Monitoring the water quality of Strawberry Creek, CA.: comparative study on different sites to address health issues

Nancy Vuong

Abstract Strawberry Creek runs through the University of California, Berkeley and in the past, it was degraded due to urban and campus development. This project looked at changes in water quality starting from the upper North Fork, through the Berkeley campus, and into western Berkeley. From November 2004 to February 2005, measurements of pH, conductivity, turbidity, dissolved oxygen, water temperature, nitrate, chlorine, and E. coli were taken at four location along Strawberry Creek to determine the effects of precipitation and location of each site. In this research, parameter such as nitrate, turbidity, and E. coli were also used to address human health concerns. The pH was unaffected by precipitation and sites. Turbidity levels at all sites exceeded the EPA standard on both rainy and non-rainy days. On non-rainy days Nitrate levels at most sites were below the EPA standard. The data showed that there were a correlation between turbidity and nitrate. Nitrate levels were highly correlated with dissolved oxygen. There were higher levels of E. coli on rainy days than on non-rainy days. E. coli levels starting at Site 2 showed an increasing trend downstream on non-rainy days. Chlorine Total remained in a steady range on both rainy and non-rainy days, but higher levels at Site 3 due to pipe leakage of drinking water. Most parameters were affected by precipitation and significantly differ in most sites, which resulted in certain areas being more polluted and more unsafe for human usage.

Introduction

Streams are common in most urban communities in the United States. Most streams are occupied by a variety of human activities and interactions (SWRCB 2000). These interactions affect the chemical and biological characteristics of the stream, such as pH, phosphate, nitrate, chlorine, and *E. coli* (Water Quality Associates 1992). Contaminated water may contain harmful chemicals or pathogens, which may affect people who drink, wash, or play in the polluted streams. Polluted substances include toxic chemical released from automobiles, inorganic nutrients from fertilizers, and other various human activities that may negatively affect water quality in Strawberry Creek, which may become hazardous to human health (EPA 2005).

Strawberry Creek runs through the campus of University of California and the city of Berkeley. In the past, this creek was degraded due to urban and campus development such as improper disposal of oil and other materials deposited into the storm drainage system. High bacteria counts from animal feces, sewage, and chemical contamination led to poor water quality, decreased aquatic and terrestrial organisms, and the destruction of stream banks (Charbonneau and Resh 1992). In 1987, UC Berkeley developed the Environmental, Health, and Safety program (EH&S) and the EH&S developed a management plan to restore the creek, which upgraded the sewage system and installed new pipes (Charbonneau 1987). The EH&S objectives are to identify both point and non-point sources, develop creek and watershed mitigation strategies, and monitor the water quality that runs through the campus to comply with the Clean Water Act (Charbonneau 1987). The law states that recreational water must meet standard state water quality criteria (EPA 2005). The improvements decreased the major pollutant, faecal coliform bacteria, in the South Fork, but the North Fork remained unimproved because of its urban location upstream (Charbonneau 1987).

Several past studies by Carlson, Frazier, Cheung, and Charbonneau focused on the portion of Strawberry Creek that runs through campus measuring pH, dissolved oxygen, and coliform bacteria. Carlson (1971) concluded that the pH of the creek was high. Frazier (1983) noted that the dissolved oxygen levels were within the limits set by the Regional Water Quality Control Board (RWQCB). Cheung (1986) found that levels of pH and dissolved oxygen met the RWQCB standards, but there were high levels of coliform concentration. Charbonneau (1987) showed that coliform bacteria remained high in the North Fork compared to the South Fork in the Berkeley campus. Chemical monitoring of Strawberry Creek would provide information on pollutants that are entering from non-point sources, such as storm sewers (Riley 1998). Not only can creek monitoring help determine if the water quality standards are being violated, but it can also help identify the source of the pollution (Riley 1998). There were many water quality research done on the campus portion of Strawberry Creek, but fewer has been done off campus (personal comment from Prof. Berry). Factors that may affect the water quality are precipitation and location. Precipitation increases flow rate, which carries more contaminants in the water as it flows downstream. The downstream water is affected by the accumulation of upstream pollutants. Since the City of Berkeley lack a water management plan, I hypothesize that the water quality of Strawberry Creek's North Fork located on campus is different compared to the section that runs off campus on both rainy and non-rainy days (no precipitation). In addition, the creek water located off and on campus may not be suitable for human contact and consumption.

The purpose of this research is to assess water quality at different locations along the North Fork of Strawberry Creek. In this study, the following eight parameters will be measured: pH, conductivity, turbidity, dissolved oxygen, water temperature, nitrate, chlorine total, and *Escherichia coli* (*E. coli)*. Levels of turbidity, dissolved oxygen, nitrate, chlorine total and *E. coli* are the main parameters that will be used to test the water suitability for human contact. High levels of nitrate and *E. coli* are indicative of urban run-off, irrigation, or sewage pipe leakage. The results of all parameters are observed to determine the effectiveness of the campus water quality management compare to off campus. This study reveals the effects of location and precipitation, along with human health concerns.

Methods

The headwaters of Strawberry Creek are located in Strawberry Canyon, on the east side of the Berkeley campus (37°52' N; 122°15'W) in Alameda County, California. Upon reaching the urban area, the creek is naturally separated into North and South Forks. For the research, four different sites were chosen along the creek to represent the campus and urban streams, where the city lacks a water management plan. The four sites were located at the urbanized North Fork on La Loma Street (Fig. 1, Site 1), at the un-urbanized North Fork near North Gate and another near Eucalyptus Grove on campus (Site 2 and 3 respectively), and at Strawberry Creek in the western part of the City of Berkeley (Site 4).

Between November 2004 and February 2005, triplicate samples for pH, conductivity, turbidity, dissolved oxygen, water temperature, nitrate, and chlorine total were collected weekly between 8:00 to 10:00 AM. The *E. coli* levels were measured monthly based on one sample per site. Conductivity, pH, turbidity, dissolved oxygen, water temperature, and salinity were measured using the Water Quality Checker U-10 multi-meter (Horiba, Stone Mountain, United States). Before the use of the multi-meter, it was calibrated with a buffer solution of pH 4. Nitrate, phosphate, and chlorine total were measured using the DR/820: DR/850 Datalogging Colorimeter (Hach, Ames, United States). Before taking measurements of each water sample with the parameters' reagent, the colorimeter was calibrated with the creek water. *E. coli* was measured using an IDEXX system. The IDEXX Colilert method system is EPA-approved and is found in the *Standard Methods for Examination of Water and Wastewater* (IDEXX Laboratories 2005). The 10 ml water samples with the addition of a reagent were poured into quanti-trays, incubated for 24 hours at 37° Celsius, and observed under florescent light. The fluorescent yellow wells represented *E. coli* (IDEXX Laboratories 2005). The number of wells that appeared yellow under the florescent light was plotted on a standard chart provided by the EPA to get the levels of *E. coli* in Most Probable Number (MPN) (IDEXX Laboratories kit 2005).

All results were averaged for each week and differentiated into rainy and non-rainy days, over a four-month period and the standard deviation was calculated. The ANOVA tests were done on each site for each parameter on both rainy and non-rainy days to obtain a p-value, the analyses of variance with 95 % confidence level, and determine whether there were significant differences among each site. Bacterial analyses were performed by graphing the results, for example, geometric mean of bacterial analysis and precipitation variation in *E. coli* levels. Parameters, such as turbidity, water temperature, dissolved oxygen, and nitrate were plotted on a scattered graph and obtained the R-squared value to determine whether there were correlations.

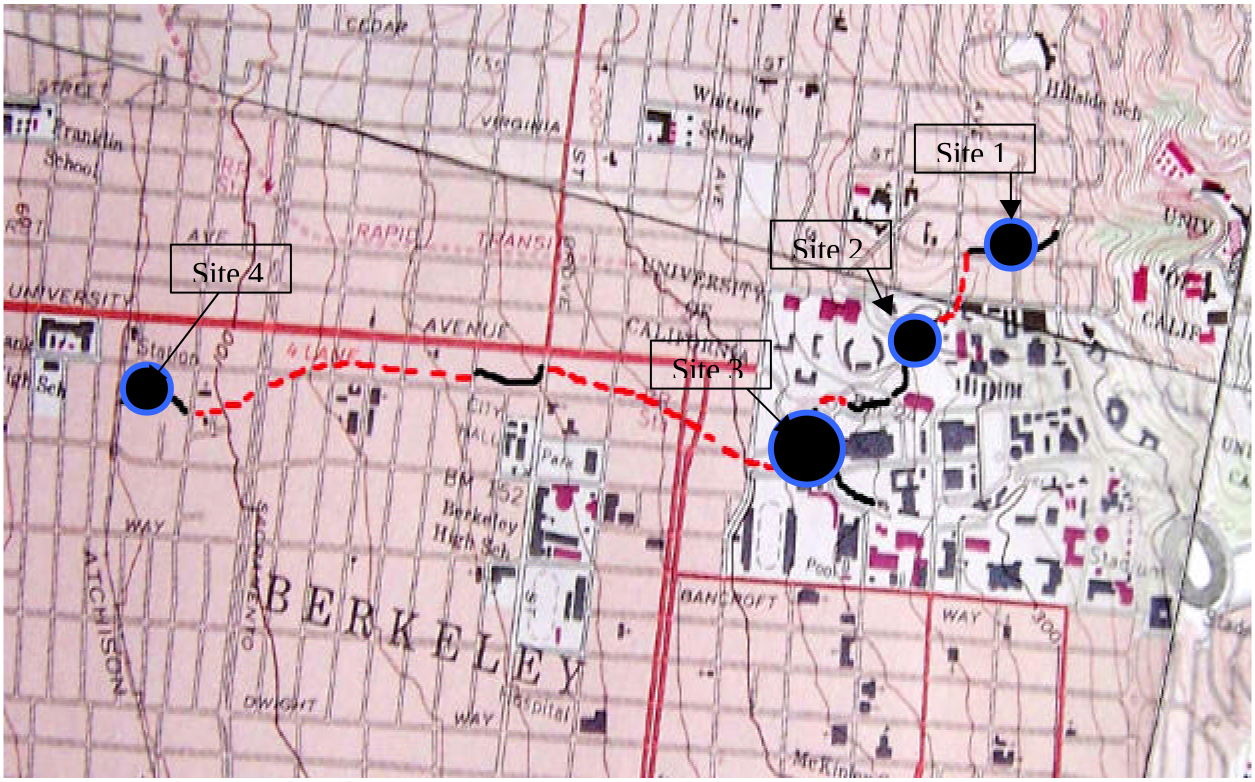

Figure 1. Strawberry Creek study sites

Results

Each weekly sample was averaged for each parameter in each site. The ANOVA tests were applied to each parameter to obtain a p-value with 95 % confidence level and determine its significant difference among each site (Table 1).

	Non-rainy Days	Rainy Days
pH	-	-
Conductivity	-	+
Turbidity	+	+
DO	-	+
Water Temp	-	+
Nitrate	-	+
Chlorine Total	-	+
E. coli	-	+

Table 1. Strawberry Creek analyses of variance with 95 % confidence level of each parameter on both rainy and non-rainy days for all sites, (-) = no significant difference, (+) = significant difference

The pH was the only parameter that showed similarities among all sites with a p-value of 0.06. The pH typically ranged from 6.5 to 8.5 (Fig. 2 and 3); except on week 13 of rainy days, Site 1 had a pH of 9.9 and Site 4 had a pH of 5.4.

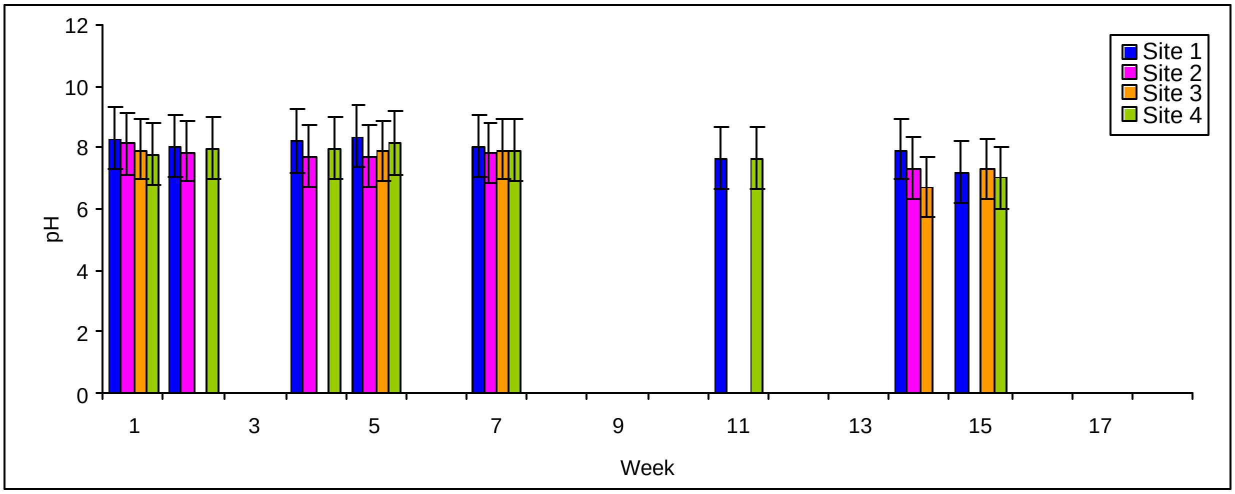

Figure 2. Strawberry Creek pH level on non-rainy days different sites

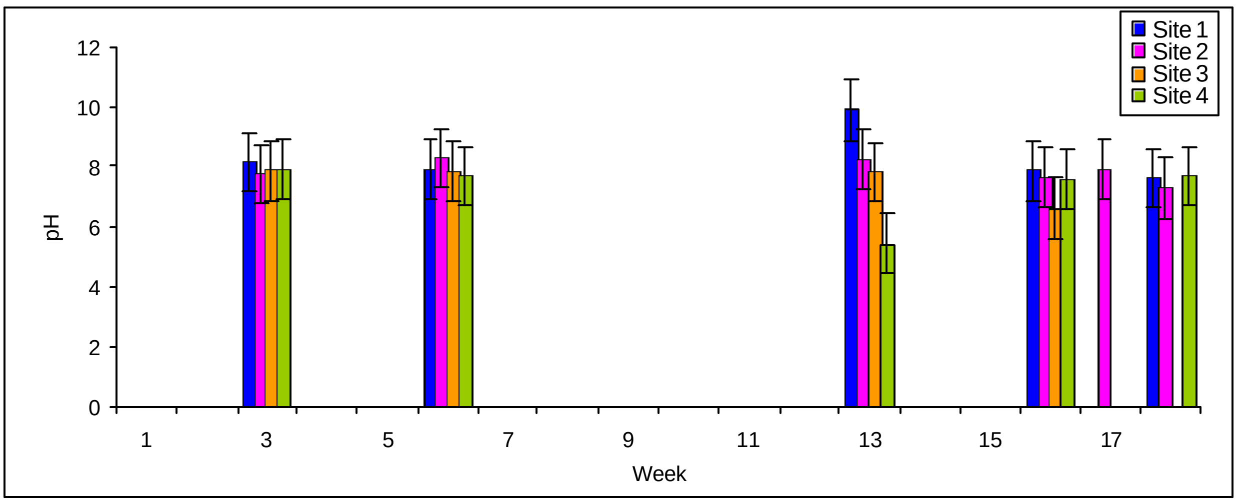

Figure 3. Strawberry Creek pH level on rainy days by different sites

The weekly sample average showed that turbidity was affected by precipitation. On non-rainy days, turbidity ranged from 1 to 15 Nephelometric Turbidity Units (NTU), where Site 1 had the highest turbidity level and Site 4 had the lowest turbidity level (Fig. 4). Turbidity level on rainy days ranged from 10 to 30 NTU (Fig. 5). Levels of turbidity were significantly different among each site on rainy and non-rainy days with p-value of 0.01 and 0.03 respectively.

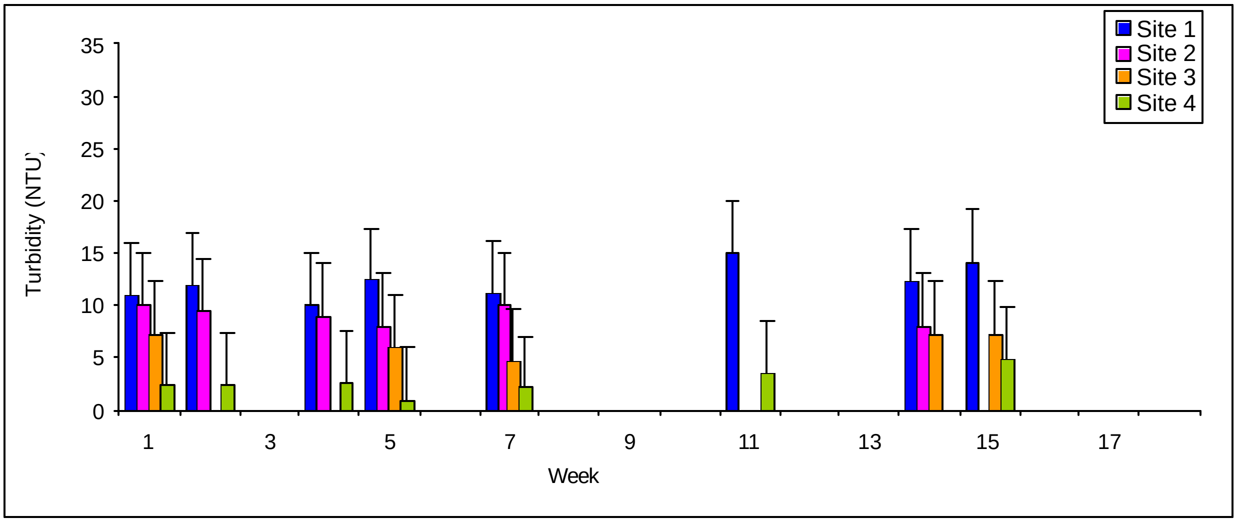

Figure 4. Strawberry Creek turbidity levels of non-rainy days by different sites.

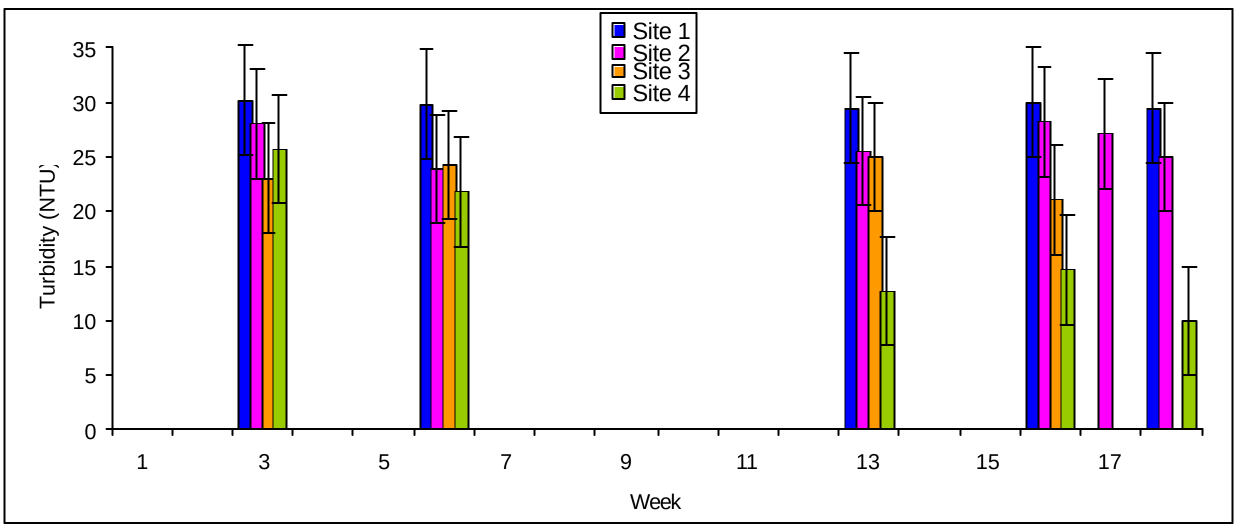

Figure 5. Strawberry Creek turbidity levels of rainy days by different sites.

On non-rainy days, nitrate levels ranged from 0.2 to 0.7 milligrams per liter (mg/l) in all three sites downstream, but upstream at Site 1, nitrate ranged from 0.90 to 1.7 mg/l (Fig. 6). On rainy days, nitrate levels ranged from 1.0 to 2.5 mg/l except at Site 1, nitrate ranged from 2.3 to 3.3 mg/l (Fig. 7). Nitrate levels from each site were significantly different on rainy days with p-value of 0.03 and no significant difference on non-rainy days with p-value of 0.15.

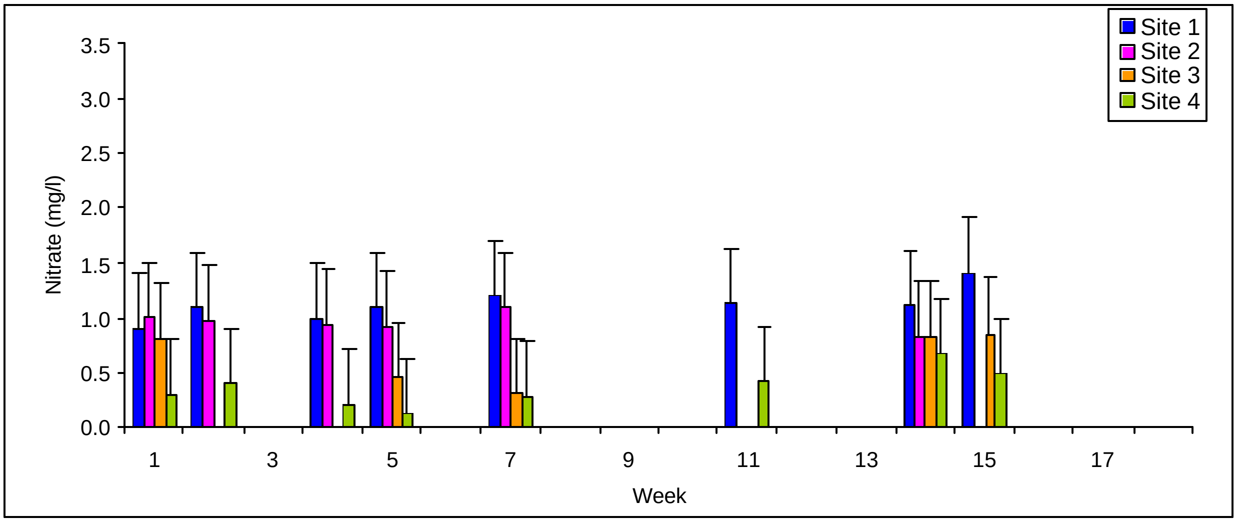

Figure 6. Strawberry Creek nitrate levels of non-rainy days by different sites

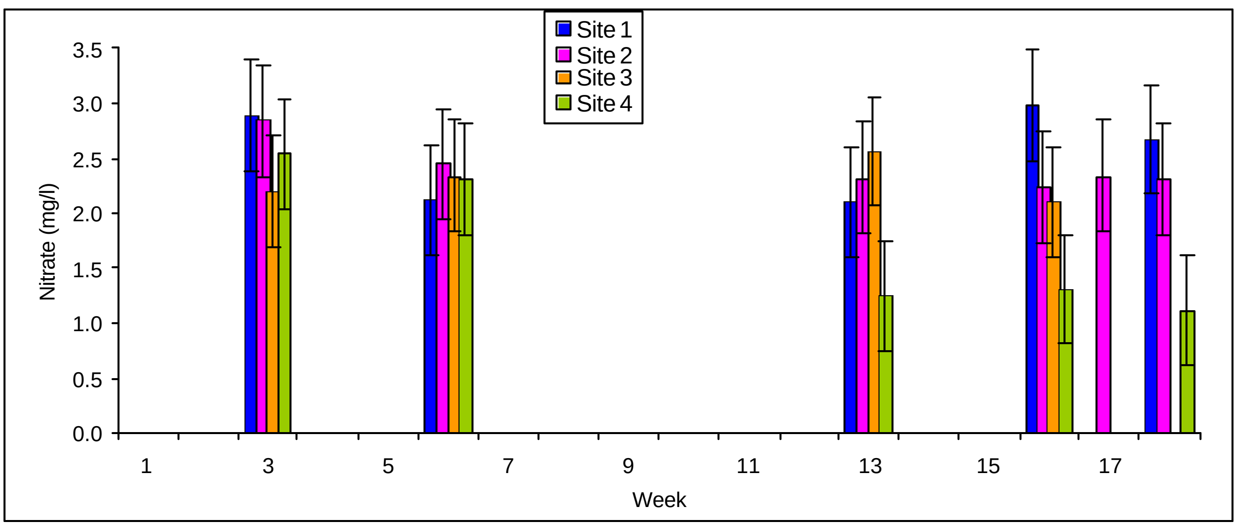

Figure 7. Strawberry Creek nitrate levels of rainy days by different sites

In two scattered plots with the best fit lines, the turbidity was set on the x-coordinate and nitrate on the y-coordinate. The approximate slope for both plots was positive 0.08 (Fig. 8 and 9). The R^2-values for both plots were 0.75 for rainy days and 0.91 for non-rainy days.

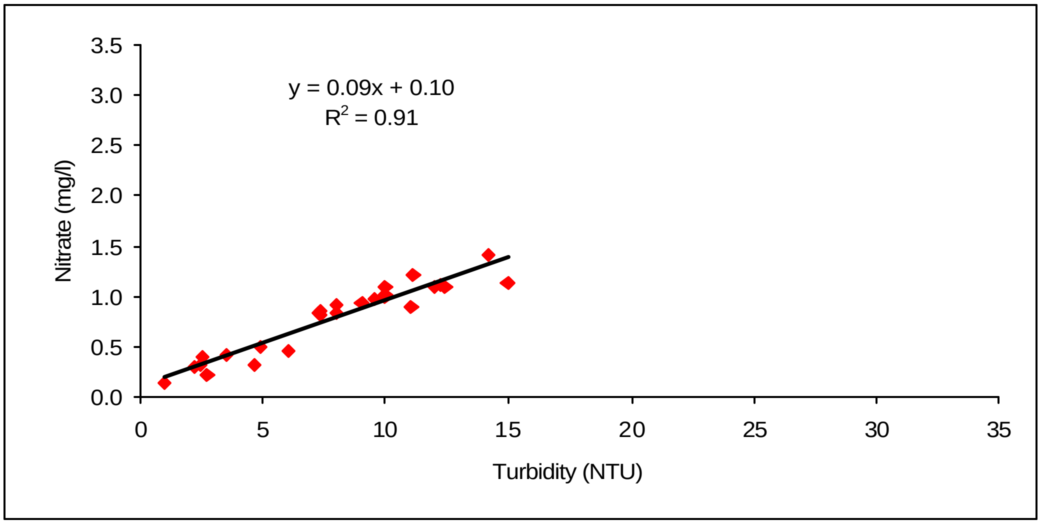

Figure 8. Strawberry Creek turbidity and nitrate levels correlation on non-rainy days

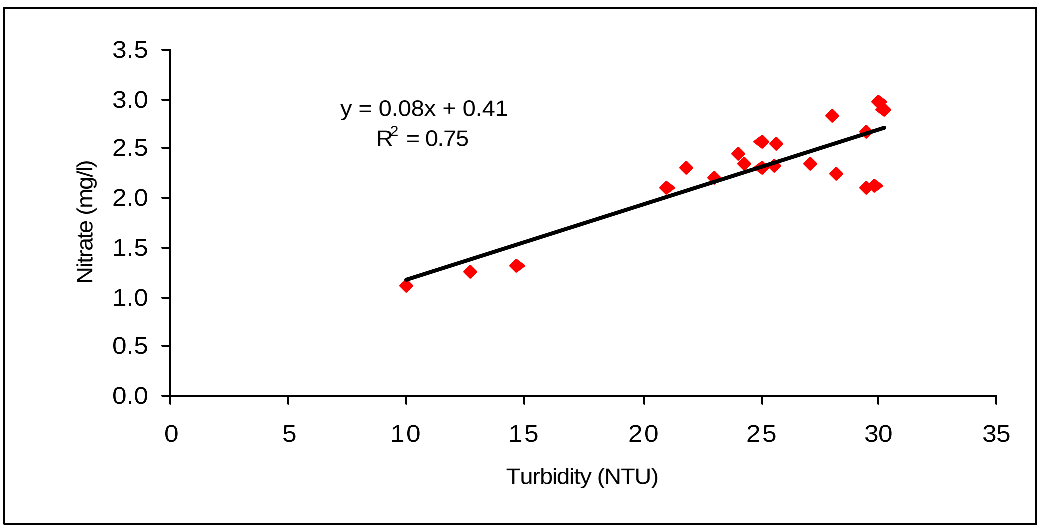

Figure 9. Strawberry Creek turbidity and nitrate levels correlation on rainy days

On non-rainy days, dissolved oxygen had no significant difference among all sites with a p-value of 0.13, but there were significant differences on rainy days with a p-value of 0.01. On non-rainy days, dissolved oxygen ranged from 11.5 to 20.0 mg/l (Fig. 10). On rainy days, dissolved oxygen ranged from 3.0 to 16.0 mg/l (Fig. 11). In other words, there were lower levels of dissolved oxygen on rainy days than on non-rainy days.

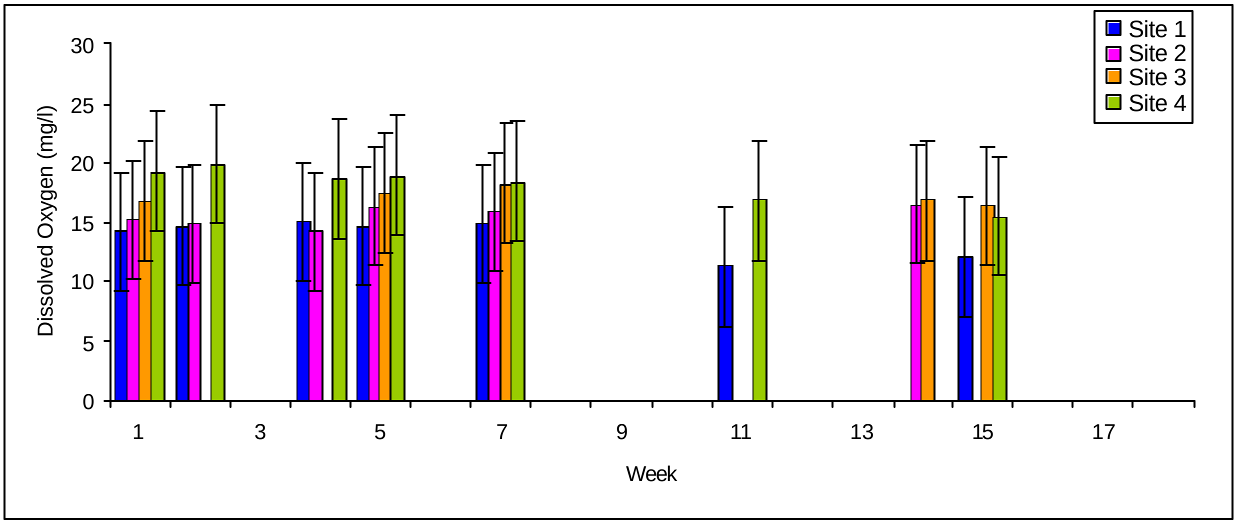

Figure 10. Strawberry Creek dissolved oxygen level on non-rainy days

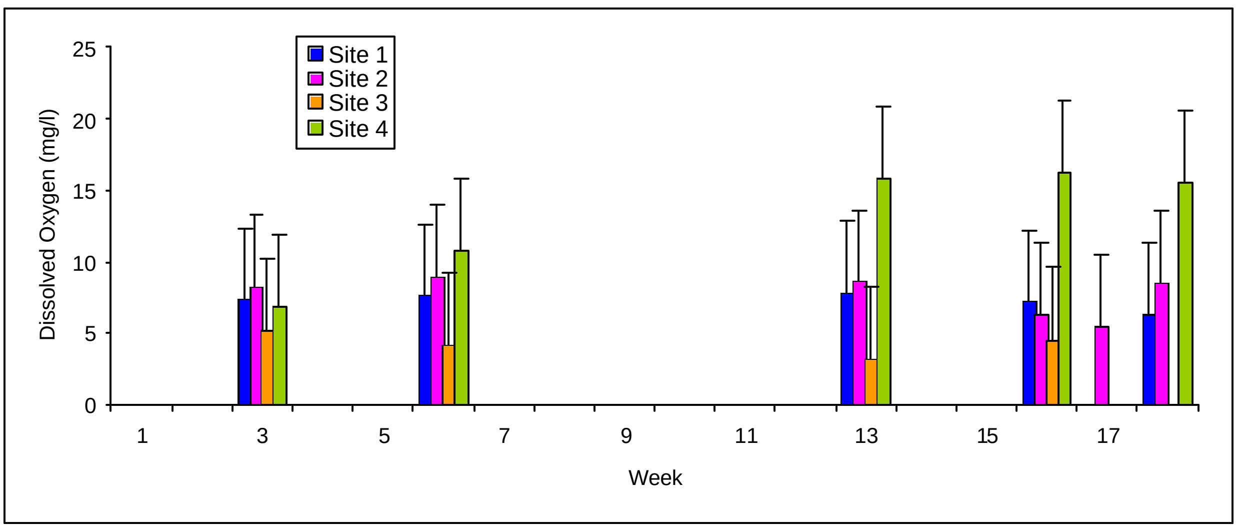

Figure 11. Strawberry Creek dissolved oxygen level on rainy days

In two scattered plots with the best fit lines, the nitrate was set on the x-coordinate and dissolved oxygen on the y-coordinate. The approximate slope for both plots was negative 5.25 (Fig. 12 and 13). The R^2-values for both plots were 0.55 for rainy days and 0.73 for non-rainy days.

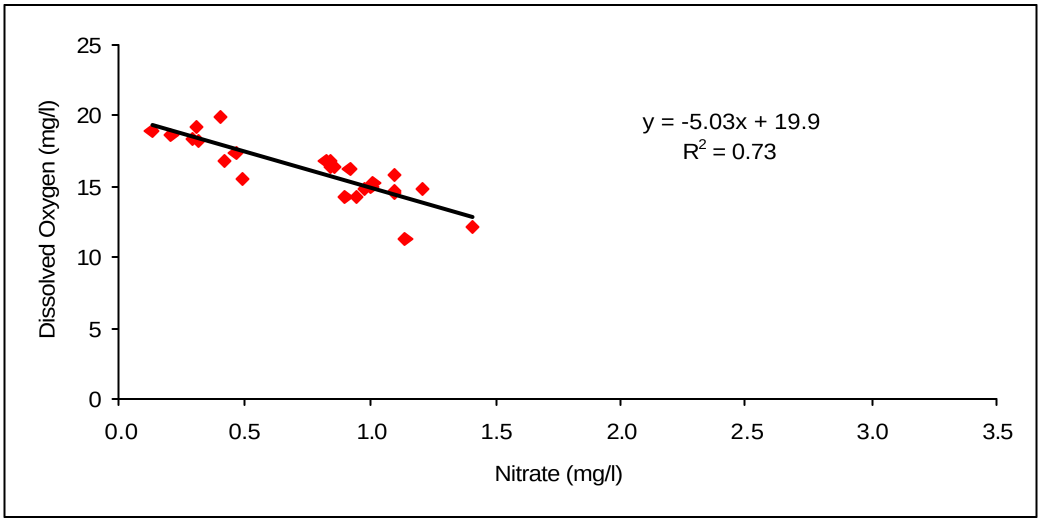

Figure 12. Strawberry Creek dissolved oxygen and nitrate levels correlation on non-rainy days

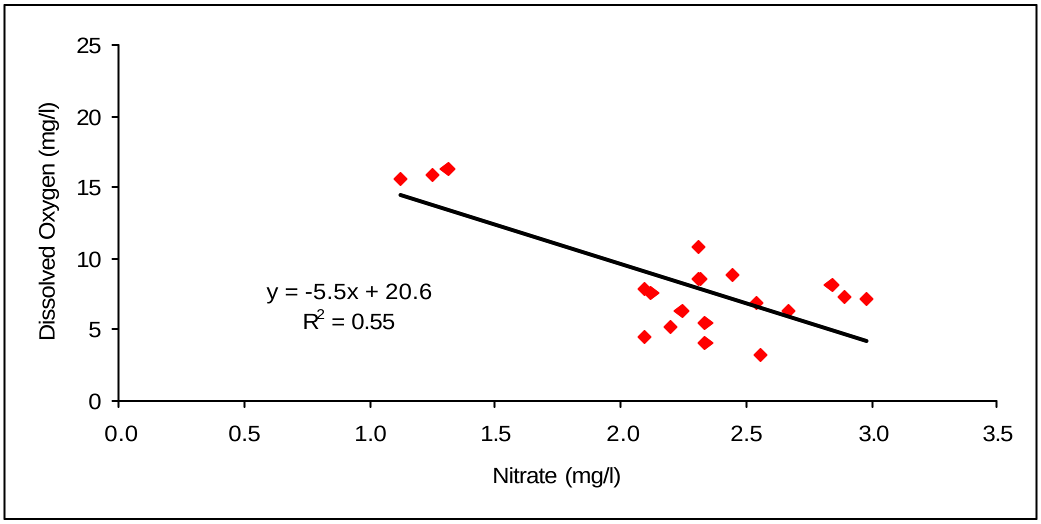

Figure 13. Strawberry Creek dissolved oxygen and nitrate level correlation on rainy days

There were no significant differences of levels of total chlorine among each site on both rainy and non-rainy days with p-value of 0.10 and 0.05 respectively. On both rainy and non-rainy days, chlorine level at most sites ranged from 0.01 to 0.20 mg/l (Fig. 14 and 15). Site 3 had a higher chlorine level ranging from 0.32 to 0.42 mg/l on week 14 and 15 for non-rainy days, and on week 3 and 13 for rainy days (Fig. 14 and 15).

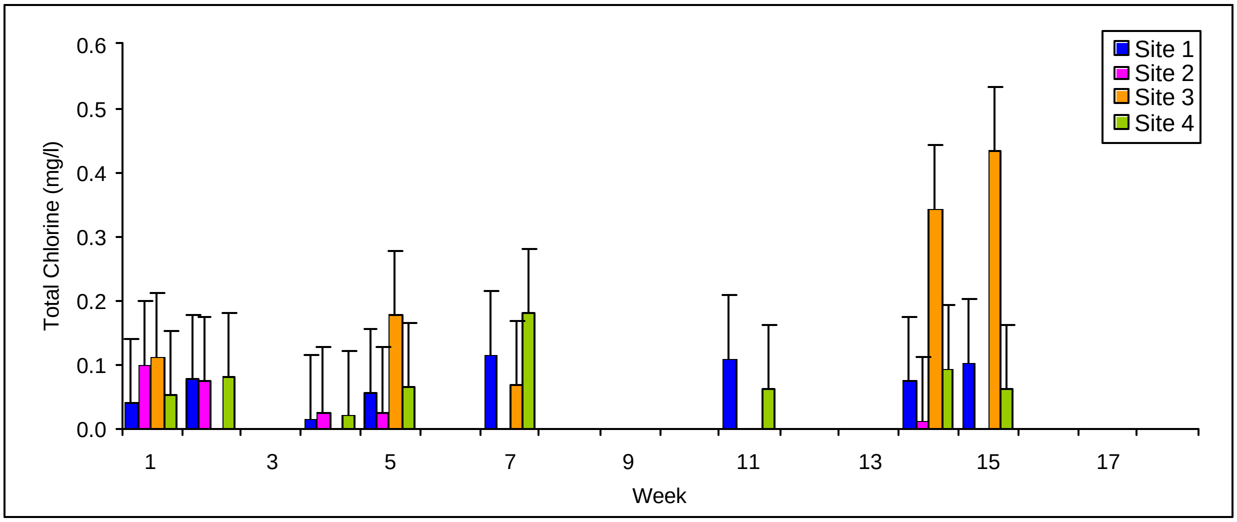

Figure 14. Strawberry Creek chlorine levels on non-rainy days by different sites

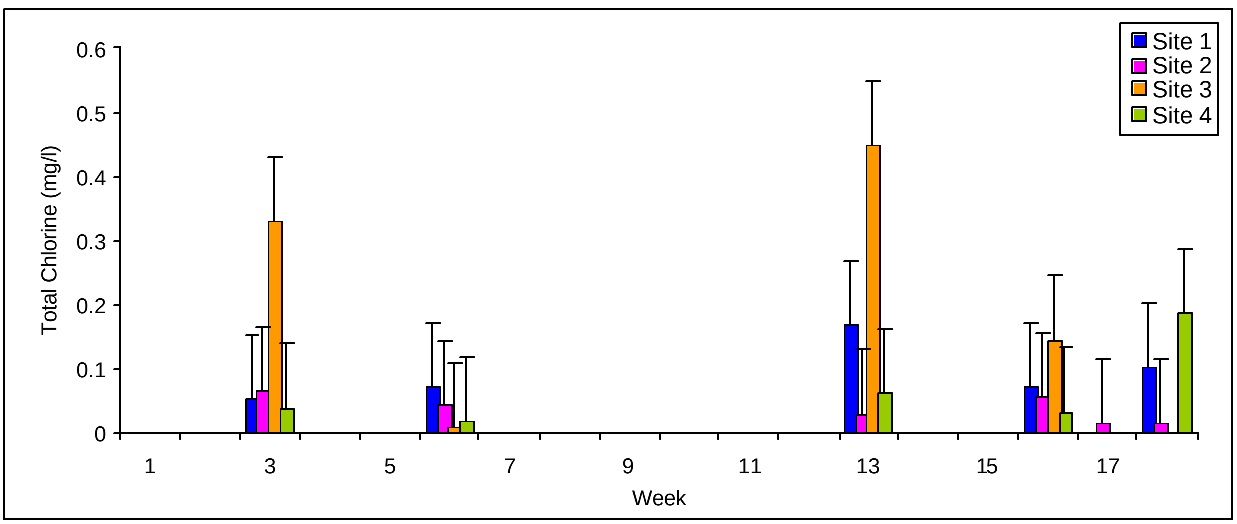

Figure 15. Strawberry Creek chlorine levels on rainy days by different sites

The *E. coli* levels were lower on non-rainy days and higher on rainy days (Fig. 16). *E. coli* concentrations were higher downstream compare to upstream. On non-rainy days, *E. coli* levels decreases from Site 1 to Site 2, but increases from Site 2 to Site 4. On rainy days, Site 1 recorded an *E. coli* level about 400 MPN and Site 2, 3, and 4 had levels above 1100 MPN. At Site 2 and 3, *E. coli* levels were close to similar on rainy days, 1200 MPN and 1250 MPN respectively, but the two sites differ on non-rainy days, 100 MPN and 300 MPN respectively. The p-values were 0.26 for non-rainy days and 0.04 for rainy days.

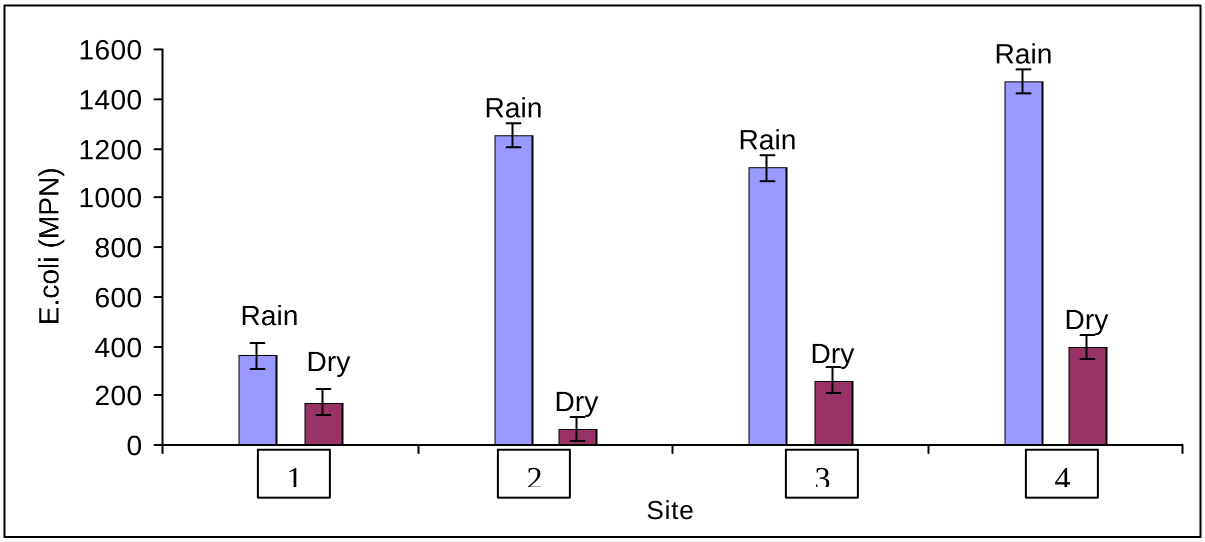

Figure 16. Strawberry Creek *E. coli* levels of rainy and non-rainy days

Discussion

E. coli levels increase downstream on both rainy and non-rainy days. Even though Site 1 is located in an urban area, it was not as polluted as the other three sites. As expected, Site 4 is the most polluted site because it runs through the western part of Berkeley, which is densely developed. An increased in *E. coli* concentration on both rainy and non-rainy days may be due to direct deposits of animal feces because dogs were often sited in the creek at Site 4 on non-rainy days. The EPA Human Health Water Quality Criteria states that water exceeding 200 MPN is not suitable for human contact or consumption (EPA 2005). The site located nearest to the headwaters is Site 1. *E. coli* levels at all sites exceeded the EPA standard, except at Site 1 and Site 2 on non-rainy days. The management plan that was developed to monitor the water quality on campus had an effect at Site 2 on non-rainy days and failed at Site 3 (Fig. 16). At Site 2, 3, and 4 of non-rainy days, *E. coli* levels increased downstream. On non-rainy days, the levels of *E. coli* at each site may be due to direct deposit of animals and accumulation of waste from surrounding areas. On rainy days, there were lower levels of *E. coli* upstream, not exceeding 400 MPN, compare to downstream with level exceeding 1000 MPN at Site 2, 3, and 4 (Fig. 16). Due to rapid flow rate, precipitation may cause a decrease in *E. coli* levels in the creek water; however, precipitation caused an increase in *E. coli* level. The increase in E. coli level may be due to more accumulation of waste in the urban area and soil erosion, which may be embedded with wastes. The *E. coli* results indicate that, at times, the water of Strawberry Creek can pose a health hazard to people and animals that come in contact with the water.

According to the EPA, pH is listed under the Secondary Water Quality Criteria, which are those contaminants listed as non-hazardous to human health. The pH levels at most sites were found within the EPA water quality standards ranging from 6.5 to 8.5 (EPA 2005). Other exceptions were found, on week 13 at Site 1 and Site 4 with the pH of 9.9 and 5.4 respectively (Fig. 2 and 3). At low pH, there may be a bitter metallic taste and an indication of corrosion from iron and copper pipes (EPA 2005). At high pH, one may expect a slippery and soda taste and a possible indication of deposits (EPA 2005).

Precipitation did not have much effect on the pH level and there were no significant differences between each site. However, turbidity, dissolved oxygen and nitrate were affected by precipitation. The data were consistent with the EPA findings that when rainfall increased, turbidity would increased, which led to an increase in water temperature and decrease in dissolved oxygen (EPA 2005). The EPA nitrate standard for human contact and consumption should be less than 1.0 mg/l. On some non-rainy days, Site 1 and Site 2 exceeded the maximum EPA criteria, while rainy days had excess amount of nitrate levels at all four sites (Fig. 6 and 7). Nitrate is mainly from non-point sources such as nitrogenous fertilizers and untreated sewage. Nitrate consumed may lead to decreasing ability of the blood to carry oxygen. High nitrate levels may cause methemoglobinemia, also known as the blue baby syndrome, where infants are more susceptible to nitrate toxicity than older children (Puckett 1995). The creek water may pose a health threat on rainy days at all sites, especially at Site 1, which had unsafe nitrate levels on both rainy and non-rainy days. The data showed that there were higher nitrate level upstream, which is contrary to my hypothesis that nitrate level increases downstream because of the cumulative effects of pipe leakage, runoffs, and irrigation. The excess amount of nitrate found at Site 1 may be due to sources causing high turbidity level such as soil erosion and urban runoff.

Turbidity measures the cloudiness and the materials, such as algae and microbes, suspended in the water (EPA 2005). Turbidity is often used to indicate the water quality and filtration effectiveness (EPA 2005). Turbidity level exceeding 1.0 NTU is considered hazardous to human health, which is associated with unsafe levels of disease-causing microorganisms such as pathogenic bacteria (EPA 2005). High levels of turbidity can cause nausea, diarrhea, and headaches (EPA 2005). The lowest turbidity level was found only on non-rainy days on week 5 at Site 4 (Fig. 4 and 5), which was 1.0 NTU, while all other sites remained high. The research showed that an increase in turbidity may lead to an increase in nitrate, but nitrate may be the one that affects the turbidity level. The sources of turbidity include soil erosion, waste discharge, and urban runoff (EPA 2005). Soil contains certain amount of nitrogenous fertilizers; therefore when soil erodes, nitrate may be deposited into the creek. As a result, nitrate and turbidity are indirectly related and may be affected by one or the other (Fig. 8 and 9). The linear regression showed that on rainy and non-rainy days, an increase in turbidity by 1 NTU, also had an increase in nitrate by 0.09 mg/l.

Levels of chlorine total from all four sites range from 0.01 to 0.45 mg/l on both rainy and non-rainy days, which were below the EPA standard of 4 mg/l. The increased in chlorine levels at Site 3 may be due to pipe leakage of drinking water, which contains chloramines, a compound of ammonia and chlorine (Fig. 14 and 15). Other sources of chlorine that would be found in Strawberry Creek may be due to irrigation water running off of saturated lawn, spills from water main leaks, and illicit connections, which are the connections to the storm drain system that should be routed to the sanitary sewer (Maranzana 2005, pers. comm.). As a result from the research, most parameters were affected by precipitation and significantly differ in most sites, which resulted in certain areas being more polluted and more unsafe for human usage.

Due to the limited amount of test and time, one cannot draw a complete conclusion from the research to determine the safety of the water for human consumption. The tests only give an approximation of what the water quality is at the time of testing. Water quality may fluctuate in a short time period because other parameters might not have been considered. Another limitation is that samples were taken between November 2004 and February 2005, which only permitted examinations to the changes in water quality over a wet season. Water quality might differ during dry seasons with lower precipitation compare to wet seasons. Long term studies are necessary to determine the equilibrium water quality.

Acknowledgements

I would like to offer special thanks to Professor Bill Berry and Steve Maranzana for their assistance and support throughout the project. I would like to thank Stephen Andrew for letting me borrow the field equipments. Thanks to all ES196 instructors, especially Cristina Castanha for her advises and guidance throughout the year.

References

Carlson, Jim. 1971. The examination of Strawberry Creek for toxic heavy metals. Unpublished report for Interdepartmental Studies 10B, Office of Environmental Health & Safety, UC Berkeley, CA. pp11.

Charbonneau R. 1987. Strawberry Creek Management Plan, Office of Environmental Health and Safety, University of California, Berkeley, California.

Charbonneau R., and V.H. Resh. 1992. Strawberry Creek on the University of California, Berkeley Campus: A history of urban stream restoration. Aquatic Conservation: Marine and Freshwater Ecosystems 2(4): 293-307.

Cheung, Lori A. 1986. Analysis of Water Quality in Strawberry Creek. UC Berkeley Environmental Sciences Senior Seminar, 1986.

Environmental Protection Agency (EPA). 2005. Water quality. [Online] http://www.calepa.ca.gov/.

Frazier, T. 1983. Water quality in Strawberry Creek. UC Berkeley Environmental Sciences Senior Seminar, 1983.

IDEXX Laboratories, Inc. 2005. Use of IDEXX system. [Online] www.idexx.com.

Puckett, L.J. 1995. Identifying the major sources of nutrient water pollution. Environmental Science & Technology : 408-414.

Riley, A.L. 1998. Restoring Streams in Cities: A Guide for Planners, Policymakers, and Citizens. Island Press, Washington D.C.

State Water Resources Control Board (SWRCB). 2000. Volume I. Nonpoint source program strategy and implementation plan, 1998-2013 (Prosip). State Water Resource Control Board, Division of Water Quality, Sacramento, CA. January 2000.

Water Quality Associates. 1992. Lake Merritt Resource Enhancement Plan.