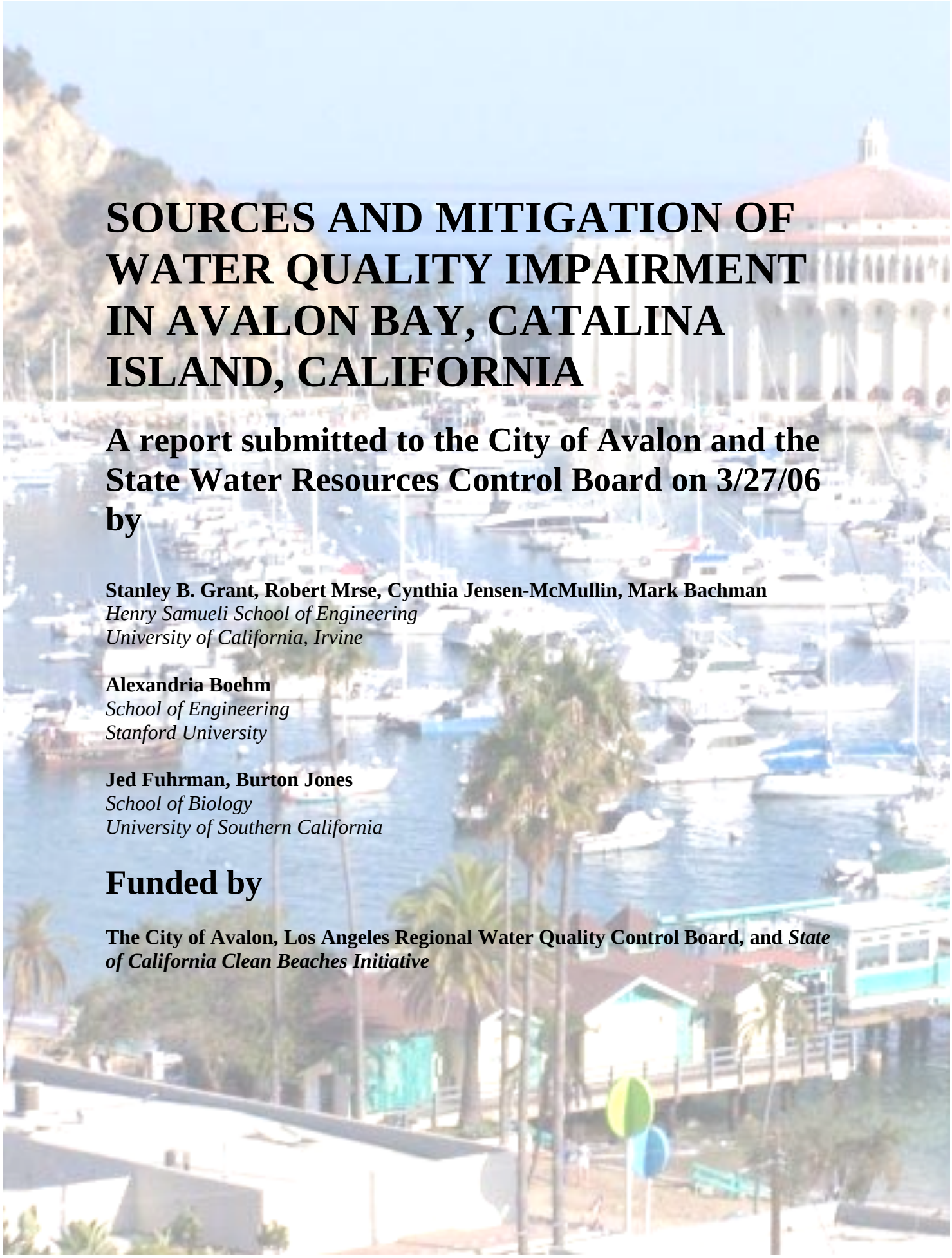

SOURCES AND MITIGATION OF WATER QUALITY IMPAIRMENT IN AVALON BAY, CATALINA ISLAND, CALIFORNIA

A report submitted to the City of Avalon and the State Water Resources Control Board on 3/27/06 by

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Summary

The City of Avalon, located on Catalina Island, is a recreational destination for boaters, fisherman, divers, beach goers, and other ocean oriented visitors. This report describes studies into the root causes of fecal indicator bacteria impairment in Avalon Bay; the report also describes and evaluates newly implemented and ongoing mitigation measures. Findings from the studies can be summarized as follows:

1. An analysis of historical Los Angeles Department of Health Services (DHS) data indicates that fecal indicator bacteria concentrations along the shoreline in Avalon Bay have been steadily increasing since 2002; the concentrations of fecal indicator bacteria are generally highest at the Middle sampling site near the Pleasure Pier;
2. Fecal indicator bacteria concentrations are highest in ankle depth waters and in the very nearshore sediments along the Avalon Bay shoreline;
3. Within Avalon Bay, fecal indicator bacteria concentrations in the water column and submarine sediments decrease rapidly with distance from the shoreline;
4. Fecal indicator bacteria concentrations are elevated in shallow groundwater beneath the City of Avalon, particularly in the region between the Pleasure Pier and the Busy Bee Restuarant;
5. Fecal indicator bacteria concentrations in ankle depth waters in Avalon Bay exhibit diurnal cycling, with higher concentrations occurring during the night-time falling tide.
6. Human fecal markers (both *Bacteroides*/*Prevotella spp*. and enterovirus) are present in Avalon Bay shoreline waters, and in the shallow groundwater beneath the City of Avalon. The human fecal markers are particularly prevelant in the shallow groundwater between the Pleasure Pier and the Busy Bee Restuarant.
7. The shallow groundwater between the Pleasure Pier and the Busy Bee Restuarant has anamolously low salinity and low pH, compared to the other shallow groundwater sites tested.
8. Dye studies conducted in Avalon Bay indicate that pollution entering the Bay from the shoreline should dissipiate relatively rapidly (within hours) due to within-Bay advection and turbulent diffusion.

These results beg the question of what might be responsible for the elevated concentrations of fecal indicator bacteria in the shallow groundwater beneath the City of Avalon. Two possibilities merit further exploration: (1) fecal indicator bacteria in the shallow ground water originate from leaking sewage collection lines in the downtown area, or (2) fecal indicator bacteria are growing in the subsurface sediments and/or shallow groundwater. Even in this second scenario leaking sewage collection lines could play a role, by providing a supply of nutrients for fecal indicator bacteria re-growth in the subsurface. Indeed, it is interesting to note that the sediments excavated from near the Pleasure Pier were organic rich and smelled of hydrogen sulfide, consistent with the idea that they may have been sewage impacted. In either case, the shallow ground water sampling results would appear to warrant follow-up investigation and possibly remediation.

The diurnal cycling of fecal indicator bacteria in Avalon Bay implies that when during the day a sample is collected can significantly affect the measured concentration of fecal indicator bacteria. Furthermore, where the samples are taken (in ankle depth or waist depth waters) can also affect measured fecal indicator bacteria concentrations. Relative to the routine Avalon Bay water quality monitoring programs carried out by the LA DHS and United Water, inconsistency in the time of day, and the location where samples are taken, could seriously confound interpretation of monitoring data. For example, samples collected early in the morning one day may contain high concentrations of fecal indicator bacteria from a source of fecal pollution. If the sampling is then repeated in the early afternoon several days later, the concentration of fecal indicator bacteria may be significantly lower, even if the source of fecal pollution is still present. Given the fact that human pathogens can be more resistant to sunlight than indicator bacteria in marine systems, Los Angeles DHS and United Water should consider sampling only at ankle depth, and adopting a consistent early morning sampling schedule for their ongoing monitoring programs.

Based on the foregoing, it is possible that a portion of the fecal indicator bacteria contamination in Avalon Bay originates from the exfiltration of sewage and/or nuisance runoff contaminated shallow groundwater. As of the writing of this report, the City continues to retrofit the sewage collection infrastructure in downtown Avalon. This retrofit project should ultimately reduce the input of fecal pollution into the shallow groundwater, and presumably improve shoreline water quality in Avalon Bay (although the latter has not yet occurred, according to our analysis of the historical DHS monitoring data). It is recommended that a follow up study be carried out to determine if contaminant levels in the shallow groundwater and surf zone are reduced following the completion of the retrofit project, and possibly to develop strategies to characterize and remediate sewage contamination in the shallow groundwater under downtown Avalon.

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Appendix: Quality Assurance Project Plan, and two papers published from data collected during this study.

Chapter 1. Introduction and Report Overview

The City of Avalon, located on Catalina Island, is a recreational destination for boaters, fisherman, divers, beach goers, and other ocean oriented visitors. In 1999 the County of Los Angeles began testing Avalon Bay for fecal indicator bacteria in accordance with AB 411. These test results frequently exceeded California single-sample standards for fecal indicator bacteria in coastal bathing waters, and as a result beaches in Avalon have been frequently posted as unfit for swimming.

In response to these test results, a series of studies and mitigations efforts were undertaken:

a) In 2000, Ms. Alison Davis in Jed Fuhrman's laboratory at USC was hired to conduct a microbial source tracking study, to determine if there was evidence of human fecal pollution in Avalon Bay. This study, which was very small in scope, found no evidence of human viruses in Avalon Bay. Based on the results of this study, the City concluded that the fecal indicator bacteria problem in Avalon Bay was due to fecal material produced by birds, in particular pigeons. Accordingly, the City focused on controlling bird populations in and around the City

b) In 2001, the City received a $500,000 grant from the State of California's Clean Beaches Initiative to further investigate the water quality problem in Avalon Bay, and pursue mitigation measures. This grant had three goals: 1) to determine the sources of fecal indicator bacteria in the Bay, 2) to conduct further microbial source tracking studies, and 3) to characterize circulation in Avalon Bay. These studies, which were conducted by Professors Stanley Grant (UCI), Burt Jones (USC), and Jed Fuhrman (USC) between September and November 2001, concluded that:

    i. Fecal indicator bacteria in Avalon Bay appear to originate from several land-side sources, including bird and animal fecal droppings, broken plumbing under wharf structures, run-off from street wash down activities, and contaminated shallow groundwater.
    ii. Within Avalon Bay, fecal indicator bacteria concentrations are highest in ankle depth water along the shoreline. Fecal indicator bacteria concentrations in the water and sediment are generally below detectable levels a very short distance (<10 m) bayward of the shoreline.
    iii. Microbial indicators of human fecal pollution (including the human-specific bacteria *Bacteroides/Provetella* and human enterovirus) were detected at several locations in Avalon Bay and in groundwater sampling pits, suggesting that human sewage may contribute to water quality impairment of Avalon Bay.
    iv. The rates of advection and turbulent diffusion within Avalon Bay (*ca.* 1 to 6 cm/s and 1 m^2/s, respectively) is sufficient to disperse contaminants introduced to the Bay within an hour or so, provided that the source of contamination is not continuous.

v. A significant fraction of the water in Avalon Bay is exchanged with the ocean over a single tide cycle.
vi. The region of the Bay impacted by the storm drain (near the beach site called "Channel") does not appear to have a circulation problem. Within one hour, pollutants released into this area of the Bay are transported 80 to 100 m into the Bay and diluted by a factor of 100 or more.

Based on these study results, the City implemented the following mitigation measures:

a) Sewer mains and manholes in the first three blocks from the waterfront were slip-lined and sealed; this effort was completed in May, 2002.
b) Bird control measures were intensified; this ongoing effort was initiated in 2001.
c) Plumbing under the wharfs was repaired and a regular twice per year inspection program initiated.
d) Street wash down procedures were modified to prevent run-off.
e) Sewer laterals in the first three blocks from the waterfront were repaired and sealed; this effort was initiated in May 2005 and completed in November 2005.

The report is organized as follows. Methods used by the LA DHS to monitor Avalon Bay water quality are described in Chapter 2, followed by an analysis of these historical water quality data in Chapter 3. Results of the Clean Beaches Initiative funded microbial source investigations and hydrographic studies are described (Chapters 4 and 5) followed by conclusions and recommendations (Chapter 6). The appendix to this report includes the Quality Assuarance Project Plan (QAPP), and several archival journal articles that were generated from the Clean Beaches Initiative studies.

Table 1-1 is a list of task products funded under the Clean Beaches Initiative grant that were previously submitted to the State Water Quality Control Board.

Table 1.1. Task products previously submitted to the State Water Quality Control Board

TASK	DESCRIPTION	SUBMISSION DATE
1	Project Management and Administration	May 2002
2	Quality Assurance Project Plan (QAPP)	May 2002
3	Microbiological Components & Bay Circulation and Exchange Study	June 2003
4	California Environmental Quality Act (CEQA) and Permits for Slip–lining	November 2001
5	Sewer Collection System Slip–lining	May 2002
6	Monitoring and Reports	March 2006

Chapter 2. Procedures used by LA County Health Care Agency for routine monitoring of water quality in Avalon Bay

Beginning in the summer of 1999, the LA County Health Care Agency began collecting water samples from five sites in Avalon Bay. These sites are designated (from north to south) Tuna (DHS 121), Busy Bee (DHS 120), Middle (DHS 119), South (DHS 118), and Channel (DHS 117) (see map in Figure 1 below).

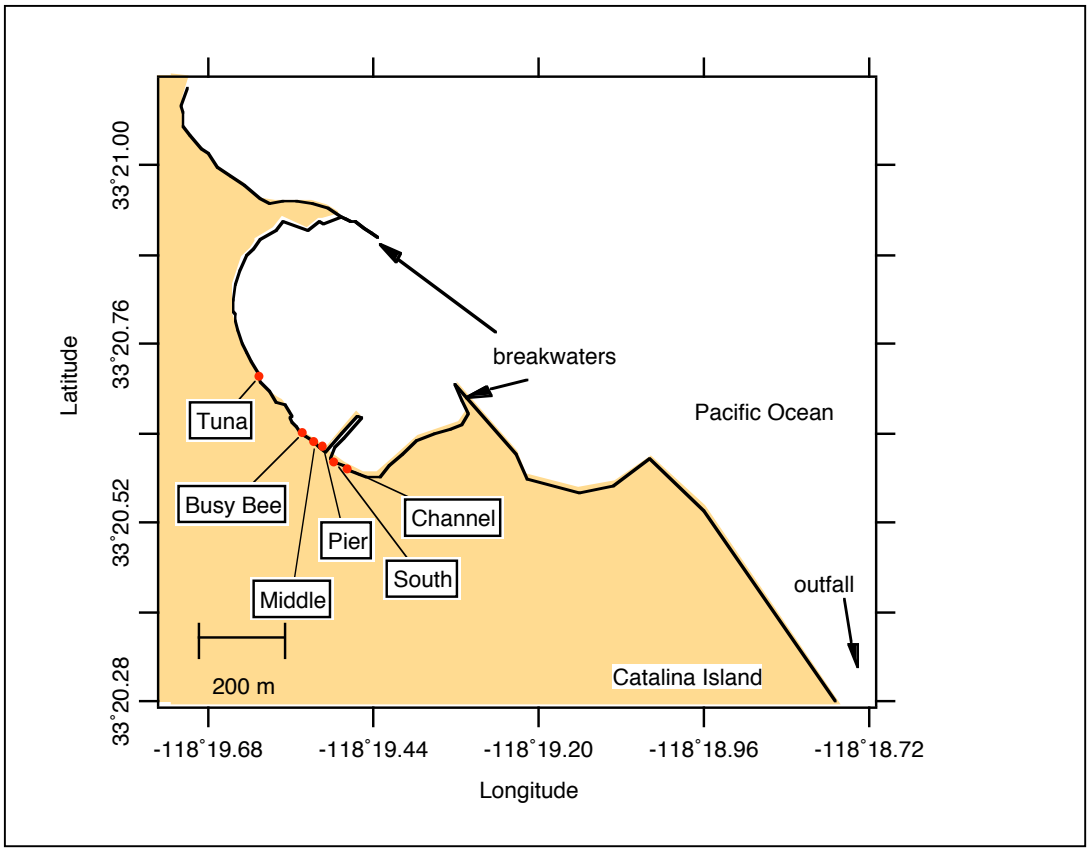

Figure 2.1. Map showing the location of LA County Department of Health Services water quality sampling sites within Avalon Bay. Water samples are collected from ankle depth water once per week in the morning, and analyzed for fecal indicator bacteria using Colilert and Enterolert tests.

Water samples are collected from each site once per week during the summer recreational period, from early April through the end of October. The sampling protocol is as follows. Typically, water samples are collected from each site at each site on Monday morning (between 8:30 and 11:00 AM , depending on boat and helicopter schedules). The samples are collected from ankle depth water on an incoming wave. The samples are flown back to the LA County Water Laboratory, and analyzed within 6 h using defined

substrate tests known commercially as Colilert and Enterolert, implemented in a 96 well quantitray format. These tests yield the concentration of total coliform (TC), *Escherichia coli* (EC), and enterococci bacteria (ENT) in units of most probably number (MPN) per 100 mL of water sample. For comparison to the single-sample standards (described next), EC is assumed to be equivalent to fecal coliform (FC).

The Colilert and Enterolert tests results are read Tuesday afternoon, and compared to the California State standards for marine bathing beaches with more than 50,000 visitors per year.

Single Sample Standards for Coastal Bathing Beaches in California:

a) TC: 10,000 MPN/100 mL
b) TC: 1,000 MPN/100 mL if the ratio of TC/FC is less than or equal to 10;
c) FC: 400 MPN/100 mL;
d) ENT: 104 MPN/100 mL

If a sample violates one or more of the above single-sample standards, LA County officials:

a) Fax a letter (or send an email) to the Avalon lifeguards telling them to post a warning sign at the location where the sample was collected.
b) Return to Avalon Wednesday morning to resample the beach site where the water quality violation occurred. The re-sampled water is tested for fecal indicator bacteria (using the Colilert and Enterolert tests described above).
c) If the re-sampled water exceeds one or more of the above water quality standards, Avalon lifeguards are instructed to leave the warning sign posted on the beach.
d) If the re-sampled water does not exceed any of the above water quality standards, the lifeguards are instructed to remove the warning sign.

Several points should be kept in mind. First, only the single-sample standards noted above are considered in assessing water quality violations; i.e., the LA County Health department does not enforce the 30-day geometric mean fecal indicator bacteria standards for coastal bathing waters. Presumably, Avalon Bay would be posted more frequently (and some sites might be posted more-or-less continuously) if the 30-day geometric mean standard was enforced. Second, there is controversy in the scientific literature regarding the use of Colilert to test for TC and EC in marine samples, because these tests can sometimes yield false positives (Pisciotta et al., 2002). Hence, it is important to assess the fraction of posting events in Avalon Bay that are triggered by exceedences of the single-sample standards for TC and EC (see Chapter 3). Third, the standard used for the EC group of bacteria (400 MPN/100 mL) is technically a fecal coliform (FC) standard, not an EC standard. EC is a subset of FC, and some studies indicate that Colilert estimates of EC are comparable to estimates of FC by standard methods (Palmer et al., 1993, Noble et al., 2004). Fourth, water samples are collected from Avalon Bay only during the summer recreation period, which begins in early April and ends in late

October. Hence, water quality data available from the LA County Health department for Avalon Bay is restricted to summer (non-storm) periods of time. Water quality in Avalon Bay is likely to be significantly worse during storms (Ahn et al., 2005). Fifth, from the studies described later in this report, it is likely that the frequency of water quality violations would be significantly lower if LA County officials collected water samples in waist-deep water. It can be argued that the County's current approach of collecting water samples from ankle depth water is more likely to detect water quality violations, and hence errs on the side of protecting human health.

References:

Ahn, J.H., Grant, SB, Surbeck CQ, et al. (2005) "Coastal water quality impact of stormwater runoff from an urban watershed in southern California" *Environmental Science and Technology* **39**:5940-5953.

Noble, RT, MK Leecaster, CD McGee, SB Weisberg, K Ritter (2004) "Comparison of bacterial indicator analysis methods in stormwater-affected marine waters" *Water Research* **38**:1183-1188.

Palmer CJ, YL Tsai, AL Lang, LR Sangermano (1993) "Evaluation of Colilert-marine water for detection of total coliform and Escherichia coli in the marine-environment" *Applied and Environmental Microbiology* **59**:786-790.

Pisciotta, JM, DF Rath,, PA Stanek et al., (2002) "Marine bacteria cause false-positive results in the Colilert-18 rapid identification test for Escherichia coli in Florida waters" *Applied and Environmental Microbiology* **68**:539-544.

Chapter 3. Water Quality Trends in Avalon Bay

This chapter provides an analysis of spatial and temporal trends in the beach water quality tests carried out in Avalon Bay. These trends are of interest because they provide insights into potential sources of fecal indicator bacteria in the Bay, they indicate which fecal indicator bacteria groups (i.e., total coliform, fecal coliform (or *Escherichia coli*), enterococci bacteria) are responsible for the majority of water quality violations in the Bay, and they shed light on the efficacy of best management practices (BMPs) implemented by the City over the past couple of years to reduce water quality impairment. For the purposes of this analysis the following abbreviations are employed:

TC: total coliform
FC: fecal coliform (or *Escherichia coli*, see discussion in Chapter 2)
ENT: enterococci bacteria

3.A. Data Analysis Methods

To analyze the Avalon historical water quality data the following approach was used. The raw fecal indicator bacteria testing results were downloaded from the LA County's website, at the following URL: http://www.lapublichealth.org/eh/ehftp/. A computer program, implemented in the program Igor (Wavemetrix), was written to compute the percentage of samples collected at a given monitoring site that violated one or more of the water quality standards in a given summer. These water quality violation rates were then plotted to determine spatial (site-by-site) and/or temporal (year-by-year) trends. The results were also compared with measurements of rainfall obtained from the Catalina Conservancy website (http://www.catalinaconservancy.org/ecology/weather/index.cfm). Two rainfall measurements are reported for each water quality sampling season: a) the total amount of rain (measured in inches) that fell in the winter preceding the summer sampling season, and b) the total amount of rain (in inches) that fell during the summer sampling season. These data were also plotted against time to determine temporal (year-by-year) trends, for direct comparison with the water quality violation results. For this analysis, six years of water quality data were utilized: 1) summer of 1999, 2) summer of 2000, 3) summer of 2001, 3) summer of 2002, 4) summer of 2003, 5) summer of 2004, and 6) summer of 2005.

3.B. Results and Analysis:

Analysis of the Avalon historical water quality data are presented below in three parts: (1) spatial trends associated with the fecal indicator bacteria data; (2) temporal trends associated with the fecal indicator bacteria data; and (3) temporal trends in the rainfall data.

3.B.1. Spatial Trends

Figure 3.1 is a plot of the percentage of samples violating water quality standards at each sampling site in Avalon Bay.

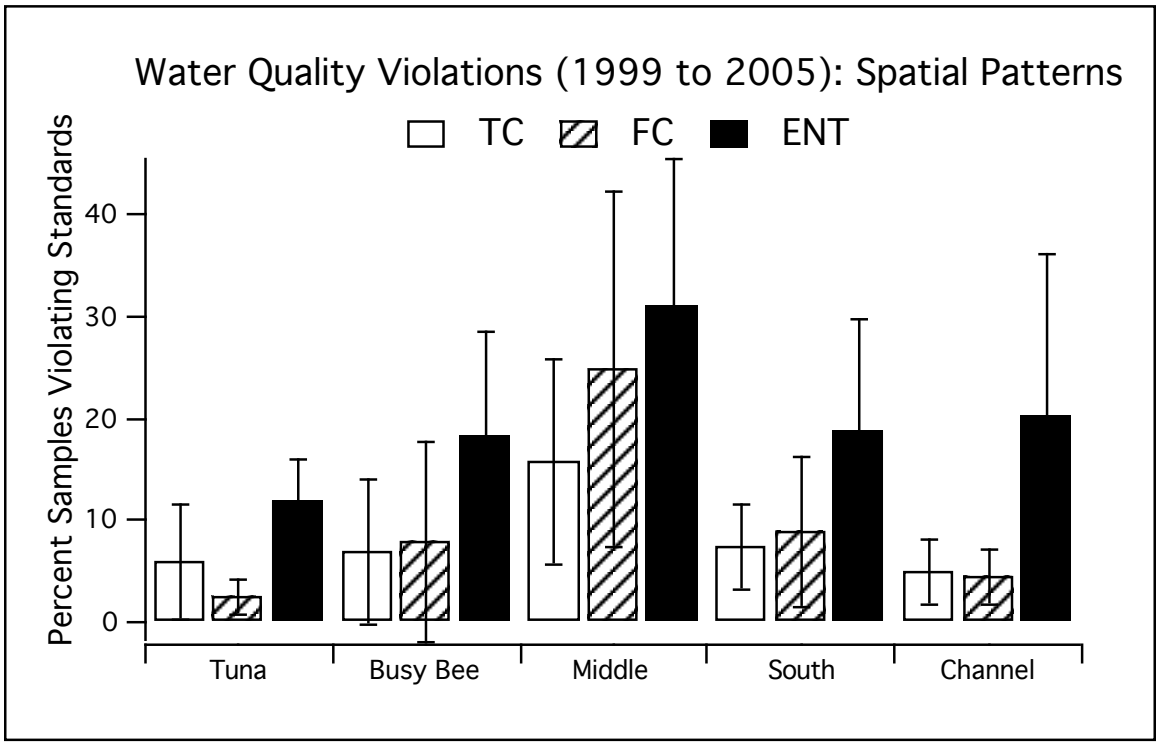

Figure 3.1. Average percentage of samples collected at a particular sampling station in Avalon Bay that violate single-sample water quality standards for total coliform (TC), fecal coliform (or *Escherichia coli*) (FC), or enterococci bacteria (ENT). Averages and standard deviations were calculated using water quality data collected during the summers of 1999 through 2005.

Based on the plot in Figure 3.1, the following trends can be identified:

a) Over the six years (from 1999 through 2005), a relatively large percentage (between 5 and 60%) of water samples collected in Avalon Bay during the summer violated one or more single-sample fecal indicator bacteria standards.
b) The water quality violations exhibit distinct spatial trends:
    i. For TC and FC, the percentage of samples violating single sample standards is highest at the Middle site, and decreases monotonically with distance north and south of the Middle site.
    ii. For ENT, the percentage of samples violating the single sample standard is also highest at Middle. However, the percentage of samples violating the single-sample standard for ENT is roughly the same (within the error indicated by the standard deviation bars) at the other sampling sites.
c) Comparing the three different fecal indicator bacteria groups (TC, FC, and ENT), a larger percentage of samples violated the single-sample standard for ENT. At some sites (e.g., Tuna), more samples violated the single-sample standard for TC than FC, while at other sites (e.g., Middle) more samples violated the single sample standard for FC than TC.
d) It would appear that water quality is worse around the Middle station, which is located near the Pleasure Pier (see map in Figure 2.1). Two possible explanations can be offered:

i. Either there is a significant source of fecal indicator bacteria located near the Middle station, and/or
ii. Bay currents act to focus fecal pollution from other locations at the Middle station.

3.B.2. Temporal Trends

Figure 3.2 is a plot of the percentage of samples violating water quality standards during each of the six years that water quality data are available for the Bay.

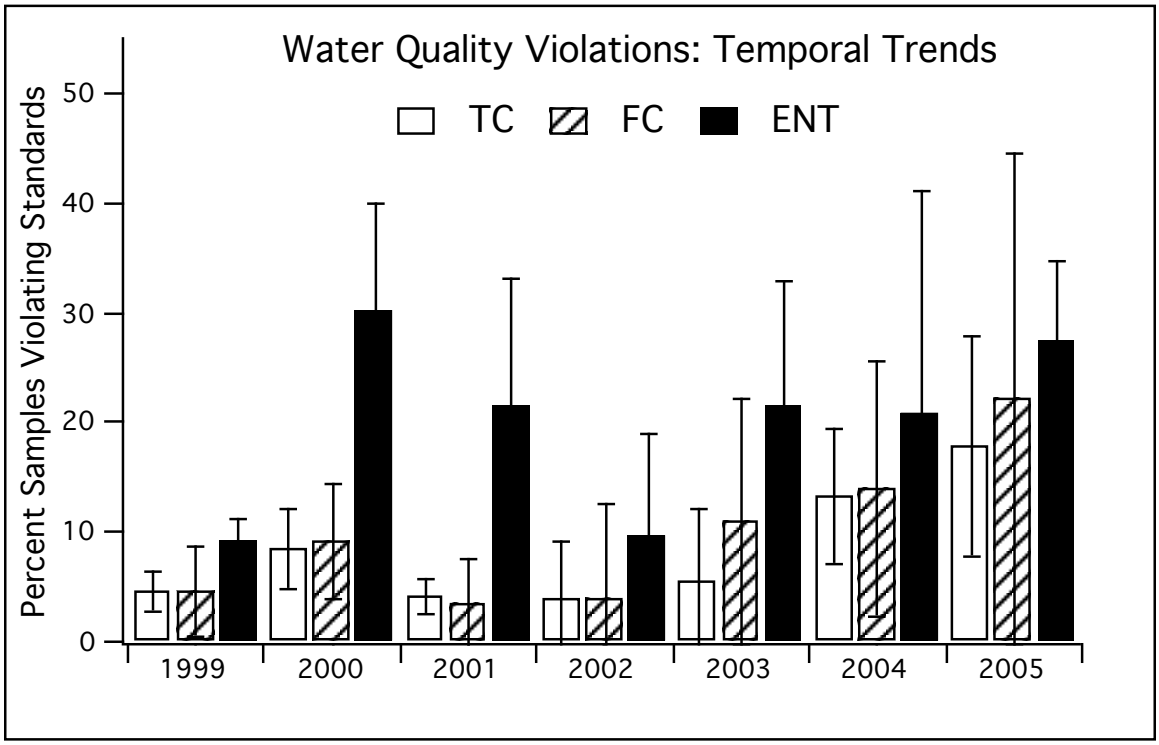

Figure 3.2. Average percentage of samples collected at all Avalon Bay sampling stations in a given year that violate single-sample water quality standards for TC, FC, or ENT. Averages and standard deviations were calculated using water quality data collected during the summers of 1999 through 2005.

Based on the plot in Figure 3.2, the following trends can be identified:

a) Every summer, water samples collected from Avalon Bay most frequently failed to meet the AB411 standard for ENT, followed by FC, and TC
b) There is considerable year-to-year variability in the frequency with which water quality standards are violated. In particular, the summers of 1999 and 2002 were relatively good years (the percentage of samples violating standards less than approximately 10%), while the summers of 2000, 2001, 2003, 2004, and 2005 were relatively bad years (the percentage of samples violating standards greater than approximately 20%).
c) Based on the temporal trends evident in Figure 3.2, it does not appear that the mitigation measures put into place after summer 2001 have led to an improvement

in Avalon Bay water quality. On the contrary, the frequency of AB411 violations appears to be increasing since 2002.

3.B.3. Rainfall Trends

Figure 3.3 is a plot of the cumulative rainfall that fell in each of the years for which water quality data are available.

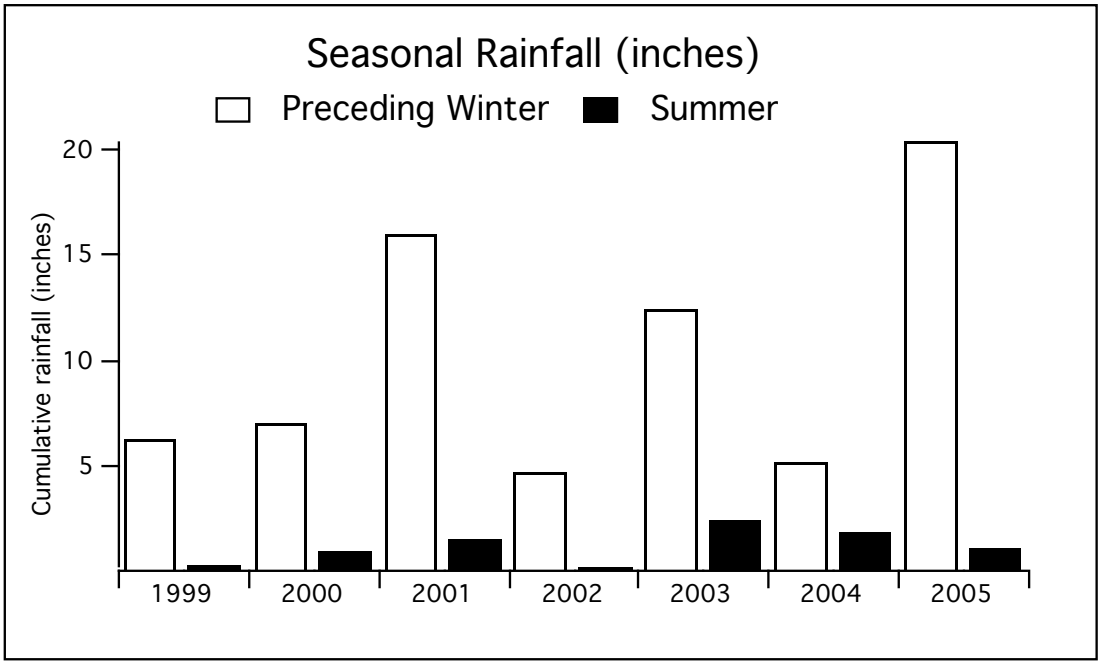

Figure 3.3. Cumulative rainfall falling on Catalina Island as measured by the Catalina Conservancy. Cumulative measured rainfall is grouped by year into two categories: rain that fell during the summer, and rain that fell the preceding winter. The author gratefully acknowledges the Catalina Conservancy for sharing these data.

Based on the plot in Figure 3.3, the following trends can be identified:

a) As expected, 3 to 10 times more rain falls on Catalina during the winter (September 1 through March 1) compared to the summer (March 1 through September 1).
b) There is considerable summer-to-summer and winter-to-winter variability in the amount of rain that falls on Catalina Island. Relative to the seven years analyzed here, the summers of 1999 and 2002 had unusually little rainfall.
c) Catalina Island experienced unusually large amounts of rainfall in the winters preceding the summers of 2001, 2003, and 2005.
d) Water quality in Avalon Bay, as measured by the frequency of single-sample AB411 standard violations, was particularly good during the two summers (1999 and 2002) that experienced unusually little rainfall (compare Figures 3.2 and 3.3).
e) While water quality in Avalon Bay may be influenced by the cumulative summer-time rainfall, a similar relationship does not appear to exist between water quality during the summer and the previous winter's rain. In some cases water quality in

the summer is worse when the previous winter is wet (e.g., 2001, 2003, and 2005), while in other cases water quality in the summer is poor when the previous winter is relatively dry (2004).

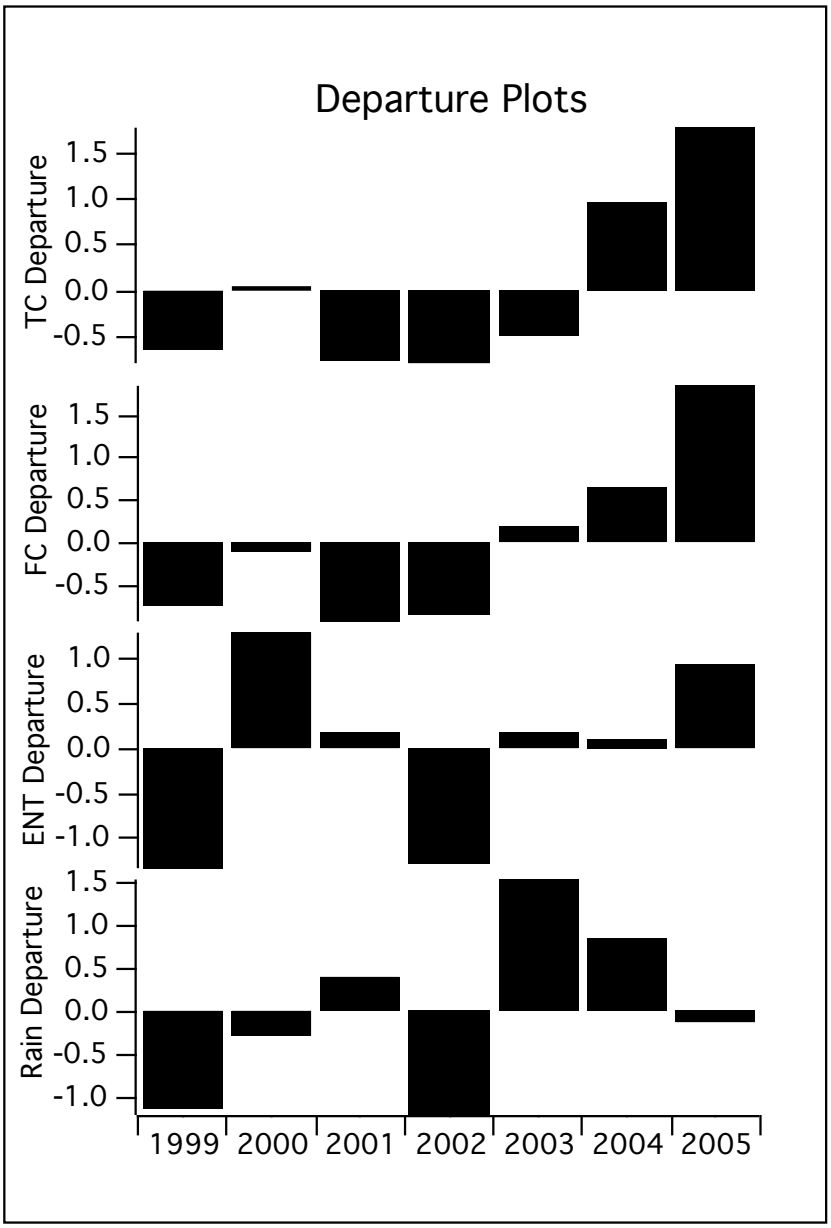

Figure 3.4. Summer-time departures from the long-term means for rainfall, and the % of samples collected from Avalon Bay that violated the sinfle-sample standard for TC, FC, and ENT. The units of "departure" are standard-

3.B.4. Departure Trends:

As noted above, a visual comparison of Figures 3.2 and 3.3 suggests that summer-time rainfall may be correlated with the frequency of fecal indicator bacteria violations in Avalon Bay (e.g., both rainfall and water quality violations were low during the summers of 1999 and 2002). To explore this potential relationship further, plots were generated of the yearly departure of rainfall and fecal indicator bacteria violation rates from their respective long-term means. This particular analysis method is commonly employed when comparing the temporal trends of measurements that have different physical units (e.g., in our case rainfall is measured in units of "inches", whereas fecal indicator bacteria violation rates are measured in units of "%"). The "departure values" for rainfall and fecal indicator bacteria violation rates were computed from the following equation:

$$\text{Departure} = \frac{(\text{Average value for a given summer}) - (\text{Long - term average})}{\text{Long - term standard deviation}} \qquad (1)$$

Application of equation 1 to the rainfall and fecal indicator bacteria data yields the plots in Figure 3.4. In the summers of 1999 and 2002, both rainfall and the fecal indicator bacteria water quality violation rates were 0.5 to 2.0 standard deviations below their respective long-term means. However, there does not appear to be a one-to-one correspondence between the departure values for rainfall, on the one hand, and water quality violation rates, on the other hand. For example, in the summer of 2002, rainfall was slightly above the long-term mean, the ENT violation rate was slightly above the long-term mean, but TC and FC violation rates were significantly below their long-term means. Thus, while summer-time rainfall may influence summer-time water quality violation rates, rainfall does not, by itself, account for the observed summer-to-summer changes in water quality in Avalon Bay.

Chapter 4. Microbial Source Tracking Investigations in Avalon Bay

This chapter summarizes the fecal indicator bacteria source tracking investigations that were carried out in Avalon Bay. These investigations were organized into the following three categories, or "tiers", of investigation:

- Tier 1: Field studies to identify spatiotemporal variability and identify hot spots of fecal indicator bacteria
- Tier 2: Measurement of fecal indicator bacteria concentrations in potential sources of pollution that might contribute to Avalon Bay impairment
- Tier 3: Novel, human-specific indicators to determine if human sewage contributes to the fecal indicator bacteria concentrations in Avalon Bay.

Results from these three tiers of investigations are summarized below. A more detailed description of the methodologies employed, and results obtained, can be found in a research article that was written about this study. A reprint of the research article, which was published in the journal *Environmental Science and Technology* (Boehm et al., 2003), can be found in the appendix of this report.

4.A. Tier 1 Studies

The goal of the Tier 1 studies was to identify spatiotemporal variability and identify hot spots of fecal indicator bacteria in and around Avalon Bay. Specifically, the following tier-one studies were carried out:

-Nearshore Bay Survey (conducted during a flood tide at night)
-Cross-shore Transect (sediment and water)
-24 hour study (document sunlight and tide effects)
-Month-long, twice daily shoreline survey (ankle and waste-depth)

A map showing the sampling locations associated with each of these studies is presented in Figure 4.1.

4.A.1. Tier 1: Nearshore Bay Survey

Objective:
To characterize the spatial distribution of fecal indicator bacteria inside and outside of Avalon Bay

Methods
Water samples were collected from a set of surf zone and offshore sites. Four different types of samples were collected:

1) ankle-depth samples from shoreline sites,
2) waist-depth samples from a subset of the shoreline sites,
3) surface samples from offshore sites, and
4) 1m depth samples from a subset of the offshore sites.

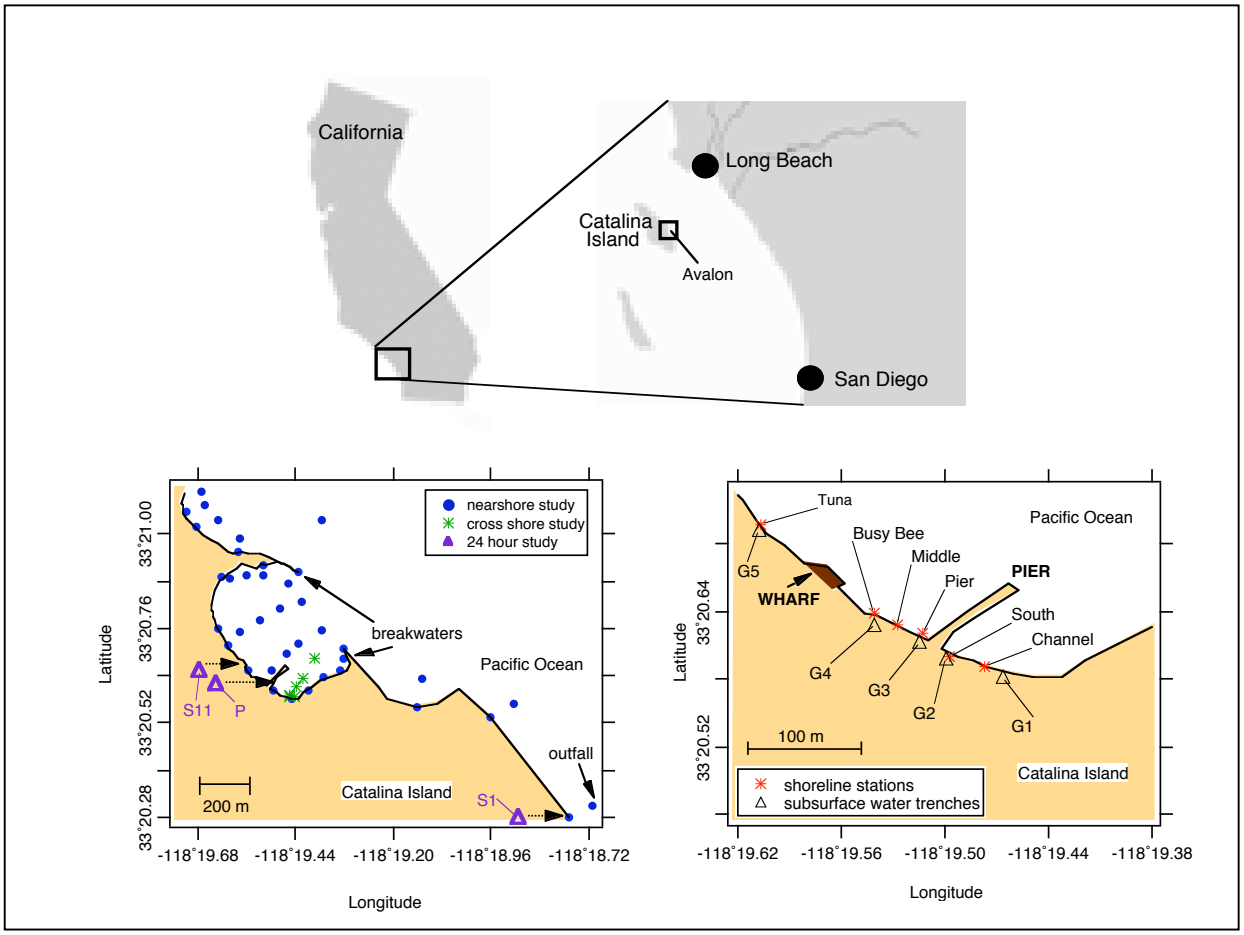

Figure 4.1. Maps showing the location of the four Tier-one studies carried out in Avalon Bay, including nearshore studies (blue circles, lower left panel), cross-shore studies (green crosses, lower left panel), 24 hour studies (purple triangles, lower left panel), and twice-daily month-long study (red asterisk, lower right panel).

The shoreline and offshore sampling sites are plotted in the lower left panel of Figure 4.1 (blue circles). Sampling occurred between 7:00 pm and 9:00 pm on Wednesday 9/19/01 during the first half of a flood tide. The study was carried out after sunset so that the effects of sunlight on fecal indicator bacteria survival and/or detection would not affect the survey results. Shoreline samples were collected by a single person at the beach; offshore samples were collected by a team of people in a small boat (the "salad boat") provided by the Avalon Harbor Patrol. Shoreline and offshore sampling were coordinated so that while ankle and waist samples were being collected from the surf zone, surface and 1m depth samples were being simultaneously collected directly offshore. Ankle depth samples and surface samples were collected from all surf zone and offshore sites, respectively. A subset of the surf zone and offshore sites were additionally sampled at waist and 1m depth. Sampling was initiated in the southern portion of the study area (at Pebbly Beach) and progressed northward. The first offshore sample (collected at 7:00 pm) was located directly over the United Water wastewater outfall.

Table 4.1. Water quality at shoreline sampling sites on 9/19/01.

[a]Surf zone sites	Latitude (dec)	Longitude (dec)	Sampling Time	[b]TC	[b]EC	TC/EC	[b]ENT	Turbidity
S1a	33.33798333	-118.3128167	19:20	63	<10	>6	10	1.8
S2a	33.34225	-118.3159833	19:25	98	<10	>10	<10	1.15
S3a	33.34266667	-118.3190167	19:35	41	<10	>4	<10	0.53
S4a	33.34511667	-118.32205	19:40	63	<10	>6	<10	0.22
S5a	33.3447	-118.32205	19:45	74	<10	>7	<10	0.13
S6a	33.34421667	-118.3221333	19:50	10	<10	>1	<10	0.2
S7a	33.3439	-118.32285	19:55	85	<10	>9	<10	0.26
S8a	33.3434	-118.3234667	20:00	41	<10	>4	<10	0.37
S9a	33.34301667	-118.3241667	20:05	109	10	11	<10	1.51
S9w	33.34301667	-118.3241667	20:35	148	31	4	20	2.36
S10a	33.34333333	-118.3249167	20:40	146	63	2	41	6.5
S10w	33.34333333	-118.3249167	20:43	211	135	2	31	2.1
S11a	33.34418333	-118.3259	20:50	3448	2755	1	933	1.6
S11w	33.34418333	-118.3259	20:52	496	341	1	74	0.8
S12a	33.34526667	-118.3267333	21:00	448	63	7	41	0.9
S12w	33.34526667	-118.3267333	21:03	512	85	5	41	0.7
S13	33.34598333	-118.3271667	21:09	41	<10	>4	10	0.37
S14a	33.34818333	-118.3269833	21:15	175	<10	>20	<10	0.27
S14w	33.34818333	-118.3269833	21:17	134	<10	>10	<10	0.23
S15a	33.34865	-118.3253167	21:21	109	10	>11	<10	0.15
S16a	33.34838333	-118.3238667	21:28	21	10	2.1	<10	0.06
S17a	33.34928333	-118.32635	21:35	<10	<10	I.D.	<10	0.09
S18a	33.3503	-118.3280667	21:40	63	21	3	10	1.7
S19a	33.35095	-118.3284167	21:44	95	10	10	<10	0.76

[a]The suffix "a" indicates sample was taken in ankle depth water; the suffix "w" indicates sample was taken in waist depth water.
[b]Units of most probable number (MPN) per100 mL of sample.
[c]Units of nephelometric turbidity units (N TU)

All ocean water samples were collected in 500 mL Nalgene bottles, immediately placed on ice, and delivered to a temporary laboratory facility in the City of Avalon, located at the Mole. Once at the lab, samples were analyzed for physical properties (pH, salinity, turbidity) and indicator bacteria, including total coliform (TC), fecal coliform (FC), and enterococci bacteria (ENT) using Colilert and Enterolert tests. A subset of the samples were also analyzed for evidence of human fecal contamination (see later discussion of Tier 3 results). The analytical methods employed are described in the QAPP which can be found in the appendix.

Findings

Tables 4.1 and 4.2 summarize data collected for the spatial survey, including coordinates of the sampling sites, time samples were collected, concentration of the indicator bacteria total coliform, *Escherichia coli*, and enterococcus bacteria (TC, EC, and ENT, respectively) in most probable number (MPN) per 100 mL of sample, and turbidity in nephelometric turbidity units (NTU).

Table 4.2. Water quality at offshore sampling sites on 9/19/01.

[a]Offshore Sites	Latitude (dec)	Longitude (dec)	Sampling Time	[b]TC	[b]EC	TC/EC	[b]ENT	[c]Turbidity
O1	33.3385	-118.3118333	19:20	<10	<10	I.D.	<10	0.8
01m	33.3385	-118.3118333	19:20	10	<10	>1	<10	0.56
O2	33.34283333	-118.3150333	19:27	20	<10	>2	<10	0.54
02m	33.34283333	-118.3150333	19:27	<10	<10	I.D.	<10	0.47
O3	33.34385	-118.3188	19:35	21	<10	>2	<10	0.59
03m	33.34385	-118.3188	19:35	41	<10	>4	<10	0.3
O4	33.34591667	-118.3228833	19:40	74	<10	>7	<10	0.22
O5	33.34533333	-118.3238333	19:45	199	<10	>20	<10	0.28
O6	33.34491667	-118.3243333	19:50	455	<10	>50	<10	0.22
O7	33.34425	-118.3249333	19:55	20	10	2	10	0.33
07m	33.34425	-118.3249333	19:55	86	<10	>9	<10	0.31
O8	33.34583333	-118.3262833	20:40	41	<10	>4	<10	0.78
08m	33.34583333	-118.3262833	20:40	121	31	4	<10	0.6
O9	33.34631667	-118.3254167	20:45	2063	21	100	<10	0.24
O10	33.34681667	-118.3246	20:46	20	20	1	<10	0.14
O11	33.34715	-118.3237333	20:48	171	41	4	<10	0.2
O11a	33.34815	-118.32665	20:53	327	<10	>30	<10	0.35
011am	33.34815	-118.32665	20:53	216	<10	>20	<10	0.3
O12	33.34825	-118.3259667	20:55	350	10	40	<10	0.26
O13	33.34828333	-118.3252667	20:58	1054	20	50	<10	0.33
O14	33.34791667	-118.3242833	21:00	282	<10	>30	<10	0.3
O15	33.35058333	-118.3229167	21:05	<10	<10	I.D.	<10	0.1
O16	33.34985	-118.32625	21:10	72	41	1	<10	0.15
016m	33.34985	-118.32625	21:10	41	10	4	<10	0.18
O17	33.35058333	-118.3271667	21:14	<10	<10	I.D.	<10	0.12
017m	33.35058333	-118.3271667	21:14	<10	<10	I.D.	<10	0.12
O18	33.35123333	-118.3276667	21:17	187	85	2	<10	0.1
018m	33.35123333	-118.3276667	21:17	110	31	3	<10	0.14
O19	33.3518	-118.32785	21:20	31	10	3	<10	0.11

[a]The suffix "m" indicates samples were taken 1m below the water surface; no suffix indicates samples were collected at the surface.
[b]Units of most probable number (MPN) per100 mL of sample.
[c]Units of nephelometric turbidity units (N TU)

The data in Tables 4.1 and 4.2 are presented graphically in Figure 4.2. With the exception of the shoreline sampling sites S10, S11, and S12—which are located near the Busy Bee monitoring site and Armstrong's Wharf—the concentrations of EC and ENT were near, or below, the lower-limit of detection (10 MPN/100 mL). The EC and ENT concentrations in ankle depth water at site S11, were significantly above the California marine bathing water single-sample standards for these two indicator bacteria (400 and104 MPN/100 mL, respectively); the concentration in waist depth water at this site were about an order of magnitude lower, but still about equal to the single-sample standard values. The concentration of TC was elevated at a number of sites inside and outside of the Bay; however, all of the TC concentrations measured in the surf zone and

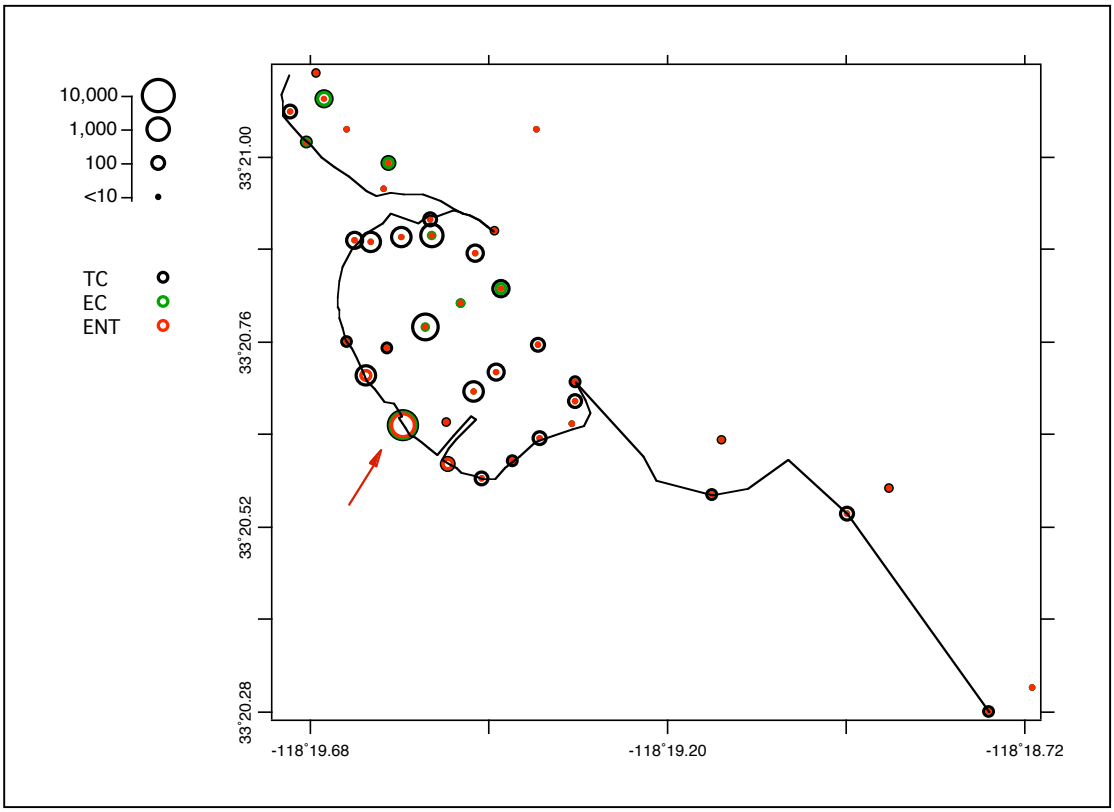

Figure 4.2. Map showing the concentration of fecal indicator bacteria measured in samples of water collected from along the shoreline, inside, and outside of Avalon Bay, Catalina Is. The size of the symbols indicates the concentration of fecal indicator bacteria (see key), and the color of the circle indicates the fecal indicator bacteria group (Total coliform, TC; *Escherichia coli*, EC; or Enterococci bacteria, ENT). The arrow indicates the location (site S11) where fecal indicator bacteria concentrations exceeded all three State standards.

offshore fell below the single-sample standard for this indicator bacteria (10,000 MPN/100 mL).

The TC/EC ratio was near unity at station S11, and greater or equal to 2 at all other sites. The combination of elevated ENT and EC concentrations at S11 and a near unity TC/EC ratio might reflect the presence of fresh fecal pollution and elevated bather health risk.

Apart from site S11, the concentration of fecal indicator bacteria in the surf zone at ankle and waist depths were generally similar (Table 4.1). Likewise, the concentration of indicator bacteria in offshore samples collected at the surface and 1m below the surface were also similar (Table 4.2). There is no clear relationship between the turbidity of samples and the concentration of fecal indicator bacteria.

Generally speaking, the concentrations of fecal indicator bacteria outside of Avalon Bay were low. Moderate concentrations of TC (100 to 1000 MPN/100 mL) were detected at several of the shoreline and offshore sites at Descanso Beach. The shoreline and offshore concentrations of EC and ENT at Descanso Beach were below the corresponding single-

sample standards. Water samples collected south of Avalon Bay--including samples collected directly over, and shoreward, of the wastewater outfall--all had very low concentrations of the three indicator bacteria (< 10 MPN/100 mL).

Interpretation and Implications.
The highest concentrations of fecal indicator bacteria were measured in surf zone water collected in ankle depth water near the Busy Bee sampling station (site S11). The concentration of fecal indicator bacteria at this site was approximately an order of magnitude lower in waist deep water, and tapered off in both up- and down-coast directions. Two weeks after the spatial study was completed (on 10/1/01), a leaking sewer line beneath Armstrong's Wharf was discovered. Samples of water leaking from the pipe had very high levels of fecal indicator bacteria (>24,192, >24,192, and 1,233 MPN/100 mL for TC, EC, and ENT, respectively). It is possible that the leaking sewer line contributed to the elevated concentration of fecal indicator bacteria at site S11.

Offshore water samples collected over the wastewater outfall (both surface samples and samples collected at 1m below the surface) to the south of Avalon Bay did not contain elevated concentrations of fecal indicator bacteria. The concentration of TC in ocean water samples collected offshore of Descanso beach were intermediate between those collected inside Avalon Bay and over the outfall. Hence, for this particular snapshot in time, it appears that the primary source of indicator bacteria in the Bay was along the shoreline in Avalon Bay. These data do not implicate out-of-bay sources, such as the sewage outfall, as the cause of surf zone water quality impairment in the Bay.

4.A.2. Tier 1: Cross-shore Transect

Objective
To characterize the distribution of fecal indicator bacteria in the sediment and water column along a cross-shore transect in Avalon Bay.

Methods
Water and sediment samples were collected from a set of cross-shore transect sites originating in the surf zone (approximately near the Channel sampling station) and progressing toward the middle of the Bay. At each transect site a diver collected:

1) A sediment sample from the sediment/water interface.
2) Water samples from the surface of the water column, and at a discrete set of intermediate depths.

The location of transect sites within the Bay are plotted in Fig. 4.1 (green asterisks). Each transect site was marked with a rope that had an anchor affixed to one end and a buoy to the other. Sealed sample bottles were installed at fixed intervals along each rope. Sampling commenced during a falling tide in the early afternoon on 9/18/01. At each site a diver manually collected approximately 1 kg of sediment from the sediment/water interface, placed the sediment into a plastic bag, and then sealed the bag. The diver then collected water samples from the overlying water column by swimming up to bottles

suspended from each rope, removing the caps, and recapping the bottles once they filled with ocean water.

Table 4.3. Concentration of indicator bacteria in sediments and water samples collected along a cross-shore transect on 9/18/01.

[a]Transect Sites	Latitude (dec)	Longitude (dec)	[b]Sample Depth (m)	[c]TC	[c]EC	[c]ENT
Awat	33.3447	-118.3232	0.00	30	<10	<10
Awat	33.3447	-118.3232	3.03	249	<10	<10
Awat	33.3447	-118.3232	4.55	<10	<10	<10
Awat	33.3447	-118.3232	7.58	<10	<10	<10
Awat	33.3447	-118.3232	10.61	<10	<10	<10
Ased	33.3447	-118.3232	11.52	10	<10	10
Cwat	33.34388333	-118.3236333	0.00	N.D.	N.D.	N.D.
Cwat	33.34388333	-118.3236333	3.03	N.D.	N.D.	N.D.
Cwat	33.34388333	-118.3236333	6.06	97	<10	<10
Csed	33.34388333	-118.3236333	6.97	41	<10	74
Dwat	33.3435	-118.32397	0.00	278	10	<10
Dwat	33.3435	-118.32397	1.52	98	<10	106
Dwat	33.3435	-118.32397	3.03	161	<10	<10
Dsed	33.3435	-118.32397	3.94	<10	<10	<10
Fwat	33.3431167	-118.32402	0.00	240	10	156
Fwat	33.3431167	-118.32402	0.91	512	10	<10
Fwat	33.3431167	-118.32402	1.82	<10	<10	<10
Fsed	33.3431167	-118.32402	2.73	41	<10	10
Ewat	33.34315	-118.32418	0	703	31	<10
Ewat	33.34315	-118.32418	0.91	1223	<10	<10
Esed	33.34315	-118.32418	2.73	98	<10	31
Hwat	33.34305	-118.32422	0	487	21	<10
Hsed	33.34305	-118.32422	0.91	52	<10	<10

[a]The suffix "wat" indicates ocean water samples; suffix "sed" indicates sediment samples from the bottom of the water column.
[b]Depth below the surface of the water column
[c]Water and sediment samples are in units of most probable number (MPN) per100 mL of water and MPN per gm of wet sediment, respectively.

Water and sediment samples were recovered from the site, and transported to the temporary laboratory at the Mole. All water samples were analyzed for fecal indicator bacteria following the procedure outlined in the QAPP (see appendix). Sediment samples were processed by suspending 50 g of sediment in 450 mL of phosphate buffered saline (PBS) solution, shaking gently, allowing the suspension to settle for 10 min., and then drawing off 10 mL of the supernatant for TC, EC, and ENT analysis.

Findings.

Table 4.3 summarizes data collected for the transect study, including the sampling site coordinates, sample depths, and the concentrations of TC, EC, and ENT in MPN per 100 mL (for water samples) or MPN per g of wet weight (for sediment samples). Due to sampling errors, two water column samples at site C, and all of the water column and sediment samples at site B, were lost.

Fig. 4.3 is a graphical representation of the data in Table 4.3. The concentration of fecal indicator bacteria in the water and sediment samples are represented by the size of circles

and squares, respectively. Samples from the furthest offshore site (station A) generally had lower concentrations of fecal indicator bacteria compared with samples collected closer to shore (sites C, D, E, and F).

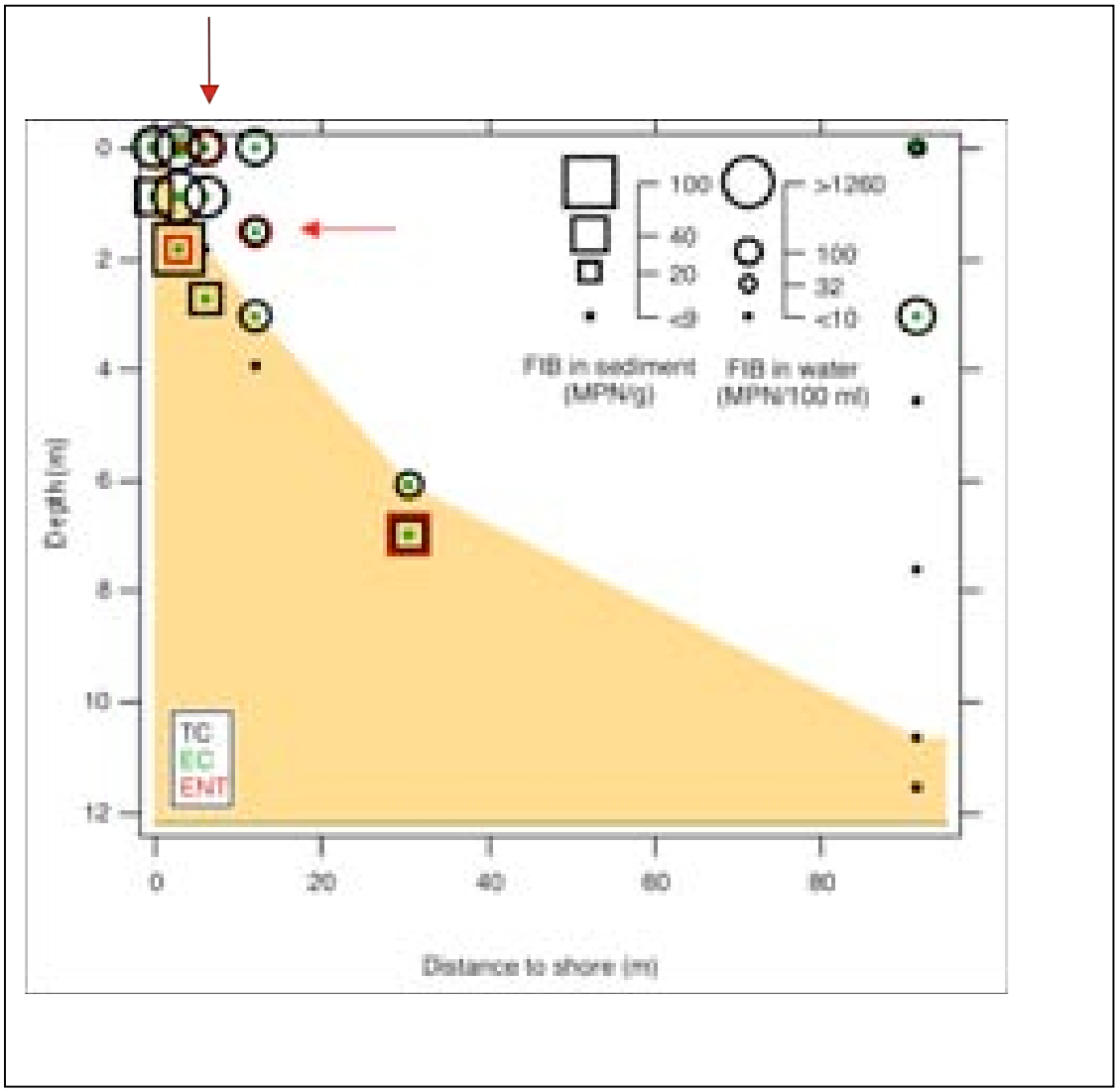

Figure 4.3. Cross-section of the water column in Avalon Bay showing the concentration of fecal indicator bacteria measurements in the water column (circles) and sediment (squares). The size of the symbols indicates the concentration of fecal indicator bacteria (see key), and the color of the circle indicates the fecal indicator bacteria group: Total Coliform (TC, black), *Escherichia coli* (EC, green); or Enterococci bacteria (ENT, red).

Indicator bacteria were detected in the sediments, but at low concentrations (<100, <10, and <75 MPN/g for TC, EC, and ENT, respectively). With the exception of two ENT measurements at sites D and F, all of the water column samples had indicator bacteria concentrations below the corresponding single sample standards. The two exceptional

samples were collected near, or at, the surface of the water column in the very near shore area.

Interpretation and Implications

The highest concentrations of fecal indicator bacteria were measured close to shore in less than 3 m of water. In contrast, the furthest offshore site (station A) had very low concentrations of fecal indicator bacteria. Collectively, these results are consistent with a very near shore source of fecal indicator bacteria. Examples of possible shoreline sources include leaking sewer lines (e.g., under Armstrong's Wharf, see last section), exfiltration of contaminated groundwater, and/or bird droppings deposited along the shoreline. Growth of fecal indicator bacteria in the beach sediments is another possible source of these contaminants (Lee et al., 2006).

4.A.3. Tier 1: Day-Night Study

Objective

To characterize day/night patterns in the concentration of indicator bacteria at shoreline sites inside and outside of Avalon Bay, and in the groundwater beneath downtown Avalon.

Methods

Water samples were collected from a set of shoreline and groundwater sites every other hour for twenty-four hours. Ankle and waist depth water was sampled at each of the shoreline sites. The location of the shoreline sites (S1, P, and S11) and groundwater site (G2) are indicated in Figure 4.1 (purple triangles in lower left panel for shoreline sites, and black triangle in lower right panel, groundwater site). The study

Table 4.4. Day/night variation in the concentration of fecal indicator bacteria at three shoreline sites, and one groundwater site.

Date and Time	Station 1			Station P			Station 11			Groundwater (x1000)		
	TC[a]	EC[a]	ENT[a]	TC[a]	EC[a]	ENT[a]	TC[a]	EC[a]	ENT[a]	TC	EC	ENT
9/20/01 21:00	41, 10	10, <10	<10, <10	246, 148	41, 31	<10, 20	110, 122	10, <10	<10, 10	.41	.1	73
9/20/01 23:00	10, 10	<10, <10	20, 10	63, 110	<10, 31	<10, <10	193,216	<10, 20	10, 10	.2	<.1	<.1
9/21/01 1:00	31, 10	<10, <10	<10, <10	109, 84	31, 10	<10, <10	173,265	97, 122	20, 20	<.1	<.1	<.1
9/21/01 3:00	10, 10	<10, <10	<10, <10	161, 201	41, 31	<10, <10	309,337	98, 132	20, 30	.1	<.1	<.1
9/21/01 5:00	<10, <10	<10, <10	<10, <10	131, 122	31, 10	10, 20	384,435	134, 226	63, 10	.1	<.1	<.1
9/21/01 7:00	10, 31	<10, <10	<10, <10	135, 31	20, <10	10, 10	301,311	213, 128	<10, 10	.31	.1	.1
9/21/01 9:00	20, 10	<10, <10	10, <10	63, 98	10, 10	<10, 10	52, 31	20, 10	<10,<10	.2	<.1	<.1
9/21/01 11:00	<10,10	<10, <10	20, <10	31, 52	<10, <10	<10, <10	122, 84	63, 31	<10, <10	1.6	1.6	<.1
9/21/01 13:00	52, 41	10, 41	<10, <10	20, 20	<10, <10	<10, <10	20, 31	10, <10	<10, <10	2.3	2.3	<.1
9/21/01 15:00	<10, <10	<10,<10	<10, <10	<10, 20	<10, <10	<10, <10	10, 10	<10, <10	<10, <10	>241	>241	<.1
9/21/01 17:00	<10, <10	<10,<10	<10, <10	175, 52	41, 20	10, <10	199, 183	74, 95	63, 10	.97	.9	<.1

9/21/01 19:00	<10	<10,<10	10, <10	52, 160	<10, 20	<10, <10	354, 399	110, 135	85, 173	2.3	.86	<.1

[a]The two numbers reported in each shoreline site correspond to the concentration of fecal indicator bacteria measured in samples collected from ankle and waist depths.

commenced on a rising tide in the evening on 9/20/01. After collection, samples were immediately placed on ice and transported to the laboratory at the Mole where they were analyzed for TC, EC, and ENT following procedures outlined in the QAPP (appendix).

Findings.

Table 4.4 summarizes the data collected during the day/night study, including sampling times, and the concentration of TC, EC, and ENT in MPN per 100 mL. The concentrations of fecal indicator bacteria are very low in all samples collected at site S1 (<100, <50, and <20 MPN/100 mL for TC, EC, and ENT, respectively). This site is located south-east of Avalon Bay, just shoreward of the United Water sewage outfall. Fecal indicator bacteria concentrations were higher at the two shoreline sites in Avalon Bay (S11 and P). The highest concentrations of indicator bacteria were measured at site

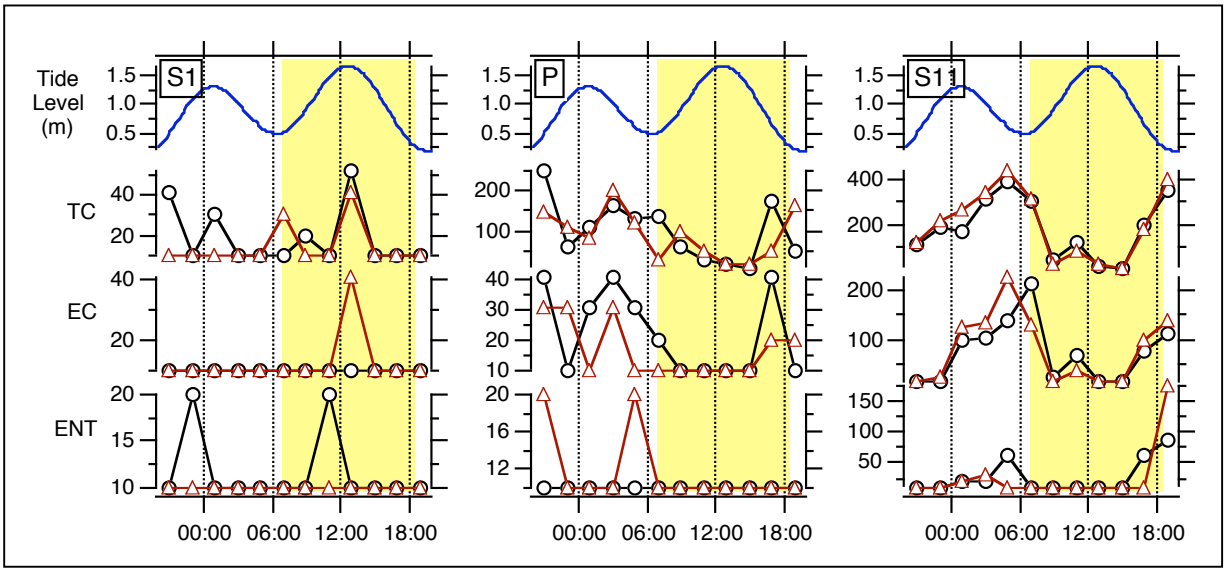

Figure 4.4. Day/night measurements of fecal indicator bacteria at two shoreline sites in Avalon Bay (S11 and P) and one shoreline site outside of Avalon Bay, shoreward of the United Water sewage outfall (S1). The top plot is tide level predicted by WXTide; the bottom graphs are the concentration of fecal indicator bacteria measured in ankle (black circles) and waist (red triangles) deep water. The yellow band indicates periods of daylight.

S11, located near the Busy Bee sampling station and Armstrong's Wharf. There is not a consistent difference between the concentration of indicator bacteria measured in ankle and waist depth water. It should be noted, however, that this particular study was carried out for a very short period of time (24 h), and most of the samples had fecal indicator bacteria concentrations below the detection limit. In other studies (e.g., the month-long study described below and the transect study described above), ankle-depth samples had significantly higher concentrations of fecal indicator bacteria, compared to waist-depth samples.

The tide level, indicator bacteria concentration, and daylight period (indicated by the yellow band) are plotted for the four sampling sites in Figure 4.4. The concentration of fecal indicator bacteria at site S1 is too low to discern a day/night or tidal trend. The fecal indicator bacteria signal at sites S11 and P, on the other hand, appears to follow a day/night pattern, with the highest concentrations occurring at night/evening during the falling tide. TC and EC concentrations in the groundwater peaked during the falling tide in the afternoon on 9/21.

The concentration of fecal indicator bacteria in the shallow ground water samples (collected from a trench located just south of the Pleasure Pier, site G2, see lower right panel, Figure 4.1) were extraordinarily high (see Table 4.4 and Figure 4.5). The peak concentration of TC and EC in the shallow groundwater was >241,000 MPN/100 mL. The peak concentration of ENT in the shallow groundwater was 73,000 MPN/100 mL (Table 4.4). By way of comparison, the California single-sample standards for these three fecal indicator bacteria in marine bathing waters are 10,000, 400 and 104 MPN/100 mL, respectively. The concentration of fecal indicator bacteria in the shallow groundwater also appears to exhibit a day/night pattern, with concentrations peaking during the day-time falling tide.

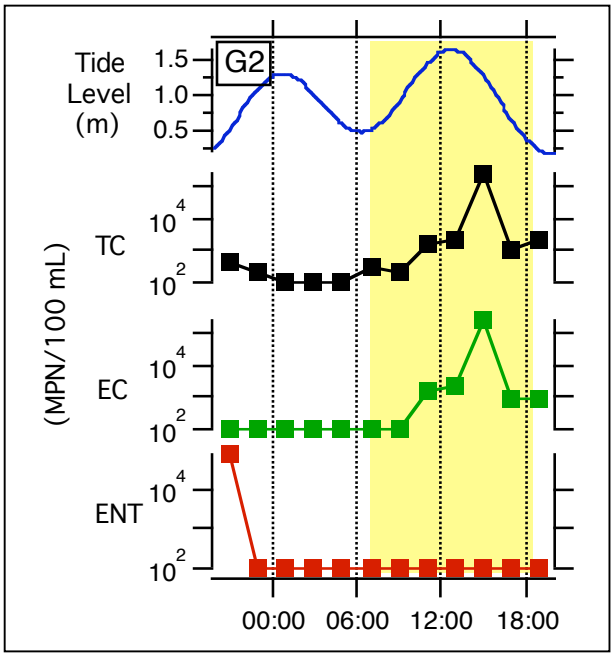

Figure 4.5. Day/night measurements of fecal indicator bacteria in groundwater, collected from a trench located 10 m south of the Pleasure Pier (site G2). The top plot is tide level predicted by WXTide; the bottom graphs are the concentration of fecal indicator bacteria. The yellow band indicates periods of daylight.

Interpretation and Implications

The concentration of TC and EC, and to a limited extent the concentration of ENT, follow a day/night pattern at sites P and S1 in Avalon Bay. At both sites, the concentration of fecal indicator bacteria is lowest when solar radiation is maximal at noon, and higher at night and during the falling tide in the late afternoon. Possible explanations for this day/night pattern include sunlight-induced die-off of fecal indicator bacteria in marine waters (Boehm et al., 2002), tidal flow of contaminated groundwater into the Bay (Boehm et al., 2004), tidal washing of contaminated sediments (Boehm and Weisberg, 2005), and day/night patterns associated with the input of runoff into the Bay from, for example, City wash-down activities (Boehm et al., 2003).

One of the most striking results to come out of this study is the very high concentration of fecal indicator bacteria in water samples collected from a trench located approximately 10 m south of the Pleasure Pier (site G2, see Figure 4.5 and Table 4.4).

Further, TC and EC exhibit a strong day/night pattern in the groundwater, with the highest concentrations occurring during the day-time falling tide. These two observations—that fecal indicator bacteria are present at high concentrations in the sub-surface water and that TC and EC exhibit a day/night pattern—are consistent with the idea presented above that exfiltration of contaminated groundwater may be a source of the fecal indicator bacteria contamination along the shoreline in Avalon Bay.

The results presented in Figure 4.5 beg the question of what might be responsible for the very high concentrations of fecal indicator bacteria in the shallow groundwater beneath the City of Avalon. Two possibilities that merit further exploration include: (1) fecal indicator bacteria in the ground water originate from leaking sewage collection lines in the downtown area, or (2) fecal indicator bacteria are growing in the subsurface sediments and/or groundwater. Even in this second scenario leaking sewage collection lines could play a role, by providing a supply of nutrients for fecal indicator bacteria re-growth in the subsurface. Indeed, it is interesting to note that the sediments excavated from this trench were organic rich and smelled of hydrogen sulfide, consistent with the idea that they may have been sewage impacted. In either case, the ground water sampling results would appear to warrant follow-up investigation and possibly remediation. Remediation of sewage contaminated sands is apparently a topic about which little is known (Eric Edwards, LA DHS, personal communication).

The day/night pattern observed at shoreline sites S11 and P suggest that the time of day a sample is collected can significantly affect the measured concentration of fecal indicator bacteria. Relative to the routine monitoring programs carried out by the LA DHS and United Water, inconsistency in the time of day samples are taken could seriously confound interpretation of monitoring data. For example, samples collected early in the morning one day may contain high concentrations of indicator bacteria from a source of fecal pollution. If the sampling is then repeated in the early afternoon several days later, the concentration of indicator bacteria may be significantly lower, even if the source of fecal pollution is still present. Given the fact that human pathogens can be more resistant to sunlight than indicator bacteria in marine systems (Wait and Sobsey, 2001), Los Angeles DHS and United Water should consider adopting a consistent early morning sampling schedule for their ongoing monitoring programs.

4.A.4. Tier 1: Month-Long, Twice Daily, Shoreline Sampling

Objective

To determine day-to-day changes in the concentration of fecal indicator bacteria at a set of shoreline sites in Avalon Bay over a period of one month.

Methods

Water samples were collected from a set of shoreline and groundwater sites twice per day for approximately one month. From 9/25/01 until 10/20/01, water samples were collected daily from the six Los Angeles DHS surf zone monitoring sites in Avalon Bay (Channel, South, Pier, Middle, Busy Bee, and Tuna) (see location of these sites in the

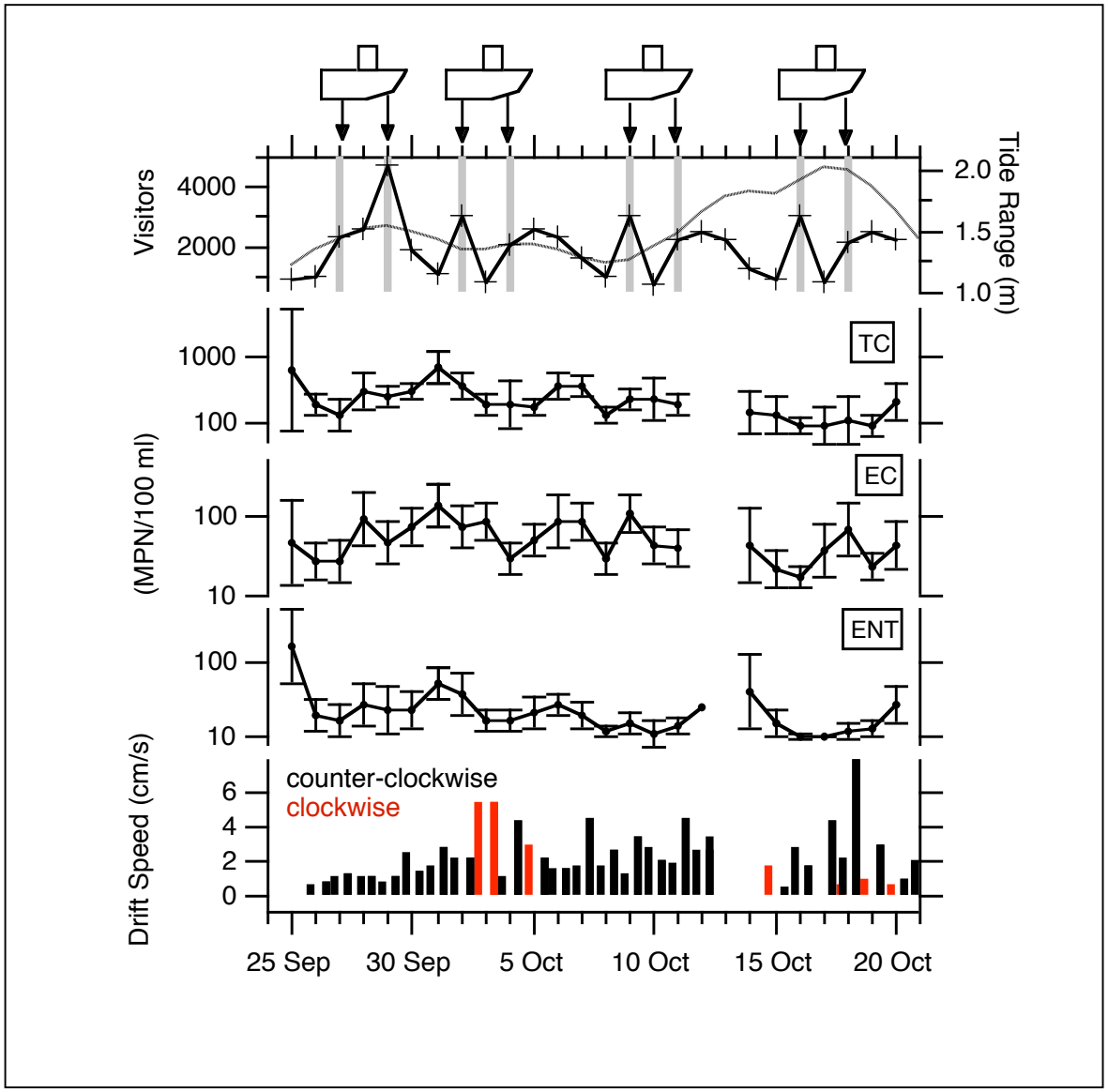

Figure 4.6. Daily measurements of fecal indicator bacteria at shoreline sites in Avalon Bay. Each point represents the log-mean (and standard deviation) of fecal indicator bacteria concentrations measured in all samples collected from the Avalon Bay shoreline on a particular day. The boats at the top of the graph indicate the arrival of large cruise ships; also shown are estimates for the number of tourists visiting the City of Avalon on a given day, and tide range (defined as the difference between the daily high-high and low-low tide). The bottom panel indicates whether shoreline waters were circulating clockwise or counter-clockwise, determined from the orange-drop experiments (see methods section).

lower right panel, Fig. 4.1). Daily samples were also collected from five groundwater trenches in the downtown area (see location of groundwater trenches in the lower right

panel, Fig. 4.1); these groundwater data will be presented in Section 4.A.5 of this report. Shoreline sites were sampled at ankle and waist depths in the morning, and only at ankle depth in the evening. After collection, samples were immediately placed on ice, and transported to the Mole where they were analyzed for TC, EC, ENT, and turbidity following procedures outlined in the QAPP (see appendix). Before the morning sampling run, an orange was dropped off of the Pleasure Pier in approximately 1 m of water, and then tracked for approximately 20 min. From these orange drop experiments, estimates of the littoral drift direction and velocity were obtained.

Findings

Tables 4.5 through 4.10 summarize the data collected during the month-long study, including the sample's depth (ankle or waist), collection date and time, concentration of TC, EC, and ENT in MPN per 100 mL, and turbidity.

A total of 418 samples were collected during the survey from the routine monitoring sites shown in Figure 4.1 (bottom right panel, red asterisks). Of the 280 ankle depth samples collected during the month-long study, none exceeded the single-sample standard for TC (0%), twelve exceeded the single-sample standard for FC (4%), and thirty exceeded the single-sample standard for ENT (10%). Of the 138 waist-depth samples collected, none exceeded the single-sample standards for TC and FC, and three (2%) exceeded the single-sample standard for ENT. Five of the samples collected during the month-long study had ENT concentrations in excess of 500 MPN/100 mL, and most of these were ankle depth samples (taken in the evening) from the Channel station.

Figure 4.6 is a graphical representation of the TC, EC, and ENT concentrations measured at the shoreline sites during the month-long study. The concentration of TC was elevated (>500 MPN/100 mL) for one five day period (9/28 through 10/3), and sporadically throughout the study, at stations Middle, Pier, and Busy Bee. The TC concentration was elevated less frequently at stations South and Channel, although the TC concentration at these two stations was quite high (>1000 MPN/100 mL) at the beginning of the study. The EC concentration was generally low at all shoreline stations, with the exception of a couple of events around October 1st at stations Pier, Middle, and Busy Bee, and again on October 18th at station Middle. The ENT concentration was elevated (>50 MPN/100 mL) at all stations (except Tuna) from September 26th through October 3rd, and again around October 16th and October 21st. Between these periods, the ENT concentration in the surf zone was generally low (<10 MPN/100 mL). Station Tuna, located at the north-east edge of the study area, had chronically high concentrations of TC and low concentrations of ENT and EC.

Correlations between the daily log-mean fecal indicator bacteria concentrations and number of visitors, tide range, and littoral drift speed were not strong. In addition, there appears to be no obvious relationship between fecal indicator bacteria concentrations and the presence of cruise ships or the direction of circulation within the Bay.

Interpretation and Implications.
As described in the research article written about these data (see Appendix), the concentrations of fecal indicator bacteria measured during the month-long daily sampling was highest at the Middle station (located near the Pleasure Pier), and tapered off both north and south of the Middle station. This spatial pattern is consistent with the results reported in Chapter 2 of this report, which was based on an analysis of six years of historical fecal indicator bacteria measurements in Avalon Bay. Further, TC/EC ratios computed from the daily month-long samples indicates that the TC/EC ratios are lowest at Middle and Pier stations, and increase north and south. These two observations—that the fecal indicator bacteria concentrations are highest and the TC/EC ratios are lowest in the vicinity of the Middle Station and Pleasure Pier—are consistent with the idea that this region of the shoreline is a source of fecal indicator bacteria pollution.

There is no evidence that the arrival of tourists on cruise ships, or on ferries, is correlated with high levels of fecal indicator bacteria in the Bay. Indeed, in several cases the concentration of fecal indicator bacteria were high when there were no cruise ships anchored outside of the Bay, and when the number of passengers disembarking at the Mole was low.

A higher frequency of water quality violations were observed for water samples collected from ankle deep water, compared to water samples collected from waist depth water. This result is consistent with the transect study described above (Section 4.A.2), which found that fecal indicator bacteria concentrations are highest in the very shallow (i.e., ankle-depth) waters along the shoreline.

Table 4.5. Results of twice-daily month-long sampling at the Channel sampling site (N33° 20.591', W118° 19.477').

Sample Type	Sampling Date and Time	[a]TC	[a]EC	TC/EC	[a]ENT	[b]Turbidity
ankle	9/25/01 18:39	6131	20	307	583	0.43
ankle	9/26/01 9:31	216	<10	N.D.	10	2.92
waist	9/26/01 9:32	419	10	42	10	2.3
ankle	9/26/01 18:20	N.D.	N.D.	N.D.	52	1.8
ankle	9/27/01 7:03	1	1	1	<10	1.5
waist	9/27/01 7:05	85	20	4	<10	2.6
ankle	9/27/01 19:16	314	1	314	30	1.32
ankle	9/28/01 6:22	337	181	1.9	<10	2.7
waist	9/28/01 6:24	228	185	1.2	<10	2.45
ankle	9/28/01 19:02	41	1	41	<10	1.15
ankle	9/29/01 7:37	63	10	6.3	<10	0.93
waist	9/29/01 7:39	135	10	14	<10	2.98
ankle	9/29/01 17:48	404	275	1.5	1467	3.48
ankle	9/30/01 7:56	1222	10	122	31	1.47
waist	9/30/01 7:58	134	1	134	<10	0.8
ankle	9/30/01 17:40	359	231	1.6	84	2.5
ankle	10/1/01 7:21	405	106	3.8	134	2.7

waist	10/1/01 7:22	520	97	5.4	97	2.62
ankle	10/1/01 18:10	318	120	2.7	345	3.11
ankle	10/2/01 7:52	98	52	1.9	<10	2.44
waist	10/2/01 7:53	122	52	2.3	<10	3.95
ankle	10/2/01 18:11	1414	278	5	771	3.7
ankle	10/3/01 8:14	148	41	3.6	31	3.71
waist	10/3/01 8:16	109	41	2.7	63	3.17
ankle	10/3/01 18:00	41	10	4.1	<10	1.35
ankle	10/4/01 8:05	1420	98	14.5	20	3.45
waist	10/4/01 8:07	860	74	11.6	<10	2.94
ankle	10/4/01 18:06	10	<10	>1	10	1.1
ankle	10/5/01 11:21	240	10	24.0	<10	1.58
waist	10/5/01 11:22	210	20	10.5	<10	1.1
ankle	10/5/01 18:12	41	10	4.1	<10	1.68
ankle	10/6/01 8:14	404	74	5.5	<10	1.87
waist	10/6/01 8:15	426	41	10.4	41	1.4
ankle	10/6/01 18:20	161	31	5.2	10	1.47
ankle	10/7/01 7:30	504	457	1.1	41	2.42
waist	10/7/01 7:31	313	278	1.1	10	1.39
ankle	10/7/01 18:25	201	<10	>20	31	2.24
ankle	10/8/01 7:33	110	31	3.5	<10	1.64
waist	10/8/01 7:35	98	20	4.9	10	1.75
ankle	10/8/01 18:39	31	31	1.0	31	2.07
ankle	10/9/01 7:45	109	52	2.1	<10	1.02
waist	10/9/01 7:47	73	<10	>7.3	<10	0.89
ankle	10/8/01 18:03	135	10	13.5	20	3.6
ankle	10/10/01 8:11	185	30	6.2	<10	2.59
waist	10/10/01 8:12	246	20	12.3	<10	2.09
ankle	10/10/01 18:27	248	96	2.6	41	2.24
ankle	10/11/01 8:19	41	<10	>4.1	10	1.63
waist	10/11/01 8:20	278	110	2.5	<10	2.04
ankle	10/11/01 18:15	305	74	4.1	<10	1.42
ankle	10/12/01 8:00	N.D.	N.D.	N.D.	<10	1.85
waist	10/12/01 8:01	N.D.	N.D.	N.D.	<10	1.09
ankle	10/14/01 17:42	223	209	1.1	135	3.54
ankle	10/15/01 8:24	20	<10	>2	<10	1.31
waist	10/15/01 8:26	63	<10	>6.3	<10	0.92
ankle	10/15/01 18:41	4884	631	7.7	187	4.44
ankle	10/16/01 8:24	41	<10	>4.1	<10	1.59
waist	10/16/01 8:25	86	20	4.3	<10	1.63
ankle	10/17/01 17:40	189	63	3.0	10	2.82
ankle	10/17/01 8:42	52	<10	>5.2	<10	1.25
waist	10/17/01 8:43	20	<10	>2	<10	1.19
ankle	10/17/01 18:27	30	30	1.0	<10	1.08
ankle	10/18/01 8:46	86	41	2.1	<10	1.79
waist	10/18/01 8:47	63	41	1.5	<10	0.97
ankle	10/18/01 17:32	10	<10	>1	20	1.27

ankle	10/19/01 8:06	135	31	4.4	<10	3.34
waist	10/19/01 8:07	203	10	20.3	20	2.9
ankle	10/19/01 18:15	41	10	4.1	<10	0.87
ankle	10/20/01 8:49	135	10	13.5	<10	2.07
waist	10/20/02 8:51	74	31	2.4	10	1.81
ankle	10/20/01 17:35	52	10	5.2	10	1.02

[a]Units of most probable number (MPN) per100 mL of sample.
[b]Units of nephelometric turbidity units (N TU)

Table 4.6. Results of twice-daily month long sampling at the South sampling site (N33° 20.600', W118° 19.497').

Sample Type	Sampling Date and Time	[a]TC	[a]EC	TC/EC	[a]ENT	[b]Turbidity
ankle	9/25/01 18:41	4611	31	149	481	2.79
ankle	9/26/01 9:29	120	10	12.0	>10	3
waist	9/26/01 9:29	189	20	9.5	10	2.52
ankle	9/26/01 18:22	563	97	5.8	135	3
ankle	9/27/01 7:07	63	20	3.2	<10	2.45
waist	9/27/01 7:08	74	20	3.7	<10	2.71
ankle	9/27/01 19:19	404	122	3.3	201	2.5
ankle	9/28/01 6:27	189	86	2.2	<10	3.1
waist	9/28/01 6:28	161	74	2.2	<10	2.7
ankle	9/28/01 19:04	108	20	5.4	226	4.5
ankle	9/29/01 7:42	146	20	7.3	10	3.82
waist	9/29/01 7:46	146	31	4.7	10	2.04
ankle	9/29/01 17:52	605	216	2.8	354	5.55
ankle	9/30/01 8:01	422	256	1.6	10	4.92
waist	9/30/01 8:02	211	97	2.2	10	2.55
ankle	9/30/01 17:43	335	218	1.5	161	4.25
ankle	10/1/01 7:25	581	97	6.0	41	3.45
waist	10/1/01 7:26	723	148	4.9	20	2.9
ankle	10/1/01 18:14	201	86	2.3	63	2.96
ankle	10/2/01 7:56	201	52	3.9	<10	3.9
waist	10/2/01 7:57	203	11	18.5	31	3.2
ankle	10/2/01 18:12	109	<10	>109	41	1.94
ankle	10/3/01 8:19	327	231	1.4	<10	2.82
waist	10/3/01 8:20	213	120	1.8	31	3.02
ankle	10/3/01 18:02	31	31	1.0	<10	1.19
ankle	10/4/01 8:09	419	85	4.9	10	3.4
waist	10/4/01 8:10	435	41	10.6	<10	1.74
ankle	10/4/01 18:07	20	<10	>2	20	1.05
ankle	10/5/01 11:24	259	98	2.6	10	3
waist	10/5/01 11:25	110	20	5.5	<10	1.37
ankle	10/5/01 18:14	109	52	2.1	31	2.15
ankle	10/6/01 8:18	231	63	3.7	52	3.02
waist	10/6/01 8:19	350	109	3.2	41	2.67
ankle	10/6/01 18:21	332	<10	>33.2	20	2.14
ankle	10/7/01 7:34	122	98	1.2	20	1.69

waist	10/7/01 7:35	249	218	1.1	<10	1.69
ankle	10/7/01 18:27	738	<10	>73.8	<10	1.24
ankle	10/8/01 7:38	146	63	2.3	20	1.34
waist	10/8/01 7:40	171	73	2.3	<10	1.71
ankle	10/8/01 18:40	107	96	1.1	10	1.97
ankle	10/9/01 7:52	235	132	1.8	10	1.52
waist	10/9/01 7:56	146	74	2.0	20	1.79
ankle	10/8/01 18:05	85	10	8.5	20	2.75
ankle	10/10/01 8:14	199	<10	>20	10	5.23
waist	10/10/01 8:15	246	20	12.3	10	4.97
ankle	10/10/01 18:30	288	175	1.6	10	2.41
ankle	10/11/01 8:23	86	10	8.6	<10	3.03
waist	10/11/01 8:25	132	30	4.4	10	2.7
ankle	10/11/01 18:17	311	155	2.0	10	5.04
ankle	10/12/01 8:04	N.D.	N.D.	N.D.	<10	3.73
waist	10/12/01 8:05	N.D.	N.D.	N.D.	<10	2.6
ankle	10/14/01 17:43	52	31	1.7	98	3
ankle	10/15/01 8:26	63	10	6.3	10	2.47
waist	10/15/01 8:29	63	<10	>6.3	20	2.32
ankle	10/15/01 18:43	201	97	2.1	52	6.21
ankle	10/16/01 8:27	171	<10	>17.1	20	5.12
waist	10/17/01 8:28	156	30	5.2	<10	7.56
ankle	10/17/01 17:41	146	41	3.6	<10	2.09
ankle	10/17/01 8:45	63	41	1.5	<10	2.15
waist	10/17/01 8:46	74	52	1.4	10	1.89
ankle	10/17/01 18:29	74	20	3.7	<10	0.8
ankle	10/18/01 8:49	327	158	2.1	10	2.37
waist	10/18/01 8:50	776	631	1.2	<10	3.5
ankle	10/18/01 17:34	10	10	1.0	<10	0.53
ankle	10/19/01 8:09	52	20	2.6	<10	2.19
waist	10/19/01 8:10	74	63	1.2	10	1.33
ankle	10/19/01 18:15	63	10	6.3	<10	0.81
ankle	10/20/01 8:52	399	288	1.4	161	3.44
waist	10/20/01 8:54	231	52	4.4	52	2.41
ankle	10/20/01 17:35	41	<10	>4.1	<10	1.16
ankle		<10	<10	N.D.	N.D.	0.97

[a]Units of most probable number (MPN) per100 mL of sample.
[b]Units of nephelometric turbidity units (NTU)

Table 4.7. Results of twice-daily month long sampling at the Pier sampling site (N33^o 20.620', W118^o 19.513').

Sample Type	Sampling Date and Time	[a]TC	[a]EC	TC/EC	[a]ENT	[b]Turbidity
ankle	9/25/01 19:15	546	62	9	63	1.81
ankle	9/26/01 9:15	226	10	23	10	1.7
waist	9/26/01 9:16	199	31	6	20	1.51
ankle	9/26/01 18:29	369	98	4	30	3.38

ankle	9/27/01 7:11	121	30	4	10	0.76
waist	9/27/01 7:12	52	<10	>52	20	0.47
ankle	9/27/01 19:30	313	121	3	10	1.58
ankle	9/28/01 6:31	259	85	3	<10	2.26
waist	9/28/01 6:33	187	74	3	20	2.47
ankle	9/28/01 19:09	285	85	3	52	2.7
ankle	9/29/01 7:50	199	41	5	<10	1.43
waist	9/29/01 7:52	148	41	4	10	2.23
ankle	9/29/01 17:58	1106	318	3	265	4.5
ankle	9/30/01 8:05	197	84	2	10	2.23
waist	9/30/01 8:06	309	109	3	<10	1.68
ankle	9/30/01 17:46	798	703	1	41	2.75
ankle	10/1/01 7:29	1585	364	4	41	3.39
waist	10/1/01 7:30	1036	327	3	51	2.59
ankle	10/1/01 18:22	199	20	10	<10	4.45
ankle	10/2/01 8:00	561	393	1	63	2.6
waist	10/2/01 8:02	428	173	2	73	2.5
ankle	10/2/01 18:15	364	134	3	41	3.33
ankle	10/3/01 8:23	350	314	1	31	2.12
waist	10/3/01 8:25	419	305	1	10	2.09
ankle	10/3/01 18:05	122	63	1.9	<10	1.25
ankle	10/4/01 8:13	203	52	3.9	20	1.29
waist	10/4/01 8:14	143	52	2.8	31	0.89
ankle	10/4/01 18:21	110	20	5.5	41	1.65
ankle	10/5/01 11:27	189	31	6.1	10	1.12
waist	10/5/01 11:28	158	41	3.9	<10	0.66
ankle	10/5/01 18:16	63	52	1.2	10	1.08
ankle	10/6/01 8:23	393	364	1.1	41	3.87
waist	10/6/01 8:24	579	512	1.1	31	2.62
ankle	10/6/01 18:23	120	<10	>12	20	1.33
ankle	10/7/01 7:38	262	109	2.4	10	1.45
waist	10/7/01 7:39	250	168	1.5	10	1.9
ankle	10/7/01 18:30	221	73	3.0	20	1.6
ankle	10/8/01 7:45	245	110	2.2	<10	30.8
waist	10/8/01 7:46	228	109	2.1	<10	1.15
ankle	10/8/01 18:42	122	98	1.2	10	1.27
ankle	10/9/01 8:01	250	155	1.6	20	1.9
waist	10/9/01 8:03	216	121	1.8	20	1.5
ankle	10/8/01 18:16	161	148	1.1	10	4.21
ankle	10/10/01 8:17	512	110	4.7	<10	3.84
waist	10/10/01 8:19	798	132	6.0	63	2.92
ankle	10/10/01 18:32	135	41	3.3	20	2.67
ankle	10/11/01 8:29	106	20	5.3	20	1.38
waist	10/11/01 8:30	63	<10	>6.3	10	1.4
ankle	10/11/01 18:24	148	52	2.8	10	1.93
ankle	10/12/01 8:09	N.D.	N.D.	N.D.	<10	2.39
waist	10/12/01 8:10	N.D.	N.D.	N.D.	10	2.79

ankle	10/14/01 17:47	135	31	4.4	41	3.86
ankle	10/15/01 8:32	63	<10	>6.3	<10	2.27
waist	10/15/01 8:39	86	20	4.3	<10	3.13
ankle	10/15/01 18:50	85	10	8.5	<10	5.6
ankle	10/17/01 8:32	85	<10	>8.5	10	2.82
waist	10/17/01 8:34	110	20	5.5	10	2.75
ankle	10/17/01 17:47	122	41	3.0	<10	3
ankle	10/17/01 8:48	86	74	1.2	<10	1.21
waist	10/17/01 8:49	143	131	1.1	<10	1.44
ankle	10/17/01 18:33	6867	6488	1.1	<10	0.6
ankle	10/18/01 8:53	189	135	1.4	<10	0.83
waist	10/18/01 8:54	295	160	1.8	<10	0.42
ankle	10/18/01 17:39	95	72	1.3	<10	1.1
ankle	10/19/01 8:13	41	31	1.3	<10	1.05
waist	10/19/01 8:15	98	63	1.6	10	1.08
ankle	10/19/01 18:20	110	52	2.1	31	1.31
ankle	10/20/01 8:57	388	145	2.7	10	1.25
waist	10/20/01 8:58	441	146	3.0	10	0.92
ankle	10/20/01 17:43	40	30	1.3	52	2.42

[a]Units of most probable number (MPN) per100 mL of sample.
[b]Units of nephelometric turbidity units (N TU)

Table 4.8. Results of twice-daily month long sampling at the Middle sampling site (N33° 20.628', W118° 19.527').

Sample Type	Sampling Date and Time	[a]TC	[a]EC	TC/EC	[a]ENT	[b]Turbidity
ankle	9/25/01 19:25	547	233	2	171	3.32
ankle	9/26/01 9:10	146	41	4	20	2.3
waist	9/26/01 9:11	85	52	2	20	1.36
ankle	9/26/01 18:20	743	354	2	305	3.3
ankle	9/27/01 7:14	74	10	7	10	5.15
waist	9/27/01 7:15	85	20	4	<10	0.8
ankle	9/27/01 19:32	1354	573	2	318	4.18
ankle	9/28/01 6:35	195	20	10	<10	1.12
waist	9/28/01 6:37	305	41	7	52	1.68
ankle	9/28/01 19:11	410	86	5	85	4.7
ankle	9/29/01 7:54	327	74	4	10	2.65
waist	9/29/01 7:56	221	41	5	10	1.68
ankle	9/29/01 17:59	269	95	3	62	3.48
ankle	9/30/01 8:08	336	51	7	10	1.46
waist	9/30/01 8:09	281	63	4	10	0.68
ankle	9/30/01 17:47	359	74	5	256	1.9
ankle	10/1/01 7:32	3609	581	6	135	1.81
waist	10/1/01 7:34	3448	341	10	84	3.2
ankle	10/1/01 18:24	253	181	1	41	2.05
ankle	10/2/01 8:05	933	209	4	85	2.12
waist	10/2/01 8:06	884	175	5	85	2.03
ankle	10/2/01 18:17	107	10	11	10	3.26

ankle	10/3/01 8:28	327	228	1	52	2.09
waist	10/3/01 8:29	295	233	1	41	1.35
ankle	10/3/01 18:08	171	120	1.4	<10	2.46
ankle	10/4/01 8:17	189	10	18.9	31	0.83
waist	10/4/01 8:18	135	10	13.5	20	0.85
ankle	10/4/01 18:25	31	10	3.1	10	1.23
ankle	10/5/01 11:30	435	282	1.5	109	2.5
waist	10/5/01 11:31	487	313	1.6	72	1.96
ankle	10/5/01 18:18	131	41	3.2	20	2.31
ankle	10/6/01 8:26	379	323	1.2	20	2.14
waist	10/6/01 8:28	457	359	1.3	10	1.97
ankle	10/6/01 18:24	512	41	12.5	41	1.55
ankle	10/7/01 7:40	377	85	4.4	10	2.1
waist	10/7/01 7:41	238	52	4.6	31	1.69
ankle	10/7/01 18:32	231	63	3.7	20	2.64
ankle	10/8/01 7:48	265	41	6.5	<10	1.21
waist	10/8/01 7:50	203	<10	>20.3	10	1.23
ankle	10/8/01 18:43	31	10	3.1	<10	1.49
ankle	10/9/01 8:04	299	161	1.9	30	2.6
waist	10/9/01 8:05	441	187	2.4	31	2.93
ankle	10/8/01 18:18	185	63	2.9	<10	3
ankle	10/10/01 8:21	554	134	4.1	10	3.18
waist	10/10/01 8:22	1850	399	4.6	20	2.39
ankle	10/10/01 18:33	132	20	6.6	10	3.11
ankle	10/11/01 8:31	173	30	5.8	<10	2.14
waist	10/11/01 8:33	195	52	3.8	30	2.33
ankle	10/11/01 18:28	489	233	2.1	52	3.78
ankle	10/12/01 8:12	N.D.	N.D.	N.D.	135	4.99
waist	10/12/01 8:13	N.D.	N.D.	N.D.	546	5.48
ankle	10/14/01 17:50	183	52	3.5	74	6.37
ankle	10/15/01	143	20	7.2	<10	3.1
ankle	10/15/01 18:54	148	122	1.2	<10	2.42
ankle	10/17/01 8:37	145	30	4.8	10	30.7
waist	10/17/01 8:38	97	10	9.7	<10	2.69
ankle	10/17/01 17:50	20	<10	>2	<10	1.15
ankle	10/17/01 8:53	134	63	2.1	10	1.57
waist	10/17/01 8:54	63	30	2.1	10	1.5
ankle	10/17/01 18:37	63	10	6.3	<10	0.6
ankle	10/18/01 8:57	1100	1100	1.0	<10	2.42
waist	10/18/01 8:58	857	833	1.0	<10	2.72
ankle	10/18/01 17:43	41	31	1.3	<10	0.63
ankle	10/19/01 8:16	74	20	3.7	<10	0.92
waist	10/19/01 8:17	109	31	3.5	<10	0.8
ankle	10/19/01 18:23	63	52	1.2	<10	0.78
ankle	10/20/01 8:59	554	148	3.7	134	1.56
waist	10/20/01 9:00	763	211	3.6	41	1.04
ankle	10/20/01 17:45	110	<10	>11	31	1.9

[a]Units of most probable number (MPN) per100 mL of sample.

[b]Units of nephelometric turbidity units (N TU)

Table 4.9. Results of twice-daily month long sampling at the Busy Bee sampling site (N33° 20.638', W118° 19.541').

Sample Type	Sampling Date and Time	[a]TC	[a]EC	TC/EC	[a]ENT	[b]Turbidity
ankle	9/25/01 19:30	278	135	2	187	2.2
ankle	9/26/01 9:06	110	20	6	>10	1.46
waist	9/26/01 9:05	143	10	14	>10	1.05
ankle	9/26/01 18:32	122	74	2	N.D.	1.75
ankle	9/27/01 7:17	132	10	13	10	1.05
waist	9/27/01 7:19	109	30	4	10	0.81
ankle	9/27/01 19:35	573	143	4	41	1.93
ankle	9/28/01 6:39	419	84	5	52	1.58
waist	9/28/01 6:42	408	86	5	20	3.04
ankle	9/28/01 19:13	880	335	3	86	2.98
ankle	9/29/01 8:00	328	52	6	10	1.37
waist	9/29/01 8:02	336	31	11	<10	1.55
ankle	9/29/01 18:02	173	10	17	31	2.98
ankle	9/30/01 8:12	195	41	5	20	1.02
waist	9/30/01 8:13	305	41	7	20	1.17
ankle	9/30/01 17:48	187	86	2	85	1.32
ankle	10/1/01 7:37	3654	546	7	41	1.7
waist	10/1/01 7:39	3784	459	8	74	2.01
ankle	10/1/01 18:25	1374	301	5	336	3.27
ankle	10/2/01 8:09	402	142	3	143	1.79
waist	10/2/01 8:12	1658	122	14	98	2.09
ankle	10/3/01 8:32	282	175	2	10	1.62
waist	10/3/01 8:33	243	213	1	<10	1.26
ankle	10/3/01 18:09	265	86	3.1	31	2.2
ankle	10/4/01 8:21	457	31	14.7	51	1.54
waist	10/4/01 8:23	368	30	12.3	<10	1.13
ankle	10/4/01 18:28	<10	<10	N.D.	10	1
ankle	10/5/01 11:34	345	145	2.4	181	2.07
waist	10/5/01 11:35	259	121	2.1	121	1.67
ankle	10/5/01 18:19	120	41	2.9	10	1.73
ankle	10/6/01 8:33	328	272	1.2	41	2.52
waist	10/6/01 8:35	384	384	1.0	10	2.06
ankle	10/6/01 18:25	121	<10	>12.1	52	1.63
ankle	10/7/01 7:43	1046	134	7.8	30	1.71
waist	10/7/01 7:45	988	148	6.7	86	1.8
ankle	10/7/01 18:33	146	<10	>14.6	<10	1.56
ankle	10/8/01 7:52	298	10	29.8	<10	1
waist	10/8/01 7:54	233	10	23.3	<10	0.71
ankle	10/8/01 18:44	52	10	5.2	<10	0.79
ankle	10/9/01 8:07	318	240	1.3	10	1.43
waist	10/9/01 8:12	441	305	1.4	20	1.48
ankle	10/8/01 18:20	601	110	5.5	31	4.43

ankle	10/10/01 8:24	988	30	32.9	10	1.36
waist	10/10/01 8:25	1354	31	43.7	10	0.84
ankle	10/10/01 18:34	132	20	6.6	<10	1.8
ankle	10/11/01 7:42	203	110	1.8	10	1.35
waist	10/11/01 7:43	496	231	2.1	<10	1.4
ankle	10/11/01 18:29	537	63	8.5	41	2.14
ankle	10/12/01 8:15	N.D.	N.D.	N.D.	<10	2.2
waist	10/12/01 8:16	N.D.	N.D.	N.D.	262	3.43
ankle	10/14/01 17:53	110	10	11.0	<10	4.7
ankle	10/15/01 8:41	63	10	6.3	10	2.38
waist	10/15/01 8:43	84	10	8.4	10	1.57
ankle	10/15/01 18:56	132	20	6.6	20	3.45
ankle	10/17/01 8:40	74	10	7.4	10	2.22
waist	10/17/01 8:41	85	<10	>8.5	10	1.89
ankle	10/17/01 17:51	41	<10	>4.1	<10	1.32
ankle	10/17/01 8:57	121	41	3.0	10	1.1
waist	10/17/01 8:59	52	20	2.6	10	0.71
ankle	10/17/01 18:41	41	10	4.1	<10	0.54
ankle	10/18/01 9:00	97	52	1.9	<10	0.82
waist	10/18/01 9:01	85	74	1.1	<10	0.99
ankle	10/18/01 17:45	52	31	1.7	10	0.6
ankle	10/19/01 8:19	122	10	12.2	10	2
waist	10/19/01 8:21	122	31	3.9	20	1.39
ankle	10/19/01 18:24	74	20	3.7	20	1
ankle	10/20/01 9:02	1722	269	6.4	<10	0.59
waist	10/20/01 9:03	1233	197	6.3	41	1.08
ankle	10/20/01 17:47	41	<10	>4.1	98	1.49
ankle	??	108	<10	>10.8	N.D.	1.03

[a]Units of most probable number (MPN) per100 mL of sample.
[b]Units of nephelometric turbidity units (N TU)

Table 4.10. Results of twice-daily month long sampling at the Tuna sampling site (N33° 20.716', W118° 19.606').

Sample Type	Sampling Date and Time	[a]TC	[a]EC	TC/EC	[a]ENT	[b]Turbidity
ankle	9/25/01 19:50	30	10	3	31	0.5
ankle	9/26/01 8:57	110	<10	>110	>10	0.2
waist	9/26/01 8:59	135	10	14	10	0.31
ankle	9/26/01 18:36	97	52	2	<10	0.8
ankle	9/27/01 7:23	156	40	4	<10	0.18
waist	9/27/01 7:24	63	<10	>63	<10	0.25
ankle	9/27/01 19:40	240	<10	>240	<10	0.47
ankle	9/28/01 6:47	110	31	4	<10	0.6
waist	9/28/01 6:48	231	121	2	20	0.46
ankle	9/28/01 19:19	404	63	6	<10	1.09
ankle	9/29/01 8:10	132	31	4	<10	0.31
waist	9/29/01 8:11	110	10	11	10	0.35
ankle	9/29/01 18:05	1576	368	4	20	1.19

ankle	9/30/01 8:17	295	97	3	10	0.5
waist	9/30/01 8:18	216	52	4	<10	0.16
ankle	9/30/01 17:53	318	41	8	<10	0.53
ankle	10/1/01 7:43	272	41	7	20	0.6
waist	10/1/01 7:43	228	<10	>228	<10	1.25
ankle	10/1/01 18:31	160	31	5	<10	0.54
ankle	10/2/01 8:16	512	31	17	<10	1.86
waist	10/2/01 8:17	384	74	5	10	1.79
ankle	10/2/01 18:27	563	108	5	31	1.56
ankle	10/3/01 8:39	457	31	15	10	0.46
waist	10/3/01 8:39	364	20	18	<10	0.8
ankle	10/3/01 18:15	211	41	5	10	1.4
ankle	10/4/01 8:27	1259	74	17.0	41	0.83
waist	10/4/01 8:27	1187	86	13.8	10	0.64
ankle	10/4/01 18:35	288	20	14.4	<10	0.82
ankle	10/5/01 11:39	246	52	4.7	10	0.16
waist	10/5/01 10:39	169	52	3.3	10	0.24
ankle	10/5/01 18:21	231	41	5.6	41	1.04
ankle	10/6/01 8:40	2046	332	6.2	31	0.48
waist	10/6/01 8:41	1664	288	5.8	41	0.45
ankle	10/6/01 18:30	63	10	6.3	121	1.23
ankle	10/7/01 7:52	373	185	2.0	<10	0.39
waist	10/7/01 7:52	341	204	1.7	<10	0.37
ankle	10/7/01 18:37	1722	140	12.3	135	1.7
ankle	10/8/01 8:01	52	<10	>5.2	<10	0.32
waist	10/8/01 8:02	110	20	5.5	<10	0.67
ankle	10/8/01 18:49	275	<10	>27.5	<10	0.63
ankle	10/9/01 8:18	256	110	2.3	10	0.75
waist	10/9/01 8:19	341	134	2.5	10	0.47
ankle	10/10/01 8:30	20	<10	>2	<10	1.19
waist	10/10/01 8:30	63	31	2.0	<10	0.42
ankle	10/10/01 18:39	8.1	30.7	0.3	0.69	20
ankle	10/11/01 8:39	175	20	8.8	10	0.4
waist	10/11/01 8:40	63	<10	>6.3	30	0.38
ankle	10/11/01 18:35	581	10	58.1	<10	0.44
ankle	10/12/01 8:22	N.D.	N.D.	N.D.	20	0.81
waist	10/12/01 8:23	N.D.	N.D.	N.D.	<10	0.58
ankle	10/14/01 18:00	379	52	7.3	10	0.83
ankle	10/15/01 8:50	487	20	24.4	<10	0.34
waist	10/15/01 8:51	683	30	22.8	<10	0.32
ankle	10/15/01 19:05	368	20	18.4	30	1.01
ankle	10/17/01 8:48	63	10	6.3	<10	0.75
waist	10/17/01 8:48	74	<10	>7.4	<10	0.23
ankle	10/17/01 17:58	193	30	6.4	<10	1.17
ankle	10/17/01 9:04	85	10	8.5	<10	0.27
waist	10/17/01 9:04	63	<10	>6.3	<10	0.2
ankle	10/17/01 18:50	464	63	7.4	10	1.97

ankle	10/18/01 9:07	10	<10	>1	<10	0.2
waist	10/18/01 9:08	31	<10	>3.1	<10	0.25
ankle	10/18/01 17:52	1112	216	5.1	86	2.46
ankle	10/19/01 8:25	41	<10	>4.1	<10	0.14
waist	10/19/01 8:26	72	<10	>7.2	<10	0.82
ankle	10/19/01 18:32	763	84	9.1	41	2.25
ankle	10/20/01 9:06	231	86	2.7	132	0.39
waist	10/20/01 9:06	110	<10	>1	<10	0.26
ankle	10/20/01 17:55	368	<10	>36.8	10	1

[a]Units of most probable number (MPN) per100 mL of sample.
[b]Units of nephelometric turbidity units (N TU)

4.A.5. Tier 1: Month-Long, Twice Daily, Groundwater Sampling

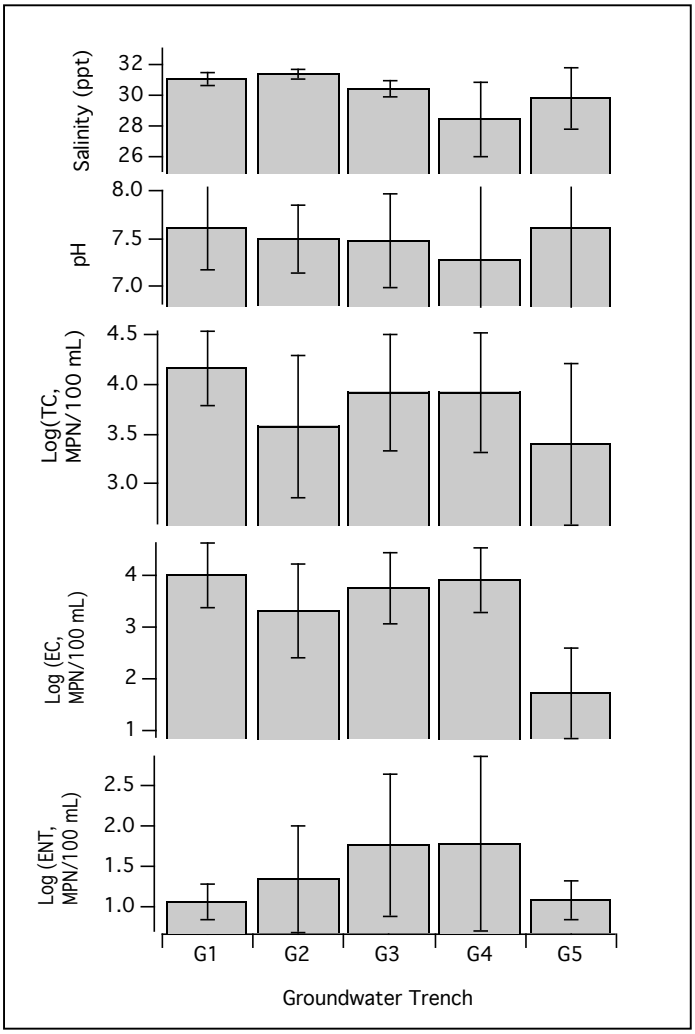

Figure 4.7. Water quality of shallow groundwater. Bars represent the average (or log-mean) of salinity, pH, ENT, EC, and TC. Error bars represent one standard deviation.

Objective

To determine day-to-day changes in the concentration of indicator bacteria in the shallow groundwater beneath the downtown area of Avalon over a period of one month.

Methods

City personnel used a backhoe to dig five trenches located north-east and south-west of the Pleasure Pier (black triangles, lower right panel of Figure 4.1). The trenches were approximately 1.5 m deep, and located approximately 10 m inland of the surf zone. From 9/25/01 until 10/20/01, groundwater samples were collected daily, placed on ice, and transported to the Mole where they were analyzed for fecal indicator bacteria (TC, EC, and ENT), turbidity, pH, and salinity following procedures outlined in the QAPP. Some groundwater samples were missed due to insufficient water in the trench; in addition, several of the trenches were filled in during a portion of the study.

Findings.
Tables 4.11 through 4.15 summarize the data collected during the month-long study, including the collection date and time, concentration of TC, EC, and ENT in MPN per 100 mL, turbidity, salinity, and pH. Of the 88 ground water samples collected, 45 (51%) exceeded the single-sample standard for TC, 63 (72%) exceeded the single-sample standard for FC, and 17 (19%) exceeded the single-sample standard for ENT. Groundwater sampling sites G1, G2, G3, and G4 all had consistently high concentrations of TC and EC. Sites G1 and G5 had very low concentrations of ENT; the concentration of ENT at all other sites was sporadically high.

Figure 4.7 is a graphical representation of the shallow ground water data. Very high concentrations of TC and EC were measured in all of the groundwater trenches during the month-long study. Very frequently the concentration of these two indicator bacteria exceeded the upper detection limit of 24,192 MPN/100 mL. There is not a significant correlation between the concentration of TC and EC measured in the trenches and either tide stage (ebb or flood) nor tide range (spring or neap) (data not shown).

Overall, the concentration of ENT was highest in trenches G3 and G4, and lower in the other trenches (G1, G2, and G5). Interestingly, the salinity and pH in trench G4 was relatively low compared to the other trench sites. This low salinity signal likely reflects the subsurface mixing of saltwater (from the ocean) and a source of freshwater from natural and/or human (e.g., sewer main leaks, runoff infiltration, etc) sources.

Interpretation and Implications
The shallow groundwater underneath the City of Avalon is strongly influenced by the tidal intrusion of oceanwater. Evidence includes:

1) The research team observed that the water level in the trenches was highly correlated with tide stage. As the tide rises, so does the water level in the trenches.

2) The salinity of groundwater is very close to that of seawater (32 ppt, see Tables 4.11 through 4.15). Therefore, groundwater beneath downtown Avalon consists primarily of infiltrated ocean water. The possible exception is trench G4 (near the Pleasure Pier) which had lower salinity and pH, compared to the other trenches, and hence is likely a mixture of oceanwater and a source of low salinity –low pH water.

The nature of groundwater flow in the downtown area, and the full extent of the shallow groundwater contamination, were not characterized because these issues fell outside of the scope of the current study. However, there are several reasons to suspect that leaking sewer lines may contribute to the observed fecal indicator bacteria concentrations in the shallow groundwater:

1) An earlier study conducted in 1993 found that approximately 36% of the average daily wastewater flow into the local sewage treatment plant originated from base inflow and infiltration into the sewage collection system, a large portion of which is probably

groundwater infiltration. If groundwater infiltrates into the sewage collection system, it is possible that untreated sewage contaminates the surrounding groundwater.

2) After the 1993 study, approximately 30 m of the sewage collection system was slip-lined in the downtown area (between the downtown fountain and the Pleasure Pier). The base inflow into the sewage treatment plant apparently reduced after this slip-lining project, consistent with the idea that a significant portion of the base inflow originated from groundwater infiltration.

3) During the month-long survey (from 9/25 through 10/20/01) carried out as part of the current investigation, very high concentrations of fecal indicator bacteria were measured at all groundwater sampling locations in the downtown area, particularly at sites G3 and G4.

Based on the foregoing discussion, it is possible that a portion of the fecal indicator bacteria signal in Avalon Bay originates from the exfiltration of sewage and/or nuisance runoff contaminated groundwater. As of the writing of this report, the City continues to retrofit the sewage collection infrastructure in downtown Avalon. This project should ultimately reduce the input of fecal pollution into the shallow groundwater, and presumably improve shoreline water quality in Avalon Bay (although the latter has not yet occurred, according to the analysis in Chapter 3 of this report). It is recommended that a follow up study be carried out to determine if contaminant levels in the groundwater and surf zone are reduced following the completion of the retrofit project, and possibly to develop strategies to characterize and remediate sewage contamination in the shallow groundwater under downtown Avalon.

Table 4.11. Results of daily month long sampling at the shallow groundwater trench G1 (N33^o 20.6 W118^o 19.499')

Sampling Date and Time	[a]TC	[a]EC	TC/EC[c]	[a]ENT	Salinity (ppt)	[b]Turbidity	pH
9/25/01 18:46	>24192	15531	N.D.	10	31.6	50.2	7.81
9/26/01 18:18	9870	100	98.7	100	31.7	8.25	7.79
9/27/01 19:13	>24192	11199	N.D.	10	31.9	45.6	7.79
9/28/01 19:00	>24192	>24192	N.D.	20	31	145	7.73
10/5/01 12:41	2359	1793	1.3	10	31.1	13	7.8
10/6/01 12:26	4884	3654	1.3	10	31.1	8.9	7.72
10/7/01 12:59	2481	2481	1	10	31.1	4.73	7.8
10/8/01 13:34	2613	1872	1.4	10	31.1	6.09	7.77
10/9/01 12:47	>24192	>24192	N.D.	10	31.3	140	7.31
10/10/01 16:09	>24192	>24192	N.D.	10	31	10.5	7.24
10/11/01 18:14	>24192	>24192	N.D.	10	30.9	17.5	7.31
10/14/01 17:40	>24192	>24192	N.D.	10	30.6	4.6	7.54
10/15/01 18:40	>24192	24192	N.D.	10	30.1	4.75	7.59
10/18/01 08:45	19863	8664	2.3	10	30.8	5.87	7.49
10/19/01 08:04	14136	7270	1.9	10	30.7	3.12	7.45
10/20/01 08:48	>24192	>24192	N.D.	10	30.9	2.67	7.52

[a]Units of most probable number (MPN) per100 mL of sample.
[b]Units of nephelometric turbidity units (NTTU)

Table 4.12. Results of daily month long sampling at the shallow groundwater trench G2.

Sampling Date and Time	[a]TC	[a]EC	TC/EC[c]	[a]ENT	Salinity (ppt)	[b]Turbidity	pH
9/25/01 19:05	9208	9208	1	10	31.9	30.1	7.63
9/26/01 18:23	100	100	1	100	31.8	8.8	7.65
9/27/01 19:21	1669	1210	1.37934	10	32	12.9	7.65
10/5/01 12:42	2909	457	6.36543	20	31.2	26.2	7.69
10/6/01 12:28	10462	2143	4.88194	61	31.2	24.6	7.59
10/7/01 13:01	2247	1872	1.20032	10	30.6	12.9	7.74
10/8/01 13:37	>24192	>24192	N.D.	3448	31	448	7.75
10/10/01 16:13	>24192	>24192	N.D.	108			
10/11/01 18:19	>24192	>24192	N.D.	193	31.3	325	7.15
10/14/01 17:44	>24192	>24192	N.D.	10	31.3	8.3	7.41
10/15/01 18:46	17329	17329	1	10	31.2	7.89	7.43
10/16/01 17:42	>24192	>24192	N.D.	10	31.2	6.67	7.35
10/17/01 18:31	12997	9208	1.41149	10	31.2	4.39	7.34
10/18/01 17:36	4360	1658	2.62967	10	31.3	3.32	7.3
10/19/01 18:18	2602	1401	1.85724	10	31.3	2.51	7.39
10/20/01 17:38	663	191	3.4712	10	31.4	2.82	7.37

[a]Units of most probable number (MPN) per100 mL of sample.
[b]Units of nephelometric turbidity units (NTU)
[c]N.D., not determined

Table 4.13. Results of daily sampling at trench G3 (N33° 20.582' W118° 19.466').

Sampling Date and Time	[a]TC	[a]EC	TC/EC[c]	[a]ENT	Salinity (ppt)	[b]Turbidity	pH
9/25/01 19:10	2613	1354	1.92984	2247	29.6	125	7.58
9/26/01 18:27	100	100	1	100	29.1	210	7.51
9/28/01 19:08	17329	17329	1	1112			
10/5/01 12:45	1892	1674	1.13023	97	30.2	2.84	7.61
10/6/01 12:31	8146	6131	1.32866	676	29.9	14	7.46
10/7/01 13:04	3873	2909	1.33139	272	30.2	5.7	7.51
10/8/01 13:39				1010	30.3	968	7.35
10/9/01 12:52	>24192	>24192	N.D.	670	30.3	68.3	7.62
10/10/01 16:16	>24192	>24192	N.D.	265	30.8	9.3	7.17
10/11/01 18:26	>24192	>24192	N.D.	20	30.8	32.8	7.35
10/14/01 17:48	>24192	>24192	N.D.	10	30.7	5.29	7.55
10/15/01 18:52	>24192	>24192	N.D.	10	30.8	30.1	7.51
10/16/01 17:48	>24192	>24192	N.D.	10	30.6	4.8	7.53
10/17/01 18:35	>24192	>24192	N.D.	10	30.7	3.59	7.49
10/18/01 17:41	15531	8164	1.90238	10	30.7	4.96	7.43
10/19/01 18:21	3130	1989	1.57366	10	30.7	7.51	7.59
10/20/01 17:44	7701	1793	4.29504	10	30.7	7.06	7.42

[a]Units of most probable number (MPN) per100 mL of sample.
[b]Units of nephelometric turbidity units (NTU)
[c]N.D., not determined

Table 4.14. Results of daily month long sampling at the shallow groundwater trench G4 (N33^o 20.602' W118^o 19.502').

Sampling Date and Time	[a]TC	[a]EC	TC/EC[c]	[a]ENT	Salinity (ppt)	[b]Turbidity	pH
9/25/01 19:40	15531	15531	1	108	31.2	29.5	7.25
9/26/01 18:33	100	100	1	100	30.9	22	7.27
9/27/01 19:37	3076	2909	1.05741	382	31.1	16	7.31
10/1/01 18:28	>24192	>24192	N.D.	198	29.9	59	7.12
10/2/01 18:23	>24192	>24192	N.D.	24192	22.3	0.03	7.17
10/3/01 18:10	>24192	>24192	N.D.	24192			
10/5/01 12:48	3448	2481	1.38976	10	30.7	14.3	7.44
10/6/01 12:33	3255	2359	1.37982	10	30.8	6.64	7.32
10/7/01 13:06	2282	2282	1	10	30.4	29.2	7.39
10/8/01 13:42				153	28.9	386	7.04
10/9/01 12:54	>24192	>24192	N.D.	208	28.9	20.7	6.94
10/10/01 16:18	>24192	>24192	N.D.	51	29	5.34	6.96
10/11/01 07:38							
10/14/01 17:54	>24192	>24192	N.D.	10	26.7	13.3	7.17
10/15/01 18:58	9804	9804	1	10	26.6	18.4	7.37
10/16/01 17:52	12997	12997	1	10	26.4	7.97	7.32
10/17/01 18:44:00	10462	9804	1.06712	10	26.7	5.98	7.47
10/18/01 17:47:00	12997	12033	1.08011	10	26.9	12.2	7.37
10/19/01 18:26:00	17329	17329	1	10	27.3	6.68	7.43
10/20/01 17:48:00	5172	4352	1.18842	10	27.5	3.71	7.55

[a]Units of most probable number (MPN) per100 mL of sample.
[b]Units of nephelometric turbidity units (NTU)
[c]N.D., not determined

Table 4.15. Results of daily month long sampling at the shallow groundwater trench G5 (N33^o 20.613' W118^o 19.515').

Sampling Date and Time	[a]TC	[a]EC	TC/EC[c]	[a]ENT	Salinity (ppt)	[b]Turbidity	pH
9/26/01 18:38	100	100	1	100	28.4	17.8	7.54
9/27/01 19:42	520	10	52	10	28.8	11.5	7.62
9/28/01 19:20	313	10	31.3	10	38.4	20.3	7.51
9/29/01 18:04	259	10	25.9	10	28.9	2.31	7.56
9/30/01 17:52	>24192	86	N.D.	10	29.4	31.6	7.52
10/1/01 18:31	>24192	10	N.D.	20	29.6	5.7	7.55
10/2/01 18:28	1281	10	128.1	10	29.7	3.75	7.58
10/3/01 18:16	8164	20	408.2	10	29.7	2.93	7.59
10/4/01 18:35	1674	10	167.4	10	29.7	4.34	7.62
10/5/01 12:51	1968	20	98.4	10	29.5	2.3	7.61
10/6/01 12:36	>24192	31	N.D.	10	29.3	7.6	7.6
10/7/01 13:09	1281	31	41.3226	10	29	15.6	7.6
10/8/01 13:45				10	28.9	3.47	7.76
10/9/01 12:59	>24192	2282	N.D.	10	28.6	573	7.71
10/10/01 16:23	8164	4884	1.67158	31	28.7	16.5	7.66
10/11/01 18:37	820	122	6.72131	10	29.1	88.5	7.61
10/14/01 17:59	>24192	249	N.D.	10	30.2	16.1	7.72

10/15/01 19:03	>24192	1725	N.D.	10	30.1	41.6	7.77
10/16/01 17:57	336	10	33.6	10	30.3	4.6	7.68
10/17/01 18:52	565	30	18.8333	10	30.2	9	7.65
10/18/01 17:53	223	10	22.3	10	30.2	56.7	7.62
10/19/01 18:31	85	10	8.5	10	29.8	1.76	7.62
10/20/01 17:54	10	10	1	10	29.5	0.8	7.54

[a]Units of most probable number (MPN) per100 mL of sample.
[b]Units of nephelometric turbidity units (NTU)
[c]N.D., not determined

4.B. Tier 2: Source Water Testing

Objective

To characterize the concentration of fecal indicator bacteria in samples of nuisance runoff, shallow groundwater, bird feces, and drains that might impact water quality in Avalon Bay.

Methods

Samples of nuisance runoff, shallow groundwater, broken drains under wharfs, and bird droppings were collected during a dry weather period between September 18-21, 2001. Samples were tested for physical parameters (pH, salinity, turbidity), TC, FC, and ENT. Samples were collected in 500 mL Nalgene bottles, capped, and immediately placed on ice. A brief description of the sampling site, and its latitude and longitude, were recorded in a lab notebook, and a picture of the site was taken. The samples were transported back to a temporary laboratory at the Mole where they were analyzed for physical characteristics and fecal indicator bacteria following procedures described in the QAPP (Appendix). All bacterial and physical tests were completed within six hours of collection.

Findings

Tables 4.16, 4.17, and 4.18 summarize the data collected during the source survey, including the sample ID, coordinates, time and date of collection, concentration of TC, EC, and ENT in MPN/100 mL, TC/EC ratio, and turbidity, salinity, and pH. All of the nuisance runoff samples had very high concentrations of fecal indicator bacteria (well above the respective single-sample standards), and most had relatively high turbidity (Table 4.16). Many of the groundwater samples also contained very concentrations of TC and EC, and occasionally ENT (consistent with the results presented in the Section 4.A.5, see Table 4.17). Gull and pigeon droppings collected from the dock at the mole generally contained high concentrations of ENT (in some cases >2,319,200 MPN/100 mL) (Table 4.18).

Interpretation and Implications

Samples of nuisance runoff, groundwater, and bird feces all harbor very high concentrations of fecal indicator bacteria. Hence, any of these sources may contribute to the Avalon Bay's contamination problems. Many of the storm drains in downtown Avalon have been retrofitted with dry weather flow diverters. However, the research team noticed that runoff from street wash-down activities routinely exceed diverter capacity. When this happens, wash down water flows out of the storm drains, across the

beach and into the Bay. The dry weather runoff harbors very high concentrations of indicator bacteria, and hence may contribute intermittently to surf zone water quality impairment. It is recommended that the City modify its wash-down activities, and/or increase dry weather diverter capacity, in the downtown area to minimize the flow of dry weather runoff into the ocean. As of the writing of this report, these recommendations have been acted on by City personnel.

Table 4.16. Water quality of nuisance runoff samples.

Sample ID	Latitude	Longitude	Sampling Date Time	[b]TC	[b]EC	TC/EC	[b]ENT	[c]Turbidity, Salinity, pH
R-1	N33° 20.703'	W118° 19.624'	9/18 at 16:05	>24,192	>24,192	N.D.	>24,192	80.7, 0.7, 8.64
R-2	N33° 20.622'	W118° 19.632'	9/18 at 16:15	>24,192	>24,192	N.D.	11, 863	7.2, 0.9, 8.55
R-3	N33° 20.662'	W118° 19.592'	9/18 at 16:20	>24,192	>24,192	N.D.	>24,192	37.2, 1.2, 8.27
R-4	N33° 20.706'	W118° 19.599'	9/18 at 16:25	>24,192	N.D.	N.D.	>24,192	80.7, 0.7, 8.64
R-11	N33° 20.634'	W118° 19.618'	9/19 at 11:30	>24,192	17,329	>2	8,164	231, 1, 8.58
R-101	N33° 20.574'	W118° 19.471'	9/20 at 16:00	>24,192	>24,192	N.D.	>24,192	N.D., 5.3, 7.58
R-102	N33° 20.580'	W118° 19.457'	9/20 at 17:30	>24,192	11,199	>2	10,462	N.D., 0.8, 8.24
R-103	N33° 20.643'	W118° 19.551'	9/21 at 05:15	19,863	14,136	1	N.D.	80, 33.3, 8.36

Table 4.17. Water quality of groundwater samples.

Sample ID	Latitude	Longitude	Sampling Date Time	[b]TC	[b]EC	TC/EC	[b]ENT	[c]Turbidity, Salinity, pH
G1	N33° 20.6	W118° 19.499'	9/18 at 18:00	>24,192	>24,192	N.D.	11	N .D.
G3	N33° 20.582'	W118° 19.466'	9/19 at 12:25	>24,192	2,143	>10	10	~216,33.3, 7.32
G4	N33° 20.602'	W118° 19.502'	9/19 at 12:30	7701	3654	2	<10	50.7,33.2, 7.28
G5	N33° 20.613'	W118° 19.515'	9/19 at 12:32	161	10	16	<10	~601, 31.7, 7.28
G6	N33° 20.635'	W118° 19.537'	9/19 at 12:40	663	98	7	31	~179,31.8,6.79
G7	N33° 20.717'	W118° 19.607'	9/19 at 13:05	<10	<10	N.D.	<10	95,31.5, 7.24
G8	N33° 20.582'	W118° 19.466'	9/19 at 16:15	>24,192	>24,192	N.D.	>24,192	N.D., 28.3, 7.44
G9	N33° 20.591'	W118° 19.523'	9/19 at 14:20	86	<10	>9	<10	3.7,13.6, 7.9
G10	N33° 20.591'	W118° 19.523'	9/19 at 14:20	74	<10	>7	<10	1.4, 13.7, 7.86
R-100	N33° 20.591'	W118° 19.523'	9/20 at 15:45	>24,192	<10	>2400	<10	0.17,13.6, 7.91

Table 4.18. Water quality of misc. samples.

Sample ID	Latitude	Longitude	Sampling Date	[b]TC	[b]EC	TC/EC	[b]ENT	[c]Turbidity, Salinity,

			Time					pH
R-5	N33° 20.696'	W118° 19.594'	9/18 at 16:35	108	20	5	<10	0.27, 33.4, 8.16
R-6	N33° 20.696'	W118° 19.594'	9/18 at 16:25	<10	<10	N.D.	<10	0.62, 0.5, 7.69
R-7	N33° 20.668'	W118° 19.560'	9/18 at 16:40	<10	<10	N.D.	<10	0.9, 0.1, 7.06
R-8	N33° 20.693'	W118° 19.326'	9/18 at 17:20	52	<10	>5	<10	0.29, 33.2, 8.1
R-9	N33° 20.662'	W118° 19.342'	9/18 at 16:10	63	31	2	<10	0.8, 33.3, 6.6
R-10	N33° 20.662'	W118° 19.342'	9/18 at 16:15	21	10	2	<10	0.25, 33.2, 8.75
R-12	N33° 20.648'	W118° 19.482'	9/22 at 05:15	?	?	?	?	0.75, 31.9, 8 .14
SG1	Dock at Mole	Dock at Mole	AM on 9/28	>2,319,200	>2,319,200		>2,319,200	N.D.
SG2	Dock at Mole	Dock at Mole	AM on 9/28	17,300	17,300	1	2,000	N.D.
SG3	Dock at Mole	Dock at Mole	AM on 9/28	<100	<100	N.D.	<100	N.D.
Q5	Dock at Mole	Dock at Mole	AM on 9/28	10	10	1	1274	N.D.
SG7	Dock at Mole	Dock at Mole	AM on 9/28	137,600	137,600	1	<1000	N.D.
SG1	Dock #2 sign	Dock #2 sign	AM on 9/28	>2,319,200	>2,319,200		>2,319,200	

4.C. Tier 3: Human Virus (HV) and Human Fecal Bacteria (HF) testing

Objective

To assess if Avalon Bay (and sources of water potentially impacting Avalon Bay) harbor human fecal pollution using molecular assays.

Methods

Water samples were collected from locations that were determined to be hot-spots of fecal indicator bacteria (based on results presented in previous sections of this chapter) and then tested for human-specific bacteria *Bacteroides/Prevotella* and enterovirus as described below.

(a) Human-Specific Fecal (HF) Bacteria

Bacteria from water samples were collected by filtration of 1-4 L (depending on amount that could be filtered without clogging; for shallow groundwater samples, the sample volume was typically 40-150 mL) through 47 mm diameter, 0.22 μm pore size Durapore filters or 20 L through 142 mm diameter Durapore filters (Millipore Corporation, Bedford, MA). No prefilters were used. Different types of samples required different DNA extraction procedures in order to minimize inhibition by humic acid-like

substances. DNA from seawater was extracted by hot 1% SDS lysis and purified by phenol extraction (Fuhrman et al., 1988), while effluent, shallow groundwater, and fecal samples were extracted by commercially available kits [Qiagen stool kit (Valencia, CA) or Bio 101 soil kit (Qbiogene, Carlsbad, CA)] following manufacturer's instructions. DNA concentrations were measured by Pico Green fluorescence with a Bio-Rad fluorometer (Hercules,CA). Amplification of the human-specific *Bacteroides/Prevotella* marker followed the procedure of Bernhard and Field (2000) using the PCR primers that amplify partial rDNA that encode16S rRNA from the human fecal specific group. Most amplifications were from 1 and 10 ng of extracted DNA, equivalent to about 5-50 mL of seawater, chosen to provide an optimal compromise between sensitivity and avoidance of inhibition of the assay. All sets of assays included negative controls (no DNA added) and positive controls in which a small amount (1-100 pg) of human fecal DNA extract was added to replicates of the field samples to see if reactions were inhibited by substances from the sample. Only one analytical run had negative controls showing a positive result, and when the run was repeated, the negative control was negative. Any negative result from the positive controls rendered the overall result for that sample inconclusive. Inconclusive samples were re-run with less DNA amplified in an attempt to reduce inhibition. The PCR method utilized here successfully amplified the human marker from <1 pg of DNA extracted from human feces, which we conservatively estimate as equivalent to at least 1 μg of fecal matter in the sample volume.

(b) Human Enterovirus (HV)

The method employed for detection of enterovirus in seawater is a modification of the real time RT-PCR method developed by Monpoeho and co-workers (Monpoeho et al., 2000) for identifying enterovirus in sewage sludge. A total of 2-20 L of water was filtered through glass fiber filters (Gelman type AE, Pall-Gelman Corp., East Hills, NY). Filters were frozen immediately after collection in the field. At the lab, filters were extracted with a Qiagen RNeasy mini kit (Valencia, CA) into a final volume of 30 μL. Of this, 5 μL was tested in duplicate along with a positive control spiked with cultured poliovirus using a quantitative PCR apparatus (Bio-Rad, Hercules, CA) (Monpoeho et al., 2000). Negative controls and a poliovirus standard set were run in parallel during each test. Results were considered positive if probe fluorescence developed within 50 cycles and inconclusive if no probe fluorescence developed but spiked samples were inhibited more than 50% or the negative control showed a positive result. The detection limit was approximately 1 plaque-forming unit (PFU) of enterovirus per volume water filtered (2-20 L of seawater). It should be noted that 1 PFU could contain on the order of 100 virus particles.

Results.

Table 4.19 summarizes the results from the *Bacteriodes/Prevotella* (HF) and enterovirus (HV) analyses as well as the corresponding fecal indicator bacteria concentrations, when available, in choronological order. The following water samples were analyzed for HF and/or HV: 7 within-Bay samples collected during the Bay survey, 1 nuisance runoff sample (R102), 1 pipe discharge sample (R101), 6 subsurface water samples and 18 shoreline samples. Five out of 18 (28%) shoreline samples tested postive for HF while 3

out of 12 (25%) tested for HV were positive. None of the within-Bay samples tested positive for either HF or HV. One out of 5 subsurface water samples was positive for HF, and 1 out of 4 was positive for HV. Both positive samples came from trench G4 which, as noted in Section 4.A.5, had relatively low salinity, relatively low pH, and relatively high concentrations of ENT (see Figure 4.7). Inhibiting substances made most measurements on shallow groundwater from this trench and other trenches inconclusive. Runoff and pipe discharge samples were also inconclusive.

A positive result for HV or HF indicates that nucleic acid specific to enterovirus or *Bacteroides/Prevotella* was present in a water sample. A positive result does not indicate that organisms present in the water were viable or (if enterovirus) infectious. As far as is currently known and published, the HV and HF markers detect only enterovirus and *Bacteroides/Prevotella* of human origin. We conducted a number of positive and negative control experiments to illustrate this at our field site. Samples from the sewage effluent plume southeast of Avalon Bay were positive; samples from the open channel outside the bay were negative; and animal fecal samples, including that from local Bison, were negative. A comparison of these HF and HV results to those of the standard bacteriological tests (Table 4.19) shows that none of the shoreline samples that were positive exceeded DHS single-sample standards for fecal indicator bacteria. The sample with the strongest HF signal was from shoreline station Pier on September 25, in which even 0.01 ng of DNA, representing only 0.02 mL of seawater, tested positive. Note that this sample had a low-to-moderate ENT concentration (63 MPN/100 mL), slightly over half of the single-sample standard of 104 MPN/100 mL. On the other hand, of all samples tested for both fecal indicator bacteria and the HF marker, one exceeded the DHS standard for ENT yet was negative in the HF test (Channel sample on October 22). These results are consistent with previous work in Southern California showing little correlation between fecal indicator bacteria and enteroviruses detected by RT-PCR.

Interpretation and Implications

The multiple instances of positive HF and HV assay results at shoreline stations indicate that human fecal contamination exists in Avalon Bay. Given the rapid mixing of water in the Bay (see Chapter 5 of this report), small-scale local contamination events should dissipate over a time scale of hours not weeks. The positive HF and HV results in the subsurface water sample are consistent with the extraordinarily high concentrations of fecal indicator bacteria detected there, and together these results suggest that the shallow groundwater beneath the City of Avalon is contaminated with sewage, probably from a leaking sewer trunk line. Indeed, as noted earlier, an infiltration study commissioned by the City found that as much as 30% of sewage treated by the local sanitation district originated from the infiltration of saline subsurface water. It is particularly interesting to note that the shallow groundwater sampling site that was most frequently positive for human markers of fecal contamination (site G4), was also anamolous relative to having high concentrations of ENT, and relatively brackish salinity (i.e., lower than ocean water salinity, see Figure 4.7 and Table 4.14). It is possible that brackish salinity observed at this particular shallow groundwater sampling station reflects the mixing of ocean water with low-salinity water from leaking sewage collection lines.

Table 4.19. Results of human bacteria and virus testing.

Sample ID	Sample Descriptiion	Sampling Date	HF Marker	HV Marker	[b]TC	[b]EC	[b]ENT
1	Bay	9/19/01	(–)	(I)	<10	<10	<10
2	Shoreline	9/19/01	(–)	N.D.	63	<10	<10
3	Bay	9/19/01	(–)	N.D.	20	<10	<10
4	Bay	9/19/01	(–)	(–)	74	<10	<10
5	Bay	9/19/01	(–)	(–)	20	10	10
6	Bay	9/19/01	N.D.	(I)	41	<10	<10
7	Bay	9/19/01	(–)	N.D.	327	<10	<10
8	Bay	9/19/01	(–)	N.D.	282	<10	10
R102	Runoff	9/20/01	(–)	(I)	>24,192	11,199	10,462
R101	Pipe Discharge	9/20/01	N.D.	(I)	>24,192	>24,192	>24,192
G4	Shallow Groundwater	9/21/01	N.D.	(+)	738	<10	<10
Pier, ankle	Shoreline water	9/25/01	(+)	(–)	546	62	63
Tuna, ankle	Shoreline water	9/25/01	(+)	(I)	30	<10	<10
South, ankle	Shoreline water	10/07/01	(–)	(+)	738	<10	<10
Middle, ankle	Shoreline water	10/07/01	(–)	N.D.	231	63	20
Tuna, ankle	Shoreline water	10/08/01	(–)	(–)	52	<10	<10
Busy Bee, ankle	Shoreline water	10/08/01	(+)	(–)	52	10	<10
G4	Shallow groundwater	10/08/01	(+)	N.D.	N.D.	N.D.	153
Tuna, ankle	Shoreline water	10/20/01	(–)	(I)	368	<10	10
South, ankle	Shoreline water	10/21/01	(+)	(–)	41	<10	<10
Busy Bee, ankle	Shoreline water	10/21/01	(–)	(–)	41	<10	98
Channel, ankle	Shoreline water	10/22/01	(–)	N.D.	97	51	164
Tuna, ankle	Shoreline water	10/22/01	(+)	(I)	160	41	10
Pier, ankle	Shoreline water	10/28/01	(–)	(+)*	N.D.	N.D.	N.D.
Channel, ankle	Shoreline water	10/28/01	(–)	(+)	N.D.	N.D.	N.D.
G2	Shallow groundwater	10/28/01	(–)	(I)	N.D.	N.D.	N.D.
G3	Shallow groundwater	10/28/01	(–)	(I)	N.D.	N.D.	N.D.
Busy Bee, ankle	Shoreline water	10/29/01	(–)	N.D.	N.D.	N.D.	N.D.
South, ankle	Shoreline water	10/29/01	(–)	N.D.	N.D.	N.D.	N.D.
Tuna, ankle	Shoreline water	10/29/01	(–)	N.D.	N.D.	N.D.	N.D.

G4	Shallow groundwater	10/29/01	(–)	N.D.	N.D.	N.D.	N.D.

(I) indicates that test was inconclusive, (-) indicates a negative result, (+) indicates a positive result, and (+)* indicates positive result for one of two duplicates. See Figure 2 of the Environmental Science and Technology paper written on these results (Report Appendix) for the location in Avalon Bay of the first eight samples analyzed for the HF and/or HV markers.

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Chapter 5. Hydrographic and Circulation Studies in Avalon Bay

This chapter summarizes a set of hydrographic and circulation studies in Avalon Bay intended to answer the following questions:

- Are high concentrations of fecal indicator bacteria in Avalon Bay arising from a source inside or outside the Bay?
- Are high concentrations of fecal indicator bacteria in Avalon Bay from a surface, near bottom, or distributed source?
- Does Avalon Bay circulation act to preferentially transport sources of microbial pollution onto the Avalon Bay shoreline?
- How rapidly are nearshore sources of microbial pollution dispersed away from the shoreline?
- How rapidly are Avalon Bay sources of microbial pollution flushed to the ocean?

Three approaches were used to answer these questions. A hydrographic survey was performed to look for possible external sources of bacteria, such as the treated wastewater discharge from the outfall, and sources near the mouth of the harbor. Acoustic Doppler Current Meters (ADCPs) were place across the mouth of the harbor to understand the exchange that occurs between the harbor and the external ocean. And a fluorescent dye, Rhodamine WT, was used to examine dispersion and mixing within the harbor.

5.1. Materials and Methods

5.1.1. Hydrographic Surveys

Hydrographic surveys were conducted in two modes. Outside of the harbor, a CTD/rosette system was used so that both continuous vertical profiles and discrete water samples could be obtained. The water samples were then analyzed for bacteria and viruses, following procedures described in Chapter 4. The continuous profiles included measurements of temperature, salinity, dissolved oxygen, beam attenuation, and chlorophyll fluorescence. These profiles were obtained with a Seabird 9/11+ CTD attached to a General Oceanics rosette equipped with twelve 10-liter Niskin bottles. Within the harbor, a series of vertical profiles were obtained with a Seabird Seacat CTD equipped for the measurement of pressure, temperature and depth. A Seapoint rhodamine fluorometer was attached to the Seacat CTD when the dye was deployed in October for measuring the concentration of Rhodamine WT in situ (see below for more details).

5.1.2. Current Profiling

Three RDI acoustic Doppler current profiler (ADCP) current meters were deployed across the mouth of the harbor. Each of the current meters was in 28-29 meters of water depth. The locations of the current meters are shown in Figure 5.1. The current meter in the center of the mouth was a 600 KHz ADCP that was able to profile from about 2 meters above the bottom to within 2 meters of the surface, essentially obtaining a complete water column profile. The ADCPs to the north and south of the central mooring

were 1200 KHz instruments that profiled the lower 15 meters of the water column and were able to measure the exchange below the pycnocline.

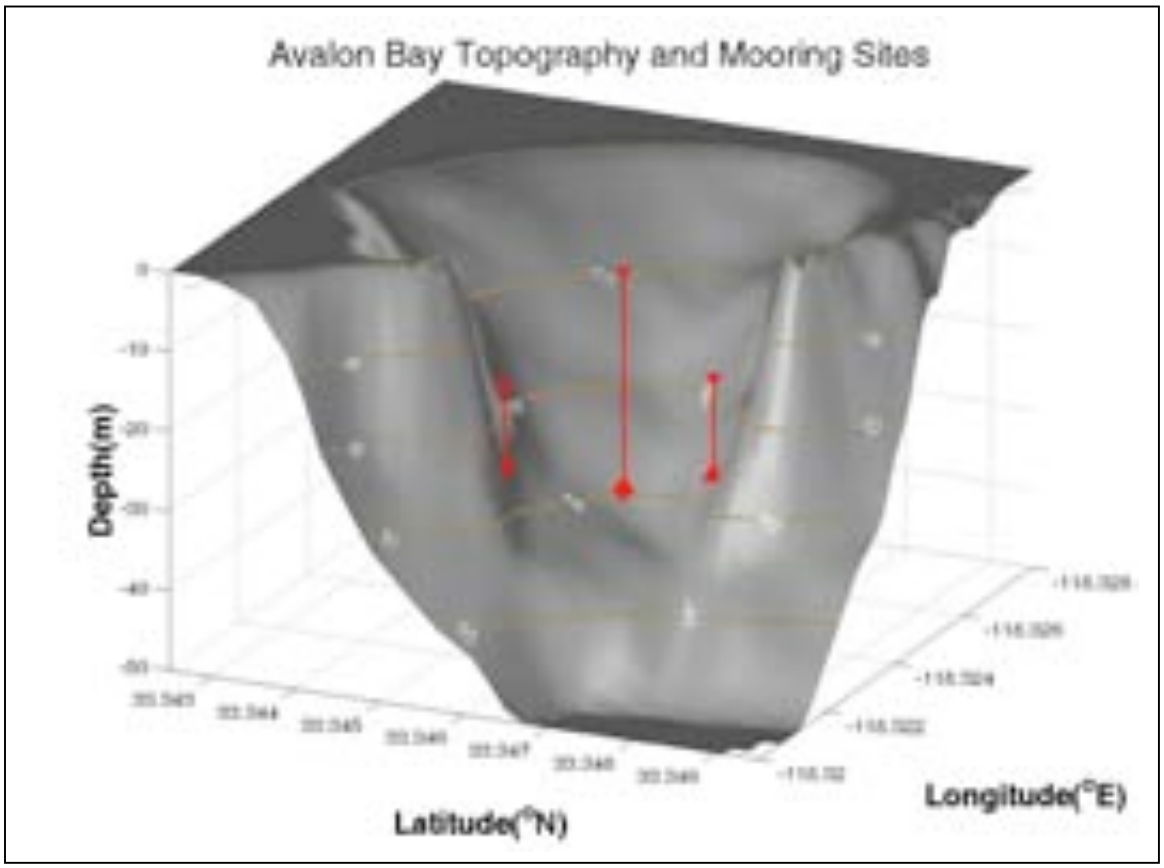

Figure 5.1. Topographical map of Avalon Harbor showing the location and depth range of the three acoustic Doppler current profilers (ADCPs) placed across the mouth of the harbor from September 25 through November 6, 2001.

5.1.3. Avalon Bay Dye Studies

A series of dye studies were performed to examine the mixing and dispersion within the harbor. Rhodamine WT was used as the tracer. The reasons for using Rhodamine WT are that it has a relatively low light-induced decay rate and therefore is relatively conservative in surface waters, it does not readily adsorb onto particles, and it is detectable at down to part-per-billion (ppb) concentrations using sensitive fluorometric techniques. The dye was released with the intention of having an initial concentration of between 10 and 50 $\mu g \cdot L^{-1}$, concentrations that are easily detectable visually and allow for a dilution of up to 500-fold while still detectable with fluorometers. The dye was deployed at the surface in three different patterns. The dye was deployed as either a line across the mouth of the harbor, a cross-pattern within the harbor, or as an approximately square patch of dye in the southern corner of the harbor. The dye was measured with a SeaPoint in situ fluorometers attached to a Seacat CTD that was deployed from a skiff. A time series of images of the dye were obtained with a standard 3 megapixel digital

camera, Canon GL-1, from a helicopter that hovered over the harbor for a period of about one hour for each experiment. The RGB images were then analyzed to distinguish the dye from the ambient color of the water and adjacent land features. The time series of dye images were orthorectified so that they each had the same spatially uniform geometry. Then the dye was statistically analyzed for both advection and diffusion rates. The current speeds were estimated from the propagation of the centerline of the dye. The horizontal eddy diffusion rates were estimated from the rate of horizontal spreading of the dye patches (see article in Appendix for more details).

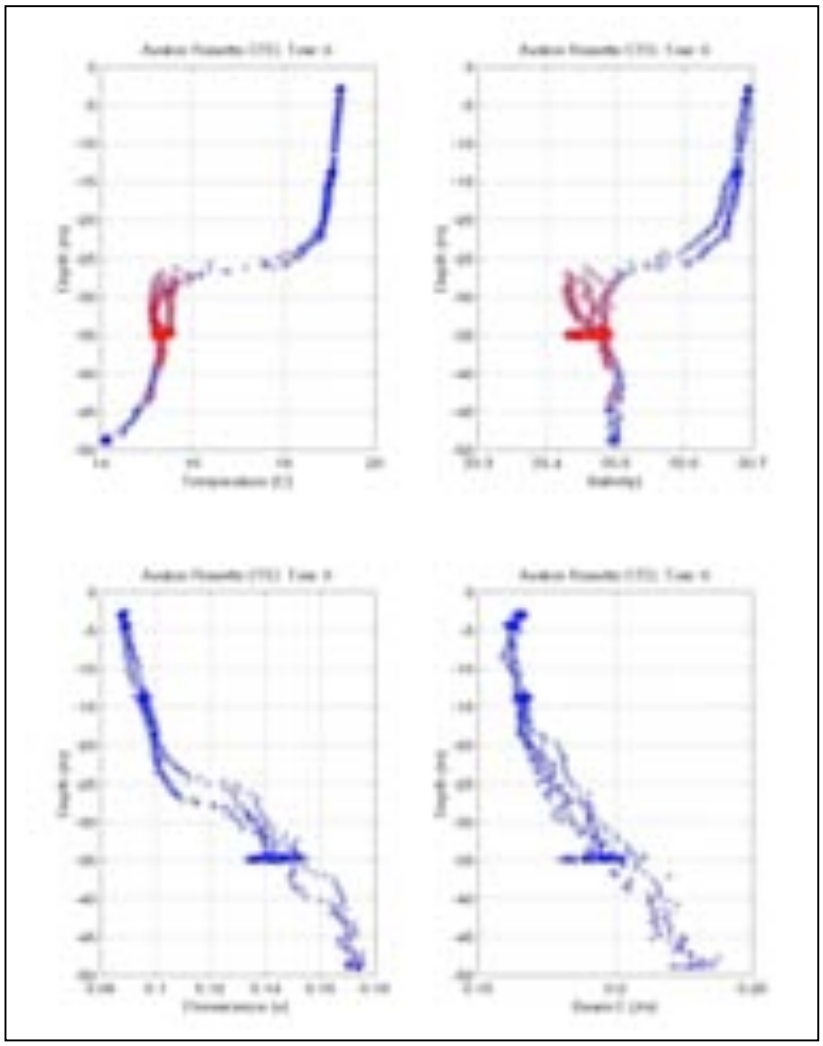

Figure 5.2. Vertical profile of temperature, salinity, chlorophyll fluorescence and beam attenuation over the Avalon outfall, and directly offshore from the outfall. The red circles indicate the points that correspond to the region containing the treated sewage effluent mixed with the ambient seawater.

5.2. Results

5.2.1. Hydrographic Observations

On September 26, the day after the current meters were deployed, several hydrographic measurements were made between the harbor mouth and the sewage outfall southeast from the harbor mouth. Two questions were addressed with this data set: 1) does the sewage effluent plume encroach on the harbor mouth? 2) Is there any evidence of freshwater sources that might be sources of bacteria within the harbor?

We were able to detect the sewage effluent in one profile near the outfall and immediately offshore from the outfall. Figure 5.2 shows the vertical distribution of temperature, salinity, chlorophyll fluorescence, and beam attenuation near the outfall; also see the temperature/salinity plot in Figure 5.3. We expect that the outfall signal will

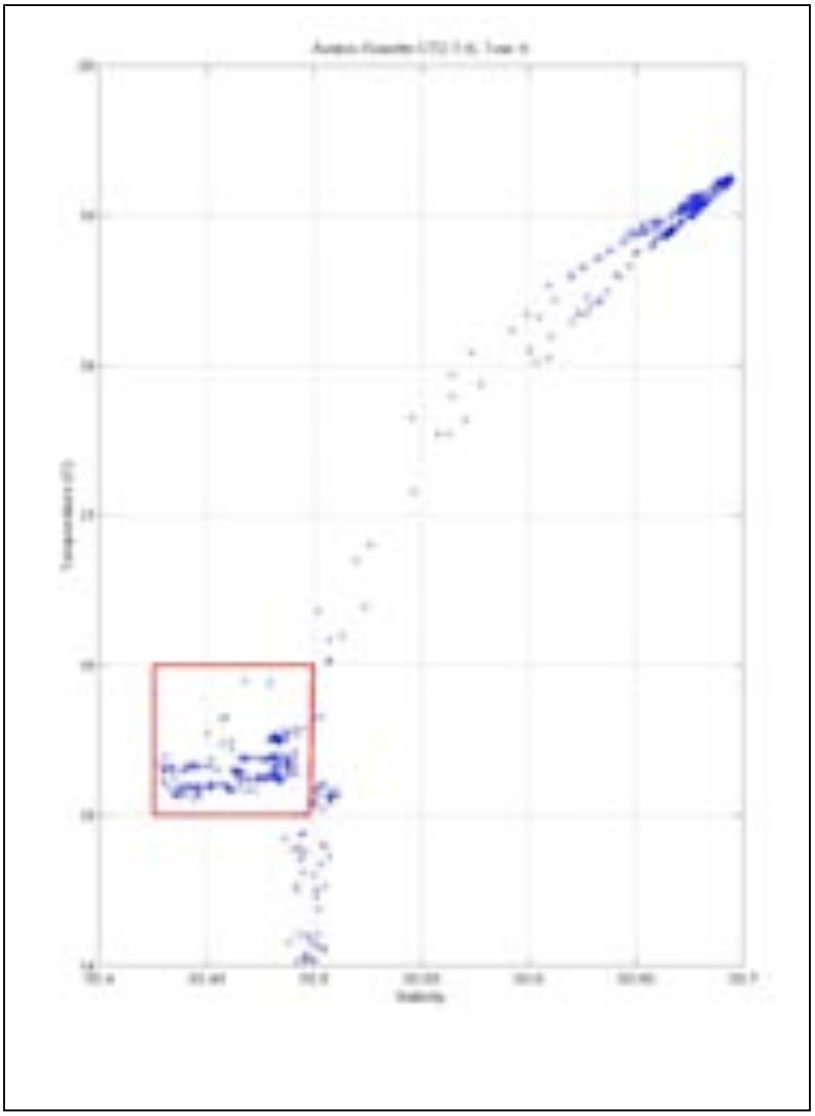

Figure 5.3. Temperature-salinity scatter plot for CTD/Rosette tow 6 shown in Figure 5.2. The red box outlines the data where the salinity is less than the ambient salinity for the measured temperature. This region is characteristic of the water where the outfall effluent has mixed with ambient seawater. The points included within the red box are drawn as red circles in Figure 5.2.

be characterized by low salinity and perhaps increased beam attenuation which is indicative of suspended particulate material. Previous research on the Palos Verdes continental shelf has shown this to be the case in the plume of Los Angeles County's White Point outfall (e.g., Wu et al., 1994). A similar situation has also been observed for the Sand Island outfall on the southern side of Oahu (Petrenko et al., 1997).

Within the harbor, strong stratification exists between the surface and bottom of the system (data not shown). There is no direct evidence of the effluent plume within the harbor. Given the strong stratification that is present near the outfall we do not expect a high likelihood of material from below the pycnocline entering the nearshore zone even if plume were present.

5.2.2. Current Profiling

Three ADCP current meters were deployed across the harbor mouth from September 25, 2001 through November 6, 2001 for a total of period of 42 days. We present three sets of results from these current meters: 1) spectral analysis of the temporal components contributing to the variability; 2) analysis of the tidal components (tidal ellipses) contributing to the variability; and 3) volume exchange of water across the mouth of the harbor.

We have examined the temporal components that contribute to the exchange across the harbor for the three locations and for various depths within the water column. Two of the strongest components of the flow through the mouth are the semidiurnal tide (M2, period 12.42 hours) and the mixed luni-solar diurnal tide (K1, 23.93 hours). The inertial period is characteristic of a given latitude and indicates the ocean response time to a force acting on the ocean. The inertial period at this latitude is 21.8 hours and is expected to be associated with eddies that impinge on the harbor mouth. These eddies can be generated by winds or large current systems. The tidal ellipses for the M2 and K1 tides are shown in Figures 5.4 and 5.5, respectively. From the central mooring it is clear that there are distinct layers within the water column. In the upper layer, the major axis of flow is orthogonal to the mouth, while in the deeper layer between 18 and 28 meters, the major tidal axis is across the mouth. At the south mooring, the deeper ellipses (23 and 28 meters) are oriented east-west and at 18 meters the major M2 tidal axis is north-south.

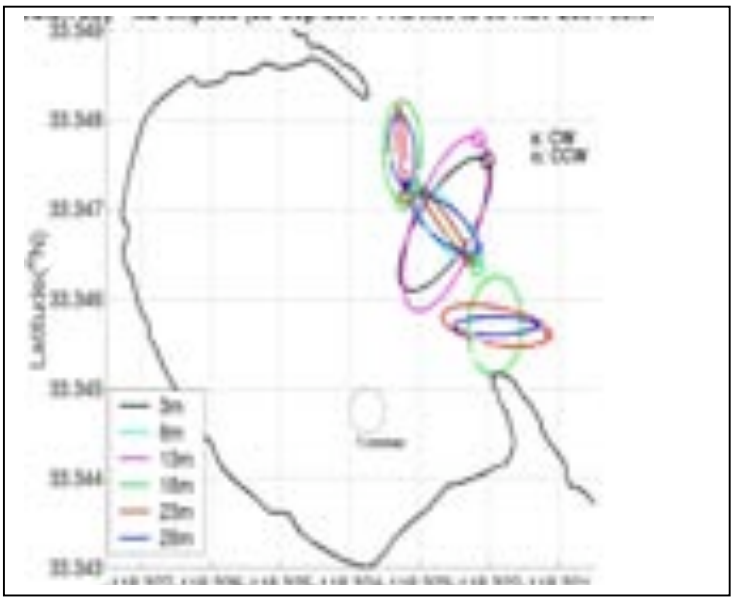

Figure 5.4. Tidal ellipses for the M2 lunar semidiurnal tide for the period between September 25 and November 6, 2001.

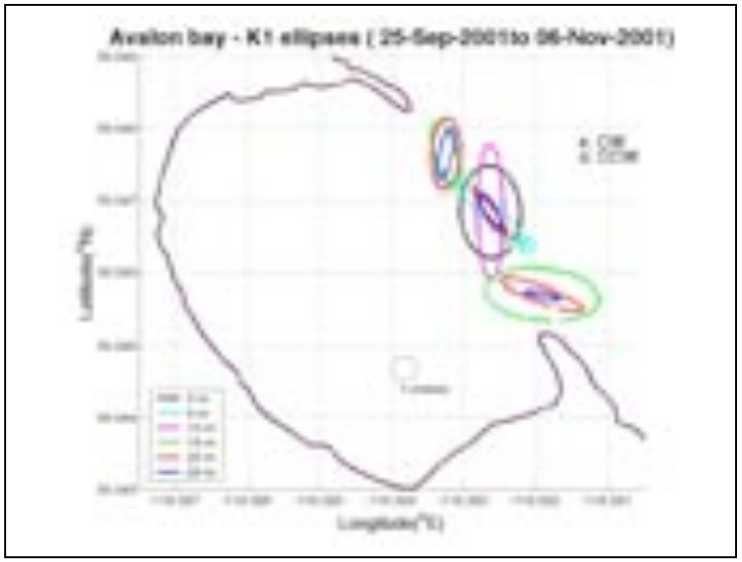

Figure 5.5. Tidal ellipses for the K1 diurnal tide for the period between September 25 and November 6, 2001. Colors indicate the depth of the ellipse.

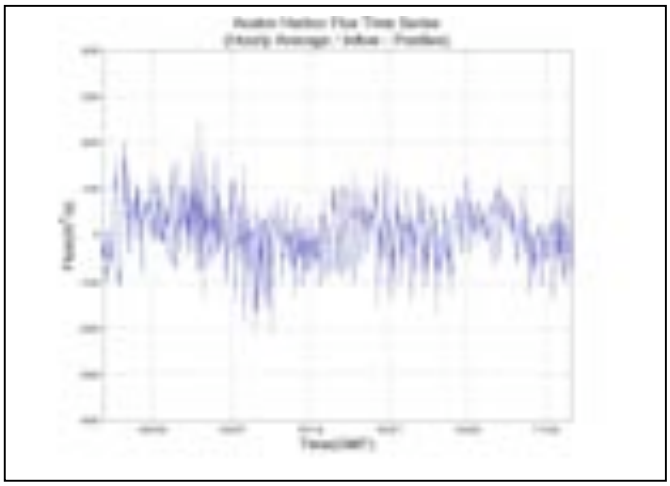

Figure 5.6. Hourly average of the flux across the harbor mouth between 15 and 29 meters depth. A positive value indicates a flux into bay and negative values indicate fluxes out of the bay.

We have examined the volume flux of water across the lower half (15-28 meters depth) of the water column at the mouth of the harbor. The time series of the flux is shown in Figure 5.5. We estimate the volume of the harbor to be about 2.7 million (2.7×10^6) cubic meters. The sustained volume flux needed to exchange the entire volume of the harbor in one tidal cycle, 12.4 hours, is about 63 m^3/s. There are short periods when the flow exceeds this rate, but these are generally short-lived. What is surprising is that there are periods when there is either sustained net inflow into, or sustained net outflow from, the harbor within the lower layer. Between September 27 and October 6, the net flow is into the harbor within the lower layer. We must therefore assume that there is a net outflow from the harbor in the upper layer during this period.

5.2.3. Dye Studies of Circulation within Avalon Harbor

Table 5.1. summarizes the dye injection experiments conducted in Avalon Harbor; wind conditions during these experiments are plotted in Figure 5.7. The dye studies were intended to address three questions: 1. Does the nearsurface harbor circulation act to preferentially transport sources of microbial pollution onto the Avalon shoreline? 2. How rapidly are nearshore sources of microbial pollution dispersed away from the shoreline? 3. How rapidly are harbor sources of microbial pollution flushed into the ocean?

Table 5.1. Details of dye studies in Avalon Bay.

Date (PDT)	Times (PDT)			Experiment	Tidal Phase
	Injection Start	Injection End	Last image		
Oct. 8, 2001	0932	0938	1017	Line across mouth of harbor	Flood tide
Oct. 10, 2001	1125	1138	1232	Cross-pattern within harbor	Flood tide
Oct. 11, 2001	1428	1431	1528	Patch in southern corner of harbor	Flood tide
Oct. 12, 2001	0806	0808	-	Patch in southern corner of harbor	Ebb tide

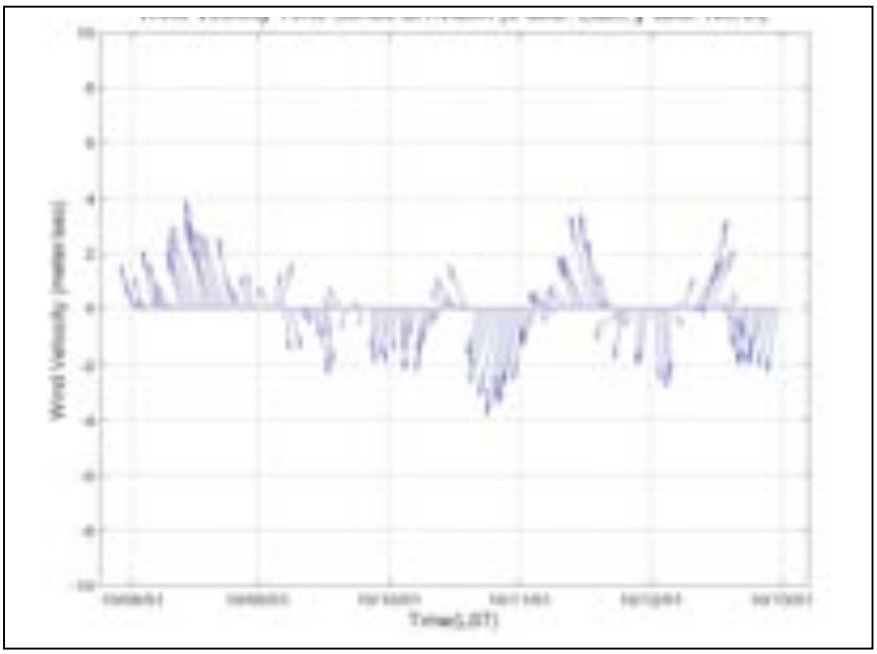

Figure 5.7. Five-day time series of winds recorded at Avalon Airport between October 8 and October 12, 2001.

The first dye experiment on October 8 was intended to examine the exchange across the mouth of the harbor during a flooding tide. The experiment began at 0932 PDT. Low tide occurred 0611 and the following high tide occurred at 1303. Thus the dye was deployed about midway through the flood tide cycle when maximal tidally driven currents would be expected. The concentration of the dye released was relatively low and dispersed below visible detection in less than one-half hour. Because of the low concentration and short duration of detectability, the dye injection rate and hence final concentration was increased for subsequent experiments.

Figure 5.8. Initial 9 minutes of dye dispersion on October 8, 2001. The white line extending across the mouth indicates the initial centerline of the dye and subsequent times are indicated by the colored lines. Although the time period is short, the out of harbor flow at the north end of the mouth and the flow into the harbor at the south end of the mouth are evident.

The time series of dye location at the mouth of the harbor is shown in Figure 5.8. The obvious result from these observations is that the flow was into the harbor along the southern half of the harbor mouth and out of the harbor along the northern half of the harbor mouth during the period of observation. The flow is eddy-like indicating a clockwise (anticyclonic) rotational flow within the harbor.

On October 10, a second dye study was performed. The dye was deployed in two lines approximately perpendicular

Figure 5.9. Aerial photograph of the lines of dye placed in the harbor on October 10, 2001 to examine the circulation and diffusion within the harbor. In this figure, the first line of dye extending from left to right across the center of the image has already begun to disperse, especially evident in the region to the left of the pier. The line running vertically in the image has just been completed. The boat deploying the dye can be seen near the beach at the top of the image.

to each other (Figure 5.9). One extended along the long axis of the harbor from the SSE toward the NNW end of the harbor, and the other line extended across the short axis of the harbor from nearshore toward the center of the mouth of the harbor. This experiment provided significant information about the harbor. During the dye study on October 10 winds at Avalon airport were predominantly toward the south at speeds ranging from 5-7 knots (9-13 m/s, Figure 5.7). The direction of winds was consistent with the wind direction indicated by the flag located at the end of the breakwater at the Mole.

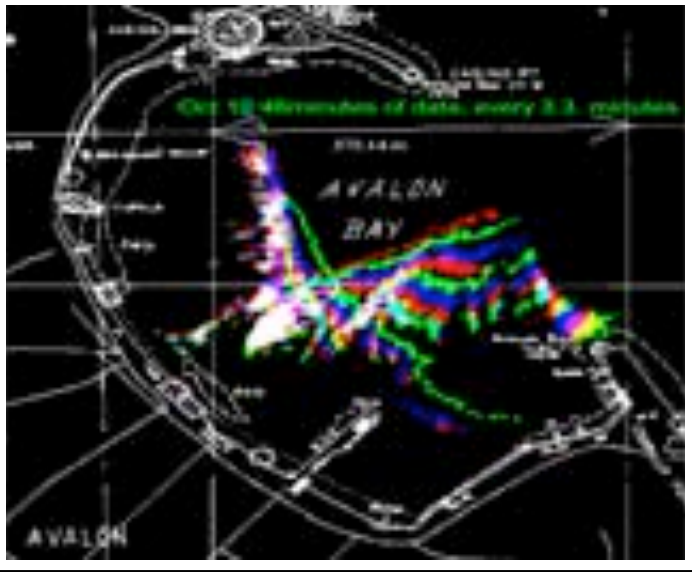

Figure 5.10. Time series of dye dispersion on Oct. 10 when dye was deployed in a cross pattern within the harbor. The initial lines are indicated by the red line extending from near the shore toward the center of the mouth and by the green line extending from near the Casino down toward the SSE end of the harbor between the pier and Mole. Subsequent times are indicated by the sequential lines extending away from the initial lines.

Consistent with the wind forcing, the dye advection in the outer part of the harbor was toward the south with the outer edge of the cross-harbor line advecting toward the Mole (Figure 5.10). In the inner harbor north of the pier, the transport rate of the dye was slower but was also toward the southern end of the harbor.

The dye concentration, as estimated from the camera color images, remained relatively constant throughout the experiment and the spreading of the lines of from their centerlines allowed estimates of the rate of horizontal eddy diffusion. The

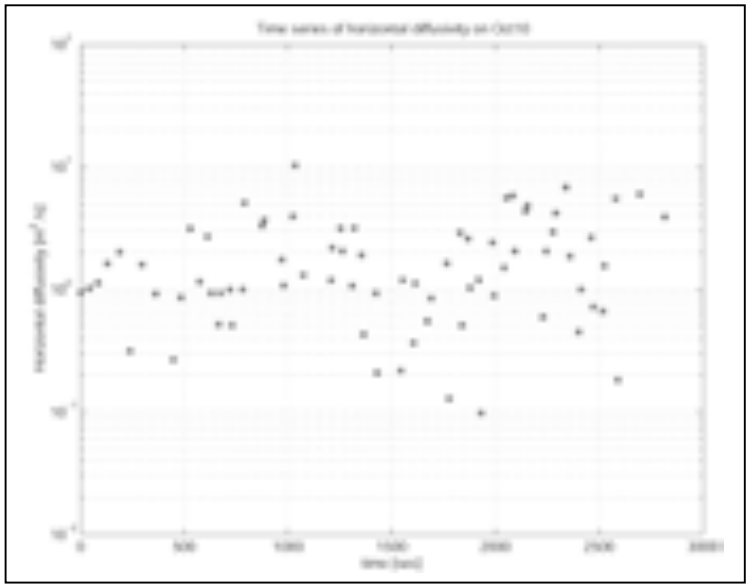

Figure 5.11. Time series of estimates of the horizontal eddy diffusion coefficient during the 46 minute time series of dye images from October 10. The time span of these estimate is the same as the time span of the dye patch evolution shown in Figure 5.10.

Figure 5.12. The patch of dye placed in the southern corner of the harbor on October 12, 2001 is outlined in yellow. The storm drain can be seen behind the patch of dye. The boat within the yellow lines has just completed release of the dye and is beginning to sample the dye concentrations with an in situ

results of the measurements are shown in Figure 5.11. The values of the horizontal diffusion rate ranged from about 10^{-1} to 10^{1} $m^2 \cdot s^{-1}$, but were typically about 1 $m^2 \cdot s^{-1}$.

The third and fourth dye studies were performed in the southern corner of the harbor in front of the storm drain that enters the harbor there. Dye was placed in a patch approximately 10 meters square in front of the storm drain and then tracked for about one hour (Figure 5.12). The first of these two experiments was conducted on October 11, 2001 during a flooding tide. Low tide was at 1148 and high tide was at 1732 on October 11. The experiment occurred between 1428 and 1528 PDT. During the day, the winds measured at the Avalon Airport were toward the ENE at speeds of 8-10 knots (15-18.5 m/s). However, based on flag direction at the mole during the study, the winds affecting the harbor were blowing toward the SSE. Presumably this difference is due to orographic effects of the island.

The dispersion of the dye field is shown in Figure 5.13. The patch was initially about a square about 10 meters on a side. As time progressed the dye patch initially stretched out along the southern edge of the harbor moving toward the mole. After moving along the shore for a distance of about 80 meters, the dye patch began to move northward away from the shore and spreading

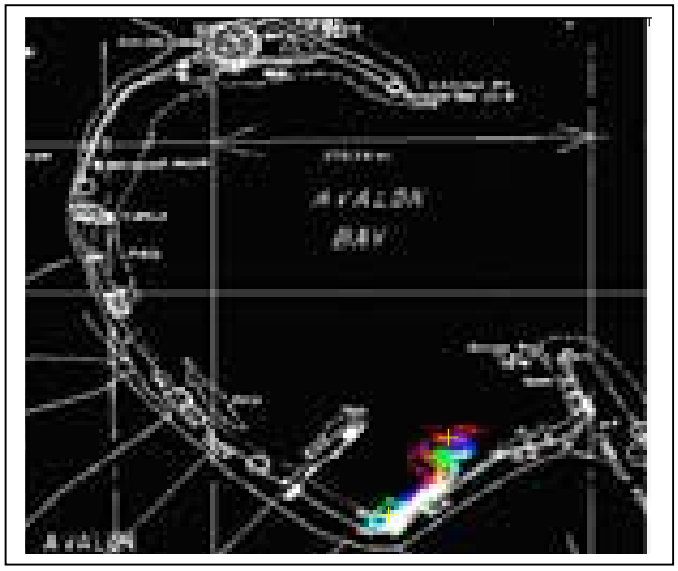

Figure 5.13. Figure shows evolution of the dye field on October 11, 2001. The green lines in the lower corner indicate the initial boundary of the dye patch. The two yellow plus (+) symbols indicate the center of the dye patch at the beginning and end of the time series. These two points were used to estimate the average speed of advection of the dye patch.

horizontally. After about 45 minutes the dye had dispersed to the point where it was no longer traceable with the camera.

On October 12, 2001 the same experiment was repeated placing the dye in the same pattern in front of the storm drains at the southern end of the harbor. On the 12th, however, the experiment was performed during an ebbing tide. High tide was 0729 and low tide at 1250 PDT. The dye study was performed between 0806 and 0900. During this study the dye was followed with an in situ fluorometer. Despite the different phase of the tidal cycle, the dispersion of the patch followed a nearly identical pattern to the dispersion observed on October 11. It initially spread near the shore toward the Mole and then spread into the harbor about 80-100 meters away from the initial source. The time frame of dye disappearance was nearly identical to that on the preceding day.

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Chapter 6. Conclusions and Recommendations

This chapter summarizes the major conclusions from the suite of studies carried out at Avalon Bay, and recommendations for future work.

6.1. Conclusions—Historical Water Quality Trends

Based on an analysis of historical water quality and rainfall trends in Avalon Bay, the following conclusions can be formulated:

1. A large percentage (between 10 and 60%) of water samples collected from Avalon Bay violate one or more single-sample quality standards set forth by AB 411.
2. The frequency with which Avalon Bay water samples violate single-sample standards varies by site. The highest violation frequencies coincide with the Pleasure Pier (Station Middle), and lower violation frequencies occur at sites located north and south of the Pleasure Pier. This spatial pattern would appear to implicate the existence of surface and/or subsurface sources of fecal pollution that discharge to Avalon Bay near the Pleasure Pier.
3. The frequency with which Avalon Bay water samples violate single-sample standards exhibits considerable summer-to-summer variability. In general terms, the summers of 1999 and 2002 were better than average, while the other summers (2000, 2001, 2003-2005) were near or worse than average.
4. The two summers that had lower-than-average violation frequencies were also the two summers that experienced less-than-average rainfall. This would tend to implicate summer-time rainfall as one possible factor that influences the delivery of fecal indicator bacteria to Avalon Bay. If the fecal indicator bacteria originate from leaking sewer lines in the main beach area, summer-time rainfall might act to enhance the transport of fecally contaminated shallow groundwater into the surf zone.
5. The mitigation measures implemented by the City after 2001 do not appear to have improved water quality in Avalon Bay. Instead, since 2002 water quality in Avalon Bay appears to have steadily worsened.

6.2. Conclusions—Source Tracking

Based on source tracking studies the following conclusions can be formulated:

Tier 1: Nearshore Survey.

Based on nearshore survey of water quality inside and outside of Avalon Bay:

a) The highest concentrations of fecal indicator bacteria are inside of Avalon Bay; concentrations of fecal indicator bacteria are lower to the north (Descanzo Beach) and south (shoreward of the wastewater outfall) of Avalon Bay.
b) Within Avalon Bay, fecal indicator bacteria concentrations were highest in ankle depth water near the Busy Bee sampling station. The concentration of fecal indicator bacteria at this site was

approximately an order of magnitude lower in waist depth water, and tapered off in both up- and down-coast directions.

c) Two weeks after the spatial study was completed (on 10/1/01), a leaking sewer line beneath Armstrong's Wharf was discovered. Samples of water leaking from the pipe had very high levels of indicator bacteria (>24,192, >24,192, and 1,233 MPN/100 mL for TC, EC, and ENT, respectively). It is possible that the leaking sewer line contributed to the elevated concentration of fecal indicator bacteria at the Busy Bee site.

d) These data support the idea that the primary source of fecal indicator bacteria in the Bay is inside Avalon Bay, along the shoreline, and near the Pleasure Pier. Out-of-bay sources, such as the sewage outfall, are not a likely cause of surf zone water quality impairment in Avalon Bay.

Tier 1: Cross-Shore Transect.

Based on a cross-shore transect study conducted inside Avalon Bay:

a) The concentration of fecal indicator bacteria in the water column and sediment in Avalon Bay is highest very close to shore, in less than 3 m of water.

b) The concentration of fecal indicator bacteria in shallow water very close to shore is consistent with a shoreline source of these bacteria.

c) Examples of possible shoreline sources of fecal indicator bacteria include leaking sewer lines (e.g., like the one found under Armstrong's Wharf), exfiltration of sewage contaminated shallow groundwater, bird droppings deposited along the shoreline, and growth of fecal indicator bacteria in beach sediments.

Tier 1: 24 hour (Diurnal) Study.

Based on hourly sampling for 24 hours at several sites in Avalon Bay:

a) The concentration of TC and EC, and to a limited extent the concentration of ENT, follow a day/night pattern at several sites in Avalon Bay; in particular, the concentration of fecal indicator bacteria is lowest when solar radiation is maximal at noon, and higher at night and during the falling tide in the late afternoon.

b) Possible explanations for the day/night cycling of fecal indicator bacteria in Avalon Bay include sunlight-induced die-off of fecal indicator bacteria in marine waters, tidal flow of contaminated groundwater into the Bay, tidal washing of contaminated sediments, and day/night patterns associated with the input of runoff into the Bay from, for example, City wash-down activities.

c) Very high concentrations of fecal indicator bacteria were measured in samples of shallow groundwater collected approximately 10 m south of the Pleasure Pier.

d) TC and EC in the shallow groundwater also exhibited a day/night pattern, with higher concentrations during the day-time falling tide.
e) These last two observations—that fecal indicator bacteria are present at high concentrations in the shallow groundwater and that TC and EC exhibit a day/night pattern—are consistent with the idea that exfiltration of contaminated groundwater may be a source of the fecal indicator bacteria contamination along the shoreline in Avalon Bay.

Tier 1: Month-long, Twice Daily Shoreline Sampling

Based on month-long twice-daily sampling of shoreline sites in Avalon Bay:

a) The concentration of fecal indicator bacteria measured during the month-long daily sampling was highest at the Middle station (near the Pleasure Pier), and tapered off both north and south of the Middle station.
b) This spatial pattern is consistent with the analysis (presented in Chapter 3) of six years of historical fecal indicator bacteria measurements in Avalon Bay which found the highest concentrations at the Middle Station, near the Pleasure Pier.
c) TC/EC ratios are lowest at Middle and Pier stations, and increase north and south.
d) These two observations—that the fecal indicator bacteria concentrations are highest and the TC/EC ratios are lowest in the vicinity of the Middle Station and the Pleasure Pier—are consistent with the idea that this region of the shoreline is a source of fecal indicator bacteria pollution.
e) There is no evidence that the arrival of tourists on cruise ships, or on ferries, is correlated with high levels of fecal indicator bacteria in the Bay. Indeed, in several cases the concentration of fecal indicator bacteria were high when there were no cruise ships anchored outside of the Bay, and when the number of passengers disembarking at the Mole was low.
f) A higher frequency of water quality violations were observed for water samples collected from ankle depth water, compared to water samples collected from waist depth water. This result is consistent with the transect study described above, which found that fecal indicator bacteria concentrations are highest in the very shallow (i.e., ankle-deep) waters along the shoreline.

Tier 1: Month-long, Twice Daily Shallow Groundwater Sampling

Based on month-long twice-daily sampling of shallow groundwater beneath downtown Avalon:

a) Of the 88 shallow ground water samples collected, 45 (51%) exceeded the single-sample standard for TC, 63 (72%) exceeded

the single-sample standard for FC, and 17 (19%) exceeded the single-sample standard for ENT.

b) Groundwater sampling sites G1, G2, G3, and G4 (located in downtown Avalon, shoreward of, respectively, DHS sampling sites Channel, South, Pier, and Busy Bee) all had consistently high concentrations of TC and EC.

c) Sites G1 and G5 (located shoreward of the Channel and Tuna sampling sites) had very low concentrations of ENT; the concentration of ENT in all other shallow groundwater sampling sites was sporadically high.

d) Over the month-long study, there was not a consistent (and significant) correlation between the concentration of TC and EC measured in the shallow groundwater and either tide stage (ebb or flood) nor tide range (spring or neap)

e) The highest fecal indicator bacteria concentrations were observed in sampling site G4, located north of the Pleasure Pier. TC and EC concentrations in this trench frequently exceeded the detection limit of our assay (24,192 MPN/100 mL).

f) Compared to the other shallow groundwater sampling sites, shallow groundwater at site G4 had anamolously low salinity and pH. The low salinity signal at G4 likely reflects the subsurface mixing of saltwater (from the ocean) and a source of freshwater from natural and/or human (e.g., sewer main leaks, runoff infiltration, etc) sources.

g) The nature of groundwater flow in downtown Avalon, and the full extent of the shallow groundwater contamination plume, were not characterized because these issues fell outside of the scope of the current study. However, there are several reasons to suspect that leaking sewer lines may contribute to the observed fecal indicator bacteria concentrations in the shallow groundwater:

    1. An earlier study conducted in 1993 found that approximately 36% of the average daily wastewater flow into the local sewage treatment plant originated from base inflow and infiltration into the sewage collection system, a large portion of which is probably groundwater infiltration. If groundwater infiltrates into the sewage collection system, it is possible that untreated sewage contaminates the surrounding groundwater.
    2. After the 1993 study, approximately 30 m of the sewage collection system was slip-lined in the downtown area (between the downtown fountain and the Pleasure Pier). The base inflow into the sewage treatment plant apparently reduced after this slip-lining project,

consistent with the idea that a significant portion of the base inflow originated from groundwater infiltration.

3. During the month-long survey (from 9/25 through 10/20/01) carried out as part of the current investigation, very high concentrations of fecal indicator bacteria were measured at all groundwater sampling locations in the downtown area, particularly at sites G3 and G4.

Tier 2: Source Water Testing

Based on the concentration of fecal indicator bacteria measured in samples of nuisance runoff, shallow groundwater, bird feces, and drains:

a) Samples of nuisance runoff, groundwater, and bird feces all harbor very high concentrations of fecal indicator bacteria. Hence, any of these sources may contribute to the Avalon Bay's contamination problems.
b) Many of the storm drains in downtown Avalon have been retrofitted with dry weather flow diverters. However, the research team noticed that runoff from street wash-down activities routinely exceed diverter capacity. When this happens, wash down water flows out of the storm drains, across the beach and into the Bay.
c) The dry weather runoff harbors very high concentrations of indicator bacteria, and hence may contribute intermittently to surf zone water quality impairment.
d) It is recommended that the City modify its wash-down activities, and/or increase dry weather diverter capacity, in the downtown area to minimize the flow of dry weather runoff into the ocean. As of the writing of this report, these recommendations have been acted on by City personnel.

Tier 3: Human Fecal Marker Studies

Molecular assays for human markers of fecal contamination indicate:

a) Multiple instances of positive Human Fecal Bacteria (HF) and Human Virus (HV) assay results at shoreline stations indicate that human fecal contamination exists in Avalon Bay.
b) Some samples of shallow groundwater were also positive for HF and HV, consistent with the extraordinarily high concentrations of fecal indicator bacteria detected there.
c) The high fecal indicator bacteria concentrations and positive HF and HV test results are consistent with the idea that the shallow groundwater beneath the City of Avalon is contaminated with sewage, possibly from a leaking sewer trunk line.
d) It is particularly interesting to note that the shallow groundwater sampling site that was most frequently positive for human markers of fecal contamination (site G4), was also anamolous

relative to having high concentrations of ENT, and relatively brackish salinity (i.e., lower than ocean water salinity). It is therefore possible that brackish salinity observed at this particular shallow groundwater sampling station reflects the mixing of ocean water with low-salinity water from leaking sewage collection lines.

6.3. Conclusions—Hydrographic and Circulation Studies

Based on the hydrographic and current studies, the following conclusions can be formulated:

1. The rates of advection and diffusion within Avalon Harbor are not large. The typical horizontal eddy diffusion rate is 1 m^2/s and horizontal advection is on the order of 50-200 m/hr (1.4 – 5.6 cm/s).
2. While the rates are not high, they are sufficient to disperse contaminants that might be introduced near the beach within a matter of an hour provided that the source is not continuous.
3. From a very limited hydrographic survey there was no indication that the outfall plume was a source of contamination in the harbor. Although it is not possible to say that the outfall is never be a source of contamination in the harbor, it seems unlikely that it would be a frequent source of contamination.
4. A significant fraction of the Bay does appear to exchange with the tidal cycles. Our estimates from the current meters suggest that the inflow in the lower half of the water column can equal the entire volume of the harbor. However, because we were not able to sample the currents through the entire water column at two of the sites we are not certain of the exchange that occurs in the upper layer. Presumably the exchange occurring in the upper and lower layers of the water column should balance over the course of a tidal cycle.
5. Although currents could carry contaminants released outside the harbor into the harbor, the slow speeds and circulation of the harbor do not support significant transport of material to the beaches.
6. It also does not appear from our observations that there is a physical concentrating mechanism within the harbor that would cause materials that act essentially as dissolved material to accumulate and/or increase in concentration in a particular location.
7. The corner of the harbor where the storm drain discharges into the harbor does not appear to retain water for an extended period. Advection and diffusion away from the source occurs relatively rapidly. Within one hour water has advected 80-100 meters away from the corner and has diluted.

6.4. Data Synthesis

The most striking results from this study can be summarized as follows:

1. An analysis of historical DHS data suggest that the concentration of fecal indicator bacteria along the shoreline in Avalon Bay has steadily increased since 2002;
2. Fecal indicator bacteria concentrations are highest in ankle depth waters and in the very nearshore sediments along the Avalon Bay shoreline;
3. Fecal indicator bacteria concentrations are significantly elevated in shallow groundwater beneath the City of Avalon, particularly near the Pleasure Pier;
4. Based on a single 24-hour study, fecal indicator bacteria concentrations in ankle depth waters in Avalon Bay exhibit diurnal cycling, with higher concentrations occurring during the night-time falling tide.
5. An analysis of historical DHS water quality data, and month-long monitoring data collected as part of this project, indicate that shoreline concentrations of fecal indicator bacteria are highest near the Pleasure Pier.
6. Human fecal markers (both bacterial and viral) are present in the nearshore waters in Avalon Bay, and in the shallow groundwater beneath the City of Avalon. The human fecal markers are particularly prevelant in the shallow groundwater near the Pleasure Pier.
7. The shallow groundwater north of the Pleasure Pier has anamolously low salinity and low pH, compared to the other shallow groundwater sites tested.
8. Dye studies conducted in Avalon Bay indicate that pollution entering the Bay from the shoreline should dissipiate relatively rapidly (within hours) due to within-Bay advection and turbulent diffusion.

These results beg the question of what might be responsible for the very high concentrations of fecal indicator bacteria in the subsurface. Two possibilities that merit further exploration include: (1) fecal indicator bacteria in the shallow ground water originates from leaking sewage collection lines in the downtown area, or (2) fecal indicator bacteria are growing in the subsurface sediments and/or groundwater. Even in this second scenario leaking sewage collection lines could play a role, by providing a supply of nutrients for fecal indicator bacteria re-growth in the subsurface. Indeed, it is interesting to note that the sediments excavated from this trench were organic rich and smelled of hydrogen sulfide, consistent with the idea that they may have been sewage impacted. In either case, the ground water sampling results would appear to warrant follow-up investigation and possibly remediation. Remediation of sewage contaminated sands is apparently a topic about which little is known (Eric Edwards, LA DHS, personal communication).

The diurnal cycling of fecal indicator bacteria in Avalon Bay implies that when during the day a sample is collected can significantly affect the measured concentration of fecal indicator bacteria. Furthermore, where the samples are taken (in ankle depth or waist depth waters) can also affect measured fecal indicator bacteria concentrations. Relative to the routine Avalon Bay water quality monitoring programs carried out by the LA DHS and United Water, inconsistency in the time of day, and the location where samples are taken, could seriously confound interpretation of monitoring data. For example, samples collected early in the morning one day may contain high concentrations of fecal indicator bacteria from a source of fecal pollution. If the sampling is then repeated in the early

afternoon several days later, the concentration of fecal indicator bacteria may be significantly lower, even if the source of fecal pollution is still present. Given the fact that human pathogens can be more resistant to sunlight than indicator bacteria in marine systems, Los Angeles DHS and United Water should consider sampling only at ankle depth, and adopting a consistent early morning sampling schedule for their ongoing monitoring programs.

6.5. Recommendations

Based on the foregoing, it is possible that a portion of the fecal indicator bacteria contamination in Avalon Bay originates from the exfiltration of sewage and/or nuisance runoff contaminated groundwater. As of the writing of this report, the City continues to retrofit the sewage collection infrastructure in downtown Avalon. This project should ultimately reduce the input of fecal pollution into the local groundwater, and presumably improve shoreline water quality in Avalon Bay (although the latter has not yet occurred, according to the analysis in Chapter 3 of this report). It is recommended that a follow up study be carried out to determine if contaminant levels in the groundwater and surf zone are reduced following the completion of the retrofit project, and possibly to develop strategies to characterize and remediate sewage contamination in the shallow groundwater under downtown Avalon.