

**Appendix A**  
**Grant Summary Form**

# GRANT SUMMARY

Completed Grant Summaries are made available to the public on the State Water Resources Control Board's (SWRCB) website at <http://www.waterboards.ca.gov/funding/grantinfo.html>

Use the tab and arrow keys to move through the form. If field is not applicable, please put N/A in field.

**Date filled out:** April 30, 2008 (revised to reflect new project term June 14, 2013)

<b>Grant Information:</b> Please use complete phrases/sentences. Fields will expand as you type.	
1. <b>Grant Agreement Number:</b> 07-574-550-0	
2. <b>Project Title:</b> Pillar Point Harbor Source Identification Project	
3. <b>Project Purpose - Problem Being Addressed:</b> Identify sources of fecal contamination in Pillar Point Harbor and recommend opportunities for remediation	
4. <b>Project Goals</b>	
a. <b>Short-term Goals:</b> Identify potential sources of FIB using MST technology	
b. <b>Long-term Goals:</b> Reduce/remove these sources using appropriate remediation actions.	
5. <b>Project Location:</b> Pillar Point Harbor, San Mateo County, CA.	
a. <b>Physical Size of Project:</b> 324 acres	
b. <b>Counties Included in the Project:</b> San Mateo	
c. <b>Legislative Districts:</b> California State Senate, 8 <sup>th</sup> Senate District, Leland Yee.	
6. <b>Which SWRCB program is funding this grant?</b> Please "X" box that applies.	
<input type="checkbox"/> Prop 13 <input type="checkbox"/> Prop 40 <input checked="" type="checkbox"/> Prop 50 <input type="checkbox"/> EPA 319(h) <input type="checkbox"/> Other	
<b>Grant Contact:</b> Refers to Grant Project Director.	
<b>Name:</b> Kellyx Nelson	<b>Job Title:</b> Executive Director
<b>Organization:</b> San Mateo County Resource Conservation District	<b>Webpage Address:</b> <a href="http://www.sanmateorcd.org">www.sanmateorcd.org</a>
<b>Address:</b> 625 Miramontes St., Ste. 103, Half Moon Bay, CA,94019	
<b>Phone:</b> 650-712-7765 x102	<b>Fax:</b> 650-726-0494
<b>E-mail:</b> <a href="mailto:kellyx@sanmateorcd.org">kellyx@sanmateorcd.org</a>	
<b>Grant Time Frame:</b> Refers to the implementation period of the grant.	
<b>From:</b> 07/31/07	<b>To:</b> <del>03/01/2010</del> 06/30/2013
<b>Project Partner Information:</b> NA	
<b>Nutrient and Sediment Load Reduction Projection:</b> (If applicable) NA	

Please provide a hard copy to your Grant Manager and an electronic copy to your Program Analyst for SWRCB website posting. All applicable fields are mandatory. Incomplete forms will be returned.

## **Appendix B**

### **Pillar Point Harbor Circulation Study Final Report (Stefan Wuertz)**

**An Analysis of Water Circulation in Pillar Point Harbor,  
Half Moon Bay, California, based on the  
Dye Distribution Study of September 27, 2008**

Report prepared for:

San Mateo County Resource Conservation District

By

Stefan Wuertz, Ph.D.  
Professor of Environmental Engineering  
University of California, Davis

Dan Wang, Ph.D.  
Postdoctoral Scholar  
Stanford University

Kaveh Zamani, M.S.  
University of California, Davis

and

Fabian Bombardelli, Ph.D.  
Professor of Water Resource Engineering  
University of California, Davis

May 2011

## TABLE OF CONTENTS

1 Background.....	1
1.1 Fecal Pollution in Pillar Point Harbor and Motivation for Harbor Circulation Study.....	1
1.1.1 Geographical Setting.....	1
1.1.2 Water Quality.....	1
1.2 Objectives of Harbor Circulation Study.....	2
2 Study Design.....	3
3 Materials and Method.....	6
3.1 Dye Sampling and Measuring Procedure.....	6
3.2 Drogue Release and Counting.....	8
3.3 Fecal Indicator Bacteria (FIB) Sampling and Analytical Procedure .....	8
3.4 <i>Bacteroidales</i> Sampling and Analytical Procedure .....	9
4 Results.....	9
4.1 Fecal Indicator Bacteria .....	9
4.2 Fate of Drogues Released.....	15
4.3 <i>Bacteroidales</i> .....	16
4.4 Dispersion of Fluorescent Dyes in Inner and Outer Harbor.....	17
4.4.1 Fluorescein Movement Observation.....	18
4.4.2 Rhodamine Movement Observation.....	20
5 Discussion.....	20
5.1 Key Factors for Pillar Point Harbor Circulation.....	23
5.1.1 River Inflow.....	24
5.1.2 Wind Effect.....	26
5.1.3 Wave Effect.....	28
5.1.4 Tidal Effect.....	29
6 Conclusion.....	29
7 References.....	31

## LIST OF FIGURES

Figure 1. Dye release and sampling sites. Green square: Fluorescein release site; red square: Rhodamine release site. Circle A with sites A1 to A8, circle B with sites B1 to B4 and circle C with sites C1 to C8 are sampling sites in outer harbor. Site D and E are sampling sites in inner harbor. Sites O1 to O9 are control sites outside of the harbor. PPH1 to PPH10 are the 10 sites for routine monitoring in the research study “Identification of Sources of Fecal Pollution Impacting Pillar Point Harbor”. PPH1: Capistrano Outfall Pipe, PPH2: Bathhouse Outfall Pipe, PPH3: Capistrano Beach, PPH4: Denniston Creek, PPH5: Pillar Point Marsh Beach, PPH6: Mavericks Beach, PPH7: Beach House Beach, PPH8: Deer Creek Outlet, PPH9: Inner Harbor Beach, PPH10: Yacht Club Beach.....	5
Figure 2. Total coliform concentrations at the dye monitoring sites and control sites (panel 1: A circle; panel 2: C circle; panel 3: B circle and site D and E; panel 4: control sites outside of the harbor) .....	12
Figure 3. <i>E. coli</i> concentrations at the dye monitoring sites and control sites (panel 1: A circle; panel 2: C circle; panel 3: B circle and site D and E; panel 4: control sites outside of the harbor).....	13
Figure 4. Enterococci concentrations at the dye monitoring sites and control sites (panel 1: A circle; panel 2: C circle; panel 3: B circle and site D and E; panel 4: control sites outside of the harbor) .....	14
Figure 5. Fecal indicator bacteria levels at the 10 microbial source tracking sampling sites (panel 1: total coliform; panel 2: <i>E. coli</i> ; panel 3: enterococci).....	15
Figure 6. Drogue release sites and migration. (Box T: tangerine release site, Box L: lemon release site, Box O: orange release site, Box G: lime release site. Arrow: drogue moving direction. Ellipses: locations of beaching or repeated observations).....	16
Figure 7. <i>Bacteroidales</i> concentration at the four dye release sites and four control sites outside the harbor (sampled at 8 am on 9/27/2008) .....	17
Figure 8. Fifteen-minute tide data for Pillar Point Harbor, San Mateo County, CA, September 27, 2008. Source: Balance Hydrologics Inc.....	19
Figure 9. Critical zones for deposition and scour in Pillar Point Harbor.....	22
Figure 10. Deer Creek and Denniston Creek watersheds .....	24
Figure 11. Deer Creek gage 15-minute flow, San Mateo County, California. Source: Balance Hydrologics, Inc. ....	25

Figure 12. Denniston Creek gage 15-minute flow, San Mateo County, California, Hydrography through 10-23-2008 Source: Balance Hydrologics, Inc. ....25

Figure 13. Wind direction observed in the tracer study period (27-29 Sept 2008) and monthly mean wind direction averaged over the period of 1980-2001 (NBDC Station #46012).....27

Figure 14. Wind speed observation 27-29, September 2008 and monthly mean wind speed averaged over the period of 1980-2001 (NBDC Station # 46012).....28

Figure 15. Wave height measured by NBDC station # 40612 (27-29 Sept 2008),  $H_s$  in the period of 1980-2001 same buoy station (Top right).....29

Figure 16. Schematic of tidal current patterns in Pillar Point Harbor.....30

## LIST OF TABLES

Table 1. Fluorescein and Rhodamine Manufacturer and Dosage Used .....	6
Table 2. Exceedance Rate of Total Coliforms.....	9
Table 3. Exceedance Rate of <i>E. coli</i> for Fresh Water Only .....	9
Table 4. Exceedance Rate of Enterococci levels.....	11

## APPENDICES

Appendix A: Raw data on Fluorescent Dyes and Microbial Indicators.....	
Appendix A1 Fluorescent dye concentration.....	
Appendix A2 FIB concentration.....	
Appendix B: Fluorescein Distribution.....	
Appendix C: Rhodamine Distribution.....	
Appendix D: General Consideration of Harbor Circulation and Flushing.....	
D 1 Significance of Circulation Study.....	3
D 2 Circulation Processes.....	4
D 2.1 Tidal Prism.....	4
D 2.2 Wind Effect.....	6
D 2.3 River Discharge.....	7
D 2.4 Predicting of Flushing/Circulation.....	7

## **Scope of Work**

The San Mateo County Resource Conservation District (SMCRCD) has contracted Dr. Wuertz per agreement dated November 1, 2010, to summarize and interpret the Dye Release Study carried out on September 27, 2008 by Balance Hydrologics, Inc. The study involved the release of two dyes, Rhodamine and Fluorescein, at specific locations in the harbor to track how dyes dissipate, providing information about how water constituents travel within the harbor.

The following items were provided for review of the study:

- Draft Internal Report by Balance Hydrologics to SMCRCD (per Barry Hecht, Principal, Balance Hydrologics)
- A range of technical and nontechnical documents pertaining to the study

Sections of the Balance Hydrologics internal report are included verbatim by permission.

## Acknowledgements

Carolann Towe, of the San Mateo County SMCRCO, conceived the idea of a circulation study and developed and implemented the complex programs to coordinate the volunteers, under the direction of Kellyx Nelson, and with the assistance of Ellen Gartside. Ms. Towe, who has studied fecal coliform along the San Mateo Coast for many years, collected samples during the study in addition to coordinating volunteers. Technical design and execution of the study was by Dr. Carla Grandy, Travis Baggett and Bonnie de Berry at Balance Hydrologics, under the leadership of Barry Hecht. We gratefully acknowledge their help and willingness in providing information for this report.

Members of the Technical Advisory Board of the ongoing research study “Identification of Sources of Fecal Pollution Impacting Pillar Point Harbor” by SMCRCO provided helpful advice during the planning stages of the study. In particular, John Oram gave key advice during preliminary dye release experiments and Steve Peters participated as volunteer kayaker. Dan Temko and harbor staff assisted throughout all stages by sharing their knowledge and providing logistical support such as placing the buoys. Saul Chaikin, veteran pilot, volunteered throughout the trial and main studies with air support, dodging the fog, while remaining at the elevation of 3000 feet required by the Federal Aviation Administration. Kellyx Nelson (SMCRCO) served as photographer from the air. Last but not least this study involved a great number of dedicated volunteers (listed by name in the Appendices) who spent many hours taking samples and helping with logistical aspects of the study. They came from diverse professional backgrounds, making the harbor circulation investigation a truly interactive event with significant input from the local community. The Balance Hydrologics project staff particularly wishes to thank their 8 co-workers from the various Balance offices and their families who volunteered.

We gratefully acknowledge the following persons who contributed time and effort to the Dye Distribution Study: Sheri Almeda, Greg Ames and Corey Ames, Ed Ballman and Alex Ballman, Allison Barden, Jim Blanchard, Rita Bosnich, Nathan Boyd, Nyssa Brennan, Gretchen Bringas, Ione Burge, Annette Cayot, Laurie Chaikin, Pat Conroy, K. Adem Cooper, Kevin Cooper, Tim Costello, Miguel Cunha, Brendan Downing, Chris Dunham, Carmen Fewless, Jeff Grandy, Andrea Grech, Rich Gruber, Richard Hagy, Leila Harris, Jennifer Heit, Mary Lou Holding, Linda Jacobson, Clive Jones, Marie Kazan-Komarek, Mary Sue Kelly, Steven King, Rosemary Lanyon, Jonathan Lear, Wendell Lee, Barry Lifland, Charlotte Lingo, Kaya MacMillen, Brian McBride, Susan McCarthy, Jeannie McDermott, Laurie McDonough, Mike Mead, Greg Merkes, Larry Miller, Carrie-Andrea Moresi, Ivan Navarro, Jill K. Newburn, Michael Newburn,

Dorothy Norris, Stephen Ochoa, Gillian O'Doherty, Molly Ortega, Jonathan Owens, Connelly Palmer, Barb Parker-Seitz, Mark Perkins, Dean Peterson, Chris Powell, Ed Richardson, Cynthia Rodgers, Jon Royail, Katherine Sharig, Bern Smith, Nancy Smith, Steven Smith, Roxy Stone, Jack Sutton, Sonya Temko, and Allison Weber.

## EXECUTIVE SUMMARY

A Dye Distribution Study was conducted in Pillar Point Harbor (PPH) from September 27 to 29, 2008. The objective was to observe flow direction, velocity and mass transport in the harbor and to allow estimation of expected residence times of constituents in the harbor at key identified locations under late-summer or early-fall dry conditions. There were no prior studies of currents and circulation due to interaction of tide, wave and wind regarding the harbor. Microbial water quality in PPH is poor and the State Water Resources Control Board has listed the location as impaired by coliform bacteria on the 303(d) list submitted to the United States Environmental Protection Agency. In 2005 and 2006, San Mateo County Department of Environmental Health repeatedly posted beaches in the Harbor as potential health hazards. Capistrano Beach was posted most frequently, approximately 50 weeks in each year. At the time of the study, Capistrano Beach had elevated levels of fecal indicator bacteria (FIB), such as *E. coli* and *Enterococcus*, on over 95% of sampling events in wet and dry conditions.

Two fluorescent dyes, Fluorescein and Rhodamine, were released at selected locations in the harbor. Circulation of these dyes was recorded by taking samples from 3 kayaking circles A, B and C that covered the entire outer harbor, two sites D and E in the inner harbor, and 9 sites outside the harbor over the course of 3 days. The two dyes have slightly higher density than water. When they were sampled 6" below the water surface, their movement indicated the prevailing water current.

The dyes were used to check the circulation in the inner and outer harbor, flow between inner and outer harbor, and flow between the outer harbor and the open ocean. Both dyes are commonly used for environmental tracking because they are visible to the naked eye at high concentrations and remain detectable by a fluorometer even at very low concentrations. They are environmentally benign at the levels used in the study and decay naturally in ultraviolet light within days to weeks of being released.

Fluorescein and Rhodamine dyes were released concurrently at four locations throughout the harbor at 8 a.m. on September 27, 2008:

- Rhodamine was released to analyze the circulation of potential contaminants near the marsh.
- Fluorescein was released approximately 100 feet offshore of Denniston Creek to track circulation near the creek and outfall pipes at Capistrano Beach.

- Rhodamine dye was dispersed throughout the inner harbor in the vicinity of the liveaboard boats at the western end of the inner harbor.
- Fluorescein dye was released to monitor circulation from and around the side of the harbor as well as to ascertain some information about the permeability of the outer breakwater.

In addition, four types of fruit (25 each) were deployed at the identical sites used for dye release. Oranges were released evenly in the Western inner harbor; tangerines were released at the dye release site in circle A, lemons in circle B and limes in circle C. They were collected and counted once they reached the shore or the harbor wall. The drogues appeared to move downwind more quickly than the dye, implying that the surface water was moving in a different direction than the underlying water.

Dye distribution patterns suggest zones of differential velocities and hence propensities of mixing in the harbor. Consequently, the outcomes of fecal contamination released at different points in the harbor are likely to be different with respect to their residence time in the harbor. Taking into consideration the limitations of the study, which did not consider vertical stratification of dyes within the harbor or provide direct wind and wave measurements, it can be concluded that the distribution of dyes was not affected appreciably by wave action or wind speed. Consequently, the observed dye distribution patterns reflect the force of tidal flows. Given that the known contributions of freshwater inflows into the harbor throughout the seasons are minor it can be concluded that flushing will generally be determined by the action of tides. It should be noted that freshwater flows may still provide considerable pollutant loads into the harbor.

Assuming that Pillar Point Harbor (PPH) can be approximately represented by a rectangle, the average per cycle exchange coefficient for PPH is of the order of 0.42, indicating that the harbor possesses a high degree of interchange of waters with the ocean, facilitating the elimination of pollutants.

Yet there is no uniform pattern of flushing with some harbor areas less likely to deplete pollution levels. The Fluorescein plume, which was released at the Northern zone of the harbor, completely washed out in five tidal cycles (2.5 tidal days). However, any constituents which are released in the shallow waters of the Northwestern side of the basin would not be flushed out after six tidal cycles (3 days), because a considerable amount of tracer mass remained inside the harbor. In case of a future tracer study, the other release point to consider for a tracer study is the Eastern end of the harbor. The general pattern of incoming jet from the ocean and ebb tide currents flushing the harbor showed the general mode of circulation in the tidal prism to be clockwise.

Besides the two fluorescent dyes and the drogues, FIB and the alternate indicator *Bacteroidales* were measured inside the harbor and at beach control sites to gain knowledge of their general abundance at the time of the experiment. In general, FIB levels were below the single maximum and geometric mean standards. Capistrano Beach (PPH3) was the exception. This site is under direct influence of two (PPH1, Capistrano Outfall Pipe; PPH2, Bathhouse Outfall Pipe) of the four freshwater inflows into the harbor; these two freshwater sources typically exceed the geometric mean water quality objectives and even the single sample maximum objectives.

# 1 BACKGROUND

## 1.1 Fecal Pollution in Pillar Point Harbor and Motivation for Harbor Circulation Study

### 1.1.1 Geographical Setting

Pillar Point Harbor, located on the northern side of Half Moon Bay and adjacent to the small town of Princeton along the central coast of California in San Mateo County, is an enclosed watershed with complex inputs and water flows. It contains an inner boat harbor, pier, and saltwater/brackish tidal marsh (Pillar Point Marsh). It receives drainage from Denniston and Deer Creeks, storm drains, outflow pipes, and large, mixed-use areas including an airport, agricultural, commercial and residential sections. Pillar Point Harbor contains five beaches: Capistrano Beach, Yacht Club Beach, Marsh Beach, Mavericks Beach, Inner Harbor Beach, and Beach House Beach.

Pillar Point Harbor comprises an inner harbor and outer harbor. The boat-berthing basin is approximately 45 acres, contains approximately 400 slips, and is located within a set of breakwaters, herein referred to as the “inner” breakwaters. The inner breakwaters were constructed in 1982. South of the inner breakwaters there is another set of breakwaters, herein referred to as the “outer” breakwaters. The outer breakwaters were built in 1961 with an extension to the west breakwater across the opening added in 1967. The outer harbor area (between the inner and outer breakwaters) encompasses approximately 279 acres resulting in an entire harbor area of 324 acres.

The harbor area houses commercial ventures including several restaurants, hotels, shops, a fertilizer plant, three commercial fish buyers, sport fishing concessions, a yacht club, two kayak rental companies, a recreational vehicle park, and a Naval Station situated on the bluff overlooking the Outer Harbor. Outside of the Outer Harbor area but within the project study area are conference facilities, residential areas, and additional commercial ventures as well as a pump station for the Sewer Authority Mid-coastside.

### 1.1.2 Water Quality

Microbial water quality in Pillar Point Harbor (PPH) is poor and the State Water Resources Control Board has listed the location as impaired by coliform bacteria on the 303(d) list submitted to the United States Environmental Protection Agency. Capistrano Beach has elevated levels of fecal indicator bacteria (FIB), such as *E. coli* and *Enterococcus* on over 95% of sampling events in wet and dry conditions. This beach has been ranked for several years by Heal the Bay's Report Card as a “Beach Bummer,” meaning that it is in the top ten most polluted beaches in California in dry weather

conditions. In 2005/2006, Capistrano Beach ranked sixth on the “Beach Bummer” list. It was the worst ranked beach in Northern California and is a Clean Beaches Task Force Priority Beach with regard to fecal pollution. Capistrano Beach is permanently posted by the San Mateo County Environmental Health Department as a potential health hazard.

The public health conditions of the impaired waters may affect commercial ventures, harbor activities, tourism, recreation, and ecological habitat in the watershed. The harbor area has approximately 100,000 visitors annually and is heavily used recreationally by boating enthusiasts, kayakers, windsurfers, campers, hikers, dog walkers, bird watchers, swimmers, waders, families, clam diggers, surfers, and thousands of spectators for the world famous Mavericks big wave surf break.

In 2005 and 2006, San Mateo County Department of Environmental Health repeatedly posted beaches in the Harbor as potential health hazards. Capistrano Beach was posted most frequently, approximately 50 weeks in each year. Marsh Beach was posted over 20 weeks in each year i.e. 42% to 51% of sampling events. Mavericks Beach was posted approximately 15 weeks each year, approximately 30% of sampling events. The county terminated sampling for Capistrano Beach and permanently posted the beach as a potential health hazard in March of 2006.

Within the local community there are numerous opinions as to the primary sources of fecal pollution impacting the harbor, including but not limited to human contamination from leaking sewer lines, avian contamination from resident and migratory bird populations including large flocks of gulls and other birds, and lack of flushing in the harbor due to the presence of two break walls. Although much effort has been expended on studying the locations of fecal pollution impacting the harbor, including water sampling and fecal indicator enumeration studies, data on identification of primary sources and their relative contributions to the overall magnitude of the pollution problem are lacking. There is an urgent need for a comprehensive study of all of the possible sources of pollution in this watershed and how these flows interact in the confines of the enclosed Pillar Point Harbor Bay.

## **1.2 Objectives of Harbor Circulation Study**

A fluorometric dye tracing study was designed by Balance Hydrologics, Inc., in coordination with San Mateo County Resource Conservation District (SMCRCD) and Prof. Stefan Wuertz at UC Davis who is the lead scientist in the ongoing research study “Identification of Sources of Fecal Pollution Impacting Pillar Point Harbor” by

SMCRCD. The objective was to observe flow direction, velocity and mass transport in the harbor and to allow estimation of expected residence times of constituents in the harbor under late-summer or early-fall conditions. During this period surface runoff is negligible, uncoupled from specific meteorological events. By sampling close to the onset of the winter rainy season, a period when surface runoff is negligible, uncoupled from specific meteorological events, the intention was to characterize the water quality characteristics of the harbor under prevailing conditions.

There were substantial outreach activities to local community members resulting in active participation by kayakers and other interested parties. The information gathered will be used in the abovementioned research study to determine the effects of harbor circulation dynamics on the fate and transport of FIB. There were no prior studies of currents and circulation due to interaction of tide, wave and wind regarding the harbor. Also there were no previous reports of variability of currents or flushing time either. In 1994 and 2006 two surveys of bathymetry were conducted by Gahagan & Bryant Associates (GBA) as part of design phase for maintenance deranging and also building 71 new berths.

## **2 STUDY DESIGN**

The main objective of the study was to inspect the water exchange through the mouth of the harbor, movement through and around the breakwater and nearshore circulation, and residency times at key identified locations. The experiment was conducted on September 27, 2008 and measurements were taken through September 29, 2008. These were quiescent days at the end of the dry season with minimum inflow from land use; therefore, the circulation results obtained from this study were under no influence of freshwater inflow. Two fluorescent dyes, Fluorescein and Rhodamine, were released at selected locations in the harbor. Circulation of these dyes was recorded by taking samples from 3 kayaking circles A, B and C that covered the entire outer harbor, two sites D and E in inner harbor and 9 sites outside the harbor (Figure 1) over the course of 3 days. The two dyes have slightly higher density than water. When they were sampled 6" below the water surface, their movement indicated the prevailing water current. Drogues including orange, tangerine, lemon and lime were also released at the dye release location to check the impact of wind.

Fecal indicator bacteria including total coliform, *E. coli* and enterococci were also measured at these sites and at the routine monitoring sites PPH1 to PPH10. The microbial source tracking (MST) indicator *Bacteroidales* for total, human-associated, cow-associated and dog-associated fecal pollution was measured at the four dye release sites and four sites outside of the harbor. *Bacteroidales* are highly abundant bacteria in the gut

of warm-blooded animals and contain genetic markers that can be used to pinpoint specific animal fecal sources. Neither FIB measurements nor MST analysis were expected to contribute new information in addition to the concentration profiles of the two fluorescent dyes because of the relatively low concentrations found in the harbor compared to beaches and freshwater discharge points. Rather, FIB and *Bacteroidales* were measured as part of the ongoing research project in Pillar Point Harbor. The information is included in this report as ancillary information.

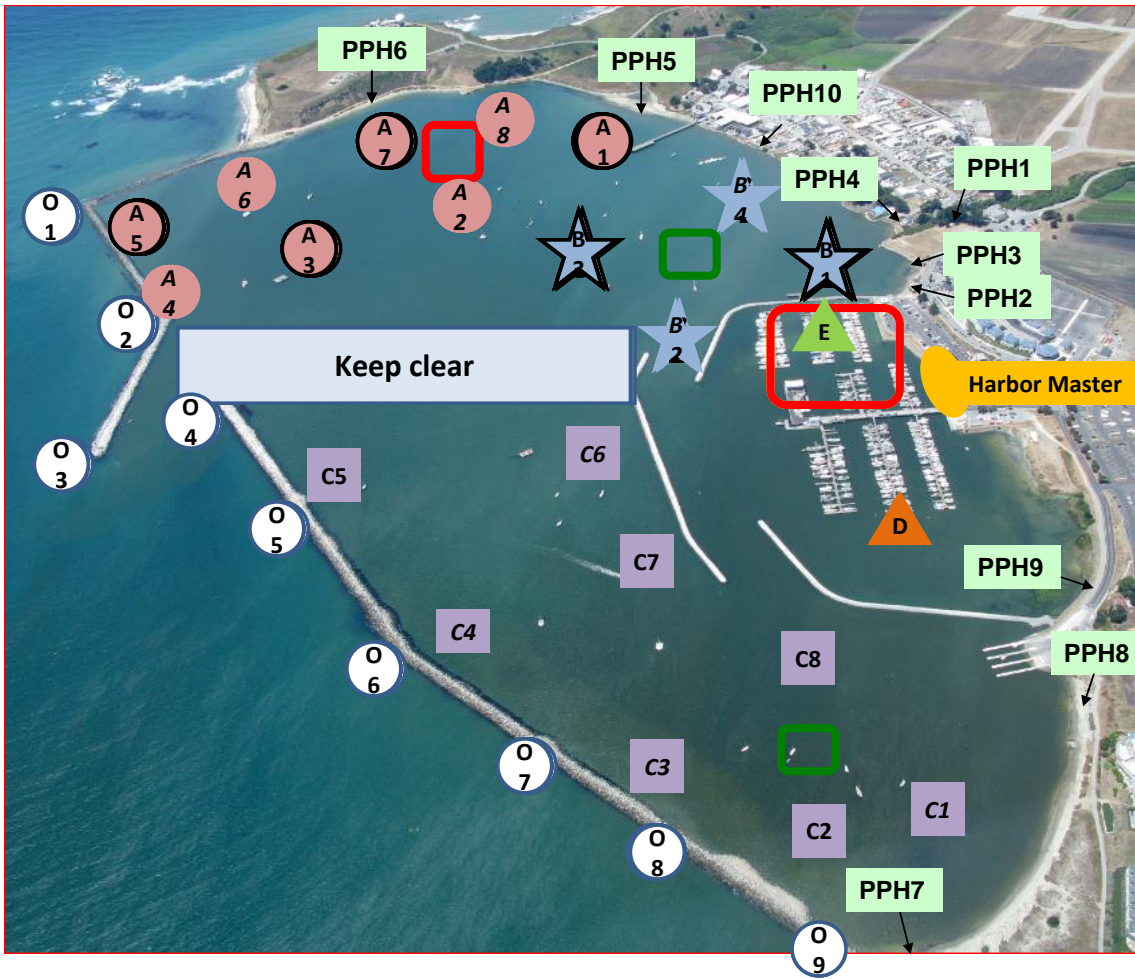


Figure 1: Dye release and sampling sites. Green square: Fluorescein release site; red square: Rhodamine release site. Circle A with sites A1 to A8, circle B with sites B1 to B4 and circle C with sites C1 to C8 are sampling sites in outer harbor. Site D and E are sampling sites in inner harbor. Sites O1 to O9 are control sites outside of the harbor. PPH1 to PPH10 are the 10 sites for routine monitoring in the research study “Identification of Sources of Fecal Pollution Impacting Pillar Point Harbor”. PPH1: Capistrano Outfall Pipe, PPH2: Bathhouse Outfall Pipe, PPH3: Capistrano Beach, PPH4: Denniston Creek, PPH5: Pillar Point Marsh Beach, PPH6: Mavericks Beach, PPH7: Beach House Beach, PPH8: Deer Creek Outlet, PPH9: Inner Harbor Beach, PPH10: Yacht Club Beach.

### 3 MATERIALS AND METHODS

#### 3.1 Dye Sampling and Measuring Procedure

The dyes Fluorescein and Rhodamine (Bright Dyes, OH and Keystone Dyes, IL) were used to check the circulation in the inner and outer harbor, flow between inner and outer harbor, and flow between outer harbor and the open ocean. These two dyes were selected as tracers to monitor circulation within the harbor. Both dyes are commonly used for environmental tracking because they are visible to the naked eye at high concentrations and remain detectable by a fluorometer even at very low concentrations. They are environmentally benign at the levels used in the study and decay naturally in ultraviolet light within days to weeks of being released.

Rhodamine was released at one location in circle A (released equidistant between sites A1, A2, A7, and A8 to analyze the circulation of potential contaminants near the marsh) and evenly distributed in the western inner harbor (in the vicinity of the liveboard boats at the western end of the inner harbor) at 8:00 Sep. 27<sup>th</sup>. Fluorescein was released at one location in circle B (100 feet offshore of Denniston Creek between sites B1 and B4 to track circulation near the creek and outfall pipes at Capistrano Beach) and one location in circle C (equidistant from sites C1, C2, C3 and C8 to monitor circulation from and around the eastern side of the harbor as well as to ascertain some information about the permeability of the outer breakwater) at 8:00 Sep. 27<sup>th</sup>. Two batches of dyes (one batch from each company) were ordered and released at each location (Table D-1). Volunteer kayakers took samples every 15 minutes from 8:00 to 16:00 on Sep 27<sup>th</sup> and from 8:00 to 10:00, 12:00 to 14:00 and 16:00 to 18:00 on Sep 28<sup>th</sup> and 29<sup>th</sup> at circle A, B and C, site D and E. At each location and sampling time, water samples were grabbed 6” below water surface using a 100-ml plastic bottle; the bottles were immediately put in 2-liter black zip lock bags to avoid exposure to sun. The bottles were then returned to the harbor master for analysis. A Turner Designs 10--AU--005--CE Field Fluorometer was used to measure dye concentrations.

**Table 1 Fluorescein and Rhodamine Manufacturer and Dosage Used**

Manufacturer	Fluorescein	Rhodamine
<b>Bright Dyes</b>	Yellow/Green	Rhodamine Red (50)
Concentration	7.7%	5%
Volume released per station	3 gallons	3 gallons
<b>Keystone Dyes</b>	Uranine K liquid	Rhodamine WT liquid
Concentration	40%	20%
Volume released per station	0.96 gallon	0.96 gallon

The Turner Designs 10--AU--005--CE Field Fluorometer was used to analyze the samples. This fluorometer was chosen because of its portability, ability to analyze samples at different temperatures, and because of the availability of support from Turner Designs. Before analyzing the samples the fluorometer was calibrated by Balance Hydrologics staff. A standard of fluorescein was created by diluting the dye as received with deionized water to a concentration of 200 ppb. That standard was further diluted using harbor water to a concentration of 50 ppb. The fluorometer was calibrated using the 50 ppb standard. The 10--AU also allows a “blank” value to be set which acts as the zero point for the analysis and subtracts the value of the fluorescence of the blank standard from all other samples. Harbor water collected prior to the release of the dye was used as the blank sample. This was done to account for the natural fluorescence present in the harbor water. The reporting range of the instrument in this configuration is from 0 to 150 ppb with greatest accuracy around 50 ppb. The 50 ppb standard was further diluted with harbor water to 25 ppb. The 25 ppb standard was used to check the calibration of the fluorometer periodically while analyzing samples and the value was recorded.

The fluorometer was set to analyze discrete samples (rather than continuous flow). Samples were transferred to a cuvette that was triple rinsed with distilled water. Once the filled cuvette was placed into the discrete sample chamber, the fluorometer was allowed to stabilize until the “time constant” reached 2 seconds, typically 10 seconds. No more than 60 seconds was allowed to pass before recording the value reported by the fluorometer. Once analyzed the sample in the cuvette was disposed of. The sample remaining in the sampling container was resealed and packed in boxes. The used cuvette was triple rinsed with distilled water, wiped clean and returned to stock to be filled with the next sample.

On September 27, 2011 the fluorometer was set up for discrete sample analysis of Fluorescein. All samples collected on this date were analyzed on site for Fluorescein and samples remaining in the sampling container were returned to the Berkeley office of Balance Hydrologics by Balance staff. Samples collected on September 28th and 29th were packed by San Mateo SMCRC and mailed to the Balance Hydrologics office in Berkeley. All samples remained in plastic bags and cardboard boxes to minimize photo-degradation of the Fluorescein and Rhodamine. Most samples were received in acceptable condition with a few samples lost in transport. All lost samples were marked as lost in the lab notes. Samples collected on 28th, and 29th of September were analyzed for Fluorescein with no adjustments made to the set-up of the Turner 10--AU from the initial September 27th configuration.

Once all samples were analyzed for Fluorescein, the fluorometer was converted for Rhodamine analysis. This involved changing internal filters and lamps and recalibration.

Calibration procedures used for the Rhodamine were the same as the procedure used for Fluorescein. The samples were reanalyzed for Rhodamine using the same methods used for Fluorescein.

In addition to samples of harbor water, QA/QC blank samples and duplicate samples were also collected. The procedure of the QA/QC samples was handled by San Mateo SMCRCDD staff. Analysis of the QA/QC samples was done intermittently during the regular sample analysis and without adjustment to the fluorometer. Results of those analyses were recorded in the onsite lab book and transcribed into the electronic spreadsheet. Additional QA/QC was performed on the transcription procedure to ensure that the electronic spreadsheet of results matched the original lab notes.

### **3.2 Drogue Release and Counting**

Four types of fruit (25 each) were released at the identical sites used for dye release. Oranges were released evenly in the western inner harbor; tangerines were released at the dye release site in circle A, lemons in circle B and limes in circle C (see Figure 2). They were collected and counted once they reached shore or the harbor wall.

### **3.3 Fecal Indicator Bacteria (FIB) Sampling and Analytical Procedure**

Hundred-milliliter water samples for fecal indicator bacteria (FIB) including total coliform, *E. coli* and enterococci were collected at the same sites where samples for dye monitoring were collected. FIB were measured four times for circle A, B and C, site D and E (8:00 and 14:00 on Sep. 27<sup>th</sup>, 9:00 on Sep. 28<sup>th</sup> and 9:00 on Sep. 29<sup>th</sup>); twice for the 10 routine sampling sites PPH1 to PPH10 (9:00 on Sep. 28<sup>th</sup> and 9:00 on Sep. 29<sup>th</sup>); and once for the control sites O1 to O9 (9:00 on Sep. 28<sup>th</sup>). Water samples were sent on ice to the San Mateo County Public Health Lab and enumerated using Colilert and Enterolert (IDEXX, Maine) within 6 h. Total coliform and enterococci were measured for all water samples; *E. coli* was measured for fresh water sites. About 10% of samples for FIB included duplicates and blanks, which were analyzed in parallel.

### **3.4 *Bacteroidales* Sampling and Analytical Procedure**

Ten-liter water samples for the microbial source tracking (MST) target *Bacteroidales* were collected at the four dye release sites and four control sites outside of the harbor (O1, O3, O6 and O9) at 8:00 on Sep. 27<sup>th</sup>. The water samples were driven to the Wuertz laboratory at UC Davis within 2 h and immediately concentrated to 100 ml using hollow fiber ultrafiltration according to a previously tested procedure (Rajal et al. 2007). DNA was extracted from the concentrated samples and four *Bacteroidales* qPCR genetic assays (universal, human-associated, cow-associated and dog-associated) were conducted as described elsewhere (Kildare et al. 2007).

## **4 RESULTS**

### **4.1 Fecal Indicator Bacteria**

FIB concentrations in water samples taken inside the harbor and at control sites were generally below the water quality objectives, only site C1 had a one-time exceedance of enterococci on Sep. 29<sup>th</sup>. The MPN value was 52/100 ml, which is higher than the allowed geometric mean of 35/100 ml for this indicator, but lower than the allowable single sample maximum value of 104/100ml. The geometric mean of a site must be calculated from the five most recent samples from that site in a 30-day period. Because site C1 was not routinely sampled but only tested during this circulation study, the water quality objective based on the geometric mean does not apply to it. Hence the site was in compliance. Of the six beach sites, which are monitored as part of the research project study “Identification of Sources of Fecal Pollution Impacting Pillar Point Harbor” by San Mateo Resource Conservation District (SMRCD), only PPH3 had ever exceeded the geometric mean water quality objective but not the single sample maximum objective, once for coliform and twice for the enterococci geometric mean (the geometric mean was calculated based on routine PPH3 monitoring data from the five most recent samples before and during the circulation study). This is because PPH3 is under direct influence of two (PPH1 and PPH2) of the four freshwater inflows into the harbor; these two freshwater inflows typically exceed the geometric mean water quality objectives and even the single sample maximum objectives.

This circulation study was done in September under dry weather condition. There was minimum freshwater input into the harbor for the previous few months. Their impact on water quality inside the harbor is small due to the dilution effect and most FIBs were

below detection limit. Only site PPH3 exceeded the geometric mean water quality objectives occasionally. Details are in Tables 2, 3 and 4 and Figures 2, 3, 4 and 5.

**Table 2 Exceedance Rate of Total Coliforms (see Figures 2 and 5)**

<b>Site/ Objective</b>	<b>No. exceedances/sample size<sup>a</sup></b>	<b>No. exceedances/sample size<sup>b</sup></b>
A circle	0/32	0/32
C circle	0/32	0/32
B circle	0/16	0/16
Site D and E	0/8	0/8
Control site	0/9	0/9
MST beach site	1/12 (PPH3)	0/12
MST inflow site	7/8 (PPH1,2,4,8)	3/8 (PPH1,8)

<sup>a</sup> Allowable geometric mean = 1000/100 ml

<sup>b</sup> Single sample maximum = 10000/100 ml

**Table 3 Exceedance Rate of *E. coli* for Fresh Water Only (see Figure 3)**

<b>Sites/ Objectives</b>	<b>No. exceedances/sample size<sup>a</sup></b>	<b>No. exceedances/sample size<sup>b</sup></b>
A circle	Not applicable	Not applicable
C circle	Not applicable	Not applicable
B circle	Not applicable	Not applicable
Site D and E	Not applicable	Not applicable
Control sites	Not applicable	Not applicable
MST beach sites	Not applicable	Not applicable
MST inflow sites	5/8 (PPH1,4,8)	5/8 (PPH1,4,8)

<sup>a</sup> Allowable geometric mean = 126/100 ml

<sup>b</sup> Single sample maximum = 235/100 ml

**Table 4 Exceedance Rate of Enterococci Levels (see Figures 4 and 5)**

<b>Sites/ Objectives</b>	<b>No. exceedances/sample size<sup>a</sup></b>	<b>No. exceedances/sample size<sup>b</sup></b>
A circle	0/32	0/32
C circle	1/32 (site C1)	0/31
B circle	0/16	0/16
Site D and E	0/8	0/8
Control sites	0/9	0/9
MST beach site	2/12 (PPH3)	0/12
MST inflow site	6/8 (PPH1,4,8)	6/8 (PPH1,4,8)

<sup>a</sup> Allowable geometric mean = 35/100 ml for marine or 33/100 ml for fresh water

<sup>b</sup> Single sample maximum = 104/100 ml for marine or 61/100 ml for fresh water

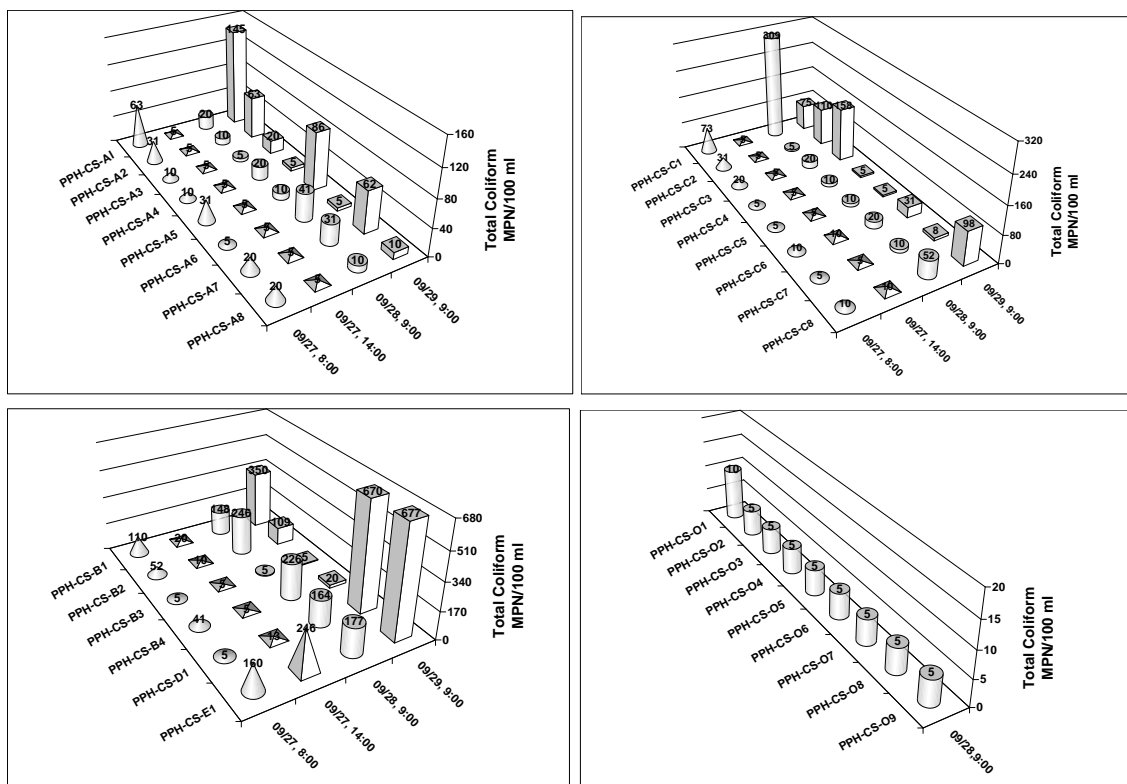


Figure 2: Total coliform concentrations at the dye monitoring sites and control sites (upper left panel: A circle; upper right panel: C circle; lower left panel: B circle and site D and E; lower right panel: control sites outside of the harbor)

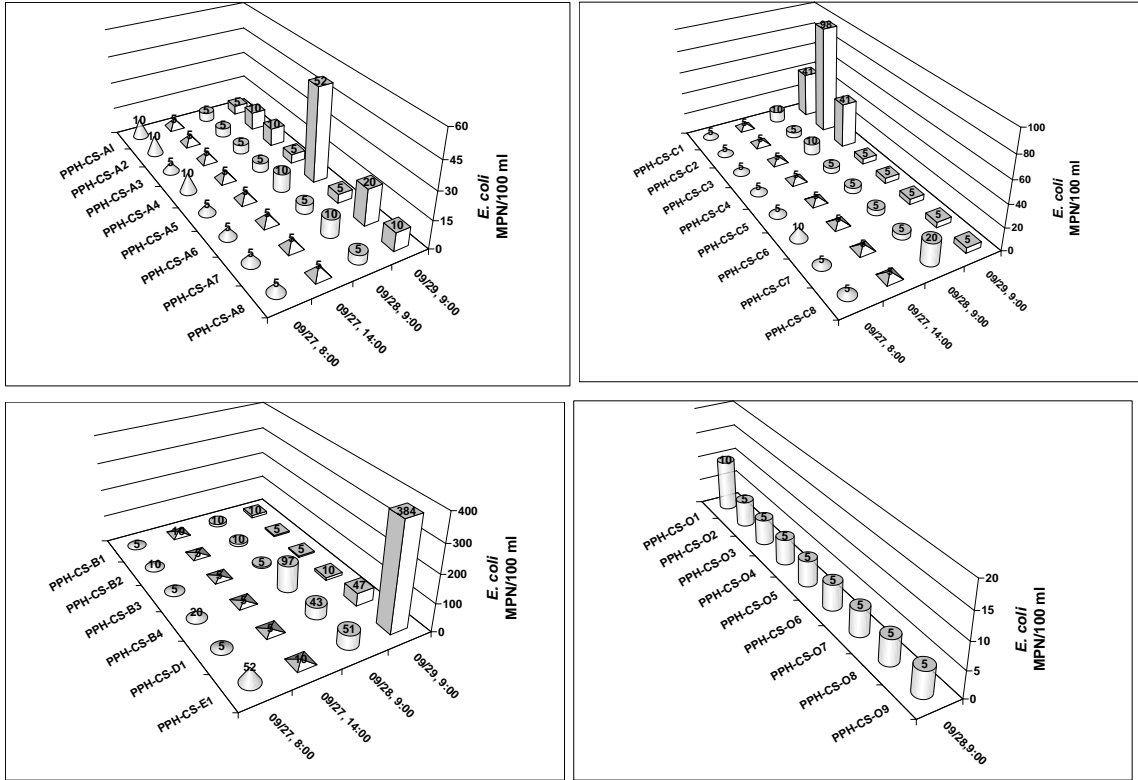


Figure 3: *E. coli* concentrations at the dye monitoring sites and control sites (upper left panel: A circle; upper right panel: C circle; lower left panel: B circle and site D and E; lower right panel: control sites outside of the harbor)

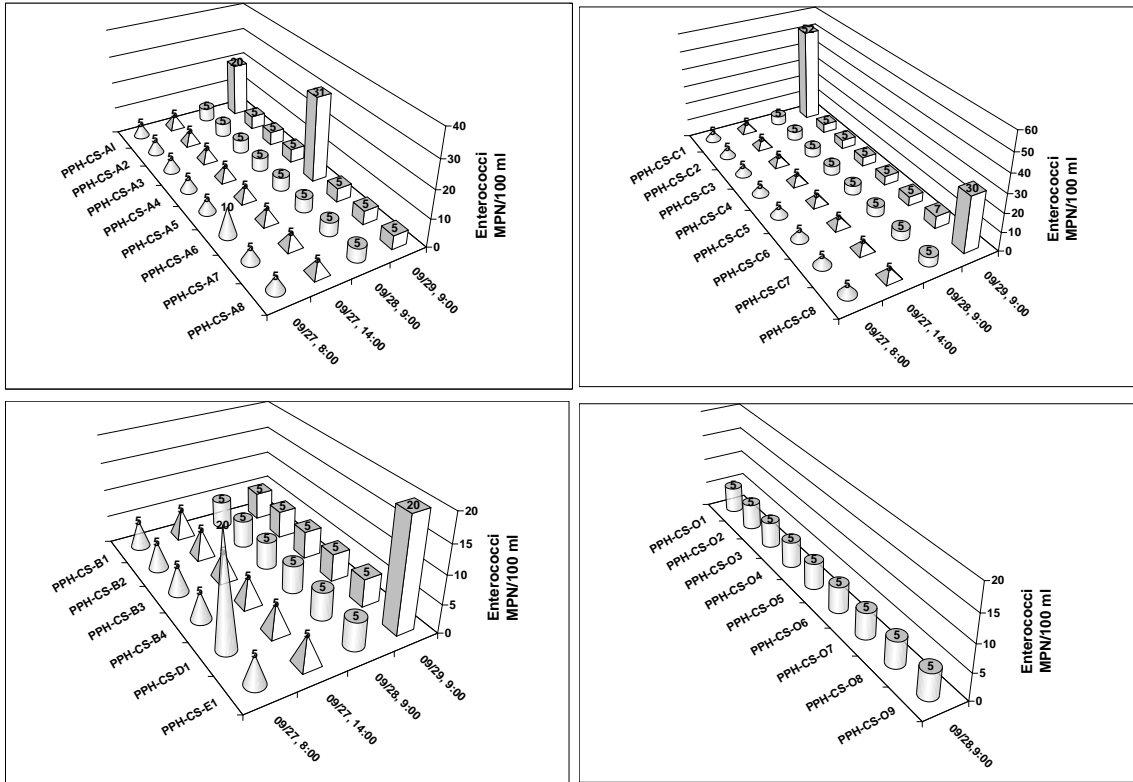


Figure 4: Enterococci concentrations at the dye monitoring sites and control sites (upper left panel: A circle; upper right panel: C circle; lower left panel: B circle and site D and E; lower right panel: control sites outside of the harbor)

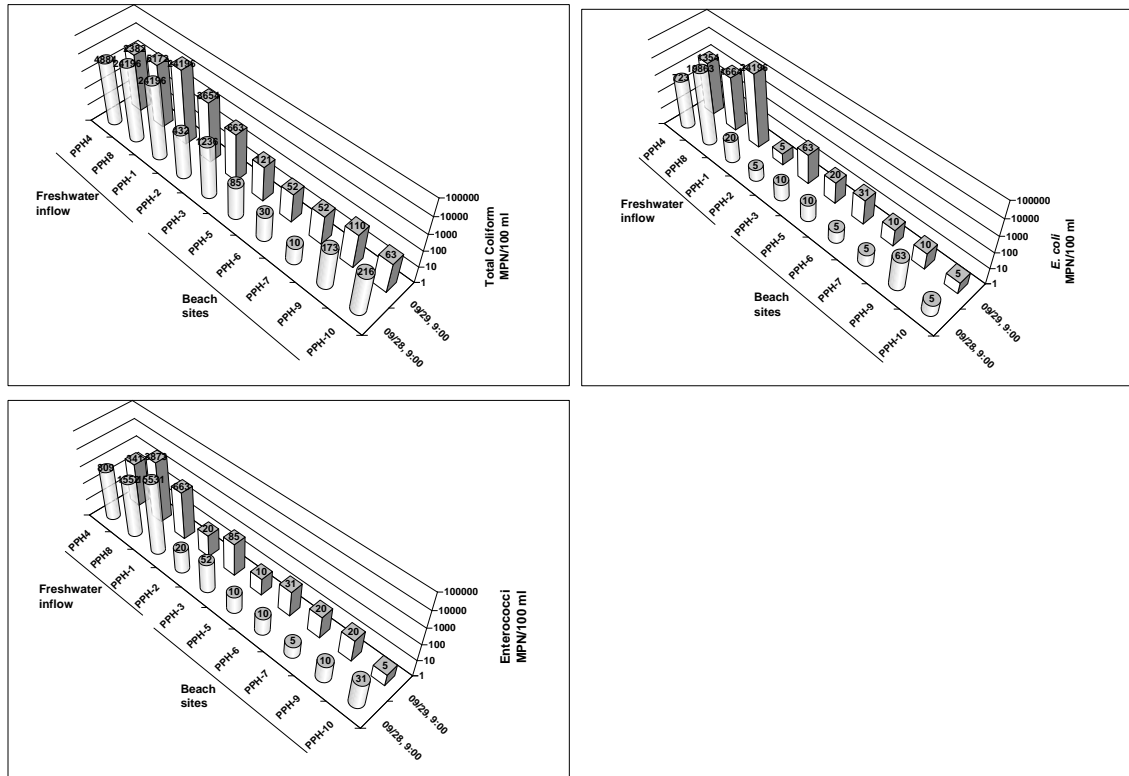


Figure 5: Fecal indicator bacteria levels at the 10 microbial source tracking sampling sites (upper left panel: total coliform; upper right panel: *E. coli*; lower left panel: enterococci)

## 4.2 Fate of Drogues Released

Fruit was chosen because it is biodegradable, non-toxic, and has a density that allows it to float with most of the fruit under water. Prior observations in the harbor had shown that floating fruit moved in a different direction than the dye, which disperses slowly through the water column. The drogues appeared to move downwind more quickly than the dye, implying that the surface water is moving in a different direction than the underlying water. Some of the tangerines released in the A circle reached the beach locations PPH5 and PPH6 about 6 h later, whereas others escaped the confines of the outer harbor as measured after 7 h (Figure 6). Lemons released inside the B circle reached beaches PPH5 and PPH6 4.5 h later, and some of them had migrated towards the opening of the break wall. Oranges released in the west inner harbor reached the beach location PPH3 in the east harbor 6 to 8 h later. Limes released in the C circle reached the outer harbor wall 1 to 5 h later.

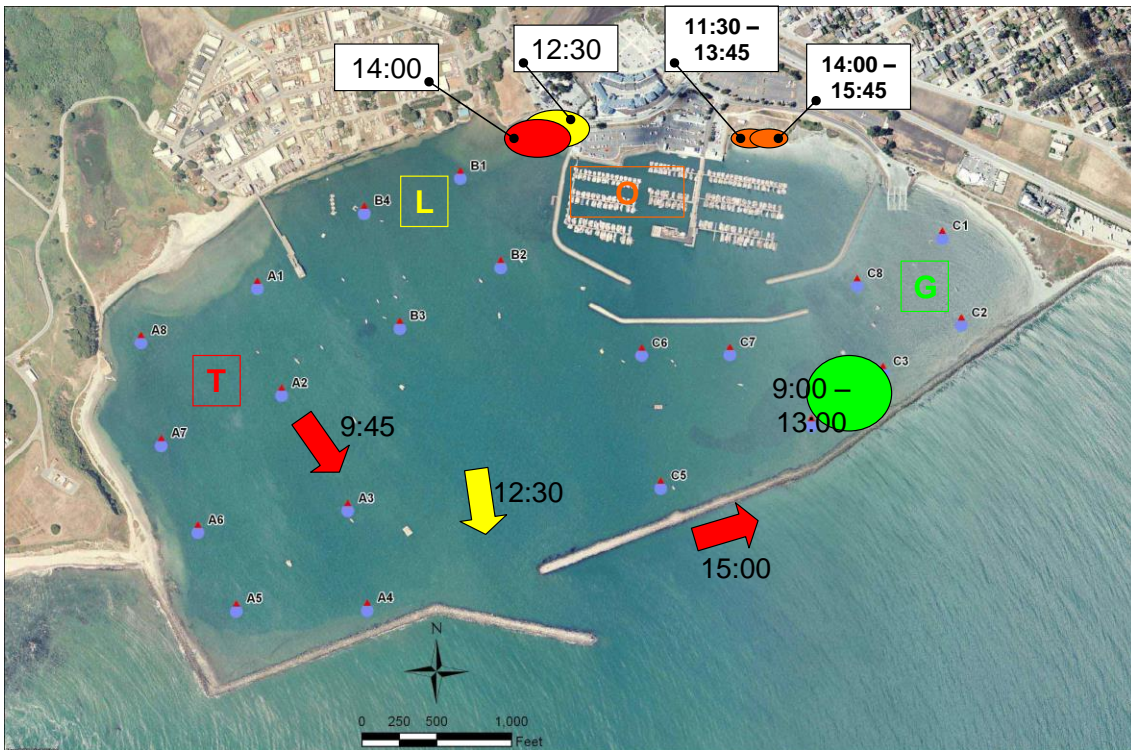


Figure 6: Drogue release sites and migration. (Box T: tangerine release site, Box L: lemon release site, Box O: orange release site, Box G: lime release site. Arrow: drogue moving direction. Ellipses: locations of beaching or repeated observations)

### 4.3 *Bacteroidales*

Microbial source tracking (MST) using *Bacteroidales* as source indicator was conducted at two groups of sites: group one consists of the 4 dye release sites in circle A, B, C and site E; group two contains the 4 control sites in the open ocean right outside of the harbor O1, O3, O6 and O9. The total *Bacteroidales* concentration was generally higher at the control sites outside of the harbor than at the sites inside the harbor (dye release sites). Our hypothesis is that kelp and fish, which have higher density at the control sites, might harbor some *Bacteroidales* species that can be detected by the universal *Bacteroidales* assay. This hypothesis remains to be verified. The human-associated *Bacteroidales* concentration was slightly higher at sites B and E than at other sites, but on the same order of magnitude than at sites A and O6. Site B is next to the most contaminated beach

site PPH3, which is under direct influence of fresh water inflow PPH1 and PPH2. Site E is in the inner harbor with much less circulation. It is also close to the liveboard boats. Long-term monitoring is needed to identify the exact reason for this human-associated signal. The dog-associated and cow-associated *Bacteroidales* concentrations in both groups of sites were at minimum level (Figure 7).

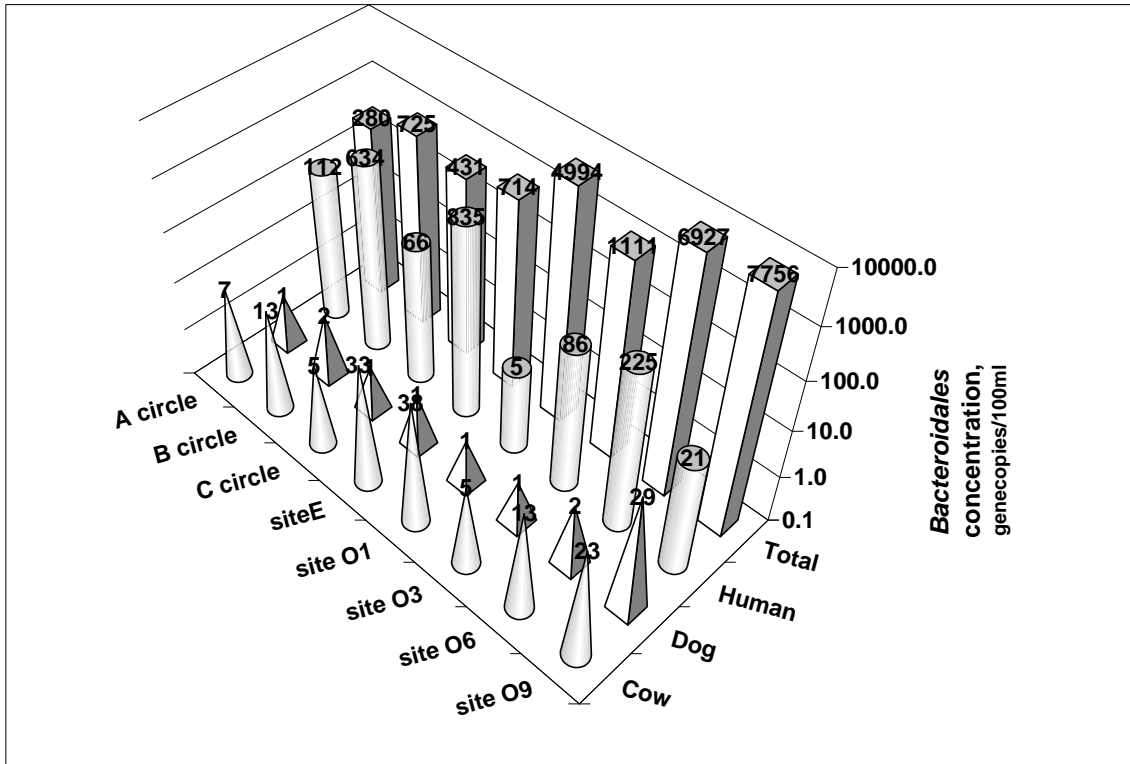


Figure 7: *Bacteroidales* concentration at the four dye release sites and four control sites outside the harbor (sampled at 8 a.m. on 9/27/2008)

#### 4.4 Dispersion of Fluorescent Dyes in Inner and Outer Harbor

Fluorescein and Rhodamine dyes were released concurrently at four locations throughout the harbor at 8 a.m on September 27, 2008. The release sites were chosen by Balance Hydrology, with input from members of the Technical Advisory Committee for the research project “Identification of Sources of Fecal Pollution Impacting Pillar Point Harbor” by San Mateo Resource Conservation District (SMRCD). The four sites were

strategically selected to gain information about circulation from and within the areas suspected to be potential sources of bacterial contamination within the harbor as follows:

- Rhodamine was released equidistant from sites A1, A2, A7, and A8 to analyze the circulation of potential contaminants near the marsh (see Figure 1).
- Fluorescein was released approximately 100 feet offshore of Denniston Creek between sites B1 and B4 to track circulation near the creek and outfall pipes at Capistrano Beach.
- Rhodamine dye was dispersed throughout the inner harbor in the vicinity of the liveaboard boats at the western end of the inner harbor.
- Fluorescein dye was released equidistant from sites C1, C2, C3 and C8 to monitor circulation from and around the eastern side of the harbor as well as to ascertain some information about the permeability of the outer breakwater.

Beginning at 8:15 a.m. and continuing until 16:00 on September 27th samples were collected by volunteer kayakers at 15-minute intervals from each of the 22 pre-identified sites within the harbor. For the two succeeding days (September 28 and 29) samples were collected approximately hourly from each of the locations. Samples were collected in bottles that were pre-labeled for the site locations. Volunteers wrote the time the sample was collected on the bottle and stored the bottles in black plastic bags, which were collected at the end of their two-hour kayaking shift. At the same time samples were being collected from the harbor, aerial photographs were obtained to monitor the movement of the visible plume. As there was heavy fog on the day of the field operation, the pilot was only able to fly during a limited period of time.

#### 4.4.1 Fluorescein Movement Observation

Fluorescein was released at 8:00 a.m. (27th) almost at the end of flood tide (Figure B-1, Figure 8). In the 10:00 -11:00 a.m. measurement window, a considerable amount of the Fluorescein was found at point C4 but not at the stations C7, C5, and C6. This could possibly be explained as follows: the constituent traveled from the gap between the inner harbor's breakwater (Figure B-3). From 12:00-13:00, in the middle of ebb tide, both Fluorescein mass distributions in zones B and C are carried by the ebb tide into the ocean and move toward the harbor's mouth (Figure B-3 to B-5). By the time span 13:00 to 14:00 (end of ebb tide) a portion of the Fluorescein mass passed the harbor entrance and was likely released into the ocean (Figure B-5). From 14:00 to 17:00 (slack tide) the

Fluorescein masses are pushed back to the stagnation points (B1, B2, B4 and C1, C2, C3, C8; Figures B-7; 8; 9).

By the next morning (8:00-10:00 a.m. on September 28, 2008) the center of mass in the B1, B2, B4 triangle was pushed to the western edge of the harbor due to the another flood tide in the night. Interestingly, the mass is dispersed within the harbor except for points A5, A6, A7 and A8 (Figure B-10). The points A5, A6, A7 and A8 are shallower than the average of the other sampling points, and the tracer was not found there. The authors assume the currents might not be too strong at the west end of the basin. By 2:00 p.m. (28th) the remainder of tracer mass again moved to the mouth in the ebb tide from the following two corridors: 1) North to west from B3 to the harbor mouth, 2) parallel to the eastern breakwater from C3, and C4 to the mouth (Figure B-11). In the period 16:00-18:00 (28th September 2008), the rest of Fluorescein mass was pushed back to the stagnation points by the flood tide (Figure B-12). Then, by 10:00 a.m. of the last day of study (29th September 2008) the remaining mass of Fluorescein is located at the stagnation points B1, B2, B4 and C1, C2, C3, C8 (Figure B-13). Finally, by 2:00 p.m. of September, 29th no more Fluorescein was detected at the sampling points (Figures B-14, B-15).

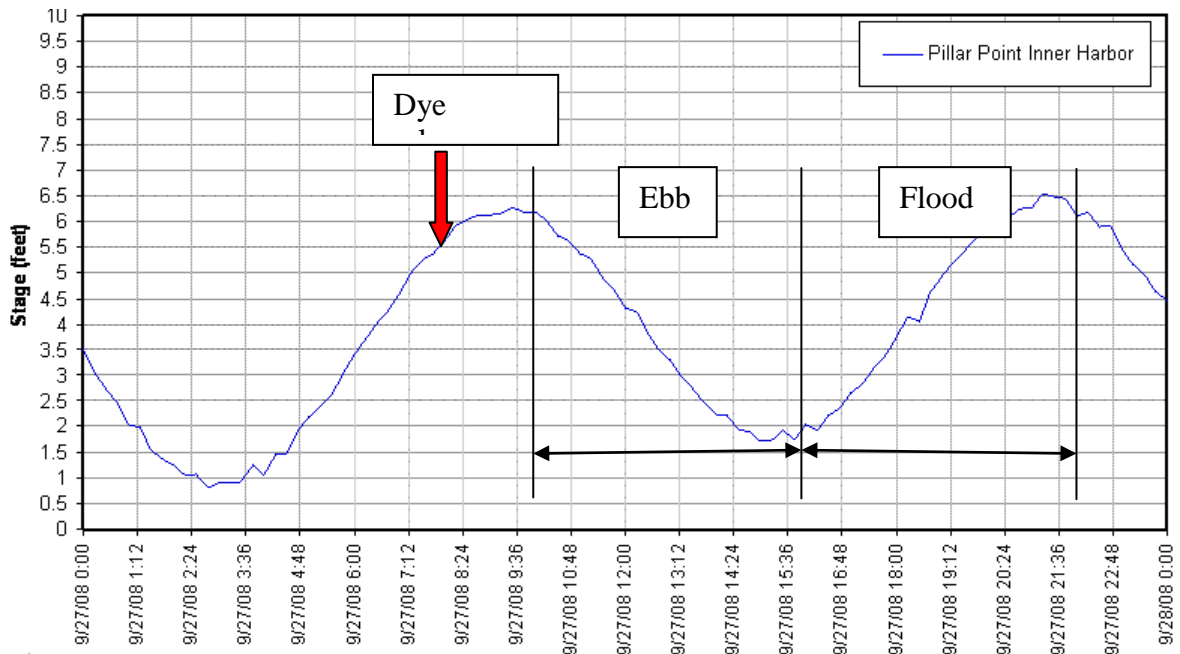


Figure 8: Fifteen-minute tide data for Pillar Point Harbor, San Mateo County, CA, September 27, 2008. Source: Balance Hydrologics Inc.

#### 4.4.2 Rhodamine Movement Observation

Rhodamine was released at 8:00 a.m. (September 27, 2008) before the slack tide and after a flood. No tracer was detected in the first three hours (Figure C-1, 2, 3). By 11:00 a.m., the Rhodamine mass moved slowly towards the harbor mouth (with Westward direction) due to the start of ebb tide and the effect of deeper depth (Figure C-4). By 12:00-13:00 a portion of Rhodamine was taken in by the ebb tide current towards the ocean and another portion moved along the inner harbor jetty towards the point C8 (Figure C-5). At 13:00-14:00 (27th September 2008), the same behavior as pervious step up to the end of ebb tide (Figure C-6). At 14:00 – 15:00 (27th September 2008), after the beginning of flood tide, both Rhodamine mass plumes were pushed back into the basin. They remained at essentially the same location in the following sampling period, 15:00-16:00 (Figure C-7, 8). By 16:00 - 17:00 the tracer was moving towards the ocean from its previous locations (Figure C-9).

The next morning (28th September, 2008), at 8:00 to 10:00 a.m., the Rhodamine mass was almost detected everywhere in the harbor, near the end of flood tide, but the tracer concentration decreased from Northern sampling points when it came to South near harbor entrance (Figure C-10). 12:00 to 2:00 PM, 28th September, 2008, by the middle of ebb tide, Rhodamine again almost detected everywhere with about the same concentration, but the total mass was less than the last hours. The lost mass was washed out and diluted in the ocean (Figure C-11). In the period of 16:00 to 18:00, after the beginning of flood tide, Rhodamine was again detected almost everywhere with the same pattern as on the previous day. However, the mass was pushed back to the North to some extent by the incoming tidal jet (Figure C-12). At 8:00 to 10:00 a.m., 29th September, by the end of flood tide, the Rhodamine mass was once again found everywhere except in the incoming jet locus right North of the harbor mouth. The concentration of dye was higher in the zones distant from the harbor entrance (Figure C-13). Finally, during 12:00-14:00 and 16:00-18:00 on the 29<sup>th</sup>, after the end of ebb tide, the Rhodamine plume dissipated all over the harbor with the same pattern as on the previous day, but the total mass is less (Figure C-14, 15).

## 5 DISCUSSION

In 1994, Gahagan & Bryant Associates, Inc. (GBA) performed a hydrographic survey of the entire harbor area as part of an effort by the San Mateo County Harbor District to

design and build an additional 71 berths inside the inner set of breakwaters and perform maintenance dredging. However, the project stalled until 2006. GBA again surveyed the entire berthing area in August 2006. The 2006 hydrographic survey was compared with the 1994 bathymetry to determine areas and rates of scour/accretion, which in turn facilitates planning for maintenance dredging projects and advances the understanding of sediment transport within the harbor. Both sediment entrainment and deposition are functions of shear velocity at the bottom. Shear velocity is proportional to the flow velocity. Therefore, the high velocity zones and stagnant zones in a harbor basin could be implicitly identified while considering the local scour/accretion.

The 2006 surveying report of GBA shows the annual net scour/accretion in different zones of harbor over a 12-year period of 1994-2006. Difference in depth was normalized in the report between 1994 and 2006 when the entire harbor experienced 37,127 cubic yards (CY) of scour and 151,787 CY of accretion, resulting in a net accretion value of 114,660 CY. Each individual zone experienced scour and accretion. Zone one has the highest rate of scour in Pillar Point Harbor (Figure 10) with an average of -0.03 ft change in elevation in a year in the 12-year period of 1994-2006. Zone two with the net accretion of +0.23 ft per year has the highest amount of sediment accumulation in that period. It can be implicitly inferred that zone two in the western end of the harbor basin is a zone of low currents. This is concomitant with what one could expect based on the geometry of the harbor. Consequently, a picture emerges where there are zones of differential velocities and hence propensities of mixing in the harbor. The outcomes of fecal contamination released at different points in the harbor are likely to be different with respect to their residence time in the harbor.

Several confounding factors have to be considered when evaluating the dye tracing study. They include a limited budget, shortage of basic data, instrument precision, limited training of volunteers, and the complex multi-dimensional nature of harbor circulation. Additional field measurements and numerical modeling would be needed to reach a solid understanding of pollution migration patterns in the harbor basin. Consequently, there are some important limitations of the study:

1. Working with a limited budget while sampling a large area in a short amount of time, the sampling grid was relatively coarse. The sampling interval was 15 minutes on the first day and 2-4 h on the following two days. The latter sampling interval resulted in a relatively low resolution, and some of the samples were not useful because of mislabeling or other errors caused by short-term training of the volunteer sampling crew.



Figure 9: Critical zones for deposition and scour in Pillar Point Harbor

2. The short three-day field study period in September only provided a snapshot of the condition of the water quality in the harbor. The study was conducted in the absence of runoff and with relatively small waves and calm wind conditions; these factors determine the baseline conditions in the harbor. However, the water circulation on this day may not accurately depict the full spectrum of conditions. Preferably, there would have been several sampling periods to measure the effect of variable conditions.
3. Breakwater permeability may affect flushing and circulation of constituents within the harbor basin. The study was conducted without a full understanding of the current situation of permeability of the breakwaters. The recent hydrographic analysis that was completed for the harbor showed significant sediment accumulation along the inside of the outer harbor breakwater arm. In the dye release study samples were collected both inside and directly outside the breakwaters and very low concentrations were detected outside the breakwater, which seems to indicate that the permeability is reduced. The study team did not, however, sample specifically for the purpose of testing breakwater permeability in the harbor.

4. The wind and wave data was based on a National Buoy Data Center (NBDC) buoy number 46012, which is located approximately 35 km away from the harbor entrance towards the ocean; thus considering the same condition in Pillar Point Harbor and the buoy is a very rough assumption. But wind-induced currents are limited to the outer skin of a water-body and in most cases they have secondary influence compared to tide- induced currents.
5. In the tracer study, samples were taken at the surface to eliminate the need for special equipment and for ease of volunteers. This approach did not provide any information about the vertical distribution of the dye. As a result, effects of potential stratification within the harbor could not be considered in the analysis of motion of Fluorescein and Rhodamine dyes. In other words, there was no information on the three-dimensional conditions of flow velocities and water densities in different points of the harbor. Stratification may generate bidirectional flows in the harbor, and may thus contribute to the motion patterns of fruit and tracers. At this point, it is almost impossible to assess with some degree of certainty what those changes might be. Notwithstanding, the horizontal distribution is still useful to estimate the main trends in pollution migration in the harbor.
6. The drogue study was done utilizing fruit; therefore, it should be considered to only give a basic idea and rough qualitative inference for several reasons. First, since the size of a fruit is large compared to fecal contamination, the trajectory of fruit is the result of the integration of velocities. Second, fruit had interaction effects with the current and did not necessarily represent the constituents' transport behavior subjected to the same current. Third, fruit is buoyant in the top layer of the water-body where the influence of wind is not a secondary effect but could affect the circulation study.

## **5.1 Key Factors for Pillar Point Harbor Circulation**

There are six mechanisms that can influence the fate of contaminants in a harbor: river inflow, marine discharge of ground water, wind-induced currents, wave effect, tidal prism, and artificial mixing. To the best of our knowledge there are no currents in PPH induced by water pumping or other anthropogenic activities, and marine discharge of ground water into the basin can in principle be assumed to be small compared to the overall harbor volume. The remaining four potential mechanisms are briefly discussed below.

### 5.1.1 River Inflow

Two creeks, Deer Creek and Denniston Creek, drain runoff water into the Pillar Point Harbor basin (Figure 10). The former collects the runoff from a 1.05 sq. mile watershed and the latter drains a 3.83 sq. mile watershed (almost 3.5 times larger than the Deer Creek Watershed). Based on the 2008 and 2009 hydrologic records collected in the Prospect Way station, the flow in the larger creek reached a daily peak of 5.5 cfs in January and February of 2008. That is to say the flow in Denniston Creek was less than 1 cfs in 9 out of 12 months during 2008 and 2009.



Figure 10: Deer Creek and Denniston Creek watersheds

The harbor pavement run off and the surrounding areas likely also drain directly into the harbor basin. The positive effect of the riverine fresh water inflow - for Pillar Point Harbor's flushing mechanism - is negligible when the inflow volume is compared to the volume of water and tidal prism in the harbor basin. On the other hand, we considered Deer Creek, Denniston Creek, and the harbor pavement inflow as a possible source of pollution for Pillar Point Harbor. The circulation study was conducted after more than a month of no runoff-generating rainfall. The discharge records of the creeks are shown in Figures 11 and 12. As a result, the effect of riverine inflow is concluded to be negligible in the tracer study of September 27, 2008 due to very low discharge.

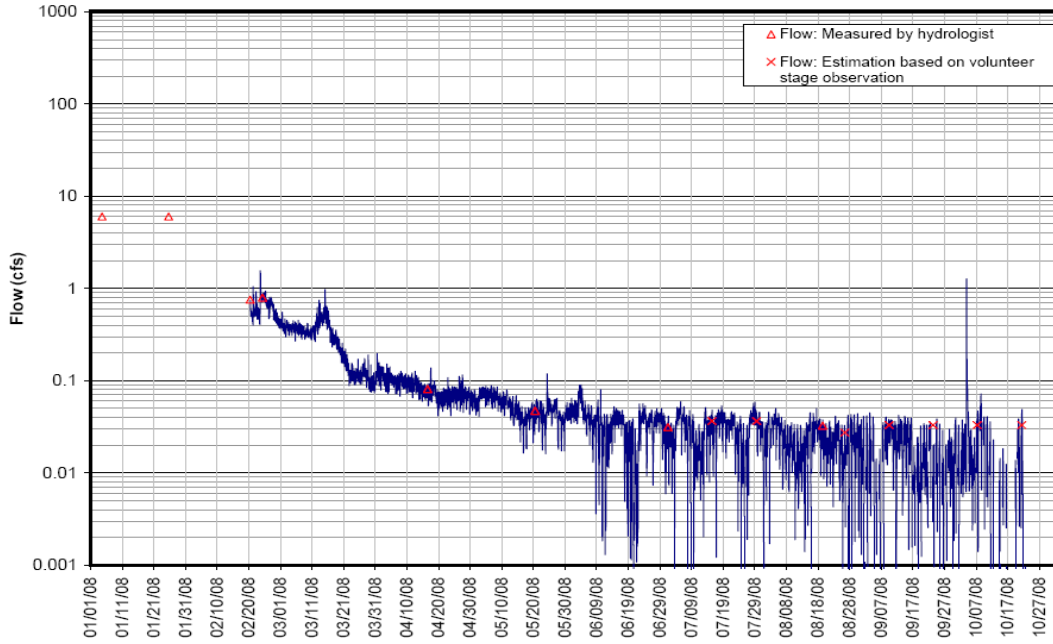


Figure 11: Deer Creek gage 15-minute flow, San Mateo County, California.  
 Source: Balance Hydrologics, Inc.

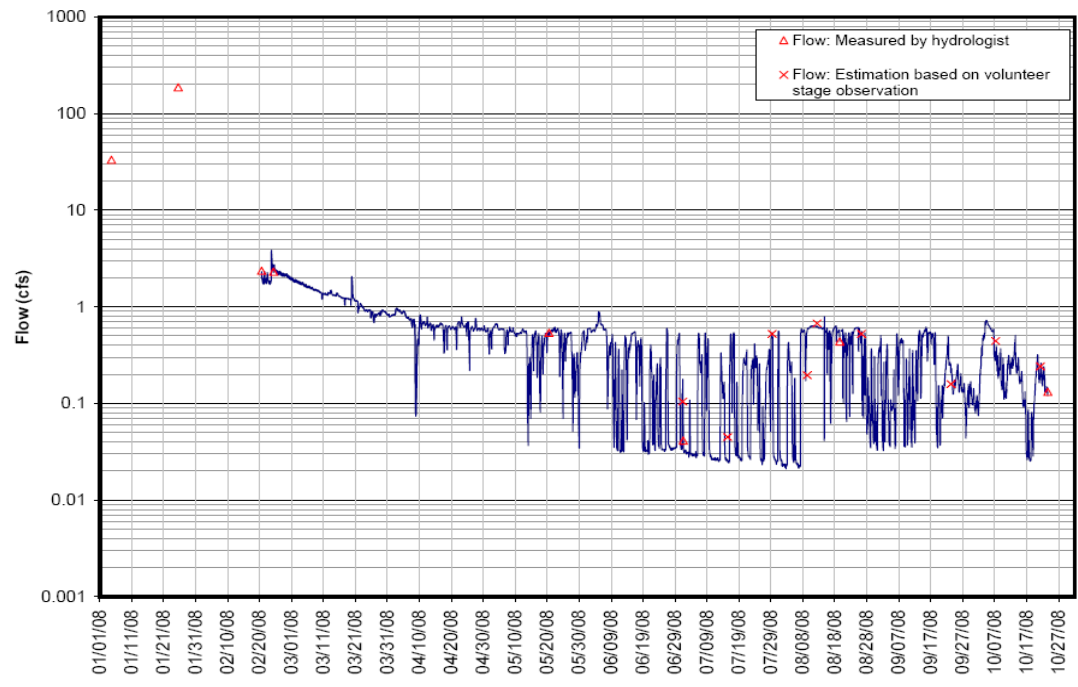


Figure 12: Denniston Creek gage 15-minute flow, San Mateo County, California,  
 Hydrograph through 10-23-2008. Source: Balance Hydrologics, Inc.

### 5.1.2 Wind Effect

During the field study period (9/27/08 - 9/29/08) the prevailing wind direction was 50% of the time coming from the North-West,  $\approx 10\%$  from the North, and  $\approx 12\%$  from the West at Station #46012 of National Buoy Data Center (NBDC, Figures 13 and 14). The buoy is located approximately 35 km away from the harbor entrance in the ocean. Therefore, the data cannot be applied directly and need to be corrected to account for hills and vegetation around the harbor. (Perhaps the wind data from the Half Moon Bay Airport could be employed for future studies.) The wind-induced currents are important only on the free surface of a water body (1-2 m) and they will be between 2-4 % of the wind speed at the surface (Shore Protection Manual, 1984). The wind speed at the Station 46012 was between 5.9 m/s to 0.5 m/s in the study period. Since a correction factor for PPH is not available the authors roughly assumed the wind would have a secondary role (in principle) compared to tidal prism in the harbor flushing process.

To determine the duration of winds, the definition of constant wind presented in the Coastal Engineering Manual (2003) and Shore Protection Manual (1984) was used. In this way, wind duration at the *i*th hourly data point was considered to be equal to the number of preceding consecutive and acceptable hours, which satisfies the following conditions:

$$|D_i - \bar{D}| < 15^\circ$$

$$|U_i - \bar{U}| < 2.5 \text{ m/s}$$

where  $\bar{U}$  and  $\bar{D}$  are the average of preceding consecutive and acceptable hourly wind speed and direction, respectively.  $U_i$  and  $D_i$  are wind speed and direction at the *i*th hourly data point. As can be seen from Figures 13 and 14, wind duration in the study period (27th to 29th September, 2008) was more than 45 min<sup>1</sup> most of the time. On the other hand since the dimensions of wind fetch in Pillar Point Harbor is relatively short (1.4 km  $\times$  2 km) there is always a fetch-limited situation within the harbor. As recommended by the Coastal Protection Manual (2003) and Sorenson (1993), with these numbers (Fetch length about 1.5 kilometer and minimum duration of one hour) wind wise currents in the range of 1% of the standard 10 m wind speed could be expected in the harbor. From Figure 14 and the basic calculation we have:

$$7 \text{ knots} = 3.6 \frac{\text{m}}{\text{s}} : \text{Average wind speed}$$

$$3.6 \times 60 \times 60 \times 0.01 \cong 130 \text{ m/hr} : \text{Maximum of wind induced current speed}$$

---

<sup>1</sup>  $t_{\text{min}} = 77.23 \frac{(\text{Fetch Length})^{0.67}}{(U_i)^{0.51}} = 77.23 \frac{(1400)^{0.67}}{(4.1-9.81)^{0.51}} = 45 \text{ minute}$

One might expect wind to play the second most important role in the circulation of water and its constituents within Pillar Point Harbor; yet it is still a secondary mechanism compared to tidal prism (Coastal Engineering Manual, 2003; Sorenson, 1993).

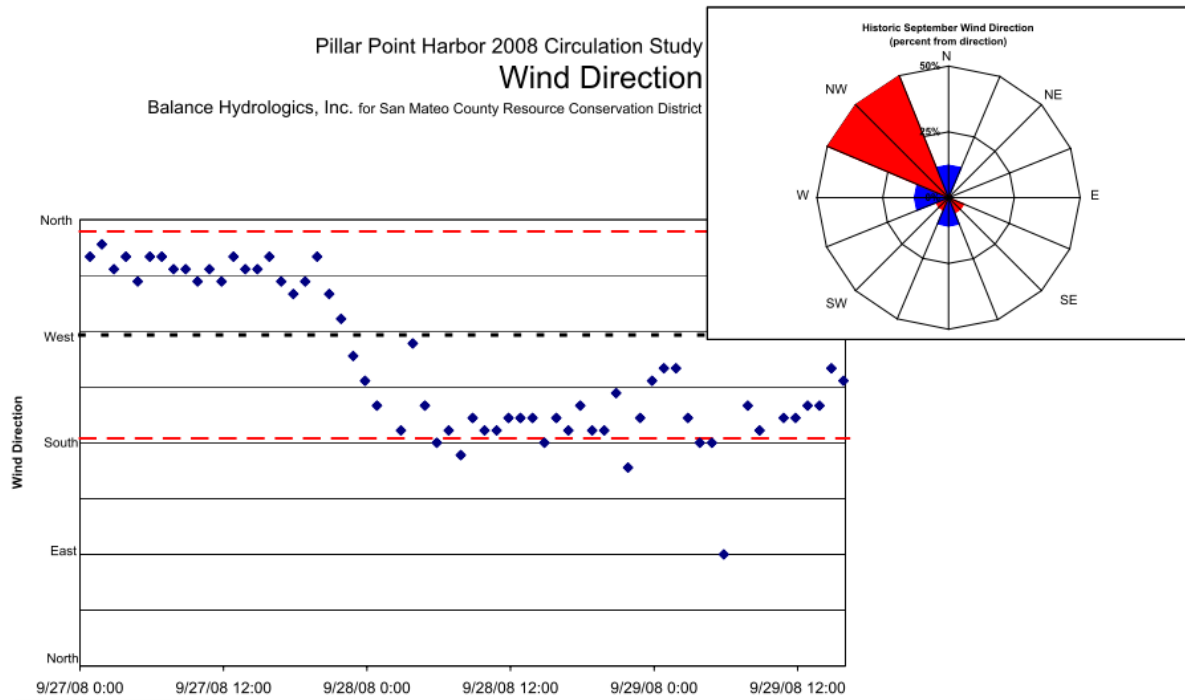


Figure 13: Wind direction observed in the tracer study period (27-29 Sept 2008) and monthly mean wind direction averaged over the period of 1980-2001 (NBDC Station #46012)

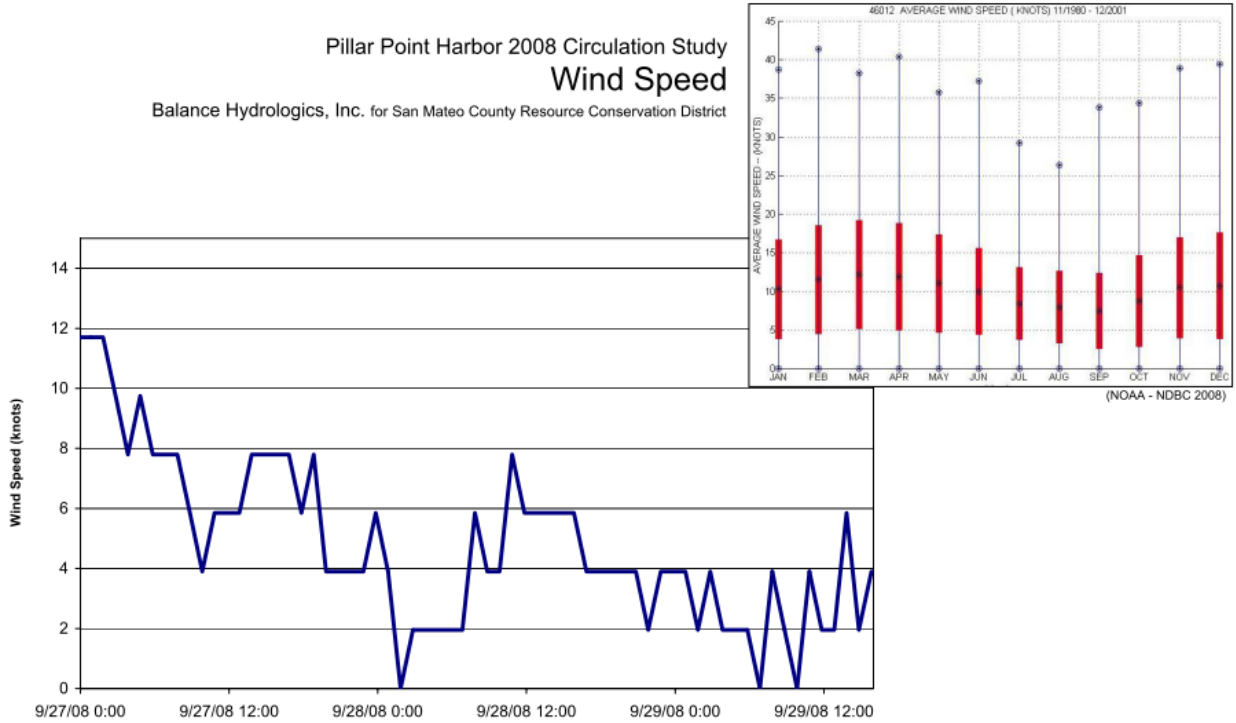


Figure 14: Wind speed observation 27-29, September 2008 and monthly mean wind speed averaged over the period of 1980-2001 (NBDC Station # 46012)

### 5.1.3 Wave Effect

Currents are the main means of transport of pollutants in water bodies. Although waves have a secondary effect in constituent transport they still play a role in the mixing process. In the tracer study period (9/27/08 to 9/29/08) the wave height at the NBDC station number 4601 was between 1 and 2 m (Figure 15). This buoy is far from the harbor entrance and for the present analysis, we did not have the means to convert the waves of buoy 4601 to waves at Pillar Point Harbor. However, since the harbor entrance is inclined with respect to the N-S direction and also covered by a breakwater arm, and considering the small opening of the entrance compared to the breakwater length, the diffracted waves inside the harbor would not be of a significant height. With simple “back-of-the-envelope” calculations using common refraction formulas and tables it could be concluded that the harbor is likely well protected from waves. The field observations of kayakers taking water samples also confirmed that the height of diffracted waves in the harbor was short during the tracer study.

Pillar Point Harbor 2008 Circulation Study  
**Wave Height**

Balance Hydrologics, Inc. for San Mateo County Resource Conservation District

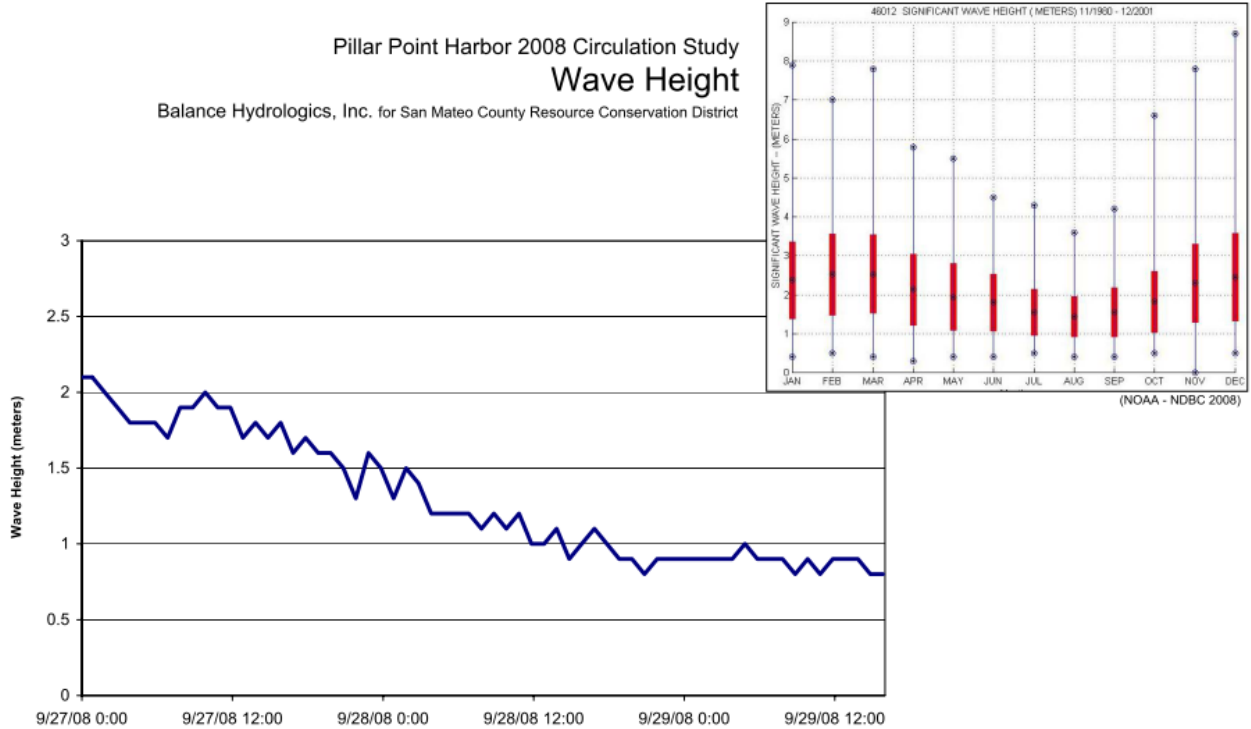


Figure 15: Wave height measured by NBDC station # 40612 (27-29 Sept 2008),  $H_s$  in the period of 1980-2001 same buoy station (Top right)

#### 5.1.4 Tidal effect

Tides constitute the main driving mechanism of flushing and circulation in Pillar Point Harbor. With finer resolution measurements and longer periods of measurement the pattern recognition techniques could be employed to establish the correlation between tidal currents and flushing of pollution.

## 6 CONCLUSIONS

Taking into account all the relevant limitations of the study, the following inferences and suggestions are provided:

- Assuming that Pillar Point Harbor (PPH) can be approximately represented by a rectangle, the curves in Figure D-1 (Falconer 1980) are applicable. Adopting a ratio  $L/B$  of about 0.45, we can conclude that the exchange coefficient for PPH is of the order of 0.42, close to the highest value of 0.5. This analysis does not take into account the inner breakwaters, which would alter the curves given by Falconer

(1980). The value of exchange coefficient indicates that the harbor possesses a high degree of interchange of waters with the ocean, facilitating the elimination of pollutants.

- The Fluorescein plume, which was released at the Northern zone of the harbor, completely washed out in **five tidal cycles** (2.5 tidal days).
- Any constituents which are released in the shallow waters of the Northwestern side of the basin are **NOT flushed out after six tidal cycles** (3 day) because a considerable amount of tracer mass remained inside the harbor.
- In case of a future tracer study, the other release point to consider for a tracer study is the Eastern end of the harbor (points C1 and C2).
- In future studies it is recommended to add at least two sampling points for finer resolution:
  - A point in the middle of (B1, B2, C1, C8) or inner harbor
  - Another point in the middle of (A3, B3, C5, C6).
- The general pattern of incoming jet from the ocean and ebb tide currents flushing the harbor is roughly estimated as shown in Figure 16. The white arrows show the current pattern in the flood tide and the red arrows are associated with the currents during ebb tide. Arrow size is approximately proportional to the strength of flow. The general mode of circulation in the tidal prism is clockwise as indicated by black arrows.

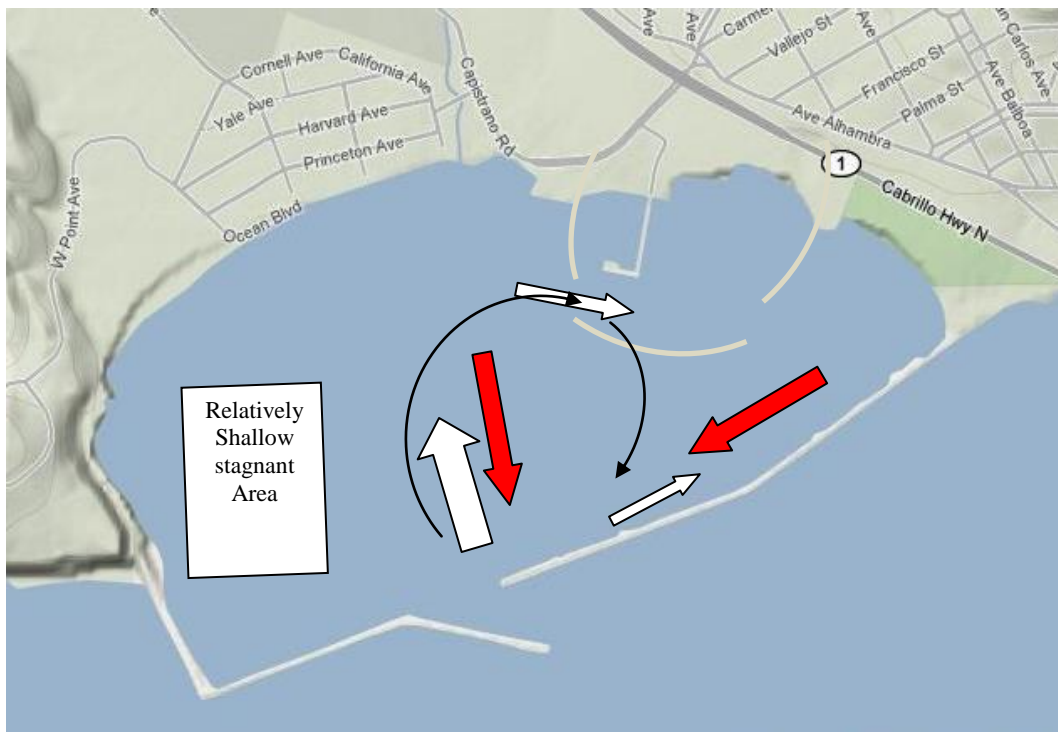


Figure 16: Schematic of tidal current patterns in Pillar Point Harbor

## 7 REFERENCES

- Abbott, M. B., Price, W. A., 1993, "Coastal, Estuarial and Harbour Engineers' Reference Book", Chapman and Hill, London, UK.
- ASCE Manual on Engineering Practice No. 50, (1994), "Planning and Design Guidelines for Small Craft Harbors", American Society of Civil Engineers, New York, NY.
- Coastal Engineering Manual (2003), Engineer Manual - EM 1110-2-1100, US Army Corps of Engineers.
- Falconer, R. A. 1980. "Modelling of Planform Influence on Circulation in Harbors," *Proceedings, 17th International Conference on Coastal Engineering*, American Society of Civil Engineers, pp 2726-2744.
- Kildare, B.J., Leutenegger, C.M., McSwain, B.S., Bambic, D.G., Rajal, V.B. and Wuertz, S. (2007) 16S rRNA-based assays for quantitative detection of universal, human-, cow- and dog-specific fecal *Bacteroidales*: a Bayesian approach. *Water Res.* 41:3701-3715.
- Lin, C.-P., Lott, J. W., and Mehta, A. J. 1986. "Turbidity-Sedimentation in Closed-End Channels," *Proceedings, 20th International Conference on Coastal Engineering*, American Society of Civil Engineers, pp 1336-1350.
- Nece, R. E., Falconer, R. A., and Tsutumi, T. 1976. "Planform Influence on Flushing and Circulation in Small Harbors," *Proceedings, 15th International Conference on Coastal Engineering*, American Society of Civil Engineers, pp 3471-3486.
- Nece, R. E., Smith, H. N. and Richey, E. P. 1980. "Tidal Circulation and Flushing in Five Western Washington Marinas," Technical Report 63, Harris Hydraulics Laboratory, University of Washington, Seattle.
- Neumann, G., and Pierson, W. J. 1966. *Principles of Physical Oceanography*, Prentice-Hall, Englewood Cliffs, NJ.
- Novak, P., Cabelka, J., 1981. "Models in Hydraulic Engineering: Physical Principles and Design Applications", Pitaman Publishing Inc.
- Rajal, V. B., B. S. McSwain, D.E. Thompson, C. M. Leutenegger, B. Kildare, and S. Wuertz. (2007) Validation of hollow fiber ultrafiltration and real time PCR using bacteriophage PP7 as surrogate for the quantification of viruses from water samples. *Water Res.* 41:1411-1422.
- Schwartz, R. A., and Imberger, J., 1988. "Flushing Behavior of a Coastal Marina," *Proceedings, 21st International Conference on Coastal Engineering*, American Society of Civil Engineers, pp 2626-2640.
- Shore Protection Manual, 4th edition, 1984, US Army Engineers Waterway Experiment Station, US Government Printing Office, Washington, DC.
- Sorenson, R., M., 1993, "Basic Wave Mechanics: For Coastal and Ocean Engineers", Wiley.
- Sorenson, R., M., 2006, "Basic Coastal Engineering", 3rd edition, Springer.

Spyropoulou, S., 2009, "*Observation and modelling of hydrodynamics and residence times in Bilbao Harbour*". MSc Thesis, Erasmus Mundus Programme Coastal and Marine Management.

## **Appendix C**

### **Pillar Point Harbor Source Identification Project Description (RCD)**

# **Identification of Sources of Fecal Pollution Impacting Pillar Point Harbor**

## **Project Description**

### **PROJECT SUMMARY**

“Identification of Sources of Fecal Pollution Impacting Pillar Point Harbor” is a project of the San Mateo County Resource Conservation District (RCD), funded by the State Water Resources Control Board. The goal of this project is to assess and identify sources of fecal pollution in Pillar Point Harbor and recommend opportunities for remediation.

Water will be sampled in select locations and tested for the presence and abundance of bacteria that occur with fecal pollution, and bacteria samples will be genetically tested to determine their original host source. The primary focus is Capistrano Beach, which has well documented levels of fecal pollution. The secondary focus is the five other beaches and liveaboard boats in the harbor.

Specific objectives for implementation of water quality remediation projects will be developed based on research and analysis. The project will identify constraints, impediments, opportunities, and priorities to remediate water quality on the beaches in Pillar Point Harbor and cost-effective, feasible water quality improvement projects. It develops a timeline for implementing the proposed methods to achieve water quality objectives and the parties responsible, as well as a monitoring plan and performance measures to track implementation of projects.

These investigations and the resulting prioritized recommendations are essential for a second phase to implement projects to improve water quality at public beaches in the Pillar Point Harbor. Stakeholders are committed to a second phase in which they pursue implementation of these recommendations and recognize this first phase as an essential step toward that end. Stakeholders value that the overall vision of this project is to reduce the number of days that the beaches are posted or closed, requiring implementation of proposed projects.

### **LOCATION**

The project study area is the Pillar Point Outer Harbor in El Granada, California (see Attachment A: Map of Project Location). The geographical focus extends to any potential drainages and/or pollution sources which empty into or otherwise impact the harbor and its beaches, such as creeks, marshes, storm drains, sewer systems, runoff, leach fields, springs, wells, boat discharge, pet and avian fecal contamination, sediment, and wrack.

### **SITE DESCRIPTION**

Pillar Point Harbor is an enclosed watershed with complex inputs and water flows. It contains an inner boat harbor, pier, and saltwater/brackish tidal marsh (Pillar Point Marsh). It receives drainage from Denniston and Deer Creeks, storm drains, outflow pipes, and large, mixed use areas including an airport, agricultural, commercial and residential sections. Pillar Point

Harbor contains five beaches: Capistrano Beach, Yacht Club Beach, Marsh Beach, Mavericks Beach, Inner Harbor Beach, and Beach House Beach.

Pillar Point Harbor comprises an inner harbor and outer harbor. The inner harbor berths 180 commercial fishing vessels and approximately 200 recreational boats, and is encompassed within the much larger outer harbor area. The harbor area houses commercial ventures including several restaurants, hotels, shops, a fertilizer plant, three commercial fish buyers, sport fishing concessions, a yacht club, two kayak rental companies, a recreational vehicle park, and an Air Force facility situated on the bluff overlooking the Outer Harbor. Outside of the Outer Harbor area but within the project study area are conference facilities, residential areas, and additional commercial ventures as well as a pump station for the Sewer Authority Mid-coastside.

The project area is also within the boundaries of the James V. Fitzgerald Marine Reserve Critical Coastal Area (CCA) Pilot Project. The marine reserve is a designated Area of Special Biological Significance and the CCA pilot project, jointly administered by the State Water Resources Control Board and the California Coastal Commission, is to foster collaboration among local stakeholders and government agencies to better coordinate resources and focus efforts on coastal watersheds in critical need of protection from polluted runoff. The CCA will develop an action plan to reduce non-point source pollution by 2010 and intends to coordinate closely with this project to identify and remediate sources of fecal contamination in Pillar Point Harbor.

## **NEED FOR PROJECT**

The public health impact of the impaired waters may impact commercial ventures, harbor activities, tourism, recreation, ecological habitat, and sources of drinking water for municipal utilities in the watershed. The harbor area has approximately 100,000 visitors annually and is heavily used recreationally by boating enthusiasts, kayakers, windsurfers, campers, hikers, dog walkers, bird watchers, swimmers, waders, families, clam diggers, surfers, and thousands of spectators for the world famous Mavericks big wave surf break.

Pillar Point Harbor water quality chronically is so poor that the State Water Resources Control Board recently listed the location as impaired by coliform bacteria on the 303(d) list submitted to the United States Environmental Protection Agency. Capistrano Beach has elevated levels of fecal indicator bacteria, such as *E. coli* and *Enterococcus* on over 95% of sampling events in wet and dry conditions. This beach has been ranked for several years by the Heal the Bay's Report Card as a "Beach Bummer," meaning that it is in the top ten most polluted beaches in California in dry weather conditions. In 2005/2006, Capistrano Beach ranked sixth on the "Beach Bummer" list. It was the worst ranked beach in Northern California and is a Clean Beaches Task Force Priority Beach with regard to fecal pollution. Capistrano Beach is permanently posted by the San Mateo County Environmental Health Department as a potential health hazard.

In 2005 and 2006, San Mateo County Department of Environmental Health repeatedly posted beaches in the Harbor as potential health hazards. Capistrano Beach was posted most frequently, approximately 50 weeks in each year. Marsh Beach was posted over 20 weeks in

each year, 42% to 51% of sampling events. Mavericks Beach was posted approximately 15 weeks each year, approximately 30% of sampling events. The county terminated sampling for Capistrano Beach and permanently posted the beach as a potential health hazard in March of 2006.

Within the local community there are numerous opinions as to the primary sources of fecal pollution impacting the harbor, including human contamination from leaking sewer lines, avian contamination from resident and migratory bird populations including large flocks of gulls and other birds, and lack of flushing in the harbor due to the presence of two breakwalls. Although much effort has been expended on studying the locations of fecal pollution impacting the harbor, including water sampling and fecal indicator enumeration studies, data on identification of primary sources and their relative contributions to the overall magnitude of the pollution problem are lacking. There is an urgent need for a comprehensive study of all of the possible sources of pollution in this watershed and how these flows interact in the confines of the enclosed Pillar Point Harbor bay.

## **ROLES AND RESPONSIBILITIES**

The RCD is a non-regulatory public benefit district to help people protect, conserve, and restore natural resources through information, education, and technical assistance programs. For this project, the RCD is responsible for administration, project management, and outreach as described in the Scope of Work, and is ultimately responsible for the quality of the project deliverables. This includes hiring consultants for technical expertise in hydrology, geology, microbial source tracking, and laboratory work.

A Technical Advisory Committee (TAC), including a Lead Researcher, guides and contributes expertise to all aspects of the project. The TAC meets several times per year as a group, while subgroups and individuals may contribute expertise to the project as needs and opportunities arise. The Lead Researcher will provide oversight for the design of the research components of the project. The TAC establishes appropriate methodology to identify the sources of fecal pollution and recommends strategies for remediation. As such, expertise on the TAC includes harbor function and infrastructure, wastewater treatment function and infrastructure, abatement of fecal indicator bacteria, hydrology and geology, microbiology, public health, microbial source tracking, and water quality (see Attachment B: Technical Advisory Committee).

## **SCOPE OF WORK<sup>1</sup>**

### **Task 1: Administer and Manage Project (8/07- 6/13).**

---

<sup>1</sup> Work on this project was underway when the State Water Resources Control Board issued notice to stop work in December 2008 due to the state's economic crisis. The project was delayed over a year and data collection was interrupted mid-season, disrupting the sampling plan and scope of work for the project. The RCD obtained an extension on the timeline and additional funds to restart data collection. The scope of work in this document begins with the original beginning date and continues through the amended completion date, and contains the revised sampling plan.

Project administration includes creating, coordinating, and convening a Technical Advisory Committee (TAC); soliciting, contracting with, and coordinating consultants; managing contracts; working with consultants and the TAC on development of project process and products, including reports; participating in committees and public meetings; and reporting and administering the grant.

*Responsible Party: RCD*

Task 2: Assess and Analyze Existing Data Relevant to Potential Sources of Fecal Contamination Impacting Pillar Point Harbor (10/07- 4/08).

Perform a full search for all existing data, review and analyze with respect to the following:

- 2.1 hydrology of contributing watersheds, marsh, and harbor
- 2.2 geologic setting
- 2.3 natural and human-made conditions
- 2.4 sedimentation and beach sand shifting
- 2.5 sewer and other sewerage inflow and infiltration studies
- 2.6 existing microbial source tracking data
- 2.7 enumeration data for fecal indicators with regard to tidal and flow conditions, temporal issues, weather, rain events, seasons, first flush events, etc.
- 2.8 watershed sanitary surveys and similar analyses and related watershed data
- 2.9 residency time for harbor water circulation

*Responsible Parties: RCD, Balance Hydrologics, Lead Researcher*

Task 3: Investigate Sources of Fecal Contamination Impacting Pillar Point Harbor (11/07-12/12).

- 3.1 Investigate sources of fecal contamination known to impact Capistrano Beach.
  - 3.1.1. Perform microbial source tracking to identify and estimate relative contributions of fecal pollution arising from human, avian, dog, horse, cattle and other host sources.
  - 3.1.2. Track pollutants to their sources by scoping storm drains and sewer lines and conducting hydrologic studies and sanitary surveys with enumeration.
  - 3.1.3. Investigate role of sediment as a potential source of elevated levels of fecal indicators, including sampling Denniston Creek and the Pillar Point Marsh during storms.

*Responsible Parties: RCD, Balance Hydrologics, Lead Researcher, San Mateo County Public Health Lab*

- 3.2 Investigate potential sources of fecal contamination to remaining beaches in Pillar Point Harbor: Mavericks, Marsh, Yacht Club, Beach House, Inner Harbor, and Pillar Point Marsh beaches.

- 3.2.1. Sample beaches, lagoons, creeks, monitoring wells, bluff seeps, and storm drains, and assess by fecal indicator enumeration of *E. coli* and *Enterococcus* and by watershed sanitary surveys.
- 3.2.2. For sites which are identified as major sources of fecal pollution, perform microbial source tracking to identify and estimate relative contributions of fecal pollution arising from human, avian, dog, horse, cattle and other host sources. Utilize phylochip technology to identify sources of fecal pollution in partnership with Lawrence Berkeley National Laboratory.

*Responsible Parties: RCD, Lead Researcher, San Mateo County Public Health Lab*

- 3.3 Investigate other factors which may impact fecal contamination in Pillar Point Harbor with respect to the following and perform microbial source tracking as required:
  - 3.2.3. hydrologic parameters, including currents, flow, salinity, and residency time
  - 3.2.4. impact of birds, domestic animals, recreational vehicles, leach fields, and boats
  - 3.2.5. sewer line integrity
  - 3.2.6. inflow sources, including the marsh, runoff, outflow from Denniston Creek and Deer Creek, storm drains and storm sewers

*Responsible Parties: RCD, Balance Hydrologics, Lead Researcher, San Mateo County Public Health Lab*

Task 4: Conduct Public Outreach and Community Participation (8/07- 4/13).

Facilitate public outreach and education about the project and coordinate stakeholders by notifying and encouraging the participation of affected and interested public and private landowners, utilities, resource agencies, and others as necessary and appropriate, providing opportunities for public input into the project effort. Outreach activities will include a public workshop, creation and maintenance of a web page for the project, and enabling/encouraging any member of the public to ask questions and provide input on the project at regularly scheduled public meetings of the Resource Conservation District Board of Directors.

*Responsible Parties: RCD, Balance Hydrologics, Lead Researcher*

Task 5: Develop Implementation Goals and Strategies (12/12- 4/13).

Develop and prioritize specific objectives for implementation of water quality remediation projects based on the research and analysis. Identify specific constraints, impediments, opportunities, and priorities to remediate water quality on the beaches in Pillar Point Harbor. Offer specific cost-effective, feasible water quality improvement projects. Develop milestones and timeline for implementing the proposed methods to achieve specific water quality objectives and the parties responsible for meeting these objectives. Draft monitoring plan and specific performance measures to track implementation of specific projects.

Some opportunities for remediation that can be implemented during the project may be identified and undertaken, and potentially earlier than April 2013.

*Responsible Parties: RCD, Lead Researcher, Balance Hydrologics*

**SAMPLING PLAN**

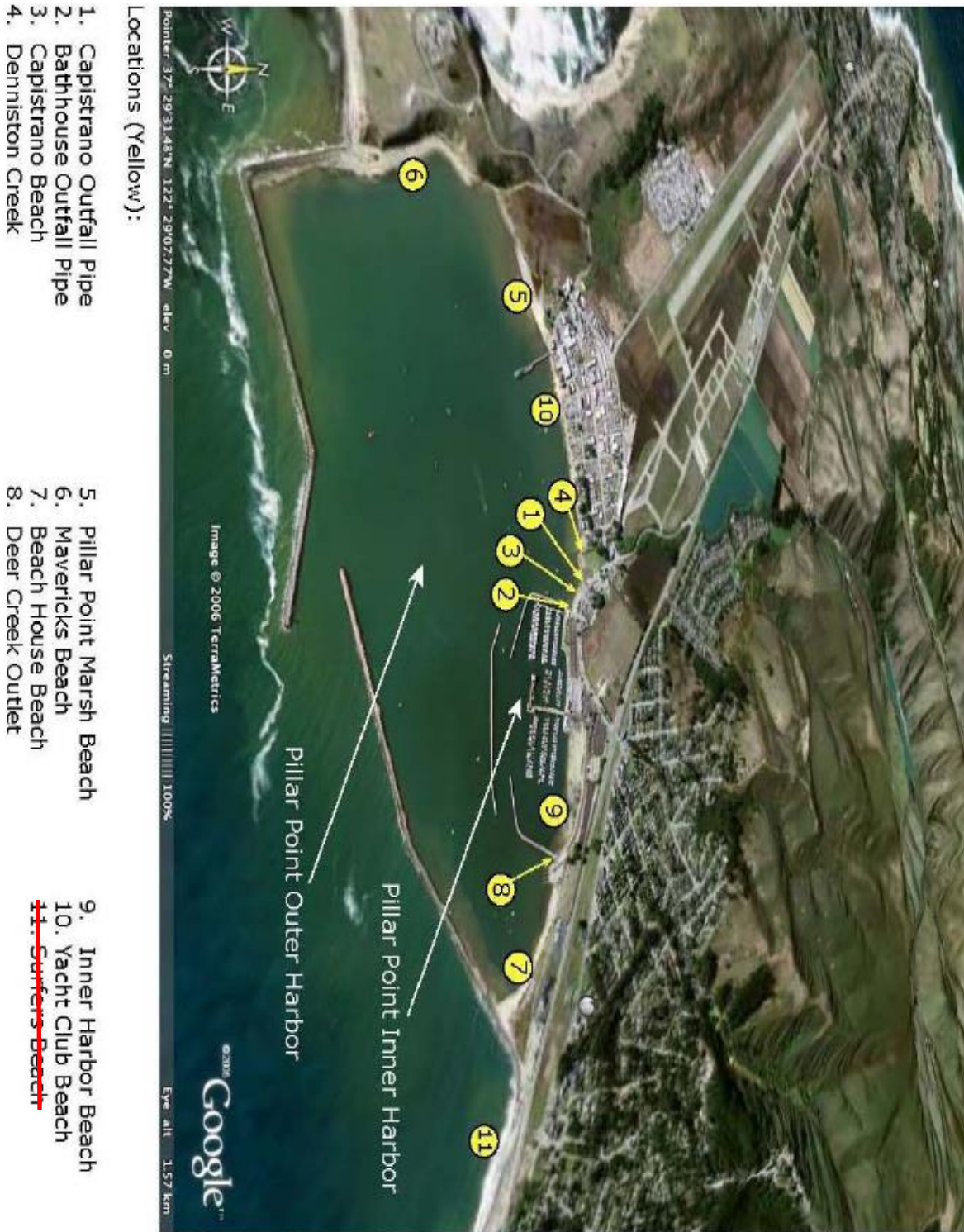
Numerous types of flows and drainages are to be investigated, including outflows from Denniston and Deer Creeks, outfall pipes, storm drains, runoff from blacktop and impervious surfaces, agricultural and commercial operations. Flows originating from wave action and/or wave generated surges breaching harbor walls, water circulation within the harbor, tidal surges, currents, other issues associated with enclosed beaches, and potential drainage from sewer lines will also be investigated. Effects of wet and dry weather upon these flows will be analyzed. Water flows draining into the harbor with well documented elevated levels of fecal indicators include Capistrano and Bathhouse Outfall Pipes and Denniston Creek, and these flows will be a primary focus of the project.

The plan below outlines the revised sampling approach based on modifications made after reviewing findings from enumerated and MST samples. Previous sampling approaches and the timeframe in which sampling was performed is noted in the table.

<b>Site #</b>	<b>Site Name</b>	<b>Approach</b>
6	Mavericks Beach	2007-2011 Sampled during wet and dry weather events for FIB and MST. Sediment sampled twice for MST at this site.
		Current: Sampling ceased at this site in 2011.
5	Marsh Beach	2007-2011 Sampled bi-weekly for FIB and during wet and dry weather events for FIB and MST. Sediment and biofilm sampled twice for MST at this site.
		Current: Sampling ceased at this site in 2011.
10	Yacht Club Beach	2007-2011 Sampled during wet and dry weather events for FIB and MST. Sediment sampled twice for MST at this site.
		Current: Sampling ceased at this site in 2011.
4	Denniston Creek	2007-2011 Sampled bi-weekly at mouth and upstream sites for FIB. Sampled during wet and dry weather events for MST and FIB. Sampled twice for sediment and biofilm for MST.
		Current: Sampled weekly at mouth of creek and two upstream sites for FIB. Also sampled during First Flush and wet weather events for MST and FIB. Additional MST sampling planned at mouth and upstream.
1	Capistrano Pipe	2007-2011: Sampled bi-weekly for FIB at drain mouth and upstream sites. Sampled during wet and dry weather events for MST and FIB. Sampled twice for sediment and biofilm for MST.
		Current: Sampled weekly at mouth and one upstream site for FIB. Also sampled during First Flush and wet weather events for FIB and MST. Additional MST sampling planned at mouth and upstream.
3	Capistrano Beach	2007-2011: Sampled bi-weekly for FIB at drain mouth

		and upstream sites. Sampled during wet and dry weather events for MST and FIB. Sampled twice for sediment for MST.
		Current: Sampled weekly for FIB. Also sampled during First Flush and wet weather events. Additional MST sampling planned.
2	Bathroom Outfall	2007-2011: Sampled bi-weekly for FIB at drain mouth and upstream sites. Sampled during wet and dry weather events for MST and FIB. Sampled twice for sediment and biofilm for MST.
		Current: Sampled weekly at mouth and one upstream site for FIB. Also sampled during First Flush and wet weather events for FIB and MST. Additional MST sampling planned at mouth and upstream.
9	Inner Harbor Beach	2007-2011 Sampled during wet and dry weather events for FIB and MST.
		Current: Sampling ceased at this site in 2011.
8	Deer Creek	2007-2011 Sampled during wet and dry weather events for MST and FIB at mouth and upstream sites. Sampled twice for sediment and biofilm for MST.
		Current: Sampled weekly for FIB. Also sampled during wet and dry weather events and First Flush for MST and FIB. Additional MST sampling planned at mouth and upstream.
7	Beachhouse Beach	2007-2011 Sampled during wet and dry weather events for MST and FIB. Sampled twice for sediment for MST.
		Current: Sampled weekly for FIB.
Liveboard boats		2007-2012 Sampled near boats at liveboard docks twice for FIB and MST.
		Current: No current sampling for FIB or MST.
Upstream sites		2007-2011 Some sampling performed at upstream sites. Not sampled for MST.
		Current: Some upstream sites sampled during wet weather and dry weather events for MST and FIB. Additional MST sampling planned.
Contingent MST		Additional MST sampling at targeted sites based on previous FIB and MST results. Current contingent MST work includes additional sampling at outflow and upstream sites.
Phylochip Analysis		50 samples to be analyzed at Lawrence Berkeley Labs from prioritized sites based on MST and FIB results.

## Attachment A: Map of Project Location



Locations (Yellow):

- 1. Capistrano Outfall Pipe
- 2. Bathhouse Outfall Pipe
- 3. Capistrano Beach
- 4. Denniston Creek
- 5. Pillar Point Marsh Beach
- 6. Mavericks Beach
- 7. Beach House Beach
- 8. Deer Creek Outlet
- 9. Inner Harbor Beach
- 10. Yacht Club Beach
- ~~11. Surfers Beach~~

**Attachment B:  
Technical Advisory Committee**

	<b>Member</b>	<b>Expertise</b>
1	Barry Hecht Balance Hydrologics	Hydrology and geology of region
2	Bruce Fujikawa, PhD Public Health Laboratory San Mateo County	Public health / laboratory procedures
3	Chuck Duffy Granada Sanitary District	Sanitary District function
4	Dean Peterson Environmental Health Services San Mateo County	Environmental health
5	Julie Casagrande Planning Department San Mateo County	Knowledge of local planning and water quality issues
6	Greg Smith Environmental Health Services San Mateo County	Familiar with Public Health Lab operations Environmental health
7	Jill Murray, PhD Creeks Division City of Santa Barbara	Microbial source tracking in Santa Barbara region
8	Jim Howard Natural Resources Conservation Service	Upland uses, conservation practices, and best management practices, NRCS programs and conservation standards
9	Scott Grindy Harbor Master, Pillar Point Harbor San Mateo County Harbor District	Harbor function
10	Peter Grenell General Manager San Mateo County Harbor District	Harbor function, water quality monitoring in Pillar Point Harbor
11	Keith Mangold	Regional watershed knowledge
12	Sarah Damron Surfrider San Mateo County Chapter	Regional volunteer water quality monitoring Surfrider laboratory function
13	Stefan Wuertz ( <i>lead researcher for project</i> ) Civil and Environmental Engineering UC Davis	Microbial source tracking, biofilms, aerobic wastewater treatment, bacterial and viral pathogens
14	Steve Peters Environmental Health Services County of Santa Cruz	Microbial source tracking at Santa Cruz County beaches
15	Steven Leonard Sewer Authority Mid-Coastside	Sewer authority function
16	Tony Pullin Sewer Authority Mid-Coastside	Sewer authority function, familiar with ongoing water quality sampling
17	John Largier Dept. of Environmental Science and Policy UC Davis	Microbial source tracking, coastal processes, harbor circulation

## Attachment C: Performance Measures

Project Goals	Desired Outcomes	Output Indicators	Outcome Indicators	Measurement Tools and Methods	Targets
Investigate sources of fecal contamination impacting Pillar Point Harbor in order to develop strategies for remediation.	<ol style="list-style-type: none"> <li>1. Assessment and analysis of existing data.</li> <li>2. Creation of Technical Advisory Committee.</li> <li>3. Investigation of sources of fecal contamination.</li> </ol>	<ol style="list-style-type: none"> <li>1. Written report summarizing assessment and analysis of existing data.</li> <li>2. Regular meetings of TAC.</li> <li>3. Draft report of sources of fecal contamination.</li> <li>4. Public workshop to share information.</li> </ol>	<ol style="list-style-type: none"> <li>1. Participation and input of TAC.</li> <li>2. Ability to develop and prioritize strategies for remediation of fecal contamination.</li> <li>3. Attendance and local interest in public workshop.</li> </ol>	<ol style="list-style-type: none"> <li>1. Attendance of participants in TAC meetings.</li> <li>2. Surface Water Ambient Monitoring Program</li> <li>3. Targeted sampling protocol.</li> </ol>	<ol style="list-style-type: none"> <li>1. Identification of causes of contamination sufficient to develop strategies to remediate.</li> </ol>
Develop and prioritize strategies to remediate fecal contamination in Pillar Point Harbor.	<ol style="list-style-type: none"> <li>1. Recommended strategies to remediate fecal contamination.</li> </ol>	<ol style="list-style-type: none"> <li>1. Regular meetings of TAC.</li> <li>2. Milestones and timeline for implementing remediation activities.</li> <li>3. Identification of parties who may implement recommendations.</li> <li>4. Draft monitoring plan and performance measures to track implementation of projects.</li> <li>5. Public workshop to share information.</li> </ol>	<ol style="list-style-type: none"> <li>1. Participation and input of TAC.</li> <li>2. Attendance and local interest in public workshop.</li> </ol>	Non-point source pollution management measures as identified in the <i>California Non-Point Source Encyclopedia</i> and by the US EPA	<ol style="list-style-type: none"> <li>1. Written recommended goals and strategies by May 2013.</li> </ol>

## **Appendix D**

### **Identification of Sources of Fecal Pollution Impacting Pillar Point Harbor Report (UC Davis)**

# **Identification of Sources of Fecal Pollution Impacting Pillar Point Harbor**

A Final Report Submitted to  
San Mateo County Resource Conservation District

Prepared by

Minji Kim

Prof. Stefan Wuertz

Department of Civil and Environmental Engineering

University of California, Davis

One Shields Avenue, Davis, CA 95616

**January 2014**

Funding for this project has been provided in full or in part through an agreement with the State Water Resources Control Board. The contents of this document do not necessarily reflect the views and policies of the State Water Resources Control Board, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

## ACKNOWLEDGEMENTS

The authors would like to acknowledge and thank all of the individuals and organizations that were involved in and supported this project to improve the microbial water quality in Pillar Point Harbor. Current and former staff of the San Mateo County Resource Conservation District (SMCRCD) conceived the idea of a source tracking study and developed and implemented the complex programs to coordinate the volunteers. Furthermore, SMCRCD staff and volunteers collected samples during the study, assisted in selecting specific sampling sites, scheduling sampling time, collecting FIB samples, coordinating the volunteers during first flush events and organizing technical advisory committee meetings. These individuals include: Karissa Anderson, Alex Beakes, Ellen Gartside, Chelsea Moller, Renee Moldovan, Kellyx Nelson, Shannon Thomas, Carolann Towe and hundreds of RCD volunteers.

Ms. June Wong, a laboratory technician at San Mateo County Public Health Laboratory analyzed fecal indicator bacteria in water samples under the direction of Dr. Bruce Fujikawa. We also gratefully acknowledge Prof. Jiyoung Lee at Ohio State University for her generous offer to analyze 25 water samples with a gull assay recently developed in her research group. Dr. Orin Shanks at United States Environmental Protection Agency provided guidance in the use of a human source tracking assay. Dr. Yvette Piceno, Dr. Lauren Tom, and Dr. Eric Dubinsky are thanked for analyzing 50 water samples using PhyloChip assay and providing a summary report under the leadership of Dr. Gary Andersen.

Members of the Technical Advisory Board actively provided helpful advice about the project results and monitoring plan throughout the project period. In particular, Dr. Jill Murray made key contributions about estimation of fecal discharge to Capistrano Beach from the Inner Harbor and Barry Hecht provided real time data about Denniston Creek and insights into the effects of urban runoff on streams. Dr. John Largier provided guidance about the interpretation of freshwater and seawater mixing effect. Harbor District staff guided live-aboard boat sampling and also helped in the sample collection.

Dr. Dan Wang was the project officer at UC Davis for the first half of the study and also developed the probabilistic source tracking model. Lastly, the following staff researchers, graduate students, and visiting students at University of California, Davis are thanked for their assistance in water sampling, laboratory processing, feedback of the monitoring results, Dr. Alexander Schriewer, Yujie Jin, Katja Fricke, and Sinéad Murphy.

## EXECUTIVE SUMMARY

Pillar Point Harbor (PPH) is a popular recreational area and home to a vital commercial fishing industry located on the northern side of Half Moon Bay. The PPH study area is enclosed by an outer and inner harbor and contains several beaches within the outer harbor. PPH receives complex drainage inputs from freshwater creeks, storm drains, outflow pipes, and large, mixed-use areas including an airport, agricultural, commercial and residential sections. Water quality is poor at certain beaches in PPH based on fecal indicator bacteria (FIB) levels and the State Water Resources Control Board has listed the location as impaired by coliform bacteria on the 303(d) list submitted to the United States Environmental Protection Agency (USEPA). In order to provide information about the primary sources of fecal contamination at PPH and to assist with the selection of remediation strategies to reduce fecal pollution, the microbial source tracking (MST) study was initiated.

MST monitoring was conducted by University of California, Davis (UCD) in 2008 and 2011-12 to estimate relative contributions of fecal pollution originating from human, bovine, dog, horse and avian sources. The San Mateo County Resource Conservation District (SMCRCD) monitored FIB, including total coliform, *Escherichia coli* and *Enterococcus*, regularly and concurrently with MST sampling events to evaluate microbial water quality in the area. A total of 514 water samples were collected for FIB analysis, and a total of 225 samples from water, sediment, and biofilm matrices were collected for genetic analysis.

Numerous types of inflows and drainages exist at PPH and its watersheds, including outflows from creeks, outfall pipes, storm drains, runoff from pavements and other impervious surfaces, agricultural and commercial operations. The MST and FIB sampling sites were selected on the basis of historical FIB data and major freshwater inputs to PPH. To investigate the sources of fecal pollution and their relative contributions to beaches, 10 primary locations were selected as sampling sites. In 2012, 7 upstream sampling sites were added, based on GIS land-use analysis and site accessibility, to estimate fecal loadings in the waterways within the urban area located between PPH and the upstream landscape.

MST samples were collected to cover the wet and dry season as well as first flush events. For wet season and first flush sampling events, the water samples were collected in three phases based on precipitation conditions, as pre-, during, and post-rain samples. MST water samples were taken at all 10 sampling sites including 4 freshwater inflows and 6 beaches at PPH in 2008 and 2011. In 2012, we focused MST sampling on Capistrano Beach and the 4 inflow sites on the basis of 2-yr FIB and MST monitoring results from 2008 and 2011. Additionally, samples close to live-aboard boat locations were collected once in 2011 and 2012. Based on FIB weekly monitoring in 2012, upstream MST sampling events were conducted at selected locations in

2012. Sediment and biofilm samples were collected during the dry and wet season. Either one or two biofilm samples (submerged aquatic vegetation) were also obtained at the sites. A probabilistic model developed at UCD was applied to all MST samples to estimate the true concentration of host-associated *Bacteroidales*. FIB samples were taken bi-weekly at Capistrano Beach and its inflow site in 2008 and 2011. In 2012, FIB samples were obtained (bi)weekly at Capistrano Beach and the 4 inflow sites as well as 5 upstream locations.

There was site-specific FIB variation among the 10 primary sampling locations (reference page 3 Fig. 1 Aerial view of the 10 primary sampling sites at PPH). All 4 inflow sites including Capistrano Outfall Pipe, Bathhouse Outfall Pipe, Denniston Creek and Deer Creek Outlet frequently exceeded the FIB criteria. FIB counts were usually low at all beaches at PPH except for Capistrano Beach. FIB spatial and seasonal analysis revealed that the Bathhouse Outfall Pipe and Deer Creek had significantly increased *E. coli* levels during the dry season, while *Enterococcus* levels at Capistrano Beach were higher during the wet season. FIB monitoring upstream of Capistrano Beach showed fecal loading into the waterway from the urban area.

Human-associated *Bacteroidales* (BacHum) were not commonly detected at any of the sites using two independent assays; the few positive samples yielded mostly low marker concentrations, which are considered a minor source. Predictive analysis of live-aboard boat site monitoring data suggests that the contribution of potential human feces from live-aboard boats to the water quality of Capistrano Beach is not significant. Dog-associated *Bacteroidales* (BacCan) were frequently detected at Capistrano Beach. While the dog marker was also often found at Mavericks, the spatial distribution of BacCan in nearby beaches indicates that the presence of dog marker at Capistrano Beach was more likely introduced from freshwater inflows rather than from Mavericks Beach. Bovine-associated *Bacteroidales* were frequently found at Deer Creek Outlet and bovine was considered as a predominant source of fecal pollution at this site especially in the dry season, indicating that this input was constant and not only during runoff events. Upstream MST monitoring revealed that dog feces introduced into the waterway reaches Capistrano Outfall Pipe and Deer Creek Outlet after passing through the urban area located between Pillar Point Harbor and the upper watershed. Given the geographical setting (upper watershed is undeveloped open space) and similar FIB or MST results along the waterway upstream wildlife is likely to be the predominant source of fecal pollution at Denniston Creek. There was little evidence of fecal pollution derived from gulls or horses based on assays indicative of gull-associated *Catellibacillus* and horse-associated *Bacteroidales*. During sediment and biofilm MST monitoring, high levels of universal *Bacteroidales* (BacUni) derived from all warm-blooded animals were detected in both sediments and biofilms even when the levels in water were not high. This indicates that previously introduced microbial populations accumulate more and persist longer when associated with sediments and biofilms. The gradual decrease of BacUni in sediments and biofilms during the wet season suggests that sediment re-suspension

occurs via natural turbulence. Therefore, sediments and biofilms are considered to play an important role for water quality in PPH.

In conclusion, this monitoring study has provided significant insights into fecal contamination in PPH.

- Human fecal sources exist but do not account for the majority of fecal pollution found at Capistrano Beach or elsewhere in the harbor.
- Dogs represent a significant, but not the main, fecal source at Capistrano Beach.
- Resident fecal populations in sediments and biofilms are periodically re-suspended during events of turbulence and can lead to temporal increases in FIB levels.
- The main fecal source at Deer Creek is bovine followed by canine.
- The study eliminated other beaches in PPH as areas of concern and pin-pointed the freshwater inflows as the vectors for bacteria entering the Harbor.

Although there were uncharacterized fecal sources not attributable to the host-associated genetic markers used, this study provides useful information to select appropriate management practices to reduce fecal pollution. Equally important, it provided strong evidence that humans, gulls, marine mammals and horses are not significant sources of contamination. This is valuable information to prevent the expenditure of significant resources on efforts that would not have reduced contamination.

## TABLE OF CONTENTS

1. Introduction.....	1
1.1 Fecal pollution in Pillar Point Harbor .....	1
1.1.1 Geographical setting.....	1
1.1.2 Water quality .....	1
1.2 Objectives of the PPH monitoring project .....	2
1.3 Monitoring design and sampling locations .....	2
1.3.1 Sampling locations .....	2
1.3.2 Monitoring design .....	6
2. Materials and methods .....	8
2.1 Sample collection .....	8
2.2 Sample processing.....	8
2.3 QPCR analytical procedure.....	9
2.4 Data analysis .....	11
2.5 PhyloChip analysis.....	12
3. Results.....	14
3.1 Fecal indicator bacteria .....	14
3.1.1 Site-specific FIB counts in 2008 and 2011 .....	14
3.1.2 Spatial and seasonal variation of FIB counts .....	16
3.1.3 Upstream FIB monitoring .....	18
3.2 Microbial source tracking.....	20
3.2.1 <i>Bacteroidales</i> at key locations.....	20
3.2.2 Live-aboard boat.....	27
3.2.3 Bird, horse, and additional human assay results .....	30
3.2.4 Upstream MST monitoring .....	31
3.2.5 <i>Bacteroidales</i> in sediments and biofilm .....	32
3.2.6 Quality assurance/quality control (QA/QC).....	33
3.3 PhyloChip analysis .....	35
4. Discussion.....	38
4.1 Fecal indicator bacteria .....	38

4.1.1 Spatial distribution of FIB concentration .....	38
4.1.2 Seasonality of FIB concentration .....	38
4.1.3 Upstream FIB monitoring .....	39
4.2 Microbial source tracking.....	39
4.2.1 Canine fecal pollution .....	39
4.2.2 Putative sources of human fecal contamination .....	40
4.2.3 Bovine fecal pollution .....	41
4.2.4 Equine and seagull fecal pollution .....	41
4.2.5 Resident fecal indicator populations in sediments and biofilms .....	41
4.3 PhyloChip analysis .....	42
5. Conclusion .....	44
6. References .....	46
7. Appendices.....	49
Appendix A: MST sampling dates and water quality parameters	
Appendix B: FIB concentrations	
Appendix C: Concentrations and sample limits of detection of <i>Bacteroidales</i>	
Appendix D: Bird, horse, and additional human assay results	
Appendix E: Supplementary information about water circulation at PPH	
Appendix F: PhyloChip source identification study	

## LIST OF TABLES

Table 1 Latitude and longitude of primary sampling sites .....	2
Table 2 Latitude and longitude of live-aboard boat sampling sites .....	4
Table 3 Latitude and longitude of upstream sampling sites .....	5
Table 4 Type and number of MST samples collected .....	7
Table 5 Primer and probes used in this project.....	10
Table 6 Estimation of fecal discharge to Capistrano Beach from the Inner Harbor .....	27
Table 7 <i>Bacteroidales</i> concentrations in field blanks .....	34
Table 8 Replicate percent differences in environmental samples and field duplicates .....	35

## LIST OF FIGURES

Figure 1 Aerial view of the 10 primary sampling sites at PPH .....	3
Figure 2 Aerial view of live-aboard boat sampling sites .....	4
Figure 3 Aerial view of upstream sampling sites.....	5
Figure 4 Biofilms samples (submerged aquatic vegetation) at Bathhouse Outfall Pipe (A) and Denniston Creek (B) .....	7
Figure 5 Site-specific range of <i>E. coli</i> (top) and <i>Enterococcus</i> (bottom) levels at the 10 study sites in 2008 and 2011.....	15
Figure 6 Spatial and temporal variation of <i>E. coli</i> (top) and <i>Enterococcus</i> (bottom) levels at 4 freshwater inflow sites and Capistrano Beach (PPH-3) in 2011 -2012 .....	17
Figure 7 Weekly <i>E. coli</i> (top) and <i>Enterococcus</i> (bottom) levels at 4 freshwater inflow sites and corresponding upstream sites and at Capistrano Beach (PPH-3) from May to December in 2012 .....	19
Figure 8 Seasonal variations of host-associated <i>Bacteroidales</i> concentrations at Capistrano Outfall Pipe (PPH-1) throughout the 2008 and 2011-2012 monitoring period .....	22
Figure 9 Seasonal variations of host-associated <i>Bacteroidales</i> concentrations at Bathhouse Outfall Pipe (PPH-2) throughout the 2008 and 2011-2012 monitoring period .....	23
Figure 10 Seasonal variations of host-associated <i>Bacteroidales</i> concentrations at Capistrano Beach (PPH-3) throughout the 2008 and 2011-2012 monitoring period.....	24
Figure 11 Seasonal variations of host-associated <i>Bacteroidales</i> concentrations at Denniston Creek (PPH-4) throughout the 2008 and 2011-2012 monitoring period .....	25
Figure 12 Seasonal variations of host-associated <i>Bacteroidales</i> concentrations at Deer Creek Outlet (PPH-8) throughout the 2008 and 2011-2012 monitoring period.....	26
Figure 13 Nonmetric multidimensional scaling (NMDS) ordinations of bacteria community structure.....	36
Figure 14 NMDS ordinations of bacteria community structure based on detected taxa .....	37

## ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of variance
BMP	Best management practice
CFU	Colony forming unit
cfs	Cubic feet per second
FIB	Fecal indicator bacteria
g	Gram
gc	Gene copies
GM	Geometric mean
L	Liter
μ	Micro
m	Milli or meter
MPN	Most probable number
MST	Microbial source tracking
NMDS	Nonmetric multidimensional scaling
OTU	Operational taxonomic unit
PPH	Pillar Point Harbor
ppt	Parts-per-thousand
QA/QC	Quality assurance/quality control
qPCR	Quantitative polymerase chain reaction
RNA	Ribonucleic acid
RPD	Replicate percent difference
RWQC	Recreational water quality criteria
SMCRCD	San Mateo County Resource Conservation District
S <sub>LOD</sub>	Sample limit of detection
UCD	University of California, Davis
USEPA	United States Environmental Protection Agency

# **1. Introduction**

In 2008 the San Mateo County Resource Conservation District (SMCRCD) received funding under the Proposition 50 Clean Beaches Initiative Grant Program for multi-year monitoring in Pillar Point Harbor (PPH), which had impaired water quality based on the presence of fecal indicator bacteria (FIB). Both FIB enumeration and microbial source tracking (MST) have since been applied to characterize water quality and identify potential sources of FIB in PPH and its associated watersheds. This report discusses data collected in 2008, before the project was temporarily put on hold, and from 2011 – 2012.

## **1.1 Fecal pollution in Pillar Point Harbor**

### *1.1.1 Geographical setting*

PPH is a popular recreational area and home to a vital commercial fishing industry located on the northern side of Half Moon Bay and adjacent to the small town of Princeton along the central California coast in San Mateo County. PPH study area is enclosed by an outer and inner harbor and contains several beaches – Capistrano Beach, Marsh Beach, Mavericks Beach, Beach House Beach, Inner Harbor Beach, and Yacht Club Beach – within the outer harbor. PPH receives complex drainage inputs from freshwater creeks, storm drains, outflow pipes, and large, mixed-use areas including an airport, agricultural, commercial and residential sections. The harbor area domiciles various commercial ventures such as restaurants, hotels, recreational shops, commercial fish buyers, a fertilizer plant, and a Naval Station situated on the western bluff. Outside the Outer Harbor, but within the project area, there are residential areas, conference facilities, and additional commercial ventures as well as a pump station for the Sewer Authority Mid-coastside. The project area is also within the boundaries of the James V. Fitzgerald Marine Reserve Critical Coastal Area Pilot Project. The Reserve is a designated Area of Special Biological Significance and a biologically significant habitat for diverse species as well as a popular recreational area.

### *1.1.2 Water quality*

Water quality at some sites in PPH is poor based on fecal indicator bacteria (FIB) levels and the State Water Resources Control Board has listed the location as impaired by coliform bacteria on the 303(d) list submitted to the United States Environmental Protection Agency (USEPA). In 2005 and 2006, San Mateo County Department of Environmental Health repeatedly posted beaches in the harbor as potential health hazards. Capistrano Beach was posted most frequently, approximately 50 weeks in each year. Marsh Beach was posted over 20 weeks in each year. Mavericks Beach was posted approximately 15 weeks each year, approximately 30% of sampling events. The county terminated sampling for Capistrano Beach and permanently posted the beach as a potential health hazard in March of 2006.

## 1.2 Objectives of the PPH monitoring project

The main objective of this project was to provide information about the primary sources of fecal contamination at beaches in PPH and to assist with the selection of remediation strategies to reduce fecal pollution. MST monitoring was conducted by University of California, Davis (UCD) in 2008 and 2011-12 to estimate relative contributions of fecal pollution originating from human, bovine, dog, horse and avian sources. MST samples were collected in wet and dry seasons as well as first flush events which are the first large rains of the wet season. The SMCRCDC monitored FIB, including total coliform, *E. coli* and *Enterococcus*, regularly and concurrently with MST sampling events to evaluate microbial water quality in the area. Sediments and biofilm were also collected to investigate the role of sediments and biofilms as a potential source of elevated levels of fecal pollution. Based on the research and analysis, specific objectives for implementation of water quality remediation strategies were developed.

## 1.3. Monitoring design and sampling locations

### 1.3.1 Sampling locations

Numerous types of inflows and drainages exist at PPH and contributing watersheds, including outflows from creeks, outfall pipes, storm drains, runoff from pavement and other impervious surfaces, agricultural and commercial operations. The MST and FIB sampling sites were selected on the basis of historical FIB data and major freshwater inputs to PPH. To investigate the sources of fecal pollution and their relative contributions to beaches, 10 primary locations were selected as sampling sites (Table 1 and Figure 1). Among the 10 sites, PPH-1, 2, 4, and 8 are freshwater inflows and others are marine water beaches.

Table 1 Latitude and longitude of primary sampling sites

Site ID	Type	Site name	Latitude	Longitude
PPH-1	Inflow	Capistrano Beach	37°30'13''N	122°29'08''W
PPH-2	Inflow	Bathhouse Outfall Pipe	37°30'11''N	122°29'06''W
PPH-3	Beach	Capistrano Beach	37°30'12''N	122°29'07''W
PPH-4	Inflow	Denniston Creek	37°30'14''N	122°29'13''W
PPH-5	Beach	Marsh Beach	37°30'04''N	122°29'38''W
PPH-6	Beach	Mavericks Beach	37°29'55''N	122°29'45''W
PPH-7	Beach	Beach House Beach	37°30'08''N	122°28'37''W
PPH-8	Inflow	Deer Creek Outlet	37°30'08''N	122°28'38''W
PPH-9	Beach	Inner Harbor Beach	37°30'11''N	122°28'52''W
PPH-10	Beach	Yacht Club Beach	37°30'09''N	122°29'27''W



Locations (Yellow):

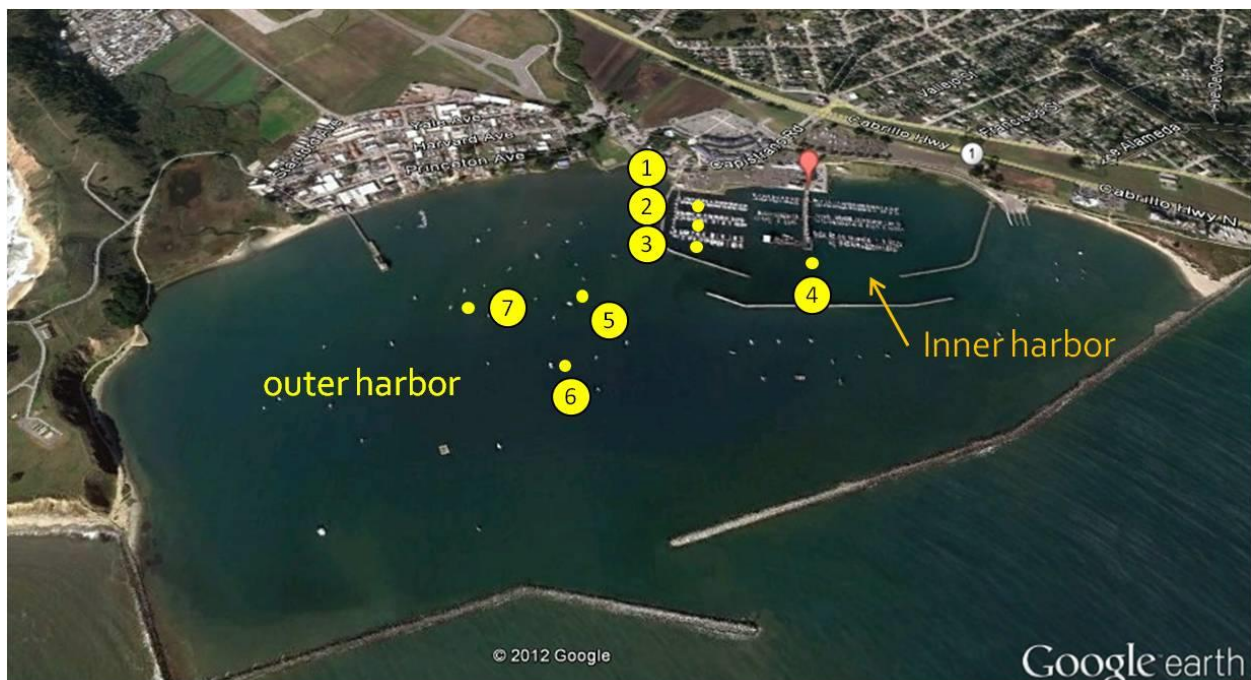
- |                            |                             |                       |
|----------------------------|-----------------------------|-----------------------|
| 1. Capistrano Outfall Pipe | 5. Pillar Point Marsh Beach | 9. Inner Harbor Beach |
| 2. Bathhouse Outfall Pipe  | 6. Mavericks Beach          | 10. Yacht Club Beach  |
| 3. Capistrano Beach        | 7. Beach House Beach        |                       |
| 4. Denniston Creek         | 8. Deer Creek Outlet        |                       |

Figure 1 Aerial view of the 10 primary sampling sites at PPH.

In an effort to estimate possible fecal loadings caused by live-aboard boats at PPH, MST and FIB samples were collected at 3 boat docks located at the western side of Inner Harbor, one pump station where live-aboard boats empty their onboard tanks, and at 3 locations near live-aboard boats anchored in Outer Harbor (Table 2 and Figure 2).

Table 2 Latitude and longitude of live-aboard boat sampling sites

Site ID	Site description	Latitude	Longitude
Dock A	Inner Harbor Dock	37°30'13''N	122°29'04''W
Dock B	Inner Harbor Dock	37°30'10''N	122°29'05''W
Dock C	Inner Harbor Dock	37°30'07''N	122°29'04''W
Pump	Sanitary pumping station	37°30'07''N	122°28'92''W
OH 1	Outer Harbor	37°30'07''N	122°28'67''W
OH 2	Outer Harbor	37°29'93''N	122°29'03''W
OH 3	Outer Harbor	37°30'08''N	122°29'17''W



Locations (Yellow):

- |                         |                             |                      |
|-------------------------|-----------------------------|----------------------|
| 1. Dock A, Inner Harbor | 4. Sanitary pumping station | 5. OH1, Outer Harbor |
| 2. Dock B, Inner Harbor |                             | 6. OH2, Outer Harbor |
| 3. Dock C, Inner Harbor |                             | 7. OH3, Outer Harbor |

Figure 2 Aerial view of live-aboard boat sampling sites

Upstream FIB and MST monitoring was conducted in 2012 to estimate spatial distribution of fecal loadings in the waterways of 4 primary inflows draining to PPH and to find areas of fecal inputs within the urbanized area. Seven upstream sampling sites were added based on GIS land-use analysis and site accessibility (Table 3 and Figure 3). One to three upstream sites were chosen per inflow site.

Table 3 Latitude and longitude of upstream sampling sites

Site ID	Site description	Latitude	Longitude
PPH-1B	Upstream of Capistrano Outfall Pipe	37°30'19''N	122°29'07''W
PPH-2B	Upstream of Bathhouse Outfall Pipe	37°30'35''N	122°28'40''W
PPH-DN2	Upstream of Denniston Creek	37°30'23''N	122°29'14''W
PPH-DN3	Upstream of Denniston Creek	37°30'35''N	122°29'17''W
PPH-DN4	Upstream of Denniston Creek	37°30'57''N	122°29'20''W
PPH-DR4	Upstream of Deer Creek Outlet	37°30'22''N	122°28'34''W
PPH-DR6	Upstream of Deer Creek Outlet	37°30'33''N	122°28'14''W



Locations (Yellow):

- |                                |                                |                                |
|--------------------------------|--------------------------------|--------------------------------|
| 1. PPH-1B (upstream of PPH-1)  | 3. PPH-DN2 (upstream of PPH-4) | 6. PPH-DR4 (upstream of PPH-8) |
| 2. PPH-2B (upstream of PPH-2)  | 4. PPH-DN3 (upstream of PPH-4) | 7. PPH-DR6 (upstream of PPH-8) |
| 5. PPH-DN4 (upstream of PPH-4) |                                |                                |

Figure 3 Aerial view of upstream sampling sites. Arrows indicate inflow sampling sites, and numbers in a circle denote upstream sampling sites of each inflow.

### *1.3.2 Monitoring design*

A total of 514 FIB water samples (excluding quality assurance/quality control (QA/QC) samples) were taken at the 10 primary sites at PPH and upstream FIB monitoring sites. In 2008, FIB water samples were collected biweekly from February to August at Capistrano Outfall Pipe (PPH-1), Bathhouse Outfall Pipe (PPH-2), and Capistrano Beach (PPH-3). In 2011, biweekly FIB monitoring was conducted at PPH-3 and all 4 inflow sites (Capistrano Outfall Pipe, PPH-1; Bathhouse Outfall Pipe, PPH-2; Denniston Creek, PPH-4; and Deer Creek Outlet, PPH-8). In 2012, FIB samples were obtained (bi)weekly at Capistrano Beach and the 4 inflow sites as well as 5 upstream locations including upstream sites of PPH-1 (PPH-1B), PPH-2 (PPH-2B), PPH-4 (PPH-DN2 and 3), and PPH-8 (PPH-DR4). FIB samples were also concurrently collected along with MST sampling event throughout the project period.

A total of 225 MST samples (excluding QA/QC samples) from water, sediment, and biofilm matrices were collected at PPH in 2008, 2011 and 2012 and analyzed to identify sources of fecal pollution (Table 4). MST water samples were obtained in the dry season (May to September) and wet season (October and March), and during the first flush events in the wet season. For wet season and first flush sampling events, water samples were collected in three phases based on precipitation conditions, as pre-, during, and post-rain samples. In 2008, wet season samples were taken in February; however, due to the drought that year they were taken in the absence of precipitation. MST water samples were taken at all 10 sampling sites (Figure 1) including 4 freshwater inflows and 6 beaches at PPH in 2008 and 2011. In 2012, we focused MST sampling on Capistrano Beach and the 4 inflow sites on the basis of 2-yr FIB and MST monitoring results from 2008 and 2011. Additionally, samples close to live-aboard boat locations were collected once in 2011 (November) and 2012 (February). Based on FIB weekly monitoring in 2012, upstream MST sampling events were conducted in October and December 2012.

Sediment and biofilm samples were collected in dry and wet season. In dry season of 2011 (August), sediment samples were taken from 4 inflow sites, 3 beaches including Capistrano Beach, Mavericks Beach, and Inner Harbor Beach and Pillar Point Marsh. One or two biofilm samples (submerged aquatic vegetation) were also obtained at the sites. In 2012, sediment samples were collected at Capistrano Beach and 4 inflows during wet (February) and dry season (July). Biofilm samples were obtained at the Bathhouse Outfall Pipe and Denniston Creek only where submerged aquatic vegetation was abundant throughout the sites (Figure 2).

Table 4 Type and number of MST samples collected

Matrix	Season or condition	2008	2011	2012	Total
Water	Dry season	10	10	5	25
	Wet season	10	34	15	59
	First flush	30	30	11	71
	Live-aboard boat	-	7	3	10
	Upstream	-	-	13	13
Sediment	Dry	-	8	5	13
	Wet	-	-	15	15
Biofilm	Dry	-	11	2	13
	Wet	-	-	6	6
Total		50	100	75	225



Figure 4 Biofilm sample (submerged aquatic vegetation) at Bathhouse Outfall Pipe (A) and Denniston Creek (B)

## 2. Materials and methods

### 2.1 Sample collection

Water samples were collected from target sites during dry season (May – September), wet season (October – April), and first flush events (October) in 2008, 2011, and 2012. In the wet season and first flush MST sampling events, water samples were collected at three stages based on rainfall phases (pre-, during-, and post-rain). At each sampling event, one field blank and one field duplicate sample were produced for QA/QC purpose. For MST analysis, approximately 10 to 20 liters of water were obtained by directly submerging sample carboys in beach water or by collecting water in sterile scoops below the inflow surface water followed by transferring to sample carboys. Sediment and biofilm samples were gathered using sterile spoons or wooden sticks and placed in sterile bottles. Water from identical sampling sites was filled into the bottles to minimize oxygen contact and dehydration of sediment and biofilm samples. One-hundred milliliter water samples for FIB analysis were collected concurrently with MST samples or (bi)weekly using sterile 100-ml bottles. Water quality parameters including temperature, pH, conductivity, salinity (YSI 63, YSI Inc., OH), turbidity (Hach 2100P, Hach, CO), and dissolved oxygen (YSI 55, YSI Inc., OH) were measured with handheld instruments when samples were collected. Total suspended solids (TSS) concentrations in water were measured according to Standard Method 2540D (APHA 1998). Water contents of sediment and biofilm samples were determined by measuring weight differences before and after drying sediments or biofilm at 105°C for 24 h. After collection, water samples for FIB analysis were placed on ice and submitted to the San Mateo County Public Health Lab to be enumerated. MST samples were kept chilled with ice packs and transported to the Wuertz Lab at UCD within 6 h. Upon arrival, MST samples were kept at 4°C in a temperature-controlled room followed by filtration within 48 hours.

### 2.2 Sample processing

FIB samples were quantified using Colilert and Enterolert (IDEXX, ME) within 6 hours after samples were collected. Total coliform, *E. coli* and Enterococci were measured for all water samples using 10 ml of 100 ml of samples for each analysis. The lowest and highest limits of detection were 10 and 24196 MPN/100 ml, respectively. Field blanks and duplicates were analyzed in parallel for QA/QC.

Water samples (10 – 20 liters) were concentrated to approximately 100 – 200 ml, using Fresenius hollow fiber filters with an ultrafiltration (HFF) system according to a previously tested Wuertz Lab procedure (Rajal et al. 2007). The surrogate *Acinetobacter baylyi* ADP1 was added into all MST samples prior to filtration to calculate filtration recoveries by comparing the amount of *A. baylyi* recovered before and after the filtration (Schriewer et al. 2010). The pre-filtration (feed) and post-filtration (retentate) samples were subjected to nucleic acid extraction. Nucleic acids

from 500- $\mu$ l aliquots from feed and retentate samples were extracted using the Invitrogen PureLink Viral RNA/DNA extraction Kit (Invitrogen, CA) according to the manufacturer's instructions. The final eluted volume of nucleic acids was 100  $\mu$ l, and DNA extracts were kept in a -80°C freezer until used for quantitative polymerase chain reaction (qPCR) analysis.

Sediment and biofilm samples were processed by adding 50 g of sediment or 10 g of biofilm sample to 50 ml of 1% Tween80/NaOH at pH 7.0 eluant in a 250-ml sterile bottle, followed by vigorous hand-shaking for 2 min to detach microorganisms attached to sediment surfaces. After 10 min of settlement of suspended particles in the eluant solution, the supernatants were collected and used for DNA extraction. Nucleic acids in the supernatant were extracted using the UltraClean Water DNA isolation kit (Mo Bio Laboratory Inc., CA) with a 0.22- $\mu$ m sterile membrane filter according to the manufacturer's protocols.

### 2.3 QPCR analytical procedure

TaqMan qPCR assays for *Bacteroidales* and *Acinetobacter* (Haugland et al. 2010; Kildare et al. 2007; Schriewer et al. 2010; Silkie and Nelson 2009) and SYBR green qPCR assays for *Catelliboccus* (Lu et al. 2008) targeting the 16S rRNA gene (Table 5) were performed using a StepOne Real-Time PCR system (Applied Biosystems, CA). Assays for universal *Bacteroidales* derived from all warm-blooded animals, human-, bovine-, dog-, horse-associated *Bacteroidales*, and gull-associated *Catelliboccus marimamaliium* and *Catelliboccus* spp. were applied to identify host-specific contributions to the fecal pollution of monitored sites. The *Acinetobacter* assay was used to calculate filtration recoveries by measuring target gene concentrations of *Acinetobacter* in feed and retentate samples. Each 25- $\mu$ l qPCR reaction volume contained 12.5  $\mu$ l of TaqMan Environmental Master Mix 2.0 (Applied Biosystems, CA), 10  $\mu$ l of nucleic acid extract, and optimized concentrations of forward and reverse primers and probe. Reaction mixture (25  $\mu$ l) for qPCR SYBR green assay contained 12.5  $\mu$ l of Maxima SYBR Green/ROX qPCR Master Mix (2x) (Fermentas, MD), 10  $\mu$ l of nucleic acid extract, and optimized concentrations of forward and reverse primers. Thermal cycling conditions for TaqMan assay were 2 min at 50°C and 10 min at 95°C, followed by 40 cycles of 15 s at 95°C and 1 min at 60°C. For the horse assay, the 40 cycles of 15 s at 92°C and 1 min at 60°C was used instead. The amplification protocol for SYBR green assay consisted of 50°C for 2 min and 95°C for 10 min followed by 40 cycles of 95°C for 15 s and 64°C for 1 min, and then a melt curve of 95°C for 15 s, 60°C for 20 x, and 0.3°C/s to 95°C. A serial dilution approach was employed for each sample to mitigate potential inhibitors during qPCR reaction. The sample limit of detection ( $S_{LOD}$ ) of each MST sample was calculated based on assay limit of detection, filtration efficiency, and inhibition factor (Schriewer et al. 2010). Genetic marker concentrations were reported as gene copies per milliliter of water (gc/ml) or gram dry weight of sediments and biofilm (gc/g).

Table 5 Primers and probes used in this study

Assay	Primer and probe	Oligonucleotide sequence (5'-3') <sup>A</sup>	Concn (nM)	Reference
Universal <i>Bacteroidales</i> (BacUni-UCD)	UniBac 520f	CGTTATCCGGATTTATTGGGTTTA	400	Kildare et al. (2007)
	Uni/Cow 690r1	CAATCGGAGTTCTTCGTGATATCTA	400	
	Uni/Cow 690r2	AATCGGAGTTCCCTCGTGATATCTA	400	
	Uni/Cow 656p	FAM-TGGTGTAGCGGTGAAA-MGB	80	
Human-associated <i>Bacteroidales</i> (BacHum-UCD)	H160f	TGAGTTCACATGTCCGCATGA	400	Kildare et al. (2007)
	H241r	CGTTACCCCGCCTACTATCTAATG	400	
	H193p	FAM-TCCGGTAGACGATGGGGATGCGTT-TAMRA	80	
Bovine-associated <i>Bacteroidales</i> (BacCow-UCD)	BacCow CF128f	CCAACYTTCCCGWTACTC	400	Kildare et al. (2007)
	BacCow CF305r	GGACCGTGTCTCAGTTCCAGTG	400	
	BacCow CF257p	FAM-TAGGGGTTCTGAGAGGAAGGTCCCC-TAMRA	80	
Dog-associated <i>Bacteroidales</i> (BacCan-UCD)	Bac Can 545f1	GGAGCGCAGACGGGTTTT	400	Kildare et al. (2007)
	Uni/Cow 690r1	CAATCGGAGTTCTTCGTGATATCTA	400	
	Uni/Cow 690r2	AATCGGAGTTCCCTCGTGATATCTA	400	
	Uni/Cow 656p	6-FAM-TGGTGTAGCGGTGAAA-MGB	80	
<i>Acinetobacter</i> (Acinet)	Acinet-137F	GATGCAACCGGAAGAACCTTA	400	Schriewer et al. (2010)
	Acinet-210R	TTCCCGAAGGCACCAATC	400	
	Acinet-159p	FAM-CTGGCCTTGACATAGTAGAACTTTCC-TAMRA	80	
<i>C. marimammalium</i> (Gull-2)	Gull-2f	TGCATCGACCTAAAGTTTTGAG	400	Lu et et al. (2008)
	Gul-2r	GTCAAAGAGCGAGCAGTTACTA	400	
<i>Catelliboccus spp.</i> (referred to as Gull-OSU)	f-primer	Sequences not yet published	250	Un- published to date
	r-primer		250	
	probe		125	
Horse-associated <i>Bacteroidales</i> (HorseBact)	Ho-622F	TGCGTAGGCGGGAAGTCA	450	Silkie and Nelson (2009)
	Ho-622F-w.7	AGCGCAGGCGGAGTGAT	450	
	Ho-722R	GAATTCATCGCCCTCTAGTGT	450	
	Ho-722r-w.7	AGTTCCGCCTTCCTCTCCC	450	
	HoF2-644	6 FAM-CAGCCGTAAAATMGYCGG-MGBNFO	200	
Human-associated <i>Bacteroidales</i> (referred to HF183TaqMan)	HF183f	ATCATGAGTTCACATGTCCG	2000	Haugland et al. (2010)
	BthetR1	CGTAGGAGTTTGGACCGTGT	2000	
	BthetP1	FAM-CTGAGAGGAAGGTCCCCACATTGGA-TAMRA	160	

<sup>A</sup> FAM, 6-carboxyfluorescein; TAMRA, 6-carboxytetramethylrhodamine, MGB, minor groove binder

## 2.4 Data analysis

Quantitative PCR techniques were applied for rapid and quantitative detection of host-associated genetic markers in this MST study. However, it should be acknowledged that qPCR assays for host-associated markers are not absolutely specific and sensitive for the target sequence. The factors that may lead to the occurrence of false information include 1) the variation of presence and abundance of target genetic markers in individuals; 2) non-specific amplification by primer sets for targeting other hosts; 3) non-amplification by a primer set designed for that host; and 4) measurement errors during the qPCR process. Therefore, a probabilistic model (Wang et al. 2010) based on the Law of Total Probability was developed at UCD to estimate true source associated contribution using the Monte Carlo method.

The statistical model is proposed based on availability of a universal fecal genetic marker (BacUni) and individual host-associated markers (BacHum, BacBov and BacCan) targeting *Bacteroidales* populations in fecal samples. For example, the DNA sequences in an environmental sample that will be amplified by the human assay may be derived from human, bovine, dog or other sources of fecal material. That is, measured *Bacteroidales* DNA concentration by BacHum assay is the summation of a) DNA originating from human source and amplified by BacHum assay; b) DNA originating from bovine/dog/other sources and amplified by BacHum assay; and c) measurement error. In the statistical model, the conditional probabilities such as DNA originating from human, cow, dog and other sources that are amplified by BacHum assay were estimated from representative fecal samples of known origin. Then, the distributions of the probabilities of obtaining false information are estimated from representative fecal samples. Also measurement error is derived from the sample precision error of replicated qPCR reaction. The percentage measurement error was assumed to have a normal distribution  $(0, 0.1^2)$ . For a given environmental sample, measured *Bacteroidales* DNA concentrations by BacUni, BacHum, BacBov, BacCan assay are obtained after amplification of target DNA with the 4 qPCR assays. The statistical model then calculates the true concentration of *Bacteroidales* DNA derived from human, bovine, dog and other fecal sources using the Monte Carlo method. At each run, a set of possible values of the probabilities from their distribution is randomly selected and substituted into the model equation to calculate a set of possible values of *Bacteroidales* true concentrations. The process is repeated 10,000 times to obtain the empirical distribution of *Bacteroidales* true concentrations. From the distributions, the statistical parameters mean, standard deviation and confidence interval of the true concentrations can be computed. The raw and model adjusted results are shown in Appendix C. We noticed that the conditional probability can sometimes be larger than 1 in the model output. After verifying the inhibition and probability parameters, the raw data were used instead of the model output in that case. Also note that horse-associated *Bacteroidales* measured by BactHorse assay and human-associated *Bacteroidales* assessed by HF183TaqMan assay in this study were not adjusted by

the model since the model's performance was validated only for BacUni, BacHum, BacBov, and BacCan assays.

A T-test or Analysis of variance (ANOVA) was used to investigate variations in the data between sites and sampling phases using SPSS Statistics 20.0 (Chicago, IL). The Mann-Whitney rank sum test was used when the data did not satisfy normality tests. Differences were considered significant when the p-value was less than 0.05.

In a box plot, non-detect data of FIB and MST were assumed to be one-half of the detection limit instead of assigning them a zero, which is one of the most commonly used conventional statistical analyses to substitute non-detect values. The number of non-detects out of total samples tested are indicated below each box in the box plots. FIB counts above the upper detection limit, 24196 MPN/100 ml, was replaced with 25,000 MPN/100 ml.

## **2.5 Phylochip analysis**

PhyloChip analysis was conducted on 50 extracts of MST water samples (including QA/QC samples) by Lawrence Berkeley National Laboratory (LBNL) to characterize the microbial community structure of each sample and look for specific bacterial taxa related to fecal sources. Since Capistrano Beach (PPH-3) is the main concern of fecal contamination at Pillar Point Harbor, MST samples collected at PPH-3 and two inflows (Capistrano Outfall Pipe, PPH-1; Bathhouse Outfall Pipe, PPH-2) directly entering to PPH-3 were chosen for PhyloChip analysis. Specifically, the 50 samples consisted of 14 to 16 samples collected from PPH-1, 2, and 3 during a 2011 – 2012 monitoring period, 2 upstream MST samples collected in 2012 and 4 QA/QC samples (Appendix F).

The PhyloChip analysis procedures are described in Dubinsky et al. (2012). Briefly, bacterial 16S rRNA gene was amplified from each sample using PCR with universal primers 27F (5'-AGAGTTTGATCCTGGCTCAG-3') and 1492R (5'-GGTTACCTTGTTACGACTT-3'). Each PCR reaction contained 1x Ex Taq buffer (Takara Bio Inc., Japan), 0.025 units/ $\mu$ l Ex Taq polymerase, 0.8 mM dNTP mixture, 1.0  $\mu$ g/ $\mu$ l BSA, and 200 pM each primer and 1 ng DNA (gDNA) as template. Each sample was amplified in 4 replicate 25  $\mu$ l reactions spanning annealing temperatures ranging from 50-56°C. Thermal cycling conditions for PCR were 3 min at 95°C, followed by 30 cycles of 30s at 95°C, 25s at 50-56°C, and 2 min at 72°C, followed by a final extension of 10 min at 72°C. After PCR was completed, pooled PCR products were purified then fragmented with DNAaseI. The fragmented products were labeled with biotin followed by hybridization overnight onto Phylochip microarray. The microarray was then stained and scanned to provide raw Phylochip data in the form of fluorescent image files. The fluorescent image files were analyzed by the standard OTU approach determining the presence of 59,316 different bacterial OTUs as well as by the probe-based approach considering intensity values of each of the PhyloChip's 1,015,124 probe features individually. After PhyloChip analysis, 5

samples with low FIB and *Bacteroidales* concentrations were selected to represent baseline bacterial community structure (Sample 18, 19, 26, 34, 38; Appendix F). Probe intensity values of 45 samples were divided by the probe's baseline values calculated by the 5 selected samples to calculate fold change from the baseline condition. Probe intensities with fold change values of at least 10 times the baseline value were considered enriched in the sample. The number of enriched probes in each water sample was compared to the source identifier probes of sewage, septage, human stool, shorebirds, cat, dog, cow, horse, elk/deer, pig, raccoon and seal/sea lions.

### 3. Results

Twenty-three MST and over eighty FIB monitoring events were carried out at several beaches and inflows draining into PPH throughout the project period. Some samples could not be collected due to severe environmental conditions, like no stream flow during dry season or submerged inflow outfall pipe/outlets due to high tide at sampling time. MST sampling date and sample water quality parameters in 2011 and 2012 are shown in Appendix A.

#### 3.1 Fecal indicator bacteria

##### 3.1.1 Site-specific FIB counts in 2008 and 2011

Water samples for FIB analysis were collected at all 10 primary sampling sites (Table 1 and Figure 1) along with MST sampling events in 2008 and 2011 (Appendix B). Biweekly water samples were taken from Capistrano Beach (PPH-3) and two inflows directly entering the beach in 2008. Biweekly FIB monitoring was conducted at PPH-3 and all 4 inflows in 2011.

Based on the 2-year FIB monitoring results, we found that the presence and abundance of FIB at PPH were site-related (Figure 5). Among the 10 sites, including 4 freshwater inflows and 6 beaches, Bathhouse Outfall Pipe (PPH-2) and Deer Creek Outlet (PPH-8) commonly had high *E. coli* concentrations above the single sample criterion for *E. coli* (235 MPN/100 ml) (USEPA 1986) (Figure 5-top). Over 70% and 90% of samples collected at PPH-2 and PPH-8 were in excess of the *E. coli* criterion, respectively. The median value of samples at PPH-2 and PPH-8 were 759 and 1,119 MPN/100 ml, respectively, which were up to 10-fold higher than the *E. coli* criterion. The other inflows, Capistrano Outfall Pipe (PPH-1) and Denniston Creek (PPH-4), also had high *E. coli* counts. Approximately 30% of all samples tested exceeded the *E. coli* criterion in both inflow sites. Although the *E. coli* criterion is not applicable to marine water, PPH-3 was directly affected by PPH-1 and 2 and showed relatively high *E. coli* counts compared to other beaches. The FIB levels on the other five beaches including Pillar Point Marsh Beach (PPH-5), Mavericks Beach (PPH-6), Beach House Beach (PPH-7), Inner Harbor Beach (PPH-9), and Yacht Club Beach (PPH-10) were usually low with median values ranging from 10 to 52 MPN/100 ml.

A similar site-specific tendency was observed for *Enterococcus* counts at the 10 sites in 2008 and 2011. All 4 freshwater inflows frequently exceeded the single sample *Enterococcus* criterion of 61 MPN/100 ml in freshwater (USEPA 1986) (Figure 5-bottom). About 60 to 90% of all samples tested were above the *Enterococcus* criterion at the inflow sites. Among them, PPH-8 had the highest *Enterococcus* median value of 1,918 MPN/100 ml, which was more than 30-fold higher than the water quality criterion. PPH-3 occasionally showed elevated *Enterococcus* counts (17% of all samples) above the single-sample *Enterococcus* criterion in marine water of 104 MPN/100 ml. In contrast, approximately half of FIB samples collected from the other beaches showed less than 10 MPN/100 ml of *Enterococcus*. Overall, FIB counts were significantly higher

at all 4 inflow sites compared to those on beaches ( $p < 0.05$ ), and all beaches at PPH except for PPH-3 were rarely in exceedance of the FIB criteria. Consequently, we stopped monitoring at the five beaches in 2012 and conducted more frequent FIB monitoring at the inflow sites and PPH-3.

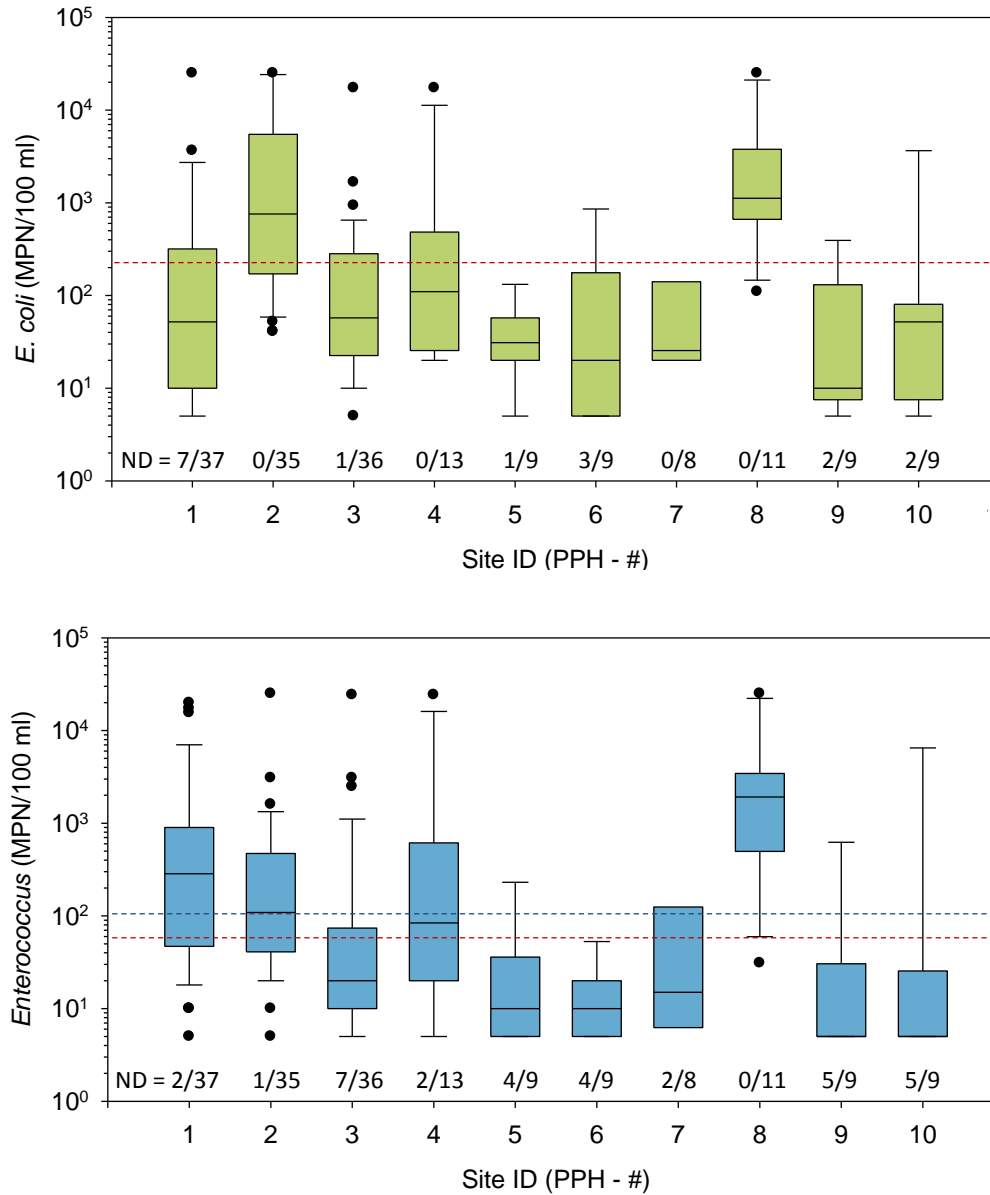


Figure 5 Site-specific range of *E. coli* (top) and *Enterococcus* (bottom) levels at the 10 study sites in 2008 and 2011. The number of non-detects out of total samples tested is shown below each box. The lower and upper boundaries of each box indicate the 25<sup>th</sup> and 75<sup>th</sup> percentiles, respectively. Whiskers below and above the box indicate the 10<sup>th</sup> and 90<sup>th</sup> percentiles, respectively. The red and blue dotted lines show FIB single-sample maximum criteria in freshwater and marine water, respectively.

### 3.1.2 Spatial and seasonal variation of FIB counts

FIB samples collected (bi)weekly in 2011 and 2012 were analyzed to investigate spatial and seasonal variation of FIB levels at all 4 inflow sites and PPH-3. FIB samples collected in 2008 were not included in this analysis to focus on recent trends in FIB counts. FIB results from each site were separated by season in box plots.

*E. coli* concentrations at PPH-2 and PPH-8 continuously exceeded the *E. coli* criterion of 235 MPN/100 ml, in both dry and wet season (Figure 6-top). *E. coli* concentrations at PPH-8 were higher during the dry season compared to the wet season ( $p < 0.05$ ) whereas seasonal variation of *E. coli* was not found at PPH-2 ( $p > 0.05$ ). At PPH-1, 31% (dry season) and 51% (wet season) of samples tested exceeded the *E. coli* criterion, but *E. coli* median values were not significant different in dry and wet season ( $p > 0.05$ ). While *E. coli* levels at PPH-1 and PPH-2 directly emptying to PPH-3 did not show seasonal variation, Capistrano Beach (PPH-3) had higher *E. coli* counts in the wet season compared to in the dry season ( $p < 0.05$ ).

Seasonal variability of *Enterococcus* concentrations were found at PPH-3 ( $p < 0.05$ ) but not at any of the inflow sites ( $p > 0.05$ ). Like *E. coli*, *Enterococcus* levels at PPH-3 were higher in the wet season than the dry season. Approximately 20% and 45% of samples were above the FIB criterion (104 MPN/100 ml, marine water) in the dry and wet season, respectively. The 4 inflow sites had consistently high *Enterococcus* above the *Enterococcus* criterion in both dry and wet season. About 77 to 89% of FIB samples taken from PPH-1 and PPH-2 exceeded the *Enterococcus* criteria (61 MPN/100 ml, fresh water) in both seasons. All samples collected at PPH-8 had exceedances for the FIB criterion.

Overall, FIB levels at PPH-3 revealed that *E. coli* and *Enterococcus* concentrations were elevated on the beach during the wet season compared to the dry season. The two inflows, PPH-1 and PPH-2, directly affecting PPH-3 consistently exceeded the criteria.

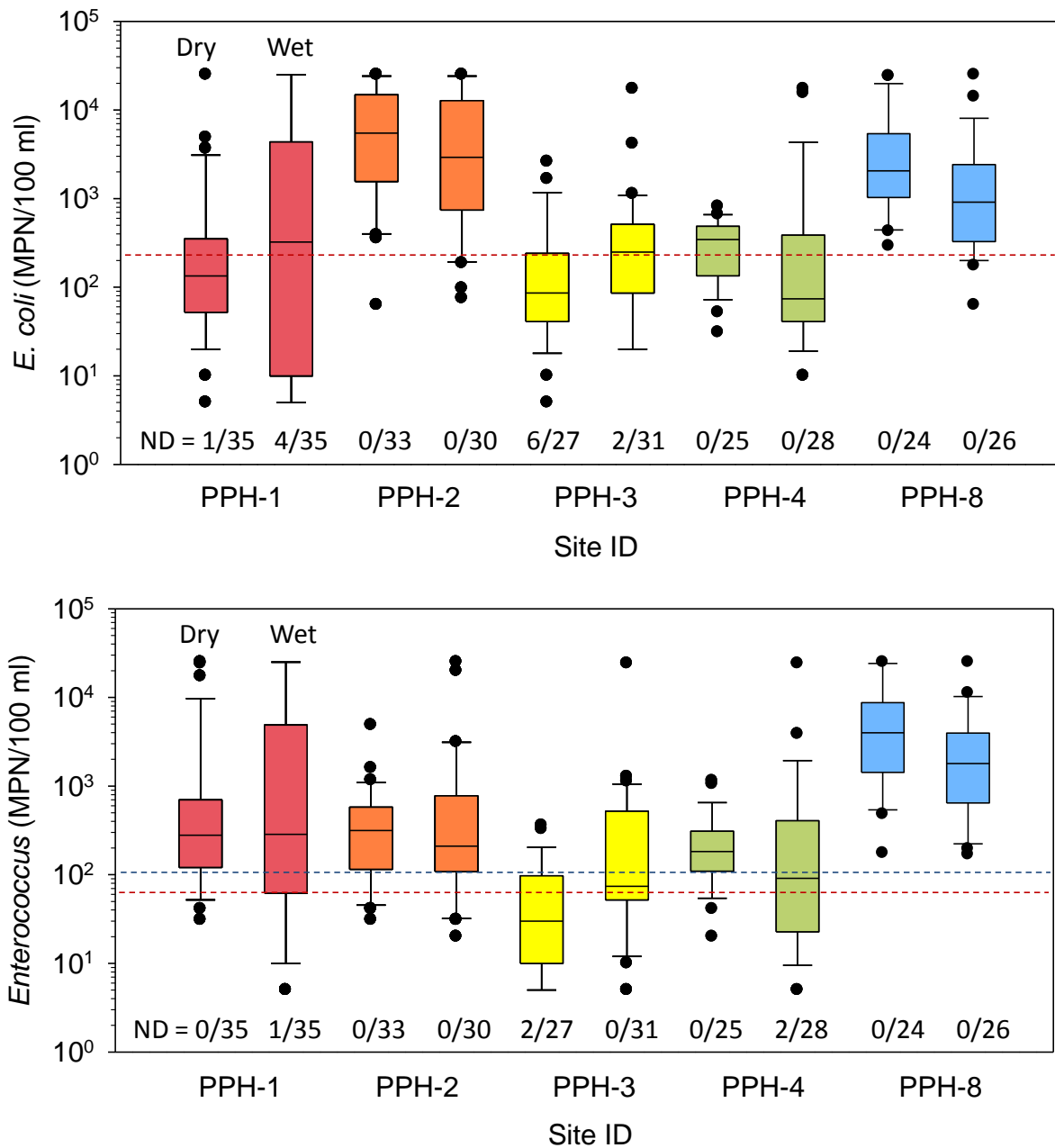


Figure 6 Spatial and temporal variation of *E. coli* (top) and *Enterococcus* (bottom) levels at 4 freshwater inflow sites and Capistrano Beach (PPH-3) in 2011 -2012. The number of non-detects out of total samples tested is reported below each box. Each site was classified with different colors. FIB counts were plotted separately by the dry (May – September) and wet season (October – April). The red and blue dotted lines show FIB single sample maximum values in freshwater and marine water, respectively.

### 3.1.3 Upstream FIB monitoring

Upstream FIB samplings were conducted weekly from May to December in 2012 to detect potential fecal loadings within the urban area where inflows pass through before empty to PPH. The FIB sanitary monitoring provided information about areas of runoff input and helped to select target locations prior to upstream MST sampling. The upstream sampling locations related to each inflow site were determined based on GIS land-use analysis and practical accessibility for sampling. One or two upstream sites for each inflow were selected, and FIB concentrations at 5 upstream sites were monitored weekly for 8 months in 2012: PPH-1B, PPH-2B, PPH-DN2, PPH-DN3, and PPH-DR4 (Table 3 and Figure 3).

*E. coli* concentrations were significantly increased at PPH-2 and PPH-8 compared with their corresponding upstream sites, PPH-2B and PPH-DR4, respectively ( $p < 0.05$ ). The *E. coli* median value at PPH-2 was approximately 100-fold higher than that of PPH-2B, which was a considerable difference. The difference in the median values of PPH-8 and PPH-DR4 was about 2.5-fold. Although *E. coli* counts at the two upstream sites were significantly lower than their counterparts downstream, we should note that 38% (PPH-2B) and 88% (PPH-DR4) of samples collected at the upstream sites were also above the *E. coli* criterion. The *E. coli* levels at PPH-1 and PPH-4 did not show a significant difference between upstream and downstream sites ( $p > 0.05$ ).

The spatial variations of *Enterococcus* between upstream and downstream sites showed similar tendency to *E. coli* at all inflows. PPH-2 and PPH-8 had significantly higher *Enterococcus* concentrations compared with their upstream sites ( $p < 0.05$ ). However, 62% and 100% of samples collected at PPH-2B and PPH-DR4, respectively, were already in exceedance of *Enterococcus* criterion. The *Enterococcus* levels at PPH-1 and PPH-4 did not significantly change while the water transported to downstream ( $p < 0.05$ ).

In an effort to find more sampling sites located above the existing upstream sites, we added two new upstream sites, PPH-DN4 and PPH-DR6, located above the existing upstream sites for MST monitoring.

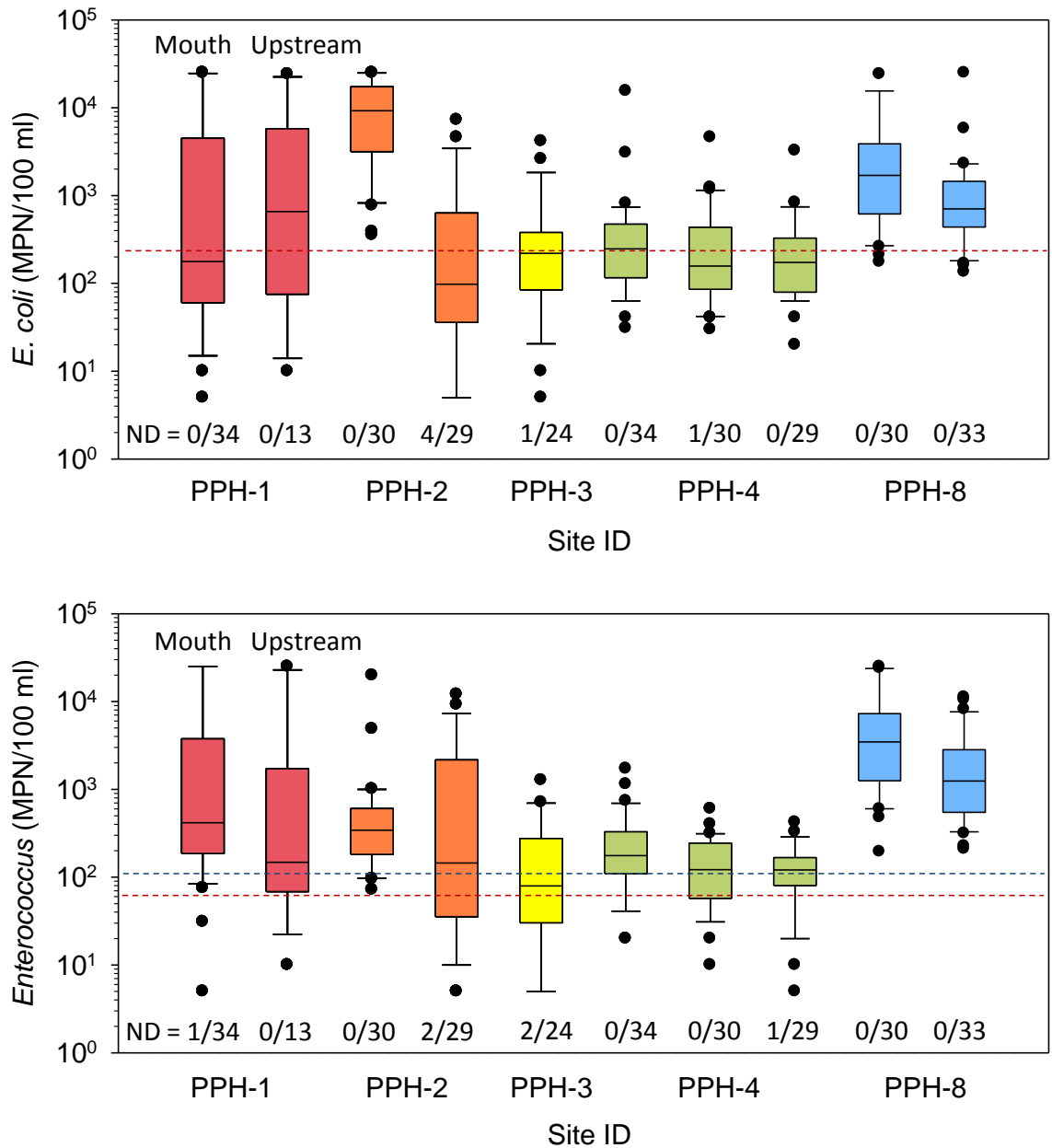


Figure 7 Weekly *E. coli* (top) and *Enterococcus* (bottom) levels at 4 freshwater inflow sites and corresponding upstream sites and at Capistrano Beach (PPH-3) from May to December in 2012. The number of non-detects out of total samples tested is shown below each box. Each site was classified with different colors. FIB counts were plotted separately by the inflow sites (mouth) and their upstream site (upstream). The red and blue dotted lines show FIB single sample maximum criteria in freshwater and marine water, respectively.

## 3.2 Microbial source tracking

### 3.2.1 *Bacteroidales* at key locations

A total of 23 MST water sampling events were conducted throughout the project period (Appendix B). Universal *Bacteroidales* derived from all warm-blooded animals and human-, bovine-, and dog-associated *Bacteroidales* were measured in freshwater inflow and beach water samples to investigate the sources of fecal pollution at PPH. Measured concentrations of host-associated *Bacteroidales* marker including BacHum, BacCan and BacBov marker were adjusted using a statistical probabilistic model developed at UCD.

At PPH-1, the universal *Bacteroidales* marker, BacUni, was detected in all samples collected in both dry and wet season (Figure 8), and no seasonal variation was observed ( $p > 0.05$ ). The BacUni median values in the dry and wet season were 4,414 and 1,494 gc/ml, respectively. Human-associated *Bacteroidales* were detected once with notably high concentration (769 gc/ml) in the dry season in 2012 but not in 2008 and 2011. The human-associated *Bacteroidales* marker, BacHum, concentrations were usually low (less than 20 gc/ml) in wet season. The dog-associated *Bacteroidales* marker, BacCan, was detected 1 out of 3 samples in dry season and 3 out of 17 samples in wet season, dog was a predominant source of fecal pollution in the positive samples. The bovine-associated *Bacteroidales* marker, BacBov, was not detected in any of samples collected at PPH-1.

PPH-2 had notably high levels of BacUni in both seasons (Figure 9), with median concentrations of 17,395 (dry season) and 6,975 gc/ml (wet season). The BacUni median concentrations at PPH-2 were approximately 4-fold magnitude higher than those at PPH-1. Although BacHum was detected in 13% of wet season samples, the concentrations were negligible ( $< 10$  gc/ml). BacCan, was commonly detected in wet season (40% of samples were positive) and contribute a significant amount of BacUni detected in the same samples.

At Capistrano Beach (PPH-3), BacUni was detected at all samples in both seasons (Figure 10). Like FIB, the BacUni median concentrations were higher in wet season (1139 gc/ml) than dry season (89 gc/ml). Although BacHum was detected in 20% of samples in wet season, its concentrations were usually low. The average BacHum concentration of the positive samples were 19 gc/ml. BacCan was more often observed in wet season (33% of samples were positive), with high ratio of dog to universal *Bacteroidales* concentration (up to 52%), which indicates that dog feces contributed a significant amount of fecal pollution when detected.

Denniston Creek (PPH-4) had similar levels of BacUni in dry and wet season with the median values of 633 and 705 gc/ml, respectively (Figure 11). BacHum signals were detected once in each season, however, the concentrations were lower than 10 gc/ml, which was little evidence of human fecal pollution at the sites. BacCan was detected at high concentrations once in dry

season (698 gc/ml), twice in wet season (620 gc/ml, during rain; 7805 gc/ml, during first flush) in 2011.

Deer Creek Outlet (PPH-8) showed high BacUni levels in both seasons, with median concentrations of 2,896 in dry season and 4,999 gc/ml in wet season. BacBov was detected in all samples in dry season and half of samples in wet season. The BacBov concentrations in dry season made up 39 to 100% of the BacUni concentrations at PPH-8. In addition, elevated BacCan levels were more frequently detected in wet season (73% of samples were positive), with a median values of 1,921 gc/ml in positive samples.

The other 5 beaches including PPH-5, 6, 7, 9, and 10 had relatively low BacUni concentrations compared to Capistrano Beach (PPH-3) throughout the monitoring period in 2008 and 2011. The BacUni median values at the 5 beaches ranged from 138 to 347 gc/ml (Appendix B1 and 2) whereas BacUni median value at PPH-3 was 802 gc/ml. In contrast, BacCan signals were detected in 27% of samples at PPH-6 where dog walkers and dogs on the beach were most frequently found during MST sampling. BacCan signals were found in 25% of samples collected at PPH-5 which is neighboring to PPH-6 whereas no BacCan was detected at PPH-10 which is adjacent to PPH-5. Human- or bovine-associated *Bacteroidales* were hardly detected in the 5 beaches. Based on MST as well as FIB monitoring results in 2008 and 2011, we ceased MST monitoring at the 5 beaches since their contributions to fecal pollution at PPH were considered minor.

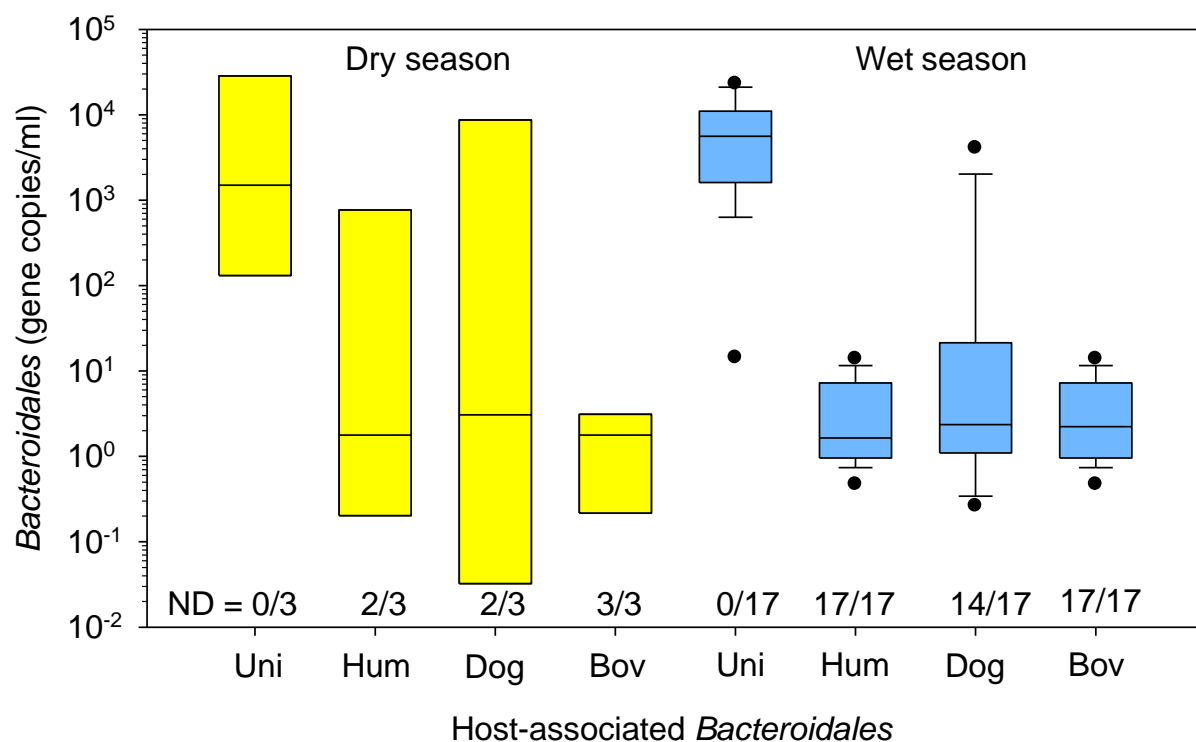


Figure 8 Seasonal variations of host-associated *Bacteroidales* concentrations at Capistrano Outfall Pipe (PPH-1) throughout 2008 and 2011-2012 monitoring period. Non-detect data were assumed to be one-half of the sample limits of detection. The number of non-detects out of total samples tested is shown below each box. The lower and upper boundaries of each box indicate the 25<sup>th</sup> and 75<sup>th</sup> percentiles, respectively. Whiskers below and above the box indicate the 10<sup>th</sup> and 90<sup>th</sup> percentiles, respectively. Dry season and wet season results were plotted separately by yellow and blue boxes, respectively. Each box indicates universal, human-, dog-, and cow-associated *Bacteroidales* levels in order.

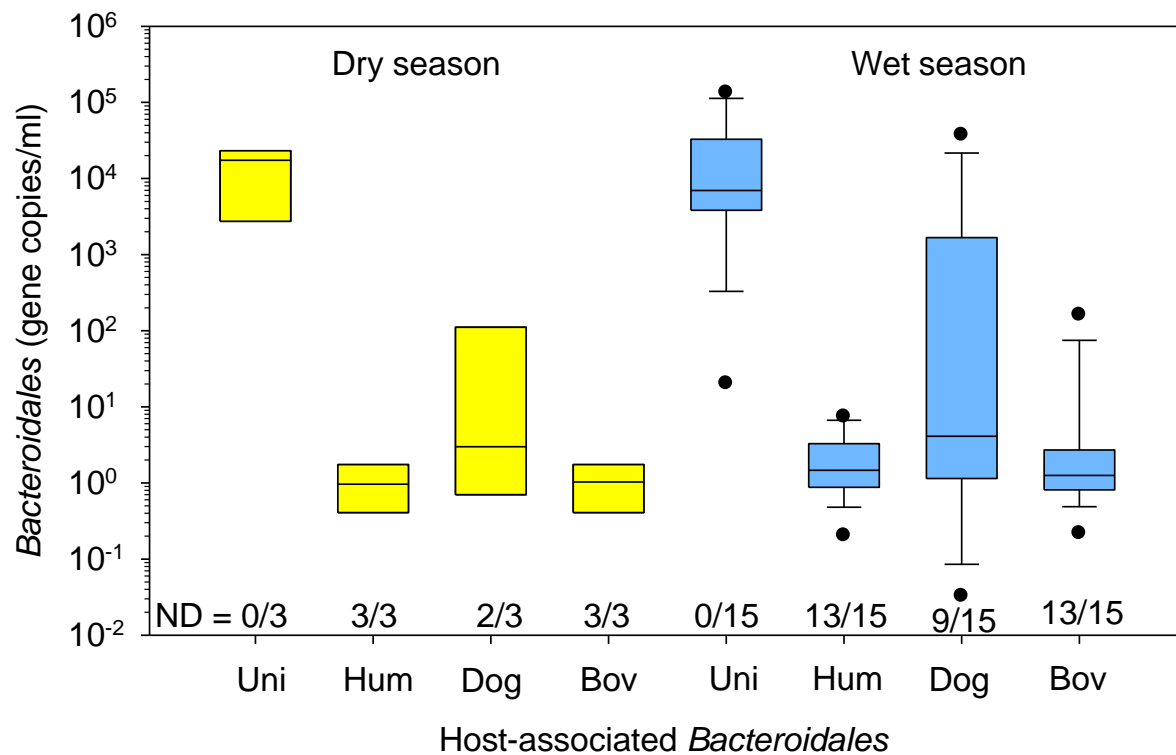


Figure 9 Seasonal variations of host-associated *Bacteroidales* concentrations at Bathhouse Outfall Pipe (PPH-2) throughout 2008 and 2011-2012 monitoring period. Non-detect data were assumed to be one-half of the sample limits of detection. The number of non-detects out of total samples tested is shown below each box. Dry season and wet season results were plotted separately by yellow and blue boxes, respectively. Each box indicates universal, human-, dog-, and cow-associated *Bacteroidales* levels in order.

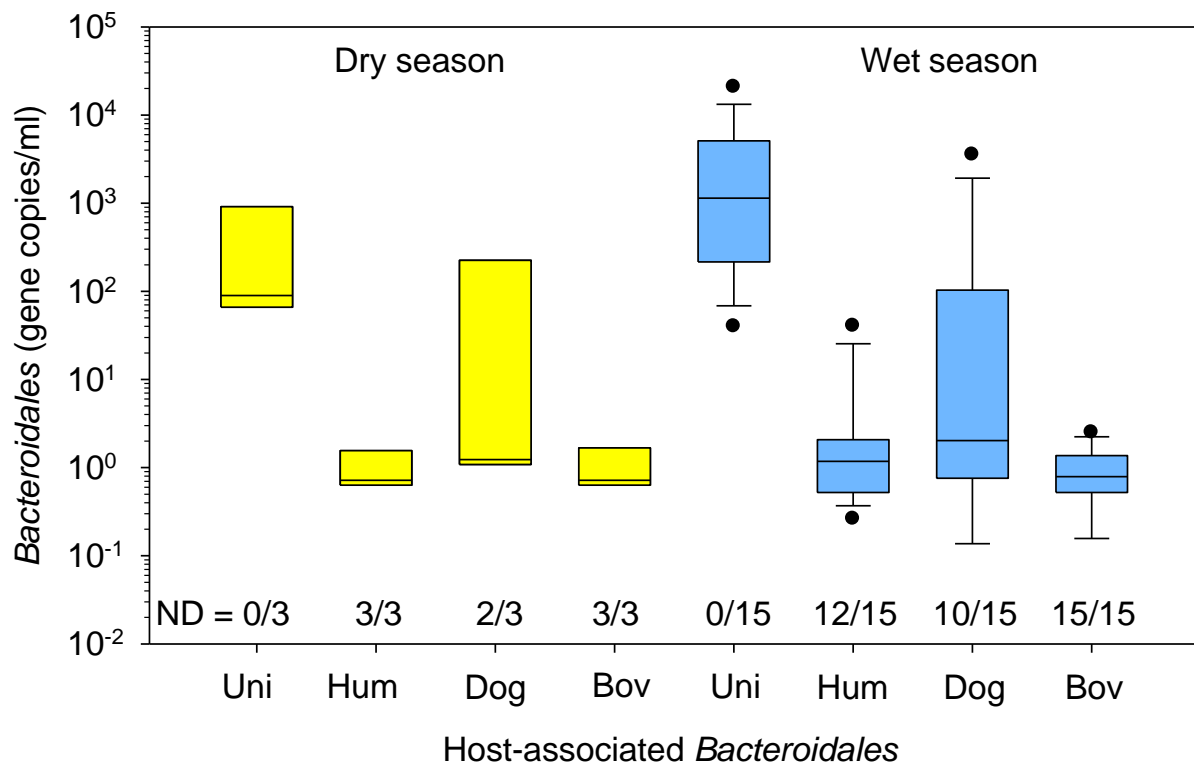


Figure 10 Seasonal variations of host-associated *Bacteroidales* concentrations at Capistrano Beach (PPH-3) throughout 2008 and 2011-2012 monitoring period. Non-detect data were assumed to be one-half of the sample limits of detection. The number of non-detects out of total samples tested is shown below each box. Dry season and wet season results were plotted separately by yellow and blue boxes, respectively. Each box indicates universal, human-, dog-, and cow-associated *Bacteroidales* levels in order.

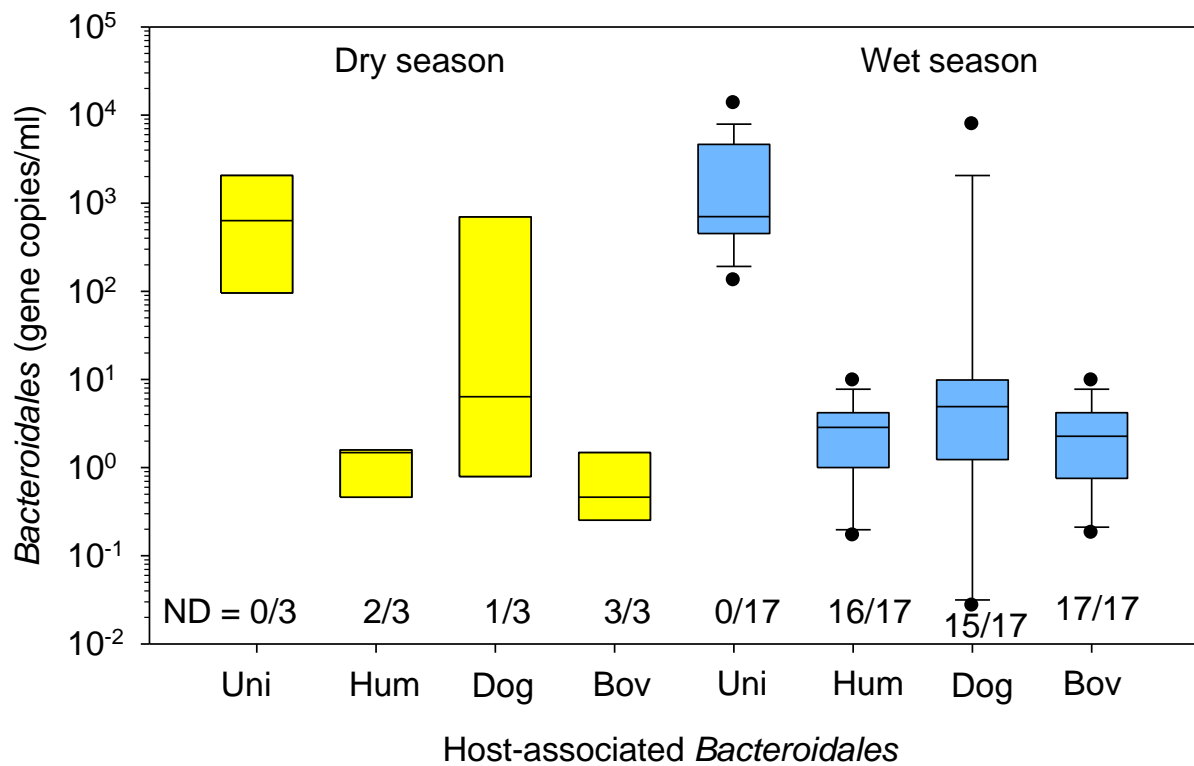


Figure 11 Seasonal variations of host-associated *Bacteroidales* concentrations at Denniston Creek (PPH-4) throughout 2008 and 2011-2012 monitoring period. Non-detect data were assumed to be one-half of the sample limits of detection. The number of non-detects out of total samples tested is shown below each box. Dry season and wet season results were plotted separately by yellow and blue boxes, respectively. Each box indicates universal, human-, dog-, and cow-associated *Bacteroidales* levels in order.

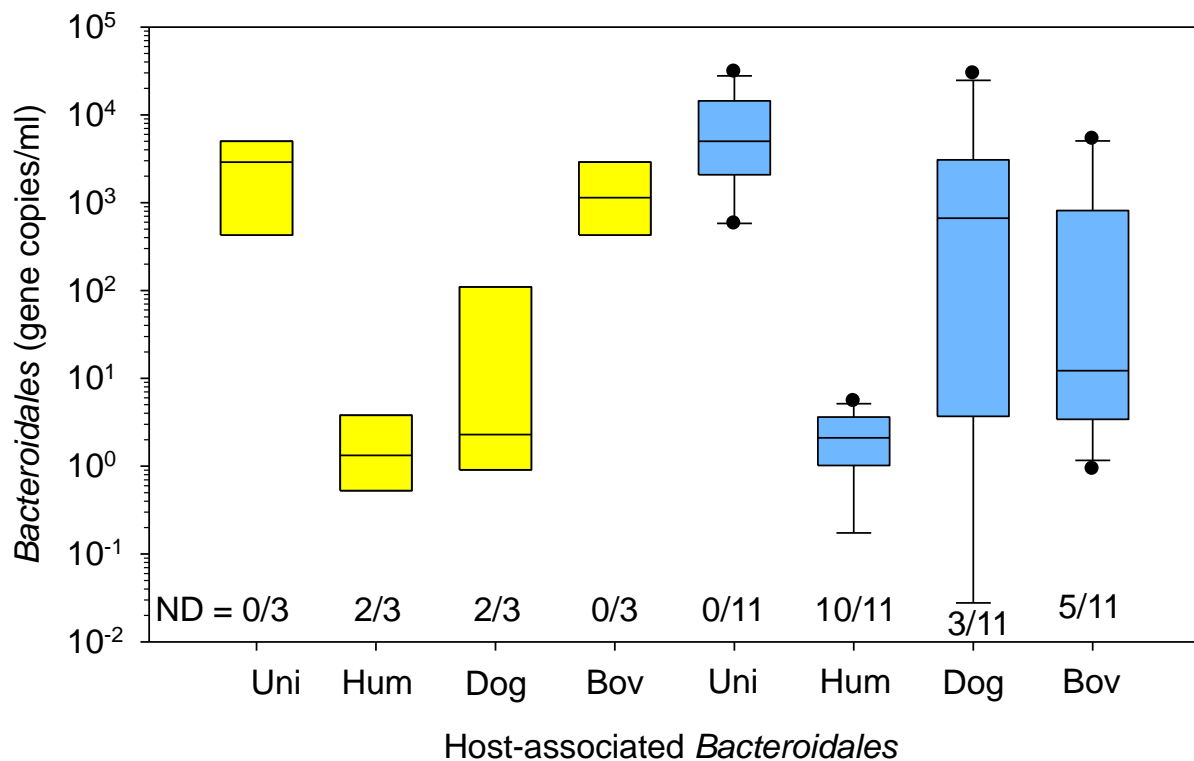


Figure 12 Seasonal variations of host-associated *Bacteroidales* concentrations at Deer Creek Outlet (PPH-8) throughout 2008 and 2011-2012 monitoring period. Non-detect values were replaced to one-half of the sample limit of detection. The numbers of non-detects out of total samples collected were written at the bottom of box plot. Lower and upper boundaries of boxes denote the 25<sup>th</sup> and 75<sup>th</sup> percentiles. Lower and upper bars show the 10<sup>th</sup> and 90<sup>th</sup> percentiles. Dry season and wet season results were separately plotted by yellow and blue boxes, respectively. Each box indicates universal, human-, dog-, and cow-associated *Bacteroidales* levels in order.

### 3.2.2 Live-aboard boat

Live-aboard boat sampling events were conducted two times in 2011 and 2012 to determine possible fecal pollution from numerous live-aboard boats located in the harbor. FIB and MST water samples were collected at 3 boat docks in the Inner Harbor, one pumping station where live-aboard boats empty their tanks, and 3 locations adjacent to boats anchored in Outer Harbor (Table 2 and Figure 2).

In 2011, all water samples showed notably low *Enterococcus* counts less than 10 MPN/100 ml except one sample collected at one of three boat docks in the Inner Harbor. *E. coli* concentrations in all samples were low with the range of non-detect to 64 MPN/100 ml. In MST analysis, human-associated *Bacteroidales* were detected at all three docks ranged from 6 to 25 gc/ml. The average universal marker concentrations found at the boat docks were 380 gc/ml. The BacHum marker was not detected in any samples collected at the pump station and at outer harbor. Outer Harbor had relatively low BacUni concentrations compared to Inner Harbor. Overall, the FIB and MST analysis did not show strong signal of fecal pollution in live-aboard boat samples except one sampling with high *Enterococcus* concentration. The Inner Harbor is located within a set of breakwaters, and the boat-berthing basin is approximately 45 acres and contains approximately 400 slips. To estimate the effect of possible fecal pollution in Inner Harbor on water quality in the vicinity beaches, especially PPH-3 (Capistrano Beach), a set of calculations was performed (Table 6) using information from the dye circulation study and other references.

Table 6 Estimation of fecal discharge to Capistrano Beach from the Inner Harbor

#### Assumptions

1. Inner Harbor continuously discharges 5 kg feces per day.
  - Generation of feces is approximately 500 g/person·day.
  - Number of people in a boat is assumed to be 2.
  - Number of live-aboard boats in the Inner Harbor is approximately 100.
  - 50% of boats are assumed to be in use.
  - 10% of boats are assumed to discharge their waste illegally
  - Therefore, fecal discharge from inner harbor is  $0.5 \times 2 \times 100 \times 0.5 \times 0.1 = 5$  kg/d
2. *Enterococcus* cells in human stool range from  $10^5$  to  $10^8$  CFU/g (Slanetz and Bartley 1957; Jett et al. 1994)
3. Decay rate constant of *Enterococcus* in seawater under natural sunlight is  $0.17 \text{ h}^{-1}$  (Bae and Wuertz 2009).
4. Precipitation and re-suspension of *Enterococcus* is not considered for this calculation.
5. Fecal pollution generated in the Inner Harbor spreads to the vicinity of Inner Harbor as predicted in our dye circulation study (Appendix E). The mechanism of transport consists of 1) leakage through breakwater and 2) dispersion via the gap between the Inner Harbor breakwaters.

1) Discharge by leakage

The distribution of fluorescein dye as a function of time was used to estimate the amount of fecal loading via leakage through breakwaters from Inner Harbor to Capistrano Beach as follows:

a) Fluorescein was released outside the Inner Harbor near Capistrano Beach and b) fluorescein was not detected near the gap of Inner Harbor's breakwaters on the day of release. According to the circulation study, the concentration gradients of fluorescein between Inner Harbor and Capistrano Beach were in the range of 0.5 – 10% on the day of release. We assume that leakage from Inner Harbor to Capistrano Beach would also fall within this range. That is, 0.5 – 10% of fecal loading in Inner Harbor can be transported to Capistrano Beach via leakage of breakwater.

2) Discharge by dispersion

Circulation of rhodamine dye was used to determine the amount of dispersion of fecal material from Inner Harbor to Capistrano Beach via the gap of Inner Harbor breakwater. Since rhodamine was released from two points, one in Inner Harbor and one in Outer Harbor, the dye detected at Capistrano Beach could be transported from both locations. We assumed that half the concentration of rhodamine detected was originated from Inner Harbor. Therefore, the concentration gradient of rhodamine dye between Inner Harbor and Capistrano Beach was in the range of 5 – 50%. That is, 5 – 50 % of fecal loading in the Inner Harbor can reach Capistrano Beach by dispersion of water flow between the open space of breakwater.

6. Residence time of feces near Capistrano Beach is assumed to be 3 days (Appendix E).

- According to our circulation study, fluorescein dye released near Capistrano Beach was flushed out from the northern zone to the Outer Harbor in 2.5 days. Thus, the length of time of fecal material to be flushed out from Capistrano Beach is assumed as 3 days for a conservative estimate.

7. Area of Capistrano Beach (water) is 50,000 m<sup>2</sup>, and average depth of Capistrano Beach is 3 m (Kornicker and Harrison-Nelson 1997).

- 200 m\*250 m = 50,000 m<sup>2</sup> (approximation of length and width of the area as measured by Google Earth)

***Estimation of Enterococcus at Capistrano Beach caused by live-aboard boats***

**1. Best-case scenario ( Application of lower values from leakage and dispersion ranges)**

W (loading to Capistrano Beach)

$$= 5 \text{ kg/d} * 0.005 \text{ (discharge by leakage)} + 5 \text{ kg/d} * 0.05 \text{ (discharge by dispersion)}$$

$$= 0.275 \text{ kg/d} = 275 \text{ g/d}$$

Q (flow rate at Capistrano Beach)

$$= V \text{ (volume of Capistrano Beach)} / t \text{ (residence time)}$$

$$= (50,000 \text{ m}^2 * 3 \text{ m}) / 3 \text{ d} = 5 * 10^4 \text{ m}^3/\text{d}$$

$$\begin{aligned}
& C \text{ (concentration of } \textit{Enterococcus} \text{ at Capistrano Beach)} \\
& = W / Q * (\text{no. of cells per g of feces}) * (\text{decay of } \textit{Enterococcus}) \\
& = \frac{275 \text{ (g/d)}}{5 * 10^4 \text{ (m}^3\text{/d)}} * 10^8 \text{ (CFU/g)} * \exp^{-0.17(\text{h}^{-1}) * 24(\text{h})} \\
& = 0.9 * 10^4 \text{ g/m}^3 = 0.9 * 10^{-2} \text{ g/ml} = 0.9 \text{ CFU/100 ml}
\end{aligned}$$

2. Worst-case scenario (application of higher value from leakage and dispersion ranges)

$$\begin{aligned}
& W \text{ (loading to Capistrano Beach)} \\
& = 5 \text{ kg/d} * 0.1 \text{ (discharge by leakage)} + 5 \text{ kg/d} * 0.5 \text{ (discharge by dispersion)} \\
& = 3 \text{ kg/d} = 3000 \text{ g/d}
\end{aligned}$$

$$Q \text{ (flow rate at Capistrano Beach)} = 5 * 10^4 \text{ m}^3\text{/d}$$

$$\begin{aligned}
& C \text{ (concentration of } \textit{Enterococcus} \text{ at Capistrano Beach)} \\
& = W / Q * (\text{no. of cells per g of feces}) * (\text{decay of } \textit{Enterococcus}) \\
& = \frac{3000 \text{ (g/d)}}{5 * 10^4 \text{ (m}^3\text{/d)}} * 10^8 \text{ (CFU/g)} * \exp^{-0.17(\text{h}^{-1}) * 24(\text{h})} \\
& = 1.0 * 10^5 \text{ g/m}^3 = 1.0 * 10^{-1} \text{ g/ml} = 10 \text{ CFU/100 ml}
\end{aligned}$$

According to the best-case scenario, 275 g/d of fecal pollution arrives at Capistrano Beach when 5 kg/d of fecal material is released in Inner Harbor. And *Enterococcus* is unlikely to be detectable at Capistrano Beach (0.9 CFU/100ml) even when the highest *Enterococcus* numbers in feces ( $10^8$  CFU/g feces) was assumed. In the worst-case scenario, 3 kg/d of fecal material can be transported from Inner Harbor to Capistrano Beach by leakage and dispersion when 5 kg/d of fecal waste is released in the Inner Harbor. In this case, *Enterococcus* could be detected on Capistrano Beach (10 CFU/100 ml) if the highest *Enterococcus* concentration in human stool ( $10^8$  CFU/g feces) was assumed.

The calculation showed that 10 CFU/100 ml of *Enterococcus* could be detected at PPH-3 due to fecal loadings from the Inner Harbor. However, the amount of *Enterococcus* would be only about 10 % of EPA's single sample maximum criteria of 104 CFU/100 ml for *Enterococcus* in marine water. Therefore, the effect of potential fecal release in Inner Harbor on water quality at Capistrano Beach is minor.

In order to determine if the human marker was consistently detected at Inner Harbor, additional live-aboard boat sampling was conducted in 2012. The BacHum marker was not detected in any sample collected at the three docks, and BacUni levels decreased about 10-fold compared to samples collected in 2011. *Enterococcus* levels in all live-aboard boat water samples were less than 10 MPN/100 ml.

### 3.2.3 Bird, horse, and additional human assay results

Two avian assays targeting *Catellibacterium marimammalium* or *Catellibacterium spp.* and an assay targeting horse-associated *Bacteroidales* were applied to MST samples to find potential fecal sources from seagull and horses (Appendix D). An additional human assay (HF183) was also tested to find potential human signals, which could not be detected by the BacHum marker mostly used for detection of human feces in this study.

#### a) Bird assay

We applied the gull-associated *C. marimammalium* SYBR green qPCR assay (Gull 2 assay; Lu et al. 2008) to all MST samples collected in 2011 to identify fecal pollution in water caused by gulls. Although many gulls and sea birds were observed at several beaches during MST sampling, the gull marker was hardly detected in the samples. While the gull assay performed well with gull feces collected at PPH, no water samples were positive with the assay.

In 2012, a voluntary offer was provided from our collaborator in a separate project, Lee Lab at Ohio State University, to analyze a few of our MST samples collected at PPH with their new gull assay. The new gull assay targets *Catellibacterium spp.* 16S rRNA gene and TaqMan probe is used for qPCR analysis. To identify possible gull feces that might not be detected with Gull 2 assay, a total 25 of samples were sent to Lee Lab in Feb 2012 (Appendix D1). The samples were DNA extracts of water samples collected at PPH-1, 2, 3, and 4 as well as fecal DNA extracts of gull, human, cow, and dog. Nuclease free water was also added for QA/QC. The sample IDs were coded for the purpose of blind analysis. For the SYBR green qPCR assay, each 20  $\mu$ l of the reaction mixture contained 2  $\mu$ l of DNA extract, 10  $\mu$ l of TaqMan® universal PCR materi mix (Applied Biosystems, CA), 250 nM of each forward and reverse primer, and 125 nM of probe labeled with 6-carboxyfluorescein (FAM). Each sample was tested in triplicates. The thermal protocol included an initial cycle at 50°C for 2 min and 95°C for 10 min, followed by 45 cycles of denaturation at 95°C for 15 s, annealing and extension at 60°C for 1 min.

Among 25 samples tested, *Catellibacterium spp.* were quantified in only 3 samples of gull fecal DNA extracts ranged from  $4.7 \times 10^2$  to  $1.6 \times 10^3$  gc/ul of DNA extracts. None of environmental and non-seagull fecal DNA samples was detected by the new gull assay, which was consistent with the results of Gull 2 assay performed at UCD.

#### b) Horse-assay

To find any potential fecal sources other than humans, bovine and dogs, horse-associated *Bacteroidales* assay (HorseBact) developed in 2009 (Silkie and Nelson 2009) was applied to all samples collected at PPH-1, 2, 3, 4 and 8 in 2011 and wet season of 2012. Prior to application of horse assay to environmental samples, we performed qPCR on fecal samples from horses, humans, cows, dogs and gulls to verify the specificity and sensitivity of HorseBact assay. The

detected HorseBact marker concentrations in each fecal sample were normalized against the BacUni marker concentrations found in the same sample. The assay gave 100 % sensitivity and specificity for fecal DNA extracts for 21 samples tested. All 6 horse feces collected in the vicinity of PPH showed strong signals whereas no signals were detected in cow, dog, gull fecal samples. However, qPCR results on MST water samples revealed that no horse-associated *Bacteroidales* were detected any of the samples analyzed (Appendix D2).

### *c) Additional Human-assay*

With BacHum assay, we hardly found strong signals of human-associated *Bacteroidales* in MST samples collected in 2011 and 2012. To determine whether there were human-associated *Bacteroidales* not detected by BacHum assay, we applied an additional human assay recently developed (Haugland et al. 2010) to all MST samples collected at PPH-3 and all inflow sites in 2011 and wet season of 2012. The new human assay (HF183 TaqMan assay) targets human-associated *Bacteroidales* 16s rRNA gene V2 region and has different primers and probe set used in BacHum assay. The standard operating procedure was kindly provided to our lab by Orin Shanks, United States Environmental Protection Agency. To verify the specificity and sensitivity of the HF183 qPCR assay, qPCR on DNA extracts from human, cow, dog, gull, horse feces were conducted before qPCR analysis on MST samples. Among 54 MST samples tested, one sample collected at PPH-2 on Feb 6<sup>th</sup> 2012 showed human-associated *Bacteroidales* signals of 228 gc/ml. In the BacHum assay, BacHum marker (116 gc/ml) was also measured in the sample, however, the detected concentration was revealed as a false positive signal after the probabilistic model was used. The false positive BacHum concentration might be derived from the presence of significantly high concentration of BacCan (11,096 gc/ml) in the same sample. Overall, no additional human marker signal was found in all MST samples tested with HF183 TaqMan assay.

### *3.2.4 Upstream MST monitoring*

Based on weekly FIB monitoring results, we decided to conduct upstream MST sampling at the upstream sites of PPH-1, PPH-2, and PPH-8 – hereafter those upstream sites were referred to PPH-1B, PPH-2B, and PPH-DR4, respectively – in 2012 first flush events (Table 3 and Figure 3). At PPH-1B, BacCan was detected at high concentration during first flush (394 gc/ml), and the ratio of BacCan to BacUni was 23% (Appendix C3). BacCan was also found at its downstream, PPH-1, during (1,504 gc/ml) and after first flush (4,075 gc/ml), and the BacCan concentrations significantly contributed to BacUni concentrations detected in the samples. At PPH-2B, high levels of BacCan (2,381 gc/ml) was detected before first flush started whereas the BacCan concentrations significantly decreased during (208 gc/ml) and after (less than  $S_{LOD}$  of 2.3 gc/ml) first flush. The BacUni concentrations at PPH-2B were high before (9,530 gc/ml) and during first flush (7,602 gc/ml) but after first flush (220 gc/ml). While BacUni concentration at PPH-2B after first flush was very low, its downstream site, PPH-2, had considerably high BacUni concentration after first flush (4,8079 gc/ml), which showed the evidence of FIB input within

urban/residential area. However, elevated host marker was not observed at PPH-2B throughout the first flush events. AT PPH-DR4, BacCan and BacBov were consistently detected in pre-, during, and post-first flush events. BacBov concentrations were considerably increased during rain (3,437 gc/ml). The highest BacCan concentration (4,767 gc/ml) was detected in post-first flush sample at the site, which was a predominant host source of fecal pollution at PPH-DR4 after first flush stopped. The elevated BacCan concentration was also found at its downstream, PPH-8 collected at the same day.

Upstream MST sampling was conducted again in December 2012 at additional upstream sites. Along with the upstream sites sampled in the first flush events, two upstream sites (PPH-DN3 and DN4) of Denniston Creek and one upstream site (PPH-DR6) of Deer Creek were also investigated for better understanding about spatial fecal loading distribution. PPH-DN3 was near highway 1 and PPH-DN4 was at the northwestern boundary of urban and rural area. PPH-DR6 was located between PPH-DR4 and northern urban/rural boundary. BacUni concentrations at all upstream sites were ranged from 1,936 to 9,641 gc/ml. BacHum was detected at PPH-DR6, however the concentration was minor (13.5 gc/ml). Instead, high concentrations of BacBov were detected at both upstream sites of Deer Creek (7,972 gc/ml in PPH-DR4; 6,014 gc/ml in PPH-DR6). BacCan marker was also detected at the sites, and PPH-DR4, located in the downstream urban area had 4-fold magnitude increased BacCan concentration compared to PPH-DR6. BacCan marker was also detected at PPH-1B, which was consistent result with first flush sample at the site. No host-associated marker was detected in PPH-2B and PPH-DN3 and DN4. Comparable concentrations of BacUni were detected at PPH-DN3 and PPH DN4.

### 3.2.5 *Bacteroidales* in sediments and biofilm

From August 2011 to July 2012, 21 sediment and 28 biofilm samples were collected and analyzed (Appendix C4). Dry season samples were collected in 2011 and 2012. In wet season, sediment and biofilm samples were collected at 3 phases according to rain condition, pre-, during, and post-rain event. *Bacteroidales* target gene concentrations were expressed as gene copies per dry weight of sediment or biofilm.

Universal *Bacteroidales* were detected in all sediment and biofilm samples, and BacUni concentrations were usually higher in biofilm compared to those in sediment collected at the same sites. BacUni concentrations in biofilm ranged from  $1.6 \times 10^3$  to  $5.4 \times 10^5$  gc/g of dry weight of biofilm. In 4 inflows and Capistrano Beach (PPH-3), BacUni signals in sediments were significantly elevated in dry season samples compared with wet season samples ( $p < 0.05$ ). In dry season, the BacUni median concentration of sediment samples was more than 10-fold magnitude higher compared to that in wet season. All sediment and biofilm samples except sediments at Denniston Creek (PPH-4) and Deer Creek (PPH-8) showed decreased BacUni levels when it rained compared to those detected before rain. At PPH-3, water samples collected concurrently with the wet season sediment samples had about 10-fold elevated BacUni

concentration when it rained although Capistrano Outfall Pipe (PPH-1) and Bathhouse Outfall Pipe (PPH-2) directly entering PPH-3 did not show increased BacUni levels in water samples during rain, which indicated that release (re-suspension) of universal *Bacteroidales* in sediments at PPH-3 occurred by natural turbulence might increase the UniBac levels in the overlying water.

Human-associated *Bacteroidales* were detected once at PPH-1 (756 gc/g) in the dry season. The concentration of BacHum contributed less than 1% of universal *Bacteroidales* detected at the same time at the creek. Except for the one detection, BacHum signals were hardly detected in sediment and biofilm samples. In addition, bovine-associated *Bacteroidales* were not found in any of sediment and biofilm samples. The average  $S_{LODS}$  for BacHum and BacBov were about 50 gc/g of sediment or biofilm for all samples. Dog-associated *Bacteroidales* were found in both sediment and biofilm samples at PPH-2 in wet season. The dog marker was also detected in the corresponding water sampling. In dry season, the BacCan marker was found at high concentrations at PPH-3 and PPH-8. However, their existences were inconsistent in 2011 and 2012.

Dog-associated *Bacteroidales* were found in both sediment and biofilm samples at PPH-2 in the wet season. The dog marker was also detected in the corresponding water samples. In the dry season, the BacCan marker was found at high concentrations at PPH-3 and PPH-8. However, their occurrences were inconsistent in 2011 and 2012. At PPH-3, dog-associated *Bacteroidales* contributed a significant amount (18%) of universal *Bacteroidales* in sediments collected in dry season 2012 where as the dog marker was not detected in samples collected in 2011. At PPH-8, a high ratio (68%) of dog marker to universal marker was found in 2011 but not in 2012. BacCan marker was also found in biofilm samples at PPH-4 in the dry season 2012 even though the dog marker was not observed in sediment samples.

### 3.2.6 Quality assurance/Quality control (QA/QC)

At all sampling events except 2 events, one field blank and one field duplicate sample for MST as well as for FIB analysis were produced for quality assurance/quality control (QA/QC) purposes. Among 21 field blanks, BacUni marker was detected 3 times in 2008, 3 times in 2011 and once in 2011 (Table 7). A carryover might have occurred during the filtration of samples with higher concentrations of the universal *Bacteroidales*. However, the BacUni concentrations were orders of magnitude lower than concentrations in samples collected at all sampling sites in each event. BacHum marker was detected at Field blank 1 and 2 collected in wet season and dry season in 2008. Although the BacHum marker concentration in field blank 1 was less than 10 gc/ml, the median value of BacHum marker found in the 10 environmental water samples collected in dry season 2008 was 16 gc/ml. In addition, the relatively low BacHum concentrations still contributed a significant amount of BacUni levels at several sites in dry season 2008. Therefore, MST samples collected in 2008 dry season were not included in final analysis. Even though the human marker was also observed in field blank 2, the concentration

was quite low, and detected BacHum levels at other site were significantly higher or BacHum concentrations were negligible compared to BacUni concentrations. Hence, MST samples collected in dry season 2011 were involved in final analysis. BacCan and BacBov markers were not detected in any of field blanks.

The variability of field duplicates was calculated by comparing the concentrations of paired environmental sample and associated field duplicate samples (Table 8). High variability over 100% of replicate percent difference (RPD) was not found in all field duplicate samples. BacCan marker was detected in a sample of the dry season 2008 but in its duplicate (field duplicate 2), however the BacCan levels contributed less than 1% of BacUni concentration detected in the same. Similarly, although BacHum marker was detected only in field duplicate, the detected concentration was very low, 5 gc/ml, which could be considered minor effect on water quality at the site.

Table 7 *Bacteroidales* concentrations in field blanks

Sampling Date	Sample	BacUni	BacHum (gene copies/ml)	BacBov	BacCan
02/07/08	Field blank 1	7.9	7.9	n.d. <sup>A</sup>	n.d.
07/29/08	Field blank 2	4.7	1.1	n.d.	n.d.
10/03/08	Field blank 3	6.6	n.d.	n.d.	n.d.
03/19/11	Field blank 4	n.d.	n.d.	n.d.	n.d.
03/29/11	Field blank 5	n.d.	n.d.	n.d.	n.d.
04/06/11	Field blank 6	7.5	n.d.	n.d.	n.d.
04/07/11	Field Blank 7	25.9	n.d.	n.d.	n.d.
04/08/11	Field Blank 8	2.9	n.d.	n.d.	n.d.
07/06/11	Field Blank 9	n.d.	n.d.	n.d.	n.d.
10/03/11	Field Blank 10	n.d.	n.d.	n.d.	n.d.
10/05/11	Field Blank 11	n.d.	n.d.	n.d.	n.d.
10/07/11	Field Blank 12	n.d.	n.d.	n.d.	n.d.
11/07/11	Field Blank 13	n.d.	n.d.	n.d.	n.d.
02/06/12	Field Blank 14	n.d.	n.d.	n.d.	n.d.
02/07/12	Field Blank 15	8.4	n.d.	n.d.	n.d.
02/09/12	Field Blank 16	n.d.	n.d.	n.d.	n.d.
07/09/12	Field Blank 17	n.d.	n.d.	n.d.	n.d.
10/21/12	Field Blank 18	n.d.	n.d.	n.d.	n.d.
10/22/12	Field Blank 19	n.d.	n.d.	n.d.	n.d.
10/29/12	Field Blank 20	n.d.	n.d.	n.d.	n.d.
12/17/12	Field Blank 21	n.d.	n.d.	n.d.	n.d.

<sup>A</sup> n.d. not detected

Table 8 Replicate percent differences in environmental samples and field duplicates (for water samples)

Sampling Date	Sample	BacUni	BacHum	BacBov	BacCan
		RPD <sup>A</sup>			
02/07/08	Field duplicate 1	58%	13%	ND <sup>B</sup>	ND
07/29/08	Field duplicate 2	74%	79%	ND	ND1 <sup>C</sup>
10/03/08	Field duplicate 3	NA	NA	NA	NA
03/19/11	Field duplicate 4	NA	NA	NA	NA
03/29/11	Field duplicate 5	47%	ND	ND	ND
04/06/11	Field duplicate 6	25%	ND	ND	ND
04/07/11	Field duplicate 7	14%	ND	ND	ND
04/08/11	Field duplicate 8	69%	ND	ND	ND
07/06/11	Field duplicate 9	76%	ND	ND	ND
10/03/11	Field duplicate 10	81%	ND	ND	ND
10/05/11	Field duplicate 11	87%	ND	ND	ND
10/07/11	Field duplicate 12	33%	ND	ND	8%
11/07/11	Field duplicate 13	42%	12%	ND	ND
02/06/12	Field duplicate 14	80%	ND	ND	42%
02/07/12	Field duplicate 15	34%	ND	ND	ND
02/09/12	Field duplicate 16	3%	ND	ND	ND
07/09/12	Field duplicate 17	25%	ND	19%	ND
10/21/12	Field duplicate 18	86%	ND	ND	22%
10/22/12	Field duplicate 19	30%	ND	ND	ND
10/29/12	Field duplicate 20	29%	ND	ND	44%
12/17/12	Field duplicate 21	44%	ND1	ND	44%

<sup>A</sup> Replicate percent difference (RPD) =  $( | \text{Concentration}_{\text{sample}} - \text{Concentration}_{\text{duplicate}} | / \text{mean}(\text{concentration}_{\text{sample}}, \text{concentration}_{\text{duplicate}}) ) \times 100\%$ . For reference, factors of 3- and 10-fold differences in concentrations equate to RPDs of 100% and 163.6%, respectively.

<sup>B</sup> ND = both the environmental and field duplicate were non-detect

<sup>C</sup> ND1 = measurement was positive in one sample and negative in the other

### 3.3 PhyloChip analysis

PhyloChip analysis revealed that the composition of microbial taxa varied among samples with different sites and FIB concentrations. Multivariate analysis of OTU abundance data showed that Capistrano Outfall Pipe (PPH-1) and Bathhouse Outfall Pipe (PPH-2) contained similar microbial community structure but differ from Capistrano Beach (PPH-3) (Figure 13). The fact that samples with high fecal indicator counts (coliforms, *Enterococcus*, *Bacteroidales*) appeared to be grouped together, regardless of site, indicates that bacterial communities in freshwater inflows and seawater were more similar during contamination events (Figure 14).

In probe analysis, 12 samples showed over 20% of shorebird source ID probes enriched (Appendix F2), which indicates the presence of shorebird source in the samples. Twenty percent or greater occurrence of source ID probes in the enriched subset was indicative of the source when mixed with other sources or the complex microbial background of receiving waters (Dubinsky et al. 2012; Cao et al. in press). A mammal and human source were found in 4 (#7, 12, 39, 45) but the signals were weak. In one sample (#39) a human source was indicated with 37% of human-specific probes enriched. No other fecal sources tested appeared to be associated with enriched bacteria in any of the samples. Several samples lacked any signal from fecal sources evaluated in this study.

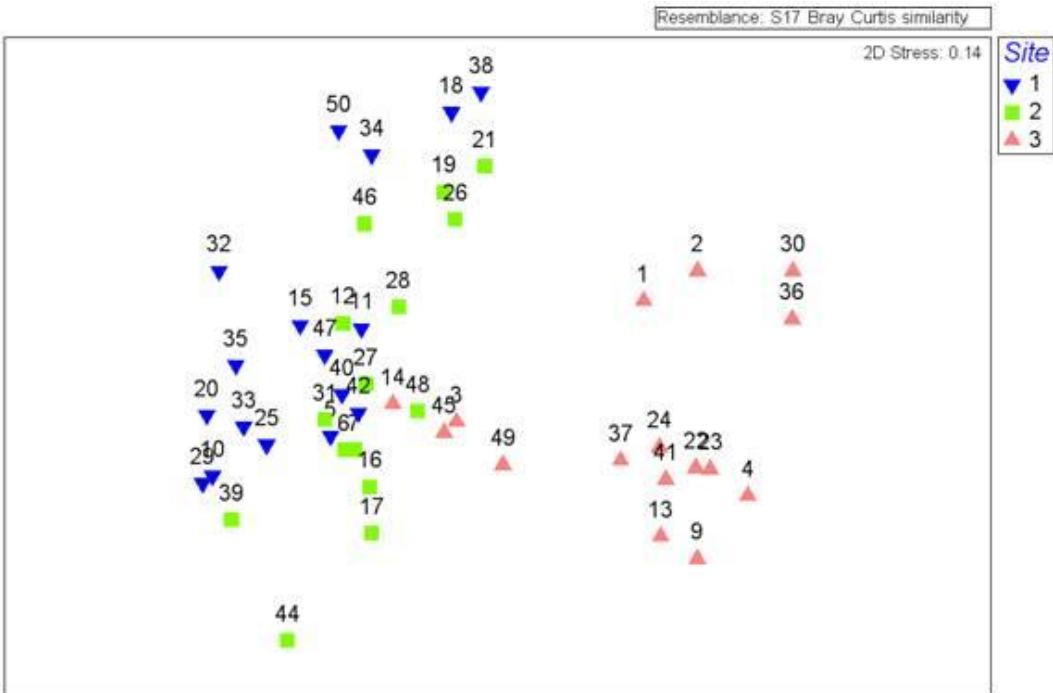


Figure 13 Nonmetric multidimensional scaling (NMDS) ordinations of bacteria community structure. Numeric labels are sample numbers and symbols are coded by sample location. Site 1, 2, and 3 refer to Capistrano Outfall Pipe (PPH-1), Bathhouse Outfall Pipe (PPH-2), and Capistrano Beach (PPH-3). A description of each sample can be found in appendix F1.

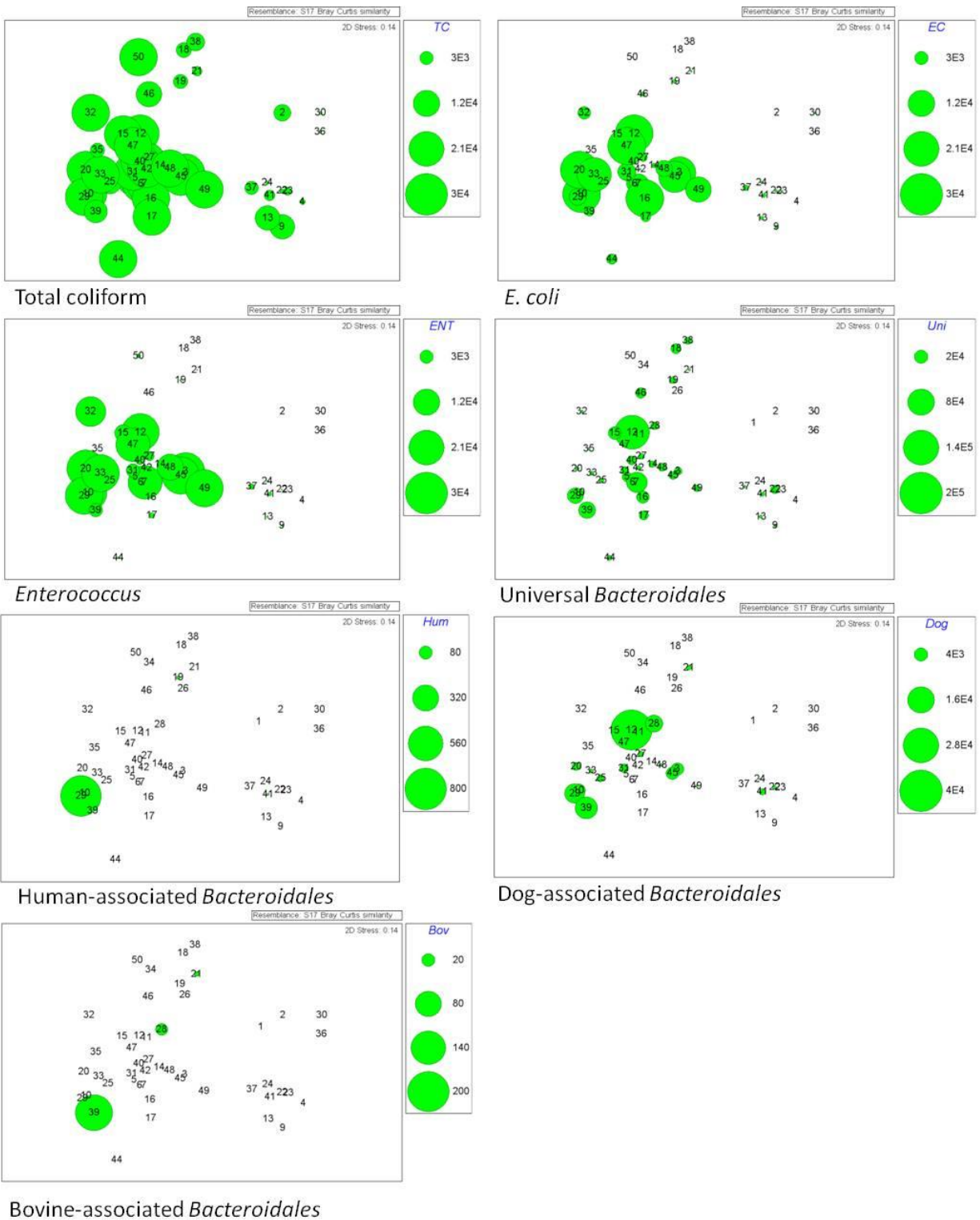


Figure 14 NMDS ordination of bacteria community structure based on detected taxa. Numeric labels are sample numbers. Size of bubble indicates the concentration of fecal indicator at each site.

## 4. Discussion

The main goal of this project was to identify sources of fecal pollution found in Pillar Point Harbor and recommend opportunities for mitigation. Water was sampled at selected locations and tested for the abundance of FIB and of genetic markers to pinpoint their original human or animal sources. The levels of host-associated *Bacteroidales* in sediments and biofilm were also analyzed to explore their role as potential sources of elevated levels of bacteria.

### 4.1 Fecal indicator bacteria

#### 4.1.1 Spatial distribution of FIB concentration

FIB monitoring at 10 primary locations revealed that there was a site-specific distribution of FIB in water in PPH. All 4 inflow sites showed high *E. coli* and *Enterococcus* concentrations above the allowable water quality criteria, while FIB counts were usually low at all beaches except for Caspitrano Beach (PPH-3). FIB concentrations above criteria were often detected at PPH-3. Elevated FIB levels at PPH-3 have been frequently reported historically, and the beach was permanently posted as a potential health hazard by San Mateo County Department of Environmental Health in 2006. Unlike other beaches in PPH, PPH-3 is adjacent to inflow sites at Capistrano Outfall Pipe (PPH-1) and Bathhouse Outfall Pipe (PPH-2) with very high FIB concentrations. PPH-1 and 2 are outfall pipes receiving storm drains, surface runoff, and discharge from St. Augustine Creek (PPH-2 only), and they discharge directly into PPH-3. While elevated FIB concentrations were rare on the other beaches and only found in the wet season when stormwater runoff might directly affect beaches, PPH-3 received perennial inflows and high FIB levels were measured. The site-specific variation of FIB on beaches suggests that the elevated levels of *E. coli* and *Enterococcus* at PPH-3 were associated with the impaired water quality of inflowing water.

#### 4.1.2 Seasonality of FIB concentration

The analysis of 2-yr biweekly FIB monitoring in 2011-2012 showed that there was a seasonal variation of FIB counts at PPH-3. Elevated *Enterococcus* concentrations at PPH-3 more frequently exceeded the FIB criteria in the wet season compared to the dry season. The seasonal variation may be due to the unequal die-off rates of FIB under different temperatures and the increased flow rate of inflows in the wet season. Previous studies have shown that FIB decayed faster at higher temperatures compared to lower temperatures (Madema et al. 1997; Noble et al. 2004; Okabe and Shimazu 2007). Therefore, it is plausible that the relatively low seawater temperature in the wet season (May – September) compared to the dry season (October – April) enables *Enterococcus* to survive longer. The less pronounced seasonal variation of *E. coli* counts at PPH-3 might be caused by the more rapid decay in seawater of *Enterococcus* compared to *E. coli* (Noble et al. 2004). According to our field measurement, PPH-1 and 2 had consistently low flow rates (less than 5 gallon per sec (18.9 liters per sec in metric)) in both seasons, whereas

PPH-4 and PPH-8 had elevated flow rates in the wet season. Based on the hydrologic records at Pilarcitos Creek located at Half Moon Bay (<http://waterdata.usgs.gov>), the average monthly mean discharge was approximately 21 cfs (595 liters per sec) in the wet season and 5 cfs (142 liters per sec) in the dry season. Therefore, it is likely that increased flow rates in inflows in the wet season could bring more fecal pollution to PPH-3.

#### *4.1.3 Upstream FIB monitoring*

Upstream FIB monitoring results suggest that considerable amounts of fecal loading were introduced from the urban area. PPH-2B and PPH-DR4, which were located at the northern boundary or in the middle of the urban/residential area, showed significantly lower FIB counts compared to levels downstream. Potential fecal inputs from overflows or leaking septic and/or sewer system pipes, runoff from residential and public area, and domestic animals could have accumulated in the waterway while the water flowed through the urban area. Note that more than 70% of FIB samples at PPH-DR4 were in exceedance of the *E. coli* criterion, suggesting considerable fecal loading from the upper watershed. In an effort to find the area of fecal input from the upstream site, we allocated one additional sampling point for MST monitoring. Spatial variation along the Denniston Creek waterway was not found. PPH-DN2 and DN3 were located in a suburban area, and there was no significant difference in FIB levels between the upstream sites and the downstream site, Denniston Creek (PPH-4). Notably, even the FIB counts at PPH-DN2 and DN3 frequently exceeded the FIB criteria. The Denniston Creek watershed measures approximately 2,725 acres and collects surface runoff from the rural valley and suburban areas before it drains into PPH (California Coastal Commission 2008). The rural valley accounts for over half of the Denniston Creek watershed. Given the large area of wildlife habitat, it is plausible that various species of animals that reside along the waterway in the rural valley made a significant contribution to fecal pollution in Dennison Creek.

## **4.2 Microbial Source Tracking**

### *4.2.1 Canine fecal pollution*

In MST monitoring, we found that BacUni concentrations were relatively low at all beaches except PPH-3, similar to FIB site-specific variability. However, BacCan was often detected at Mavericks Beach (PPH-6) where we saw many dog walkers during MST sampling events. Therefore, the presence of BacCan provided clear evidence that dog waste affected microbial water quality on the beach. BacCan was also frequently detected at PPH-3; however, the influence of dog feces from PPH-6 on water quality at PPH-3 may not be significant. According to our dye circulation study conducted in 2008, a tracer dye released in the vicinity of PPH-6 remained mostly near the beach even after 5 tidal cycles, while the dye released at the northern zone of the harbor was completely washed out in the same time period (Wuertz et al. 2011). The experiment indicated that water circulation near PPH-6 was quite limited on that day. The lack of

BacCan presence at Yacht Club Beach (PPH-10) adjacent to PPH-6 also suggests that BacCan observed at PPH-3 was unlikely to have been transported from PPH-6. Since the dye circulation study was conducted under calm wind conditions, which represented the baseline conditions in the harbor, it is possible that increased wind speed could affect the circulation of water in the harbor and consequently transport fecal contaminants further away to other beaches. Regardless, the dog signals found at PPH-6 are not significant for the purpose of this study because of low concomitant FIB levels on the beach. It is very plausible that BacCan detected at PPH-3 was introduced from PPH-1 and PPH-2 where the dog marker was also frequently detected. PPH-1 and PPH-2 drain directly into PPH-3, and they consistently showed high FIB concentrations. The relatively low salinity of Capistrano Beach (median value of 29.5 ‰ in MST sampling events) compared to annual mean sea surface salinity of ocean water (35 ‰) supports the notion that freshwater inflows affect microbial water quality on the beach.

Upstream MST sampling revealed that dog feces were introduced in the upper waterway of PPH-1 and PPH-8 within the urbanized area when it rained. In contrast, the BacCan concentrations at PPH-2 decreased when it rained, which indicates that influence of dog waste at the site were reduced due to increased flow rate during rain. Since PPH-2B is located near the northern boundary of the urban area, it is plausible that water entering PPH-2B from the upper rural valley contained less dog feces. In a comparison of upstream and downstream sites, high levels of BacUni were detected at PPH-2 after the rain had stopped whereas BacUni levels at PPH-2B were quite low. The increased BacUni concentrations found at PPH-2 during rain suggest that there was a significant amount of fecal sources loading into the waterway within the urban area when it rained. Based on qPCR analysis, we verified that the fecal pollution was not derived from humans and dogs that are presumable hosts affecting water quality in urban/residential area. The possible sources are domestic animals such as chicken, cats, and rats but there is little information about the true hosts affecting water quality in the watershed. The presence of similar BacUni concentrations at PPH-DN3 and DN4 suggests that additional fecal inputs were less likely added to Denniston Creek when the inflow passed through the suburban area before it discharged into the harbor. This spatial distribution was consistent with the FIB monitoring results in Denniston Creek. The high FIB and BacUni concentrations, the absence genetic host markers tested by qPCR, and the geographical setting of the watershed all suggest that the primary sources of fecal pollution at PPH-4 were wild animals habituating in the upper rural valley.

#### *4.2.2 Putative sources of human fecal contamination*

Human-associated *Bacteroidales* were less commonly detected at all MST water samples. Except for one sample with an elevated concentration of BacHum at PPH-1 in the dry season of 2012, BacHum was rarely detected throughout the MST monitoring period. On the occasion when BacHum was elevated at PPH-1, PPH-3 was not positive for the human marker. Since the high BacHum concentration was detected in the dry season when less water flowed from PPH-1, the

influence of fecal contaminants in the inflow to PPH-3 was limited. Given the large number of live-aboard boats in the Inner Harbor, we investigated whether the live-aboard boats caused fecal pollution in the Inner Harbor and consequently affected water quality at PPH-3. Calculations based on FIB and MST marker concentrations (Table 6) suggest that live-aboard boats are not a major source of human fecal pollution in the harbor. The application of another validated human marker (HF183 Taq Man assay) confirmed the absence of human-derived fecal pollution in the majority of MST samples. We conclude that there was little evidence of human pollution from overflows, leaking septic tanks or sewer systems, or live-aboard boats in PPH.

#### 4.2.3 Bovine fecal pollution

Bovine-associated *Bacteroidales* were frequently found at Deer Creek (PPH-8) during the MST monitoring period. All samples collected in the dry season contained significant amounts of BacBov (formerly known as BacCow), and the bovine marker was also commonly detected in the wet season. The BacCan marker also increased at PPH-8 in the wet season and was a major source of fecal pollution in many MST samples collected at PPH-8. Deer Creek is a small perennial creek flowing through the rural valley and unincorporated community of El Granada (California Coastal Commission 2008). FIB monitoring results revealed that the creek contained significant sources of fecal pollution. After upstream land-use analysis we identified cattle farming located near the urban and rural boundary where Deer Creek passes through. The SMCRCDC has been working with landowners to provide technical assistance and help with implementation of best management practices; however, a notable amount of fecal pollution from bovine sources was regularly quantified in 2012 toward the end of the project period.

#### 4.2.4 Equine and seagull fecal pollution

Given the presence of equestrian operations and potential use of manure compost, we applied a horse-associated *Bacteroidales* assay (Silkie and Nelson 2009) to inflow and Capistrano Beach MST samples. In another MST monitoring recently conducted by the Wuertz lab at the mouth of creeks in the Fitzgerald Marine Reserve, the same horse marker was frequently found even though concentrations were not significant. In PPH water samples, however, horse-associated *Bacteroidales* were not detected in any of the samples tested. We hypothesized that the large flocks of gulls and other birds in the area could contribute fecal pollution to the harbor. Two separate gull assays targeting gull-associated *Catellibacillus marimammalium* or *Catellibacillus* spp. were employed independently in two laboratories. Each team reported the absence of detectable gull-associated markers in beach water samples and inflows. Therefore, we conclude that fecal pollution at PPH was not attributable to gulls or horses.

#### 4.2.5 Resident fecal indicator populations in sediments and biofilms

Sediment and biofilm samples evaluated in this study revealed the abundance and seasonality of universal *Bacteroidales*. UniBac levels in all sediment samples were significantly higher in the

dry season compared to the wet season. In addition, the significantly higher concentrations of BacUni in sediments and biofilm compared to BacUni levels in water strongly suggest that fecal microbial populations accumulated in sediments and biofilms. While survival of *Bacteroidales* in surface water can be limited due to their lack of oxygen tolerance (Bae and Wuertz 2009; Bae and Wuertz 2012; Okabe and Shimazu 2007; Walters and Field 2006), it is plausible for *Bacteroidales* to accumulate and persist longer in sediment and biofilm under favorable conditions including oxygen depletion, nutrient availability, prevention from predator and UV radiation (Anderson et al. 2005; Craig et al. 2004; Lee et al. 2006). The absence of dog-associated *Bacteroidales* in water vis-à-vis their presence in sediments at PPH-3 supports the notion of extended persistence of *Bacteroidales* in sediments. The accumulated microorganisms can be resuspended and transported with elevated water flow during and after rainfall. In the wet season, natural turbulence caused by precipitation and runoff can disturb the sediment surface, and microorganisms attached to sediment and biofilm may be released. The seasonal *Enterococcus* variation at PPH-3 showing elevated FIB counts in the wet season as opposed to the seasonal trend of inflows could be partly influenced by the resuspension of accumulated FIB in sediments. The fact that BacUni in sediments and biofilms decreased after rain suggests that microorganisms associated with sediments and biofilms were released when it rained. Therefore, fecal bacteria in sediments and biofilms can influence microbial water quality in Pillar Point Harbor and may be responsible for elevated FIB concentrations after rainfall.

#### 4.3 PhyloChip analysis

PhyloChip analysis showed that shorebird was the most frequently detected host source in the samples tested. This result was not consistent with findings of the gull-associated *Catellibacterium* qPCR assays that did not find any gull signals using two bird assays separately conducted by two labs. The shorebird fecal samples collected for a reference set of PhyloChip profiles included western and California gulls (9), Canada geese (4), pelican (3), pigeon (2), and cormorant (1) (Dubinsky et al. 2012). In contrast, Gull-2 qPCR assay used in this project was quite specific for seagulls and other waterfowl such as Canada geese and pelican were not detected with the Gull-2 marker (Lu et al. 2008). Based on the PhyloChip and qPCR results, the shorebird signal that occurred in samples could be derived from waterfowl but not gulls. However, given the presence of large flock of gulls at PPH, it is less plausible that gull feces had less effect on water quality at PPH compared to other shorebird. PhyloChip analysis is based on relative abundance of identifier taxa whereas qPCR assay quantifies the actual gene copies of target sequences. Although shorebird signals were detected in PhyloChip analysis, it might not be the major source of fecal contamination in the samples. The  $S_{LOD}$  of Gull-2 qPCR assay used in this study ranged from 1 to 28 gc/ml, which was much lower than universal *Bacteroidales* concentrations detected at the sites. Therefore, we concluded that shorebird contamination found in the samples did not significantly contribute to impaired water quality at PPH. Overall, except shorebird, the source-specific probes were not enriched in most of samples in PhyloChip analysis

whereas dog-associated *Bacteroidales* were often detected by qPCR assay in the samples. In the absence of enriched source ID probes in many samples could be due to the lack of site-specific reference samples and the limited depth of existing reference samples used to define fecal source identifiers.

## 5. Conclusions

- FIB concentrations showed site-specific variation. All 4 inflow sites including Capistrano Outfall Pipe, Bathhouse Outfall Pipe, Denniston Creek and Deer Creek Outlet frequently exceeded the FIB criteria. FIB counts were usually low at all beaches in PPH except at Capistrano Beach. The seasonal FIB variation at Capistrano Beach was explained by the different discharge and unequal die-off rate of FIB in the dry and wet season.
- High concentrations of human-associated *Bacteroidales* were rarely detected. The application of a second human assay and an alternate PhyloChip method both confirmed the absence of human fecal traces in most samples tested. FIB and MST monitoring results as well as predictions based on a dye-release study clearly demonstrated that live-aboard boats are not a source of fecal pollution at Capistrano Beach.
- Dog-associated *Bacteroidales* were frequently detected at Capistrano Beach. Although the dog marker was also found at Mavericks Beach, the spatial distribution of dog-associated *Bacteroidales* on beaches indicates that the presence of the dog marker at Capistrano Beach was due to freshwater inflows alone and not to transfer between beaches.
- Bovine-associated *Bacteroidales* were frequently found at Deer Creek Outlet throughout the MST monitoring period. This marker indicates the main fecal source at Deer Creek Outlet followed by the dog marker.
- Upstream FIB monitoring showed that fecal loading into inflows occurred from the urban area. Likewise, MST monitoring revealed that dog feces were introduced in the waterways of Capistrano Outfall Pipe and Deer Creek Outlet on passage through the urban area. Given the geographical setting and the universal *Bacteroidales* marker levels along Denniston Creek, the predominant source of fecal pollution in the creek is considered to be wildlife.
- Although there are large flocks of gulls, two quantitative gull-associated PCR assays rarely detected full feces in PPH. Qualitative PhyloChip analysis found shorebird signals in several samples tested; however, their contribution to water quality is considered insignificant given the low sample limits of detection of the qPCR assay. Similarly, horse-associated *Bacteroidales* were not detected in any of the samples tested. It follows that fecal pollution in PPH is not attributable to gulls or horses.
- The fact that high levels of universal *Bacteroidales* were detected in sediments and biofilms when the levels in water were not high showed that previously introduced fecal microbial populations accumulated and persisted longer when associated with sediments and biofilms. The gradual decrease of universal *Bacteroidales* in sediments and biofilm according to rain conditions suggests that sediment re-suspension occurred by natural turbulence. Therefore, sediments and biofilm play an important role in microbial water quality in PPH.

- The monitoring study provided significant insights into fecal contamination in PPH to select appropriate management practices to reduce fecal pollution. Equally important, it provided strong evidence that humans, gulls, marine mammals and horses are not significant sources of contamination. This is valuable information to prevent the expenditure of significant resources on efforts that would not have reduced contamination.

## 6. References

- American Public Health Association (APHA) (1998) Total suspended solids dried at 103-105°C. Part 2540 D. In *Standard Methods for the Examination of Water and Wastewater*, 20<sup>th</sup> edition. Washington DC, pp 2-57 to 58.
- Anderson, M.L., Whitlock, J.E. and Harwood, V.J. (2005) Persistence and differential survival of fecal indicator bacteria in subtropical waters and sediments. *Appl Environ Microbiol* 71, 3041-3048.
- Bae, S. and Wuertz, S. (2009) Rapid decay of host-specific fecal *Bacteroidales* cells in seawater as measured by quantitative PCR with propidium monoazide. *Water Res* 43(19), 4850-4859.
- Bae, S. and Wuertz, S. (2012) Survival of host-associated *Bacteroidales* cells and their relationship with *Enterococcus* spp., *Campylobacter jejuni*, *Salmonella enterica* Serovar Typhimurium, and Adenovirus in freshwater microcosms as measured by propidium monoazide-quantitative PCR. *Appl Environ Microbiol* 78, 922-932.
- California Coastal Commission. Nonpoint Source Watershed Assessment: James V. Fitzgerald Marine Reserve Critical Coastal Area. December 2008. The document was accessed online at <http://www.sanmateorcd.org/CCA%20Watershed%20Assessment>.
- Cao, Y., L.C. Van De Werfhorst, E. A. Dubinsky, B. D. Badgley, M. J. Sadowsky, G. L. Andersen, J. F. Griffith and P. A. Holden (2013) Evaluation of Molecular Community Analysis Methods for Discerning Fecal Sources and Human Waste. *Water Res*. In press.
- Craig, D.L., Fallowfield, H.J. and Cromar, N.J. (2004) Use of macrocosms to determine persistence of *Escherichia coli* in recreational coastal water and sediment and validation with in situ measurements. *J Appl Microbiol* 96, 922-930.
- Dubinsky, E.A., L. Esmaili, J. R. Hulls, Y. Cao, J. F. Griffith and G. L. Andersen (2012) Application of phylogenetic microarray analysis to discriminate sources of fecal pollution. *Environ Sci Technol* 46:4340-4347.
- Haugland, R. A., Varma, M., Kelty, C. A., Peed, L., Sivaganesan, M., and Shanks, O. C. (2010) Evaluation of genetic markers from the 16S rRNA gene V2 region for use in quantitative detection of selected *Bacteroidales* species and human fecal waste by real-time PCR, *Syst Appl Microbiol* 33, 348-357.
- Jett, B., Huycke, M.M, and Gilmore, M. (1994) Virulence of enterococci. *Clin Microbiol Reviews* 7(4): 462-478.

- Kildare, B.J., Leutenegger, C.M., McSwain, B.S., Bambic, D.G., Rajal, V.B. and Wuertz, S. (2007) 16S rRNA-based assays for quantitative detection of universal, human-, cow-, and dog-specific fecal *Bacteroidales*: A Bayesian approach. *Water Res* 41, 3701-3715.
- Kornicker, L.S. and Harrison-Nelson E. (1997) Myodocopid Ostracoda of Pillar Point Harbor, Half Moon Bay, California, Smithsonian Institution Press, Washington, D.C.
- Lee, C.M., Lin, T.Y., Lin, C.C., Kohbodi, G.A., Bhatti, A., Lee, R. and Jay, J.A. (2006) Persistence of fecal indicator bacteria in Santa Monica Bay beach sediments. *Water Res* 40, 2593-2602.
- Lu, J.R., Santo Domingo, J.W., Lamendella, R., Edge, T. and Hill, S. (2008) Phylogenetic diversity and molecular detection of bacteria in gull feces. *Appl Environ Microbiol* 74, 3969-3976.
- Medema, G.J., Bahar, M. and Schets, F.M. (1997) Survival of *Cryptosporidium parvum*, *Escherichia coli*, faecal enterococci and *Clostridium perfringens* in river water: Influence of temperature and autochthonous microorganisms. *Water Sci Technol* 35, 249-252.
- Noble, R.T., Lee, I.M. and Schiff, K.C. (2004) Inactivation of indicator micro-organisms from various sources of faecal contamination in seawater and freshwater. *J Appl Microbiol* 96, 464-472.
- Okabe, S. and Shimazu, Y. (2007) Persistence of host-specific *Bacteroides-Prevotella* 16S rRNA genetic markers in environmental waters: effects of temperature and salinity. *Appl Microbiol Biotechnol* 76, 935-944.
- Rajal, V.B., McSwain, B.S., Thompson, D.E., Leutenegger, C.M., Kildare, B.J. and Wuertz, S. (2007) Validation of hollow fiber ultrafiltration and real-time PCR using bacteriophage PP7 as surrogate for the quantification of viruses from water samples. *Water Res* 41, 1411-1422.
- Schriewer, A., Miller, W.A., Byrne, B.A., Miller, M.A., Oates, S., Conrad, P.A., Hardin, D., Yang, H.H., Chouicha, N., Melli, A., Jessup, D., Dominik, C. and Wuertz, S. (2010) Presence of *Bacteroidales* as a predictor of pathogens in surface waters of the central California coast. *Appl Environ Microbiol* 76, 5802-5814.
- Silkie, S.S. and Nelson, K.L. (2009) Concentrations of host-specific and generic fecal markers measured by quantitative PCR in raw sewage and fresh animal feces. *Water Res* 43, 4860-4871.
- Slanetz L. and Bartley C. (1957) Numbers of enterococci in water, sewage, and feces determined by the membrane filter technique with an improved medium. *J Bacteriol* 74(5): 591-595.

United States Environmental Protection Agency (USEPA) (1986) *Ambient water quality criteria for bacteria*. Office of Water Regulations and Standards. Washington, DC. EPA550/5-84-002. January.

Walters, S.P. and Field, K.G. (2006) Persistence and growth of fecal *Bacteroidales* assessed by bromodeoxyuridine immunocapture. *Appl Environ Microbiol* 72, 4532-4539.

Wang, D., Silkie, S.S., Nelson, K.L. and Wuertz, S. (2010) Estimating true human and animal host source contribution in quantitative microbial source tracking using the Monte Carlo method. *Water Res* 44, 4760-4775.

Wuertz, S., Wang, D., Zamani, K. and Bombardelli, F (2011). An analysis of water circulation in Pillar Point Harbor, Half Moon Bay, California, based on the dye distributions. Study of September 27, 2008. Report prepared for San Mateo County Resource Conservation District.

## 7. Appendices

### Appendix A: MST sampling dates and water quality parameters

Date	Site (PPH-#)	Temp. (°C)	pH	Conduc. <sup>B</sup> (mS)	Salinity (ppt)	DO <sup>C</sup> (mg/l)	Turbidity (NTU)	TSS <sup>D</sup> (mg/l)
02/07/08 (wet season)	1	15.8	7.4	0.9	0.5	6.1	-	-
	2	12.7	7.8	0.4	0.2	7.3	-	-
	3	14.5	7.5	37.0	30.0	6.0	-	-
	4	10.0	7.4	0.2	0.1	7.4	-	-
	5	12.0	7.9	42.3	30.3	- <sup>A</sup>	-	-
	6	11.3	7.6	34.3	30.0	7.3	-	-
	7	12.8	7.8	34.4	29.0	7.1	-	-
	8	11.5	7.8	0.3	0.2	7.2	-	-
	9	12.6	7.8	35.5	30.1	6.5	-	-
	10	12.6	7.8	36.0	30.7	6.8	-	-
7/29/08 (dry season)	1	19.5	7.9	0.9	0.5	4.9	-	-
	2	16.3	7.8	32.2	24.3	6.9	-	-
	3	18.2	8.2	40.5	30.3	9.2	-	-
	4	15.1	7.9	0.3	0.2	8.6	-	-
	5	14.5	7.6	30.9	31.3	7.7	-	-
	6	15.1	8.0	29.9	29.7	8.8	-	-
	7	15.6	8.1	38.9	30.9	9.5	-	-
	8	14.8	8.3	0.4	0.2	8.5	-	-
	9	15.9	8.1	39.7	31.4	8.7	-	-
	10	14.8	7.7	38.5	31.2	6.1	-	-
10/3/08 (first flush pre-rain)	1	15.8	7.5	1.0	0.6	-	-	-
	2	17.1	7.5	5.8	3.8	-	-	-
	3	17.6	7.5	39.4	29.9	-	-	-
	4	17.8	7.8	0.2	0.1	-	-	-
	5	16.9	7.5	39.1	30.1	-	-	-
	6	16.5	7.6	38.4	30.0	-	-	-
	7	16.5	7.8	38.5	29.8	-	-	-
	8	17.1	8.1	3.0	1.9	-	-	-
	9	16.3	7.7	38.1	29.5	-	-	-
	10	17.7	7.8	40.2	30.4	-	-	-
10/03/08 (first flush during rain)	1	13.8	7.2	2.7	1.8	-	-	-
	2	13.1	7.6	0.4	0.3	-	-	-
	3	13.1	7.4	36.0	30.2	-	-	-
	4	12.9	7.5	0.2	0.1	-	-	-
	5	13.1	7.7	35.8	30.0	-	-	-
	6	13.8	7.7	36.7	30.3	-	-	-
	7	13.3	7.8	36.6	30.6	-	-	-
	8	13.0	7.7	0.4	0.3	-	-	-
	9	14.5	7.7	36.4	29.4	-	-	-
	10	14.6	7.7	37.0	29.9	-	-	-
10/03/08	1	15.3	7.7	0.8	0.5	-	-	-

(first flush post-rain)	2	15.7	8.2	0.5	0.3	-	-	-
	3	15.6	7.6	35.7	28.3	-	-	-
	4	14.8	7.7	0.2	0.1	-	-	-
	5	19.0	7.7	39.7	29.0	-	-	-
	6	15.2	7.8	37.6	30.0	-	-	-
	7	15.8	7.7	38.2	30.3	-	-	-
	8	17.0	8.1	0.4	0.2	-	-	-
	9	16.0	7.9	38.2	30.0	-	-	-
	10	14.9	7.6	37.3	30.1	-	-	-
	03/19/11 (wet season during rain)	1	11.4	7.8	0.2	0.1	-	-
2		10.7	7.6	0.2	0.1	-	-	96
4		-	7.7	0.1	0.1	-	-	206
8		-	8.3	0.4	0.3	-	-	8
03/29/11 (wet season post-rain)	1	16.5	7.5	0.9	0.5	-	-	n.d. <sup>E</sup>
	2	13.7	8.2	0.2	0.1	-	-	24
	3	15.7	7.7	34.5	27.0	-	-	268
	4	14.0	8.2	0.2	0.1	-	-	71
	5	17.2	7.6	37.4	28.2	-	-	225
	6	16.9	7.7	36.4	27.9	-	-	140
	7	15.3	7.8	27.6	21.6	-	-	19
	9	14.5	7.5	35.9	28.9	-	-	33
	10	16.5	7.6	37.1	28.8	-	-	215
	04/06/11 (wet season pre-rain)	1	15.1	7.4	0.8	0.3	-	-
2		12.0	8.3	0.3	0.2	-	-	n.d.
3		13.2	7.6	35.7	29.9	-	-	151
4		12.3	8.1	0.2	0.1	-	-	26
5		15.4	7.7	36.9	29.2	-	-	456
6		15.1	7.7	37.0	28.6	-	-	68
7		11.9	7.8	27.5	23.2	-	-	436
9		12.4	7.7	35.8	30.6	-	-	25
10		13.2	7.7	36.5	30.5	-	-	66
04/07/11 (wet season during rain)		1	15.0	7.4	0.8	0.5	-	-
	2	11.6	8.0	0.3	0.2	-	-	7
	4	10.9	8.0	0.2	0.1	-	-	20
04/08/11 (wet season post-rain)	1	15.3	7.6	0.9	0.5	-	-	n.d.
	2	11.6	8.3	0.3	0.2	-	-	n.d.
	3	12.7	7.6	36.1	30.7	-	-	113
	4	9.7	8.4	0.2	0.1	-	-	37
	5	13.1	7.8	36.3	30.5	-	-	61
	6	12.9	7.7	35.7	29.9	-	-	107
	7	13.7	7.7	36.8	30.8	-	-	66
	9	13.4	7.8	36.8	30.7	-	-	13
	10	13.0	7.8	36.3	30.5	-	-	64
	07/06/11 (dry season)	1	17.6	7.5	0.9	0.5	7.9	2.2
2		15.4	7.5	1.0	0.5	6.3	4.1	n.d.
3		15.2	7.8	24.1	18.4	8.3	6.2	14
4		13.9	7.7	0.2	0.1	9.5	8.4	7

	5	18.9	8.1	40.9	30.1	8.6	18.8	48
	6	17.3	8.1	40.4	30.9	10.7	11.1	50
	7	14.1	7.8	36.3	29.7	5.7	4.0	13
	8	16.7	8.2	0.3	0.2	10.4	7.2	7
	9	18.2	7.8	39.7	29.6	10.5	3.9	16
	10	18.4	8.0	40.0	29.7	10.7	15.8	39
10/03/11	1	18.2	7.9	0.9	0.5	4.5	12.4	40
(first flush	2	16.8	7.9	2.1	1.3	5.5	4.5	6
pre-rain)	3	16.2	7.8	38.2	29.8	7.2	14.8	94
	4	14.2	8.4	0.2	0.1	7.4	7.5	21
	5	15.1	8.0	38.4	30.9	6.5	9.3	82
	6	15.1	8.0	38.3	30.8	6.5	4.7	28
	7	16.8	7.7	39.5	30.6	6.3	15.3	94
	8	14.8	8.2	0.4	0.3	7.9	7.1	11
	9	16.0	7.6	39.1	30.7	7.3	3.3	8
	10	15.7	7.8	38.9	30.8	6.9	11.0	64
10/05/11	1	15.6	8.4	0.1	0.1	7.0	75.3	201
(first flush	2	15.6	7.1	0.1	0.1	6.8	64.5	408
during rain)	3	15.7	7.1	17.6	12.9	7.0	41.4	204
	4	15.5	8.3	0.2	0.1	7.4	123.0	276
	5	15.1	7.6	37.8	30.3	6.3	142.0	304
	6	15.1	7.5	37.0	29.6	7.5	88.6	463
	7	15.7	7.6	38.5	30.6	7.3	14.9	52
	8	15.6	7.9	0.2	0.1	7.0	12.9	716
	9	15.7	7.6	34.3	26.8	6.1	18.0	139
	10	15.2	7.7	37.3	26.3	6.7	106.0	674
10/07/11	1	18.9	7.3	0.9	0.5	5.9	2.9	7
(first flush	2	16.5	8.4	0.8	0.5	6.9	2.9	n.d.
post-rain)	3	19.5	7.5	36.1	25.8	5.7	45.5	81
	4	14.0	7.6	0.2	0.1	6.8	10.0	9
	5	18.0	7.9	40.8	30.7	6.0	6.0	13
	6	19.6	8.0	42.3	30.7	7.2	25.6	69
	7	18.4	7.7	38.6	28.6	6.0	15.6	87
	8	14.9	8.2	0.4	0.2	7.3	5.5	52
	9	18.7	7.8	41.1	30.4	6.5	6.5	21
	10	18.7	7.9	41.2	30.5	6.9	18.4	87
11/16/11	Dock A	12.9	7.7	36.5	30.8	7.0	2.6	14
(live-aboard	Dock B	13.6	7.7	36.5	30.4	7.6	2.3	18
boats)	Dock C	13.2	7.8	36.4	30.6	7.4	2.6	14
	Pump	12.9	7.8	36.2	30.6	7.4	1.8	11
	OH 1	13.2	6.9	35.4	29.4	7.5	1.4	12
	OH 2	12.8	7.8	36.2	30.7	7.0	2.0	15
	OH 3	12.9	7.6	36.1	30.5	7.1	2.1	14
02/06/12	1	14.1	7.6	0.8	0.5	6.6	2.3	36
(wet season	2	13.2	8.1	1.2	0.8	8.1	17.3	39
pre-rain)	3	13.6	7.5	35.2	29.2	7.1	63.8	137
	4	11.8	8.5	0.2	0.1	8.2	3.5	12
	8	11.8	8.9	0.6	0.4	8.6	3.6	204

	Dock A	14.3	6.9	37.3	30.4	7.8	-	7
	Dock B	13.3	7.4	36.6	30.6	7.3	-	n.d.
	Dock C	13.6	7.5	36.9	30.6	7.3	-	n.d.
02/07/12	1	14.7	7.7	1.4	0.9	7.1	4.9	49
(wet season	2	13.4	7.8	1.5	1.0	7.5	4.6	6
during rain)	3	12.9	7.4	33.9	28.4	7.5	21.9	38
	4	12.1	8.4	0.3	0.2	8.6	10.7	23
	8	11.8	8.5	0.6	0.4	8.2	9.6	51
02/09/12	1	12.4	7.4	0.9	0.6	7.3	2.1	28
(wet season	2	10.7	7.7	1.0	0.7	8.8	6.7	61
post-rain)	3	10.3	7.3	33.4	30.0	7.7	52.0	107
	4	9.3	7.9	0.3	0.2	8.7	11.7	10
	8	9.7	8.0	0.5	0.3	8.9	12.9	12
07/09/12	1	18.5	7.0	0.7	0.5	5.8	-	16
(dry season)	2	15.0	7.4	2.1	1.5	9.3	-	10
	3	14.0	7.5	37.6	31.9	8.8	-	81
	4	13.6	7.7	0.2	0.1	10.6	-	n.d.
	8	13.3	7.8	0.4	0.2	11.2	-	11
10/21/12	1	18.7	7.6	0.9	0.5	7.0	8.1	8
(first flush	3	17.1	7.8	42.6	32.8	9.7	5.5	15
pre-rain)	4	15.3	8.0	0.2	0.1	10.2	5.0	n.d.
	2B	14.2	7.4	0.5	0.3	8.4	81.3	113
	DR4	14.8	8.2	0.4	0.2	10.2	6.6	33
10/22/12	1	14.4	8.5	0.1	0.1	9.9	18.1	11
(first flush	3	13.9	7.7	30.2	24.2	9.1	23.9	38
during rain)	4	13.9	7.7	0.2	0.1	10.1	22.6	48
	1B	-	6.6	0.0	0.1	7.7	300	530
	2B	-	7.0	0.2	0.2	5.5	236	273
	DR4	-	7.3	0.2	0.2	10.5	74.7	128
10/29/12	1	18.4	3.0	0.9	0.5	4.1	9.7	7
(first flush	2	15.3	9.3	6.6	4.2	6.8	6.5	71
post-rain)	3	16.7	7.8	47.7	36.2	5.3	80.0	167
	4	13.8	8.0	0.3	0.2	10.2	5.0	7
	8	14.6	9.3	0.7	0.4	8.7	4.2	9
	2B	13.1	8.1	0.6	0.4	6.6	28.4	40
	DR4	13.8	8.0	0.5	0.3	7.9	12.3	21
12/17/12	1B	13.8	7.2	0.2	0.2	9.5	8.6	n.d.
(upstream)	2B	12.3	7.1	0.3	0.2	8.9	19.0	14
	DN3	11.6	7.9	0.2	0.1	10.9	45.1	32
	DN4	11.8	7.8	0.2	0.1	10.9	14.6	13
	DR4	12.6	8.1	0.3	0.2	11.0	46.6	61
	DR6	12.3	7.6	0.3	0.2	10.8	44.9	53

<sup>A</sup> - Not analyzed

<sup>B</sup> Conductivity

<sup>C</sup> Dissolved oxygen

<sup>D</sup> Total suspended solids

<sup>E</sup> n.d. not detected. Laboratory limit of detection of TSS was 5 mg/l.

**Appendix B: FIB concentrations**

**Appendix B1 *E. coli* concentrations at Capistrano Beach and the four inflows in 2008 and 2011-2012**

(Unit: MPN/100 ml)

Date	Site	PPH-1	PPH-2	PPH-3	PPH-4	PPH-8
02/07/08		<10 <sup>A</sup>	52	10	20	110
03/11/08		10	199	31	- <sup>C</sup>	-
03/25/08		<10	132	86	-	-
04/08/08		30	395	52	-	-
04/22/08		<10	41	20	-	-
05/16/08		<10	318	10	-	-
06/03/08		<10	171	10	-	-
06/17/08		20	1842	31	-	-
07/01/08		278	480	495	-	-
07/15/08		121	41	<10	-	-
07/29/08		313	74	63	173	-
08/12/08		31	171	85	-	-
04/06/11		<10	75	75	63	-
04/07/11		10	246	-	31	-
04/08/11		<10	309	20	20	-
04/20/11		30	432	529	20	-
05/04/11		350	63	97	-	-
05/18/11		243	4611	98	-	-
06/01/11		134	2098	160	-	-
06/15/11		63	1334	41	-	-
06/29/11		703	1785	359	-	-
07/06/11		31	1860	30	52	292
07/13/11		3654	-	1664	650	-
07/27/11		52	906	41	-	-
08/10/11		52	417	52	-	-
08/24/11		20	6131	41	318	1100
09/07/11		2723	5475	20	-	-
09/21/11		86	759	31	-	-
10/03/11		323	1658	203	110	2359
10/05/11		>24196 <sup>B</sup>	>24196	17329	17329	>24196
10/07/11		2723	5475	512	187	3784
10/20/11		959	24196	305	2248	-
11/03/11		52	11199	201	-	1112
11/16/11		20	-	933	-	2595
12/01/11		63	24196	20	-	5475
12/15/11		909	24196	328	-	663
12/29/11		10	17329	20	-	1119
01/12/12		63	4352	86	-	63
01/26/12		10	1467	132	-	1553
02/06/12		529	1483	96	10	556

02/07/12	31	4611	249	85	14136
02/09/12	10	1017	63	63	4884
02/23/12	41	780	20	10	336
03/08/12	1017	878	455	41	2359
03/22/12	<10	638	75	52	479
04/05/12	<10	97	813	30	624
04/18/12	75	187	1126	932	305
05/10/12	156	388	97	98	1019
05/17/12	20	355	10	31	5172
05/24/12	10	771	457	86	1607
05/31/12	134	4352	73	233	2014
06/07/12	20	14136	241	389	2359
06/14/12	20	24196	52	359	712
06/21/12	156	17329	-	134	5475
06/28/12	181	17329	-	657	670
07/05/12	173	12997	-	512	428
07/09/12	4884	>24196	84	364	15531
07/12/12	602	17329	-	426	3448
07/19/12	20	9804	-	161	24196
07/26/12	110	6867	-	206	11199
08/02/12	<10	2909	-	529	15531
08/09/12	393	4106	199	813	3076
08/16/12	52	8664	1050	345	1223
08/23/12	63	24196	31	364	1789
08/30/12	161	1793	187	98	457
09/06/12	243	11199	2613	663	3076
09/13/12	97	>24196	<10	148	1054
09/20/12	1296	7701	86	462	24196
09/27/12	86	15531	350	135	2104
10/04/12	435	>24196	144	428	262
10/11/12	3873	19863	-	262	211
10/18/12	10	9804	122	15531	327
10/21/12	548	-	-	148	-
10/22/12	>24196	-	-	3076	-
10/29/12	>24196	6488	341	231	2187
11/05/12	15531	-	299	63	-
11/13/12	5475	24196	4160	122	712
11/19/12	4352	2603	285	63	-
11/29/12	6488	3255	246	41	1211
12/03/12	24196	5475	388	504	327
12/10/12	>24196	1291	645	63	175

<sup>A</sup> Lower limit of detection, 10 MPN/100 ml

<sup>B</sup> Upper limit of detection, 24196 MPN/100 ml

<sup>C</sup> - Not analyzed

**Appendix B2 *Enterococcus* concentrations at Capistrano Beach and the four inflows in 2008 and 2011-2012**

(Unit: MPN/100 ml)

Date	Site	PPH-1	PPH-2	PPH-3	PPH-4	PPH-8
02/07/08		<10 <sup>A</sup>	20	10	31	31
03/11/08		42	75	64	- <sup>C</sup>	-
03/25/08		42	99	10	-	-
04/08/08		20	10	<10	-	-
04/22/08		613	96	<10	-	-
05/16/08		84	63	10	-	-
06/03/08		199	275	10	-	-
06/17/08		839	609	10	-	-
07/01/08		959	472	2481	-	-
07/15/08		3076	63	31	-	-
07/29/08		435	<10	20	173	-
08/12/08		135	109	<10	-	-
04/06/11		10	20	20	<10 <sup>A</sup>	-
04/07/11		20	41	-	20	-
04/08/11		2419	31	20	<10	-
04/20/11		10	888	74	20	-
05/04/11		657	121	63	-	-
05/18/11		627	1160	51	-	-
06/01/11		420	269	10	-	-
06/15/11		52	31	173	-	-
06/29/11		605	743	75	-	-
07/06/11		259	75	20	63	175
07/13/11		17329	-	3076	1054	-
07/27/11		41	135	<10	-	-
08/10/11		193	41	20	-	-
08/24/11		74	1597	10	84	1376
09/07/11		3873	41	10	-	-
09/21/11		820	52	<10	-	-
10/03/11		4884	471	10	144	11199
10/05/11		19863	>24196 <sup>B</sup>	24196	24196	>24196
10/07/11		15531	3076	520	158	3448
10/20/11		598	106	61	3873	-
11/03/11		241	231	74	-	1918
11/16/11		1046	-	74	-	3255
12/01/11		98	282	<10	-	1396
12/15/11		285	379	134	-	3255
12/29/11		41	110	<10	-	496
01/12/12		221	41	52	-	169
01/26/12		20	135	337	-	4884
02/06/12		454	3130	52	107	1178
02/07/12		52	691	241	31	1439
02/09/12		62	1374	52	41	9804

02/23/12	97	169	108	41	3654
03/08/12	161	137	771	20	2489
03/22/12	73	171	109	31	789
04/05/12	<10	31	738	10	235
04/18/12	75	187	1126	932	305
05/10/12	670	95	359	20	598
05/17/12	241	384	10	41	4352
05/24/12	4611	72	120	75	3873
05/31/12	813	464	97	135	3076
06/07/12	265	497	327	145	2247
06/14/12	120	4884	30	110	1664
06/21/12	417	788	-	341	5172
06/28/12	305	560	-	119	959
07/05/12	275	1010	-	384	2755
07/09/12	24196	109	<10	282	24196
07/12/12	146	211	-	189	1576
07/19/12	75	594	-	109	19863
07/26/12	97	318	-	121	24196
08/02/12	31	131	-	259	>24196
08/09/12	121	396	109	1145	9208
08/16/12	-	301	85	324	7270
08/23/12	213	145	10	183	9208
08/30/12	279	318	<10	259	5172
09/06/12	414	350	31	320	4106
09/13/12	2909	638	31	169	1354
09/20/12	697	200	<10	298	4352
09/27/12	160	315	109	211	481
10/04/12	4884	738	31	420	657
10/11/12	262	189	-	168	195
10/18/12	<10	417	41	650	2400
10/21/12	1223	-	-	364	-
10/22/12	>24196	-	-	1723	-
10/29/12	>24196	19863	683	148	7270
11/05/12	2014	-	98	134	-
11/13/12	1679	2495	1274	75	7270
11/19/12	6488	160	52	52	-
11/29/12	1535	899	74	20	1674
12/03/12	>24196	336	384	738	645
12/10/12	>24196	96	712	41	644

<sup>A</sup> Lower limit of detection, 10 MPN/100 ml

<sup>B</sup> Upper limit of detection, 24196 MPN/100 ml

<sup>C</sup> - Not analyzed

**Appendix B3 *E. coli* concentrations at upstream sites in 2012**

(Unit: MPN/100 ml)

Site Date	PPH-1B	PPH-2B	PPH-DN2	PPH-DN3	PPH-DR4
05/10/12	667	<10 <sup>B</sup>	110	199	168
05/17/12	10	<10	52	41	161
05/24/12	388	41	135	262	706
05/31/12	657	<10	262	388	201
06/07/12	836	41	249	420	1354
06/14/12	213	31	238	275	932
06/21/12	1046	<10	86	146	1553
06/28/12	- <sup>A</sup>	10	1178	637	345
07/05/12	41	63	906	173	281
07/09/12	-	-	-	-	-
07/12/12	110	1076	187	228	1112
07/19/12	-	86	41	63	>24196 <sup>C</sup>
07/26/12	-	122	144	-	5794
08/02/12	-	345	738	122	2098
08/09/12	-	-	443	213	1793
08/16/12	-	-	171	213	1198
08/23/12	-	-	262	379	1296
08/30/12	-	-	63	74	670
09/06/12	-	7270	1236	833	2282
09/13/12	-	2495	-	-	1112
09/20/12	-	3448	307	223	1553
09/27/12	-	1515	98	63	420
10/04/12	-	279	650	743	620
10/11/12	-	450	432	173	456
10/18/12	-	355	4611	3255	744
10/21/12	-	816	-	-	384
10/22/12	19863	4611	-	-	2310
10/29/12	-	52	132	134	457
11/05/12	-	134	41	63	613
11/13/12	-	134	121	63	537
11/19/12	-	98	85	20	487
11/29/12	-	52	30	96	816
12/03/12	10462	75	122	145	135
12/10/12	20	10	62	85	565
12/17/12	988	259	-	203	959

<sup>A</sup> - Not analyzed

<sup>B</sup> Lower limit of detection, 10 MPN/100 ml

<sup>C</sup> Upper limit of detection, 24196 MPN/100 ml

**Appendix B4 *Enterococcus* concentrations at upstream sites in 2012**

(Unit: MPN/100 ml)

Site Date	PPH-1B	PPH-2B	PPH-DN2	PPH-DN3	PPH-DR4
05/10/12	10	10	41	31	315
05/17/12	122	<10 <sup>C</sup>	20	<10	209
05/24/12	52	10	243	422	1246
05/31/12	934	98	85	121	676
06/07/12	657	30	122	109	985
06/14/12	85	20	122	86	728
06/21/12	402	41	282	226	677
06/28/12	- <sup>A</sup>	20	109	119	591
07/05/12	98	4352	292	161	373
07/09/12	-	-	-	-	-
07/12/12	41	7270	315	160	465
07/19/12	-	9208	160	189	1119
07/26/12	-	1243	63	-	11199
08/02/12	-	145	189	134	6867
08/09/12	-	-	74	108	1585
08/16/12	-	-	187	281	3873
08/23/12	-	-	185	132	1785
08/30/12	-	-	109	173	5172
09/06/12	-	6867	602	328	1576
09/13/12	-	339	-	-	1333
09/20/12	-	4106	199	158	2755
09/27/12	-	3076	256	86	504
10/04/12	-	279	402	288	620
10/11/12	-	199	185	146	456
10/18/12	-	185	246	110	744
10/21/12	-	496	-	-	384
10/22/12	>24196 <sup>B</sup>	12033	-	-	2310
10/29/12	-	173	122	121	457
11/05/12	-	85	10	75	613
11/13/12	-	52	31	10	537
11/19/12	-	52	41	63	487
11/29/12	-	41	31	20	816
12/03/12	19863	75	110	97	135
12/10/12	148	<10	41	20	565
12/17/12	3255	279	-	355	1054

<sup>A</sup> - Not analyzed

<sup>B</sup> Upper limit of detection, 24196 MPN/100 ml

<sup>C</sup> Lower limit of detection, 10 MPN/100 ml

**Appendix C: Concentrations and sample limits of detection of *Bacteroidales***

**Appendix C1 Model adjusted *Bacteroidales* concentrations in water in 2008**

(Unit: gene copies/ml)

Date	Sample	Universal <i>Bacteroidales</i>		Human <i>Bacteroidales</i>		Bovine <i>Bacteroidales</i>		Dog <i>Bacteroidales</i>	
		Concn <sup>A</sup>	S <sub>LOD</sub> <sup>B</sup>	Concn	S <sub>LOD</sub>	Concn	S <sub>LOD</sub>	Concn	S <sub>LOD</sub>
02/07/08	PPH-1	402.0	0.3	15.0	0.6	n.d.	0.6	n.d.	0.1
	PPH-2	21.3	0.3	16.2	0.5	n.d.	0.6	n.d.	0.1
	PPH-3	157.3	1.1	49.2	1.9	n.d.	2.1	n.d.	0.3
	PPH-4	44.7	0.3	n.d. <sup>C</sup>	0.6	n.d.	0.6	n.d.	0.1
	PPH-5	854.2	1.0	48.0	1.7	n.d.	1.8	327.1	0.3
	PPH-6	1185.2	2.7	n.d.	4.6	n.d.	4.9	118.5	0.7
	PPH-7	428.6	3.1	195.2	5.4	n.d.	5.8	n.d.	0.9
	PPH-8	57.8	0.4	n.d.	0.7	n.d.	0.7	n.d.	0.1
	PPH-9	116.0	0.4	11.4	0.6	n.d.	0.7	n.d.	0.1
	PPH-10	227.1	1.1	18.0	1.9	n.d.	2.1	n.d.	0.3
07/29/08	PPH-1	1494.6	0.2	n.d.	0.4	n.d.	0.4	n.d.	0.1
	PPH-2	23169.6	1.1	n.d.	1.9	n.d.	2.1	111.1	0.3
	PPH-3	910.5	1.8	n.d.	3.1	n.d.	3.3	224.4	0.5
	PPH-4	633.4	0.3	1.6	0.5	n.d.	0.5	6.4	0.1
	PPH-5	4726.3	1.2	61.3	2.0	n.d.	2.2	n.d.	0.3
	PPH-6	206.3	2.0	74.4	3.4	n.d.	3.6	n.d.	0.5
	PPH-7	86.8	1.2	64.9	2.0	n.d.	2.2	n.d.	0.3
	PPH-8	2896.2	0.5	3.8	0.8	1138.9	0.8	109.7	0.1
	PPH-9	91.0	0.6	n.d.	1.0	n.d.	1.1	n.d.	0.2
	PPH-10	479.0	0.8	56.2	1.4	n.d.	1.5	n.d.	0.2
10/03/08	PPH-1	23029.2	3.1	n.d.	5.4	n.d.	5.8	n.d.	0.9
	PPH-2	99165.1	0.2	n.d.	0.4	n.d.	0.4	n.d.	0.1
	PPH-3	3544.0	2.7	n.d.	4.7	n.d.	5.0	n.d.	0.7
	PPH-4	132.7	0.2	n.d.	0.3	n.d.	0.4	n.d.	0.1
	PPH-5	150.6	1.3	n.d.	2.2	n.d.	2.3	3.8	0.4
	PPH-6	45.6	1.0	11.2	1.8	n.d.	1.9	n.d.	0.3
	PPH-7	1380.2	2.8	n.d.	4.8	6.3	5.1	1380.2	0.8
	PPH-8	576.1	1.0	n.d.	1.7	n.d.	1.9	n.d.	0.3
	PPH-9	201.6	1.2	n.d.	2.0	n.d.	2.2	n.d.	0.3
	PPH-10	32.8	1.3	n.d.	2.2	n.d.	2.4	n.d.	0.4
10/03/08	PPH-1	3221.4	2.6	n.d.	4.5	n.d.	4.8	n.d.	0.7
	PPH-2	32832.5	2.4	n.d.	4.2	n.d.	4.5	n.d.	0.7
	PPH-3	20785.5	NA <sup>D</sup>	15.4	NA	n.d.	NA	n.d.	NA
	PPH-4	6441.0	1.5	n.d.	2.5	n.d.	2.7	n.d.	0.4
	PPH-5	452.4	1.8	167.9	3.1	n.d.	3.3	31.6	0.5
	PPH-6	1652.8	0.7	n.d.	1.3	n.d.	1.4	n.d.	0.2
	PPH-7	1064.2	2.9	n.d.	5.0	n.d.	5.4	136.1	0.8
	PPH-8	2576.1	NA	n.d.	NA	357.0	NA	n.d.	NA
	PPH-9	217.5	1.7	59.6	2.9	n.d.	3.1	27.9	0.5
	PPH-10	137.8	1.5	n.d.	2.5	n.d.	2.7	n.d.	0.4

10/03/08	PPH-1	20522.0	1.9	n.d.	3.3	n.d.	3.5	n.d.	0.5
	PPH-2	2205.1	0.9	7.4	1.5	n.d.	1.6	n.d.	0.2
	PPH-3	649.0	1.7	40.4	2.9	n.d.	3.1	n.d.	0.5
	PPH-4	555.1	0.2	n.d.	0.4	n.d.	0.4	n.d.	0.1
	PPH-5	204.4	2.1	n.d.	3.6	n.d.	3.9	n.d.	0.6
	PPH-6	230.5	1.3	29.0	2.2	n.d.	2.4	129.4	0.4
	PPH-7	118.2	1.4	14.3	2.4	n.d.	2.5	n.d.	0.4
	PPH-8	5577.9	1.2	n.d.	2.0	3964.7	2.2	188.4	0.3
	PPH-9	20.3	1.7	n.d.	2.9	n.d.	3.1	n.d.	0.5
	PPH-10	106.4	1.1	14.4	1.8	n.d.	2.0	n.d.	0.3

<sup>A</sup> Concentration

<sup>B</sup> Sample limit of detection

<sup>C</sup> n.d. not detected.

**Appendix C2 Model adjusted *Bacteroidales* concentrations in water in 2011**

(Unit: gene copies/ml)

Date	Sample	Universal		Human		Bovine		Dog	
		<i>Bacteroidales</i>		<i>Bacteroidales</i>		<i>Bacteroidales</i>		<i>Bacteroidales</i>	
		Concn <sup>A</sup>	S <sub>LOD</sub> <sup>B</sup>	Concn	S <sub>LOD</sub>	Concn	S <sub>LOD</sub>	Concn	S <sub>LOD</sub>
03/19/11	PPH-1	9176.4	5.1	n.d. <sup>C</sup>	3.2	n.d.	3.2	n.d.	5.5
	PPH-2	6822.3	8.5	n.d.	5.3	17.2	5.3	6822.3	9.1
	PPH-4	2796.3	17.6	n.d.	11.0	n.d.	11.0	619.5	18.9
	PPH-8	602.6	6.8	n.d.	4.2	n.d.	4.2	n.d.	7.3
03/29/11	PPH-1	14.3	1.5	n.d.	0.9	n.d.	0.9	n.d.	1.6
	PPH-2	20.3	2.2	n.d.	1.4	n.d.	1.4	n.d.	2.4
	PPH-3	87.7	3.8	n.d.	2.4	n.d.	2.4	n.d.	4.1
	PPH-4	206.7	13.6	n.d.	8.5	n.d.	8.5	n.d.	14.6
	PPH-5	433.7	8.9	n.d.	5.5	n.d.	5.5	n.d.	9.5
	PPH-6	64.6	2.1	n.d.	1.3	n.d.	1.3	n.d.	2.3
	PPH-7	59.5	3.4	n.d.	2.1	n.d.	2.1	n.d.	3.6
	PPH-9	30.6	1.3	n.d.	0.8	n.d.	0.8	n.d.	1.4
	PPH-10	49.8	1.6	n.d.	1.0	n.d.	1.0	n.d.	1.7
	04/06/11	PPH-1	783.7	2.6	n.d.	1.6	n.d.	1.6	n.d.
PPH-2		535.5	10.5	n.d.	6.6	n.d.	6.6	535.5	11.3
PPH-3		215.9	6.6	n.d.	4.1	n.d.	4.1	n.d.	7.1
PPH-4		1118.8	9.9	n.d.	6.2	n.d.	6.2	n.d.	10.7
PPH-5		345.3	7.4	n.d.	4.6	n.d.	4.6	345.3	8.0
PPH-6		156.5	5.2	n.d.	3.2	n.d.	3.2	n.d.	5.6
PPH-7		604.9	9.3	n.d.	5.8	n.d.	5.8	n.d.	9.9
PPH-9		344.3	5.2	n.d.	3.3	n.d.	3.3	n.d.	5.6
PPH-10		224.6	6.7	n.d.	4.2	n.d.	4.2	n.d.	7.2
04/07/11		PPH-1	5607.0	4.4	n.d.	2.7	n.d.	2.7	n.d.
	PPH-2	5124.7	7.7	6.1	4.8	n.d.	4.8	n.d.	8.2
	PPH-4	4968.6	13.4	n.d.	8.3	n.d.	8.3	n.d.	14.4
04/08/11	PPH-1	11319.3	7.2	n.d.	4.5	n.d.	4.5	n.d.	7.7
	PPH-2	12582.9	3.6	n.d.	2.3	n.d.	2.3	n.d.	3.9
	PPH-3	289.8	1.4	n.d.	0.9	n.d.	0.9	n.d.	1.5
	PPH-4	3551.5	2.8	n.d.	1.8	n.d.	1.8	n.d.	3.0
	PPH-5	563.1	1.6	n.d.	1.0	n.d.	1.0	n.d.	1.7
	PPH-6	3032.8	8.2	n.d.	5.1	n.d.	5.1	580.8	8.8
	PPH-7	619.3	4.1	n.d.	2.6	n.d.	2.6	n.d.	4.4
	PPH-9	825.1	5.6	n.d.	3.5	n.d.	3.5	n.d.	6.0
	PPH-10	287.1	4.9	n.d.	3.0	n.d.	3.0	n.d.	5.2
	07/06/11	PPH-1	131.4	5.7	n.d.	3.6	n.d.	3.6	n.d.
PPH-2		2738.0	1.3	n.d.	0.8	n.d.	0.8	n.d.	1.4
PPH-3		66.0	2.0	n.d.	1.3	n.d.	1.3	n.d.	2.2
PPH-4		95.9	1.5	n.d.	0.9	n.d.	0.9	n.d.	1.6
PPH-5		54.0	2.4	n.d.	1.5	n.d.	1.5	n.d.	2.6
PPH-6		58.3	1.7	n.d.	1.1	n.d.	1.1	7.8	1.9
PPH-7		55.5	2.4	n.d.	1.5	n.d.	1.5	n.d.	2.6

10/03/11	PPH-8	427.9	1.7	n.d.	1.1	427.9	1.1	n.d.	1.8
	PPH-9	79.4	1.5	n.d.	0.9	n.d.	0.9	n.d.	1.6
	PPH-10	29.7	1.7	n.d.	1.1	n.d.	1.1	n.d.	1.8
	PPH-1	18589.4	2.8	n.d.	1.7	n.d.	1.7	n.d.	3.0
	PPH-2	9230.0	2.1	n.d.	1.3	n.d.	1.3	n.d.	2.3
	PPH-3	1138.8	1.8	n.d.	1.1	n.d.	1.1	n.d.	1.9
	PPH-4	5711.9	7.3	n.d.	4.5	n.d.	4.5	n.d.	7.8
	PPH-5	119.7	2.4	n.d.	1.5	n.d.	1.5	n.d.	2.6
	PPH-6	95.8	2.0	n.d.	1.3	n.d.	1.3	n.d.	2.2
	PPH-7	60.0	2.4	n.d.	1.5	n.d.	1.5	n.d.	2.5
10/05/11	PPH-8	15745.0	6.8	n.d.	4.2	5311.1	4.2	665.6	7.2
	PPH-9	296.8	1.4	n.d.	0.9	n.d.	0.9	n.d.	1.5
	PPH-10	485.2	3.8	n.d.	2.3	n.d.	2.3	n.d.	4.0
	PPH-1	1640.2	44.5	n.d.	27.8	n.d.	27.8	n.d.	47.7
	PPH-2	133783.2	3.7	n.d.	2.3	n.d.	2.3	37306.0	4.0
	PPH-3	6807.5	1.7	n.d.	1.0	n.d.	1.0	3545.2	1.8
	PPH-4	13558.1	2.0	n.d.	1.2	n.d.	1.2	7805.2	2.1
	PPH-5	1368.3	13.0	n.d.	8.1	n.d.	8.1	n.d.	14.0
	PPH-6	28752.6	13.0	n.d.	8.1	n.d.	8.1	n.d.	14.0
	PPH-7	226.1	0.9	n.d.	0.5	n.d.	0.5	n.d.	0.9
10/07/11	PPH-8	30873.0	11.6	n.d.	7.3	814.2	7.3	29455.3	12.5
	PPH-9	2655.8	4.3	n.d.	2.7	n.d.	2.7	n.d.	4.6
	PPH-10	3166.9	8.9	n.d.	5.5	n.d.	5.5	n.d.	9.5
	PPH-1	893.4	4.8	n.d.	3.0	n.d.	3.0	n.d.	5.1
	PPH-2	6975.0	4.7	n.d.	2.9	n.d.	2.9	1676.3	5.0
	PPH-3	802.2	2.5	n.d.	1.5	n.d.	1.5	n.d.	2.7
	PPH-4	4341.4	9.2	n.d.	5.7	n.d.	5.7	n.d.	9.8
	PPH-5	346.6	1.6	n.d.	1.0	n.d.	1.0	n.d.	1.7
	PPH-6	95.1	3.9	n.d.	2.4	n.d.	2.4	n.d.	4.1
	PPH-7	272.4	2.8	n.d.	1.8	n.d.	1.8	272.4	3.0
11/07/11	PPH-8	14438.4	6.0	n.d.	3.8	8.1	3.8	2382.8	6.5
	PPH-9	77.1	2.3	n.d.	1.4	n.d.	1.4	32.2	2.4
	PPH-10	97.3	1.5	n.d.	0.9	n.d.	0.9	n.d.	1.6
	OH 1	72.6	4.3	n.d.	2.7	n.d.	2.7	n.d.	4.6
	OH 2	131.8	7.5	n.d.	4.7	n.d.	4.7	n.d.	8.1
	OH 3	124.9	2.7	n.d.	1.7	n.d.	1.7	n.d.	2.9
	Pump	295.7	18.1	n.d.	11.3	n.d.	11.3	n.d.	19.4
	Dock A	190.7	14.7	25.2	9.2	n.d.	9.2	n.d.	15.8
	Dock B	158.9	3.5	5.5	2.2	n.d.	2.2	n.d.	3.8
	Dock C	789.9	1.3	17.0	0.8	n.d.	0.8	n.d.	1.4

<sup>A</sup> Concentration

<sup>B</sup> Sample limit of detection

<sup>C</sup> n.d. not detected.

**Appendix C3 Model adjusted *Bacteroidales* concentrations in water in 2012**

(Unit: gene copies/ml)

Date	Sample	Universal		Human		Bovine		Dog	
		<i>Bacteroidales</i>		<i>Bacteroidales</i>		<i>Bacteroidales</i>		<i>Bacteroidales</i>	
		Concn <sup>A</sup>	S <sub>LOD</sub> <sup>B</sup>	Concn	S <sub>LOD</sub>	Concn	S <sub>LOD</sub>	Concn	S <sub>LOD</sub>
02/06/12	PPH-1	2685.6	17.9	n.d. <sup>C</sup>	11.2	n.d.	11.2	1110.3	19.2
	PPH-2	31606.1	8.2	n.d.	5.1	161.1	5.1	11096.4	8.8
	PPH-3	123.2	3.8	n.d.	2.4	n.d.	2.4	56.9	4.1
	PPH-4	566.0	31.1	n.d.	19.4	n.d.	19.4	n.d.	33.3
	PPH-8	2079.1	17.6	n.d.	11.0	n.d.	11.0	314.7	18.9
	Dock A	55.7	2.8	n.d.	1.7	n.d.	1.7	n.d.	3.0
	Dock B	105.0	4.9	n.d.	3.1	n.d.	3.1	n.d.	5.3
	Dock C	96.2	1.7	n.d.	1.1	n.d.	1.1	n.d.	1.8
02/07/12	PPH-1	2141.1	28.5	n.d.	17.8	n.d.	17.8	n.d.	30.6
	PPH-2	4606.0	15.0	n.d.	9.4	n.d.	9.4	n.d.	16.1
	PPH-3	1767.2	2.5	2.0	1.6	n.d.	1.6	837.0	2.7
	PPH-4	228.8	23.3	n.d.	14.5	n.d.	14.5	n.d.	25.0
	PPH-8	4998.6	12.0	n.d.	7.5	13.5	7.5	1459.0	12.9
02/09/12	PPH-1	10747.3	35.2	n.d.	22.0	n.d.	22.0	n.d.	37.8
	PPH-2	3823.5	2.8	n.d.	1.8	n.d.	1.8	682.5	3.0
	PPH-3	39.9	4.4	n.d.	2.7	n.d.	2.7	n.d.	4.7
	PPH-4	704.6	13.3	n.d.	8.3	n.d.	8.3	n.d.	14.3
	PPH-8	3075.1	7.0	n.d.	4.3	n.d.	4.3	3075.1	7.5
07/09/12	PPH-1	28460.4	10.0	768.5	6.2	n.d.	6.2	8689.8	10.7
	PPH-2	17395.5	5.6	n.d.	3.5	n.d.	3.5	n.d.	6.0
	PPH-3	89.8	2.3	n.d.	1.4	n.d.	1.4	n.d.	2.5
	PPH-4	2054.9	4.7	n.d.	3.0	n.d.	3.0	697.8	5.1
	PPH-8	5009.9	4.3	n.d.	2.7	2893.8	2.7	n.d.	4.6
10/21/12	PPH-1	8882.8	2.6	n.d.	1.6	n.d.	1.6	n.d.	2.8
	PPH-3	8155.7	1.7	n.d.	1.0	n.d.	1.0	298.7	1.8
	PPH-4	566.6	3.6	n.d.	2.2	n.d.	2.2	n.d.	3.9
	PPH-2B	9530.1	6.0	n.d.	3.7	n.d.	3.7	2381.4	6.4
	PPH-DR4	2093.1	3.2	121.9	2.0	116.7	2.0	135.0	3.5
10/22/12	PPH-1	1574.2	29.6	n.d.	18.5	n.d.	18.5	1504.0	23.5
	PPH-3	5090.7	0.8	n.d.	0.5	n.d.	0.5	103.2	0.7
	PPH-4	652.5	4.7	n.d.	2.9	n.d.	2.9	n.d.	3.7
	PPH-1B	1722.5	8.2	n.d.	5.1	n.d.	5.1	394.3	6.5
	PPH-2B	7602.5	3.4	n.d.	2.1	n.d.	2.1	208.2	2.7
	PPH-DR4	19630.1	15.4	n.d.	9.6	3436.9	9.6	138.7	12.2
10/29/12	PPH-1	7901.3	3.4	n.d.	2.1	n.d.	2.1	4075.4	3.6
	PPH-2	48078.8	4.0	n.d.	2.5	n.d.	2.5	n.d.	4.3
	PPH-3	4674.8	2.5	n.d.	1.6	n.d.	1.6	n.d.	2.7
	PPH-4	348.4	1.8	3.2	1.1	n.d.	1.1	n.d.	1.9
	PPH-8	5876.6	5.7	n.d.	3.5	12.2	3.5	5876.6	6.1
	PPH-2B	220.0	3.7	n.d.	2.3	n.d.	2.3	n.d.	4.0
	PPH-DR4	4766.6	5.2	n.d.	3.2	29.3	3.2	4766.6	5.5

12/17/12	PPH-1B	6767.2	6.2	n.d.	2.8	n.d.	2.8	6068.3	3.5
	PPH-2B	1935.9	8.5	n.d.	3.8	n.d.	3.8	n.d.	4.8
	PPH-DN3	2327.3	5.5	n.d.	2.5	n.d.	2.5	n.d.	3.1
	PPH-DN4	3899.7	5.0	n.d.	2.2	n.d.	2.2	n.d.	2.8
	PPH-DR4	9640.7	7.7	n.d.	3.4	7971.7	3.4	1939.3	4.4
	PPH-DR6	6014.3	4.8	13.5	2.1	5517.1	2.1	496.6	2.7

<sup>A</sup> Concentration

<sup>B</sup> Sample limit of detection

<sup>C</sup> n.d. not detected.

**Appendix C4 Model adjusted *Bacteroidales* concentrations in sediments and biofilm in 2011 – 2012**

(Unit: gene copies/g of dry weight)

Date	Sample	Universal		Human		Bovine		Dog	
		<i>Bacteroidales</i>		<i>Bacteroidales</i>		<i>Bacteroidales</i>		<i>Bacteroidales</i>	
		Concn <sup>A</sup>	S <sub>LOD</sub> <sup>B</sup>	Concn	S <sub>LOD</sub>	Concn	S <sub>LOD</sub>	Concn	S <sub>LOD</sub>
08/24/11	1S	6660.1	85.0	n.d. <sup>C</sup>	53.0	n.d.	53.0	n.d.	91.1
	2S	20619.9	80.7	n.d.	50.3	n.d.	50.3	n.d.	86.5
	3S	5474.5	83.2	n.d.	51.9	n.d.	51.9	n.d.	89.2
	4S	2759.4	84.5	n.d.	52.7	n.d.	52.7	n.d.	90.5
	5S	6078.4	77.7	n.d.	48.5	n.d.	48.5	n.d.	83.3
	6S	2811.4	85.9	n.d.	53.6	n.d.	53.6	n.d.	92.1
	8S	14491.1	87.4	n.d.	54.5	n.d.	54.5	9853.3	93.6
	9S	1057.0	64.2	n.d.	40.0	n.d.	40.0	n.d.	68.8
	1B-1	15393.1	32.1	n.d.	20.0	n.d.	20.0	n.d.	34.4
	1B-2	21475.2	32.1	n.d.	20.0	n.d.	20.0	n.d.	34.4
	2B	77181.5	32.1	n.d.	20.0	n.d.	20.0	n.d.	34.4
	3B-1	7070.7	32.1	n.d.	20.0	n.d.	20.0	n.d.	34.4
	3B-2	25088.4	32.1	n.d.	20.0	n.d.	20.0	n.d.	34.4
	4B-1	31457.9	32.1	n.d.	20.0	n.d.	20.0	n.d.	34.4
	4B-2	37622.2	32.1	n.d.	20.0	n.d.	20.0	n.d.	34.4
	5B-1	13900.2	32.1	n.d.	20.0	n.d.	20.0	n.d.	34.4
	5B-2	53963.4	32.1	n.d.	20.0	n.d.	20.0	n.d.	34.4
	6B-1	6909.1	32.1	n.d.	20.0	n.d.	20.0	n.d.	34.4
	6B-2	36625.4	32.1	n.d.	20.0	n.d.	20.0	n.d.	34.4
	02/06/12	1S	8549.5	63.7	n.d.	39.7	n.d.	39.7	n.d.
2S		4189.0	12.1	n.d.	7.6	n.d.	7.6	1461.2	13.0
3S		809.3	64.2	n.d.	40.0	n.d.	40.0	n.d.	68.8
4S		77.2	20.8	n.d.	13.0	n.d.	13.0	n.d.	22.3
8S		172.7	63.6	n.d.	39.6	n.d.	39.6	n.d.	68.2
2B		543592.2	388.3	n.d.	242.1	n.d.	242.1	131728.4	416.3
4B		9404.4	364.2	n.d.	227.0	n.d.	227.0	n.d.	390.4
02/07/12	1S	826.2	21.2	n.d.	13.2	n.d.	13.2	n.d.	22.8
	2S	4257.5	60.6	n.d.	37.8	n.d.	37.8	n.d.	64.9
	3S	242.2	21.4	n.d.	13.3	n.d.	13.3	n.d.	22.9
	4S	204.3	20.8	n.d.	13.0	n.d.	13.0	n.d.	22.3
	8S	494.5	21.2	n.d.	13.2	n.d.	13.2	99.3	22.7
	2B	1661.4	258.8	n.d.	161.4	n.d.	161.4	n.d.	277.5
	4B	8155.6	485.6	n.d.	302.7	n.d.	302.7	n.d.	520.6
02/09/12	1S	1405.9	21.2	n.d.	13.2	n.d.	13.2	n.d.	22.8
	2S	1341.2	60.6	n.d.	37.8	n.d.	37.8	n.d.	64.9
	3S	191.5	21.4	n.d.	13.3	n.d.	13.3	n.d.	22.9
	4S	170.6	62.5	n.d.	38.9	n.d.	38.9	n.d.	67.0
	8S	120.1	21.2	n.d.	13.2	n.d.	13.2	n.d.	22.7
	2B	5030.5	258.8	n.d.	161.4	n.d.	161.4	n.d.	277.5
	4B	3953.5	485.6	n.d.	302.7	n.d.	302.7	n.d.	520.6

07/09/12	1S	319555.6	10.5	756.4	6.6	n.d.	6.6	45.2	11.3
	2S	442828.9	10.8	n.d.	6.7	n.d.	6.7	n.d.	11.5
	3S	3316.7	10.3	n.d.	6.4	n.d.	6.4	592.1	11.1
	4S	1665.5	10.2	n.d.	6.4	n.d.	6.4	n.d.	11.0
	8S	1353.8	10.3	n.d.	6.4	n.d.	6.4	n.d.	11.0
	2B	79346.8	28.0	n.d.	17.5	n.d.	17.5	n.d.	30.0
	4B	75016.8	86.8	n.d.	54.1	n.d.	54.1	22351.2	93.1

<sup>A</sup> Concentration

<sup>B</sup> Sample limit of detection

<sup>C</sup> n.d. not detected.

**Appendix C5 Model adjusted and measured *Bacteroidales* concentrations in water**

(Unit: gene copies/ml)

Date	Sample	Universal <i>Bacteroidales</i>	Human <i>Bacteroidales</i>		Bovine <i>Bacteroidales</i>		Dog <i>Bacteroidales</i>	
			Model <sup>A</sup>	Raw <sup>B</sup>	Model	Raw	Model	Raw
02/07/08	PPH-1	402.0	15.0	15.8	n.d.	n.d.	n.d.	n.d.
	PPH-2	21.3	16.2	16.0	n.d.	n.d.	n.d.	n.d.
	PPH-3*	157.3	49.2	48.9	n.d.	n.d.	n.d.	n.d.
	PPH-4	44.7	n.d. <sup>C</sup>	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-5	854.2	48.0	51.3	n.d.	n.d.	327.1	21.6
	PPH-6	1185.2	n.d.	n.d.	n.d.	n.d.	118.5	7.9
	PPH-7	428.6	195.2	193.2	n.d.	n.d.	n.d.	n.d.
	PPH-8	57.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-9	116.0	11.4	11.5	n.d.	n.d.	n.d.	n.d.
	PPH-10	227.1	18.0	18.2	n.d.	n.d.	n.d.	n.d.
07/29/08	PPH-1	1494.6	n.d.	2.2	n.d.	n.d.	n.d.	n.d.
	PPH-2	23169.6	n.d.	23.0	n.d.	n.d.	111.1	8.3
	PPH-3	910.5	n.d.	n.d.	n.d.	n.d.	224.4	14.8
	PPH-4	633.4	1.6	3.1	n.d.	n.d.	6.4	0.4
	PPH-5	4726.3	61.3	71.3	n.d.	n.d.	n.d.	n.d.
	PPH-6	206.3	74.4	73.7	n.d.	n.d.	n.d.	n.d.
	PPH-7	86.8	64.9	64.0	n.d.	n.d.	n.d.	n.d.
	PPH-8	2896.2	3.8	8.6	1138.9	63.9	109.7	7.4
	PPH-9	91.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-10	479.0	56.2	56.5	n.d.	n.d.	n.d.	n.d.
10/03/08	PPH-1	23029.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-2	99165.1	n.d.	4.5	n.d.	n.d.	n.d.	n.d.
	PPH-3	3544.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-4	132.7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-5	150.6	n.d.	n.d.	n.d.	n.d.	57.9	3.8
	PPH-6	45.6	11.2	11.2	n.d.	n.d.	n.d.	n.d.
	PPH-7	1380.2	n.d.	n.d.	6.3	n.d.	1380.2	159.7
	PPH-8	576.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-9	201.6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-10	32.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
10/03/08	PPH-1	3221.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-2	32832.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-3	20785.5	15.4	63.8	n.d.	n.d.	n.d.	n.d.
	PPH-4	6441.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-5	452.4	167.9	167.2	n.d.	n.d.	31.6	2.2
	PPH-6	1652.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-7	1064.2	n.d.	n.d.	n.d.	n.d.	136.1	9.0
	PPH-8*	2576.1	n.d.	n.d.	357.0	357.0	n.d.	n.d.
	PPH-9*	217.5	59.6	59.6	n.d.	n.d.	27.9	27.9
	PPH-10	137.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
10/03/08	PPH-1	20522.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

	PPH-2	2205.1	7.4	12.5	n.d.	n.d.	n.d.	n.d.
	PPH-3	649.0	40.4	41.4	n.d.	n.d.	n.d.	n.d.
	PPH-4	555.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-5	204.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-6	230.5	29.0	29.9	n.d.	n.d.	129.4	8.6
	PPH-7	118.2	14.3	14.3	n.d.	n.d.	n.d.	n.d.
	PPH-8	5577.9	n.d.	n.d.	3964.7	217.1	188.4	12.7
	PPH-9	20.3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-10	106.4	14.4	14.5	n.d.	n.d.	n.d.	n.d.
03/19/11	PPH-1	9176.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-2	6822.3	n.d.	n.d.	17.2	n.d.	6822.3	634.2
	PPH-4*	2796.3	n.d.	n.d.	n.d.	n.d.	619.5	619.5
	PPH-8	602.6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
03/29/11	PPH-1	14.3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-2	20.3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-3	87.7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-4	206.7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-5	433.7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-6	64.6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-7	59.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-9	30.6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-10	49.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/06/11	PPH-1	783.7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-2	535.5	n.d.	n.d.	n.d.	n.d.	535.5	64.3
	PPH-3	215.9	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-4	1118.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-5	345.3	n.d.	n.d.	n.d.	n.d.	345.3	42.5
	PPH-6	156.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-7	604.9	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-9	344.3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-10	224.6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/07/11	PPH-1	5607.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-2	5124.7	6.1	18.1	n.d.	n.d.	n.d.	n.d.
	PPH-4	4968.6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/08/11	PPH-1	11319.3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-2	12582.9	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-3	289.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-4	3551.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-5	563.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-6*	3032.8	n.d.	n.d.	n.d.	n.d.	580.8	580.8
	PPH-7	619.3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-9	825.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-10	287.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/06/11	PPH-1	131.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-2	2738.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-3	66.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-4	95.9	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-5	54.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

	PPH-6*	58.3	n.d.	n.d.	n.d.	n.d.	7.8	7.8
	PPH-7	55.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-8	427.9	n.d.	n.d.	427.9	35.4	n.d.	n.d.
	PPH-9	79.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-10	29.7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
10/03/11	PPH-1	18589.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-2	9230.0	n.d.	1.4	n.d.	n.d.	n.d.	n.d.
	PPH-3	1138.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-4	5711.9	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-5	119.7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-6	95.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-7	60.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-8	15745.0	n.d.	n.d.	5311.1	294.3	665.6	44.5
	PPH-9	296.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-10	485.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
10/05/11	PPH-1	1640.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-2	133783.2	n.d.	5.8	n.d.	n.d.	37306.0	2452.4
	PPH-3	6807.5	n.d.	n.d.	n.d.	n.d.	3545.2	232.5
	PPH-4	13558.1	n.d.	n.d.	n.d.	n.d.	7805.2	512.5
	PPH-5	1368.3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-6	28752.6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-7	226.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-8	30873.0	n.d.	n.d.	814.2	45.0	29455.3	1938.7
	PPH-9	2655.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-10	3166.9	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
10/07/11	PPH-1	893.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-2	6975.0	n.d.	8.0	n.d.	n.d.	1676.3	110.3
	PPH-3	802.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-4	4341.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-5	346.6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-6	95.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-7	272.4	n.d.	2.7	n.d.	n.d.	272.4	31.0
	PPH-8*	14438.4	n.d.	n.d.	8.1	8.1	2382.8	2382.8
	PPH-9*	77.1	n.d.	n.d.	n.d.	n.d.	32.2	32.2
	PPH-10	97.3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
11/07/11	OH1	72.6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	OH2	131.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	OH3	124.9	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	Pump	295.7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	Dock A	190.7	25.2	25.2	n.d.	n.d.	n.d.	n.d.
	Dock B	158.9	5.5	5.8	n.d.	n.d.	n.d.	n.d.
	Dock C	789.9	17.0	18.7	n.d.	n.d.	n.d.	n.d.
02/06/12	PPH-1	2685.6	n.d.	n.d.	n.d.	n.d.	1110.3	72.5
	PPH-2	31606.1	n.d.	116.2	161.1	15.9	11096.4	734.1
	PPH-3*	123.2	n.d.	n.d.	n.d.	n.d.	56.9	56.9
	PPH-4	566.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-8*	2079.1	n.d.	n.d.	n.d.	n.d.	314.7	314.7
	Dock A	55.7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

	Dock B	105.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	Dock C	96.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
02/07/12	PPH-1	2141.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-2	4606.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-3	1767.2	2.0	11.2	n.d.	n.d.	837.0	55.1
	PPH-4	228.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-8*	4998.6	n.d.	n.d.	13.5	13.5	1459.0	1459.0
02/09/12	PPH-1	10747.3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-2	3823.5	n.d.	2.8	n.d.	n.d.	682.5	44.9
	PPH-3	39.9	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-4	704.6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-8	3075.1	n.d.	n.d.	n.d.	n.d.	3075.1	241.4
07/09/12	PPH-1	28460.4	768.5	872.0	n.d.	n.d.	8689.8	572.1
	PPH-2	17395.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-3	89.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-4	2054.9	n.d.	n.d.	n.d.	n.d.	697.8	46.4
	PPH-8	5009.9	n.d.	n.d.	2893.8	159.3	n.d.	n.d.
10/21/12	PPH-1	8882.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-3	8155.7	n.d.	n.d.	n.d.	n.d.	298.7	20.0
	PPH-4	566.6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-2B	9530.1	n.d.	n.d.	n.d.	n.d.	2381.4	156.9
	PPH-DR4	2093.1	121.9	124.6	116.7	6.6	135.0	9.3
10/22/12	PPH-1	1574.2	n.d.	n.d.	n.d.	n.d.	1504.0	98.5
	PPH-3	5090.7	n.d.	n.d.	n.d.	n.d.	103.2	7.4
	PPH-4	652.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-1B	1722.5	n.d.	n.d.	n.d.	n.d.	394.3	25.9
	PPH-2B	7602.5	n.d.	n.d.	n.d.	n.d.	208.2	13.7
	PPH-DR4	19630.1	n.d.	n.d.	3436.9	192.9	138.7	10.2
10/29/12	PPH-1	7901.3	n.d.	n.d.	n.d.	n.d.	4075.4	268.0
	PPH-2	48078.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-3	4674.8	n.d.	4.7	n.d.	n.d.	n.d.	n.d.
	PPH-4	348.4	3.2	3.9	n.d.	n.d.	n.d.	n.d.
	PPH-8	5876.6	n.d.	n.d.	12.2	n.d.	5876.6	519.9
	PPH-2B	220.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-DR4	4766.6	n.d.	n.d.	29.3	n.d.	4766.6	626.4
12/17/12	PPH-1B	6767.2	n.d.	10.9	n.d.	n.d.	6068.3	399.1
	PPH-2B	1935.9	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-DN3	2327.3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-DN4	3899.7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	PPH-DR4	9640.7	n.d.	8.2	7971.7	136.7	1939.3	128.5
	PPH-DR6	6014.3	13.5	12.5	5517.1	410.5	496.6	32.6

<sup>A</sup> Model corrected concentration

<sup>B</sup> Measured concentration (raw data)

<sup>C</sup> n.d. not detected.

\* Model's parameter set do not work for the sample. Raw data were used for analysis.

**Appendix C6 Model adjusted and measured *Bacteroidales* concentrations in sediments and biofilm**

(Unit: gene copies/g of dry weight)

Date	Sample	Universal <i>Bacteroidales</i>	Human <i>Bacteroidales</i>		Bovine <i>Bacteroidales</i>		Dog <i>Bacteroidales</i>	
			Model <sup>A</sup>	Raw <sup>B</sup>	Model	Raw	Model	Raw
08/24/11	1S	6660.1	n.d. <sup>C</sup>	n.d.	n.d.	n.d.	n.d.	n.d.
	2S	20619.9	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	3S	5474.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	4S	2759.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	5S	6078.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	6S	2811.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	8S	14491.1	n.d.	n.d.	n.d.	n.d.	9853.3	646.9
	9S	1057.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	1B-1	15393.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	1B-2	21475.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	2B	77181.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	3B-1	7070.7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	3B-2	25088.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	4B-1	31457.9	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	4B-2	37622.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	5B-1	13900.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	5B-2	53963.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	6B-1	6909.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	6B-2	36625.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	02/06/12	1S	8549.5	n.d.	n.d.	n.d.	n.d.	n.d.
2S		4189.0	n.d.	n.d.	n.d.	n.d.	1461.2	95.9
3S		809.3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
4S		77.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
8S		172.7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
2B		543592.2	n.d.	n.d.	n.d.	n.d.	131728.4	8684.8
4B		9404.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
02/07/12	1S	826.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	2S	4257.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	3S	242.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	4S	204.3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	8S*	494.5	n.d.	n.d.	n.d.	n.d.	99.3	99.3
	2B	1661.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	4B	8155.6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
02/09/12	1S	1405.9	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	2S	1341.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	3S	191.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	4S	170.6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	8S	120.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	2B	5030.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	4B	3953.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

07/09/12	1S*	319555.6	756.4	756.4	n.d.	n.d.	45.2	45.2
	2S	442828.9	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	3S	3316.7	n.d.	n.d.	n.d.	n.d.	592.1	38.8
	4S	1665.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	8S	1353.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	2B	79346.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	4B	75016.8	n.d.	n.d.	n.d.	n.d.	22351.2	1468.9

<sup>A</sup> Model corrected concentration

<sup>B</sup> Measured concentration (raw data)

<sup>C</sup> n.d. not detected.

\* Model's parameter set do not work for the sample. Raw data were used.

## Appendix D Bird, Horse, and additional Human assay results

### Appendix D1 Comparison of qPCR results of the 25 samples analyzed by gull-OSU assay or gull-2 assay

Sample ID <sup>A</sup>	Sample description		qPCR results (gc/μl of DNA extract)	
	Sampling date	Sampling site	OSU <sup>C</sup>	UCD <sup>D</sup>
1	03/29/11	PPH-3	n.d. <sup>E</sup>	n.d.
2	04/06/11	PPH-3	n.d.	n.d.
3	04/08/11	PPH-3	n.d.	n.d.
4	07/06/11	PPH-3	n.d.	n.d.
5	10/03/11	PPH-3	n.d.	n.d.
6	10/05/11	PPH-3	n.d.	n.d.
7	10/07/11	PPH-3	n.d.	n.d.
8	02/06/12	PPH-3	n.d.	n.d.
9	02/07/12	PPH-3	n.d.	n.d.
10	02/09/12	PPH-3	n.d.	n.d.
11	04/06/11	PPH-1	n.d.	n.d.
12	04/06/11	PPH-4	n.d.	n.d.
13	07/06/11	PPH-1	n.d.	n.d.
14	07/06/11	PPH-2	n.d.	n.d.
15	07/06/11	PPH-4	n.d.	n.d.
16	10/03/11	PPH-1	n.d.	n.d.
17	10/03/11	PPH-2	n.d.	n.d.
18	10/03/11	PPH-4	n.d.	n.d.
19	Gull feces DNA (6) <sup>B</sup>		1.61 x 10 <sup>3</sup>	1.43 x 10 <sup>2</sup>
20	Gull feces DNA (1)		4.67 x 10 <sup>2</sup>	4.45 x 10 <sup>1</sup>
21	Gull feces DNA (1)		5.39 x 10 <sup>2</sup>	9.65 x 10 <sup>0</sup>
22	Human feces DNA (5)		n.d.	n.d.
23	Cow feces DNA (5)		n.d.	n.d.
24	Dog feces DNA (5)		n.d.	n.d.
25	Blank (nuclease free water)		n.d.	n.d.

<sup>A</sup> Coded sample name labeled on tubes sent to OSU for a blind test

<sup>B</sup> Number in parenthesis indicates the number of individual fecal samples used for DNA extraction, for example, (6) means that 6 individual gull feces were combined prior to DNA extraction

<sup>C</sup> SYBR green qPCR assay targeting *Catellibacterium marimammalium* was used

<sup>D</sup> TaqMAN qPCR assay targeting *Catellibacterium spp.* was used.

<sup>E</sup> n.d. not detected

**Appendix D2 *C. marimammalium* (Gull-2) and horse- (HorseBact) or human-associated *Bacteroidales* (HF183 TaqMan) concentrations in water in 2011 and wet season 2012**

(Unit: gene copies/ml)

Date	Sample	Gull2 SYBR green assay		HorseBact assay		HF183 TaqMan assay	
		Concn <sup>A</sup>	S <sub>LOD</sub> <sup>B</sup>	Concn	S <sub>LOD</sub>	Concn	S <sub>LOD</sub>
03/19/11	PPH-1	n.d. <sup>C</sup>	3.2	n.d.	3.2	n.d.	38.2
	PPH-2	n.d.	5.3	n.d.	5.3	n.d.	63.3
	PPH-4	n.d.	11.0	n.d.	11.0	n.d.	131.6
	PPH-8	n.d.	4.2	n.d.	4.2	n.d.	50.9
03/29/11	PPH-1	n.d.	0.9	n.d.	0.9	n.d.	11.3
	PPH-2	n.d.	1.4	n.d.	1.4	n.d.	16.8
	PPH-3	n.d.	2.4	n.d.	2.4	n.d.	28.3
	PPH-4	n.d.	8.5	n.d.	8.5	n.d.	33.9
04/06/11	PPH-1	n.d.	1.6	n.d.	1.6	n.d.	19.3
	PPH-2	n.d.	6.6	n.d.	6.6	n.d.	78.9
	PPH-3	n.d.	4.1	n.d.	4.1	n.d.	49.7
	PPH-4	n.d.	6.2	n.d.	6.2	n.d.	74.4
04/07/11	PPH-1	n.d.	2.7	n.d.	2.7	n.d.	32.9
	PPH-2	n.d.	4.8	n.d.	4.8	n.d.	57.4
	PPH-4	n.d.	8.3	n.d.	8.3	n.d.	100.2
04/08/11	PPH-1	n.d.	4.5	n.d.	4.5	n.d.	53.6
	PPH-2	n.d.	2.3	n.d.	2.3	n.d.	27.2
	PPH-3	n.d.	0.9	n.d.	0.9	n.d.	10.6
	PPH-4	n.d.	1.8	n.d.	1.8	n.d.	21.3
07/06/11	PPH-1	n.d.	3.6	n.d.	3.6	n.d.	42.7
	PPH-2	n.d.	0.8	n.d.	0.8	n.d.	9.8
	PPH-3	n.d.	1.3	n.d.	1.3	n.d.	15.2
	PPH-4	n.d.	0.9	n.d.	0.9	n.d.	11.1
	PPH-8	n.d.	1.1	n.d.	1.1	n.d.	12.7
10/03/11	PPH-1	n.d.	1.7	n.d.	1.7	n.d.	20.8
	PPH-2	n.d.	1.3	n.d.	1.3	n.d.	16.0
	PPH-3	n.d.	1.1	n.d.	1.1	n.d.	13.5
	PPH-4	n.d.	4.5	n.d.	4.5	n.d.	54.4
	PPH-8	n.d.	4.2	n.d.	4.2	n.d.	50.6
10/05/11	PPH-1	n.d.	27.8	n.d.	27.8	n.d.	333.1
	PPH-2	n.d.	2.3	n.d.	2.3	n.d.	28.0
	PPH-3	n.d.	1.0	n.d.	1.0	n.d.	12.5
	PPH-4	n.d.	1.2	n.d.	1.2	n.d.	14.9
	PPH-8	n.d.	7.3	n.d.	7.3	n.d.	87.0
10/07/11	PPH-1	n.d.	3.0	n.d.	3.0	n.d.	35.7
	PPH-2	n.d.	2.9	n.d.	2.9	n.d.	35.2
	PPH-3	n.d.	1.5	n.d.	1.5	n.d.	18.6
	PPH-4	n.d.	5.7	n.d.	5.7	n.d.	68.1
	PPH-8	n.d.	3.8	n.d.	3.8	n.d.	45.1
02/06/12	PPH-1	n.d.	11.2	n.d.	11.2	n.d.	134.0

	PPH-2	n.d.	5.1	n.d.	5.1	227.5	61.2
	PPH-3	n.d.	2.4	n.d.	2.4	n.d.	28.5
	PPH-4	n.d.	19.4	n.d.	19.4	n.d.	232.4
	PPH-8	n.d.	11.0	n.d.	11.0	n.d.	20.9
02/07/12	PPH-1	n.d.	17.8	n.d.	17.8	n.d.	213.2
	PPH-2	n.d.	9.4	n.d.	9.4	n.d.	112.3
	PPH-3	n.d.	1.6	n.d.	1.6	n.d.	19.0
	PPH-4	n.d.	14.5	n.d.	14.5	n.d.	174.2
	PPH-8	n.d.	7.5	n.d.	7.5	n.d.	90.1
02/09/12	PPH-1	n.d.	22.0	n.d.	22.0	n.d.	263.4
	PPH-2	n.d.	1.8	n.d.	1.8	n.d.	21.1
	PPH-3	n.d.	2.7	n.d.	2.7	n.d.	32.8
	PPH-4	n.d.	8.3	n.d.	8.3	n.d.	99.5
	PPH-8	n.d.	4.3	n.d.	4.3	n.d.	52.0

<sup>A</sup> Concentration

<sup>B</sup> Sample limit of detection

<sup>C</sup> n.d. not detected.

## Appendix E Supplementary information about water circulation at PPH

In our circulation study, Fluorescein dye was released at B and C, and Rhodamine was released throughout the western Inner Harbor and at A to estimate the movement of water. (Figure E1). All dyes were released at 8 am on 9-27-08. Rhodamine and Fluorescein were detected at each location indicated as red triangles (A1 – A8, B1 – B4, C1 – C8, D and E).



Figure E1: Dye release and sampling sites

Regarding Fluorescein concentration, elevated Fluorescein (up to 0.10 ppb) was detected in Inner Harbor (site E) from 12 pm on 9-27-08 till 10 am on 9-28-08 (Figure E2). Fluorescein detected in Inner Harbor could be affected from the leakage through breakwaters and the dispersion via the gap of Inner Harbor's breakwater along with current flow. The Fluorescein detected at site E at that time was mainly attributed to the leakage of breakwater since high Fluorescein (1 – 5 ppb) was detected outside of the inner harbor breakwater but the mouth of breakwater gap from 9 am to 4 pm on 9-27-08 (Fig. 3). The permeated dye at site E from Capistrano Beach was lower than one order magnitude at most (0.05 – 0.1 ppb) compared to the amount in Capistrano Beach (5 – 10 ppb) during the period (Figure E3).

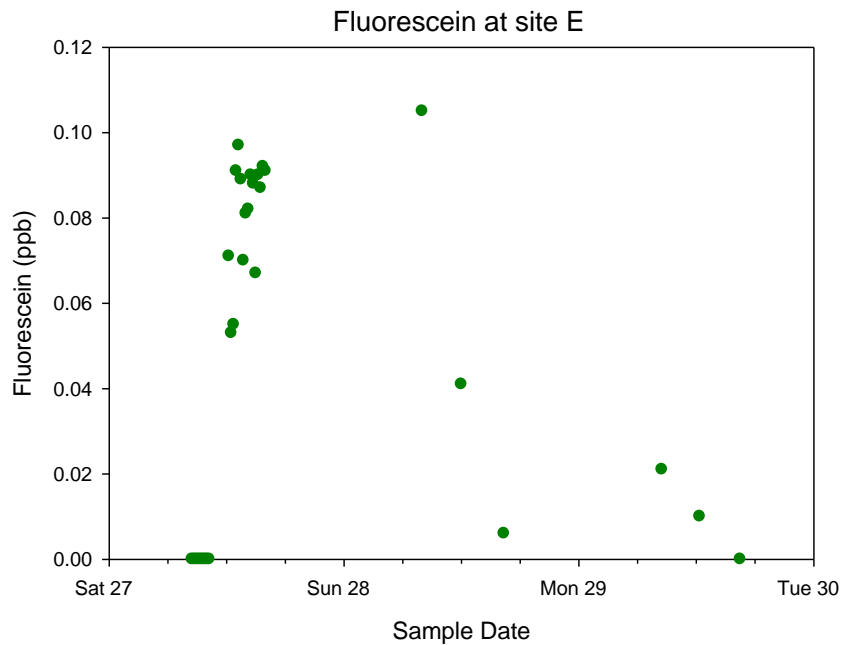


Figure E2 Fluorescein concentration as a function of time at site E



Figure E3 Fluorescein concentration as a function of time at site E. Fluorescein concentration (ppb) during 9 – 10 am (top), 12 – 1 pm (middle) and 3 – 4 pm (bottom) on 9-27-08.

Fluorescein was peaked (0.1 ppb) at 8 am on 9-28-08, which was caused by leakage through the breakwater and current coming through the gap of inner harbor's breakwaters (Figure E4).



Figure E4 Fluorescein concentration (ppb) at site E during 8 – 10 am on 9-28-08

Fluorescein in the outer harbor was washed out in 2.5 days (Figure E5), and Fluorescein in the inner harbor was also flushed out after 4 pm 09-29-09 (Figure E2).



Figure E5 Fluorescein concentration (ppb) at site E during 4 – 6 am on 9-29-08

Regarding Rhodamine concentration, elevated concentrations were detected at site E from 12 pm to 4 pm on 9-27-08 (Figure E6).

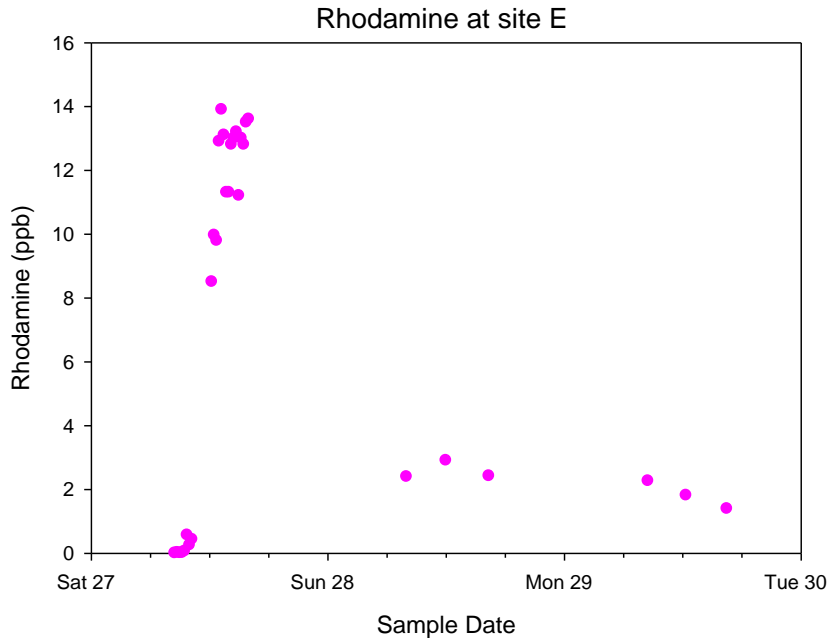


Figure E6 Rhodamine concentration as a function of time at site E

During 12 – 1 pm on 9-27-08, Rhodamine was detected inside Inner Harbor as well as the vicinity of Inner Harbor (Figure E7 top). The high Rhodamine concentration in Inner Harbor was mainly attributed by Rhodamine which is released at Inner Harbor rather than interruption of Rhodamine released at site A since Rhodamine concentration of outside Inner Harbor was quite lower than the dye in Inner Harbor.



Figure E7 Rhodamine concentration (ppb) during 12 – 1 pm on 9-27-08 (top), 8 – 10 am on 9-28-08 (middle) and 8 – 10 am on 9-29-08 (bottom)

In Capistrano Beach, Rhodamine was detected from 8-10 am on 9-28-08 till throughout the study period (9-29-08). Rhodamine in Capistrano Beach could be transferred from two points, one in inner harbor and one in site A which was western part of outer harbor. According to Fluorescein results, the leakage through Inner Harbor's breakwater contributed less than 10%. Thus, Rhodamine which was affected to Capistrano Beach from Inner Harbor was mainly attributed by dispersion rather than leakage. During the period, Rhodamine concentrations detected in Capistrano Beach and Inner Harbor were 0.5 – 5 ppb and 1 – 5 ppb, respectively (Figure 7 middle and bottom). Rhodamine concentration was alleviated during traveling, and the concentration gradient of Rhodamine between Inner Harbor and Capistrano Beach is 1/10 to 1. However, Rhodamine was still detected in Inner Harbor during the period, which indicated the proportion of Rhodamine affected to Capistrano Beach from Inner Harbor was less than 1. Since Capistrano Beach was affected by Rhodamine released from two locations, it is impossible to exactly quantify the impact of Rhodamine from Inner Harbor to Capistrano. If we assumed that Rhodamine concentration was attributed from the two sites equally, the amount of Rhodamine arrived to Capistrano beach from Inner harbor could be calculated as  $1/20 - 1/2$ .

To put it shortly,

- The permeability of the inner harbor's breakwater was low. The range of permeability was from  $1/200$  to  $1/10$  of inner harbor's concentration based on Fluorescein concentration gradient. It took 4 hours for Fluorecein to penetrate breakwater and be released to Inner Harbor.
- Dye could also go out through the gap of the inner harbor's breakwaters along with flow. It took one day for Rhodamine to reach Capistrano Beach by dispersion via the gap. The range of dispersion effect from Inner Harbor to Capistrano Beach was  $1/20 - 1/2$ , which was the half of their concentration gradient.

## Appendix F PhyloChip source identification study

### Appendix F1 Description of samples submitted for PhyloChip analysis

Sample ID <sup>A</sup>	Sampling Date	Sampling Site <sup>B</sup>	FIB concentration <sup>E</sup>			<i>Bacteroidales</i> concentration <sup>I</sup>			
			TC	EC	ENT	Uni	Hum	Bovine	Dog
			(MPN/100 ml)			(gene copies/ml)			
1	3/29/2011	3	n.a. <sup>F</sup>	n.a.	n.a.	88	0	0	0
2	7/6/2011	3	4884	30	20	66	0	0	0
3	10/5/2011	3(dup) <sup>C</sup>	>24196 <sup>G</sup>	17329	24196	6807	0	0	3545
4	2/9/2012	3	528	63	52	40	0	0	0
5	2/9/2012	1	>24196	10	62	10747	0	0	0
6	2/7/2012	2	24196	4611	691	4606	0	0	0
7	10/29/2012	2	>24196	6488	19863	48079	0	0	0
8	10/3/2011	Blank <sup>D</sup>	<10 <sup>H</sup>	<10	<10	0	0	0	0
9	10/3/2011	3(dup)	10462	213	63	1139	0	0	0
10	10/29/2012	1	>24196	>24196	>24196	7901	0	0	4075
11	3/19/2011	1	n.a.	n.a.	n.a.	9176	0	0	0
12	10/5/2011	2	>24196	>24196	>24196	133783	0	0	37306
13	10/3/2011	3	10462	213	63	1139	0	0	0
14	10/29/2012	3	6488	341	683	4675	0	0	0
15	10/3/2011	1	>24196	323	4884	18589	0	0	0
16	7/9/2012	2	>24196	>24196	109	17396	0	0	0
17	10/3/2011	2	>24196	1658	471	9230	0	0	0
18	4/8/2011	1	3873	<10	10	11319	0	0	0
19	4/7/2011	2	3448	246	41	5125	6	0	0
20	10/22/2012	1	>24196	>24196	>24196	1574	0	0	1504
21	4/6/2011	2	1565	75	20	535	0	3	535
22	10/21/2012	3	272	110	20	8156	0	0	299
23	7/9/2012	3	1076	84	<10	90	0	0	0
24	2/6/2012	3	211	96	52	123	0	0	57
25	2/6/2012	1	10112	529	454	2686	0	0	1110
26	3/29/2011	2	n.a.	n.a.	n.a.	20	0	0	0
27	2/9/2012	2	14136	1017	1374	3823	0	0	683
28	3/19/2011	2	n.a.	n.a.	n.a.	6822	0	17	6822
29	7/9/2012	1	>24196	4884	24196	28460	769	0	8690
30	4/6/2011	3	160	75	20	216	0	0	0
31	10/7/2011	2	>24196	5475	3076	6975	0	0	1676
32	10/7/2011	1	>24196	2723	15531	893	0	0	0
33	10/22/2012	1B	>24196	19863	>24196	1722	0	0	394
34	3/29/2011	1	n.a.	n.a.	n.a.	14	0	0	0
35	4/6/2011	1	3448	<10	10	784	0	0	0
36	4/8/2011	3	121	20	20	290	0	0	0
37	10/7/2011	3	3076	512	520	802	0	0	0
38	4/7/2011	1	5475	10	20	5607	0	0	0
39	2/6/2012	2	9139	1483	3130	31606	0	161	11096
40	10/21/2012	1	>24196	548	1223	8883	0	0	0
41	2/7/2012	3	1935	249	241	1767	2	0	837

42	2/7/2012	1	24196	31	52	2141	0	0	0
43	10/5/2011	Blank	<10	<10	<10	0	0	0	0
44	7/6/2011	2	>24196	1860	75	2738	0	0	0
45	10/5/2011	3	>24196	17329	24196	6807	0	0	3545
46	4/8/2011	2	11199	309	31	12583	0	0	0
47	10/5/2011	1	>24196	>24196	19863	1640	0	0	0
48	10/22/2012	2B	>24196	4611	12033	7603	0	0	208
49	10/22/2012	3	>24196	11199	24196	5091	0	0	103
50	7/6/2011	1	24196	31	259	131	0	0	0

<sup>A</sup> Coded sample name labeled on tubes sent to Lawrence Berkeley National Laboratory for a blind test

<sup>B</sup> 1, Capistrano Outfall Pipe; 2, Bathhouse Outfall Pipe; 3, Capistrano Beach; 1B, upstream site of Capistrano Outfall Pipe; 2B, upstream site of Bathhouse Outfall Pipe

<sup>C</sup> Duplicate sample for QA/QC purpose

<sup>D</sup> Field Blank sample for QA/QC purpose

<sup>E</sup> TC, total coliform; EC, *E. coli*; ENT, *Enterococcus*

<sup>F</sup> n.a. Not analyzed

<sup>G</sup> Higher than upper sample limit of detection, 24196 MPN/100 ml

<sup>H</sup> Less than lower sample limit of detection, 10 MPN/100 ml

<sup>I</sup> Model adjusted concentrations of *Bacteroidales* qPCR results (Uni, universal *Bacteroidales*; Hum, human-associated *Bacteroidales*; Bovine, bovine-associated *Bacteroidales*; Dog, dog-associated *Bacteroidales*)

**Appendix F2 Percent of source ID probes enriches in each sample**

Sample ID	Mammal (190) <sup>A</sup>	Human (698)	Grazers (2233)	Dog/Cat (2457)	Pig (6374)	Raccoon (2351)	Pinniped (2558)	Shorebird (264)
1	4.2	1.7	0.9	1.6	0.5	0.5	0.8	0.8
2	0	0.4	0.2	1.3	0.2	0.2	0	0
3	20.5 <sup>B</sup>	11.2	7.5	5.0	3.8	5.1	3.6	23.9
4	0	0.6	0.3	1.8	0.2	0.2	0	0.4
5	4.2	1.9	2.3	1.0	0.9	1.1	1.8	1.5
6	5.3	3.9	4.2	1.0	1.2	2.6	1.2	8
7	25.3	18.5	11.9	7.2	6.0	8.1	3.6	33.7
8	0	0.1	0	0	0	0	0	0.4
9	3.7	8.6	0.9	2.7	0.6	0.3	0.2	0.4
10	0	0.4	2.7	0.5	1.1	6.8	1.4	31.1
11	2.6	1.6	1.2	0.7	0.5	3.5	0.4	18.9
12	22.6	9.6	8.7	4.4	4.8	8.1	4.8	35.2
13	1.6	1.7	0.7	1.5	0.3	0.6	0.2	0.4
14	5.3	3.2	1.4	1.0	0.7	1.3	0.6	6.1
15	1.1	1.6	1.7	1.1	1.8	2.7	0.5	23.1
16	6.3	5.0	1.7	1.9	1.7	2.3	0.9	11.0
17	7.9	1.6	2.4	1.3	1.4	4.5	1.4	24.6
20	1.6	0.7	1.5	1.1	0.5	9.0	0.2	45.5
21	0	0	0.1	0	0	0	0	0.4
22	11.6	16.5	6.3	7.2	2.3	3.6	1.4	7.2
23	0.5	4.3	2.8	2.3	1.0	2.0	1.0	4.5
24	0	1.1	1.0	1.8	0.3	0.6	0.2	1.9
25	0.5	0.4	0.4	0.3	0.4	1.0	0.1	10.6
27	8.4	7.4	4.3	2.6	1.7	3.7	0.9	9.1
28	11.6	6.4	1.6	2.2	0.7	1.9	0.8	8.0
29	2.1	1.4	1.5	0.6	0.9	4.6	0.4	28.8
30	2.6	2.0	0.4	2.9	0.8	0.1	0.1	0
31	6.3	1.4	1.1	0.9	1.1	4.1	1.2	27.3
32	1.1	0.3	0.4	0.3	0.4	3.4	0.5	24.6
33	3.2	1.0	0.6	0.4	0.3	4.0	0.4	17.8
35	0.5	0.3	0.1	0	0.1	0	0.2	0.8
36	0.5	0.4	0.1	1.4	0.1	0.2	0.1	0.4
37	5.3	2.6	1.7	2.3	0.5	1.0	0.9	1.9
39	44.2 <sup>C</sup>	37.1	10.1	18	5.9	6.6	6.2	14.4
40	0	2.4	2.1	1.2	0.9	1.4	0.4	3.4
41	4.2	3.4	1.9	2.8	0.6	1.3	0.4	3.0
42	1.6	0.4	0.6	0.4	0.3	0.8	0.7	3.0
43	0	0	0	0	0	0	0	0
44	0	0	0.4	0.7	0.4	0.2	0	0.4
45	21.1	11.9	6.9	3.7	2.9	5.3	3.4	28.0
46	2.1	1.3	0.6	1.0	0.7	0.3	0.2	1.5
47	0.5	0.4	0.6	0.5	0.2	5.7	0.2	35.2
48	5.3	4.9	2.7	2.4	0.9	1.3	0.7	3.4

49	5.3	8.6	6.5	3.7	2.1	3.0	1.4	7.6
50	1.6	1.6	0.5	1.4	0.3	0.3	0.4	1.1

<sup>A</sup> Total probes for each source shown in parentheses

<sup>B</sup> Sources with 20-40% of probes enriched highlighted in yellow

<sup>C</sup> Sources with >40% of probes enriched highlighted in orange

## **Appendix E**

### **Fitzgerald Marine Reserve Pollution Reduction Program Monitoring Report (San Francisco Estuary Institute and UC Davis)**

# **James V. Fitzgerald Area of Special Biological Significance Pollution Reduction Program**

## **Microbial Source Tracking Study Summary Reports**

Grant Identification Number 10-402-550

**Prepared by  
Nicole David, San Francisco Estuary Institute  
&  
Minji Kim, University California, Davis  
Prof. Stefan Wuertz, University California, Davis**

**For the  
County of San Mateo**

February 2013

*Funding for this study was provided in full or in part through an Agreement with the State Water Resources Control Board. The contents of this document do not necessarily reflect the views and policies of the State Water Resources Control Board, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.*



## Executive Summary & Recommendations

The James V. Fitzgerald Area of Special Biological Significance (ASBS) is located to the north of the City of Half Moon Bay in unincorporated San Mateo County and extends from 4th Street in Montara south to the Pillar Point Harbor breakwater. The Fitzgerald Marine Reserve (Reserve) is located within the boundary of the ASBS. The Reserve is recognized by many as one of the richest, most biodiverse intertidal environments on the California coast and is a popular recreational area as well. Three main creeks drain to the Reserve – Montara, Dean, and San Vicente Creek. Kanoff and Martini Creeks are located immediately to the north of the ASBS boundary.

The Pacific Ocean at the Reserve and San Vicente Creek are on the 303 (d) List of Impaired Water Bodies due to elevated coliform bacteria, and Total Maximum Daily Loads are scheduled to be completed by 2019. This microbial source tracking (MST) study was undertaken due to the 303d listing, numerous exceedances of water quality objectives, and the frequency of needed beach and creek postings warning visitors that San Vicente Creek and the Reserve may not be suitable for contact recreation. This study was conducted as part of the James V. Fitzgerald ASBS Pollution Reduction Program, a multi-faceted program designed to reduce pollutant loading and protect natural resources and beneficial uses of the ASBS. The main goal of this MST study was to provide information about the primary sources of fecal contamination within the ASBS watershed and to assist with the selection of appropriate Best Management Practices (BMPs) to reduce fecal pollution.

MST monitoring was conducted from January 2012 through October 2012 within Martini, Kanoff, Montara, Dean, and San Vicente Creeks. The San Francisco Estuary Institute (SFEI) monitored fecal indicator bacteria (FIB), including total coliform, *Escherichia coli*, and *Enterococcus* spp., at multiple locations within each creek during two rainy season events (January 20, 2012 and March 14, 2012) and two dry season events (July 9, 2012 and August 15, 2012). The purpose of the FIB monitoring was to determine FIB levels throughout the watersheds and investigate seasonal and land use-related spatial trends. Researchers from the University of California, Davis (UCD) collected samples from the same five creeks at sites located immediately upstream of the confluences with the Pacific Ocean during a rainy season event (March 2012), dry season event (July 2012), and during first flush (October 2012) and conducted genetic analysis of host-associated *Bacteroidales* to determine the contribution of human, bovine, dog, and horse sources to fecal contamination. SFEI collected a total of 78 water samples for FIB analysis, and UCD collected a total of 58 samples from water, sediment, and biofilm matrices for genetic analysis.

The sites were located within the unincorporated communities of Montara and Moss Beach. The watersheds are rural in nature, although there are small commercial and medium to high density residential areas located within all of the watersheds, except for Martini Creek. A large portion of the watersheds is open space including McNee Ranch State Park and Rancho Corral de Tierra, part of the Golden Gate National Recreation Area managed by the National Park Service. Potential sources of fecal contamination within the five watersheds include wildlife, recreation (i.e., dog walking, beach and park use), equestrian facilities, other confined animal

facilities/livestock, agriculture, leaking pipes or overflows from septic and/or sanitary sewer systems, and other residential-related sources (i.e., pets, compost).

The results of FIB monitoring, conducted by SFEI, showed that FIB concentrations in the five drainages were elevated during both the dry and wet seasons and often exceeded water quality objectives for contact recreation. FIB concentrations were generally lower in the dry season than in the rainy season. In Martini and Kanoff Creeks, the less urbanized watersheds, FIB levels were lower than the more urbanized watersheds of Montara, Dean, and San Vicente Creeks. Due to the study design and limited timeframe, consistent spatial trends in FIB concentrations related to specific land use types were not detected. One notable increase in FIB occurred in Montara Creek during the January 2012 rainy season event when *E. coli* and *Enterococcus* levels were approximately six times higher at the Pacific Ocean confluence site in comparison to the next site upstream. Increases were also observed between these sites during the two dry season events. Within this reach of Montara Creek, there are several land use types; therefore, the primary contributing source could not be identified.

The results of the genetic analysis, conducted by UCD, showed that concentrations of the universal *Bacteroidales* marker, derived from all warm-blooded animals, increased during rain and was generally lower in the dry season. Increased levels of *Bacteroidales* were significantly higher in the wet season event in comparison to the first flush event. Differences in first flush and the rainy season events could be due to differences in microorganism survival related to environmental conditions such as temperature, differences in source loading related to the degree of ground saturation, groundwater levels, resulting runoff, and observed streamflow at the beginning of the storm season versus the end of the storm season, and/or the resuspension of sediments and release of microorganisms from sediment and biofilms as the result of higher streamflow and turbulence.

Of the four host-specific markers that were analyzed (dog, horse, bovine, and human), dog-associated *Bacteroidales* was the most frequently detected host marker in the water, as well as in sediments and biofilms at all sites in the wet season. On the contrary, the dog-associated marker was less frequently detected during the dry season and first flush event. The bovine-associated marker was detected in water, sediments, or biofilms at all sites during the rainy season, most notably from Kanoff and San Vicente Creeks, but was not detected during the dry season or first flush events. Horse-associated *Bacteroidales* were found at high concentrations in water at Dean and San Vicente Creeks during rain in the wet season. The horse marker was also detected at all sites during the dry season, but did not appear to be a predominant source of fecal contamination. Human-associated *Bacteroidales* were detected in water at all sites during the first flush event, but were not present during the dry season and were only detected in two samples during the rainy season event. During the dry season, at all sites except Montara Creek, less than 5% of the universal *Bacteroidales* concentrations were made up of the tested host-specific markers, which indicates that uncharacterized fecal sources, such as wildlife or other domestic animals, likely contributed a large amount of fecal pollution.

The results of this MST study provide good insight and a first glimpse into the understanding and control of fecal contamination sources in watersheds draining into the Pacific Ocean in the vicinity of the ASBS. FIB levels were highest during the rainy season. This study confirms

fecal contamination from human, dog, bovine, and horse sources, and of these, dog appears to be the most prevalent source during the rainy season. While there may be other more significant sources of fecal pollution that were not characterized as part of this study, such as wildlife or other domestic animals, this study provides useful information to guide the selection of BMPs to reduce fecal pollution.

Recommendations for further work and BMPs include:

- Continued MST within the five watersheds including:
  - Additional monitoring for the existing host-associated *Bacteroidales* markers used in this study (increased sites and sampling frequency)
  - Genetic analysis using new host-associated markers or improved MST techniques (i.e., Phylochip, techniques to distinguish between intact and impaired cells allowing for determination of the age of fecal pollution), as available
  - Implementation of a bacterial tracer experiment
- Implementation of an education and outreach program to address dog waste
- Implementation of BMPs to address horse waste
- Investigation of potential sources of bovine contamination including research on:
  - Presence of cows within the watersheds
  - Contribution potential from applied manure compost and level of use within the watersheds
  - Specificity of the bovine-associated marker
- Development of a project to investigate the condition of septic systems and provide education and outreach on proper maintenance
- Development of a plan to investigate the potential for source contributions related to the sanitary sewer system. If needed, a future project could include a system condition assessment, enhanced program for maintenance and leak/overflow prevention, and public education and outreach on proper sewer lateral maintenance

# **Fecal Indicator Bacteria In Creeks Draining Into The Pacific Ocean In Montara and Moss Beach, CA**

As Part Of The

## **Monitoring Program for the James V. Fitzgerald Area of Special Biological Significance Pollution Prevention Program**

**Grant Identification Number 10-402-550**

December 2012

Nicole David

San Francisco Estuary Institute



## **Summary**

Bacteria, such as coliform, *Enterococcus*, and *E. coli*, can be used as indicators for fecal contamination in surface waters. The goal of this study was to identify potential sources of fecal indicator bacteria in different reaches of creeks draining from Montara Mountain to the Pacific Ocean in the vicinity of the James V. Fitzgerald Area of Special Biological Significance and to inform future bacterial loading reduction efforts in those creeks. Fecal indicator bacteria concentrations exceeded U.S. EPA recommended standards at most sites during the dry and the wet season. However, concentrations were generally lower in the dry season. In addition to the high total coliform concentrations at all creek sites during the wet season, some counterintuitive observations were noted for Martini and Kanoff Creek for *E. coli* and *Enterococcus*. Bacteria concentrations in the upper reaches of the creeks were generally higher than downstream locations even though likely urban sources of fecal contamination (e.g., pet waste, sewer and septic system effluent) would be expected to be concentrated in the central and lower reaches of the creeks. Similar observations to the ones made in this study have been made in other watersheds. As expected, Martini and Kanoff Creek showed lower bacteria concentrations than the more urbanized watersheds of Dean, San Vicente, and Montara Creek. Montara Creek was the only creek out of the five monitored creeks where increased bacterial loading was observed from the upstream to the downstream reaches. However, the understanding of the complex bacteria loading in mountainous creeks and the transport and fate of the indicator bacteria downstream are not, at this point, well understood despite multiple decades of use of these indicators in state and federally promulgated water quality standards.

## **Introduction**

Impairment of the James V. Fitzgerald Marine Reserve (Reserve) and Area of Special Biological Significance (ASBS) due to fecal bacteria is of concern to the State of California, County of San Mateo, and local stakeholders. The Pacific Ocean at the Reserve and San Vicente Creek are listed on the 303 (d) List of impaired water bodies due to elevated coliform bacteria, and total maximum daily loads are scheduled to be completed by 2019. The original 2002 listings were based on three years of fecal indicator bacteria (FIB) monitoring data collected by the San Mateo County Environmental Health Department and associated exceedances of Basin Plan and Ocean Plan objectives for water contact recreation. The 303d listing, numerous exceedances of water quality objectives, frequency of needed beach and creek postings at the Reserve, and the potentially associated consequences for public and

ecosystem health led to the monitoring of fecal contamination, using FIB in five creeks draining watersheds in Montara and Moss Beach, CA. Fecal contamination can lead to acute gastrointestinal illnesses in humans after contact with the water (U.S. EPA 1997). High levels of FIB in water can indicate the potential presence of pathogens known to cause diseases like cholera, typhoid, dysentery, cryptosporidiosis, and hepatitis. Indicator bacteria are usually harmless but are easy to measure, more numerous than, and strongly correlated to waterborne pathogens and fecal matter. However, since some of the indicators are also common in nature, e.g., some coliform species of the total coliform group, it is not certain that their presence necessarily indicates fecal contamination (U.S. EPA 2004).

Total coliform is the indicator that was originally recommended in 1968 by the Federal Water Pollution Control Administration of the Department of the Interior as a screening indicator for waterborne illness. The two other indicators that were monitored during this study, *E. coli* and *Enterococcus*, were actually indicators that showed stronger correlation to contact-associated gastroenteritis than total coliform (U.S. EPA 2004). Also, *Enterococcus* has the ability to survive in salt water, and therefore more closely resembles many pathogens. Additionally, it can point to a more human-related source than other subgroups of the fecal streptococcus group that it belongs to (U.S. EPA 1997). Since the primary source of waterborne pathogens are thought to be fecal pollution from humans and other warm-blooded animals (National Research Council 2000), fecal contamination is often associated with an increase in nutrient concentrations, predominantly nitrate and phosphorus, that can cause excessive algae growth and diminish the vital amount of oxygen in the water (U.S. EPA 2000).

Conceptually, source models for bacteria indicate higher bacterial loading from impervious land segments and urban areas, usually located in the central and downstream reaches of creeks. Potential sources within these reaches include equestrian facilities, other confined animal facilities, pet waste, wildlife, homeless encampments, and failing or leaking septic and sewer systems. The upper reaches have the potential for bacterial contributions from wildlife, recreational uses (i.e., equestrian and dog walking), and where present, livestock and pastures. Shorter residence times due to steeper slopes and higher precipitation usually do not allow for any degradation in the upper reaches while die-off can influence the amount of bacteria in the lower watersheds (Kim et al. 2007).

Often, the source for dry weather bacterial loading can be attributed to human sources, e.g., septic system and sewer leaks (Jensen et al. 2003), since there is very little runoff facilitated loading during the dry season. There could be a greater potential risk for septic system leaks in the studied area due to tectonic activity that could potentially lead to fractures in septic tanks or pipes.

Several factors contribute to the elimination of pathogen indicators in water. These factors include pH, temperature, solar radiation, nutrients, pesticides, and organic matter (Moore et al. 1988). We assume creek water pH to be near, or more likely above, neutral and to not affect the breakdown of bacteria but none of the influencing factors were measured in this study. Additionally, during larger runoff events, when the hydraulic retention time in the studied creeks is around 1-2 days, it is not likely that a depletion of bacteria occurred due to nutrient enrichment, pesticides, organic matter, or sunlight (Easton et al. 2005).

## **Methods**

### *Site Description*

The five studied creeks are located in unincorporated San Mateo County, traversing a rural to urban land use gradient and draining into the Pacific Ocean in Montara and Moss Beach (Figure 1). The coastal communities of Montara and Moss Beach border the Reserve and ASBS. Their population in the 2010 census was 2,909 and 3,103, respectively. The communities are situated approximately 20 miles (32 km) south of San Francisco and 50 miles (80 km) north of Santa Cruz. Montara and Moss Beach cover an area of 3.9 square miles (10.0 km<sup>2</sup>) and 2.3 square miles (5.8 km<sup>2</sup>), respectively. Montara and Moss Beach have mild weather throughout the year. January average maximum temperature (56.9°F or 13.8°C) and September average maximum temperature (73.1°F or 22.8°C) span a narrow range based on the long-term record ([www.weather.com](http://www.weather.com)). Typical of central California, most of the rainfall occurs from November through April, normally totaling more than 27 inches (69 cm). Nearby Montara Mountain, part of the Santa Cruz Mountains, rises to an elevation of 1,898 feet (578 m) above sea level. The area is characterized by the Franciscan Complex, a geological term for an accreted terrain of heterogeneous rocks (altered volcanic rocks (greenstones), deep-sea cherts, sandstone, limestone, serpentines, shales, and high-pressure metamorphic rock) found on and near the San Francisco Peninsula (Conradson et al. 1999). All five creeks originate on Montara Mountain. Martini and Kanoff Creek reach the ocean at

Montara State Beach, just north of the Reserve and ASBS boundary. Montara, Dean, and San Vicente creeks reach the ocean within the ASBS and Reserve boundary.

The monitored creeks are between two and four miles (3.2 – 6.4 km) long with an elevation drop of up to 1,500 ft (457 m) down to sea level. The sampling locations were selected to span from the creek mouths at the ocean to between 0.05 (100 m) and 2 (3,220 m) miles upstream depending on accessibility of the sites (Figure 1, Table 1). The monitored creek reaches span rural and urban land use. All five watersheds have confined animal facilities, estuarine habitat, public recreation, and open space (i.e., Fitzgerald Marine Reserve, McNee Ranch State Park, Golden Gate National Recreation Area Rancho Corral de Tierra, public beach access, trails), rare or endangered species habitat, rural/dirt roads, a state highway, wetlands, and septic and sewer systems. Montara, Dean, and San Vicente watersheds also have equestrian facilities and equestrian uses. With the exception of Dean Creek, all watersheds also have agriculture (row crops or flower farms). Medium-density residential land use is present in all watersheds but Martini Creek, and medium to high-density residential use occurs in Montara Creek and San Vicente Creek watersheds. Very low-density residential land use is seen in all watersheds but Dean Creek. The Montara State Marine Reserve and the Fitzgerald Marine Reserve are located at the bottom of the Montara, Dean, and San Vicente Creek watersheds. Municipal water sources or reservoirs are located in Montara Creek and San Vicente Creek watersheds. Neighborhood commercial use occurs in Kanoff Creek and Dean Creek watersheds.

Figure 1. Map of creeks and sampling locations within the study area. The lower number sampling sites are near the beach, and the higher numbers are upstream. Latitudes and longitude are listed in Table 1.



Table 1. Coordinates of the sampling locations.

Name	Type	Lat	Long
Montara 1	creeks	37.53702965100	-122.51870163100
Montara 2	creeks	37.53702159000	-122.50690645000
Montara 3	creeks	37.53824482600	-122.50458058400
Montara 4	creeks	37.53917476400	-122.50193763200
Montara 5	creeks	37.54588612500	-122.49564108500
Dean1	creeks	37.52559298300	-122.51649793800
Dean 2	creeks	37.52657534100	-122.51407348700
Dean 3	creeks	37.52786750200	-122.51036398900
Dean 4	creeks	37.53126339000	-122.50354886200
Dean 5	creeks	37.53522603900	-122.49270097100
Kanoff 1	creeks	37.54827006100	-122.51351154200
Kanoff 2	creeks	37.54577145000	-122.51145700200
Kanoff 3	creeks	37.54502965600	-122.50438831900
Kanoff 4	creeks	37.54641298000	-122.50252041900
Vicente 1	creeks	37.52409674000	-122.51749720200
Vicente 2	creeks	37.52342099500	-122.51572146100
Vicente 3	creeks	37.52290874600	-122.51125722200
Vicente 4	creeks	37.52276008600	-122.50876680900
Vicente 5	creeks	37.52252634900	-122.50626229600
Martini 1	creeks	37.55248063700	-122.51227370900
Martini 2	creeks	37.55390466800	-122.50704581500

### *Field Methods*

Three fecal indicators, total coliform, *E. coli*, and *Enterococcus*, were monitored in five creeks that drain the Montara and Moss Beach areas (Figure 1, Table 1). Two sampling events were conducted during the wet season coinciding with rainfall (January 20, 2012 and March 14, 2012), and two sampling events were conducted during the dry season (July 9, 2012 and August 15, 2012).

Approximately 100 mL of creek water were collected into plastic sampling containers at all sites. Water samples were collected mid-column at equal distance from both creek banks. Water samples were only collected when the creek had flowing water. Pondered water was not sampled and marked as dry conditions on the field data sheet. The sampling containers were pre-preserved with sodium

hydrochlorite and after filling were kept on ice until delivery to the lab. All samples were delivered to the San Mateo County Public Health Laboratory within six hours of collection.

Parallel to the collection of water samples, researchers from the Civil and Environmental Engineering Laboratory at UC Davis conducted genetic analysis of water samples from the beach sites during one of the rain events (pre-, during, and post-rainfall) and one of the dry season events that were monitored for this study. UC Davis' creek samples were assessed to determine the occurrence of genetic markers for *Bacteroidales*. This additional microbial source tracking will provide information on the likelihood of fecal contamination from human, bovine, dog, and horse sources.

#### *Analytical Methods*

For the analysis of *Enterococcus*, 10 ml of the sample was pipetted to a sterile container of 90 ml de-ionized water. A packet of the Enterolert™ test kit (IDEXX Laboratories, Westbrook, Maine, USA) was mixed into the dilution. The sample was poured into an IDEXX Quanti-Tray and then into a 41 °C incubator. Results were read after 24 hours. Reported counts were obtained from the IDEXX Quanti-Tray 2000 MPN Table. The test method employed to detect *Enterococcus* is called Enterolert from IDEXX. It uses the Defined Substrate Technology (DST). When B-glucosidase enzyme from the *Enterococcus* is mixed with 4-methyl umbellifery B-D-glucoside from the Enterolert test kit, the sample fluoresces. It can detect *Enterococcus* at 10 colony-forming units (cfu) per 100 mL. The reporting limit is 24,196 most probable number (MPN) per 100 mL.

For the analysis of total coliform and *E. coli*, a pouch of the Colilert® 18 test kit (IDEXX Laboratories, Westbrook, Maine, USA) was mixed into a 10 to 1 dilution sample. The sample was poured into a Quanti-Tray and was incubated at 35 °C. Results were read between 18 to 22 hours after incubation. Reported counts were obtained from the IDEXX Quanti-Tray 2000 MPN Table. Colilert® 18 test kit uses the DST to detect total coliform and *E. coli*. Ortho-nitrophenyl-B-D-galactopyranoside (ONPG) from the Colilert® 18 test kit detects B-D-galactosidase enzyme from the total coliform bacteria by turning the sample to yellow. 4-methylumbelliferyl-B-D-glucuronide (MUG) from the test kit detects the enzyme B-glucuronidase produced by *E. coli* when the sample fluoresces. It can detect total coliform and *E. coli* at 10 cfu per 100/mL. The reporting limit is 24,196 MPN per 100 mL.

## Results

FIB concentrations were generally elevated above guidelines at all sites during the wet and the dry season sampling events. Out of 78 samples collected, 73 (94%) exceeded the U.S. Environmental Protection Agency's (EPA) freshwater criterion for contact recreation for *Enterococcus* (U.S. EPA 2003) of 33 MPN/100 mL. Exceedances ranged from 52 to 24,196 MPN/100mL. *E. coli* concentrations exceeded the EPA criterion of 126 MPN/100 mL in 63 out of 78 samples (81%). Exceedances for *E. coli* ranged from 175 to 24,196 MPN/100 mL. Even though the EPA criterion is derived from the geometric mean of at least five samples collected over the course of 30 days, the exceedances at most sites in this study were so far above the criterion that potential adverse impact due to the high concentrations in the studied watersheds should remain a concern especially in areas where there is high potential for human exposure.

The five *Enterococcus* samples that did not exceed the criterion were all collected in the dry season (four samples on July 9, 2012 and one sample on August 15, 2012). Out of those five samples, two samples were collected from the central reach of Dean Creek, two samples were from the lower reach of Kanoff Creek (including the beach site), and one sample was from the upstream portion of Montara Creek. However, at these locations the low concentrations were not observed during both dry season events.

Out of the 15 *E. coli* samples that did not exceed the criterion, four were collected during the wet season (all four on January 20, 2012) and 11 were collected during the dry season (six in July and five in August). The lower reach of Martini Creek (including the beach site) and the lower and central reaches of Kanoff Creek showed lower concentrations in January. In July and August, Dean Creek seemed to have lower bacterial concentrations with four samples below the suggested criterion and D3 (central reach) repeating the low July concentration in August. Also, Ma2 (lower reach) repeated the low bacterial concentrations from January and July in August. Furthermore, the upper Montara Creek watershed showed bacterial concentrations below the EPA criterion in July and August.

Wet weather samples (high flow conditions) were usually higher in FIB concentrations than the dry weather samples (low flow conditions). This trend has been observed in previous studies (Giddings and Oblinger 2004, Kistemann et al. 2002). FIB concentrations were also higher during the second rain event of the wet season that was monitored. Precipitation later in the wet season that often concurs with

saturated soils will facilitate bacterial transport from the surrounding areas to the creeks. Additionally in this study, the second monitored storm was of higher intensity, with increased streamflow and higher creek stages, also aiding the transport of bacteria.

### *Martini Creek*

Martini Creek had only two sampling sites due to the rural nature of the upper watershed and the difficulty for access. Upstream of site Ma2 the land use includes some open space, for example McNee Ranch State Park and Corral de Tierra, managed by the Golden Gate National Recreation Association. Pets are allowed on all trails and horses are permitted on designated trails. An equestrian facility is located immediately upstream and downstream of Ma2. Additionally, a small agricultural field is located downstream of Ma 2. Bacterial input into Martini Creek seemed to be less than in the other studied watersheds probably due to the lack of urbanization (Figure 2). The dry season samples (July 9 and August 15, 2012) showed a pattern that was expected to be more visible throughout this study, with lower bacterial concentrations in the upper watershed (*E. coli*: 10 and 20 MPN/100 mL, respectively and *Enterococcus*: 96 and 52 MPN/100 mL, respectively) and higher concentrations in the lower reaches and at the beach sites (*E. coli*: 259 and 41 MPN/100 mL and *Enterococcus*: 292 and 842 MPN/100 mL, respectively). This expectation is caused by the hypothesis that more urban bacterial sources in the downstream reaches of the creeks would lead to higher bacterial input. Even though there is no urban development in the Martini Creek watershed, the beach site of Martini Creek includes a popular parking lot with beach access that does not have any restroom facilities.

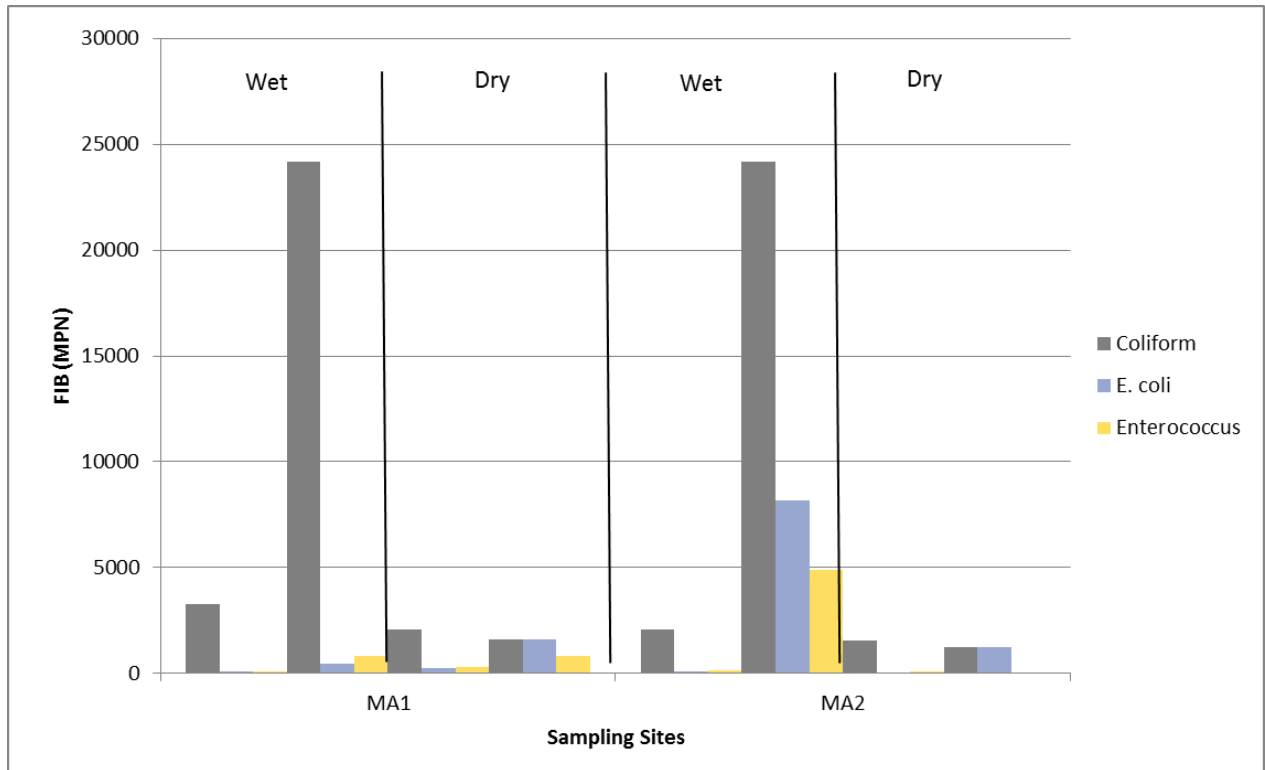


Figure 2. Fecal Indicator Bacteria in Martini Creek, displayed as most probable numbers. Ma1 indicates the beach site. The x-axis shows the sampling sites, the y-axis shows FIB concentrations in MPN/100 mL.

However, decreasing concentrations of *E. coli* and *Enterococcus* at the beach site of Martini Creek and the central reaches of other monitored creeks during the second rainy season event could be due to relatively clean subsurface runoff from agricultural irrigation that dilutes creek water in the vicinity of the sampling point or possibly relatively clean groundwater flows. Therefore, a conclusion to spatial and/or temporal bacterial loading in this watershed cannot be made.

#### *Kanoff Creek*

Four sites were sampled along Kanoff Creek with the central and upstream reaches of the creek touching the northern boundary of the community of Montara and draining urbanized areas. K1 is located at Montara State Beach, K2 and K3 include some open space to the north and residential areas immediately south of the sampling locations. K4 is located downstream of Mc Nee Ranch State Park, and confined animals are immediately located downstream of K4 and between K2 and K3. *E. coli* concentrations at the beach site (K1) were relatively low compared to K2 (approximately 0.25 mile

upstream) during the wet season (Figure 3). *E. coli* concentrations were also low at K3 compared to K4. These lower concentrations could be related to die off or reduced bacterial survival in water without any significant bacterial input into the creek upstream of the beach site K1 or K3. Meanwhile, concentrations for *Enterococcus* showed almost the opposite distribution. The upper watershed sites were dry during the dry season sampling events and the lower sites were low in comparison to wet season concentrations, with 50% of the samples being below EPA guidelines. Martini and Kanoff Creek in their entirety and Montara Creek in the uppermost watershed had lower bacterial concentrations than the other creek sites that were located within the urban boundaries of Montara and Moss Beach (Figure 7).

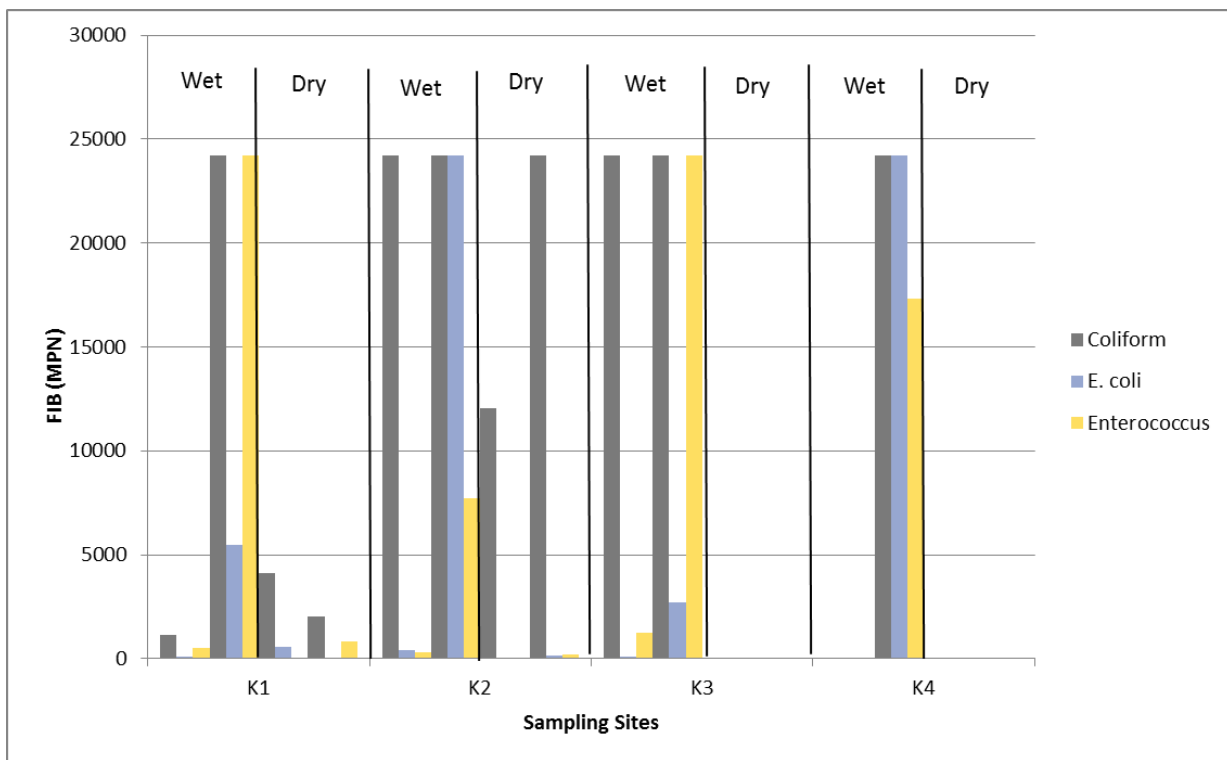


Figure 3. Fecal Indicator Bacteria in Kanoff Creek, displayed as most probable numbers. K1 indicates the beach site. Sites with no data were not collected during the dry season due to no flow in the creek bed. The x-axis shows the sampling sites, the y-axis shows FIB concentrations in MPN/100 mL. Note low *E. coli* concentrations at beach site during the wet season sampling.

### *Montara Creek*

Montara Creek is one of the longer creeks monitored for this study. Samples were collected at five sites along the creek with the upstream site being located above the urban influence. Sites Mo1 through Mo4 drain residential areas in the community of Montara and the creek flows into the Pacific Ocean at the Montara Lighthouse. Open space is the dominant land use of the upper watershed, with limited agricultural fields and floriculture present in the upper watershed as well. Equestrian facilities are located between Mo1 and Mo2 and between Mo4 and Mo5. The sampling results from the Montara Creek sites showed a bacterial concentration pattern that indicates low bacterial presence in the upstream reaches, elevated bacterial presence in the central reaches, and high bacterial concentrations at the downstream sites (Figure 4). This is the pattern that was expected to show for most creeks due to higher bacterial loading in the urban areas from potential pet waste, leaking sewer lines, etc. (Jensen et al. 2003).

A six-times increase in *Enterococcus* and *E. coli* (Figure 8) concentrations was observed in Montara Creek between Mo2 (downstream reach) and Mo1 (beach site) during the first rainy season event.

Additionally, a two to three-time increase was observed during both dry season sampling events. This was a longer stretch of the creek (about 0.5 miles long, between the south end of Cedar Street and the Montara Lighthouse) that should be investigated further for bacterial loading. This increase may be attributed to the increase in horse/confined animal facilities that are within this stretch between Mo2 and Mo1. These could be a potential source for bacteria but the source may also be related to pets, homeless encampments, or sewer/septic systems, which also occur in this reach.

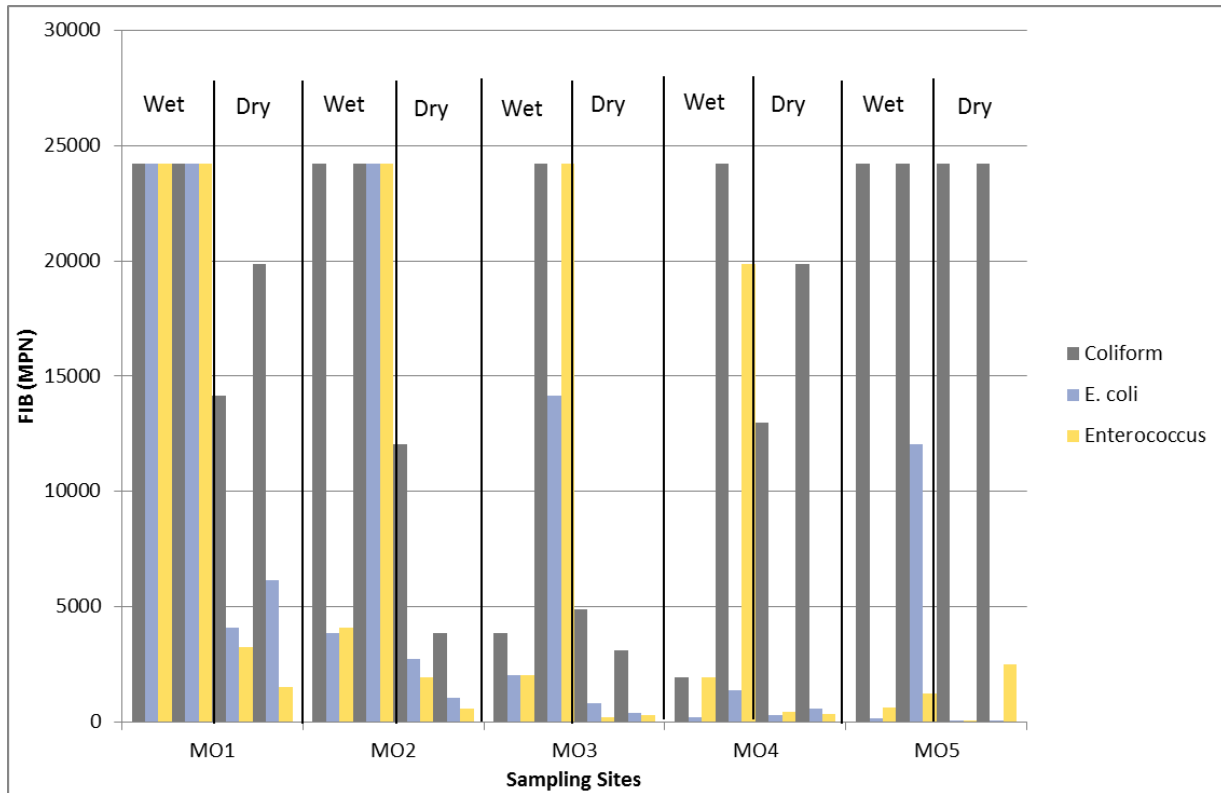


Figure 4. Fecal Indicator Bacteria in Montara Creek, displayed as most probable numbers. Mo1 indicates the beach site. The x-axis shows the sampling sites, the y-axis shows FIB concentrations in MPN/100 mL.

#### Dean Creek

Dean Creek parallels Sunshine Valley Road almost through its entire length with medium-density residential use between D4 and D1. Upstream of D4 very low-density residential use occurs. A small commercial area is located in the lower reaches of the creek (between D3 and D1). Equestrian facilities exist in the upper reach of the creek. High concentrations (greater than 24,196 MPN per 100 mL) of all three bacterial indicators were observed during the March wet season sampling at all but the upstream sampling site (Figure 5). The primary change in land use from site D5 to D4 is the increase in equestrian facilities along Sunshine Valley Road. However, trails and horse facilities are also present upstream of D5. Dry season sampling showed high concentrations of total coliform but not of *Enterococcus* and *E. coli*, except for the most upstream site that had high concentrations (greater than 24,196 MPN per 100 mL) for all three indicators during the July sampling event. Sites D4 and D5 in the upstream reach of the creek did not have any flow during the August sampling event, therefore the July peak in concentrations could not be confirmed.

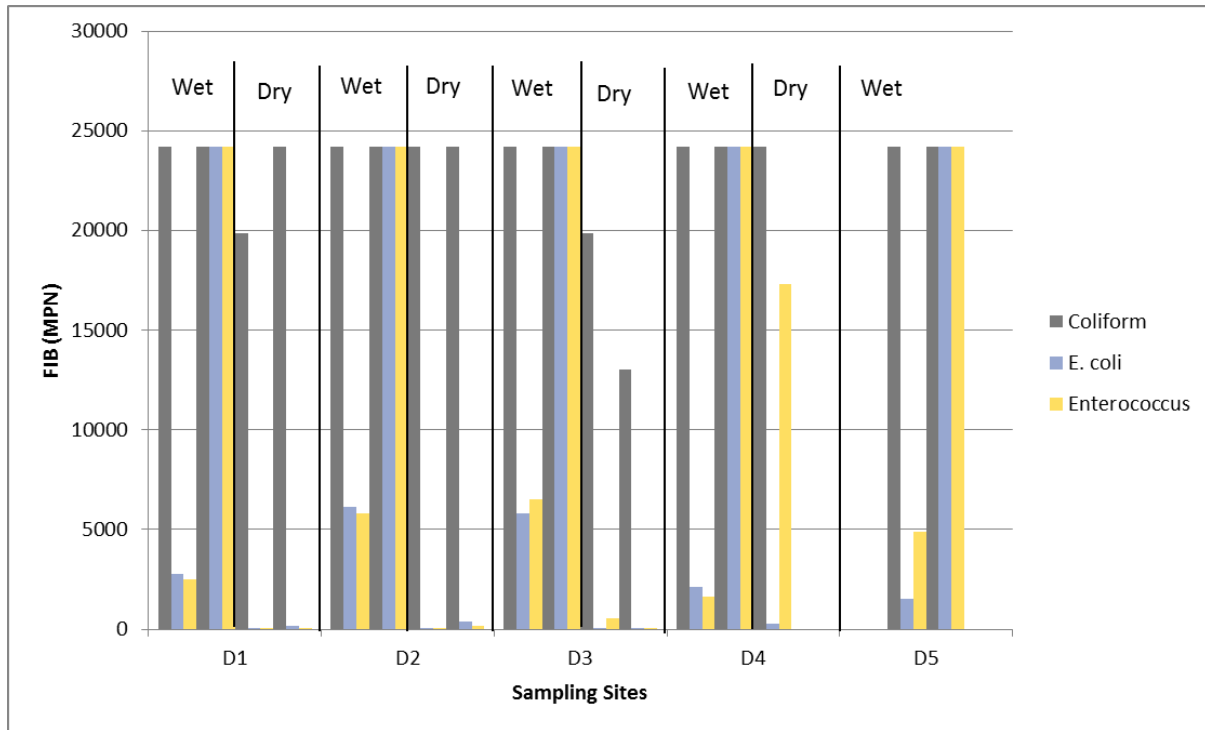


Figure 5. Fecal Indicator Bacteria in Dean Creek, displayed as most probable numbers. D1 indicates the beach site. Sites with no data were not collected during the dry season due to no flow in the creek bed. The x-axis shows the sampling sites, the y-axis shows FIB concentrations in MPN/100 mL.

#### *San Vicente Creek*

San Vicente Creek is, together with Montara Creek, one of the longer creeks monitored in this study. The upper watershed of San Vicente Creek is mostly open space. Agricultural use and row crops are present in the watershed upstream of V5. Like Dean Creek, San Vicente Creek also has equestrian facilities upstream of V5 and downstream of V4, in addition to trails and reservoirs. Similar to Dean Creek, San Vicente Creek showed high concentrations of all three indicator bacteria during the March sampling event except for the most upstream location (Figure 6). For all other sampling events *Enterococcus* input seemed to be elevated at V2 and V3 and decreasing toward the beach site (V1) again. However, the beach site was still far above the federal standard (between 45 to 690 times higher) recommended for safe water contact for all sampling events.

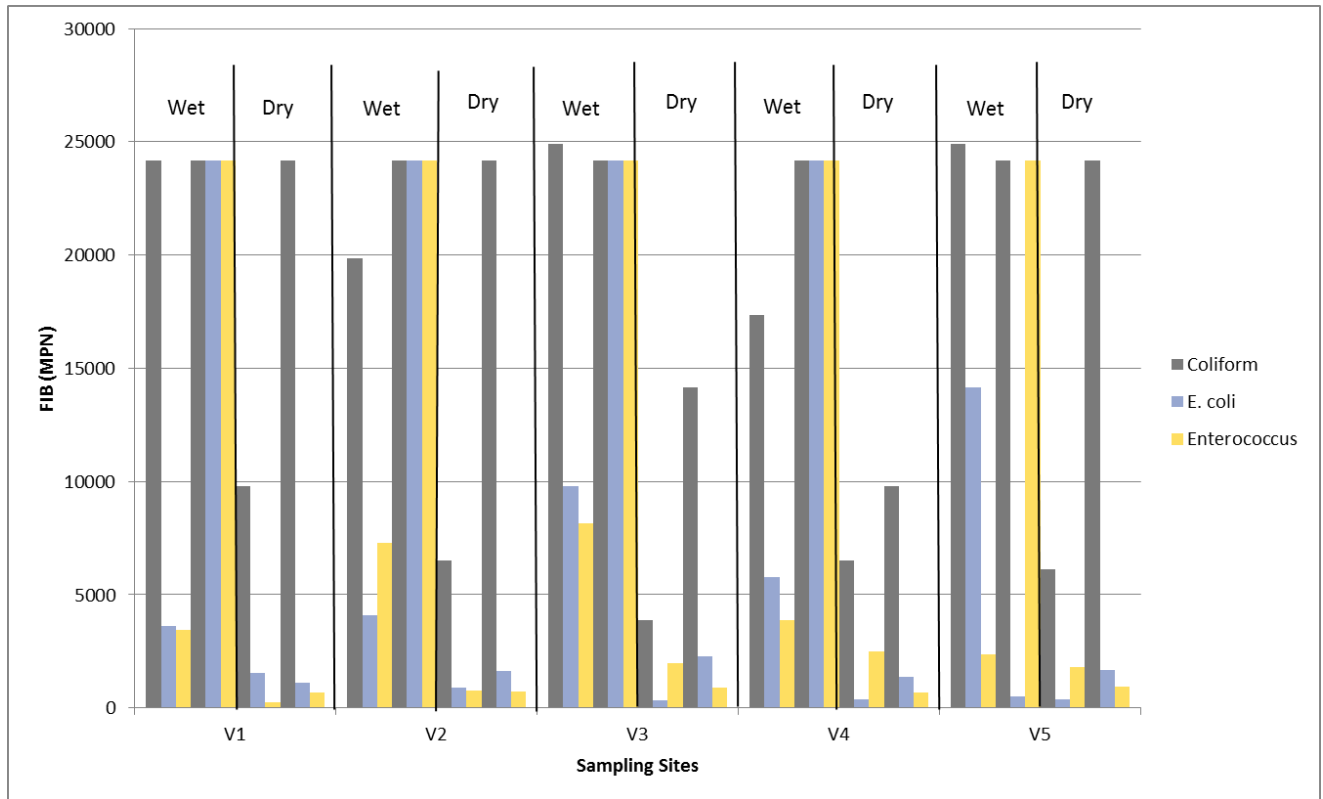


Figure 6. Fecal Indicator Bacteria in San Vicente Creek, displayed as most probable numbers. V1 indicates the beach site. The x-axis shows the sampling sites, the y-axis shows FIB concentrations in MPN/100 mL.

Another notable observation was that during the January sampling event the *E. coli* concentration at V5 was much higher than the *Enterococcus* concentration (14,136:2,382) (Figure 7 and 8), suggesting that the bacteriological contamination originates rather from an animal source than a human source. However, the recognition that the number of fecal streptococci (which include *Enterococcus*) in animal feces is considerably higher than fecal coliform numbers (which include *E. coli*) is highly debated. The second wet season event in March showed very high concentration for *E. coli* and *Enterococcus* at almost all sites along San Vicente Creek.

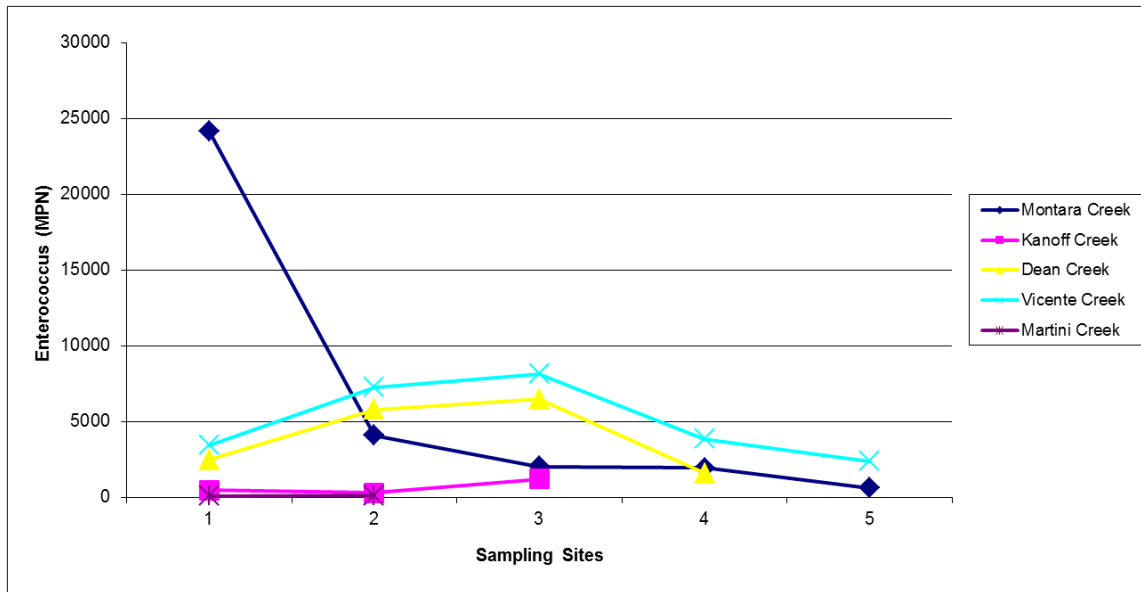


Figure 7a. *Enterococcus* concentrations on January 20, 2012. Creeks sites ranging from 5 (upstream) to 1 (beach sites).

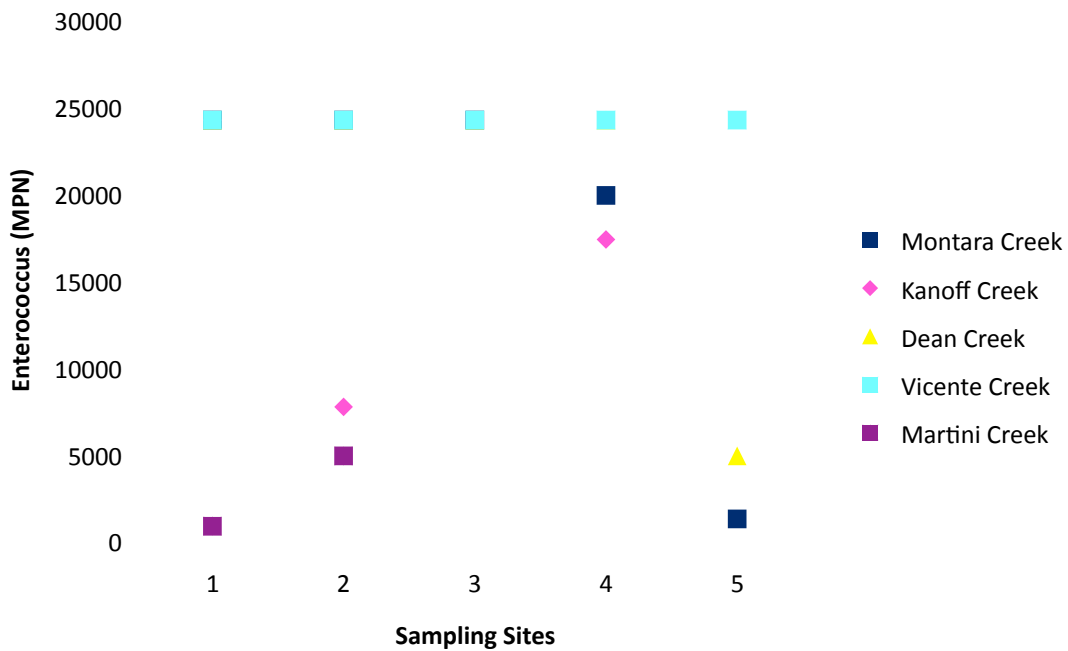


Figure 7b. *Enterococcus* concentrations on March 14, 2012. Creeks sites ranging from 5 (upstream) to 1 (beach sites). San Vicente Creek data for sites 1 and 2 overlap results from Montara Creek.

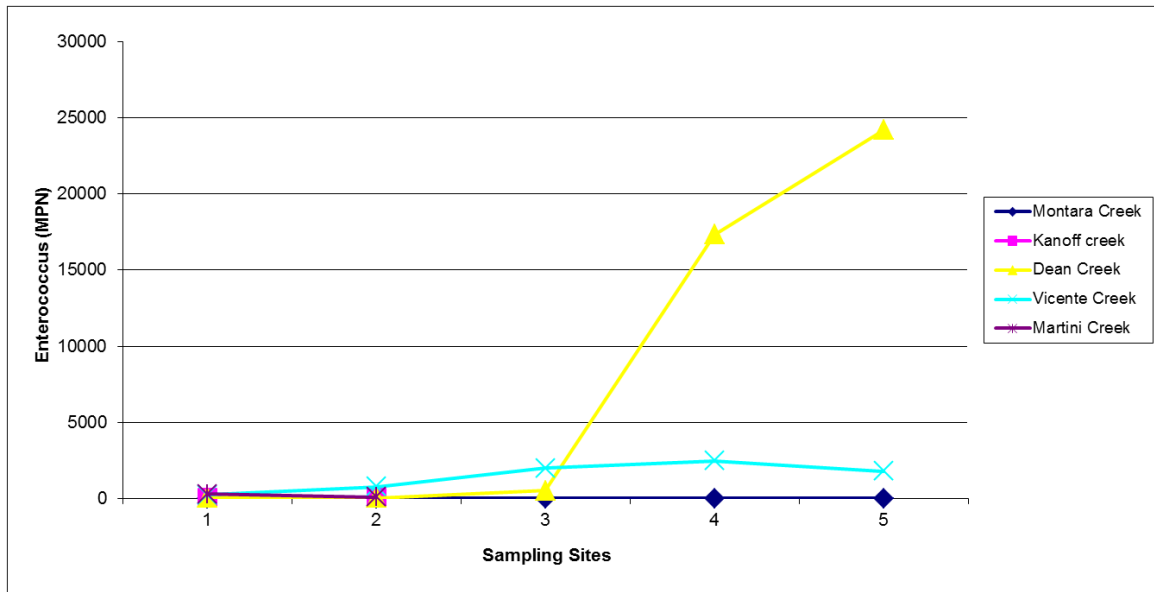


Figure 7c. *Enterococcus* concentrations on July 9, 2012. Creeks sites ranging from 5 (upstream) to 1 (beach sites).

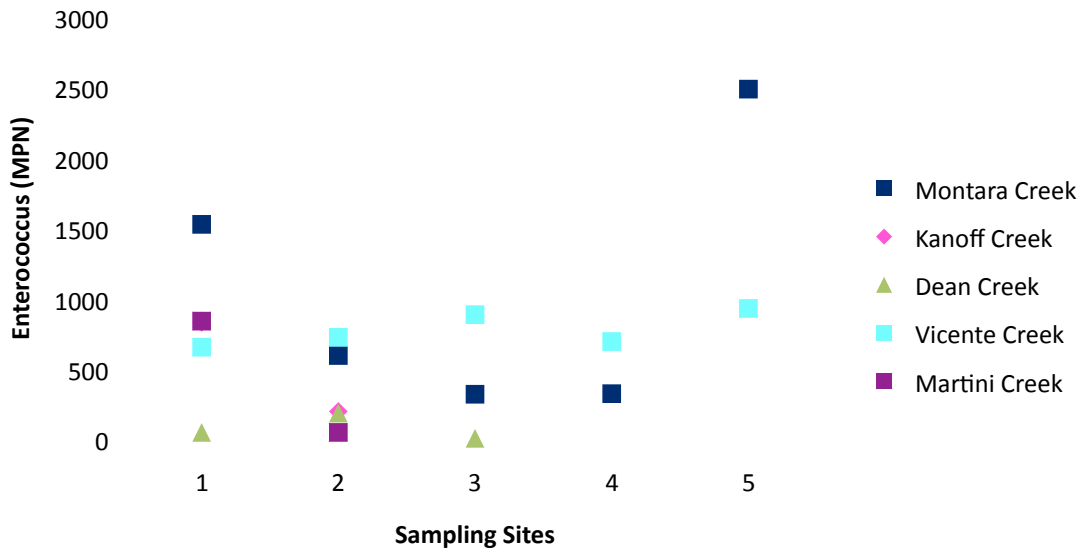


Figure 7d. *Enterococcus* concentrations on August 15, 2012. Creeks sites ranging from 5 (upstream) to 1 (beach sites).

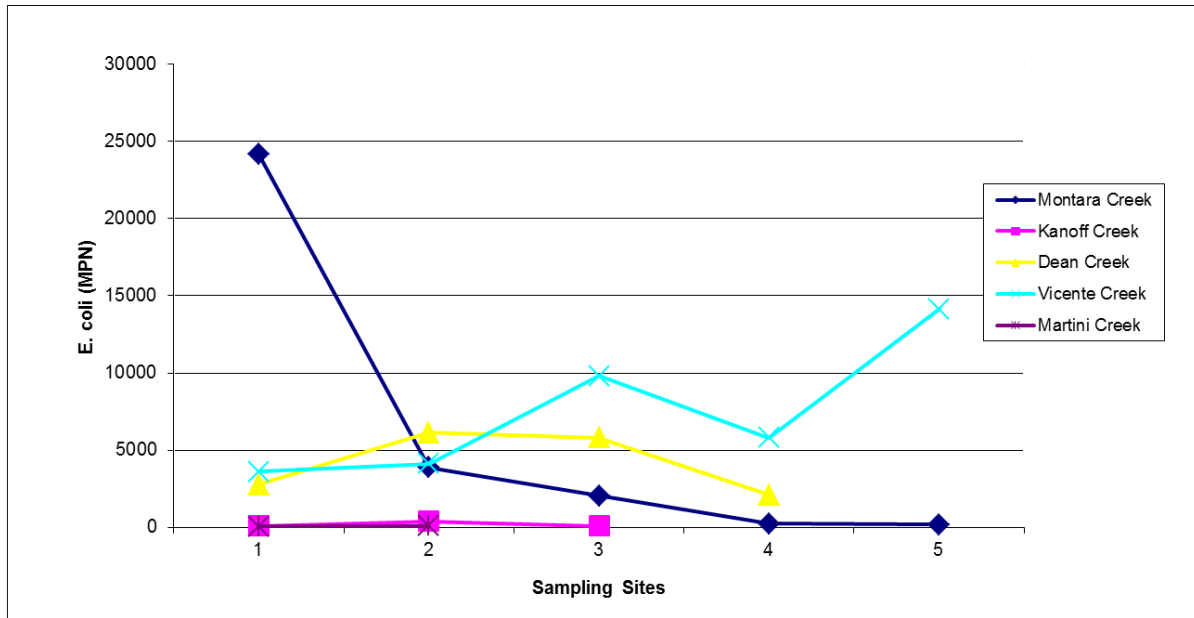


Figure 8a. *E. coli* concentrations on January 12, 2012. Creeks sites ranging from 5 (upstream) to 1 (beach sites).

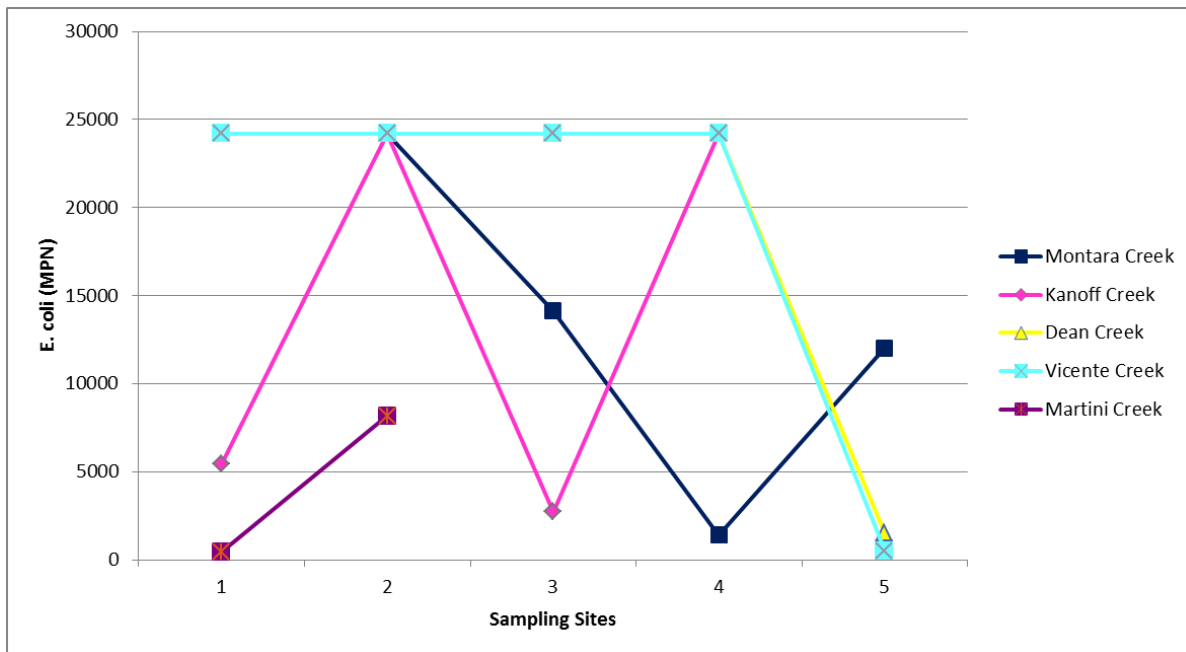


Figure 8b. *E. coli* concentrations on March 14, 2012. Creeks sites ranging from 5 (upstream) to 1 (beach sites). San Vicente Creek data for sites 1 and 2 overlap results from Montara Creek.

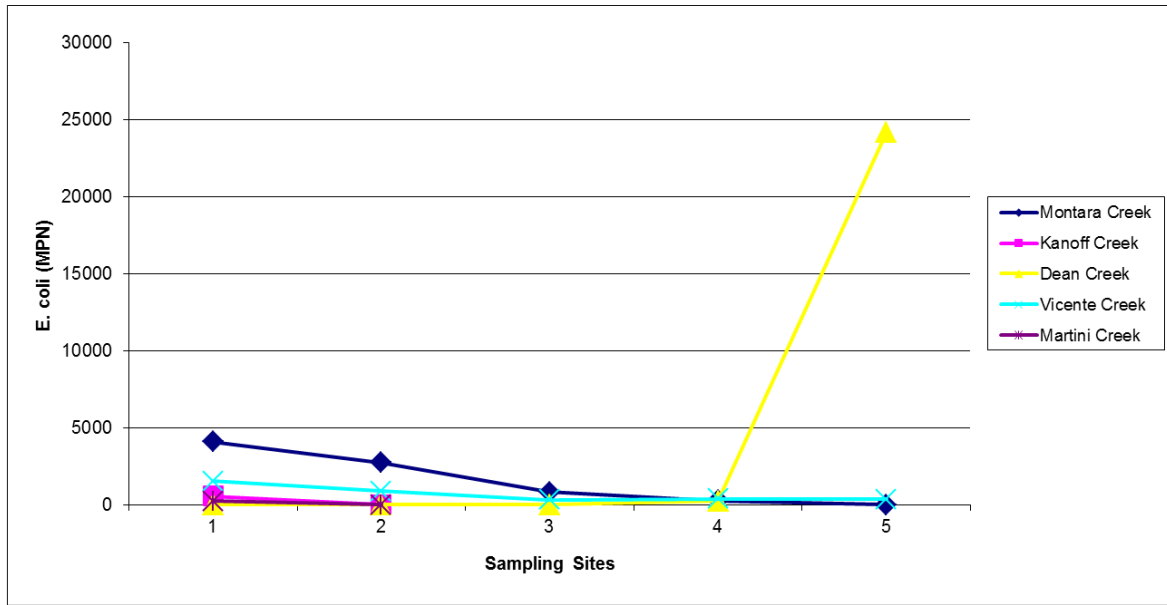


Figure 8c. *E. coli* concentrations on July 9, 2012. Creeks sites ranging from 5 (upstream) to 1 (beach sites).

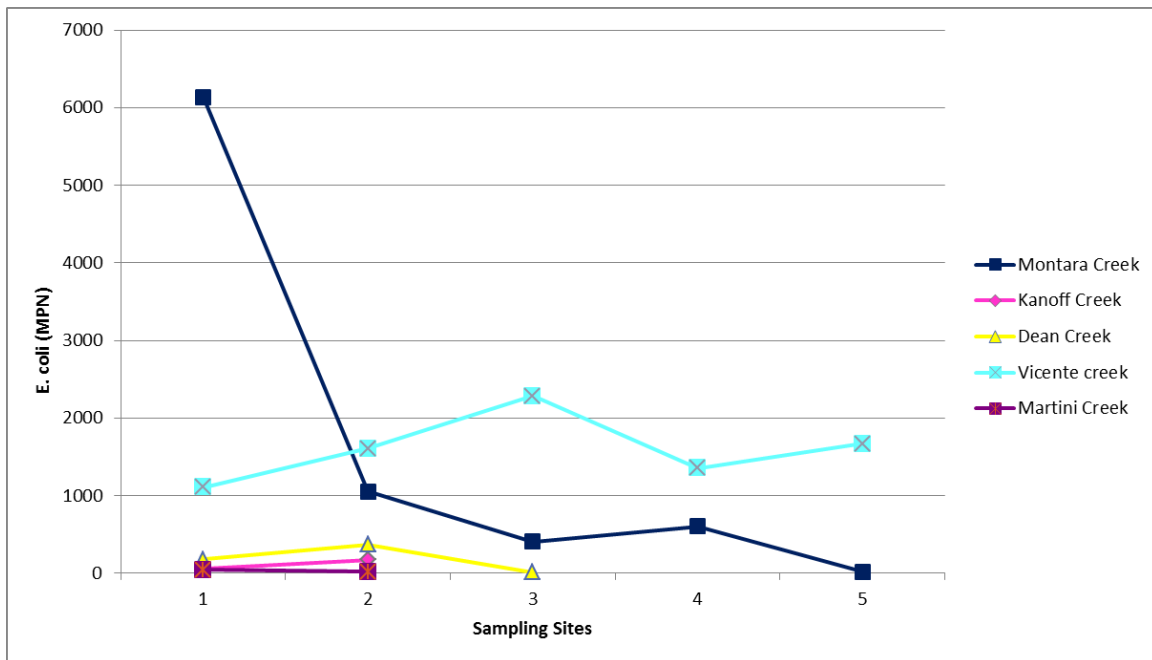


Figure 8d. *E. coli* concentrations on August 15, 2012. Creeks sites ranging from 5 (upstream) to 1 (beach sites).

## Conclusion

FIB concentrations exceeded EPA recommended standards at most sites during both the dry and the wet season. However, the concentrations were generally lower in the dry season. The bacterial concentrations in Martini and Kanoff Creek, the less urbanized watersheds, were generally lower than in the more urbanized watersheds.

The dynamic of bacterial loading in creeks traversing a rural to urban gradient is very complex and cannot be fully understood using the sampling design employed during this study. However, the study results presented demonstrate that concerns about possible impacts to humans and wildlife exposed may be warranted if the mechanisms for exposure or sources are not controlled. The results suggest that a bacterial tracer experiment would be beneficial in identifying possible sources of spatial and temporal bacteria loading. By introducing a bacteria tracer, using a unique soil bacteria at a specific concentration, attenuation of bacteria and spatial distribution could be quantified. In combination with stream gauges, loads of bacterial contamination could be calculated canceling out the effects of dilution from subsurface drainage, tributary influent, and groundwater interactions. A tracer experiment including flow data would cancel out some of the variation and noise that the data exhibited during this study.

One notable change in bacterial loading potentially occurred in Montara Creek between the south end of Cedar Street and the Montara Lighthouse. During the January sampling event concentrations for *Enterococcus* and *E. coli* were at least six times higher when creek water reached the beach at the Lighthouse. A two to three-time increase was observed between those sites during both dry season sampling events. Further investigation to address the source of this bacterial loading is recommended, especially since this is a stretch of Montara Creek between the communities of Montara and Moss Beach that is not densely populated with probably less than 5% impervious surfaces.

Genetic source tracking of bacteria at the farthest downstream sites for all five creeks was conducted by UC Davis. The samples for the UC Davis study and this study were collected concurrently during one rainy season and one dry season event. Additional information may be provided by combining the results of both studies.

## References

- Easton J.H., Gauthier J.J., Lalor M., Pitt R.E. 2005. Die-off of Pathogenic *E. coli* O157:H7 in Sewage Contaminated Waters. *AWRA Journal of the American Water Resources Association*, Vol. 41, pp. 1187-1193.
- Conradson D., Welch V., Breen B., Corelli T., Danielson M., DeMouthe J., Long D., Niesen T, Oxley B. 1999. *The Natural History of the Fitzgerald Marine Reserve*. Friends of Fitzgerald Marine Life Refuge, Moss Beach, CA, USA.
- Giddings E. M., Oblinger C. J. 2004. Fecal-Indicator Bacteria in the Newfound Creek Watershed, Western North Carolina, During a High and Low Streamflow Condition. *USGS Scientific Investigations Report 2004 – 5257*.
- Jensen S.F., Norton C., Collins K.J. 2003. *Emigration Watershed Non-point Pollution Assessment: Coliform Bacteria Water Quality Analysis*. Final Project Report. Salt Lake County Department of Public Works, Engineering Division, Water Resources Planning and Restoration Program.
- Kim S.M., Benham B.L., Brannan K.M., Zeckoski R.W., Yagow J.R. 2007. Water Quality Calibration Criteria from Bacteria TMDL Development. *Applied Engineering in Agriculture*, Vol. 23, pp. 171 – 176.
- Kisteman T., ClaBen T., Koch C., Dangerndorf F., Fisheder R., Gebel J., Vacata V., Exner M. 2002. Microbial Load of Drinking Water Reservoir Tributaries during Extreme Rainfall and Runoff. *Applied Environmental Microbiololy.*, Vol. 68, pp. 2188-2197.
- Moore J.A., Smyth J., Baker S., Miner J.R. 1988. *Evaluating Coliform Concentrations in Runoff from Various Animal Waste Management Systems*. Special Report 817. Agricultural Experimental Stations, Oregon State University, Corvallis, OR, USA.
- National Research Council. 2000. *Infectious Diseases. From Monsoon to Microbes: Understanding the Ocean’s Role in Human Health*. National Academy of Science, 43 - 58.

US Environmental Protection Agency. 1997. Monitoring Water Quality. Office of Water. US Environmental Protection Agency 841-B-97-003, Washington, DC, USA.  
<http://www.epa.gov/owow/monitoring/volunteer/stream/vms511.html>

US Environmental Protection Agency. 2000. Implementation Guidance for Ambient Water Quality Criteria for Bacteria, May 2002 Draft. U. S. Environmental Protection Agency, Washington, D. C.  
<http://www.epa.gov/ost/standards/bacteria/bacteria.pdf>.

US Environmental Protection Agency. 2003. Bacterial Water Quality Standards for Recreational Waters (Freshwater and Marine Waters). Office of Water, EPA-823-R-03-008, Washington, DC, USA.

US Environmental Protection Agency. 2004. EPA Proposes More Protective Water Quality Standards for Bacteria. U. S. Environmental Protection Agency Washington, D. C.  
<http://epa.gov/waterscience/beaches/bacteria-rule-fs.htm>

**JAMES V. FITZGERALD AREA OF SPECIAL  
BIOLOGICAL SIGNIFICANCE  
POLLUTION REDUCTION PROGRAM**

**MICROBIAL SOURCE TRACKING STUDY  
SUMMARY REPORT**

Submitted by

Minji Kim

Prof. Stefan Wuertz

Department of Civil and Environmental Engineering

University of California, Davis

One Shields Avenue, Davis, CA 95616

**February 2013**

## TABLE OF CONTENTS

Abstract.....	1
1. Introduction.....	2
2. Materials and methods .....	3
2.1 Sample collection and processing .....	3
2.2 Nucleic acid extraction .....	5
2.3 <i>Bacteroidales</i> and <i>Acinetobacter</i> qPCR.....	5
2.4 Statistical analysis .....	6
3. Results.....	7
3.1 <i>Bacteroidales</i> in surface water .....	7
3.2 <i>Bacteroidales</i> in sediments and biofilm .....	9
4. Discussion.....	16
5. Conclusion .....	19
6. References.....	20

## LIST OF TABLES

Table 1 Latitude and longitude of MST sampling sites monitored in 2012 .....	4
Table 2 MST sampling schedules and water quality parameters.....	11
Table 3 Concentrations and sample limits of detection for host-associated <i>Bacteroidales</i> in water at creeks in wet and dry season .....	12
Table 4 Concentrations and sample limits of detection of host-associated <i>Bacteroidales</i> in water in first flush events .....	13
Table 5 Concentrations and sample limits of detection of host-associated <i>Bacteroidales</i> in sediments and biofilm in wet and dry season.....	14
Table 6 Concentrations and sample limits of detection of host-associated <i>Bacteroidales</i> in field blanks.....	15
Table 7 Replicate percent differences in environmental samples and field duplicates (for water samples).....	15

## LIST OF FIGURES

Figure 1 A map of the James V. Fitzgerald ASBS and watersheds. Numbers denote MST sampling locations.....	4
Figure 2 Photos of collected biofilm samples (submerged aquatic vegetation) at Kanoff Creek (A) and Montara Creek (B) .....	5

## ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of variance
ASBS	Area of special biological significance
BMP	Best management practice
cm	Centimeter
FIB	Fecal indicator bacteria
g	Gram
gc	Gene copies
L	Liter
μ	Micro
m	Milli or meter
MST	Microbial source tracking
PMA	Propidium monoazide
QA/QC	Quality assurance/quality control
qPCR	Quantitative polymerase chain reaction
RNA	Ribonucleic acid
RPD	Replicate percent difference
S	Siemens
SFEI	San Francisco Estuary Institute
S <sub>LOD</sub>	Sample limit of detection
UCD	University of California, Davis

## **Abstract**

The James V. Fitzgerald Marine Reserve (Reserve) is a biologically significant habitat for diverse species as well as a popular recreational area. However, impaired water quality due to fecal contamination has been reported at the Reserve and San Vicente Creek. We conducted a microbial source tracking (MST) study based on genetic analysis of host-associated *Bacteroidales* to determine the contribution of human, bovine, dog, and horse sources to fecal contamination in the five watersheds draining to the Pacific Ocean in the vicinity of the Reserve. A total of 58 samples from water, sediment, and biofilm matrices were collected during 7 monitoring events in 2012.

Universal *Bacteroidales* derived from all warm-blooded animals were detected at all sites in 7 sampling events. Concentrations of universal marker in water were elevated during rain in the wet season and first flush events compared to concentrations before and after rain. In the dry season, universal *Bacteroidales* concentrations in water at all sites were generally lower than those in the wet season and first flush sampling events. Biofilm samples usually contained higher universal marker concentrations compared to sediment samples collected at the same sites. Human-associated *Bacteroidales* were not often detected in the wet and dry seasons but were prevalent in water throughout the first flush events. Bovine-associated *Bacteroidales* were found in water at Kanoff and San Vicente Creek during rain in the wet season. Bovine marker was frequently found in sediments or biofilm at all sites throughout the wet season. Dog-associated *Bacteroidales* were the most frequently detected host marker in water as well as in sediments and biofilm at all sites in the wet season. On the contrary, dog marker was less frequently detected in dry and first flush events. Horse-associated *Bacteroidales* were found at high concentrations in water at Dean and San Vicente Creek during rain in the wet season. During the dry season, the horse marker was detected at all sites, but it was not a predominant fecal source in water. The horse marker was more often detected in sediment and biofilm samples than in water samples.

The monitoring study provides good insights into the prevalence of host-associated *Bacteroidales* at five creeks draining into the Reserve. Future monitoring studies that can distinguish host-associated *Bacteroidales* DNA from intact and impaired cells could allow

determination of the age of fecal pollution and may provide more information about potential health risks.

## **1. Introduction**

The James V. Fitzgerald Marine Reserve (Reserve) is a biologically significant habitat for diverse species as well as a popular recreational area. However, impaired water quality due to fecal contamination has been reported at the Reserve and San Vicente Creek. As part of the monitoring plan of this Area of Special Biological Significance (ASBS) Pollution Reduction Program, we conducted a microbial source tracking (MST) study based on genetic analysis of *Bacteroidales*. The main goal was to provide information about the primary sources of fecal contamination in the five watersheds draining to the Pacific Ocean in the vicinity of the Reserve and to assist in the selection of the appropriate best management practices (BMPs) to reduce fecal pollution. A total of 58 samples (excluding QA/QC samples) from water, sediment, and biofilm matrices were collected at the five creeks during 7 monitoring events in 2012. All samples were analyzed to determine the prevalence of universal, human-, bovine-, dog-, and horse-associated *Bacteroidales*. In addition, the probabilistic model developed at University of California, Davis (UCD) was applied to estimate the true value of host-associated *Bacteroidales*. Fecal indicator bacteria (FIB) including total coliforms, *Escherichia coli*, and *Enterococcus* spp. were monitored concurrently with MST by the San Francisco Estuary Institute (SFEI).

## 2. Materials and methods

### 2.1 Sample collection and processing

Water samples were collected from the five creeks draining to the Pacific Ocean in the vicinity of the Reserve including Martini, Kanoff, Montara, Dean, and San Vicente Creeks (Figure 1 and Table 1). In order to capture all potential sources, samples were collected immediately upstream of the creek confluences with the Pacific Ocean. Water samples were collected 7 times through the wet season (March), dry season (July), and first flush events (October) in 2012. In the wet season and first flush sampling events, water samples were collected at three stages based on rainfall conditions (pre-, during-, and post-rain). At every sampling event, one field blank and one field duplicate sample were produced for quality assurance/quality control (QA/QC) purposes. Water grab samples (10 to 20 L) were obtained by directly submerging sample carboys or by using sterile scoops just below the water surface after pre-rinsing in the creek. Sediment and biofilm (submerged aquatic vegetation) samples were collected using sterile spoons and placed in sterile bottles (Figure 2). Additional surface water was filled into the bottle to minimize oxygen contact and dehydration of sediment and biofilm samples. Water quality parameters including temperature, pH, conductivity, salinity, and dissolved oxygen concentration were measured *in situ*. Total suspended solids (TSS) were determined using a Standard Method 2540D (APHA 1998). After collection, samples were kept chilled with ice packs and transported to the laboratory within 6 hours. Upon arrival, the samples were kept at 4°C in a temperature-controlled room followed by processing within 48 hours. For better quantification of nucleic acids, 10 to 20 L water samples were concentrated to approximately 150 mL using a Fresenius hollow fiber ultrafiltration (HFF) system (Rajal et al. 2007). The surrogate *Acinetobacter baylyi* ADP1 was added into all water samples to calculate filtration recoveries by comparing concentrations of *A. baylyi* in subsamples of pre-filtration (feed) and post-filtration (retentate) samples.

Sediment samples were processed by adding 50 g of sediments and 50 mL of 1% Tween 80/NaOH, pH 7.0 solution in a 250-mL sterile bottle followed by vigorous hand-shaking of the mixture for 2 min to elute microorganisms attached to sediment surfaces. After 10 min of deposition of suspended particles in water, the supernatants were collected and used for quantitative polymerase chain reaction (qPCR). The DNA concentrations in supernatants were

converted to those of dry weight of sediments. Biofilm samples were processed in the same manner. Dry weights of sediments and biofilm were determined after drying at 105°C for 24 hours.

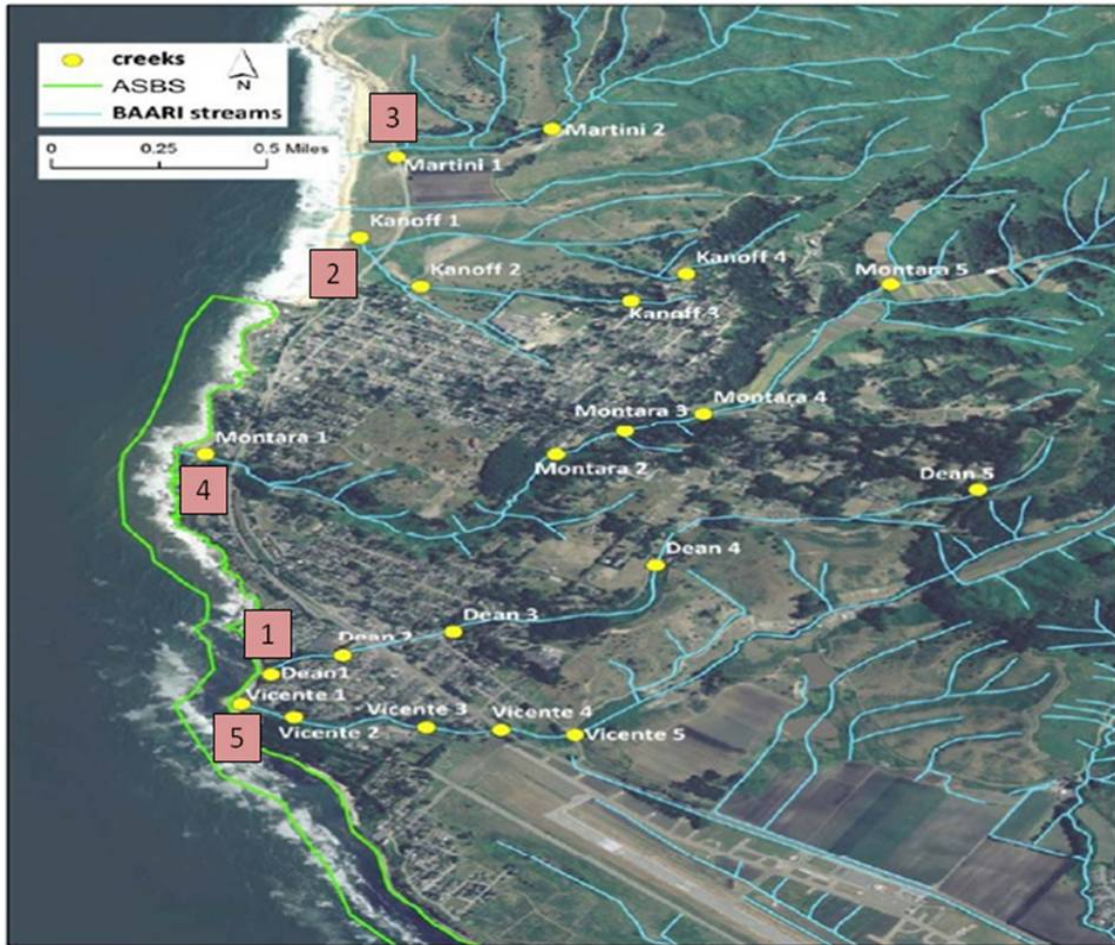


Figure 1. A map of the James V. Fitzgerald ASBS and watersheds. Numbers denote MST sampling locations.

Table 1. Latitude and longitude of MST sampling sites monitored in 2012

Site number	Site name	Latitude	Longitude
1	Dean	37.52559298300	-122.51649793800
2	Kanoff	37.54827006100	-122.51351154200
3	Martini	37.55248063700	-122.51227370900
4	Montara	37.53702965100	-122.51870163100
5	Vicente	37.52409674000	-122.51749720200



Figure 2. Photos of collected biofilm samples (submerged aquatic vegetation) at Kanoff Creek (A) and Montara Creek (B)

## 2.2. Nucleic acid extraction

Nucleic acids of a 500- $\mu$ L aliquot from feed and retentate water samples were extracted using the Invitrogen PureLink Viral RNA/DNA extraction Kit (Invitrogen, Carlsbad, CA, USA) according to the manufacturer's instructions. Final eluted volume of DNA was 100  $\mu$ L. For sediments and biofilm samples, DNA in an aliquot of supernatant ranging from 10 to 40 mL was extracted using the UltraClean Water DNA isolation kit (Mo Bio Laboratories INC. Carlsbad, CA) with a 0.22- $\mu$ m sterile membrane filter according to the manufacturer's protocols. Phenol-Chloroform DNA purification was applied to all sediment and biofilm samples and part of water samples after nucleic acid extraction.

## 2.3. *Bacteroidales* and *Acinetobacter* qPCR

TaqMan qPCR assays for *Bacteroidales* and *Acinetobacter* targeting the 16S rRNA (Kildare et al. 2007; Schriewer et al. 2010; Silkie and Nelson 2009) were performed using a StepOne Real-Time PCR System (Applied Biosystems, Foster City, CA). Assays for universal *Bacteroidales* derived from all warm-blooded animals as well as human-, bovine-, dog-, and horse-associated

*Bacteroidales* were applied to identify host-specific contributions to the fecal contamination of monitored sites. The *Acinetobacter* assay was used to calculate filtration recoveries by measuring concentrations of *Acinetobacter* in feed and retentate samples. Each 25- $\mu$ L qPCR reaction volume contained 12.5  $\mu$ L of TaqMan Environmental Master Mix 2.0 (Applied Biosystems, Foster City, CA), 10  $\mu$ L of nucleic acid extract, and optimized concentrations of forward and reverse primers and probe. Thermal cycling conditions were 2 min at 50°C and 10 min at 95°C, followed by 40 cycles of 15 s at 95°C and 1 min at 60°C. For the horse assay, the 40 cycles were modified to 15 s at 92°C and 1 min at 60°C. A serial dilution approach was employed for each sample to mitigate potential inhibitors during qPCR reaction. The recoveries and sample limits of detection ( $S_{LOD}$ ) of *Acinetobacter* and *Bacteroidales* genetic markers were calculated (Schriewer et al. 2010).

## 2.4 Statistical analysis

Data were analyzed using Excel 2007 (Microsoft Corp.). The probabilistic model (Wang et al. 2010) developed at UCD was applied to estimate true concentrations of host-associated *Bacteroidales* using the statistical package R (<http://www.r-project.org/>). The model was validated only for BacUni, BacHum, BacCow and BacCan assays (Kildare et al. 2007) and not the horse assay. Hence the data for horse-associated *Bacteroidales* measured in this study were not adjusted using the model. Analysis of variance (ANOVA) was used to investigate variations in the data between sites and sampling phases using SPSS Statistics 20.0 (Chicago, Illinois, USA). Differences were considered significant when the  $p$ -value was less than 0.05.

### 3. Results

Seven environmental monitoring events at the five creeks draining into the Pacific Ocean in the vicinity of the Reserve were carried out during the period of March 2012 through October 2012 (Table 2). Some environmental samples could not be collected due to conditions such as no streamflow during the dry season or heavy streamflow during the wet season, which was unsafe for sampling. FIB results from wet and dry seasons will be included in the SFEI report as part of pilot BMP water quality monitoring. FIB monitoring results throughout the 7 sampling events were used for reference but not included in this report.

#### 3.1. *Bacteroidales* in surface water

Universal *Bacteroidales* were detected at all sites in 7 sampling events at concentrations ranging from  $1.1 \times 10^2$  to  $2.5 \times 10^5$  gc/mL (Tables 3 and 4). In the wet season events performed in March 2012, concentrations of universal marker during rain were significantly increased at all five creeks compared to concentrations before and after rain (ANOVA,  $p < 0.05$ ). Approximately 10 to 500 times elevated concentrations of universal marker were observed at every site during rain. In addition, in the first flush sampling events conducted in October 2012, universal marker concentrations were up to 10-fold higher during first flush rain compared to those in the pre- and post-rain events. However, the differences between the three event types (pre-, during-, and post-rain) were not significant (ANOVA,  $p = 0.08$ ). There were approximately 2.5 – 4 cm (3/14/12) and 1.5 - 3 cm (10/22/12) of rainfall on the days of wet season rain and first flush rain, respectively, in the vicinity of the Reserve according to Community Collaborative Rain, Hail, and Snow Network (<http://www.cocorahs.org>). In the dry season, universal *Bacteroidales* concentrations at all sites were generally lower than those in the wet season and first flush sampling events. According to the spatial distribution of universal *Bacteroidales*, universal marker concentrations were usually highest at Dean Creek and lowest at Martini Creek throughout the wet season samplings. In the dry season, Montara Creek showed the highest universal marker concentrations compared to other sites. In the first flush events, highest universal *Bacteroidales* concentrations were found at Montara (before and during the first flush rain) and San Vicente Creek (after the first flush rain).

Human-associated *Bacteroidales* were detected at Dean (326 gc/mL, pre-rain) and Montara Creek (66 gc/mL, during-rain) in the wet season. The concentration of human marker at Dean Creek contributed approximately 10% of universal *Bacteroidales* at the creeks. Except for the two sites, human marker was hardly detected in the wet season sampling events. In the first flush events, human-associated *Bacteroidales* were detected at all sampling sites during and after first flush rain. The concentrations ranged from 3.6 gc/mL at Montara Creek to 561 gc/mL at Kanoff Creek.

Bovine-associated *Bacteroidales* were detected at Kanoff and San Vicente Creek during rain in the wet season. In San Vicente Creek, bovine-associated *Bacteroidales* contributed a significant amount (44%) of universal *Bacteroidales* during the rain. However, bovine marker was not found in the dry season and first flush events, and the S<sub>LODS</sub> were lower than 5 gc/mL for the events.

Dog-associated *Bacteroidales* were the most frequently detected host marker at all sites in the wet season samplings, and its concentrations were also higher than those of other host markers. When it rained in the wet season, dog marker concentrations ranged from  $3.2 \times 10^3$  to  $1.5 \times 10^5$  gc/mL. On the contrary, dog-associated *Bacteroidales* were rarely detected in dry and first flush samples. The only sites that were positive for the dog marker in dry and first flush events were Montara and Dean Creek, respectively.

Horse-associated *Bacteroidales* were detected at high concentrations at Dean (3080 gc/mL) and San Vicente Creek (1079 gc/mL) when it rained in the wet season. In the dry season sampling event, horse marker was found at all sites; however, the concentration range was between 3.9 and 51 gc/mL, which contributed less than 5% of universal *Bacteroidales* at each site.

The bird-associated *Catelicoccus marimammalium* assay (Lu et al. 2009) was applied to wet season samples to investigate the prevalence of bird marker in water samples; however, all samples tested were negative (data not shown). The S<sub>LODS</sub> ranged from 0.7 to 24 gc/mL. The bird assay was not used for samples collected in dry and first flush events.

Among the 7 field blanks, universal marker was detected once in a blank sample of the wet season during rain sampling event (Table 6). A carryover might have occurred during the

filtration of samples with highest concentrations of the universal *Bacteroidales* detected in the wet season during rain events. However, the concentration was orders of magnitude lower than concentrations in samples collected at all sampling sites in the event. None of the host-associated markers was detected in any field blanks. The variability of field duplicates was calculated by comparing the concentrations of paired environmental samples and associated field duplicate samples (Table 7). High variability over 100% of replicate percent difference (RPD) was found in the human marker concentrations of the field duplicate 2. Relatively low concentrations of human-associated *Bacteroidales* in the water sample and duplicate (less than 100 gc/ml) could result in the high RPD. The contribution of human source to universal marker was less than 1% at the site. In addition, horse marker was detected in a sample of the post-first flush event but not in its duplicate (duplicate 7); the measured concentration in the positive sample was very low at 11 gc/mL.

### 3.2. *Bacteroidales* in sediments and biofilm

Throughout the wet and dry season events, a total 19 of sediment and 5 of biofilm samples were collected and analyzed (Table 4). Three biofilm and one sediment sample could not be collected in the wet season due to elevated water depth and heavy water flow. Universal *Bacteroidales* were detected in all samples. Biofilm samples usually contained higher universal marker concentrations compared to sediment samples collected at the same sites (ANOVA,  $p < 0.05$ ), ranging from  $2.7 \times 10^3$  to  $9.9 \times 10^5$  gc/g of dry weight of biofilm. At all sites but Martini Creek universal *Bacteroidales* concentrations in sediments increased when it rained in the wet season. When rain stopped, the levels of universal marker in sediments decreased compared to those during rain; however, Dean and Montara Creek showed dramatically elevated concentrations of universal *Bacteroidales* in sediments after rain. In the dry season, all sites but Montara were found to have relatively high universal marker in sediments compared to surface water (ANOVA,  $p < 0.05$ ).

Human-associated *Bacteroidales* were only detected in sediments at Dean Creek before and after rain during the wet season, which was consistent with results for surface water samples. However, the contribution of the human marker in sediments to the universal signals at the creek was less than 10%. In the dry season, the human marker was not found in any sediment or

biofilm samples. (Note that sediment and biofilm samples were not collected during first flush events).

Bovine-associated *Bacteroidales* were frequently found at all sites throughout the wet season ranging from 16 to 18660 gc/g of dry weight of sediment or biofilm. Moreover, the bovine marker was a dominant source of fecal pollution in sediments at Kanoff (during rain), Montara (after rain) and San Vicente Creek (during and after rain) in the wet season. Interestingly, bovine-associated *Bacteroidales* in water samples were only detected during rain but not before and after rain. During the dry season, bovine-associated *Bacteroidales* were not detected in any sediment or biofilm samples.

Dog-associated *Bacteroidales* were also commonly detected in sediments and biofilm at all creeks except at Dean Creek in the wet and dry seasons. The dog marker contributed a significant amount of universal *Bacteroidales* in sediments and biofilm at many sites. The highest concentrations were detected in biofilm at Kanoff (24337 gc/g of dry weight, pre-rain) and Montara Creek (16475 gc/g of dry weight, post-rain). The levels of dog marker in the overlying water, which was sampled concurrently with sediment and biofilm samples at Kanoff or Montara Creek, were not significant (less than 500 gc/mL). This result shows that previously introduced dog-associated *Bacteroidales* could be accumulated and could persist longer when associated with sediments and biofilm.

Horse-associated *Bacteroidales* were consistently detected at Martini, Montara, and San Vicente Creek in both the wet and dry seasons. Horse marker was more frequently detected in sediment and biofilm samples than in water samples. The range of detected horse-associated *Bacteroidales* concentrations at all sites was from 13 to 1861 gc/g of dry weight of sediments or biofilm.

Table 2. MST sampling schedule and water quality parameters

Event	Date	Site	Matrix <sup>A</sup>	Temp. (°C)	pH	Conduc. <sup>C</sup> (µS)	Salinity (ppt)	DO <sup>D</sup> (mg/L)	TSS <sup>E</sup> (mg/L)
1 Wet season (pre-rain)	03/12/12	Dean	W, S	11.8	8.08	979	0.7	10.25	n.d. <sup>F</sup>
		Kanoff	W, S, B	14.4	7.89	549	0.3	10.03	17.6
		Martini	W, S	10.3	8.59	177	0.1	11.20	n.d.
		Montara	W, S, B	11.0	8.58	512	0.3	12.03	16.0
		Vicente	W, S	11.6	8.34	242	0.2	10.72	n.d.
2 Wet season (during-rain)	03/14/12	Dean	W, (S) <sup>B</sup>	13.5	8.26	247	0.2	10.37	527.5
		Kanoff	W, S, (B)	12.6	7.70	224	0.1	10.58	112.5
		Martini	W, S	12.7	7.94	192	0.1	10.92	290.0
		Montara	W, S, (B)	12.1	8.14	146	0.1	10.80	1170.0
		Vicente	W, S	12.5	7.81	187	0.1	10.51	1028.0
3 Wet season (post-rain)	03/20/12	Dean	W, S	10.3	7.89	675	0.5	10.97	7.1
		Kanoff	W, S, (B)	10.4	7.94	513	0.3	10.91	n.d.
		Martini	W, S	10.4	7.91	175	0.1	11.70	9.0
		Montara	W, S, B	9.9	8.09	309	0.2	11.84	13.1
		Vicente	W, S	10.5	8.23	200	0.1	11.33	87.6
4 Dry season	07/09/12	Dean	W, S	13.8	7.88	645	0.3	9.94	26.2
		Kanoff	W, S, B	15.5	7.52	441	0.3	10.72	7.9
		Martini	W, S	13.8	7.49	219	0.1	11.35	n.d.
		Montara	W, S, B	13.8	7.67	580	0.2	10.89	26.3
		Vicente	W, S	13.8	7.31	446	0.2	10.51	n.d.
5 First flush (pre-rain)	10/21/12	Dean	(W)						
		Kanoff	W	16.3	7.95	358	0.2	9.77	25.6
		Martini	W	14.2	7.91	194	0.1	10.65	n.d.
		Montara	W	14.2	7.98	745	0.5	10.18	62.1
		Vicente	W	13.7	7.70	275	0.2	10.19	17.0
6 First flush (during-rain)	10/22/12	Dean	W	13.2	8.80	137	0.1	10.52	715.8
		Kanoff	W	12.7	7.64	376	0.2	9.94	69.2
		Martini	W	12.9	7.79	211	0.1	10.61	12.7
		Montara	W	13.1	7.57	334	0.2	10.48	379.0
		Vicente	W	12.2	7.45	315	0.2	10.01	132.0
7 First flush (post-rain)	10/29/12	Dean	W	14.5	7.86	1313	0.8	9.17	10.8
		Kanoff	W	16.6	7.65	421	0.2	9.74	8.8
		Martini	W	14.8	7.90	200	0.1	10.51	n.d.
		Montara	W	14.9	7.78	709	0.4	10.20	n.d.
		Vicente	W	14.4	7.66	263	0.2	9.95	13.0

<sup>A</sup> Environmental samples collected at the sites (W: water; S: sediments; B: biofilm).

<sup>B</sup> Samples in parenthesis were initially planned but not collected due to severe weather conditions

<sup>C</sup> Conductivity

<sup>D</sup> Dissolved oxygen

<sup>E</sup> Total suspended solids

<sup>F</sup> n.d. not detected. Laboratory limit of detection was 5 mg/L.

Table 3. Concentrations and sample limits of detection for host-associated *Bacteroidales* in water at creeks in wet and dry season

Sampling date	Site	Universal <i>Bacteroidales</i>		Human <i>Bacteroidales</i>		Bovine <i>Bacteroidales</i>		Dog <i>Bacteroidales</i>		Horse <i>Bacteroidales</i>	
		Concn <sup>A</sup>	S <sub>LOD</sub> <sup>B</sup>	Concn	S <sub>LOD</sub>	Concn	S <sub>LOD</sub>	Concn	S <sub>LOD</sub>	Concn	S <sub>LOD</sub>
(gene copies per mL)											
03/12/12	Dean	3110.7	1.2	325.8	0.7	n.d.	0.7	n.d.	1.3	n.d.	0.7
	Kanoff	107.7	16.6	n.d. <sup>C</sup>	10.4	n.d.	10.4	72.6	17.8	n.d.	10.4
	Martini	335.3	4.3	n.d.	2.7	n.d.	2.7	n.d.	4.6	n.d.	2.7
	Montara	1658.9	15.5	n.d.	9.7	n.d.	9.7	482.3	16.6	n.d.	9.7
	Vicente	882.4	8.6	n.d.	5.4	n.d.	5.4	674.9	9.3	n.d.	5.4
03/14/12	Dean	250950.3	39.1	n.d.	24.4	n.d.	24.4	154194.0	41.9	3079.6	24.4
	Kanoff	50939.5	20.5	n.d.	12.8	3936.9	12.8	6688.5	22.0	n.d.	12.8
	Martini	3235.8	31.5	n.d.	19.7	3.8	19.7	3235.8	33.8	n.d.	19.7
	Montara	78745.9	23.9	65.8	14.9	87.7	14.9	13106.1	25.7	n.d.	14.9
	Vicente	102544.5	27.4	n.d.	17.1	45257.0	17.1	30495.3	29.4	1078.9	17.1
03/20/12	Dean	3733.3	8.7	n.d.	5.5	n.d.	5.5	1178.4	9.4	n.d.	5.5
	Kanoff	1256.2	11.4	n.d.	7.1	n.d.	7.1	n.d.	12.2	n.d.	7.1
	Martini	133.8	12.0	n.d.	7.5	n.d.	7.5	n.d.	12.9	n.d.	7.5
	Montara	673.3	9.6	n.d.	6.0	n.d.	6.0	116.6	10.3	n.d.	6.0
	Vicente	1445.9	5.9	n.d.	3.7	n.d.	3.7	n.d.	6.3	n.d.	3.7
07/09/12	Dean	591.3	5.9	n.d.	3.7	n.d.	3.7	n.d.	6.3	4.7	5.2
	Kanoff*	815.1	3.6	n.d.	2.2	n.d.	2.2	n.d.	3.8	3.9	3.1
	Martini*	377.3	12.5	n.d.	7.8	n.d.	7.8	n.d.	13.4	16.0	11.0
	Montara*	2470.7	5.2	n.d.	3.3	n.d.	3.3	501.0	5.6	50.8	4.6
	Vicente*	235.5	4.0	n.d.	2.5	n.d.	2.5	n.d.	4.3	6.6	3.6

<sup>A</sup> Concentration

<sup>B</sup> Sample limit of detection

<sup>C</sup> n.d. not detected.

\* DNA purification step was applied to the samples

Table 4. Concentrations and sample limits of detection of host-associated *Bacteroidales* in water in first flush events

Sampling date	Site name	Universal <i>Bacteroidales</i>		Human <i>Bacteroidales</i>		Bovine <i>Bacteroidales</i>		Dog <i>Bacteroidales</i>		Horse <i>Bacteroidales</i>	
		Concn <sup>A</sup>	S <sub>LOD</sub> <sup>B</sup>	Concn	S <sub>LOD</sub>	Concn	S <sub>LOD</sub>	Concn	S <sub>LOD</sub>	Concn	S <sub>LOD</sub>
(gene copies per mL)											
10/21/12	Dean	NA <sup>C</sup>									
	Kanoff*	2087.8	2.0	91.3	0.4	n.d. <sup>D</sup>	0.4	n.d.	2.1	n.d.	1.9
	Martini	1408.5	3.9	0.0	0.9	n.d.	0.9	n.d.	4.2	n.d.	3.9
	Montara	4415.9	3.2	0.0	0.7	n.d.	0.7	n.d.	3.4	n.d.	3.1
	Vicente*	3907.0	2.1	99.5	0.5	n.d.	0.5	n.d.	2.2	24.5	2.0
10/22/12	Dean	10315.6	5.1	168.9	0.6	n.d.	0.8	3188.3	3.9	n.d.	3.6
	Kanoff*	2446.0	2.3	560.6	0.3	n.d.	0.3	n.d.	1.7	n.d.	1.6
	Martini*	1666.1	13.5	78.4	1.6	n.d.	2.0	n.d.	10.3	n.d.	9.4
	Montara	21954.7	1.7	3.6	0.2	n.d.	0.3	n.d.	1.3	21.2	1.2
	Vicente*	8113.1	1.6	94.7	0.2	n.d.	0.2	n.d.	1.2	n.d.	1.1
10/29/12	Dean*	3775.7	4.6	99.0	0.7	n.d.	0.7	n.d.	2.6	10.5	2.3
	Kanoff*	4927.6	2.5	85.1	0.4	n.d.	0.4	n.d.	1.4	n.d.	1.2
	Martini*	2408.0	3.1	264.7	0.5	n.d.	0.5	n.d.	1.7	n.d.	1.5
	Montara*	2290.1	1.8	242.4	0.3	n.d.	0.3	n.d.	1.0	n.d.	0.8
	Vicente*	2209.9	1.8	89.9	0.3	n.d.	0.3	n.d.	1.0	10.6	1.1

<sup>A</sup> Concentration

<sup>B</sup> Sample limit of detection

<sup>C</sup> NA not available to collect

<sup>D</sup> n.d. not detected.

\* DNA purification step was applied to the samples

Table 5. Concentrations and sample limits of detection of host-associated *Bacteroidales* in sediments and biofilm in wet and dry season

Sampling date	Site	Universal <i>Bacteroidales</i>		Human <i>Bacteroidales</i>		Bovine <i>Bacteroidales</i>		Dog <i>Bacteroidales</i>		Horse <i>Bacteroidales</i>	
		Concn <sup>B</sup>	S <sub>LOD</sub> <sup>C</sup>	Concn	S <sub>LOD</sub>	Concn	S <sub>LOD</sub>	Concn	S <sub>LOD</sub>	Concn	S <sub>LOD</sub>
		(gene copies per g of dry weight of sediments or biofilm)									
03/12/12	Dean	396.3	30.7	26.2	19.2	100.9	19.2	n.d.	33.0	n.d.	19.2
	Kanoff	168.5	31.0	n.d. <sup>D</sup>	19.4	n.d.	19.4	n.d.	33.3	n.d.	19.4
	Martini	1655.4	22.6	n.d.	14.1	n.d.	14.1	892.2	24.2	22.7	14.1
	Montara	596.3	30.5	n.d.	19.0	n.d.	19.0	n.d.	32.7	46.4	19.0
	Vicente	3711.7	30.3	n.d.	18.9	89.6	18.9	286.8	32.5	253.3	18.9
	Kanoff <sup>A</sup>	79840.7	146.0	n.d.	91.0	18659.8	91.0	24337.2	156.5	1860.7	91.0
	Montara <sup>A</sup>	2691.9	360.7	n.d.	224.9	n.d.	224.9	515.3	386.8	210.5	224.9
03/14/12	Kanoff	1375.0	29.0	n.d.	18.1	347.7	18.1	383.7	31.1	n.d.	18.1
	Martini	349.2	30.3	n.d.	18.9	28.5	18.9	101.6	32.5	36.9	18.9
	Montara	1738.2	29.8	n.d.	18.6	16.0	18.6	196.7	32.0	12.8	18.6
	Vicente	5014.0	29.8	n.d.	18.6	2649.8	18.6	n.d.	31.9	76.0	18.6
03/20/12	Dean	10229.3	30.2	181.4	18.9	603.9	18.9	n.d.	32.4	90.3	18.9
	Kanoff	262.5	29.1	n.d.	18.2	77.4	18.2	n.d.	31.2	n.d.	18.2
	Martini	1520.6	31.6	n.d.	19.7	n.d.	19.7	n.d.	33.9	28.5	19.7
	Montara	18370.8	30.9	n.d.	19.3	6983.7	19.3	3898.0	33.2	48.1	19.3
	Vicente	636.1	30.9	n.d.	19.3	201.2	19.3	439.4	33.1	17.5	19.3
	Montara <sup>A</sup>	71535.4	130.8	n.d.	81.6	n.d.	81.6	16474.5	140.2	973.4	81.6
07/09/12	Dean	2551.1	15.3	n.d.	9.6	n.d.	9.6	n.d.	16.5	61.9	9.6
	Kanoff	3585.9	32.1	n.d.	20.0	n.d.	20.0	n.d.	34.4	271.8	20.0
	Martini	551.3	15.2	n.d.	9.5	n.d.	9.5	n.d.	16.3	30.6	9.5
	Montara	640.5	15.3	n.d.	9.5	n.d.	9.5	625.5	16.4	73.5	9.5
	Vicente	3655.6	15.4	n.d.	9.6	n.d.	9.6	1968.1	16.5	168.3	9.6
	Kanoff <sup>A</sup>	986013.4	113.0	n.d.	70.5	n.d.	70.5	n.d.	121.2	1255.2	70.5
	Montara <sup>A</sup>	582339.0	172.0	n.d.	107.2	n.d.	107.2	347711.1	184.4	1601.5	107.2

<sup>A</sup> Biofilm samples

<sup>B</sup> Concentration

<sup>C</sup> Sample limit of detection

<sup>D</sup> n.d. not detected

Table 6. Concentrations and sample limits of detection of host-associated *Bacteroidales* in field blanks

Sampling date	Sample	Universal <i>Bacteroidales</i>		Human <i>Bacteroidales</i>		Bovine <i>Bacteroidales</i>		Dog <i>Bacteroidales</i>		Horse <i>Bacteroidales</i>	
		Concn <sup>A</sup>	S <sub>LOD</sub> <sup>B</sup>	Concn	S <sub>LOD</sub>	Concn	S <sub>LOD</sub>	Concn	S <sub>LOD</sub>	Concn	S <sub>LOD</sub>
(gene copies per mL)											
03/12/12	Field blank 1	n.d. <sup>C</sup>	1.7	n.d.	1.1	n.d.	1.1	n.d.	1.8	n.d.	1.1
03/14/12	Field blank 2	14.8	3.7	n.d.	2.3	n.d.	2.3	n.d.	4.0	n.d.	2.3
03/20/12	Field blank 3	n.d.	1.4	n.d.	0.9	n.d.	0.9	n.d.	1.5	n.d.	0.9
07/09/12	Field blank 4	n.d.	8.2	n.d.	5.1	n.d.	5.1	n.d.	8.8	n.d.	7.2
10/21/12	Field blank 5	n.d.	0.5	n.d.	0.1	n.d.	0.1	n.d.	0.5	n.d.	0.5
10/22/12	Field blank 6	n.d.	0.6	n.d.	0.1	n.d.	0.1	n.d.	0.5	n.d.	0.5
10/29/12	Field blank 7	n.d.	0.5	n.d.	0.1	n.d.	0.1	n.d.	0.3	n.d.	0.2

<sup>A</sup> Concentration

<sup>B</sup> Sample limit of detection

<sup>C</sup> n.d. not detected

Table 7. Replicate percent differences in environmental samples and field duplicates (for water samples)

Sampling date	Sample	Universal <i>Bacteroidales</i>	Human <i>Bacteroidales</i>	Bovine <i>Bacteroidales</i>	Dog <i>Bacteroidales</i>	Horse <i>Bacteroidales</i>
		RPD <sup>A</sup>				
03/12/12	Field duplicate 1	28%	ND <sup>B</sup>	ND	23%	ND
03/14/12	Field duplicate 2	55%	118%	1%	57%	ND
03/20/12	Field duplicate 3	73%	ND	ND	ND	ND
07/09/12	Field duplicate 4	48%	ND	ND	ND	86%
10/21/12	Field duplicate 5	49%	32%	ND	ND	15%
10/22/12	Field duplicate 6	20%	4%	ND	ND	ND
10/29/12	Field duplicate 7	32%	72%	ND	ND	ND1 <sup>C</sup>

<sup>A</sup> Replicate percent difference (RPD) = ( | Concentration<sub>sample</sub> - Concentration<sub>duplicate</sub> | / mean (concentration<sub>sample</sub>, concentration<sub>duplicate</sub>)) x 100%.

For reference, factors of 3- and 10-fold differences in concentrations equate to RPDs of 100% and 163.6%, respectively.

<sup>B</sup> ND = both the environmental and field duplicate were non-detect

<sup>C</sup> ND1 = measurement was positive in one sample and negative in the other

## 4. Discussion

The main goal of the MST study was to investigate the sources of fecal pollution in the five watersheds draining to the Pacific Ocean in the vicinity of the Reserve. Analysis of 34 water samples during 7 events in 2012 revealed that there is a temporal distribution of host-associated *Bacteroidales* in water in the Reserve. Dog-associated *Bacteroidales* were a predominant source of fecal contamination at several sites during the wet season, while the marker was hardly detected in water in first flush events. Interestingly, human-associated *Bacteroidales* were frequently found in the first flush sampling events but not often during the wet season. Bovine-associated *Bacteroidales* were only observed during rain in the wet season throughout all 7 events in 2012. Horse-associated *Bacteroidales* were detected at all creeks in dry season and at Dean, Montara, and San Vicente Creeks during wet season and first flush even though its contributions to universal *Bacteroidales* were still minor (less than 5% of universal *Bacteroidales* concentrations). In dry season event, at all sites except Montara Creek, less than 5% of universal *Bacteroidales* concentrations were made up of host markers tested in this project. This result indicates that uncharacterized fecal sources such as wildlife or other domestic animals contributed a large amount of fecal pollution during the dry season. The watersheds monitored in this study contain unincorporated communities, agricultural fields, equestrian facilities, a small commercial area, public beaches, and open space/recreational areas within coastal bluff, coastal scrub, and riparian habitat (California Coastal Commission, 2008). All creeks except Martini Creek flow through medium to high density residential areas. Overflows or leaking septic and/or sewer system pipes and runoff from residential and public areas could contribute to the elevated levels of human- and dog-associated *Bacteroidales*. The presence of bovine and horse markers could be derived from the use of manure compost and equestrian operations. In addition, it is plausible, given the large area of wildlife habitat, that various species of animals that reside along the waterways also made a significant contribution to fecal loading to the Reserve.

Regarding universal *Bacteroidales*, the concentrations generally increased when it rained in the wet season and first flush events. However, it was evident that the increased amounts during rainfall in the wet and first flush events were quite different. Even though there were similar amounts of rainfall during the rainy sampling days in March and October (2.5 – 4 versus 1.5- 3

cm), the increased levels of *Bacteroidales* were significantly higher in the wet season event compared to the first flush event. The fact that universal marker was detected at higher concentrations during rain in the wet season event could be due to unequal survival of *Bacteroidales* in the given environments or due to release of microorganisms from sediments and biofilm. It is plausible that the relatively cool water temperature in March (8°C) compared to October (13°C) enabled *Bacteroidales* in water to persist longer during the wet season (Okabe and Shimazu 2007). Dissolved oxygen concentrations in water were not very different in March and October (10.6 versus 10.3 mg/L), which indicates that dissolved oxygen concentrations in water were not the main effect of the different levels of *Bacteroidales*. It is also possible that the higher flow rate in creeks in the wet season could resuspend microorganisms in sediments and biofilm, which would then result in increased bacteria levels in the water. According to daily discharge data (<http://waterdata.usgs.gov>) of Pilarcitos Creek which located nearby the Reserve, considerably higher discharge was observed at the sampling time of wet season rain (approximately 40 cubic feet per second) than first flush rain (less than 10 cubic feet per second). Even though the rainfall totals were similar in the two events, the streamflow could be different due to the degree of ground saturation and groundwater levels. Flow rates at each creek were not directly measured during the events; however, the total suspended solids (TSS) levels during rain in the wet season were significantly higher in March compared to those in October (ANOVA,  $p < 0.05$ ), indicating elevated flow rates during rain in the wet season compared to first flush. While survival of *Bacteroidales* is limited in surface water due to its obligate anaerobic metabolism, it may be possible for cells to grow or persist longer in sediments with anaerobic conditions. In addition, sediments can provide favorable environments for microorganisms (Anderson et al. 2005; Craig et al. 2004; Lee et al. 2006). Microorganisms in surface water could settle to the bottom and attach to sediments. Release of those cells in sediments and biofilm into the overlying water can occur during times of turbulence. Therefore, the accumulated microorganisms in sediments and biofilm along the waterway could be resuspended and transported with the elevated flow to the Reserve when it rained.

Sediment and biofilm samples evaluated in this study revealed the presence of high amounts of host-associated *Bacteroidales*. Universal *Bacteroidales* concentrations in sediments generally increased during rain. A probable reason is that the introduced amounts of *Bacteroidales* from

Okabe, S. and Shimazu, Y. (2007) Persistence of host-specific *Bacteroides-Prevotella* 16S rRNA genetic markers in environmental waters: effects of temperature and salinity. *Appl Microbiol Biotechnol* 76, 935-944.

Rajal, V.B., McSwain, B.S., Thompson, D.E., Leutenegger, C.M., Kildare, B.J. and Wuertz, S. (2007) Validation of hollow fiber ultrafiltration and real-time PCR using bacteriophage PP7 as surrogate for the quantification of viruses from water samples. *Water Res* 41, 1411-1422.

Schriewer, A., Miller, W.A., Byrne, B.A., Miller, M.A., Oates, S., Conrad, P.A., Hardin, D., Yang, H.H., Chouicha, N., Melli, A., Jessup, D., Dominik, C. and Wuertz, S. (2010) Presence of *Bacteroidales* as a predictor of pathogens in surface waters of the central California coast. *Appl Environ Microbiol* 76, 5802-5814.

Silkie, S.S. and Nelson, K.L. (2009) Concentrations of host-specific and generic fecal markers measured by quantitative PCR in raw sewage and fresh animal feces. *Water Res* 43, 4860-4871.

Wang, D., Silkie, S.S., Nelson, K.L. and Wuertz, S. (2010) Estimating true human and animal host source contribution in quantitative microbial source tracking using the Monte Carlo method. *Water Res* 44, 4760-4775.

the water during the rain event were much higher than the levels of *Bacteroidales* released from sediments and biofilm at the creek confluence. Elevated levels of bovine-associated *Bacteroidales* at Kanoff and San Vicente Creek during rainfall were consistent with the increased presence and concentrations of the bovine marker in water in the same events. The fact that bovine-associated *Bacteroidales* were detected during, as well as, after rain even though the marker was only detected during rain in the overlying water suggests that *Bacteroidales* could persist longer when they were associated with sediments. It is important to remember that MST genetic analysis is based on the detection of DNA that can persist long after cell death. Recently, the application of propidium monoazide (PMA) prior to qPCR has been shown to be a useful technique for the discrimination of DNA from intact and impaired cells by inhibiting DNA amplification from damaged cells (Bae and Wuertz 2009). Since PMA reacts with DNA in impaired cell and extracellular DNA upon light exposure, high levels of solid particles (> 1000 mg/L) in a concentrated water sample after filtration can hinder the photolysis of PMA by blocking light exposure of impaired cells. Therefore, the PMA application was planned for sediment and biofilm samples rather than water samples because sediment eluants should have fewer solids than concentrated water after filtration. However, relatively high sample limits of detection of the eluants resulted in needs of higher eluant volumes to be concentrated on the sterile membrane filters during DNA extraction, which might result in the failure of the PMA application for sediment and biofilm samples in this study (data not shown). It is not known what mechanisms between PMA and eluants from sediment/biofilm samples produced the impractically high DNA concentrations in the PMA-treated samples compared to untreated samples. We applied nucleic acid purification with phenol-chloroform to minimize the unknown inhibitions but did not include the results of PMA-treated samples in this report. As part of resolving the PMA issue, samples without PMA treatments were also analyzed with/without DNA purification. Even though it is inevitable to lose a certain fraction of DNA during purification, every sample showed higher genetic marker concentrations after DNA purification compared with before purification. Host-associated *Bacteroidales* were detected at high concentrations compared to unpurified sample (unpurified sample data not shown). This result indicates that unknown inhibitors existed in the sediment and biofilm samples and controlled by DNA purification when PMA was not applied to the samples. Overcoming the problem in analyzing PMA treated environmental samples will be helpful for further monitoring studies.

## 5. Conclusions

- Universal *Bacteroidales* concentrations increased when it rained. The increased amounts should vary with the flow rate of the creek since a high flow rate could resuspend sediments, which results in an increase in host-associated genetic markers in the overlying water column.
- Human-associated *Bacteroidales* were detected once at Dean (pre-rain) and Montara (during rain) in the wet season but were not often detected in either wet or dry seasons. The human marker was prevalent in water throughout the first flush events.
- Bovine feces affected water quality at sampling sites during rain during the wet season but not during the dry season or first flush event. The marker considerably contributed to the fecal loading at Kanoff and San Vicente Creek.
- Dog-associated *Bacteroidales* contributed a significant amount of universal *Bacteroidales* detected at all creeks in the wet season. The dog marker was not found during the dry season and first flush events except at Montara Creek (dry season) and at Dean Creek (during rain in the first flush events).
- The fact that the high levels of bovine or dog marker were detected in sediments and biofilm when their levels in water were not high showed that previously introduced host markers in the creek could persist longer when associated with sediments and biofilm.
- Horse-associated *Bacteroidales* were found at high concentrations in water at Dean and San Vicente Creek during rain in the wet season. Horse feces were also present in all creeks in the dry season, but it is not a predominant fecal source. Higher concentrations of the horse genetic marker in sediments compared to those in water during the dry season suggest the accumulation or re-growth of horse-associated *Bacteroidales* in sediments in the dry season.
- The monitoring study provides good insights into the prevalence of host-associated *Bacteroidales* at five creeks draining into the Reserve.
- Future monitoring studies that can distinguish host-associated *Bacteroidales* DNA from intact and impaired cells will allow determination of the age of fecal pollution and may provide more information about potential health risks.

## 6. References

- American Public Health Association (APHA) (1998) Total suspended solids dried at 103-105°C. Part 2540 D. In *Standard Methods for the Examination of Water and Wastewater*, 20<sup>th</sup> edition. Washington DC, pp 2-57 to 58.
- Anderson, M.L., Whitlock, J.E. and Harwood, V.J. (2005) Persistence and differential survival of fecal indicator bacteria in subtropical waters and sediments. *Appl Environ Microbiol* 71, 3041-3048.
- Bae, S. and Wuertz, S. (2009) Discrimination of viable and dead fecal Bacteroidales bacteria by quantitative PCR with propidium monoazide. *Appl Environ Microbiol* 75, 2940-2944.
- Craig, D.L., Fallowfield, H.J. and Cromar, N.J. (2004) Use of macrocosms to determine persistence of *Escherichia coli* in recreational coastal water and sediment and validation with in situ measurements. *J Appl Microbiol* 96, 922-930.
- California Coastal Commission. Nonpoint Source Watershed Assessment: James V. Fitzgerald Marine Reserve Critical Coastal Area. December 2008. The document was accessed online at <http://www.sanmateorcd.org/CCA%20Watershed%20Assessment>.
- Kildare, B.J., Leutenegger, C.M., McSwain, B.S., Bambic, D.G., Rajal, V.B. and Wuertz, S. (2007) 16S rRNA-based assays for quantitative detection of universal, human-, cow-, and dog-specific fecal *Bacteroidales*: A Bayesian approach. *Water Res* 41, 3701-3715.
- Lee, C.M., Lin, T.Y., Lin, C.C., Kohbodi, G.A., Bhattl, A., Lee, R. and Jay, J.A. (2006) Persistence of fecal indicator bacteria in Santa Monica Bay beach sediments. *Water Res* 40, 2593-2602.
- Lu, J.R., Santo Domingo, J.W., Lamendella, R., Edge, T. and Hill, S. (2008) Phylogenetic diversity and molecular detection of bacteria in gull feces. *Appl Environ Microbiol* 74, 3969-3976.

## **Appendix F**

### **Pillar Point Harbor Source Identification Project Public Meeting Presentation (RCD and UC Davis)**

# Identification of Sources of Fecal Pollution Impacting Pillar Point Harbor

*Minji Kim*

Graduate student

*Stefan Wuertz*

Professor

Department of Civil & Environmental Engineering  
University of California, Davis

# Background

- Pillar Point Harbor (PPH) overview
  - Enclosed harbor
  - Popular recreational area
  - Vital commercial fishing industry
- Water quality concerns
  - Capistrano Beach impaired by coliform bacteria
- Our approach
  - Quantify bacteria
  - Understand their source
  - Consider hydrology



# Technical Advisory Committee

- Balance Hydrologics – *Barry Hecht*
- San Mateo County
  - Public Health Lab – *Bruce Fujikawa*
  - Environmental Health Division- *Dean Peterson, Greg Smith*
  - Public Works Department- *Julie Casagrande*
- Granada Sanitary District – *Chuck Duffy*
- City of Santa Barbara – *Jill Murray*
- Natural Resources Conservation Service – *Jim Howard*
- San Mateo Co. Harbor District – *Peter Grenell, Scott Grindy, Dan Temko*
- Keith Mangold, local citizen
- Surfrider– *Sarah Damron, Ed Larenas*
- UC Davis, Dept. of Environmental Science and Policy – *John Largier*
- Santa Cruz County Environmental Health Services – *Steve Peters*
- Sewer Authority Midcoastside – *Steven Leonard*

# Outline

- Project objectives
- Monitoring design
- Fecal indicator bacteria (FIB)
- Microbial source tracking (MST)
- PhyloChip
- Conclusions



# Project objectives

- To provide information about the primary sources of fecal contamination in PPH
  - FIB monitoring
  - MST study
- To help the selection of remediation strategies for mitigation

# Monitoring parameters

- Fecal indicator bacteria (FIB)
  - Cultivation method: IDEXX
  - *Escherichia Coli*, *Enterococcus*
- Microbial source tracking (MST)
  - Molecular method: qPCR  
(quantitative polymerase chain reaction)
  - Genetic markers of source identifiers  
(human, canine, bovine, equine, gulls)



# Sampling locations

- 10 primary locations at PPH



Locations (Yellow):

1. Capistrano Outfall Pipe
2. Bathhouse Outfall Pipe
3. Capistrano Beach
4. Denniston Creek

5. Pillar Point Marsh Beach
6. Mavericks Beach
7. Beach House Beach
8. Deer Creek Outlet

9. Inner Harbor Beach
10. Yacht Club Beach

# Sampling locations (continued)

## Photos of inflow and beach sites

### 4 inflow sites



Capistrano  
Outfall Pipe



St. Augustine  
Creek Outlet



Denniston  
Creek



Deer Creek  
Outlet

### 6 beaches



7



9



3



10



5



6

# Sampling locations (continued)

- Live-aboard boat sampling sites



Locations (Yellow):

- |                         |                             |                      |
|-------------------------|-----------------------------|----------------------|
| 1. Dock A, Inner Harbor | 4. Sanitary pumping station | 5. OH1, Outer Harbor |
| 2. Dock B, Inner Harbor |                             | 6. OH2, Outer Harbor |
| 3. Dock C, Inner Harbor |                             | 7. OH3, Outer Harbor |

# Sampling locations (continued)

## Upstream sampling sites



Locations (Yellow):

- |                                |                                |                                |
|--------------------------------|--------------------------------|--------------------------------|
| 1. PPH-1B (upstream of PPH-1)  | 3. PPH-DN2 (upstream of PPH-4) | 6. PPH-DR4 (upstream of PPH-8) |
| 2. PPH-2B (upstream of PPH-2)  | 4. PPH-DN3 (upstream of PPH-4) | 7. PPH-DR6 (upstream of PPH-8) |
| 5. PPH-DN4 (upstream of PPH-4) |                                |                                |

# Sampling summary

- FIB sampling

- 514 FIB water samples
- 2008, 2011-2012
- (Bi)weekly + concurrently with MST

- MST monitoring

- 225 MST water, sediments, and biofilm samples
- 2008, 2011-2012
- Dry (May-Sep)+ wet (Oct-Apr) season + first flush

# Sampling summary (continued)

- Type and number of MST samples

Matrix	Season or condition	2008	2011	2012	Total
<b>Water</b>	Dry season	10	10	5	25
	Wet season	10	34	15	59
	First flush	30	30	11	71
	Live-aboard boat	-	7	3	10
	Upstream	-	-	13	13
<b>Sediment</b>	Dry	-	8	5	13
	Wet	-	-	15	15
<b>Biofilm</b>	Dry	-	11	2	13
	Wet	-	-	6	6
<b>Total</b>		<b>50</b>	<b>100</b>	<b>75</b>	<b>225</b>

# Monitoring results

- **Fecal indicator bacteria (FIB)**
  - Site-specific
  - Seasonal
  - Upstream
- **Microbial source tracking (MST)**
  - Universal
  - Canine
  - Human
  - Bovine
  - Equine
  - Gull
  - Sediments and biofilms
- **PhyloChip**

# Fecal indicator bacteria (FIB)

## Site-specific FIB counts

- 2-yr (2008, 2011) results
- Highest overall FIB counts at inflow sites**
  - PPH 1, 2, 4 & 8
  - Above the water quality criteria
- Consistently highest beach FIB at Capistrano Beach (PPH-3)**
  - FIB levels above criteria often found
  - Directly affected by PPH-1 and 2
- Low FIB counts in other beaches**
  - FIB counts usually low at all beaches except for Capistrano Beach



Locations (Yellow):

- |                            |                             |                       |
|----------------------------|-----------------------------|-----------------------|
| 1. Capistrano Outfall Pipe | 5. Pillar Point Marsh Beach | 9. Inner Harbor Beach |
| 2. Bathhouse Outfall Pipe  | 6. Mavericks Beach          | 10. Yacht Club Beach  |
| 3. Capistrano Beach        | 7. Beach House Beach        |                       |
| 4. Denniston Creek         | 8. Deer Creek Outlet        |                       |

# FIB (continued)

## Seasonal FIB counts

- 2-yr (2011-2012) (bi)weekly monitoring at **5 key sites**
- **Seasonal variation at Capistrano Beach (PPH-3)**
  - **Higher** FIB counts in **wet** season
  - fast die-off rates of FIB in dry season
  - Increased flow rate of inflows in wet season
- **Less seasonality at Inflow sites**
  - **Higher** *E. coli* levels at **Deer Creek Outlet (PPH-8)** during **dry** season
  - No FIB seasonal variation found in other inflow sites

dry season



wet season



Capistrano Outfall Pipe (PPH-1)

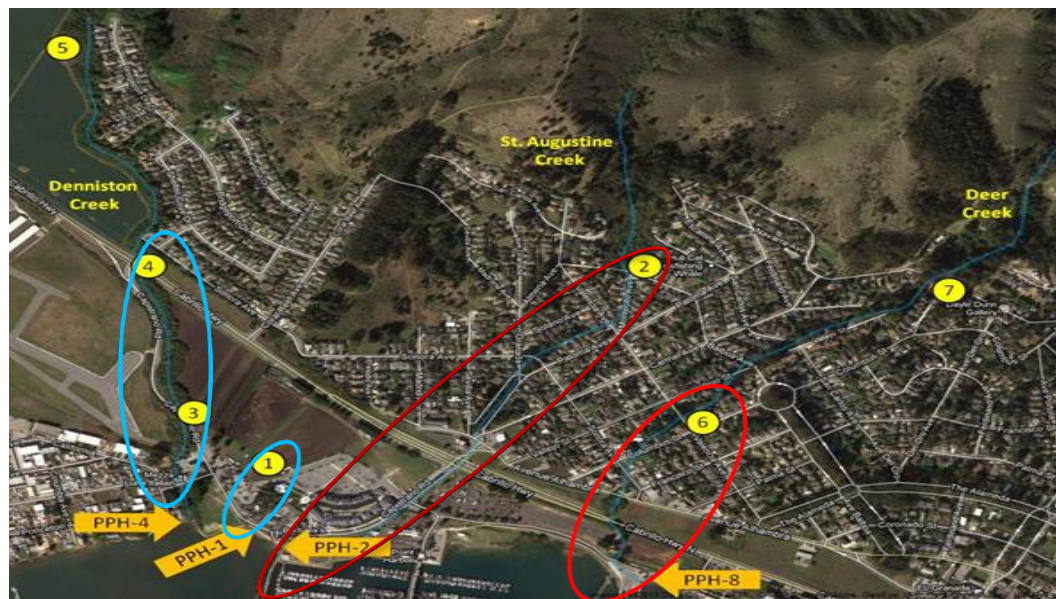


St. Augustine Creek Outlet (PPH-2)

# FIB (continued)

## Upstream monitoring

- 2012 (May-Dec) weekly at **inflow** and corresponding **upstream** sites
- Significantly **different FIB counts (red circle)**
  - **St. Augustine Outfall Outlet (PPH-2)** and **Deer Creek Outlet (PPH-8)**
  - Considerable amounts of **fecal input within the urban area**
- **Similar FIB counts (blue circle)**
  - **Capistrano Outfall Pipe (PPH-1)** and **Denniston Creek (PPH-4)**
- Added two new upstream sites for MST upstream monitoring (#5, 7)



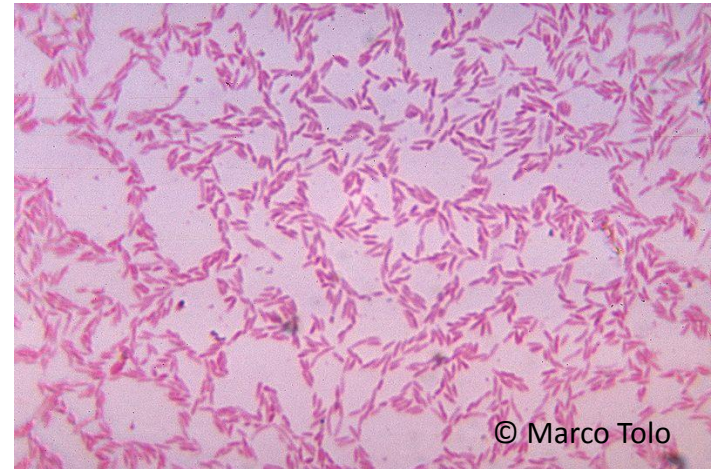
# Monitoring results

- Fecal indicator bacteria (FIB)
  - Site-specific
  - Seasonal
  - Upstream
- **Microbial source tracking (MST)**
  - **Universal**
  - **Canine**
  - **Human**
  - **Bovine**
  - **Equine**
  - **Gull**
  - **Sediments and biofilms**
- PhyloChip

# Microbial source tracking (MST)

## Universal *Bacteroidales*

- Universal *Bacteroidales* (BacUni)
  - Derived from all warm-blooded animals
  - **Detected** in **all** MST samples
- **Site-specific** variation at 10 sites (2008, 2011)
  - **High** levels at all **inflow** sites (PPH-1, 2, 4, 8)
  - Relatively **high** at **Capistrano Beach** (PPH-3)
  - Usually **low** at **other beaches** except PPH-3



© Marco Tolo

# MST (continued)

## Canine fecal pollution



- Canine-associated *Bacteroidales* (BacCan)
- Inflow sites
  - Marker **sometimes** (PPH-1, PPH-4) or **frequently** (PPH-2, PPH-8) detected at **high** levels
- Mavericks Beach
  - Marker **often** detected (27%)
  - When FIB counts were high, canine marker concentration was high
  - Dog waste on the beach **affected water quality**, but counts were **rarely high**
- Capistrano Beach
  - Marker **often** detected in **wet** season (33%) at **high** levels
  - Introduced from **inflows** (PPH-1, PPH-2) rather than Mavericks Beach



© Kd rome

# MST (continued)

## Canine fecal pollution



- Upstream MST sampling
  - Samples collected at **first flush** events (Nov 2012) and **wet** season (Dec 2012)
- Monitoring results
  - Detected at **high** levels **during rain** at upstream sites of Capistrano Outfall Pipe and Deer Creek Outlet (**red star**)
  - Detected **before rain** but significantly **decreased during and after rain** at upstream site of St. Augustine Creek Outlet (**orange star**)
  - **Not** detected at upstream sites of Denniston Creek (**green star**)

➔ **Canine feces is a significant, but not primary, source of bacteria at Capistrano Beach**



# MST (continued)

## Human fecal pollution



- Human-associated *Bacteroidales* (BacHum)
- Inflow sites
  - **Sometimes** detected (<20%) at inflow sites in wet season but its concentrations were **minor**
  - High concentration found only one time at **Capistrano Outfall Pipe**. However, **not an influence** to Capistrano Beach due to low water flow.
- Beaches
  - **Rarely** detected
- Second human marker assay (HF183 TaqMan)
  - Another validated human marker applied

➔ **Human feces is not a significant source of bacteria at Capistrano Beach**

# MST (continued)

## Human fecal pollution



- Live-aboard boat sampling
  - Samples collected at boat docks in **Inner Harbor, pumping station and Outer Harbor**
  - **Low FIB** counts
  - **Low** human marker at boat docks in **2011**
  - **No** human marker in **2012**
  - **Limited potential effect** of human fecal release from live-aboard boats to Capistrano Beach based on low counts and circulation study.



➔ **Live-aboard boats not a significant source of bacteria at Capistrano Beach**

# MST (continued)

## Bovine fecal pollution



- Bovine-associated *Bacteroidales* (BacBov)
- **Deer Creek Outlet (PPH-8)**
  - **High** concentrations detected consistently in **dry season (100%)** and frequently in **wet season (50%)**
  - Upstream sites also showed high levels
- **Other inflows and beaches**
  - Bovine detected only once and at low concentration-**not significant**

➔ **Bovine feces is the main bacteria source at Deer Creek Outlet**



# MST (continued)

## Equine fecal pollution



- Equine-associated *Bacteroidales* (HorseBact)
- Assay validation
  - Positive for horse fecal samples (6) collected in San Mateo County
  - Negative for any other feces from humans (5), cows (5), dogs (5), and gulls (6)
  - **HorseBact** assay **works** well
- MST samples analyzed
  - Collected at **4 inflow** sites and **Capistrano Beach** in 2011 and wet season of 2012
- Results
  - **Not detected** in any of MST samples tested

➔ **Horse feces is not a source of bacteria in the PPH**

# MST (continued)

## Seagull fecal pollution



- Large flocks of gulls and other birds at PPH
- Gull MST assays
  - *Catelicoccus marimammalium* SYBR green assay (UCD)
  - *Catelicoccus* spp. TaqMan assay (OSU)
  - Independently tested in the two laboratories
  - **Not detected** in any samples

➔ **Gull feces not a significant source of bacteria in PPH**



© 2012 Callyn Yorke

# MST (continued)

## Sediments and biofilms

- Sediment: very fine to coarse sand beneath water
  - Biofilm : submerged aquatic vegetation beneath water surface
  - Universal *Bacteroidales* in sediments and biofilms
    - Detected in all **sediment** and **biofilm** samples
    - **Biofilm** > **sediments** > water
    - **Dry** season > wet season
- ➡ Fecal bacteria accumulate in sediments and biofilms
- In wet season, BacUni in sediments **decreased** when it **rained**
- ➡ **Release** (re-suspension) of bacteria by natural turbulence during high flow



(Example of biofilm samples)

# MST (continued)

## Sediments and biofilms

- Host-associated *Bacteroidales*
  - **Canine** marker detected in sediments and biofilms at **St. Augustine Creek Outlet** (PPH-2) in **wet** season. Also detected in water samples.
  - **High** levels of **canine** marker found in sediments at **Capistrano Beach** (PPH-3) and **Deer Creek Outlet** (PPH-8) in **dry** season.
  - **Canine** marker detected in **sediments** even when **not** detected in **water** at Capistrano Beach

### Fecal bacteria in sediments and biofilms:



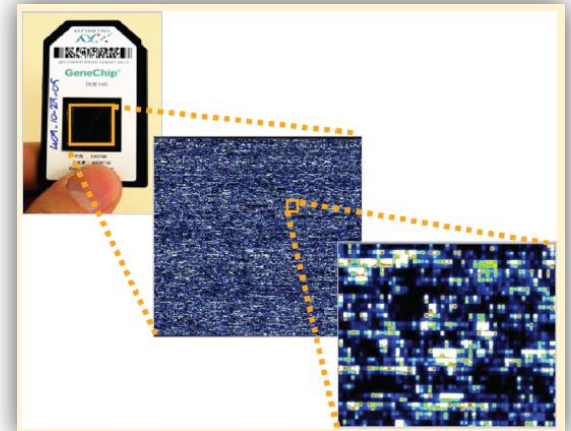
**Influence bacteria levels in PPH**

# Monitoring results

- Fecal indicator bacteria (FIB)
  - Site-specific
  - Seasonal
  - Upstream
- Microbial source tracking (MST)
  - Universal
  - Canine
  - Human
  - Bovine
  - Equine
  - Seagull
  - Sediments and biofilms
- **PhyloChip**

# PhyloChip

- PhyloChip microarray analysis
  - Developed at Lawrence Berkeley National Laboratory
  - Analyze **relative proportions of microorganisms** in samples
  - Compare specific bacterial taxa in samples with **fecal source identifiers** including sewer, septage, human stool, shorebird, cat, dog, cow, horse, elk/deer, pig, raccoon, seal/sea lion
- MST samples for PhyloChip analysis
  - **50** DNA extracts of MST water samples chosen
  - Capistrano Outfall Pipe (PPH-1)
  - St. Augustine Creek Outlet (PPH-2)
  - Capistrano Beach (PPH-3)



© Dubinsky et al. 2012

# PhyloChip results

- Site-specific results
  - Inflow sites (PPH-1, 2) had **similar** microbial community but **different** from Capistrano Beach (PPH-3)
  - Bacterial community in freshwater and seawater were **more similar** during **contamination** events (high FIB counts)
- Estimation of fecal source identifiers
  - **Shorebird** source found in **25%** of PhyloChip samples  
**Not consistent** with the findings of MST assays, but **not a significant source** PhyloChip (relative abundance) vs. MST (absolute concentration)
  - Mammal and human source found in **4 of the 50** samples but signals weak
  - No other fecal sources appeared

➔ **PhyloChip analysis confirmed MST results: human, equine and bovine feces not significant sources of bacteria at Capistrano Beach.**

**Other sources like cats, pigs, raccoons, pinnipeds were not found in PhyloChip analysis**

# Beach-by-Beach Results



# Conclusions

- Capistrano Beach has **higher FIB** than other beaches and highest in the **wet** season.
- Human: not a major source of fecal contamination
  - Marker was detected but **is not a significant source** of bacteria at Capistrano Beach.
  - The application of a **second MST** assay and **PhyloChip** method both confirmed that human marker is not a significant source.
  - **Live-aboard boats** were not a major source of fecal bacteria at Harbor beaches during the study period.
- Bovine: main fecal source at Deer Creek
  - Bovine marker was **frequently found** at Deer Creek Outlet and its upstream sites with high concentrations.
  - Bovine is **predominant** source of fecal pollution at Deer Creek.

# Conclusions (continued)

- Canine: considerably affects water quality
  - Canine is a **significant, but not primary** fecal source at **Capistrano Beach**.
  - Canine fecal bacteria at Capistrano Beach was introduced from freshwater **inflows** rather than other nearby beaches.
  - Upstream MST monitoring revealed that **canine feces** entered into the waterway of Capistrano Outfall Pipe and Deer Creek Outlet in the **urban area**.
  - Canine represents a significant source at Deer Creek Outlet during wet weather.
- Gull: minor impact on water quality
  - Although there are large flocks of gulls, two gull-associated MST assays **not detected** gull feces in PPH.
  - Qualitative PhyloChip analysis found shorebird signals in several samples; however, their contribution to high bacteria counts is **insignificant**.
- Equine: no evidence of fecal pollution
  - Equine-associated *Bacteroidales* were **not detected** in any of MST samples.

# Conclusions (continued)

- Sediments and biofilms: play an important role
  - FIB **accumulate** and **persist** longer when associated with sediments and biofilms.
  - FIB in sediments and biofilms are periodically **resuspended** by turbulence and lead to increases in FIB levels in water.
- The monitoring study
  - Provided **significant insights** into fecal contamination in PPH
  - Will assist with the selection of appropriate **recommendations** to reduce fecal pollution
- What we do know vs. what we don't know- what we ruled out and ruled in, what we didn't test.

# Thoughts about recommendations

- Pursue stormwater filtering technologies.
- Reduce sediment and biofilm reduction in stormwater drainage system.
- Encourage proper disposal of dog feces.
- Further investigate fecal sources from wildlife and stormwater drainage system.
- Continue upstream bovine best management practices.

# Acknowledgements

- San Mateo County Resource Conservation District (SMCRCD) staff and volunteers (conceiving the idea of a source tracking study, selecting specific sampling sites, collecting FIB samples and much else)
- Balance Hydrologics (conducting circulation study and modeling hydrology)
- June Wong and Dr. Bruce Fujikawa at San Mateo County Public Health Laboratory (analyzing fecal indicator bacteria in water samples)
- Prof. Jiyoung Lee at Ohio State University (analyzing PPH samples with a gull assay recently developed in her research group)
- Dr. Orin Shanks at United States Environmental Protection Agency (providing guidance in the use of a human source tracking assay)
- Dr. Yvette Piceno, Dr. Lauren Tom, Dr. Eric Dubinsky, Dr. Gary Andersen at Lawrence Berkeley National Laboratory (conducting PhyloChip analysis)
- Technical Advisory Board members (providing helpful advice)
- Wuertz lab : Dan Wang (developing the probabilistic source tracking model) and group members (assisting sampling and lab processing, reviewing monitoring results)

# How to get a copy of today's presentation

- RCD website: [www.sanmateorcd.org](http://www.sanmateorcd.org)
- Request an electronic copy from the RCD:  
Karissa Anderson, Project Coordinator  
[karissa@sanmateorcd.org](mailto:karissa@sanmateorcd.org)  
(650) 712-7765 x104

**Thank you!**

## **Appendix G**

### **Pillar Point Harbor Source Identification Project Literature Review (RCD)**

**Identification of Sources of Fecal Pollution Impacting Pillar Point Harbor:  
Literature Review**



May 31, 2008  
San Mateo County Resource Conservation District

## TABLE OF CONTENTS

1. <u>Executive Summary</u>	Page: <u>3-5</u>
2. <u>Tables</u>	<u>6-10</u>
3. <u>Appendices</u>	<u>11-75</u>

## **EXECUTIVE SUMMARY**

---

### **INTRODUCTION**

The objective of this analysis is to provide the research team with data and information which already exists in order to develop a strategy for determining a project overview and detailed project plan. An analysis of the data revealed a number of data gaps. There are a number of studies that are pending release or were not received, which will provide further valuable information. These will be reviewed and this document amended when those studies become available. Documents that are still pending are as follows:

- Kleinfelder Report: San Mateo County Midcoast Groundwater Study, Phase II San Mateo County, California
- Fitzgerald Marine Reserve Critical Coastal Area Project:  
Preliminary Watershed Assessment  
Historical Ecology
- Vandenberg Pillar Point Air Force Station site specific studies

The enumeration data for fecal indicators with regard to tidal and flow conditions, temporal issues, weather, rain events, seasons, first flush events, etc. has not been addressed in this document as the data was not available in the original reports and will require the reconstruction of the conditions through the use of historical weather information, rain gauge data and tidal charts. Enumeration data is included.

### **LOCATION**

The project study area is the Pillar Point Outer Harbor in El Granada, California. The geographical focus extends to any potential drainages and/or pollution sources which empty into or otherwise impact the harbor and its beaches, such as creeks, marshes, storm drains, sewer systems, runoff, leach fields, springs, wells, boat discharge, pet and avian fecal contamination, sediment, and wrack.

### **PROJECT SUMMARY**

The goal of this project is to assess and identify sources of fecal pollution in Pillar Point Harbor and recommend opportunities for remediation. Water will be sampled in select locations and tested for the presence and abundance of bacteria that occur with fecal pollution. Bacteria samples will be genetically tested to determine their original host source. The primary focus is Capistrano Beach, which has well documented levels of fecal pollution. The secondary focus is the five other beaches and live-aboard boats in the harbor.

The project then develops specific objectives for implementation of water quality remediation projects based on research and analysis. It identifies constraints, impediments, opportunities, and priorities to remediate water quality on the beaches in Pillar Point Harbor and cost-effective, feasible water quality improvement projects. It develops a timeline for implementing the proposed methods to achieve water quality objectives and the parties responsible, as well as a monitoring plan and performance measures to track implementation of projects.

## **SITE DESCRIPTION**

Pillar Point Harbor is an enclosed watershed with complex inputs and water flows. It contains an inner boat harbor, pier, and saltwater/brackish tidal marsh (Pillar Point Marsh). It receives drainage from Denniston and Deer Creeks, storm drains, outflow pipes, and large, mixed use areas including an airport, agricultural, commercial and residential sections. Pillar Point Harbor contains five beaches: Capistrano Beach, Yacht Club Beach, Marsh Beach, Mavericks Beach, Inner Harbor Beach, and Beach House Beach.

Pillar Point Harbor comprises an inner harbor and outer harbor. The inner harbor berths 180 commercial fishing vessels and approximately 200 recreational boats, and is encompassed within the much larger outer harbor area. The harbor area houses commercial ventures including several restaurants, hotels, shops, a fertilizer plant, three commercial fish buyers, sport fishing concessions, a yacht club, two kayak rental companies, a recreational vehicle park, and a Naval Station situated on the bluff overlooking the Outer Harbor. Outside of the Outer Harbor area but within the project study area are conference facilities, residential areas, and additional commercial ventures as well as a pump station for the Sewer Authority Mid-Coastside.

The project area is also within the boundaries of the James V. Fitzgerald Marine Reserve Critical Coastal Area (CCA) Pilot Project. The marine reserve is a designated Area of Special Biological Significance and the CCA pilot project, jointly administered by the State Water Resources Control Board and the California Coastal Commission, is to foster collaboration among local stakeholders and government agencies to better coordinate resources and focus efforts on coastal watersheds in critical need of protection from polluted runoff. The CCA will develop an action plan to reduce non-point source pollution by 2010 and intends to coordinate closely with this project to identify and remediate sources of fecal contamination in Pillar Point Harbor.

## **METHODOLOGY**

Following the first Technical Advisory Committee (TAC) meeting in October 2007 a request for data sources relevant to Pillar Point Harbor was sent to all TAC members. Balance Hydrologics, Pillar Point Harbor Master's Office, Granada Sanitary District (GSD), Sewer Authority Mid-Coastside (SAM), San Mateo County Environmental Health Services (SMCEHS), and the Santa Cruz Department of Environmental Health Services (SCEHS) submitted recommendations for literature to be reviewed. San Mateo County Resource Conservation District staff conducted independent literature searches. Some information was found on the internet and in the Half Moon Bay public library.

Fourteen reports from Balance Hydrologics and eighteen reports from the Pillar Point Harbor Master's office were reviewed. Two reports and five files of correspondence and relevant information were received from the GSD. A binder of information containing correspondence and relevant information was received from SAM. SMCEHS submitted twelve files of correspondence and relevant information electronically. SCEHS submitted six reports electronically.

The literature reviewed has been divided into two categories: reports and correspondence/relevant information. Appendix 1: lists all of the reports in chronological order. The type of information found in the reports has been summarized in Table 1: Known Existing Information. Detailed summaries for each report are found in Appendix 2.

The literature identified as correspondence/relevant information has been organized into Pillar Point Project files. Correspondence refers to communication between the various agencies involved with Pillar Point Harbor. Relevant information refers to items such as newspaper articles, maps, etc. These files are identified by topic or by who the correspondents are; i.e. the file titled Granada Sanitary District/Sewer Authority Mid-Coastside contains all correspondence received by the San Mateo County Resource Conservation District between the Granada Sanitary District and the Sewer Authority Mid-Coastside. There are fifteen files of correspondence and six files of relevant information containing a total of 120 documents. Appendix 3: lists the files of correspondence and relevant information. Detailed summaries of all correspondence and relevant information are in Appendix 4.

Two indices to sort the literature have been created. The index to sort the reports is in digital format and can be obtained by contacting the SMCRCDC. The reports are listed chronologically by a document number determined by the year the report was published. All document numbers begin with the prefix: PPH.R, which stands for Pillar Point Harbor Report. This is followed by the year the report was published. If there is more than one report for a given year, they are designated by a lower case letter. For example, PPH.R.88.a, PPH.R.88.b would refer to two reports published in 1988.

The index to sort the correspondence/relevant information is in digital format and can be obtained by contacting the SMCRCDC. The information is listed chronologically within the Pillar Point file categories (refer to Appendix 3). All document numbers begin with the prefix: PPH.C, which stands for Pillar Point Harbor Correspondence. This is followed by the Pillar Point Harbor file number, the year and the month the item was written. If there is more than one document for a given month, they are designated by a lower case letter. For example, PPH.C.1.91.09.a, PPH.C.1.91.09.b refers to two items from Pillar Point Harbor file 1 that were both published in September 1991.

The SMCEHS has collected samples for fecal indicator bacteria (FIB) at various sites within Pillar Point Harbor under the auspices of AB 411. The San Mateo County Chapter of the Surfrider Foundation has collected FIB samples within Pillar Point Harbor as part of their Blue Water Task Force citizen volunteer water monitoring program. Table 2 summarizes the time periods for the collection of FIB data by this agency and organization.

All documents and electronic files have been duplicated and are housed at the SMCRCDC.

## **TABLES**

Table 1: Known Existing Information

Table 2: Data Gaps

Table 3: Fecal Indicator Bacteria for Pillar Point Harbor

**TABLE 1: KNOWN EXISTING INFORMATION FROM REPORTS**

(Number of reports related to column headings are listed by location and identified in the Document Reference column.)

	<b>WATERSHED: HYDROLOGY/ GEOLOGY INCL. SEDIMENTATI ON</b>	<b>LANDUSE</b>	<b>HABITAT</b>	<b>FIB</b>	<b>FUNCTION</b>	<b>NATURAL &amp;/OR MAND- MADE CONDITIONS</b>	<b>SEWER/SEWERA GE INFLOW &amp; INFILTRATION STUDIES</b>	<b>DOCUMENT REFERENCE (ALL WITH PREFIX PPH.R)</b>
<b>DENNISTON CREEK</b>	<b>5</b>	<b>5</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	74.a; 77.a; 87.a; 91.e; 02.a
<b>DEER CREEK</b>	<b>1</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	99.a
<b>PILLAR POINT MARSH</b>	<b>6</b>	<b>6</b>	<b>1</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	77.a; 87.a; 91.e; 92.b; 02.a; 03.a
<b>PILLAR POINT HARBOUR</b>	<b>10</b>	<b>6</b>	<b>3</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	75.a; 76.a; 82.a; 86.a; 86.b; 89.d; 89.e; 90.a; 91.a; 91.c; 91.d; 94.a; 95.a; 95.b; 95.c; 97.a; 97.b; 07.a; 07.b
<b>UPLAND</b>	<b>6</b>	<b>4</b>	<b>3</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	88.a; 88.b; 89.a; 89.c; 92.a; 94.b; 01.a
<b>STORM DRAINS/SEWER</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	
<b>OTHER</b>	<b>2</b>	<b>2</b>	<b>1</b>	<b>5</b>	<b>1</b>	<b>0</b>	<b>0</b>	72.a; 89.b; 01.b; 03.b; 06.a; 06.b; 06.c; 08.a

**TABLE 2: DATA GAPS**

Key

x = no data  
 xx = some data  
 xxx = full data set

TOPIC	AVAILABLE LITERATURE	WHAT WE HAVE	DATA GAP
Storm Drain Flushing	x	Documents that allude to the need for, and commitment to do this, but no documentation of this work.	Any storm drain flushing data or report
Enumeration Data:			
i) FIB	xx	No data for some sites, minimal data for some sites and substantial data for some sites	Refer to FIB Table 3
ii) Bacteriophage	xx	Two random tests for a number of sites	Consistent sampling data to establish a conclusive source
iii) MST	x		
Storm Drain/Sewerline Maps	xx	Two line diagrams with limited legends and information. Limited to the area surrounding HMB Brewery and Barbara's Fish Trap	Maps for the entire Pillar Point Area – inclusive from the launch ramp to the Westpoint Parking lot
Sewer, other inflow and infiltration studies.	x	This has been referred to in various correspondences but there are no documented studies.	
Landuse Maps	x		
Oral History	xx	Limited to two accounts from local residents	Decisions, actions and/or communications regarding these studies
Smoke, Dye, TV and Soil Tests	xx	Data collected from 7 tests conducted 1991-2005	
Natural and/or human-made conditions	x	CCA pending document on historical ecology.	
Watershed data: Hydrology/Geology			
i) Denniston Creek	xx	Several studies incl. larger area and	

		aquifer – most recent being 1991	
ii) Pillar Point Marsh	xx	Several studies, feasibility of utilizing ground water, biological survey 1977	
iii) Deer Creek Outlet	xx	One study, feasibility of sediment basin	
iv) Harbor	xx	Numerous studies, biota, chemical & physical soil analysis, bathymetry and urban master plan	Circulation study, breakwall permeability studies. sedimentation and beach sand shifting
v) Reclaimed Marsh Area (behind HMB Brewery/Oceano Hotel)	x		

**TABLE 3: FECAL INDICATOR BACTERIA FOR PILLAR POINT HARBOUR**

(Fecal Indicator Bacteria Data for Pillar Point Harbor)

<b>SITE</b>	<b>DATE</b>	<b>SOURCE</b>
Capistrano Outfall Pipe	6/99-2/01;4/02-2/06	SMC EHS AB411
Bathhouse Outfall Pipe	6/05-4/07	Surfrider San Mateo
Capistrano Beach	6/99-2/01;4/02-2/06	SMC EHS AB411
	6/05-4/07	Surfrider San Mateo
Denniston Creek	9/05-4/07	Surfrider San Mateo
Pillar Point Marsh Beach	6/99-10/07	SMC EHS AB411
Mavericks Beach	8/04-10/07	SMC EHS AB411
Beach House Beach	No data	
Deer Creek	No data	
Inner Harbor Beach	No data	
Yacht Club Beach	No data	
Offshore	No data	

## **APPENDICES**

Appendix 1: List of Reports in Chronological Order

Appendix 2: Report Summaries

Appendix 3: List of Pillar Point Project Files: Correspondence/Relevant Information

Appendix 4: Correspondence/Relevant Information Summaries

## **Appendix 1: List of Reports**

### **Pillar Point Harbor Report List**

This appendix lists the reports received from the various agencies involved with the Pillar Point Harbor project and other pertinent background information.

**Document Number:** PPH.R.72.a

**Title:** Preliminary geologic map of San Mateo County, California: USGS Miscellaneous Field Studies Map MF-328

**Author:** Brabb, E.E. and Pampeyan, E.H.

**Date:** 1972

**Type:** Report

**Source:** Balance Hydrologics

**Media Type:** Hard Copy, Electronic

**Document Number:** PPH.R.74.a

**Title:** Ground water investigation, Denniston Creek vicinity, San Mateo County, California: Unpublished consulting report, 12 p.

**Author:** Lowney-Kaldveer Associates

**Date:** 1974

**Type:** Report

**Source:** Balance Hydrologics

**Media Type:** Electronic

**Document Number:** PPH.R.75.a

**Title:** Biological Survey of Pillar Point Harbor, Progress Report

**Author:** Marine Ecological Institute

**Date:** 1975

**Type:** Study

**Source:** Pillar Point Harbor Master's Office

**Media Type:** Hard Copy

**Document Number:** PPH.R.76.a

**Title:** Biological Survey of Pillar Point Harbor, El Granada, CA.

**Author:** Marine Ecological Institute

**Date:** 1976

**Type:** Study

**Source:** Pillar Point Harbor Master's Office

**Media Type:** Hard Copy

**Document Number:** PPH.R.77.a

**Title:** Environmental study of the Pillar Pt. Marsh, San Mateo County, California: Part I. Baseline data: Consulting report prepared for the Coastside County Water District, draft, 34 p. + numerous tables and appendices.

**Author:** Flint, P.S.

**Date:** 1977

**Type:** Report

**Source:** Balance Hydrologics

**Media Type:** Electronic

**Document Number:** PPH.R.82.a

**Title:** Geotechnical Engineering Investigation Pillar Point Marina, El Granada, CA

**Author:** Woodward-Clyde Consultants

**Date:** 1982

**Type:** Report

**Source:** Pillar Point Harbor Master's Office

**Media Type:** Hard Copy

**Document Number:** PPH.R.86.a

**Title:** Princeton Study Area, Background Report

**Author:** Department of Environmental Management

**Date:** 1986

**Type:** Report

**Source:** Granada Sanitary District

**Media Type:** Hard Copy

**Document Number:** PPH.R.86.b

**Title:** Comprehensive Condition Survey: East and West Breakwaters, Half Moon Bay, San Mateo, CA

**Author:** US Army Corps of Engineers;

**Date:** 1986

**Type:** Report

**Source:** Pillar Point Harbor Master's Office

**Media Type:** Hard Copy

**Document Number:** PPH.R.87.a

**Title:** Half Moon Bay Airport/Pillar Point Marsh ground water basin, phase I study report (preliminary report): Unpublished Report

**Author:** Earth Science Associates and Luhdorff & Scalmanini

**Date:** 1987

**Type:** Report

**Source:** Balance Hydrologics

**Media Type:** Electronic

**Document Number:** PPH.R.88.a

**Title:** El Granada ground water investigation report: Kleinfelder & Associates consulting report prepared for the San Mateo County Planning Department.

**Author:** Laduzinsky, D., Hecht, B., and Woyshner, M.

**Date:** 1988

**Type:** Report

**Source:** Balance Hydrologics

**Media Type:** Hard Copy, Electronic

**Document Number:** PPH.R.88.b

**Title:** Biology Montara-Moss Beach Water Wells EIR. Administrative draft for Kleinfelder

**Author:** Renshaw, D.L.

**Date:** 1988

**Type:** Report

**Source:** Balance Hydrologics

**Media Type:** Hard Copy, Electronic

**Document Number:** PPH.R.89.a

**Title:** Appendix: Plants & Animals Identified in the Montara-Moss Beach Study Area

**Author:** Renshaw, D.L.

**Date:** 1989

**Type:** Report

**Source:** Balance Hydrologics

**Media Type:** Electronic

**Document Number:** PPH.R.89.b

**Title:** An Evaluation of Waste Water Disposal and Water Quality in the San Lorenzo River Watershed: Preliminary Report

**Author:** County of Santa Cruz Health Services Agency

**Date:** 1989

**Type:** Report

**Source:** Santa Cruz Department of Environmental Health

**Media Type:** Electronic

**Document Number:** PPH.R.89.c

**Title:** Groundwater Extraction in the Urban Mid-Coastside Communities of San Mateo County

**Author:** California Coastal Commission

**Date:** 1989

**Type:** Report

**Source:** Balance Hydrologics

**Media Type:** Hard Copy

**Document Number:** PPH.R.89.d

**Title:** Soil and Foundation Study for Proposed Boardwalk-pathway, Pillar Point, Half Moon Bay, San Mateo Co, CA

**Author:** JCP Geologist/Engineers, Cupertino, CA

**Date:** 1989

**Type:** Report

**Source:** Pillar Point Harbor Master's Office

**Media Type:** Hard Copy

**Document Number:** PPH.R.89.e

**Title:** Final Environmental Impact Report as an Addendum to the Draft Environmental Impact Report for the Pillar Point East Harbor Master Plan

**Author:** Earth Metrics Incorporated;

**Date:** 1989

**Type:** Report

**Source:** Pillar Point Harbor Master's Office

**Media Type:** Hard Copy

**Document Number:** PPH.R.90.a

**Title:** Geotechnical Engineering Study West Shoreline Access Project, Pillar Point Marina, El Granada, CA

**Author:** Levine-Fricke Consulting Engineers and Hydrogeologists.

**Date:** 1990

**Type:** Study

**Source:** Pillar Point Harbor Master's Office

**Media Type:** Hard Copy

**Document Number:** PPH.R.91.a

**Title:** Pillar Point Harbor Master Plan and Urban Waterfront Restoration Plan

**Author:** Callander Associates

**Date:** 1991

**Type:** Study

**Source:** Half Moon Bay Library

**Media Type:** Hard Copy

**Document Number:** PPH.R.91.b

**Title:** Denniston Creek Investigations Pictures

**Date:** 1991

**Type:** Internal document

**Source:** Granada Sanitary District

**Media Type:** Hard Copy

**Document Number:** PPH.R.91.c

**Title:** Results of Geotechnical Field Testing West Shoreline  
Access Project, Pillar Point Marina, El Granada, CA

**Author:** Levine-Fricke Consulting Engineers and Hydrogeologists

**Date:** 1991

**Type:** Report

**Source:** Pillar Point Harbor Master's Office

**Media Type:** Hard Copy

**Document Number:** PPH.R.91.d

**Title:** Pillar Point Boat Ramp Facility Mitigation Site Monitoring Program Baseline Data Report

**Author:** Entrix, Inc.

**Date:** 1991

**Type:** Report

**Source:** Pillar Point Harbor Master's Office

**Media Type:** Hard Copy

**Document Number:** PPH.R.91.e

**Title:** Half Moon Bay Airport/Pillar Point Marsh ground-water basin report Phase II

**Author:** Luhdorff and Scalmanini Consulting Engineers and Earth Sciences Associates

**Date:** 1991

**Type:** Study

**Source:** Balance Hydrologics

**Media Type:** Electronic

**Document Number:** PPH.R.92.a

**Title:** Initial identification of hydrogeologic and water-quality opportunities and constraints: proposed county golf course at the Cowell-Torello Property, Moss Beach, California: Consulting report submitted to Cowell-Torello Properties

**Author:** Hecht, B., White, C., and Knudsen, K.

**Date:** 1992

**Type:** Study

**Source:** Balance Hydrologics

**Media Type:** Electronic

**Document Number:** PPH.R.92.b

**Title:** Half Moon Bay Airport/Pillar Point Marsh ground-water basin report, Phase II: Supplemental Data.

**Author:** Luhdorff and Scalmanini Consulting Engineers and Earth Sciences Associates

**Date:** 1992

**Type:** Report

**Source:** Balance Hydrologics

**Media Type:** Electronic

**Document Number:** PPH.R.94.a

**Title:** Results of Chemical and Physical Testing of Sediments from the Pillar Point Marina

**Author:** Advanced Biological Testing, Inc.

**Date:** 1994

**Type:** Report

**Source:** Pillar Point Harbor Master's Office

**Media Type:** Hard Copy

**Document Number:** PPH.R.94b

**Title:** Rescission of a Portion of Categorical Exclusion E-81-1, Approved for San Mateo County in 1981

**Author:** California Coastal Commission

**Date:** 1994

**Type:** Report

**Source:** Balance Hydrologics

**Media Type:** Electronic

**Document Number:** PPH.R.95.a

**Title:** Results of Chemical and Physical Testing of Sediments from the Pillar Point Marina Surfer Beach

**Author:** Advanced Biological Testing, Inc.

**Date:** 1995

**Type:** Report

**Source:** Pillar Point Harbor Master's Office

**Media Type:** Hard Copy

**Document Number:** PPH.R.95.b

**Title:** Results of Pillar Point Harbor Intertidal Mitigation Site Investigations A: Benthic Invertebrates, B: Shorebirds

**Author:** Entrix, Inc.

**Date:** 1995

**Type:** Study

**Source:** Pillar Point Harbor Master's Office

**Media Type:** Hard Copy

**Document Number:** PPH.R.95.c

**Title:** Administrative Draft Supplemental Environmental Impact Report for the Pillar Point Harbor 71-Berth Addition and Harbor Maintenance Dredging Project

**Author:** Huffman and Associates, Inc.

**Date:** 1995

**Type:** Study

**Source:** Pillar Point Harbor Master's Office

**Media Type:** Hard Copy

**Document Number:** PPH.R.97.a

**Title:** Results of Chemical and Physical Testing of Sediments for New Construction Dredging at Pillar Point Harbor

**Author:** Advanced Biological Testing, Inc.

**Date:** 1997

**Type:** Report

**Source:** Pillar Point Harbor Master's Office

**Media Type:** Hard Copy

**Document Number:** PPH.R.97.b

**Title:** Addendum to Results of Chemical and Physical Testing of Sediments for New Construction Dredging at Pillar Point Harbor

**Author:** Advanced Biological Testing, Inc.

**Date:** 1997

**Type:** Report

**Source:** Pillar Point Harbor Master's Office

**Media Type:** Hard Copy

**Document Number:** PPH.R.99.a

**Title:** A Feasibility Study of Sediment Retention Basins for Deer Creek, El Granada, CA

**Author:** DeTemple, B.; Battalio, R.; Ruttenberg, D.

**Date:** 1999

**Type:** Study

**Source:** Pillar Point Harbor Master's Office

**Media Type:** Hard Copy

**Document Number:** PPH.R.01.a

**Title:** Water Supply Evaluation: Calendar Year 2000 Report

**Author:** Coastside County Water District

**Date:** 2001

**Type:** Report

**Source:** Balance Hydrologics

**Media Type:** Hard Copy, Electronic

**Document Number:** PPH.R.01.b

**Title:** Evaluation of Urban Water Quality, Task 4 Report, San Lorenzo River Watershed Management Plan Update

**Author:** Ricker, J.; Peters, S.; Golling, R.

**Date:** 2001

**Type:** Report

**Source:** Santa Cruz Department of Environmental Health

**Media Type:** Electronic

**Document Number:** PPH.R.02.a

**Title:** Fitzgerald Marine Reserve Master Plan

**Author:** Kittleson, G.; Hecht, B. consulting contribution excerpts found as pp. 129-140 in Brady/LSA, 2002, Fitzgerald Marine Reserve Master Plan Part Two: Environmental Setting

**Date:** 2002

**Type:** Report

**Source:** Balance Hydrologics

**Media Type:** Electronic

**Document Number:** PPH.R.03.a

**Title:** Fitzgerald Marine Reserve Draft Environmental Impact Report

**Author:** Thomas Reid Associates

**Date:** 2003

**Type:** Report

**Source:** Half Moon Bay Library

**Media Type:** Hard copy

**Document Number:** PPH.R.03.b

**Title:** San Lorenzo Urban River Plan

**Author:** City of Santa Cruz

**Date:** 2003

**Type:** Report

**Source:** Santa Cruz Department of Environmental Health

**Media Type:** Electronic

**Document Number:** PPH.R.06.a

**Title:** Assessment of Sources of Bacterial Contamination at Santa Cruz County Beaches

**Author:** Ricker, J.; Peters, S.

**Date:** 2006

**Type:** Study

**Source:** Santa Cruz Department of Environmental Health

**Media Type:** Electronic

**Document Number:** PPH.R.06.b

**Title:** The Amplification of Indicator Bacteria resulting as a Result of kelp Mound Incubation along a Protected Beach in Southern California

**Author:** McCoy, D.; Aumand, L.

**Date:** 2006

**Type:** Study

**Source:** Santa Cruz Department of Environmental Health

**Media Type:** Electronic

**Document Number:** PPH.R.06.c

**Title:** Observations in Macro and Micro Algae Contributions to Bacteria Populations and Implications for Beach Advisories

**Author:** Peters, S.

**Date:** 2006

**Type:** Study

**Source:** Santa Cruz Department of Environmental Health

**Media Type:** Electronic

**Document Number:** PPH.R.07.a

**Title:** Summary Report Pillar Point Harbor Bathymetry Study & Outer Harbor Channel Design

**Author:** Gahagan & Bryant Associates, Inc.

**Date:** 2007

**Type:** Report

**Source:** Pillar Point Harbor Master's Office

**Media Type:** Hard Copy

**Document Number:** PPH.R.07.b

**Title:** Jurisdictional Waters of the US and Wetland Determination Report: United States Air Force Pillar Point Storm Water Outfall Project

**Author:** Bayer, K.; Evans, Y.; Varney, R.; Zoidis, A.

**Date:** 2007

**Source:** Pillar Point Harbor Master's Office

**Type:** Study

**Media Type:** Hard Copy

**Document Number:** PPH.R.08.a

**Title:** Clean Marina Program Annual Review

**Author:** Kronman, M., City of Santa Barbara Waterfront Department

**Date:** 2008

**Type:** Memo

**Source:** Santa Barbara Harbor Master's Office

**Media Type:** Hard Copy, Electronic

## **Appendix 2: Report Summaries**

### **Pillar Point Harbor Literature Review**

This document summarizes the reports received from the various agencies involved with the Pillar Point Harbor project and other pertinent background information.

**Document Number:** PPH.R.72.a

**Title:** Preliminary geologic map of San Mateo County, California: USGS Miscellaneous Field Studies Map MF-328

**Author:** Brabb, E.E. and Pampeyan, E.H.

**Date:** 1972

**Type:** Report

**Source:** Balance Hydrologics

**Summary:** Open-File report, digital geologic map database compiled from previously published & unpublished data, represents general distribution of bedrock and surficial deposits in San Mateo Co., provides information of geologic structure and stratigraphy.

**Document Number:** PPH.R.74.a

**Title:** Ground water investigation, Denniston Creek vicinity, San Mateo County, California: Unpublished consulting report, 12 p.

**Author:** Lowney-Kaldveer Associates

**Date:** 1974

**Type:** Report

**Source:** Balance Hydrologics

**Summary:** Purpose of study was to evaluate potential for future subsurface water development within the area under jurisdiction of the Coastside County Water District as a basis for management of the basin.

**Document Number:** PPH.R.75.a

**Title:** Biological Survey of Pillar Point Harbor, Progress Report

**Author:** Marine Ecological Institute

**Date:** 1975

**Type:** Study

**Source:** Pillar Point Harbor Master's Office

**Summary:** This report presents initial findings of the Biological Survey of Pillar Point Harbor conducted by the Marine Ecological Institute.

**Document Number:** PPH.R.76.a

**Title:** Biological Survey of Pillar Point Harbor, El Granada, CA.

**Author:** Marine Ecological Institute

**Date:** 1976

**Type:** Study

**Source:** Pillar Point Harbor Master's Office

**Summary:** The purpose of this study was to describe the biotic resources of Pillar Point Harbor and to develop the data necessary for an Environmental Impact Statement. The entire area within the breakwater was studied for one year. Detailed observations were made with regards to water quality (temperature, salinity, transparency, and dissolved oxygen), avian and mammalian surveys, fish and macroinvertebrate surveys, benthic surveys, and diver transects.

**Document Number:** PPH.R.77.a

**Title:** Environmental study of the Pillar Pt. Marsh, San Mateo County, California: Part I. Baseline data: Consulting report prepared for the Coastside County Water District, draft, 34 p. + numerous tables and appendices.

**Author:** Flint, P.S.

**Date:** 1977

**Type:** Report

**Source:** Balance Hydrologics

**Summary:** Coastside County Water District (CCWD) undertaking the development of Denniston Creek watershed as a local water supply in two phase project. This report conducted as part of Phase II, the proposal to drill 8 wells in the Denniston Creek/airport area. A condition of the permit from the Central Coast Regional Commission for this project states that “prior to production of any proposed wells, applicant shall adopt a monitoring program for groundwater levels and quality & the biological effects in the Princeton area.” This document reports on the biota as a baseline study before the onset of the rainy season. Groundwater monitoring was performed by the District engineer. This document includes detailed descriptions of the Pillar Point Marsh: physiographic setting, brief history of land use, physical environment, geology, hydrology, soils, vegetation, and animals.

**Document Number:** PPH.R.82.a

**Title:** Geotechnical Engineering Investigation Pillar Point Marina, El Granada, CA

**Author:** Woodward-Clyde Consultants

**Date:** 1982

**Type:** Report

**Source:** Pillar Point Harbor Master’s Office

**Summary:** Provides geotechnical information and recommendations to aid in developing design criteria for proposed marina improvements.

**Document Number:** PPH.R.86.a

**Title:** Princeton Study Area, Background Report

**Author:** Department of Environmental Management

**Date:** 1986

**Type:** Report

**Source:** Granada Sanitary District

**Summary:** Provides background information about the Princeton area. Identifies potential issues for future development of this area. Pertinent information for the PPH project is found in Section 3, Public Services and Facilities. On page 3.4 it’s stated that “some of the sewer pipelines...are in need of repair or replacement.”

**Document Number:** PPH.R.86.b

**Title:** Comprehensive Condition Survey: East and West Breakwaters, Half Moon Bay, San Mateo, CA

**Author:** US Army Corps of Engineers;

**Date:** 1986

**Type:** Report

**Source:** Pillar Point Harbor Master's Office

**Summary:** This condition survey was designed to identify problems which require immediate rehabilitation and to evaluate the overall condition of the east and west breakwaters at Half Moon Bay. While many minor problems were identified, the structures were found to be in good condition. The key problems found included: possible loss of armor stone at various locations, an overlay of smaller rock over the crest of most of the west breakwater, this is not of a design size and is not keyed well to the section below. These problems could be addressed as part of a routine maintenance contract, although no immediate work is required on either breakwater. The evaluation of the overall condition of the breakwaters indicates that there is no serious design or material deficiencies.

**Document Number:** PPH.R.87.a

**Title:** Half Moon Bay Airport/Pillar Point Marsh ground water basin, phase I study report (preliminary report): Unpublished Report

**Author:** Earth Science Associates and Luhdorff & Scalmanini

**Date:** 1987

**Type:** Report

**Source:** Balance Hydrologics

**Summary:** Purpose of study was to determine safe yield of Half Moon Bay Airport/Pillar Point Marsh Ground Water Basin (the Denniston Creek sub-basin of the Half Moon Bay Aquifer.)

**Document Number:** PPH.R.88.a

**Title:** El Granada ground water investigation report: Kleinfelder & Associates consulting report prepared for the San Mateo County Planning Department.

**Author:** Laduzinsky, D., Hecht, B., and Woyshner, M.

**Date:** 1988

**Type:** Report

**Source:** Balance Hydrologics

**Summary:** This report presents a reconnaissance description of the local ground-water resources in the El Granada area and discusses factors affecting their recharge, discharge, annual and seasonal fluctuations, and water quality. Detailed information is included regarding aquifer analysis (geometry, boundaries, and properties), ground water occurrence and storage, water level fluctuations, water balance inflows (percolation, inflow from valley alluvium, reservoir recharge) and water balance outflows (infiltration to sewer pipe, ground water pumpage), water quality. Conclusions address the assessment of risks and suggested directions for management.

**Document Number:** PPH.R.88.b

**Title:** Biology Montara-Moss Beach Water Wells EIR. Administrative draft for Kleinfelder

**Author:** Renshaw, D.L.

**Date:** 1988

**Type:** Report

**Source:** Balance Hydrologics

**Summary:** This report discusses the biological impacts (direct and indirect) associated with residential development on the habitat types (riparian, coastal grasslands, wetlands, aquatic, ruderal, eucalyptus and conifer stands, residential, and developed) in the Moss Beach-Montara area. Unique features such as plant and animal species of special concern, sensitive habitats, CA wild strawberries, and weedy, undesirable plants are discussed. Various mitigations and alternatives are presented.

**Document Number:** PPH.R.89.a

**Title:** Appendix: Plants & Animals Identified in the Montara-Moss Beach Study Area

**Author:** Renshaw, D.L.

**Date:** 1989

**Type:** Report

**Source:** Balance Hydrologics

**Summary:** List of plants and animals identified during the surveys presented in the previous document as well as species identified during unpublished field research conducted from 1975-1988.

**Document Number:** PPH.R.89.b

**Title:** An Evaluation of Waste Water Disposal and Water Quality in the San Lorenzo River Watershed: Preliminary Report

**Author:** County of Santa Cruz Health Services Agency

**Date:** 1989

**Type:** Report

**Source:** Santa Cruz Department of Environmental Health;  
([http://sccounty01.co.santa-cruz.ca.us/eh/environmental\\_water\\_quality\\_home.htm](http://sccounty01.co.santa-cruz.ca.us/eh/environmental_water_quality_home.htm))

**Summary:** This report evaluates the conclusions of past studies in relation to the findings of the San Lorenzo Wastewater Management Program which has been conducted by the Santa Cruz County Health Services Agency since 1985. This program has included water quality monitoring, sanitary surveys, lot-by-lot investigations of septic system performance, and required upgrade of inadequate wastewater disposal systems. This report provides an analysis of water quality of surface water and ground water in the San Lorenzo watershed, with specific emphasis on water quality conditions which are affected by wastewater disposal in the watershed. It also presents an analysis of the effectiveness of current methods of wastewater disposal, evaluates the potential for improvements, and makes recommendations for future wastewater management in the Watershed. 335pp

**Document Number:** PPH.R.89.c

**Title:** Groundwater Extraction in the Urban Mid-Coastside Communities of San Mateo County

**Author:** California Coastal Commission

**Date:** 1989

**Type:** Report

**Source:** Balance Hydrologics

**Summary:** An update to the 1989 report presented on the issue of ground water extraction in the Mid-Coastside communities of Half Moon Bay, Princeton, El Granada, Moss Beach, and Montara. In response to the inability of water providers to service new projects, landowners have drilled individual wells to serve their projects. Commission concerns regarding the proliferation of private wells include potential impacts on environmentally sensitive habitats, particularly the Pillar Point Marsh and the adequacy of public services for new projects.

**Document Number:** PPH.R.89.d

**Title:** Soil and Foundation Study for Proposed Boardwalk-pathway, Pillar Point, Half Moon Bay, San Mateo Co, CA

**Author:** JCP Geologist/Engineers, Cupertino, CA

**Date:** 1989

**Type:** Report

**Source:** Pillar Point Harbor Master's Office

**Summary:** Presents the results of studies performed for the boardwalk-pathway located adjacent to the Marchant property and Pillar Point Harbor. This report includes a site description (surface and subsurface conditions), geology of the area, secondary seismic events (liquefaction potential, slope stability, tsunami, and coastal erosion), conclusions and recommendations.

**Document Number:** PPH.R.89.e

**Title:** Final Environmental Impact Report as an Addendum to the Draft Environmental Impact Report for the Pillar Point East Harbor Master Plan

**Author:** Earth Metrics Incorporated

**Date:** 1989

**Type:** Report

**Source:** Pillar Point Harbor Master's Office

**Summary:** The East Harbor Master Plan for Pillar Point harbor consists of numerous improvements which cover the majority of the East Harbor area. The plan is broken down into four major improvement areas: the boat launch ramp and associated parking area, the commercial dock areas (or bulkhead expansion), the Johnson Pier expansion and construction of additional berths, the R.V. park and public access ways path to the launch ramp and beach areas. This document responds to all written comments received by the San Mateo Co. harbor District. Together with the Draft EIR, dated February 1989, this document constitutes the full final EIR subject to review and certification by the SMC Harbor Commission.

**Document Number:** PPH.R.90.a

**Title:** Geotechnical Engineering Study West Shoreline

Access Project, Pillar Point Marina, El Granada, CA

**Author:** Levine-Fricke Consulting Engineers and Hydrogeologists.

**Date:** 1990

**Type:** Study

**Source:** Pillar Point Harbor Master's Office

**Summary:** This report presents the results of a geotechnical engineering study on the west shoreline of Pillar Point Harbor for the proposed project consisting of the construction of a 12-car parking lot, approximately 2400 feet of 10-foot wide graveled pedestrian pathway, and the construction of approximately 1 acre of new intertidal habitat created by soil and bedrock excavation. The existing non-functional storm drain will be replaced with a new drain outfall. The purpose of the study was to evaluate the subsurface conditions in specific areas of the access road alignment and the mitigation site and to develop recommendations for site excavation and placement of fill and shoreline protection.

**Document Number:** PPH.R.91.a

**Title:** Pillar Point Harbor Master Plan and Urban Waterfront Restoration Plan

**Author:** Callander Associates

**Date:** 1991

**Type:** Study

**Source:** Half Moon Bay Library

**Summary:** Study recommends that the West Shoreline be maintained as a natural area and Pillar Point Marsh be preserved and included in the West Shoreline Management area.

**Document Number:** PPH.R.91.b

**Title:** Denniston Creek Investigations Pictures

**Date:** 1991

**Type:** Internal document

**Source:** Granada Sanitary District

**Summary:** A binder containing photographs of:

Denniston Creek, 8/9/91

Outlet of Denniston Creek, 8/23/91

Sand on beach at the end of Columbia Ave. storm drain outlet, 8/23/91

Storm drain near Shorebird after county flushed storm drain, 8/26/91

**Document Number:** PPH.R.91.c

**Title:** Results of Geotechnical Field Testing West Shoreline Access Project, Pillar Point Marina, El Granada, CA

**Author:** Levine-Fricke Consulting Engineers and Hydrogeologists

**Date:** 1991

**Type:** Report

**Source:** Pillar Point Harbor Master's Office

**Summary:** This document concludes the geotechnical field services for the project described in the 1990 report. Based on the observations, monitoring, and field density testing conducted by Levine-Fricke personnel, they give their professional opinion that the grading activities have been conducted in substantial conformance with the project plans and specifications and meet or exceed their recommendations.

**Document Number:** PPH.R.91.d

**Title:** Pillar Point Boat Ramp Facility Mitigation Site Monitoring Program Baseline Data Report

**Author:** Entrix, Inc.

**Date:** 1991

**Type:** Report

**Source:** Pillar Point Harbor Master's Office

**Summary:** Contractor retained by San Mateo Harbor District to conduct a baseline survey and a three year monitoring program of the intertidal marine benthic invertebrate community and birds using the nearshore area at the mitigation site near the western edge of the outer breakwater. Results are presented for epibenthic surveys, infaunal samples, bird censuses, species abundance and number of species, water bird use by segment and habitat, and sensitive species. Since this is a baseline survey no effort was made to draw conclusions from the data.

**Document Number:** PPH.R.91.e

**Title:** Half Moon Bay Airport/Pillar Point Marsh ground-water basin report Phase II

**Author:** Luhdorff and Scalmanini Consulting Engineers and Earth Sciences Associates

**Date:** 1991

**Type:** Study

**Source:** Balance Hydrologics

**Summary:** Purpose of this study was to determine the safe yield of HMB Airport/Pillar Point Marsh ground-water Basin (Denniston Creek sub-basin of the HMB Aquifer). Safe yield defined as "the amount of water that can be removed without adverse impacts on marsh health." The amount of water pumped from new wells is to "be limited to a safe yield factor which will not impact water dependent sensitive habitats, riparian habitats, or marshes." This study was conducted in two parts: a review and evaluation of available data to determine appropriate methodology for determining basin yield and the collection of additional data necessary for estimation of yield and development of management practices required to use and protect ground-water resources. This report includes the following information: description of the study area; information from previous studies; available data for surface water, wells, ground water quality; geologic conditions, regional and local; hydrologic conditions, surface water hydrology, stream gauging, infiltration potential, ground-water conditions, aquifer characteristics, ground water budget; biological assessment; ground-water basin yield and management.

**Document Number:** PPH.R.92.a

**Title:** Initial identification of hydrogeologic and water-quality opportunities and constraints: proposed county golf course at the Cowell-Torello Property, Moss Beach, California: Consulting report submitted to Cowell-Torello Properties

**Author:** Hecht, B., White, C., and Knudsen, K.

**Date:** 1992

**Type:** Study

**Source:** Balance Hydrologics

**Summary:** Portions of the Cowell-Torello property at the eastern edge of unincorporated Moss Beach were evaluated for the feasibility of the development of a golf course. This report addresses the impacts of water use, particularly the draw-down from wells (if used) and the impacts of runoff containing applied chemicals on the important natural areas of Pillar Point Marsh and the Fitzgerald Marine Reserve. This document provides information on the hydrologic setting, a description of the proposed development, projected water demands, previously conducted studies of the area, known beneficial uses, environmental issues and resource vulnerability, constituents of concern and pathways of dispersion, chemical applications management plans, ground-water occurrence, current use, yields, and likely effects, and potential mitigative approaches. The summary and conclusions describes additional water demands, potential water quality effects, anticipated effects on San Vicente Creek and Pillar Point Marsh, and pertinent information still needed.

**Document Number:** PPH.R.92.b

**Title:** Half Moon Bay Airport/Pillar Point Marsh ground-water basin report, Phase II: Supplemental Data.

**Author:** Luhdorff and Scalmanini Consulting Engineers and Earth Sciences Associates

**Date:** 1992

**Type:** Report

**Source:** Balance Hydrologics

**Summary:** This report provides additional data and an update of the Phase II report through April 1992. Recent water levels measured in piezometers show that an upward vertical ground-water gradient still exists indicating that ground water continues to recharge the marsh.

**Document Number:** PPH.R.94.a

**Title:** Results of Chemical and Physical Testing of Sediments from the Pillar Point Marina

**Author:** Advanced Biological Testing, Inc.

**Date:** 1994

**Type:** Report

**Source:** Pillar Point Harbor Master's Office

**Summary:** This report evaluates the potential use of sediments from the Marina for disposal at a site offshore of Surfers Beach to aid in beach replenishment or onsite at the marina for use as fill material.

**Document Number:** PPH.R.94b

**Title:** Rescission of a Portion of Categorical Exclusion E-81-1, Approved for San Mateo County in 1981

**Author:** California Coastal Commission

**Date:** 1994

**Type:** Report

**Source:** Balance Hydrologics

**Summary:** Recommends partial rescission of the portion of San Mateo County Categorical Exclusion E-81-1 that excludes agricultural wells from the requirement for obtaining a coastal development permit from the County. Partial rescission applies only to new agricultural wells in the Pillar Point Marsh watershed. New agricultural wells in this watershed would be required to be issued coastal development permits by San Mateo County before construction.

**Document Number:** PPH.R.95.a

**Title:** Results of Chemical and Physical Testing of Sediments from the Pillar Point Marina Surfer Beach

**Author:** Advanced Biological Testing, Inc.

**Date:** 1995

**Type:** Report

**Source:** Pillar Point Harbor Master's Office

**Summary:** Reports on the sediment chemical and physical analysis carried out on two samples taken from Surfers Beach adjacent to the Marina near Half Moon Bay. Dredging is being proposed to a maintained depth of -7 feet MLLW. Samples were taken to assess the compatibility of sediment taken from the Marina and proposed for disposal at this beach site.

**Document Number:** PPH.R.95.b

**Title:** Results of Pillar Point Harbor Intertidal Mitigation Site Investigations A: Benthic Invertebrates, B: Shorebirds

**Author:** Entrix, Inc.

**Date:** 1995

**Type:** Study

**Source:** Pillar Point Harbor Master's Office

**Summary:** Two reports that describe how the marine invertebrate and shorebird communities at the west end of Pillar Point Harbor may have changed over time following mitigation conducted in conjunction with the completion of the new boat ramp at the Harbor. For the invertebrate study, transects were set up in the mitigation area and a nearby reference area to assess the success of the mitigation effort in supporting a marine benthos community similar to those occurring naturally within the boundaries of the harbor. To evaluate shorebird communities, shorebird utilization of the mitigation area was compared to several nearby reference areas. Shorebird habitat appeared to be somewhat improved over nearby reference areas, while invertebrate communities were generally similar to that of the reference area. It appears the mitigation effort was successful in enhancing the habitat for these two communities.

**Document Number:** PPH.R.95.c

**Title:** Administrative Draft Supplemental Environmental Impact Report for the Pillar Point Harbor 71-Berth Addition and Harbor Maintenance Dredging Project

**Author:** Huffman and Associates, Inc.

**Date:** 1995

**Type:** Study

**Source:** Pillar Point Harbor Master's Office

**Summary:** This EIR evaluates the environmental impacts of the Pillar Point Harbor 71-berth addition, harbor maintenance dredging, and the construction of a guest dock at the HMB Yacht Club. The project includes 71 berths for recreational boats, a public access dock, an interim parking area, and a 6000 sq.ft. restaurant. The project also includes associated dredging required to achieve navigable depths in the berth and dock areas and maintenance dredging inside the eastern outer breakwater. In addition the HMB Yacht Club is proposing construction of a guest dock adjacent to their facility on Princeton Avenue. The report provides analysis of significant and unavoidable impacts, significant impacts, mitigation measures to avoid or reduce identified significant impacts, and less-than-significant impacts.

**Document Number:** PPH.R.97.a

**Title:** Results of Chemical and Physical Testing of Sediments for New Construction Dredging at Pillar Point Harbor

**Author:** Advanced Biological Testing, Inc.

**Date:** 1997

**Type:** Report

**Source:** Pillar Point Harbor Master's Office

**Summary:** This document was prepared to support applications for permits by Pillar Point Harbor to conduct new construction dredging. Its specific purpose is to present the results of chemical and physical analyses of the sediments.

**Document Number:** PPH.R.97.b

**Title:** Addendum to Results of Chemical and Physical Testing of Sediments for New Construction Dredging at Pillar Point Harbor

**Author:** Advanced Biological Testing, Inc.

**Date:** 1997

**Type:** Report

**Source:** Pillar Point Harbor Master's Office

**Summary:** Two additional stations were sampled after the completion of the previous document. The results of the chemical and physical analyses of these sites are reported here.

**Document Number:** PPH.R.99.a

**Title:** A Feasibility Study of Sediment Retention Basins for Deer Creek, El Granada, CA

**Author:** DeTemple, B.; Battalio, R.; Ruttenberg, D.

**Date:** 1999

**Type:** Study

**Source:** Pillar Point Harbor Master's Office

**Summary:** Reports on the feasibility of using a sediment retention basin to manage and reduce inflow of sediment into Pillar Point Harbor from Deer Creek.

**Document Number:** PPH.R.01.a

**Title:** Water Supply Evaluation: Calendar Year 2000 Report

**Author:** Coastside County Water District

**Date:** 2001

**Type:** Report

**Source:** Balance Hydrologics

**Summary:** Annual report prepared by CCWD staff following compilation of water production and sales data for the prior year. This report covers water production data for the period 1972-2000 and water sales data for 1975-2000. This report also presents an updated analysis of the capability of the water supply and transmission system to meet current and projected demands. There is no substantial change from last year's report.

**Document Number:** PPH.R.01.b

**Title:** Evaluation of Urban Water Quality, Task 4 Report, San Lorenzo River Watershed Management Plan Update

**Author:** Ricker, J.; Peters, S.; Golling, R.

**Date:** 2001

**Type:** Report

**Source:** Santa Cruz Department of Environmental Health

**Summary:** The County of Santa Cruz prepared and adopted a Watershed Management Plan for the San Lorenzo River in 1979. This report is an update of the Plan with particular emphasis on investigation and control of contamination from urban run-off. Results from investigations of microbiological contamination, toxic contaminants, lagoon water quality, and urban run-off management are presented. The section addressing Microbiological Contamination includes detailed information about the potential for disease and the use of indicator organisms, testing methodologies, historical trends of bacteria in the San Lorenzo River, focused monitoring (river, ocean, storm drains, sediments, and bacterial die-off), sources of bacteriologic contamination (birds, sewage spills/leaks, storm drain systems, and upstream flood plain areas). A Health Risk study was conducted with the following information reported: background on health risks, prior incidence of water-borne disease in Santa Cruz, survey methods and results, and the relationship to indicator levels. The section on General lagoon Water Quality and Chemical Constituents in Urban Run-off includes information about past findings in the San Lorenzo River, heavy metals, pesticides /PCBs, oil and grease, and products of combustion. Conclusions and Recommendations report observed levels of impairment, sources of microbiologic contamination, management measures for reduction of sewer spills/leaks and other sources of reduction.

**Document Number:** PPH.R.02.a

**Title:** Fitzgerald Marine Reserve Master Plan

**Author:** Kittleson, G.; Hecht, B. consulting contribution excerpts found as pp. 129-140 in Brady/LSA, 2002, Fitzgerald Marine Reserve Master Plan Part Two: Environmental Setting

**Date:** 2002

**Type:** Report

**Source:** Balance Hydrologics

**Summary:** This section, pertinent to the Pillar Point Harbor project, describes the primary hydrologic features found within FMR: San Vicente Creek, Pillar Point Marsh, and Denniston Creek. The ground water and surface water hydrology, land use history and changes and water quality of Pillar Point Marsh are described.

**Document Number:** PPH.R.03.a

**Title:** Fitzgerald Marine Reserve Draft Environmental Impact Report

**Author:** Thomas Reid Associates

**Date:** 2003

**Type:** Report

**Source:** Half Moon Bay Library

**Summary:** Describes recommended implementation actions designed to avoid impacts and make improvements to water quality in San Vicente Creek and Pillar Point Marsh.

**Document Number:** PPH.R.03.b

**Title:** San Lorenzo Urban River Plan

**Author:** City of Santa Cruz

**Date:** 2003

**Type:** Report

**Source:** Santa Cruz Department of Environmental Health

**Summary:** This report articulates a community vision for the corridor encompassing the lower San Lorenzo River, Branciforte Creek, and Jessie Street Marsh as a wildlife area as well as a community recreation and public open space amenity. It contains recommendations for habitat enhancement, public access and trail improvements, public art, and community programs. It seeks to guide the city of Santa Cruz in reestablishing and improving its management of and relationship to this major and recently expanded landscape feature over the next 20 years. The report describes in detail the planning area and river reach descriptions, the physical and social settings, history of flooding, current planning, system-wide recommendations, reach-specific recommendations, design improvements, project planning and projected costs.

**Document Number:** PPH.R.06.a

**Title:** Assessment of Sources of Bacterial Contamination at Santa Cruz County Beaches

**Author:** Ricker, J.; Peters, S.

**Date:** 2006

**Type:** Study

**Source:** Santa Cruz Department of Environmental Health

**Summary:** Santa Cruz County Environmental Health Services conducted this study to determine the source and health threat of elevated bacteria levels at Santa Cruz County beaches. This document presents background information and the results from the current study. Data were generated from the analysis of over 2000 collected water samples, 1200 bacteria isolates were tested to identify their source, 2100 swimmers were interviewed for the occurrence of illness, and 4700 feet of sewer main and associated laterals were evaluated. The primary source of contamination for the beaches is coastal lagoons that discharge to the ocean with additional contributions from birds, marine mammals, kelp, and possibly boats. Microbial Source Tracking (MST) using ribotyping provided an indication of the relative magnitude of the fecal coliform contribution from various types of animals with an estimated accuracy of at least 75-90%. Results indicate that birds were the major source of contamination at all locations, averaging 60%, human contribution to the bacteria loading averaged 5%. There were higher amounts of human loading in the lagoons during summer. Most of the human loading came from urban areas, with the proportion of human loading more than four times higher in winter than summer. Other significant sources of bacteria that on average each contributed 7% of the load were dogs, rodents, and wildlife; 15% of the bacteria assessed could not be attributed to specific sources.

**Document Number:** PPH.R.06.b

**Title:** The Amplification of Indicator Bacteria as a Result of Kelp Mound Incubation along a Protected Beach in Southern California

**Author:** McCoy, D.; Aumand, L.

**Date:** 2006

**Type:** Study

**Source:** Santa Cruz Department of Environmental Health

**Summary:** Pacific Beach Point in La Jolla, CA frequently exceeds state water quality standards for indicator bacteria. Studies were designed to investigate bacterial transport mechanisms and possible bacteria amplification occurring within the extensive kelp mounds found along the beach wrack line. Initial data indicate that bacteria reaching kelp mounds via storm drains, birds, flies, and scour pond run-off undergo incubation and subsequent multiplication within the kelp debris located along the high tide wrack line. Related and on-going laboratory and on-site studies have been designed to confirm that fecal coliform and Enterococci bacteria reproduce rapidly under conditions typical of coastal beaches with large amounts of kelp present. Another potential contributor to the spread of bacterial contamination considered was brineflies. Brine flies, which congregate in large numbers on and near beached kelp, may account to spread bacteria from point sources onto freshly beached kelp where the bacteria can then incubate.

**Document Number:** PPH.R.06.c

**Title:** Observations in Macro and Micro Algae Contributions to Bacteria Populations and Implications for Beach Advisories

**Author:** Peters, S.

**Date:** 2006

**Type:** Study

**Source:** Santa Cruz Department of Environmental Health

**Summary:** Santa Cruz County Environmental Health Services conducted tests on kelp found in the tidal area of several Santa Cruz County beaches to determine if decaying kelp could be one of the sources of elevated fecal indicator bacteria that has caused two beaches to be posted with swimming advisories. Both macro and micro algae results indicate that there is an increase in bacteria overtime and can be influenced by both increased temperature and lack of circulation at public beaches.

**Document Number:** PPH.R.07.a

**Title:** Summary Report Pillar Point Harbor Bathymetry Study & Outer Harbor Channel Design

**Author:** Gahagan & Bryant Associates, Inc.

**Date:** 2007

**Type:** Report

**Source:** Pillar Point Harbor Master's Office

**Summary:** This report compares the differences between the hydrographic surveys GBA did of Pillar Point Harbor in 1994 & 2006 for the addition of 71 berths inside the inner breakwater and for maintenance dredging.

**Document Number:** PPH.R.07.b

**Title:** Jurisdictional Waters of the US and Wetland Determination Report: United States Air Force Pillar Point Storm Water Outfall Project

**Author:** Bayer, K.; Evans, Y.; Varney, R.; Zoidis, A.

**Date:** 2007

**Source:** Pillar Point Harbor Master's Office

**Type:** Study

**Summary:** Describes proposed modifications to the storm water outfall system at the Pillar Point Airforce Station in order to comply with the requirements of a violation notification issued by the State Water Resources Control Board. The violation cited the discharge of storm water, defined as a waste, into the James V. Fitzgerald Marine Reserve Area of Special Biological Significance. The proposed action is to divert the storm water into Pillar Point Harbor. Water samples from the storm water discharge showed levels of zinc, copper, nitrogen, total coliform, fecal coliform, and Enterococci in excess of water quality standards.

**Document Number:** PPH.R.08.a

**Title:** Clean Marina Program Annual Review

**Author:** Kronman, M., City of Santa Barbara Waterfront Department

**Date:** 2008

**Type:** Memo

**Source:** Santa Barbara Harbor Master's Office

**Summary:** Describes outcomes of actions taken to maintain Clean Marina Program adopted in 2002. Regarding water quality, monthly sampling conducted during dry season only. Inspection & dye-tabling of Marine Sanitation Devices (MSDs/holding tanks/porta-potties) is required for all vessels visiting SB Marina & for new live-aboards & new vessels assigned to slips. Increased signage on wharf and with "table tent" signs at restaurants to reduce number of human/sea bird interactions. Worked with fishermen to reduce feeding of birds.

### **Appendix 3: Pillar Point Harbor Project Files: Correspondence and Relevant Information**

These files were created from:

- 1) Five files obtained from the Granada Sanitary District (GSD):
  - Denniston Creek/Capistrano Rd. Storm Drain Files 1,2,3 (Referred to as GSD Files 1, 2, 3) and
  - Capistrano Rd. Beach/Storm Drain Problem (Referred to as GSD File “Cap. Rd.”)
  - Bacteriological Examination of Water Test Results: Capistrano Rd. SMC Env. Health; 5/31/85 – 2/24/86.
- 2) pdf files from San Mateo County Environmental Health Services (SMCEHS)
- 3) “Capistrano Storm Drain Binder” obtained from Sewer Authority MidCoast (SAM Binder)

#### Pillar Point Harbor Project File Number, Correspondents/Contents:

1. Granada Sanitary District (GSD) Memos and Staff Reports
2. Granada Sanitary District /Sewer Authority Mid-Coastside (SAM)
3. Granada Sanitary District/San Mateo County Environmental Health Services (SMCEHS) and San Mateo Department of Public Works
4. Granada Sanitary District /Pillar Point Harbor District
5. Sewer Authority Mid-Coastside / San Mateo County Environmental Health Services
6. Sewer Authority Mid-Coastside / Pillar Point Harbor District
7. Sewer Authority Mid-Coastside /State Regional Water Quality Control Board (SRWQCB)
8. San Mateo County Environmental Health Services Memos/Staff Reports
9. San Mateo County Environmental Health Services / Pillar Point Harbor District
10. San Mateo County Environmental Health Services / State Regional Water Quality Control Board
11. Pillar Point Harbor District/State Regional Water Quality Control Board
12. Smoke, Dye, TV, Soil Test Results
13. Newspaper Articles/Press Releases
14. Public Questions/Comments
15. Bacterial Test Results
16. Miscellaneous Correspondence
17. Maps
18. Sewer Authority Mid-Coastside Memos/Reports
19. Bacteria Regulations
20. Verbal Correspondence
21. Harbor Regulations

## Appendix 4: Summaries of the documents listed as Correspondence/Relevant Information

### A. Pillar Point Harbor File #1: Granada Sanitary District Memos and Staff Reports

**Document Number:** PPH.C.1.90.12.a.

**Date:** 9/26/90 – 12/18/90

**Type:** Field Notes: Chronology of Spill Survey

**To:** No author

**From:** No recipient

**Source:** GSD File “Cap. Rd.”

**Summary:** Pillar Point Chronology of Spill Survey with SMCEHS Field Data Sheets for bacteriological examination of water.

**Document Number:** PPH.C.1.91.08.a.

**Date:** 8/1/91

**Type:** Letter

**To:** Granada Sanitary District Board

**From:** Kamil Azoury, Carroll Resources Engineering and Management (C-REM) for Granada Sanitary District

**Source:** GSD File 3

**Summary:** Notified on 7/26/91 of potential contamination in Denniston Creek and storm drain outlet next to Barbara’s Fish Trap by Ann Jensen of SMCEHS, advised her to discuss matter with her dept. since it was perhaps more under their jurisdiction. On 8/1/91 requested SAM to clean contamination at Denniston and on sand next to storm drain, GSD requesting SMCEHS to initiate investigation of contamination since it has been reported sporadically for last several months, GSD will initiate its own investigation; he is not aware of any mass spill occurring from GSD sewers; SAM had reported there had been some stoppages in main sewer fronting Shorebird but were removed, they suspect here may be a new break in main line; he did not get impression that these stoppages were cause of reported spill by SMCEHS.

**Document Number:** PPH.C.1.91.08.b.

**Date:** 8/8/91

**Type:** Memo

**To:** Kamil Azoury, Carroll Resources Engineering and Management (C-REM) for Granada Sanitary District

**From:** Bill Kitajima, Carroll Resources Engineering and Management (C-REM) for Granada Sanitary District

**Source:** GSD File 3

**Summary:** Report of investigation around creek and storm drain as a result of public complaint regarding septic material. Storm drain appeared to be plugged with sand bags, became unplugged with high tides allowing septic material onto beach.

**Document Number:** PPH.C.1.91.08.c.

**Date:** 8/14/91

**Type:** Memo

**To:** Kamil Azoury, Carroll Resources Engineering and Management (C-REM) for Granada Sanitary District

**From:** Bill Kitajima, Carroll Resources Engineering and Management (C-REM) for Granada Sanitary District

**Source:** GSD File 3

Meeting set-up with SAM, SMCEHS, RWQCB, & GSD to discuss Denniston Creek. RWQCB suggested soil testing and water samples from restaurants, Harbor District pump station to establish a “fingerprint”, will contact Fish & Game to see what is necessary for creek clean-up.

**Document Number:** PPH.C.1.91.08.d.

**Date:** 8/29/91

**Type:** Memo

**To:** Kamil Azoury, Carroll Resources Engineering and Management (C-REM) for Granada Sanitary District

**From:** Bill Kitajima, Carroll Resources Engineering and Management (C-REM) for Granada Sanitary District

**Source:** GSD File 3

**Summary:** Meeting set-up with SAM, SMC Public Works, & GSD to discuss Denniston Creek. Describes dye testing that shows flow from various points out of storm drain (map included).

**Document Number:** PPH.C.1.91.09.a.

**Date:** 9/4/91

**Type:** Memo

**To:** Kamil Azoury, Carroll Resources Engineering and Management (C-REM) for Granada Sanitary District

**From:** Bill Kitajima, Carroll Resources Engineering and Management (C-REM) for Granada Sanitary District

**Source:** GSD File 1

**Summary:** Soil results in, no need to remove soil from creek. Meeting to be set up with GSD, SMCEHS & Public Works, SAM, Fish & Game, RWQCB. SMCEHS investigating high coliform counts. RWQCB will ask Fish & Game if they will allow modification of creek mouth so water does not sit there.

**Document Number:** PPH.C.1.91.09.b.

**Date:** 9/4/91

**Type:** Letter

**To:** Kamil Azoury, Carroll Resources Engineering and Management (C-REM) for Granada Sanitary District

**From:** Gary Vallado, General Manager, Sewer Authority Mid-Coastside

**Source:** GSD File 3

**Summary:** Collection Problem report chronologically summarizes SAM involvement with Denniston Creek.

**Document Number:** PPH.C.1.96.07.a.

**Date:** 7/2/96

**Type:** Letter

**To:** Granada Sanitary District Board

**From:** Carl Schrader, Kennedy/Jenks Consultants

**Source:** GSD File “Cap. Rd.”

**Summary:** Report on water usage and waste water discharges from Pillar Point Harbor.

**Document Number:** PPH.C.1.97.10.a.

**Date:** 10/10/97

**Type:** Memo

**To:** Bonnie Okonek

**From:** Julie Phelps

**Source:** GSD File 1

**Summary:** Bacterial test results after “bubble box” had been cleaned, recommendations from Public Works, Shorebird wash down connected to sewer as final alternative.

**Document Number:** PPH.C.1.97.11.a.

**Date:** 11/14/97

**Type:** Memo

**To:** Granada Sanitary District Board

**From:** Julie Phelps

**Source:** GSD File 1

**Summary:** Summarizes meeting between agencies regarding bacterial contamination; identification of next steps and responsible agencies: dye testing, BOD testing, connect Shorebird wash down to sewer, leak-proof dumpsters for Shorebird and Fish Trap, flushing of drain and bubble box quarterly, installation of back flow flap to be determined.

**Document Number:** PPH.C.1.98.02.a

**Date:** 2/5/98

**Type:** Meeting summary

**To/From:** Participants not identified

**Source:** GSD File 1

**Summary:** Wash down at Shorebird considered to be source, SMCEHS will take enforcement action and conduct water testing; debris boxes at both restaurants are watertight.

**Document Number:** PPH.C.1.00.12.a

**Date:** 12/5/00

**Type:** Memo

**To:** Granada Sanitary District Board

**From:** Gina Holmes, Granada Sanitary District Administrator

**Source:** GSD File 2

**Summary:** Dye test between manholes 64 & 65 revealed a leak from mainline out onto the beach & into harbor.

**Document Number:** PPH.C.1.00.12.b

**Date:** 12/13/00

**Type:** Memo

**To:** Granada Sanitary District Board

**From:** Gina Holmes, Granada Sanitary District Administrator

**Source:** GSD File 2

**Summary:** Summarizes conversation between Gina Holmes, Granada Sanitary District Administrator, and Steve Hartsell, San Mateo County Environmental Health Services,: dye test of 12/5/00 did not show heavy amount of dye, SMCEHS has been taking water samples at this location but had not reached a final conclusion; Holmes arranging for GSD engineer Robert Item & SAM field manager Pat McGowen to meet with Hartsell at Capistrano for additional tests.

**Document Number:** PPH.C.1.01.03.a

**Date:** 3/29/01

**Type:** Staff Report

**To:** Granada Sanitary District Board

**From:** Gina Holmes, Granada Sanitary District Administrator

**Source:** GSD File 2

**Summary:** Summarizes investigation of drainage source; 4 dye tests conducted between manholes 64 & 65; original assumption that main above leaking into storm drain below; results not consistent or conclusive so no report written at this time; no septic systems in this area. Next step to take samples directly from storm drain.

**Document Number:** PPH.C.1.01.10.a

**Date:** 10/15/01

**Type:** Staff Report

**To:** Granada Sanitary District Board

**From:** Gina Holmes, Granada Sanitary District Administrator

**Source:** GSD File 2

**Summary:** Summary of on-going contamination at Capistrano, two Granada Sanitary District Board members representing GSD on SAM board requesting board authorization to bring beach closure before SAM board to request SAM pursue the cause of permanent beach closure to RWQCB.

**Document Number:** PPH.C.1.01.10.b

**Date:** 10/26/01

**Type:** Memo

**To:** Granada Sanitary District Board

**From:** Howard Hoffman, Granada Sanitary District Engineer, Kennedy/Jenks Consultants

**Source:** GSD File "Cap. Rd."

**Summary:** Report of investigation of storm drain; built and maintained by San Mateo County; even though no significant rain appears to flow all the time, appears to consist mostly of groundwater, tests indicate high levels of coliform, many possible sources of bacteria including GSD wastewater.

**Document Number:** PPH.C.1.01.11.a

**Date:** 11/7/01

**Type:** E-Mail

**To:** Granada Sanitary District Board

**From:** Gina Holmes, Granada Sanitary District Administrator

**Source:** GSD File 2

**Summary:** Anticipated letter from County arrived regarding Capistrano storm drain, Howard Hoffman, Granada Sanitary District Engineer, Kennedy/Jenks Consultants contacting Steve Hartsell, San Mateo County Environmental Health Services.

**Document Number:** PPH.C.1.01.12.a

**Date:** 12/28/01

**Type:** Memo

**To:** Granada Sanitary District Board

**From:** Howard Hoffman, Granada Sanitary District Engineer, Kennedy/Jenks Consultants

**Source:** GSD File 2

**Summary:** Continued testing fails to determine how presumed wastewater leakage is occurring from sewer into storm drain; recommends digging up and changing backfill around District sewer where it crosses over County owned storm drain; estimates cost as part of capital improvement project (CIP) is \$22,000 or as a separate project at \$31,000; work could begin in March; contingency to have contractor make additional repairs, if needed, while pipe is exposed; no guarantee this will cure long-standing leakage.

**Document Number:** PPH.C.1.02.04.a

**Date:** 4/26/02

**Type:** Status Report, CIP Capistrano Ave.

**To:** Granada Sanitary District Board

**From:** Leo Karner, Resident Engineer, Granada Sanitary District

**Source:** GSD File 2

**Summary:** Two locations excavated ; South: 30 LF upstream, 15 LF downstream of the point where 12” ductile iron pipe crosses over 36” reinforced concrete storm drain; North: 15 LF upstream, 5 LF downstream of point where 12” vitrified clay pipe crosses under 12” reinforced concrete storm drain.

Groundwater entered excavation, SMCEHS sampled groundwater, no contamination found, will continue to test storm drain weekly.

**Document Number:** PPH.C.1.02.05.a

**Date:** 5/10/02

**Type:** Memo

**To:** Granada Sanitary District Board

**From:** Howard Hoffman, Granada Sanitary District Engineer, Kennedy/Jenks Consultants

**Source:** GSD File 2

**Summary:** SMCEHS reports that preliminary test results of water from storm drain look hopeful; beach still posted but posting could be removed if results remain favorable; still too soon for press release.

**Document Number:** PPH.C.1.02.08.a

**Date:** 8/8/02

**Type:** Memo

**To:** Granada Sanitary District Board

**From:** Howard Hoffman, Granada Sanitary District Engineer, Kennedy/Jenks Consultants

**Source:** GSD File "Cap. Rd."

**Summary:** Have 7 weeks of good results (bacteriological results included) on water discharging from storm drain (E. coli below 200 MPN/100 ml); recent dye studies show no leakages from sewers or building laterals to storm drains; suggested to San Mateo County that they consider installing filters on storm drain inlets to trap contaminants, have received no reply to this suggestion.

**Document Number:** PPH.C.1.02.09.a

**Date:** 9/5/02

**Type:** Memo

**To:** Granada Sanitary District Board

**From:** Nathan Nutter, Granada Sanitary District Engineer

**Source:** GSD File 2

**Summary:** Dye test conducted 8/29/02 was negative; update 9/9/02 from SMCEHS "test results from last week showed both pipe & surf meeting all EPA standards, signs will be removed this week if numbers continue to be good".

**B. Pillar Point Harbor File #2: Correspondence between Granada Sanitary District and Sewer Authority Mid-Coastside**

**Document Number:** PPH.C.2.90.07.a

**Date:** 7/26/90

**Type:** Letter

**To:** Kamil Azoury, Carroll Resources Engineering and Management (C-REM) for Granada Sanitary District

**From:** Gary Vallado, General Manager, Sewer Authority Mid-Coastside

**Source:** GSD File 1

**Summary:** Reporting and advising of possible offset or broken mainline in front of Shorebird Restaurant, between manhole 64 & manhole 63, location of possible break is 40 feet north of manhole 64; report & map from Collection Supervisor included.

**Document Number:** PPH.C.2.90.11.a

**Date:** 11/16/90

**Type:** Letter

**To:** Mark Center, Sewer Authority Mid-Coastside

**From:** Bill Kitajima, Carroll Resources Engineering and Management (C-REM) for Granada Sanitary District

**Source:** GSD File 1

**Summary:** Per FAXed report of 11/8/90, offset is to be repaired ASAP before any more overflows occur.

**Document Number:** PPH.C.2.01.10.a.

**Date:** 10/26/01

**Type:** Memo

**To:** Gina Holmes, Granada Sanitary District Administrator

**From:** David Dickson, Manager, Sewer Authority Mid-Coastside

**Source:** GSD File 2

**Summary:** Storm drain under San Mateo Co. jurisdiction; SAM & GSD would like to help in finding a solution; putting storm drain flows into GSD/SAM system a last resort only if San Mateo Co. fails to eliminate problem; if GSD decides to accept this flow Board should consider: 1) diversion is temporary pending more suitable, permanent solution, 2) SAM plant has capacity to treat diverted flow during dry weather only, 3) diverted flow included in GSD's flow for cost & capacity allocation, 4) if GSD decides to provide this solution, may want to request SAM board consider allowing temporary use of plant to treat dry weather runoff without counting this against allocated capacities.

**Document Number:** PPH.C.2.02.07.a

**Date:** 7/5/02

**Type:** E-Mail

**To:** Brenda Donald, Sewer Authority Mid-Coastside

**From:** Gina Holmes, Granada Sanitary District Administrator

**Source:** SAM Binder

**Summary:** Will make sure results are available and will pass them on to Engineers, legal, & Board. Please explain "normal" range for tests. Brenda responded and attached test results through 6/19/02, storm sewer cleaned 6/27/02, will continue sampling for several weeks & will check with Regional Board.

**Document Number:** PPH.C.2.02.07.b

**Date:** 7/5/02

**Type:** E-Mail

**To:** Gina Holmes, Granada Sanitary District Administrator

**From:** Brenda Donald, Sewer Authority Mid-Coastside

**Source:** GSD File 2

**Summary:** Explains detection limits and standards for recreational waters; KN properties has tapped into Capistrano storm sewer system, half dozen new catch basins at south end of Capistrano, asked Keet Nerhan to have soil cleaned out & make sure they don't get clogged with dirt, he was very cooperative, perhaps good idea for engineers to GIS system & require County Building Dept. to coordinate any new extensions on system until bacterial problem solved; found an old tie in, at bottom of manhole in front of restaurant, clay pipe discharging from some mystery point, SMC Public Works didn't know where it originated; catch basin at 440 Capistrano completely buried in soil with shrub growing in it.

**C. Pillar Point Harbor File #3: Correspondence between Granada Sanitary District and San Mateo County Environmental Health Services**

**Document Number:** PPH.C.3.01.02.a

**Date:** 2/21/01

**Type:** FAX

**To:** Steve Hartsell, San Mateo County Environmental Health Services

**From:** Gina Holmes, Granada Sanitary District Administrator

**Source:** GSD File 2

**Summary:** Regarding other possible sources of contamination, all businesses from Pillar Point Inn/Fish Trap north to Mezza Luna are “connected” according to GSD data base.

**Document Number:** PPH.C.3.01.10.a

**Date:** 10/2/01

**Type:** FAX

**To:** Steve Hartsell, San Mateo County Environmental Health Services

**From:** Gina Holmes, Granada Sanitary District Administrator

**Source:** GSD File 2

**Summary:** Robert Item, (GSD Engineer) recommends TVing full line from dry to culvert, map attached.

**Document Number:** PPH.C.3.01.11.a

**Date:** 11/1/01

**Type:** Letter

**To:** Joseph Carlevaris, President Granada Sanitary District Board

**From:** Steve Hartsell, San Mateo County Environmental Health Services,

**Source:** GSD File 1

**Summary:** July 1, 2000 water samples from storm drain sent to BioVir Labs, Inc for presence of Male Specific Bacteriophage (a virus almost exclusively from human waste), both samples positive; sewer dye testing found dye in storm drain outflow; presumptive evidence of link between fecal contamination in storm drain and District sewer main; have concluded that source of contamination is public sewer; notifying that GSD must find and eliminate source of release or divert storm water to public sewer for treatment & disposal; plans and permits must be approved within 30 days, work to correct problem must be completed in 60 days of receipt of notice, includes results of bacterial test.

**Document Number:** PPH.C.3.01.11.b

**Date:** 11/8/01

**Type:** Letter

**To:** Steve Hartsell, San Mateo County Environmental Health Services

**From:** Howard Hoffman, Granada Sanitary District Engineer, Kennedy/Jenks Consultants

**Source:** GSD File 1

**Summary:** Response to letter of 11/1/01. Refers to 1997 Intra-Dept. memo on PPH Storm Drain Investigation from Lorraine Lew-White, Environmental Health Program Supervisor, SMCEHS, which recommended in part that: San Mateo Public Works install a backflow prevention flap & perform quarterly cleaning of drainage system, GSD to allow Shorebird connection of wash down area to sewer. Backflow flap has not been installed; GSD believes it would be beneficial. GSD would like to know when system last cleaned. GSD has connected Shorebird to sewer. GSD may need as much as 12 months to assess situation. Until tidegate installed will be difficult for GSD to test system to develop action plan. Would be difficult to connect storm drain to sewer since sewer passes above storm drain.

**Document Number:** PPH.C.3.01.11.c

**Date:** 11/21/01

**Type:** Letter

**To:** Dean Peterson, Director San Mateo County Environmental Health Services

**From:** Gina Holmes, Granada Sanitary District Administrator

**Source:** SMCEHS capfile-005.pdf

**Summary:** Enclosed is response from Howard Hoffman, Granada Sanitary District Engineer, Kennedy/Jenks Consultants, GSD Engineer, to letter of 11/1/01 from SMCEHS.

**Document Number:** PPH.C.3.01.11.d

**Date:** 11/29/01

**Type:** Letter

**To:** Howard Hoffman, Granada Sanitary District Engineer, Kennedy/Jenks Consultants

**From:** Steve Hartsell, San Mateo County Environmental Health Services

**Source:** GSD File "Cap. Rd."

**Summary:** Installation of backflow prevention device based on hypothesis of harbor water contaminating storm drain; testing has shown that drain is always more contaminated than harbor & source is human sewage. Without better reasons cannot support request for more time. GSD has 30 days from receipt of this letter to present action plan, at which time timeline can be reviewed.

**Document Number:** PPH.C.3.02.02.a

**Date:** 2/4/02

**Type:** Letter

**To:** Howard Hoffman, Granada Sanitary District Engineer, Kennedy/Jenks Consultants

**From:** Steve Hartsell, San Mateo County Environmental Health Services

**Source:** SMCEHS capfile-003.pdf

**Summary:** Thanks for draft plan of action & timeline (dated 1/8/02), disappointed that such a long period of time is needed to get started (6 months from notification date) am pleased plan is in place; SMCEHS views this issue as a continuing threat to public health and a violation of CA health & Safety Code Section 5411; make appropriate changes & submit final draft immediately so we can officially extend time line to repair sewer line.

**Document Number:** PPH.C.3.02.06.a

**Date:** 6/18/02

**Type:** Letter

**To:** Steve Hartsell, San Mateo County Environmental Health Services

**From:** Howard Hoffman, Granada Sanitary District Engineer, Kennedy/Jenks Consultants

**Source:** SMCEHS capfile-003.pdf

**Summary:** Thank you for reports on bacterial levels, still not possible to say GSD action of encasing sewer crossing over County storm drain has solved problem of contamination from “storm drain”, storm drain in quotes because speaking of dry weather flows caused by groundwater flowing into County’s pipes. GSD has done TV inspection of County storm drain, in process of preparing map of system to better understand where continuing contamination may be originating. Review of video indicates storm drain needs to be cleaned, recommends the following: storm drain system cleaned at least annually, catch basins pumped out more than once a year, perhaps 6 times/year, catch basins be labeled “Do not dump, flows to ocean”, sample at catch basins as well as discharge onto beach. If SMC provides assistance GSD prepared to undertake further investigations & corrective action; if GSD cannot determine any other source but contamination remains prepared to construct pump station to pump nuisance storm drainage flow into sewer, this would require SMC to install backflow prevention device on end of drain, may result in additional maintenance & expense to SMC, before this step taken important to get system as clean as possible.

**Document Number:** PPH.C.3.02.08.a

**Date:** 8/20/02

**Type:** Letter

**To:** Nathan Nutter, Granada Sanitary District Engineer

**From:** Neil Cullen, San Mateo County Director of Public Works

**Source:** GSD File 2

**Summary:** Thanks for info on the use of debris & hydrocarbon filters for drainage outlets, understands GSD continuing to dye test since dye from sewer is still evident in storm drain, EHS recommending that Capistrano not be resurfaced pending resolution of problem, GSD may want to consider slip lining sewer line, attached a list of slip lining manufactures.

**Document Number:** PPH.C.3.02.08.b

**Date:** 8/21/02

**Type:** Letter

**To:** Neil Cullen, San Mateo County Director of Public Works

**From:** Nathan Nutter, Granada Sanitary District Engineer

**Source:** SMCEHS capfile-002.pdf

**Summary:** Appreciate County looking into use of debris & hydrocarbon filters for drain, believe this is cost effective & maintenance efficient means of reducing contamination; partially correct about dye testing: first test before encasing sewer revealed slight dye infiltration into system, second test after encasement revealed absence of dye indicative of successful encasement. Believe GSD has fixed their portion of the problem, recent test results from SAM revealed area of storm drain under GSD sewer line is relatively clean compared to other areas of the storm drain.

**D. Pillar Point Harbor File #4: Correspondence between Granada Sanitary District and San Mateo County Harbor District**

**Document Number:** PPH.C.4.90.04.a

**Date:** 4/25/90

**Type:** Letter

**To:** Donald Guluzzy, General Manager, San Mateo County Harbor District,

**From:** Kamil Azoury, Carroll Resources Engineering and Management (C-REM) for Granada Sanitary District

**Source:** GSD File 3

**Summary:** At last SAM meeting discussion of fecal contamination in harbor, please advise how houseboats discharge waste & if there have been any overflows.

**Document Number:** PPH.C.4.90.04.b

**Date:** 4/30/90

**Type:** Letter

**To:** Kamil Azoury, Carroll Resources Engineering and Management (C-REM) for Granada Sanitary District

**From:** Donald Guluzzy, General Manager, San Mateo County Harbor District

**Source:** GSD File "Cap. Rd."

**Summary:** Harbor District has no knowledge of overflows at harbor from any source; live-aboards follow strict ordinance code requirements; enclosed is Ch. 3: Disposal of Refuse from Harbor Districts Ordinance Code; sewer pump out facilities available at fuel dock for any & all boats at harbor, Harbor District believes Montara sewage problem that occurred due to construction project in El Granada may have been blown into harbor by high winds, Harbor District periodically sees various types of debris blown in when high winds exist but investigations show these elements have come from outside of harbor.

**Document Number:** PPH.C.4.91.06.a

**Date:** 6/14/91

**Type:** Letter

**To:** Kamil Azoury, Carroll Resources Engineering and Management (C-REM) for Granada Sanitary District

**From:** Donald Guluzzy, General Manager, San Mateo County Harbor District

**Source:** GSD File 3

**Summary:** SMC Harbor District has reviewed records, no sewage overflows in recent past, everything fine regarding sanitation.

**Document Number:** PPH.C.4.01.11.a

**Date:** 11/16/01

**Type:** Letter

**To:** Joseph Carlevaris, President Granada Sanitary District Board

**From:** Peter Grenell, General Manager, San Mateo County Harbor District

**Source:** GSD File 2

**Summary:** Refers to 11/1/01 letter from Hartsell (SMCEHS) directing GSD to eliminate source bacterial contamination within 60 days; possible source of contamination has been identified & looking forward to prompt remedial action.

**Document Number:** PPH.C.4.05.09.a

**Date:** 9/29/05

**Type:** Letter

**To:** Chuck Duffy, General Manager, Granada Sanitary District

**From:** Peter Grenell, General Manager, San Mateo County Harbor District

**Source:** GSD File "Cap. Rd."

**Summary:** PPH staff has done video inspection of sewer lines in harbor; harbor patrol took EHS staff out in patrol boat to take water samples offshore of Capistrano beach; recommending that GSD do video inspection of Capistrano line from Highway 1 to Prospect St. and inspection of the trench to see if any effluent may be contributing to the problem.

**Document Number:** PPH.C.4.05.10.a

**Date:** 10/18/05

**Type:** Letter

**To:** Peter Grenell, General Manager, San Mateo County Harbor District

**From:** Delia Comito, Granada Sanitary District Administrator

**Source:** GSD File "Cap. Rd."

**Summary:** In 2002 GSD encased approximately 50 feet of sewer main in concrete where it crosses storm drain, follow up dye tests showed no leakage from sewer, GSD televised Capistrano mainline from Highway 1 to prospect in June 2005, found no leaks, cracks, or offsets. Storm drain is owned & maintained by San Mateo County, past tests have shown that cleaning storm drain greatly reduces levels of bacteria, GSD believes it is essential for SMC to clean rain regularly; GSD has suggested SMC install inlet filters to capture garbage & debris.

**E. Pillar Point Harbor File #5: Correspondence between Sewer Authority Mid-Coastside and San Mateo County Environmental Health Services**

**Document Number:** PPH.C.5.93.08.a

**Date:** 8/2/93

**Type:** Letter

**To:** Lorraine Lew-White, Environmental Health Program Supervisor

**From:** Gary Vallado, General Manager, Sewer Authority Mid-Coastside

**Source:** SAM Binder

**Summary:** SAM has inspected Shorebird Restaurant, made the following findings: only one of four outdoor drains in washdown area is hooked up to sanitary sewer, outdoor cleanup may result in restaurant related material entering storm sewer (SMC may want to further investigate this), if SMC wishes to have restaurant modify outdoor cleanup area to allow an expanded area to drain into sanitary sewer both SAM & GSD would need to review the proposal for how this would be done, please note discharge of storm water into sanitary sewer is prohibited according GSD ordinance.

**Document Number:** PPH.C.5.97.04.a

**Date:** 4/7/97

**Type:** Letter

**To:** David Dickson, Sewer Authority Mid-Coastside

**From:** Lorraine Lew-White, Environmental Health Program Supervisor

**Source:** SAM Binder

**Summary:** Thank-you to you & staff for work and involvement with Stanford students designated to investigate storm drain at Capistrano beach

**Document Number:** PPH.C.5.99.06.a

**Date:** 6/10/99

**Type:** FAX

**To:** Dean Peterson, Director San Mateo County Environmental Health Services

**From:** Brenda Donald, Sewer Authority Mid-Coastside

**Source:** GSD File 1

**Summary:** Understand line to be flushed & resampled soon, last flushed 5/12/97, recalls flushing had little impact on bacterial counts; outfall of pipe is half submerged into beach, difficult to keep sand, seaweed and marine debris out of line (dead gull at mouth of pipe yesterday); including pages from Stanford class study done in 1997, storm sewer sampled at several locations; coliform & fecal test results from mouth of storm sewer similar to counts found upstream at ground water intrusion site; condition of pipes has deteriorated so that water is seeping in from all 3 incoming pipes, north, east, & west, last year water seemed to only be coming from eastern pipe.

**Document Number:** PPH.C.5.99.07.a

**Date:** 7/7/99

**Type:** FAX

**To:** Brenda Donald, Sewer Authority Mid-Coastside

**From:** Brian Martinez

**Source:** SAM Binder

**Summary:** After years of investigating many potential sources of contamination of storm drain at Pillar Point, believe they have found the source of bacterial contamination. As of 7/2/99 beach is open to public and safe for water contact. Area will continue to be sampled weekly to ensure levels do not increase, staff will continue to work with businesses in the area to implement BMPs to keep beach open & safe.

**F. Pillar Point Harbor File #6: Correspondence between Sewer Authority Mid-Coastside and San Mateo County Harbor District**

**Document Number:** PPH.C.6.90.04.a

**Date:** 4/24/90

**Type:** Letter

**To:** Donald Guluzzy, General Manager, San Mateo County Harbor District

**From:** W.S Heaslet, Sewer Authority Mid-Coastside, General Manager

**Source:** GSD File 3

**Summary:** April 6, 1990 contractor broke inter-tie pressure main next to intersection of Highway 1 & Capistrano, two pumping stations shut down resulting in sewage overflows; Princeton Pumping station overflow did not reach harbor; background sample near Johnson Pier on 4/9/90 showed very high total coliform, SAM Board asked Harbor District be advised of these findings, requesting Harbor District to advise SAM Board what measures are being taken to control harbor pollution.

**G. Pillar Point Harbor File #7: Correspondence between Sewer Authority Mid-Coastside and State Regional Water Quality Control Board**

**Document Number:** PPH.C.7.02.06.a

**Date:** 6/22/02

**Type:** E-mail

**To:** Ray Balcom, State Regional Water Quality Control Board

**From:** Brenda Donald, Sewer Authority Mid-Coastside

**Source:** GSD File 2

**Summary:** SMC Public Works cleaned portion of storm drain but segment with most septic sludge not cleaned yet; Monday's samples will not give clear representation of changes in pollutant levels due to sewer encasement; to get useful data remaining sludge needs to be removed as well as black sludge on beach; not sure if County is planning to finish this or not, please contact them.

**Document Number:** PPH.C.7. 02.08.a

**Date:** 8/20/02

**Type:** Letter

**To:** Ray Balcom, State Regional Water Quality Control Board

**From:** Brenda Donald, Sewer Authority Mid-Coastside

**Source:** GSD File 2

**Summary:** Summarizes activities and observations of Capistrano Storm Drain from April – July 2002 including spreadsheet of results.

**Document Number:** PPH.C.7. 02.09.a

**Date:** 9/5/02

**Type:** Letter

**To:** Ray Balcom, State Regional Water Quality Control Board

**From:** Brenda Donald, Sewer Authority Mid-Coastside

**Source:** GSD File 2

**Summary:** Addendum to report of 8/20/02; even though contamination from sewer leaks have been eliminated identifies remaining potential sources of contamination: ground water enters from breaks in storm drain system; litter, vegetation, soil enter catch basins, could be reduced by screening or filtering; bottom outfall pipe located below level of the beach, especially at high tides debris enters storm drain outlet; clay pipe outlet of unknown origin discovered buried in sediment in last catch basin before outfall, should be sealed or eliminated.

## **H. Pillar Point Harbor File #8: San Mateo County Environmental Health Services Memos and Staff Reports**

**Document Number:** PPH.C.8. 94.01.a

**Date:** 1/25/94

**Type:** Memo

**To:** All Consumer Staff

**From:** Lorraine Lew-White, Environmental Health Program Supervisor

**Source:** SAM Binder

**Summary:** Current policy on sewage spills and their effects on beach closure.

**Document Number:** PPH.C.8. 97.04.a

**Date:** 4/14/97

**Type:** Intra-Dept. Memo

**To:** Brian Zamora, Director

**From:** Lorraine Lew-White, Environmental Health Program Supervisor

**Source:** GSD File 1

**Summary:** Description and results of Stanford University's Alternative Spring Break Investigation of Capistrano Storm Drain.

**Document Number:** PPH.C.8. 99.05.a

**Date:** 5/27/99

**Type:** Letter

**To:** Dean Peterson, Director San Mateo County Environmental Health Services

**From:** Duane O'Donnell, Storm Water Pollution prevention Program, (STOPP)

**Source:** GSD File "Cap. Rd."

**Summary:** Results of survey and sampling at Capistrano Beach from 5/25/99.

**Document Number:** PPH.C.8. 99.06.a

**Date:** 6/2/99

**Type:** Inter-Departmental Correspondence

**To:** Dean Peterson, Director San Mateo County Environmental Health Services

**From:** Neil Cullen, San Mateo County Director of Public Works

**Source:** SMCEHS capfile-010.pdf

**Summary:** Refers to attached map (but no map attached) indicating drainage system on Capistrano Rd., EHS has determined that grease trap at Barbara's Fish Trap was tied to storm drain and that trap has been source of high coliform counts, EHS reporting to Board & will determine if drain needs to be flushed once grease trap has been disconnected.

**Document Number:** PPH.C.8.05.09.a

**Date:** 9/12/05

**Type:** Inter-Departmental Correspondence

**To:** San Mateo County Board of Supervisors

**From:** Charlene Silva, Director Health Dept.

**Source:** SMCEHS capfile-001.pdf

**Summary:** In 1999 State of CA passed AB 411 requiring counties to sample selected beaches, SMC exceeds frequency & number of sample locations required by State; number of beach/creek closures has declined as sewer agencies have upgraded systems. Capistrano beach has been added to the Chronicle Watch due to persistent levels of bacteria, when SAM sealed sewer line in 2002 presence of human pathogens was eliminated, on-going source of bacteria appears to be from bird & wildlife and lack of circulation in harbor; until Harbor District pursues increasing circulation likely that ambient levels of bacteria above CA standards will remain.

**Document Number:** PPH.C.8. 05.12.a

**Date:** 12/05

**Type:** Memo

**To:** Various Recipients

**From:** San Mateo County Environmental Health Services

**Source:** SMCEHS capfile.pdf

**Summary:** Time line for Capistrano Beach.

**I. Pillar Point Harbor File #9: Correspondence between San Mateo County Environmental Health Services/Department of Public Works and San Mateo County Harbor District**

**Document Number:** PPH.C.9. 91.02.a

**Date:** 2/13/91

**Type:** Letter

**To:** Donald Guluzzy, General Manager, San Mateo County Harbor District

**From:** Jeff Edwards, Cross-Connection Control

**Source:** GSD File 3

**Summary:** Description and results of sampling at Capistrano from May 1990 – February 4, 1991; water samples from storm drain show fecal coliform to fecal strep ratios of 0.3 (1/22/91 ) and 0.1 (2/4/91) indicate origin of coliform probably bird feces.

**Document Number:** PPH.C.9.05.09.a

**Date:** 9/29/05

**Type:** Letter

**To:** Neil Cullen, San Mateo County Director of Public Works

**From:** Peter Grenell, General Manager, San Mateo County Harbor District

**Source:** SMCEHS capfile-001.pdf

**Summary:** PPH staff has done video inspection of sewer lines in harbor; harbor patrol took EHS staff out in patrol boat to take water samples offshore of Capistrano beach; recommending that GSD do video inspection of Capistrano line from Highway 1 to Prospect St. and inspection of the trench to see if any effluent may be contributing to the problem.

**Document Number:** PPH.C.9.05.10.a.

**Date:** 10/7/05

**Type:** Letter

**To:** Peter Grenell, General Manager, San Mateo County Harbor District

**From:** Neil Cullen, San Mateo County Director of Public Works

**Source:** SMCEHS capfile-001.pdf

**Summary:** Thank-you for letter advising steps taken by SMC Harbor District, have done tests which led to GSD rehabilitating sewer line above storm drain, when requested by EHS flush drain system to clear of debris, not planning to video line at this time, EHS has concluded that water from storm drain is no longer source of contamination.

**Document Number:** PPH.C.9.06.02.a

**Date:** 2/1/06

**Type:** Memo

**To:** San Mateo County Harbor District Board

**From:** Dean Peterson, Director San Mateo County Environmental Health Services

**Source:** SMCEHS capfile.pdf

**Summary:** EHS has been sampling Capistrano since 1990, contributing sources of bacterial contamination have been eliminated; since GSD sealed portion of sewer main human waste has not been detected, however bacterial levels have remained elevated; birds at mouth of Denniston Creek and lack of circulation near Capistrano Beach do not allow for sufficient breakdown of coliforms, even though counts exceed State levels do not necessarily pose a threat to public health. Effective March 1, 2006 SMC will no longer perform weekly sampling at Capistrano, encourages the Harbor District to post permanent signs. Other harbors have installed devices to increase circulation, grant money available from State Regional Water Quality Control Board.

**J. Pillar Point Harbor File #10: Correspondence between San Mateo County Environmental Health Services and State Regional Water Quality Control Board (SRWQCB)**

**Document Number:** PPH.C.10. 91.11.a

**Date:** 11/18/91

**Type:** Letter

**To:** Johnson Lam, Engineer State Regional Water Quality Control Board

**From:** Brian Zamora, Director San Mateo County Environmental Health Services

**Source:** GSD File 1

**Summary:** Description and update of work being done at Denniston Creek/ Capistrano Storm Drain; July 2, 1991 – November 6, 1991.

**K. Pillar Point Harbor File #11: Correspondence between State Regional Water Quality Control Board and San Mateo County Harbor District**

**Document Number:** PPH.C.11. 84.10.a.

**Date:** 10/5/84

**Type:** Letter

**To:** Ronald McClellan, San Mateo County Harbor District General Manager

**From:** Teng-chung Wu Chief, Municipal Division

**Source:** GSD File 3

**Summary:** SAM reported on 9/4/84 that raw sewage was overflowing into storm drain & into harbor over prior weekend, lift station was down; 9/12 informed by SAM staff that lift station was not repaired; please respond in writing by 10/30/84 indicating when overflow incident began, estimate of amount discharged daily, location of discharge, interim steps taken to eliminate overflow, schedule for improving reliability of lift station, proposed procedures for identifying, reporting and correcting such outages in the future.

**Document Number:** PPH.C.11. 05.04.a.

**Date:** 4/15/05

**Type:** Letter

**To:** Bruce Wolfe, Executive Officer, State Regional Water Quality Control Board

**From:** Peter Grenell, General Manager, San Mateo County Harbor District

**Source:** SAM Binder

**Summary:** Requesting assistance for two matters: storm drain outfall in Princeton that has registered high Enterococci and E. coli counts for over a decade, storm drain continues to trickle even during dry weather indicating that storm drain system has been compromised & is being infiltrated by an unknown source; outfall on public beach, Heal the Bay now lists it as the fifth most polluted beach in CA; urgently requesting State Regional Water Quality Control Board to investigate and require appropriate agency to make necessary repairs or upgrade system. Other matter is occasional high bacterial counts in Harbor, primarily in northwest sector of outer harbor; would appreciate any technical assistance or advice to help determine source

## **L. Pillar Point Harbor File #12: Smoke, Dye, TV, and Soil Test Results**

**Document Number:** PPH.C.12.91.08.a

**Date:** 8/21/91

**Type:** Letter of Transmittal

**To:** Judy McKenzie, Granada Sanitary District

**From:** Bill Kitajima, Carroll Resources Engineering and Management (C-REM) for Granada Sanitary District

**Source:** GSD File 3

**Summary:** Copy of smoke test notice and list of property owners.

**Document Number:** PPH.C.12.91.08.b

**Date:** 8/28/91

**Type:** Data Sheet

**To:** Granada Sanitary District

**From:** Collection Systems Maintenance Systems (CSMS)

**Source:** GSD File 3

**Summary:** Smoke test data sheet and maps.

**Document Number:** PPH.C.12.91.08.c

**Date:** 8/29/91

**Type:** Data Sheet

**To:** Granada Sanitary District

**From:** Collection Systems Maintenance Systems

**Source:** GSD File 3

**Summary:** Closed circuit television inspection data sheets.

**Document Number:** PPH.C.12.91.09.a

**Date:** 9/3/91

**Type:** FAX

**To:** Kamil Azoury, Carroll Resources Engineering and Management (C-REM) for Granada Sanitary District

**From:** Wilma Frank, Chemist

**Source:** GSD File 3

**Summary:** Soil samples from Denniston Creek.

**Document Number:** PPH.C.12.91.10.a

**Date:** 10/24/91

**Type:** Meeting Notes

**To:** Various Recipients

**From:** Granada Sanitary District

**Source:** GSD File 2

**Summary:** Notes about where dye was placed; old abandoned main, lateral still connected?

**Document Number:** PPH.C.12.91.12.a

**Date:** 12/5/91

**Type:** Letter of Transmittal

**To:** State Regional Water Quality Control Board

**From:** Bill Kitajima, Carroll Resources Engineering and Management (C-REM) for Granada Sanitary District

**Source:** GSD File 1

**Summary:** Smoke test log, TV inspection log, field report on dye testing, SAM report. Only cover page, no data included

**Document Number:** PPH.C.12.98.04.a

**Date:** 4/15/98

**Type:** Letter

**To:** Darlene Reuss, San Mateo County Environmental Health Services

**From:** Wilma Frank, Chemist

**Source:** GSD File 1

**Summary:** Summarizes tests performed at Capistrano Beach: BOD, total and fecal coliform, dye tests.

**Document Number:** PPH.C.12.99.10.a

**Date:** 10/19/99

**Type:** Test Log

**To:** Granada Sanitary District

**From:** Pacific Pipeline Survey

**Source:** GSD File 1

**Summary:** Smoke test log, GSD manhole report.

**Document Number:** PPH.C.12.02.01.a

**Date:** 1/10/02

**Type:** Test Results

**To:** Granada Sanitary District

**From:** CSMS

**Source:** GSD File 2

**Summary:** Findings from closed circuit television inspection.

**Document Number:** PPH.C.12.05.06.a

**Date:** 6/13/05

**Type:** Invoice

**To:** Granada Sanitary District

**From:** CSMS

**Source:** GSD File 1

**Summary:** Video inspection, Capistrano Rd.

## **M. Pillar Point Harbor File #13: Newspaper Articles and Press Releases**

**Document Number:** PPH.C.13.01.11.a

**Date:** 11/30/01

**Type:** Article, San Mateo County Times

**Source:** GSD File 2

**Summary:** “Agencies bicker over blame for sewage leak on coast, County blames GSD, District pleads innocent”.

**Document Number:** PPH.C.13.01.12.a.

**Date:** 12/17/01

**Type:** Press Release from Granada Sanitary District

**Source:** GSD File “Cap. Rd.”

**Summary:** “GSD to undertake program to eliminate Pillar Point Harbor pollution”.

**Document Number:** PPH.C.13.01.12.b

**Date:** 12/26/01

**Type:** Article, Half Moon Bay Review

**Source:** SMCEHS capfile-003.pdf

**Summary:** “Plans under way to clean harbor beach”.

**Document Number:** PPH.C.13.02.09.a.

**Date:** 9/20/02

**Type:** Press Release from Granada Sanitary District

**Source:** GSD File “Cap. Rd.”

**Summary:** “Dye tests negative: GSD’s program to reduce PPH pollution is successful”.

**Document Number:** PPH.C.13.05.06.a

**Date:** 6/1/05

**Type:** Article, Half Moon Bay Review

**Source:** SAM Binder

**Summary:** “Pillar Point area beach fails water quality test”.

**Document Number:** PPH.C.13.05.06.b

**Date:** 6/22/05

**Type:** Matter of Opinion, Half Moon Bay Review

**From:** Sally Campbell & Peter Grenell, San Mateo County Harbor District

**Source:** GSD File “Cap. Rd.”

**Summary:** “Time for agencies to solve effluent problem.”

**Document Number:** PPH.C.13.05.07.a

**Date:** 7/6/05

**Type:** Letter to the Editor, Half Moon Bay Review

**From:** Chuck Duffy, Granada Sanitary District, General Manager

**Source:** GSD File “Cap. Rd.”

**Summary:** “GSD is doing its best to prevent pollution”.

**Document Number:** PPH.C.13.05.09.a

**Date:** 9/12/05

**Type:** San Francisco Chronicle Watch

**Source:** SMCEHS capfile-001.pdf

**Summary:** “Contamination at Half Moon Bay beach”.

**Document Number:** PPH.C.13.05.09.b.

**Date:** No Date

**Type:** San Francisco Chronicle Watch

**Source:** SMCEHS capfile.pdf

**Summary:** “Results Day 207: Permanent warning signs up in HMB”.

**Document Number:** PPH.C.13.06.06.a

**Date:** 6/28/06

**Type:** Matter of Opinion, HMB Review

**From:** Sally Campbell, San Mateo County Harbor District

**Source:** GSD File “Cap. Rd.”

**Summary:** “Pillar Point beaches don’t need any healing”.

**Document Number:** PPH.C.13.06.07.a

**Date:** 7/06

**Type:** Letter to the Editor, Moon Bay Review

**To:** HMB Review

**From:** James Alamillo, Heal the Bay

**Source:** SMCEHS capfile.pdf

**Summary:** Refers to Letter to the Editor by Sally Campbell. No data or studies to substantiate theory that cause of contamination is birds; EHS and SMC HD should conduct source investigation as required by Assembly Bill 538 & CA Ocean Plan (6/29/06).

## **N. Pillar Point Harbor File #14: Public Questions and Comments**

**Document Number:** PPH.C.14.97.10.a

**Date:** 10/24/97

**Type:** Letter

**To:** Brian Zamora, San Mateo County Environmental Health Services

**From:** John Plock, Save Our Bay (SOB)

**Source:** GSD File 1

**Summary:** SOB is going to post on its website the activities & correspondences of different organizations as they impact the MBNMS.

**Document Number:** PPH.C.14.01.10.a

**Date:** 10/30/01

**Type:** E-Mails

**To:** D. Dickson

**From:** Howard Hoffman, Granada Sanitary District Engineer, Kennedy/Jenks Consultants

**Source:** GSD File 2

**Summary:** Suggestion to treat dry weather flow, installation of tide gate.

**Document Number:** PPH.C.14.01.11.a

**Date:** 11/16/01

**Type:** Letter

**To:** Howard Hoffman, Granada Sanitary District Engineer, Kennedy/Jenks Consultants

**From:** John Plock, Save Our Bay (SOB)

**Source:** GSD File 2

**Summary:** Regarding SMCEHS letter of 11/1/01, requesting State Regional Water Quality Control Board issue notice of violation &, if necessary, enforcement order to GSD.

**Document Number:** PPH.C.14.01.11.b

**Date:** 11/21/01

**Type:** E-Mails

**To/From:** Larry Kay, Dean Peterson, Director San Mateo County Environmental Health Services, Kathryn Slater-Carter, Leonard Woren

**Source:** SMCEHS capfile-005.pdf

**Summary:** Discusses 11/1/01 letter from SMCEHS to GSD regarding contamination.

**Document Number:** PPH.C.14.01.12.a

**Date:** 12/4/01

**Type:** E-Mails

**To:** Leonard Woren

**From:** Howard Hoffman, Granada Sanitary District Engineer, Kennedy/Jenks Consultants

**Source:** GSD File 2

**Summary:** Answers questions regarding installation of tide gate.

**Document Number:** PPH.C.14.02.08.a

**Date:** 8/6/02

**Type:** E-Mails

**To:** Granada Sanitary District

**From:** John Meador

**Source:** GSD File 2

**Summary:** What is status of project to stop gross pollution of Barbara's Beach?

## **O. Pillar Point Harbor File #15: Bacterial Test Results**

**Document Number:** PPH.C.15.85.05.a

**Date:** 5/21/85, 7/22/85, 1/13/86

**Type:** Data Sheets, SMC Dept of Public Health

**Source:** GSD File "Cap. Rd.

**Summary:** Data sheets for bacteriological field testing.

**Document Number:** PPH.C.15.86.02.a

**Date:** 2/24/86, 3/31/86

**Type:** Data Sheets, SMC Dept of Public Health

**Source:** GSD File "Cap. Rd."

**Summary:** Data sheets for bacteriological field testing.

**Document Number:** PPH.C.15.91.07.a

**Date:** 7/2/91, 7/8/91, 7/16/91, 7/24/91, 7/30/91, 8/1/91, 8/7/91, 8/15/91

**Type:** Data Sheets, SMC Dept of Public Health

**Source:** GSD File 3

**Summary:** Data sheets for bacteriological field testing. .

**Document Number:** PPH.C.15.92.07.a

**Date:** 7/1/92, 9/22/92, 6/24/94, 8/9/94, 8/2/95, several without complete date (no year)

**Type:** Data Sheets, SMC Dept of Public Health

**Source:** GSD File "Cap. Rd."

**Summary:** Data sheets for bacteriological field testing.

**Document Number:** PPH.C.15.99.06.a

**Date:** 6/8/99, 5/3/89, with pictures

**Type:** Field Data Sheets, SMC Dept of Public Health

**Source:** GSD File "Cap. Rd."

**Summary:** Data sheets for bacteriological field testing. .

**Document Number:** PPH.C.15.99.07.a

**Date:** 7/7/99

**Type:** FAX

**To:** Various Recipients

**From:** SMC Dept. of Environmental Health

**Source:** SMCEHS capfile-001.pdf

**Summary:** Summary of test results: 5/11/99 – 6/29/99.

**Document Number:** PPH.C.15.00.08.a

**Date:** 8/2/00

**Type:** Test Results

**To:** SMCEHS

**From:** BioVir Laboratories, Inc

**Source:** GSD File 1

**Summary:** Results of Male Specific Bacteriophage Assay

**Document Number:** PPH.C.15.02.07.a

**Date:** 7/02  
**Type:** Summary  
**To/From:** Not identified  
**From:** SAM  
**Source:** GSD File 2  
**Summary:** Summary of test results: 5/6/02 – 7/17/02.

**Document Number:** PPH.C.15.02.07.b

**Date:** 7/4/02  
**Type:** E-Mail  
**To:** Gina Holmes, Granada Sanitary District Administrator  
**From:** Brenda Donald, Sewer Authority Mid-Coastside  
**Source:** GSD File 2  
**Summary:** SBSA test results: 6/24/02 – 7/3/02, summary of results conducted by SAM /8/02 – 7/10/02.

**Document Number:** PPH.C.15.02.07.c.

**Date:** 7/02  
**Type:** Summary  
**To/From:** Not identified  
**From:** Steve Hartsell, San Mateo County Environmental Health Services  
**Source:** GSD File 2  
**Summary:** Summary of test results: 6/12/02 – 7/24/02.

**Document Number:** PPH.C.15.02.11.a

**Date:** 11/5/02  
**Type:** E-Mail  
**To:** Brenda Donald, Sewer Authority Mid-Coastside  
**From:** Kathy Suter, SBSA  
**Source:** SAM Binder  
**Summary:** Coliform for samples locations 4 (Capistrano outfall) & 5 (Capistrano beach?): 9/19, 10/2, 10/10, 10/15/02

**Document Number:** PPH.C.15.06.02.a

**Date:** 2/3/06  
**Type:** Test Results  
**To:** San Mateo County Environmental Health Services  
**From:** BioVir Laboratories, Inc.  
**Source:** SMCEHS  
**Summary:** Results of Male Specific Bacteriophage Assay

**Document Number:** PPH.C.15.07.10.a

**Date:** 10/07  
**Type:** Digital File  
**Source:** Carol Ann Towe, San Mateo County Resource Conservation District  
**Summary:** Fecal Indicator Bacteria test results from San Mateo Surfrider Lab (SR) and SMCEHS Lab (AB 411) for several of the PPH sites:

1. Capistrano Outfall Pipe: AB411 6/99-2/01, 4/02-2/06
2. Bathhouse Outfall Pipe:
3. Capistrano Beach: AB411 6/99-2/01, 4/02-2/06; SR 6/05-4/07

4. Denniston Creek: SR 9/05-4/07
  5. PP Marsh: AB 411 6/00-10/07
  6. Mavericks Beach: 8/04-10-07
- AB 411 missing data from 2/01-4/02; Capistrano Outfall and Beach sampling discontinued by SMCEHS 2/06

## **P. Pillar Point Harbor File #16: Miscellaneous**

**Document Number:** PPH.C.16.93.08.a

**Date:** 8/17/93

**Type:** Letter

**To:** Nick Dunn, Shorebird Restaurant

**From:** Ann Jensen, San Mateo County Environmental Health Services

**Source:** GSD File 3

**Summary:** SMCEHS conducting investigation into high bacterial counts in storm drain system along Capistrano Rd., still uncertainty regarding initial cause of human-originated bacteria, have discovered excessive amount of grease & organic matter accumulated in storm drain system adjacent to Shorebird, believe this along with introduction of animal fecal matter has contributed to excessive counts of non-human bacteria; fenced wash down area has one drain connected to sewer; rear fenced area has 3 basins connected to storm drain system, discharge into storm drain is unacceptable and must cease immediately; please submit plans for correcting this situation within 30 day of receipt of letter, will also need to contact GSD & SAM regarding connecting drains to sewer system.

**Document Number:** PPH.C.16.93.09.a

**Date:** 9/28/93

**Type:** Letter

**To:** Nick Dunn, Shorebird Restaurant

**From:** Kamil Azoury, Carroll Resources Engineering and Management (C-REM) for Granada Sanitary District

**Source:** SAM Binder

**Summary:** Regarding letter from SMCEHS of 8/17/93 that suggests connecting wash down drain at restaurant to GSD collection system. This letter is to inform him of GSD regulations prohibiting connection of outside drains into GSD system since this results in rainwater intrusion into system. Rainwater entry into system is prohibited by law & will be subject to enforcement actions by GSD. Contact GSD regarding any wastes that are currently permitted for the restaurant, correction of current situation will not be through means unacceptable to GSD.

**Document Number:** PPH.C.16.98.08.a

**Date:** 8/22/98

**Type:** Letter

**To:** Brenda Donald, Sewer Authority Mid-Coastside

**From:** John Barbour, The Distillery Restaurant

**Source:** SAM Binder

**Summary:** Regarding recent conversation, proceeding with the following: refuse containers checked so they are not leaking, containers cleaned periodically at cleanout station, installation of cut-off device for storm drain nearest wash rack so no water gets into storm drain system, eliminating current sanitary sewer grease trap and replacing with new system, janitorial service will use sanitary service for any washing. Other items discussed: will contact SMC regarding outfall of current drainage into Princeton Harbor as it is too low and floods during high tides, will ask SMC to locate spring that appears to be leaching water into system, will SMC Public Works to remove all debris from storm sewer system. Because so many people involved and public health issue going to contact Supervisor Gordon to set up a meeting with EHS, Public Works, Board of Directors, himself, and Brenda (SAM).

**Document Number:** PPH.C.16.99.03.a

**Date:** 3/23/99

**Type:** FAX

**To:** Charles Van Linge

**From:** Brenda Donald, Sewer Authority Mid-Coastside

**Source:** SAM Binder

**Summary:** Capistrano Road Association has been sold, trying to track down new owners, she called Supervisor Gordon to follow-up on storm sewer repair status, will mail him background data & documents, she thinks that it's been established that source of pollution is from groundwater under the street, not adjacent businesses.

**Document Number:** PPH.C.16.99.04.a .

**Date:** 4/7/99

**Type:** FAX

**To:** Keet Nerhan

**From:** Brenda Donald, Sewer Authority Mid-Coastside

**Source:** GSD File 1

**Summary:** Ground water leaking from storm sewer under Capistrano Rd. in front of Shorebird polluting beach it discharges onto, break in storm sewer in front of northern Shorebird parking lot that has water flowing even in dry summer months, pollution has persisted even after Shorebird was closed; please see what you can do to get broken drain repaired.

**Document Number:** PPH.C.16.00.08.a

**Date:** 8/7/00

**Type:** E-Mail

**To:** Rich Gordon, SMC Supervisor

**From:** Brenda Donald, Sewer Authority Mid-Coastside

**Source:** GSD File 2

**Summary:** Total coliform & E.C. bacteria levels for Pillar Point Site #4 through the roof during month of July, heard he was considering filed trip to location, she would like to be there; suggests that there should be no dry weather flow from drain, once repaired/relocated above water table & high tide level situation should improve, clearly a Public Works project.

**Document Number:** PPH.C.16.01.10.a.

**Date:** 10/16/01

**Type:** Letter (draft)

**To:** No Recipient

**From:** Brenda Donald, Sewer Authority Mid-Coastside

**Source:** GSD File 2

**Summary:** Main source of bacteria/vector for bacteria is water that runs through storm sewer rain or shine, summer or winter; believes storm sewer needs to be re-engineered and possible rebuilt in such a way that roads & businesses along Capistrano have adequate drainage without invading dry weather water table or mean high tide level.

**Document Number:** PPH.C.16.01.11.a

**Date:** 11/2/01

**Type:** FAX

**To:** Nichole Freeling, Half Moon Bay Review

**From:** Gina Holmes, Granada Sanitary District Administrator

**Source:** GSD File 2

**Summary:** Sending SMC memo summarizing 1997 Stanford Study, under recommendations will see actions to which each Government agency entity agreed; GSD connected Shorebird (now HMB Brewery) drain to sewer in 1988.

**Document Number:** PPH.C.16.02.07.a

**Date:** 7/19/02

**Type:** E-Mails

**To:** Bernie Halloran

**From:** Brenda Donald, Sewer Authority Mid-Coastside

**Source:** SAM Binder

**Summary:** Brenda asking about Optical Brighteners as a good indication of domestic sewage since she had heard he was doing work on San Pedro Creek. He replies with a reference to a website. He is finishing a yearlong study of optical brighteners in SP Creek, results are mixed.

## **Q. Pillar Point Harbor File #17: Maps**

**Document Number:** PPH.C.17.99.06.a

**Date:** 6/3/99

**Type:** Map

**Source:** SMCEHS capfile-002.pdf

**Summary:** Capistrano Rd.

**Document Number:** PPH.C.17.

**Date:** No date

**Type:** Map

**Source:** GSD File 2

**Summary:** Storm drain system, Capistrano Rd.

## **R. Pillar Point Harbor File #18: Sewer Authority Mid-Coastside Memos/Staff Reports**

**Document Number:** PPH.C.18.88.09.a

**Date:** 9/22/88

**Type:** Redi-Letter

**To:** Gary or Bill

**From:** Collection

**Source:** SAM Binder

**Summary:** Called out for bad odor, noticed there was grease and water in storm drain that had turned septic, traced condition from storm drain to north parking lot of Shorebird, out to beach in front of Shorebird. Appears that clean-up of mats taking place outside and water is running in storm drain and stagnating, thinks probable solution would be to hook up wash down drain into grease trap, storm drain needs to be cleaned.

**Document Number:** PPH.C.18.93.07.a

**Date:** 7/26/93

**Type:** Redi-Letter

**To:** Tony Pullin, Operations Supervisor; Brenda Donald, Sewer Authority Mid-Coastside

**From:** Gary Vallado, General Manager, Sewer Authority Mid-Coastside

**Source:** SAM Binder

**Summary:** SMCEHS has requested the following: determine if Shorebird wash down drain is connected to sanitary sewer, determine if any restaurant cleaning is done outside the cleanup area and if so where does flow go, determine if possible for restaurant to expand its cleanup area and discharge to sanitary sewer.

**Document Number:** PPH.C.18.93.07.b

**Date:** 7/28/93

**Type:** Redi-Letter

**To:** Gary Vallado, General Manager, Sewer Authority Mid-Coastside, Tony Pullin, Operations Supervisor

**From:** Brenda Donald, Sewer Authority Mid-Coastside

**Source:** SAM Binder

**Summary:** Response to questions of 7/26/93:

Only one of four outdoor drains is hooked up to sanitary sewer, cleaning is done in the entire courtyard, waste oil container is stored there, entire area is greasy, if storm drain #3 (see map) is connected to grease trap then restaurant should have no greasy or high BOD storm water runoff.

**Document Number:** PPH.C.18.98.08.a

**Date:** 8/11/98

**Type:** Report

**Source:** SAM Binder

**Summary:** Non-domestic Wastewater Source Control Program Inspection Report for Shorebird Restaurant. Recommendations for mitigating pollution problem at Capistrano Beach: clean storm sewer grease trap every Monday morning, consider additional pretreatment, keep courtyard fastidiously clean, hook storm drain to sanitary sewer grease trap, insist janitorial service use sanitary sewer for wash water.

**S. Pillar Point Harbor File #19: Bacteria Regulations**

**Document Number:** PPH.C.19

**Type:** Bill Analysis: AB 411

**Source:** Internet

## **T. Pillar Point Harbor File #20: Verbal Communications**

**Document Number:** PPH.C.20.07.12.a

**Date:** December 2007

**Type:** Personal Communication

**To:** Ellen Gartside, San Mateo County Resource Conservation District

**From:** Mike Mead, Princeton resident

**Summary:** Described renovation of HMB Brewery. When trench was dug to install structural support broken pipe was covered in concrete because workers were getting sick. Suggested contacting contractors involved: Ed Kern, Oceanside Sheet Metal; George Woodstock, Tiler; Ingraham Electronics; Kelly Bretz 892 5801

**Document Number:** PPH.C.20.08.02.a

**Date:** February 2008

**Type:** Personal Communication

**To:** Ellen Gartside, San Mateo County Resource Conservation District

**From:** Brenda Donald, Sewer Authority Mid-Coastside, former SAM employee

**Summary:** Brenda made the following suggestions:

1. Harbor Village pretreatment drainage system?
2. Seabirds: monitor landfill
3. GSD should still be in full compliance, document history of infrastructure upgrades
4. Talk to San Mateo Stormwater Pollution & Prevention (STOPP) about infrastructure repair
5. Talk to SAM regarding restaurant and businesses non-domestic waste source control program

## **U. Pillar Point Harbor File #21: Harbor Regulations**

**Document Number:** PPH.C. 21.08.02.a

**Date:** February 2008

**Type:** Program Description

**Source:** Website

**Summary:** Clean Marinas California Program Guideline for: Marina Debris, Boat Sewage Discharge, Solid Waste, Liquid Waste

**Document Number:** PPH.C. 21.08.02.b

**Date:** February 2008

**Type:** Harbor Regulations

**Source:** Website

**Summary:** Rules and regulations of the San Francisco Marina Small Craft Harbor

**Document Number:** PPH.C. 21.08.02.c

**Date:** February 2008

**Type:** Form

**To:** San Mateo County Resource Conservation District

**From:** Marian Olin

**Source:** Santa Cruz Harbormaster

**Summary:** Liveaboard Permit