Measuring Enterococci Concentrations and Export During a Small Rainstorm on an Urban Creek in Santa Barbara, California

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Abstract

Over a 4-day period, beginning with a one inch rainstorm on February 2, 2004, volunteers from Channel Keeper sampled five locations along Mission Creek in Santa Barbara for enterococcus bacteria concentrations. Stream flow was continually measured at each sampling point and the increase in bacteria numbers, as the creek passed through the downtown urban area and into the ocean, calculated. Eighty two percent of the 114 samples analyzed failed to meet the enterococci standard of 104 cfu/100 ml for safe ocean-contact recreation; the most extreme example was 26,130 cfu/100 ml at the tidal limit during the peak of the storm. As runoff flowed down from the foothills and passed through increasingly developed areas, it became more contaminated with enterococci; average enterococci levels in the 24 hrs following the first rainfall steadily increased from 91 cfu/100 ml at the uppermost site to 6,018 cfu/100 ml at the tidal limit. During this interval 3.3 trillion enterococcus were flushed into the ocean from the creek: 88 percent of which originated in the downtown area. Two locations along the beach, down-current from where the creek enters the ocean, were sampled at the same time. There was a clear increase in enterococci levels along the beach associated with creek discharge. Pre-storm concentrations at the beach were negligible (<10 cfu/100mL) but rose as high as 2,110 cfu/100 ml, more than 20-times the accepted safe level; concentrations remained above the 104 cfu standard for 2 days following the storm.

Introduction

In 2001 there were 795 beach "postings" and 115 closures in San Diego, Orange and Los Angles counties (Schroeder et al., 2002). Postings are the placement of warning signs stating that at least one bacterial standard has been exceeded for unknown reasons and that there is a risk of illness associated with water contact. Closures are less frequent than postings and are usually the result of known sewage spills or persistent exceedence of bacteriologic standards. Beach postings and closures pose a threat to Santa Barbara's lucrative tourist industry by directly prohibiting or discouraging visitor use of the area's prime attractant, and by potentially fostering an impression of Santa Barbara's undesirability as a destination resort. The "percent exceedence rate" for Santa Barbara beaches, i.e., the percent of Public Health Department samples that fail one or more bacteriological standards during the year, has varied from 9 to 30 % over the past six years (SBC-PHD). While the overall trend is one of improvement with time, it remains unclear how much the length and intensity of the annual rainy season influences these results.

It is well established that bacteria concentrations along beaches are far higher during and immediately following storm events (Schiff, 1997; Lipp et al., 2001; Ackerman and Weisberg, 2003), and that high concentrations are associated with proximity to urban creeks and drains (SCCWRP, 1998; Simpson et al., 2002; Ackerman and Weisberg, 2003). Ackerman and Weisberg (2003), analyzing 5 years of fecal coliform data from Southern California, found that every storm with over 25 mm of rainfall (~1 inch) generated bacteria concentrations that exceeded standards, and almost all storms greater than 6 mm (~1/4 inch) did likewise. Concentrations usually remained elevated for 5 days after the event, but returned to acceptable public health levels within 3 days.

The Southern California Coastal Water Research Project (SCCWRP), with the help of 22 different organizations sampling 257 sites for bacteria concentrations on Feb. 20, 2000, 36 hours after a rainstorm, compared this "wet season" data with extensive "dry season" sampling done in August 1998 (SCCWRP, 1998). They estimated that 57 % of the shoreline miles from western Santa Barbara County to south of Ensenada, Mexico, failed one or more bacteriological standards following the winter storm, compared with less than 6 % during summer sampling (Figure 1). After the storm, 87 % of sampling locations in front of drains and freshwater creeks (67 % of locations within 100 meters) failed. During dry weather the corresponding percentages were 40 and 11. There were also qualitative differences: during dry weather only a single indicator was exceeded in two-thirds of the samples, and the failed result was usually only slightly above the standard; after the Feb. storm two-thirds of the samples failed multiple indicators, at least one indicator by more than twice the standard.

Despite recognition that rainy season stormflow is a major contributor of bacteria pollution to ocean beaches (as measured by indicator bacteria), the vast majority of bacteriological samples are collected during non-storm periods. Sampling during storms is relatively rare, and continuous measurement of the rise and fall of bacteria concentrations during storms on urban creeks rarer still. For example, the City of Santa Barbara follows an extensive, and exemplary, bacteria monitoring schedule as part of their Creeks Restoration and Water Quality Improvement Program. From June 2001 through May 2003 over 3100 samples were analyzed, only 16 of which were collected during storms: at 8 locations during two storms in Dec. 2002 (City of Santa Barbara, 2003).

There are a number of reasons for this: (1) storms on the Southern California coast are relatively rare and storm sampling cannot be scheduled (an average of 15 days a year with greater than ¼ inch of rain); (2) storm sampling by government employees is difficult and expensive to accomplish within the restrictions of overtime, agency regulations and administrative rules; and (3) the burden and cost of analyzing large numbers of unscheduled samples. A volunteer-based environmental organization would be exempt from many of these limitations, and Santa Barbara ChannelKeeper felt that by organizing and conducting a storm monitoring experiment it could help the County and City towards an eventual solution of the bacteria pollution problem. It might also help ameliorate the organization's environmental gadfly image, and perhaps improve relations with the various government agencies it deals with. The experiment would demonstrate the problems associated with an intensive short-term monitoring project and whether or not the organization was capable of undertaking other projects of this nature.

Accordingly, On Monday, Feb. 2, 2004 – Groundhog Day – ChannelKeeper begin sampling 5 locations on Mission Creek and two locations on East Beach (east of where Mission Creek enters the ocean) to monitor enterococci concentrations before, during and after the small storm that occurred on that day. Sampling continued until Thursday, Feb. 5. Sampling multiple sites along the stream would indicate which areas within the community were contributing the majority of bacteria. By co-locating sampling points and stream gauging stations it would be possible to quantify the change in bacteria export (the flux or actual numbers of bacteria) from site to site, and relate total export to concentrations seen along the beach.

Project Location

Mission Creek, a 2990 hectare coastal watershed (11.5 square miles), flows out of the Santa Ynez mountains (maximum catchment elev. 3944 ft) 80 miles northwest of Los Angles, California. The geology consists primarily of Tertiary marine sediments, mostly sandstones and shales, with substantial deposits of alluvial and colluvial material in the valley bottoms. The creek has two main tributaries that converge at Foothill Road: the main stem issuing from Mission Canyon (2.8 sq. miles) and Rattlesnake Creek (2.5 sq. miles). The Mission watershed begins within the Los Padres National Forest and can be roughly classified as 40 % mountains, 20 % foothills, and 40 % coastal plain. Land use is predominately urban (55 %), with chaparral scrub (35 %) and forest areas (9 %) forming the bulk of the remainder. There is little agricultural use (~2 %) within the watershed.

The watershed and the sampling sites are shown in Figure 2. The intensity of developed use increases as Mission flows downstream. The sampling locations follow a progression from completely undeveloped (Rattlesnake), to light-residential (large lots on septic systems above the main stem location labeled Mission Cyn), to increased residential development (Rocky Nook), to dense R-2 development and urban parks (above Oak Park), to complete downtown urban development at the tidal limit (Montecito Street). Catchment characteristics and land use in the Mission Creek watershed above each sampling location are shown in Table 1.

The climate is Mediterranean. Temperatures are mild, averaging 54 ° F in winter and 66 ° F in summer; there are no days of record with temperatures below 30 ° F. The average annual rainfall in Santa Barbara is 18 inches (46 cm), but the variation is extreme: a maximum of 47.0, a low of 4.5 (SBC-PWD). More than 90 % of the rain falls between Nov. and April, and a majority of the annual discharge in Mission Creek usually occurs over 3 to 7 days. There is a substantial rainfall gradient within the Mission watershed, rainfall totals at the mountain summit are usually twice those recorded in the downtown area. The stream is hydrologically “flashy” and responds within hours, and even minutes, to changes in rainfall.

The beach sampling stations were located in the normal “down current” direction from the Mission Lagoon and Laguna Channel. The Mission Lagoon, a brackish lagoon or estuary, extends 700 meters from the ocean to Montecito Street. Sometimes connected with the remnant of a large estuary on the east side of the downtown area, the Laguna Channel serves primarily as a storm drain. A low gradient insures that it is often flooded. “Beach 2” was 100 meters east of the channel, “beach 1” 300 meters further east.

Methods

Bacteria samples were collected prior to the storm: every two hours during the light drizzle with which the storm began, and hourly during, and for an extended time following, more intense rainfall; sampling intervals were then lengthened to every four hours, then 12 and finally once a day on the third and fourth days. Stream samples were collected just below the center of flow, by wading during low flow intervals, with a bottle sampler lowered from a bridge during higher flows. The sampler was rinsed 3 times with stream water prior to collecting the sample. Ocean samples were collected below the surface, knee-depth in the surf wash zone. All samples were transported on ice to the ChannelKeeper laboratory and analyzed within 4 hours.

Because of logistical constraints (the large anticipated number of samples and available incubator capacity) only enterococci concentrations were measured. IDEXX Enterolert® methodology (ASTM #D6503-99), an approved Environmental Protection Agency method (EPA, 2003a), was used for analysis. The sample, diluted with distilled, bacteria-free, water (at dilutions of 10:1 and/or 100:1), is used to fill multiple wells in an analysis tray. Enterolert uses an indicator that fluoresces when metabolized by enterococci and the number of positive “wells” after incubation for 24 hours at 41 °C provides a statistical determination of concentration. The unit of measure is the “most probable number” of “colony forming units,” abbreviated as either “MPN” or “cfu,” in 100 ml of sample. Quality control was evaluated by (1) analyzing “blank” zero bacteria samples, (2) multiple tests on a single sample using both the same and different dilutions, and (3) analyzing duplicate (split) samples at the City of Santa Barbara’s El Estero Wastewater Treatment Plant laboratory.

The five Mission Creek sampling sites were located at stream gauging stations: three maintained by the Santa Barbara Channel Long Term Ecological Project (SBC-LTER) at the University of California, Santa Barbara (UCSB) and two by the United States Geological Survey (USGS). Stream stage at the SBC-LTER stations is measured with pressure transducers and converted to flow using mathematical relationships based on channel cross-sections, slope and roughness as determined by surveys centered around the sampling points (HEC-RAS; USACE, 2002) (Robinson et al., 2003). The mathematical model is modified by actual measurements at lower flows. Flow is calculated at a 5-minute time step and subsequently aggregated to hourly discharge. Hourly flow was used for the enterococci flux calculations. When specific flow data was unavailable, as at the two malfunctioning USGS locations (Rocky Nook Park and Mission Street), data from past storms of similar magnitude (2002 to 2004), and stage measurements taken during sampling, were used to apportion flow. Enterococci data were adjusted to the nearest hourly timeslot, and linear interpolation was used to determine hourly concentrations between sampling points. Hourly enterococci concentrations were multiplied by hourly stream flow to calculate hourly flux.

Beach samples were also colorimetrically analyzed for nitrate (NO_3), ammonium (NH_4) and phosphate (SRP) using standard methods (Keeney and Nelson, 1982) on a Lachat-Zellweiger auto-analyzer by the SBCLTER.

Results and Discussion

Enterococci Concentrations

The Feb. 2, 2004 storm deposited one inch of rain on downtown Santa Barbara, 1.3 inches at the mountain crest (Figure 3). Runoff during the storm was almost solely confined to impervious surfaces (streets, roofs, sidewalks, etc.): almost no flow came from undeveloped portions of the watershed or areas with vegetation. This caused flow to dramatically increase with increasing downstream urbanization. Peak flows at Montecito Street were an order of magnitude higher than at Rocky Nook (Figure 3), two orders of magnitude higher than Rattlesnake.

Enterococci concentrations followed a similar pattern. The highest concentration occurred at Montecito Street on the rising hydrograph limb, just prior to peak flow (26,000 cfu/100ml). Flow at this time was mostly urban runoff from the lower downtown area. At the peak of storm flow (20:00 hrs or 10 PM), concentrations at Montecito Street decreased to 10,080 (Figure 4). After streets, paved areas and roofs were flushed by initial rainfall, later storm pulses fed cleaner runoff into the stream. After midnight, after the rain had stopped and creek levels began to decrease, enterococci concentrations began to rise. This was particularly noticeable in Mission Canyon and Rattlesnake, but was seen at all sampling sites (Figure 4). Probable causes may be water leaking back into the creek from temporary storage in the riparian zone, bringing with it bacteria from the soil as the water levels decline, or late contamination from delayed soil-water and shallow groundwater flows.

Figure 5 shows bacteria concentrations at Montecito Street and the Mission Lagoon during and after the storm, and the results from samples collected along the beach to the east of the Lagoon ("beach 2" and "beach 1" are 100 and 400 meters east of the Lagoon entrance, respectively). During the height of the storm, beach concentrations were approximately a thousand times lower than at Montecito Street, but after the rain stopped the difference decreased: beach concentrations at one point reached 1350 cfu/100ml, 13-times higher than the 104 public health limit and about a tenth of the Montecito St. concentration. It's interesting that "beach 1" had, at times, higher enterococci concentrations than "beach 2." At the beginning and at the end of the storm, further away from the creek mouth usually meant cleaner (less bacteria), but this was not always the case when runoff was high. Beach enterococci concentrations may not follow a simple pattern due to mixing in the surf zone and the presence of small storm drains that feed storm runoff across the beach between major creeks and culverts.

Ocean concentrations may be further complicated by groundwater and soil-water seepage through porous beach sands following the storm. Although not shown here, nitrate concentrations at the beach sampling locations remained unchanged during, and immediately after, the storm. However, two days later they began a 10-fold rise (to ~10 µM from a background concentration of 1 µM) that continued past the end of bacteriological sampling. The increase can only have been caused by delayed seepage through the dune barrier. While the 1 inch rainfall generally did not satisfy existing soil moisture deficits, much of the impervious surface runoff from the downtown section adjacent to the beach is funneled across open areas (non-impervious soils and vegetation) before reaching storm drains. The combined runoff impacting these areas may be many-fold greater than direct precipitation. Under these conditions we would see recharge of soil and ground waters, and subsequent outflows. This mechanism could be responsible for continuing high enterococci beach concentrations days after Mission Creek flow had decreased to near negligible levels (circa 2 cfs).

Average daily concentrations give a broader picture of what happened during the storm. In Figure 6a, simple averages of sample concentrations collected over 24 hr periods, beginning with the storm, show increasing bacteriological contamination with increased urbanization. The only exception to this pattern on subsequent days was the increased concentration at Mission Canyon on the second day. As mentioned previously, this may be due to delayed soil-water flows; homes adjacent to the creek in this area are on septic systems. Only Rattlesnake Creek had average daily concentrations below the public health maximum (ocean standard) throughout this period. Using the hourly flux estimates, daily volume weighted mean concentrations can also be calculated for each site (Figure 6b); the results are similar.

Enterococci Flux Estimates

The hourly flux estimates are shown in the upper panel of Figure 7. These are summarized as daily export in the middle panel. The numbers are large. On the day of the storm 3.3 trillion enterococci were flushed into the ocean; hundreds of billions on each of the successive days. The flux during the day of the storm increased 500-fold over the day before, and remained 20-times higher during subsequent days.

The lower panel in Figure 7 shows the gain in enterococci numbers from sampling station to sampling station, in other words, the total numbers of bacteria originating from areas lying between the sampling stations. Of the 3.3 trillion enterococci that were flushed into the ocean on the day of the storm, 2.9 trillion, or 88 %, came from downtown Santa Barbara. Mission Creek at Oak Park, dry prior to the storm, dried up early on the second day. Thus all the bacteria that flowed into the ocean on subsequent days came from the downtown area. The daily enterococci export is contrasted with average daily beach concentrations in Figure 8. Health Departments in California coast counties typically advise swimmers and surfers to stay away from the water for 3 days following a storm. That advice that seems pretty well founded based on our results, particularly for swimming or surfing near a creek mouth or storm drain.

Bacteriological Testing

The Santa Barbara Public Health Department collects weekly water quality samples from 20 beaches in the county (SBC-PHD). Samples are taken from “ankle to knee deep” wave wash 25 yards down-current from creek outlets and are analyzed for three types of bacteriological indicator organisms: coliform, fecal coliform and enterococcus. The County has four standards for ocean beaches, a 100 milliliter (ml) sample (about 4 ounces) must have less than (1) 400 fecal coliforms, (2) less than 104 enterococcus and (3) less than 10, 000 total coliforms unless the fecal-to-total-coliform ratio is greater than 0.1, in which case the total number of coliforms cannot exceed 1,000.

Coliforms are a family of bacteria found in the intestines (and fecal matter) of mammals. Unfortunately, they are also found in soil and plant material so high numbers may not actually indicate contamination from human and animal waste. Fecal coliforms are a narrower sub-group, more tightly restricted to organisms found in fecal matter and regarded as a better indicator of contamination. Enterococci, a sub-classification of intestinal fecal streptococci, also indicate the presence of fecal waste and have the desirable characteristic of being particularly long-lived in salt water; enterococci tests are regarded by the Environmental Protection Agency (EPA) as the best indicator of ocean contamination (EPA, 2003b).

It's important to stress that only in rare cases are these indicator bacteria themselves dangerous to human health. It is difficult and expensive to test for actual disease causing bacteria and viruses, and these tests are rarely done. Instead, bacteria easy and inexpensive to test for are used to indicate "*possible pathways of contamination*" based on studies that have shown statistical relationships between the numbers of indicator bacteria like enterococci and fecal coliforms and human disease and infection (Pruss, 1998; EPA, 2003b). For example, the EPA's allowable numbers of bacteria in a water sample are based on studies of gastrointestinal illness in swimmers. For ocean beaches, the standard is the average number of enterococci associated with illness in no more than 19 swimmers in 1000; this number is 35 enterococci.

The key word is *average*. A single sample can be used to approximate an average if limits are placed on how much error, or chance, is acceptable. Some samples will have lower numbers, some higher. Based on studies of samples collected at ocean beaches across the country, the EPA has calculated that 104 enterococci in a single water sample have a 25 % chance of being included as part of an average of 35 (the average used here is a geometric mean of at least 5 samples collected within a month, and the single sample limit is determined by the product of the geometric mean multiplied by the antilog of the log standard deviation of marine samples, 0.7, times the area under the probability curve for a confidence interval of 75 %, 0.68)

Using these studies, state and other regulatory bodies, including the SBC-PHD, have established allowable limits of indicator bacteria, depending on the type of aquatic recreational activity. The unit of measure is usually the "*most probable number*" (MPN) of bacteria in 100 ml of sample. Another term often seen is "*colony forming units*" (cfu): what are counted in the analysis are the number of bacteriological colonies formed; it's a simplifying and reasonable assumption that each colony begins with a single bacteria from the original sample. The tests are typically statistical, individual colonies are seldom directly counted, and the actual number represents an estimate.

To be a reliable measure of the possible presence of pathogenic bacteria and viruses in water a good indicator organism has to originate from similar sources, it has to exist in greater concentrations and have a longer life span in the natural environment, it has to be easily identified, and its concentration should be easily determined (Schroeder *et al.*, 2002). Aside from being easy to identify and measure, there are good reasons to believe that our current indicators of bacteriological contamination often fail all other measures. It was generally accepted that the intestinal bacteria relied on as indicators could not long survive, and more importantly, reproduce, in an open environment. The intestines of humans and other mammals are dark, warm (36-42°C) and nutrient rich; streams, rivers and ocean beaches are, in contrast, sun-lit, cold and nutrient poor, as are, generally speaking, other exposed surfaces.

However, while it is generally true that *Escheria coli* and enterococci, regarded as the most suitable indicator organisms, are found only in low concentrations in uncontaminated waters, they can survive and grow in natural waters (Francy et al., 2000; Nasser and Oman, 1999), and reproduce in plants (Solomon *et al.*, 2002) and soil (Hardina and Fujioka, 1991; Marino and Gannon, 1991; Solo-Gabriele *et al.*, 2002). Other research has shown that some pathogens may even have greater survival rates (McFeters and Stuart, 1972; McFeters *et al.*, 1974). The primary mechanism for the elimination of these bacteria from water may not be adverse environmental conditions but predation by zooplankton (Rassoulzadegan and Sheldon, 1986).

Perhaps directly applicable to Santa Barbara, Solo-Gabriele *et al.* (2000) found that river-bank soil was the principal source of dry weather *E. coli* in a Florida stream, and that *E. coli* exhibited a competitive advantage over predators as soils dried. In a study done for Caltrans, Schroeder *et al.* (2002), under dry summer conditions, washed 3 x 3 meter plots of soil and impervious surface with 100 liters of tap water (roughly equivalent to a rainfall of 0.43 inches) and sampled the resulting drainage for indicator bacteria; a selection of these results are reproduced in Table 2. In 97 samples with high indicator counts, collected mainly from drains in wet and dry weather, they found pathogenic bacteria or viruses in only 12 and concluded "urban drainage occasionally contains pathogens [but] there seems little reason to believe that the presence of pathogens is statistically correlated with the presence of indicator organisms."

There is accumulating evidence that our present tests are poor indicators of pathogenic contamination and that public health may not be adequately protected by our reliance on them. There are ongoing efforts to develop new and better methods, but replacement will be difficult. The traditional indicators, developed over the past 75 years, are now codified in Federal and State law. Any new methodology will have to compete against inertia and this time-honored acceptance, and it is doubtful whether any replacement will occur in the near future. The inadequacy of these tests should be kept in mind at a time when numerous expensive infrastructure projects to treat minor stormflows and dry weather runoff are being proposed.

That said, the epidemiological correlation between indicator bacteria and gastrointestinal illness in swimmers remains unequivocal, and the state and EPA continue to issue public health standards based these organisms. Howsoever imperfect, these tests remain the only practical, accepted methodology of evaluating public safety.

City and County Results

The County of Santa Barbara's Project Clean Water (SBC-PCW) sampled selected storms extensively during the winters of 2000, 2001 and 2002. Depending on year and event, 4 to 45 locations on creeks and drains in and around the South Coast cities of Santa Barbara, Goleta and Carpinteria were sampled (SBC-PCW, 2000; 2001; 2002). Grab samples for indicator bacteria were programmed to be collected at or near peak runoff, but given practical considerations and the three to four hours of field time spent sampling, the phrase "during the main part of the storm" is probably more appropriately applied to the data. Since the mix and numbers of sampling sites varied considerably over the years, we have simply summarized enterococci results by storm date, downtown Santa Barbara rainfall amounts, and minimum, maximum and median concentrations (Table 3). We have added results from two previously mentioned storms sampled by the City of Santa Barbara's Clean Creeks Program (City of Santa Barbara, 2003) and this project.

Results from the Groundhog Day storm were compatible with these other sampling efforts. If anything, the maximum enterococci concentration found at Montecito Street is on the lower end of the scale. Given a varying mix of sites, if we take the median as perhaps the best measure of the overall tendency of each sampled storm, the median "stormflow" enterococci concentration is 15,500 cfu/100 ml with a 95 % confidence interval of ± 9,500; the Montecito Street median of 8,500 fits comfortably within this range. Surprisingly, there is a pattern to the median concentrations listed in Table 3: the correlation coefficient between median concentration and rainfall is 0.51; -0.67 between concentration and water-year month (using October, the start of the water-year, as month 1). Based on the premise that luck sometimes favors the foolhardy, regressing median concentrations on rainfall and water-year month (enterococci = 5,500*rainfall – 4,700*month + 28,000) yielded a significant regression with an r-square of 0.69. Presumably, this could be interpreted as an increase in enterococci concentrations with increased flushing intensity, combined with a relative decrease due to antecedent flushing as the rainy season progressed.

On Nov. 28-29, 2001 Santa Barbara County sampled a relatively small storm that deposited 0.7 inches of rain on San Jose Creek (SBC-CWP, 2001); this storm followed a much larger event (1.5 inches) 5 days earlier. Bacteria samples were taken at four locations along the creek, one pre-storm, and others at four times during the rise and peak of the runoff hydrograph. San Jose creek flows through an intensifying gradient of land use: beginning in pristine Forest Service lands, it successively flows through orchard, residential, commercial and, finally, industrial areas. Sampling locations were chosen to roughly coincide with these land use boundaries. To our knowledge this is the only other intensive, consecutive sampling of bacteria stormflow concentrations in the Santa Barbara area.

Results are similar (Figure 9): pre-storm enterococci concentrations in the hundreds (200-500 cfu/100 ml), with peak concentrations in the range of 20,000 to 40,000. Interestingly, there was a noticeable contrast between *E. coli* and enterococci concentrations throughout the event. In pre-storm samples, enterococci concentrations slightly exceeded *E. coli* numbers. However, as the storm progressed, the ratio between *E. coli* and enterococci concentrations decreased to around 0.5 at the lower three sites, closer to 0.1 at the highest elevation location. Given the Public Health limits for both indicators, the expectation is exactly the opposite: higher *E. coli* numbers. Analysis of non-storm ChannelKeeper, and Santa Barbara County and City data (not shown) leads us to the conclusion that while higher-elevation, more pristine and less developed sites show lower concentrations for both indicator organisms, enterococci concentrations are noticeably higher than *E. coli* numbers. During storms, developed urban locations tend have higher *E. coli* to enterococci ratios than either undeveloped catchments or those subject to intensive irrigation. These observations, and the strong correlation between enterococci concentrations and rainfall discussed above, appear to suggest, not fecal contamination but relatively greater survivability and reproduction of these bacteria in the mild Santa Barbara climate.

Conclusion

The small Groundhog Day storm followed a month long dry spell and it was no surprise that most of the bacteria came from the developed downtown area. Almost all creek runoff during this type of storm comes from impervious areas: hard surfaces that shed water. In contrast, rain falling on drying soil is typically retained, contributing little to stream flow. There was almost no increase in Mission Creek flow above Rocky Nook Park and most of the enterococci bacteria came from the same places as the water, aided by the debris that accumulates on streets and gutters, in storm drains and along paths wherever storm water flows. This project sampled a small storm, but a big storm, a heavy, end-of-rainy-season storm, when the entire watershed from mountain crest to coast is supplying copious runoff to the creek, would probably be significantly different. As would a similar small storm during a wetter interval, one following a series of closely spaced earlier storms. The enterococci contributions from soils and from frequently flushed urban surfaces during storms remains to be documented. The exercise did show that a volunteer group could, with some forethought and a small number of dedicated members, conduct this type of sampling program. Hopefully, sampling these additional types of storms will become the focus of future projects.

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Table 1. Catchment characteristics (area and vertical relief) and land use in the Mission Creek sub-catchments above the sampling locations (Physical data were generated from a 30-m DEM, and the major land use categories were derived by interpretation of high-resolution aerial photographs (1:42,000 with a resolution of 6 feet) using an Anderson Level III land use classification.

sampling site	area	relief	Land Use: % of watershed above sampling site				
	sq. miles	ft	urban	agriculture	forest	chaparral	impervious
Rattlesnake	2.2	2883	0	1.5	10.6	89.0	0
Mission Cyn	2.8	3369	7.3	3.2	23.5	62.9	2.2
Rocky Nook	6.5	3627	18.9	2.2	15.3	62.3	5.7
Oak Park	8.2	3863	34.1	2.5	12.2	50.0	10.2
Montecito St.	11.6	3944	53.0	1.8	8.7	35.6	15.9

Table 2. Bacteriological results from dry season flushing experiments (Schroeder *et al*., 2002).

	at a park in Laguna Nigel		at a residence in San Diego		
	soil	pavement	soil	roof	pavement
total coliform	280,000	5,000	140,000	<2	<2
fecal coliform	16,000	20	100,000	<2	<2
E. coli	9,000	20	N/A	N/A	N/A
enterococcus	500,000	22,000	>2,005	75	164

Table 3. Storm flow enterococci concentrations from grab samples collected by Santa Barbara County and the City of Santa Barbara: the results are a composite evaluation from single samples collected at different sampling sites during a given storm (SBC-PCW, 2000; 2001; 2002); concentrations are in units of cfu/100 ml. Total rainfall for each storm (in inches, as measured at Santa Barbara) is included. The county sample (storms 1 through 10) includes various sampling locations along the south coast; city results (11 and 13) are a sample of Mission Creek and downtown area drains (City of Santa Barbara, 2003). The Groundhog Day storm is shown in bold italics (***12***).

	storm date	minimum	maximum	median	no. of sites	rainfall
1	01/17/2000	598	50,000	14,136	19	0.28
2	02/10/2000	2,481	241,920	24,810	45	1.04
3	04/17/2000	431	241,920	16,430	41	3.36
4	10/26/2001	1,296	241,920	46,110	17	3.13
5	01/08/2001	73	104,620	15,531	19	0.49
6	01/24/2001	598	34,480	12,033	23	1.39
7	02/09/2001	2,300	24,192	6,524	4	0.89
8	04/06/2001	132	24,192	1,576	19	1.89
9	10/30/2001	794	120,330	26,130	19	0.75
10	02/17/2002	20	24,192	1,124	19	0.47
11	12/16/2002	3,180	72,700	21,950	8	3.23
12	***02/02/2003***	***200***	***26,130***	***8,430***	***1***	***1.15***
13	02/12/2003	8,570	54,750	28,930	8	3.68

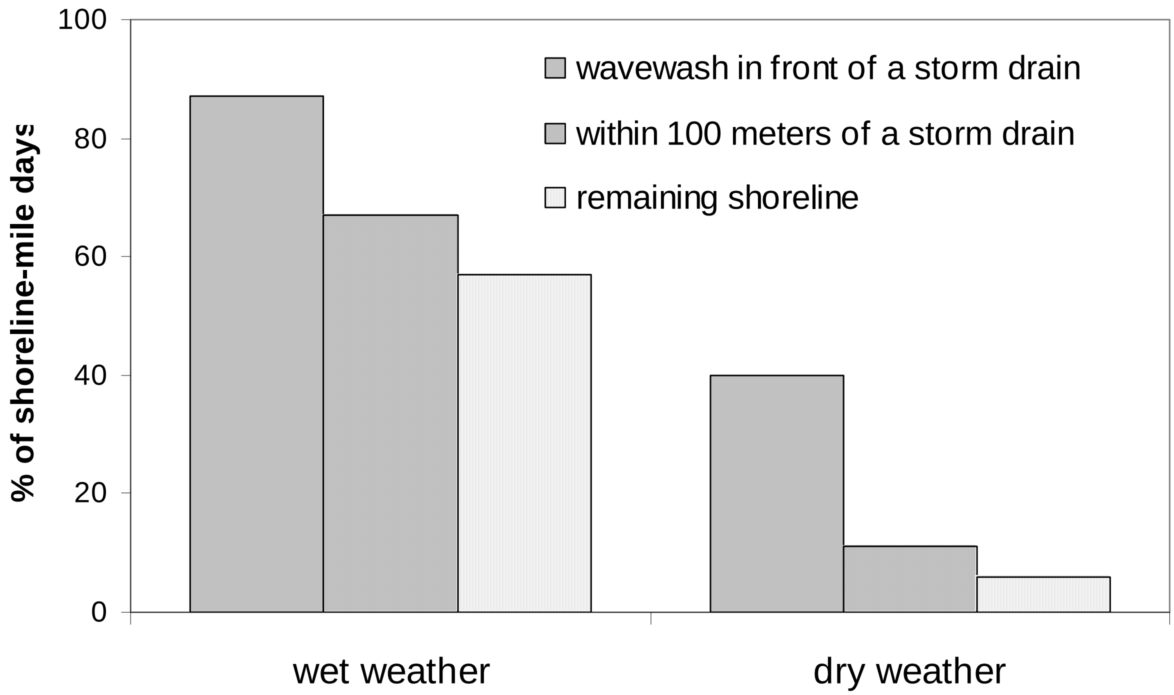


Figure 1. Percent of shoreline-mile days failing one or more bacteriological water quality tests in the Southern California Bight during wet and dry weather. The Bight extends 700 km, from Pt. Conception in Santa Barbara County to Cabo Conett, south of Ensenada, Mexico. The figure is reprinted from SCCWRP (2003) and represents a stratified random sampling of 251-307 locations in 1998-2000.

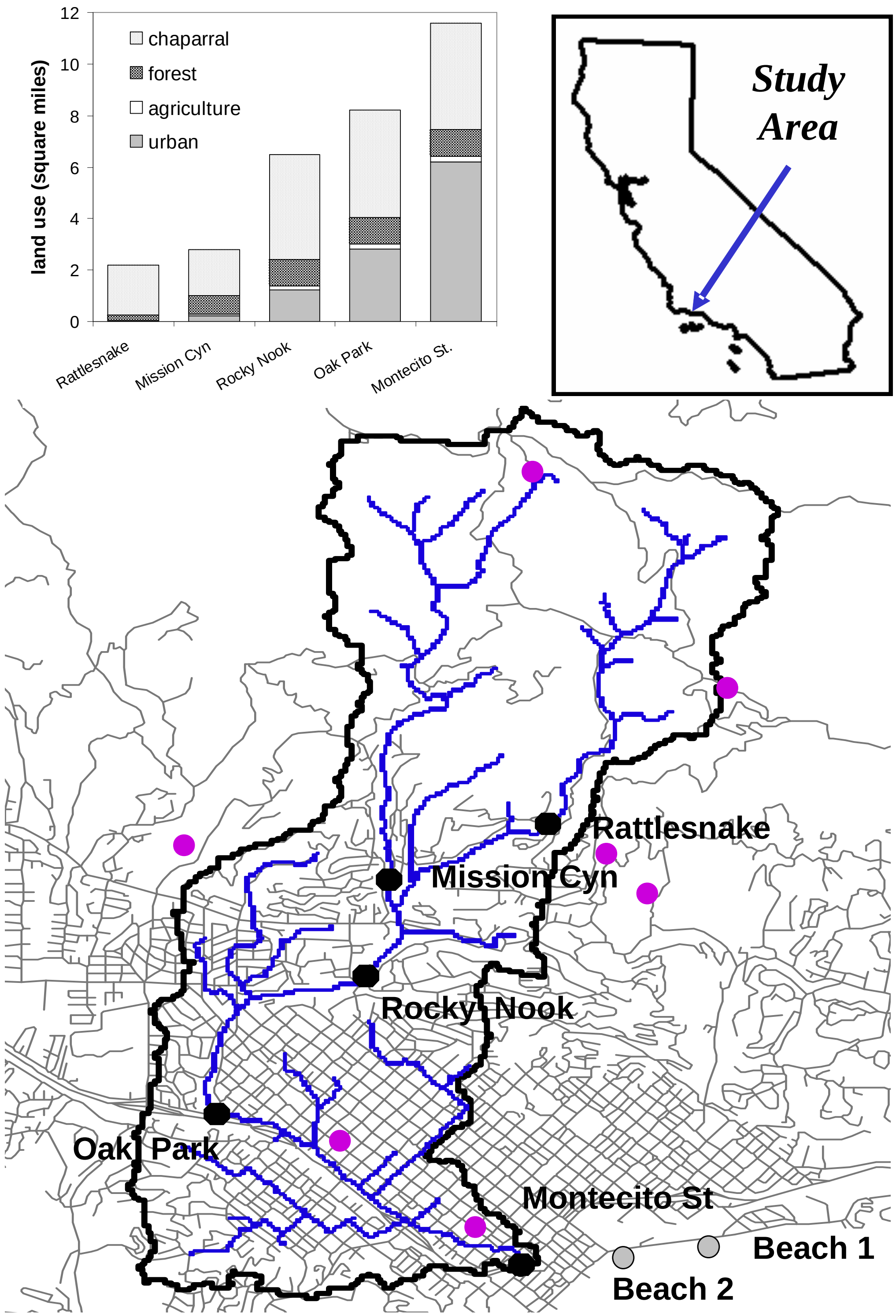


Figure 2. Location Map: the Mission Creek watershed and adjacent area. Mission Creek (dark circles) and beach (grey circles) sampling locations are indicated on the map. Locations of Santa Barbara County rain gauges are shown by #. The chart shows land uses sampled by each stream sampling station.

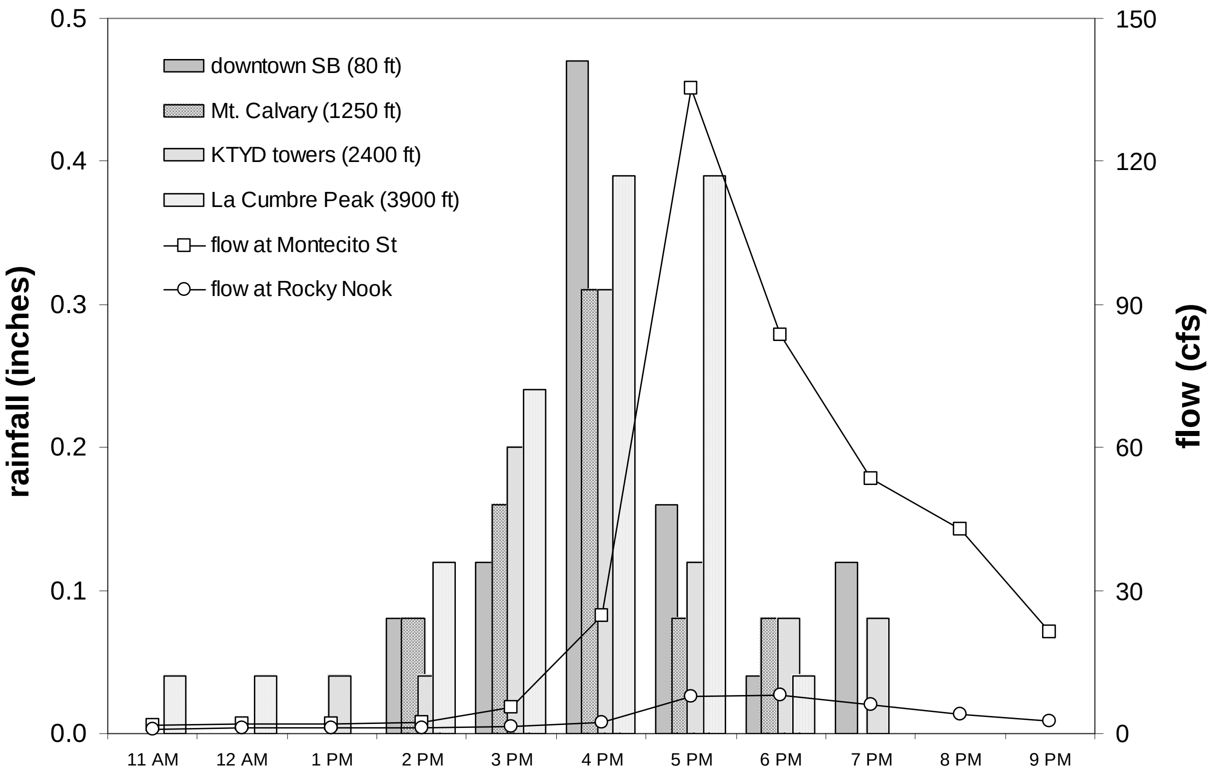
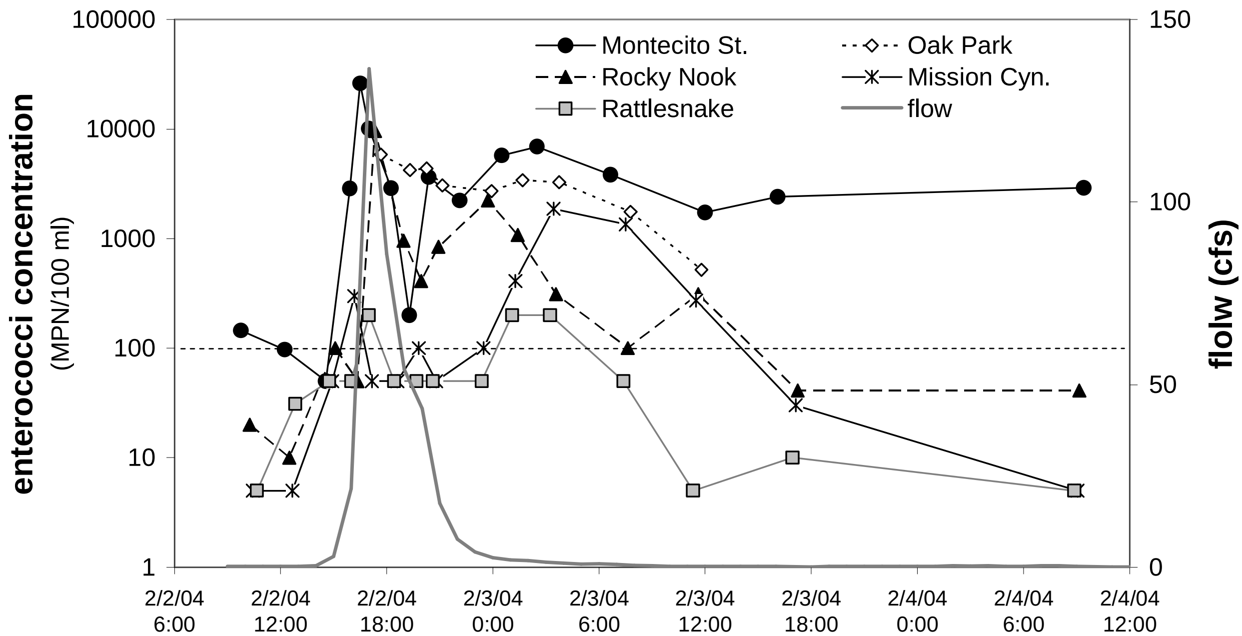


Figure 3. Rainfall during the Feb. 2, 2004 storm. The station elevation is given in parentheses; all 4 rain gauges are located within the Mission Creek watershed (data from Santa Barbara Flood Control rain gauge network). Hourly hydrograph data from Montecito Street and Rocky Nook are also shown (the flow unit is cubic feet per second, cfs).



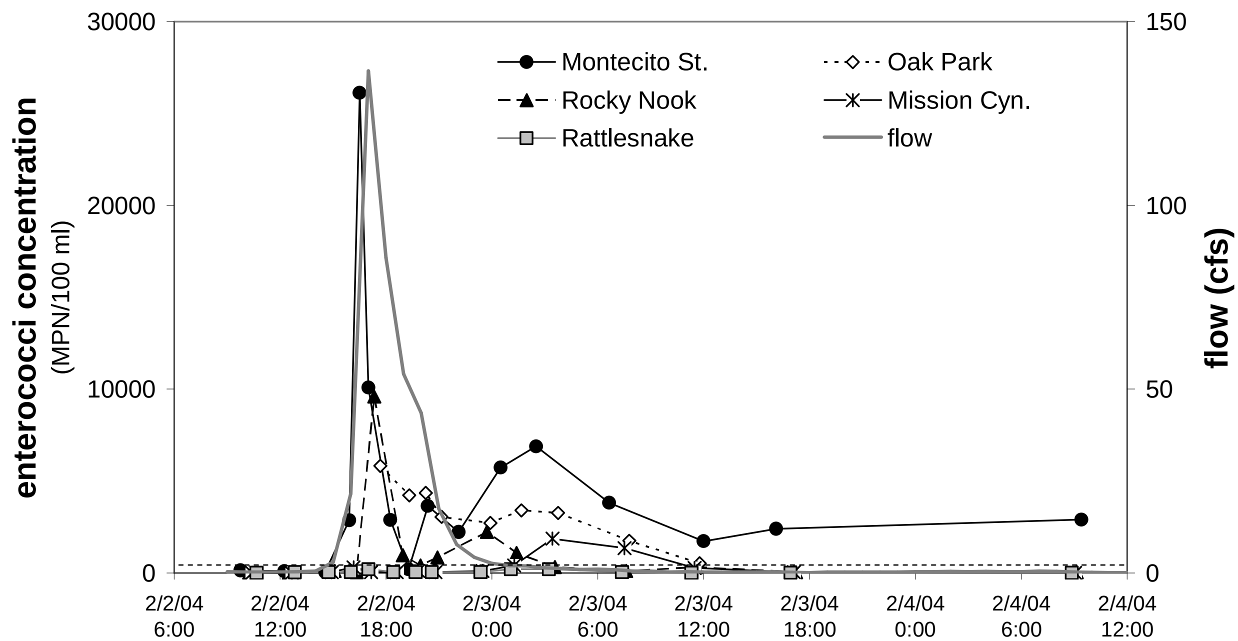


Figure 3. Enterococci concentrations at the Mission Creek sampling sites during the storm of Feb. 2, 2004. Flow at Montecito Street is shown in the background. The same data is shown in both graphs, with a log scale in the upper panel to allow both low and high values to be read, with a linear scale in the lower to better assess relative differences. The dashed horizontal line marks the Public Health enterococci limit for ocean beaches (104 MPN/100 ml).

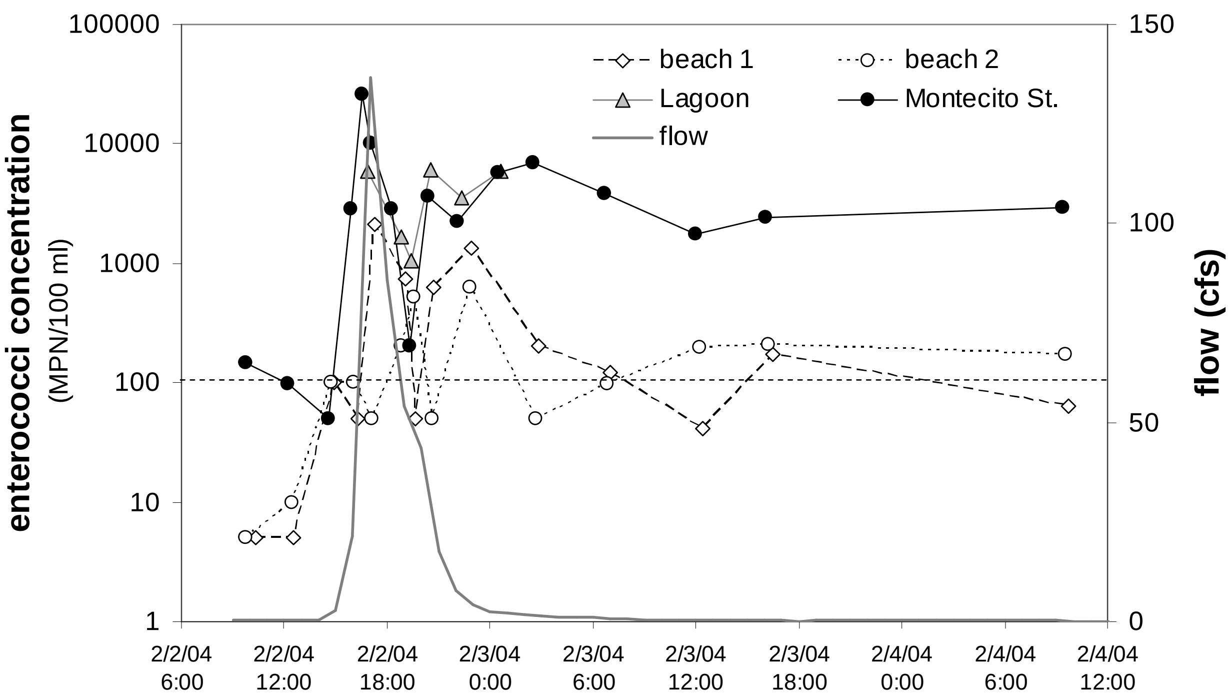


Figure 5. Enterococci concentrations in Mission Creek at Montecito Street, in the Mission-Laguna Lagoon, and at the beach sampling points during and after the Feb. 2 storm. "Beach 2" and "beach 1" are 100 and 400 meters east of the Lagoon entrance, respectively. Montecito St. flow is shown in the background; the 104 MPN enterococci beach limit is shown as a dashed line.

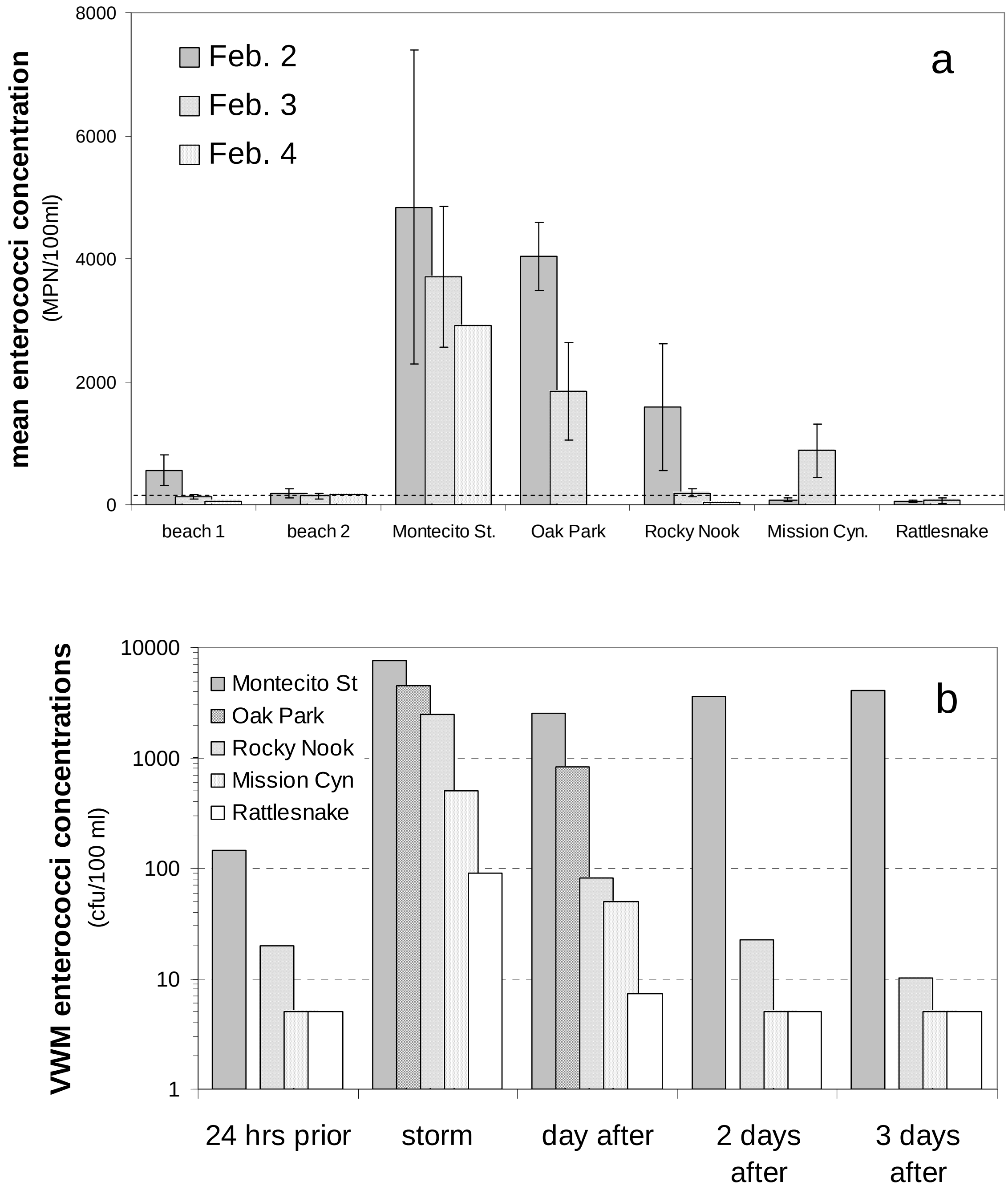


Figure 6. (a) Mean enterococci concentrations at the Mission Creek and beach sampling points for the day of the storm and two days afterward; error bars represent the standard error of the mean. (b) Volume weighted mean concentrations for the 5-day interval beginning with the day before the storm; calculated from the hourly flux estimates.

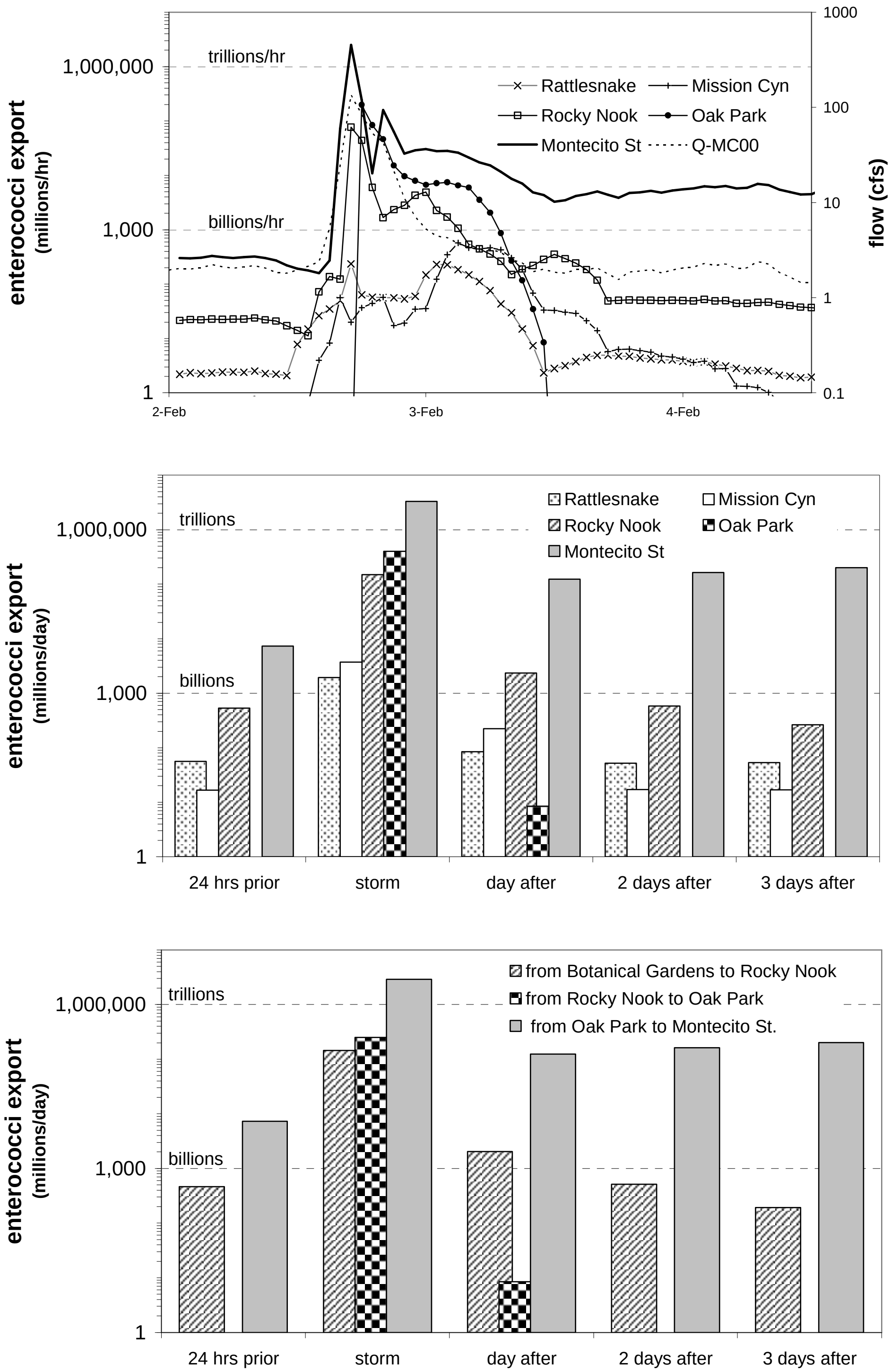


Figure 7. Variation in enterococci export (flux) in Mission Creek during and after the Feb. 2 storm: hourly export in the upper panel, daily export in the middle. The lower panel shows the gain in enterococci numbers from sampling station to sampling station during the 5-day sampling interval, i.e., the flux contribution from areas lying between sampling stations. Missing Rocky Nook to Oak Park data indicates a dry creek bed (no flow).

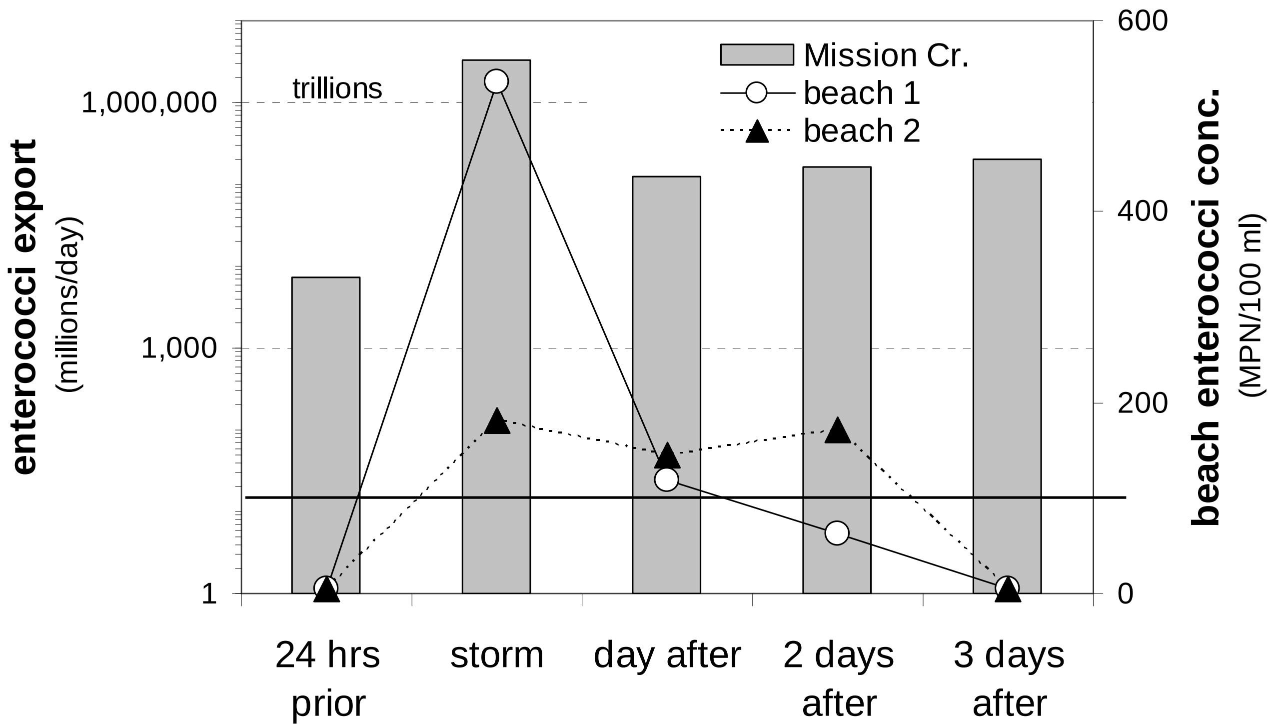
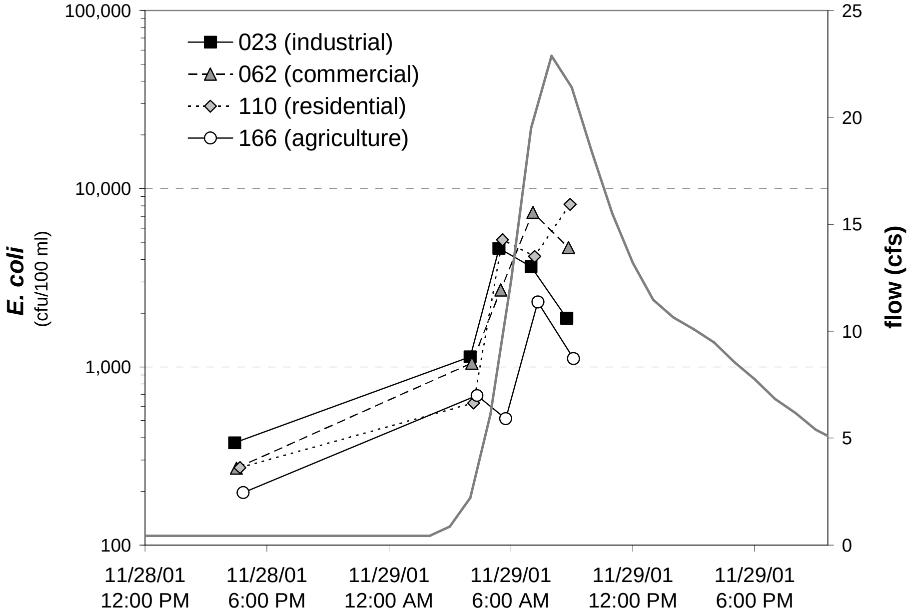


Figure 8. The total daily flux of bacteria from Mission Creek into the ocean and corresponding average daily concentrations at the beach sampling sites. The solid horizontal line marks the 104 enterococci beach limit.



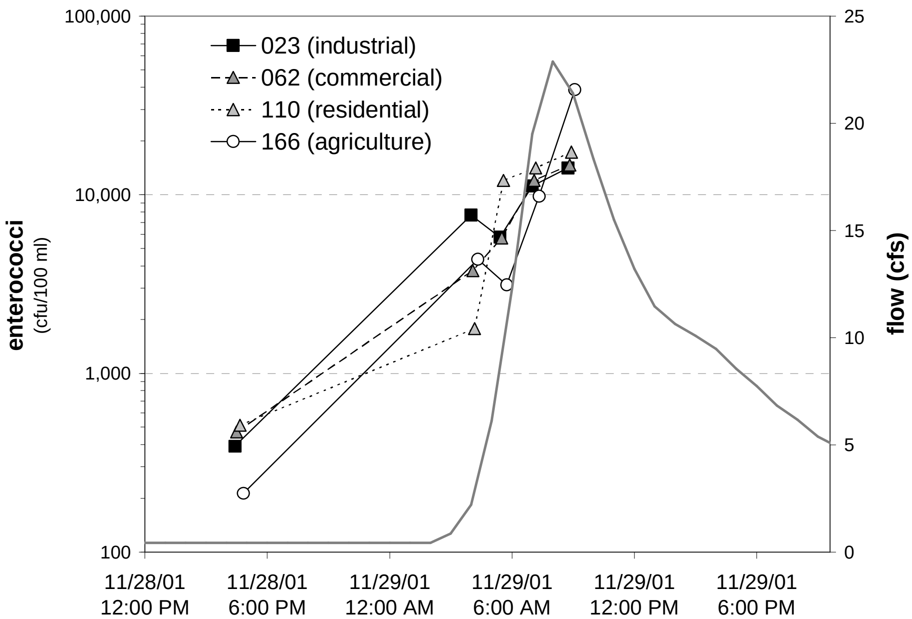


Figure 9. Enterococci (lower) and *E. coli* (upper) concentrations at four San Jose Creek locations during a small storm in Nov. 2001 (0.7 inches of rainfall) (SBC-CWP, 2001). The stream flows from Forest Service lands through an increasing intensity of land uses; locations are numbered in stations (100 ft intervals) from the creek mouth and the land uses in parentheses indicate the dominant use immediately above each sampling point.