Effect of Urban Runoff on Water Quality Indicators in Ballona Creek, CA.

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Abstract

Urban runoff has the potential to dramatically affect water quality in high-density coastal urban regions. In this study, we define water quality as a function of trash, fecal indicator bacteria (FIB), and harmful algal bloom (HAB) concentrations. Thus far, no studies have investigated the effects of runoff on all three of these water quality indicators. This study fills that gap by comparing water quality in dry and wet weather at the mouth of Ballona Creek in Marina Del Rey, California. Additionally, we examine the mechanism through which urban runoff affects water quality by measurements of total suspended solids (TSS), nitrate concentrations, salinity, and temperature. All samples and measurements were gathered at three sites at the creek-ocean interface twice weekly from February to April 2011. We observed a significant correlation between FIB and wet weather (r = 0.88), HAB and wet weather (r = 0.89) but not between trash and precipitation. TSS, salinity, and nitrate concentrations were related to abundances of FIB and HAB; nitrate from runoff or upwelling seem to support HAB whereas TSS and FIB likely enter coastal waters in runoff. Our study shows that rainfall has a negative effect on the health of Ballona Creek waters, where FIB will accumulate and persist within the creek for days after a rain event. There is not a consistent spatial pattern in all variables amongst the three sites; the furthest upstream site was more influenced by runoff whereas the further downstream sites were influenced by upwelled waters. Understanding the factors that affect coastal water quality are crucial as this has economic, ecological, and health implications for other similar geographic areas.

Introduction

More than 50 million annual beachgoers visit the Santa Monica Bay's beaches, helping to support a regional tourism industry of $10 billion each year (Dojiri et al. 2003). Due to urbanization and industrial development over the past sixty years, mass emissions of pollutants and anthropogenic wastes have been washing into the Santa Monica Bay, causing hundreds of beach closures and water quality warnings (Schiff et al. 2003). Santa Monica Bay stretches from Point Dume in Malibu to Palos Verdes in the south and is home to millions of people who share the coastal waters with the marine ecosystem.

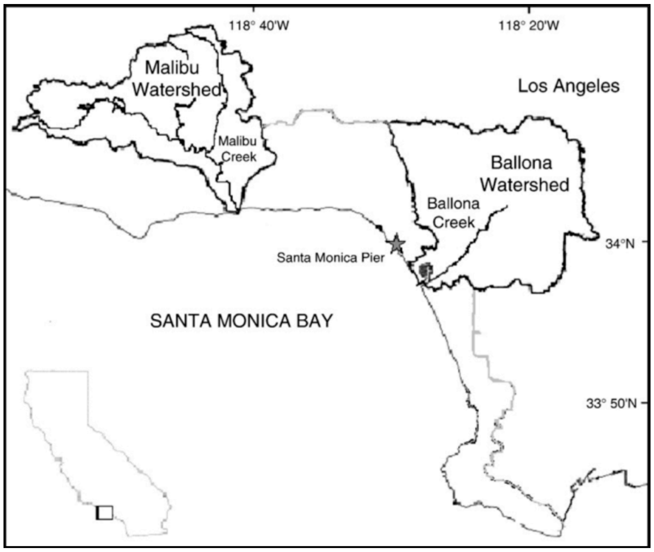

Figure 1: Santa Monica Watershed sampling locations are at the intersection of the Ballona Creek and Ocean. (Figure from Corcoran et al, 2010)

Once the Clean Water Act was revised in 1972 , regulation began to treat point source pollution. Non-point sources became the primary contribution to anthropogenic water pollution in the Santa Monica Bay. Metals, organic compounds, fertilizers, human and animal waste, and debris all move through a series of channels towards the ocean. Studies have evaluated the sources of the pollutants, their pathways, and their impacts on the Santa Monica Bay and its resources (Schiff et al. 2003 and Noble et al. 2003). Urban runoff has also been linked to harmful and unsafe conditions like algae blooms to the marine biota and has been shown to influence human health (Dojiri et al. 2003). Additionally, there are various studies linking urban runoff and fecal bacteria concentrations (Bay et al. 2003). The impervious surfaces of waterways leading to the ocean, such as the channelized Ballona Creek, pose the most damage to water quality when urban runoff and trash flow to the ocean. Watersheds with impervious surfaces lead to high volumes of discharged water and runoff due to a bypass of natural filtration. Especially during rainfall, large volumes of water, organic matter, inorganic nutrients, and trash flush through the channel amplifying the effect of urban runoff on beach water quality. More than half of the water quality failures in Santa Monica Bay have been associated with a rain event (Schiff et al. 2003).

Ballona Creek is one of the main watersheds in the Santa Monica Bay, and it covers 130 square miles of land of which 85% is industrial, commercial or residential communities (Corcoran et al. 2010). This urbanization began in 1920 when the County of Los Angeles began straightening the natural creek to protect the growing city from potential flood damage. The EPA has listed 64 bodies of water in the Los Angeles Basin impaired due to their concentrations of trace metals and bacteria under Section 303 of the Clean Water Act (Tiefenthaler et al. 2008). Ballona Creek is on the EPA 303d list of Impaired Waters and everything that ends up into the channel flows right into the Santa Monica Bay degrading the water quality in the surf zone (Tiefenthaler et al. 2008). Organizations such as Heal the Bay have monitored Santa Monica Bay water quality seasonally and the health risk to the marine ecosystem and swimmers. Our study utilized the previous knowledge acquired by Heal the Bay regarding urban runoff, and worked with students from Santa Monica High School to collect water samples from sites in Ballona Creek. We have discussed our study with Heal the Bay and our results will aid in further understanding of the effects of urban runoff on water quality.

Study Design

In this study, we define water quality as a function of trash abundance, FIB concentrations, and HAB presence. Additional secondary measures of water quality that will help to explain changes in those water quality indicators include TSS, salinity, temperature, upwelling index, and nitrate concentrations. In order to assess the effects of urban runoff, we compare these measures in dry and wet weather. We expect to see an increase in volume of trash, FIB, HAB, TSS, and nitrate concentrations after a rainfall event. We hypothesized there will be a larger volume of trash after a rainfall event as all the debris that have accumulated in the channel of Ballona Creek can be discharged into the ocean. High concentrations of TSS can block sunlight from penetrating into the water. As FIB is sunlight-inactivated, high TSS concentrations can provide an ideal growing environment allowing high bacteria concentrations (Ki et al. 2007). High nitrate concentrations can explain high HAB cell abundances, as nitrate is a major limiting nutrient for the microalgae. These two factors can interact as well: higher HAB concentrations mean that a lesser amount of sunlight is able to infiltrate through to the water and FIB concentrations are elevated for longer (Ki et al. 2007) Upwelling, the upward movement of deep, nutrient rich waters as a result of alongshore winds, can result in higher nutrient levels, therefore increasing HAB concentrations. Therefore, HAB and FIB concentrations should be highest closest to the runoff source or upwelling source. Although there have been many successful studies looking at the effects of runoff and rainfall on HAB and FIB concentrations separately, this is the first to address the relationships and interactions between all the parameters outlined above (Bay et al. 2003).

Literature Review

During the 1970’s, nonpoint source pollution, such as urban road runoff, became a prevalent issue of environmental pollution. In further studies, it became known as a primary contributor of poor water quality and a foremost anthropogenic pollution source (Dorchin 2010). Contamination makes healthy ecosystems susceptible to degradation and adversely affects human public health. Chemical analysis proves high pollutant concentrations in road's "firsts flush" or the initial burst of water immediately following a rain or storm (Dorchin, 2010). During rainy seasons, pollutants that have accumulated during dry seasons, are very likely to be introduced to the watershed in a mass flux. Furthermore, urban runoff during storm seasons possesses high-level concentrations of organic and inorganic nutrients. This flow has the ability to promote HAB growth, and results from a spatiotemporal plume analysis by Corcoran, Reifel, Jones and Shipe (2010), show immediate decreased salinity in near-shore water after a storm. This exhibits the relationship of freshwater runoff mixing with saline ocean-water. To evaluate the consequences of runoff, embryos and larvae of the green toad *Bufo viridis* were introduced to contaminated water and the growth of species was observed. Exposure of runoff and synthetic metals to toads and tadpoles led to delayed maturation and development of the species. However, the survival rate was not affected (Dorchin, 2010). Midseason runoff was linked to decreased development rates and higher morphological changes, proving that this runoff may in fact be more toxic than initial flux. The Santa Ana River provides yet another ideal environment to examine water quality effects of urban runoff. Here, FIB concentrations are within 500% of the accepted state standard (Ahn et al. 2005). With the "cross-shore" currents forcing mixture, the resultant contamination zone is within 5km of the effluent source. Though the nearby area of over 100km^2 from where the mouth of the creek meets the ocean is still highly concentrated with FIB, it remains under the state concentrations. Four rain events were observed in Santa Ana and results indicated low salinity concentrations after storm water discharge, further reinforcing the idea that freshwater dilutes salinity of ocenwater (Ahn et al. 2005). The study concluded that once the runoff was incorporated with the oceanic water of the Newport Bay, contaminants are dispersed along a parallel transect with the shoreline. Additionally, any contaminants, which were initially carried in the water, have a tendency to flow south, down the coast. Lastly, no relationship was evident between the urban runoff plume and concentration of fecal indicator bacteria. This indicates that either the runoff is quickly diluted by seawater and no longer provides ideal conditions for FIB growth (Ahn et al. 2005).

Urban Runoff and Bacteria

Governmental and environmental organizations use fecal bacteria concentrations as monitoring data to grade the water quality of specific beaches (Nobel et al. 2003). While these indicator fecal bacteria may not be pathogenic, studies have shown them to correlate with impaired water quality and the incident of illness in swimmers, specifically in the Santa Monica Bay (Haile et al. 1999). The most common indicators used today are total coliforms (TC), fecal coliforms (FC), and entercocci (ENT), which are used as surrogates for human pathogens to assess the health risk and quality of water (Evanson and Ambrose, 2006). The Santa Monica Bay beaches are among the most comprehensively monitored for bacterial water quality in the nation, with more than one-third of the sampling locations being monitored daily (Schiff et al. 2003). There are various studies monitoring fecal bacteria either at the source of storm drains, along a channel, the mouth of a plume dumping into the sea, or just along the shoreline of coastal waters.

Reeves et al. (2004) showed that fecal bacteria from urban runoff originates from the contamination in drainage channels and storm sewers. In the Huntington Beach site, there are already management practices to divert some of the urban runoff, such as forebays, where runoff accumulates until it exceeds a certain concentration and is pumped into a channel and travels to the ocean. Dry weather runoff is also diverted to sanitary sewer systems for treatment before being discharged into the ocean. Reeves' research was unique becuase it measured the concentration of fecal bacteria in the sub drains of the Talbert watershed before it hit the ocean. The four-year study found that the concentration of fecal bacteria in dry weather runoff had the highest concentration inland and lowest concentration at the coastal sites; the highest concentration runoff came from residential areas. During storm events, runoff flow rates increase, and diversions are not operating to catch some of the fecal bacteria that cause damage in the coastal water.

A study done by Dwight (2004) observed the discharge of three different rivers into the ocean: the Santa Ana River, San Gabriel River, and Los Angeles River. Each of these rivers contributes to the urban runoff pollution of the North Orange county beaches. During dry months, the mean bacteria concentrations across all sites dropped substantially. Dwight found that, following precipitation events, a plume of pollution registered as a pulse of indicator bacteria at beaches next to rivers. Over the course of time and distance, the concentrations of bacteria decreased by means of dilution and degradation while being transported through currents (2004). The closing of the Huntington Beach in 1999 was due to the precipitation events leading to large amounts of urban discharge creating turbid waters and high bacteria concentrations. The beaches near the three rivers are popular recreation locations, such as Newport and Huntington Beach, and these showed much higher total coliform concentrations compared to the other sites.

The health risk posed by exposure to fecal pollution in the surf zone depends on the relative proportion of total coliform and fecal coliform in the water, and high concentrations of FIB can increase the risk of developing gastroenteritis (Haile et al. 1999). One of the first studies to investigate health threats from urban runoff was conducted in Santa Monica Bay in 1996. During dry summer months at three storm drains, which received runoff from relatively small watersheds, swimmers near these drains were significantly more likely to become ill than those who swam farther away (Haile et al. 1999). The critical piece of this study was that it showed a strong association with precipitation directly influencing water quality and public health due to large concentrations of bacteria found in wet months.

Another study highlighted how storm water runoff altered the physical and chemical properties of the water quality in Santa Monica Bay for at least several days after a rain event. During storm events, concentration of TC, FC, and ENT surpassed state standards by as much as 300-500% (Ahn et al. 2005). Additionally, a study done by Schiff measured TC, ENT, and FC at 59 sites within the Santa Monica Bay (2003). The study analyzed rainfall data, collected over a period of five years by the National Weather Service to segregate samples into wet and dry weather categories. The analysis focused on how many days the water quality thresholds had been exceeded and how wet and dry weather had attributed to the bacteria concentrations found. Schiff and his team found that Santa Monica Bay exceeded water quality thresholds 13% of the days over the five-year period. Of that, 53% of these days occurred near storm drains and urbanized channels. During wet weather, the water quality thresholds were breached due to a high concentration of fecal bacteria. Ballona Creek, in particular, with only two other storm drains doing worse, had one of the highest percentages of shoreline mile-days exceeding water quality thresholds during wet weather.

A majority of these studies measure the fecal bacteria concentrations to a certain water quality standard – they focus on the sources of bacteria, dispersion rates, and other environmental variables affecting bacteria and the various effects on water quality. As stated before, these bacteria indicators are a weak indicator of water quality in the sense of health risk. Fecal coliform and total coliform are no longer recommended by the Environmental Protection Agency (EPA) as an indicator of water quality in recreational waters. ENT and E. coli are suggested instead. By measuring ENT concentrations in accordance with EPA standards, our study hopes to give a better understanding of water quality.

Urban Runoff and Harmful Algal Blooms

Though there has been extensive work done on runoff constituents such as nitrate and harmful algal bloom development, knowledge regarding the effects of runoff on the development of HAB is minimal. General studies have shown that low concentrations, cyanobacteria and phytoplankton pose no environmental or public health hazard. However, these organisms can contribute to poor water quality by toxin production or accumulated biomass, thus affecting oxygen content, turbidity. These factors set up ideal conditions for growth of harmful algal blooms (Ryan, 2009). To establish a connection between urban runoff and harmful algal blooms, we examined patterns of HAB's and their association with urban runoff during storms and dry weather. The algal blooms also follow the patterns of a salinity gradient created by freshwater runoff into the bay. An illustration seen in Shipe 2010, establishes the relationships between runoff flow and dispersion, changes in volume of runoff and changes in HAB concentrations.

Environmental Controls of Water Quality

Nitrate concentrations, TSS, salinity, and temperature recordings are useful variables that may help to understand periods of poor water quality in this study. High concentrations of nitrate, can promote growth of algal blooms. Algae are primary producers and are vital to sustaining a marine ecosystem; however, at high concentrations, they can lead to red tides or dead zones that can degrade the marine ecosystem. Nitrate is a naturally occurring chemical, but runoff can lead to excess concentrations of nitrate in the coastal waters.

TSS constitutes solid materials, either organic or inorganic, that are suspended in the water. At high concentrations, these solids can block sunlight penetration into the water. This light attenuation can disrupt phytoplankton production or the regulation of physical and biological processes in aquatic systems by irregular vertical mixing (Novo et al. 1991). Salinity influences the type of organisms that can live in that water body, but in this study it is useful as an indicator of freshwater runoff or open ocean conditions. Urban runoff can also affect temperature because of thermal pollution; normally, the warmer runoff plume resulting from flow through parking lots, streets, and sidewalks enters the cooler ocean. It impacts both the physical and biological characteristics of surface waters; more importantly, it affects the photosynthesis of aquatic plants, metabolic rates of aquatic organism, and their vulnerability to pollution or diseases.

Methodology

We have chosen to observe and evaluate three sites in Ballona Creek by measuring our water quality indicators, FIB and HAB and the mechanism by which they are affected, nitrate, TSS, salinity, and temperature. The first site is located on the bridge, which spans the creek, and is closest to the source of runoff. The second site is located on the halfway point of the South Jetty on the southern side where the water from the creek is not yet in direct contact with the water from the beach. Due to the current flowing south and the jetty providing a barrier to the sampling site, we expected to see a dilution of runoff as it mixes with the ocean water. Lastly, site 3, on the western tip of the jetty, will provide insight to contaminated water as it exits the Ballona channel directly mixing with open-ocean seawater.

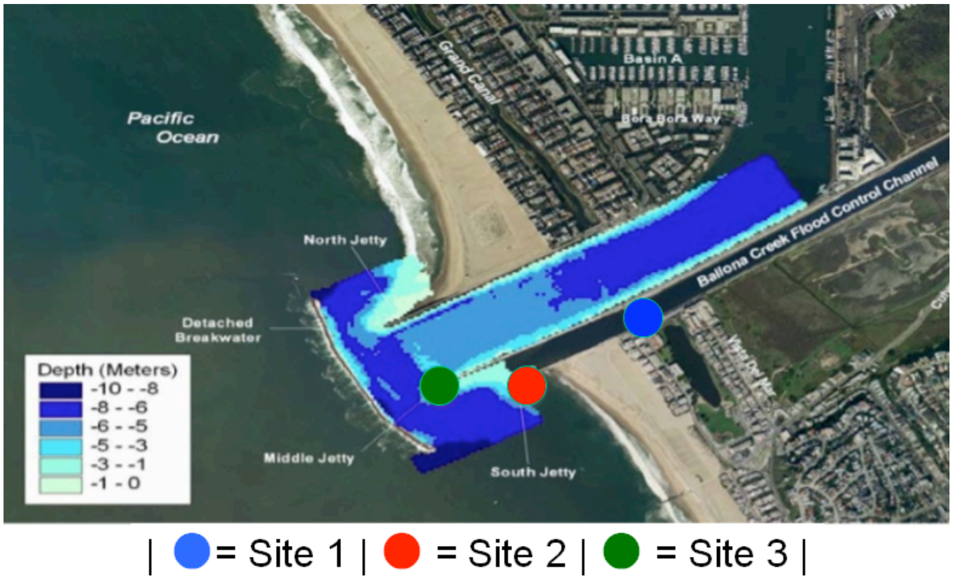

Figure 2: Ballona Creek Sampling Site Locations (U.S. Army Corps of Engineers, Los Angeles District Jan 2003)

We sampled twice a week in the early morning and also within 24 hours of rainfall from 17-February to 5-April. At each site, we collected 1.2 liters of near surface water in jugs. 1L of water, from each site, returned with us to the Shipe Lab at UCLA while the remaining 20ml, in three small vials (one for each site), was given to the students of Santa Monica High School. Next, we employed a series of tests to quantify the three major indicators of water quality, and the additional variables helped to explain changes in the water quality.

To assess FIB, Santa Monica High School students tested for ENT concentrations. The students incubated the samples with nutrients and a protein, which fluoresces during bacteria growth (Grant 2005). They then incubated samples of water for a period of 24 hours. After this time, bacteria growth was quantified using a UV light. Results were reported in units of most probable units per liter (MPN l-1) of seawater.

For HAB analysis, samples were gravity filtered on a 5-micrometer polycarbonate filter. After completion, the filter was preserved in 10ml of filtered seawater along with 1ml of formalin. The container was then lightly shaken and inverted to allow the cells to remove from the filter. 1 ml of the 11ml within the container was pipetted onto a Sedgewick-Rafter counting chamber. The cells were identified and quantified using light microscopy. At least 100 were counted to properly calculate the concentration of the entire sample. If there are less than 100 in one transect, another transect was counted until a minimum of 100 was attained. Replicate counts were made to determine variability in the method.

During one of our initial visits to Ballona Creek, our group members observed a high volume of trash accumulating along the jetty near the bridge (site 1). Because the trash accumulates between the interfaces where the water meets the rocks, we were unable to collect the specific samples of trash and therefore, took pictures of a pre-determined $1m^2$ area along the jetty that was qualitatively analyzed as part of our results section. Runoff from storm drains and street sewage adds to the majority of this trash.

To quantify the concentration of the trash and evaluate effects of dry and wet weather, we sectioned off two pieces of land approximately in 1m^2 plots along the shoreline. Our method for choosing the specific plot of land was determined by choosing a random number below 200 and walking that many steps from the jetty. The area where we collected the trash in a 1m^2 area along the beach is located in between the "wrack line," the highest point where the ocean water washes up on shore. All the trash in this area was picked up, cleaned, and classified into one of six categories - paper, plastic, metal, rubber, Styrofoam, and glass. The trash in each category was then weighed to evaluate if any particular type of trash is associated with runoff.

A gravimetric measurement of TSS was made with water samples at all three sites. 250ml of water, from each sample was vacuum filtered on a 0.6-micrometer polyvinyl chloride filter. The remaining solids were heated around 60° C for adequate removal of water and weighed. Remaining solids represent the concentration of TSS, which can be represented in mg/L by [((final weight - initial weight)/Volume of sample) x 1,000,000]. Methods used for TSS can be found in *Standard Methods of the Examination for Water and Wastewater.*

Nitrate concentrations were gauged by filtering seawater through a 0.6-micrometer filter using a syringe. This dissolved seawater was analyzed using a Nitrogen-Nitrate Reagent set. This involved using chromotopic acid, heat and measuring absorbance in a spectrophotometer. To ensure accuracy and precision, these samples were tested along with a standard sample of known concentration.

This study analyzes relative salinity values through the use of a hand-held refractometer. Salinity measurements have an error of 5 ppt due to this device used. To evaluate the contrast between wet and dry weather indicator concentrations, we grouped three rain days and three dry days, and analyzed the wet weather HAB and FIB concentrations against the dry weather HAB and FIB concentrations.

Precipitation data was taken from the LA Department of Public Works website, (http://dpw.lacounty.gov/wrd/precip/). Data was reported in 1, 3, 6, 12, 24, 36, 48, and 72 hour durations during the span of our experiment. These values were then consolidated, giving us a total rainfall per day. To take into account a lag time in data collection, we used the sum of the 5 pervious days in accordance with the sample day. An Upwelling index was obtained from Pacific Fisheries Environmental Laboratory's website, (http://www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/NA/upwell_menu_NA.html) at 33°N 119°W. Considering that we would sample at 5:45AM, we opted to use the previous day's value.

To analyze our main objective, runoff effects on water quality indicators in wet and dry weather, we separated our sampling days into two categories. The cutoff to be considered a "wet day" was .8 cm of rain, and the rest of the sampling days below this measure, were considered to be "dry days". After separating the categories we had a total of 6 wet days and 8 dry days. After placing each sample date into their perspective categories, we calculated the mean FIB and HAB for wet weather and dry weather, and compared the results we found.

Results/Discussion

The three water quality indicators, FIB, HAB, and trash were examined in both wet and dry weather. First, we evaluated 2011 precipitation relative to previous years to assess whether 2011 was a particularly wet year. The mean for 2011 precipitation (2.5 cm) was noticeably higher than for 2010 (1.0 cm) or 2009 (.68 cm). Year-to-date precipitation data for 2009 was 8.13cm, 12.4 cm for 2010, and 17.3cm for 2011. Precipitation data for 2009 and 2010 was collected for January – September while it is only available until May for 2011; however, the year-to-date 2011 precipitation is higher than the other two years even with 5 fewer months of data. March was an especially rainy month in 2011 (4.04 cm) as compared to 2009 (.05 cm) and 2010 (.21cm). We observed a big rainfall event on 3/21, consistent with this precipitation data. It is clear that 2011 is a relatively wet year compared to previous years.

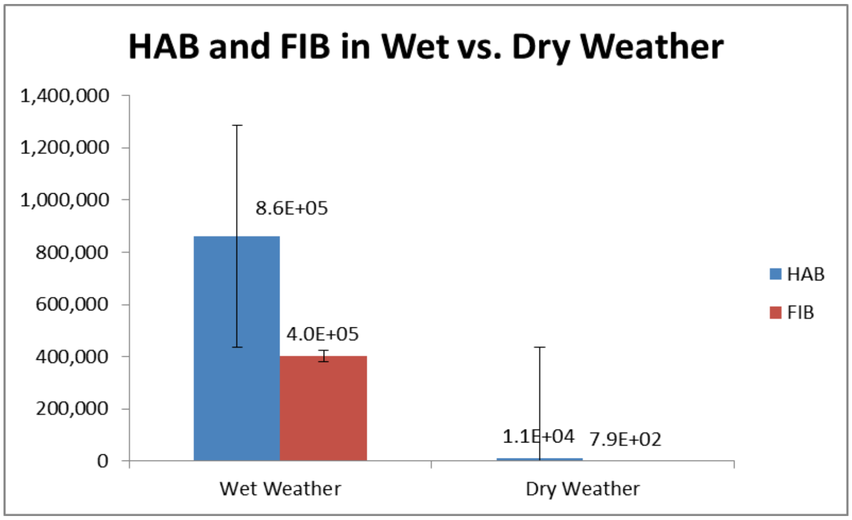

Figure 3: HAB and FIB comparisons in varying weather

As previously mentioned, rainfall has been shown to influence HAB and FIB concentrations so it is important to analyze our results in the context of this data. We hypothesized that after a rainfall event; there would be an increase in FIB, HAB, and trash at all three sites. When splitting our sample dates into two categories, wet weather days (precipitation > 0.8in) and dry weather days (precipitation < 0.8in), we found an acute difference in the mean values of FIB and HAB concentrations This suggests that rainfall has a definite detrimental effect on water quality in Ballona Creek. FIB and rain demonstrated a very high positive correlation at all three sites (r = 0.92, 0.88, 0.87 respectively, p=0.05). Additionally, HAB and rainfall had a similar correlation (r = 0.89, p= 0.05 total HAB). Further, there was a significant correlation between FIB and HAB at each site (site 1 = 0.83, site 2 = 0.81, site 3 = 0.81, p=0.05). In a study performed by Reeves (2004) it was also found that, during storms, rainfall intensity was positively correlated with the concentration of fecal bacteria and turbidity. Sometimes it was difficult to measure FIB because bacteria die off/, decay and are very sensitive to sunlight.

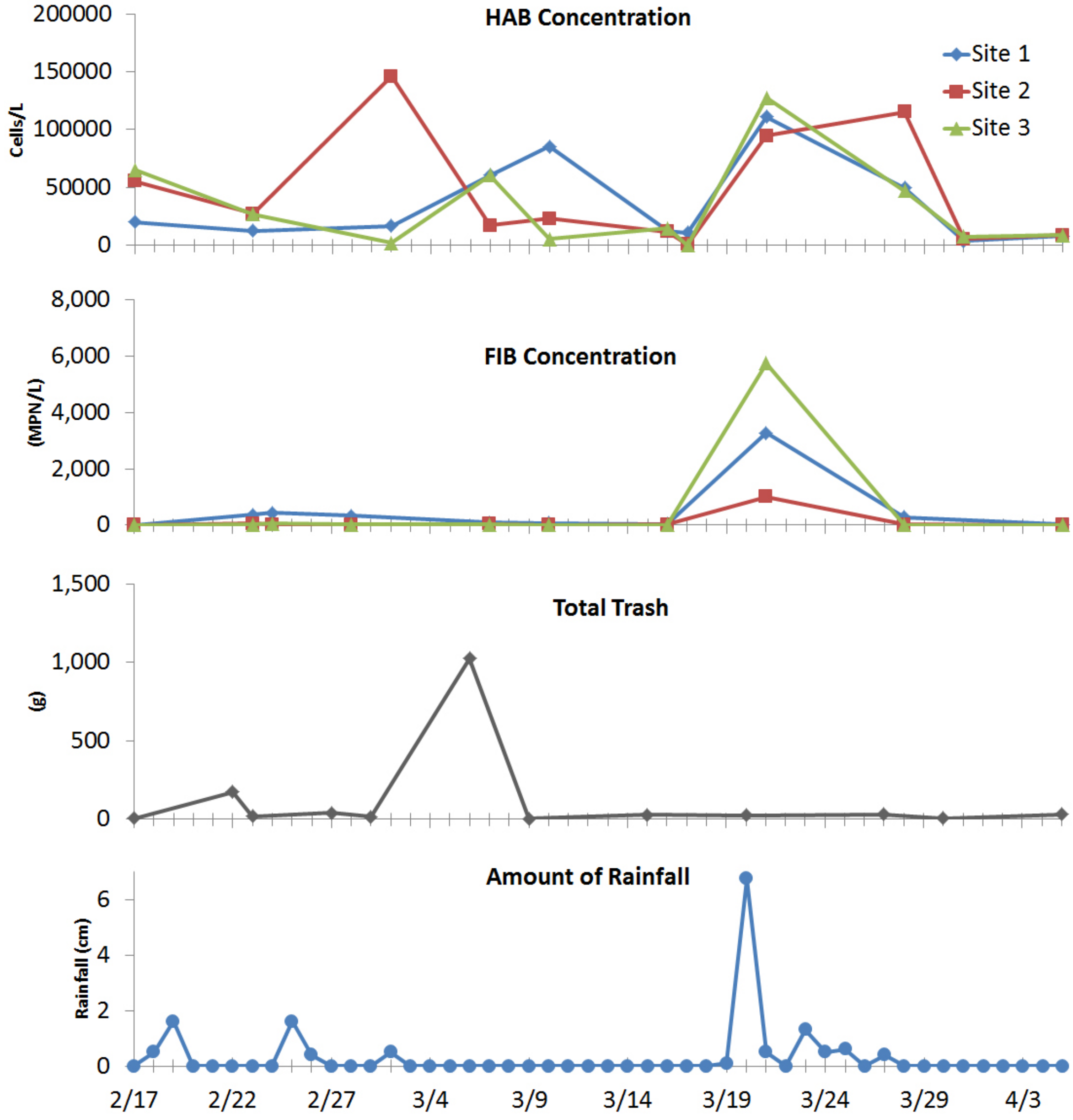

Figure 4: Time Series of HAB, FIB, Total Trash, and Rainfall

FIB, trash, and HAB concentrations were analyzed to evaluate any temporal patterns. Trash remained relatively low in abundance throughout February to March, ranging between 2 and 172 grams/m^2 with average density around 3 g/m$^{2.}$. On 3/6, there was a sudden increase in trash density to 1024 g/m^2. We observed no correlation between any of our water quality indicators to describe this 97% increase. Ideally, we would expect that rainfall would lead to trash accumulation on the beach. However, such a correlation provided no significant result and an unreliable standard error. Trash abundance may have varied due to a number of different reasons – city vehicles cleaning the trash or high tides piling up trash on the shoreline. We were unable to find a schedule of beach cleanup days to help us evaluate the data collected. Overall, there was no discernible pattern for trash over time.

FIB averaged 150 MPN/L during dry days and 380 MPN/L during wet days excluding the storm on 3/21. This heavy rainfall event (6.9cm) led to sharp increases in FIB concentrations (site 1=3300 MPN/L, site 2=1020 MPN/L, site 3=5800 MPN/L). Before the storm that caused a large increase in FIB concentrations, HAB concentrations ranged between 223,652 cells/L and 11,952 cells/L. During the storm on 3/21, HAB concentrations peaked at 333,660 cells/L. Unlike HAB, FIB did not retain high concentrations after rain events. This is predominantly noticeable after 3/21, when HAB reduces at a much slower rate. This is likely due to the lasting effect on the intensity of a storm. We conclude that this does not factor into their positive correlation, as the high growth of HAB was most likely due to the lasting effect of huge storms.

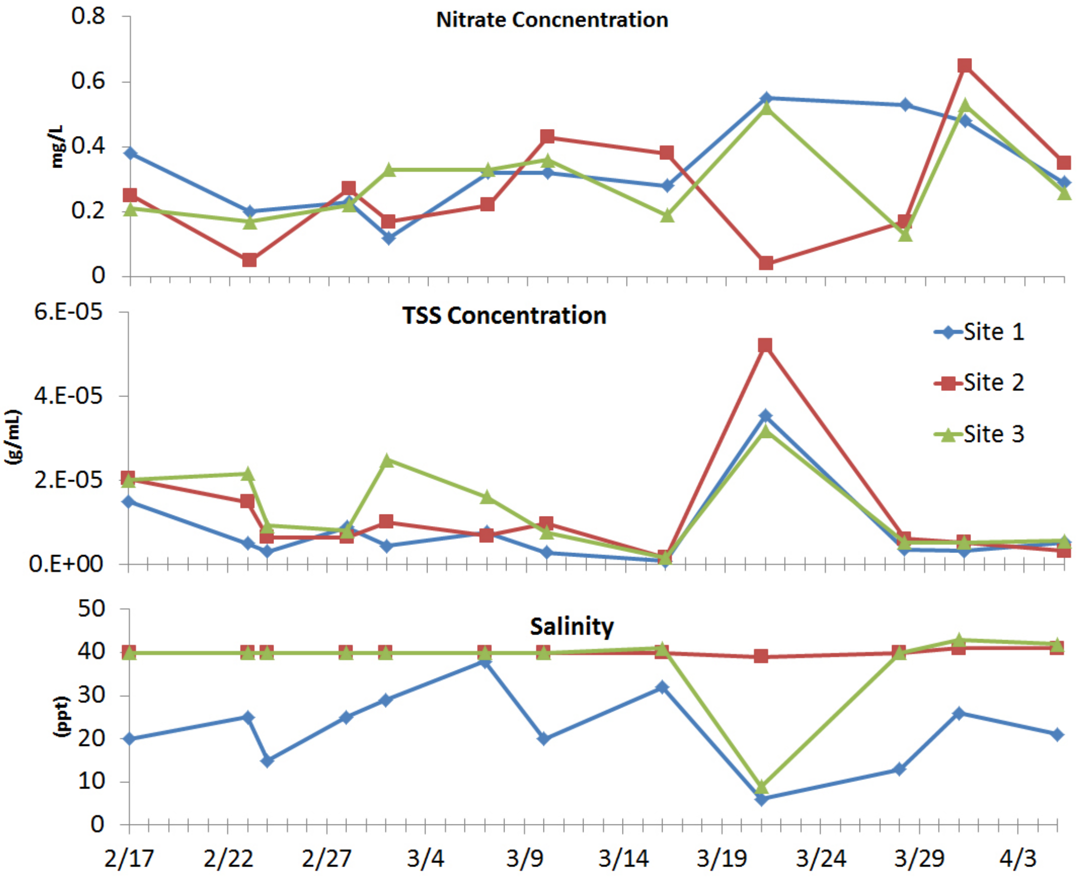

Figure 5: Time Series of Nitrate, TSS, and Salinity

The overall profiles of the environmental variables fluctuate over time. TSS concentrations fluctuated over a range, 8.0x10^{-7} - 1.6x10^{-6}, from mid-February until mid-March. On the rain event on 3/21, concentrations at all 3 sites greatly increased with the highest at 5.2x10^{-5} at site 2. The spike in TSS concentrations is attributed to the runoff washing into the creek the day before. This noticeable increase in concentration can be attributed to the flux of residue that lies on the channel becoming concentrated during days of no rainfall. On the next sampling day, 7 days later on 3/28, concentrations at all 3 sites drastically drop. This might be due to the TSS concentrations getting diluted over the course of 7 days. There was another rain event on 3/28. However, TSS concentrations on the sampling day following this rain event, 3 days later on 3/31, did not increase as they did for the previous rain event. This can be attributed to the magnitude of this rain event, 2.8cm, being much smaller than the previous.

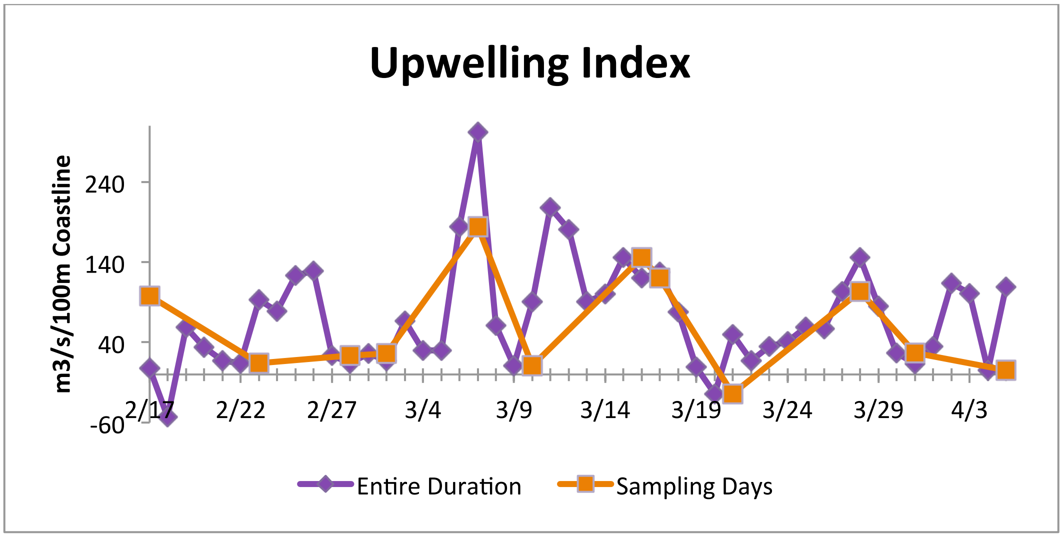

Figure 6: Time Series of Upwelling during sample period.

Upwelling values fluctuate throughout the entire study period. As mentioned before, upwelling brings nutrient-rich, saline water to the surface. The highest upwelling value, 184, was on 3/7and the effects can be clearly seen at site 1. Site 1 had a salinity of 29ppt on the previous sampling day but the value reached a maxima of 38ppt. Upwelling on 3/10 was low, with a value of 11. Nitrate concentrations reached their highest, on that day, at site 2 with a value of 0.43 mg/L. This shows that the spike in nitrate concentrations did not come from upwelled waters but from a different source. There was a rainfall event of 0.54 cm on 3/7. It is possible that this increase in nitrate concentrations is from runoff that has taken a few days to wash down to site 2. On 3/21, there is a minima of upwelling, with a value of -24. Nitrate concentrations, at site 2, also reach their minima value on that day of 0.04 mg/L. However, site 1 reaches its maxima value of nitrate concentrations, 0.55 mg/L on the same day. This can be explained by the huge rainfall event, 6.85 cm, on that day. The effects of rainfall on nitrate, at site 1, and the effect of upwelling on nitrate, at site 2, can clearly be seen in this data.

Salinity concentrations are pretty consistent from mid-February to mid-March for sites 2 and 3 but fluctuate greatly for site 1. The effect of high upwelling on 3/16 can be seen in the salinity values as site 1 reaches one of its highest values, 40ppt. Further effects from a huge rainfall event, 6.85 cm, can be seen in site 1 and site 3 as the nitrate concentrations on those days increases to 0.55 mg/L and 0.52 mg/L, respectively. This freshwater effect can also been in the salinity values at site 1, 6ppt, and site 3, 9ppt. This is interesting as it shows that the runoff can travel all the way down to the end of the jetty (site 3).

Site-specific Water Quality and Controls

Our data suggest that rain events result in suspended particles in the water at site 1, associated with a significant concentration of FIB in the water. There is a statistically significant positive correlation between TSS and rain (r =0.81, p = 0.05) for site 1. This means that concentration of suspended particles in the water increases with a rainfall event. The presence of TSS is tied to the presence of FIB as TSS concentrations cloud the water surface and block sunlight from penetrating. Since FIB is sunlight-inactivated, meaning that sun exposure kills bacteria, the positive correlation between FIB and TSS supports TSS as a factor affecting FIB concentrations (r = 0.89, p = 0.05). Because FIB is sunlight-inactivated and TSS is blocking the sunlight, we hypothesized that FIB will persist in the water even after a rain event and this is supported by our results.

There is a positive correlation between TSS and rain (r = 0.84, p = 0.05), FIB and rain (r = 0.88, p = 0.05), and TSS and FIB (r = 0.93, p = 0.05) for site 2 as well. This carries the same implications as it does for site 1. However, the average FIB concentrations at site 2 are 124.1 mpn while it is 492.9 mpn for site 1. This shows that FIB concentrations are diluted as they travel down the creek. There is a lot of influence of high salinity upwelled waters at site 2 which might contribute to the lower concentrations of FIB. Deep ocean water brought up to the surface and mixed with near shore and runoff likely diluted the FIB concentrations. Nevertheless, there is FIB present in site 2 and this can have ecological and human implications.

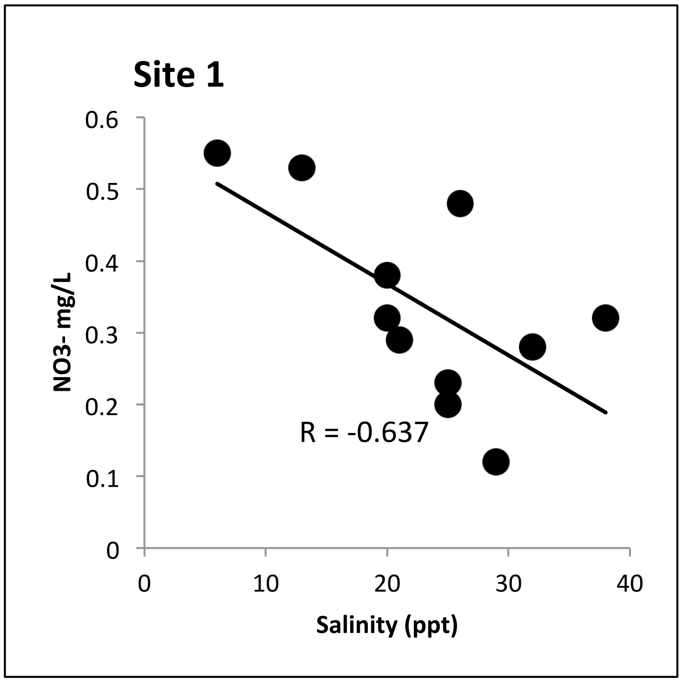

Figure 7: Site 1 Nitrate vs. Salinity Regression

At site 1(Figure 7) , there is a statistically significant negative correlation (r = -0.64, p=.05) between nitrate and salinity suggesting that the nitrate present in the water is coming from the runoff. The statistically significant positive correlations between HAB and nitrate concentrations (r = 0.89, p = .05) suggest that nutrients contained in the runoff after a rainfall event may be contributing to HAB growth.

Figure 8 demonstrates that there is a positive correlation between nitrate and salinity (r = 0.72, p = 0.05). This suggests that the source of this nitrate is upwelling; when alongshore winds blow over the water, they bring up the cold, salty, nutrient-rich deep water to the surface. Furthermore, there is a significant negative correlation between salinity and HAB (r = -0.74, p = 0.05) supporting the role of upwelling in HAB presence. HAB and nitrate concentrations are significantly correlated (r = -0.65, p = 0.05) and the increase in nitrate that supports HAB at this location. It is possible that the negative correlation reflects conditions where nitrate has already been depleted by HAB cells; thus low nitrate and high HAB concentrations.

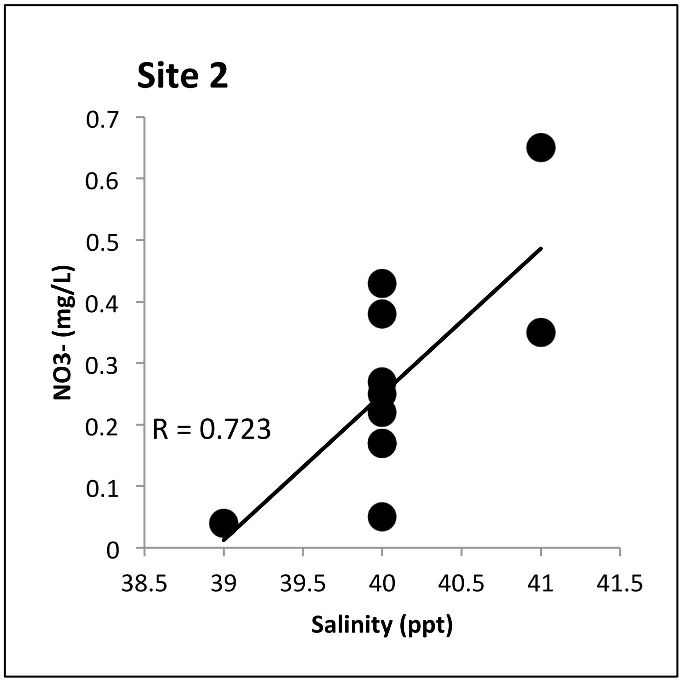

Figure 8: Site 2 Nitrate vs. Salinity Regression

At site 3, there was no statistically significant correlation between salinity and nitrate, and the water there was generally oceanic, as suggested by consistently high salinity (Figure 9). However, there was a positive significant correlation between rainfall and TSS, (r = 0.67). A positive, significant correlation between TSS and FIB concentrations (r = 0.72) and a significant negative correlation (r = -0.67), between the TSS and salinity at site 3, again supports the role of runoff in affecting water quality. Lastly, there was a weak association between nitrate and HAB with an r-value of 0.46, and this suggests the presence of nitrate in site 3 may not be directly influenced by a specific source like runoff or upwelling.

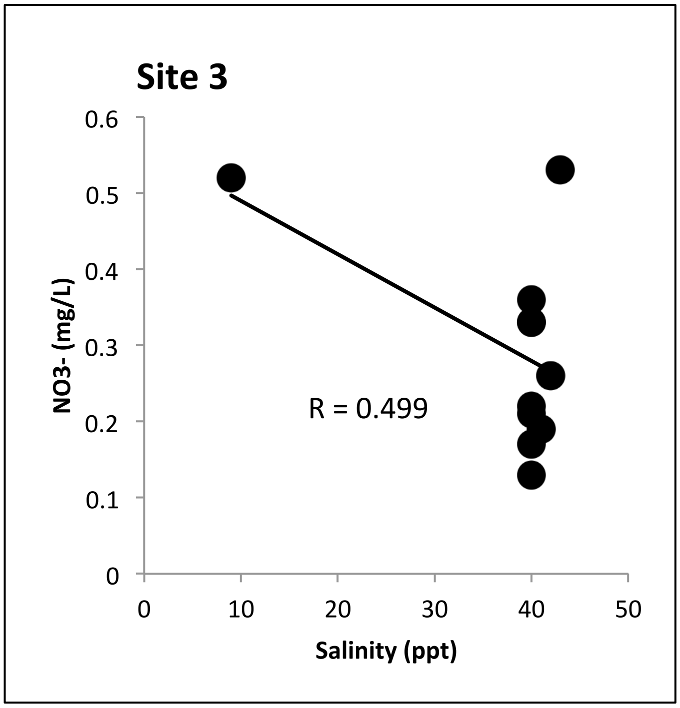

Figure 9: Site 3 Nitrate vs. Salinity Regression

Conclusion

Our study of water quality in Ballona Creek, defined by concentrations of HAB and FIB and concentration of trash, suggests that dry and wet weather conditions contribute significantly to water quality. Precipitation and water quality are closely associated, and a change in precipitation levels will directly influence the water quality. Through our findings, we can conclude that rain events have a harmful effect on Ballona Creek. Although there was no correlation between trash and rain, there were significant correlations for both HAB and FIB with rain. It is interesting to note that FIB levels are the highest at site 3 on 3/21 during the huge rainfall event. Site 3 is the farthest from the source of runoff and this suggests rain events of a large enough magnitude, 6.85cm in this case, can wash all the way down into the open ocean. FIB levels at site 1 are the lowest which is consistent with the previous idea. Huge rain events carry runoff all the way through the creek and into the open ocean. Salinity values for that day also support this. Site 3 decreases from 41 ppt, the value from the previously sampled data, to 9 ppt – a clear indicator of runoff water, which is low salinity, washing down the open ocean. Interestingly, site 2 remains saline and experiences a mere 1ppt decrease in salinity. This suggests that the mixing that occurs at the beach-ocean interface dilutes the effect of runoff. This is further supported by the fact Site 2 has the lowest FIB concentration for that day. However, this is data from a single rain event; thus, more sampling during comparable rain events is needed to understand the flow the runoff into the ocean. Further, high TSS concentrations were seen at all three sites during rain. Although nitrate concentrations were uniformly low in all samples, higher nitrate concentrations were associated with high HAB concentrations. Site 1 was the furthest upstream, the most influenced by runoff and possessed relatively higher concentrations of nitrate, which led to high concentrations of HAB. Thus, a major result was that runoff, especially during wet weather, is an important environmental factor that contributes to HAB growth, and was also associated with FIB presence. In summary, urban runoff can bring in TSS and nitrate that affect HAB and FIB concentrations but ocean dynamics, such as upwelling and mixing, can affect these two indicators as well.

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