## A Curious Relationship between E. coli and Enterococci

Members of two bacteria groups, the coliforms and fecal streptococci, are used as indicators of possible sewage contamination because they are commonly found in human and animal feces. Although they are generally not harmful themselves, they indicate the possible presence of pathogenic (disease-causing) bacteria, viruses, and protozoans that also live in human and animal digestive systems. Their presence in streams suggests that pathogenic microorganisms might also be present and that swimming and eating shellfish might pose a health risk. Since it is difficult, time-consuming, and expensive to test directly for the presence of a large variety of pathogens, water is usually tested for coliforms and fecal streptococci instead.

Bacteria are reported as the "*most probable number*" (MPN) of bacteria in 100 milliliters (100 ml, about 4 ounces) of water; a statistical test is usually used instead of directly counting bacteria, so the actual number remains an estimate. California Public Health requirements for bacteria counts are complicated and vary somewhat by jurisdiction. Basically, four separate indicator organisms are used to judge the public health risk. For freshwater recreational use (swimming), the total coliform limit is "no more than 10,000 per 100 ml in a single sample;" for enterococcus, *E. coli* and fecal coliforms, the single sample limits are 61, 235 and 400, respectively. The State of California reduces the single sample total coliform limit to 1,000, *if the fecal/total coliform ratio is greater than 0.1* (in other words, as long as more than 10 % of the coliforms are of fecal origin).





## While preparing an article for the Channelkeeper newsletter

(http://www.stream-team.org/) on the big January 2005 storm that struck Southern California, I came across something that aroused my interest: the relative concentrations of enterococci during the storm were, almost invariably, far higher than E. coli.

The two bar charts show these concentrations: we sampled on January 8 on the Ventura River (VR, bottom) when flows were still relatively modest, and on January 9 in Goleta (top) when the storm became very intense. Notice that only three Ventura locations had higher E. coli than enterococci concentrations, and this occurred at only a single Goleta site. Notice also that the Goleta differences are generally greater. I find it interesting that the higher January 9 flows seem to have relatively lower E. coli concentrations, and that the sites with the least differences are either urban (AT3) or highly contaminated (VR04). VR14 is a big exception – and it's a relatively pristine site with higher E.coli than enterococci concentrations



What brought this all to mind was this figure, which was made using Santa Barbara County's "Project Clean Water," data from a storm in November 2001(http://www.countyofsb.org/project c leanwater/). I've plotted an approximate hydrograph (discharge is modeled from County rainfall data) to give an indication of when samples were collected in reference to the storm's progress. The county monitored five locations on San Jose Creek during this event; I've only plotted two: one at either end, SJ023 below Hollister Ave. (the lower, industrial section), and SJ166 at N. Patterson above Cathedral Oaks Rd. (an upper site at the urban boundary). Concentrations at inbetween sampling points fall, more or less, between these two extremes. The first sample is a pre-storm sample; and the results are what we might expect: lower concentrations for all indicators at the upper boundary of Goleta development, higher below Hollister at the bottom end.

The last sample appears to have been taken just past the storm peak. Notice that the upper end now has higher total coliform and enterococci concentrations than the lower sampling point (the lower location was sampled about 20 minutes before the upper). There is almost no development above this location except an orchard. Notice too that *E. coli* concentrations are lower than enterococci values, and that the difference becomes greater as the storm progresses. Indeed, at the time of the last samples, *E. coli* numbers were decreasing as enterococci increased: for the last sampling, enterococci concentrations are 1.5 orders of magnitude higher than E. coli at the most undeveloped site. That this location, at the peak of the storm, had the highest enterococci numbers is quite intriguing. If I wasn't supposed to know better, I'd say that these enterococci concentrations will be relatively unrelated to pathogenic concentrations, that they are being flushed out of soil and other relatively innocuous environments, and that the high numbers indicate high survivability, and even reproduction, of enterococci in these environments.



## City of Santa Barbara, "Clean Creeks Project" data

(http://www.santabarbaraca.gov/Government/Departments/Parks\_and\_Recreation/Creeks\_Division\_Main): samples collected during storms from various drains within the City and at locations along Mission Creek. I don't know at what time these samples were collected, nor in what order, but the December event was very big storm on December 16 (peak flows ~ 1200 cfs), and the February sampling occurred during the second pulse of another reasonably sized storm on February 12 (flows ~ 200 cfs). Again there is a pattern, stronger for the second event than for the first, of higher enterococci than E. coli concentrations.

My working hypothesis is that only in heavily contaminated areas, or in dense urban clusters, will we see enterococci stormflow concentrations equal to, or less than, E. coli concentrations. The greater the percentage of undeveloped or agricultural crop land, the higher enterococci concentrations will be relative to E. coli numbers. I think the cause has to do with relatively greater survivability and reproduction of enterococci in the mild Santa Barbara climate.





If we look at non-storm samples,

we see the opposite picture: *E. coli* concentrations are usually higher than enterococci. The EPA single sample limits for freshwater contact recreation reflect this: 235 for *E. coli* vs. 61 for enterococci. The figure shows geomeans (for the time spans indicated) for Channelkeeper samples; these represent baseflow averages since it is extremely rare for a storm to coincide with a sampling day.

Notice that almost all the Goleta samples show higher E. coli than enterococci concentrations - these reflect urban nuisance waters and agricultural runoff. The only site that has higher enterococci concentrations is Maria Ygnacio, which only flows for a week or so after big storms. We see the same in Ventura: most sites have higher E. *coli* numbers except those that are (1) relatively pristine, (2) feature golf-course watering, or (3) only flow during and shortly after storms. These features are represented by sites VR09 through VR15.



This City of Santa Barbara "Clean Creeks Project" data shows five point moving geomean averages at three sampling locations along Mission Creek (MC00 is at Montecito St, at the tidal limit; MC07 is at the Mission Cyn. Bridge (a relatively pristine upper catchment area with some residential development); and RS02 is Rattlesnake at Skofield Park (allundeveloped Forest Service land).

However, unlike the previous data, these are almost all baseflow samples; in other words, samples taken between storm periods and during the April to September dry season. While the higher-elevation, more pristine and less developed sites show lower concentrations for both indicator organisms (as expected), enterococci concentrations are noticeably higher than *E. coli* at the two relatively undisturbed locations. At times E. coli concentrations at RS02 and MC07 are an order-of-magnitude lower.



**Data from the last figure is re-plotted here on a single graph to better show the contrast between enterococci and E. coli** concentrations at Rattlesnake (RS02, an undeveloped site) and Mission at Montecito St. (MC00, in the downtown area at the tidal limit). Again, these are five point moving geomeans. Notice at Montecito St., where we are dealing mainly with urban nuisance waters, *E. coli* concentrations are higher than enterococci – in line with the respective EPA limits (interestingly, the ratio of the respective limits is 3.85, i.e., 235 divided by 61, while the average ratio of the data is 3.61). However, *E. coli* concentrations at Rattlesnake are lower than enterococci; the average ratio between *E. coli* and enterococci is 0.41 – not quite, but almost – the reciprocal of the Montecito St. ratio.



**County of Santa Barbara** "Project Clean Water" data from the November 2001 storm on San Jose Creek. This was a relatively small storm which followed the biggest storm of the year five days earlier; the hydrograph is modeled flow below Hollister and should be considered approximate. I've plotted bacteria ratios for three of the locations the County sampled (the other two show similar relationships): one at either end, SJ023 at the end of Kellog, below Hollister Ave., and SJ166 at N. Patterson above Cathedral Oaks Rd., and the third at Hollister itself.

The concentration ratios are E. coli to enterococci, and fecal coliform (FC) to total coliform (TC). The FC/TC ratio is a standard California test for water quality; ratios greater than 0.1 indicate a greater probability of fecal contamination and intestinal illness, and trigger a lower total coliform limit: reduced from 10,000 to 1,000 MPN/100 ml. The County did not measure FC, so I've multiplied E. coli concentrations by 1.7 to estimate FC (1.7 is the ratio between the Calif. FC and EPA's E. coli limits, 400 and 235 MPN, respectively, and it implies that 60 % of the fecal coliforms in a sample were E. coli).

The ratios at each site track each other extremely well (except for a single point), and the relationships between locations are maintained. If we assume that both ratios indicate the relative probability of fecal contamination, the story they tell is reasonably logical and confirms what we would typically envision happening: ratios decreasing from pre-storm levels with the first flush of runoff from relatively clean impervious surfaces, increasing early on the rising hydrograph limb, and then again decreasing as the storm reaches and passes its peak. During the main part of the storm, the upper-elevation site shows about five times (half an order of magnitude) less contamination than the lower locations. If enterococci are behaving like total coliform concentrations, it is not unreasonable to believe they also must originate in sources not directly associated with fecal contamination.