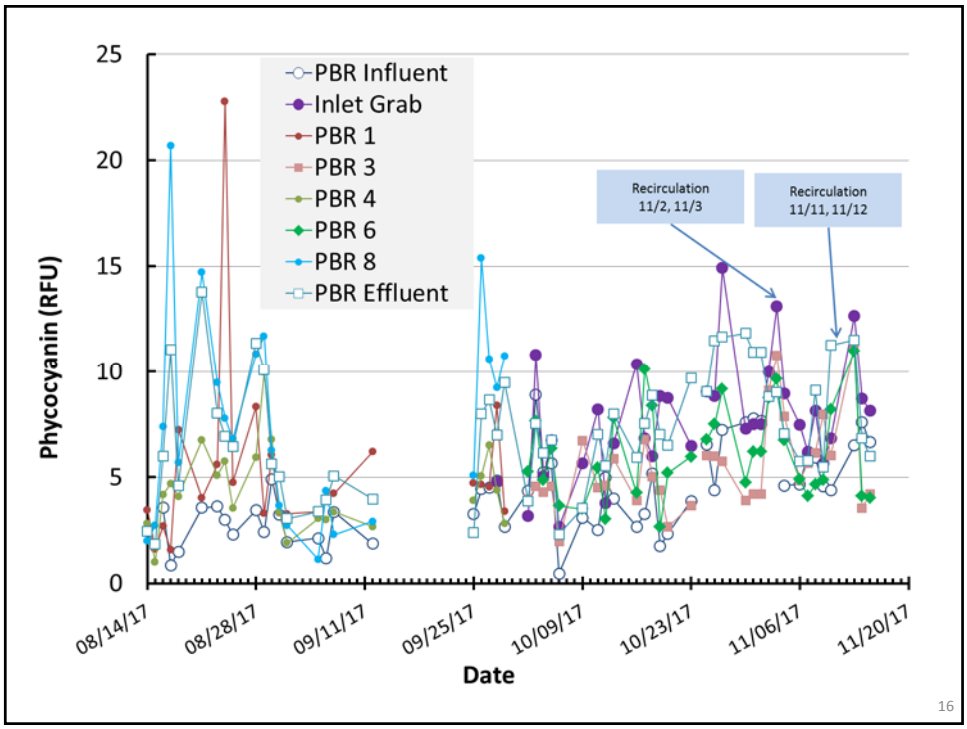

Influent Silica
Effluent Silica
Influent Flow Rate
Reactive Silica (mg/L)
Influent Flow Rate (GPM)
150
120
90
60
30
0
2.5
2
1.5
1
0.5
0
09/20/17
09/27/17
10/04/17
10/11/17
10/18/17
10/25/17
11/01/17
11/08/17
11/15/17
11/22/17
Date
11

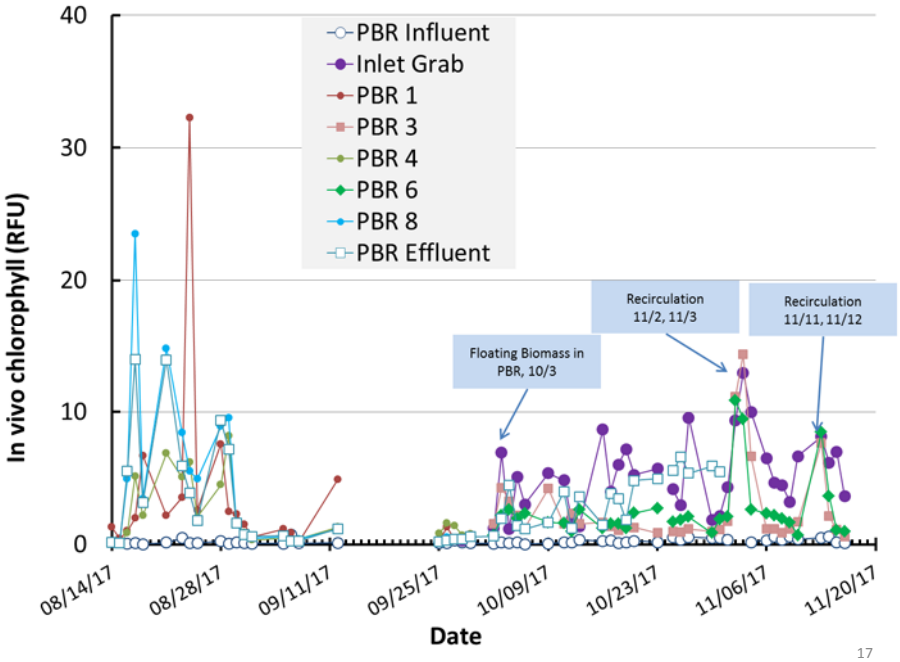

PBR Influent
Inlet Grab
PBR 1
PBR 3
PBR 4
PBR 6
PBR 8
PBR Effluent
F/2 Injection Started 9/22
Orthophosphate (mg/L)
5
4
3
2
1
0
08/14/17
08/28/17
09/11/17
09/25/17
10/09/17
10/23/17
11/06/17
11/20/17
Date
12


PBR Influent
Inlet Grab
PBR 1
PBR 3
PBR 4
PBR 6
PBR 8
PBR Effluent
Well 2 water with background nitrate 8/23
F/2 Injection Started 9/22
Nitrate-N (mg/L)
Date
25
20
15
10
5
0
08/14/17
08/28/17
09/11/17
09/25/17
10/09/17
10/23/17
11/06/17
11/20/17
13


PBR Influent
Inlet Grab
PBR 1
PBR 3
PBR 4
PBR 6
PBR 8
PBR Effluent
Recirculation 11/2, 11/3
Modified PBR Influent 9/22
Well 2 Water Started 8/23
pH drop due to silica injectoin interruption 9/25
pH
Date
20
15
10
5
0
08/14/17
08/28/17
09/11/17
09/25/17
10/09/17
10/23/17
11/06/17
11/20/17
14


10,000
8,000
6,000
4,000
2,000
0
Conductivity (µS/cm)
Well 2 Water Started 8/23
Modified PBR Influent Started 9/22
PBR Influent
Inlet Grab
PBR 1
PBR 3
PBR 4
PBR 6
PBR 8
PBR Effluent
08/14/17
08/28/17
09/11/17
09/25/17
10/09/17
10/23/17
11/06/17
11/20/17
Date
15


25
20
15
10
5
0
Phycocyanin (RFU)
PBR Influent
Inlet Grab
PBR 1
PBR 3
PBR 4
PBR 6
PBR 8
PBR Effluent
Recirculation 11/2, 11/3
Recirculation 11/11, 11/12
08/14/17
08/28/17
09/11/17
09/25/17
10/09/17
10/23/17
11/06/17
11/20/17
Date
16

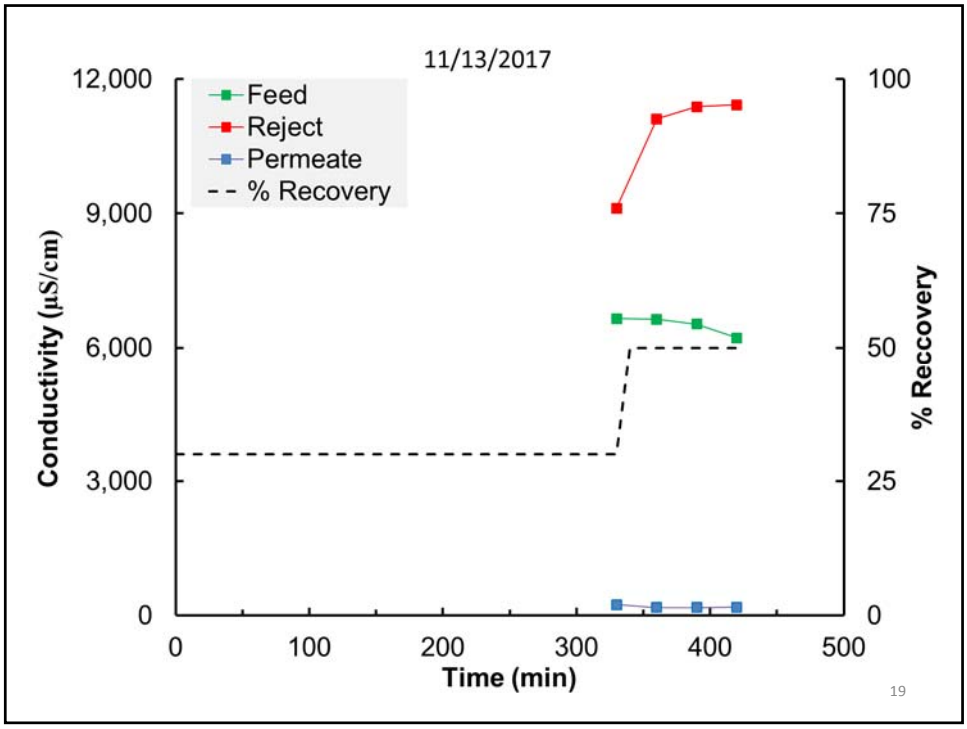


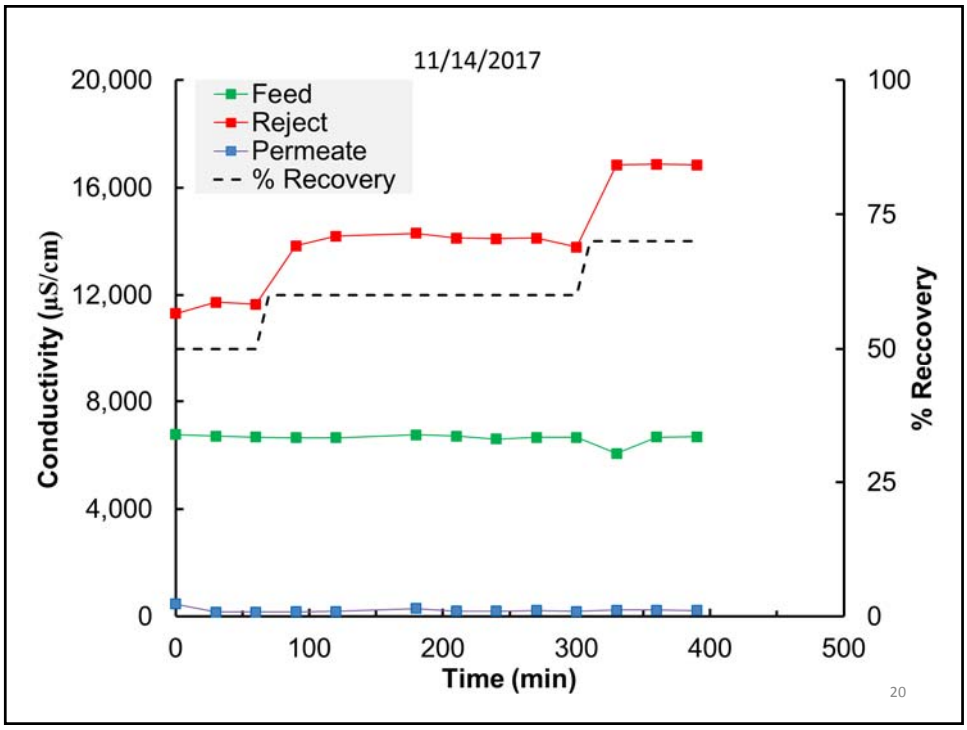
17

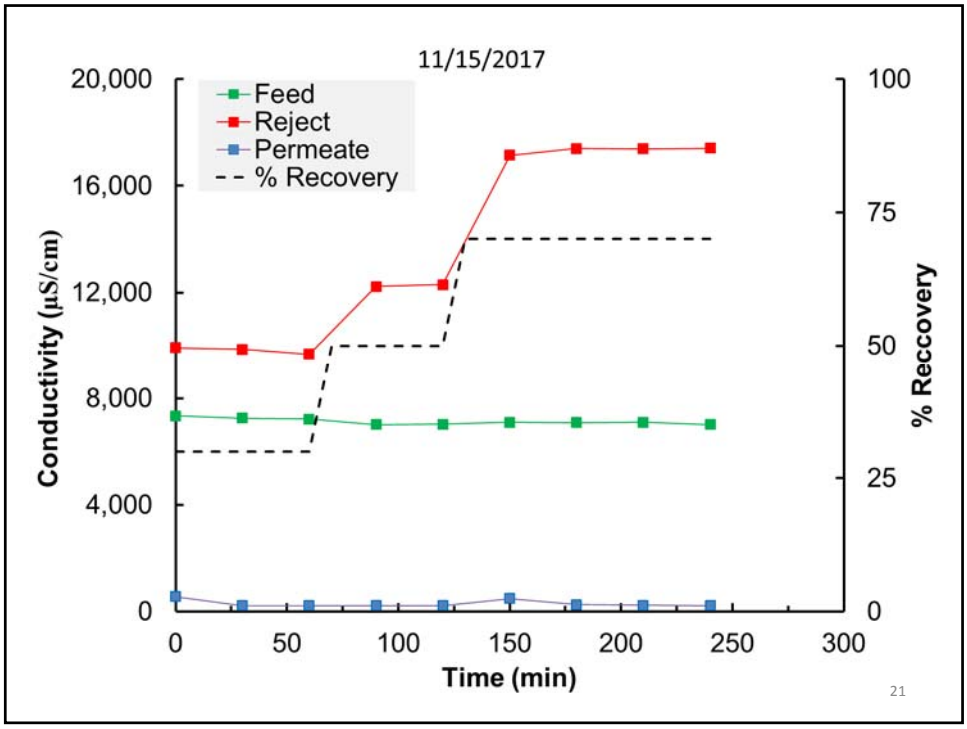
B054 Secondary RO with PBR Effluent

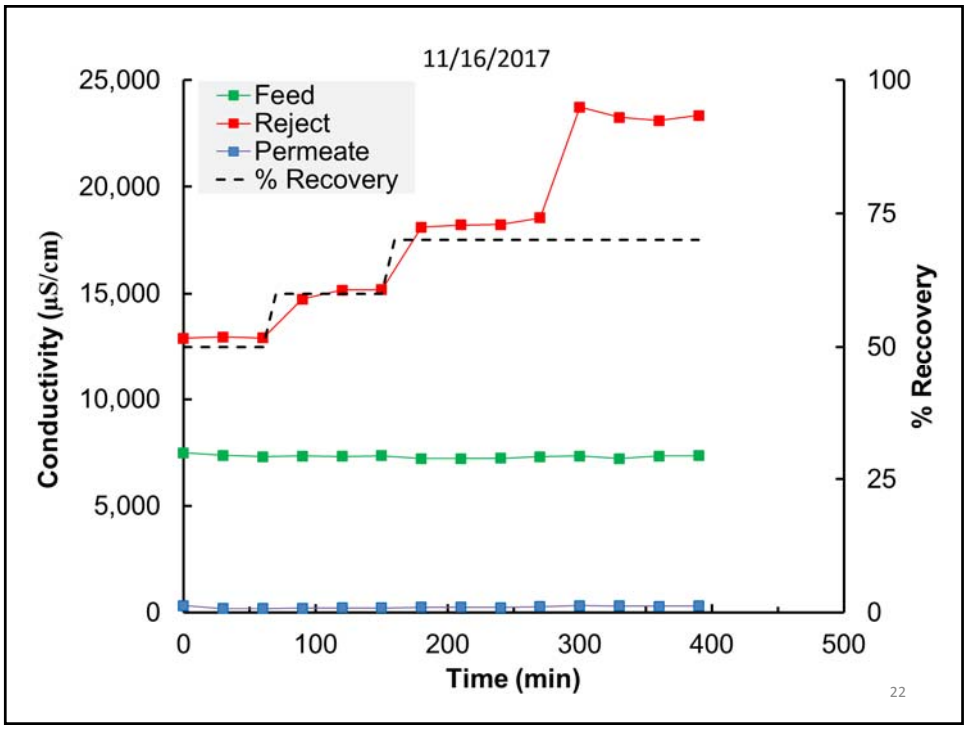
2017-11-22

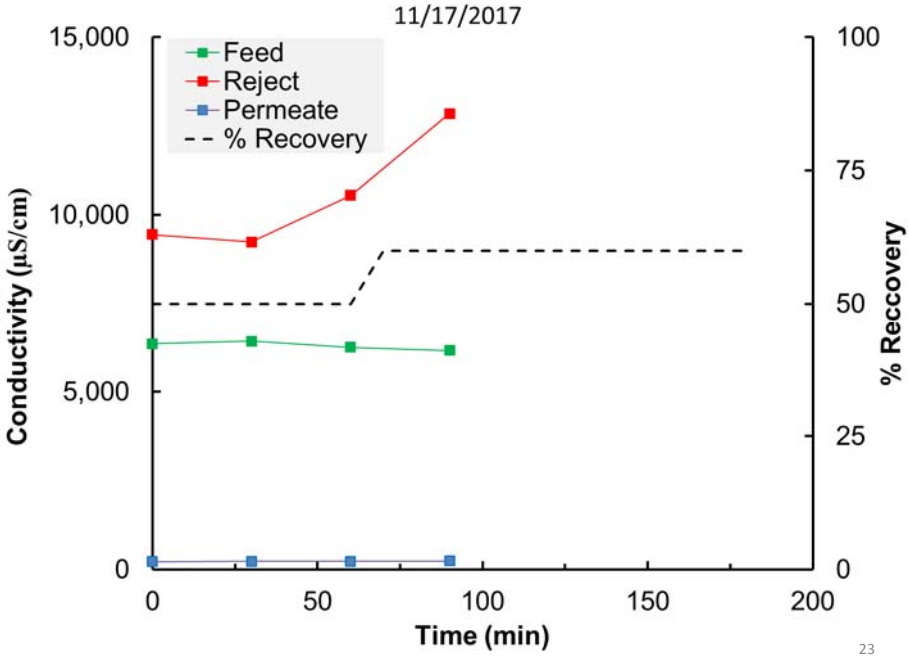
18


11/13/2017
Feed
Reject
Permeate
% Recovery
Conductivity (µS/cm)
% Reccovery
Time (min)
12,000
9,000
6,000
3,000
0
100
75
50
25
0
0
100
200
300
400
500
19


11/14/2017
Feed
Reject
Permeate
% Recovery
Conductivity (µS/cm)
% Reccovery
Time (min)
20,000
16,000
12,000
8,000
4,000
0
100
75
50
25
0
0
100
200
300
400
500
20


11/15/2017
Feed
Reject
Permeate
% Recovery
Conductivity (µS/cm)
% Reccovery
Time (min)
20,000
16,000
12,000
8,000
4,000
0
100
75
50
25
0
0
50
100
150
200
250
300
21


11/16/2017
Feed
Reject
Permeate
% Recovery
Conductivity (µS/cm)
% Reccovery
Time (min)
25,000
20,000
15,000
10,000
5,000
0
100
75
50
25
0
0
100
200
300
400
500
22



23

Mass Balance

Mass Balance (Calcium)							
Recovery %	Feed (mg/L)	Concentrate (mg/L)	Permeate (mg/L)	Mass In	Mass Out	Balance	Concentration Factor
0.3	374	600	1.2	374	420	-12%	1.6
0.3	410	1024	0.8	410	717	-75%	2.5
0.6	410	1040	0.8	410	416	-2%	2.5
0.7	410	840	0.8	410	253	38%	2.0
0.7	500	616	0.8	500	185	63%	1.2
0.6	500	1000	0.8	500	400	20%	2.0
0.7	516	600	0.8	516	181	65%	1.2
0.7	786	520	0.8	786	157	80%	0.7
0.7	480	480	0.4	480	144	70%	1.0

Mass Balance (Magnesium)							
Recovery %	Feed (mg/L)	Concentrate (mg/L)	Permeate (mg/L)	Mass In	Mass Out	Balance	Concentration Factor
0.3	339	470	2	339	330	3%	1.4
0.3	344	855	2	344	599	-74%	2.5
0.6	329	828	2	329	332	-1%	2.5
0.7	324	1,113	1	324	334	-3%	3.4
0.7	328	1,065	2	328	321	2%	3.3
0.6	338	688	1	338	275	18%	2.0
0.7	328	850	1	328	255	22%	2.6
0.7	158	1,100	0	158	330	-110%	7.0
0.7	359	1,250	1	359	375	-5%	3.5

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Mass Balance (Iron)							
Recovery %	Feed (mg/L)	Concentrate (mg/L)	Permeate (mg/L)	Mass In	Mass Out	Balance	Concentration Factor
0.3	0.01	0.02	0.01	0.01	0.0	-1%	2.0
0.3	0.07	0.20	0.01	0.07	0.1	-7%	2.9
0.6	0.07	0.22	0.01	0.07	0.1	-2%	3.1
0.7	0.08	0.30	0.02	0.08	0.1	-2%	3.8
0.7	0.03	0.04	0.01	0.03	0.0	1%	1.3
0.6	0.04	0.10	0.01	0.04	0.0	-1%	2.5
0.7	0.05	0.09	0.01	0.05	0.0	2%	1.8
0.7	0.05	0.06	0.01	0.05	0.0	3%	1.2
0.7	0.04	0.06	0.02	0.04	0.0	1%	1.5

Mass Balance (Manganese)							
Recovery %	Feed (mg/L)	Concentrate (mg/L)	Permeate (mg/L)	Mass In	Mass Out	Balance	Concentration Factor
0.3	0.029	0.039	0.000	0.029	0.027	6%	1.3
0.3	0.046	0.041	0.001	0.046	0.029	37%	0.9
0.6	0.043	0.069	0.000	0.043	0.028	36%	1.6
0.7	0.030	0.060	0.000	0.030	0.018	40%	2.0
0.7	0.060	0.082	0.001	0.060	0.025	58%	1.4
0.6	0.092	0.096	0.005	0.092	0.041	55%	1.0
0.7	0.088	0.075	0.000	0.088	0.023	74%	0.9
0.7	0.083	0.093	0.000	0.083	0.028	66%	1.1
0.7	0.063	0.098	0.000	0.063	0.029	53%	1.6

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Mass Balance (Reactive Silica)							
Recovery %	Feed (mg/L)	Concentrate (mg/L)	Permeate (mg/L)	Mass In	Mass Out	Balance	Concentration Factor
0.30	29	90	1	29	63	-122%	3.1
0.30	27	110	1	27	77	-190%	4.1
0.60	28	248	1	28	100	-257%	8.9
0.70	27	140	1	27	43	-57%	5.1
0.70	47	229	3	47	71	-50%	4.9
0.60	51	170	1	51	69	-35%	3.3
0.70	49	249	2	49	76	-57%	5.1
0.70	37	348	2	37	106	-187%	9.4
0.70	43	269	3	43	83	-94%	6.3

Mass Balance (Sulfate)							
Recovery %	Feed (mg/L)	Concentrate (mg/L)	Permeate (mg/L)	Mass In	Mass Out	Balance	Concentration Factor
0.3	3,300	2,000	3	3,300	1,401	58%	0.6
0.3	3,000	6,000	3	3,000	4,201	-40%	2.0
0.6	3,300	5,000	4	3,300	2,002	39%	1.5
0.7	3,200	6,000	4	3,200	1,803	44%	1.9
0.7	3,600	5,000	5	3,600	1,504	58%	1.4
0.6	3,500	4,000	4	3,500	1,602	54%	1.1
0.7	4,600	4,000	4	4,600	1,203	74%	0.9
0.7	3,800	7,000	5	3,800	2,104	45%	1.8
0.7	3,700	7,000	2	3,700	2,101	43%	1.9

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Mass Balance (Bicarbonate)							
Recovery %	Feed (mg/L)	Concentrate (mg/L)	Permeate (mg/L)	Mass In	Mass Out	Balance	Concentration Factor
0.3	275	3,538	216	275	2,541	-826%	12.9
0.3	110	244	61	110	189	-72%	2.2
0.6	110	281	43	110	138	-26%	2.6
0.7	104	256	49	104	111	-7%	2.5
0.7	201	610	44	201	214	-6%	3.0
0.6	207	464	43	207	211	-2%	2.2
0.7	220	464	40	220	167	24%	2.1
0.7	214	610	49	214	217	-2%	2.9
0.7	214	647	49	214	228	-7%	3.0

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APPENDIX 8

							PBR_1_B-MSTAReuk	PBR_1_S-MSTAReuk	PBR_9_B-MSTAReuk	PBR_9_S-MSTAReuk
Eukaryota	Apicomplexa	Coccidia	Eucoccidiorida	Eimeriidae	Unclassified	Unclassified	0.014830194	0	0.00708667	0.005400443
Eukaryota	Bacillariophyta	Bacillariophyceae	Bacillariales	Bacillariaceae	Nitzschia	Nitzschia palea	0.029660389	0.04073942	0	0.027002214
Eukaryota	Bacillariophyta	Bacillariophyceae	Naviculales	Naviculaceae	Navicula	Navicula sp	0.619160611	0.463410908	20.77102969	1.40951558
Eukaryota	Bacillariophyta	Fragilariophyceae	Fragilariales	Fragilariaceae	Nanofrustulum	**Nanofrustulum cf shiloi**	**41.46522319**	**7.557162499**	0.354333499	0.005400443
Eukaryota	Bacillariophyta	Unclassified	Unclassified	Unclassified	Unclassified	**Unclassified**	**17.26605369**	**20.3442481**	**71.24937992**	**77.61516444**
Eukaryota	Unclassified	Litostomatea	Unclassified	Unclassified	Unclassified	Unclassified	0	0.402301777	0.807880377	0.675055355
Eukaryota	Unclassified	Oligohymenophorea	Peniculida	Unclassified	Unclassified	Unclassified	0.037075486	0.137495544	0.198426759	0.264621699
Eukaryota	Unclassified	Oligohymenophorea	Pleuronematida	Cyclidiidae	Cyclidium	Cyclidium glaucoma	0.029660389	0.371747212	0.694493657	0.739860669
Eukaryota	Unclassified	Oligohymenophorea	Unclassified	Vorticellidae	Vorticella	Vorticella fusca	0.011122646	0.132403117	0.588193608	6.350920776
Eukaryota	Unclassified	Spirotrichea	Sporadotrichida	Oxytrichidae	Sterkiella	Sterkiella sp	0	0.02036971	0	0.016201329
Eukaryota	Unclassified	Unclassified	Choanoflagellida	Salpingoecidae	Lagenoeca	Lagenoeca sp	0.014830194	0	0	0
Eukaryota	Unclassified	Unclassified	Choanoflagellida	Salpingoecidae	Salpingoeca	Salpingoeca napiformis	0	0.015277283	0.304726809	0.064805314
Eukaryota	Unclassified	Unclassified	Unclassified	Unclassified	Unclassified	Unclassified	0.114934006	0.22915924	0.240946779	0.151212399
Fungi	Cryptomycota	Unclassified	Unclassified	Unclassified	Unclassified	**Unclassified**	**38.36200504**	**69.26210725**	**3.677981716**	**10.46605822**
No Hit	No Hit	No Hit	No Hit	No Hit	No Hit	No Hit	1.987246033	1.013393084	1.084260506	2.20878112
Plantae	Chlorophyta	Chlorophyceae	Chlamydomonadales	Chlamydomonadaceae	Chlamydomonas	Chlamydomonas sp	0.048198131	0.010184855	0.02126001	0

APPENDIX 9

B054 Water Quality Analysis of Pilot PBR

Parameters	11/14/2017 (70% Permeate Recovery)					
	Raw Well 2	PBR Influent	PBR Effluent	RO Feed	RO Concentrate	RO Permeate
pH	7.76	7.34	8.47	7.87	7.62	8.87
Conductivity (µS/cm)	6,410	6,220	6,130	6,690	16,850	230
TDS (mg/L)	4,540	4,380	4,520	4,779	12,036	164
Salinity (mg/L)	3,190	3,200	3,190	3,521	8,868	121
Color at 455 nm (Pt Co)	1	3	12	10	25	1
Turbidity (NTU)	0.182	0.58	0.52	0.663	1.03	0.18
Total Hardness (mg/L as $CaCO_3$)	2,550	2,550	2,545	2,335	6,000	4
Calcium Hardness (mg/L as $CaCO_3$)	1,320	1,270	1,240	1,090	1,270	2
Total Alkalinity (mg/L as $CaCO_3$)	230	150	195	80	190	33
Total Silica (mg/L)	23	110	56	28	69	1.8
Calcium (mg/L)	528	508	496	436	508	0.8
Magnesium (mg/L)	308	320	326	311	1,183	0.5
Iron (mg/L)	0.01	0.01	0.01	0.07	0.22	0.01
Manganese (mg/L)	0.09	0.11	0.1	0.1	0.14	0
Reactive silica (mg/L)	21	64	48	19	109	1.4
Bicarbonates (mg/l)	281	183	238	98	232	40
Sulfate (mg/L)	2,600	2,600	2,700	2,899	7,600	3
Nitrate-N (mg/L)	7.65	19.2	17	17	26	12
Orthophosphate (mg/L)	0.07	4.8	0.36	0.36	0.72	0.03
Antimony (mg/L)	0.02	0.02	0.02	0.02	0.02	ND
Arsenic (mg/L)	ND	0.01	ND	ND	ND	ND
Barium (mg/L)	0.01	0.01	ND	ND	ND	ND
Copper mg/L)	ND	ND	ND	0.07	0.18	ND
Nickel (mg/L)	0.03	0.03	0.03	0.03	0.05	ND
Selenium (mg/L)	ND	ND	ND	ND	ND	ND
Zinc (mg/L)	0.08	0.13	ND	0.07	0.26	ND
Boron (mg/L)	0.69	0.67	0.64	0.64	0.67	0.57
Total COD (mg/L)	29	32	36	76	404	0
TOC (mg/L)	0.56	0.62	2.6	5	8.2	0.35

*PBR Effluent stored in secondary containment tanks for~ week was used as RO Feed

B054 Water Quality Analysis of Pilot PBR

Parameters	11/16/2017 (70% Permeate Recovery)					
	Raw Well 2	PBR Influent	PBR Effluent	RO Feed	RO Concentrate	RO Permeate
pH	7.72	7.48	8.69	7.09	7.32	6.55
Conductivity (µS/cm)	6,356	6,132	6,328	7,220	23,260	306
TDS (mg/L)	4,540	4,380	4,520	5,157	16,614	219
Salinity (mg/L)	3,190	3,200	3,190	3,800	12,242	161
Color at 455 nm (Pt Co)	0	18	16	6	26	1
Turbidity (NTU)	0.14	0.66	0.39	0.18	1.31	0.05
Total Hardness (mg/L as $CaCO_3$)	2,550	2,580	2,560	2,520	6,820	5
Calcium Hardness (mg/L as $CaCO_3$)	1,270	1,250	1,250	1,220	1,200	1
Total Alkalinity (mg/L as $CaCO_3$)	280	260	190	175	530	35
Total Silica (mg/L)	22	130	44	54	190	2.6
Calcium (mg/L)	508	500	500	488	480	0.4
Magnesium (mg/L)	320	333	328	325	1,405	1
Iron (mg/L)	0.01	0.01	0.01	0.04	0.05	0
Manganese (mg/L)	0.09	0.11	0.08	0.12	0.17	0
Reactive silica (mg/L)	21	91	39	50	348	3
Bicarbonates (mg/l)	342	317	232	214	647	43
Sulfate (mg/L)	3,600	3,600	3,700	4,300	10,000	5
Nitrate-N (mg/L)	7.65	19.5	16.5	16.2	28	10
Orthophosphate (mg/L)	0.1	4.7	0.41	0.40	0.79	0.02
Antimony (mg/L)	0.02	0.02	0.02	0.02	0.03	ND
Arsenic (mg/L)	0.01	ND	ND	ND	ND	ND
Barium (mg/L)	ND	0.01	ND	0.01	0.04	ND
Copper mg/L)	ND	ND	ND	0.05	0.22	ND
Nickel (mg/L)	0.03	0.03	0.03	0.03	0.05	ND
Selenium (mg/L)	0.01	ND	ND	ND	0.03	ND
Zinc (mg/L)	ND	0.05	ND	0.12	0.54	ND
Boron (mg/L)	0.64	0.67	0.61	0.68	0.92	0.53
Total COD (mg/L)	32	48	55	125	375	1.4
TOC (mg/L)	0.57	0.62	2.7	3.1	6.2	0.23

*RO Feed is similar to PBR Effluent