Cultured Ecology Generation 2: Demonstrating Nutrient and Fine Particle Removal in Tahoe Basin Stormwater

Alan Heyvaert[1]
Steve Patterson[2]
Scott Brown[3]
John Reuter[4]
Collin Strasenburgh[4]

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Prepared by
[1]Desert Research Institute, Division of Hydrologic Sciences
Reno, NV 89521
[2]Bio x Design, PO Box 1293, Poteau, OK 74953
[3]Nevada Tahoe Conservation District, 400 Dorla Court,
Zephyr Cove NV 89448
[4]University of California, Davis, Department of Environmental
Science and Policy, Davis, CA 95616

Prepared for
Nevada Division of State Lands,
901 S. Stewart Street, Suite 5003,
Carson City, NV 89701
Nevada Division of Environmental Protection,
901 South Stewart St, Suite 4001,
Carson City, NV 89701

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ABSTRACT

A demonstration project utilizing cultured periphyton to treat stormwater runoff was constructed, operated, and monitored for approximately nine months (mid-February to early November) in 2008, located adjacent to a set of existing stormwater ponds in Incline Village, Nevada. The main goal of this project was to demonstrate the applicability and effectiveness of periphyton-based cultured ecologies as a biologically-based advanced treatment system to reduce fine sediment particles and nutrient loads entering Lake Tahoe. A pilot study in 2006 had provided encouraging results, so the demonstration project was designed as a second generation approach to test the cultured periphyton treatment methods in a real-world setting.

A three-tank system was constructed and seeded with locally occurring periphyton species. Once established, periphyton growth was harvested approximately every two to four weeks. Samples for water chemistry analysis were collected approximately every two weeks, once before harvesting of the periphyton, and once midway between harvests. In addition to monitoring pollutant removal from baseflow on a regular basis, the treatment of stormwater from two larger runoff events was sampled and analyzed during the demonstration period. The first event on October 3rd produced 0.33 inches of rain and lasted 7.5 hours, while the second event on November 1st produced 0.89 inches of rain over a 24 hour period. Also, two experiments were conducted to simulate stormwater runoff events, and a nitrogen fertilization experiment examined the enhancement of soluble phosphorus removal with biological uptake.

Over the course of the nine month demonstration period 4,629 grams (dry weight) of material were harvested. On a per day basis (266 days) the average mass harvested was 17.4 g/day. Between 11–14 grams of phosphorus were removed over that period from an average flow of 9.4 L/minute (2.5 gal/min), and the average orthophosphate (SRP) levels were reduced by 36 percent (±16%) from already low influent concentrations, while average nitrate concentrations were reduced by 60 percent (±48%). Nitrogen fertilization helped to reduce SRP levels to 5 µg/L or less, substantially lower than observed during operation of the first pilot system and approaching the analytical detection limit. Treatment also reduced mean nitrate effluent levels to 4 µg/L or less.

Combined results from the two natural runoff events and from the two simulated runoff experiments allowed calculation of realistic load reductions for SRP (39% ±23%), total phosphorus (34% ±12%), nitrate (41% ± 30%), total Kjeldahl nitrogen (30% ±23%), suspended sediment (29% ±29%) and fine sediment particles (16% ±13%).

The site selection process demonstrated potential for application of this cultured periphyton technology to a wide range of places and situations in the Tahoe Basin. Active deployment would require modest infrastructure development to provide the electricity and baseflow. Because the cultured periphyton system is modular, it can be sized for each site to accommodate the anticipated runoff volumes requiring treatment. As a polishing system for a detention basin or a wetland, the cultured periphyton system can remove dissolved nutrients and fine sediments to levels not achieved by basins or wetlands alone. Initial estimates indicate that runoff from a small neighborhood catchment with a design storm volume of 5,000 cubic feet could be treated over a period of three days with a setup around 3.5 times the size of this demonstration system.

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ACRONYMS AND ABBREVIATIONS

BMP	Best Management Practices
CEG2	Cultured Ecologies Generation 2
CWA	Clean Water Act
DIN	Dissolved Inorganic Nitrogen
EC	Electrical Conductivity
EIP	Environmental Improvement Program (or a project of that program)
FSP	Fine Sediment Particles
LOI	Loss-On-Ignition
LRWQCB	Lahontan Regional Water Quality Control Board
NDEP	Nevada Division of Environmental Protection
ONRW	Outstanding Natural Resource Water
RSWMP	[Tahoe] Regional Stormwater Monitoring Program
SRP	Soluble Reactive Phosphorus (orthophosphate)
TDP	Total Dissolved Phosphorus
TERC	[UCD] Tahoe Environmental Research Center
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TRPA	Tahoe Regional Planning Agency
TSS	Total Suspended Sediment
USEPA	United States Environmental Protection Agency

INTRODUCTION

Target pollutants of the Total Maximum Daily Load (TMDL) currently under development in the Lake Tahoe Basin include phosphorus, nitrogen, and fine sediment particles. Research has implicated these pollutants as key causes in the dramatic decline of Lake Tahoe's clarity over the last three decades. The current estimate (Lake Tahoe TMDL Technical Report, 2009) of the loads of these pollutants entering the lake is:

- Total Nitrogen, 397 Metric Tons (MT)/yr
- Total Phosphorus, 46 MT/yr
- Total Fine Sediment Particles, 48.14 x 1019 particles (FSP <16 μm diameter)

It is estimated that a 65% reduction in each of these pollutants is likely to be required to reach the target lake clarity of 29.7 meters average annual Secchi depth (Lake Tahoe TMDL Technical Report, 2009). Continued implementation of existing technology, including current designs for constructed wetlands and treatment basins, may not be adequate at reducing the inputs of dissolved nutrients and fine sediment particles to reverse declining clarity. The Tahoe TMDL work program and the Draft Lake Tahoe Basin Science Plan highlight the need to identify new approaches to enhance currently used BMPs and to develop and test alternative and advanced technologies (Roberts *et al.*, 2004; Draft Lake Tahoe Basin Science Plan, 2006; IWQMS, 2008).

Periphyton, though variously defined, generally refers to the assemblage of algae, cyanobacteria, diatoms, bacteria and other microorganisms that attach to—and use as a substrate for growth—the submerged surfaces of plants, rocks, soil, or other structures (Wetzel, 2001a). Periphyton has several characteristics (Wetzel, 1996) potentially useful for water quality improvements in the Tahoe Basin including:

- The creation of a mucilaginous matrix that physically traps fine sediment particles and removes them from the water column.
- The ability to remove dissolved nutrients directly from the water column.
- The ability to remove nutrients at low concentrations through assimilation during growth.
- Biological activity at cool temperatures in winter and spring before wetland macrophytes have begun growth.

The key issue is whether these potentially useful characteristics can be put to work in an effective and practical way to help achieve a reduction in TMDL pollutants.

Background

The ability of periphyton in natural systems to reduce the transfer of nutrients from wetlands to associated lakes has been recognized for some time (Howard-Williams and Allanson, 1981; Wetzel, 1996). Pioneering attempts to utilize periphyton for nutrient removal from sewage date back over 20 years (Sladeckova *et al.*, 1983). Adey *et al*. (1993) describe a system that successfully removed phosphorus from agricultural runoff in Florida. Rapid removal of phosphorus to very low concentrations in laboratory mesocosms was shown by Mulholland *et al*. (1995). Pilot studies of outdoor systems of combined submerged aquatic vegetation and periphyton in Florida also showed removal to low concentrations (DeBusk *et al*., 2004).

The capability of the sticky mucilages excreted by periphyton assemblages, and the physical binding by algal threads, to aggregate sediments and reduce erosion has also been demonstrated (Sutherland *et al*., 1998). Adey *et al*. (1993) noted the ability of periphyton to adsorb organic particulates from the water column. Removal of both organic and inorganic suspended sediments via the biofilms associated with floating plant roots was shown by Smith and Kalin (2001).

Periphyton research has a long history at Lake Tahoe (Loeb and Reuter, 1981; Reuter, Loeb and Goldman, 1983), with increased growth of algae on rocks near the shore of the lake being one of the first visible signs of a potential water quality problem in the 1960s (Hackley *et al*., 2004). A periphyton-based treatment system, unlike systems constructed around wetland macrophytes, has the potential to function in cold air and water temperatures that prevail during the Tahoe Basin spring runoff season. Periphyton research at the lake has shown a high periphyton growth rate in the spring in the relatively shallow (< 0.5 m) littoral zone (Hackley *et al*., 2004).

Construction of a pilot "cultured ecologies" system was begun in the fall of 2005 at the UCD Tahoe Environmental Research Center field lab in Tahoe City, CA. That test system was fully functional using a baseflow of emergent groundwater and monitored from April through September 2006 (Patterson *et al.*, 2007). The results of that study provided encouraging results. In two tests of synthetic stormwater processed through the system, turbidity was reduced from 135 NTU to 13, and from 52 NTU to 8. Particles less than 16 µm in diameter were removed at an efficiency of better than 80% by mass, well above the 30-40% reduction target currently modeled for Lake clarity improvement. Over 3.6 grams of phosphorus per square meter were removed in a four month test period, and it is estimated that 10 g/m^2 or more could have been removed on an annual basis (Patterson *et al*., 2007).

The next step was to test this cultured ecology system in a real-world setting, with periodic monitoring and analysis to assess its effectiveness and to investigate design refinements that would improve overall productivity and reduce maintenance requirements.

Project Goals and Objectives

The main goal of this project was to demonstrate the applicability and effectiveness of a periphyton biofilm system as an ecologically-based advanced treatment technology that could reduce stormwater pollutant loadings into Lake Tahoe. This second generation system was installed at an existing stormwater site in the Tahoe Basin and then monitored during the succeeding nine months to test the basis for a potentially wider application of this technology in the Tahoe Basin.

Several specific objectives were addressed during the period of this project, including:

- Construction and operation of a periphyton-based treatment system at an existing stormwater site with adequate baseflow and real stormwater runoff.

- Periodic monitoring of performance during the demonstration period to assess system effectiveness and to help determine the degree to which this technology may achieve treatment levels needed for anticipated TMDL numeric targets.
- Optimization experiments to determine whether nitrogen fertilization could improve the removal efficiency for soluble phosphorus to levels below what was demonstrated during the first generation pilot project.
- Development of information relevant to wider application of this technology in the Tahoe Basin concerning site requirements, design options, operation and maintenance guidelines, and costs.

METHODS

Site Selection Process

One of the key objectives of the Cultured Ecology Generation 2 (CEG2) demonstration project was to identify appropriate site selection criteria and develop a checklist that could be used as the basis for determining locations for future deployment of cultured periphyton systems.

- Site selection criteria developed included these key elements:
- A detention basin, pond, or wetland to retain stormwater runoff
- A perennial source of baseflow to maintain the cultured periphyton ecologies between storm events
- Access to electric power for the air and water pumps
- Direct sunlight throughout the year to maximize algae growth
- Ability to protect the site from vandalism and for public safety

Nevada Tahoe Conservation District (NTCD) staff contacted representatives of 12 agencies and organizations in the eastern Tahoe Basin for their suggestions about candidate sites. From these suggestions field assessments were made of seven potential sites by NTCD, Bio x Design (BXD), Desert Research Institute (DRI), and Nevada Division of State Lands (NDSL) personnel. Some sites were visited several times. Table 1 lists the sites where a field review was conducted, as well as any significant concerns identified.

After review and discussion among the project team and sponsors, the consensus was that the Village Blvd and County Club basins provided the best opportunity for the implementation of the CEG2 demonstration. In addition, the Kahle Drive wetland was viewed as having high potential for a future full-scale implementation, if some additional infrastructure was provided.

Permits were obtained from the basin operator (Washoe County) and the land owner (US Forest Service)--the latter requiring documented public input from adjacent land owners regarding visual and auditory impacts, as well as safety concerns, if any. Temporary electrical power was provided to the site by Pacific Power and Light.

Table 1. Candidate sites for CEG2.

Site	Location	Concern
Lower Pond (aka Mill Pond)	Incline Village	No urban stormwater and no perennial flow
Village Green Pond	Incline Village	No urban stormwater and no perennial flow
Glenbrook Golf Course Pond (several potential locations)	Glenbrook	No urban stormwater
Buchanan Sediment Basin	Stateline	No stormwater retention and no perennial flow
Kahle Constructed Wetlands	Stateline	Limited perennial flow, security, power access
Edgewood Golf Course Pond 6	Stateline	Potential aesthetic impact, obscured southern aspect, site access
Village Blvd and County Club basins	Incline Village	Limited perennial flow, security, power access

Site Characteristics

The Village and Country Club installation site was located in Incline Village, NV between two treatment ponds (Figure 1) that treat runoff water from areas of residential land use, and primary and secondary paved roads. Most of the runoff is delivered into the east treatment pond (pond 1) from sections of Country Club Drive, Eagle Drive and Village Boulevard. Slopes are relatively steep on Country Club and Eagle, but almost level on Village Boulevard near the treatment system. Some overland runoff could occur from exposed slopes adjacent to the north side of the treatment ponds. Water flows from the east pond to the west pond and then into Third Creek. Intercepted groundwater maintains pond levels between storm events throughout the year.

Three periphyton treatment tanks were sited on flat ground between ponds 1 and 2 (see Figures 1 and 2). Tanks were placed on a bed constructed from 8-inch square landscape pavers placed on top of the ground surface covered with a thin layer of mulch. These pavers were placed dry with no cement so they would be easy to remove when the project was completed. Autosamplers and pumps were housed in steel job boxes behind the tanks. A plywood backdrop covered with reflective flashing was constructed directly behind the culture tanks to reflect sunlight into the tanks (Figure 3). The backing structure was approximately 15 wide by 4 feet high. The entire cultured ecology system was surrounded by 5 foot high chain-link fence, approximately 16 x 16 feet square. Access into the fenced area was via a 3-foot wide locking gate. All materials including fencing and gravel were removed at the end of the test period, and the restored ground was mulched with pine needles and wood chips.

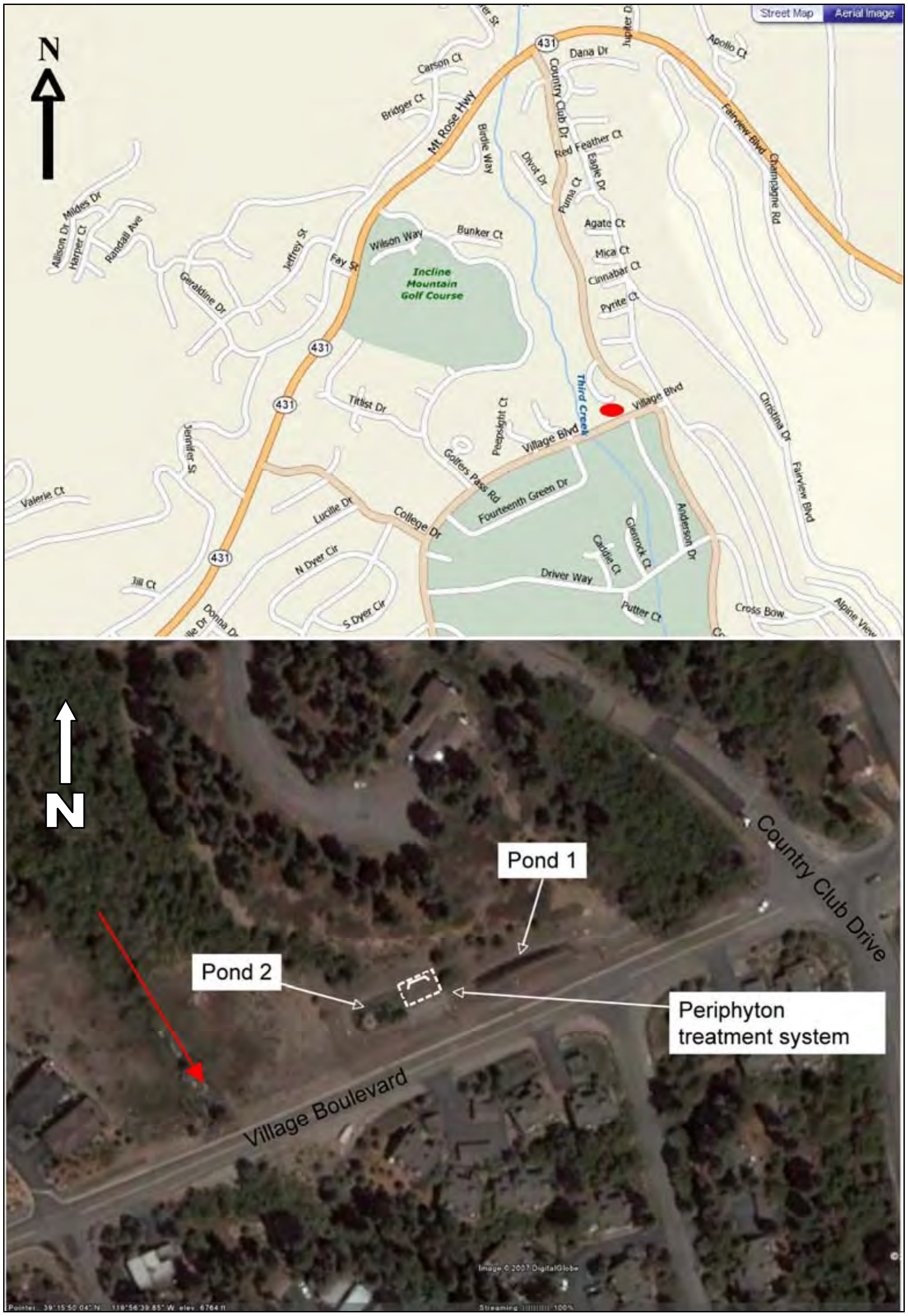


Figure 1. Location of installation site for periphyton treatment system at Village Blvd and Country Club Dr in Incline Village, NV. Red line and arrow shows location and flow direction of the Third Creek channel.

Figure 2. Footprint of periphyton treatment system prior to installation.

System Design and Operation

The physical structure of the cultured periphyton system consisted of three cells connected in series (Figures 3 and 4). Each cell consisted of a cylindrical, photosynthetic wavelength translucent fiberglass tank (1.2 m H x 0.8 m D) manufactured by Solar Components Corporation, with claimed transmissivity to light of 87 percent. Each tank held a cylindrical screen (Figure 5) that served as a periphyton growth substrate. Screen frames were constructed of 1.9 cm PVC tubing. The screen material was woven polyester shade cloth. The screens were approximately 1m high and 0.5 m in diameter, for a total one side surface area of 1.57 m^2. The footprint occupied by each cylindrical tank was 0.46 m^2. Clear acrylic lids over the algae culture tanks minimized atmospheric inputs and evaporation from the system. Note that this system was not sized to treat typical runoff volumes delivered into these stormwater ponds. Rather the set of tanks was suitable for testing an experimental on-site treatment system, drawing on a portion of the total runoff volumes passing through the ponds. A discussion of treatment capacity in terms of the number of tanks necessary for runoff treatment of typical storm volumes is available in Patterson et al. (2007).

Figure 3. Cultured Ecology Generation 2 (CEG2).

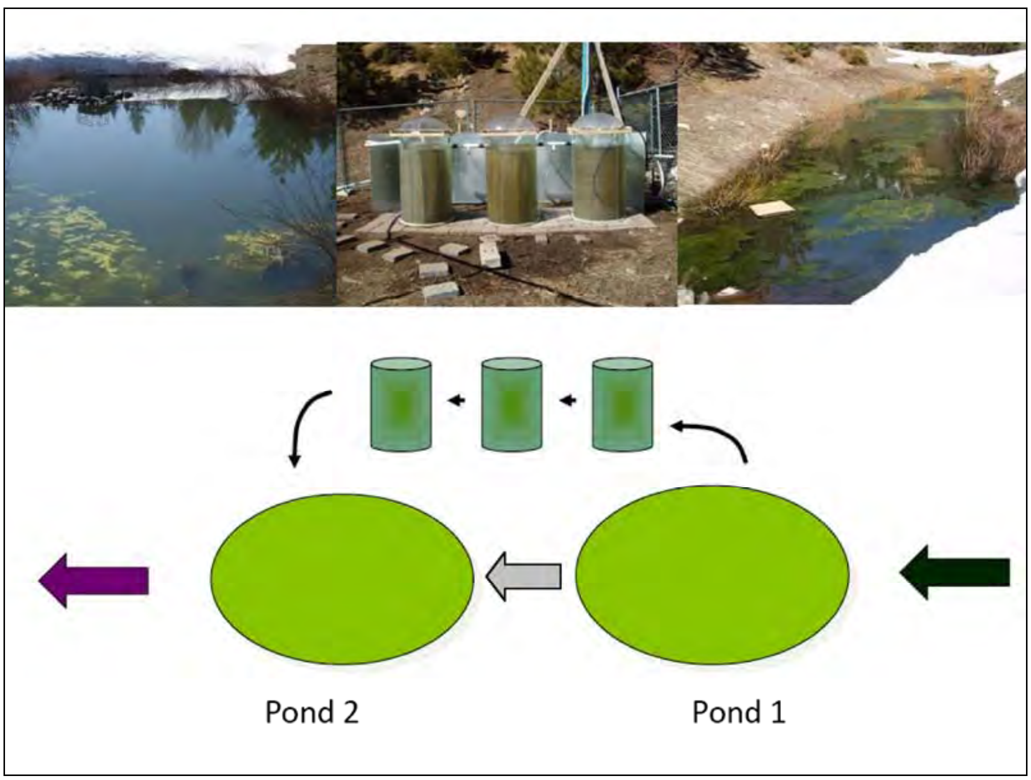


Figure 4. System layout. Water was pumped from Pond 1 (or Third Creek after 07/25/08) into the first tank, with gravity flow thereafter. A corrugated pipe connected Ponds 1 and 2 at the waterline. Pond 2 outflow is discharged into Third Creek.

a) b)

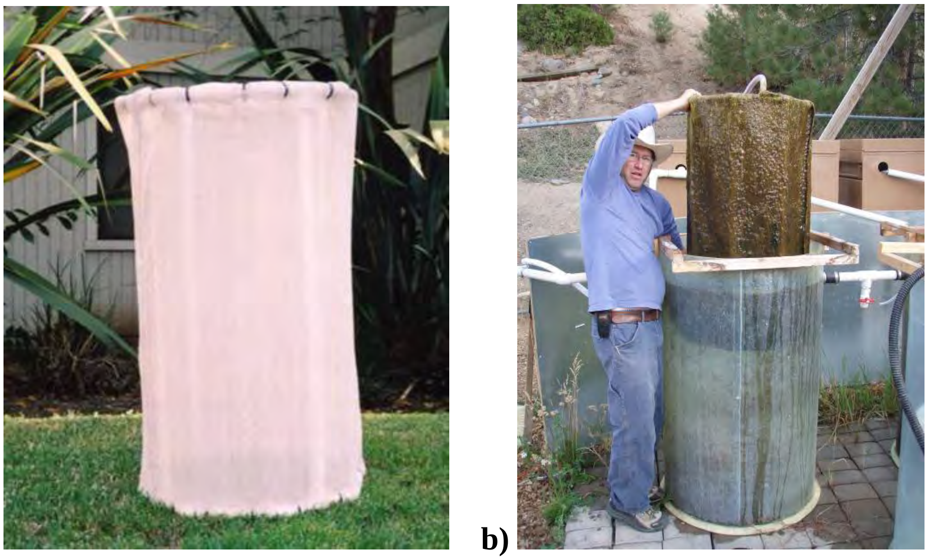


Figure 5. Periphyton substrate screen a) prior to first deployment b) with typical periphyton biofilm before harvesting.

Water for treatment was brought into the system by two different methods over the course of system operation. Initially, water was pumped from Pond 1 into the first tank, and then moved via gravity flow from tank to tank and out of the system. Treated water exiting the system was returned to Pond 2 (Figure 4). Assuming minimal evaporation, the outflow rate approximately equaled inflow. For the entire project period flow through the test system averaged 9.4 L/min (2.5 gal/min) but varied from 7.2 to 12.5 L/min (1.9–3.3 gal/min) due to variation in pump output, occasional flow restrictions caused by algae growth in the source water stormwater pond, and a change in the method of source water delivery to the system. At 9.4 L/min (564 L/hr) the nominal hydraulic retention time for the system was 3.3 hours (0.14 day), or about 1.1 hours per tank.

As discussed below, the growth of nuisance floating algae in Pond 1 caused various problems for the CEG2 system. For the latter part of the demonstration period, the source water for the system was changed to Third Creek beginning July 25, 2008. This provided cooler water through a gravity feed-line into the first tank without pumping. Subsequent movement through the tanks was the same as previously described, although average flow rate increased about 34% (from 2.11 to 2.83 gal/min).

An air compressor (Aquatic Eco-Systems SL-170) supplied a steady air stream into a 2-inch Geyser Pump™ (Geyser Pump Tech) (Figure 6) installed within each tank to produce pulsed, turbulent conditions by creating a large belch or bubble of air every nine to ten seconds. When this bubble rose to the surface it carried water along with it and caused a breaking wave at the water surface. At the same time water was drawn down along the sides of the tank to replace rising water, yielding mixed conditions throughout the tank.

Sheet metal flashing was used to create a reflective backdrop on the north side of the algae tanks (see Figures 3 and 6). This wall reflected light back into the tanks on the north side and was intended to increase algal growth and productivity by increasing the light available to the system, especially under winter low sun angle conditions.

Water and outside air temperatures were recorded hourly throughout the study period.

a) **b)**

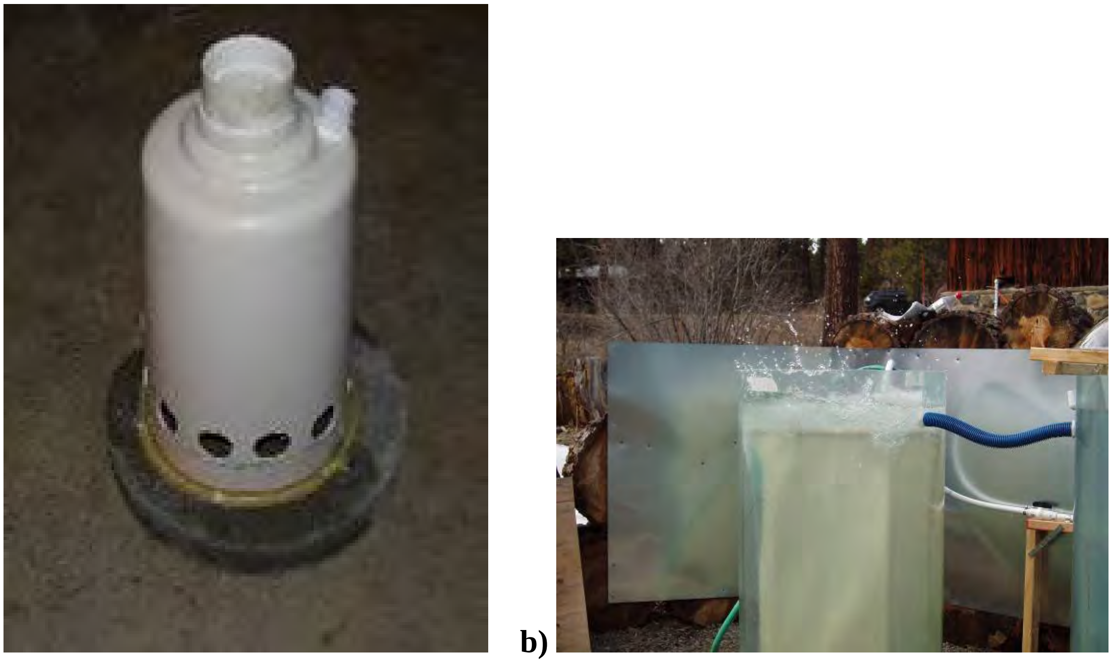


Figure 6. System components a) geyser pump b) geyser pump in action, with reflective backdrop.

Periphyton Seeding

The tanks were inoculated on multiple dates (specifically 10/23/07, 11/16/07, 5/19/08) with periphyton harvested from Tahoe Basin sources. Small rocks supporting periphyton were collected from the littoral zone of Lake Tahoe and from the Truckee River at the outflow of the lake. These rocks were placed in the tanks and algae from the rocks allowed to colonize the tank screens. Rocks were removed several weeks later, after growth had been established in the tanks. There was no attempt at species selection involved in the seeding. The idea was to inoculate the system with a variety of organisms and allow the ones best adapted to the system to survive.

Two tanks were established at the TERC field lab in Tahoe City beginning on October 10, 2007 (Figure 7), while permits and permissions to use the Village Boulevard site and electrical power were being obtained. The two tanks were moved to the Village Boulevard site the week of February 14, 2008 and a new third tank added. The three tank system was fully operational at the Village and Country Club site on February 14, 2008. Water quality autosamplers were installed and operational by February 28, 2008.

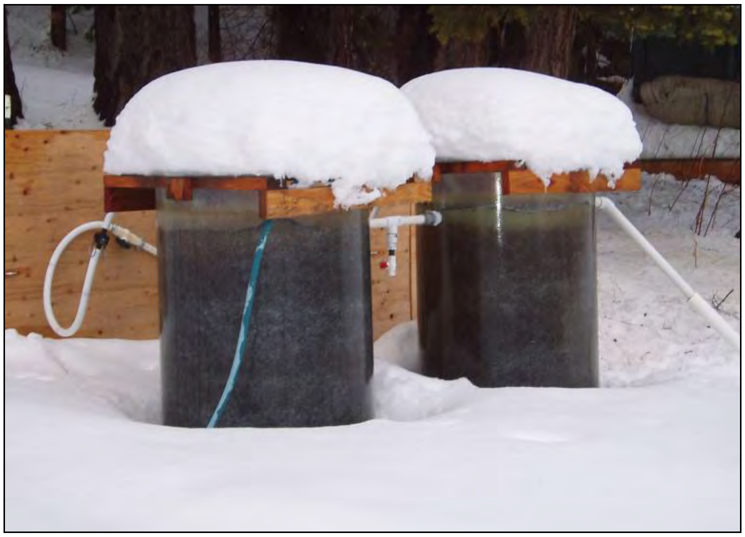


Figure 7. Tanks in snow at TERC field facility in Tahoe City.

Periphyton Harvesting

Once established, periphyton growth was periodically harvested. The period from seeding to growth of first harvestable quantities was approximately four weeks. Following initial establishment, the periphyton was harvested approximately every four weeks. One objective of regular harvesting was to keep the periphyton in an actively growing condition and to remove sequestered nutrients and fine sediment particles from the system. Harvesting removed all periphyton that could be vacuumed from the screens, but sufficient residual material remained in screen crevices to support rapid regrowth.

Harvested biomass was processed and measured separately for each tank. To conduct this harvest, the screen was removed and periphyton collected from it using a wet-dry shop vacuum (Rigid 16 gallon WD1851) (Figure 8). After screen removal, water remaining in the tank was pumped into a separate holding tank through a 75 micron mesh bag that trapped and recovered any suspended algae. The side of the culture tank was then scraped clean with a squeegee, and resulting residue was collected with the wet-dry shop vacuum. When the tank was clean, both the transferred water and periphyton screen were returned to their original tank. Material in the shop vacuum was then emptied into aluminum weighing trays and thoroughly cleaned to recover all the algae harvested from that tank.

Sampling and Analysis

Baseflow samples for water chemistry analysis were collected approximately every two weeks: once before harvesting of the periphyton, and once midway between harvests. Additional samples were collected during experimental treatments and during selected runoff events. Water quality samples were taken at four locations (Figure 9) with Isco™ automated samplers: inflow to Tank 1 (CE1), flow between Tank 1 and Tank 2 (CE2), flow between Tank 2 and Tank 3 (CE3), and outflow from Tank 3 (CE4). The automated samplers collected 1,000 mL bottles every hour over a 24 hour period. Equal volume aliquots from each individual sample bottle collected at a specific location were combined in a churn splitter, then split into three 250 mL subsamples for analysis (see Table 2 for methods).

Figure 8. Periphyton harvesting sequence: a) and b) vacuuming biofilm from screen, c) and d) pumping tank water through filter to capture dislodged periphyton.

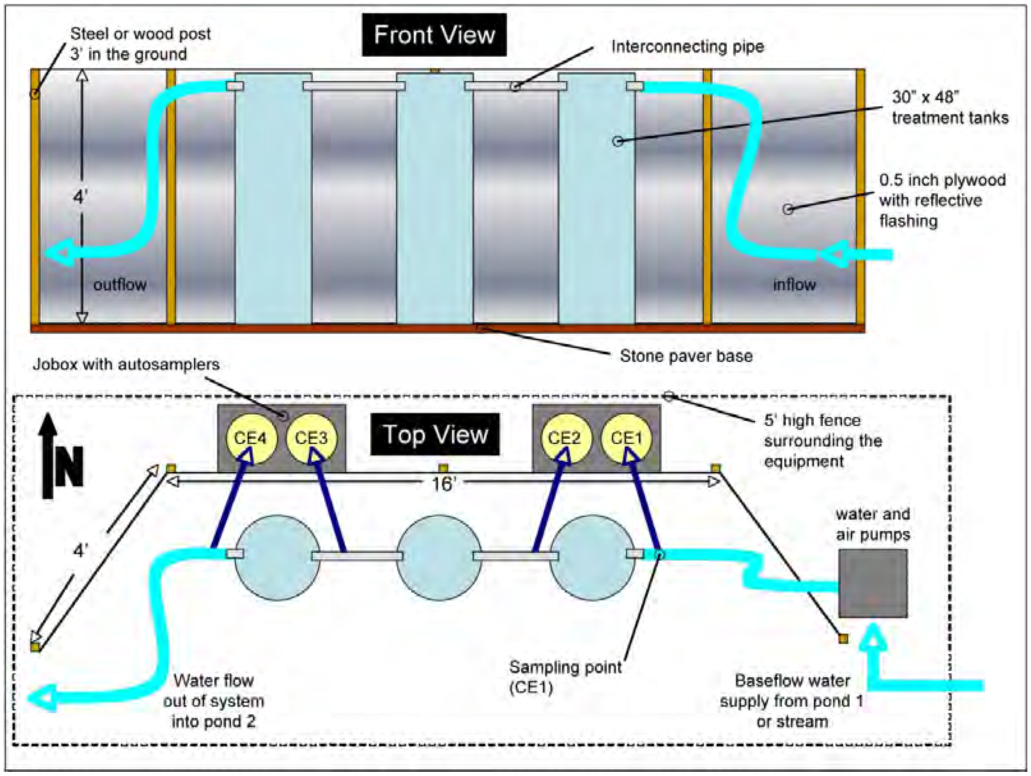


Figure 9. Locations of water quality sampling points in the system. CE1 is at the inflow to the first tank; CE2 is between tanks 1 and 2; CE3 is between tanks 2 and 3; CE4 is at the outflow from the last tank (#3) of the system.

Table 2. Analytical methods.

Parameter	Methods	Description	Detection Limit
Orthophosphate-P	EPA 365.1; or SM 4500-PE	Colorimetric, phosphomolybdate	1 µg/L
Total Phosphorus	EPA 365.1 w/ USGS I-4600-85; or EPA 365.3	Colorimetric, persulfate digestion, phosphomolybdate	1 µg/L
Nitrite-N and Nitrate-N	EPA 353.2; or EPA 353.1	Colorimetric, cadmium reduction	1 µg/L
Ammonia-N	EPA 350.1	Colorimetric, phenate	1 µg/L
Total Kjeldahl Nitrogen	EPA 351.2	Colorimetric, block digestion, phenate	50 µg/L
Total Suspended Solids	EPA 160.2; or SM 2540D	Gravimetric	0.4 mg/L
Turbidity	EPA 180.1; or SM 2130B	Nephelometric	0.1 NTU
Conductivity	SM 2510B	Probe and sensor	1 µS/cm
pH	SM 4500-HB	Probe and sensor	0.1 units
Particle Size	SM 2560	LiQuilaz, laser backscattering	NA

A 250 mL aliquot was filtered through a tared, pre-combusted, glass-fiber TSS filter. This filter was then dried and weighed. The TSS filtrate was passed through a tared 0.45 µm membrane filter, which was then dried and weighed. The sum of dry mass on these two filters represents all sampled material greater than 0.45 µm, which was reported as suspended sediment. The 0.45 µm filtered water sample was analyzed for nitrite (NO_2-N), nitrate (NO_3-N), ammonia (NH_3-N, which includes the NH_4 ammonium ion), and soluble reactive phosphorus (SRP, as orthophosphate). An unfiltered 250 mL subsample was analyzed for total phosphorus (TP) and total Kjeldahl nitrogen (TKN). The third 250 mL subsample was analyzed for turbidity, conductivity, pH and particles less than 20 µm.

The total dissolved inorganic nitrogen (DIN) was calculated as the sum of nitrate, nitrite and ammonia (including ammonium ion). Similarly, the total nitrogen (TN) was calculated as the sum of the nitrate, nitrite and total Kjeldahl nitrogen. Total dissolved phosphorus (TDP) was determined by analysis for total phosphorus on filtered samples.

The periphyton biofilm was harvested from each tank on a 3 to 6 week interval. Small subsamples were taken from each tank's harvest for identification of dominant species. These samples were placed in glass Qoorpak bottles containing Lugol's solution and stored in a dark environment at 4°C until analysis.

The remainder of the harvested periphyton biomass was placed in a disposable aluminum baking dish and weighed while wet. It was then dried in a convection oven at 55–60°C until constant weight was achieved (typically four days). The dried material was then ground to a powder by mortar and pestle and sent to the University of California at Davis (UCD) Department of Agriculture and Natural Resources Analytical Laboratory for analysis of nutrient content (total nitrogen, total phosphorus and carbon). A subsample was incinerated in a ThermoLyne 114300 Furnace at 500°C to determine loss on ignition (LOI), representing the organic (non-mineral) fraction of that sample.

Baseflow Treatment

The cultured periphyton system was operational at the Village and Country Club location for a period of approximately nine months (mid-February to early November 2008). Periodic water quality sampling was scheduled to occur twice monthly to provide a recurrent measure of overall treatment effectiveness. Autosampler ports were located at the inflow to the first tank, between each of the three tanks, and then at the outflow of the last tank (four locations as shown in Figure 9). Every other week the water quality samples were collected at all four autosampler locations on hourly intervals over a 24-hour period to represent the overall treatment characteristics during both day and night. These hourly samples from each location were composited to yield a single sample representing the average diel concentration at that location. Since flow rates through this system were relatively constant over these 24-hour periods, the composite samples were created by taking equal volume increments from each bottle.

Conditions within the system, such as nutrient concentrations, varied over time and were influenced by changes in pond temperatures and occasional minor runoff events from light rain and snowmelt. Scheduled periodic baseflow sampling was intended to capture the range of treatment efficiencies over these conditions. The sampling from larger storm runoff events were characterized separately, in greater detail, as described next.

Natural Runoff Events

The project was set up to test stormwater treatment for two larger runoff events. As with baseflow monitoring, the autosamplers collected sequential samples at each of the four locations, but the individual samples collected during these events were analyzed, rather than just single event composites. Continuous runoff rates for inflow to the treatment pond were not available, but long-term monitoring at an urban stormwater runoff site on Northwood Blvd (NW) less than 1.5 km away provides a general view of runoff patterns throughout the year for this area (Figure 10). From the time at which the periphyton treatment system was first put into operation at Village and Country Club until mid-May, there were no large runoff events at the NW site. A corresponding pattern is evident in the precipitation record from a north state-line meteorological station (NG) less than 6 km distant in Crystal Bay, NV (Figure 11). Generally, more than 0.25 inches of precipitation was required before any substantial runoff was observed at the treatment pond or at the Northwood site.

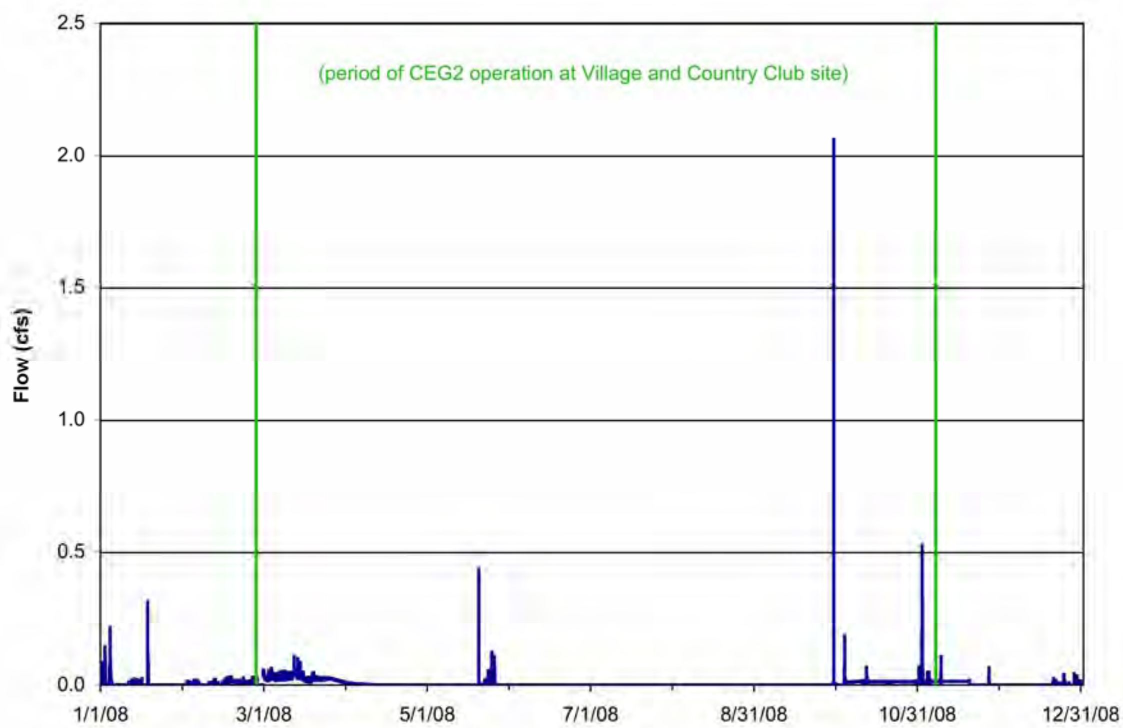


Figure 10. Continuous flow at Northwood site during 2008. Vertical green lines indicate the start and end of monitoring and testing at the Village and Country Club site for CEG2.

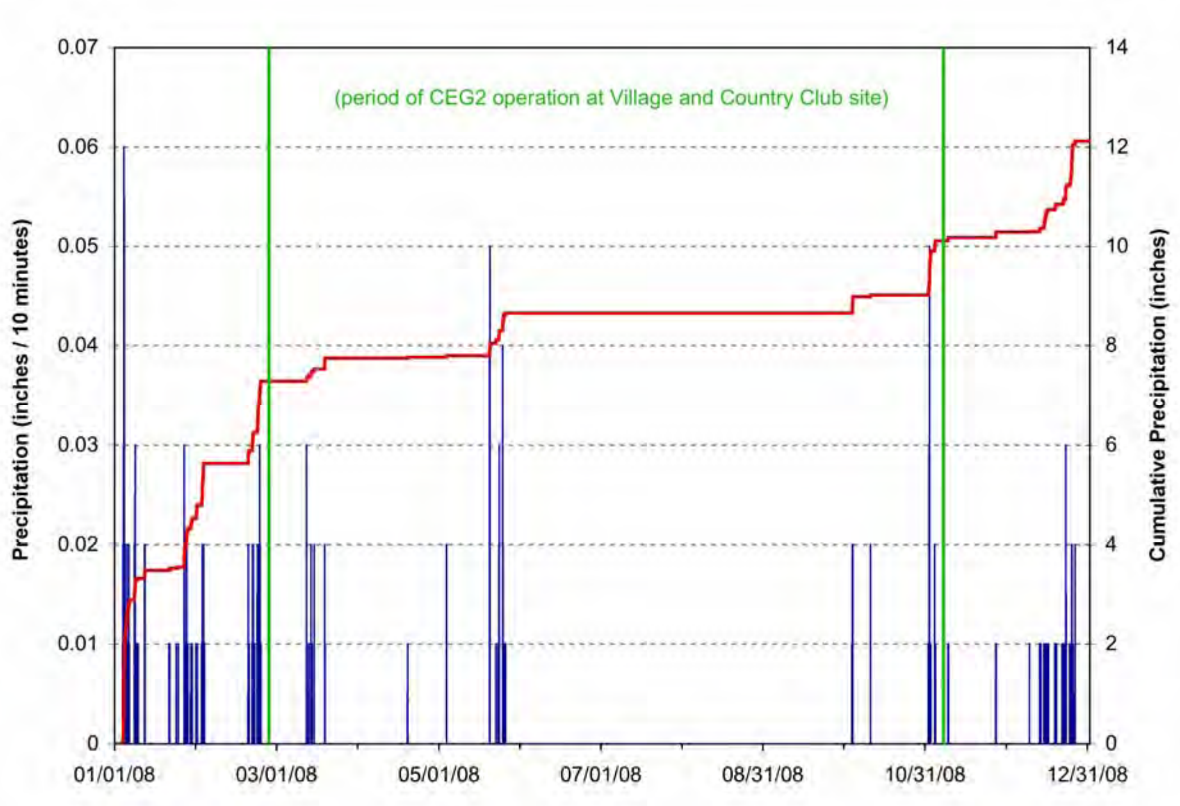


Figure 11. Precipitation intensity and cumulative volume for the north state-line meteorological station (NG) in Crystal Bay, NV. Red line shows cumulative precipitation. Vertical green lines indicate the start and end of periphyton treatment system (CEG2) monitoring and testing at the Village and Country Club site. Blue lines give precipitation intensity.

Unfortunately, the first opportunity to monitor treatment during a series of larger storm events occurred immediately after harvesting the periphyton from all three tanks on 5/19/08. Therefore, water quality sampling was not conducted during these events (May 20–25th) because the level of treatment after harvesting was expected to be very low. For several months after this, the tank harvests were set on a rotating schedule, where only one tank was harvested every ten days rather than all three tanks at once. This proved to be a significant increase in labor, however, and no events occurred for several months, so the harvest schedule was returned to a monthly interval and experiments were implemented to simulate significant runoff events.

Finally, near the end of the project period, after simulated runoff experiments (described below) were completed, two larger precipitation events occurred and these were sampled for analysis of water quality changes during the event at each of the four locations. The first event starting on October 3rd produced 0.33 inches of rain and lasted only 7.5 hours, while the second event starting November 1st produced 0.89 inches of rain over a 24 hour period (Table 3). There may have been some lag time between when precipitation was observed at the north state-line (NG) site, and when runoff passed through the receiving pond at the experimental treatment site, thus producing apparent offsets in event start times.

Table 3. Precipitation record for 2008 at the NG site meteorological station (Crystal Bay, NV). Events that occurred during the period of periphyton treatment testing at Village and Country Club site are highlighted in green for comparison to other events in the year.

WY08 NG precip event (#)	Event start	Event end	Event duration (hr:mm)	Interevent duration (hr:mm)	Event precipitation (inches)	Peak precipitation (inches/10min)	Event minimum temp (°C)	Event maximum temp (°C)	Event Type
13	1/4/08 2:00	1/6/2008 14:20	60:20	174:10	2.88	0.06	20	38	rain, snow
14	1/8/08 9:50	1/9/2008 19:30	33:40	43:30	0.44	0.03	23	33	snow
15	1/12/08 6:40	1/12/2008 10:00	3:20	59:10	0.16	0.02	31	34	snow
16	1/21/08 9:10	1/21/08 17:50	8:40	215:10	0.04	0.01	22	30	snow
17	1/24/08 3:10	1/24/08 21:20	18:10	57:20	0.03	0.01	22	29	snow
18	1/27/08 2:20	1/28/08 12:20	34:00	53:00	0.78	0.03	17	35	snow
19	1/29/08 13:50	1/30/08 4:30	14:40	25:30	0.20	0.01	17	26	snow
20	1/31/08 14:40	1/31/08 23:30	8:50	34:10	0.26	0.01	27	29	snow
21	2/2/08 15:30	2/3/08 18:40	27:10	40:00	0.84	0.02	23	29	snow
22	2/20/08 2:30	2/20/08 10:20	7:50	391:50	0.26	0.02	28	33	snow
23	2/21/08 13:20	2/24/08 20:30	79:10	27:00	1.39	0.03	21	36	snow
24	3/13/08 0:00	3/15/08 21:20	69:20	411:30	**0.25**	0.03	20	43	snow
25	3/19/08 20:10	3/19/08 23:50	3:40	94:50	**0.22**	0.02	33	34	rain
26	4/19/08 22:40	4/20/08 1:10	2:30	742:50	**0.02**	0.01	21	25	snow
27	5/4/08 13:50	5/4/08 14:10	0:20	348:40	**0.03**	0.02	44	45	rain
28	5/20/08 18:50	5/20/08 20:30	1:40	388:40	**0.25**	0.05	43	50	thunderstorm
29	5/23/08 1:20	5/24/08 9:50	32:30	52:50	**0.25**	0.03	34	49	thunderstorm
30	5/25/08 16:20	5/26/08 17:50	25:30	30:30	**0.36**	0.04	37	46	thunderstorm
1	10/3/08 18:10	10/4/08 2:00	7:50	3120:20	**0.33**	0.02	43	45	rain
2	10/10/08 14:50	10/10/08 15:00	0:10	156:50	**0.03**	0.02	31	31	trace rain
3	11/1/2008 8:00	11/2/2008 8:40	24:40	521:00	**0.89**	0.05	37	49	rain
4	11/3/2008 18:00	11/4/2008 2:30	8:30	33:20	**0.20**	0.02	30	37	snow on bare ground
5	11/8/2008 19:10	11/8/2008 21:30	2:20	112:40	0.07	0.01	36	43	rain
6	11/26/08 16:30	11/26/08 20:30	4:00	427:00	0.11	0.01	37	40	rain
7	12/9/08 9:30	12/9/08 9:30	0:00	301:00	0.01	0.01	46	46	spurious
8	12/13/2008 3:10	12/13/2008 15:10	12:00	89:40	0.07	0.01	20	32	snow
9	12/14/2008 16:40	12/16/2008 13:10	44:30	25:30	0.37	0.01	15	25	snow
10	12/18/2008 20:10	12/19/2008 10:00	13:50	55:00	0.11	0.01	26	29	snow
11	12/21/2008 12:40	12/23/2008 3:20	38:40	50:40	0.38	0.03	21	36	snow
12	12/24/08 8:20	12/26/2008 10:50	50:30	29:00	0.89	0.02	12	35	snow

During the first event, samples were collected on three-hour intervals at the inflow to the first tank (CE1) and at outflow from the system (CE4). Because of the short duration of this storm, only six samples were collected at each site. These were not composited for analysis, so analytic results represent the time-course change in concentrations during the treatment monitoring period (18 hours). The event mean concentrations (EMCs) were calculated post-analysis by using proportional time-weighted data for each sample represented in the EMC.

During the second event, 24 samples were collected at each of the four locations on two-hour intervals over a 48-hour period. Due to funding constraints at the end of this project (earlier experiments substituted for the absence of runoff events), we had to composite some samples for analyses. Therefore, the first two samples were composited at each location, then the subsequent series of 14 single samples were analyzed, after which the last nine samples were composited in sets of three. Conditions at the very beginning (during the first two samples) and toward the end of the event were considered less likely to be variable compared to the middle portion of the event; so compositing samples within these two periods was considered less likely to confound interpretation of water quality changes. Flow rate through the system was constant, so the sample composites were created by taking equal volume increments. All individual water quality samples were analyzed for turbidity prior to compositing. The EMCs were calculated post-analysis using proportional time-weighted data to represent the 48-hour sampling period.

Simulated Runoff Experiments

Given the relative lack of stormwater runoff events during most of the project period (Figure 10) it was determined that simulated runoff experiments might have to substitute for natural events. Therefore, two experiments were conducted during the project to assess treatment efficiency with elevated concentrations of nutrients and sediments delivered to the system inflow.

In the first experiment, conducted on August 14th, the bottom sediments of the Pond 1 were disturbed to enhance pond water concentrations of nutrients and fine sediment particles. Since this bottom material was in large part derived from the settling of particles delivered during past stormwater events, it was believed that that the water quality conditions created would reflect to some degree the characteristics of stormwater runoff typically observed at the site. Initial agitation consisted of bottom sediments lifted with a rake followed by stirring to fully mix the pond water. This was repeated every hour for eight hours in an attempt to maintain relatively consistent conditions within the pond during the experiment. Water quality sampling occurred at all four sites in the system every hour during the first eight hours and then on three-hour intervals during the next 15 hours. Each sample was analyzed individually without compositing. More details about this experiment are shown in Appendix B.

During the second experiment, conducted on September 17th, the inflow delivery consisted of standard stream water baseflow into Tank 1 plus spike aliquots (from a pre-mixed solution of fine road sweepings) every 10 minutes into Tank 1 over a 12 hour period. Sampling was conducted every three hours over a 24-hour period. Note that samples were not collected at CE1 (the stream water baseflow input) since there was no reason to suspect different conditions from other baseflow sampling events. Instead, samples were collected at the synthetic stormwater tank (SWT), from which aliquots were delivered directly into Tank 1 of the cultured ecologies system (where baseflow mixed with these spike aliquots). After 12 hours the spike aliquots were discontinued and flow through the system continued with stream water alone. More details about experiment 2 are shown in Appendix C.

SRP Treatment Optimization Experiments

Tahoe cultured periphyton pilot project results showed that removal of soluble reactive phosphorus (SRP) by the periphyton in that setup was limited by the supply of nitrogen in influent water (Patterson *et al*., 2007). In some Florida experiments where nitrogen was not limiting, SRP concentrations were frequently reduced to near or below the detection limit (2 µg/L) (DeBusk *et al*., 2004). Therefore, nitrogen fertilization experiments were conducted with the CEG2 system to explore the limits of SRP removal under Tahoe conditions.

After collecting approximately 16 weeks of monitoring data (3-3-08 to 6-9-08) for both influent and effluent nitrogen concentrations in the CEG2 system, calculations were made to estimate an appropriate level of nitrogen to add to the system. The goal was to drive the effluent SRP concentrations to detection limits without increasing the export of nitrate. Therefore, the initial fertilization level was intended to be quite conservative. An average influent nitrate-N concentration of 0.012 mg/L was recorded over the first 16 weeks of system operation, pre-fertiziliation. The average influent orthophosphate-P concentration during that same period was 0.008 mg/L. Using the Redfield ratio of approximately 7:1

nitrogen to phosphorus (by weight) as an optimum condition for algal growth, the "ideal" nitrogen level during that time would have been 0.056 mg/L nitrate. The difference between the average concentration and the calculated ideal was 0.044 mg/L. For the first run of nitrogen fertilization, therefore, the nitrogen addition level was set at half that amount, or 0.022 mg/L.

After 10 weeks at this level, test results showed that virtually all nitrogen continued to be removed by the algae. Therefore, for the second short run of nitrogen supplementation, the fertilization level was increased to 0.10 mg/L nitrate-N, approximately twice the calculated "ideal" nitrate level, to determine if nitrate would be exported, or if the algae would continue to remove all of it. The results are discussed below.

RESULTS AND DISCUSSION

Periphyton Harvesting and Biomass Analysis

Over the course of the nine month demonstration period 4,629 grams (dry weight) of material were harvested (Figure 12). On a per day basis (266 days) the average production was 17.4 g/day. Based on an average phosphorus concentration of 0.24 percent (Table 4), the periphyton harvests removed a total 11.11 grams of phosphorus. The footprint occupied by each tank was approximately 0.46 m^2, and taken together all three tanks occupied approximately 1.38 m^2. Therefore, the average system dry mass production of 17.4 g/day was equivalent to 12.6 $g/m^2/day$. In comparison, Adey *et al.* (1993) reported dry biomass production levels of from 15 to 27 $g/m^2/day$ in Florida algal turf experiments. The Florida system operated with warmer temperatures, greater average insolation, and without nitrogen limitation.

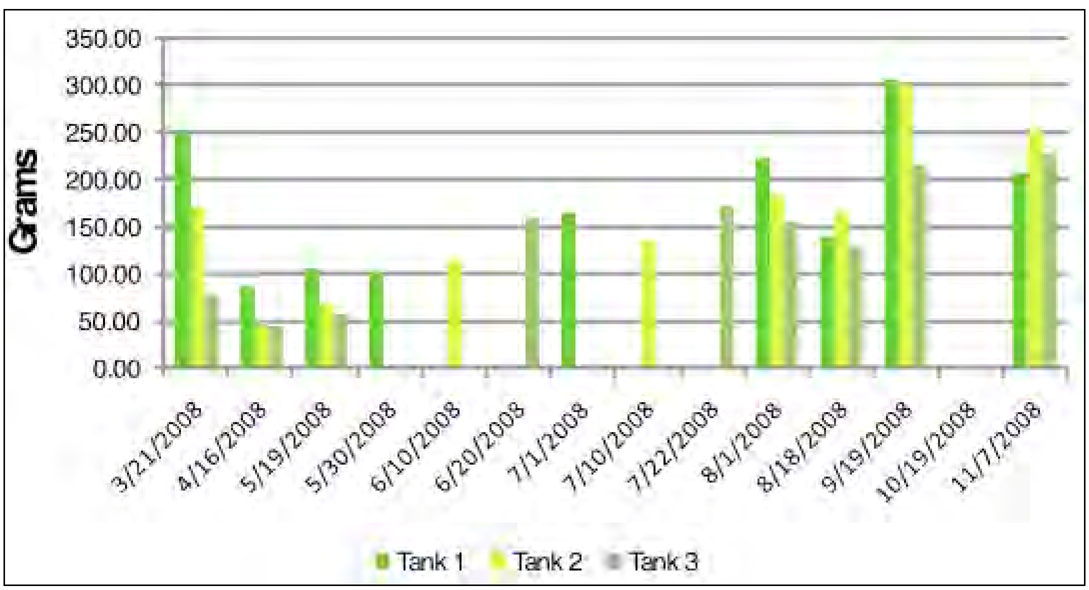


Figure 12. Dry weight of total harvested periphyton mass, shown by harvest date.

Table 4. Composition of periphyton harvest material.

Sample ID	Harvest Date	Dry Mass (g)	DM [SOP 505.02] %	N (Total) [SOP 520.03] %	C (Total) [SOP 520.03] %	P (Total) [SOP 590.01] %
Tank 1	3/21/2008	247.42	94.5	1.39	17.1	0.20
Tank 2	3/21/2008	172.50	94.9	1.21	17.5	0.22
Tank 3	3/21/2008	79.53	94.6	1.22	18.4	0.22
Tank 1	4/16/2008	87.00	95.5	1.07	19.3	0.23
Tank 2	4/16/2008	47.03	94.6	1.06	18.1	0.21
Tank 3	4/16/2008	43.91	94.8	1.04	18.9	0.27
Tank 1	5/19/2008	107.04	93.9	1.37	21.3	0.25
Tank 2	5/19/2008	68.28	93.9	1.45	22.3	0.25
Tank 3	5/19/2008	57.42	94.1	1.59	22.7	0.25
Tank 1	5/30/2008	102.28	96.3	1.08	13.0	0.25
Tank 2	6/10/2008	115.04	95.5	1.57	16.2	0.21
Tank 3	6/20/2008	158.04	95.5	1.61	14.9	0.17
Tank 1	7/1/2008	164.596	95.5	1.75	15.4	0.19
Tank 2	7/10/2008	135.721	94.0	1.97	15.8	0.14
Tank 3	7/22/2008	171.368	94.0	1.89	15.9	0.13
Tank 1	8/1/2008	222.372	94.0	1.80	17.3	0.21
Tank 2	8/1/2008	184.872	94.3	1.80	16.1	0.15
Tank 3	8/1/2008	155.794	94.3	1.86	15.8	0.13
Tank 1	8/18/2008	139.704	95.6	1.41	19.4	0.21
Tank 2	8/18/2008	165.233	95.3	1.34	18.3	0.19
Tank 3	8/18/2008	126.759	95.4	1.26	18.2	0.19
Tank 1	9/19/2008	305.134	94.8	2.21	25.9	0.38
Tank 2	9/19/2008	300.707	94.4	1.74	22.7	0.30
Tank 3	9/19/2008	216.302	94.7	1.95	21.8	0.23
Tank 1	11/7/2008	207.825	94.8	2.27	24.1	0.52
Tank 2	11/7/2008	251.98	94.7	2.41	23.2	0.46
Tank 3	11/7/2008	227.44	95.0	2.35	22.3	0.41

Because the system also removed fine mineral particles, not all of the harvested mass was biomass. In addition, the inorganic content of diatom cells, the dominant taxa type in the CEG2 periphyton mass, is variable and can be relatively high (40–50%) due to silica in the residual frustules. Loss-on-ignition results do not distinguish between the inorganic silica that is a component of diatom cells from the inorganic sediment particles trapped in the periphyton’s mucilaginous mass. This makes it challenging to estimate with precision the weight contribution of the mineral portion of harvested mass. Most of the larger mineral particles were presumably retained in the stormwater pond and only the finer particle fraction entered the periphyton treatment system, with most of the mineral sediment contribution delivered during stormwater events and experiments. In synthetic stormwater experiments with the cultured ecology pilot system, where the size fraction of mineral input during experiments was more tightly controlled, it was found that even a large quantity of very fine sediments did not add significantly to the weight of the harvested mass (Patterson et al., 2007). Based on these earlier results, therefore, the mineral, non-biogenic fraction of the CEG2 harvest results is presumed to be low compared to the total production of biomass. Thus, even large quantities of fine mineral particles (<20 µm) captured by the system would contribute relatively negligible mass to the total amount harvested.

The biomass harvest results are consistent with the results of the pilot system. During the first four months of its operation the pilot system produced an average 9.8 g/day of biomass, and an estimated annual potential phosphorus removal of 10 g/m^2 (Patterson *et al*., 2007). The nine-month demonstration with the CEG2 system removed over 11 grams of phosphorus per square meter, which is consistent with the estimate from the earlier pilot system (10 g P m^{-2} yr^{-1}).

Cool weather productivity is exemplified by the 3/21/08 harvest (based on growth starting 2/14/08) where a total of almost 500 grams of dry mass was harvested from the three tanks. Productivity declined for April and May harvests to 178 and 233 grams, respectively. Based on the results of nutrient sampling and analysis (see Sampling and Analysis section), this decline was a result of a decline in the nutrients available to the system. Algal blooms in Pond 1 assimilated much of the available nitrogen and phosphorus and reduced the amount available for periphyton growth. In subsequent months, as algal growth in the stormwater pond declined, nutrient concentrations in the influent rose and productivity improved.

In most sample periods (e.g., 3/21, 4/16, 5/19, 8/1, 9/19) productivity was highest in the first tank and declined in tanks 2 and 3. This is consistent with observed lower nutrient concentrations. However, on 8/18 and 11/7, second tank productivity is higher than first tank, and on 9/19 the first and second tank productivity was essential equal. It is not clear what caused these differences. As noted in the site selection section, as a photosynthetically driven system, full sunlight is important to CEG2 function. It is possible that slight shading of the first tank reduced light availability as the sun angle declined during this period.

For a period of a little over two months (5/13 to 7/23), a malfunctioning air pump periodically reduced the internal pulsed mixing regime within each tank; repairs to the pump were ultimately unsatisfactory. A new air pump was installed on 7/23/08 and no further problems were observed. Since this period of time corresponds to the period when harvests were being conducted on a 10-day rotating schedule, and follows the period of reduced productivity because of reduced nutrients in the influent, it is difficult to assess precisely what impact the reduced internal pulsing had on productivity. However, overall productivity during this period, while higher than April and May, was lower than March or October. Based upon available solar energy, July should have been a period of very high productivity. Perhaps the reduced productivity during this period can be attributed to the reduced pulsed turbulent flow in each tank.

Species Identification

The dominant algal type growing in the periphyton treatment tanks was always filamentous diatom (Table 5), usually *Synedra* (Figure 13) and *Aulacoseira* (Figure 14). Other common diatoms included *Amphora*, *Rhapalodia*, and *Gomphonema*. The nitrogen-fixing, blue-green algae *Anabaena* was present on some occasions, although never dominant. Green filamentous *Spirogyra* was also present, but cell numbers never amounted to more than a few percent.

The filamentous attached algal species typically dominant in periphyton communities are desirable from treatment system perspective because of their attached growth habit. This reduces export of algal cells and facilitates harvest. Beginning around April, Pond 1 began to support algae growth best described as *metaphyton*, rather than periphyton. Metaphyton is algal growth that is only loosely associated with a substrate, and easily detached and floating free from it (Wetzel, 2001a). This free-floating metaphyton was continuously exported from the pond into the CEG2 tanks along with the water being pumped into them. While the turbulent flow regime did not favor the growth of metaphyton taxa in the CEG2 tanks, the continuous "seeding" of the system with these taxa did seem at times to inhibit the growth of the more desirable attached species. It also meant that many of the fragmented algal filaments were exported from the system, possibly increasing measured turbidity levels.

Table 5. Algae identified in harvested material from periphyton tanks. Analyses were not conducted on Tank 1 or Tank 3 samples from 8/1/08 and 8/18/08 harvests.

	Percent Dominance						
Tank 1	4/16/08	5/19/08	5/30/08	7/1/08	8/1/08	8/18/08	9/12/08
Amphora		1	0.1	13	--	--	
Anabaena				20	--	--	
Aulacoseira	31	28	9		--	--	52
Cocconeis	1	3	0.3	0.5	--	--	
Diatoma mesodon		1	0.1		--	--	
Eunotia		1		1	--	--	1
Fragelaria					--	--	
Gomphonema	8	4	4	2	--	--	2
Meridion circulare	3	1			--	--	
Nitzchia acicularis	5	3			--	--	3
Pinnularia viridis					--	--	
Placoneis		1	1	0.5	--	--	
Rhapalodia		0.3		8	--	--	
Spirogyra	11	2	0.1	0.5	--	--	
Stephanodiscus					--	--	4
Synedra	39	51	85	55	--	--	34
Unknown Species	2	5			--	--	4
Total	100	100	100	100	na	na	100

Tank 2	4/16/08	5/19/08	6/10/08	7/11/08	8/1/08	8/18/08	9/12/08
Amphora		0.2	0.4	30	30	11	5
Anabaena		4	2				
Aulacoseira	47	22	5	2	1	13	59
Cocconeis	1		0.1			4	1
Diatoma mesodon		5	0.4	1			
Eunotia		0.2		1		1	
Fragelaria	1					7	
Gomphonema	4	3	3	2	1	4	1
Meridion circulare	2	0.2					
Nitzchia acicularis	3			3	1		
Pinnularia viridis				1	1	1	
Placoneis			0.3				
Rhapalodia			1	21	24	8	
Spirogyra	2	2	0.4				
Stephanodiscus							13
Synedra	37	64	88	39	31	41	19
Unknown Species	3				11	10	2
Total	100	100	100	100	100	100	100

Tank 3	4/16/08	5/19/08	6/20/08	7/22/08	8/1/08	8/18/08	9/12/08
Amphora			3	33	--	--	7
Anabaena		6			--	--	
Aulacoseira	38	21	4	1	--	--	70
Cocconeis	2	1			--	--	
Diatoma mesodon		1	1		--	--	
Eunotia			1	1	--	--	
Fragelaria	1				--	--	
Gomphonema	2	3	3	1	--	--	1
Meridion circulare	1	0.4			--	--	
Nitzchia acicularis	4				--	--	
Pinnularia viridis					--	--	
Placoneis		1			--	--	
Rhapalodia			4	25	--	--	2
Spirogyra	2	1	0.2		--	--	
Stephanodiscus					--	--	20
Synedra	49	66	84	37	--	--	
Unknown Species	1			2	--	--	
Total	100	100	100	100	na	na	100

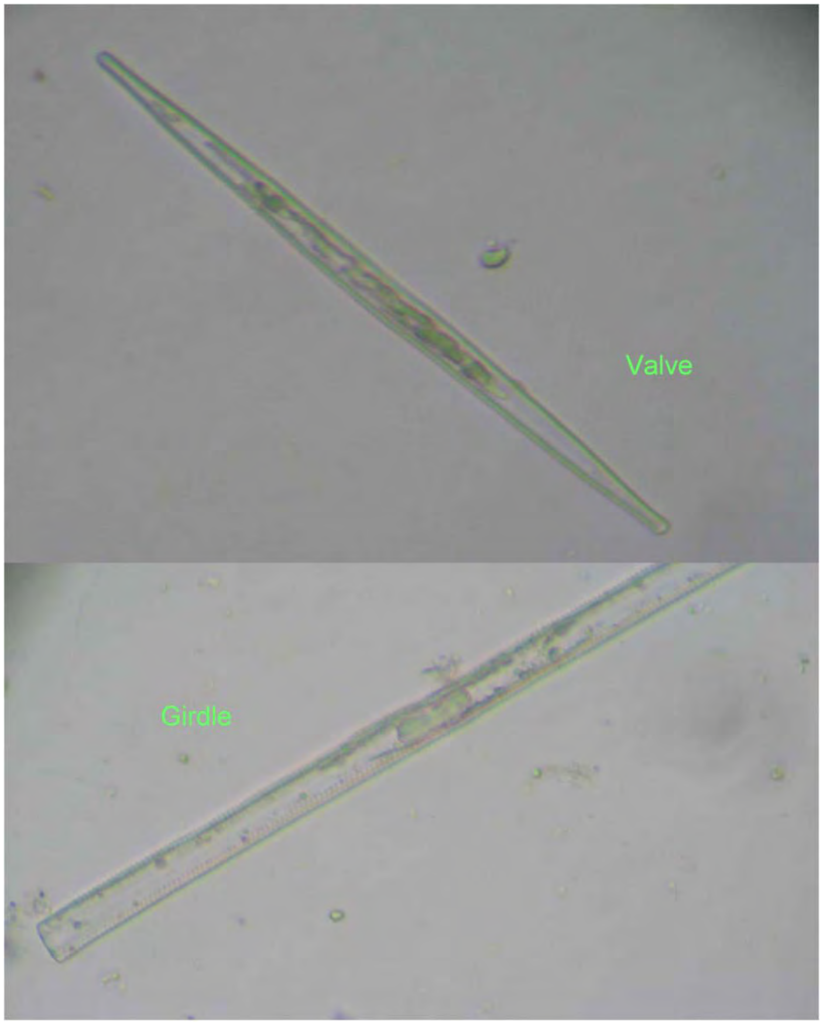


Figure 13. Valve and girdle views of Synedra, an araphid diatom dominant in the periphyton treatment tanks.

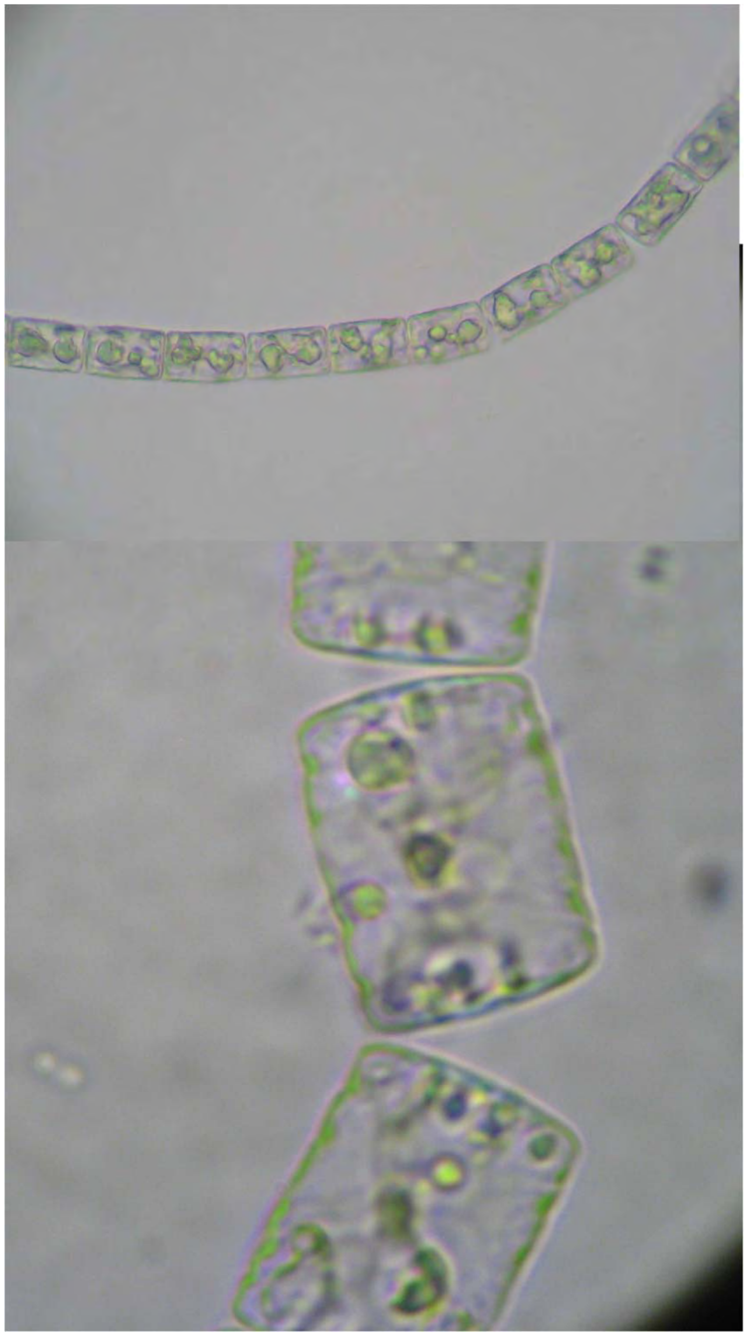


Figure 14. Aulacoseira (formerly Melosira), another dominant diatom in the periphyton treatment tanks.

Baseflow Water Quality Treatment

Baseflow diel sampling was conducted on a bimonthly basis from March to November, as previously described. In addition two runoff events were sampled during this period. To evaluate overall treatment effectiveness the differences in concentrations for EMCs between the inflow (C1) and outflow (C4) points of the treatment system are shown in Figure 15 for each of these sampling events.

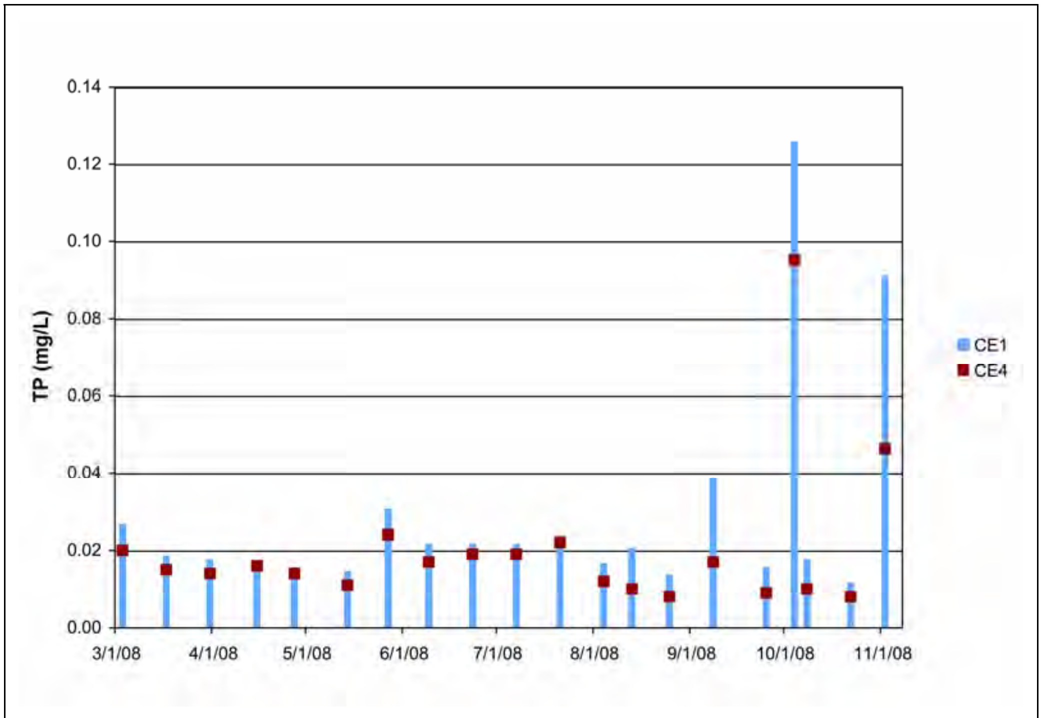
It is evident that significant reductions occur in phosphorus concentrations (SRP, TDP and TP), and perhaps in nitrate, but the other constituents are not as easy to interpret. Suspended sediment, for example, is generally lower in outflow after treatment when the inflow concentrations are high, but low inflow concentrations in the summer generated higher outflow concentrations (perhaps representing an export of algal fragments). Similarly, turbidity is generally lower after treatment, but not always, while total nitrogen treatment is variable at low concentrations (<0.2 mg/L), but appears significant at higher concentrations.

Box-and-whisker plots can not show the overall differences between inflow and outflow EMCs due to aggregate overlapping of constituent concentration ranges encountered at inflow and outflow sites throughout the project period. They do not provide the appropriate statistical view of significant differences. Instead, since it is the set of differences between each paired inflow and outflow EMC that is of interest, a student's t-test was performed on the paired EMC samples of all eighteen baseflow events (shown in Figure 15) to evaluate the extent and statistical significance of treatment effects. These results are presented in Table 6, derived from the data provided in Appendix D. Positive Pearson correlations confirm that sample pairing is appropriate for this statistical analysis, so the tests were conducted at successive points in the system (C1 paired with C2, then C3 and C4) to determine whether treatment effectiveness increased with additional tanks.

There were statistically significant (p-value <0.01) reductions in nitrate, dissolved phosphorus (both SRP and TDP), and total phosphorus. The 95% confidence intervals for these constituents do not cross zero, so treatment between CE1 and CE4 was significant in each case, with estimated phosphorus reductions ranging from 24–36%, and mean nitrate reductions of 60%. The 95% confidence interval for nitrate reductions was larger than for the phosphorus species, so these results were more variable than for phosphorus. Also, the difference between inflow and outflow concentrations increased with each additional treatment tank for both phosphorus and nitrate, and was increasingly significant (see p-values in Table 6).

There was no statistically significant difference in suspended sediment, turbidity, electrical conductivity, ammonium, or TKN. Effluent pH increased slightly over influent levels. This is consistent with algal production of oxygen during daylight hours, as elevated oxygen levels can lead to increased pH (Dierberg *et al.*, 2002).

Although influent nitrate levels varied considerably during the project period, including during intervals of nitrate fertilization, the periphyton biofilm generally removed nitrate to very low levels. Relatively high influent nitrate concentrations during March were substantially reduced in the effluent (Figure 15). But the treatment was less effective in April, when influent nitrate concentrations were lower because algae began to grow in the source pond (Figure 16) and took up more of the available nitrate before it entered the treatment system. Subsequently, in June as algae levels in the source pond declined there was an increase in the nitrate influent concentration and in corresponding treatment effectiveness.



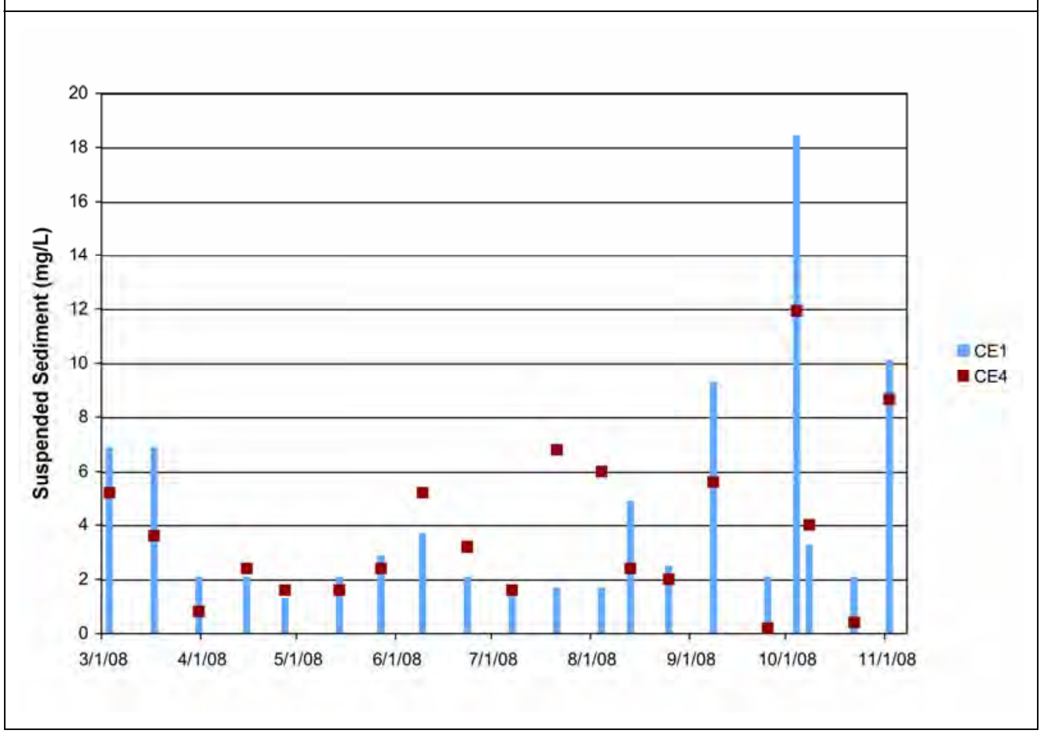


Figure 15. Composite concentrations (EMCs) flowing into (CE1) and out of (CE4) the periphyton treatment system. All composites represent full diel (24-hour) periods, except the results from storm events on 10/4/08 (18 hour event mean composites) and 11/1/08 (48 hour event mean composites).

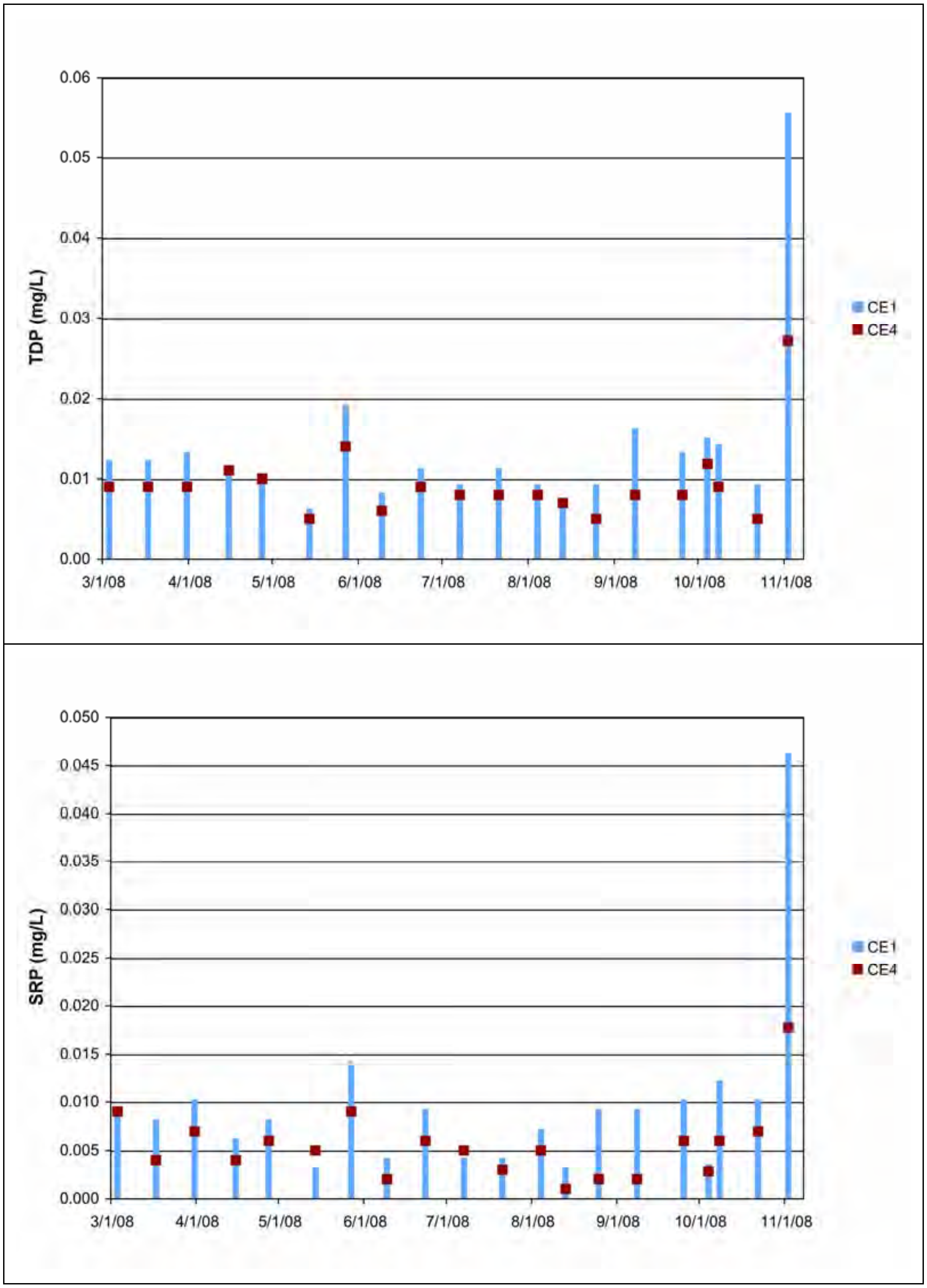
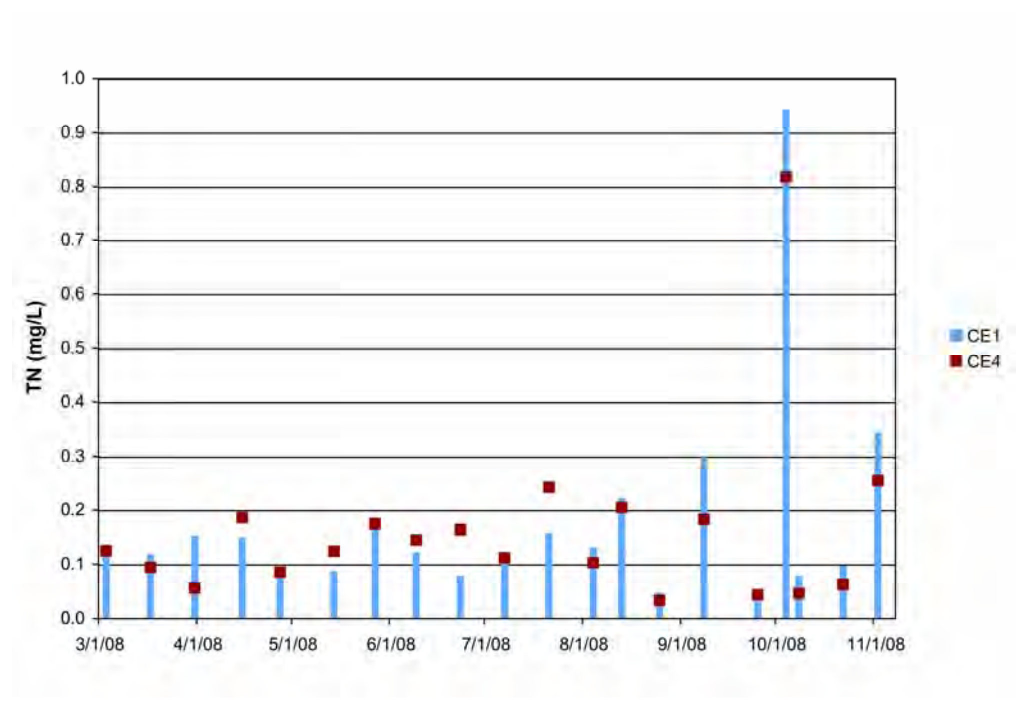


Figure 15. Composite concentrations (EMCs) flowing into (CE1) and out of (CE4) the periphyton treatment system. All composites represent full diel (24-hour) periods, except the results from storm events on 10/4/08 (18 hour event mean composites) and 11/1/08 (48 hour event mean composites) (continued).



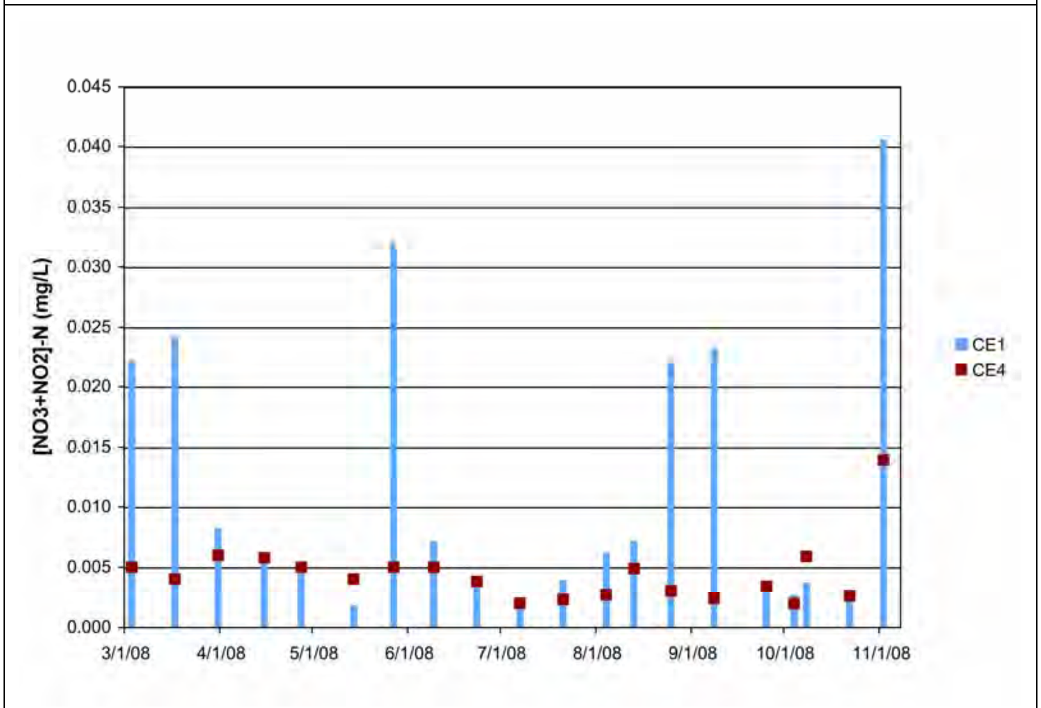


Figure 15. Composite concentrations (EMCs) flowing into (CE1) and out of (CE4) the periphyton treatment system. All composites represent full diel (24-hour) periods, except the results from storm events on 10/4/08 (18 hour event mean composites) and 11/1/08 (48 hour event mean composites) (continued).

The ammonia data are somewhat perplexing, as there seem to have been periods of unexplained ammonia production within the treatment system (see Appendix D). This is unexpected, considering what must have been relatively high oxygen levels within the system due to constant aeration. In future tests a continuous monitoring of dissolved oxygen levels throughout the diel cycle could be useful.

Table 6. Results from the Student t-test for paired samples from baseflow EMCs at CE1, CE2, CE3 and CE4. This series compares the means for statistically significant differences between CE2 vs CE1, CE3 vs CE1, and CE4 vs CE1. (CE4 and CE1 are shown in Figure 15). Statistically significant differences (alpha=0.05) are highlighted cells. Note that negative values for mean reductions indicate increased concentrations at C4.

Parameter	Suspended Sediment (mg/L)	LOI (wt %)	Turbidity (NTU)	EC (µS/cm)	pH	$[NO_3+NO_2]$-N (mg/L)	NH_3-N (mg/L)	SRP (mg/L)	TDP (mg/L)	TP (mg/L)	TKN (mg/L)	0.5-20 µm Particles (#/mL)
Mean CE1:	3.200	0.667	3.189	157.184	7.493	0.010	0.008	0.008	0.011	0.019	0.112	67,815
Mean CE2:	2.933	0.640	3.138	148.158	7.642	0.008	0.010	0.006	0.010	0.018	0.127	60,557
Mean of the differences:	0.267	0.027	0.051	9.026	-0.149	0.002	-0.002	0.001	0.002	0.001	-0.015	7,258
Pearson Correlation:	0.660	0.064	0.852	0.810	0.909	0.394	0.486	0.796	0.815	0.910	0.882	0.923
p-value (two-tail):	0.519	0.830	0.821	0.354	0.002	0.377	0.143	0.007	0.003	0.077	0.058	0.331
Mean CE1:	3.200	0.667	3.189	157.184	7.493	0.010	0.008	0.008	0.011	0.019	0.112	67,815
Mean CE3:	3.711	0.767	3.480	141.542	7.739	0.005	0.009	0.006	0.009	0.025	0.155	71,208
Mean of the differences:	-0.511	-0.101	-0.291	15.642	-0.246	0.005	-0.001	0.002	0.002	-0.005	-0.043	-3,393
Pearson Correlation:	0.855	0.429	0.753	0.786	0.755	0.302	0.361	0.728	0.863	0.795	0.837	0.959
p-value (two-tail):	0.134	0.237	0.467	0.138	0.002	0.032	0.171	0.002	<0.001	0.468	0.101	0.982
Mean CE1:	3.200	0.667	3.189	157.184	7.493	0.010	0.008	0.008	0.011	0.019	0.112	67,815
Mean CE4:	3.056	0.752	2.959	146.467	7.782	0.004	0.009	0.005	0.008	0.015	0.117	60,634
Mean of the differences:	0.144	-0.085	0.230	10.717	-0.289	0.006	-0.001	0.003	0.003	0.005	-0.006	7,181
Pearson Correlation:	0.418	0.397	0.672	0.788	0.770	0.062	0.265	0.627	0.736	0.676	0.676	0.886
p-value (two-tail):	0.793	0.367	0.458	0.347	<0.001	0.017	0.289	<0.001	<0.001	0.001	0.634	0.408
Mean Reduction (CE1-CE4)	5%	-13%	7%	7%	-4%	60%	-13%	36%	26%	24%	-5%	11%
95% CI	(± 36%)	(± 29%)	(± 20%)	(± 15%)	(± 2%)	(± 48%)	(± 25%)	(± 16%)	(± 10%)	(± 12%)	(± 22%)	(± 27%)

On average, SRP effluent concentrations were reduced by 44% from already low influent concentrations (average 0.009 µg/L). Additionally, nitrogen fertilization beginning in June helped to further reduce SRP levels, on occasion to 3 µg/L or lower (Figure 15). It was estimated that approximately 3,600,576 L of water flowed through the system over the course of the 266 day demonstration period. Using an average SRP concentration of 0.009 mg/L would suggest that about 32 g of SRP entered the system. Effluent SRP for the same period was 18 grams. Therefore the system removed up to 14 grams of SRP, which is roughly consistent with the 11 grams of TP removal estimated from algal biomass analysis. The difference may be due in part to export of particulate organic matter (periphyton fragments), or result from uncertainties in analysis and assumptions in the calculation of extrapolated estimates.

Figure 16. Floating algae production in the source stormwater pond (3-21-09).

Stormwater Runoff Event Concentrations and Pollutographs

There were three relatively large runoff events at the test site during the entire project period. The first was a series of pulses (May 20-24) that was not sample because it occurred shortly after periphyton had been harvested in May. The second (10/4/08) and third (11/1/08) events occurred near the end of the project but with enough periphyton growth for testing treatment effects, so these two events were sampled repeatedly throughout the runoff phase.

Unlike samples collected during the baseflow diels, which were analyzed as single event composites, the samples collected during runoff events were analyzed individually and then EMCs were calculated. Thus, each of the two monitored runoff events yield a series of pollutographs that illustrate patterns of treatment effectiveness during these events. The time series plots shown for these events (Figures 17 and 18) do not include the constituents that did not change in concentration with treatment (e.g. NH_3-N). However, the complete analytic series is provided in Appendix E.

The runoff event in October was relatively small and of short duration, due in part to the extremely dry conditions that had developed without any precipitation since May. This small runoff event did not produce large spikes in the constituent concentrations of inflow water. However, treatment is evident for both TP and TDP during this event, with lower outflow concentrations in all samples collected (at every third hour from 07:34 through 22:44 on October 4th) during the runoff. Suspended sediment also showed reduced concentrations in the outflow, but changes in concentrations of nitrate ([NO_3+NO_2]-N), and possibly SRP were modest at best, and likely not significant.

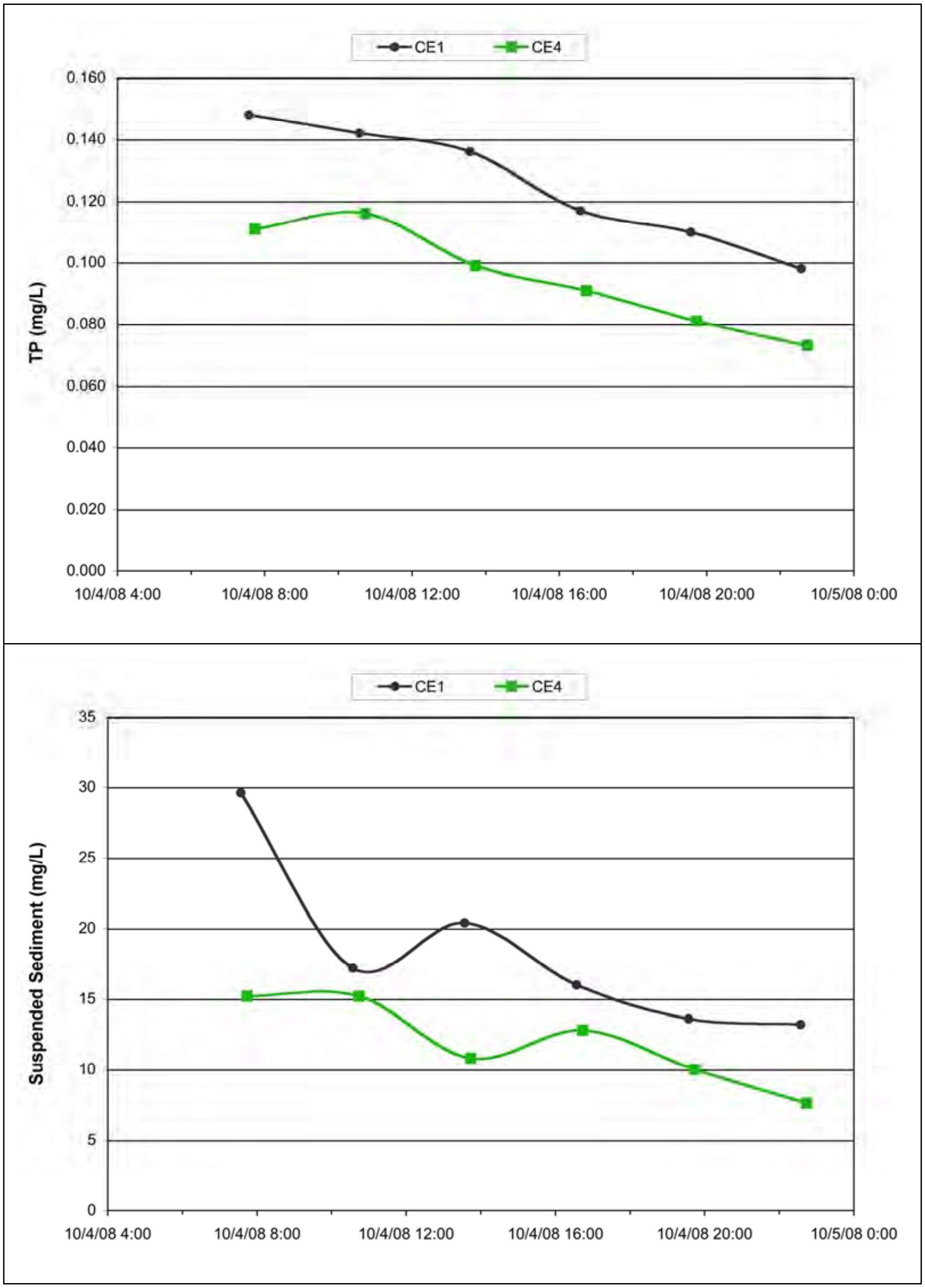


Figure 17. Pollutographs of periphyton treatment during runoff associated with a moderate size rainstorm (0.33 inches) on October 3-4, 2008. Flow was constant through the system at about 11 L/min (2.9 gal/min).

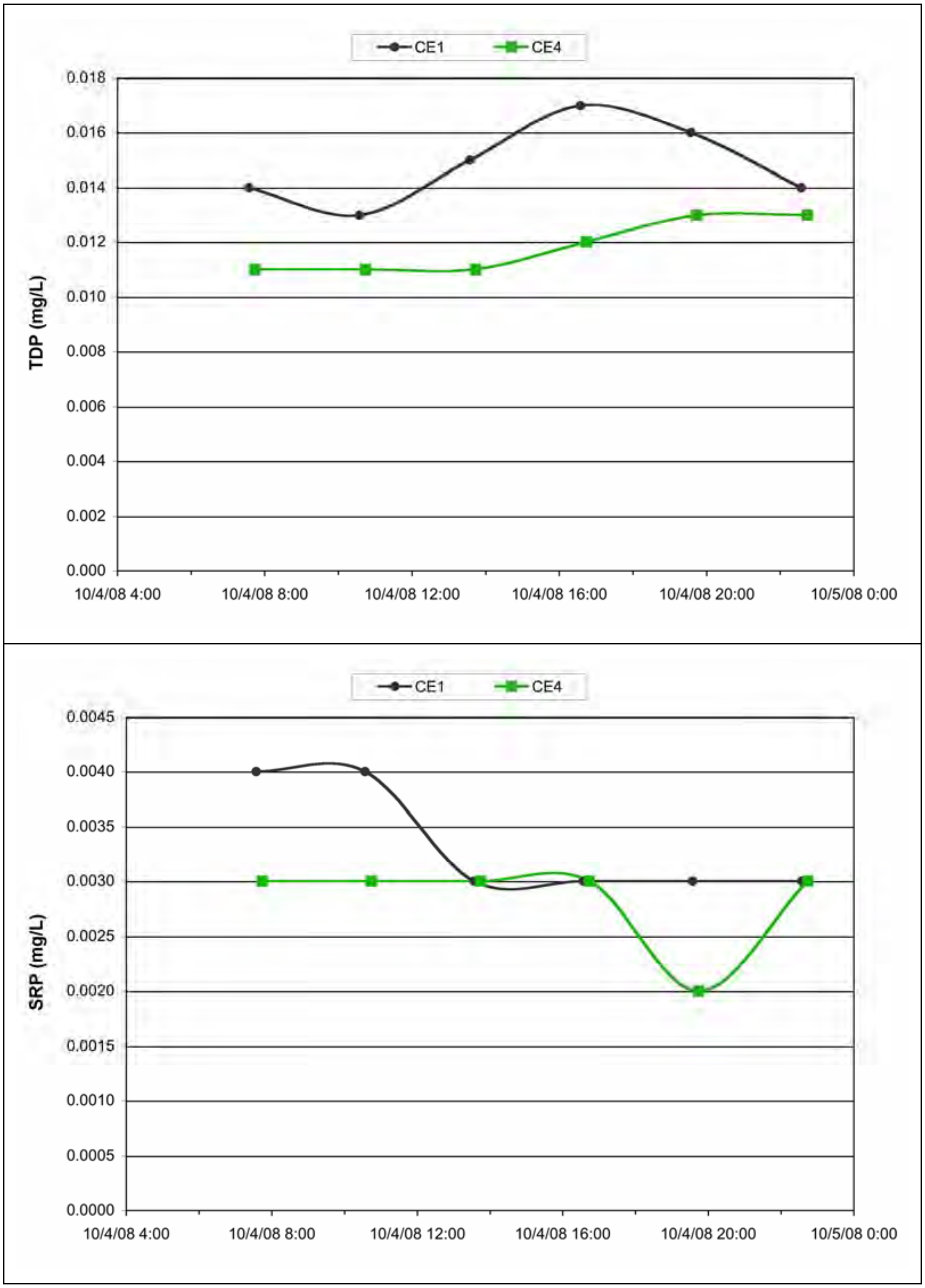


Figure 17. Pollutographs of periphyton treatment during runoff associated with a moderate size rainstorm (0.33 inches) on October 3-4, 2008. Flow was constant through the system at about 11 L/min (2.9 gal/min) (continued).

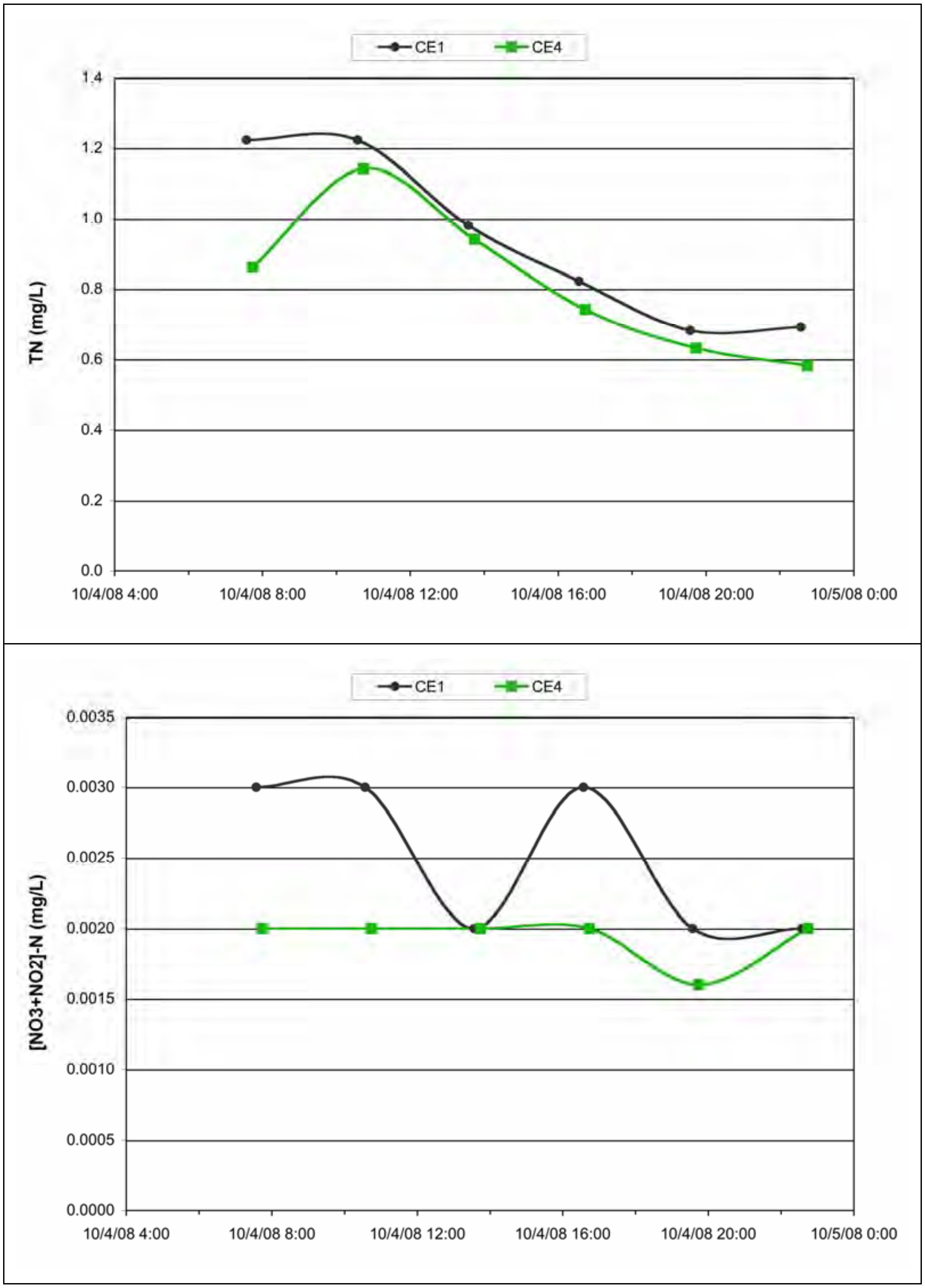


Figure 17. Pollutographs of periphyton treatment during runoff associated with a moderate size rainstorm (0.33 inches) on October 3-4, 2008. Flow was constant through the system at about 11 L/min (2.9 gal/min) (continued).

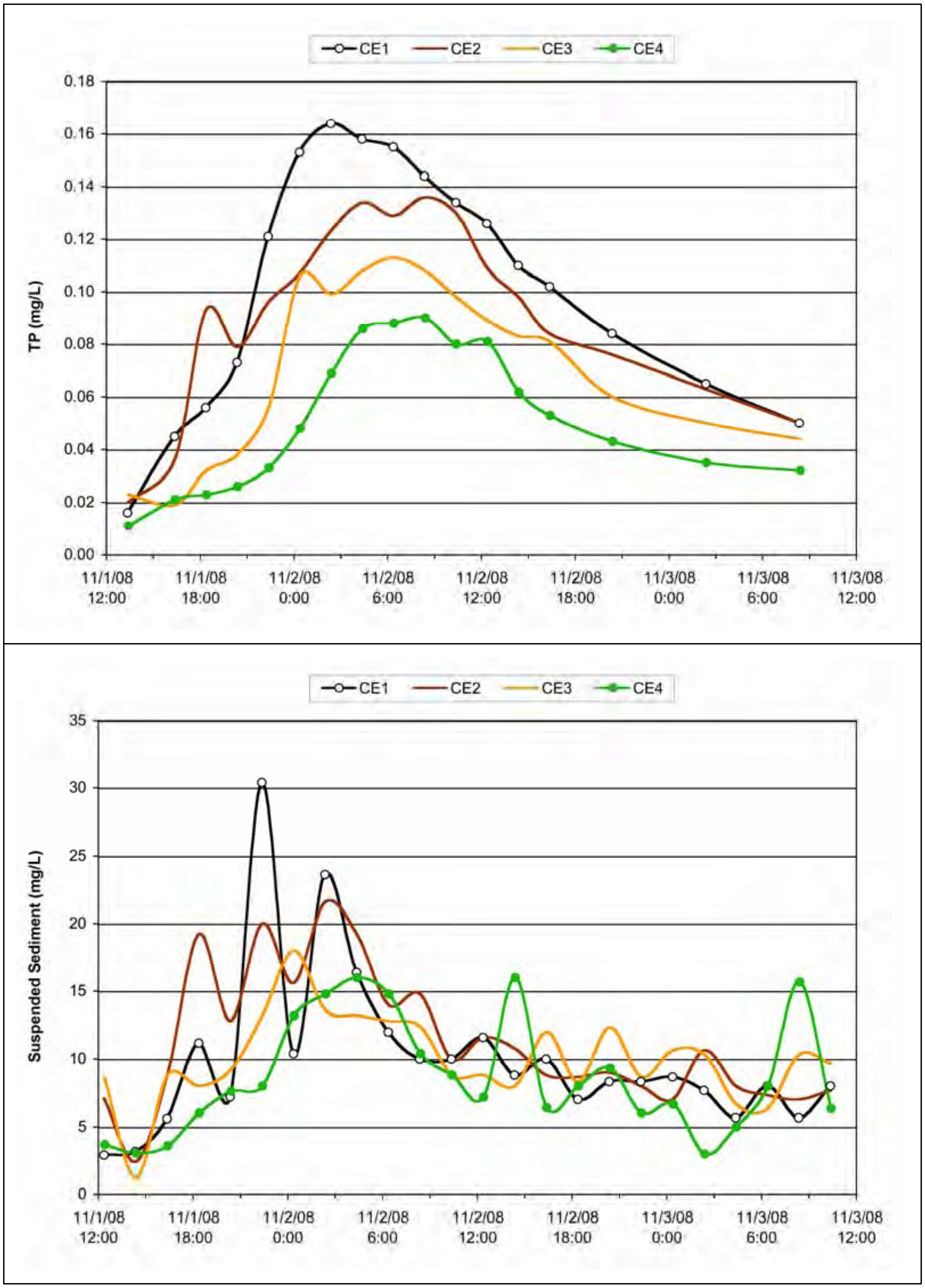


Figure 18. Pollutographs of periphyton treatment during runoff associated with a relatively large rainstorm (0.89 inches) on November 1-2, 2008. Flow was constant through the system at about 9.2 L/min (2.5 gal/min) and discrete samples were taken simultaneously at all four locations.

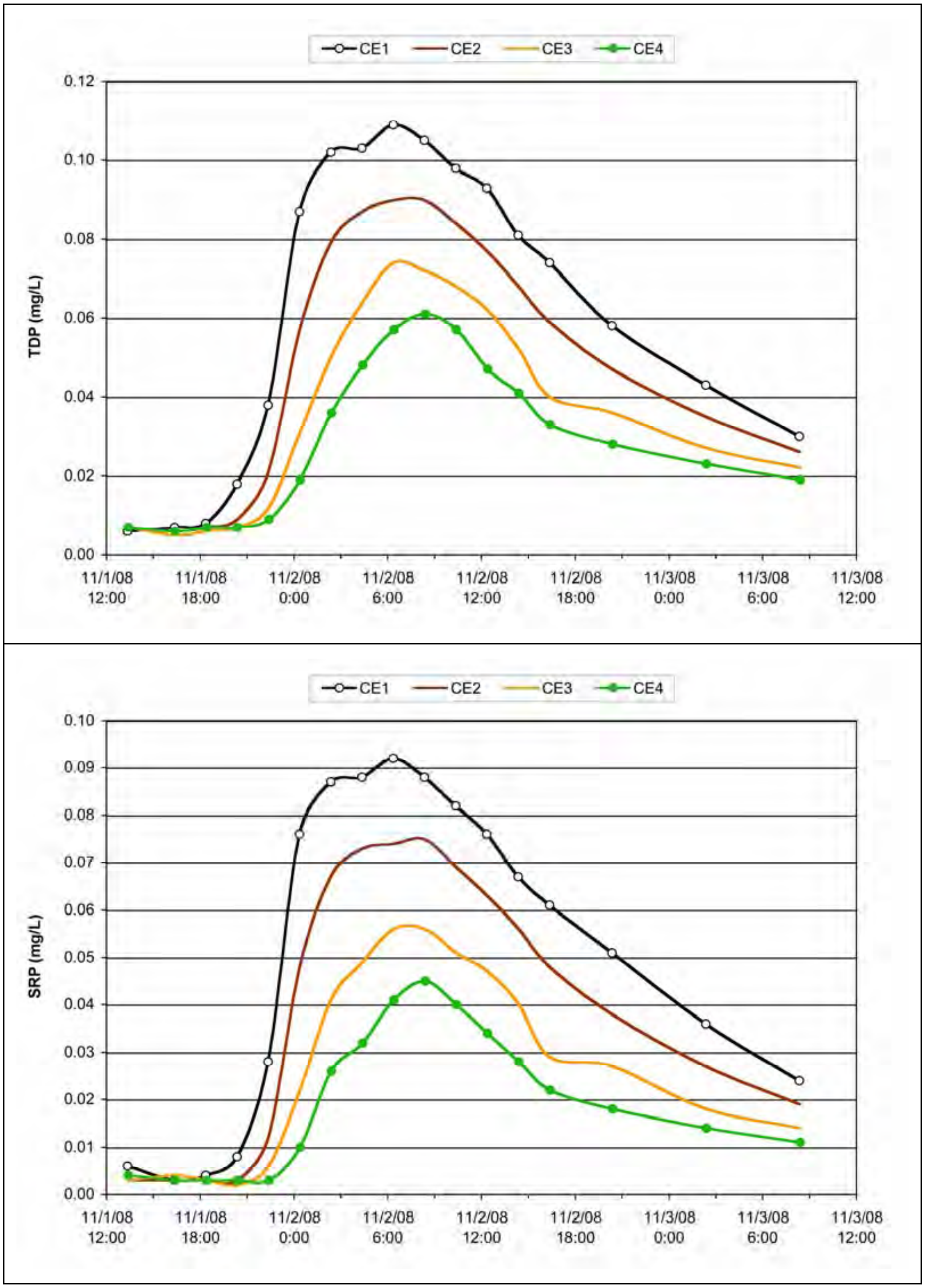


Figure 18. Pollutographs of periphyton treatment during runoff associated with a relatively large rainstorm (0.89 inches) on November 1-2, 2008. Flow was constant through the system at about 9.2 L/min (2.5 gal/min) and discrete samples were taken simultaneously at all four locations (continued).

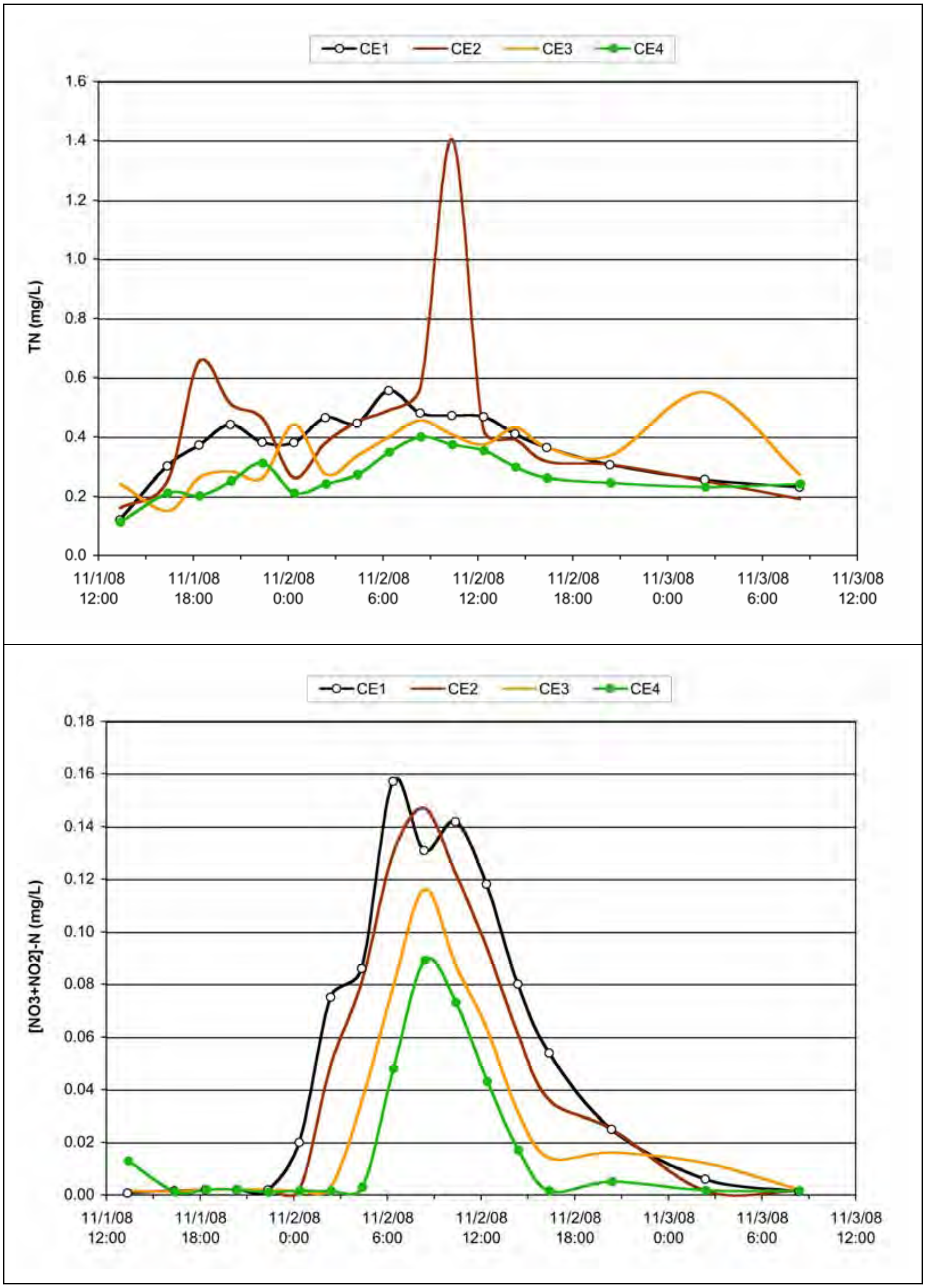


Figure 18. Pollutographs of periphyton treatment during runoff associated with a relatively large rainstorm (0.89 inches) on November 1-2, 2008. Flow was constant through the system at about 9.2 L/min (2.5 gal/min) and discrete samples were taken simultaneously at all four locations (continued).

By contrast, there was a large storm front in early November that produced a sustained pulse of runoff to the stormwater ponds, and constituent concentrations show a clear spike associated with that event. This was exactly what was needed to provide a realistic on-site test of stormwater treatment by the periphyton biofilm system, and monitoring had been extended beyond the project end date in hope of such an opportunity. It had been six weeks since the last harvest (September 19th). Although periphyton growth had slowed somewhat with shorter days and colder temperatures, there was thick layer of biofilm on the screens and tanks ready for treatment testing. This event lasted much longer than the October event. Samples were collected at two hour intervals over a 48 hour period, with each one analyzed for chemical concentrations during the peak of the runoff period (from 16:21 on Nov 1st through 16:24 on Nov 2nd), and a sufficient number analyzed during the long trailing limb of the runoff period to complete the picture (see Appendix E). Pollutographs from this event are easier to interpret than they were from the October event, with obviously decreasing concentrations of TP, TDP, SRP and nitrate at each additional treatment tank. This suggests that more tanks or treatment surface area could have provided additional benefit. Although it was not feasible to add more tanks in this demonstration scale project, it might be a useful optimization procedure in future tests to assess the lowest practical concentrations attainable with a fully functional periphyton biofilm system.

Treatment efficiency for turbidity during the November event was modest (Figure 19) and suspended sediment concentrations did not change significantly, although there is some evidence of decreased fine particle concentrations. The overall change in particle concentration (FSP <20 µm) was from 9.8×10^5 particles/mL at CE1 to 8.1×10^5 at CE4, a reduction of about 18% in runoff water that was already low in FSP concentration relative to typical Tahoe urban runoff (3.5×10^7; Lake Tahoe TMDL Technical Report, 2009). No significant treatment of FSP was observed during the October event, although there was a net reduction in suspended sediment concentrations (Table 7).

Calculated EMC results from both the October and November events show reductions in TP, TDP, TKN, suspended sediment, and perhaps turbidity (Table 7). Note, however, that small changes in very small numbers can give unrealistically high percentage reductions (see October SRP and nitrate). These low values are subject to analytic uncertainty, so the apparent reductions are not considered significant. Estimates for constituent load reductions during these events will be presented later in the document.

Table 7. Percentage EMC reductions calculated from stormwater runoff sampling during October and November events. Samples during the October event were collected only at sites CE1 and CE4. Negative values for event reductions indicate increased concentrations at CE4 relative to CE1.

Event ID	Location	Sample	Date Time	Suspended Sediment (mg/L)	LOI (wt %)	Turbidity (NTU)	EC (µS/cm)	pH	[NO3+NO2]-N (mg/L)	NH3-N (mg/L)	SRP (mg/L)	TDP (mg/L)	TP (mg/L)	TKN (mg/L)	0.5-20 µm Particles (#/mL)
Event 1	CE1	EMC	10/4/08 15:04	18.3	60.7%	9.72	77.6	6.86	0.003	0.015	0.003	0.015	0.125	0.935	1,040,479
Event 1	CE4	EMC	10/4/08 15:14	11.9	61.7%	9.07	86.1	6.99	0.002	0.015	0.003	0.012	0.095	0.815	1,019,259
Event 2	CE1	EMC	11/2/08 11:21	10.0	40.7%	11.97	93.18	7.38	0.040	0.007	0.046	0.055	0.090	0.300	984,955
Event 2	CE2	EMC	11/2/08 11:22	11.3	43.4%	10.81	94.79	7.28	0.034	0.006	0.036	0.045	0.082	0.346	892,327
Event 2	CE3	EMC	11/2/08 11:23	10.0	48.8%	9.66	87.83	7.25	0.022	0.006	0.025	0.034	0.064	0.328	912,877
Event 2	CE4	EMC	11/2/08 11:24	8.6	47.6%	9.30	91.51	7.32	0.014	0.006	0.018	0.027	0.046	0.241	809,817
		Event 1	reduction	35%	-2%	7%	-11%	-2%	23%	-1%	15%	20%	24%	13%	2%
		Event 2	reduction	14%	-17%	22%	2%	1%	66%	7%	61%	51%	49%	20%	18%

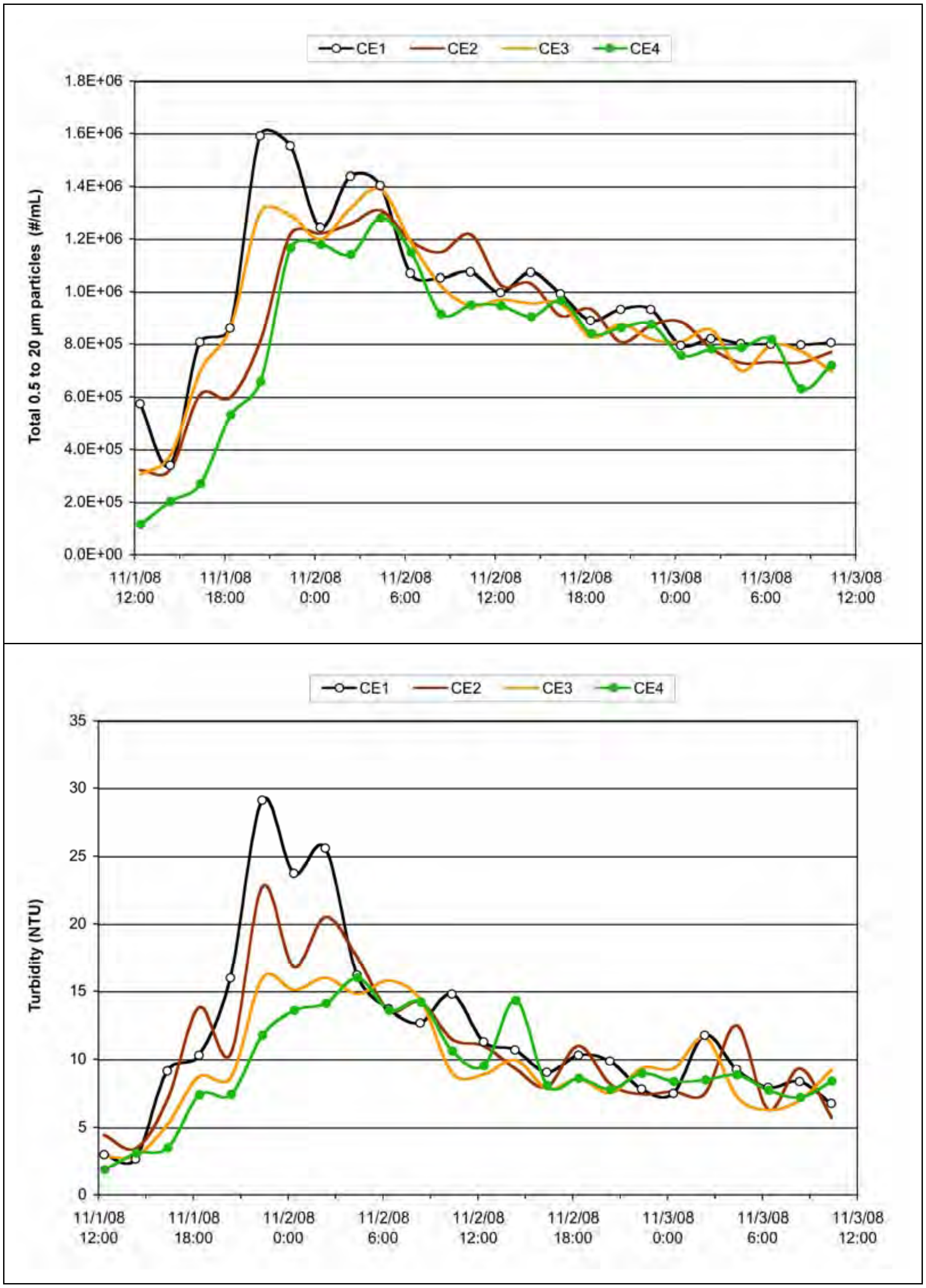


Figure 19. Time series plots for total fine sediment particles and turbidity in samples from periphyton treatment system during runoff event associated with a relatively large rainstorm (0.89 inches) on November 1-2, 2008. Discrete samples were taken simultaneously at all four locations.

Simulated Runoff Experiments

Toward the end of the project period two simulated runoff experiments were developed and conducted because there had been no natural events to sample during the monitoring period to that date. They were not considered ideal, as they are unlikely to reflect normal runoff conditions and water quality characteristics. However, they do provide additional information on treatment effects, and so the results are presented below (and in Appendix F) to augment results from the natural runoff events discussed previously.

In the twenty-four hour experiment of August 14th, stormwater pond sediments were mixed into the overlying water for inflow delivery to the treatment system; clearly producing elevated levels of suspended sediment, TN, total phosphorus, and perhaps SRP as well (Figure 20). Curiously, the influent concentrations of nitrate seem to have decreased over time while the within tank concentrations increased, but the reason for this is unknown.

Pollutant reductions from periphyton treatment were evident for suspended sediment, turbidity, TP, and TN. The EMCs for each sampling point in the periphyton treatment system support these results, showing a 49% or greater reduction in average concentration for suspended sediment and turbidity from inflow to outflow, a 38% reduction in total phosphorus, and 23% for TKN (Table 8). EMCs may indicate a slight reduction in dissolved phosphorus, but clearly the apparent reductions in SRP and nitrate are subject to analytical uncertainty. Of these percentage reductions, not more than 10% could have been due to any dilution effect from baseflow water existing in the three tanks (ca. 1,494 liters) at the start of the experiment, relative to total outflow volume during the experiment (10L/min, 14,400 L).

At the start of the second experiment on September 17, high levels of suspended sediment, turbidity, total phosphorus, and total nitrogen (Figure 21) were due to initial spiking of Tank 1 with concentrated synthetic stormwater (represented by SWT in Table 8). Thereafter, the concentrations observed at CE2 during synthetic stormwater delivery (after an indeterminable level of treatment in Tank 1) appear to be in the range of about 50% or more of the levels seen during the natural stormwater runoff event of November 1-2. This indicates that experimental concentrations were slightly less than the runoff concentrations expected of a relatively large storm event at the site.

Table 8. Percentage EMC reductions calculated for two simulated runoff experiments. Note that CE4 was compared to CE2 concentrations in the second experiment, when the concentrated SWT was used for spiking inflow water. Negative values indicate increased concentrations at C4 relative to inflow.

Event ID	Location	Sample	Date Time	Suspended Sediment (mg/L)	LOI (wt %)	Turbidity (NTU)	EC (µS/cm)	pH	[NO3+NO2]-N (mg/L)	NH3-N (mg/L)	SRP (mg/L)	TDP (mg/L)	TP (mg/L)	TKN (mg/L)	0.5-20 µm Particles (#/mL)
Exp 1	CE1	EMC	8/14/08 21:12	61.0	26.1%	42.2	146.7	7.32	0.004	0.006	0.005	0.011	0.083	0.43	560,855
Exp 1	CE2	EMC	8/14/08 21:12	46.4	28.8%	32.9	138.0	7.40	0.009	0.008	0.004	0.010	0.069	0.40	512,297
Exp 1	CE3	EMC	8/14/08 21:12	37.4	30.5%	27.2	136.1	7.48	0.006	0.007	0.004	0.010	0.062	0.40	510,173
Exp 1	CE4	EMC	8/14/08 21:12	28.5	32.0%	21.7	133.5	7.50	0.004	0.006	0.004	0.009	0.052	0.33	498,670
Exp 2	SWT	EMC	9/17/08 14:31	291.7	35.9%	208.5	175.2	7.22	0.006	0.015	0.100	0.121	0.554	2.42	2,738,824
Exp 2	CE2	EMC	9/17/08 20:32	10.5	58.6%	4.1	70.9	7.63	0.007	0.007	0.004	0.007	0.039	0.19	56,790
Exp 2	CE3	EMC	9/17/08 20:33	20.3	72.9%	3.3	67.1	7.49	0.003	0.005	0.002	0.006	0.034	0.16	96,374
Exp 2	CE4	EMC	9/17/08 20:34	3.5	76.3%	1.3	69.5	7.67	0.002	0.005	0.002	0.005	0.030	0.07	38,135
	(CE1-CE4)	Exp 1	reduction	53%	-23%	49%	9%	-3%	8%	2%	23%	16%	38%	23%	11%
	(CE2-CE4)	Exp 2	reduction	67%	-30%	69%	2%	-1%	68%	19%	58%	28%	23%	65%	33%

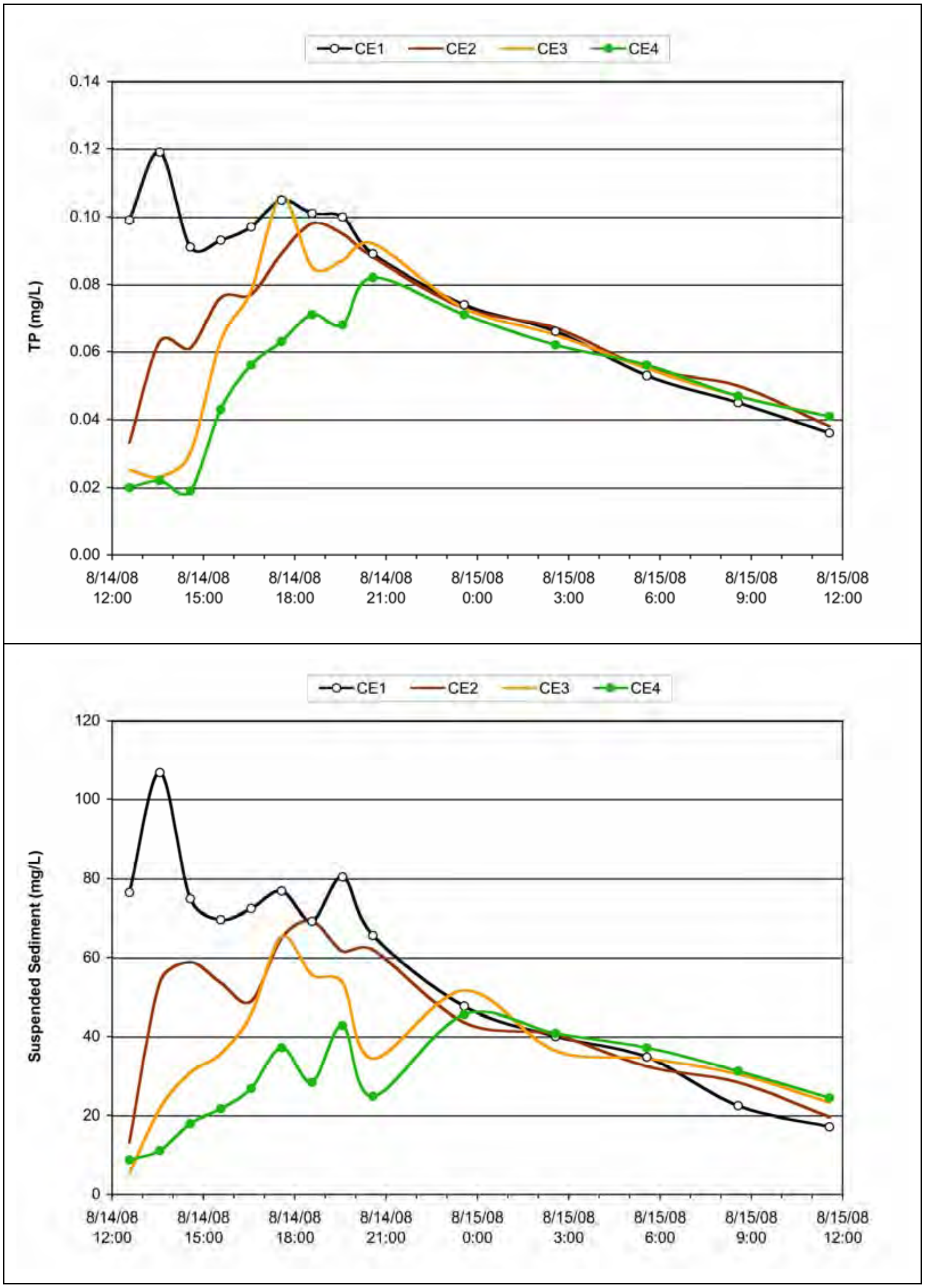


Figure 20. Simulated runoff experiment on August 14th, created by stirring pond sediments on hourly intervals over an eight hour period and sampling at all four points every hour for the first eight hours and every three hours thereafter. Flow was constant through the system at 10 L/min (2.6 gal/min). Discrete samples were taken simultaneously at all four locations.

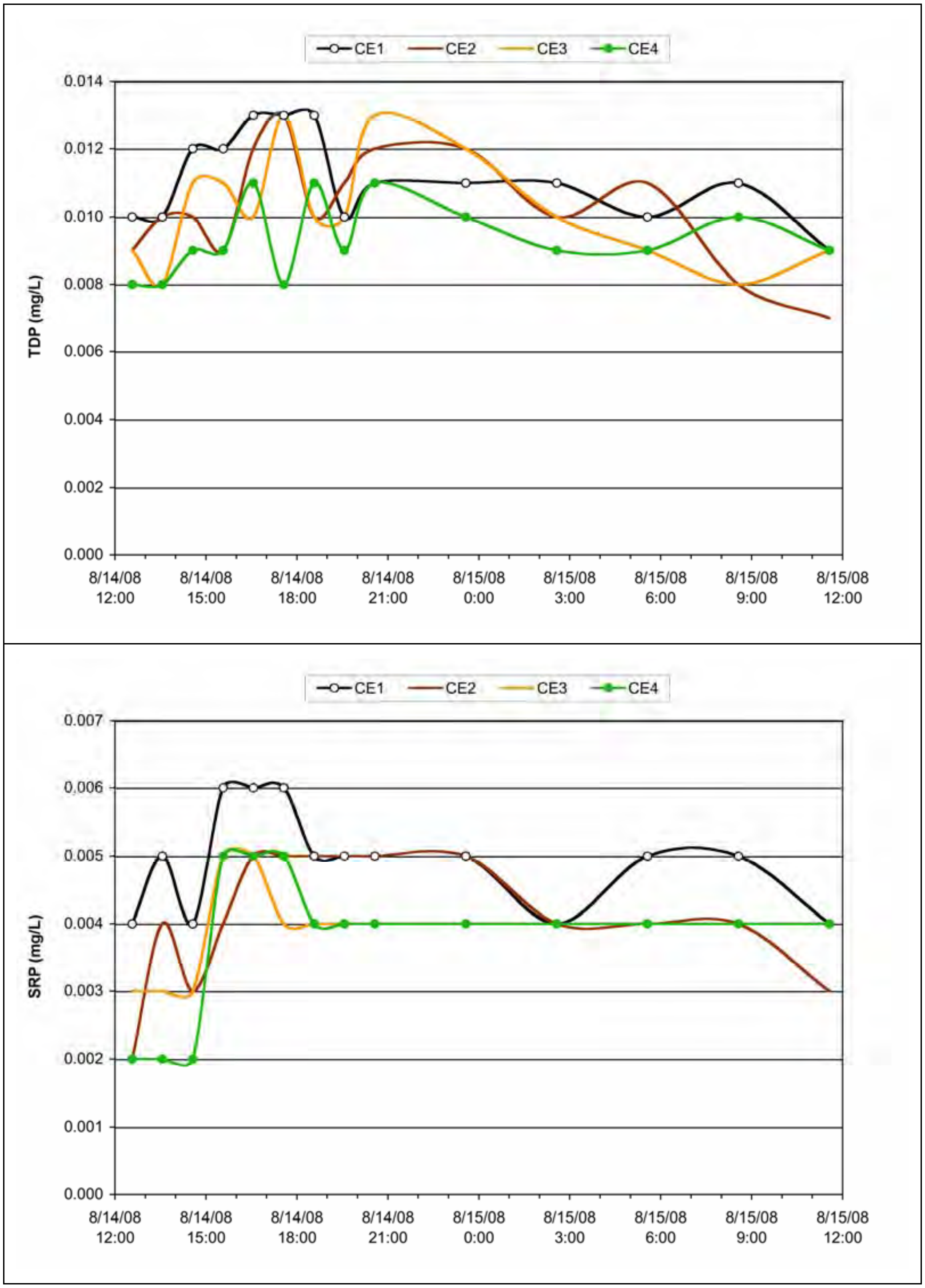


Figure 20. Simulated runoff experiment on August 14th, created by stirring pond sediments on hourly intervals over an eight hour period and sampling at all four points every hour for the first eight hours and every three hours thereafter. Flow was constant through the system at 10 L/min (2.6 gal/min). Discrete samples were taken simultaneously at all four locations (continued).

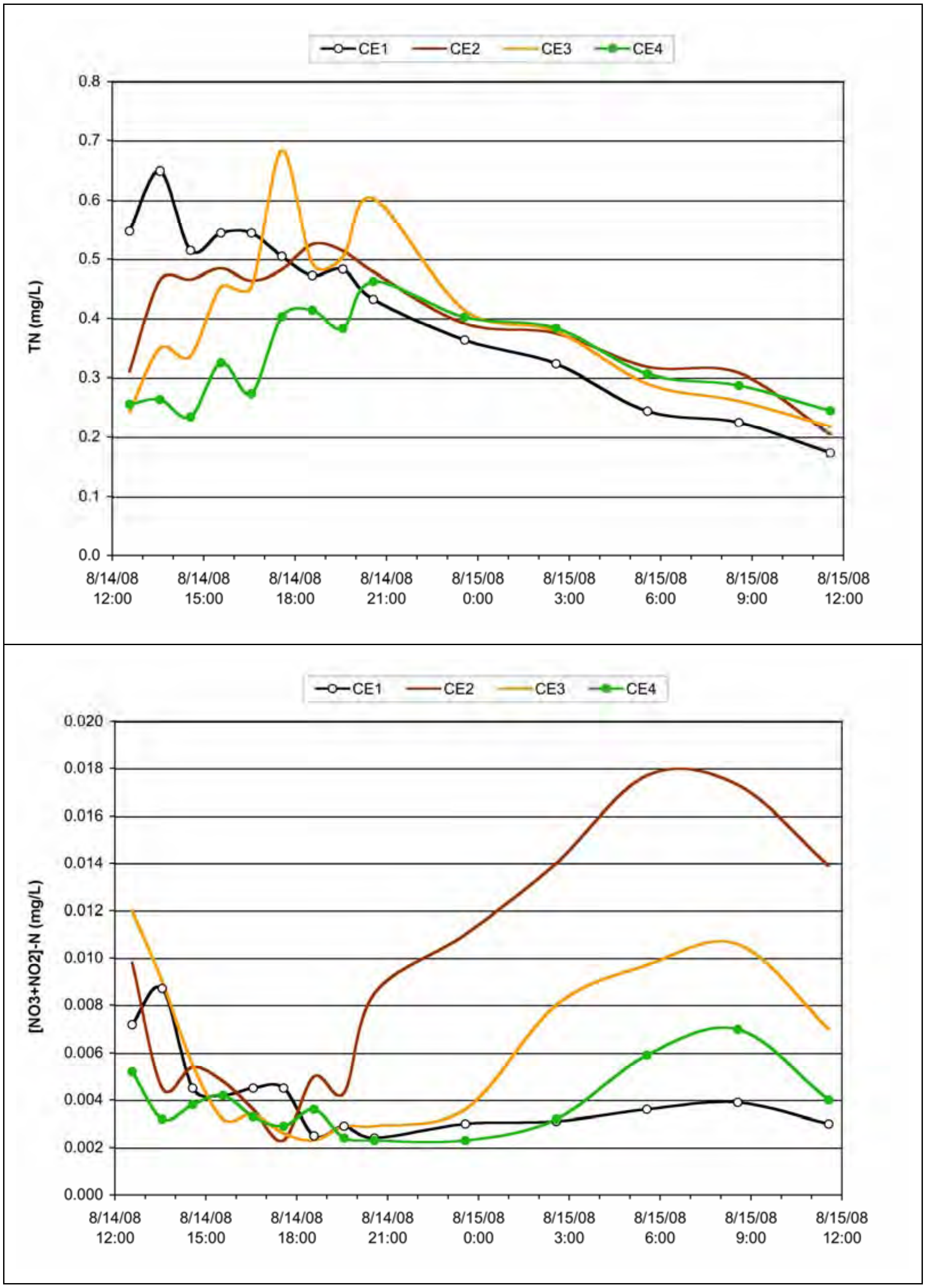


Figure 20. Simulated runoff experiment on August 14th, created by stirring pond sediments on hourly intervals over an eight hour period and sampling at all four points every hour for the first eight hours and every three hours thereafter. Flow was constant through the system at 10 L/min (2.6 gal/min). Discrete samples were taken simultaneously at all four locations (continued).

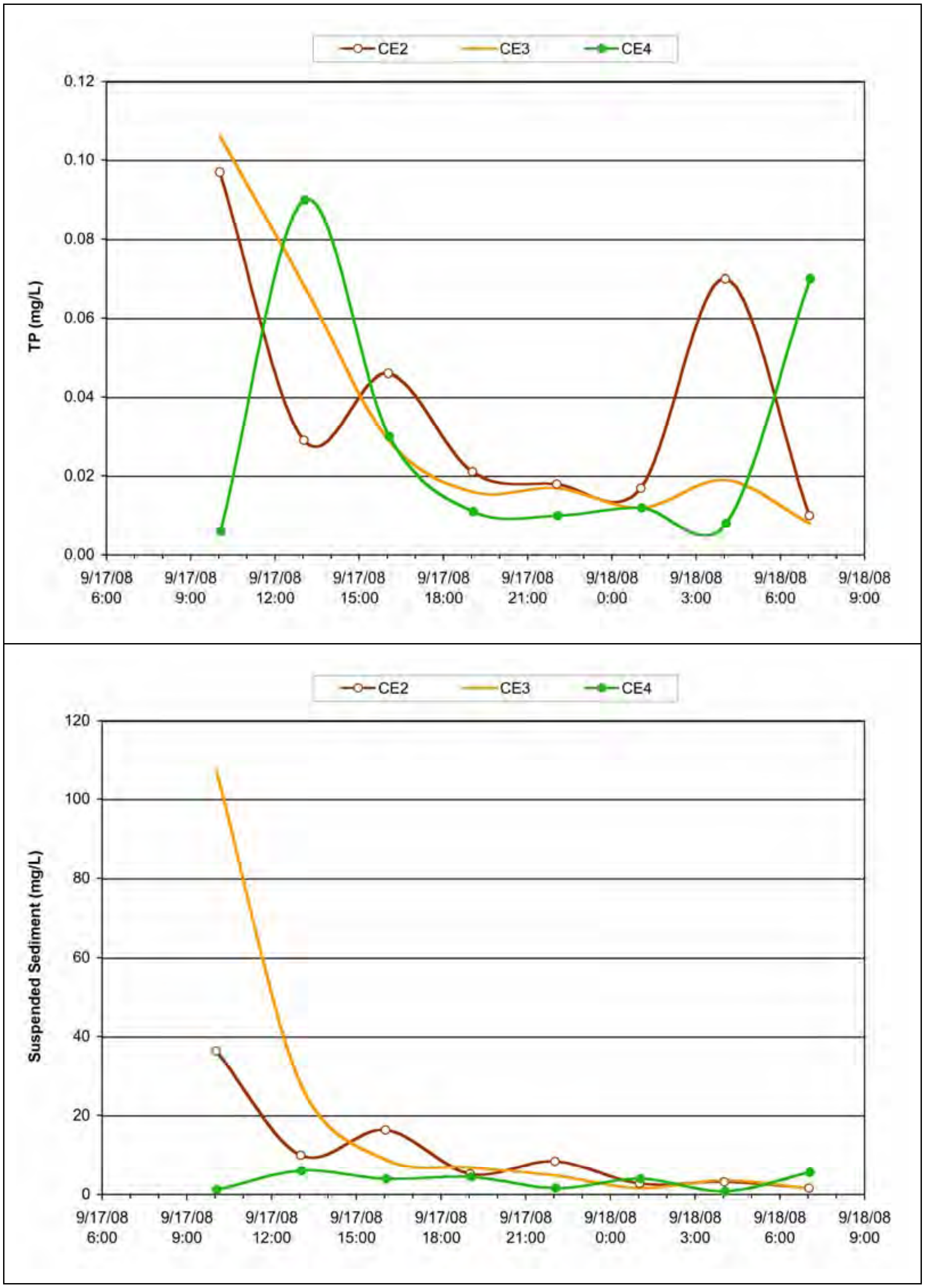


Figure 21. Simulated runoff experiment on September 17th, created by adding an initial spike and then aliquots of synthetic stormwater solution to Tank 1 every ten minutes over a twelve hour period. Sampling occurred at CE2–CE4 every three hours for 24 hours. Flow was constant through the system at 8.5 L/min (2.25 gal/min). Discrete samples were taken simultaneously at all four locations.

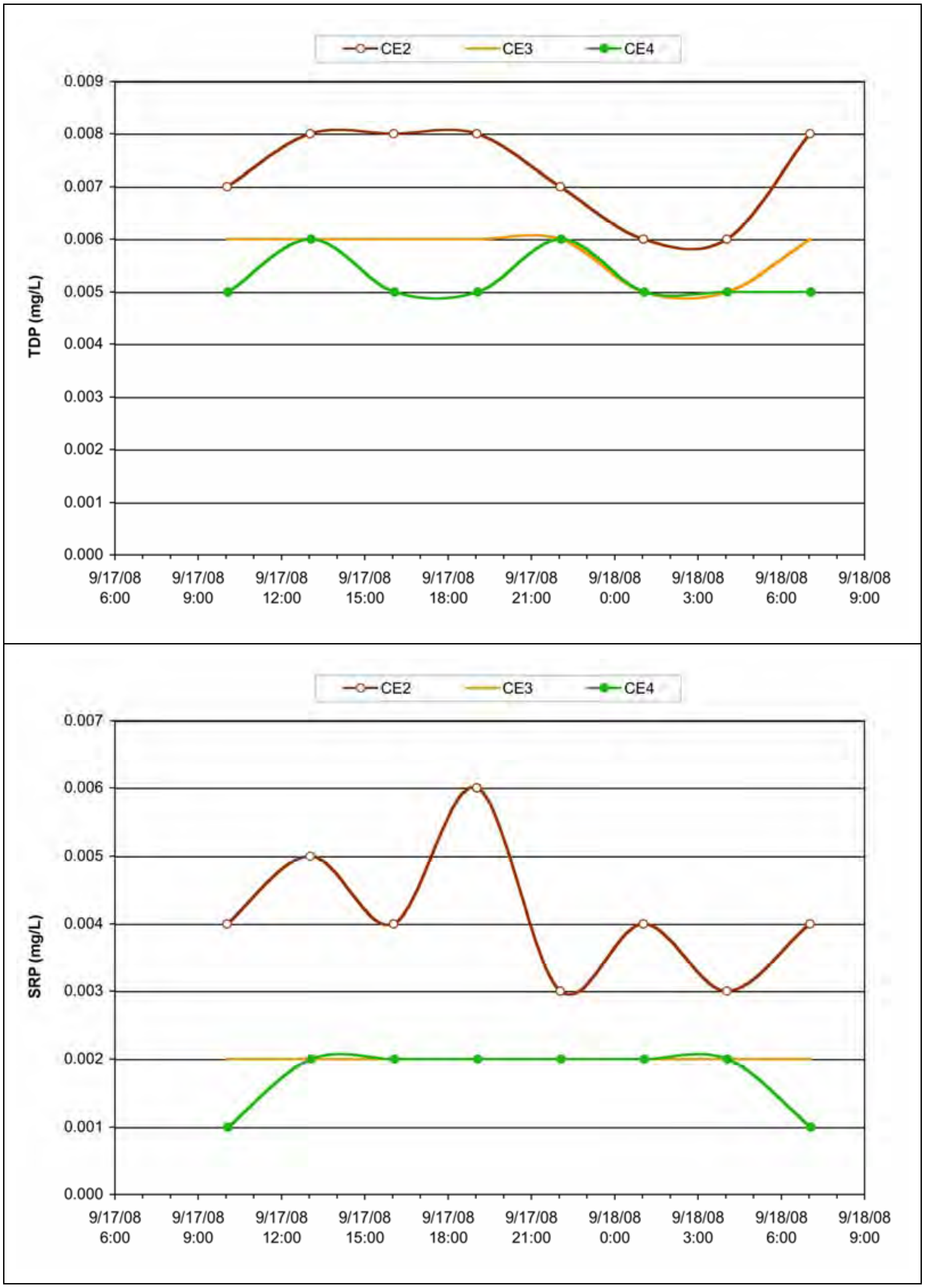


Figure 21. Simulated runoff experiment on September 17th, created by adding an initial spike and then aliquots of synthetic stormwater solution to Tank 1 every ten minutes over a twelve hour period. Sampling occurred at CE2–CE4 every three hours for 24 hours. Flow was constant through the system at 8.5 L/min (2.25 gal/min). Discrete samples were taken simultaneously at all four locations (continued).

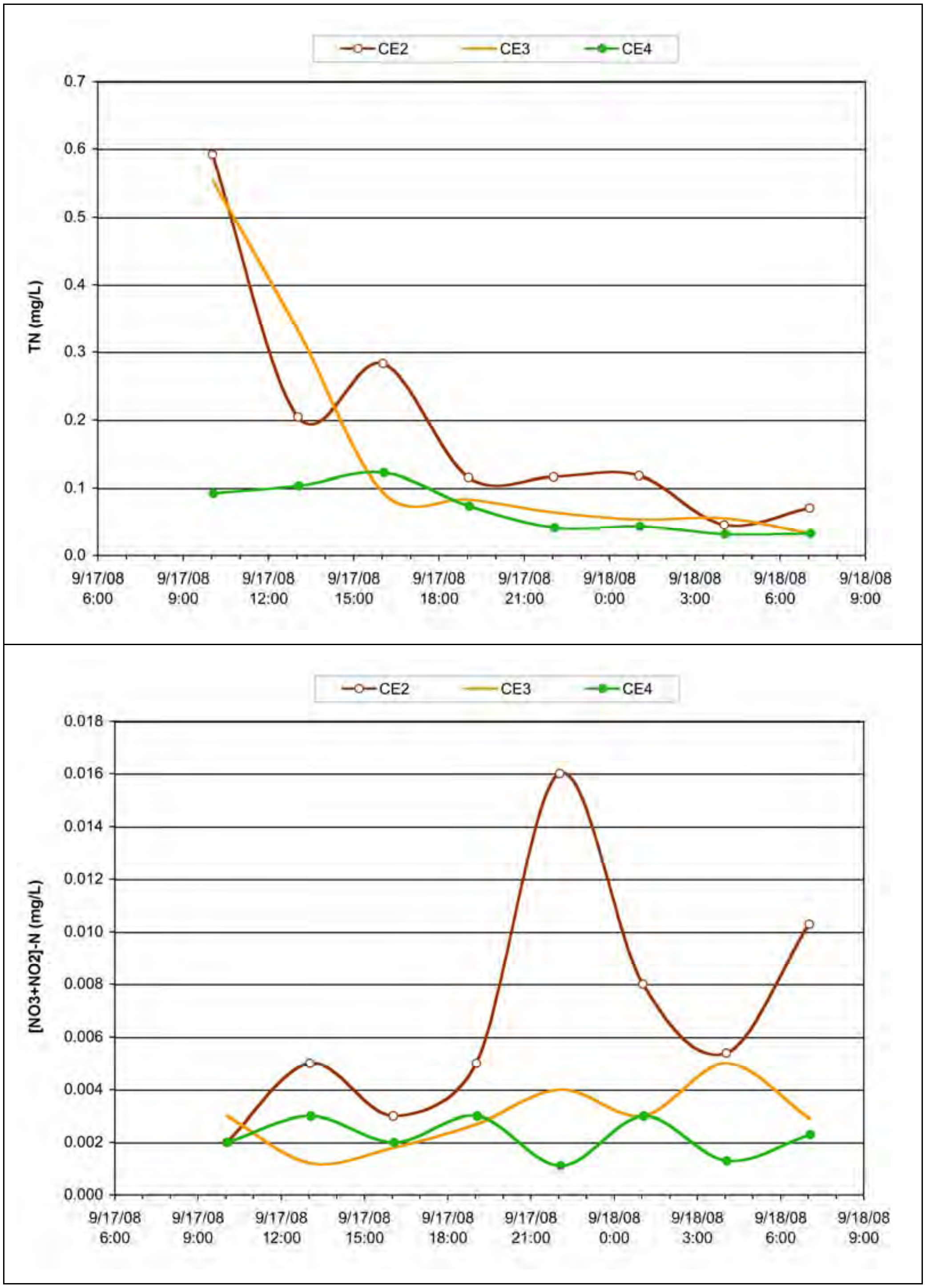


Figure 21. Simulated runoff experiment on September 17th, created by adding an initial spike and then aliquots of synthetic stormwater solution to Tank 1 every ten minutes over a twelve hour period. Sampling occurred at CE2–CE4 every three hours for 24 hours. Flow was constant through the system at 8.5 L/min (2.25 gal/min). Discrete samples were taken simultaneously at all four locations (continued).

During the second experiment, periphyton treatment clearly yielded reductions (from CE2) in turbidity, nitrate, SRP, total dissolved phosphorus (TDP) and TKN. The EMCs calculated for this 24 hour experiment also showed modest reductions in total phosphorus and in suspended sediment (Table 8). Concentrations of total particles less than 20 microns were lower by an order of magnitude compared to the November runoff event, but the periphyton treatment still reduced the total particle effluent numbers by about 33% during this experiment (Figure 22).

In the second experiment it would have been better to deliver synthetic stormwater aliquots into a mixing tank with constant baseflow input added, and then to measure delivery concentrations in the first tank (the usual CE1 sampling point) instead of from the stormwater tank (SWT concentrations). This would have provided information on treatment afforded by the first tank, which was not well represented in these results since the mixed inflow concentrations were not available. However, it just means the results obtained from this experiment are conservative, as the treatment provided by that first tank is not included in this analysis.

It also would have been better to deliver synthetic stormwater into the system over a full 24-hour period or longer (instead of 12 hours). That would have allowed the system to adjust to a steady state, which would have provided results easier to interpret and a better indication of treatment effectiveness. Unfortunately, we did not have the equipment for creating and continually mixing a uniform synthetic stormwater in sufficient quantity for this approach.

Load Reductions from Periphyton Treatment

Combining the monitoring results from the two natural events and from the two experiments, it is possible to derive estimates for treatment effectiveness by the periphyton system as it was configured and operated for this demonstration project. The loading estimates from all four events (natural and simulated) are aggregated in Table 9. These were calculated from event volumes, using the duration and constant flow rates measured during treatment, as described previously. Overall effectiveness in load reductions ranged from 29–39% for the various phosphorus species, and from 7–41% for the nitrogen species. The highest removal rates were observed for nitrate (41% ±30%) and SRP (39% ±23%), while suspended sediment was reduced by 29% (±29%) and total FSP were reduced by 16% (±13%). These results are quite similar to the mean reductions in concentrations estimated from baseflow sampling events (Table 6).

Overall, the runoff concentrations delivered into this treatment system were in the low to average range (Tables 7 and 8) relative to other areas with urban runoff in the Tahoe Basin (Lake Tahoe TMDL Technical Report, 2009). Nevertheless, the periphyton treatment system was fairly effective at producing pollutant load reductions, especially considering that it is generally easier to show higher percentage reductions with BMP treatment when the influent concentrations are elevated to begin with. On the other hand, this system is not designed to accommodate heavy pollutant concentrations and loads. More than likely it will find its ultimate use as a polishing component of an integrated system (treatment train) to help drive effluent concentrations down to the very low levels that will be needed before discharging stormwater into Lake Tahoe or to other water bodies in the Tahoe Basin.

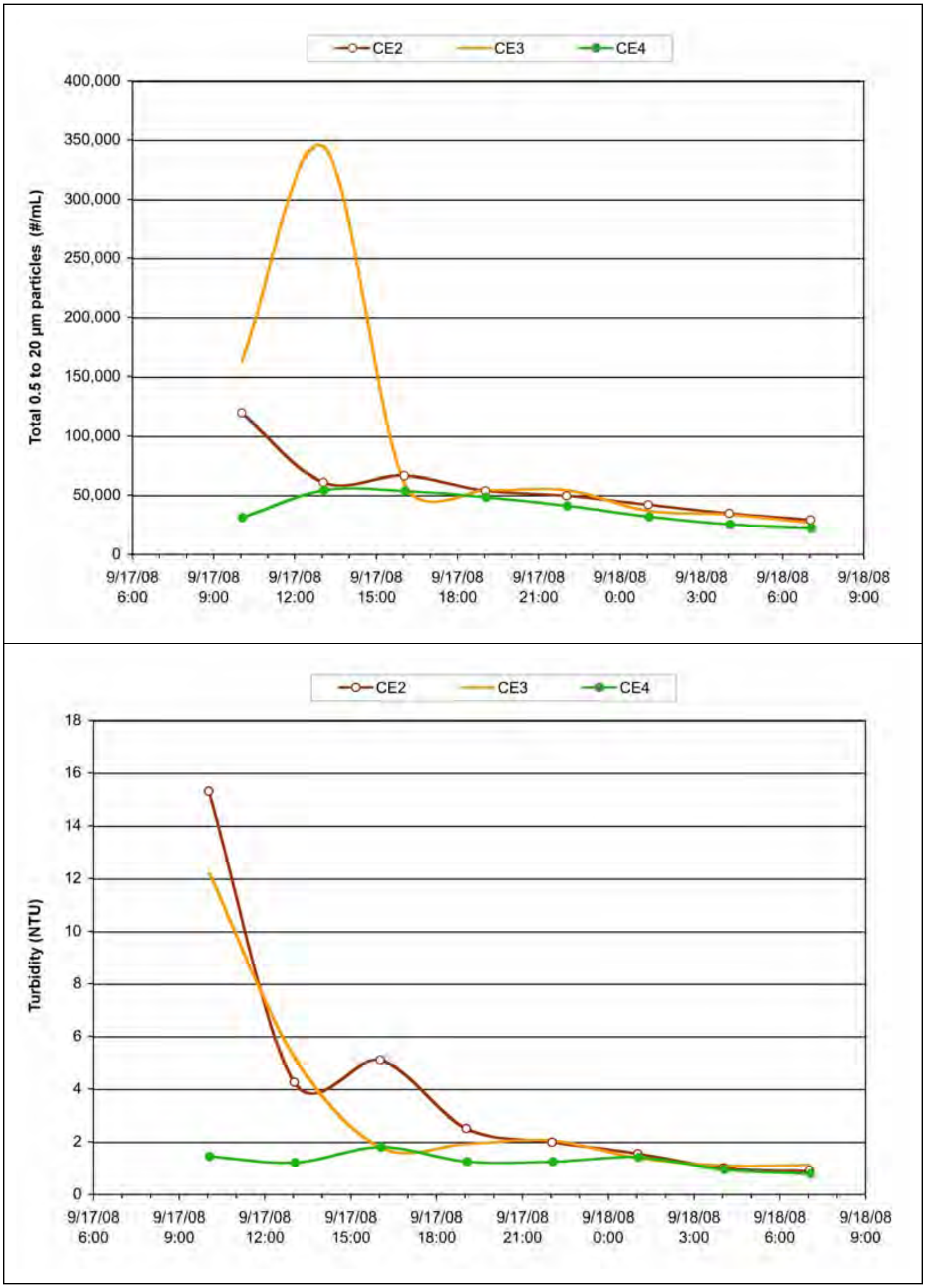


Figure 22. Total fine sediment particles and turbidity during simulated runoff experiment of September 17th. Synthetic stormwater solution was delivered to the treatment system and sampling occurred every three hours at CE2, CE3, and CE4. Discrete samples were taken simultaneously at all four locations.

Table 9. Event load reduction estimates and confidence intervals from two natural events and two simulated runoff experiments. Note that CE4 was compared to CE2 concentrations in the second experiment, when the concentrated SWT was used for spiking inflow water.

Event ID	Location	Sample	Date Time	Suspended Sediment (mg)	[NO3+NO2]-N (mg)	NH3-N (mg)	SRP (mg)	TDP (mg)	TP (mg)	TKN (mg)	0.5-20 µm Particles (#)
Event 1	CE1	EMC	10/4/08 15:04	217,800	30	178	40	176	1,487	11,108	1.2E+13
Event 1	CE4	EMC	10/4/08 15:14	141,768	23	180	34	141	1,131	9,682	1.2E+13
Event 2	CE1	EMC	11/2/08 11:21	265,696	1,070	172	1,220	1,466	2,396	7,938	2.6E+13
Event 2	CE4	EMC	11/2/08 11:24	229,156	369	160	471	720	1,228	6,381	2.1E+13
Exp 1	CE1	EMC	8/14/08 21:12	878,400	60	91	71	160	1,201	6,130	8.1E+12
Exp 1	CE4	EMC	8/14/08 21:12	410,194	55	88	55	135	742	4,711	7.2E+12
Exp 2	CE2	EMC	9/17/08 20:32	128,520	84	80	50	89	471	2,280	7.0E+11
Exp 2	CE4	EMC	9/17/08 20:34	42,228	27	64	21	64	363	796	4.7E+11
			mean reduction	29%	41%	7%	39%	29%	34%	30%	16%
			95% CI	(± 29%)	(± 30%)	(± 9%)	(± 23%)	(± 15%)	(± 12%)	(± 23%)	(± 13%)

SRP Treatment Optimization Experiments

Nitrogen fertilization experiments designed to reduce soluble reactive phosphorus (SRP) concentrations were begun on 8/9/08 and ended 10/30/08. During that period approximately 1.8 mg/L of potassium nitrate (yielding 0.022 mg/L of nitrate-N) was injected into the first algae tank at a rate of approximately 60 mL/hr. On 10/26/08 the concentration was increased to 8.3 mg/L (0.01 mg/L nitrate-N) for the last few days. Nitrate and phosphorus concentrations recorded during this time period are shown in Table 10.

Table 10. Influent and effluent nitrate (NO_3-N) and orthophosphate (SRP) concentrations during the nitrogen fertilization period.

Sample ID	Date	NO3-N (mg/L)	SRP (mg/L)
CE1-ASC	8/13/08 9:25	0.006	0.003
CE2-ASC	8/13/08 9:28	0.012	0.002
CE3-ASC	8/13/08 9:31	0.007	0.002
CE4-ASC	8/13/08 9:34	0.004	0.001
CE1-ASC	8/25/08 10:00	0.021	0.009
CE2-ASC	8/25/08 10:01	0.013	0.007
CE3-ASC	8/25/08 10:02	0.004	0.005
CE4-ASC	8/25/08 10:03	0.002	0.002
CE1-ASC	9/8/08 8:01	0.022	0.009
CE2-ASC	9/8/08 8:02	0.005	0.003
CE3-ASC	9/8/08 8:03	0.001	0.003
CE4-ASC	9/8/08 8:04	0.002	0.002
CE1-ASC	9/25/08 8:01	0.002	0.01
CE2-ASC	9/25/08 8:02	0.007	0.008
CE3-ASC	9/25/08 8:03	0.004	0.007
CE4-ASC	9/25/08 8:04	0.003	0.006
CE1-ASC	10/8/08 8:01	0.003	0.012
CE2-ASC	10/8/08 8:02	0.020	0.007
CE3-ASC	10/8/08 8:03	0.008	0.007
CE4-ASC	10/8/08 8:04	0.005	0.006
CE1-ASC	10/22/08 13:40	0.002	0.010
CE2-ASC	10/22/08 13:45	0.011	0.009
CE3-ASC	10/22/08 13:50	0.003	0.008
CE4-ASC	10/22/08 13:55	0.002	0.007

Sampling location CE1 in Table 10 represents the inflow out of Pond 1 into Tank 1. This was measured before nitrogen fertilizer was added into Tank 1. CE2 represents outflow from Tank 1, so it is the influent concentration plus fertilizer minus the amount removed by algae in Tank 1. On most occasions, nitrate concentrations in samples taken at CE2 during the fertilizer test period are higher than at CE1, but effluent levels (CE4) exiting the system never exceeded 0.005 mg/L.

The average effluent nitrate concentration during the fertilization experiment period was 0.003 mg/L (n=6, range 0.002 to 0.005 mg/L). The average influent SRP concentration of 0.009 mg/L (n=6, range 0.003 to 0.012 mg/L) was reduced to an average effluent SRP of 0.004 mg/L (n=6, range 0.001 to 0.007 mg/L).

The peristaltic pump injecting potassium nitrate into the CEG2 system malfunctioned on several occasions over the course of the experiment, so that the delivery of extra nitrogen to the system was somewhat inconsistent. Nevertheless, a consistent reduction of orthophosphate-P was observed over the period. The effluent orthophosphate-P levels recorded here are substantially lower than those observed during operation of the first pilot system, and are near the analytical detection limit of 0.001 mg/l. The observed values also are consistent with those seen in periphyton based systems in Florida, in which nitrogen was not limiting (DeBusk *et al*., 2004).

The results of the fertilization tests demonstrate the potential for periphyton-based systems to remove orthophosphate-P to very low concentrations (0.002 mg/L), under typical Tahoe climate conditions, when nitrogen levels are supplemented. More work is needed to substantiate this potential.

CONCLUSIONS

The Cultured Ecology Generation 2 Demonstration Project served its purposes well. A great deal was learned from the process of seeking a real-world location and then installing, operating, and monitoring the system at an existing stormwater runoff site for nine months.

Although several confounding factors affected the operation and performance of the CEG2 system, the potential use of cultured periphyton as an ecologically-based water quality improvement system for the Tahoe Basin was confirmed. Outflow concentrations for several species of both phosphorus and nitrogen were reduced during baseflow and for many of the events and experiments.

- During the nine-month demonstration period the treatment system removed between 11 to 14 grams of phosphorus (11 g based on biomass analysis, 14 g based on input-output analysis) from a three-tank system with average 9.4 L/minute (2.5 gal/min) flow.
- Results from experimental stormwater delivered into the treatment system showed a 49% or greater reduction in average concentration for suspended sediment and turbidity, a 23% or better reduction in total phosphorus, and 16% or more for reductions in TDP, SRP, and TKN.
- Results from the natural October stormwater runoff event showed nearly equivalent reductions as listed above for suspended sediment, nitrogen, and phosphorus.

However, there was no significant evidence of nitrate reduction from treatment during this event.

- Results from the large November stormwater runoff event showed similar patterns with reductions of more than 49% in both TP and TDP concentrations; the SRP was reduced by 61% and nitrate by 66%. There was some evidence of reduction in turbidity and suspended sediment from treatment during this event.
- Over the nine month period of baseflow operation and monitoring, already low influent concentrations to the treatment system were reduced further; the average SRP levels (0.008 mg/L) were reduced by 36% (±16%), the average TP concentrations (0.019 mg/L) were reduced by 24% (±12%), and average nitrate levels (0.010 mg/L) were reduced by 60% (±48%).
- With nitrogen fertilization used to stimulate biological uptake, the soluble reactive phosphorus levels were reduced to concentrations as low as 3 µg/L. These effluent SRP concentrations were substantially lower than those observed during operation of the pilot system (Patterson et al., 2007), and approach analytical detection limits.
- Periphyton treatment reduced nitrate levels to as low as 2 µg/L, even when additional nitrate was added to the system as fertilizer to enhance phosphorus uptake.

When interpreting these project results, several factors that influenced the function of the system during its operational period should be kept in mind. These include the following:

(1) Drawing water from an existing stormwater pond created the unexpected difficulty of a constant inflow and “seeding” of the cultured ecology system with non-target, non-periphyton species. At the same time, the bloom of these non-targeted algae species in the pond also substantially reduced nutrient levels for several months. Both of these factors contributed to less effective periphyton growth, especially in the early months.

(2) Influent sources were not consistent throughout the demonstration period. Source water influent to the system was changed from the stormwater pond to creek flow on July 25, 2008; which effectively reduced problematic algae flow into the system, but also slightly changed the influent chemical characteristics.

(3) For a period of a little over two months (5/13 to 7/23) a malfunctioning air pump reduced the internal pulsed mixing regime within each tank; repairs to the pump were ultimately unsatisfactory. A new air pump was installed on 7/23/08 and no further problems were observed.

(4) In the last months of operation, a changed sun angle meant that the first tank was shaded in the morning and consequently algal productivity decreased.

(5) The nitrogen pump malfunctioned repeatedly, reducing the data available on effects of nitrogen fertilization for improved SRP removal.

In spite of these challenges and the inherent complications of ecological systems, the Cultured Ecology Generation 2 system successfully demonstrated the potential for periphyton-based stormwater treatment in the Tahoe Basin. This ecologically oriented technology uses a coupling of naturally occurring Tahoe microorganisms, the sun’s energy, and modest technological infrastructure to help achieve Tahoe Basin goals for the reduction of nutrients and fine sediments from urban stormwater runoff. While performance results were influenced by the real-world complications noted above, overall performance of the system was consistent with promising results from the earlier pilot system (Patterson et al., 2007).

Considerations for Future Applications

The site selection process showed potential for applying the cultured periphyton technology to a wide range of places and situations in the Tahoe Basin (a site selection criteria checklist is provided in Appendix A).

Future projects should plan to include modest infrastructure development. In most places electrical service will have to be provided, and while baseflow opportunities usually exist in the vicinity of many dry basins, a conveyance system may be needed to transport it.

If stormwater ponds will be the source of water to be treated, then they must be managed and monitored as part of the system, probably considered as a treatment train. However, shading of runoff storage ponds would be desirable to prevent an excessive growth of non-targeted species of algae.

The process of selecting a site also highlighted the need for future deployments to include a provision for site housing and security.

A critical consideration is that the productivity and functioning of the system is driven by available light. Even modest shading will have a detrimental impact.

Future systems in the Basin should consider using nitrogen fertilization to further reduce effluent levels of soluble reactive phosphorus.

Although it was not possible to add additional tanks for this demonstration scale project, it would be useful to conduct an optimization procedure in future tests to assess the lowest practical concentrations attainable with a fully functional periphyton biofilm system.

The cultured periphyton system is modular. Therefore, the number of tanks can be increased as necessary to accommodate the general size of runoff flows anticipated for treatment in a particular location. For example, to treat the runoff from a small neighborhood catchment with a design storm volume of 5,000 cubic feet over a period of three days would require a setup around 3.5 times the size of the CEG2 demonstration system. This translates into roughly 9 to 12 tanks, arranged in 3 or 4 groups of 3-tank treatment trains. [At 9.4 L/minute (2.5 gal/min) the demonstration system treated 482 cf/day. To treat 5,000 cf over a three-day period would require treating 1,667 cf/day.]

That having been said, the most economical implementation scale will probably be based on sizing criteria that consider the most effective use of human labor, rather than on biological conditions. Larger scale application could make more efficient use of labor. Also, as mechanical systems change in future designs, especially in harvest technology, the ratio of human time required per installation will begin to decrease.

Probably the greatest impediment to future scaling up and widespread deployment of the cultured periphyton system is the labor required for harvest. Future trials of alternative harvesting methods, including the development of mechanical systems, as well as trials of different harvest interval periods are needed.

The cultured periphyton system is a stormwater treatment *system*. It requires oversight and maintenance, and as described, will require infrastructure development as part of its installation and operation. As a polishing system for a detention basin or wetland, it can remove dissolved nutrients and fine sediments to levels not achievable by basins or wetlands alone. The oversight and maintenance costs, particularly the labor of regular harvests, are the current hurdle to more widespread deployment. The estimated annual oversight and maintenance cost for the three tank system was $16,800 (Appendix A). The per-unit-of-water-treated costs of some activities would decline as the system was scaled up, but harvest costs would remain large. As part of the demonstration project, modified techniques to reduce the time and labor required for harvest were implemented on a regular basis, including trials of new pumps, piping, and filters. Continued efforts in this area, with additional mechanization, may make it possible to further reduce the costs of harvest. Additional refinement of periphyton harvesting methods and improved system designs to reduce harvest labor is probably the most important step toward making the system more broadly useful.

On the other hand, it may also be possible to utilize the insights gained here about the function and role of periphyton in water quality for other types of treatment systems. The most obvious example would be the construction of a submerged aquatic vegetation (SAV) and periphyton-based treatment wetland. Patterson (2007) proposed such a wetland modeled on the near-lake lagoons present in the Upper Truckee and Taylor Creek marshes. In some cases, Florida SAV and periphyton-based wetlands have demonstrated very high phosphorus removal potential without requiring harvesting (Knight et al., 2003).

Other methods of increasing surface area for periphyton growth within existing stormwater ponds may also be worthy of trials. As one of the deans of 20th century limnology stated:

"(C)losely aggregated, attached algal-microbial-substratum communities…function as the main mediator of nutrient and pollution retention…All management strategies must maximize physical contact and duration of contact between water and biofilm communities." (Wetzel, 2001b).

In short, the "next generation" of cultured periphyton for stormwater quality improvement in the Tahoe Basin may find several paths forward, rather than only one, for the use of periphyton in stormwater quality treatment systems.

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APPENDIX A. DESIGN GUIDELINES

Siting Criteria

Site selection analysis for this project showed the potential for applying the cultured periphyton technology in a range of places and situations in the Tahoe Basin. However, future projects will need to include provision for the development of a more robust infrastructure. In most places electrical wires will have to be run and in many situations water pipes will need to be laid to bring baseflow to basin locations. It was found, however, that baseflow opportunities existed in the vicinity of many basins, if appropriate infrastructure was provided to transport it. In addition, a site housing configuration will be required to deter vandalism and theft.

Table A-1. Site selection checklist.

Criteria	**Rationale**
A stormwater detention basin or treatment wetland, with sufficient appropriate adjacent space to install system.	A basin is required that will detain a volume of stormwater that can be cycled through the cultured ecology over a period of days (2 to 3) following a storm. The basin allows the treatment flow rate to be independent of any particular storm runoff rate. Is there an opportunity to optimally locate the culture tanks and pump or siphon stormwater to the equipment?
Access to baseflow	The maintenance of periphyton growth requires a constant baseflow through the tanks. This baseflow is also treated by the system, resulting in a nutrient load reduction on an ongoing basis. Are opportunities for baseflow available near the site that could be transported to the site with appropriate infrastructure development?
Access to electric power	24/7 power is required for air pump and water pump. Solar electricity may be an option in some situations. In some situations gravity flow may be sufficient for water movement, and the only power required would be for air pumps.
Direct sun (no shading of tanks)	The system runs on sunlight and requires maximum sunlight throughout its seasons of operation. Even modest shading can have detrimental effects on productivity.
Site security, safety, likelihood of vandalism	Pumps could be stolen, tanks could be damaged, someone messing with the electrical system could be injured.
Sufficient space for housing and fencing around equipment	- snow management - neighborhood aesthetics - provide reflective backing to the culture tanks - deter curiosity and vandalism
Ease of access to equipment in winter	Can a truck be pulled up to tanks or must we snowshoe in to gain access?
Ability to permit/permission from property owner	Will permission be difficult to get, will it have a time limit or other restrictions?

Freeze issues	In general, the cultured periphyton system has proven robust in Tahoe winters, as long as water is continuously flowing through the system. If continuous flow is interrupted, there could be issues with influent and effluent pipes freezing if they are lengthy and exposed to ambient temperatures Another issue could be a basin freezing solid and therefore interrupting baseflow.
Anticipated salt content in stormwater	Modest levels of salt are not a problem for algae growth, however high salt content in the stormwater could inhibit growth. At what level and under what urban conditions this might be a problem are not clear.

Construction Costs

The following estimate is for a three tank system like the CEG2 demonstration system.

Table A-2. Construction and installation costs.

Materials and Supply Items	Unit	Quantity	Unit Price	Cost	Notes
Solar algae tanks (30" dia. X 48" H)	tank	3	466.33	1,398.99	Unit price includes shipping
Tank covers	cover	3	220.00	660.00	Unit price includes shipping
Screen assemblies (PVC frame and polyester mesh)	screen	3	30.00	90.00	
Air compressor (3/4 HP)	compressor	1	770.00	770.00	Unit price includes shipping
Geyser pump (2")	pump	3	545.00	1,635.00	Unit price includes shipping
Water pump (3.6 gal/min, self-priming) (system supply)	pump	1	300.00	300.00	Unit price includes shipping. Should have a second pump as backup.
Metal box for protection and storage of pumps	box	1	192.00	192.00	
Miscellaneous supplies (e.g., flexible PVC air lines, water hoses, plumbing connections between tanks, etc.)	lump sum	1	275.00	275.00	
Sheet metal (reflective backdrop)	4' x 8' sheet	2	82.50	165.00	
Plywood (reflective backdrop)	4' x 8' sheet	2	25.00	50.00	
Metal T-posts (reflective backdrop)	post	7	2.95	20.65	
Paving blocks	square foot	144	3.47	499.68	
Wood chip mulch	cubic yard	1	42.00	42.00	
Chainlink fencing (5' height)	linear foot	64	7.25	464.00	
Power pole	installation	1	1,138.00	1,138.00	
Electricty (Sierra Pacific Power)	monthly	18	31.17	561.06	
Water pump (1/2 HP) (harvest)	pump	1	335.00	335.00	
Mesh bags (harvest)	bag	6	12.50	75.00	
Vacuum cleaner (harvest)	vacuum cleaner	1	160.00	160.00	
Plastic trays (harvest)	tray	4	5.00	20.00	
TOTAL				**$ 8,851.38**	

1.These costs represent the estimated cost of constructing a treatment system the same size and configuration as the demonstration system. The cost includes only construction expenses. Research costs have been excluded.

Operation and Maintenance

The demonstration project included significant monitoring and stormwater experiments, the labor costs of which can only roughly be separated from routine oversight and maintenance, so the costs below are estimates only. The costs shown are for operation and maintenance of the system, not for analytical monitoring or experiments. Oversight and maintenance costs could probably be spread over a larger system. With current design and harvest techniques, harvest costs would be additive for larger systems (i.e., more tanks).

Table A-3. Annual O&M labor cost.

Task Description	Persons required (or desirable)	Hours per week	Hours per harvest	Harvests per year	Cost per year (@$30/hr)
System oversight, includes:	1	8			
Check water pump operation					
Check water inflow screen for blockage					
Check system for water leaks					
Measure flow rate					
Check air bubbling rate					
Check air pump operation					
Check to see how algae are growing					
Reseeding as necessary					
Clean clogged inflow water supply					
Reintroduce siphon					
Replace broken air pump parts					
Replace broken water pump					
Snow removal					
Total annual oversight (52 weeks)		416			$12,480.00
Periphyton harvest, includes:	2		6	12	
Preparation, set-up, and breakdown of equipment					
Harvesting of screens					
Harvesting of residual algae in tank					
Total annual harvest (12 harvests/year)				144	$4,320.00
Total annual labor cost					**$16,800.00**

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APPENDIX B. EXPERIMENT 1 PROTOCOL

Experiment 1 took place on August 14, 2008.

Purpose: Elevated sediment and nutrient conditions were created by delivering mechanically agitated retention basin water to the system, intended to mimic storm conditions.

Procedure:

Mechanically agitate the bottom of the retention pond:

Initial agitation consisting of raking the bottom sediment with a small leaf rake on an extension pole to lift the sediment into suspension and then stirring with the rake to mix the pond water without further displacing sediment from the bottom.

Periodic agitation for the first eight hours consisting of raking and stirring every hour and stirring alone every hour on alternating half hour schedules.

Move the influent line from the stream to Pond 1at t=0. Activate detention basin pump plumb to inflow of system.

Water quality sampling begins at t=0 for each of the four autosampler locations: CE1 – inflow to the system from the detention basin, CE2 – outflow of the first tank, CE3 –outflow of the second tank, CE4 – outflow of the third tank (end of system). Samples are collected hourly at CE1, CE2, CE3, and CE4 over a period of 8 hours and then every three hours for the next fifteen hours.

After a 24 hour period has passed, samples are taken back to the lab to be analyzed. Turbidity nutrients, EC, pH, and TSS to be run on every sample hour for the first eight hours and every 3 hours for the remainder of the samples for each of the four locations.

After all the water quality samples are collected (24 hours) return the influent line to the stream, run for 24 hours, then harvest of all three tanks.

Note: The baseflow rate and N-fertilization rates remain unchanged over the course of the experiment.

Schedule:

8/14/08 at 12:00: Experiment began with detention basin mechanically agitated.

8/14/08 at 12:30: Water quality sampling commenced.

8/15/08: Samples processed and analyzed.

8/16/08: All three tanks harvested and the system reset.

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APPENDIX C. EXPERIMENT 2 PROTOCOL

Experiment 2 was conducted on September 17, 2008.

Purpose: Deliver synthetic stormwater to the system, causing elevated nutrient and sediment concentrations intended to mimic storm conditions.

Procedure:

Mix a batch of synthetic stormwater by adding 2 kg of Washoe County fine street sweepings to a 50 gallon mixing tank filled with spring water. Mix the solution at a mixing rate of 1700 rpm for 72 hours. Let the solution sit for 5 hours and decant off the middle section into seven 5 gallon buckets, discarding the settled (coarse geologic) and floating (organic) material. Clean the mixing tank and transport set-up to the CEG2 site.

Set the delivery tank up on-site and add the decanted solution to the mixing tank. Use an air circulation system to mix the synthetic stormwater in the mixing tank. The bubbling acts as a mixer, keeping the particles in suspension for the duration of the experiment.

Spike the first tank in the cultured ecologies treatment system with 13.5 L of the synthetic stormwater. This will establish a relatively high concentration in tank 1 to begin the experiment, and then subsequent aliquots will serve to maintain elevated concentrations for a simulated storm runoff event.

After the initial spike, use a Sigma 900MAX autosampler to deliver 900 mL of synthetic stormwater into the first tank on 10-minute intervals. Let the dispenser run 12 hours, for a total introduction of 78.3 L of concentrated synthetic stormwater (including initial spike).

Water quality sampling begins three hours after initial spiking of tank 1 with synthetic stormwater mixture. Autosampler locations will be located at outflow from the stormwater tank (SWT), outflow from the first periphyton tank (CE2), outflow from the second periphyton tank (CE3), and outflow of the third tank (CE4). Samples were collected every three hours over a 24-hour period at CE2, CE3 and CE4, and over a 12-hour period from the SWT (while stormwater is dispensed).

After the 24 hour period has passed, samples are taken back to the lab to be analyzed. Turbidity, nutrients, EC, pH, TSS and PSD will be run on samples from each of the four locations.

After this experiment ends the system will run for 24 hours with creek water baseflow, followed by a harvest of all three tanks.

Note: Baseflow and N-fertilization rates remain unchanged during the experiment.

Schedule:

9/11/08: synthetic stormwater batch is made at UCD Tahoe City lab.

9/16/08: mixing of stormwater stops, solution decanted and equipment moved to CEG2 site, experiment then set-up to be run the following day.

9/17/08 at 7 am: synthetic stormwater introduced to the system.

9/17/08 at 10 am: experiment 2 sampling began.

9/18/08 at 7 am: samples collected, processed and subsequently analyzed.

9/19/08: All three tanks harvested and the system reset.

APPENDIX D. BASEFLOW WATER QUALITY DATA.

Location	Sample Type	Date Time	Suspended Sediment (mg/L)	LOI (wt %)	Turbidity (NTU)	EC (µS/cm)	pH	[NO3+NO2]-N (mg/L)	NH3-N (mg/L)	SRP (mg/L)	TDP (mg/L)	TP (mg/L)	TKN (mg/L)	0.5-20 µm Particles (#/mL)
CE1	GSC	3/3/08 12:25	6.8	<0.1%	7.90	182.80	7.41	0.022	0.007	0.009	0.012	0.026	0.11	na
CE1	grab	3/17/08 12:20	6.8	50.0%	4.86	241.40	7.44	0.024	0.009	0.008	0.012	0.018	0.09	45,951
CE1	grab	3/31/08 12:45	2.0	100.0%	4.90	237.80	7.37	0.008	0.007	0.010	0.013	0.017	0.14	7,946
CE1	ASC	4/15/08 8:01	2.0	100.0%	3.36	182.40	7.61	0.005	0.009	0.006	0.011	0.016	0.14	16,242
CE1	ASC	4/27/08 9:38	1.2	100.0%	3.18	200.20	7.81	0.005	0.007	0.008	0.010	0.015	0.07	17,731
CE1	ASC	5/14/08 8:01	2.0	60.0%	3.25	209.40	7.76	0.002	0.003	0.003	0.006	0.014	0.08	54,627
CE1	ASC	5/27/08 10:01	2.8	80.0%	3.92	155.00	7.59	0.032	0.011	0.014	0.019	0.030	0.13	118,312
CE1	ASC	6/9/08 7:51	3.6	100.0%	2.60	166.00	7.96	0.007	0.003	0.004	0.008	0.021	0.11	61,721
CE1	ASC	6/23/08 7:31	2.0	100.0%	2.33	253.20	7.96	0.004	0.008	0.009	0.011	0.021	0.07	84,010
CE1	ASC	7/7/08 9:01	1.6	100.0%	2.03	174.60	7.94	0.002	0.012	0.004	0.009	0.021	0.10	142,864
CE1	ASC	7/21/08 8:01	1.6	100.0%	2.77	130.00	7.78	0.004	0.009	0.004	0.011	0.021	0.15	254,932
CE1	ASC	8/4/08 8:46	1.6	<0.1%	1.67	71.72	7.73	0.006	0.008	0.007	0.009	0.016	0.12	53,018
CE1	ASC	8/13/08 9:25	4.8	66.7%	2.60	101.70	7.63	0.007	0.008	0.003	0.007	0.020	0.21	51,816
CE1	ASC	8/25/08 10:00	2.4	50.0%	1.78	83.05	6.74	0.022	0.011	0.009	0.009	0.013	0.02	na
CE1	ASC	9/8/08 8:01	9.2	50.0%	5.17	199.60	6.65	0.023	0.013	0.009	0.016	0.038	0.27	62,470
CE1	ASC	9/25/08 8:01	2.0	<0.1%	1.64	85.89	6.80	0.003	0.010	0.010	0.013	0.015	0.04	na
CE1	ASC	10/8/08 8:01	3.2	83.3%	1.57	77.83	7.16	0.004	0.007	0.012	0.014	0.017	0.07	26,824
CE1	ASC	10/22/08 13:40	2.0	60.0%	1.87	76.72	7.53	0.002	0.002	0.010	0.009	0.011	0.09	18,762
CE2	GSC	3/3/08 12:23	7.6	71.4%	7.49	222.80	7.99	0.008	0.006	0.010	0.011	0.026	0.13	na
CE2	grab	3/17/08 12:15	5.6	50.0%	5.73	227.50	7.88	0.008	0.008	0.007	0.009	0.019	0.12	47,900
CE2	grab	3/31/08 12:42	0.8	<0.1%	4.65	212.30	7.64	0.006	0.006	0.008	0.010	0.016	0.06	7,661
CE2	ASC	4/15/08 8:02	1.2	100.0%	3.32	195.60	7.59	0.005	0.009	0.005	0.009	0.016	0.13	17,971
CE2	ASC	4/27/08 9:39	2.4	100.0%	1.95	237.40	7.90	0.005	0.005	0.008	0.010	0.015	0.08	15,397
CE2	ASC	5/14/08 8:02	2.0	100.0%	2.19	209.60	7.82	0.003	0.011	0.004	0.006	0.013	0.12	83,277
CE2	ASC	5/27/08 10:02	2.4	100.0%	6.30	149.40	7.96	0.019	0.010	0.010	0.017	0.027	0.15	130,501
CE2	ASC	6/9/08 7:52	4.4	<0.1%	3.15	198.80	8.11	0.004	0.006	0.004	0.007	0.018	0.12	68,536
CE2	ASC	6/23/08 7:32	2.4	83.3%	2.73	195.80	7.96	0.004	0.009	0.008	0.010	0.022	0.12	48,595
CE2	ASC	7/7/08 9:02	1.6	100.0%	2.03	151.80	7.99	0.002	0.028	0.003	0.010	0.020	0.13	124,901
CE2	ASC	7/21/08 8:02	2.8	71.4%	2.65	167.20	7.89	0.002	0.014	0.004	0.009	0.023	0.21	163,151
CE2	ASC	8/4/08 8:49	2.0	80.0%	1.64	72.19	7.67	0.006	0.010	0.007	0.009	0.017	0.15	45,201
CE2	ASC	8/13/08 9:28	2.8	33.3%	2.43	57.37	7.70	0.013	0.011	0.002	0.009	0.019	0.20	41,898
CE2	ASC	8/25/08 10:01	5.6	100.0%	1.52	70.84	6.96	0.014	0.008	0.007	0.008	0.010	0.03	na
CE2	ASC	9/8/08 8:02	4.0	60.0%	3.06	73.08	6.83	0.006	0.011	0.003	0.010	0.028	0.31	49,185
CE2	ASC	9/25/08 8:02	1.2	<0.1%	1.51	64.64	6.95	0.009	0.011	0.008	0.009	0.011	0.04	na
CE2	ASC	10/8/08 8:02	2.0	<0.1%	2.29	79.63	7.24	0.021	0.005	0.007	0.011	0.018	0.06	45,418
CE2	ASC	10/22/08 13:45	2.0	100.0%	1.85	80.90	7.48	0.012	0.006	0.009	0.007	0.010	0.12	na
CE3	GSC	3/3/08 12:20	7.2	50.0%	7.41	220.00	8.29	0.005	0.006	0.009	0.010	0.023	0.12	na
CE3	grab	3/17/08 12:10	6.4	70.0%	4.96	237.90	8.33	0.005	0.007	0.005	0.009	0.019	0.12	45,105
CE3	grab	3/31/08 12:40	1.6	33.3%	3.12	254.20	7.74	0.006	0.007	0.009	0.011	0.017	0.07	7,311
CE3	ASC	4/15/08 8:03	3.6	85.7%	4.02	202.60	7.78	0.005	0.016	0.005	0.009	0.016	0.19	19,449
CE3	ASC	4/27/08 9:40	2.4	66.7%	2.13	165.70	7.91	0.005	0.008	0.006	0.010	0.014	0.08	16,040
CE3	ASC	5/14/08 8:03	2.0	60.0%	2.23	196.50	7.98	0.004	0.010	0.005	0.005	0.009	0.11	86,782
CE3	ASC	5/27/08 10:03	1.2	100.0%	7.54	134.80	7.95	0.010	0.010	0.010	0.016	0.025	0.18	113,567
CE3	ASC	6/9/08 7:53	4.8	85.7%	3.39	198.10	8.08	0.006	0.008	0.003	0.007	0.021	0.16	95,658
CE3	ASC	6/23/08 7:33	2.8	100.0%	2.78	177.10	8.00	0.003	0.011	0.006	0.010	0.022	0.08	87,854
CE3	ASC	7/7/08 9:03	2.0	100.0%	2.08	110.70	7.97	0.002	0.019	0.004	0.008	0.021	0.15	115,605
CE3	ASC	7/21/08 8:03	1.6	100.0%	2.12	157.40	7.94	0.003	0.015	0.006	0.012	0.022	0.20	234,128
CE3	ASC	8/4/08 8:52	1.2	<0.1%	1.53	64.13	7.55	0.003	0.010	0.005	0.008	0.015	0.11	50,038
CE3	ASC	8/13/08 9:31	3.6	87.5%	1.56	52.65	7.73	0.008	0.004	0.002	0.008	0.016	0.21	22,508
CE3	ASC	8/25/08 10:02	6.8	88.9%	2.13	77.42	7.26	0.005	0.006	0.005	0.007	0.009	0.05	na
CE3	ASC	9/8/08 8:03	11.2	75.0%	10.20	68.45	6.92	0.002	0.008	0.003	0.011	0.161	0.72	75,331
CE3	ASC	9/25/08 8:03	2.0	100.0%	1.40	76.56	7.11	0.005	0.013	0.007	0.008	0.009	0.03	na
CE3	ASC	10/8/08 8:03	2.8	100.0%	2.64	83.03	7.26	0.009	0.005	0.007	0.012	0.015	0.09	27,536
CE3	ASC	10/22/08 13:50	3.6	77.8%	1.40	70.52	7.50	0.003	0.006	0.008	0.007	0.009	0.12	na
CE4	GSC	3/3/08 12:15	5.2	40.0%	6.78	211.30	8.34	0.005	0.006	0.009	0.009	0.020	0.12	na
CE4	grab	3/17/08 12:05	3.6	60.0%	4.64	241.80	8.23	0.004	0.008	0.004	0.009	0.015	0.09	44,553
CE4	grab	3/31/08 12:35	0.8	100.0%	2.81	260.60	7.81	0.006	0.006	0.007	0.009	0.014	0.05	6,247
CE4	ASC	4/15/08 8:04	2.4	100.0%	2.43	232.80	7.86	0.006	0.018	0.004	0.011	0.016	0.18	28,594
CE4	ASC	4/27/08 9:45	1.6	100.0%	1.94	234.40	7.99	0.005	0.014	0.006	0.010	0.014	0.08	15,653
CE4	ASC	5/14/08 8:04	1.6	100.0%	3.25	205.60	8.12	0.004	0.010	0.005	0.005	0.011	0.12	70,296
CE4	ASC	5/27/08 10:04	2.4	<0.1%	5.41	178.50	7.80	0.005	0.007	0.009	0.014	0.024	0.17	122,565
CE4	ASC	6/9/08 7:54	5.2	75.0%	3.11	190.40	8.23	0.005	0.007	0.002	0.006	0.017	0.14	102,424
CE4	ASC	6/23/08 7:34	3.2	100.0%	1.97	173.90	8.14	0.004	0.009	0.006	0.009	0.019	0.16	83,379
CE4	ASC	7/7/08 9:04	1.6	100.0%	2.13	97.38	8.06	0.002	0.015	0.005	0.008	0.019	0.11	107,035
CE4	ASC	7/21/08 8:04	6.8	52.9%	4.42	154.00	7.96	0.002	0.007	0.003	0.008	0.022	0.24	147,354
CE4	ASC	8/4/08 8:55	6.0	100.0%	1.51	53.46	7.55	0.003	0.009	0.005	0.008	0.012	0.10	42,421
CE4	ASC	8/13/08 9:34	2.4	75.0%	1.76	33.80	7.66	0.005	0.011	0.001	0.007	0.010	0.20	27,107
CE4	ASC	8/25/08 10:03	2.0	100.0%	1.90	74.10	7.38	0.003	0.004	0.002	0.005	0.008	0.03	na
CE4	ASC	9/8/08 8:04	5.6	50.0%	1.90	75.83	6.93	0.002	0.010	0.002	0.008	0.017	0.18	63,499
CE4	ASC	9/25/08 8:04	<0.4	<0.1%	1.53	72.06	7.18	0.003	0.009	0.006	0.008	0.009	0.04	na
CE4	ASC	10/8/08 8:04	4.0	100.0%	1.87	73.91	7.32	0.006	0.009	0.006	0.009	0.010	0.04	29,575
CE4	ASC	10/22/08 13:55	0.4	100.0%	3.90	72.56	7.51	0.003	0.004	0.007	0.005	0.008	0.06	18,802

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APPENDIX E. STORMWATER RUNOFF WATER QUALITY DATA

Analytic results and calculated EMCs from stormwater runoff event of October 3-4, 2008.

Location	Sample	Date Time	Suspended Sediment (mg/L)	LOI (wt %)	Turbidity (NTU)	EC (µS/cm)	pH	[NO3+NO2]-N (mg/L)	NH3-N (mg/L)	SRP (mg/L)	TDP (mg/L)	TP (mg/L)	TKN (mg/L)	0.5-20 µm Particles (#/mL)
CE1	2	10/4/08 7:34	29.6	73.1%	9.91	106.8	6.91	0.003	0.018	0.004	0.014	0.148	1.22	925,987
CE1	3	10/4/08 10:34	17.2	38.5%	8.65	100.4	6.81	0.003	0.019	0.004	0.013	0.142	1.22	1,108,893
CE1	4	10/4/08 13:34	20.4	67.6%	11.50	56.71	6.78	0.002	0.015	0.003	0.015	0.136	0.98	1,071,467
CE1	5	10/4/08 16:34	16.0	60.6%	8.86	57.35	6.82	0.003	0.013	0.003	0.017	0.117	0.82	1,096,687
CE1	6	10/4/08 19:34	13.6	50.0%	9.45	82.43	6.94	0.002	0.012	0.003	0.016	0.11	0.68	1,057,073
CE1	7	10/4/08 22:34	13.2	74.2%	9.94	62.09	6.92	0.002	0.013	0.003	0.014	0.098	0.69	982,767
CE4	2	10/4/08 7:44	15.2	40.0%	9.31	96.91	6.94	0.002	0.015	0.003	0.011	0.111	0.86	958,627
CE4	3	10/4/08 10:44	15.2	78.6%	9.05	90.03	6.88	0.002	0.017	0.003	0.011	0.116	1.14	1,040,580
CE4	4	10/4/08 13:44	10.8	50.0%	9.00	84.5	7.07	0.002	0.017	0.003	0.011	0.099	0.94	1,053,860
CE4	5	10/4/08 16:44	12.8	77.8%	8.31	87.43	7.05	0.002	0.015	0.003	0.012	0.091	0.74	1,070,147
CE4	6	10/4/08 19:44	10.0	68.0%	9.41	80.92	7.01	0.002	0.015	0.002	0.013	0.081	0.63	1,065,727
CE4	7	10/4/08 22:44	7.6	55.6%	9.31	77.05	6.97	0.002	0.012	0.003	0.013	0.073	0.58	926,613
CE1	EMC	10/4/08 15:04	18.3	60.7%	9.72	77.6	6.86	0.003	0.015	0.003	0.015	0.125	0.935	1,040,479
CE4	EMC	10/4/08 15:14	11.9	61.7%	9.07	86.1	6.99	0.002	0.015	0.003	0.012	0.095	0.815	1,019,259

Analytic results and calculated EMCs from stormwater runoff event of November 1-3, 2008.

Location	Sample	Date Time	Suspended Sediment (mg/L)	LOI (wt %)	Turbidity (NTU)	EC (µS/cm)	pH	[NO3+NO2]-N (mg/L)	NH3-N (mg/L)	SRP (mg/L)	TDP (mg/L)	TP (mg/L)	TKN (mg/L)	0.5-20 µm Particles (#/mL)
CE1	0001	11/1/08 12:21	2.9	28.6%	2.98	164.00	7.48	na	na	na	na	na	na	574,807
CE1	0102	11/1/08 13:21	na	na	na	na	na	0.001	0.005	0.006	0.006	0.016	0.120	na
CE1	0002	11/1/08 14:21	3.2	<0.1%	2.66	167.70	7.61	na	na	na	na	na	na	339,173
CE1	0003	11/1/08 16:21	5.6	44.4%	9.14	112.50	7.61	0.002	0.008	0.003	0.007	0.045	0.300	806,723
CE1	0004	11/1/08 18:21	11.2	65.2%	10.30	109.70	7.49	0.002	0.008	0.004	0.008	0.056	0.370	860,560
CE1	0005	11/1/08 20:21	7.2	47.1%	16.00	112.00	7.41	0.002	0.009	0.008	0.018	0.073	0.440	1,590,400
CE1	0006	11/1/08 22:21	30.4	25.7%	29.10	59.41	7.32	0.002	0.007	0.028	0.038	0.121	0.380	1,552,920
CE1	0007	11/2/08 0:21	10.4	53.3%	23.70	35.25	7.24	0.020	0.006	0.076	0.087	0.153	0.360	1,243,907
CE1	0008	11/2/08 2:21	23.6	38.3%	25.60	36.59	7.22	0.075	0.006	0.087	0.102	0.164	0.390	1,438,133
CE1	0009	11/2/08 4:21	16.4	25.8%	16.20	37.72	7.14	0.086	0.006	0.088	0.103	0.158	0.360	1,403,753
CE1	0010	11/2/08 6:21	12.0	42.1%	13.70	66.55	7.04	0.157	0.007	0.092	0.109	0.155	0.400	1,070,260
CE1	0011	11/2/08 8:21	10.0	31.3%	12.70	66.22	7.14	0.131	0.007	0.088	0.105	0.144	0.350	1,051,587
CE1	0012	11/2/08 10:21	10.0	47.1%	14.80	73.58	7.19	0.142	0.007	0.082	0.098	0.134	0.330	1,075,020
CE1	0013	11/2/08 12:21	11.6	53.8%	11.30	76.04	7.14	0.118	0.007	0.076	0.093	0.126	0.350	996,253
CE1	0014	11/2/08 14:21	8.8	27.3%	10.70	83.87	7.18	0.080	0.007	0.067	0.081	0.110	0.330	1,073,633
CE1	0015	11/2/08 16:21	10.0	66.7%	9.03	81.88	8.61	0.054	0.007	0.061	0.074	0.102	0.310	991,727
CE1	0016	11/2/08 18:21	7.0	45.5%	10.30	82.77	7.29	na	na	na	na	na	na	889,327
CE1	0017	11/2/08 20:21	8.3	63.6%	9.87	85.33	7.31	na	na	na	na	na	na	932,347
CE1	1618	11/2/08 20:21	na	na	na	na	na	0.025	0.006	0.051	0.058	0.084	0.280	na
CE1	0018	11/2/08 22:21	8.3	<0.1%	7.78	96.55	7.33	na	na	na	na	na	na	931,827
CE1	0019	11/3/08 0:21	8.7	30.8%	7.47	98.37	7.37	na	na	na	na	na	na	794,107
CE1	0020	11/3/08 2:21	7.7	40.0%	11.80	112.50	7.40	na	na	na	na	na	na	819,867
CE1	1921	11/3/08 2:21	na	na	na	na	na	0.006	0.006	0.036	0.043	0.065	0.250	na
CE1	0021	11/3/08 4:21	5.7	50.0%	9.25	113.10	7.34	na	na	na	na	na	na	801,507
CE1	0022	11/3/08 6:21	8.0	11.1%	7.91	111.60	7.40	na	na	na	na	na	na	799,453
CE1	0023	11/3/08 8:21	5.7	66.7%	8.35	116.00	7.42	na	na	na	na	na	na	796,927
CE1	2224	11/3/08 8:21	na	na	na	na	na	0.001	0.006	0.024	0.030	0.050	0.230	na
CE1	0024	11/3/08 10:21	8.0	72.7%	6.73	137.10	7.41	na	na	na	na	na	na	804,693
CE2	0001	11/1/08 12:22	7.1	75.0%	4.43	164.30	7.11	na	na	na	na	na	na	319,673
CE2	0102	11/1/08 13:22	na	na	na	na	na	0.001	0.005	0.003	0.007	0.020	0.160	na
CE2	0002	11/1/08 14:22	2.5	20.0%	3.44	143.70	7.55	na	na	na	na	na	na	320,623
CE2	0003	11/1/08 16:22	8.8	50.0%	7.01	142.20	7.54	0.002	0.007	0.003	0.006	0.036	0.250	608,517
CE2	0004	11/1/08 18:22	19.2	42.9%	13.80	125.80	7.46	0.002	0.008	0.003	0.007	0.093	0.650	597,833
CE2	0005	11/1/08 20:22	12.8	48.3%	10.40	113.40	7.50	0.002	0.008	0.003	0.009	0.079	0.510	809,197
CE2	0006	11/1/08 22:22	20.0	31.1%	22.70	68.42	7.50	0.002	0.007	0.012	0.021	0.096	0.460	1,217,907
CE2	0007	11/2/08 0:22	15.6	16.1%	16.80	41.56	7.49	0.002	0.005	0.048	0.057	0.107	0.260	1,219,567
CE2	0008	11/2/08 2:22	21.6	27.5%	20.50	38.07	7.50	0.049	0.005	0.067	0.079	0.123	0.330	1,256,547
CE2	0009	11/2/08 4:22	19.2	32.4%	17.50	40.49	7.41	0.081	0.005	0.073	0.087	0.134	0.370	1,308,393
CE2	0010	11/2/08 6:22	14.0	26.9%	13.60	50.79	7.23	0.130	0.006	0.074	0.090	0.129	0.360	1,192,540
CE2	0011	11/2/08 8:22	14.8	44.4%	14.20	63.61	7.18	0.147	0.007	0.075	0.090	0.136	0.420	1,148,447
CE2	0012	11/2/08 10:22	10.0	45.0%	11.50	73.64	7.10	0.122	0.006	0.069	0.084	0.130	1.280	1,215,760
CE2	0013	11/2/08 12:22	11.6	57.1%	11.00	80.55	7.14	0.094	0.006	0.063	0.077	0.109	0.330	1,025,120
CE2	0014	11/2/08 14:22	10.8	64.7%	9.31	77.14	7.12	0.061	0.006	0.056	0.068	0.098	0.330	1,032,527
CE2	0015	11/2/08 16:22	8.8	28.6%	7.92	82.48	7.11	0.036	0.006	0.048	0.059	0.084	0.280	907,080
CE2	0016	11/2/08 18:22	8.7	50.0%	11.00	83.99	7.15	na	na	na	na	na	na	933,180
CE2	0017	11/2/08 20:22	9.0	35.7%	8.17	89.28	7.16	na	na	na	na	na	na	806,847
CE2	1618	11/2/08 20:22	na	na	na	na	na	0.025	0.007	0.038	0.047	0.076	0.280	na
CE2	0018	11/2/08 22:22	8.0	41.7%	7.40	97.54	7.11	na	na	na	na	na	na	870,733
CE2	0019	11/3/08 0:22	7.0	11.1%	7.60	98.30	7.15	na	na	na	na	na	na	884,660
CE2	0020	11/3/08 2:22	10.7	45.5%	7.47	102.20	7.23	na	na	na	na	na	na	784,720
CE2	1921	11/3/08 2:22	na	na	na	na	na	0.002	0.006	0.027	0.035	0.063	0.250	na
CE2	0021	11/3/08 4:22	8.0	53.8%	12.50	110.30	7.25	na	na	na	na	na	na	727,400
CE2	0022	11/3/08 6:22	7.3	84.6%	6.26	123.50	7.24	na	na	na	na	na	na	730,900
CE2	0023	11/3/08 8:22	7.0	45.5%	9.32	127.80	7.30	na	na	na	na	na	na	728,947
CE2	2224	11/3/08 8:22	na	na	na	na	na	0.001	0.005	0.019	0.026	0.050	0.190	na
CE2	0024	11/3/08 10:22	7.7	63.6%	5.68	136.00	7.25	na	na	na	na	na	na	768,733

APPENDIX E. (continued)

Location	Sample	Date Time	Suspended Sediment (mg/L)	LOI (wt %)	Turbidity (NTU)	EC (µS/cm)	pH	[NO3+NO2]-N (mg/L)	NH3-N (mg/L)	SRP (mg/L)	TDP (mg/L)	TP (mg/L)	TKN (mg/L)	0.5-20 µm Particles (#/mL)
CE3	0001	11/1/08 12:23	8.6	73.9%	2.81	125.60	7.26	na	na	na	na	na	na	302,780
CE3	0102	11/1/08 13:23	na	na	na	na	na	0.002	0.004	0.003	0.007	0.023	0.240	na
CE3	0002	11/1/08 14:23	1.2	100.0%	2.91	134.80	7.58	na	na	na	na	na	na	376,033
CE3	0003	11/1/08 16:23	8.8	57.1%	5.22	133.50	7.59	0.001	0.006	0.004	0.005	0.019	0.150	697,253
CE3	0004	11/1/08 18:23	8.0	66.7%	8.72	142.50	7.51	0.002	0.007	0.003	0.006	0.032	0.260	863,060
CE3	0005	11/1/08 20:23	9.2	47.1%	8.64	128.50	7.47	0.002	0.008	0.002	0.007	0.038	0.280	1,303,067
CE3	0006	11/1/08 22:23	13.2	40.0%	16.00	74.06	7.48	0.002	0.006	0.006	0.012	0.056	0.260	1,288,873
CE3	0007	11/2/08 0:23	18.0	46.3%	15.10	47.34	7.46	0.002	0.006	0.022	0.031	0.106	0.440	1,198,500
CE3	0008	11/2/08 2:23	13.6	29.6%	16.00	32.33	7.25	0.003	0.005	0.041	0.050	0.099	0.270	1,317,680
CE3	0009	11/2/08 4:23	13.2	24.1%	14.80	30.24	7.16	0.036	0.006	0.049	0.064	0.108	0.300	1,388,300
CE3	0010	11/2/08 6:23	12.8	41.7%	15.80	42.03	7.14	0.079	0.006	0.056	0.074	0.113	0.320	1,187,667
CE3	0011	11/2/08 8:23	12.4	45.5%	14.30	60.53	7.03	0.116	0.007	0.056	0.072	0.108	0.340	1,021,947
CE3	0012	11/2/08 10:23	8.8	42.9%	8.94	69.29	6.98	0.087	0.006	0.051	0.068	0.098	0.320	945,713
CE3	0013	11/2/08 12:23	8.8	35.3%	8.88	74.08	7.03	0.063	0.006	0.047	0.062	0.089	0.310	968,973
CE3	0014	11/2/08 14:23	8.0	<0.1%	9.95	81.84	7.10	0.031	0.006	0.040	0.052	0.083	0.400	955,073
CE3	0015	11/2/08 16:23	12.0	22.2%	7.79	78.08	6.99	0.014	0.006	0.029	0.040	0.081	0.350	953,560
CE3	0016	11/2/08 18:23	8.3	64.7%	8.56	69.07	7.13	na	na	na	na	na	na	825,107
CE3	0017	11/2/08 20:23	12.3	52.6%	7.49	77.13	7.07	na	na	na	na	na	na	875,787
CE3	1618	11/2/08 20:23	na	na	na	na	na	0.016	0.006	0.027	0.036	0.060	0.320	na
CE3	0018	11/2/08 22:23	8.7	88.9%	9.33	80.59	7.11	na	na	na	na	na	na	818,500
CE3	0019	11/3/08 0:23	10.7	81.3%	9.31	95.08	7.14	na	na	na	na	na	na	808,020
CE3	0020	11/3/08 2:23	10.3	57.1%	11.60	102.10	7.19	na	na	na	na	na	na	853,347
CE3	1921	11/3/08 2:23	na	na	na	na	na	0.012	0.005	0.018	0.027	0.050	0.540	na
CE3	0021	11/3/08 4:23	6.7	41.7%	7.22	93.51	7.37	na	na	na	na	na	na	697,907
CE3	0022	11/3/08 6:23	6.3	53.8%	6.24	120.30	7.30	na	na	na	na	na	na	794,787
CE3	0023	11/3/08 8:23	10.3	12.5%	6.99	113.20	7.29	na	na	na	na	na	na	771,993
CE3	2224	11/3/08 8:23	na	na	na	na	na	0.002	0.005	0.014	0.022	0.044	0.270	na
CE3	0024	11/3/08 10:23	9.7	46.7%	9.23	102.20	7.46	na	na	na	na	na	na	695,113
CE4	0001	11/1/08 12:24	3.7	80.0%	1.86	128.70	7.72	na	na	na	na	na	na	113,737
CE4	0102	11/1/08 13:24	na	na	na	na	na	0.013	0.004	0.004	0.007	0.011	0.100	na
CE4	0002	11/1/08 14:24	3.1	75.0%	3.10	135.40	7.64	na	na	na	na	na	na	203,207
CE4	0003	11/1/08 16:24	3.6	22.2%	3.48	156.00	7.52	0.001	0.005	0.003	0.006	0.021	0.210	271,300
CE4	0004	11/1/08 18:24	6.0	100.0%	7.34	136.80	7.62	0.002	0.008	0.003	0.007	0.023	0.200	531,920
CE4	0005	11/1/08 20:24	7.6	72.7%	7.39	129.80	7.62	0.002	0.007	0.003	0.007	0.026	0.250	659,127
CE4	0006	11/1/08 22:24	8.0	61.1%	11.80	92.47	7.61	0.001	0.008	0.003	0.009	0.033	0.310	1,164,947
CE4	0007	11/2/08 0:24	13.2	<0.1%	13.60	57.91	7.56	0.002	0.006	0.010	0.019	0.048	0.210	1,177,680
CE4	0008	11/2/08 2:24	14.8	53.1%	14.10	34.23	7.45	0.002	0.006	0.026	0.036	0.069	0.240	1,140,620
CE4	0009	11/2/08 4:24	16.0	34.5%	16.00	36.75	7.30	0.003	0.006	0.032	0.048	0.086	0.270	1,279,927
CE4	0010	11/2/08 6:24	14.8	46.7%	13.60	39.76	7.22	0.048	0.006	0.041	0.057	0.088	0.300	1,148,640
CE4	0011	11/2/08 8:24	10.4	44.4%	14.20	55.09	7.08	0.089	0.006	0.045	0.061	0.090	0.310	914,267
CE4	0012	11/2/08 10:24	8.8	40.0%	10.60	64.50	7.03	0.073	0.006	0.040	0.057	0.080	0.300	948,520
CE4	0013	11/2/08 12:24	7.2	10.0%	9.52	72.99	6.80	0.043	0.006	0.034	0.047	0.081	0.310	946,413
CE4	0014	11/2/08 14:24	16.0	70.8%	14.30	73.39	6.90	0.017	0.006	0.028	0.041	0.062	0.280	903,700
CE4	0015	11/2/08 16:24	6.4	25.0%	8.04	80.64	7.01	0.002	0.007	0.022	0.033	0.053	0.260	964,860
CE4	0016	11/2/08 18:24	8.0	26.7%	8.57	85.40	7.02	na	na	na	na	na	na	839,620
CE4	0017	11/2/08 20:24	9.3	42.9%	7.76	91.39	7.17	na	na	na	na	na	na	862,433
CE4	1618	11/2/08 20:24	na	na	na	na	na	0.005	0.006	0.018	0.028	0.043	0.240	na
CE4	0018	11/2/08 22:24	6.0	18.7%	8.94	92.93	7.22	na	na	na	na	na	na	875,560
CE4	0019	11/3/08 0:24	6.7	72.7%	8.34	95.08	7.23	na	na	na	na	na	na	755,993
CE4	0020	11/3/08 2:24	3.0	77.8%	8.46	102.30	7.30	na	na	na	na	na	na	780,607
CE4	1921	11/3/08 2:24	na	na	na	na	na	0.002	0.005	0.014	0.023	0.035	0.230	na
CE4	0021	11/3/08 4:24	5.0	50.0%	8.84	107.10	7.38	na	na	na	na	na	na	786,407
CE4	0022	11/3/08 6:24	8.0	13.3%	7.69	115.40	7.39	na	na	na	na	na	na	816,560
CE4	0023	11/3/08 8:24	15.7	92.9%	7.17	92.97	7.35	na	na	na	na	na	na	631,007
CE4	2224	11/3/08 8:24	na	na	na	na	na	0.002	0.007	0.011	0.019	0.032	0.240	na
CE4	0024	11/3/08 10:24	6.3	11.1%	8.38	119.30	7.48	na	na	na	na	na	na	718,547
CE1	EMC	11/2/08 11:21	10.0	40.7%	11.97	93.18	7.38	0.040	0.007	0.046	0.055	0.090	0.300	984,955
CE2	EMC	11/2/08 11:22	11.3	43.4%	10.81	94.79	7.28	0.034	0.006	0.036	0.045	0.082	0.346	892,327
CE3	EMC	11/2/08 11:23	10.0	48.8%	9.66	87.83	7.25	0.022	0.006	0.025	0.034	0.064	0.328	912,877
CE4	EMC	11/2/08 11:24	8.6	47.6%	9.30	91.51	7.32	0.014	0.006	0.018	0.027	0.046	0.241	809,817

Note: one outlier was removed in the calculation of EMCs (pH at CE1 on 11/2/08 16:21).

APPENDIX F. SIMULATED RUNOFF WATER QUALITY DATA

Results from the simulated runoff experiment of August 14, 2008. Samples were collected at all four sampling points. Also shown are EMCs calculated for the experimental period.

Location	Sample	Date Time	Suspended Sediment (mg/L)	LOI (wt %)	Turbidity (NTU)	EC (µS/cm)	pH	[NO3+NO2]-N (mg/L)	NH3-N (mg/L)	SRP (mg/L)	TDP (mg/L)	TP (mg/L)	TKN (mg/L)	0.5-20 µm Particles (#/mL)
CE1	1	8/14/08 12:34	76.4	22.5%	45.0	110.3	7.71	0.007	0.003	0.004	0.010	0.099	0.54	na
CE1	3	8/14/08 13:34	106.8	21.5%	65.3	117.0	7.77	0.009	0.004	0.005	0.010	0.119	0.64	na
CE1	5	8/14/08 14:34	74.8	23.5%	51.9	137.5	7.57	0.005	0.004	0.004	0.012	0.091	0.51	na
CE1	7	8/14/08 15:34	69.6	24.0%	46.3	165.5	7.55	0.004	0.004	0.006	0.012	0.093	0.54	na
CE1	9	8/14/08 16:34	72.4	23.5%	47.2	160.8	7.75	0.005	0.005	0.006	0.013	0.097	0.54	na
CE1	11	8/14/08 17:34	76.8	24.6%	56.7	162.3	7.53	0.005	0.004	0.006	0.013	0.105	0.50	na
CE1	13	8/14/08 18:34	69.2	24.1%	54.0	212.9	7.06	0.003	0.005	0.005	0.013	0.101	0.47	na
CE1	15	8/14/08 19:34	80.4	18.9%	54.9		7.01	0.003	0.004	0.005	0.010	0.100	0.48	na
CE1	16	8/14/08 20:34	65.6	27.0%	44.7	154.8	7.03	0.002	0.008	0.005	0.011	0.089	0.43	na
CE1	19	8/14/08 23:34	47.6	28.2%	35.8	142.3	7.19	0.003	0.013	0.005	0.011	0.074	0.36	na
CE1	22	8/15/08 2:34	40.0	23.6%	32.0	141.1	7.26	0.003	0.010	0.004	0.011	0.066	0.32	na
CE1	25	8/15/08 5:34	34.8	32.9%	25.4	134.9	7.21	0.004	0.011	0.005	0.010	0.053	0.24	na
CE1	28	8/15/08 8:34	22.4	37.0%	18.7	135.9	6.95	0.004	0.009	0.005	0.011	0.045	0.22	681,807
CE1	31	8/15/08 11:34	17.2	34.5%	12.7	131.2	6.83	0.003	0.004	0.004	0.009	0.036	0.17	439,903
CE2	1	8/14/08 12:34	13.2	53.8%	6.2	52.3	7.95	0.010	0.005	0.002	0.009	0.033	0.30	41,521
CE2	3	8/14/08 13:34	53.6	28.3%	32.6	135.2	7.92	0.005	0.005	0.004	0.010	0.063	0.46	na
CE2	5	8/14/08 14:34	58.8	26.5%	37.8	153.1	7.79	0.005	0.006	0.003	0.010	0.061	0.46	na
CE2	7	8/14/08 15:34	53.6	26.8%	35.7	137.2	7.83	0.005	0.003	0.004	0.009	0.076	0.48	na
CE2	9	8/14/08 16:34	48.8	23.9%	34.9	168.8	8.01	0.004	0.005	0.005	0.012	0.077	0.46	na
CE2	11	8/14/08 17:34	64.8	25.7%	44.1	160.9	7.90	0.002	0.004	0.005	0.013	0.089	0.48	na
CE2	13	8/14/08 18:34	69.2	25.8%	51.9	154.9	6.72	0.005	0.008	0.005	0.010	0.098	0.52	na
CE2	15	8/14/08 19:34	61.6	26.6%	45.9	154.4	6.99	0.004	0.012	0.005	0.011	0.095	0.51	na
CE2	16	8/14/08 20:34	62.0	27.8%	45.4	150.9	7.08	0.009	0.013	0.005	0.012	0.088	0.47	na
CE2	19	8/14/08 23:34	43.6	25.7%	35.0	127.5	7.27	0.011	0.015	0.005	0.012	0.073	0.38	na
CE2	22	8/15/08 2:34	40.4	23.4%	29.6	142.4	7.12	0.014	0.013	0.004	0.010	0.067	0.36	na
CE2	25	8/15/08 5:34	32.4	24.7%	27.0	141.3	7.02	0.018	0.010	0.004	0.011	0.055	0.30	na
CE2	28	8/15/08 8:34	28.4	31.7%	20.2	135.3	6.81	0.017	0.010	0.004	0.008	0.050	0.29	621,167
CE2	31	8/15/08 11:34	19.6	32.4%	14.8	117.5	7.20	0.014	0.005	0.003	0.007	0.038	0.19	403,427
CE3	1	8/14/08 12:34	5.2	50.0%	2.5	54.4	7.71	0.012	0.006	0.003	0.009	0.025	0.23	28,111
CE3	3	8/14/08 13:34	21.6	36.6%	14.4	80.4	7.84	0.009	0.005	0.003	0.008	0.023	0.34	26,415
CE3	5	8/14/08 14:34	30.8	31.3%	22.2	136.6	8.05	0.006	0.005	0.003	0.011	0.030	0.33	39,236
CE3	7	8/14/08 15:34	35.6	23.4%	22.9	160.5	8.08	0.003	0.004	0.005	0.011	0.063	0.45	326,472
CE3	9	8/14/08 16:34	45.6	26.2%	27.8	179.7	8.11	0.003	0.005	0.005	0.010	0.078	0.45	na
CE3	11	8/14/08 17:34	65.2	33.3%	38.7	165.9	8.02	0.003	0.005	0.004	0.013	0.106	0.68	na
CE3	13	8/14/08 18:34	55.6	25.6%	42.5		6.76	0.002	0.008	0.004	0.010	0.085	0.49	na
CE3	15	8/14/08 19:34	53.6	31.9%	37.3	158.7	7.42	0.003	0.005	0.004	0.010	0.087	0.50	na
CE3	16	8/14/08 20:34	34.4	32.1%	42.2	149.5	7.26	0.003	0.011	0.004	0.013	0.092	0.60	na
CE3	19	8/14/08 23:34	51.6	28.0%	33.9	135.8	7.11	0.004	0.012	0.004	0.012	0.073	0.41	na
CE3	22	8/15/08 2:34	36.4	18.8%	33.2	122.0	7.16	0.008	0.012	0.004	0.010	0.065	0.37	na
CE3	25	8/15/08 5:34	34.4	23.7%	26.0	139.8	7.03	0.010	0.009	0.004	0.009	0.055	0.28	na
CE3	28	8/15/08 8:34	30.4	28.3%	22.0	148.4	6.92	0.011	0.010	0.004	0.008	0.047	0.25	604,797
CE3	31	8/15/08 11:34	23.2	37.8%	15.2	137.4	7.21	0.007	0.004	0.004	0.009	0.041	0.21	415,550
CE4	1	8/14/08 12:34	8.8	42.1%	4.8	44.0	7.57	0.005	0.007	0.002	0.008	0.020	0.25	86,540
CE4	3	8/14/08 13:34	11.2	41.7%	5.8	73.3	7.94	0.003	0.005	0.002	0.008	0.022	0.26	33,282
CE4	5	8/14/08 14:34	18.0	35.9%	10.6	116.5	8.26	0.004	0.005	0.002	0.009	0.019	0.23	85,430
CE4	7	8/14/08 15:34	21.6	25.0%	15.0	139.5	8.14	0.004	0.004	0.005	0.009	0.043	0.32	244,707
CE4	9	8/14/08 16:34	26.8	18.0%	18.5	154.2	8.22	0.003	0.004	0.005	0.011	0.056	0.27	292,185
CE4	11	8/14/08 17:34	37.2	26.2%	23.8	159.8	8.15	0.003	0.004	0.005	0.008	0.063	0.40	na
CE4	13	8/14/08 18:34	28.4	31.5%	25.6	157.5	7.05	0.004	0.009	0.004	0.011	0.071	0.41	na
CE4	15	8/14/08 19:34	42.8	30.6%	29.4	153.9	7.30	0.002	0.004	0.004	0.009	0.068	0.38	na
CE4	16	8/14/08 20:34	24.8	30.9%	38.9	156.3	7.18	0.002	0.008	0.004	0.011	0.082	0.46	na
CE4	19	8/14/08 23:34	45.6	30.2%	33.0	140.6	7.08	0.002	0.009	0.004	0.010	0.071	0.40	na
CE4	22	8/15/08 2:34	40.8	27.5%	33.1	140.8	7.19	0.003	0.008	0.004	0.009	0.062	0.38	na
CE4	25	8/15/08 5:34	37.2	29.1%	28.6	144.7	7.19	0.006	0.008	0.004	0.009	0.056	0.30	na
CE4	28	8/15/08 8:34	31.2	41.5%	20.5	136.4	6.84	0.007	0.007	0.004	0.010	0.047	0.28	596,557
CE4	31	8/15/08 11:34	24.4	38.5%	16.5	151.7	6.92	0.004	0.004	0.004	0.009	0.041	0.24	400,783
CE1	EMC	8/14/08 21:12	61.0	26.1%	42.2	146.7	7.32	0.004	0.006	0.005	0.011	0.083	0.43	560,855
CE2	EMC	8/14/08 21:12	46.4	28.8%	32.9	138.0	7.40	0.009	0.008	0.004	0.010	0.069	0.40	512,297
CE3	EMC	8/14/08 21:12	37.4	30.5%	27.2	136.1	7.48	0.006	0.007	0.004	0.010	0.062	0.40	510,173
CE4	EMC	8/14/08 21:12	28.5	32.0%	21.7	133.5	7.50	0.004	0.006	0.004	0.009	0.052	0.33	498,670

Note: for consistency, the EMCs for particle concentrations at each site represent the average of values from samples 28 and 31.

APPENDIX F. (continued)

Results from the simulated runoff experiment of September 17, 2008. Samples were collected at three hour intervals from three of the usual sampling points (CE2–CE4). CE1 represents average Third Creek baseflow into Tank 1 for that time of year. Concentrations shown for the stormwater tank (SWT) are prior to aliquot delivery, mixing, and dilution in Tank 1; thus, the SWT values represent concentrated synthetic stormwater solution delivered at ten-minute intervals over a twelve hour period (following the initial spike of concentrated synthetic stormwater dispensed into Tank 1 to produced elevated concentrations). Also shown are EMCs calculated for the experimental period.

Location	Sample	Date Time	Suspended Sediment (mg/L)	LOI (wt %)	Turbidity (NTU)	EC (µS/cm)	pH	[NO3+NO2]-N (mg/L)	NH3-N (mg/L)	SRP (mg/L)	TDP (mg/L)	TP (mg/L)	TKN (mg/L)	0.5-20 µm Particles (#/mL)
SWT	1	9/17/08 10:01	326.0	34.9%	221.0	272.5	6.89	0.007	0.020	0.098	0.117	0.581	2.57	2,797,707
SWT	2	9/17/08 13:01	298.0	36.0%	213.0	147.8	7.12	0.006	0.013	0.104	0.119	0.577	2.48	2,847,813
SWT	3	9/17/08 16:01	318.4	34.3%	220.0	138.3	7.41	0.006	0.014	0.098	0.123	0.580	2.43	2,719,197
SWT	4	9/17/08 19:01	224.4	38.2%	180.0	142.0	7.45	0.006	0.014	0.098	0.124	0.478	2.20	2,590,580
CE2	1	9/17/08 10:02	36.4	56.0%	15.3	72.5	7.43	0.002	0.002	0.004	0.007	0.097	0.59	119,397
CE2	4	9/17/08 13:02	10.0	52.0%	4.3	62.4	7.63	0.005	0.007	0.005	0.008	0.029	0.20	60,813
CE2	7	9/17/08 16:02	16.4	62.5%	5.1	77.5	7.93	0.003	0.006	0.004	0.008	0.046	0.28	66,245
CE2	10	9/17/08 19:02	5.2	91.7%	2.5	80.8	7.84	0.005	0.006	0.006	0.008	0.021	0.11	53,696
CE2	13	9/17/08 22:02	8.4	90.9%	2.0	69.1	7.60	0.016	0.011	0.003	0.007	0.018	0.10	49,293
CE2	16	9/18/08 1:02	2.8	28.6%	1.5	57.3	7.58	0.008	0.007	0.004	0.006	0.017	0.11	41,778
CE2	19	9/18/08 4:02	3.2	87.5%	1.0	76.9	7.52	0.005	0.007	0.003	0.006	0.070	0.04	34,263
CE2	22	9/18/08 7:02	1.6	0.0%	0.9	70.6	7.51	0.010	0.006	0.004	0.008	0.010	0.06	28,829
CE3	1	9/17/08 10:03	107.2	64.0%	12.2	57.4	7.23	0.003	0.003	0.002	0.006	0.106	0.55	162,893
CE3	4	9/17/08 13:03	27.6	73.8%	5.2	66.1	7.33	0.001	0.003	0.002	0.006	0.068	0.33	344,187
CE3	7	9/17/08 16:03	8.8	61.9%	1.8	69.5	7.62	0.002	0.004	0.002	0.006	0.029	0.09	59,481
CE3	10	9/17/08 19:03	6.8	64.3%	1.9	74.4	7.65	0.003	0.007	0.002	0.006	0.016	0.08	54,281
CE3	13	9/17/08 22:03	4.8	41.7%	2.0	76.7	7.52	0.004	0.006	0.002	0.006	0.017	0.06	54,210
CE3	16	9/18/08 1:03	1.6	100.0%	1.4	70.6	7.56	0.003	0.005	0.002	0.005	0.012	0.05	36,426
CE3	19	9/18/08 4:03	3.6	77.8%	1.1	54.8	7.52	0.005	0.006	0.002	0.005	0.019	0.05	33,337
CE3	22	9/18/08 7:03	1.6	100.0%	1.1	67.4	7.50	0.003	0.006	0.002	0.006	0.008	0.03	26,181
CE4	1	9/17/08 10:04	1.2	0.0%	1.4	60.1	7.58	0.002	0.002	0.001	0.005	0.006	0.09	30,688
CE4	4	9/17/08 13:04	6.0	100.0%	1.2	65.4	7.53	0.003	0.006	0.002	0.006	0.090	0.10	54,084
CE4	7	9/17/08 16:04	4.0	100.0%	1.8	72.2	7.96	0.002	0.002	0.002	0.005	0.030	0.12	53,347
CE4	10	9/17/08 19:04	4.4	100.0%	1.2	80.3	7.78	0.003	0.005	0.002	0.005	0.011	0.07	48,198
CE4	13	9/17/08 22:04	1.6	75.0%	1.2	79.6	7.62	0.001	0.006	0.002	0.006	0.010	0.04	40,818
CE4	16	9/18/08 1:04	4.0	100.0%	1.4	76.8	7.63	0.003	0.007	0.002	0.005	0.012	0.04	31,332
CE4	19	9/18/08 4:04	0.8	50.0%	0.9	68.3	7.63	0.001	0.006	0.002	0.005	0.008	0.03	24,763
CE4	22	9/18/08 7:04	5.6	85.7%	0.8	53.1	7.63	0.002	0.008	0.001	0.005	0.070	0.03	21,854
SWT	EMC	9/17/08 14:31	291.7	35.9%	208.5	175.2	7.22	0.006	0.015	0.100	0.121	0.554	2.42	2,738,824
CE2	EMC	9/17/08 20:32	10.5	58.6%	4.1	70.9	7.63	0.007	0.007	0.004	0.007	0.039	0.19	56,790
CE3	EMC	9/17/08 20:33	20.3	72.9%	3.3	67.1	7.49	0.003	0.005	0.002	0.006	0.034	0.16	96,374
CE4	EMC	9/17/08 20:34	3.5	76.3%	1.3	69.5	7.67	0.002	0.005	0.002	0.005	0.030	0.07	38,135
CE1	average	9/17/08	2.9	25.0%	1.7	73.9	7.06	0.003	0.010	0.004	0.008	0.013	0.11	44,647