TECHNICAL PAPER #0506

SEDIMENTS AS A REFERVOIR OF INDICATOR BACTERIA IN A COASTAL EMBAYMENT: MISSION BAY, CALIFORNIA

Prepared by:

Stephen Gruber
Larissa Armand
Andrew Martin
Weston Solutions, Inc. (WESTON®)

For Presentation at:

StormCon® 2005

July 18-21, 2005
JW Marriott Grande Lakes
Orlando, FL, USA

05P-0778-3

SEDIMENTS AS A RESERVOIR OF INDICATOR BACTERIA IN A COASTAL EMBAYMENT – MISSION BAY, CALIFORNIA

Stephen Gruber, Larissa Aumand, and Andrew Martin, Weston Solutions, Inc., Carlsbad, CA

ABSTRACT

Mission Bay is a large, heavily-used coastal embayment within the City of San Diego that includes over 27 miles of recreational shoreline. Historically, exceedances of state water quality standards for indicator bacteria (total coliform, fecal coliform, and enterococcus) have been a persistent problem at some beaches in Mission Bay. A 2-year comprehensive study was conducted to investigate and identify the numerous potential sources of bacterial contamination in the Bay receiving waters and surrounding watershed. As part of the investigation, intertidal sediments were assessed at some sites to determine the extent to which the beach sands act as a reservoir for indicator bacteria. The results suggested that bacterial densities in upper intertidal beach sands were significantly greater than those in lower intertidal beach sands. In addition, when the sediments in the upper intertidal zone were resuspended during simulated swimming activity, bacterial densities in the water column were an order of magnitude greater than those in samples collected when sediments were not disturbed. This pattern was not observed when the experiment was conducted in the lower intertidal zone. This phenomenon suggests that swimming activity may lead to greater bacterial densities in the water column and helps explain the pattern of bacterial contamination observed at some sites in Mission Bay. The study also has potentially-important implications for other recreational beaches in southern California.

INTRODUCTION

Mission Bay, located in the City of San Diego, California, is used by millions of people each year for a variety of recreational activities. Unfortunately, elevated levels of indicator bacteria (total coliform, fecal coliform, and enterococcus) have affected water quality in some areas of Mission Bay. As a result, in 1998, the entire bay was listed as an impaired water body under Section 303(d) of the Clean Water Act for exceedances of indicator bacterial standards (i.e., AB411 criteria). To address this problem, the City of San Diego obtained a Clean Beaches Initiative Grant (funded under Proposition 13) to conduct the Mission Bay Bacteria Source Identification Study to identify and remediate sources of bacterial contamination to the Bay.

A review of historical data suggested that there were differences between the densities of indicator bacteria on summer holidays (Memorial Day, Fourth of July, and Labor Day) versus non-holiday summer days at some beach sites in Mission Bay. At Bonita Cove, for instance, the mean density of enterococcus during summer holidays (449 MPN/100 ml) was significantly greater than during non-holiday days (79 MPN/100 ml) ($p = 0.016$). The large difference in enterococcus levels between holidays and non-holidays suggested that during these two time periods there may be different mechanisms at work related to bacterial densities in the water column.

A possible explanation for this pattern was the resuspension of intertidal sediments by swimming activity on holiday weekends. Numerous studies have suggested that beach sediments often contain higher densities of indicator bacteria than the overlying water column (An et al. 2002, Grant et al. 2001, Solo-Gabrielle et al. 2000, Howell et al. 1996). In addition, enteric bacteria have been shown to survive and, to a certain extent, even to grow in both freshwater and marine sediments (Grant et al. 2001, Solo-Gabriele et al. 2000, Davies et al. 1995, Hood and Ness 1982).

The study had two primary objectives: (1) determine if intertidal sediments (i.e., beach sands) of Mission Bay act as a reservoir for indicator bacteria; and (2) assess the extent to which bacteria in sediments impact receiving water quality when the sediments are resuspended.

MATERIALS AND METHODS

Bacterial levels in intertidal sediments were characterized at two locations: Bonita Cove (Site 1), and Leisure Lagoon (Site 9) (Figures 1 and 2). At each site, two types of assessments were conducted: beach face transects, which provided a profile of bacterial densities in the intertidal sediments from the high to low tide marks; and sediment resuspension analysis, which provided a measure of the extent to which resuspension of beach sediments contributed to bacterial levels in the receiving water.

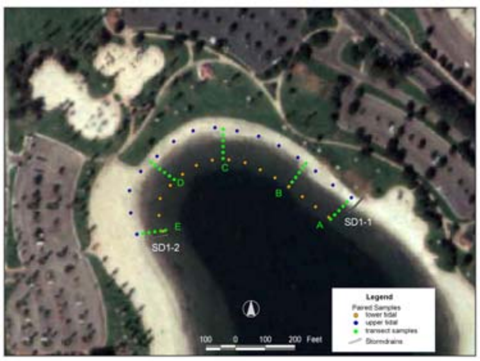

Figure 1. Sampling stations for the sediment investigation at Bonita Cove.

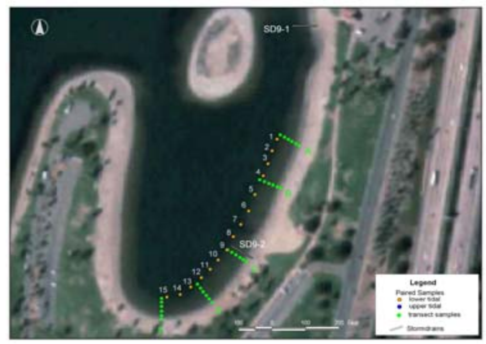

Figure 2. Sampling stations for the sediment investigation at Leisure Lagoon.

Beach Face Transects. Bacterial densities were measured along beach face transects at Bonita Cove and Leisure Lagoon. At each site, five transects were positioned along the beach face. Each transect ran perpendicular to the Bay from a tidal height of 0 to +6 feet above Mean Lower Low Water (MLLW). Along each transect, samples of surficial sediment were collected at tidal height positions of 0, +1, +2, +4, +5, and +6 above MLLW. At each of the two sites assessed, a total of 30 sediment samples were taken (5 transects x 6 stations).

Sediment Resuspension. At each site, a total of 15 stations were positioned along the beach face parallel to the water and identified with survey flags. At each of the 15 stations, two consecutive water samples were taken. The first was a "clear-water" sample, which was taken without disturbing the underlying sediments. Immediately after the clear-water sample had been collected, the sampler disturbed the sediments at that location by mixing the beach sediment into the water column with his feet (similar to what a swimmer would do). A sample was then taken from the water column that contained the resuspended sediment. We refer to this as the resuspended sediment sample.

Laboratory Analyses. All sediment and receiving water samples were analyzed at the MEC Analytical Systems Microbiology Laboratory in Carlsbad, California. Fecal coliforms were analyzed using multiple tube fermentation based on Standard Methods 9221E. Enterococcus bacteria were enumerated using a chromogenic technique (IDEXX Enterolert), based on Standard Methods 9223. Bacterial densities in sediments are presented in MPN/g dry weight.

RESULTS

Bonita Cove. At Bonita Cove, fecal coliform densities in intertidal sediments were similar at tidal heights of +6, +5, +4, and +2 feet above MLLW, with geometric means of the five transects ranging from 32.5 to 101 MPN/g dry sediment (Figure 3). At tidal heights of +1 and 0 feet above MLLW, fecal coliform densities dropped dramatically, with geometric means of 1.4 and 2.6 MPN/g, respectively. Mean fecal coliform densities in the upper intertidal sediments (+6, +5, +4, and +2 feet above MLLW) were significantly greater ($p < 0.0001$) than those in the lower intertidal sediments (+1 and 0 feet above MLLW). Densities of enterococci in intertidal sediments showed a similar pattern to that observed for fecal coliforms. The results suggest that sediments in the upper intertidal zone at Bonita Cove act as a reservoir for indicator bacteria.

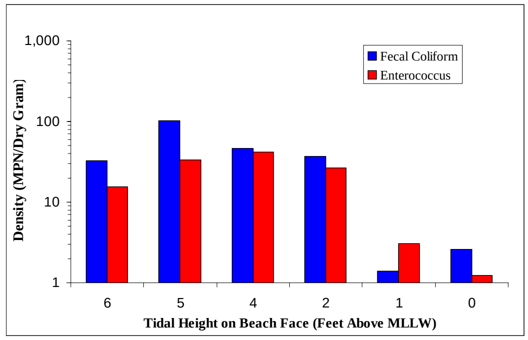

Figure 3. Fecal coliform and enterococcus densities in intertidal sediments at Bonita Cove. Bars represent the geometric means of 5 samples.

During the Sediment Resuspension Study at low tide, there was no significant difference ($p > 0.05$) between the mean clear water and resuspended sediment bacterial densities for either fecal coliform or enterococcus (Figure 4). In contrast, when the study was repeated during high tide, there was a marked difference in bacterial densities between the clear water and resuspended sediment samples. For enterococcus, the geometric mean density of the clear water samples was low at high tide (9.1 MPN/100 ml), similar to the results observed during low tide. However, after sediment resuspension at high tide, the enterococcus geometric mean density had increased two orders of magnitude to 1,096 MPN/100 ml. At all 15 stations, the resuspended sediment samples at high tide were one to two orders of magnitude greater than the corresponding clear water samples. The results for fecal coliforms were similar to those for enterococcus. The results suggest that the bacteria maintained in the upper intertidal sediments impact water quality when the sediments are disturbed (e.g., during swimming activity).

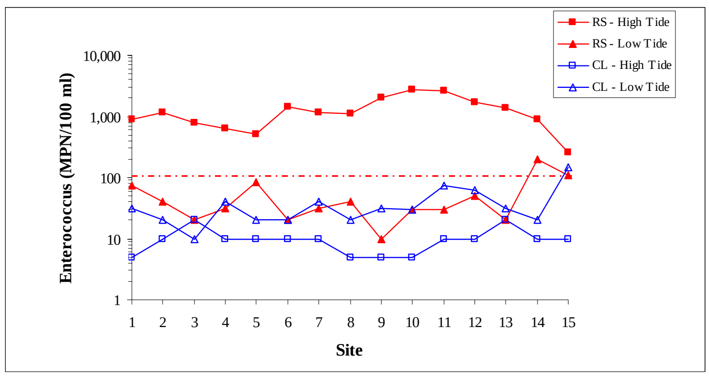

Figure 4. Enterococcus densities in receiving water at Bonita Cove. CL refers to clear water samples and RS refers to samples taken after sediment resuspension. The dashed red line represents the AB411 standard for enterococcus of 104 MPN/100 ml.

Leisure Lagoon. At Leisure Lagoon, bacterial densities in intertidal sediments were similar to those found at Bonita Cove (Figure 5). Bacterial densities in the upper intertidal sediments at Leisure Lagoon (+6, +5, and +4 feet above MLLW) were greater than those in the lower intertidal sediments (+2, +1, and 0 feet above MLLW). When data from the upper intertidal sediments were pooled and compared to those in the lower intertidal sediments, there was a significant difference between the two means for both fecal coliform ($p=0.0043$) and enterococcus ($p = 0.0028$).

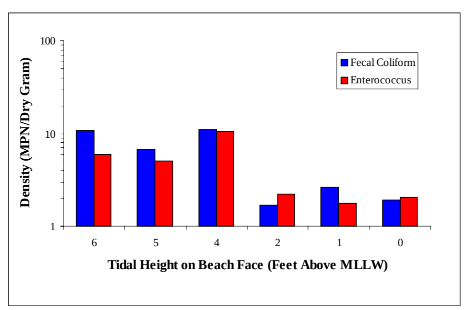

Figure 5. Fecal coliform and enterococcus densities in intertidal sediments at Leisure Lagoon by tidal height. Bars represent the geometric means of 5 samples.

The sediment resuspension study was conducted at Leisure Lagoon only during high tide. The pattern was similar to that observed at Bonita Cove (Figure 6). The mean fecal coliform density for resuspended sediment samples (574 MPN/100 ml) was an order of magnitude greater than the mean of clear water samples (21.9 MPN/100 ml). The difference was statistically significant ($p < 0.0001$). The pattern for enterococcus was similar to that of fecal coliforms.

Sediments centered around Site 8 were influenced by storm drain discharge, resulting in elevated bacterial densities in the area.

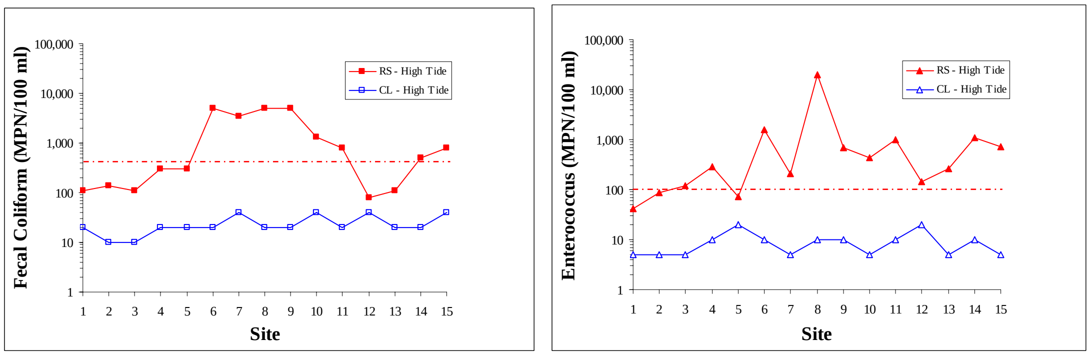

Figure 6. Fecal coliform and enterococcus densities in receiving water at Leisure Lagoon. CL refers to clear water samples and RS refers to samples taken after sediment re-suspension. The dashed red lines represent the AB411 standards of 400 MPN/100 ml for fecal coliform and 104 MPN/100 ml for enterococcus.

DISCUSSION

During the course of this study, we observed numerous birds on the beach, primarily gulls and shorebirds, and found that bird feces on the beach face was common. Although the magnitude of the fecal matter on the beach was not quantified, it was clear that the vast majority of the fecal matter was found in the upper intertidal zone. To better understand the relationship between fecal deposition and tidal stage, we graphed the tidal pattern in Mission Bay and graphically separated the upper and the lower intertidal zones (Figure 7). In the figure below, red represents the proportion of the upper intertidal zone that is exposed over time (i.e., not covered with water), yellow represents the proportion of the lower intertidal zone that is exposed over time, and blue represents sea water. The graph demonstrates that the upper intertidal zone on Mission Bay beaches is exposed for a much greater period of time than the lower intertidal zone. When the tidal cycle in Mission Bay was examined over an entire year, we found that the upper intertidal zone was exposed 86% of the time throughout the year and the lower intertidal zone was exposed 14% of the time.

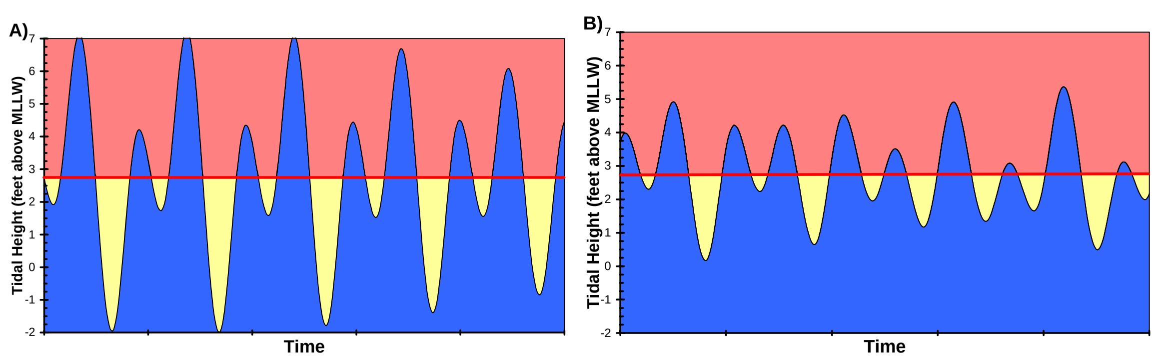

Figure 7. Relative amount of time that the upper intertidal zone (red) and the lower intertidal zone (yellow) is exposed (e.g., not under water) during spring (A) and neap tides (B).

A greater period of exposure in the upper intertidal zone allows for a greater period of time for the birds to populate and defecate on that area of the beach. We believe this simple relationship accounts for the large amount of fecal matter observed in the upper intertidal zone as well as the greater bacterial densities found in the upper intertidal zones at Bonita Cove and Leisure Lagoon. In addition, several studies have suggested that enterococcus and fecal coliform bacteria do not survive well in the presence of seawater. During neap tides, the lower intertidal zone in Mission Bay is covered with seawater the majority of the time, which would act to limit bacterial survival. During the same period, the upper intertidal zone is exposed, allowing for the accumulation of fecal matter from the birds.

The results of the sediment resuspension study clearly indicate that the sediments in the upper intertidal zone at Bonita Cove act as a reservoir for indicator bacteria. If the sediments are left undisturbed, then the bacteria sorbed to them do not tend to make their way into the water column. However, when these sediments are disturbed and resuspended in the water column, as a result of swimming activity for instance, bacterial densities in the water column can increase dramatically.

LITERATURE CITED

An, Y.J., Kampbell, D.H., and Breidenbach, G.P. 2002. *Escherichia coli* and total coliforms in water and sediments at lake marinas. Environ. Pollut. 37: 291-299.

Davies, C.M., Long, J.A.H., Donald, M., and Ashbolt, N.J. 1995. Survival of fecal microorganisms in marine and freshwater sediments. Appl. Microbiol. 61: 1888-1896.

Grant, S.B., Sanders, B.F., Boehm, A.B., Redman, J.A., Kim, J.H., Mrse, R.D., Chu, A.K., Gouldin, M., McGee, C.D., Gardiner, N.A., Johes, B.H. Svejkovsky, J., Leipzig, G.V., and Brown, A. 2001. Generation of enterococci bacteria in a coastal saltwater marsh and its impact on surf zone water quality. Environ. Sci. Technol. 35: 2407-2416.

Hood, M.A., Ness, G.E. 1982. Survival of *Vibrio cholerae* and *Escherichia coli* in estuarine waters and sediments. Appl. Environ. Microbiol. 43: 578-584.

Howell, J.M., Coyne, M.S., and Cornelius, P.L. 1996. Effect of sediment particle size and temperature on fecal bacteria mortality rates and the fecal coliform/fecal streptococci ratio. J. Environ. Qual. 25: 1216-1220.

Solo-Gabrielle, H.M., Wolfert, M.A., Desmarais, T.R., and Palmer, C.J. 2000. Sources of *Escherichia coli* in a coastal subtropical environment. Appl. Environ. Microbiol. 66: 230-237.