Monitoring the water quality of Sausal Creek, Oakland, Ca.: A comparative study on methods to detect urban pollution

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Abstract

Polluted urban creeks can affect the aquatic ecosystem and the human health of the community. Raw sewage entering a water system, either directly or via a leaking pipe, can spread pathogens such as *Vibrio cholerae* and *Escherichia coli*. Monitoring by regulatory agencies may be inadequate, so testing for sewage leaks by community organizations can be beneficial for locating systems that are in need of repair. Various methods were tested to compare their effectiveness in detecting sewage pollution and feasibility for a community group to use the methods for regular monitoring. Sausal Creek provided a good urban model because a sewage leak in the mid-stretch of the creek has degraded the water quality downstream. Two sites were chosen upstream from the leak and two downstream. At each site ammonia, dissolved oxygen, pH, conductivity, temperature, flow rate, total coliforms, *E. coli*, and insect abundance were measured. *E. coli* levels increased from a geometric mean of 1500 MPN at site 2 upstream from the point source to 22,000 MPN at site 3, creating an environment 50 times above the EPA objective. Ammonia and dissolved oxygen were also found to be effective on-site indicators of the sewage pollution, but may not be exclusively caused by sewage pollution. The bacterial analysis is an excellent indicator, but due to the necessity of laboratory facilities would probably not be suitable for most community groups. A cross-referencing plan of measuring ammonia, dissolved oxygen, and insect abundance is recommended to efficiently monitor an urban creek for sewage pollution. The observed recovery distance indicates that monitoring sites should be one kilometer or less in spacing to ensure that point source pollution is detected.

Introduction

With increased population growth more sewage is being produced by human beings around the world. Many areas do not treat this sewage and it enters the environment directly, overloading natural systems with organic nutrients and spreading pathogens that live in animal and human feces. In most developed nations sewage is treated, yet leaks in faulty pipes may allow untreated sewage to enter the environment. Either directly or through faulty pipes, this organic pollution has serious impacts on the aquatic ecosystem. The resulting drop in dissolved oxygen levels and increased ammonia downstream can create a region where a limited number of species that are tolerant to such conditions will survive, therefore decreasing species diversity (Buell and Girard 1994). The sewage can also be hazardous to humans that are in contact with the water, through drinking, washing, or by children playing in the contaminated water. Exposure to pathogenic strains of *Escherichia coli* that can be present in warm-blooded animal feces can cause diarrhea, and other pathogens, such as *Vibrio cholerae*, can be fatal (Buell and Girard 1994). Other human pathogens transmitted in water include *Salmonella typhi* (Typhoid fever), *Legionella pneumophilia* (Legionnaire's disease), Hepatitis A virus, *Giardia intestinalis* (Giardiasis), Poliovirus, and *Cryptosporidium parvum* (Cryptosporidiosis) (Black 1999). It is estimated that 30,000 people die every day in developing countries due to a lack of clean water (Black 1999). Although the effects are minimal compared to those in developing countries, North Americans may also be exposed to these risks. According to a Center for Disease Control estimate, 960,000 U.S. citizens will become ill from contaminated water annually, and 900 will die (Black 1999).

Introduction of disease agents can be caused by problems in the distribution and treatment system (Gleick 1998). It is therefore beneficial for neighborhood groups and nonprofit organizations to be able to monitor the health of their streams and public health risks. Coliform bacteria tests have been the best indicators of sewage pollution because these bacteria are found in the digestive tracts of humans and enter the environment through the discharge of wastewater that is not 100% disinfected. However, these tests require laboratory facilities and may not be available to community groups. Ammonia is produced from the hydrolysis of urea in urine or by decomposition of other nitrogenous materials in sewage. Sewage is the main source of ammonia added by humans, and the presence of

ammonia at high concentrations in a flowing stream indicates recent pollution somewhere in the vicinity (Friends of Sausal Creek 1999). Ammonia can be measured on-site, as can be dissolved oxygen, which drops after a sewage leak because of increased consumption of oxygen by decomposing material. Depletion of dissolved oxygen can cause shifts in the kinds of aquatic organisms found in an area. The range of species of aquatic organisms therefore decreases after a pollution input because of the toxic ammonia and anaerobic conditions. Sampling insects such as the Orders Plecoptera, Ephemeroptera, and Trichoptera can be an indicator of water quality because certain species are sensitive to pollution and will not be found in contaminated areas (Cummins and Merritt 1996). The examination of aquatic insect communities can therefore be a useful means of monitoring changes occurring within watersheds. Temperature and salinity affect the capacity of the water to hold dissolved oxygen, so increases in temperature and conductivity will affect dissolved oxygen levels and therefore species diversity as well (Friends of Sausal Creek 1999). The pH is also important because most organisms have adapted to a specific pH and may die if the pH changes even slightly. For example, the toxicity level of ammonia to fish varies tremendously within a small range of pH values (Friends of Sausal Creek 1999).

Sausal Creek in Oakland, Ca. provided a good urban model to test methods because preliminary data showed a sewage leak in the middle stretches of the creek that has degraded the water quality downstream (Aquatic Outreach Institute 1999). Two sites were chosen upstream of the point source and two sites downstream from the contamination source. I tested the hypothesis that insect sampling, ammonia, and dissolved oxygen methods are more feasible for community monitoring and just as effective as bacterial analysis for indicating pollution from sewage. I also tested the hypothesis that dissolved oxygen and insect abundance would not recover by my lowest site, approximately one kilometer downstream from the pollution source. This distance was estimated based on similar studies measuring the effects of sewage pollution on insect abundance and water quality (Mishra and Saxena 1984). The effects of the sewage leak on bacterial levels were also predicted to be more evident during my dry season sampling than during spring sampling by the Friends of Sausal Creek because of lower creek flow. It was predicted that conductivity would increase downstream from the sewage leak due to total dissolved solids in sewage, and alternatively, that the pH would decrease in the contaminated area. The results of this study can be used

on planning future methods and monitoring sites to efficiently pinpoint sewage leaks so they can be reported and repaired, thereby minimizing health risks and decreasing degradation to the aquatic environment.

Methods

Study site and sampling locations Sausal Creek originates from three branches above Highway 13 in the Oakland Hills. Shepherd, Palo Seco, and Cobbledick Creeks join to make up Sausal Creek, which runs through the lower hills, Dimond Canyon, and the Fruitvale area before entering the San Francisco Bay at the Oakland/Alameda Estuary near the Fruitvale Avenue Bridge (Fig. 1).

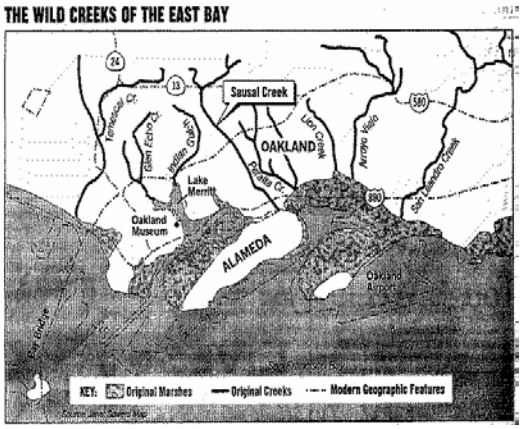

Figure 1. Sausal Creek (Friends of Sausal Creek 1999)

A sewage leak has been detected in the mid-stretch of the creek, above Highway 580 and below Dimond Park (Hayes 1999) (Fig. 2.) Four sites were studied, two upstream and two downstream from the pollution source. Site 1 on the Palo Seco branch is within Joaquin Miller Park and provides a reference site because preliminary data showed normal levels of dissolved oxygen and prevalence of pollution sensitive insects (Friends of Sausal Creek 1999). The three lower sites are within one and a half kilometers in an urban neighborhood. The creek flows from site 2 into a culvert and under MacArthur Blvd where the sewage leak has been detected (Hayes 1999). Site 3 is approximately 100 meters downstream from the point source, and the lowest site is another one kilometer downstream (Fig. 2).

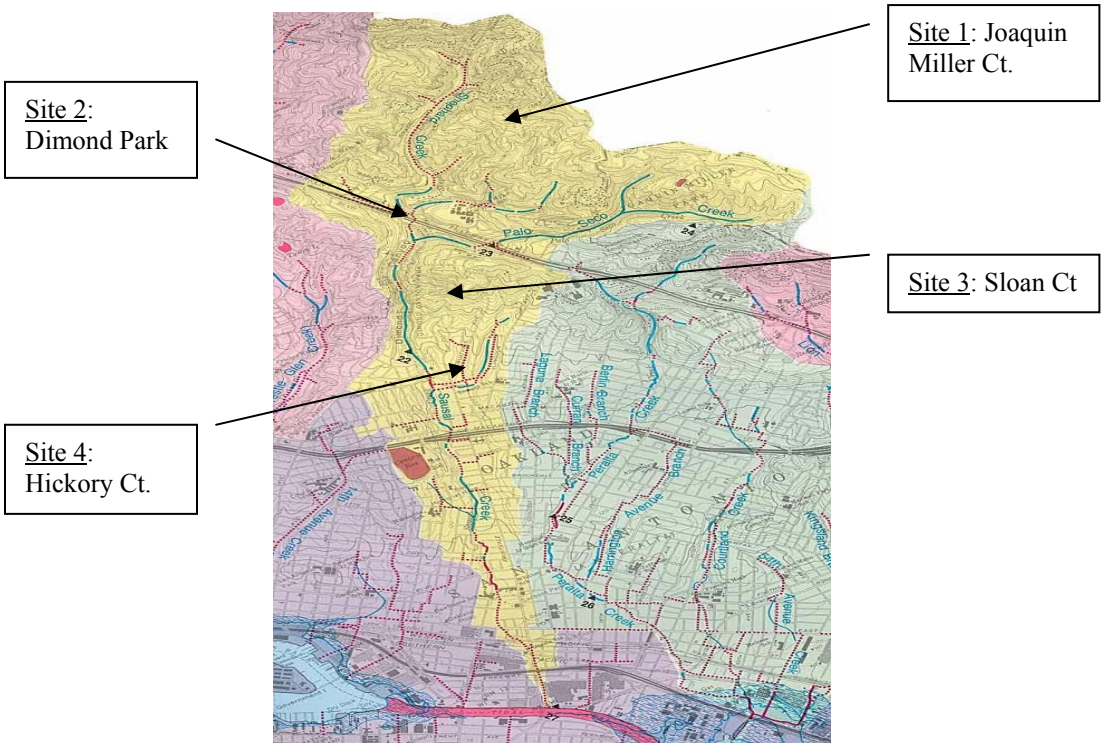

Figure 2. Sampling sites on Sausal Creek (Oakland Museum 1999)

Field tests In this study the indicators total coliforms, *E. coli*, ammonia, dissolved oxygen, pH, conductivity, and insect abundance and diversity were measured and compared for their ability to detect a sewage leak. Temperature and flow rate were also measured to assess natural influences on the other indicators. At each site the on-site methods of ammonia, dissolved oxygen, pH, conductivity, temperature, and flow rate were measured weekly over five weeks in the morning, strictly between 7:00-9:00 AM. Sampling was started at the most upstream site and continued downstream. The following equipment was used: LaMotte brand ammonia and dissolved oxygen kits, pH and TDS probes, a thermometer, stopwatch, measuring tape, and a small orange (for flow rate measurements). To measure the mean flow rate, three rates were taken at each site at a quarter, half and three quarter's the distance across and averaged. These on-site tests were done between the dates

of August 26 and September 22, 1999. All results were averaged over the five weeks and the standard deviation was calculated.

Bacterial analyses Bacterial analysis was also done weekly over five weeks starting September 8, 1999. The samples were also collected mornings, starting upstream. The 100 ml water samples were analyzed for total coliforms and *E. coli* at the EPA Region IV Laboratory in Richmond, Ca. according to the Colilert method. This method takes advantage of the characteristic that coliforms and *E. coli* possess the enzyme B-D-galactosidase and will degrade *ortho*-nitrophenyl-B-D galactopyranoside to produce a yellow product. *E. coli* also cleaves methylunbelliferyl-B-glucurinide and produces a fluorescent product which can be seen under UV light (USEPA 1999). The Colilert method requires only 24 hours to read and relies on the Poisson distribution to relate the pattern of coliform and *E. coli* results to a Most Probable Number (MPN) value per 100 ml sample (USEPA 1999). Materials needed for the Colilert method include Colilert 51-well Quanti-Trays, Colilert 24-hour media, sterile test tubes, dilution bottles, 100 ml sample bottles, pipette tips, a Quanti-Tray sealer, and a UV lamp (USEPA 1999). Following EPA standard operating procedure, a replicate sample was collected with each weekly batch for quality assurance. This replicate sample is a second sample collected at any site and analyzed in the exact same manner as the initial sample. A factor of two or more difference between a sample and it's replicate would indicate errors or contamination during field sampling or laboratory analysis (USEPA 1999). Samples were chilled on ice immediately after collection and during transportation to the laboratory. The samples were run as both full volume and 1:100 dilutions to ensure accurate detection of results over 2400 per 100 ml. The geometric mean and standard deviation of the five samples were determined for each site.

Insect sampling Insect sampling was done at each site on September 29 and October 6, 1999. Collection was made using a kick net with a mesh size of 1.5 mm and sampling included one minute of kicking and 30 seconds of scraping substrate by hand. Large debris was carefully removed and samples were placed in 95% ethanol and returned to the laboratory for identification. Insect identification to the genus level was based on a guide to aquatic insects of North America (Merritt and Cummins 1996), and other organisms were identified to class level using a guide to freshwater invertebrates (Covich and Thorpe 1991). Insect abundance was quantified by the total number of individual organisms of Class Insecta

found at each site, and insect diversity was quantified by the total number of distinct genus groups of Class Insecta found at each site.

Results

The results of the indicators measured on-site are given in Table 1. Results are presented as an average of five weekly measurements with the standard deviations. The pH and conductivity levels did not show a significant change due to the sewage leak. The pH continuously decreased downstream from an average of 8.70 (S.D. = 0.13) at site 1 to 8.36 (S.D. = 0.15) at site 4. Conductivity had especially high deviations between samples, as is shown at site 1 with an average of 482 μS and a standard deviation on 322 μS. Contrarily, dissolved oxygen and ammonia both gave consistent results and were good indicators of the sewage leak. Flow rate is significantly lower at site 3 because the creek is wider and shallower here than at the other sites.

Table 1. Average of five weekly samples

	Site 1		Site 2		Site 3		Site 4	
	Average	S.D.	Average	S.D.	Average	S.D.	Average	S.D.
dissolved ox. (ppm)	**8.5**	**2**	**8.4**	**0.8**	**6.5**	**1.15**	**7.5**	**0.612**
pH	**8.7**	**0.13**	**8.58**	**0.13**	**8.42**	**0.17**	**8.36**	**0.152**
conductivity (us)	**482**	**322.1**	**326**	**123.6**	**352**	**77.9**	**340**	**144**
ammonia (ppm)	**0.04**	**0.055**	**0.28**	**0.13**	**0.6**	**0.137**	**0.21**	**0.055**
temperature (C)	**13.6**	**0.418**	**14.9**	**1.14**	**15.5**	**0.612**	**15.8**	**0.57**
flow rate (m/s)	**0.26**	**0.021**	**0.282**	**0.167**	**0.192**	**0.034**	**0.23**	**0.067**

Table 1. Water quality measurements and indicators from Sausal Creek sampling sites.

Due to low levels of ammonia detected at site 1 the deviation was high, but at site 4 where the average level was .6 ppm the standard deviation was only .14 ppm. Temperature was relatively consistent between the three lower sites with averages differing by only .9 degrees Celsius. A significant change in dissolved oxygen levels (Fig. 3) and ammonia levels (Fig. 4) were apparent at site 3, downstream from the sewage leak.

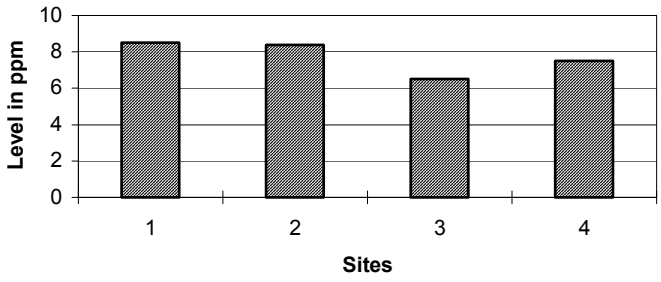

Figure 3. Average dissolved oxygen levels

8.5	8.4	6.5	7.5 do ave
0.04	0.28	0.6	0.21 ammoia

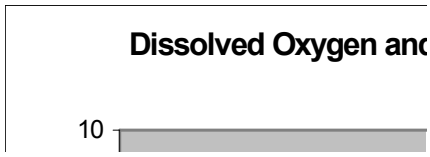

Figure 4. Average ammonia levels

Average ammonia levels were negligible at site 1, .28 ppm (S.D.=.06) at site 2, and increased to an average of .6 ppm (S.D.=.13) at site 3 and dropped to .21 ppm (S.D.=.06) at the lowest site. Dissolved oxygen levels started high at an average of 8.5 ppm (S.D.=2.0) and 8.4 ppm (S.D.=.80) at sites 1 and 2, respectively, then dropped to 6.5 ppm (S.D.=1.2) at site 3 and recovered lightly to 7.5 ppm (S.D.=.61) at site 4.

Bacterial analysis indicated an increased level of both total coliforms and *E.coli* at site three, just downstream from the sewage leak. Both levels decrease by site 4, but the coliform levels are still above the EPA objective of 2000 MPN per 100-ml sample (12). Results are recorded in most probable number (MPN) per 100 ml of water sample. Anne Hayes of the Aquatic Outreach Institute also did bacterial analysis during the spring high flow season. The same methods were used for collection and analysis at the EPA Region IX Lab (Fig. 5). This wet season sampling includes data collected at a site further downstream at Peroly Ct. (site 5), but does not include levels measured at site 1.

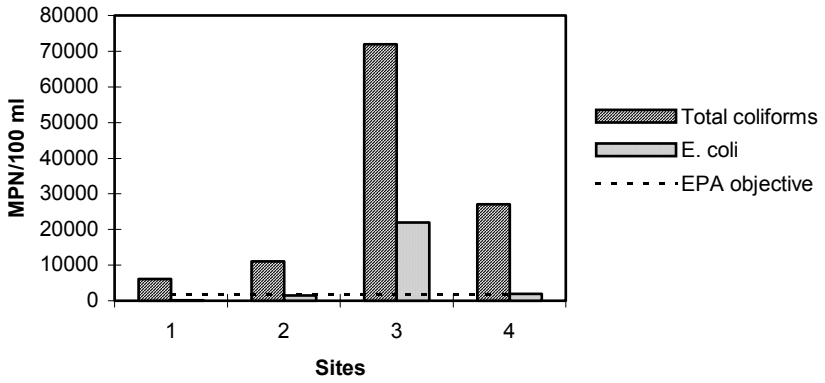

Figure 5. Geometric mean of bacterial analysis. EPA objective is 2000 MPN of total coliforms, set for non-contact water recreation (USEPA 1986).

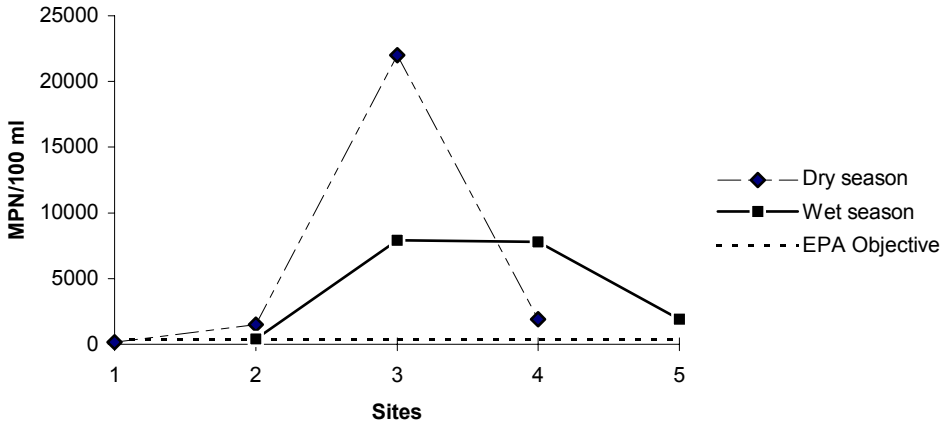

Figure 6. Seasonal variation in *E. coli* levels. EPA objective is 406 MPN *E. coli*, set for "lightly used" water contact recreation (USEPA 1986).

Bioassessment data represent a combination of organisms found in the two samples collected at each site (Table 2). While there were numerous insects collected which are typical of unpolluted water, the numbers and taxonomic diversity, especially of pollution-sensitive taxa, were fairly low in any given site or sample (Fig. 7).

	Site 1	Site 2	Site 3	Site 4
Class Insecta:				
Ephemoeroptera Heptageniidae Epeorus	10	2	0	0
Ephemoeroptera Leptophlebiidae Paraleptophlebia	5	1	0	0
Odonata Anisoptera Aeshnidae	1	0	0	0
Odonata Anisoptera Cordulegastridae Cordulegaster	0	0	2	2
Plecoptera Perlidae Calineuria	6	3	0	0
Plecoptera Taeniopterygidae Taenionema	3	0	0	0
Subphylum Crustacea:				
Amphipoda Hyallela	0	2	0	0
Phylum Annelida:				
Oligochaeta	4	23	34	21
Hirudinea	0	2	0	0
Phylum Mollusca:				
Gastropoda	0	7	3	1
No. of pollution-sensitive species	5	3	1	1
Total no. of pollution-sensitive organisms	25	6	2	2

Table 2. Bioassessment data for Sausal Creek benthic invertebrates.

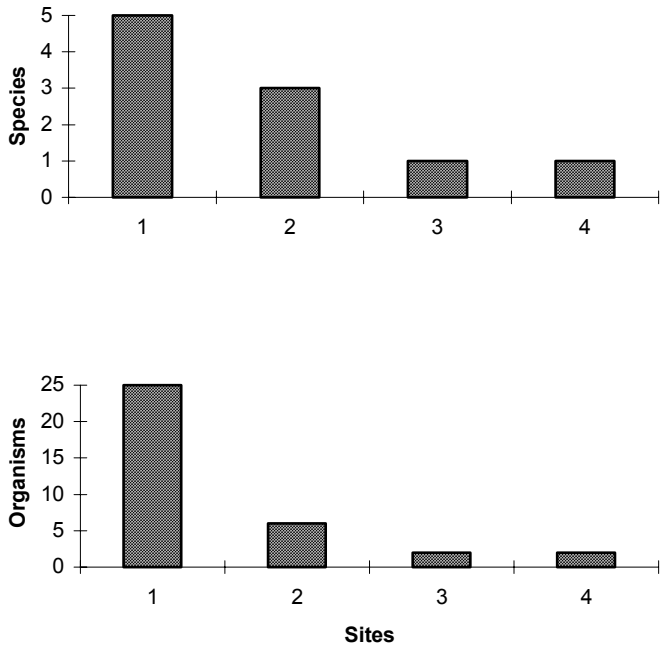

Figure 7. Species diversity and abundance

Discussion

Results of this study indicate that dissolved oxygen and ammonia levels were significantly disrupted by a sewage leak into Sausal Creek. The change in levels was easily detectable by simple tests performed on site. Bacterial analysis for *E. coli* and total coliforms confirmed a contaminated zone downstream from the leak and provided evidence that the polluted area is severely exceeding EPA objectives for freshwater bacterial counts. Insect abundance and diversity decreased at each site heading downstream, but the largest decrease in abundance occurred between sites 1 and 2 upstream from the sewage leak. Therefore insect sampling appears to be a good indicator of overall water quality, but with a small number of samples can not be considered an effective indicator of the sewage input.

A similar study found that grab sampling was not viable for detecting point source pollution sources because of diurnal variability in concentrations (Whelen *et al.* 1999). However, when all grab samples for bacterial analysis, insect abundance and diversity, and the other field tests were routinely taken in the early morning the contamination from the point source sewage leak on Sausal Creek was easily detected. It is possible that concentrations at other times during the day may have fluctuated. In another study, samples collected for bacterial analysis declined between 66-68% when collected in the afternoon, compared to early morning sampling (Obiri-Danso *et al.* 1999). This suggests that all grab samples consistently collected in the early morning should be effective in detecting point pollution sources. All results were fairly consistent with low standard deviations except conductivity readings. This may be explained by error in calibration of the conductivity probe and/or natural fluctuations between samples. Temperature and flow rate were measured to ensure consistencies between sites and sampling dates because significant fluctuations would disrupt levels in the other indicators. Temperature remained relatively consistent between the three lower sites with averages differing by only .9 degrees Celsius. Flow rate, however, was significantly lower at site three below the sewage leak because at this site the creek bed is wider and shallower. This may have influenced the bacteria and ammonia concentrations, creating higher peaks in these levels than would have been measured if the flow rate was greater and the pollutants could be flushed downstream.

Bacterial analysis revealed that site three directly downstream from the sewage leak is exceeding EPA objectives by over 35 times for coliforms and by about 50 times for *E. coli*.

The EPA criteria is based on five weekly samples collected from lightly used recreational areas for *E. coli* and non-contact water recreation for coliforms (USEPA 1986). The same criteria are not available for each test, but both could be applicable to Sausal Creek which people are usually not in contact with, except during the warm months when many children do play in the creek as it runs through Dimond Park. The high levels detected upstream from the leak indicate general poor water quality due to other pollution sources and may create a public health risk to children playing in the creek. Total coliforms, however, can have both plant and animal origins, whereas *E. coli* bacteria are produced only in the digestive tracts of warm-blooded animals, including humans (USEPA 1999). Therefore, the high coliform levels upstream could indicate other leaks in the sewer that runs along the creek, but since *E. coli* levels are not high these coliforms probably have other sources. The low levels of *E. coli* detected at sites one and two may be caused by contamination from dogs that are taken on the creek side trails and the large increase of *E. coli* at site three is due to the fecal matter in the sewage input just upstream from the monitoring site.

The field tests and bacterial analysis were conducted weekly over five weeks based on both EPA and California recommended criteria (USEPA 1999). However, insect samples were only collected over two weeks and therefore the poor results may have been due to the low sample size. It would be recommended to take more samples, but due to the time required to identify each set of samples, it is not feasible that volunteer monitors would be able to increase samples and monitor all four sites. Although the data collected from the two samples at each site were limited, it was sufficient to indicate the poor water quality downstream and would be useful information for future monitoring. Also, when insect abundance is naturally higher during the spring, as was seen with preliminary results, two samples at each site would provide better comparison between sites.

The data collected were sufficient to answer most of my original hypotheses. Insect sampling and tests for dissolved oxygen and ammonia were found to be simple and more feasible for a community group to use than bacterial analysis in a laboratory. However, alone the indicators are not as effective as bacterial analysis. Ammonia levels increased significantly upstream from the sewage leak due to other sources, so although there was an increase after the sewage leak, without bacterial results such an increase in ammonia could not be assumed to have been caused by a sewage leak. Dissolved oxygen levels did drop

after the sewage input, but it showed almost full recovery by the lowest site, so unless a monitoring site was just by chance directly downstream from the sewage input, the dissolved oxygen drop would probably not be detected. As mentioned, insect sampling is tedious and would require many samples at each site and would probably not be feasible for most volunteer groups. However, if all three tests are conducted regularly and cross-referenced they should provide adequate data indicating a point pollution source.

It was anticipated that dissolved oxygen and insect abundance would not recover by the lowest monitoring site approximately one kilometer downstream from the sewage leak. During my dry season study period with low flow rates it appeared that dissolved oxygen levels did almost fully recover by the lowest site. Insect abundance, however, did not recover and is likely because it was found to indicate overall water quality degradation and was not significantly influenced by the sewage leak.

The hypothesis that water quality degradation due to the sewage leak would be worse in the dry season was proven by the drastic peak in *E. coli* levels at site three during the late summer sampling compared to the spring sampling. Even though this localized contamination was worse, seasonal comparisons showed that during higher flows the pollution is more diluted near the source, but gets flushed downstream from the leak and is detectable further downstream. Based on these conclusions, sampling during the dry season is important because it reveals the worst case scenario of effects directly downstream from a point pollution source.

Conductivity and pH indicators were not as effective at detecting the contaminated zone as expected. Although pH decreased steadily downstream it did not indicate a significant change at site three. Conductivity was expected to increase at site three, and there was a slight increase from 326 μS (S.D.=124) at site two to 352 μS (S.D.=77.9) at site three. Since the standard deviations are so high this can not be considered significant and overall the conductivity is considered inconclusive because of the possibility of errors in the method used.

Conclusion It is recommended that monitoring sites be spaced one kilometer or less in distance. Partial recovery of ammonia, dissolved oxygen, and bacterial levels was observed at the lowest site, so sites further in spacing would potentially be too far in distance to detect the contaminated zone downstream from a point pollution source. However, for

many urban creeks, like Sausal Creek, monitoring at this spacing would be limited by poor accessibility due to culverting underground and private creek side property. In conclusion, this study has recommended methods that could be used to monitor urban creeks for sewage pollution. A cross-referencing plan between the on-site indicators of ammonia, dissolved oxygen, and insect sampling would be both feasible and efficient for use by a community group.

Acknowledgements

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