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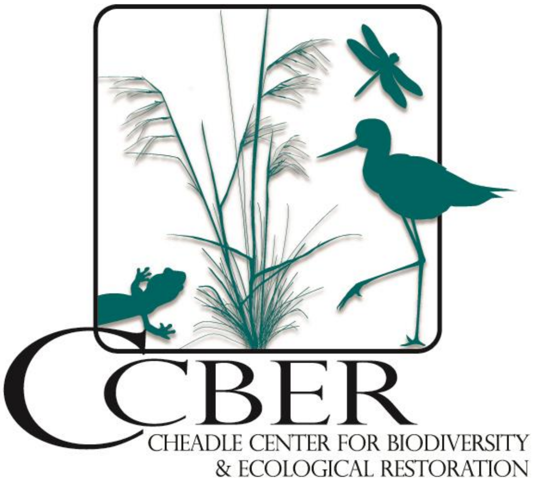

Campus Lagoon Water Quality Assessment

2016

Lisa Stratton *Director of Ecosystem Restoration*

Campus Lagoon Water Quality Assessment
2016 Update

CCBER

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Cheadle Center for Biodiversity and Ecological Restoration
(CCBER)
March 2016

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Introduction

In July 2011, the Cheadle Center for Biodiversity and Ecological Restoration (CCBER) completed an assessment report on the water quality of the Campus Lagoon based on data collected from various surveys conducted over a five-year period (2006 – 2011). Here we present an update to the 2011 report with new data obtained from a recent (Dec. 2015 – Feb. 2016) survey of the quality of storm water run-off in the lagoon watershed and inclusion of data from a data sonde installed between 2009 and 2011.

Using multiple lines of evidence, we assessed the state of the Campus Lagoon in terms of its ability to support aquatic life and provide UCSB's campus an aesthetically pleasing backdrop. In addition, we evaluated the potential impacts of an increase in the current watershed (155 ac) by 28.4 acres or 18%. The eastern watersheds of campus currently drain over the bluffs and, through the proposed infrastructure project, would be directed to drain into the lagoon. The Campus Lagoon is 31 acres (12.5 ha) with a volumetric capacity of 4,630,000 ft^3 (131,000 m^3) (Jones & Stokes, 1999). A summary of lagoon background information can be found in the Lagoon Management Plan (Jones and Stokes, 1999) and Penfield and Smith's UCSB Lagoon Hydrology Report (8/28/2008 and 2011 update to that report). We have focused on lagoon water quality using data from a variety of water quality sampling projects over the past five years.

Sea water currently flows into the lagoon at a rate of 650 gallons per minute (gpm), which is equivalent to 9.8 times the capacity of the lagoon over the course of a year's flow. Annual flow totals from nuisance flows of irrigation water (~ 50 gpm from multiple storm drains) equal 80% of the lagoon capacity, or less than one tenth of the overall flow, while annual storm water flows, estimated at 1-acre foot (43,560 ft^3) per acre of watershed, equal 1.5 – 2 times the lagoon capacity, or an additional 20% of the flow. An increase in the current watershed by 18% would increase both storm water flows and low (dry season) runoff.

In addition, the infrastructure project will redirect seawater currently flowing off the bluff (~ 150 gpm) to the lagoon and increase sea water flows by 25% from 650 gpm to 800 gpm. These higher seawater flow rates would increase the proportion of sea water flow to total estimated flow from 70% to 82% which translates to an increase by 2.2 times the capacity of the lagoon and a reduction in residence time from 30 days to 25 days. However, due to stratification, it is unclear if all of the lagoon water is recirculated by the seawater system.

To assess the water quality of the lagoon, we collected data on nine water quality indicators: dissolved oxygen, nitrogen, ammonium, phosphorous, metals (copper, lead, nickel, and zinc), oil and grease, chlorophyll a, water clarity, and the stratification of salinity and temperature. We assessed five of the water quality indicators using cutpoints set by the EPA (Table 1). In addition, we assessed four sediment quality indicators: total organic carbon, metals, benthic index, and sulfide levels. Each of these indicators are described and evaluated with regard to the Campus Lagoon in the following sections of this report.

Table 1. Indicators and cutpoint values used in water quality assessment (from the EPA National Coastal Condition Report III (2004), and IV (2012)).

Water Quality Indicators	**Poor Quality**	**Fair Quality**	**Good Quality**
Dissolved Oxygen	< 2 mg/L	2 - 5 mg/L	> 5 mg/L
Nitrogen	> 1.0 mg/L	0.5 - 1.0 mg/L	< 0.5 mg/L
Phosphorous (2004)	> 0.1 mg/L	0.01 - 0.1 mg/L	< 0.01 mg/L
Phosphorous (2012)	> 0.1 mg/L	0.07 - 0.1 mg/L	< 0.07 mg/L
Chlorophyll *a*	> 20 ug/l	5.0 - 20 ug/l	< 5.0 ug/l
Water Clarity (% light penetration to 1 m)	< 10%	10 - 20%	> 20%

Dissolved Oxygen

Dissolved oxygen (DO) concentration plays a significant role in determining the carrying capacity of a body of water because oxygen is a limiting factor for aerobic life. The absence of oxygen results in septic conditions along with the production of odors and offensive gases (e.g., hydrogen sulfide). Dissolved oxygen concentrations are affected by a number of physical factors, including circulation (e.g. degree of stratification), water temperature, and turbulence (wind, currents) as well as biological factors driven by the local food web. While algae and phytoplankton, the base of the food web, provide oxygen during the day through photosynthesis, at night the same organisms respire and consume oxygen. These relatively short-lived organisms die and their decay provides the carbon and nitrogen that is consumed by oxygen-demanding organisms. The dying plant material falls to the bottom of the lagoon and builds up a layer of floccy, carbon-rich sediments which lead to low DO layers due to aerobic decay processes and the oxidation of reduced chemical species. The degree of oxygen demand can extend through the depth profile and create situations in which oxygen is depleted throughout the lagoon profile which can be stressful to larger resident mobile organisms such as fish. Additionally, steep diurnal variations in DO can also cause problems for organisms, thus effectively wiping out populations due to the extreme variability.

The EPA and State Water Resources Control Board have developed standards based on DO to evaluate bodies of water. Because of the variation in DO by time of day, depth, and season, there is no single measurement that either condemns or releases a water body from this judgment, but rather a set of conditions considered over a longer time window. Nevertheless, DO is more indicative of a water body's health than any other single indicator (e.g. nutrients, sediment quality, benthic index) because it synthesizes the effects of the other factors and has the most direct and immediate impact on living organisms.

Dissolved oxygen can be measured as a concentration in mg/L or in percent saturation which is the proportion between oxygen present and the maximum amount that can be held under equilibrium conditions at a given water temperature. Dissolved oxygen levels in a zone within 50cm of the bottom that are below 2 mg/L are considered 'poor' or low quality, between 2 and 5 mg/L are considered 'fair' or moderate quality, and above 5mg/L are considered 'good' or high quality (Table 1, CWA Sect 305b Report 2006: CA Water quality condition assessment report and National Coastal Condition Report II, USEPA, 2004). In addition, the Central Coast Regional Water Quality Control Board's (CCRWQCB) Basin Plan sets a standard of a minimum of 5 mg/L, which complements the EPA standards.

In addition to meeting minimum standards, an extreme diurnal variation in dissolved oxygen can make it difficult for organisms to adjust to these changes. A strong variation between maximum (afternoon) and minimum (predawn) levels of DO can also serve as an indicator of excessive biostimulation, which is an excess of nutrients leading to excessive algal production with its resultant effect of high daytime concentrations of dissolved oxygen via photosynthesis followed by extremely low nighttime concentrations caused by respiration. The CCRWQCB uses a nighttime oxygen depression in excess of 1.25 mg/L as evidence of probable excessive biostimulation. While this might be overly conservative, an oxygen depression of greater than 2.5 mg/L should definitely be taken as a warning sign. However, low DO unassociated with diel variation, particularly at lower depths in the lagoon is more likely to be caused by the decomposition of organic matter, its digestion and re-mineralization.

High daytime DO values (>13mg/L or greater than 120% saturation) can also be taken as an indication of excessive oxygen production from particularly high levels of photosynthetic activity from algae caused in turn, by excessively high nutrient availability.

Dissolved Oxygen Data

Dissolved oxygen concentrations have been monitored in the lagoon a number of ways. Since 2007, regular sampling of DO with a portable YSI 85 was conducted at the sample sites shown in Figure 1 at three depths: at the surface, the bottom, and, if the water is deep enough, at 1 meter from the surface. In January 2009, CCBER installed a YSI 6600 data sonde at 1.25 meters from the surface in 2.5-meter-deep water in front of the UCEN as part of a Southern California Coastal Water Research Project (SCCWRP) study. The SCCWRP Bight 2008 Study was a comparative study of lagoons and estuaries in the southern California bight. We present data from both studies.

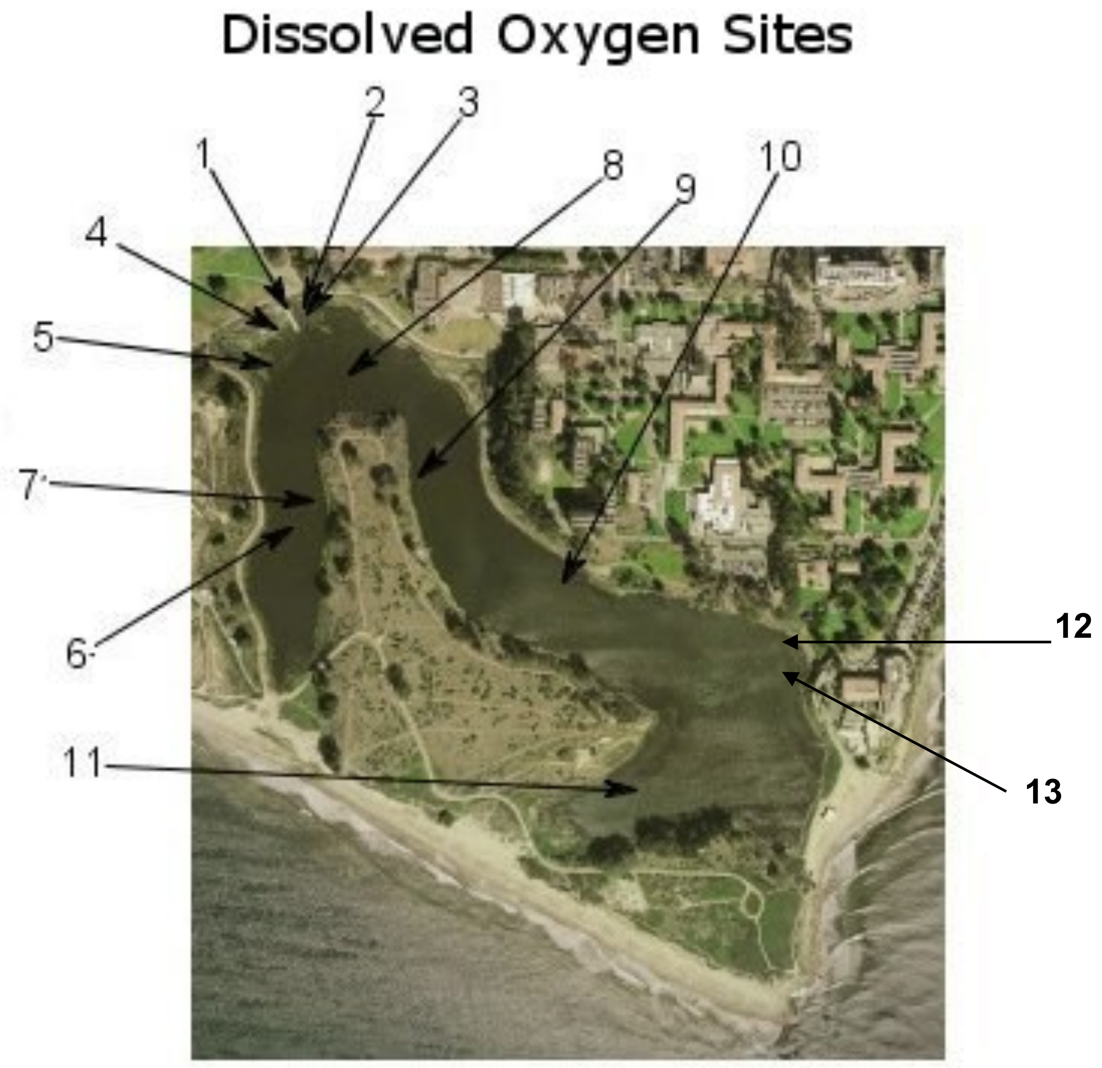


Figure 1. Dissolved oxygen sampling sites. Sites were sampled in the morning (6-7am) and in the afternoon (3-5pm) on a biweekly or slightly less regular schedule at the surface, 1 meter from the surface and the bottom (~ 2.5 m) using a YSI 85.

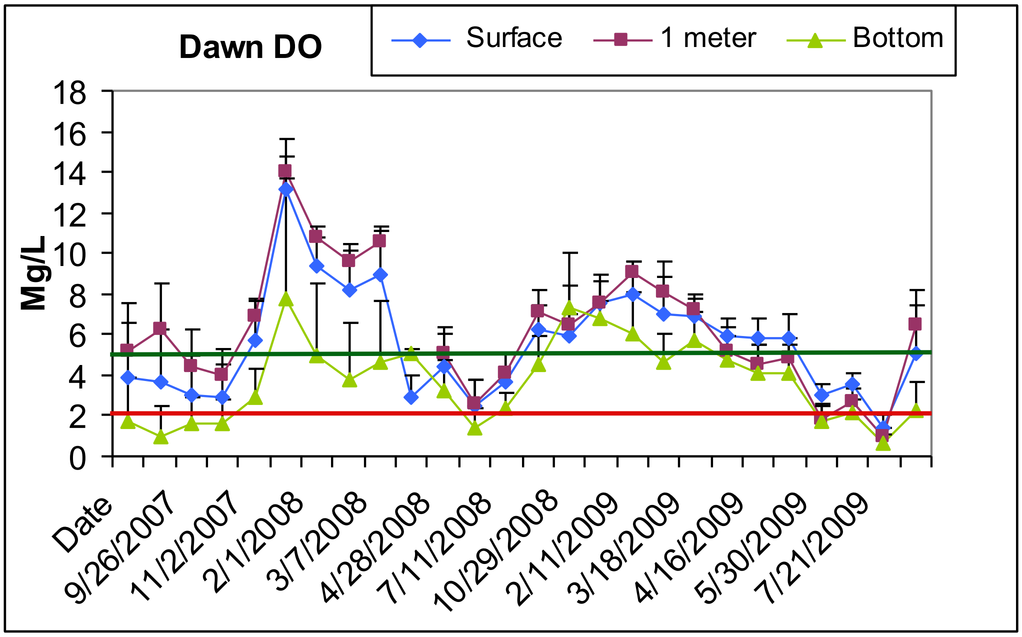


Figure 2. Dawn (6-7am) dissolved oxygen (mg/L) from 12 sites and three depths around the lagoon with standard errors. The figure shows that during the summer, DO levels throughout the lagoon fell below the CCRWQCB recommended levels of 5 mg/L and at times are below the 'poor' level of 2 mg/L indicating extremely low DO levels at the bottom of the lagoon.

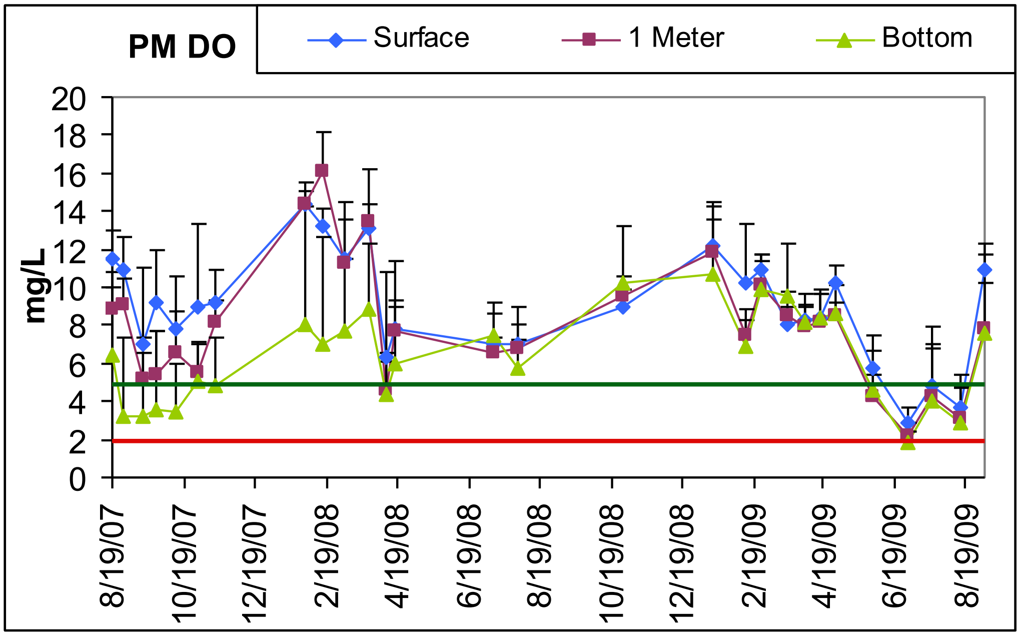


Figure 3. Afternoon (3-5pm) dissolved oxygen levels at 12 sites and three depths. Even in the afternoons, after peak photosynthesis, there were periods during the summer when DO levels throughout the lagoon fell below the 5 mg/L standards.

A difference between morning (~ 6:30-7:30am) and afternoon (3:30-5pm) DO concentrations, or diel variation, reflects the effects of algal or phytoplankton blooms in the lagoon (Figure 4).

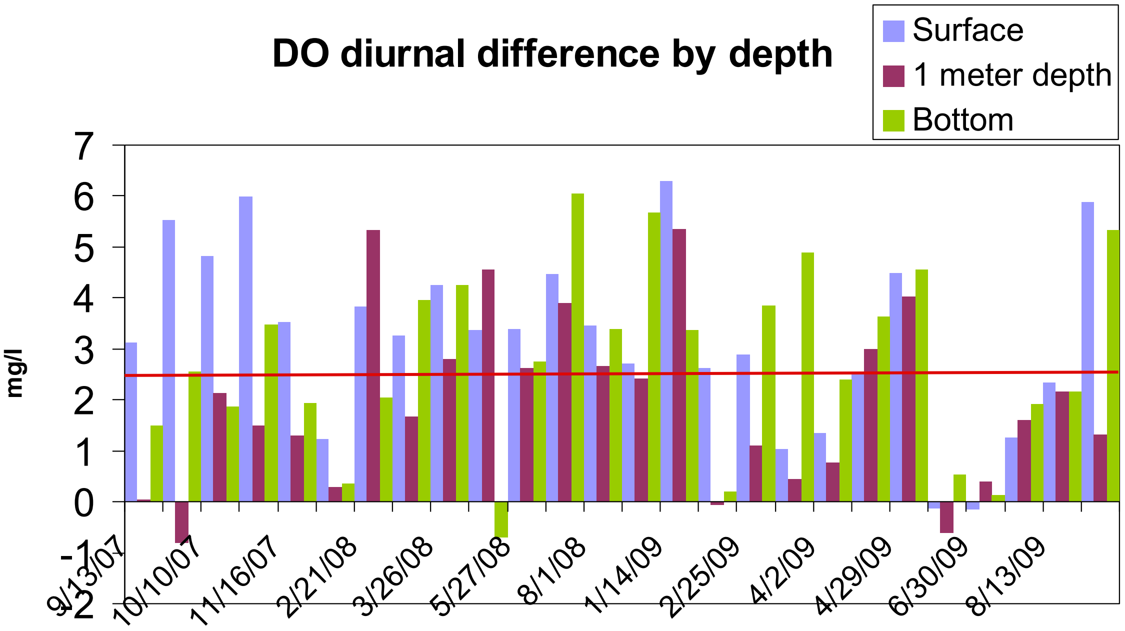


Figure 4. Differences between morning and afternoon DO levels often exceeded the conservative 2.5 mg/L criteria, which indicate that the lagoon suffers from impacts of biostimulation from algal and phytoplankton blooms throughout most of the year and at nearly all depths.

The above data are supported by a follow-up study of eight different sampling points (Figure 5), where dissolved oxygen depth profiles were conducted on a finer scale to gain a more detailed perspective on how extensive the dissolved oxygen deficit was by depth. At each of the eight sites, DO concentration was recorded at the bottom, at 10, 20, 30 and 60cm from bottom, and at the surface. This study was conducted from October, 2010 to February, 2011, and includes six sample periods divided between pre-dawn and afternoon (Figures 6, 7a and 7b).

The resulting data demonstrate that, even after the turbulence from winter rains, the average DO concentration across all sites and all depths within 30 cm of the bottom (n=48) for all sample periods was below 5 mg/L. In the bottom 30 cm, conditions were fair to poor with overall means of 1.8 mg/L at the bottom to 3.6 mg/L at 30 cm, while levels at 60 cm from the bottom in the morning averaged 4.5 mg/L and 6.9 mg/L in the afternoon – just above the 5 mg/L threshold. Differences between morning and evening DO levels at the surface (8.2 mg/L and 5.9 mg/L) were greater than 2.3 mg/L, even during the relatively high dissolved oxygen periods in winter. In comparison to a 1999 study of southern California Estuaries (Condition of Estuaries of California for 1999: A statistical Summary), fewer than 20% of small estuaries had DO levels this low at 50cm from the bottom (pg. 69).

Figure 5. Dissolved oxygen depth profile & sediment sampling sites.

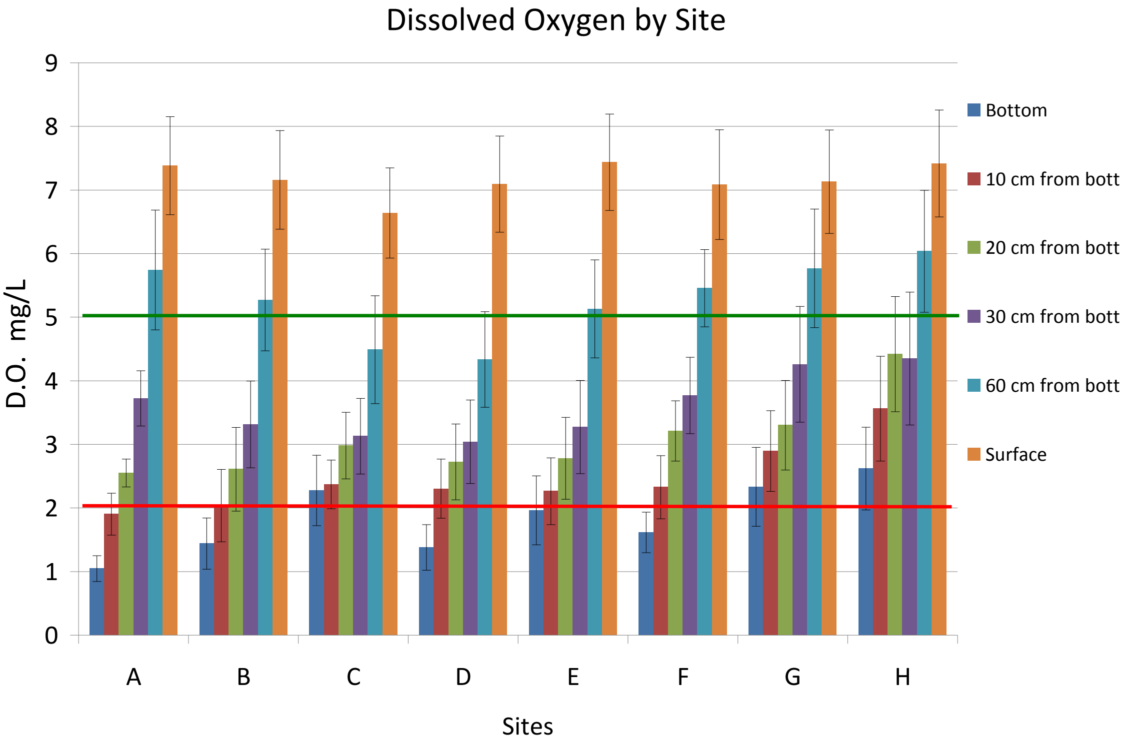


Figure 6. Dissolved oxygen by site and depth with standard errors. Graph shows the mean of 8 (morning and afternoon combined) sampling events from October 2010 to February 2011, with standard errors. Across the lagoon, low DO is a problem at all sites even in the winter, and at three sites (F, G, and H) that get the most wind turbulence.

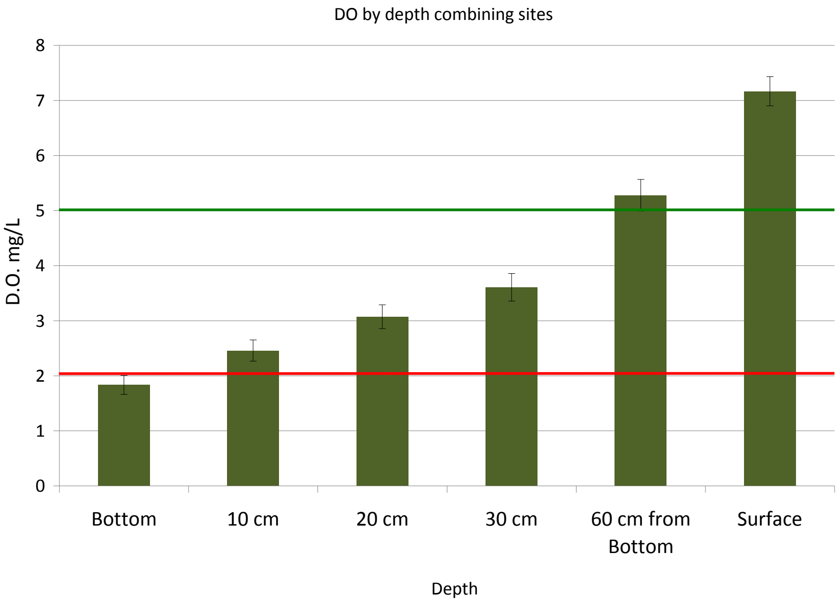


Figure 7a. Average dissolved oxygen by depth (shown as centimeters from the bottom of the lagoon), across 8 sites and 8 sampling events from October 2010 to February 2011, with standard errors. Dissolved oxygen is lowest at the deepest site, but is clearly below the EPA and CCRWQCB standards of 5mg/L in the bottom 50 cm of the lagoon.

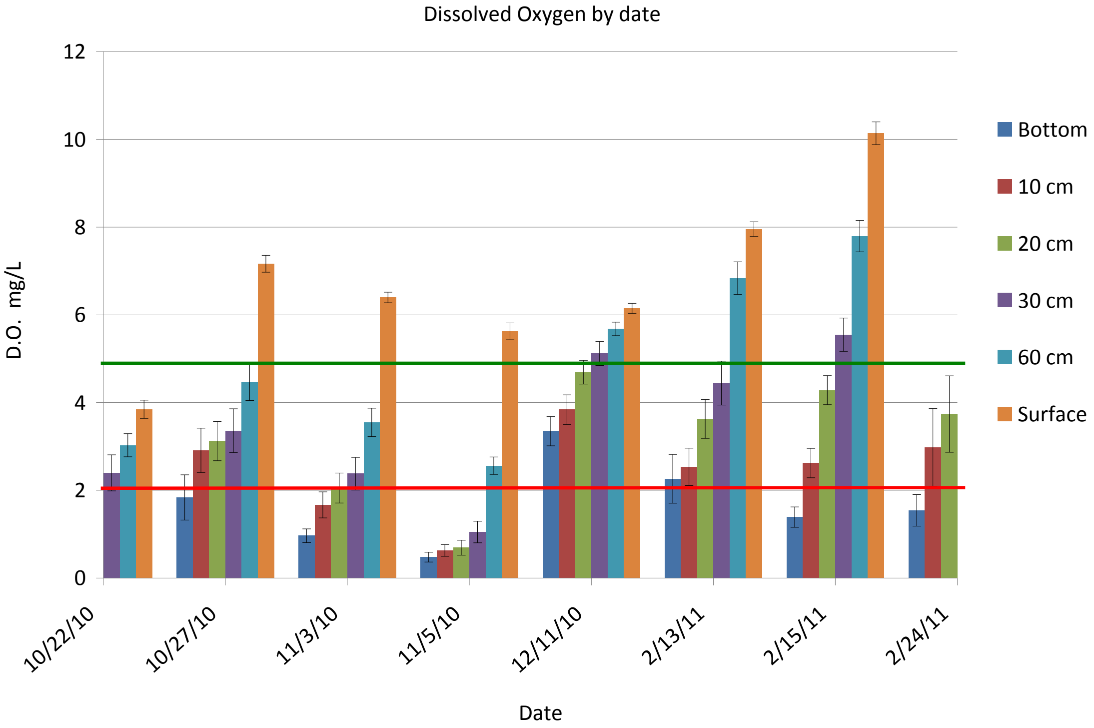


Figure 7b. Dissolved oxygen for all sites by date and depth. DO remains low despite inputs of rain and changes in season from the summer/fall conditions which are generally the poorest.

One of the goals of this more in-depth study of dissolved oxygen was to assess whether samples from the eastern portion of the lagoon had higher dissolved oxygen levels due to being consistently windier and the area where the lower-nutrient seawater inflows occur. However, samples F, G, and H (Figure 5), have just as poor oxygen conditions as the more isolated and protected areas of the lagoon where macro-algal blooms concentrate. In researching historical use of the lagoon we found the following map which indicates that the eastern portion of the lagoon was actually used for sewage disposal and thus may be particularly high in nutrients (Figure 8).

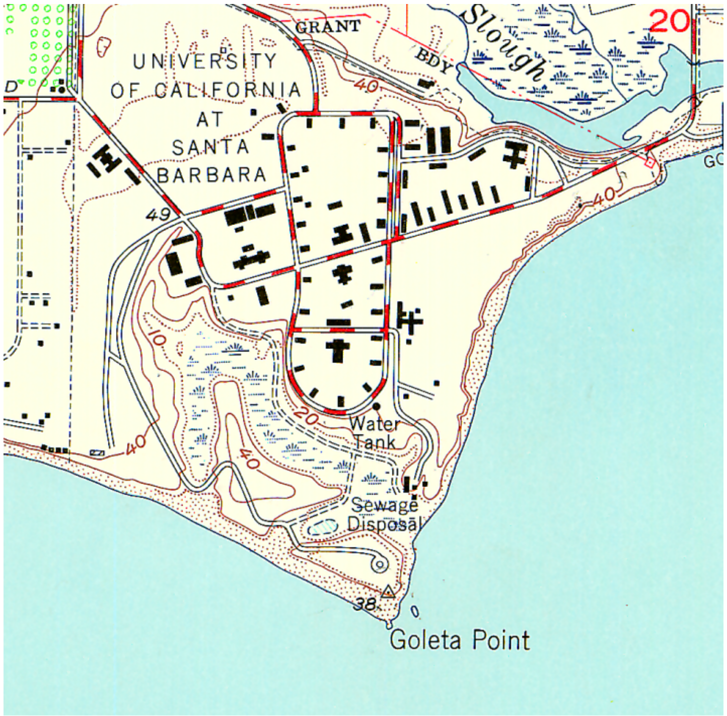


Figure 8. This 1950's USGS topographic map of the lagoon indicates that the eastern portion of the lagoon may have been used for sewage disposal.

Seasonal variation in DO concentration is also evident in data collected with a YSI 6600 sonde from January 2009 to December 2011 (Figure 9). The sonde was installed at 1.25 meters from the surface in a 2.5-meter-deep area of the lagoon located in front of the UCEN (Figure 11), and recorded DO concentration data (along with other parameters) at an interval of 15 minutes.

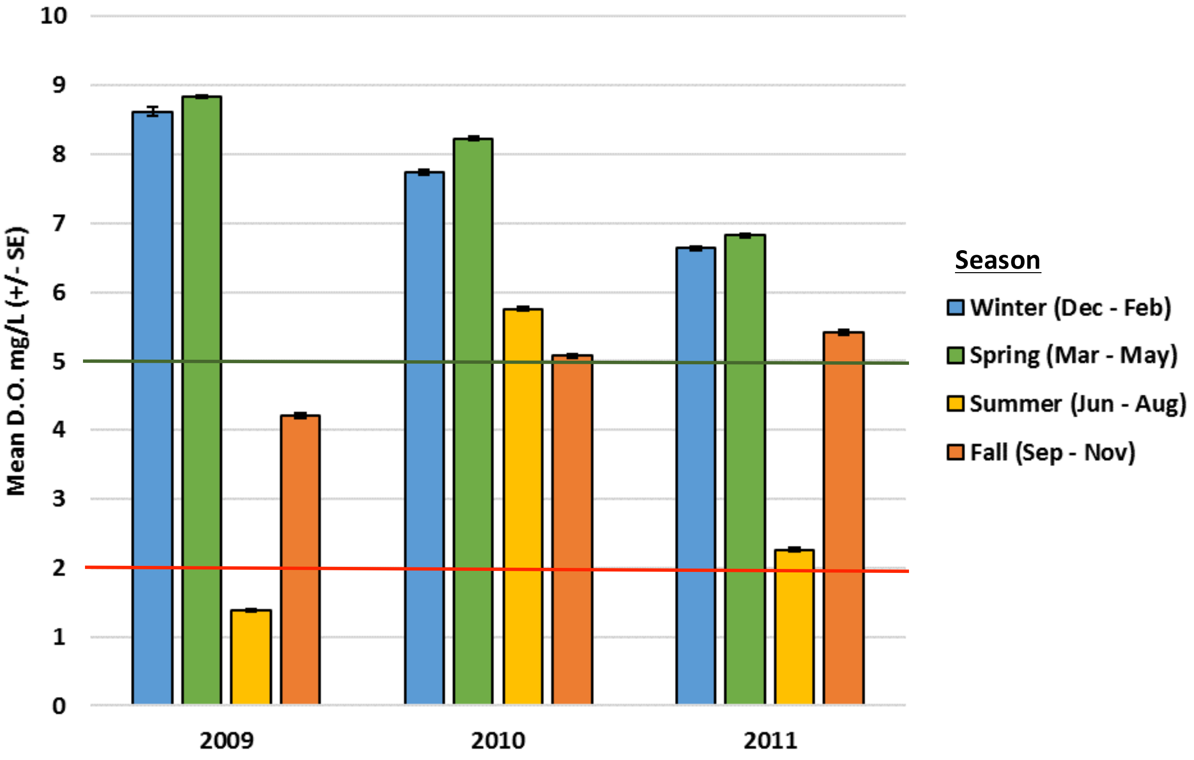


Figure 9. Mean and standard error (SE) dissolved oxygen (D.O.) in milligrams per liter (mg/L) per season, recorded every 15 minutes between January 2009 to December 2011. The sensor was placed at a depth of approximately 1.25 meters in a 2.5-meter-deep area of the lagoon located near the UCEN. Note that the "Winter" season for 2010 and 2011 includes December of the previous year. The green and red lines represent the EPA recommended good and poor water quality cutpoints for DO, respectively.

Dissolved Oxygen Summary

It is our perception that the Campus Lagoon goes through an annual cycle of several phases of plant growth from phytoplankton blooms in the winter and spring to *Ruppia maritima* (Widgeon grass, submerged aquatic vegetation) blooms in the early summer, and surface-coating macroalgae (*Enteromorpha intestinalis*) blooms in the warmer periods of the summer and fall. The variation in algae and plant blooms reflects a combination of forces impacting plant growth including nutrient availability, temperature and light penetration. Phytoplankton can respond rapidly to dissolved and suspended nutrients distributed from nutrient-rich run-off and turbulence sourced re-suspension of nutrients from the re-mineralization of particulate matter at the bottom of the lagoon. Phytoplankton can flourish at a wider variety of temperatures than can macroalgae. As the phytoplankton die, they drift to the bottom and decay. Oxygen levels begin to decline in the deeper depths of the lagoon and over time nutrients are re-mineralized via bacteria and other organisms. This provides a ready supply of sediment-sourced nutrients to support a bloom of *Ruppia maritima,* a submerged aquatic plant, which provides resources for fish and ducks, but eventually dies and decays on the bottom of the lagoon. As temperatures warm, the remaining nutrients in the water profile are taken up by macroalgal blooms of floating *Enteromorpha,* which not only block out light and reduce phytoplankton resources, but also create highly variable DO concentrations diurnally and eventually die, settle to the bottom and are broken down into inorganic constituents. These nutrient-rich sediments, derived from historic nutrient runoff, end up providing a continuous source of nutrients for the lagoon that is disassociated from the winter influx of nutrients from the storm drains feeding the lagoon.

Nutrient Fluxes and the Campus Lagoon as a 'sump'

Nitrogen

Nitrogen is generally the most important limiting nutrient for controlling eutrophication in estuaries; however, phosphorous can become the limiting factor when nitrogen is abundant (US EPA 2003). Dissolved inorganic nitrogen (nitrate, nitrite and ammonium) make up the most important fraction of nitrogen in terms of eutrophication. Studies by Leydecker and Grabowsky in their Goleta Stream Team study found that soluble reactive phosphate (SRP) comprises roughly 90% of total phosphorous and that nitrate and nitrite comprise ~ 85% of total N in urban, suburban and agricultural runoff into Goleta Slough. Brackish water interferes with total N analyses, so we used the MSI laboratory for the inorganic components of N, N03, N02 and NH4 and orthophosphate measurements within the lagoon and from the storm drains. We also sent storm drain samples to Creek Environmental Lab for total N and total P analysis. These methods produced comparable results.

Several studies have been conducted over the years to assess storm drain nutrient concentrations during storm and dry conditions as well as nutrient concentrations of water within the lagoon and leaving the lagoon.

a. In 2004, Kelly Buell, a student, conducted a study in (summarized in Appendix 1 in Anchor report) which found high levels of nitrogen and orthophosphate in storm drains which drain into, as well as within, the Campus Lagoon.

b. Anchor Environmental briefly characterized the flows from watersheds on the east of campus that will be directed into the lagoon once the infrastructure project is implemented (Appendix 1 of Anchor Report, 2006). This study found that storm drains in the center and east side of campus exceeded nutrient levels associated with causing algal blooms for total nitrogen (> 1.0 mg/L N) and phosphorous (> 0.1 mg/L P) under both storm and non-storm conditions.

CCBER has conducted studies of nutrient levels in storm drain water that are summarized in three reports by Christiana Herr (Lagoon Water Quality and Stormwater Treatment, 2007), and by Nathan Simons (Water Quality of Campus Storm Drain Runoff, 2008, and Lagoon Water and Sediment Quality Report 2007-2008), as well as more recent studies that are summarized here. Maps of the sampling locations for these and the recent winter 2015-2016 CCBER surveys are presented in Figures 10 and 11.

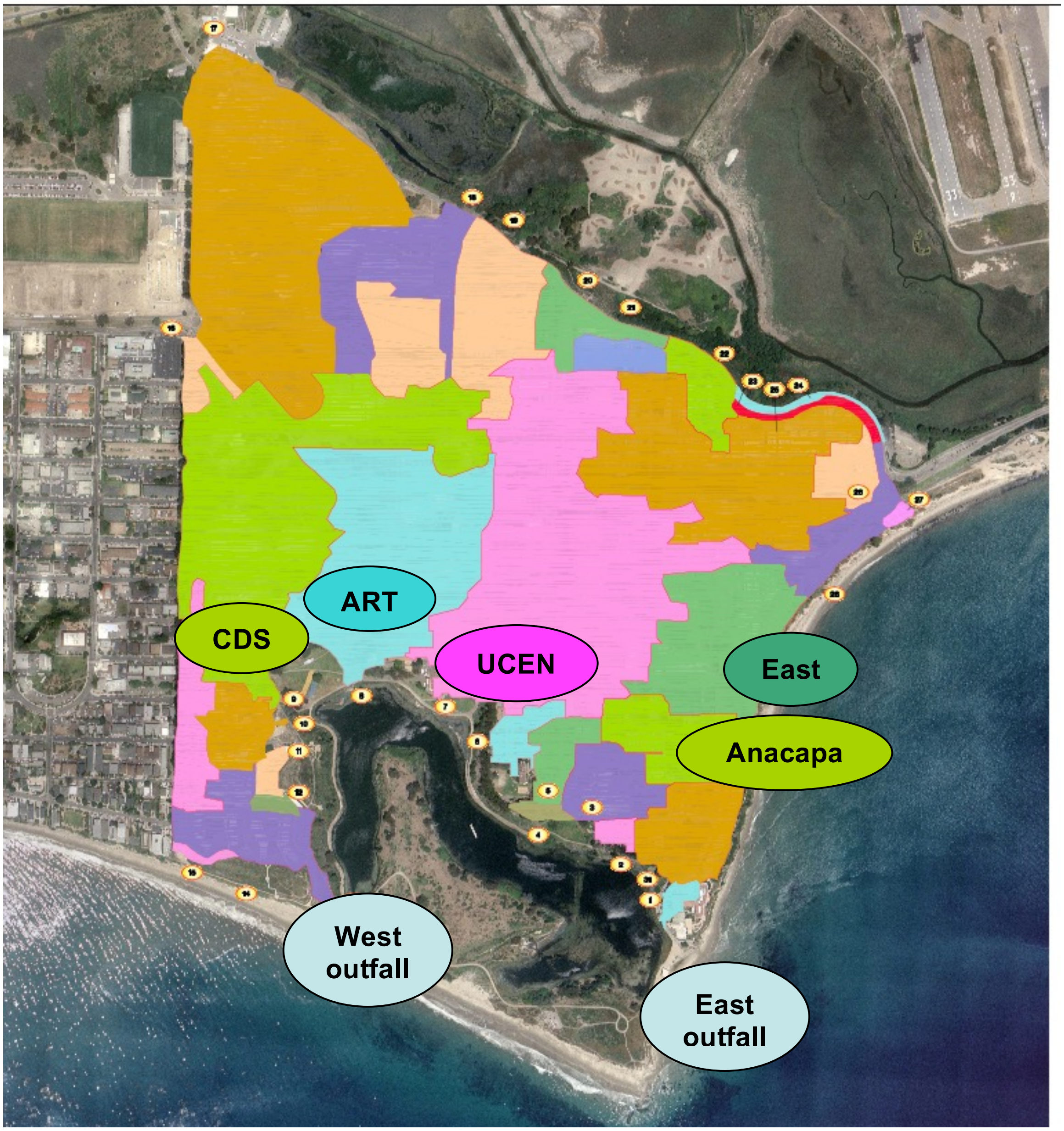


Figure 10. Watershed map of campus showing storm drain outfalls as small yellow circles. CCBER sampled the storm drains of the labeled watersheds and the lagoon ocean outfalls for the studies conducted between 2007 to 2010.

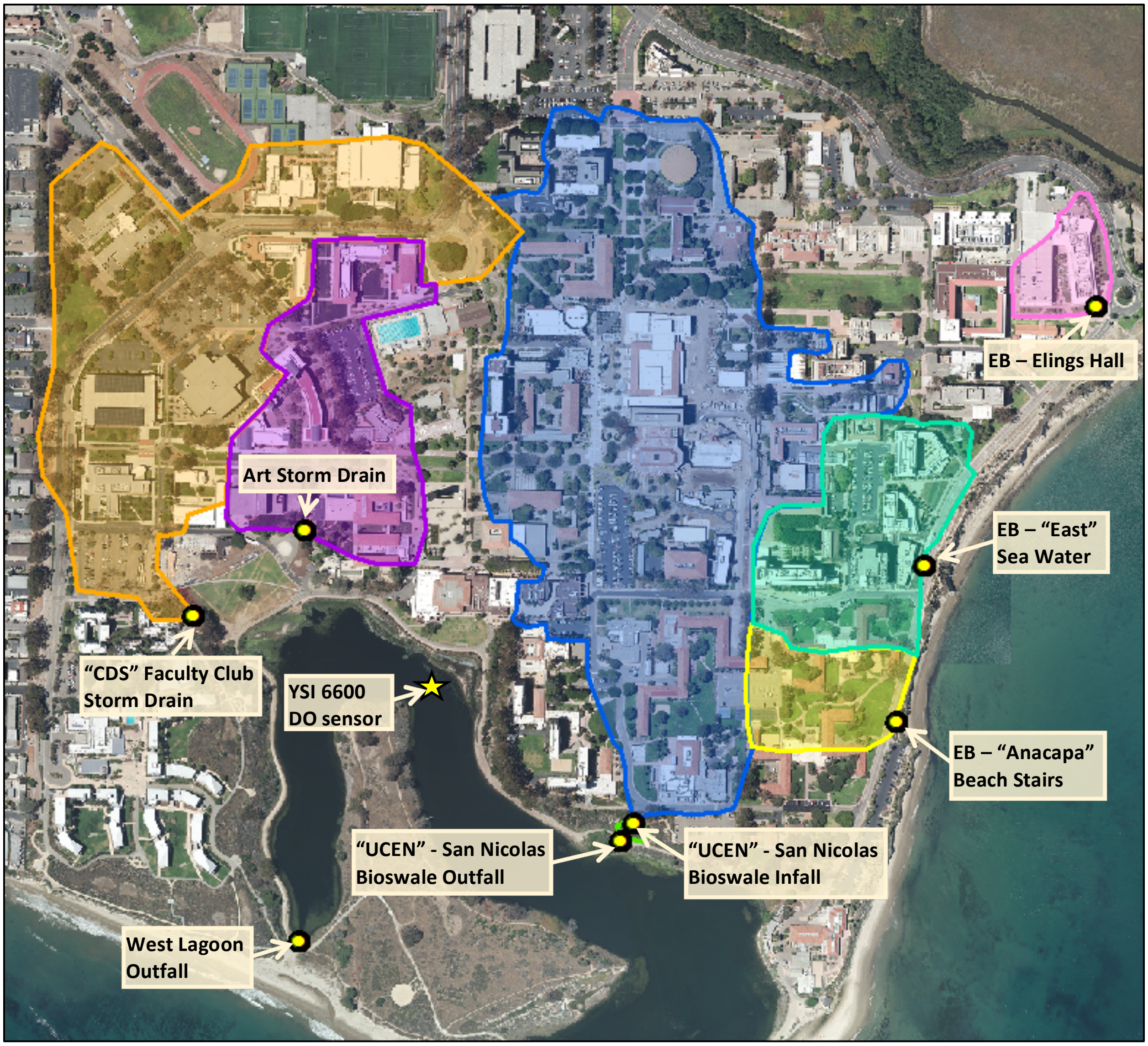


Figure 11. Map of the eight locations (yellow circles) and associated drainage areas of campus sampled by CCBER for the assessment of nutrients, metals and oil and grease in winter 2015-2016. The three drains on the east side of campus are abbreviated 'EB' for East Bluffs. Also shown is the location where the YSI-6600 dissolved oxygen (DO) sensor was installed from January 2009 – December 2010.

Data from CCBER studies are summarized in the figures on the following pages. Note that the red and green lines indicate the EPA recommended nutrient cutpoints for poor and good water quality (Table 1). Values above the red line indicate high nutrient levels, reflecting poor water quality, while values below the green line indicate low nutrient levels, reflecting good water quality. These studies demonstrate that nitrogen and phosphorous inputs far exceed recommended levels.

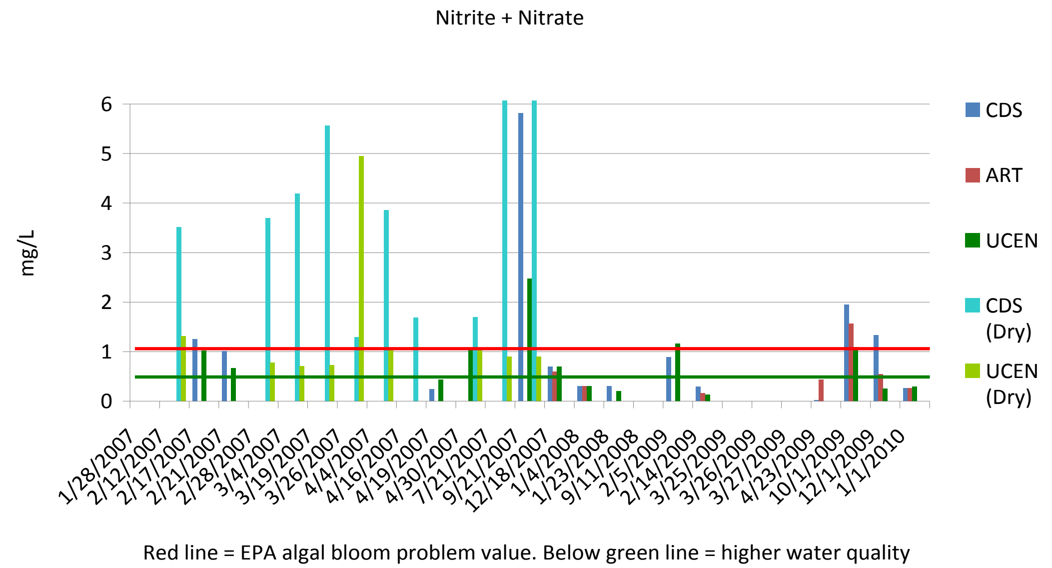


Figure 12. The nitrogen concentration (mg/L) from Nitrite+Nitrate found in the three primary storm drains entering the Campus Lagoon (together representing 120 of the 150 acres of watershed area currently tributary to the lagoon). Samples were taken in the dry and wet seasons between January 2007 to January 2010. While most samples are associated with 'moderate water quality', they represent only inorganic species of nitrogen, and therefore, the situation is worse than portrayed.

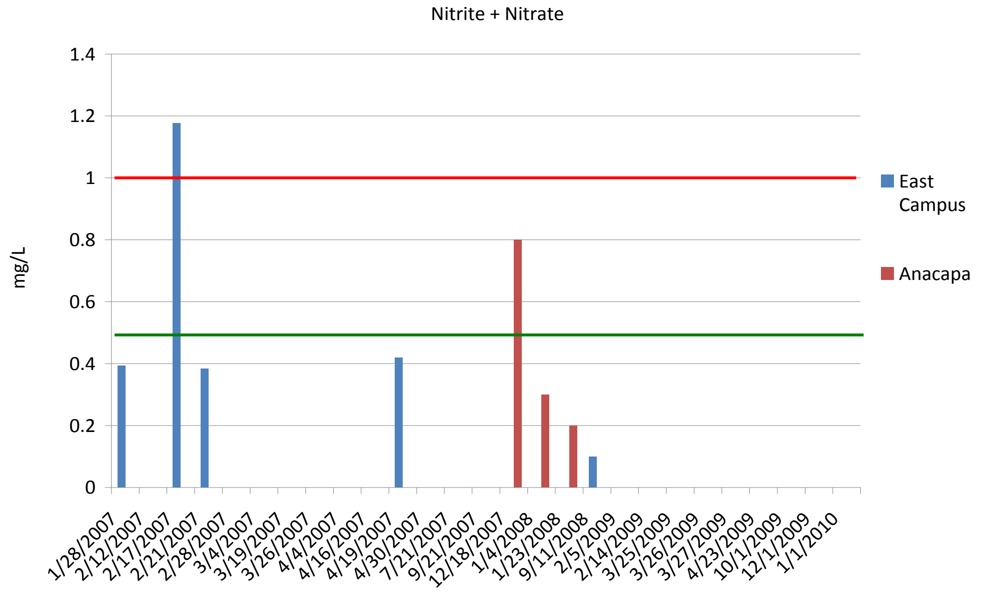


Figure 13. Nitrogen levels from studies between January 2007 to January 2010 of two of the east campus drains that are proposed to be diverted to the lagoon. Samples taken in 2006 by Anchor Environmental show much higher nitrogen levels than these few samples.

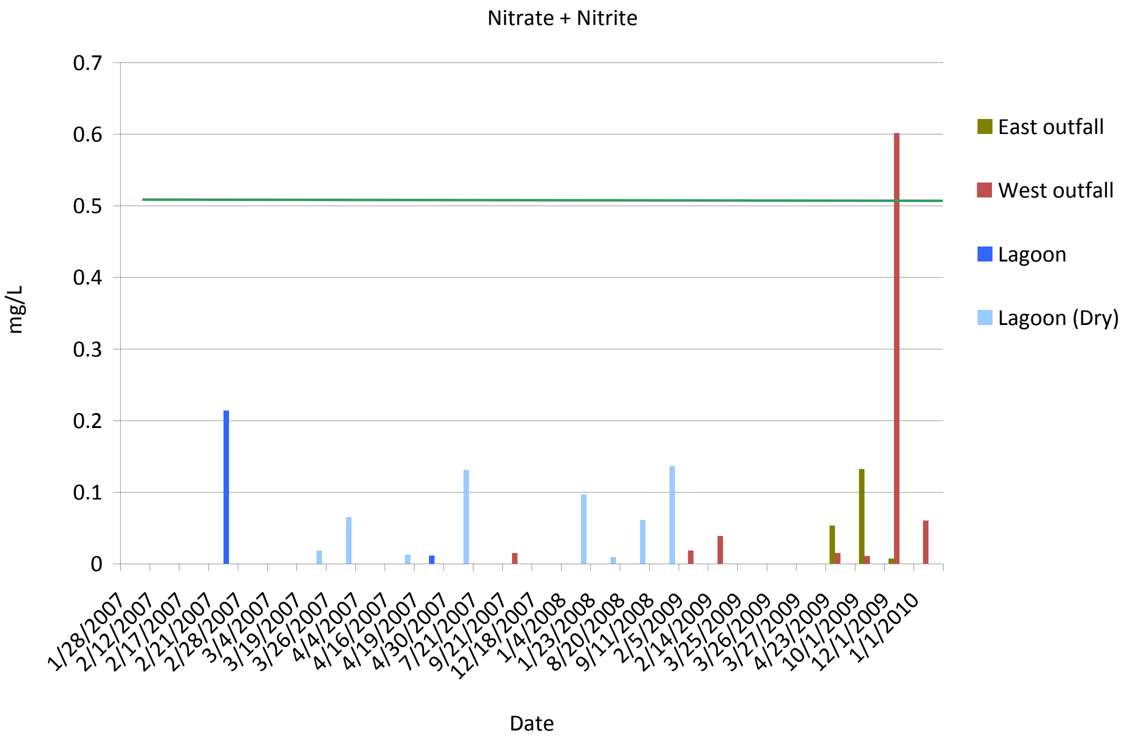


Figure 14. Nitrogen levels in water leaving the lagoon between January 2007 to January 2010 are generally associated with higher water quality, indicating that nitrogen is taken up by algae and phytoplankton within the lagoon.

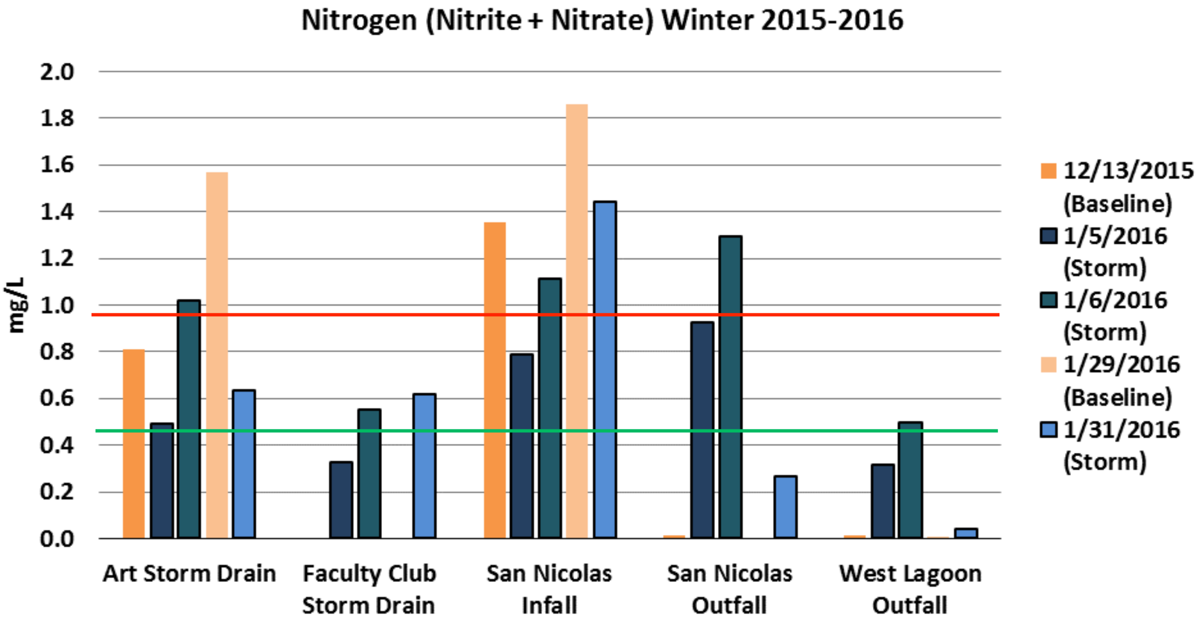


Figure 15. Nitrogen levels in water collected at five locations during two low or "dry" flows (Baseline) and three storm events in winter 2015-2016. Figure 11 contains a map of sampling locations. Baseline samples could not be obtained at the Faculty Club Storm Drain and in one case at the San Nicolas Outfall as flows were too low. Red and green lines represent EPA recommended cutpoints (see Table 1).

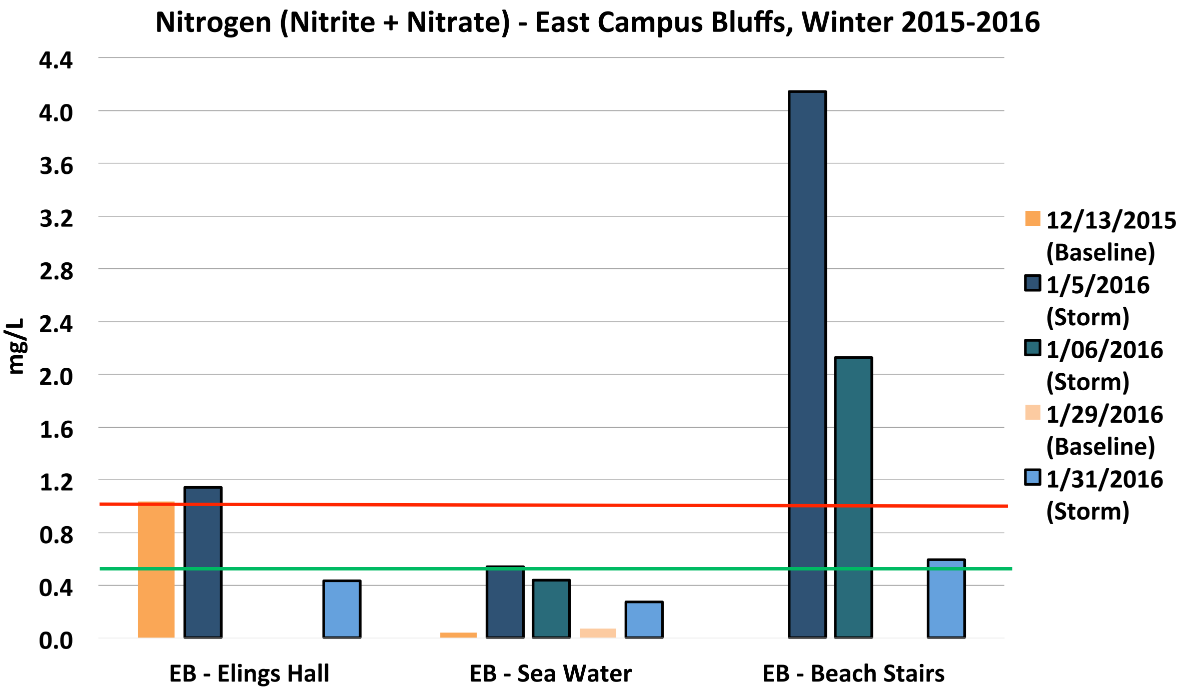


Figure 16. Nitrogen levels in water collected at three east campus locations during two low or "dry" flows (Baseline) and three storm events in winter 2015-2016. 'EB' stands for East Bluffs. Figure 11 contains a map of sampling locations. Baseline samples could not be obtained at the Elings Hall and Beach Stairs drains as they were dry. Note the high nitrogen concentration in the first storm of the winter season at the Beach Stairs drain, which collects run-off from the east campus residence halls area (primarily a lawn). Red and green lines represent EPA recommended cutpoints (see Table 1).

The results summarized in the preceding figures indicate that nitrogen inputs from the current storm drains that feed the lagoon, and the future inputs from east campus bluffs exceed the EPA standards (Table 1) and may be the main cause of algal blooms. Nutrient levels leaving the lagoon are quite low overall, indicating that the majority of nutrient resources are normally tied up in living and dead organic matter in the lagoon. The lower nutrient levels in water flowing out of the lagoon and into the ocean (West Lagoon outfall, Figure 15) reflect the effectiveness of the plant/algae/phytoplankton response to elevated nitrogen supplies. However, that response has consequences associated with the buildup of organic matter in the lagoon sediment, which can lead to anoxic conditions and the potential recirculation of re-mineralized nutrients such that the benefits of bioswales and other pre-treatment wetlands are not experienced by the fish because the nutrients within the lagoon sediments may exceed those flowing into the lagoon.

Ammonia Toxicity

Ammonium (NH4) and un-ionized ammonia (NH3) exist in an equilibrium which is affected by temperature, pH and salinity. High levels of ammonia (NH3) can be toxic to fish and other aquatic organisms.

Measured ammonium levels in the storm drains are quite high and can cause ammonia concentrations to exceed levels set by the EPA (Table 2). However, fish do not live in the storm drains but in the lagoon, where ammonium levels are diluted and modified by changes in temperature and pH. At the storm drain outlets, concentrations of ammonia can sometimes exceed EPA levels. EPA salt water criteria for ammonia are set for Acute (1 hr) and Chronic (4 days) exposure situations.

Table 2. Saltwater Criteria for un-ionized ammonia (NH3) (EPA, 1989)

Acute (one-hour average)	0.233 mg/L
Chronic (four-day average)	0.035 mg/L

Using the calculator at: http://www.dep.state.fl.us/labs/docs/unnh3calc.xls,
we found that levels of ammonium in water collected from the storm drains between 2007 to 2010 (Figure 17) ranged from a high 1mg/L NH4 to an average of 0.27 mg/L NH4. In water within the lagoon and leaving the lagoon at the outfalls, ammonium concentrations averaged (0.08-0.025 mg/L).

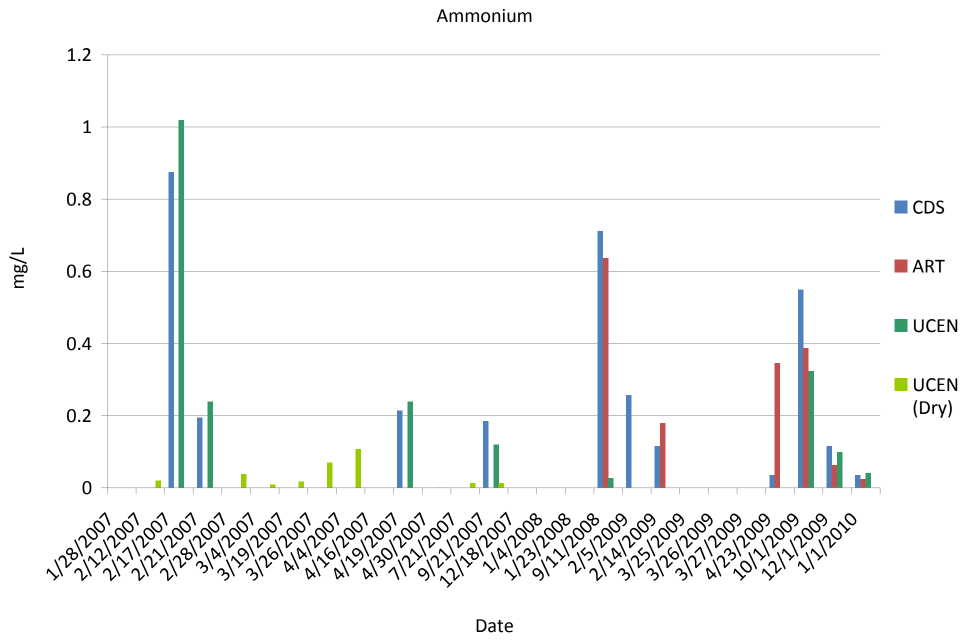


Figure 17. Average values for Ammonium (NH4) for the storm drains between 2007 to 2010 are: CDS (0.299 mg/L, n=11); Art (0.272, n=6); UCEN (0.234, n=9)

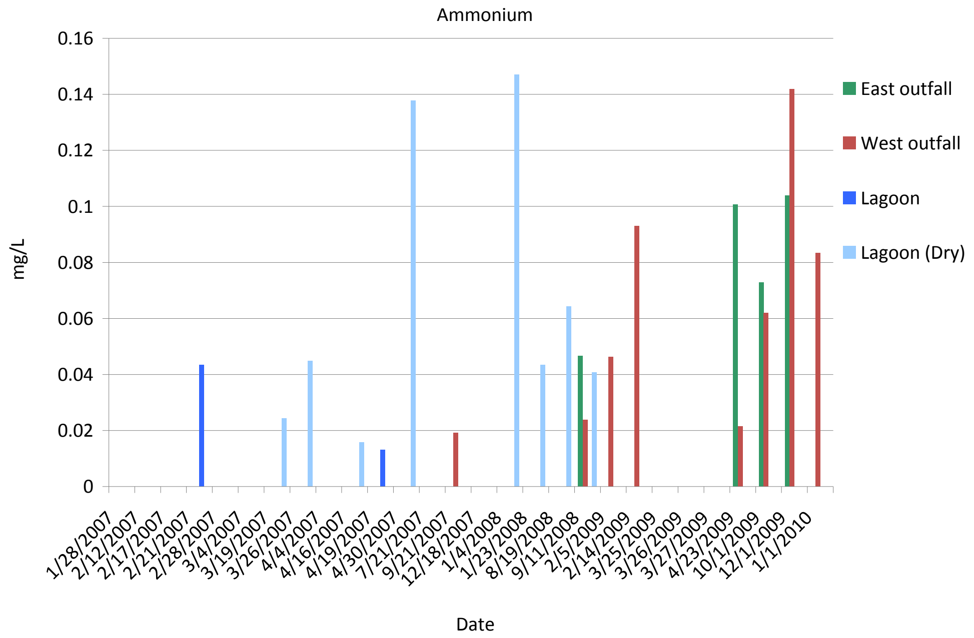


Figure 18. Ammonium (NH4) averages for the lagoon between 2007 to 2010 are: East outfall (0.081 mg/L, n=4), West outfall (0.061 mg/L, n=8), and around the lagoon (0.024, n=10).

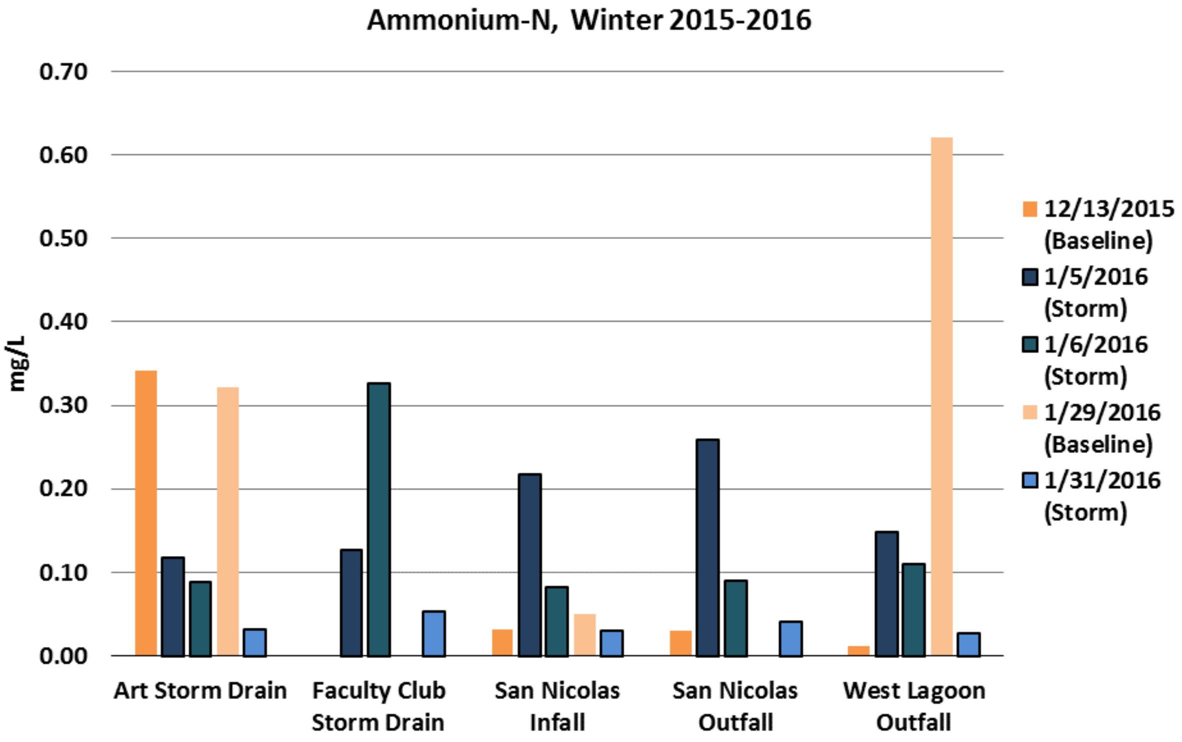


Figure 19. Ammonium (NH4) concentration (mg/L) in water collected from five locations during two low or "dry" flows (Baseline) and three storm events in winter 2015-2016. Figure 11 contains a map of sampling locations. Baseline samples could not be obtained at the "Faculty Club Storm Drain" and in one case at the "San Nicolas Outfall" as flows were too low.

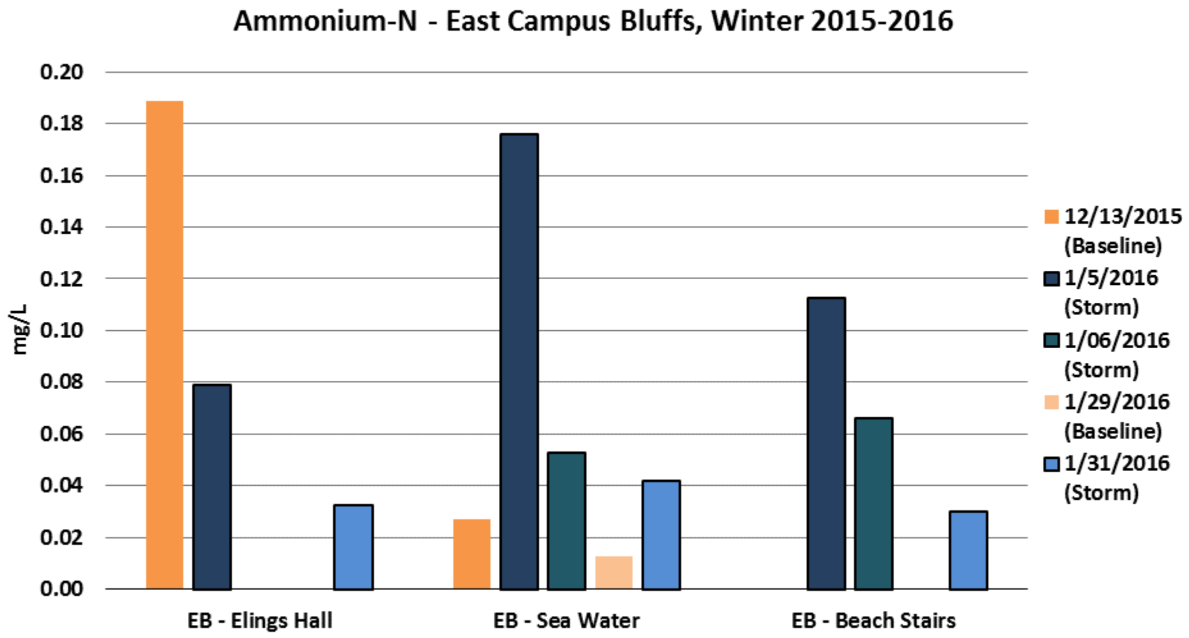


Figure 20. Ammonium (NH4) concentration (mg/L) in water collected from three east campus storm drains during two low or “dry” flows (Baseline) and three storm events in winter 2015-2016. ‘EB’ stands for East Bluffs. Figure 11 contains a map of sampling locations. Baseline samples could not be obtained at the “Elings Hall” and “Beach Stairs” drains as they were dry.

We used an American Fisheries Society algorithm to compute the un-ionized ammonia (NH3) levels at different temperatures, reflecting three temperatures that characterize the lagoon (15, 20, and 22 C in Figure 21) and pH (using 7, 8, 8.5 & 9.2 from frequency data in Figure 22 from data collected from data sonde 2009-2011). The results were tested with a range of salinities from 22 parts per thousand (ppt), which is characteristic of the lagoon in winter time when sea water flows are diluted by storm flows, to 35 ppt (salinity of sea water) which is characteristic of the rest of the year due to it being dominated by sea water flow. Salinity had no significant impact on the results. From multiple iterations (Appendix 1) we found that pH has the most significant impact on the conversion to the toxic, un-ionized form of Ammonia. At measured ammonium (NH4) values greater than 0.25 mg/L, and pH values greater than 9.2, there were toxic levels of un-ionized ammonia based on the EPA standards (Table 2). Thus, conditions near the storm drain outlets could be toxic in all seasons except in the fall when pH levels tend to remain below 9.

An earlier study of benthic invertebrates as food resources for shorebirds around the lagoon edge by Spencer Tang (CCBER Report) found significantly lower densities of benthic invertebrates near the storm drain outfalls relative to other shallow edges along the lagoon shoreline. This may reflect some impacts associated with variable levels of ammonia toxicity adjacent to the UCEN and Commencement Green. However, it is likely that these effects are quite localized and temporary, and may therefore have lower impacts on larger organisms. This synthesis demonstrates, however, that high pH levels in the lagoon may be an additional issue because high pH values may reflect imbalance in the natural chemical processes.

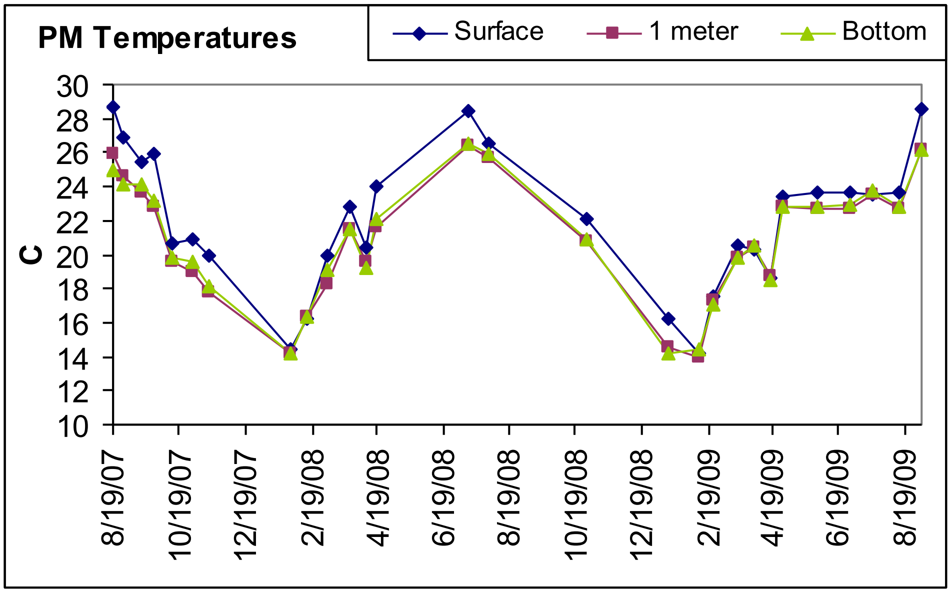


Figure 21. Temperature variation over time and by depth in the lagoon.

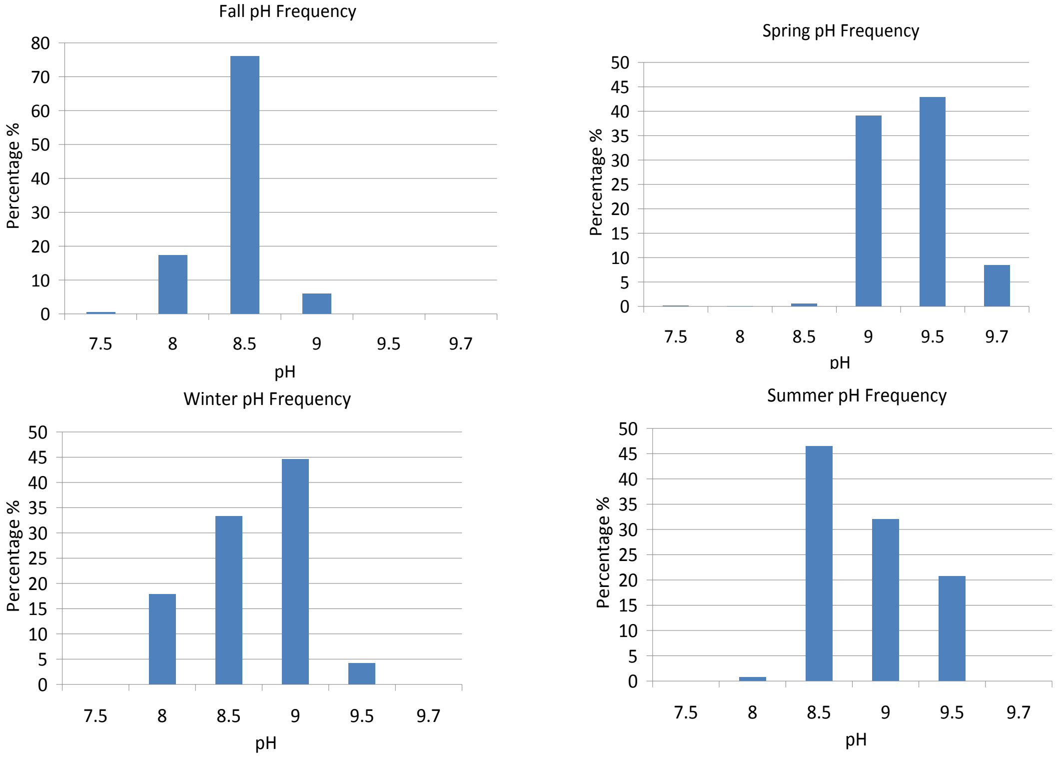


Figure 22. Histogram of pH values over the seasons demonstrate that in every season, except the fall, pH values in the lagoon exceed 9 and high pH is associated with a higher proportion of toxic Ammonia (NH3) in the equilibrium between NH4 and NH3. Data collected from data sonde 2009-2011.

Phosphorous

Phosphorous levels are high in the lagoon, and in general the system is extremely N-limited relative to the available phosphorous (Figure 23). From the figure it is clear that there is much more orthophosphate available than nitrogen relative to the proportions necessary for plant growth shown in the solid lines.

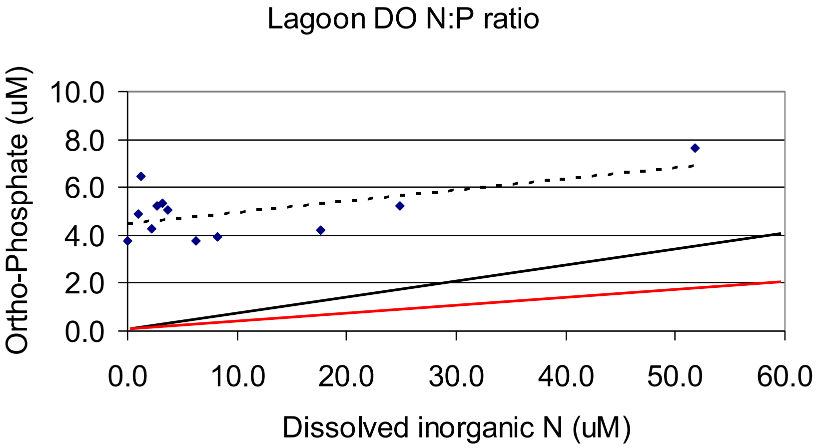


Figure 23. Ratio of nitrate to orthophosphate from 11 samples within the lagoon (April 2008). Black line shows 16:1 (N:P) line reflecting phytoplankton requirements and red line reflects 30:1 ratio for macroalgae and seagrass requirements.

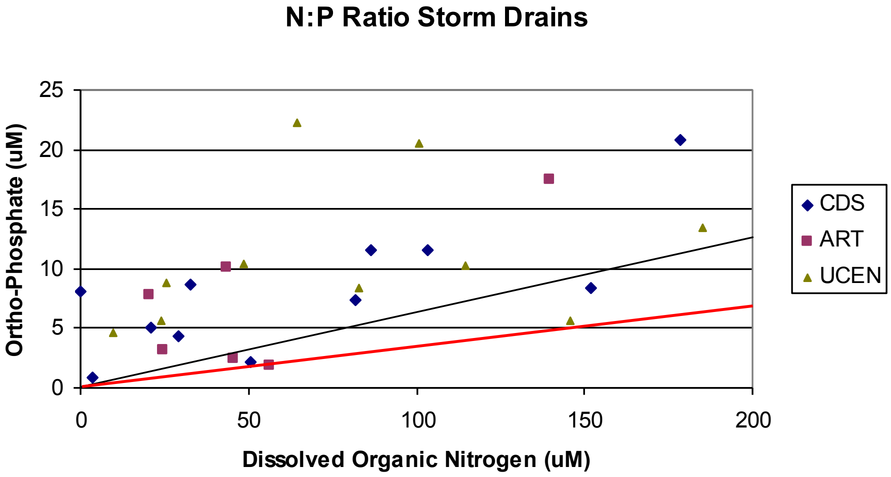


Figure 24. The nitrate to orthophosphate ratio of water entering the lagoon from storm drains shows that nitrogen is still the key limiting nutrient, with a few samples that show some limitation by phosphorous (black line = 16:1 requirements). And yet, the lagoon is rich in phosphorous and once nitrogen rich water reaches the lagoon, P is no longer limiting.

Phosphate levels of water within and leaving the lagoon are generally in the fair quality range (0.07-0.1 mg/L) during the dry season, but can be poor quality (> 0.1 mg/L) during storm flows. In contrast, phosphorous levels in storm drains are consistently at or significantly above the cutpoint level for poor water quality (Figures 25-29). The lagoon acts as a major sink for phosphorous and is therefore not a limiting factor as nitrogen is to plant growth in this particular system. These measurements of the soluble fraction of phosphate neglects to measure the particulate phosphorous which is likely high and also settles at the bottom of the lagoon providing a consistently plentiful source of P.

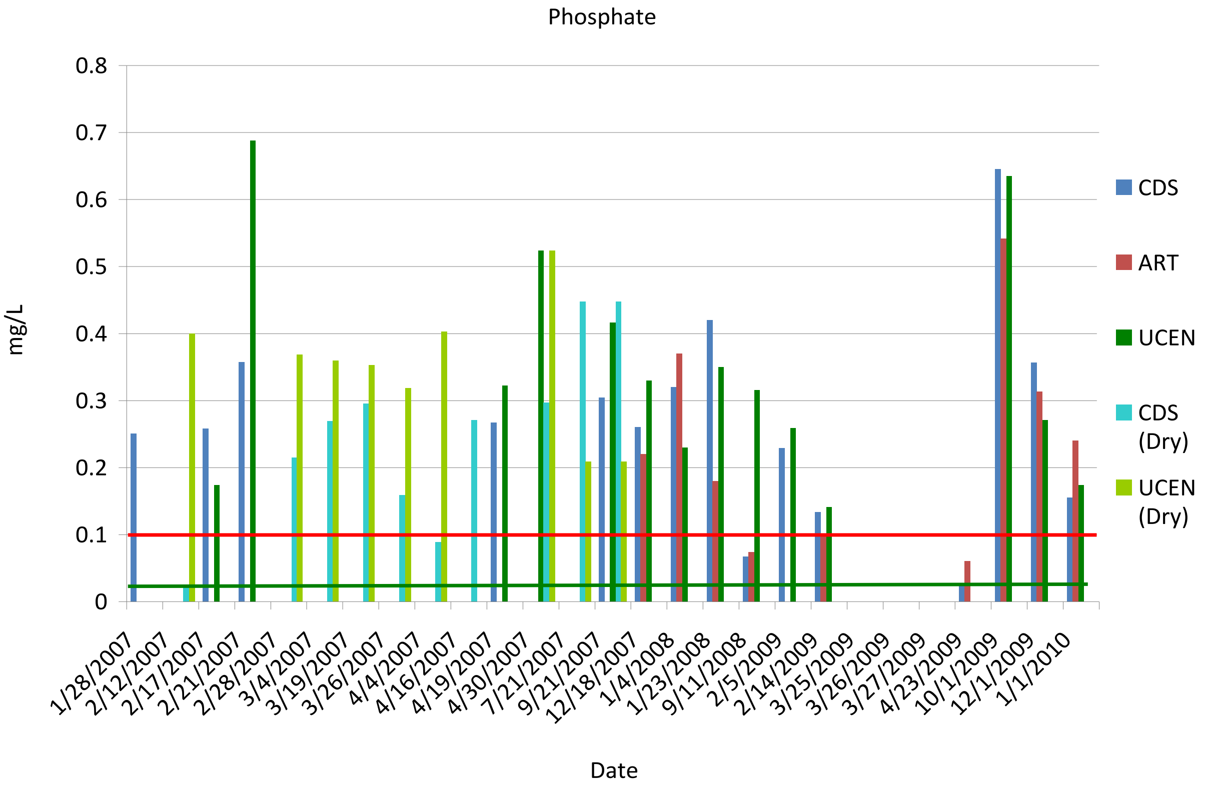


Figure 25. Phosphorous fraction of ortho-phosphate concentrations (mg/L) in water from storm drains are consistently high in both storm and non-storm samples.

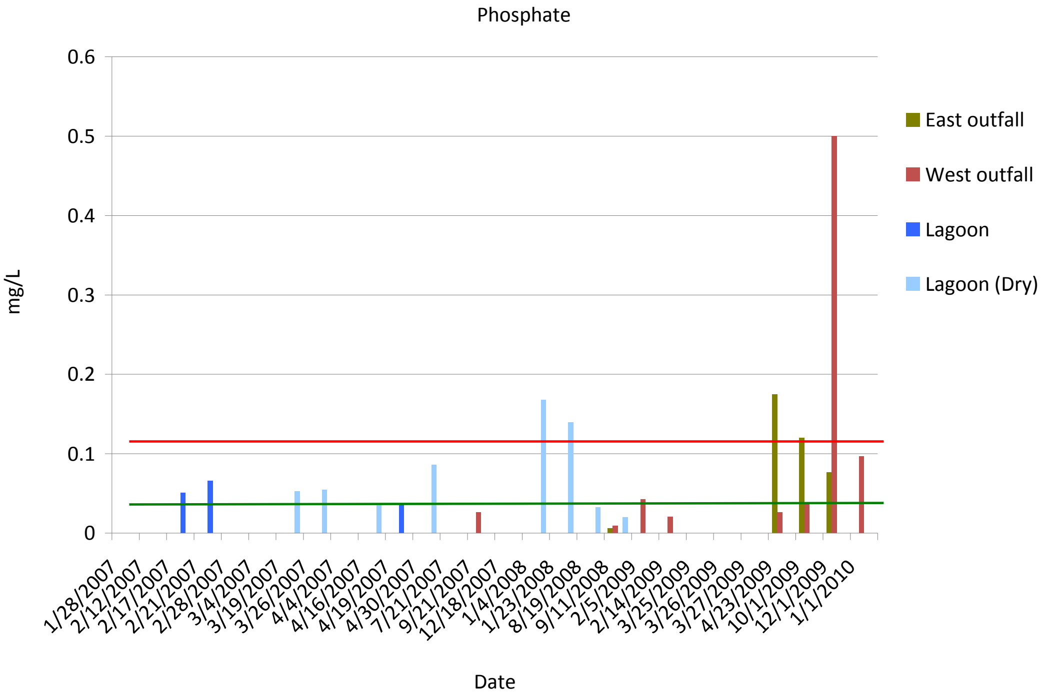


Figure 26. Unlike nitrogen levels, ortho-phosphate concentrations leaving the lagoon regularly exceed the EPA recommendations, reflecting a superabundance of phosphorous. Coastal soils in this region are believed to be high in phosphorous and therefore this element is unlikely to be a limiting factor for algal blooms.

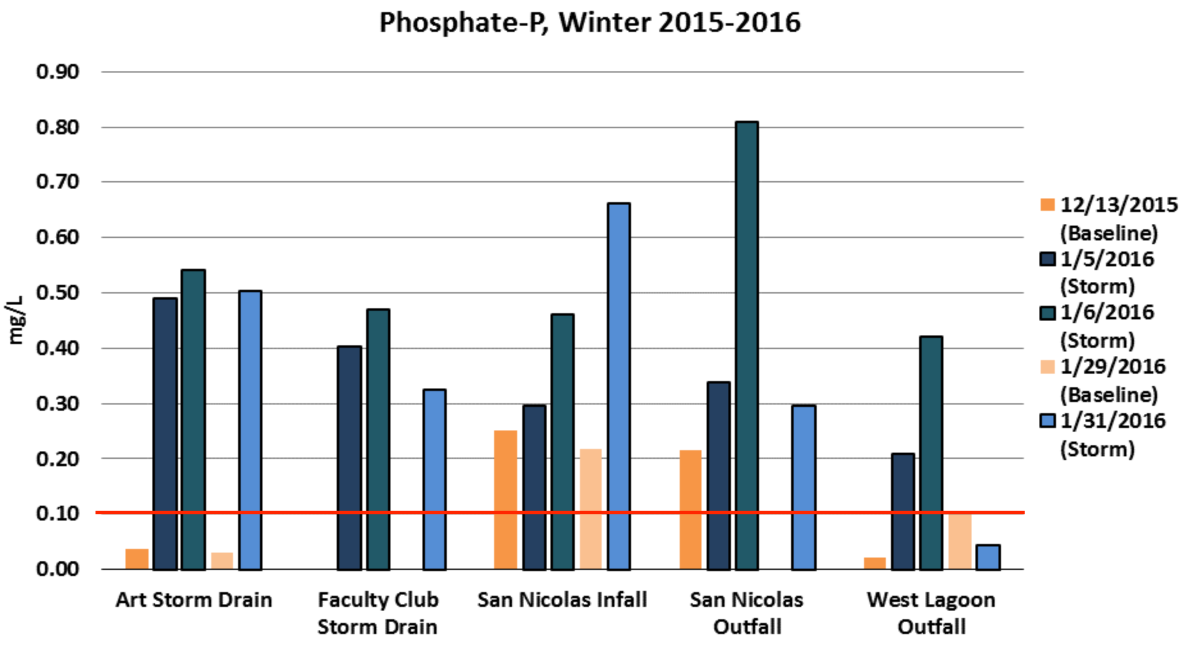


Figure 27. Ortho-phosphate concentration (mg/L) in water collected from five locations during two low or "dry" flows (Baseline) and three storm events in winter 2015-2016. Figure 11 contains a map of sampling locations. Baseline samples could not be obtained at the "Faculty Club Storm Drain" and in one case at the "San Nicolas Outfall" as flows were too low. The red line represents the EPA cutpoint of 0.1 mg/L.

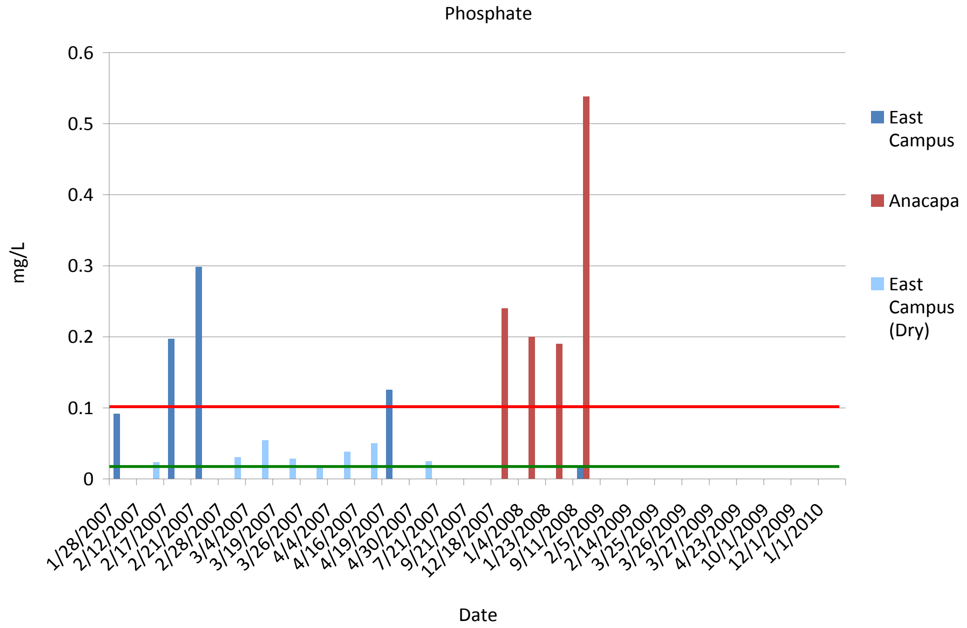


Figure 28. Ortho-phosphate concentrations (mg/L) in water sampled from east campus storm drains between January 2007 to January 2010 also exceeded the EPA standards of total phosphorous concentrations associated with algal blooms. The green line indicates levels above which algal blooms may occur and the red line indicates levels where algal blooms are likely to be problematic.

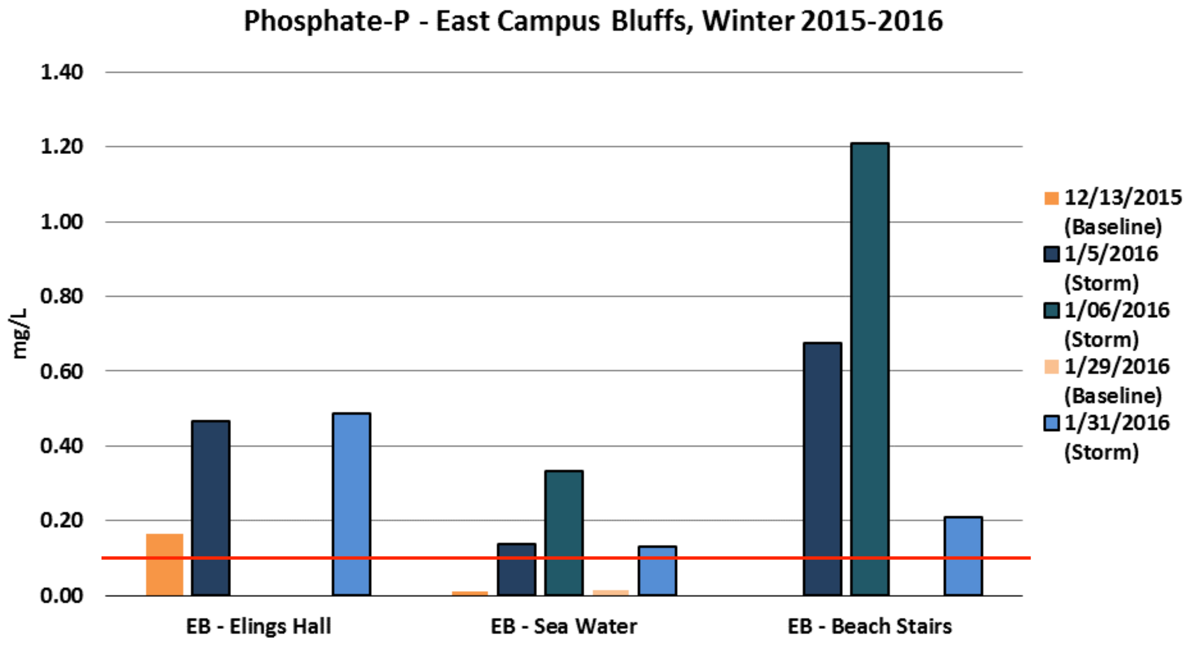


Figure 29. Ortho-phosphate concentration (mg/L) in water collected from three east campus storm drains during two low or “dry” flows (Baseline) and three storm events in winter 2015-2016. ‘EB’ stands for East Bluffs. Figure 11 contains a map of sampling locations. Baseline samples could not be obtained at the “Elings Hall” and “Beach Stairs” drains as they were dry. The red line represents the EPA cutpoint of 0.1 mg/L.

Chlorophyll *a*

Chlorophyll *a* indicates phytoplankton growth and macro-algal growth, which respond to high nutrient levels. In Figure 30, chlorophyll *a* levels consistently exceed levels associated with poor water quality (Table 1) by significant amounts in the winter, spring and occasionally in the summer. These data were obtained with a regularly maintained YSI data sonde (YSI 6600) installed at a depth of approximately 1.25 meters in a 2.5-meter-deep area of the lagoon located near the UCEN, and reflect near monthly means of chlorophyll fluorescence data taken every 15 minutes, hence the very low standard errors. Samples of suspended chlorophyll from the SCCWRP study ranged from 40 to near zero between November 2008 and September 2009, which generally correlates with the monthly means shown in Figure 30. The growth of phytoplankton reduces water clarity, contributes to fluctuating DO levels and, eventually, dead phytoplankton contributes to sediment particulate organic material which decomposes and reduces oxygen availability and releases nutrients through diffusion and other processes.

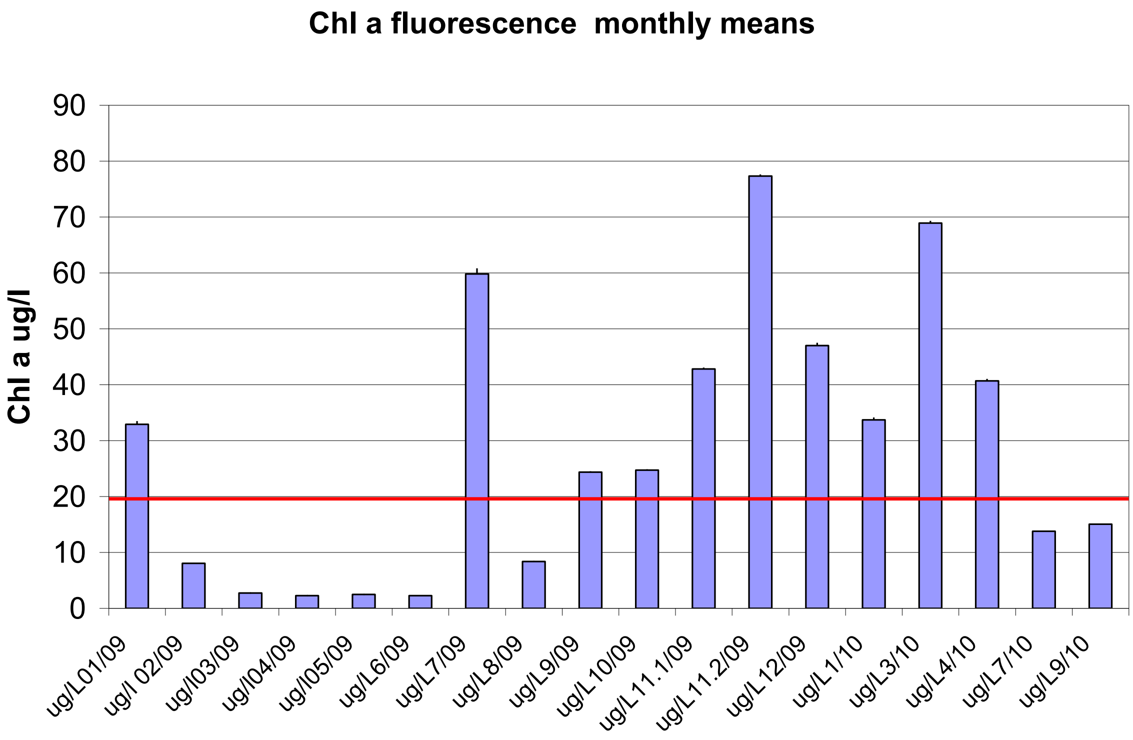


Figure 30. Chl. *a* fluorescence levels during the 2009-2010 year, showing winter peaks in chl. *a*. This finding reflects the lagoon's eutrophic condition. Levels of chlorophyll *a* that exceed 20 ug/l are associated with low water quality (red line) and levels below 5 ug/l are associated with high water quality (EPA 2012).

High chlorophyll *a* levels were associated with low DO levels assessed at five sample locations around the lagoon on the surface and near the bottom (2m deep). High chlorophyll *a* levels were also associated with a consistent diurnal dissolved oxygen difference of at least 2 mg/L which reflects biostimulatory effects of algal growth, as described earlier.

Water Clarity

Chlorophyll levels are associated with water clarity because dense phytoplankton populations reduce water clarity. Secchi disk measurements taken during 2009-2010 (n=64) had a mean of 0.449m and a standard deviation of 0.16m. The percent light availability at 1 meter ((z) = e^{kz} where k = 1/secchi disk value (m)) = 2.22, which gives a light penetration of 9.6% within a range of 4.6% - 31% (one standard deviation). This indicated that on average the lagoon water clarity is lower than the 10% minimum set for fair water quality. However, clarity can sometimes exceed the 20% value associated with good water quality. This degree of variability reflects the variation in phytoplankton activity in the lagoon, while the mean of 9.6% clearly indicates that, in general, water clarity is poor.

Oil and Grease

Oil and grease come in many different types and forms, and are composed of thousands of organic compounds with varying physical, chemical and toxicological properties. Consequently, a national recommended numeric water quality criterion for oil and grease has not been possible to establish (EPA 1986, CEPA 2006). However, studies have indicated that aquatic life can be negatively affected by petroleum product concentrations as low as 1 microgram per liter (ug/L) (EPA 1986, CEPA 2006).

Concentrations of oil and grease in baseline ("dry" season) and storm water ("wet" season) flows into and out of the lagoon, and over the east campus bluffs, were assessed in a survey by Anchor Environmental in 2006, and recently by CCBER in winter 2015-2016. The findings of these surveys are summarized in tables 3 and 4, respectively. With the exception of one east campus bluffs storm water sample in the 2006 survey, all samples contained oil and grease concentrations below 5 milligrams per liter (mg/L), which is consistent with typical concentrations found in studies reviewed by the California EPA's Office of Environmental Health Hazard Assessment (OEHHA) (CEPA 2006). The OEHHA reports that, at concentrations of 5 mg/L or lower, the components of oil for which criteria have been established (arsenic, cadmium, chromium, lead and zinc), are likely to occur at concentrations that are well below aquatic life water quality criteria, yet may pose a long-term risk through accumulation in sediment (CEPA 2006).

Table 3. Oil and Grease concentration (milligrams per liter) in water samples collected for an Anchor Environmental study of the Campus Lagoon water quality in 2006.

Site and Location	Date	Oil and Grease (mg/L)
CL-UCSB-1 East Campus (Wet)	2/27/2006	6.4
CL-UCSB-2 East Campus (Wet)	3/3/2006	4.49
CL-UCSB-3 East Campus (Wet)	3/6/2006	2.9
CL-UCSB-4 East Campus (Dry)	3/17/2006	ND
CL-UCSB-5 UCEN Center, Mesa Rd (Wet)	3/22/2006	2.2
CL-UCSB-6 Campus Lagoon (Dry)	3/31/2006	ND
CL-UCSB-7 UCEN Center, Mesa Rd (Wet)	4/3/2006	1.4
CL-UCSB-8 UCEN Center, Mesa Rd (Wet)	4/10/2006	2.7

The results of the recent CCBER survey also suggest that the San Nicolas bioswale helps reduce the amount of oil and grease entering the lagoon, as indicated by the non-detection and lower concentrations of oil and grease observed in baseline and storm water flows out of the San Nicolas bioswales, relative to the flows into the bioswale (Table 4).

Table 4. Mean and standard error (SE) concentration of oil and grease (milligrams per liter) in water collected from baseline ("dry" season) and storm water ("wet" season) flows at eight sites for a CCBER survey of Campus Lagoon water quality. Water samples were collected between December 13, 2015 to January 31, 2016. Three sample locations are from storm drains that currently flow over the East Bluffs (EB). ND = Not Detected. A table of all data for each sample is provided in Appendix 2.

Sample Site & Type	**Oil and Grease (mg/L)**	
	Mean	SE
Site 1 – EB Storm Drain - Elings Hall		
Baseline - no flow (n = 0)	-	-
Storm Water (n = 3)	4.5	1.22
Site 2 – EB Storm Drain – Sea Water		
Baseline (n = 2)	2.23	0.79
Storm Water (n = 3)	2.77	0.89
Site 3 – EB Storm Drain – Beach Stairs		
Baseline - no flow (n = 0)	-	-
Storm Water (n = 3)	3.37	0.47
Site 4 – San Nicolas Bioswale Infall		
Baseline (n = 2)	2.14	0.76
Storm Water (n = 3)	4.78	1.30
Site 5 – San Nicolas Bioswale Outfall		
Baseline – low flow (n = 1)	ND	ND
Storm Water (n = 3)	2.69	0.66
Site 6 – Art Storm Drain		
Baseline – low flow (n = 0)	-	-
Storm Water (n = 3)	3.93	1.18
Site 7 – CDS/Faculty Club Storm Drain		
Baseline – very low flow (n = 0)	-	-
Storm Water (n = 3)	3.35	1.00
Site 8 – West Lagoon Outfall		
Baseline (n = 2)	3.85	0.09
Storm Water (n = 3)	2.63	0.45

Metal Concentrations in Water

The EPA maintains a table of National Recommended Water Quality Criteria for Aquatic Life (www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table). This table lists a Criterion Maximum Concentration (CMC) and Criterion Continuous Concentration (CCC) for pollutants in both Freshwater and Saltwater. The CMC represents the acute concentration of a pollutant to which aquatic life can be exposed to for a short time (1 hour) without deleterious effects, while the CCC represents the highest chronic concentration of a pollutant to which aquatic life can be exposed to for an extended period of time (4 days) without deleterious effects. Table 5 lists the CMC and CCC values for four metals assessed in Campus Lagoon water by Anchor Environmental and CCBER.

Table 5. EPA Criterion Maximum Concentration (CMC – acute) and Criterion Critical Concentration (CCC – chronic) values for four metals assessed in Campus Lagoon

Metal	CMC acute (ug/L)	CCC chronic (ug/L)
Copper (Cu)	4.8	3.1
Lead (Pb)	210	8.1
Nickel (Ni)	74	8.2
Zinc (Zn)	90	81

Studies by Anchor Environmental in 2006 and by CCBER in 2009 found levels of copper and zinc that far exceeded the recommended CMC values, and Anchor Environmental also found levels of lead and nickel that exceeded CCC values in east campus storm drains during the dry and wet seasons (Table 6, and Figure 31 for copper). Anchor Environmental reported copper concentrations between 8 to 33 ug/L in water collected from storm drains. Similarly, CCBER found that copper levels from storm drains and the lagoon ranged from 9.3 to 20 ug/L, which significantly exceeded the CMC value of 4.8 ug/L. A set of 19 samples from a wide range of lagoon sites averaged 31 ug/L (Figure 32).

Table 6. Summary of analyses by Anchor Environmental (2006) and a 2009 CCBER surveys of metals (Copper - Cu, Nickel - Ni, Lead - Pb, and Zinc - Zn) in storm water and lagoon water. Values (micrograms per liter) highlighted in red exceed the Criteria Maximum Concentration (CMC), and those in yellow exceed the Criteria Continuous Concentration (CCC). <DL = below Detection Level.

Sample ID	**Cu (ug/L)**	**Pb (ug/L)**	**Ni (ug/L)**	**Zn (ug/L)**
Anchor Study (wet unless indicated dry)				
East Campus 3/1/2006 (Dry)	**6.8**	0.44	**10.3**	**89.8**
East Campus 2/27/2006	**38.3**	**8.4**	**8.7**	**270**
East Campus 3/3/2006	**18.2**	6.3	5.8	**189**
East Campus 3/6/2006	**19**	4.1	5.2	**160**
UCEN 3/22/2006	**8.3**	1.45	2.1	60.05
UCEN 4/2/2006	**10**	3.3	**8.6**	75
UCEN 4/10/2006	**30.8**	2.4	6.7	**151.5**
CCBER 2009 Survey				
Detection Limit	*0.7*	*11*	*0.5*	*13*
UCEN Storm Drain 1M	**19**	<DL	2.1	**94**
UCEN Storm Drain 2M	**20**	<DL	2.0	**94**
CDS 2M	**9.0**	<DL	2.6	56
CDS 1M	**9.3**	<DL	2.6	59
West Lagoon 1M	<DL	<DL	1.1	<DL
Bioswale 1M	2.5	<DL	1.7	35

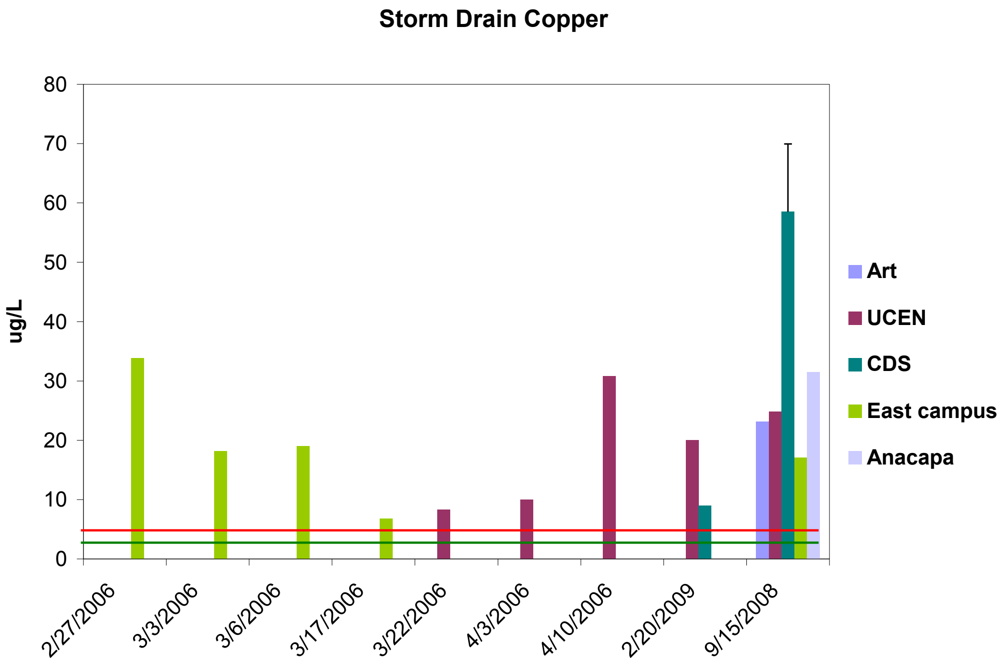


Figure 31. Storm drain copper levels shown with CMC (red line) criteria levels and CCC (green line) levels indicating that run-off is contributing excess copper to the Campus Lagoon.

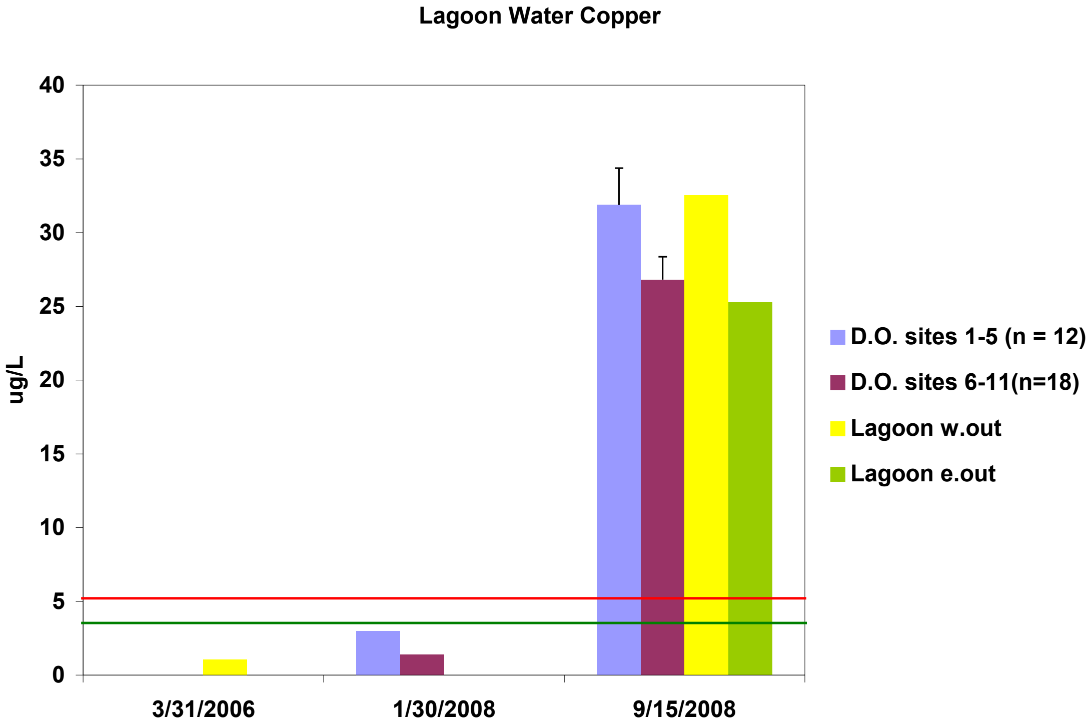


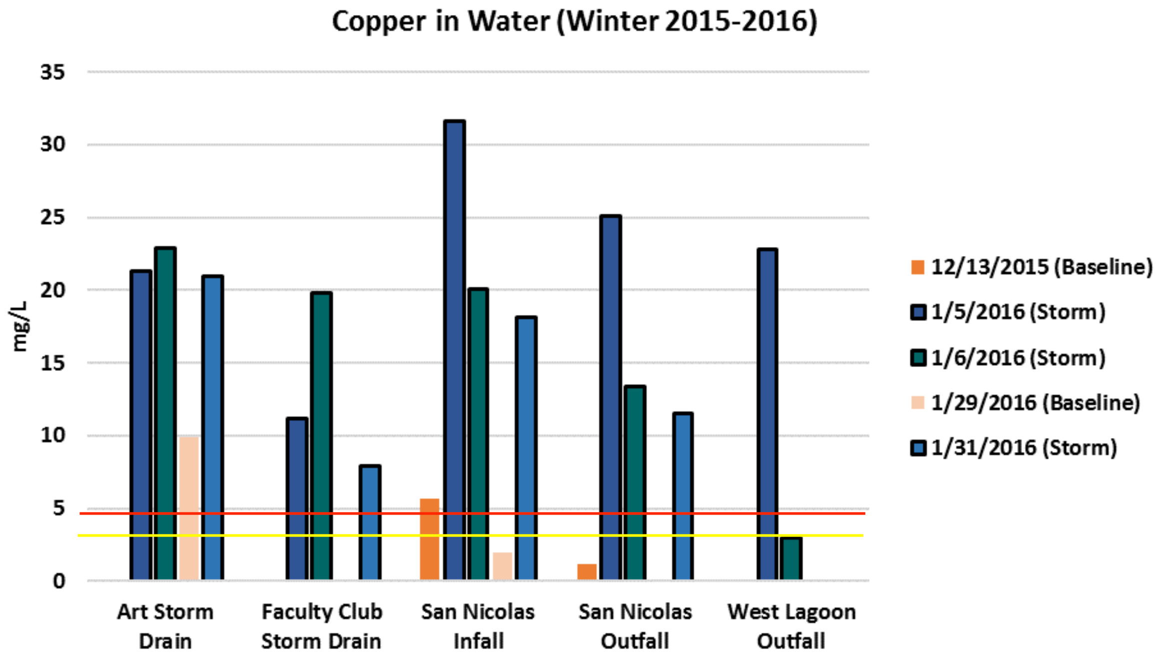
Figure 32. Lagoon water column copper concentrations shown from within the lagoon. Copper levels were extensively sampled within the lagoon and can exceed the CMC levels significantly suggesting that there is a potential copper problem in the lagoon.

The results of a 2016 winter survey by CCBER were consistent with those from the earlier studies, with copper levels in storm water ("wet" season) samples far exceeding the recommended CMC value at all eight sample sites, and in a baseline ("dry" season) sample at one site (Table 7 and Figure 33). The CCC for lead was exceeded in one storm water sample collected from a storm drain downstream from the CDS unit near the campus Faculty Club, while the Nickel CCC value was exceeded in storm water from one east campus drain, and in baseline ("dry" season) flows of two drains that flow into the lagoon. It is also worth noting that the metal concentrations of baseline and storm water flows out of the San Nicolas bioswale were lower than the concentrations of the run-off flowing into the wetland, although copper levels still exceeded the CMC value (Table 7 and Appendix 2).

Table 7. Mean and standard error (SE) concentration (micrograms per liter) of metals (Copper – Cu, Lead – Pb, and Nickel – Ni) in water collected from baseline ("dry" season) and storm water ("wet" season) flows at eight sites for a CCBER survey of Campus Lagoon water quality. Water samples were collected between December 13, 2015 to January 31, 2016. Three sample locations are from storm drains that currently flow over the East Bluffs (EB). ND = Not Detected. Values highlighted in red exceed the Criteria Maximum Concentration (CMC), and values highlighted in yellow exceed the Criteria Continuous Concentration (CCC). A table of all data for each sample is provided in Appendix 2.

1. For each site where lead was detected, this was from only one of the samples.
2. Nickel was only detected in one storm water sample for Site 2, and two of the three storm water samples from Site 5.

Sample Site & Type	Cu (ug/L)		[1]Pb (ug/L)		[2]Ni (ug/L)	
	Mean	SE	Mean	SE	Mean	SE
Site 1 – EB Storm Drain - Elings Hall						
Baseline - no flow (n = 0)	-	-	-	-	-	-
Storm Water (n = 3)	**14.59**	4.51	1.00	0.27	3.73	1.01
Site 2 – EB Storm Drain – Sea Water						
Baseline (n = 2)	ND	ND	6.56	2.32	ND	ND
Storm Water (n = 3)	**14.21**	2.73	ND	ND	2.83	0.77
Site 3 – EB Storm Drain – Beach Stairs						
Baseline - no flow (n = 0)	-	-	-	-	-	-
Storm Water (n = 3)	**14.90**	1.95	1.09	0.30	**14.42**	3.87
Site 4 – San Nicolas Bioswale Infall						
Baseline (n = 2)	**3.82**	1.30	5.56	1.97	**9.94**	1.11
Storm Water (n = 3)	**23.27**	3.43	5.18	1.41	3.13	0.26
Site 5 – San Nicolas Bioswale Outfall						
Baseline – low flow (n = 1)	1.19	0	ND	ND	7.44	0
Storm Water (n = 3)	**16.67**	3.47	2.12	0.58	3.05	0.87
Site 6 – Art Storm Drain						
Baseline – low flow (n = 1)	**9.88**	0	ND	ND	**43.50**	0
Storm Water (n = 3)	**21.73**	0.48	6.97	1.90	5.92	1.62
Site 7 – CDS/Faculty Club Storm Drain						
Baseline – very low flow (n = 0)	-	-	-	-	-	-
Storm Water (n = 3)	**12.96**	2.90	**8.77**	2.39	6.30	2.04
Site 8 – West Lagoon Outfall						
Baseline (n = 2)	ND	ND	ND	ND	ND	ND
Storm Water (n = 3)	**12.88**	5.85	0.83	0.22	4.11	1.40



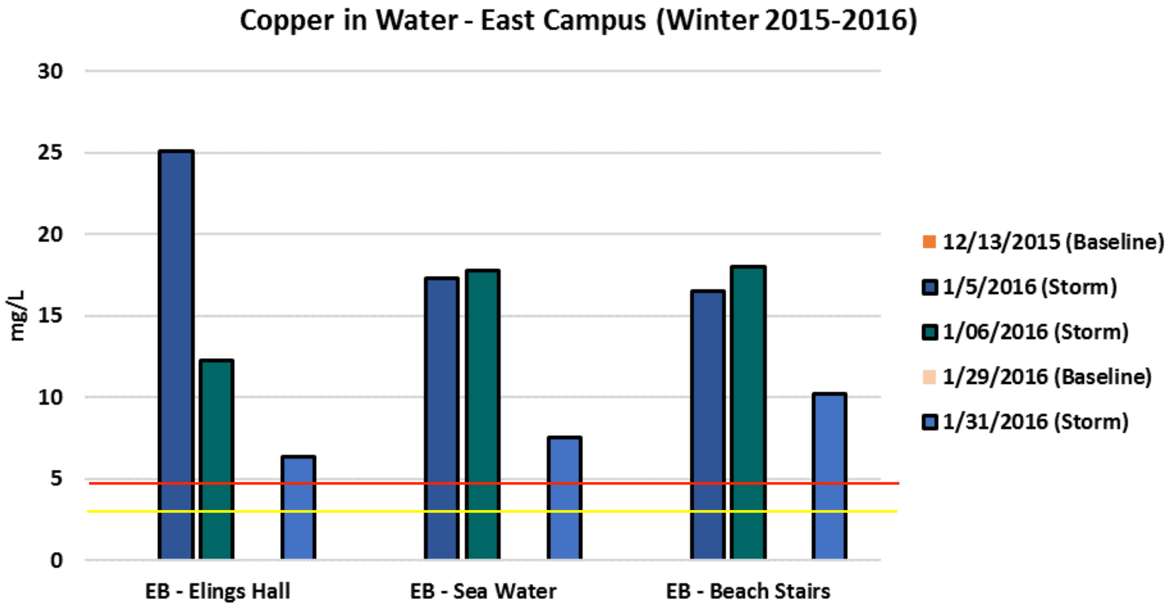


Figure 33. Copper concentration (ug/L) in water collected from five locations (top chart) and three east campus storm drains (bottom chart) during two low or “dry” flows (Baseline) and three storm events in winter 2015-2016. ‘EB’ stands for East Bluffs. The red line indicates the CMC threshold of 4.8 ug/L, and the yellow line indicates the CCC threshold of 3.1 ug/L. Baseline samples could not be obtained at the “Faculty Club Storm Drain”, “Elings Hall”, “Beach Stairs”, and in one case at the “Art Storm Drain” and “San Nicolas Outfall” sites because the drains were either dry or the flows were too low. Note that copper was not detected in “Baseline” samples from the West Lagoon Outfall and EB-Sea Water sites. Figure 11 contains a map of sampling locations.

Metal Concentrations in Sediment

Along with the evidence that copper and zinc are entering the lagoon at potentially toxic levels to aquatic organisms and that metals have a tendency to settle, CCBER sampled the lagoon sediments (top muck level and lower, denser sediments) at 10 locations around the lagoon – adjacent to outfalls and within the more open water portions of the lagoon. Sediment standards are based on toxicity tests and fall within the categories listed in the table below.

NOAA (2006) has established some basic screening criteria for sediment metal concentrations at which they believe there are possible effects on organisms (Table 8). When five or more metals exceed the Effects Range Low (ERL), then a body of water is considered to have moderate quality. When levels for 1 metal exceed the Effects Range Median (ERM), then the rating is low quality. None of the lagoon sediment samples exceeded the ERM, however three of the four metals studied exceeded the ERL range, suggesting that metals are a potential problem for the lagoon and should be further studied.

Table 8. Sediment threshold levels (mg/Kg) x1000 for ppb from NOAA 2006

	Threshold	**Low Effects (ERL)**	**Probable Effects**	**Median Effects (ERM)**	**Apparent Effects**
Copper	18.7	34	108.2	270	390
Lead	30	46.7	112	218	400
Nickel	15.9	20.9	42.8	51.6	110
Zinc	124	150	410	410	410

Figures 34-37 below show sediment metal concentrations relative to ERL (orange line) and probable effects range (red line), which was exceeded by copper and lead.

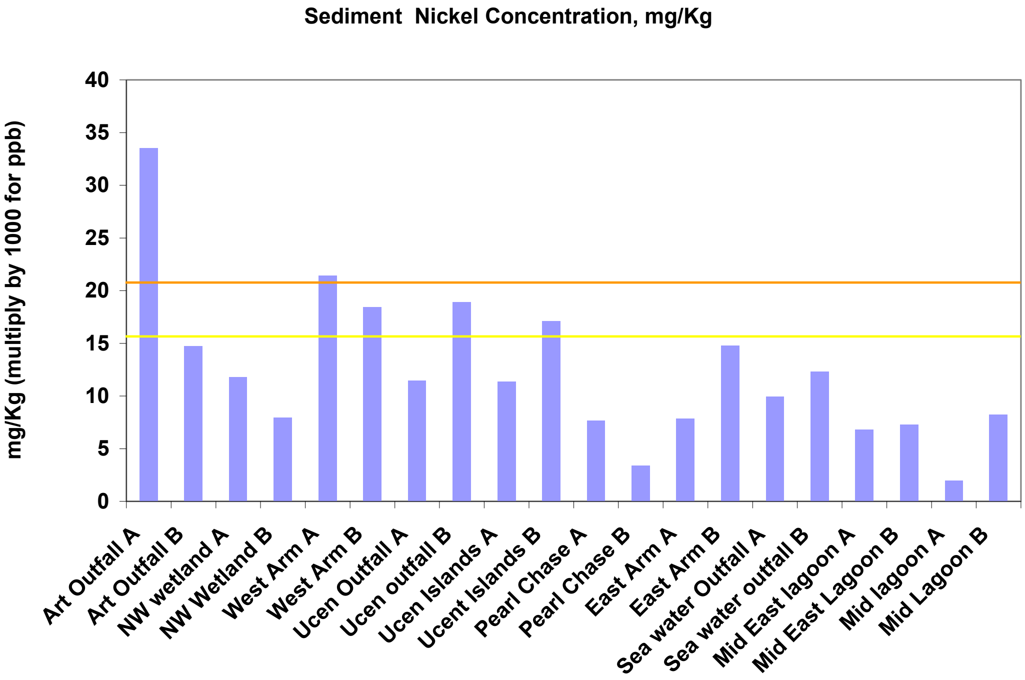


Figure 34. Sediment nickel concentrations at two depths and 10 sites around the lagoon. Only exceed ERL from Art Building drain and within the west arm of the lagoon.

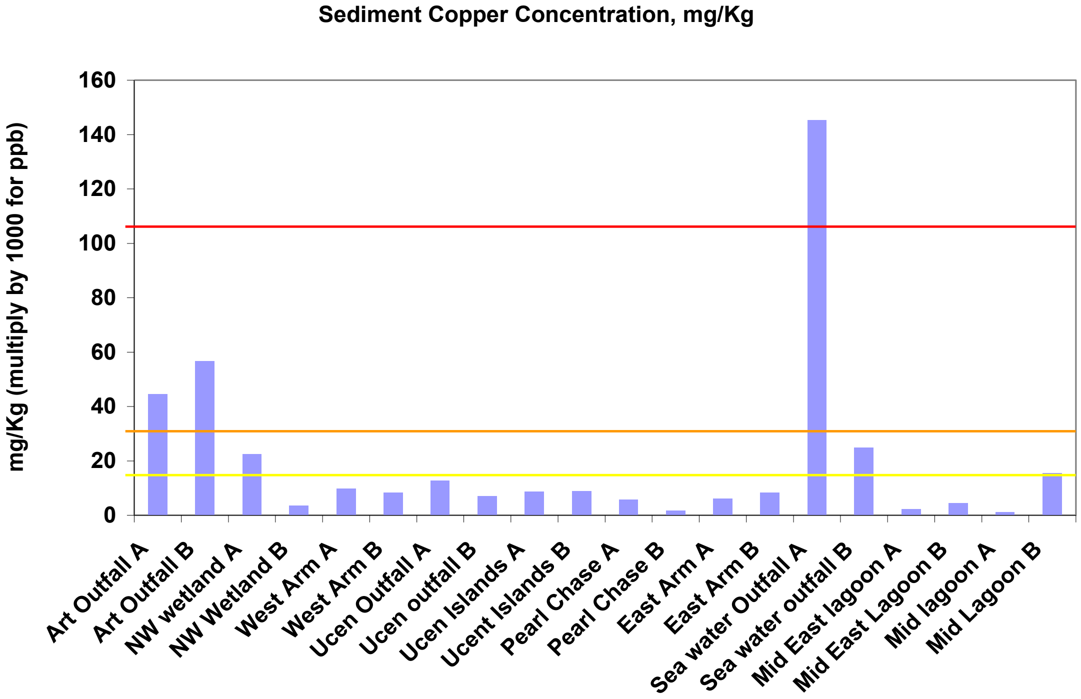


Figure 35. Sediment copper concentrations at two depths and 10 sites. Exceed ERL from Art Building outfall and near Pearl Chase Park.

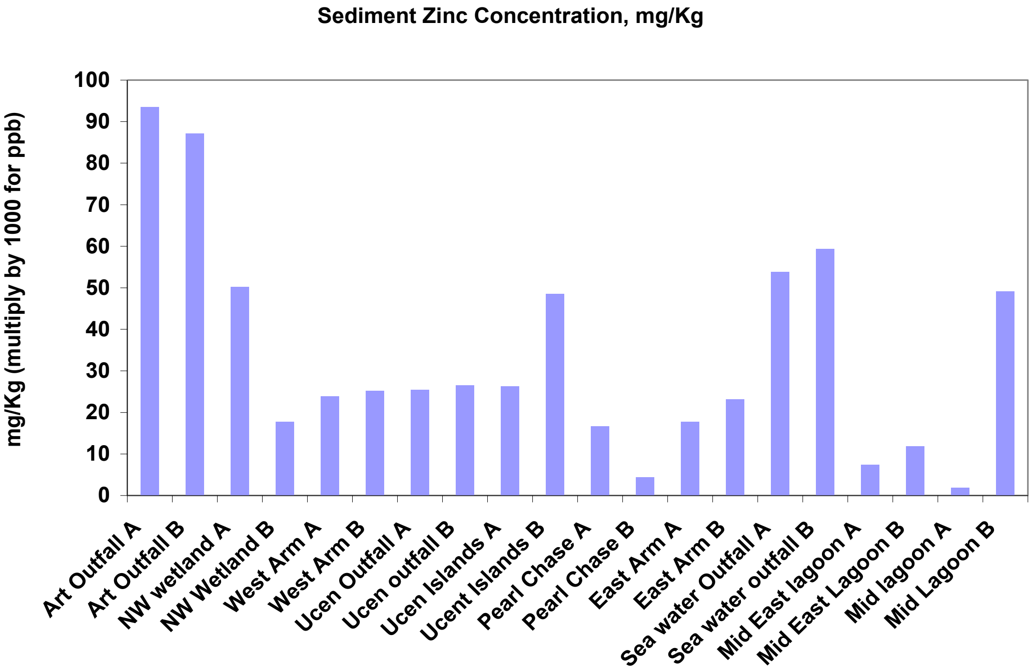


Figure 36. Sediment zinc concentrations at 2 depths and 10 sites. The concentrations do not exceed ERL at any sites.

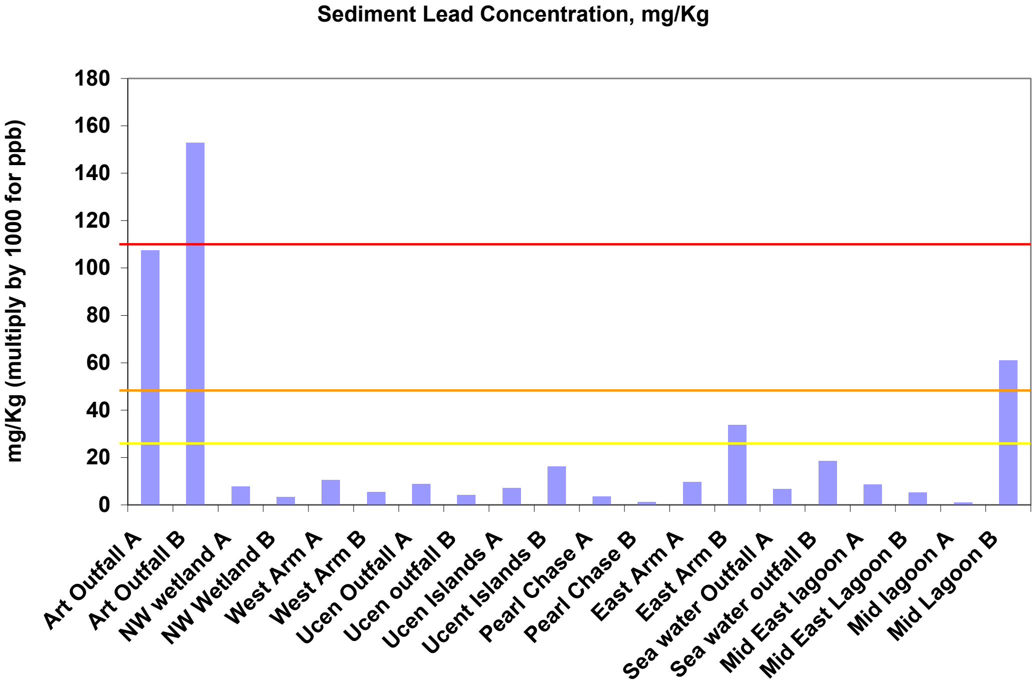


Figure 37. Sediment lead concentration at two depths and 10 sites. Exceed ERL at Art Building outfall and in the middle of the lagoon.

Table 9 shows the same data as the graphs in a numeric form with the threshold highlighted in yellow, the ERL highlighted in orange, and the higher Probable Effects level highlighted in red.

Table 9. Concentration (mg per Kg) of metals (Copper, Nickel, Lead, and zinc) in Campus Lagoon sediment samples collected in 2009.

Sample ID & Location (A = surface sediment, B= grey sediment below)	**Cu (mg/Kg)**	**Pb (mg/Kg)**	**Ni (mg/Kg)**	**Zn (mg/Kg)**
1A - Art Outfall A	45	107	34	93
1B – Art Outfall B	57	153	15	87
2A - NW wetland A	22	7.8	12	50
2B - NW Wetland B	3.5	3.3	7.9	18
3A - West Arm A	9.9	10	21	24
3B - West Arm B	8.4	5.5	18	25
4A - Ucen Outfall A	13	8.8	11	25
4B - Ucen Outfall B	7.1	4.1	19	27
5A - Ucen Islands A	8.7	7.0	11	26
5B - Ucen Islands B	9.0	16	17	49
6A - Pearl Chase A	5.7	3.6	7.7	17
6B - Pearl Chase B	1.8	1.2	3.4	4.4
7A - East Arm A	6.1	9.6	7.9	18
7B - East Arm B	8.3	34	15	23
8A - Sea water Outfall A	145	6.7	10	54
8B - Sea water Outfall B	25	19	12	59
9A - Mid East lagoon A	2.3	8.5	6.8	7.4
9B - Mid East Lagoon B	4.5	5.1	7.3	12
10A - Mid lagoon A	1.2	0.84	2.0	1.9
10B - Mid Lagoon B	15	61	8.2	49

Copper levels in the sediments exceed the low and probable effects levels adjacent to the Art Building storm drain outfall into the lagoon (57 ug/L) and adjacent to the seawater outfall on the eastern side of the lagoon (145 ug/L). Elsewhere, copper levels in the sediments are less than the threshold levels. Nickel levels exceed the lowest threshold (15 – 19 ug/L) and the low level effects level in several areas of the lagoon. Lead exceeds the levels in only one of 20 samples in the lagoon.

The combination of high copper levels in storm drain water, and in the sediments adjacent to the storm drains, suggest that copper pollution needs to be attenuated before greater impacts take place within the lagoon sediments. The sediment samples adjacent to the storm drain flow from the Art Building area had the highest sediment copper levels, which could reflect the use of copper and other metals that are used in glazing, photography and other activities. This suggests that the disposal of waste in these facilities should be examined. Another typical source of copper is from car brakes, which is washed off roads and into the storm drains during rain events.

Sediment Organic Carbon

CCBER processed a detailed collection of sediment samples collected in the fall of 2010 and analyzed for carbon and nitrogen in 2 cm slices from the surface to the bottom of the sediment, using a mass spectrometer. The upper levels of the sediment have extremely high organic carbon content, indicative of the build-up of decaying organic matter in the sediments and associated high oxygen demand, and the potential for resuspension of re-mineralized organic matter. The carbon concentrations reflect low water quality as the values exceed the 5% concentration associated with low water quality in the upper 6 cm and moderate quality (between 2 and 5% carbon) in the 6 cm to 26 cm depths (Figure 38a).

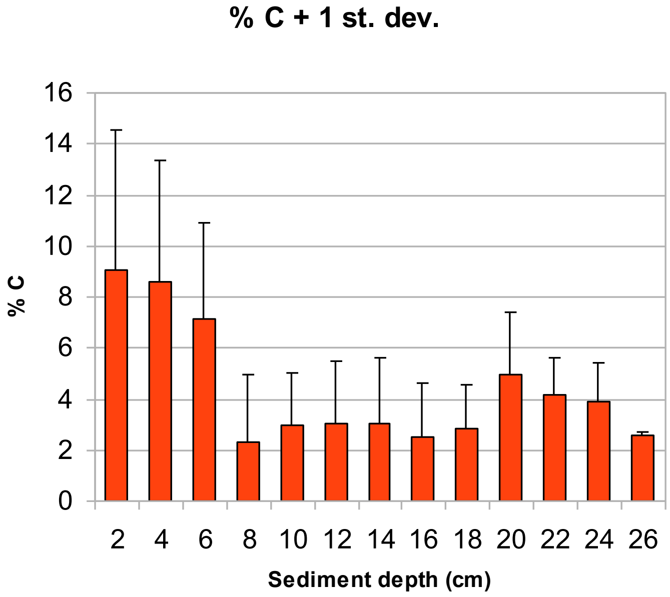


Figure 38a. Total organic carbon from sediment samples collected from eight sites in fall 2010 and shown in 2 cm slices. Not only are organically rich sediments deep but they also have very high carbon content.

This data is also mirrored in the six set of samples collected as part of the SCCWRP Bight 2008 Study (McLaughlin et al. 2012), in which the Campus Lagoon C:N ratios were 10 +/-1 (Figure 38b).

The EPA standards indicate that % Carbon contents greater than 5% indicate low quality water while levels less than 2% indicate higher water quality. The top 6 centimeters far exceed the EPA levels (averaging 5%) and the deeper layers all exceed 2 %. This reflects an accumulation of organic matter due to excessive carbon growth as algae and phytoplankton as well as a chronic lack of flushing in the system. The stratification in the system further reduces the rate of decomposition. This organic matter is continuously being converted to plant-available nutrients which means that the nutrients are recycled in the system.

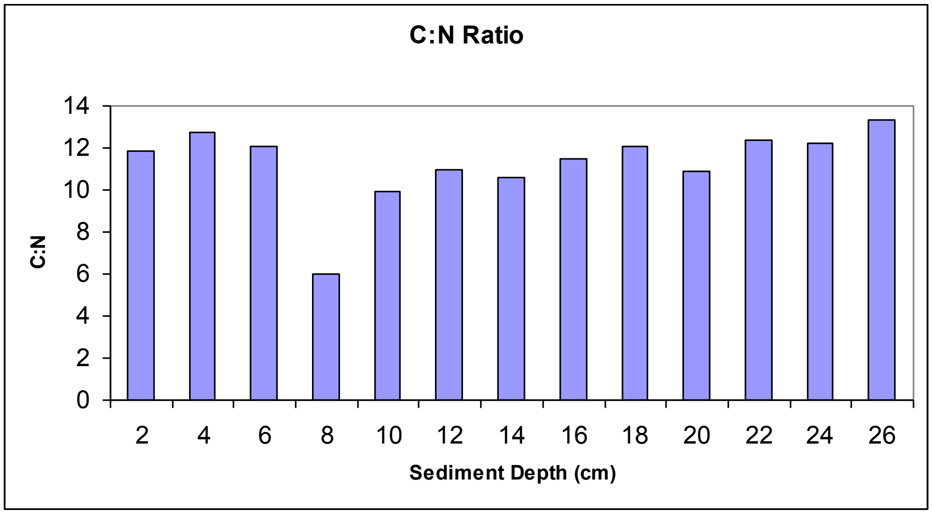


Figure 38b. Carbon to nitrogen ratios reflect high carbon content of sediments throughout the sediment profile.

Benthic Index

A comprehensive benthic assessment was conducted during the 2010-2011 winter, with samples collected from 8 sites around the lagoon (4 replicates of .0007m^2 cores to 5 cm depth). Samples were sorted in the Hechinger lab and identified to the extent possible (Figure 39). The data were analyzed using the Index of Benthic Integrity (IBI), the Relative Benthic Integrity (RBI) and the Benthic Response Index (BRI). All of the calculations indicated that the Campus Lagoon is a highly disturbed environment. Interestingly, there were many samples with shell and mollusk fragments but no live organisms. This suggests that the lagoon once hosted an array of mollusks, which are generally an indicator of higher water quality. The high concentration of polychaete and oligochaete worms further suggests that the system is highly impacted. This is supported by the low DO levels, high metal concentrations, and a recent study of sediments that found extremely high sulfide concentrations, further reflecting the low oxygen environment in the sediments.

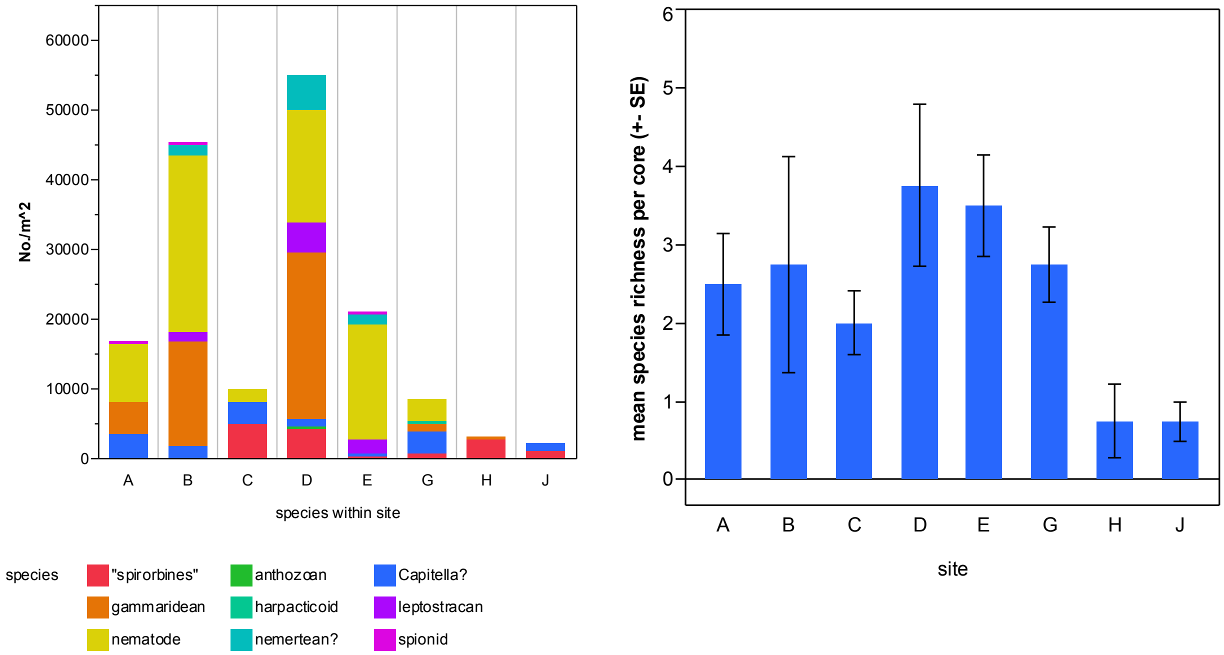


Figure 39. Species distribution, scaled to 1 meter squared, and species richness by site (n=4).

Sulfide levels

Using devices called “peepers”, we sampled lagoon sediment pore water in April 2011 in order to develop a better understanding of the chemical activity within the sediments. Following the protocols described in the SCCWRP report (Eutrophication and Nutrient Cycling in Famosa Slough: a summary of Baseline Data, 2010), we determined that sulfide levels ranged from 6.7 uM to 5,800 uM. Sediment odors were strongly sulfidic (rotten egg smell), indicating that bacteria had switched to using sulfur instead of oxygen in their reactions due to low to non-existent oxygen levels. The floccy, organic sediment depths were, in places, over 2 feet deep, suggesting a very slow decomposition rate and lack of flushing of organic material.

Stratification

Lagoon temperatures are sampled continuously at three depths (surface, 1 meter and bottom) in the three main arms of the lagoon as well as in the shallow areas (< 30 cm) along the shore. These data indicate that temperature-driven stratification appears to happen only occasionally in the warm summer months. However, data on salinity from the dissolved oxygen sampling regime reveal a strong salinity-driven stratification (Figures 40 and 41). The fresh water perches on top of the heavier, saline water, which reduces circulation within the lagoon and contributes to eutrophication at depth and poor environmental conditions for benthic organisms.

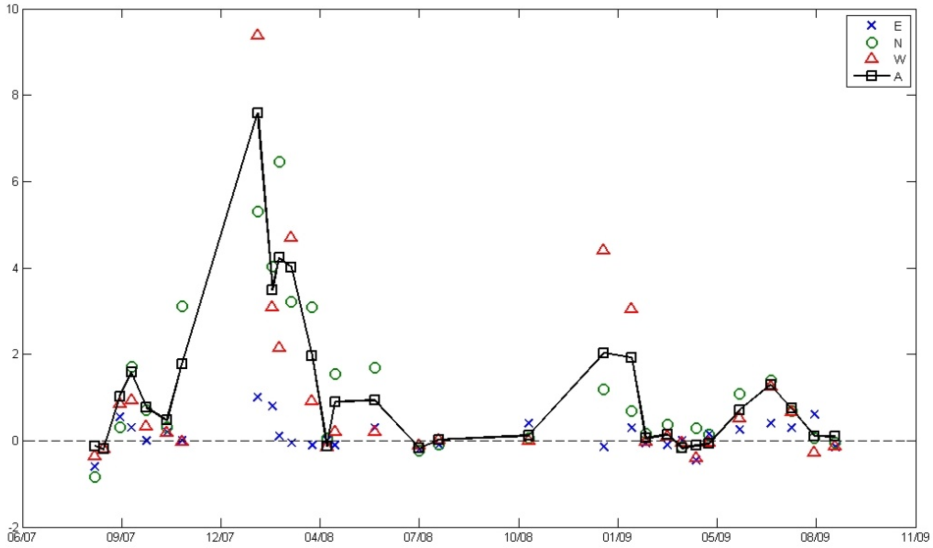


Figure 40. Depicted is the salinity stratification (difference in salinity between the surface and bottom samples) over two years from the dissolved oxygen sampling in the three arms of the lagoon indicating that stratification is strongest in the winter when fresh water enters the lagoon, and most reduced in the summer and fall.

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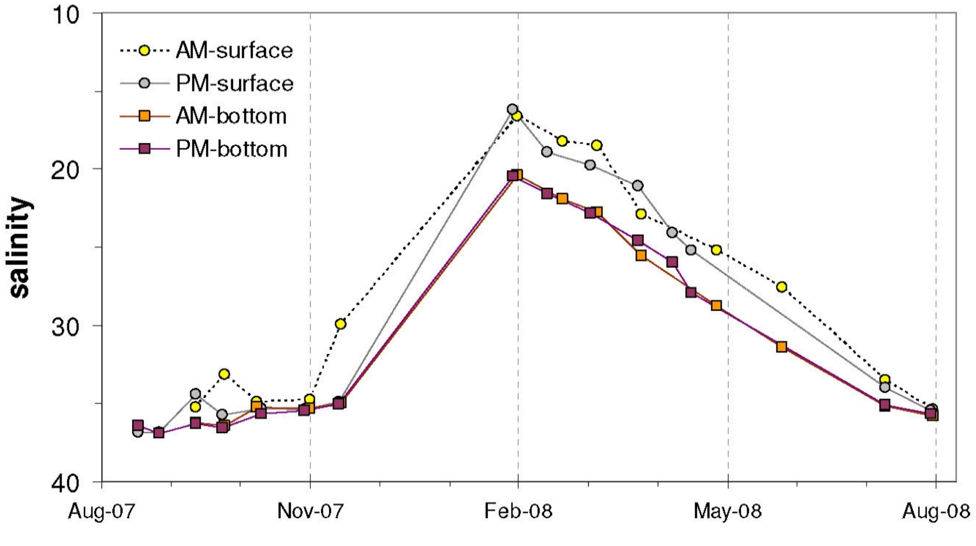

Figure 41. This figure further shows that salinity stratification of about 5ppt between the bottom and surface of the lagoon can occur from December to August.

The stratification also has the effect of keeping the sulfide-smelling sediment processes suppressed beneath the surface water which may be beneficial to people, but not to organisms on the lagoon bottom.

Bioswales

The primary problem facing the lagoon is the ongoing inputs of high nutrient concentrations from the storm drains during both dry and wet seasons (e.g. figure 15 and 29) These nutrients support the growth of phytoplankton, *Ruppia maritima* (submerged aquatic vegetation) and large blooms of macro algae such as *Enteromorpha intestinalis*. CCBER has been overseeing the management of the bioswales at Manzanita as well as the storm water management system at San Clemente. A water quality experiment was run several times in the Manzanita bioswales, and indicates that bioswales can play an important role in reducing nitrogen runoff in the dry and wet season (Figure 42a & b).

In this experiment, which was replicated several times, reclaimed water was used to fill the small pools in the bioswales until the point of overflowing on June 3, 2009 (5,950 gallons). Water was sampled in the six pools along the bioswales daily until they dried and no water was available. The results are the mean of six samples per day (figure 42a and b). Using nutrient-rich reclaimed water reflects the likely nutrient levels of irrigation water as well as first flush events from roofs that have received nitrogen deposition from the air or from bird guano. This experiment demonstrated two important benefits that bioswales provide. The first is that over 5,950 gallons of water could be absorbed by the 160 x 4 ft. swale without run-off. This reflects its ability to handle a 5/8ths inch storm event within the watershed (16,000 sf, 1/3 acre), which is close to the 85th percentile storm event in Santa Barbara County of ¾ of an inch. Thus, in many cases, little to no run-off would be produced from the watershed serving that bioswale from low flow or small storm events. This would significantly reduce nutrient rich inputs to the lagoon if more stormwater could be flowed through bioswales from campus and conserving the rainwater would reduce irrigation needs on campus.

The second major observation is that the most problematic nutrient, nitrogen, is significantly diminished by the biologic processes that occur in bioswales (Figure 42a and 42b). Ammonium (NH4) is converted by bacteria to inorganic Nitrate and then Nitrite, which can be taken up by plants or denitrified into the air. The NH4 levels in figure 42a drop over time and the $NO_3/0_4$ levels peak and then drop precipitously over time in figure 42b. This process is clearly indicated from the time-sequence figures below. Furthermore, the bioswales dry out within five days, which means they don't hold water long enough to support mosquito life cycles.

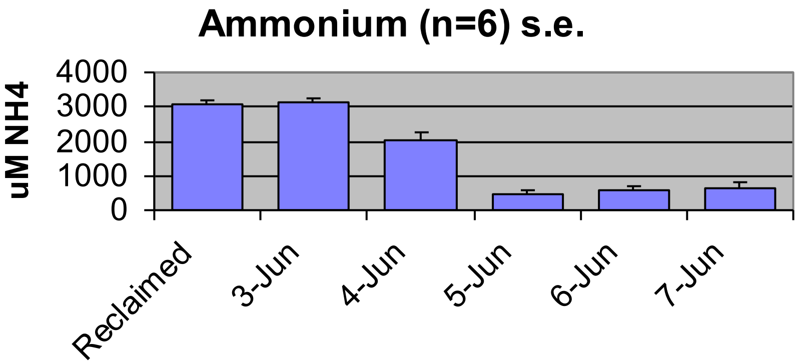

Figure 42a. Ammonium concentration over time in bioswale pools, June 2009.

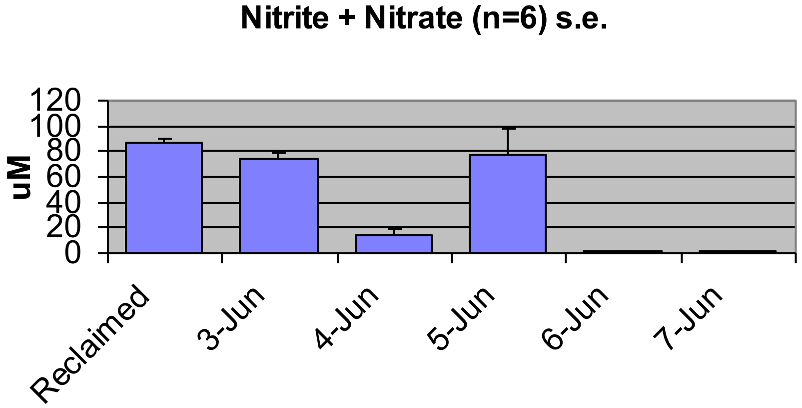

Figure 42b. Nitrogen (Nitrite+Nitrate) concentration over time in bioswales pools, June 2009.

In addition, UCSB recently constructed a treatment wetland called San Nicolas wetland. Samples from a recent study of that wetland demonstrate a significant reduction in nutrients leaving the system relative to those entering from the storm drain (Figure 43). The San Nicolas treatment wetland was constructed in fall 2010 and planted during the winter and spring of 2010-11. In May, 2011, a series of five dry season samples were collected from the two storm drains which enter the pool (DLG watershed and the 50 Acre watershed). The 50-acre watershed is the one that entered the lagoon through the storm drain named the "UCEN" drain in earlier figures. This storm drain was re-directed to this site as part of phase 1A of the infrastructure project. In addition, water was collected from within the pool itself (San Nic Pool) and from the outfall of the pool where it enters a small stream (San Nic Outfall), and then just before it enters the lagoon after the water has traversed the stream and been filtered through the wetland vegetation and willow woodland (Outfall to Lagoon).

This system has an approximate capacity of 1800 cubic feet, or 13,464 gallons, and a dry season flow rate of 12-15 gallons per minute. This means that water has a residence time of approximately 18 hours in the pool and another short period of time in the creek and wetland before flowing into the lagoon. The nutrient levels in figure 43 show a significant decline, which makes a significant difference in lagoon nutrient inputs during the dry season. Results from the recent CCBER survey in winter 2015-2016 provide further evidence of the effectives of bioswales in reducing the flow of nutrients (e.g. nitrogen) as well as metals (e.g. copper) and oil and grease into the lagoon (see figures 15 and 33, and tables 4 and 7).

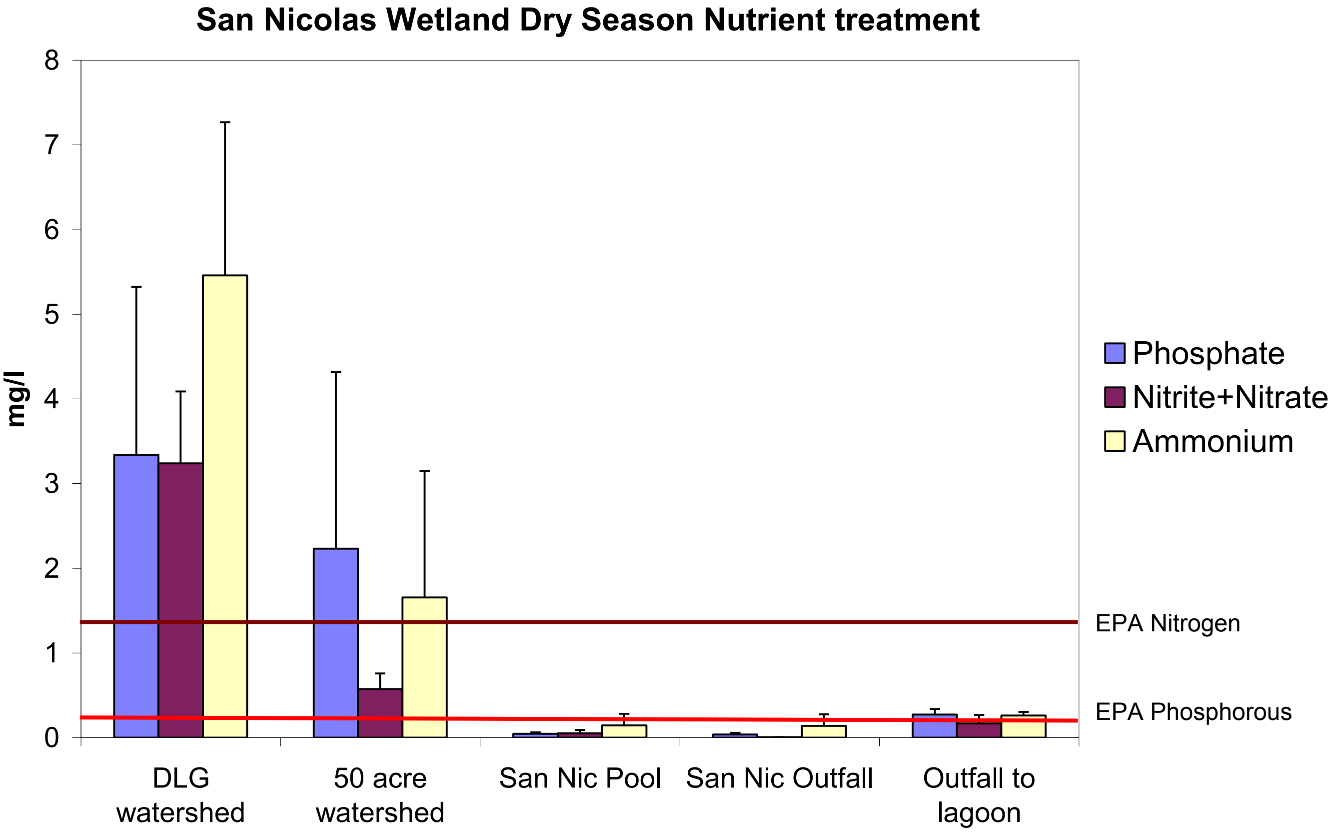

Figure 43. Shows steep decline in nutrients from the storm drains (left two) to the pool and outfalls. EPA Nitrogen and Phosphorous levels associated with algal blooms are shown as labeled lines.

Summary and Recommendations

All measures of lagoon water quality support the conclusion that the lagoon is an impaired water body suffering from the effects of excessive nutrient inputs and subsequent eutrophication (Table 10a and b). This process is reflected in the phytoplankton and algal blooms, and the seasonally and spatially low dissolved oxygen and depleted benthic fauna. In addition, concentrations of various metals, in particular copper, suggest that metal toxicity near storm drain outfalls may be a problem, combined with occasional high pH-triggered ammonia toxicity events, which serve to further impact benthic invertebrates and the food web as a whole. These issues combine with the density-based stratification to create sulfide-dominated sediment pore water due to a lack of oxygen availability and an abundance of organic matter decaying in the sediments. Results from the 2016 sampling confirms the results below in terms of an overall assessment of the state of the lagoon.

Table 10a. Campus Lagoon water quality status compared to indicators and cutpoint values used in water quality assessment (EPA 2004 and 2012).

Water Quality Indicators	**Poor Quality**	**Fair Quality**	**Good Quality**
Dissolved Oxygen (DO)	<2 mg/L	2-5 mg/L	>5 mg/L
Lagoon DO	*Bottom 50 cm year round.*	*Full water profile seasonally in this range (April-Sept)*	*Surface waters in the winter*
Nitrogen	>1.0 mg/L	0.5-1.0 mg/L	<0.5 mg/L
Storm drain Nitrogen	*Dry season runoff frequently exceeds*	*Majority of storm events generate levels in this range*	
Lagoon Nitrogen			*Generally within the lagoon, levels are reduced by algal growth*
Phosphorous	>0.1 mg/L	0.01-0.1 mg/L	<0.01 mg/L
Storm drain phosphorous	*Dry and wet season runoff greatly exceed*		
Lagoon phosphorous		*Frequently within moderate range*	
Chlorophyll *a*	>20 ug/l	5.0-20 ug/l	< 5.0 ug/l
Lagoon Chl. a	*Seasonally, far exceed these levels*		*Can be in this range depending on annual variation in conditions*
Water Clarity (% light penetration to 1 m)	< 10%	10-20%	>20%
Lagoon water clarity	*Mean of 9.6%*		*Occasionally above 20%*

Table 10b. Campus Lagoon sediment quality status compared to indicators and cutpoint values used in water quality assessment (NOAA 2006).

Sediment Quality Indicators	**Low Quality**	**Moderate Quality**	**High Quality**
Total Organic Carbon	>5%	2-5%	<2%
Lagoon organic carbon	*Top 6 cm of sediments 6-10 %*	*6-26 cm depth have these levels.*	
Sediment Contamination	1 or more contaminants exceed Effects Range Median (ERM)	5 or more contaminants exceed Effects Range Low (None exceed ERM)	< 5 contaminants exceed Effects Range Low (ERL)
Lagoon sediment contamination			*While only 4 metals exceed ERL, the concentrations were surprisingly high.*
% of Expected Species Richness Normalized for Salinity	<75%	75-90%	>90%
Lagoon Benthic Indices	*IBI, RBI, BRI all indicate a highly disturbed system*		

The proposed addition of 18% more watershed area to the lagoon will correlate to an absolute increase in pounds of nutrients and metals entering the lagoon, unless these waters are first filtered through a system of bioswales, which is our highest recommendation. This synthesis study suggests that re-suspended nutrients from the sediments may also contribute to nutrient problems in the lagoon. The benthic nutrients derived from decomposing organic matter could be reduced through three different strategies: 1) draining and removing the accumulated organic sediments, 2) initiating a regular program of removing large, floating, macro algal blooms in the late summer and early fall before they die and sink to the bottom, 3) addressing the high levels of nutrients entering the storm drains (see figures 15, 16, 27 and 29) by converting lawns to more drought tolerant vegetation that requires little to no fertilization and irrigation, 4) installing more energy diffusion boxes to reduce disturbance of sediments where storm drains enter the lagoon, in particular the Art Building and the Faculty Club (CDS) drains. The benefits of removing the floating algal blooms are that, once it is dry, it decomposes to very small volumes while effectively removing significant nutrients from the system and improving lagoon aesthetics. In a study CCBER participated in with SCCWRP comparing eutrophication in estuaries and lagoons in the southern California bight, the preliminary results from the Campus Lagoon reflect consistently higher biomass and cover of macroalgae and *Ruppia maritima* than any of the other 20 lagoons (McLaughlin et al. 2012). Phytoplankton levels were comparable to other lagoons in the study.

Proposed increases in seawater flow to the lagoon associated with redirecting seawater flows off the bluff, will likely improve water quality overall since seawater is lower in nutrients than storm water and acts as a diluting and circulation force during the dry season. Several additional measures could be taken to improve circulation and potentially reduce stratification in the lagoon, including creating larger openings in the side of the west weir that could occasionally be opened to lower the lagoon level by 6-10 inches. The combination of a rapid outflow of water would help reduce mussel growth in the outfall pipe and could potentially be timed to release nutrient rich water and allow refilling with sea water. The occasional exposure of the lagoon shore would increase oxygen availability to the shallow areas and may reduce sulfide (rotten egg) smells near the UCEN and Pearl Chase Park, where they can be strong. At 800 gpm, it would take nine days to raise the lagoon water level by 1 foot (31 acre feet = 10,101,394 gal).

In addition, establishing cooperative actions under EH&S with campus building managers (i.e. in the Art Building) and improving filtration off roadways for heavy metals would substantially improve the state of the lagoon. Implementing these strategies in combination with support for a regular water quality monitoring program, including a multi-sensor YSI data sonde (~ $14,000), and storm water sample processing will help determine triggers for more extensive measures to improve water quality in the lagoon.

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Water Quality of Campus Storm Drain Runoff. 2008a. CCBER (Nate Simons)

Appendix 1 - Ammonia Toxicity Table

From the table below, the un-ionized ammonia (N of NH3) levels which exceed the Chronic (lower) criterion (0.035 mg/L) are highlighted in yellow. These values occur when the lagoon is more basic (pH >= 9.2) and at the higher levels of ammonium (NH4) (0.27 and 0.5 mg/L) characteristic of storm water flows from the storm drains. Levels within the lagoon and at the lagoon outfalls are generally an order of magnitude lower and do not pose risks of toxicity to aquatic life. Thus conditions out the storm drain outfalls can be toxic at certain pH values.

Temp (C)	**Measured pH (NBS)**	**Working pH**	**Total Ammonia Nitrogen (mg/L)**	**Salinity (g/kg)**	**Ionic Strength (M)**	**pKa (infinite dilution)**	**pKa (SW)**	**Mole Fraction**	**Un-ionized Ammonia-N (mg/L)**
0.00	7	6.84	0.00	35	0.723	10.084	10.20	.00044	.00000
15.00	8	7.84	0.02	35	0.723	9.564	9.67	.01463	.00029
15.00	8	7.84	0.80	35	0.723	9.564	9.67	.01463	.01170
15.00	8	7.84	0.27	35	0.723	9.564	9.67	.01463	.00395
15.00	8	7.84	0.50	35	0.723	9.564	9.67	.01463	.00731
15.00	8.5	8.34	0.02	35	0.723	9.564	9.67	.04484	.00090
15.00	8.5	8.34	0.08	35	0.723	9.564	9.67	.04484	.00359
15.00	8.5	8.34	0.27	35	0.723	9.564	9.67	.04484	.01211
15.00	8.5	8.34	0.50	35	0.723	9.564	9.67	.04484	.02242
15.00	9.2	9.04	0.02	35	0.723	9.564	9.67	.19046	.00381
15.00	9.2	9.04	0.08	35	0.723	9.564	9.67	.19046	.01524
15.00	9.2	9.04	0.27	35	0.723	9.564	9.67	.19046	.05143
15.00	9.2	9.04	0.50	35	0.723	9.564	9.67	.19046	.09523
20.00	8	7.84	0.02	35	0.723	9.403	9.51	.02114	.00042
20.00	8	7.84	0.08	35	0.723	9.403	9.51	.02114	.00169
20.00	8	7.84	0.27	35	0.723	9.403	9.51	.02114	.00571
20.00	8	7.84	0.50	35	0.723	9.403	9.51	.02114	.01057
20.00	8.5	8.34	0.02	35	0.723	9.403	9.51	.06392	.00128
20.00	8.5	8.34	0.08	35	0.723	9.403	9.51	.06392	.00511
20.00	8.5	8.34	0.27	35	0.723	9.403	9.51	.06392	.01726
20.00	8.5	8.34	0.50	35	0.723	9.403	9.51	.06392	.03196
20.00	9.2	9.04	0.02	35	0.723	9.403	9.51	.25496	.00510
20.00	9.2	9.04	0.08	35	0.723	9.403	9.51	.25496	.02040
20.00	9.2	9.04	0.27	35	0.723	9.403	9.51	.25496	.06884
20.00	9.2	9.04	0.50	35	0.723	9.403	9.51	.25496	.12748
22.00	8	7.84	0.02	35	0.723	9.339	9.45	.02439	.00049

Temp (C)	Measured pH (NBS)	Working pH	Total Ammonia Nitrogen (mg/L)	Salinity (g/kg)	Ionic Strength (M)	pKa (infinite dilution)	pKa (SW)	Mole Fraction	Un-ionized Ammonia-N (mg/L)
22.00	8	7.84	0.08	35	0.723	9.339	9.45	.02439	.00195
22.00	8	7.84	0.27	35	0.723	9.339	9.45	.02439	.00658
22.00	8	7.84	0.50	35	0.723	9.339	9.45	.02439	.01219
22.00	8.5	8.34	0.02	35	0.723	9.339	9.45	.07325	.00147
22.00	8.5	8.34	0.08	35	0.723	9.339	9.45	.07325	.00586
22.00	8.5	8.34	0.27	35	0.723	9.339	9.45	.07325	.01978
22.00	8.5	8.34	0.50	35	0.723	9.339	9.45	.07325	.03663
22.00	9.2	9.04	0.02	35	0.723	9.339	9.45	.28374	.00567
22.00	9.2	9.04	0.08	35	0.723	9.339	9.45	.28374	.02270
22.00	9.2	9.04	0.27	35	0.723	9.339	9.45	.28374	.07661
22.00	9.2	9.04	0.50	35	0.723	9.339	9.45	.28374	.14187

Appendix 2 – CCBER 2016 Survey Data

Table A. Concentration (milligrams per liter) of oil and grease in water collected from baseline ("dry" season) and storm water ("wet" season) flows at eight sites for a CCBER survey of Campus Lagoon water quality. Water samples were collected between December 13, 2015 to January 31, 2016. Three sample locations are from storm drains that currently flow over the East Bluffs (EB). "Baseline" samples were not able to be collected at some locations as there was no flow or very low flow. ND = Not Detected.

Site Name	Sampling Date	Sampling Time	Sampling Type	Oil & Grease Concentration (mg/L)
East - Elings Hall	1/5/2016	5:55	Storm Water	ND
East - Elings Hall	1/6/2016	10:10	Storm Water	ND
East - Elings Hall	1/31/2016	11:20	Storm Water	4.50
East - Sea Water	12/13/2015	11:45	Baseline	2.23
East - Sea Water	1/29/2016	14:00	Baseline	ND
East - Sea Water	1/5/2016	6:15	Storm Water	ND
East - Sea Water	1/6/2016	10:18	Storm Water	1.76
East - Sea Water	1/31/2016	11:30	Storm Water	3.78
East – Beach Stairs	1/5/2016	10:50	Storm Water	3.74
East – Beach Stairs	1/6/2016	10:30	Storm Water	2.25
East – Beach Stairs	1/31/2016	11:40	Storm Water	4.13
San Nicolas Infall	12/13/2015	12:30	Baseline	ND
San Nicolas Infall	1/29/2016	14:15	Baseline	2.14
San Nicolas Infall	1/5/2016	6:45	Storm Water	ND
San Nicolas Infall	1/6/2016	10:45	Storm Water	ND
San Nicolas Infall	1/31/2016	11:50	Storm Water	4.78
San Nicolas Outfall	12/13/2015	12:45	Baseline	ND
San Nicolas Outfall	1/5/2016	6:50	Storm Water	1.65
San Nicolas Outfall	1/6/2016	10:47	Storm Water	2.14
San Nicolas Outfall	1/31/2016	11:55	Storm Water	4.29
Art Storm Drain	1/5/2016	7:05	Storm Water	ND
Art Storm Drain	1/6/2016	9:45	Storm Water	2.86
Art Storm Drain	1/31/2016	12:05	Storm Water	5.00
Faculty Club Storm Drain	1/5/2016	7:30	Storm Water	ND
Faculty Club Storm Drain	1/6/2016	9:25	Storm Water	2.47
Faculty Club Storm Drain	1/31/2016	12:30	Storm Water	4.23
West Lagoon Outfall	12/13/2015	14:10	Baseline	3.97
West Lagoon Outfall	1/29/2016	14:35	Baseline	3.72
West Lagoon Outfall	1/5/2016	7:45	Storm Water	2.03
West Lagoon Outfall	1/6/2016	9:05	Storm Water	2.14
West Lagoon Outfall	1/31/2016	12:16	Storm Water	3.72

Table B. Concentration (micrograms per liter) of metals (Copper – Cu, Lead – Pb, and Nickel – Ni) in water collected from baseline (“dry” season) and storm water (“wet” season) flows at eight sites for a CCBER survey of Campus Lagoon water quality. Water samples were collected between December 13, 2015 to January 31, 2016. Three sample locations are from storm drains that currently flow over the East Bluffs (EB). “Baseline” samples were not able to be collected at some locations as there was no flow or very low flow. ND = Not Detected.

Site Name	Sampling Date	Sampling Time	Sampling Type	Cu (ug/L)	Pb (ug/L)	Ni (ug/L)
1. EB - Elings Hall	1/5/2016	5:55	Storm Water	25.10	1.000	3.65
1. EB - Elings Hall	1/6/2016	10:10	Storm Water	12.30	ND	3.80
1. EB - Elings Hall	1/31/2016	11:20	Storm Water	6.37	ND	ND
2. EB - Sea Water	12/13/2015	11:45	Baseline	ND	ND	ND
2. EB - Sea Water	1/29/2016	14:00	Baseline	ND	6.560	ND
2. EB - Sea Water	1/5/2016	6:15	Storm Water	17.30	ND	2.83
2. EB - Sea Water	1/6/2016	10:18	Storm Water	17.80	ND	ND
2. EB - Sea Water	1/31/2016	11:30	Storm Water	7.52	ND	ND
3. EB – Beach Stairs	1/5/2016	10:50	Storm Water	16.50	1.090	23.80
3. EB – Beach Stairs	1/6/2016	10:30	Storm Water	18.00	ND	10.90
3. EB – Beach Stairs	1/31/2016	11:40	Storm Water	10.20	ND	8.57
4. San Nicolas Infall	12/13/2015	12:30	Baseline	5.66	ND	8.37
4. San Nicolas Infall	1/29/2016	14:15	Baseline	1.98	5.560	11.50
4. San Nicolas Infall	1/5/2016	6:45	Storm Water	31.60	5.180	2.57
4. San Nicolas Infall	1/6/2016	10:45	Storm Water	20.10	ND	3.18
4. San Nicolas Infall	1/31/2016	11:50	Storm Water	18.10	ND	3.65
5. San Nicolas Outfall	12/13/2015	12:45	Baseline	1.19	ND	7.44
5. San Nicolas Outfall	1/5/2016	6:50	Storm Water	25.10	ND	3.60
5. San Nicolas Outfall	1/6/2016	10:47	Storm Water	13.40	2.120	2.49
5. San Nicolas Outfall	1/31/2016	11:55	Storm Water	11.50	ND	ND
6. Art Storm Drain	1/29/2016	14:55	Baseline	9.88	ND	43.50
6. Art Storm Drain	1/5/2016	7:05	Storm Water	21.30	ND	3.79
6. Art Storm Drain	1/6/2016	9:45	Storm Water	22.90	6.970	9.89
6. Art Storm Drain	1/31/2016	12:05	Storm Water	21.00	ND	4.08
7. Faculty Club Storm Drain	1/5/2016	7:30	Storm Water	11.20	ND	4.70
7. Faculty Club Storm Drain	1/6/2016	9:25	Storm Water	19.80	8.770	11.20
7. Faculty Club Storm Drain	1/31/2016	12:30	Storm Water	7.89	ND	3.01
8. West Lagoon Outfall	12/13/2015	14:10	Baseline	ND	ND	ND
8. West Lagoon Outfall	1/29/2016	14:35	Baseline	ND	ND	ND
8. West Lagoon Outfall	1/5/2016	7:45	Storm Water	22.80	0.825	2.33
8. West Lagoon Outfall	1/6/2016	9:05	Storm Water	2.95	ND	5.89
8. West Lagoon Outfall	1/31/2016	12:16	Storm Water	ND	ND	ND