MISSION BAY
Clean Beaches Initiative Bacterial Source Identification Study

Final Report

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MISSION BAY
Clean Beaches Initiative
Bacterial Source Identification Study

Final Report

Prepared For:

State Water Resources Control Board

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"Funding for this project has been provided in full or in part through a contract with the State Water Resources Control Board (SWRCB) pursuant to the Costa-Machado Water Act of 2000 (Proposition 13) and any amendments thereto for the implementation of California's Nonpoint Source Pollution Control Program. The contents of this document do not necessarily reflect the views and policies of the SWRCB, nor does mention of trade names or commercial products constitute endorsement or recommendation for use."

Table of Contents

APPENDICES

List of Tables

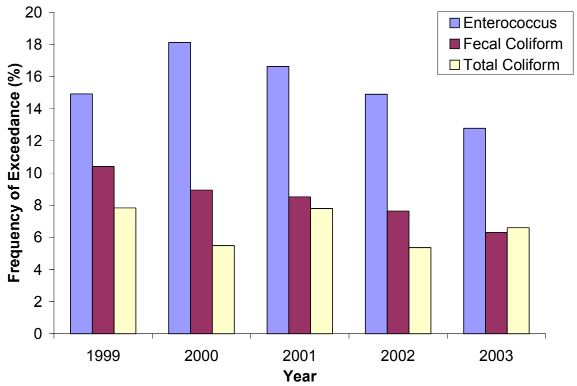
List of Figures

Introduction

Mission Bay, located in the City of San Diego, California is used by millions of people each year for a variety of recreational activities. The bay encompasses numerous smaller bays, coves, inlets, and stretches of beach that make it one of the City's most desirable places for aquatic recreation. Unfortunately, elevated levels of indicator bacteria (total coliform, fecal coliform, and enterococcus) have affected water quality in some areas of Mission Bay. Historically, the bay has had more beach postings and closures as a result of elevated bacterial levels than other beaches in San Diego County. As a result, the entire bay was listed as an impaired water body in 1998 under Section 303(d) of the Clean Water Act for exceedances of indicator bacterial standards (i.e., AB411 criteria). Although high levels of indicator bacteria in the bay have been well-documented, the sources of the bacteria have remained elusive. To address this problem, the City of San Diego obtained a Clean Beaches Initiative Grant (funded under Proposition 13) to conduct the Mission Bay Bacteria Source Identification Study. The purpose of the two year study was to identify sources of bacterial contamination in Mission Bay and recommend appropriate actions and activities to eliminate the input of those sources. The study was prepared for the California State Water Resources Control Board by the City of San Diego and MEC-Weston Solutions, Inc.

The City recognizes Mission Bay as a precious civic resource and for years has taken action to protect its water quality. These efforts span decades and continue today. The City Metropolitan Wastewater Department has renewed its infrastructure, including sewer main replacements, trunk sewers, and pump station upgrades within the Mission Bay area at a cost of over $120 million between 1985 and 1996. In the early 1990s, the City constructed the Mission Bay Sewage Interceptor System (MBSIS), a $10 million state-of-the-art low flow storm drain diversion system that encircles the bay. The system diverts dry weather flows, typically with high bacterial densities, from existing storm drains to the sanitary sewer system for treatment. In 2002, the City of San Diego's Storm Water Pollution Prevention Program received a $3 million dollar grant from the State Water Resources Control Board for water quality improvements in Mission Bay. A total of $1.3 million was appropriated for this study and the remainder was used for continued infrastructure improvements within the Mission Bay watershed. In addition, the City's Storm Water Pollution Prevention Program created the Mission Bay Water Quality Management Plan to better manage and coordinate the water quality projects being conducted in Mission Bay.

These efforts have been effective in reducing exceedances of water quality standards for bacteria in Mission Bay and, in recent years, the number of exceedances has decreased. In addition, many of the recreational beach areas in Mission Bay do not suffer from bacterial water quality exceedances, suggesting that input of bacteria to the bay is site-specific. Identifying the sources of elevated bacterial levels throughout this complex coastal embayment is a high priority for the City and the primary focus of this study.



Average percentage of bacterial analyses in Mission Bay that exceeded single sample criteria from 1999 through 2003.

Major Tasks of the Study

The overall goal of this study was to identify the sources of bacterial contamination to Mission Bay. There were six major investigative tasks designed to achieve this goal. Tasks 1 through 3 were conducted in Phase I from July 2002 through June 2003 and Tasks 4 through 6 were conducted in Phase II from July 2003 through June 2004.

- **Task 1 –** Investigate potential sources of human sewage from park restroom Infrastructure.
- **Task 2 –** Investigate potential sources of human sewage from moored or anchored boats.
- **Task 3 –** Conduct visual observations and bacterial assessments of other potential sources in the park.
- **Task 4 –** Identify the host origin (human, avian, etc.) of bacteria using Molecular Source Tracking techniques.
- **Task 5 –** Determine if bacteria are being transported from the grassy areas of Mission Bay Park to the receiving waters of the bay via groundwater.
- **Task 6 –** Determine if the sediments in Mission Bay act as a source of bacteria to the receiving waters at area beaches.

Mission Bay Investigation Sites

Twelve sites with persistently elevated bacterial densities were identified for the study.

Task 1 – Sources of Human Sewage from Park Infrastructure

A typical CCTV investigation of a sewer lateral line in Mission Bay Park

In Task 1, a total of 16 comfort stations (restrooms) around the 12 investigation sites were evaluated to determine if leaking infrastructure from these facilities was a source of bacteria to the bay. The lateral lines of the comfort stations, which carry sewage to the sewer mains, were visually inspected with a closed-circuit television (CCTV) system to assess their physical condition. The inspections revealed the integrity of the lateral lines of all of the comfort stations investigated were intact and were not a likely source of bacteria to the bay. The sewer mains themselves were not inspected as part of this study because they had been replaced within the last two decades.

Task 2 – Sources of Human Sewage from Moored Boats

Boats in Santa Barbara Cove at the Mission Bay Yacht Club

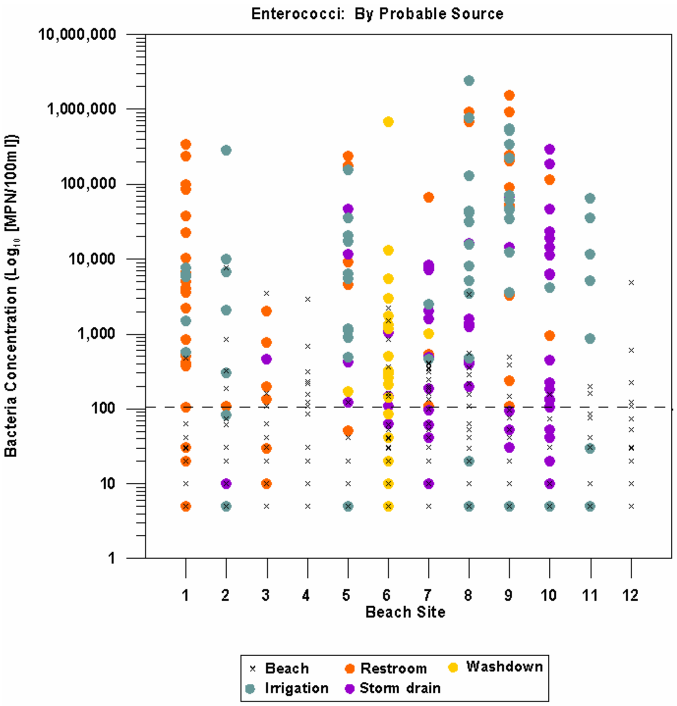
In Task 2, illicit discharge of sewage from boat holding tanks was investigated as a potential source of bacteria at three locations in Mission Bay where boats moor or anchor: Bonita Cove, Santa Barbara Cove, and De Anza Cove. At each site, samples were collected for bacterial analyses in surface waters surrounding the moored or anchored boats and from a beach location where routine monitoring is conducted. The samples near the boats were collected by kayak. Each site was sampled on three separate days. Very low densities of all three bacterial indicators were detected throughout the study at all three sites. In most cases, the densities were below or just above the detection limits. The lack of elevated levels of indicator bacteria from any of the samples collected indicates illegal discharge of sewage from moored and anchored boats was not occurring during the time of sampling. The results also suggest illegal sewage dumping from moored and anchored boats is not a likely chronic source of bacterial contamination at the beach. However, the illegal discharge of sewage holding tanks from moored boats is inherently episodic and the results of the study do not rule out the potential for isolated events.

Task 3 – Visual Observations Study

Sampling receiving water at Bonita Cove

Task 3 was designed to assess the numerous potential sources of bacteria to Mission Bay other than leaking comfort station infrastructure and illicit discharge from moored and anchored boats. The potential sources assessed included fecal matter from birds and feral and wild animals that inhabit the park, the homeless population, the behavior of some park visitors, and park management practices, such as comfort station cleaning and irrigation procedures. Task 3 included comprehensive visual observations conducted in conjunction with samples taken for analysis of indicator bacteria. Observations and sampling took place during three periods between mid-August and mid-October 2002: low-use, medium-use, and high-use. Within each of these periods, the study included three days of observation (sunrise to sunset). During each day of observation, samples for bacterial analyses (total coliform, fecal coliform, and enterococcus) were taken at 12 sampling locations, three times per day. The results were compared to standards for the three indicator bacteria. In addition, "spot sampling" was conducted at areas where bacterial influx to the bay was expected (e.g., flowing storm drains).

A total of approximately 1,300 man-hours of visual observations were made during the nine days of the study (over 100 hours per site). In addition, over 500 samples from receiving waters and suspected sources were collected and analyzed for indicator bacteria.



Plot of enterococcus density by site and probable source during the Visual Observations Task. The dashed line represents the AB411 single sample criteria of 104 MPN/100 ml.

After all of the spot samples had been assessed, the data were categorized by probable source and summarized by site. It was clear from the analysis that each of the 12 sites had a unique set of potential bacterial sources. For instance, most of the samples taken at Bonita Cove (Site 1) were from drainage around comfort stations, most samples at North Pacific Passage (Site 10) were from flowing drains, and most samples from Campland (Site 6) were from boat washdown. The other sites had a mixture of potential sources.

It was clear from the results of Phase I that each of the 12 sites examined had a unique set of characteristics related to potential bacterial sources. At many sites assessed in Phase I, potential bacterial sources initially identified were found not to have an impact on bacterial densities in the receiving waters. The list included illicit discharge of sewage from boats, comfort station infrastructure, the homeless, and RV pump-out stations. In addition, management actions initiated by the City allowed for the removal of potential sources such as comfort station washdown and pet waste at most sites. The results of Phase I were also important in focusing attention on the more likely sources of bacterial influx to the bay identified at the end of the study, such as birds, storm drains, groundwater, and irrigation runoff.

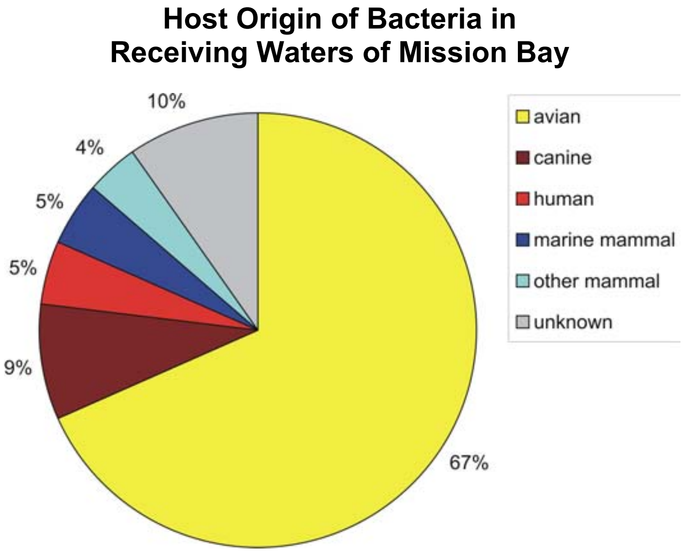
Task 4 – Microbial Source Tracking

One of the major goals of this study was to identify the host origin (human, avian, etc.) of the indicator bacteria found in Mission Bay. To this end, two molecular source tracking (MST) techniques were employed:

1) **Ribotyping –** A Ribotype is the unique genetic fingerprint of a single bacterial cell, also known as an isolate. Ribotyping analysis relies on a comparison of the fingerprint from bacteria collected from the site (Mission Bay receiving water, storm drain effluent, etc.) to a library database of DNA fingerprints derived from known or confirmed host animal fecal specimens. The results of the Ribotyping assessment allow us to determine the host origin (human, avian, canine, etc.) of bacteria in the receiving waters as well as the suspected conduit or reservoir from which the bacteria were derived (e.g., storm drains, sediments, organic debris, etc.).

2) **Host-Specific PCR –** The polymerase chain reaction (PCR) technique takes advantage of host-specific genetic differences in an anaerobic bacteria, *Bacteroides*, a major bacterial resident present in feces of warm blooded animals. The HS-PCR assay provides a rapid first step in tracking bacterial host origin and allows us to determine the presence or absence of human fecal contamination.

The results of Phase I were used to focus the efforts of the MST Task on sites that had the highest number of exceedances of AB411 criteria: Bonita Cove, Fanuel Park, Wildlife Refuge, Campland, De Anza Cove, Visitor's Center, and Leisure Lagoon. A total of 1,097 receiving water isolates were analyzed. The results of the Ribotyping analysis indicate that birds are the dominant source of the indicator bacteria in the receiving waters of Mission Bay. Avian sources accounted for 67% of all the bacterial isolates collected from the receiving waters in this study, followed by Unknown and Canine. The percentage of bacterial isolates that originated from Human sources was very small, accounting for only 5% of the total number of isolates.



Results of Ribotyping analysis of receiving water samples collected at all sites studied in Mission Bay between July 2003 and April 2004.

The results of the HS-PCR analyses for Mission Bay receiving water samples strongly support the Ribotyping results. Of the 175 receiving water samples analyzed with the HS-PCR assay, only 9% contained bacterial DNA that was positive for bacteria from human origin.

Because each of the sites assessed in Mission Bay had different characteristics related to bacterial sources and pathways, the dominant suspected source (e.g., storm drain effluent) or sources at each site were assessed using MST along with the receiving waters. In this way, the origin of bacteria in a storm drain, for instance, could be assessed. A summary of the bacterial host origin in receiving waters and major suspected source is presented in the table below.

Summary of Ribotyping results showing the percentage of isolates from the major hosts identified in receiving water and suspected source water (storm drains, etc.). The dominant host origin in each sample type is highlighted in red.

Site	Sample Type	Avian	Canine	Marine Mammal	Other Mammal	Unknown	Human
Bonita Cove	Receiving Water	75	7	2	5	5	6
	Storm Drain	68	10	0	12	10	0
Fanuel Park	Receiving Water	69	7	10	3	4	7
	Storm Drain	60	20	0	15	5	0
Campland	Receiving Water – Dry*	79	8	1	7	1	4
	Receiving Water – Wet	69	10	5	1	13	2
De Anza Cove	Receiving Water – Dry	64	5	4	6	12	9
	Storm Drain – Dry	48	19	0	29	0	4
	Receiving Water – Wet	80	3	8	2	5	2
	Storm Drain – Wet	49	29	0	19	3	0
Visitor's Center	Receiving Water	66	14	8	4	6	2
	Storm Drain	49	27	0	13	11	0
	Cudahy Creek	66	23	0	3	7	1
Leisure Lagoon	Receiving Water	46	16	1	3	29	5
	Storm Drain	58	16	0	22	4	0

* Dry refers to samples collected from July 1, 2003 through November 10, 2003. Wet refers to samples collected from November 11, 2003 through April 7, 2004.

It is clear from the results that a large majority of the indicator bacteria in Mission Bay receiving waters and major sources (e.g., storm drains) originates from birds. This was a consistent observation at all sites. In addition, the proportion of bacteria from human origin was very small in the receiving waters and particularly the storm drains. The very low percentage in the storm drains suggests the small amount of bacteria from human origin present in the receiving waters of Mission Bay originates on the beach rather than from Mission Bay Park or the upstream watershed.

In addition to identifying the host origin of bacteria, the genetic fingerprint provided by the Ribotyping assay was used to determine the proportion of the bacteria in the receiving waters also found in the effluent from suspected sources. A high degree of similarity between the genetic fingerprints of bacteria in the receiving water and those in storm drain effluent, for instance, suggests that the storm drain is a source of bacteria to the receiving waters. This assessment was completed for the sites in Mission Bay and, in general, there was good agreement between the genetic fingerprints of bacteria in the storm drains and those in the receiving waters. These results suggest that storm drains are a source of indicator bacteria to the receiving waters at the sites assessed.

Task 5 – Bacterial Fate and Transport

During the Phase I investigations, very high densities of indicator bacteria were found in the grassy areas of Mission Bay Park. Excessive irrigation at some sites facilitated the transport of the bacteria in the grass to the receiving waters through the Mission Bay Park storm drains. The primary goal of the Fate and Transport study was to determine if bacteria in the grass are also being transported from the grassy areas of the park to the receiving waters via groundwater. Two types of assessments were conducted:

1. An assessment of bacterial densities in soil beneath the grassy areas of Mission Bay Park; and
2. An assessment of bacterial densities in groundwater at the same locations and at the beach face springs.

Drilling groundwater wells

Three sites were assessed in the Fate and Transport study: De Anza Cove, Visitor's Center, and Leisure Lagoon. At each site, a series of three wells was drilled along a transect in line with the beach face spring, perpendicular to the bay receiving waters. At each well, three sampling probes attached to sterile tubing were inserted into the soil at depths of 4, 7, and 12 feet below the surface of the ground. Groundwater was extracted from each of the wells using a peristaltic pump and fecal coliform and enterococcus bacteria were enumerated.

The results of the study revealed that the grassy areas of the three sites assessed (and likely other areas in Mission Bay Park) contain a large reservoir of both fecal coliform and enterococcus bacteria. The origin of the bacteria was determined to be predominantly avian. However, an analysis of bacterial density with depth from the soil core samples indicated the migration of bacteria from the park surface to the groundwater is limited to the upper 18 inches of soil by layers of clay and other fine-grained material. Virtually no indicator bacteria were found in the groundwater wells or beach face springs. The results indicated the grassy areas of the park and the soil directly beneath it contain a large reservoir of indicator bacteria, but the bacteria is not transported to the receiving waters of Mission Bay via groundwater seepage through the beach. However, the bacteria can be transported to the bay via excessive irrigation and subsequent flow through the park storm drains. The observations made in Phase I suggested that this is occurring at several sites in Mission Bay.

Task 6 – Sediment Investigation

The primary goal of the Sediment Investigation Task was to determine if the sediments in Mission Bay act as a source of bacteria to the receiving waters at area beaches. Investigations were conducted to determine the potential for receiving water bacterial contamination originating from two types of sediments in Mission Bay:

1) Sediments in deltas at the mouths of the three major drainages that discharge to Mission Bay (Rose Creek, Cudahy Creek, and Tecolote Creek), which may contaminate adjacent beaches via tidal currents; and
2) Intertidal sediments, which may contaminate receiving water via resuspension when the sediments are disturbed. Intertidal sediments were assessed at Bonita Cove, De Anza Cove, and Leisure Lagoon.

For the delta sediment study investigation, two surveys were conducted: dry season (October 2003) and wet season (January 2004). During both surveys, sediment cores were taken from an inflatable raft and analyzed for fecal coliform and enterococcus bacteria from sediments at the surface and at a depth of four inches. In addition, bacteria from the surficial sediments and receiving waters at AB411 monitoring sites adjacent to the beaches were analyzed to determine the bacteria's host origin.

Collecting sediment cores from Tecolote Creek delta

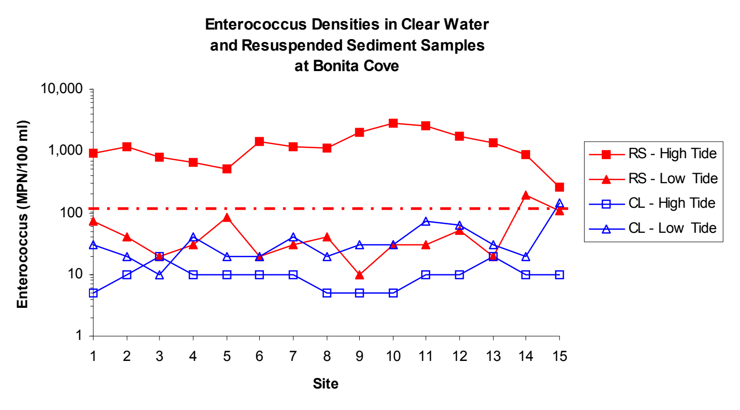
During the dry weather survey, fecal coliform and enterococcus densities were generally low at all three sites in samples taken from the sediment surface as well as at depth (four inches below the surface). During the wet weather survey, the mean enterococcus density in surficial sediments increased dramatically at all three sites. The most remarkable differences between the two surveys, however, were in enterococcus densities at depth. At Rose Creek, the mean enterococcus density at depth (4,703 MPN/g) was significantly greater than the dry weather mean at depth and an order of magnitude higher than any other value measured in either survey. Enterococcus densities at two of the three samples collected at depth from Cudahy Creek were also extremely high (3,047 and 1,375 MPN/g) and similar in magnitude to samples collected at depth at Rose Creek.

Ribotyping analysis of the samples from Tecolote Creek indicated that the majority of the bacteria found in the sediment and receiving waters during the wet season originated from Avian sources. When the Ribotypes from the receiving water were compared to those from the sediment, we found that 45% of the isolates matched, which suggests that the delta sediment at Tecolote Creek may act as a source of bacteria to the receiving waters. However, the receiving water samples were collected during extremely high tides when currents that would transport bacteria from the sediments to the receiving water monitoring site were maximal. When the data were applied to a simple transport model, the results suggest that under most conditions, current velocities are insufficient to transport bacteria associated with delta sediments to the receiving water monitoring sites. Thus, sediments in the deltas of the major drainages to Mission Bay are unlikely sources of bacteria to the receiving waters under most conditions.

To assess the extent to which intertidal sediments on the beach impact bacterial densities in the receiving waters, two types of assessments were conducted:

1) Beach face transects, which provided a profile of bacterial densities in the intertidal sediments from the high to low tide marks.
2) Sediment resuspension analysis, which provided a measure of the extent to which resuspension of beach sediments contributed to bacterial levels in the receiving water.

The results of the beach face transect assessment indicated that there was a strong spatial pattern of bacterial densities along the beach face. Bacteria in beach face sediment samples collected in the upper intertidal zone were typically an order of magnitude greater than those in the lower intertidal zone. Thus, the beach face sands in the upper intertidal zone acts as a reservoir for fecal coliform and enterococcus bacteria. The sediment resuspension assessment was designed to determine if bacteria associated with the upper intertidal beach face sediments were a source of bacteria to the receiving waters when the sediments are disturbed (e.g., from swimmer activity). To test this possibility, two consecutive receiving water samples were taken. The first was a “clear water” sample, which was taken using standard protocols in which the underlying sediments were not disturbed. Immediately after the clear water sample had been collected, the sampler disturbed the beach face sediments at that location by mixing the sediment into the water column with his feet (similar to what a swimmer would do). A sample was then taken from the water column that contained the resuspended sediment. We refer to this as the “resuspended sediment” sample.



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

The results of the resuspension study indicate that the bacterial reservoir maintained in the beach face sediments within the upper intertidal zone are released to the receiving waters when they are disturbed. When the experiment was repeated in the lower intertidal zone, there was no difference between the “clear water” and resuspended beach sediment samples, reflecting the low bacterial densities found in the lower intertidal beach face sediments. These results suggest that upper intertidal beach face sediments can act as a source of bacteria to the receiving waters of Mission Bay when the sediments are resuspended. This mechanism is thought to be a substantial source of indicator bacteria at several sites in Mission Bay.

Bacterial Amplifiers

Towards the end of the completion of the six investigative tasks conducted in this study, two additional investigations were carried out. They were based on observations made over the course of the study that organic debris (eel grass, algae, etc.) washed up on beaches and deposited in some storm drains appeared to be associated with elevated bacterial densities at some sites.

Two studies were conducted to assess the extent to which organic debris contributed to elevated bacterial densities in the receiving waters:

1) a field study, which investigated the wrack line (primarily organic debris, such as eel grass and algae) that is deposited on some beaches in the upper intertidal zone; and

2) a laboratory study, which investigated the potential for growth of indicator bacteria under conditions typically found in a tidally-influenced storm drain.

The objective of both studies was to assess the extent to which these two areas amplified the indicator bacterial load in the receiving waters of Mission Bay.

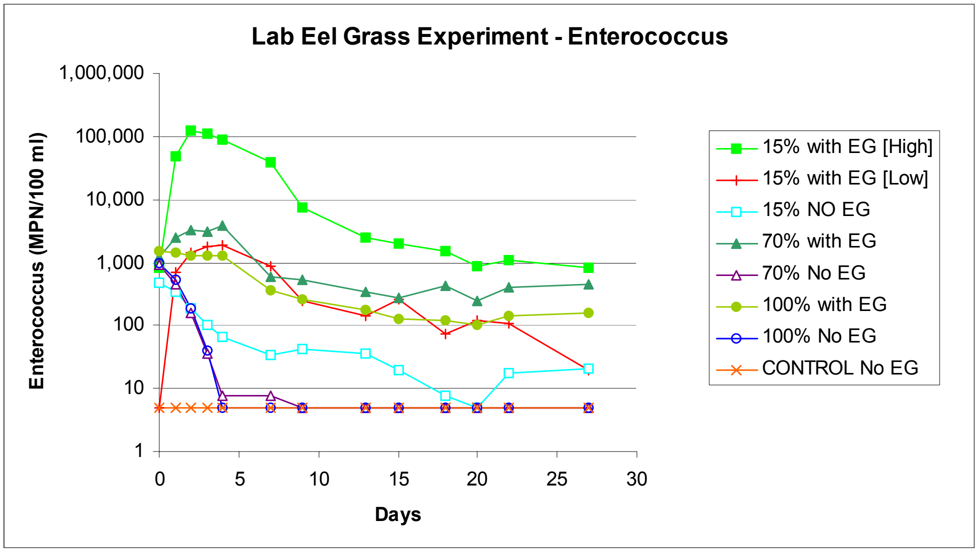
Wrack line on beach at Riviera Shores

In the wrack line investigation, samples of the wrack were collected over an eleven day period after the wrack had been deposited on the beach by a high, spring tide. Bay water did not make contact with the wrack during the sampling period. Wrack samples were collected from two sites (Riviera Shores and Visitor's Center) and analyzed for fecal coliform and enterococcus bacteria. The results indicated that, at both sites, indicator bacterial densities were maintained at elevated levels for the entire eleven day period, suggesting that the wrack line acted as a bacterial reservoir.

At the end of the initial sampling period, receiving water samples were collected over a tidal cycle as the subsequent spring tide washed over the wrack line. Bacterial densities were low during low tide at the beginning of the tidal cycle before the water made contact with the wrack line. As the tide rose, bacterial densities increased, peaking when the water made maximal contact with the wrack, then decreased as the tide receded. These results strongly suggest the indicator bacteria retained in the wrack line are released to the receiving waters during high tide when the bay water makes contact with the wrack. In this way, the wrack amplifies the initial bacterial load. This mechanism is thought to be an important source of indicator bacteria to the receiving waters at several sites in Mission Bay, particularly in areas where no other bacterial sources have been identified.

The second investigation of bacterial amplification simulated in the laboratory the conditions inside a tidally influenced storm drain. Flasks containing clumps of sterilized eel grass and varying dilutions of sterilized seawater were inoculated with indicator fecal coliform and enterococcus bacteria. The flasks were maintained in the dark under controlled conditions. Bacterial densities were then monitored over a 27-day period.

The results of this simulation for enterococcus are shown in the graph below. The results show that indicator bacteria can survive for an extended period of time in the presence of an organic substrate (eel grass) in 100% seawater (salinity of 32 parts per thousand) and 70% seawater (23 ppt). Survival was reduced in the absence of eel grass. The most remarkable results of the study were for bacteria in 15% seawater (approximately 5 ppt) in the presence of eel grass. Both fecal coliform and enterococcus densities increased dramatically in this environment by several orders of magnitude within the first few days of the experiment. Extremely high densities were maintained for nearly a week before leveling off, but elevated densities continued to be maintained throughout the course of the 27-day study.



Enterococcus densities over time under simulated storm drain conditions. EG refers to flasks containing eel grass. [High] and [Low] refer to initial bacterial inoculant densities.

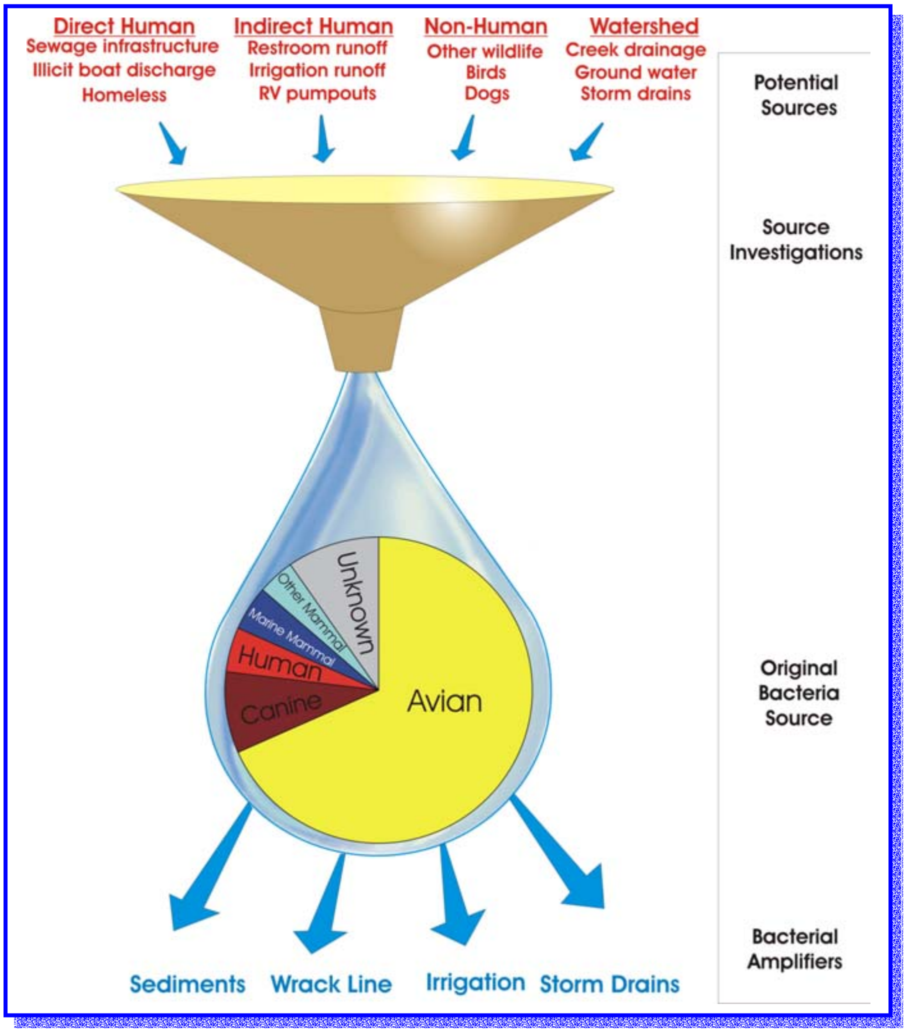
The results of the storm drain simulation experiment suggest that both fecal coliform and enterococcus bacteria can survive for prolonged periods of time in coastal storm drains, particularly in the presence of an organic substrate. When freshwater is present in the storm drain, as is often the case due to groundwater intrusion, bacterial densities can increase by several orders of magnitude within a few days of the initial deposition. In this way, storm drains that discharge to Mission Bay can act as bacterial incubators, amplifying the original bacterial load in both magnitude and time.

Summary of Findings

The overall results of the Mission Bay Source Identification Study are summarized below.

- The infrastructure of comfort stations within Mission Bay Park is an unlikely source of fecal pollution to the bay.
- Illegal sewage discharge from moored and anchored boats is not a likely chronic source of bacterial contamination at the beach, although the results of the study do not rule out the potential for isolated discharge events.
- The results from the Visual Observations Task suggested that several potential bacterial sources identified at the beginning of the study were not likely to be contributing bacteria to the bay. These included rodents and wildlife other than birds, leaking garbage cans, trash or food in the park, illicit boat discharge, improper use of recreational vehicle pump-outs, the homeless population, and pet waste (except at Hidden Anchorage). The results also indicated that each site examined in the study was unique in terms of potential bacterial sources.
- Results from both Microbial Source Tracking methods utilized in Phase II confirmed that the large majority of the indicator bacteria in Mission Bay originates from birds and contributions from human sources are insignificant.
- The Fate and Transport study showed that groundwater is an unlikely source of bacteria to the receiving waters of Mission Bay. However, bacteria in the grassy areas of the park are transported to the bay via storm drains due to excessive irrigation.
- The results of the sediment investigation suggested that the deltas of the major drainages to Mission Bay are unlikely sources of bacteria to the receiving waters under most conditions. However, indicator bacteria retained in the intertidal sediments (particularly those in the upper intertidal zone) can act as a source of bacteria to the receiving waters when the sediments are disturbed.
- The wrack line and tidally influenced storm drains at some sites in Mission Bay can amplify the initial bacterial load.

The study is summarized in the conceptual model below.



Recommendations

Overall, the results of this study suggest that the majority of the indicator bacteria in Mission Bay originates from birds and that the initial load generated from avian sources can then be amplified by processes related to four areas:

1. irrigation runoff,
2. storm drains,
3. intertidal sediments, and
4. the wrack line

Because little can be done about the number of birds in Mission Bay, recommendations on reducing bacterial densities in the bay receiving waters focused on these four areas. The City is actively pursuing management actions to address these recommendations.

Introduction

Background

Mission Bay is a large coastal embayment located within the City of San Diego used by millions of residents and tourists throughout the county. Unfortunately, high levels of bacteria indicative of fecal pollution (total coliform, fecal coliform, and enterococcus) have been detected in Mission Bay since monitoring began in the 1960s, thus diminishing the recreational value of many of the bay's coastline areas. In 1998, the entire bay was listed as an impaired water body under Section 303(d) of the Clean Water Act for exceedances of indicator bacterial standards (i.e., AB411 criteria). Although high levels of indicator bacteria in the bay have been well documented, the sources of the bacteria had not been investigated in any comprehensive way prior to this study. As a result, the State Water Resources Control Board (SWRCB) approved a Clean Beaches Initiative Grant (funded under Proposition 13) for the City of San Diego to conduct a bacterial source identification study in Mission Bay. This report summarizes the results of the comprehensive two-year study.

For decades, the City has recognized Mission Bay as a precious civic resource and has taken action to protect its water quality. The City Metropolitan Wastewater Department has renewed its infrastructure, including sewer main replacements, trunk sewers, and pump station upgrades within the Mission Bay area at a cost of over $120 million between 1985 and 1996. In the early 1990s, the City constructed the Mission Bay Sewage Interceptor System (MBSIS), a $10 million state-of-the-art low flow storm drain diversion system that encircles the bay. The system diverts dry weather flows, typically with high bacterial densities, from existing storm drains to the sanitary sewer system for treatment. In 2002, the City of San Diego's Storm Water Pollution Prevention Program received a $3 million dollar grant from the State Water Resources Control Board for water quality improvements in Mission Bay. A total of $1.3 million was appropriated for this study and the remainder was used for continued infrastructure improvements within the Mission Bay watershed.

In addition, the City's Storm Water Pollution Prevention Program created the Mission Bay Water Quality Management Plan to better manage and coordinate the water quality projects being conducted in Mission Bay. The Plan was implemented by the City of San Diego under the direction of the City's Storm Water Pollution Prevention Program with assistance from a Mission Bay Clean Water Technical Advisory Committee, the Mayor's Clean Water Task Force, and the Mayor and City Council. There are seven projects that are administered under the Plan that provide important information for understanding and controlling bacterial pollution in Mission Bay. One of these projects is the Mission Bay Bacterial Source Identification Study and the subject of this report. The other six projects address a wide range of subjects related to contamination of Mission Bay, including a contaminant dispersion model, an epidemiological study, a water quality survey, an evaluation of benthic and pelagic communities in the bay, and best management practices and engineering solutions to reduce pollutant loading.

These efforts have been effective in reducing the levels of indicator bacteria at many areas of Mission Bay and, in recent years, the number of exceedances of AB411 standards has decreased (Figure 1-1). In addition, many of the recreational beach areas in Mission Bay do not suffer from bacterial water quality exceedances, suggesting that input of bacteria to the bay is site-specific. Identifying the sources of elevated bacterial levels throughout this complex coastal embayment is a high priority for the City and the primary focus of this study.

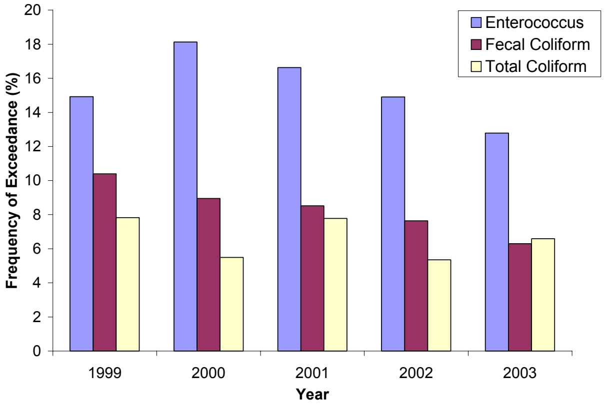


Figure 1-1. Average percentage of bacterial analyses in Mission Bay that exceeded single sample criteria from 1999 through 2003 (Source: MEC-Weston 2004).

Project Scope

The purpose of this study was to plan, design and implement a bacterial source identification study to identify sources of bacterial contamination in Mission Bay and recommend appropriate actions and activities to eliminate the input of those sources to the bay. To help focus the scope of work at the onset of the project, a literature review was conducted on reports that assessed bacterial densities in Mission Bay and in waterbodies with similar characteristics. The results suggested that elevated bacterial densities in Mission Bay were likely not derived from one or a few large sources, as has been found in other areas of southern California (e.g., Huntington Beach). Rather, it appeared likely that sources were dependent on characteristics specific to each individual site. The complexity of factors affecting bacterial pollution in Mission Bay required the development of a study plan with breadth, yet also allowed for independent specificity in approaching each site's unique composition of potential sources.

The study design utilized a tiered approach that focused first on potential sources of bacteria from human origin, since these sources are most likely to impact bathers in Mission Bay. Secondly, a broad scale assessment was designed to investigate the numerous other potential bacterial sources that had been suggested. Finally, subsequent studies were used to identify the host origin (human, avian, etc.) of bacteria in the bay and to assess mechanisms identified in the initial studies by which bacteria may be transported to the bay's receiving waters.

The project was conducted in two phases. Phase I was initiated on July 1, 2002 and was completed on June 30, 2003. The goal of Phase I was to assess bacterial contamination of Mission Bay on a broad scale and identify the major bacterial sources to the bay's receiving waters. There were three major investigative tasks designed to achieve this goal:

Task 1 – Investigate sources of human sewage from restroom infrastructure within Mission Bay Park;
Task 2 – Investigate sources of human sewage from illicit discharge of sewage from moored or anchored boats;
Task 3 – Conduct visual observations and bacterial assessments of other potential bacterial sources within Mission Bay Park.

The results of Phase I greatly reduced the list of potential bacterial sources in Mission Bay and identified several areas that warranted further investigation. Phase II of the study was initiated on July 1, 2003 and was completed on June 30, 2004. Three major investigative tasks were designed in Phase II to investigate the major potential sources identified in Phase I and to identify the host origin (human, avian, etc.) of the enteric bacteria in Mission Bay:

Task 4 – Identify the origins of enteric bacteria in the bay using microbial source tracking (MST) techniques;
Task 5 – Investigate the transport mechanisms of bacteria from the surface of Mission Bay Park to the bay receiving waters (i.e., fate and transport study);
Task 6 – Investigate the extent to which sediment acts as a source of bacteria to bay receiving waters.

In addition to performing the investigative tasks, staff from the City of San Diego and MEC Analytical Systems – Weston Solutions, Inc. (MEC) held bi-weekly project update meetings and worked with other City departments. Coordination with the City Park and Recreation Department was integral to the study's success. Park staff readily provided information on Mission Bay Park, was very proactive in the improvement of management activities to reduce potential bacteria sources to the Bay, and regularly attended project meetings. Representatives of the City Real Estate Assets Department also attended project meetings and helped to facilitate communication between researchers and tenants on the bay. The City Metropolitan Wastewater Department provided essential maps and assisted researchers in field investigations. The Transportation Department, Streets Division notified researchers of potential sources of pollution within the storm water conveyance system. The involvement of multiple departments within the City helped to facilitate a seamless implementation of study objectives. Additionally, a cooperative effort in data sharing with the San Diego County Department of Environmental Health allowed for increased statistical analyses.

The results of the investigative tasks, additional follow-up efforts, and management actions taken within the scope of the two-year study are summarized in this report.

Project Area

Mission Bay is considered by many to be one of the most beautiful areas in the City of San Diego. Located just north of downtown San Diego, Mission Bay and the park that surrounds it is used year-round for walking, jogging, picnicking, and a variety of water contact sports, including swimming, sailing, water skiing, and fishing. Mission Bay Park is the largest known human-constructed aquatic park in the world, encompassing over 27 miles of shoreline (Corrao Brady and Hirsch 1995). In the 1940s, the marshland that was located where Mission Bay is now was dredged to form the existing bay and park. As it is today, the bay itself encompasses numerous smaller bays, coves, inlets, and stretches of beach that make it such a desirable place for aquatic recreation (Figure 1-2).

Figure 1-2. Map of Mission Bay showing major geographic features.

Mission Bay is connected to the ocean through a large rip-rapped channel on the bay's southwest corner (Figure 1-2). Tidal flushing is thought to be fairly good near the channel, but circulation is restricted in the eastern portion of the bay, particularly near the mouth of Tecolote Creek. The Mission Bay watershed encompasses three hydrologic areas that drain to the eastern portion of the bay via Rose and Tecolote Creeks. In addition, there are approximately 100 storm drains that carry urban runoff to Mission Bay.

Historically, many of the high bacterial counts in Mission Bay have been attributed to sewer overflows and other sources that convey bacteria to the bay through the storm drain system. To respond to this problem, the City of San Diego constructed the Mission Bay Sewage Interceptor System (MBSIS), a storm drain diversion system that encircles the bay. The overall purpose of the MBSIS is to protect the water quality of Mission Bay by diverting pollutants that flow through the storm drains to the sewer system before they enter the bay. The MBSIS was initiated in 1987 when a Mission Bay Interceptor Master Plan was developed, which provided a blueprint for its construction (Hirsch 1987). The first step of the Master Plan was to prioritize the storm drains in Mission Bay relative to their potential for carrying human sewage to the bay. The criteria used for this prioritization included the size of the storm drain, whether it was an outlet for a sanitary sewage pump station, its proximity to a trunk sewer, and its potential for collecting sewage spills. Based on the prioritization, 23 storm drains were ranked with a priority of zero, indicating that they had no sewage spill potential. These storm drains were subsequently removed from the Master Plan and are not part of the current MBSIS.

It is important to note that potential sources of bacteria other than human sewage (e.g., urban runoff, bird fecal matter, etc.) were not included in this prioritization. During Phase I of this study, there were several storm drains identified that were not discussed in the Master Plan and are not included in other City storm drain maps. The potential for these storm drains to convey human sewage to the bay was considered low in the Master Plan and are therefore not part of the diversion system. However, they can convey bacteria to the bay from other sources, such as bird waste or urban runoff from areas within Mission Bay Park.

During the Visual Observations investigative task of this study, storm drains were observed to be flowing at several of the investigation sites. Because these flows were often associated with elevated bacterial levels, the condition of the storm drains and the MBSIS was also assessed in subsequent follow-up investigations. A more complete discussion of the MBSIS and an assessment of its ability to divert dry weather flows are presented in the appendices (see report organization at the end of this section).

Bacterial Standards

To have a complete understanding of the issue related to bacterial densities in Mission Bay, it is important to include a discussion of the criteria used to determine when a water body is considered out of compliance. The primary criteria used to assess bacteria levels in coastal waters in southern California (including Mission Bay) are based upon the densities of three groups of bacteria: total coliforms, fecal coliforms, and enterococcus. Collectively these bacteria are referred to as indicator bacteria because their abundance in the environment provides an indication of the presence of pathogenic microorganisms and may indicate fecal contamination. The numeric standards for these three indicators, known as AB411 criteria, are presented in Table 1-1.

Table 1-1. Assembly Bill 411 (AB411) bacteriological standards.

Bacterial Indicator	30-Day Limit[1]	Single Sample Limit
Total Coliform	1,000 MPN/ 100 ml[2]	1,000 MPN/ 100 ml if Fecal > 10% of Total, or 10,000 MPN/100 ml[3]
Fecal Coliform	200 MPN/ 100 ml	400 MPN/ 100 ml
Enterococcus	35 MPN/ 100 ml	104 MPN/ 100 ml

1 = 30 day limit is based on the geometric mean of at least five weekly samples
2 = MPN is Most Probable Number
3 = Total coliform single sample limit of 10,000 MPN drops to 1,000 when the fecal coliform value is greater then 10% of total coliform value

The history and background of the AB411 criteria are presented below for each indicator.

Assembly Bill 411 (AB411), also known as “The Right to Know Bill”, was sponsored by Assemblyman Howard Wayne and was enacted in October of 1997. The Bill requires that for the months of April through October, weekly bacterial monitoring be performed at all beaches with more than 50,000 annual visitors that are adjacent to storm drains with summer flow. Any beaches found to exceed the bacterial limits enforced by the Bill are posted with warning signs to notify the public of potential health risks. The criteria set forth in AB411 were in effect years before the Bill was passed. However, the Bill was created to update and enforce bacteriological safety standards set forth in the California Code of Regulations to provide a regulatory framework by which the numerical limits can be stringently enforced. The criteria established for total coliforms, fecal coliforms, and enterococcus were derived separately over the past several decades and are discussed here individually.

Total Coliforms. Total coliforms have been the basis for determining water quality for over a century. Coliform bacteria was the first family of organisms used in epidemiological studies to determine the effects of contaminated water on the health of recreational bathers. In the 1940s and 1950s, the U.S. Public Health Service performed epidemiological studies on bathers in Lake Michigan, the Ohio River, and Long Island Sound (USEPA 1986). The most significant of these was the Ohio River study (USEPA 1986). This study compared illness observed in bathers exposed for three days to water with high and low coliform densities. The study found that significantly higher illness rates occurred in bathers exposed to water containing a geometric mean of 2,300 coliforms per 100 ml compared to 43 coliforms per 100 ml. There was no difference in illness rates in bathers exposed to water containing lower coliform densities of 732 versus 32 coliforms per 100 ml. Two additional marine bathing beach studies showed no association between illness and swimming in water containing up to 815 coliforms per 100 ml (USEPA 1986).

In 1986 the U.S. Environmental Protection Agency (EPA) summarized the results of these studies and found that a 30-day geometric mean of 1,000 coliforms per 100 ml was an acceptable level for recreational water safety (USEPA 1986). In addition, an instantaneous maximum of 10,000 coliforms per 100 ml was set as the single sample standard. In an epidemiological study of 15,000 swimmers in Santa Monica Bay, this ‘instantaneous maximum’ was determined to be reasonable (Haile et al. 1996). Researchers found that exposures at levels greater than the 10,000 coliform per 100 ml resulted in a 200% increase in certain health risks, supporting the EPA 10,000 coliform limit.

Fecal Coliforms. AB411 criteria include a single sample standard of 400 fecal coliforms per 100 ml and a 30-day geometric mean of 200 fecal coliforms per 100 ml. These numeric standards were based on the Ohio River study previously mentioned. In this study, it was determined that approximately 18% of the total coliforms found in the Ohio River were of the fecal coliform group. As discussed above, the EPA summary of total coliforms found a limit of 2,300 total coliforms to be the point in which illness was significantly increased. Interestingly, the limit of 400 fecal coliforms per 100 ml was generated by simply multiplying the value for total coliform (2,300 per 100 ml) by 18%. The National Technical Advisory Committee of the Department of the Interior was authorized to make recommendations regarding the safety of recreational waters and argued that a detectable increase in disease was not acceptable. Therefore, the criteria of 400 fecal coliform per 100 ml was set at 200 per 100 ml as the 30-day geometric mean criteria. The Santa Monica Bay epidemiological study (Haile et al. 1996) found the 400 fecal coliform per 100 ml limit to be reasonable. It was found that exposures to levels greater than that were related to an 88% increase in the risk of skin rashes. Both the total and fecal coliform limits expressed above are consistent with the State Water Resources Control Board's (SWRCB) California Ocean Plan used today.

Enterococcus. The AB411 standards for enterococcus include a single sample standard of 104 enterococcus per 100 ml, with a 30-day geometric mean of 35 per 100 ml. In the 1970s, the EPA performed epidemiological studies involving 27,000 people at several beaches in New York, Louisiana, and Massachusetts (Cabelli 1983). The investigators found that enterococcus was the best of the 3 indicator bacteria for the prediction of human illness associated with recreational waters (gastrointestinal illnesses were related to enterococcus densities by correlation coefficients of 0.75 to 0.96, compared to 0.12 to 0.46 for total coliforms and 0.01 to 0.51 for fecal coliforms). The study was used by the EPA in 1986 to estimate that swimmers exposed to enterococcus in water at levels of 104 per 100 ml (or 35 per 100ml for the 30-day mean) would result in 19 cases of gastrointestinal illness or other effects per 1,000 people exposed. In 1986, these limits were entered in the U.S. EPA Ambient Water Quality Criteria for Bacteria Guidance. In 1996, the Santa Monica Bay epidemiological study helped to confirm the enterococcus criteria (Haile et al. 1996). The study found that when instantaneous enterococcus maximum limits were exceeded (the study used 106 as the limit, versus 104), exposed swimmers experienced a 323% increase in diarrhea with blood and a 44% increase in vomiting and fever.

The bacterial limits for recreational water quality enforced by AB411 have been well established and confirmed over the past five decades. What continues to change and improve with time is the enforcement of these limits. In 2000, Assemblyman Howard Wayne created AB1946 as a follow-on bill to AB411. This Bill improves on requirements for data collection and public notification. As of January 1, 2001, this Bill requires the state to collect more accurate information on the actions taken at beaches found to be contaminated. The Bill requires the SWRCB, the primary agency responsible for regulating AB411 criteria, to post beach data from throughout the state on a monthly basis. In addition, every June the SWRCB compiles all data into an annual report, which is made available on its website.

Review of Similar Studies

There are a large number of studies that have been conducted in recent years assessing the sources and transport of bacteria to coastal receiving waters. Many of the studies are initiated in response to levels of indicator bacteria that exceed federal or state water quality standards for the protection of human health (e.g., TMDLs). A comprehensive review of these studies is beyond the scope of this project. However, several of the studies that are more pertinent to the conditions in Mission Bay are reviewed briefly here.

Determining the sources of bacteria in a watershed is often difficult due to the complex nature of point and non-point sources, environmental interactions, the numerous potential sources of bacteria that may be found within a watershed (e.g., urban runoff, storm water flows, birds or other wildlife, human sewage, etc.), the partitioning of bacteria within various environmental compartments (particularly sediment), and the transport of bacteria to surface waters via groundwater flow. These variables are further complicated by the effects of environmental parameters, such as water temperature and daylength, which results in diurnal and seasonal patterns in bacterial densities. A recent study conducted by Boehm et al. (2002) demonstrates this complexity. The study assessed numerous variables in determining the sources of fecal indicator bacteria at Huntington Beach, California. The study examined long and short-term patterns of fecal indicator bacteria densities at a heavily used recreational beach. The results of the study demonstrated the complexity of interpreting indicator bacterial patterns in coastal water bodies. Causes of the variability inherent to bacterial densities in environmental samples were attributed to numerous potential sources of bacteria and environmental influences, including historical changes in the treatment and disposal of wastewater and dry weather runoff, El Niño events, seasonal variations in rainfall, spring-neap tidal cycles, sunlight-induced mortality of bacteria, and nearshore mixing. The authors noted the difficulty in interpreting the results of bacterial monitoring programs and in identifying bacterial sources due to the complex interactions of both local and external processes.

Grant et al. (2001) also assessed the variability of fecal indicator bacteria in southern California, however, this study focused on the generation of enterococcus bacteria in a coastal marsh. The study found that during ebb tides, densities of enterococcus bacteria approximately doubled as the water flowed through the marsh from the upland watershed to the ocean, but during flood tides the pattern was reversed. In addition, the highest densities of enterococcus were found during spring tides when the mud flats were most likely to be washed by tidal action. Urban runoff that drained to the marsh was not identified as a primary source of bacteria. These results suggested that the mud flats themselves were the source of enterococcus bacteria to the receiving waters. The authors suggested that coastal marshes provide habitat for a variety of birds and that bird feces may be the original source of the bacteria. Subsequent retention and possible growth of the bacteria in the marsh sediments and vegetation may provide a reservoir of bacteria in the marsh that is released to the receiving waters and transported to area beaches.

Numerous studies have suggested that beach sediments often contain higher densities of fecal indicator bacteria than the overlying water column (An et al. 2002, Grant et al. 2001, Obiri-Danso and Jones 2000, Solo-Gabriele et al. 2000, Howell et al. 1996). In addition, studies on the survival of bacteria indicate that sediments that contain a large amount of organic matter provide an environment favorable for growth. Fecal bacteria have been shown to survive and, to a certain extent, even to grow in both freshwater and marine sediments (Grant et al. 2001, Solo-Gabriele et al. 2000, Davies et al. 1995, Hood and Ness 1982). During summer months, this bacteria may be resuspended in the water column by swimmers, possibly resulting in exceedances of water quality standards. One recent study conducted in Southern California found a seasonal pattern of fecal coliform storage in sediments during low-flow conditions and subsequent resuspension of bacteria to the water column when the sediments were disturbed (Steets and Holden 2003). A similar study conducted in Florida suggested that *E. coli* bacteria multiplied in tidal riverbank soils after their initial deposition during storms and were resuspended and carried to the river mouth during ebbing tides (Solo-Gabriele et al 2000). The extent to which bacteria is stored in the sediments of Mission Bay is unknown, but given the small grain size at some sites and numerous bacterial sources close to area beaches, the potential for bacterial storage is high at some locations. This is particularly true at sites located near the mouths of creeks where sediment transported during winter storms is deposited in the delta.

Assessing the sources of bacteria within a water body is further complicated by the movement of bacteria via surface and groundwater flows. There is increasing research on the fate and transport of pathogenic microorganisms related to environmental and public health concerns (Lo et al. 2002, Abu-Ashour et al. 1998, Sinton et al. 1997). Numerous studies have demonstrated that bacteria are transported via groundwater from areas of intensive deposition (e.g., livestock operations and septic tank leach field) to local surface waters (Lo et al. 2002, Viraraghavan and Ionescu 2002, Jenkins et al. 1994, Joy et al. 1998). Moreover, tracer studies have demonstrated that human enteric pathogens move rapidly from septic tanks into nearby coastal waters, particularly in areas with sandy soils (Harvey and George 1989, Lipp et al. 2001, Paul et al. 1995). Movement of pathogens from depositional areas to surface waters may be particularly high during wet seasons when seasonal recharge results in an elevated water table (Cable et al. 1997). In coastal areas, tidal influences result in daily fluctuations in groundwater levels (Horn 2002, Li and Barry 2000, Sun 1997, Inouchi et al. 1990), which facilitates the transport of microbes that are able to penetrate the subsurface during saturated conditions (Bicki and Brown 1991). Many of the conditions described in the studies that facilitate the groundwater transport of microorganisms to local surface waters are found at several sites in Mission Bay.

Identifying the origin of bacteria in a waterbody is a critical component in understanding the contaminant problem and, ultimately, in remediating that problem. In recent years, microbial source tracking (MST) methods have been developed for discriminating between human and non-human sources of fecal contamination (Bernhard et al. 2003, Griffith et al. 2003, Simpson et al. 2002, Bernhard and Field 2000a and 2000b, Harwood et al. 2000). These methods have proven to be powerful tools for tracking bacterial sources and have been used successfully for studies where enumeration of traditional indicator bacteria have provided limited results (e.g., TMDLs). One recent study used the Host-Specific PCR (HS-PCR) method in conjunction with other source tracking tools to assess the origins of bacteria in Avalon Bay on Catalina Island (Boehm et al. 2003). MST was critical in identifying and eventually remediating a leaking sewage line that was one of several bacterial sources in the local watershed. In another study, sources of *E. coli* contamination in the Morro Bay Estuary were investigated using the Ribotyping assay (Kitts et al. 2002). Results from this study revealed that enteric bacteria originated from a variety of sources (e.g., birds, livestock, and human sewage) and that bacterial densities were dependent on site specific conditions within the study area.

Although the studies cited above provide clues as to the numerous potential sources of indicator bacteria in coastal embayments, they also suggest that identifying those sources is complicated and site specific. Mission Bay is a large, complex water body and finding solutions to the elevated bacterial densities found there requires site specific information. Several studies have been conducted examining the bacterial levels in Mission Bay (Kinnetics 1994, Kinnetics 1995, MEC 2001, Schiff and Kinney 2001, Hanley 2002). A review of studies conducted prior to 1994 can be found in Kinnetics (1994). This study included a thorough review and analysis of data from the City of San Diego, the Metropolitan Wastewater Department - Environmental Monitoring and Technical Services Division, and the County of San Diego Department of Health Services. The study was designed to assess the relationship between bacteria densities and storm drain runoff. The study found a strong correlation between wet weather runoff and bacterial densities throughout the bay. The report did not explain the chronic exceedances of bacterial standards during dry weather sampling, but suggested that direct flows of sanitary sewage to the bay through sewage overflows or leaks into the storm drain system are not the main cause of bacterial contamination to Mission Bay.

In 1995, a follow-up to the Kinnetics (1994) study was conducted that examined the potential sources of indicator bacteria in the watershed draining to Mission Bay during wet weather (Kinnetics 1995). The study developed a sampling program to assess indicator bacterial densities in three watersheds that discharge to Mission Bay during rain events that occurred between January and March in the 1994/1995 wet season. The study found that there were high levels of indicator bacteria throughout the watershed during rain events and that high densities in the bay were not directly a result of contamination from sanitary sewage or other obvious point sources. In addition, dry weather testing of storm drain outfalls throughout the Mission Bay watershed did not find illicit or cross connections to the sewer system that would convey sewage to the bay via the storm drain system. The authors concluded that bacterial contamination of storm water and the bay was associated with ubiquitous environmental sources from urban and non-urban land uses, rather than from leakages of the sanitary sewer system. The report recommended that inspections of the dry weather interceptor system should be made in the summer to insure that the system is working properly (i.e., not filled with sediment, etc.).

In 2001, the City of San Diego and MEC Analytical Systems, Inc. conducted an assessment of the bacterial data collected in Mission Bay from 1993 to 2000 (MEC 2001). The study assessed microbial water quality among 20 sampling sites routinely monitored in Mission Bay and identified temporal trends of bacterial densities at each site for the period of 1993 through 2000. The assessment found 12 areas in Mission Bay where AB411 standards were consistently exceeded during dry weather conditions (Figure 1-3). The exceedances were due mostly to elevated levels of enterococcus densities. In addition, sites located on the western side of the bay were generally less contaminated than those on the eastern side of the bay. Similar results were found in the Kinnetics study (Kinnetics 1994). Although the MEC (2001) study did not attempt to assess the sources of fecal contamination to Mission Bay, it was important in identifying those areas where levels of indicator bacteria have been consistently high.

The results of the MEC (2001) study were used to identify the 12 sites that were assessed in Phase I of the Mission Bay Bacterial Source Identification Study. They are shown in Figure 1-4. In addition, many of the concepts outlined above were used to assess the bacterial origin, density, and mechanisms of transport to the Mission Bay receiving waters.

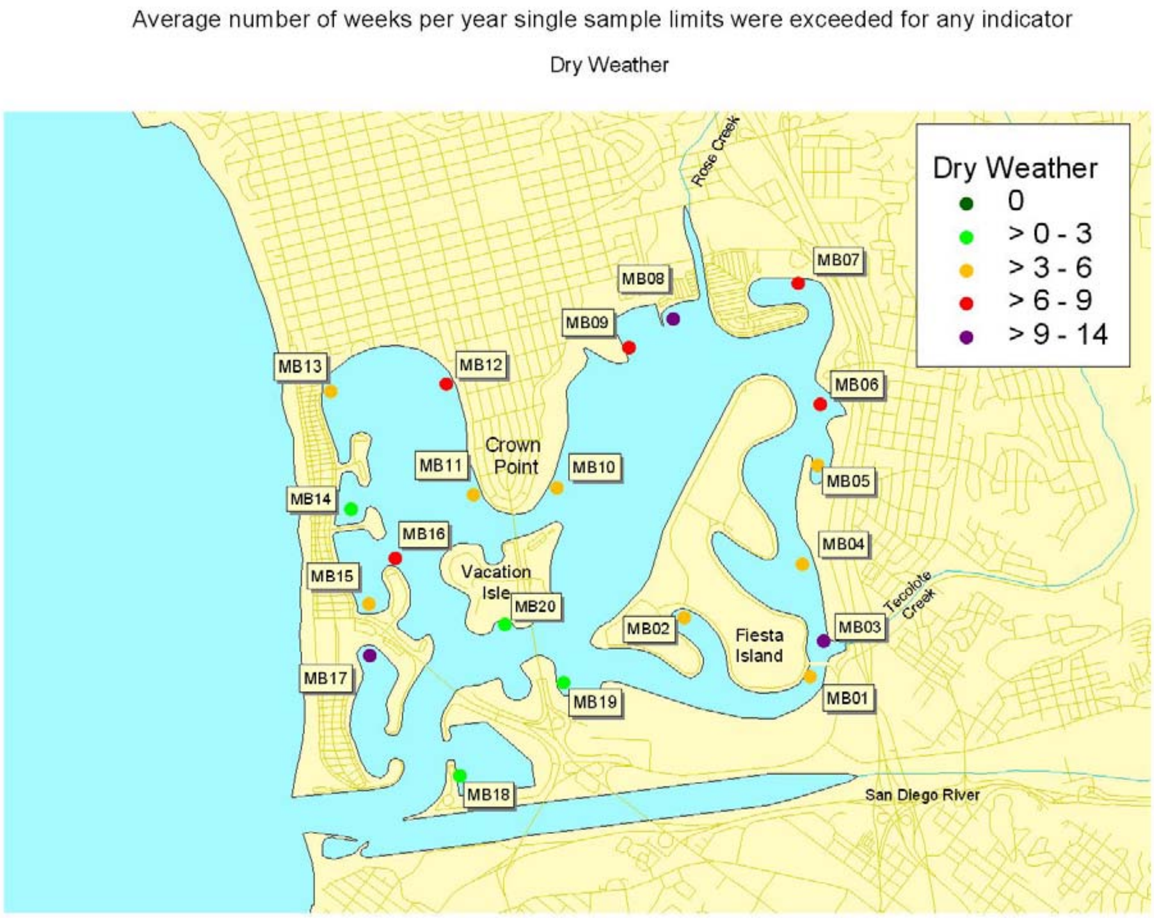


Figure 1-3. Map of Mission Bay showing areas with the greatest number of exceedances of indicator bacterial standards (from MEC 2001) from 1993 to 2000. The colored dots represent the average number of weeks per year (year-round data) that single sample standards were exceeded for total coliform, fecal coliform, and enterococcus densities during dry weather (at least 72 hours after a rain event).

Figure 1-4. Site map of Mission Bay showing the twelve sites investigated in this study.

Report Organization

The report is organized into 17 sections. An executive summary at the beginning of the document summarizes the major findings of the study, the study's conclusions, and recommendations to the City for reducing bacterial levels in Mission Bay.

Section 1 discusses the project scope, site description, AB411 criteria, and review of similar studies.

Section 2 provides an overview of the six major tasks and subsequent follow-up studies conducted over the course of the two year project.

Sections 3 through 14 provide site-specific summaries of all the studies conducted at each of the 12 sites. Each section includes a summary of the long-term temporal trends at each site, bacterial sources identified in Phase I and Phase II, and site-specific conclusions.

Section 15 is a summary of findings of all aspects of Phase I.

Section 16 provides a summary of the recommendations submitted to the City for reducing bacterial levels in Mission Bay.

Section 17 is the literature cited in the report.

The appendices include a glossary of terms used in the report, full reports of the six major investigative tasks, weekly monitoring and bacterial data, an assessment of the MBSIS, reports of the follow-up studies conducted, and an annotated bibliography.

SECTION 2

Baywide Overview

Introduction

This section provides and overview of the two-year study, including summaries of the six investigative tasks outlined in Section 1. The purpose of this section is to provide the reader with a brief summary of the results in Mission Bay as a whole. As mentioned previously, the results of the investigative task were very site specific. Thus, individual site assessments in Sections 3 through 14 provide a more detailed analysis by site. The complete reports for each of the six investigative tasks are provided in Appendices B through G and include detailed methods, results, and discussion sections for each of the studies.

Mission Bay is a large, complex waterbody with a myriad of potential sources of bacteria indicative of fecal contamination. The potential sources identified prior to the study's design included birds or other wildlife, domestic dogs, the homeless population, leaking sewage infrastructure, illicit discharge of sewage from moored or anchored boats, groundwater and creek and storm drain runoff. The potential sources initially identified for each of the 12 sites in Mission Bay assessed in this study are summarized in Table 2-1.

Table 2-1. Potential sources of indicator bacteria to Mission Bay by site identified at the beginning of the study. A red Y indicates potential sources identified for investigation.

Site #	Site Name	Illicit Boat Discharge	Restroom Infrastructure	Birds and Other Wildlife	Irrigation Runoff	Storm Drains	Restroom Wash down	Homeless	Dog Waste	RV Pump outs	Creek Drainage	Groundwater	Other
1	Bonita Cove	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y
2	Bahia Point	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y
3	Fanuel Park	N	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y
4	Riviera Shores	N	N	Y	N	Y	N	Y	Y	N	N	Y	Y
5	Wildlife Refuge	N	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y
6	Campland	N	Y	Y	N	N	Y	Y	Y	N	Y	Y	Y
7	De Anza Cove	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y
8	Visitor's Center	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
9	Leisure Lagoon	N	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y
10	N. Pacific Passage	N	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y
11	Tecolote Creek	N	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y
12	Hidden Anchorage	N	N	Y	N	Y	N	Y	Y	N	N	Y	Y

Task 1 – Sources of Human Sewage from Park Infrastructure

Mission Bay Park comfort station

Prior to the initiation of this study, the integrity of lateral lines that deliver sewage from the park comfort stations (i.e., restrooms) to the main sewer lines had not been examined as a potential source of bacterial contamination to the bay receiving waters. In addition, the comfort stations on the northeast and southeast areas of Mission Bay have sumps and lift pumps, which had also not been inspected. The infrastructure that services the sanitary systems within Mission Bay Park presented a potentially large source of bacterial contamination to the bay.

The primary objective of the park infrastructure investigation was to examine the integrity of the sewage lines that carry waste from the park comfort stations to the sewer mains and determine the extent to which they may contribute bacteria to the waters of Mission Bay.

Materials and Methods

There are 23 permanent comfort station facilities located in Mission Bay Park (Figure 2-1). Of these, a total of 16 were investigated as part of this study. Eleven of these are in close proximity to one of the 12 designated sampling sites. Three of the additional five are located on the west side of the bay (Ventura Point, El Carmel Point, and Santa Clara Point), one is located on the northeastern side of Crown Point, and one is located on Vacation Isle at Paradise Point. All of the comfort stations associated with a site were investigated, except the private facilities at Campland and the Visitor's Center building. Two of the 12 sites have no comfort stations associated with them (Riviera Shores and Hidden Anchorage).

The lateral lines of each of the comfort stations were investigated using close circuit television (CCTV) to look for cracks, tree roots, sedimentation, and other evidence of integrity problems. The system consists of a push camera connected via a 250-foot long cable to a video monitor and VCR. The camera was inserted down the sump or line to be investigated and pushed the length of the pipe (up to 250 feet). A typical investigation started inside the comfort station facility, but lines were also accessed from clean outs located outside the facility along the pipe's length. The camera image was viewed on the monitor and recorded by the VCR. The locations of any pipe transitions or potential problem areas were identified on the tape as was the audio recording of the technician's observations.

Figure 2-1. Map of Mission Bay showing study site locations and comfort stations.

Following the camera investigation, the tape was reviewed for pipe integrity. The tape was digitized on a compact disc for future reference and a report was generated for each facility outlining any areas of concern. All of the CCTV work was completed by experienced technicians and engineers at Affordable Pipeline Services, a sub-contractor on the project.

A typical CCTV investigation of a sewer lateral line in Mission Bay Park

Results

An overview of the results of the CCTV investigation is presented in Table 2-2.

Table 2-2. Summary of CCTV investigations at Mission Bay Park comfort station laterals.

Site Number	Facility Name	Facility Number	Date of Investigation	General Condition
1	Bonita Cove North	521	9/19/02	Good –no major cracks or break in line
1	Bonita Cove East	1056	9/19/02	Good –no major cracks or break in line
2	Bahia Point	834	9/19/02	Good –no major cracks or break in line
3	Fanual Park	9950	9/26/02	Good –no major cracks or break in line
5	Crown Point North	522	9/26/02	Good –no major cracks or break in line
7	De Anza Cove	10087	9/26/02	Good –no major cracks or break in line
8	Visitor's Center	1091	10/17/02	Fair – line has some corrosion
9	Leisure Lagoon North	1092	10/24/02[1]	Good –no major cracks or break in line
9	Leisure Lagoon South	1093	10/24/02[1]	Good –no major cracks or break in line
10	North Pacific Passage	1094	10/31/02[1]	Good –no major cracks or break in line
11	Tecolote Creek	1406	10/03/02	Good – no major cracks or break in line
nd	Ventura Point	10096	10/03/02	Fair – one large root mass
nd	Paradise Point	1087	10/3/02	Good – no major cracks or break in line
nd	El Carmel Point	579	10/10/02	Good – no major cracks or break in line
nd	Santa Clara Point	9939	10/10/02	Fair – one length of pipe was corroded
nd	Crown Point South	576	10/10/02	Good – no major cracks or break in line

nd = no data, there is no designated site in this study associated with that facility.

Conclusions

The results of the CCTV investigations suggest that the lateral lines of the Mission Bay Park comfort stations are not a source of indicator bacteria to Mission Bay. Aside from some corrosion of the cast iron pipes and root intrusions of the clay pipes at some sites, the integrity of most of the lines investigated was intact. However, there were two facilities that were recommended for further investigation: Facility 10096 at Ventura Point and Facility 9939 at Santa Clara Point. At Facility 10096 at Ventura Cove, a root mass was observed approximately 100 feet south of the comfort station. At Facility 9939 at Santa Clara Point, corrosion of a short section of cast iron pipe was observed. Neither of the problems identified at these sites were thought to be severe enough to allow sewage to enter the bay.

Task 2 – Sources of Human Sewage from Moored Boats

Because of its sheltered waters and beautiful scenery, Mission Bay is heavily used by recreational boaters. The largest harbor area in Mission Bay is Quivira Basin, located in the southwestern portion of the bay, which has numerous boat slips and two sewage pump-out stations. In addition, owners of boats up to 25 feet in length may use moorings in three locations in the southwest portion of the bay: Mariners Basin, Santa Barbara Cove, and San Juan Cove. On the northwestern portion of Mission Bay, boat mooring/anchorage and dock facilities are available at Campland Marina and De Anza Cove. Although Mission Bay has been designated a “No-Discharge” area and no human waste (treated or untreated) may be discharged to the bay, fecal contamination problems persist in some areas that are associated with boat moorings and anchorages. Three of these areas historically have had high bacterial counts: Bonita Cove, Bahia Point (adjacent to Santa Barbara Cove), and De Anza Cove. These areas were the focus of the boat mooring portion of this investigation.

There were two objectives of this study:

1) Using indicator bacterial densities (total coliforms, fecal coliforms, and enterococcus), assess the extent to which illicit discharge of sewage was occurring from moored and anchored boats at three locations in Mission Bay: Bonita Cove, Santa Barbara Cove, and De Anza Cove.
2) Determine the extent to which illicit discharge of sewage, if occurring, is impacting the receiving waters at beaches adjacent to moored and anchored boats.

Materials and Methods

The investigation took place around boats moored at the three previously mentioned sites in Mission Bay: Bonita Cove and Santa Barbara Cove (just west of Bahia Point) in the southwestern portion of the bay and De Anza Cove in the northeastern part of the bay (see Figure 2-1 for site locations).

Anchored boats in Bonita Cove

Bonita Cove is the only 72-hour boat anchorage in Mission Bay. Thus, the number of boats anchored in Bonita Cove at any one time is variable, depending on the time of year or special events. Typically, there are five to 25 boats anchored at this site at any time. The beach sampling location is at the northern-most end of Bonita Cove.

Boats in Santa Barbara Cove at the Mission Bay Yacht Club

Santa Barbara Cove houses numerous boats (estimated at around 60 boats) in the southern portion of Mission Bay, just west of Bahia Point. It is also home to the Mission Bay Yacht Club, which contains boats and dock facilities on the northern portion of the Cove. The beach sampling point for this site is at the end of Bahia Point. High levels of indicator bacteria have been measured at Bahia Point, which is directly across the bay from the Mission Bay Yacht Club.

Moored boats in De Anza Cove

The moored boats in De Anza Cove are located along the southwestern portion of the Cove. Typically, there are 10 to 20 boats moored here, most of which are owned by residents of De Anza Harbor Resort. The beach sampling site for De Anza Cove is approximately 600 feet from the moored boats on the north shore of the Cove in front of a large storm drain.

At each site, the boat mooring investigation took place over three consecutive days. Bonita Cove was sampled on August 13, 14, and 15, 2002 (Tuesday through Thursday). Santa Barbara Cove and De Anza Cove were sampled on August 19, 20, and 21, 2002 (Monday through Wednesday). On each sampling day, five samples were collected at each site: one from the beach adjacent to the moored or anchored boats and four along the perimeter of the moored boats, between the boats and the beach sampling site. At each site, the beach samples were collected from the same locations as those sampled as part of the AB411 receiving water monitoring. The protocol for the boat mooring sampling is detailed below.

To assure consistency among results, the protocol for samples collected at the beach sites was the same as that employed by the San Diego County of Environmental Health for the AB411 receiving water monitoring. The samples from the perimeter of the moored and anchored boats were taken from a kayak paddled around the perimeter of the boats. Four samples around the boats were taken at each site. The sampling locations were evenly distributed on a visual transect along the perimeter of the boats that was representative of the number of boats present. The transect was positioned approximately 25 feet from the boats, between the boats and the beach sampling site. Samples were taken from the side of the kayak, approximately six inches below the surface of the water. The aseptic technique used at the beach sites was also employed for each of the four boat sampling locations. Because the purpose of these samples was to determine if illegal dumping was occurring, the sampling technician was as discrete as possible when taking samples, attempting to appear to be a recreational boater. All samples were kept on ice in the dark from the time of sample collection until delivery to the analytical laboratory.

The timing of sample collection was coordinated with tides, using tide charts. Because the focus of this portion of the study was to determine if indicator bacteria measured on the beach originate from moored or anchored boats, samples were collected when the tide was most likely to be moving bacteria from the boats (if present) to the shore. In Bonita Cove, sampling took place during a flooding tide because the moored boats are seaward of the beach sampling site. At Santa Barbara Cove and De Anza Cove, samples were collected on an ebbing tide because the beach sampling sites are seaward of the moored boats. All bacteria samples were analyzed at the MEC Analytical Systems Microbiology Laboratory for total coliform, fecal coliform, and enterococcus. In the laboratory, total and fecal coliforms were enumerated using multiple tube fermentation based on Standard Methods 9221B&E. Enterococcus bacteria were enumerated using a chromogenic technique (Enterolert), based on Standard Method 9223.

Results

The results of the bacterial analyses from samples collected around the moored or anchored boats at all three sites are summarized in Table 2-3. Very low densities of all three indicator bacteria were detected throughout the study at all three sites. In most cases, the densities were below or just above the detection limits. The only exception was the beach sample taken at De Anza Cove on August 21. The density of total coliforms in this sample was slightly elevated (1,300 MPN/100 ml), but densities of fecal coliform and enterococcus bacteria at this site were well below AB411 criteria. High levels of total coliforms, in the absence of fecal coliforms or enterococcus, may have been caused by elevated levels of suspended solids in the sample. It is very unlikely that the source of the elevated total coliforms at this site was illicit discharge of sewage from moored or anchored boats.

Table 2-3. Summary of bacterial densities in samples collected from around moored or anchored boats at Bonita Cove, Santa Barbara Cove, and De Anza Cove as part of the Boat Mooring investigation. All values are in MPN/100 ml.

Bacterial Indicator	Parameter	Bonita Cove	Santa Barbara Cove	De Anza Cove
Total Coliform	Minimum Density	< 20	< 20	< 20
	Maximum Density	80	80	20
	Geometric Mean	< 20	< 20	< 20
Fecal Coliform	Minimum Density	< 20	< 20	< 20
	Maximum Density	20	20	< 20
	Geometric Mean	< 20	< 20	< 20
Enterococcus	Minimum Density	< 10	< 10	< 10
	Maximum Density	63	200	30
	Geometric Mean	10	< 10	< 20

Conclusions

This study was designed to determine if illegal dumping of holding tanks from boats moored in the three study areas was a persistent source of indicator bacteria on the beach. The lack of elevated levels of indicator bacteria from any of the samples at all sites indicates that illegal discharge of sewage from moored boats was not occurring during the time of sampling. The results also suggest that illegal sewage dumping from moored boats is not a chronic source of bacterial contamination at the beach.

However, it is important to remember that this study covered only a single sampling series over a three day period at each site. Although this is a reasonable study design for determining possible sources of human sewage from moored boats, the potential for illegal dumping from moored boats still exists and this study is by no means a comprehensive assessment of that potential. The illegal discharge of sewage holding tanks from moored boats is inherently episodic. If illegal dumping is occurring, it is likely only from a limited number of boats and only for a limited duration.

Task 3 – Visual Observations Study

Other than those sources identified and investigated in Tasks 1 and 2, numerous other potential sources were identified that may have been contributing to the bacterial problem in Mission Bay. The other potential sources initially identified included fecal matter from birds and feral and wild animals that inhabit the park, the homeless population, and the behavior of some park visitors. In addition, park management practices were thought to have the potential to contribute to the influx of indicator bacteria to the bay from these and other sources. In order to assess the extent to which these possible sources contribute bacteria to the bay, a comprehensive Visual Observations Study was initiated as Task 3 of Phase I. The study had the following objectives:

1) Through visual observations, record the behavior and activities of park visitors and wildlife as well as management practices within Mission Bay Park that may be contributing to bacterial contamination of the receiving waters.
2) During the observation period, sample those sources of potential bacterial influx to the bay.

Materials and Methods

Protocol. To facilitate a more complete spatial coverage of potential contamination areas in Mission Bay, the bay was divided into four quadrants for investigation activities: Northeast, Northwest, Southeast, and Southwest Mission Bay. A total of 12 sites within the bay were selected for the observational investigation, with a minimum of two sites within each quadrant (see Figure 2-1 and Table 2-4 for site locations). Sites were selected based on a review of dry weather (at least 72 hours after a rain event) exceedances of bacterial counts and a statistical review of seven years of sampling data (MEC 2001).

Samples for bacterial enumeration were taken from the same locations as the AB411 monitoring sites. The San Diego County Department of Environmental Health samples numerous sites in Mission Bay on a weekly basis for indicator bacteria (personal communication, Clay Clifton, County of San Diego Department of Environmental Health). Eleven of these sites are the same as the beach sites that were sampled in the visual observations investigation. One site, Hidden Anchorage, was sampled in the visual observations study, but is not monitored by Department of Environmental Health.

Table 2-4. Sampling sites and descriptions for Mission Bay visual observations investigation.

MEC Site Number	DEH[1] Site Number	Site Name	Site Description	Latitude[2]	Longitude
1	MB-170	Bonita Cove	At swimming beach at North end of Mariner's Basin, across from Belmont Park	32.7717	-117.2467
2	MB-160	Bahia Point	Northeast shoreline of Bahia Point near stormdrain	32.7750	-117.2450
3	MB-120	Fanual Park	At swimming beach in front of playground	32.7917	-117.2450
4	MB-110	Riviera Shores	La Cima at Riviera Shores, just north of Cima Street	32.7833	-117.2400
5	MB-090	Wildlife Refuge	At swimming beach on northern Crown Point next to wildlife refuge fence	32.7883	-117.2317
6	MB-080	Campland	At beach at Campland resort, just west of Rose Creek entrance	32.7950	-117.2217
7	MB-070	De Anza Cove	On north shore, between swim beach & 1st stormwater outlet, east of comfort stations	32.7933	-117.2117
8	MB-060	Visitor's Center	On sandy shore near stormdrain outlet, south of Visitor's Center	32.7883	-117.2100
9	MB-050	Leisure Lagoon	Semi-enclosed sandy beach, northeast of Hilton Hotel	32.7850	-117.2083
10	MB-042	North Pacific Passage	To the west of Hilton Hotel, between stormdrain outlets, near launch area	nd	nd
11	MB-030	Tecolote Creek	West of the playground, next to the PWC area	32.7717	-117.2083
12	nd	Hidden Anchorage	On east shore, near stormdrain outlet	nd	nd

[1] County of San Diego County Department of Environmental Health

[2] GPS coordinates are in decimal degree format (HDDD.DDDD) and NAD 83 datum

nd = no data available

The visual observations were conducted in conjunction with water sample collection for analysis of indicator bacteria. Observations and sampling took place during three periods between mid-August and mid-October, 2002: low-use, medium-use, and high-use. During each day of observation, samples were taken at each of the 12 sampling locations, three times per day. In addition, "spot sampling" was conducted at areas where bacterial influx to the bay was expected (e.g., flowing storm drains). Three shifts of six individual samplers per day covered the 12 stations. The first shift began just before sunrise and the last shift ended at sunset. Thus, the period of observation included all park maintenance activities and the majority of visitor activities. Within a shift, each sampler monitored two adjacent sampling areas and completed two field observation forms per shift.

Visual Observations. Field crews were dressed as park-goers to be as discrete as possible so as not to influence the behavior of park visitors or maintenance crews. Each sampler was equipped with a camera to photograph any potential bacteria sources, bacterial sampling equipment, Visual Observation Field Data Forms to document their observations, and a cell phone to communicate with each other, the couriers, and the project task leader. All observations were recorded on the Visual Observation Field Data Forms. Visual observations were split into three categories: visitor behavior, park maintenance procedures, and wildlife distribution patterns.

Visitor behaviors that were observed and documented included: approximate number of people involved in specific activities, including swimming and boating; illegal discharges into the storm drains, including illegal dumping of recreational vehicle sewage holding tanks; proper use of the recreational vehicle sewage holding tank pump-out stations, including runoff observations; failure of pet-owners to pick-up pet waste; trash and food disposal behaviors; and number of homeless persons present. Park maintenance operations being observed and documented included: comfort station cleaning and wash-down operations, including any associated runoff; sump pump-out operations at comfort stations, including any associated runoff; trash disposal methods; and landscape irrigation patterns (e.g., are sprinklers hitting trash cans and/or comfort station areas and generating runoff). Wildlife distribution patterns were observed and documented to include abundance and number of different species present, including birds, rodents, and other animals. Field crews made additional observations of any flowing or ponded water visible in storm drains and/or on surface areas. Observations included water quality information such as color, clarity, odor, and floatables. In addition, any flowing or ponded water observed during the period of observation was sampled for bacterial analysis (sample details are discussed below).

Bacterial Sampling. Two types of samples for bacterial analyses were collected during the study: site samples and spot samples. Site samples were collected at each of the 12 pre-determined sites at the beginning of each shift (i.e., three times per day). Spot samples were taken from any other potential source of bacteria to the bay observed during the observational study (e.g., flowing storm drains, runoff from comfort stations during cleaning, ponded water in grass, etc.). To assure consistency among results, the protocol for collection of the site samples was the same as that employed by the San Diego County of Environmental Health for AB411 monitoring.

Spot samples were collected using the same aseptic technique as employed for the site samples. Couriers picked up the bacterial samples from the field and delivered them to the laboratory within the required holding time. All samples were kept on ice in the dark from the time of sample collection until delivery to the analytical laboratory.

Laboratory Analyses. All bacteria samples were analyzed at the MEC Analytical Systems Microbiology Laboratory in Carlsbad, California or at Environmental Engineering Laboratories in San Diego, California. The three indicator bacteria enumerated in this study were total coliform, fecal coliform, and enterococcus. In the laboratory, total and fecal coliforms were analyzed using multiple tube fermentation based on Standard Methods 9221B&E. Enterococcus were enumerated using a chromogenic technique (Enterolert), based on Standard Method 9223.

Results

Monitoring Schedule. The visual observations study occurred on a total of nine days between the end of August and mid-October, 2002 (Table 2-5).

Table 2-5. Visual Observation Monitoring Days, 2002.

Sampling Date	Day of Week	Sampling Category
August 25	Sunday	High Use
August 29	Thursday	Medium Use
August 31	Saturday	High Use
September 2	Monday	High Use
September 8 *	Sunday	Medium Use
September 13	Friday	Medium Use
September 18	Wednesday	Low Use
September 24	Tuesday	Low Use
October 8	Tuesday	Low Use
October 9	Wednesday	Low Use

Visual Observations Overview. A total of approximately 1,300 man-hours of visual observations were made during the nine days of the study (over 100 hours per site). The results of the observations suggested that numerical assessments would not be meaningful for some of the observations. For instance, rodents and wildlife other than birds were observed at only two sites throughout the study area and were not considered to be a meaningful source of bacterial contamination of Mission Bay. Similar results were found for other sections of the field data forms, such as trash/food disposal, number of boats in the water, illicit boat discharge, and improper use of recreational vehicle pump-outs.

The homeless population was also assessed in the field data forms. Prior to the investigation, the homeless population was considered to be a potential source of bacterial contamination in some areas of Mission Bay. Homeless individuals were found at several sites or associated drainages throughout the study area, including Bonita Cove, Bahia Point, Fanuel Park, Wildlife Refuge, Visitor’s Center, Leisure Lagoon, and Tecolote Creek. However, in all cases, there was no evidence that these individuals were contributing fecal contamination to the bay. In fact, at most sites, the homeless population appeared to be attracted to the area because of the public comfort stations. Although the potential for fecal contamination from the homeless population in and around Mission Bay remains a possibility, the results of the visual observations suggest that the potential is very low. One possible exception to that is Site 11 (Tecolote Creek). Several homeless people were observed living under the Interstate 5 bridge just upstream of the sampling point. Although there was no evidence of human feces in the area, the close proximity of these individuals to the sampling point increases the potential for elevated levels of indicator bacteria.

Three sections of the field data forms lent themselves to a numerical assessment: number of birds, number of swimmers, and number of dogs on the beach. These data are summarized in Table 2-6. It is important to note that the values presented in Table 2-6 are the average of the summed values of the six observations (two observations for each of three shifts) made per day for each of the categories. The values from each of the observations were derived from the midpoint of a range of values presented in the field data forms. For instance, for the number of swimmers category, the field data forms provided four choices: none, <10, 10-50, and other. If the 10-50 choice was circled, the middle value of that range (30) was used for tabulation. This value was added to the other five observations made on that day arrived at in the same manner. The numbers for each day were then averaged to yield the values in Table 2-6.

Although the data summarized in Table 2-6 does not represent actual numbers in each category, some interesting patterns are apparent. For instance, the mean relative abundance of birds at Hidden Anchorage (78) was much lower than at any of the other sites. Bird abundance was also low at Fanuel Park (mean of 156) and Riviera Shores (mean of 182) on the northwestern end of Mission Bay. In contrast, the mean relative abundance at Wildlife Refuge (732) was much higher than any of the other sites. This is to be expected because, although the sampling area for the Wildlife Refuge site was south of the Kendall Frost Wildlife Preserve, an estimate of bird abundance was made in the Wildlife Preserve. Relative bird abundance was also high at Bonita Cove, Campland, and Leisure Lagoon.

Table 2-6. Summary of major visual observations (birds, swimmers, and dogs on beach) by site. Values represent the average relative values for all nine days of the study.

Beach Site	Birds	Swimmers	Dogs on Beach
1 - Bonita Cove	501	45	24
2 - Bahia Point	240	42	19
3 - Fanuel Park	156	26	43
4 - Riviera Shores	182	8	31
5 Wildlife Refuge	732	44	48
6 - Campland	521	57	48
7 - De Anza Cove	435	21	33
8 - Visitor's Center	479	18	35
9 - Leisure Lagoon	559	83	48
10 - North Pacific Passage	249	24	45
11 - Tecolote Creek	382	34	31
12 - Hidden Anchorage	78	16	61

The relative number of people observed swimming in Mission Bay was lowest at Riviera Shores. The observations suggested that very few people used the beach area of Riviera Shores, although a substantial number of people were observed on the bike path and in boats offshore. The sites with the greatest number of swimmers was Leisure Lagoon, followed by Campland, and Bonita Cove. It is interesting to note that for all sites except Hidden Anchorage, the number of swimmers was greatest during the two days that coincided with the Labor Day weekend (August 31 and September 2). This was particularly dramatic at Site 4 (Riviera Shores) where people were observed swimming only over the Labor Day weekend. After Labor Day, the number of swimmers in Mission Bay decreased dramatically at all sites (except Hidden Anchorage).

The number of dogs on the beach (Table 2-6) was greatest at Hidden Anchorage. This is to be expected since Hidden Anchorage is the only site among the 12 monitored where dogs are allowed to be off leash. Numerous observations were made throughout the study of dogs running loose on the beach at Hidden Anchorage on the west side of the cove. Pet waste was also observed on the beach more frequently at this site than any other in the study. The relative abundance of dogs on the beach was similar among the other 11 sites.

Bacteriology Overview. Two kinds of bacterial samples were taken during the course of the study: 1) site samples, which were taken at the sampling site on the beach monitored by the Department of Environmental Health; and 2) spot samples, which were taken from a variety of areas within Mission Bay Park where surface or groundwater was evident (flowing storm drains, ponded water in grass, comfort station washdown, etc.). Several sections of the field data forms incorporated areas of elevated potential bacterial contamination to the bay. These included comfort station irrigation, comfort station washdown, flowing storm drains, and washdown of boats and vehicles. Each of these potential sources was associated with spot samples taken during the observation period.

A total of 324 site samples and 198 spot samples were analyzed in the study. After all of the spot samples had been assessed, the data were categorized by the following probable sources: 1) irrigation; 2) restroom (comfort station) cleaning; 3) storm drain; and 4) boat or vehicle washdown. Figure 2-2 summarizes the results of the total coliform densities for all the spot and receiving water site samples categorized by site. It is clear from Figure 2-2 that each of the 12 sites had a unique set of potential bacterial sources. For instance, most of the samples taken at Bonita Cove (Site 1) were from restroom cleaning, most samples at North Pacific Passage (Site 10) were from flowing drains, and most samples from Campland (Site 6) were from boat washdown. The other sites had a mixture of potential sources. No spot samples were taken at Sites 4 and 12.

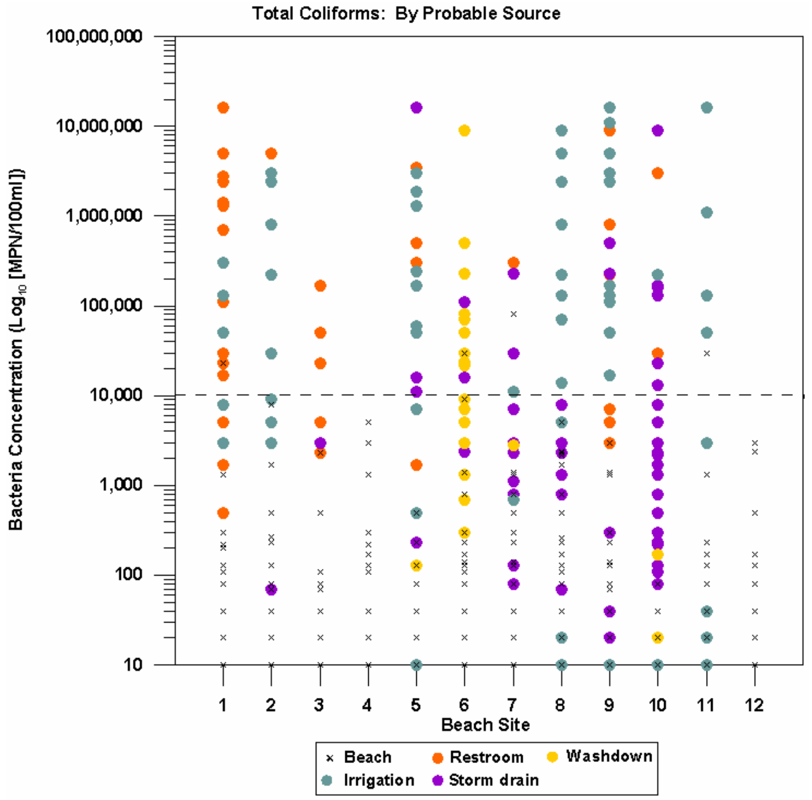


Figure 2-2. Plot of total coliform density by site and probable source. The dashed line represents the AB411 single sample criteria of 10,000 MPN/100 ml.

The dashed line in Figure 2-2 at 10,000 MPN/100 ml represents the AB411 criteria single sample limit for total coliform bacteria. The AB411 criterion for total coliforms is also exceeded if the fecal coliform density is greater than 10% of the total coliform density. It is clear from Figure 2-2 that the majority of the spot samples exceeded the AB411 criteria for total coliforms.

This is particularly true for samples taken from comfort station washdown and irrigation. In contrast, most of the storm drain samples were below the AB411 criteria. The majority of the total coliform densities from samples collected in the receiving waters were well below the total coliform criterion at most sites and there were no apparent temporal patterns. De Anza Cove (Site 7) and Visitor's Center (Site 8) had the greatest number of exceedances.

The fecal coliform data collected from spot samples and receiving water site samples during the Visual Observations Task are presented graphically in Figure 2-3. The dashed line at 400 MPN/100 ml in Figure 2-3 represents the AB411 criteria single sample limit for fecal coliform bacteria. The general pattern observed for total coliforms is also evident for the fecal coliform densities. However, a larger proportion of the spot samples exceeded the AB411 criteria. The criterion was also exceeded in the site samples at least once for all sites except Wildlife Refuge (Site 5) and North Pacific Passage (Site 10). As with the total coliform data, De Anza Cove (Site 7) and Visitor's Center (Site 8) had the greatest number of exceedances of the AB411 criterion for fecal coliforms.

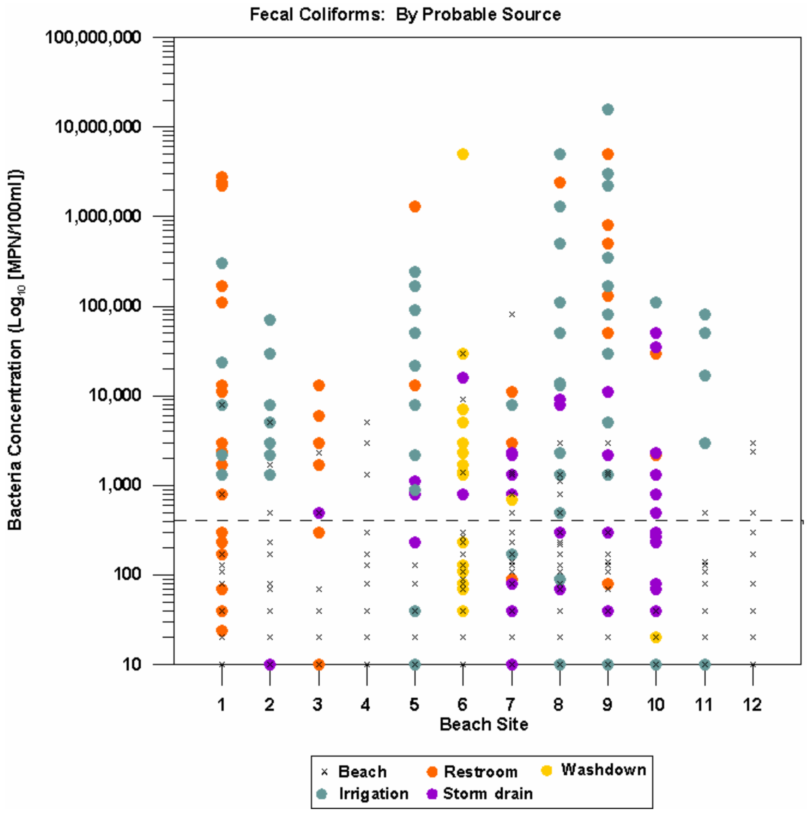


Figure 2-3. Plot of fecal coliform density by site and probable source. The dashed line represents the AB411 single sample criteria of 400 MPN/100 ml.

A summary of the enterococcus densities in spot samples and receiving water site samples are presented in Figure 2-4. The dashed line in Figure 2-4 at 104 MPN/100 ml represents the AB411 single sample criterion for enterococcus. Of the three indicators, the criterion for enterococcus was exceeded most frequently in this study in both spot samples and site samples. For spot samples, the enterococcus densities were elevated in all of the source categories sampled. In receiving water samples, the AB411 criterion for enterococcus was exceeded at least once at all 12 sites. The greatest number of exceedances of the enterococcus criterion occurred at De Anza Cove (Site 7). Surprisingly, the site with the next highest number of exceedances was Riviera Shores (Site 4), which had relatively low densities of total and fecal coliforms.

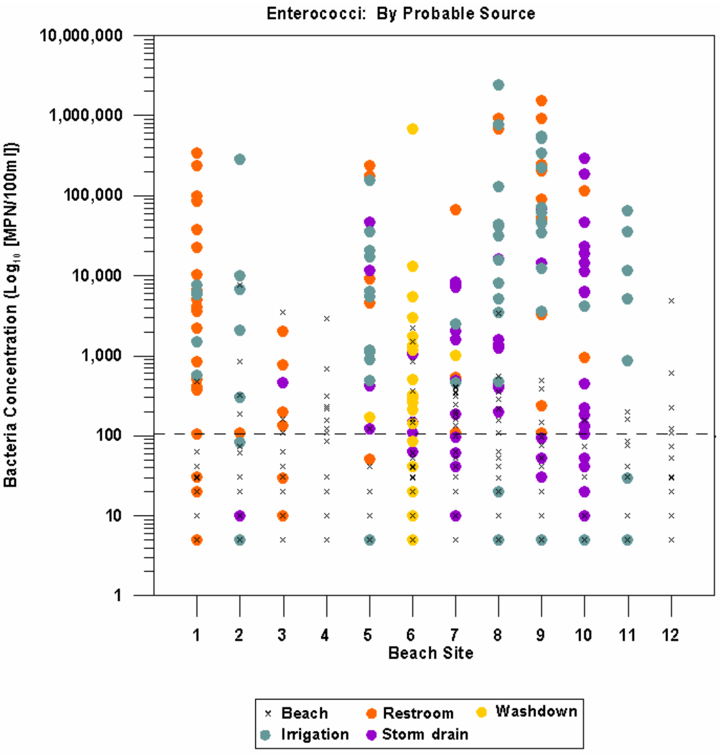


Figure 2-4. Plot of enterococcus density by site and probable source. The dashed line represents the AB411 single sample criteria of 104 MPN/100 ml.

Conclusions

It is clear from the results of the investigative tasks conducted in Phase I that each of the 12 sites examined in this study had a unique set of characteristics related to potential bacterial sources. At many sites assessed in Phase I more potential bacterial sources identified initially were found not to have an impact on bacterial densities in the receiving waters. The list included illicit discharge of sewage from boats, comfort station infrastructure, the homeless, and RV pump-out stations. In addition, management actions initiated by the City allowed for the removal of potential sources such as comfort station washdown and pet waste at most sites. The results of Phase I were also important in focusing attention on the more likely sources of bacterial influx to the bay that were identified at the end of the study, such as birds, storm drains, groundwater, and irrigation runoff. A summary of the potential bacterial sources remaining at each site at the end of Phase I and those that were no longer thought to be present or were remediated are presented in Table 2-7.

Table 2-7. Potential sources of indicator bacteria to Mission Bay by site identified at the end of Phase I. A green N indicates potential sources that are no longer thought to be present or were remediated as part of Phase I. A red Y indicates potential sources in need of further investigation.

Site #	Site Name	Illicit Boat Discharge	Restroom Infrastructure	Birds and Other Wildlife	Irrigation Runoff	Storm Drains	Restroom Wash down	Homeless	Dog Waste	RV Pump Outs	Creek Drainage	Groundwater	Delta Sediment	Intertidal Sediment	Wrack*	Other
1	Bonita Cove	N	N	Y	Y	Y	N	N	N	N	N	Y	N	Y	Y	N
2	Bahia Point	N	N	Y	Y	Y	N	N	N	N	N	Y	N	Y	Y	N
3	Fanuel Park	N	N	Y	N	Y	N	N	N	N	N	Y	N	Y	Y	N
4	Riviera Shores	N	N	Y	N	Y	N	N	N	N	N	Y	N	Y	Y	N
5	Wildlife Refuge	N	N	Y	Y	Y	N	N	N	N	N	Y	N	Y	Y	N
6	Campland	N	N	Y	N	N	N	N	N	N	Y	Y	Y	Y	Y	N
7	De Anza Cove	N	N	Y	Y	Y	N	N	N	N	N	Y	N	Y	Y	N
8	Visitor's Center	N	N	Y	Y	Y	N	N	N	N	Y	Y	Y	Y	Y	N
9	Leisure Lagoon	N	N	Y	Y	Y	N	N	N	N	N	Y	N	Y	Y	N
10	N. Pacific Passage	N	N	Y	N	Y	N	N	N	N	N	Y	N	Y	Y	N
11	Tecolote Creek	N	N	Y	N	Y	N	N	N	N	Y	Y	Y	Y	Y	N
12	Hidden Anchorage	N	N	Y	N	N	N	N	N	N	N	Y	N	Y	Y	N

* see Glossary (Appendix A) for definitions.

Investigative Follow-Up Studies

Following the completion of the field work and initial analyses of the three major investigative tasks in this project, a series of follow-up studies were conducted. The follow-up studies were designed to investigate potential sources of bacteria or mechanisms of bacterial transport at individual sites. Because of the site-specific nature of bacterial pollution in Mission Bay, more than one study was conducted at some sites while none were conducted at others. Each site was investigated for different parameters and specific potential sources. Descriptions of the follow-up studies and their results are provided in the respective site sections, and complete investigation reports are presented in their entirety in Appendix K.

Task 4 – Microbial Source Tracking

In Phase I of this study, high bacterial levels were measured from samples originating from numerous sources. In some cases, the host origin (human, avian, etc.) of the bacteria was fairly obvious and easily remediated (e.g., bacteria found in restroom washdown originate from humans). However, in the majority of cases, the origin of bacteria was unknown. Flowing storm drains, for example, can convey bacteria from human, avian, and other wildlife sources. In addition, most of the 12 sites studied had several potential sources. Identifying the origin of bacteria to a waterbody is a critical component in understanding the contaminant problem and, ultimately, in remediating that problem. In recent years, microbial source tracking (MST) methods have been developed for discriminating between human and non-human sources of fecal contamination. These methods have proven to be powerful tools for tracking bacterial sources and have been used successfully for studies where common indicator bacteria (total coliform, fecal coliform, and enterococcus) have provided limited results. In this study, we used two separate molecular typing techniques to identify the host origin of the bacteria in Mission Bay.

1) **Host-Specific PCR –** The polymerase chain reaction (PCR) technique takes advantage of host-specific genetic differences in an anaerobic bacteria, *Bacteroides*, a major bacterial resident present in feces of warm blooded animals. The HS-PCR assay provides a rapid first step in tracking bacterial host origin and allows us to determine the presence or absence of human fecal contamination in a particular water sample.
2) **Ribotyping –** Ribotyping analysis relies on a comparison of the DNA fingerprint within an individual *E. coli* bacterial cell (known as an isolate) derived from the waterbody in question to a library database of DNA fingerprints derived from known or confirmed host animal fecal specimens. The results of the Ribotyping assessment allow us to determine the host origin (human, avian, canine, etc.) of the bacteria in the receiving waters as well as the suspected conduit or reservoir from which the bacteria were derived (e.g., storm drains, sediments, organic debris, etc.).

The Microbial Source Tracking Task had two primary objectives:

1) determine the host origin of bacteria in the Mission Bay receiving waters; and
2) identify potential sources or pathways (e.g., storm drains, groundwater, irrigation, etc.) that may contribute to elevated bacterial levels in the bay.

Materials and Methods

The MST techniques employed in this study required thorough spatial and temporal coverage to achieve adequate results. Therefore, the results of Phase I were used to focus the efforts of the MST Task on sites that had the highest number of exceedances or were particularly problematic. The following sites were assessed in the MST Task: Bonita Cove, Fanuel Park, Wildlife Refuge, Campland, De Anza Cove, Visitor's Center, and Leisure Lagoon (Figure 2-5).

The sampling protocol was designed to maximize spatial and temporal coverage within the constraints of the study. Maximal spatial coverage was achieved by sampling several stations at each site. Samples were taken from the receiving waters at stations centered around the San Diego County Department of Environmental Health (DEH) AB411 monitoring location and extending approximately 500 feet on either side, as indicated by the red hatching in Figure 2-5. For the PCR analyses, four to five stations were sampled at each site and the samples were analyzed individually. For the Ribotyping analyses, ten stations were sampled at each site and the samples were composited in the MEC Microbiology laboratory. Because the results of Phase I indicated distinct site-specific differences relative to bacterial sources, the sampling protocol for each site was unique. The protocol for each site is summarized in Table 2-8.

Table 2-8. Microbial Source Tracking study design by site. For this study, Dry Season was from July 1 to November 10, 2003 and Wet Season was from November 11, 2003 to April 7, 2004.

Site	Season	Technique	Water Type
Bonita Cove (Site 1)	Dry Season (Holiday and non-Holiday)	HS-PCR Ribotyping	Receiving Water Storm Drains Groundwater
Fanuel Park (Site 3)	Dry Season	HS-PCR Ribotyping	Receiving Water Storm Drains
Wildlife Refuge (Site 5)	Dry Season	HS-PCR	Receiving Water Groundwater
Campland (Site 6)	Dry Season	HS-PCR Ribotyping	Receiving Water
	Wet Season	HS-PCR Ribotyping	Receiving Water
De Anza Cove (Site 7)	Dry Season	HS-PCR Ribotyping	Receiving Water Storm Drains Groundwater
	Wet Season	HS-PCR Ribotyping	Receiving Water Storm Drains Groundwater
Visitor's Center (Site 8)	Wet Season	PCR Ribotyping	Receiving Water Storm Drains Groundwater Spring Cudahy Creek
Leisure Lagoon (Site 9)	Dry Season	PCR Ribotyping	Receiving Water Storm Drains Groundwater

Base map source: SANDAG

Figure 2-5. Map of Mission Bay showing investigation and sampling sites for the Microbial Source Tracking Task.

Results

For our MST efforts that utilized the Ribotyping technique, a total of 1,097 receiving water *E. coli* isolates were analyzed. As illustrated in Figure 2-6, the results of the Ribotyping analysis indicate that birds are the dominant source of the enteric bacteria in the receiving waters of Mission Bay. This was true for both dry and wet season surveys. Avian sources account for 67% of all the bacterial isolates collected from the receiving waters in this study (dry and wet season data combined). The next largest source was classified as Unknown because the DNA fingerprints of these isolates did not match any of those in the MST Library database. The third largest source was Canine, which accounted for 9% of the isolates collected. Importantly, the percentage of bacterial isolates that originated from Human sources was very small, accounting for only 5% of the total number of isolates collected.

Bacterial Host Origin in Receiving Waters of Mission Bay – Dry and Wet Season Combined

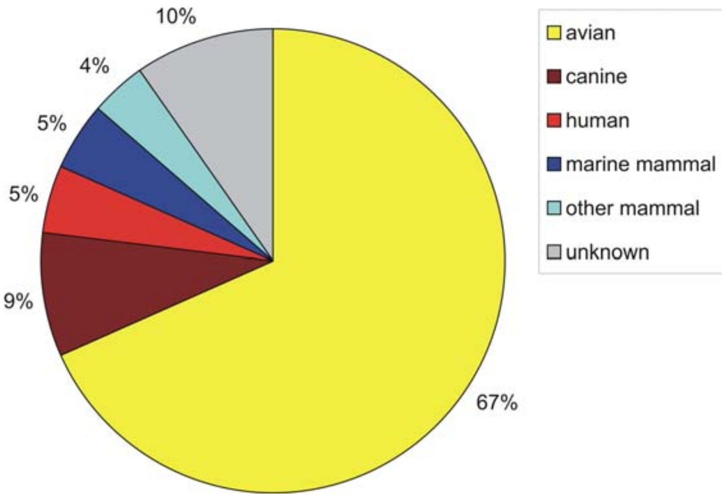


Figure 2-6. Results of Ribotyping analysis of receiving water samples collected at all sites studied in Mission Bay between July 2003 and April 2004.

In the HS-PCR analysis, two specific molecular markers are used to characterize the bacterial DNA in the sample: a General marker, which indicates the presence of fecal bacteria from any warm blooded source, and a Human marker, which indicates the presence of bacteria from human origin. Currently, the assay does not identify the origin of bacteria from animals other than humans.

The results of the HS-PCR analyses for Mission Bay receiving water samples strongly support the Ribotyping results presented above. Of the 175 samples analyzed with the HS-PCR assay, 78 % were positive for the General marker, suggesting that fecal bacteria are common in Mission Bay, as would be expected. However, only 9 % of the samples analyzed contained bacterial DNA that was positive for the Human marker. These results are very similar to those obtained in the Ribotyping assay and indicate that bacteria originating from humans accounts for a very small proportion of the enteric bacteria found in Mission Bay. The results of the HS-PCR analyses are presented in Figure 2-7.

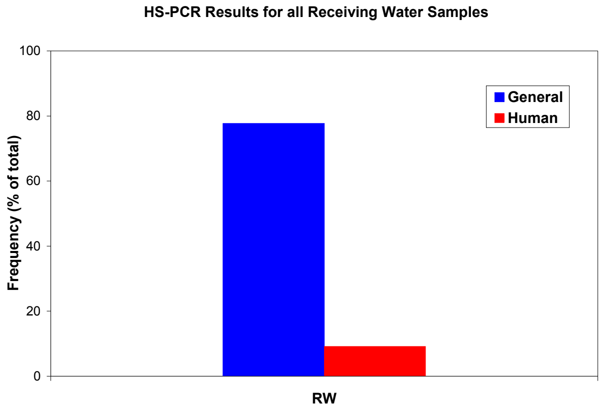


Figure 2-7. Results of HS-PCR analysis of receiving water samples collected at all sites studied in Mission Bay between July 2003 and April 2004.

Because each of the sites assessed in Mission Bay had different characteristics related to bacterial sources and pathways, the dominant suspected source (e.g., storm drain effluent) or sources at each site were assessed using MST along with the receiving waters. In this way, the origin of enteric bacteria in a storm drain, for instance, could be assessed. A summary of the bacterial host origin in receiving waters and major suspected source is summarized in Table 2-9 for each site assessed in the study.

Table 2-9. Summary of Ribotyping results showing the percentage of isolates from the major hosts identified in receiving water and suspected source water (storm drains, etc.). The dominant host origin in each sample type is highlighted in red.

Site	Sample Type	Avian	Canine	Marine Mammal	Other Mammal	Unknown	Human
Bonita Cove	Receiving Water	75	7	2	5	5	6
	Storm Drain	68	10	0	12	10	0
Fanuel Park	Receiving Water	69	7	10	3	4	7
	Storm Drain	60	20	0	15	5	0
Campland	Receiving Water – Dry*	79	8	1	7	1	4
	Receiving Water – Wet	69	10	5	1	13	2
De Anza Cove	Receiving Water – Dry	64	5	4	6	12	9
	Storm Drain – Dry	48	19	0	29	0	4
	Receiving Water – Wet	80	3	8	2	5	2
	Storm Drain – Wet	49	29	0	19	3	0
Visitor's Center	Receiving Water	66	14	8	4	6	2
	Storm Drain	49	27	0	13	11	0
	Cudahy Creek	66	23	0	3	7	1
Leisure Lagoon	Receiving Water	46	16	1	3	29	5
	Storm Drain	58	16	0	22	4	0

* Dry refers to samples collected from July 1, 2003 through November 10, 2003. Wet refers to samples collected from November 11, 2003 through April 7, 2004.

It is clear from the results presented in Table 2-9 that a large majority of enteric bacteria in Mission Bay receiving waters and major sources (e.g., storm drains) originates from birds. This was a consistent observation at all sites. As mentioned previously, the proportion of enteric bacteria from human origin is very small in the receiving waters. However, this proportion is even smaller in samples collected from the storm drains. None of the storm drains assessed contained bacteria from human origin except De Anza Cove during dry season (4%) and Cudahy Creek during wet season (1%). The very low percentage in the storm drains suggests that the small amount of bacteria from human origin that is present in the receiving waters of Mission Bay originates on the beach rather than from Mission Bay Park or the upstream watershed. We believe the most likely source of bacteria from human origin in Mission Bay is shedding from swimmers.

In addition to identifying the host origin of bacteria in a water body, the genetic fingerprint provided by the Ribotyping assay can be used to determine the proportion of the bacteria in the receiving waters that is also found in the effluent from suspected sources. A high degree of similarity between receiving water and storm drain effluent, for instance, suggests that the storm drain is a source of bacteria to the receiving waters. This assessment was completed for the sites in Mission Bay and, in general, there was good agreement between suspected sources and the receiving waters. Details of this assessment are provided for each site in Sections 3 through 14.

Conclusions

The results of the Ribotyping and HS-PCR assays employed in the Microbial Source Tracking Task indicate that a large majority of the enteric bacteria in Mission Bay originates from birds. This was true for both receiving water and suspected source samples, such as storm drain effluent. Canine was the second most common host origin identified at most sites. The percentage of enteric bacteria originating from humans was small at all sites in both receiving water and storm drain effluent samples. The small amount of bacteria from humans that was found in the receiving waters is thought to be introduced to the water column via swimmer shedding rather than the upstream watershed. In general, there was good agreement between the genetic fingerprints of bacteria found in the storm drains and those found in the receiving waters, suggesting that storm drain effluent is a source of enteric bacteria to Mission Bay.

Task 5 – Bacterial Fate and Transport

There is increasing research on the fate and transport of pathogenic microorganisms related to environmental and public health concerns (Lo et al. 2002, Abu-Ashour et al. 1998, Sinton et al. 1997). Numerous studies have demonstrated that bacteria are transported via groundwater from areas of intensive deposition (e.g., livestock operations and septic tank leach field) to local surface waters (Lo et al. 2002, Viraraghavan and Ionescu 2002, Jenkins et al. 1994, Joy et al. 1998). Moreover, tracer studies have demonstrated that human enteric pathogens are capable of moving rapidly from septic tanks into nearby coastal waters, particularly in areas with sandy soils (Harvey and George 1989, Lipp et al. 2001, Paul et al. 1995). Movement of pathogens from depositional areas to surface waters may be particularly high during wet seasons when seasonal recharge results in an elevated water table (Cable et al. 1997). In coastal areas, tidal influences result in daily fluctuations in groundwater levels (Li and Barry 2000, Sun 1997, Inouchi et al. 1990), which may facilitate the transport of microbes that are able to penetrate the subsurface during saturated conditions (Bicki and Brown 1991).

Many of the conditions described in the studies that facilitate the groundwater transport of microorganisms to local surface waters are found at several sites in Mission Bay. One of the most striking results of the Visual Observations Task of Phase I was the high bacteria levels that were observed in the grassy areas of Mission Bay Park surrounding the bay. Water samples taken from grassy areas within the park (i.e., puddles from irrigation) exceeded AB411 criteria at all sites where a sample was collected. The combination of high bacterial levels in the grass, a moist environment from irrigation, sandy soils, and shallow groundwater suggested that bacteria may be conveyed from the park to the bay receiving waters via groundwater transport.

Baywide Overview

The primary goal of the Fate and Transport study was to determine if bacteria are being transported from the grassy areas of Mission Bay Park to the receiving waters of the bay via groundwater. Two types of assessments were conducted:

1. An assessment of bacterial densities in soil beneath the grassy areas of Mission Bay Park; and
2. An assessment of bacterial densities in groundwater at the same locations and at the beach face springs.

Materials and Methods

Three sites were assessed in the Fate and Transport study: De Anza Cove, Visitor's Center, and Leisure Lagoon (Figure 2-1). At each of the three sites, a series of three wells was drilled along a transect in line with the beach face spring, perpendicular to the bay receiving waters. Well 1 was positioned 25 feet from the edge of the grass/sand interface, Well 2 was positioned 12.5 feet from the edge of the grass, and Well 3 was positioned at the edge of the grass adjacent to the beach face. At each well, three sampling probes attached to sterile tubing were inserted into the soil at depths of 4, 7, and 12 feet below the surface of the ground. Groundwater was extracted from each of the wells using a peristaltic pump and fecal coliform and enterococcus bacteria were enumerated.

Drilling groundwater wells

Groundwater sampling from beach face spring

In addition to the samples extracted from the wells, groundwater was also sampled from the beach face spring at each site. Groundwater samples from the beach were taken approximately ten feet above the top edge of the spring, measured along the beach face, at a depth of 12 to 24 inches below the surface of the beach face. Samples were taken using a four-foot long sampling rod connected to a six inch long, sterilized probe that was hammered into substrate. Groundwater was extracted with a peristaltic pump via sterile tubing connected to the probe.

In addition to the groundwater monitoring wells, two soil cores were also taken at each site adjacent to Wells 1 and 3. The cores were taken with a 24-inch long chrome plated push core soil probe fitted with a cross handle and sterile butyrate liner. The sampler was pushed manually through the turf and into the soil to a depth of approximately 22 inches below the ground surface. The sampler was then extracted from the soil and the liner containing the soil core was removed using sterile technique. In the laboratory, fecal coliform and enterococcus were enumerated and the grain size characteristics were determined at four to five strata within the 22-inch long core.

Results

The results of the groundwater and soil core monitoring for all three sites assessed in the Fate and Transport study are summarized in Table 2-10.

Table 2-10. Summary of bacterial densities in samples collected during the fate and transport study at De Anza Cove, Visitor's Center, and Leisure Lagoon in March, 2004. Densities are in units of MPN/100 ml for water samples and MPN/100 dry gram for soil samples.

Sample Type	Minimum Density	Maximum Density	Geometric Mean	Minimum Density	Maximum Density	Geometric Mean
DE ANZA COVE						
	Fecal Coliform			Enterococcus		
Soil cores from park	< 1	4,000	2.40	< 1	14,900	170
Groundwater from park wells	< 20	20	< 20	< 10	< 10	< 10
Groundwater from beach spring	< 20	< 20	< 20	< 10	< 10	< 10
VISITOR'S CENTER						
	Fecal Coliform			Enterococcus		
Soil cores from park	< 1	11,200	24.5	< 1	78,900	284
Groundwater from park wells	< 20	20	< 20	< 10	41	< 10
Groundwater from beach spring	< 20	< 20	< 20	< 10	< 10	< 10
LEISURE LAGOON						
	Fecal Coliform			Enterococcus		
Soil cores from park	<1	59,700	8.6	<1	9,000	84
Groundwater from park wells	< 20	20	< 20	< 10	< 10	< 10
Groundwater from beach spring	< 20	20	< 20	< 10	< 10	< 10

The results of the study revealed that the grassy areas of the three sites assessed in the Fate and Transport investigation (and likely other areas in Mission Bay Park) contain a large reservoir of both fecal coliform and enterococcus bacteria. The origin of the bacteria was determined to be predominantly avian. However, an analysis of bacterial density with depth from the soil core samples indicated that the migration of bacteria from the park surface to the groundwater is limited to the upper 18 inches of soil by layers of clay and other fine-grained material. Virtually no indicator bacteria were found in the groundwater wells or the beach face springs at De Anza Cove or the other sites investigated in the fate and transport study. In addition, none of the samples collected from groundwater at the beach face springs during the Microbial Source Tracking Task at these or other sites contained indictor bacteria. These results indicate that the grassy area of De Anza Cove and the soil directly beneath it contains a large reservoir of indicator bacteria, but the bacteria is not transported to the receiving waters of Mission Bay via groundwater seepage through the beach.

Conclusions

In Figure 2-8, we constructed a simple conceptual model to demonstrate the mechanisms of bacterial fate and transport assessed in this study. The results of the study suggest that enterococcus and, to a lesser extent, fecal coliform bacteria emanating from the original host animals (primarily birds) are able to survive and possibly reproduce in the grass and upper sediment layers of Mission Bay Park. In this way, the upper 18 inches of soil beneath grassy areas of the park (red zone in Figure 2-8) acts as a large reservoir for fecal indicator bacteria that has the potential of impacting the receiving waters of Mission Bay. This reservoir appears to be trapped by layers of clay in the soil that prevent the bacteria from migrating to the saturated groundwater zone, which is at a depth of approximately 5 to 6 feet. Groundwater springs on the beach face at Mission Bay Park appear to be hydrologically connected to the

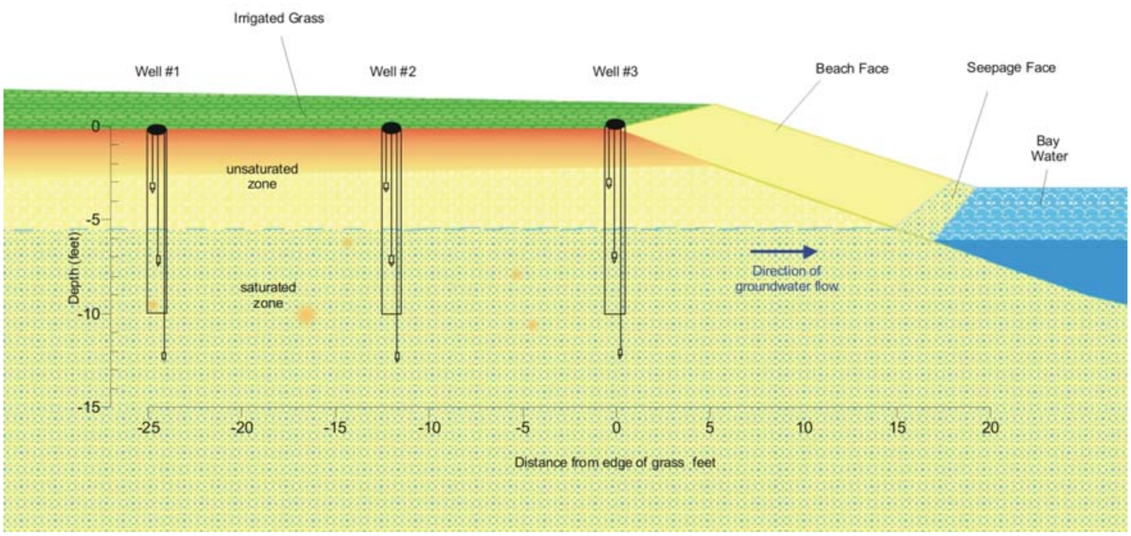


Figure 2-8. Conceptual model of bacterial fate and transport in Mission Bay Park. The red zone from the surface to a depth of approximately 18 inches represents the area of elevated indicator bacterial densities.

groundwater beneath the surface bacterial reservoir. The lack of bacteria collected from these springs during the fate and transport task and the groundwater portion of the MST Task suggest that shallow groundwater is not a source of fecal indicator bacteria to Mission Bay from either the high bacterial load in the grassy areas of Mission Bay Park or from other potential sources. However, the high densities of indicator bacteria in the soil can be released to the receiving waters during erosion events, which can occur through excessive irrigation.

Task 6 – Sediment Investigation

Numerous studies have suggested that beach sediments often contain higher densities of fecal indicator bacteria than the overlying water column (An et al. 2002, Grant et al. 2001, Obiri-Danso and Jones 2000, Solo-Gabrielle et al. 2000, Howell et al. 1996). In addition, studies on the survival of bacteria indicate that sediments present an environment favorable for growth. Enteric bacteria have been shown to survive and, to a certain extent, even to grow in both freshwater and marine sediments (Grant et al. 2001, Solo-Gabriele et al. 2000, Davies et al. 1995, Hood and Ness 1982). During summer months, these bacteria may be resuspended in the water column by swimmers, resulting in exceedances of water quality standards and the potential for increased exposure of swimmers to waterborne pathogens. One recent study conducted in Southern California found a seasonal pattern of fecal coliform storage in sediments during low-flow conditions and subsequent resuspension of bacteria to the water column when the sediments were disturbed (Steets and Holden 2003). A similar study conducted in Florida suggested that *E. coli* bacteria multiplied in tidal riverbank soils after their initial deposition during storms and were resuspended and carried to the river mouth during ebbing tides (Solo-Gabriele et al 2000).

The primary goal of the Sediment Investigation Task was to determine if the sediments in Mission Bay act as a source of bacteria to the receiving waters at area beaches. Investigations were conducted to determine the potential for receiving water bacterial contamination originating from two types of sediments in Mission Bay:

1. Sediments in deltas at the mouths of the three major drainages that discharge to Mission Bay, which may contaminate adjacent beaches via tidal currents; and
2. Intertidal sediments, which may contaminate receiving water via resuspension when the sediments are disturbed.

Materials and Methods

The three major creeks that discharge to Mission Bay terminate near three receiving water sites that were sampled in Phase I of this study. For the delta sediment Investigation, sediment from the deltas of these creeks and water from the adjacent receiving water sites were sampled. The sites are shown in Figure 2-9:

1. Rose Creek, which discharges near Campland (Site 6)
2. Cudahy Creek, which discharges near Visitor's Center (Site 8); and
3. Tecolote Creek, which discharges near the Tecolote Creek site (Site 11).

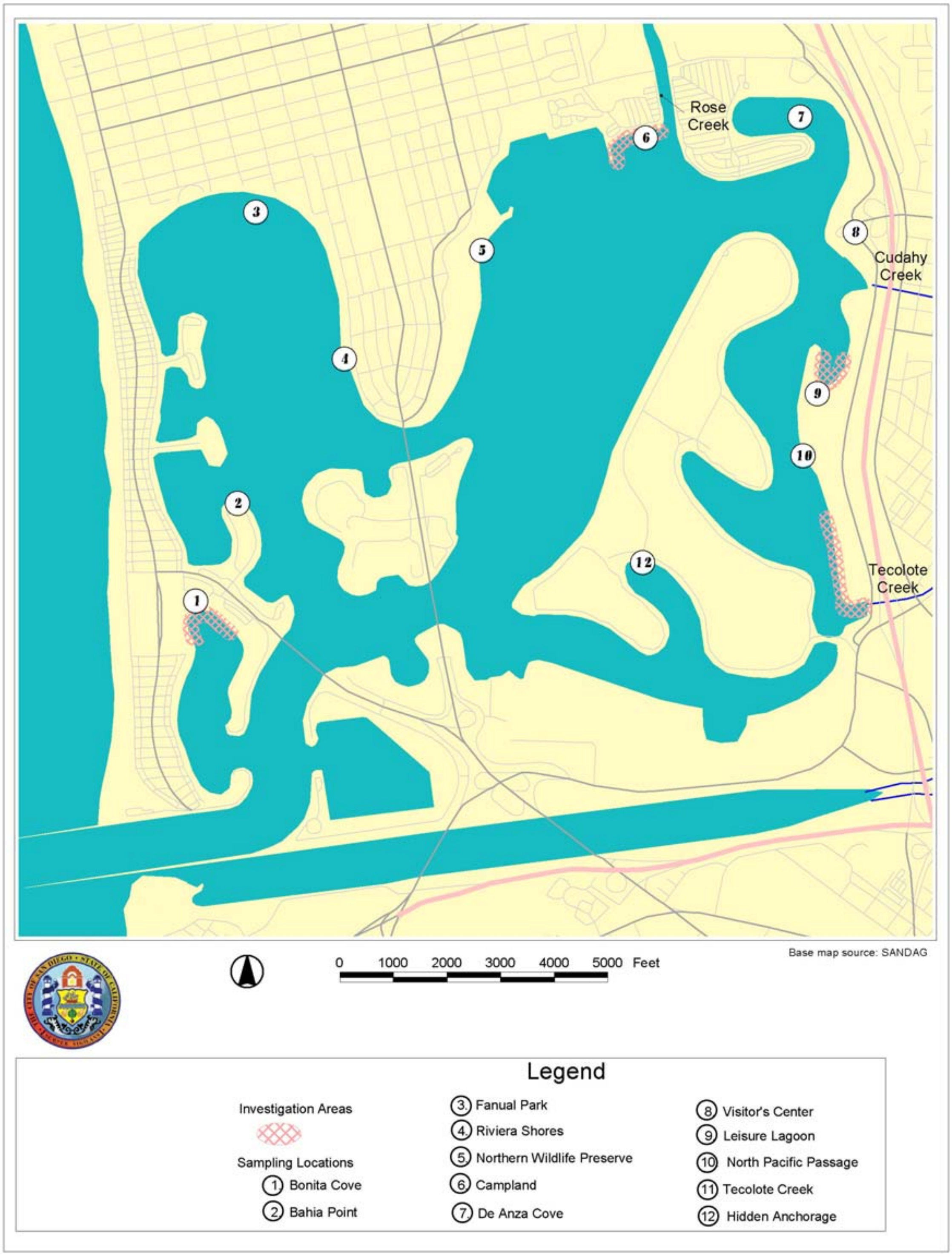


Figure 2-9. Map of Mission Bay showing investigation and sampling sites for the sediment investigation.

Intertidal sediments were also investigated at three sites (Figure 2-8):

1. Bonita Cove (Site 1),
2. De Anza Cove (Site 7), and
3. Leisure Lagoon (Site 9).

These sites were chosen because they tend to be used most frequently by swimmers during the summer months. If bacteria associated with intertidal sediments is resuspended during swimming activity, it is most likely occurring at these sites.

The delta sediment study was conducted during two separate surveys:

1) A dry season survey, conducted on October 24, 2003, prior to the first rains of the wet season; and
2) A wet season survey, conducted on January 14, 2004 after substantial runoff had entered the Bay from wet season storms.

During both surveys, sediment cores were taken from an inflatable raft (Zodiac) at six randomly selected stations within each delta. Sediment cores were taken with a hand core that consisted of 10-foot long aluminum push rod attached to an aluminum block connected to a sterile 3 inch diameter sterile, plastic tube approximately 20 inches long. After the cores had been extracted and capped, they were transferred to shore for processing. The tube was cut with a reciprocating saw equipped with a sterilized blade, approximately 2 cm above the top of the sediment layer. The top 1 cm of the sediment core was then removed with a sterile spoon and placed into a sterile 100-ml plastic bottle and capped. Surficial sediments from each of these cores were analyzed for indicator bacteria (fecal coliform and enterococcus). The same procedure was used to extract sediment from a depth of four inches from the first three cores at each delta.

In addition, bacteria from the surficial sediments and receiving waters at AB411 monitoring sites adjacent to the beaches were analyzed to determine the bacteria's host origin. During the wet season survey, fecal coliform bacteria were present in the deltas sediments at high enough densities at Cudahy Creek and Tecolote Creek to allow for a molecular comparison between bacteria in the sediments to those in the receiving water. Receiving water samples were collected during one of the largest tides of the year to maximize the potential for sediment transport from the deltas to the receiving waters.

Collecting sediment cores from Tecolote Creek delta

Cutting sediment core to remove sediment sample

In intertidal sediments, two types of assessments were conducted:

1. Beach face transects, which provided a profile of bacterial densities in the intertidal sediments from the high to low tide marks.

2. Sediment resuspension analysis, which provided a measure of the extent to which resuspension of beach sediments contributed to bacterial levels in the receiving water.

For the beach face assessment, five transects were positioned along the beach face (Figure 2-10). Each transect ran perpendicular to the shoreline from a tidal height of 0 to +6 feet above Mean Lower Low Water (MLLW). The transects were put in place during a low tide (below 0 MLLW). Along each transect, six stations representing tidal height positions from 0 to +6 feet above MLLW were identified with survey flags. The transect stations were: 0, +1, +2, +4, +5, and +6 feet above MLLW. At each of the transect points, one surficial (approximately 1 cm deep) sediment sample consisting of approximately 50 g of sediment was taken using a sterile 100-ml plastic bottle and analyzed in the laboratory for fecal coliform and enterococcus bacteria.

Figure 2-10. Photograph of beach at Bonita Cove showing Upper and Lower Intertidal Zones.

For the sediment resuspension studies, the study protocol was slightly different at each site as summarized in Table 2-11.

Table 2-11. Sediment resuspension studies conducted by site in Mission Bay.

Site	Date of Study	Tidal Condition	Sampling Time	Indicators Assessed*
Bonita Cove	May 19, 2003	Low Tide (- 1.5 feet)	0730 hrs	ENT
	April 16, 2004	High Tide (+ 5.1 feet)	0800 hrs	ENT and FC
De Anza Cove	May 21, 2003	Low Tide (- 0.5 feet)	0930 hrs	ENT
Leisure Lagoon	April 29, 2004	High Tide (+ 4.4 feet)	0530 hrs	ENT and FC

* ENT = enterococcus, FC = fecal coliform

At each site, a total of 15 stations were positioned along the beach face parallel to the water and identified with survey flags. At each of the 15 stations, two consecutive receiving water samples were taken. The first was a “clear water” sample, which was taken using standard protocols in which the underlying sediments were not disturbed. Immediately after the clear water sample had been collected, the sampler disturbed the sediments at that location by mixing the beach sediment into the water column with his feet (similar to what a swimmer would do). A sample was then taken from the water column that contained the resuspended sediment. We refer to this as the “resuspended sediment” sample. In addition to the samples described above, a composite sediment sample was taken at each site for grain size analysis.

Results

The results of the bacterial monitoring in delta sediments are presented in Figure 2-11. During the dry season survey, fecal coliform and enterococcus densities were generally low at all three sites in samples taken from the sediment surface as well as at depth (four inches below the surface). During the wet season survey, surficial sediment fecal coliform densities at Rose Creek and Cudahy Creek were similar to those taken during the dry season survey (Figure 2-11A). However, at Tecolote Creek, the mean surficial fecal coliform density in the wet season survey (20 MPN/g) was significantly greater than that of the dry season survey (< 1 MPN/g) ($p < 0.0001$). Enterococcus densities in the delta sediments changed the most between the dry and wet season surveys. The mean enterococcus density in surficial sediments during the wet season survey was 38 times higher than the mean dry season density at Cudahy Creek ($p = 0.0006$) and over 100 times higher at Tecolote Creek ($p < 0.0001$) (Figure 2-11C). At Rose Creek, the mean surficial enterococcus density during the wet season survey was twice that of the dry season survey, but the difference was not statistically significant.

The most remarkable differences between the two surveys were in enterococcus densities at depth (Figure 2-11D). At Rose Creek, the mean enterococcus density at depth (4,703 MPN/g) was significantly greater than the dry season mean at depth ($p < 0.0016$) and an order of magnitude higher than any other value measured in either survey. Enterococcus densities at two of the three samples collected at depth from Cudahy Creek were also extremely high (3,047 and 1,375 MPN/g) and similar in magnitude to samples collected at depth at Rose Creek.

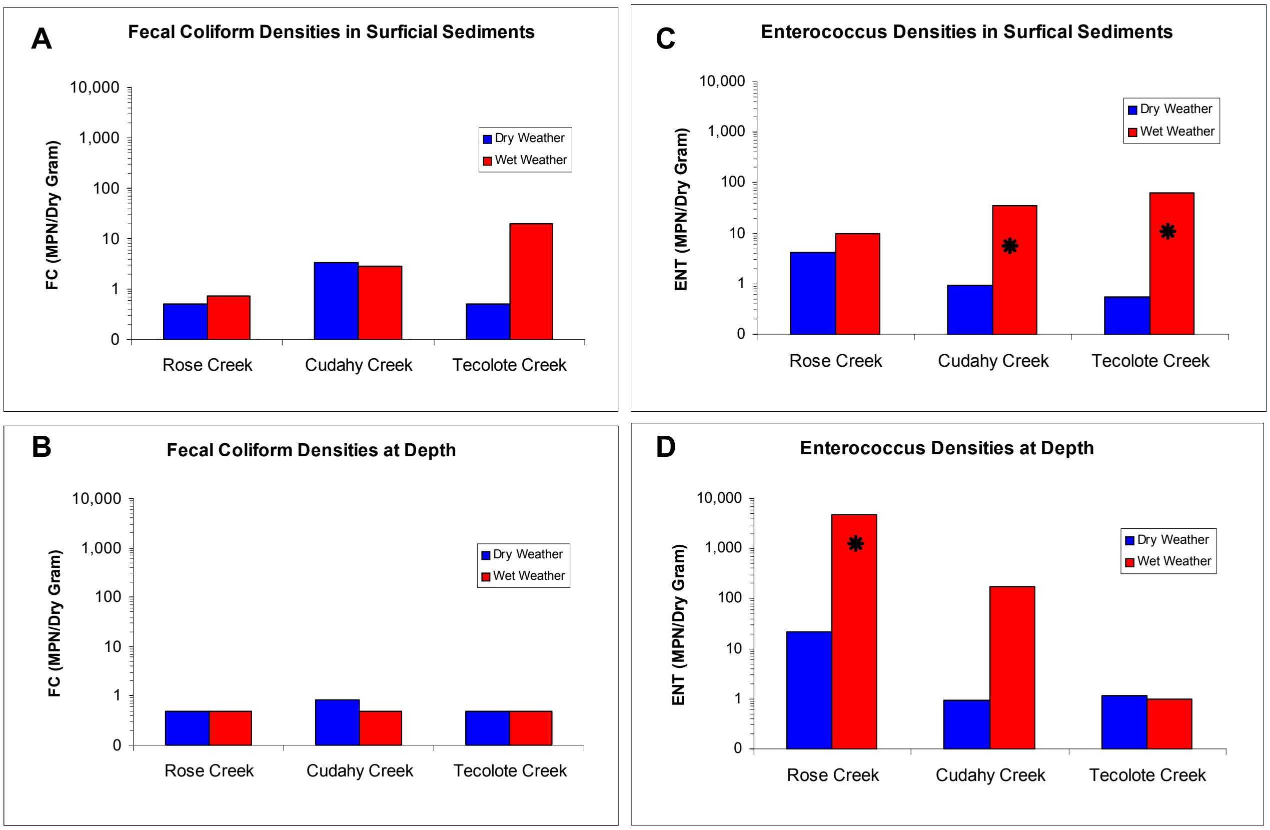


Figure 2-11. Graphs of fecal coliform and enterococcus densities in surficial sediments (top 1 cm) and at a depth of four inches from deltas at Rose Creek, Cudahy Creek, and Tecolote Creek. Bars represent the geometric means of bacterial densities collected during the dry and wet season surveys (* represents statistical significance between survey means).

E. coli were present in sufficient enough quantities for Ribotyping only at Cudahy Creek and Tecolote Creek during the wet season survey. At Cudahy Creek, 71% of the isolates in the sediment and 66% of the isolates in the receiving water were of Avian origin. Only 17% of all the Ribotypes collected in the receiving water matched those in the sediment at Cudahy Creek.

At Tecolote Creek, *E. coli* isolates were obtained only during the wet season survey. In the sediment, a total of 69 isolates were obtained. Of these 55% were of Avian origin, 26% were of Canine origin, and 15% were from other mammalian sources (Figure 2-12). In the receiving water at Tecolote Creek, Ribotyping analysis determined that the majority (84%) of isolates were also of Avian origin. We next searched for matches between the Tecolote Creek sediment and receiving water-derived Ribotype data sets (Figure 2-12C). Strikingly, we found that 45% of the isolates obtained from the receiving water did match isolates identified in the sediments.

Wet Season Ribotyping Results at Tecolote Creek

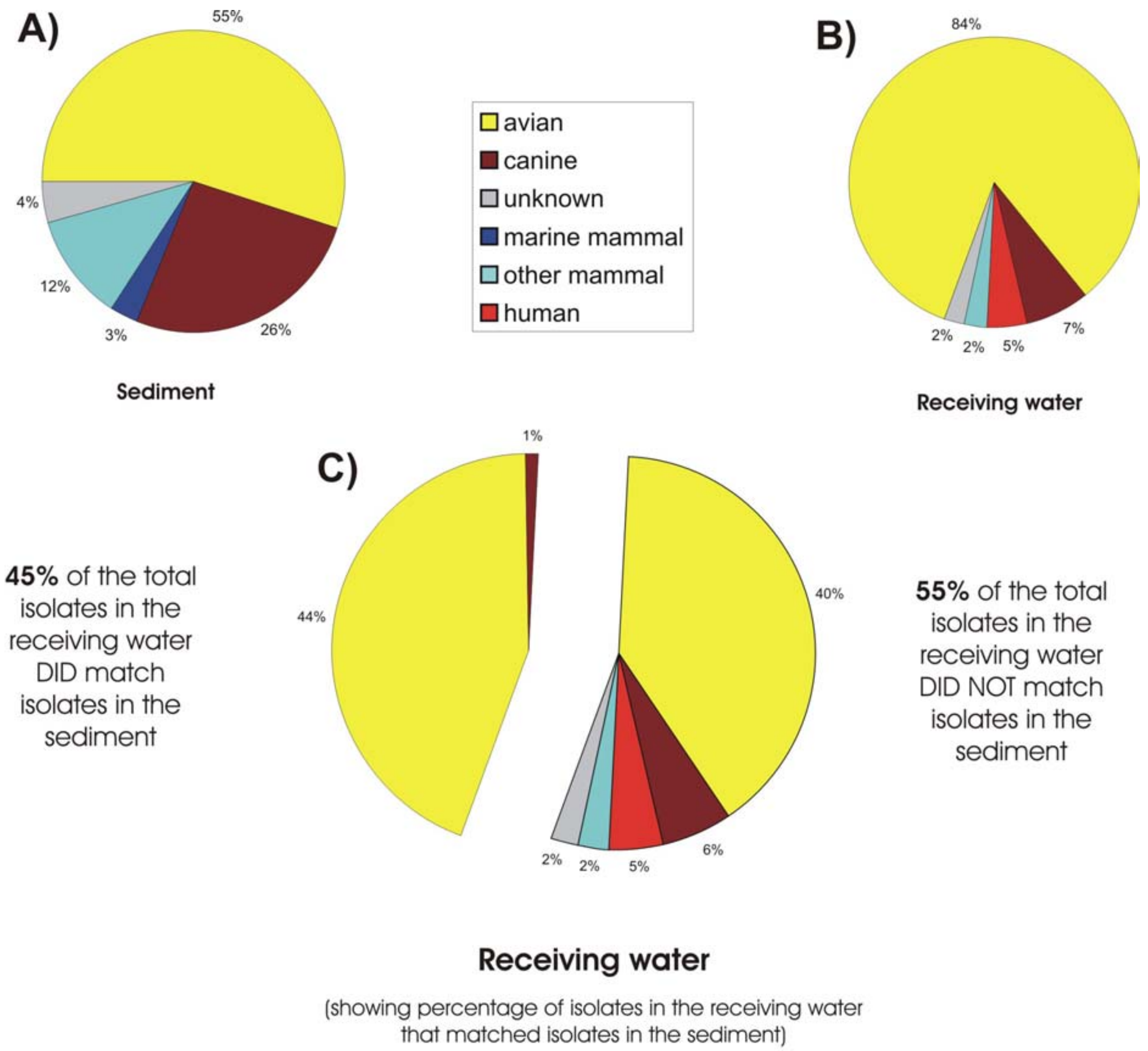


Figure 2-12. Results of Ribotyping analysis at Tecolote Creek during the wet season survey. The pie charts show the origin of bacterial isolates in delta sediments (A), receiving water (B), and the proportion of isolates in receiving water that matched those in sediment (C).

Two types of assessments involving intertidal sediments were conducted: Beach face transects and sediment resuspension studies. Enumeration of bacteria along the beach face was conducted at two sites: Bonita Cove and Leisure Lagoon. Sediment resuspension studies were conducted at three sites: Bonita Cove, De Anza Cove, and Leisure Lagoon.

The results for Bonita Cove are presented below to illustrate the pattern of indicator bacterial densities observed in intertidal sediments. The results of the intertidal sediment studies at Bonita Cove are presented in Figure 2-13. Fecal coliform densities in intertidal sediments were similar at tidal heights of +6, +5, +4, and +2 feet above MLLW, with geometric means of the five transects ranging from 32.5 to 101 MPN/g dry sediment. At tidal heights of +1 and 0 feet above MLLW, fecal coliform densities dropped dramatically, with geometric means of 1.4 and 2.6 MPN/g, respectively. Mean fecal coliform densities in the upper intertidal sediments (+6, +5, +4, and +2 feet above MLLW) were significantly greater ($p < 0.0001$) than those in the lower intertidal sediments (+1 and 0 feet above MLLW). Enterococcus densities in intertidal sediments showed a similar pattern to that observed for fecal coliforms.

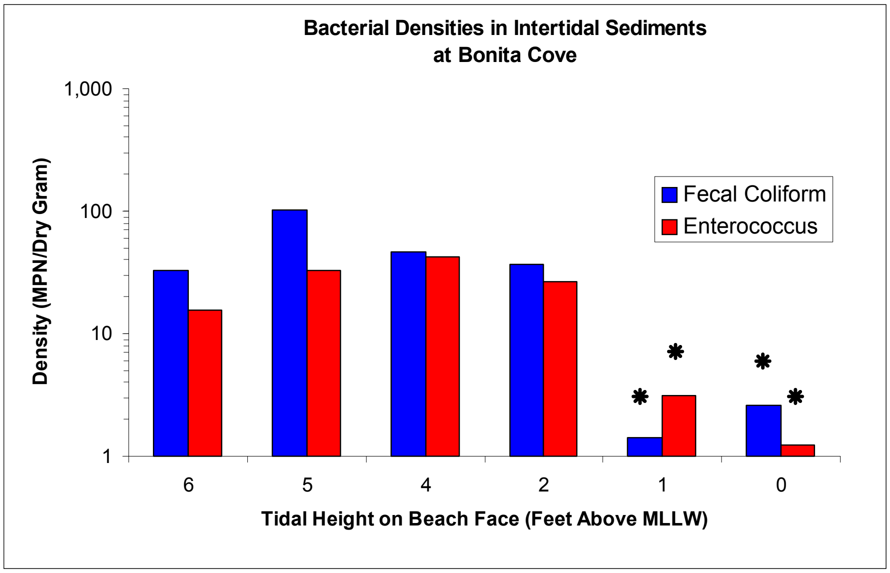


Figure 2-13. Fecal coliform and enterococcus densities in intertidal sediments at Bonita Cove. Bars represent the geometric means of 5 samples, * represents significant differences between upper and lower intertidal sediments.

During the sediment resuspension study conducted at low tide at Bonita Cove, there was no significant difference ($p > 0.05$) between the mean clear water and resuspended sediment bacterial densities for either fecal coliform or enterococcus. In contrast, when the study was repeated during high tide, there was a marked difference in bacterial densities between the clear water and resuspended sediment samples. For enterococcus, the geometric mean density of the clear water samples was low at high tide (9.1 MPN/100 ml), similar to the results observed during low tide. However, after sediment resuspension at high tide, the enterococcus geometric mean density had increased two orders of magnitude to 1,096 MPN/100 ml. At all 15 stations the resuspended sediment samples at high tide were one to two orders of magnitude greater than the corresponding clear water samples ($p < 0.0001$). These results are shown graphically in Figure 2-14.

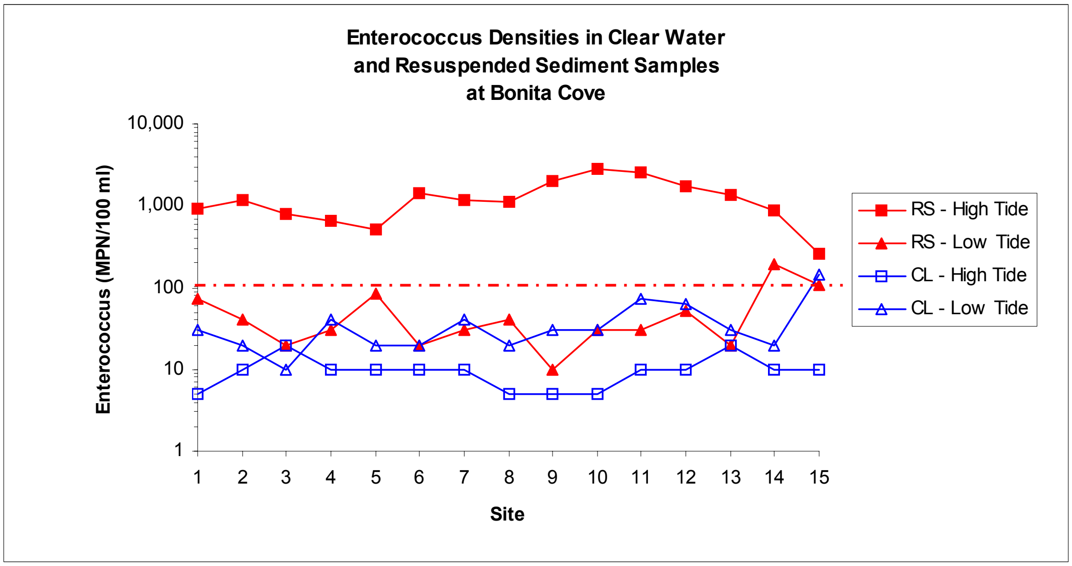


Figure 2-14. Graph of enterococcus densities in receiving water at Bonita Cove during the sediment resuspension study. CL refers to clear water samples and RS refers to samples taken after sediment resuspension. The dashed red line represents the AB411 standard for enterococcus of 104 MPN/100 ml.

When the intertidal sediment studies were conducted at Leisure Lagoon, the results were very similar to those discussed for Bonita Cove. However, at Leisure Lagoon, bacterial densities in sediments at stations around storm drain SD9-2 were much greater than those at similar tidal heights elsewhere at this site. These results suggest that effluent from the storm drain (which drains a small grassy area and parking lot) had inoculated the sediments with bacteria near the discharge.

The sediment resuspension study at De Anza Cove was conducted during a very low tide. However, in contrast to the low tide sediment resuspension study conducted at Bonita Cove, there was a significant difference in mean enterococcus density between clear water and resuspended sediment samples. We attributed this to the smaller grain size found in intertidal sediments at De Anza Cove and the numerous storm drains that discharge to the beach in this area of Mission Bay.

Conclusions

The results of the sediment investigation allow us to reach several conclusions about the extent to which sediments influence bacterial densities in the receiving water of Mission Bay. The results of both the delta sediment investigation and the sediment resuspension study suggest that the relationship between sediments and receiving water is dependent on the specific characteristics of each site. The conclusions of the two studies are summarized by site below.

Rose Creek – Surficial sediments in the Rose Creek delta contained low bacterial densities in both dry and wet season surveys. Although densities were high at depth during both surveys, the sediments do not appear to have an impact on bacterial densities in the receiving waters at Campland in either dry or wet season periods.

Cudahy Creek – Sediments in the Cudahy Creek delta act as a reservoir for indicator bacteria, particularly during the wet season. However, the extent to which bacteria in the sediment impact the receiving waters appears to be relatively minor.

Tecolote Creek – Sediments in the Tecolote Creek delta contain low bacterial densities in the dry season and high bacterial densities in the wet season. During the wet season, it is likely that bacteria in the sediment are transported to the receiving waters only during periods of maximal tidal currents. The majority of time, the sediments are not a source of bacteria to the receiving waters.

Bonita Cove – Sediments in the upper intertidal zone at Bonita Cove act as a reservoir for indicator bacteria. When the sediments are disturbed (e.g., through swimmer activity), the bacteria is released to the water column resulting in elevated bacterial densities. Sediments in the lower intertidal zone do not act as a reservoir for indicator bacteria.

Leisure Lagoon – As with Bonita Cove, sediments in the upper intertidal zone at Leisure Lagoon act as a reservoir for indicator bacteria that can be released to the water column when the sediments are disturbed. In addition, effluent from storm drain SD9-2 (which drains a small grassy area and parking lot) appears to have elevated the bacterial densities in the nearby beach sediments.

De Anza Cove – Sediments in the lower intertidal zone at De Anza Cove act as a reservoir for indicator bacteria that can be released to the water column when the sediments are disturbed. In addition, it is likely that sediments in the upper intertidal zone at De Anza Cove play the same role.

Bacterial Amplifiers

Towards the end of the completion of the six investigative tasks conducted in this study, two additional investigations were carried out. They were based on observations made over the course of the study that organic debris (eel grass, algae, etc.) washed up on beaches and deposited in some storm drains in Mission Bay appeared to be associated with elevated bacterial densities at some sites.

Two studies were conducted to assess the extent to which organic debris contributed to elevated bacterial densities in the receiving waters:

1. a field study, which investigated the wrack line that is deposited on some beaches in the upper intertidal zone; and

2. a laboratory study, which investigated the potential for growth of indicator bacteria under conditions typically found in a tidally-influenced storm drain.

The objective of both studies was to assess the extent to which these two areas amplified the indicator bacterial load in the receiving waters of Mission Bay.

Materials and Methods

Two sites were assessed in the wrack line study: Riviera Shores and Visitor's Center. At both of these sites, a heavy wrack line frequently accumulates on the beach face in the upper intertidal zone. At each site, samples of wrack that had been deposited during a spring high tide were collected over an eleven day period during the subsequent neap tide. The wrack was stranded on the beach face during this time and did not come in contact with the receiving waters of Mission Bay. Five samples were collected each day from the same location in the wrack line at each site. At the end of the 11-day period, receiving water was collected over a tidal cycle before, during, and after the tide washed over the wrack line.

For the laboratory storm drain simulation study, sterilized eel grass was added to flasks containing water of varying salinities and kept in the dark under a constant temperature of 15°C. The study design for the laboratory experiment is summarized in Table 2-12.

Table 2-12. Sampling design for laboratory bacterial amplification study.

	15% Seawater	70% Seawater	100% Seawater	Negative Controls
Treatment	2 replicates with eelgrass	2 replicates with eelgrass	2 replicates with eelgrass	1 with eelgrass
	2 replicates without eel grass	2 replicates without eel grass	2 replicates without eel grass	1 sterile water only

Except for the negative controls, each of the flasks was inoculated with fecal coliform and enterococcus bacteria that had been isolated from samples collected from the effluent of Cudahy Creek. Densities of both indicator bacteria were then monitored over time.

Results of Wrack Line Study

The results of the bacterial enumeration from wrack samples collected at Riviera Shores are presented in Figure 2-15. At Riviera Shores, samples of the wrack line contained elevated densities of both fecal coliform and enterococcus bacteria. Mean fecal coliform densities ranged from 3 to 335 MPN/100 g of wrack and mean enterococcus density ranged from 170 to over 1,000 MPN/100 g of wrack. Elevated bacterial densities in the wrack were maintained over time, suggesting that the wrack line provides an environment conducive to the maintenance and possibly the growth of both enterococcus and fecal coliform bacteria.

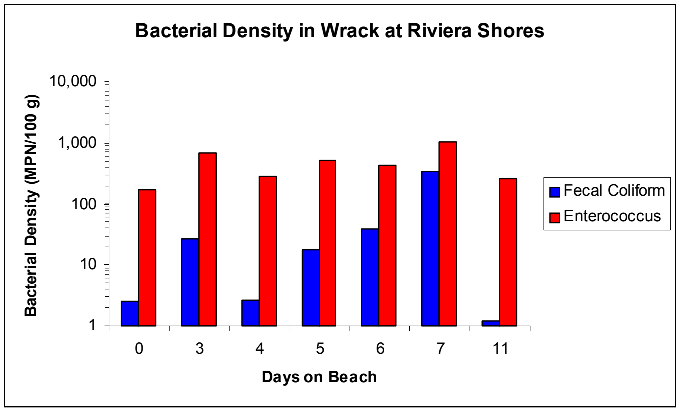


Figure 2-15. Densities of enterococcus and fecal coliforms in wrack line at Riviera Shores. Each bar represents the geometric mean of five samples.

The study conducted at Visitor's Center provided similar results, but bacterial densities were much higher in the wrack line. Mean fecal coliform densities ranged from 41 to 18,550 MPN/100 g of wrack and enterococcus densities ranged from 5,250 to over 83,000 MPN/100 g.

The results of the receiving water sampling that took place as the tide washed over the wrack line are shown in Figure 2-16. At Riviera Shores, bacterial densities were low in the early morning when the edge of the receiving waters were in the lower intertidal zone. Densities increased dramatically at 0600 hours when the receiving waters first made contact with the upper intertidal zone and peaked at 0800 hours when the receiving waters were in contact with the wrack material. As the tide receded into the lower intertidal zone starting at about 1000 hours, bacterial densities decreased. Thus, greater bacterial densities occur in the upper intertidal zone on the beach when the receiving water comes in contact with the wrack line. Similar results were obtained at Visitor's Center. These results help explain the pattern of greater enterococcus densities in the upper intertidal zone that have been observed at some sites in Mission Bay.

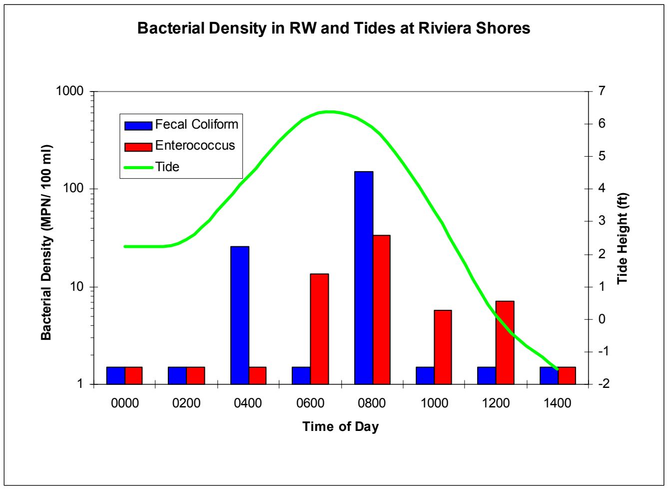


Figure 2-16. Densities of enterococcus and fecal coliform bacteria in receiving water versus tidal height at Riviera Shores. Each bar represents the geometric mean of five samples.

Results of Storm Drain Simulation Study

The storm drain simulation experiment was designed to reproduce the range of conditions experienced inside a coastal storm drain in Mission Bay: a dark, UV protected environment, with a large influx of freshwater from the upstream drainage and groundwater, and substantial amounts of organic debris. The results of the experiment are shown graphically in Figures 2-17 for fecal coliforms and 2-18 for enterococcus. The trends in bacterial densities demonstrate the effects of two variables on bacterial survival and growth: salinity and the presence of a nutrient source. In the 70% (22 ppt) and 100% (32 ppt) seawater salinities, no bacterial growth was observed. In the absence of eel grass, both fecal coliform and enterococcus densities decreased dramatically to near zero in two to four days, reflecting the harsh effects of seawater on indicator bacteria. Both indicator bacteria survived for a longer period of time in 70% and 100% seawater in the presence of eel grass and a similar pattern was observed for bacteria in 15% (5 ppt) salinity seawater without eel grass.

The most compelling results of the study, however, were for bacteria in 15% seawater in the presence of eel grass. Both fecal coliform and enterococcus densities increased dramatically in this environment by several orders of magnitude within the first few days of the experiment. Extremely high densities were maintained for nearly a week, before leveling off, but elevated densities continued to be maintained throughout the course of the 27-day study. It is also interesting to note that the prolonged survival of enterococcus in the presence of eel grass in all three salinities tested was maintained at a density slightly above the AB411 criteria of 104 MPN/100 ml (see dashed red line in Figure 2-18). Although further studies are needed to assess the strength of this relationship, these results suggest that enterococcus, in the presence of an organic substrate, can survive for prolonged periods of time in storm drains at densities that exceed the AB411 criteria for receiving waters.

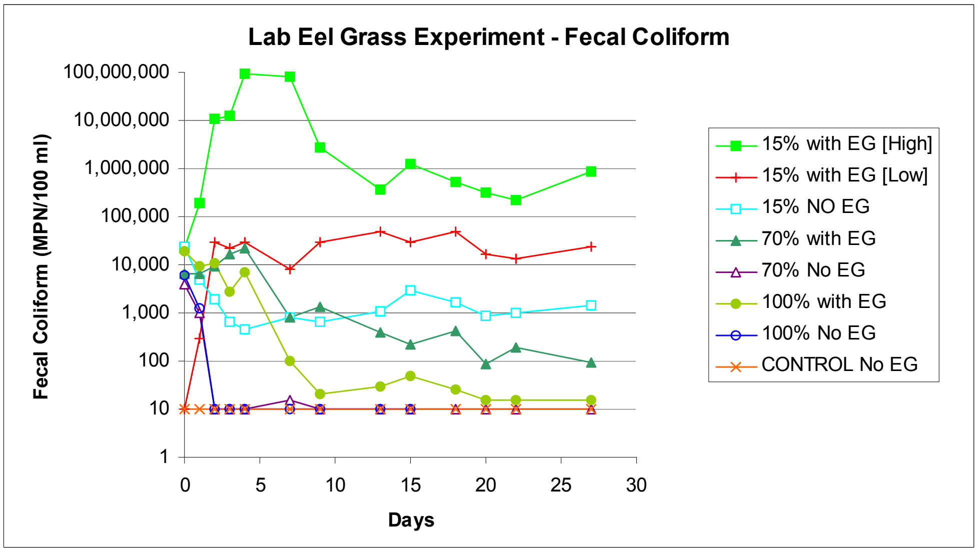


Figure 2-17. Fecal coliform densities over time under simulated storm drain conditions. Percentages in legend refer to percent of seawater salinity (e.g.,15% = approximately 5 parts per million salinity). [High] = high inoculant density and [Low] refers to low inoculant density.

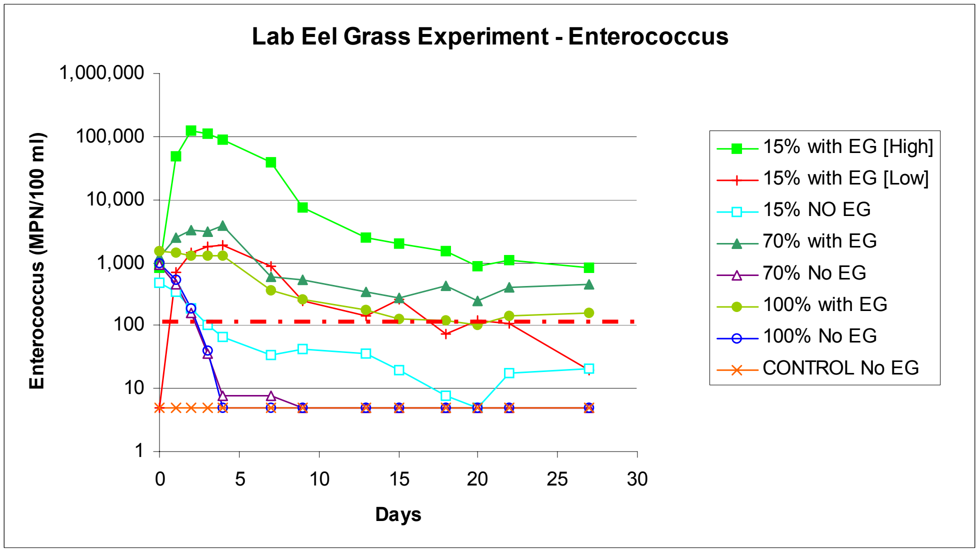


Figure 2-18. Enterococcus densities over time under simulated storm drain conditions. The dashed red line represents the AB411 criterion for enterococcus of 104 MPN/100 ml.

Conclusions

In several areas of Mission Bay, a wrack line is frequently observed in the upper intertidal zone of the beaches. Wrack is particularly prevalent along the eastern shore of Sail Bay and the eastern side of Mission Bay from De Anza Cove to Visitor's Center. The results of the wrack line study indicate that organic debris stranded on the beach in Mission Bay can act as a reservoir for indicator bacteria. Although the data presented here do not necessarily suggest that bacteria is reproducing in this environment, the data do indicate that both fecal coliform and enterococcus bacteria can survive for prolonged periods of time within the wrack matrix. The results also show that when the receiving water makes contact with the wrack, the bacterial reservoir is released to the water column. In this way, the wrack line in Mission Bay acts as a bacterial amplifier, maintaining the initial bacterial load over time.

The storm drain simulation study was designed to reproduce the range of conditions experienced inside a coastal storm drain in Mission Bay: a dark, UV protected environment, with a large influx of freshwater from the upstream drainage and groundwater, and substantial amounts of organic debris. The results suggest that, under these conditions, both fecal coliform and enterococcus bacteria can survive for prolonged periods of time and can increase by several orders of magnitude within a few days of the initial deposition. In this way, the storm drains that discharge to Mission Bay can act as bacterial incubators, amplifying the original bacterial load in both magnitude and time. The results also provide strong evidence for the importance of maintaining clean storm drains and diversion structures and suggest that modifications to the storm drains that would limit these conditions be considered as a best management practice to reduce bacterial loads to Mission Bay.

Study Overview

The investigative tasks performed as part of Phase II of this study were instrumental in identifying the origin of the enteric bacteria in Mission Bay and defining the impact of bacterial sources that were identified in Phase I. In addition, the results of follow-up studies gave us a better understanding of the processes of bacterial amplification that occur on Mission Bay beaches and in storm drains that discharge to the bay. A summary of the sources of bacteria in Mission Bay as we understand them at the end of this study is presented in Table 2-13.

A conceptual schematic of the study is presented in Figure 2-19. We present it here to summarize the overall process of the study. In it, we can see that the myriad of potential sources of indicator bacteria that were initially identified in Mission Bay was reduced to a much smaller list of likely sources through the step-wise progression of the investigative tasks and effective management actions taken by the City. The results of the Microbial Source Tracking Task were instrumental in determining that, overall, the majority of enteric bacteria in Mission Bay originates from birds. The initial load generated from avian sources can then be amplified by processes related to intertidal sediments, the wrack line, irrigation runoff, and storm drains. Because little can be done about the number of birds in Mission Bay, we believe that the most effective management solutions in reducing indicator bacterial densities should focus on these four areas.

Table 2-13. Summary of indicator bacterial sources by site at the end of the two-year study. A green N indicates potential sources that are no longer thought to be present or were remediated as part of the study. A red Y indicates potential sources that remain at each site.

Site #	Site Name	Illicit Boat Discharge	Restroom Infrastructure	Birds and Other Wildlife	Irrigation Runoff	Storm Drains	Restroom Wash down	Homeless	Dog Waste	RV Pump outs	Creek Drainage	Groundwater	Delta Sediment	Intertidal Sediment	Wrack	Other
1	Bonita Cove	N	N	Y	Y	Y	N	N	N	N	N	N	N	Y	N	N
2	Bahia Point	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N
3	Fanuel Park	N	N	Y	N	Y	N	N	N	N	N	N	N	Y	Y	Y
4	Riviera Shores	N	N	Y	N	N	N	N	N	N	N	N	N	N	Y	N
5	Wildlife Refuge	N	N	Y	Y	Y	N	N	N	N	N	N	N	Y	N	N
6	Campland	N	N	Y	N	N	N	N	N	N	N	N	N	Y	Y	N
7	De Anza Cove	N	N	Y	Y	Y	N	N	N	N	N	N	N	Y	Y	N
8	Visitor's Center	N	N	Y	Y	Y	N	N	Y	N	Y	N	Y	Y	Y	N
9	Leisure Lagoon	N	N	Y	Y	Y	N	N	N	N	N	N	N	Y	N	N
10	N. Pacific Passage	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N
11	Tecolote Creek	N	N	Y	N	N	N	N	N	N	Y	N	Y	N	N	N
12	Hidden Anchorage	N	N	Y	N	N	N	N	N	N	N	N	N	Y	N	N

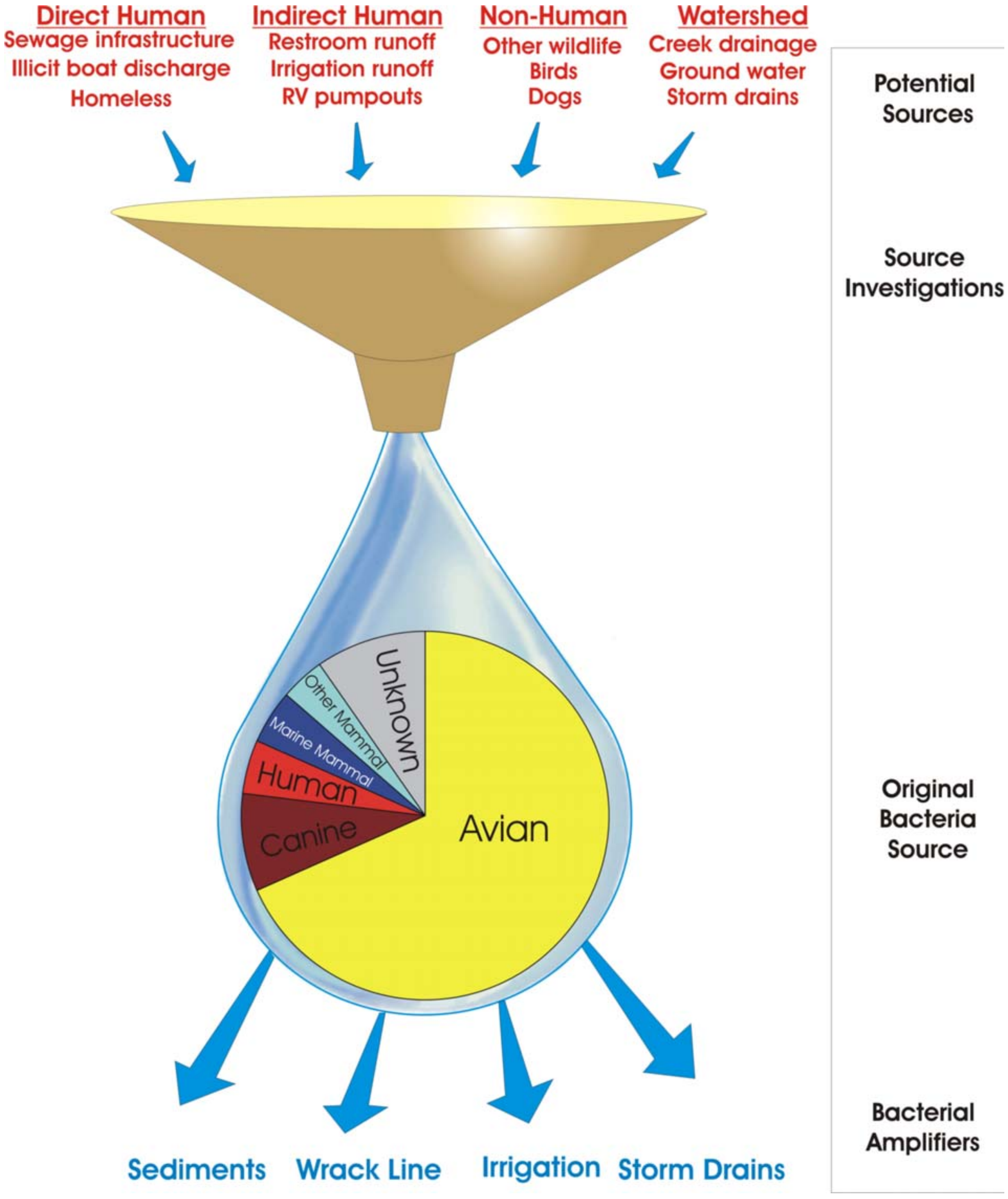


Figure 2-19. Conceptual schematic summarizing the Mission Bay Bacterial Source Identification Study.

SECTION 3

Bonita Cove

Site Conditions

Bonita Cove is a small inlet located on the southwest side of Mission Bay (Figure 3-1). It is bordered on the north by West Mission Bay Drive and on the east by Mission Boulevard. Bonita Cove is the closest of the 12 sites to the entrance of Mission Bay and the only area in the bay where boats are allowed to anchor for up to 72 hours. The park area surrounding the cove consists of large grassy areas, playgrounds, and parking lots. There are no major creek drainages that discharge to this side of the bay, but there are several storm drains in the area. Storm drain SD1-1, on the northeast side of Bonita Cove is un-diverted and conveys water from nearly all of the northeast side of the area shown in Figure 3-1. Storm drains SD1-2 and SD1-3 are both part of the MBSIS. The drainages for these two storm drains consist primarily of urban runoff from Mission Boulevard and adjacent parking lots. There are two comfort stations at Bonita Cove: one located on the north end and one on the east. The AB411 monitoring site is located on the beach directly in front of the northernmost comfort station.

Figure 3-1. Aerial photograph of Bonita Cove.

Temporal Trends

A review of the historical data for Bonita Cove suggests that there are no strong seasonal trends in densities of indicator bacteria at this site. A graph of the enterococcus densities from 1993 through 2003 is presented in Figure 3-2. The magenta line in the figure shows that enterococcus densities peak during winter in some years, but high levels are also seen in summer. The lack of strong seasonal trends at Bonita Cove may reflect the lack of freshwater input from large urban drainages at this site as well as other areas on the west side of Mission Bay. In addition, the bird population at Bonita Cove does not tend to change much from season to season (Kisner 2002). Similar results for sites on the west side of the bay were found in previous reviews of historical indicator bacteria data (Kinnetics 1994). In 2002, exceedances of AB411 were rare at Bonita Cove during the winter months, but occurred frequently with the onset of summer. The same pattern was observed in 2003.

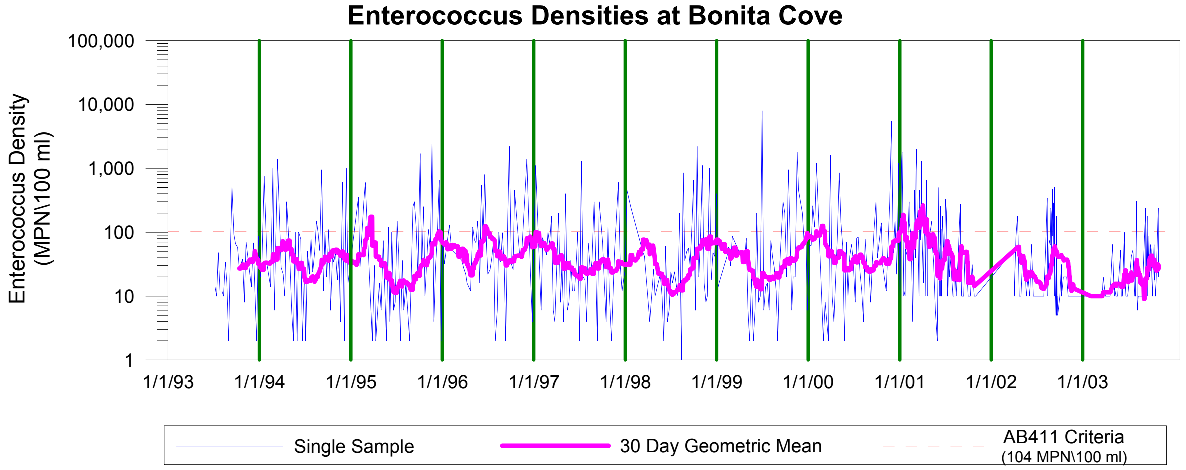


Figure 3-2. Enterococcus densities at Bonita Cove from 1993 through 2003. No data were available from November 2001 through April 2002 (source: San Diego County Department of Environmental Health).

Figure 3-2 includes samples collected from the receiving water at Bonita Cove during the Visual Observations Task (Task 3) conducted in the summer of 2002 as well as samples collected during the Weekly Monitoring in the winter of 2002/2003. For the Visual Observations Task, samples were collected three times daily (morning, mid-day, evening) on nine days between August 25 and October 9, 2002. In general, the samples taken as part of this study had low indicator bacterial densities at Bonita Cove. The one notable exception was the sample taken during the early morning on September 2, 2002. AB411 criteria for all three indicator bacteria were exceeded during this period, however, samples taken later on the same day contained very low bacterial densities, suggesting the source of bacteria was transient and ephemeral. The complete report for the Visual Observations Task is presented in Appendix D.

Following the completion of the major tasks of Phase I, weekly monitoring at Bonita Cove was performed from November 2002 through March 2003. The monitoring included visual observations and sample collection of receiving waters for indicator bacteria analyses. Over the course of the 22-week sampling period, there were no exceedances of any of the three indicator bacterial standards. Complete results of the weekly monitoring are presented in Appendix J.

Bacterial Sources – Phase I

Sources of bacterial contamination at Bonita Cove were investigated under all three Tasks conducted during Phase I. The comfort stations' infrastructure was inspected under Task 1 and the effects of comfort station washdown procedures were studied in Task 3. In addition, excessive irrigation practices and storm drain infrastructure were investigated as potential sources of bacterial contamination as part of the Visual Observations Task (Task 3). Illicit discharges of sewage from anchored boats in Bonita Cove were examined to fulfill Task 2. The complete reports for Tasks 1, 2, and 3 are presented in Appendices B, C, and D, respectively.

Comfort Stations

There are two comfort stations that serve Bonita Cove. Comfort Station 521 is located on the north end and Comfort Station 1056 is located on the east side. A total of 23 samples were collected from the runoff associated with washdown procedures of both comfort stations during the Visual Observations Task. All but two of these exceeded AB411 criteria for any of the three indictor bacteria. Table 3-1 summarizes the results of samples collected from the Bonita Cove comfort stations.

Table 3-1. Summary of bacterial densities in wash water samples collected from Bonita Cove Comfort Stations 521 and 1056.

Parameter	Minimum Concentration (MPN/100 ml)	Maximum Concentration (MPN/100 ml)	Geometric Mean (MPN/100 ml)
Total Coliform	500	16,000,000	138,213
Fecal Coliform	24	2,800,000	7,558
Enterococcus	Non Detect	344,800	1,726

The comfort stations in Mission Bay were usually washed down with hoses in the early morning during the study period. At Bonita Cove, excess water was observed coming out of the comfort stations and flowing across the concrete foundation pad. Pools of water were often observed where the concrete met the grassy area of the park, even late in the afternoon, hours after the washdown had occurred. French drains were present on the bay side of Comfort Station 521 on the North end of Bonita Cove, but they appeared to be draining very slowly. The drains lead to a leach field that was approximately 60 feet from the beach. The high levels of bacteria found in the ponded water resulting from daily cleaning of both comfort stations at Bonita Cove represented a potentially significant source of bacteria to the bay. However, there was no evidence of a direct pathway on the surface of the grass from the comfort stations to the receiving waters.

French drains outside Comfort Station 521

In October 2002, a recommendation was made to the City of San Diego Park and Recreation Department to examine the comfort station washdown procedures at all of the comfort stations in Mission Bay Park. A best management practice (BMP) of containing the washdown water within the confines of the comfort station was implemented, where drains inside the comfort station could then convey the wash water to the sanitary sewer system. The weekly monitoring activities confirmed washdown runoff was confined to the comfort stations and not flowing across the concrete to grassy areas. Thus, this BMP program instituted by the City in the spring of 2003 appeared to have been effective at eliminating this source of bacteria to Mission Bay.

As part of Task 1, the structural integrity of the lateral lines (sewer lines that carry wastewater from the park's comfort stations to the City's sewer mains) was inspected by closed circuit television for Comfort Stations 521 and 1056. These inspections were conducted on September 19, 2002 and showed that the lateral lines for both comfort stations were in good condition and were an unlikely source of indicator bacteria at this site.

Irrigation

Ponded water in the grassy areas of the park around Bonita Cove occurred from excessive irrigation. In the fall of 2003, samples collected of this ponded water contained high densities of all three indicator bacteria (Table 3-2). In all cases, the areas of ponded water (and associated water quality samples) were not directly influenced by the comfort station washing procedures described above. During the visual observations, there were no obvious human fecal sources that could account for the high levels of indicator bacterial densities. Visual observations did indicate a large bird population, particularly on the eastern side of Bonita Cove and birds were frequently observed in the grassy areas of the park. Samples collected from the puddles as part of the Microbial Source Tracking Task in Phase II indicate that the majority of the enteric bacteria in the puddles at Bonita Cove and other areas in the park originate from birds. These results are detailed in Appendix F.

Irrigation at Bonita Cove

Table 3-2. Summary of bacterial densities for samples collected from ponded water on grassy areas surrounding Bonita Cove.

Parameter	Minimum Concentration (MPN/100 ml)	Maximum Concentration (MPN/100 ml)	Geometric Mean (MPN/100 ml)
Total Coliform	3,000	5,000,000	78,500
Fecal Coliform	1,300	300,000	10,471
Enterococcus	565	10,220	3,664

Bacteria can be transported from the grassy areas of the park to the receiving waters via sheet transport across the surface of the grass or through irrigation runoff that flows to the bay through the storm drains. At Bonita Cove, there was no evidence of substantial erosion of the banks adjacent to the grass, so sheet transport of bacteria is unlikely. However, excess irrigation water was observed flowing down the gutters and out the storm drains at this site. In this way, the reservoir of bacteria identified in the grass can be transported to the bay via storm drains, particularly storm drain SD1-1, which is un-diverted.

Storm Drains

Storm drains were identified as a potential source (and mechanism of transport) of bacteria to Bonita Cove. Six storm drains discharge directly to Bonita Cove, and one storm drain discharges to the Mission Bay Channel directly south of Bonita Cove. However, there are only three storm drains in the immediate area surrounding the AB411 monitoring site (Figure 3-1). Inspections of the storm drains and diversion system were conducted on April 2, 2003. The inspections found malfunctioning infrastructure such as clogged diversion systems and tide flex valves. Problems associated with the diversion structures for storm drains SD1-2 and SD1-3 were particularly egregious and prevented the diversion of dry weather flow to the sewer system. Appendix I provides a thorough discussion of the results of this inspection.

Flow from storm drain SD1-2

Illicit Discharge from Anchored Boats

The potential for bacterial contamination from the illicit discharge of sewage from the boats moored and anchored at Bonita Cove was initially assessed during the boat mooring investigation (Task 2). This study was designed to determine if illegal dumping of holding tanks from boats moored or anchored in Mission Bay was a source of indicator bacteria on the beach. Samples for bacterial analyses were collected by kayak around the anchored boats on each of three days in mid-August, 2002. An additional sample was collected each day from the beach at the AB411 monitoring site for Bonita Cove. Very low densities of all three indicator bacteria were detected throughout the boat mooring study. Seventy-three percent (11 of 15) of the samples had either non-detect results or bacterial densities equal to the detection limit for all three indicators. The remaining samples had at least one indicator bacteria with a density above the detection limit, but none of the results exceeded the AB411 criteria.

The results of the boat mooring study suggested that the illegal dumping of sewage from moored boats was not a source of bacteria at Bonita Cove during the sampling period. However, since the sampling duration was limited, and illegally dumping is likely episodic (if it is occurring), the potential for illicit sewage discharge from boats as a source of bacterial contamination to adjacent beaches could not be ruled out. It was reasonable to assume that the most likely time for illegal discharges from boat holding tanks would be when the greatest number of boats were using the anchorages. Therefore, a recommendation was made to the City to repeat the sampling protocol during a high use weekend (e.g., Memorial Day, 2003) when there was a greater likelihood of collecting a sample during a discharge event. Sampling at night or early morning when illegal discharges were most likely to occur was also recommended.

This recommendation was implemented in a follow-up study conducted over Memorial Day weekend, 2003. The first step in the follow-up study was to review the historical data of bacterial densities in Mission Bay (1993 through 2000) collected by the City of San Diego and the San Diego County Department of Environmental Health. The results suggested that there were differences between the densities of indicator bacteria on summer holidays (Memorial Day, Fourth of July, and Labor Day) verses non-holiday summer days at some beach sites. For this assessment, the holiday period included seven days centered around the actual holiday date and the non-holiday period was all other days after Memorial Day and before Labor Day. At Bonita Cove the mean density of enterococcus during summer holidays (449 MPN/100 ml) was significantly greater than that during non-holiday days (79 MPN/100 ml) (p = 0.016). The large difference in enterococcus levels between holidays and non-holidays (Figure 3-3) suggested that there may be different mechanisms at work during these two time periods related to bacterial densities in the water column.

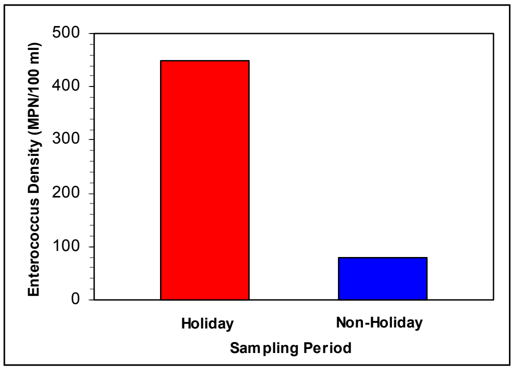


Figure 3-3. Mean enterococcus densities in receiving water during summer holidays and non-holidays at Bonita Cove.

There were two scenarios that would most likely explain the observed differences in enterococcus densities between holiday and non-holiday periods: 1) beach sediments acted as a bacterial reservoir and high bacterial densities observed during holiday periods were associated with resuspended sediments that developed with the increase in swimmers during holidays; or 2) illicit discharge of sewage holding tanks of boats that anchor at Bonita Cove during holidays was the source of the bacteria.

Sediment resuspension studies conducted at Bonita Cove are discussed below under Phase II bacterial sources. To further explore the second scenario, a follow-up study was conducted to assess the potential for illicit discharge of boat holding tanks during a summer holiday. Samples were collected on Saturday night of Memorial Day weekend (May 24, 2003) at approximately 9:00 p.m. and Monday morning (May 26, 2003) at approximately 5:00 a.m. On each day, 15 surface water samples were collected by kayaking through the anchored boats. In addition, a sample was taken from the beach at the AB411 monitoring site. Similar to the results of the first study on illicit discharge from boats (Task 2), data from the follow-up study indicated no direct source of enterococcus from the anchored boats at Bonita Cove. On May 24, 2003, one sample taken at the Bonita Cove beach just exceeded the enterococcus AB411 standard, but all other samples taken on both dates had enterococcus densities of < 10 MPN/100ml. The complete results of the second investigation are presented in Appendix K.1. The results of the boat mooring studies suggested that there was no illicit discharge of sewage from the anchored boats at Bonita Cove during the two sampling periods. Further, chronic discharge of sewage from boats is an unlikely source of indicator bacteria to the receiving waters.

Bacterial Sources – Phase II

Bonita Cove was assessed in two of the three investigative tasks of Phase II: Microbial Source Tracking and the Sediment Investigation. The studies are presented in detail in Appendices E and G, respectively and summarized below.

Bacterial Host Origin

Groundwater sampling from beach face spring

The design of the microbial source tracking study conducted at Bonita Cove incorporated the results from Phase I and included a dry weather assessment (July 1 through November 6, 2003) during both holiday and non-holiday periods. Samples were collected from the receiving water, storm drains SD1-1 and SD1-2, and from a groundwater spring.

As with other sites in Mission Bay, none of the four samples collected from the groundwater spring at Bonita Cove contained indictor bacteria. These results suggest that groundwater seepage through the beach face is not a source of bacteria at this site.

Indicator bacteria were found in the storm drain effluent and receiving water samples taken at Bonita Cove. *E. coli*, a member of the fecal coliform group, were isolated from the receiving water samples and were analyzed using the Ribotyping assay, one of two microbial source tracking techniques employed in the study (see discussion in Appendix E). Here, the term Ribotype refers to the unique genetic fingerprint of a single bacterial cell, also known as an isolate. Once a data set of “unknown” Ribotypes (such as the initial Ribotypes derived from receiving water isolates) is obtained, the Ribotype Library Database, which contains over 110,000 Ribotypes from known animal sources throughout North America, is searched for matches.

The results of the Ribotyping assay for the storm drain and receiving water samples collected at Bonita Cove are presented in Figure 3-4. Sixty-eight percent of the storm drain-derived Ribotypes were found to match Ribotypes of Avian origin (Figure 3-4A). The minority source groups of Ribotypes derived from storm drain effluent samples were identified as having other mammalian (12%) and Canine (10%) origins, while 10% of the Ribotypes could not be identified in the Library Database (Unknown).

Bonita Cove receiving water Ribotypes were analyzed for both Holiday and Non-Holiday periods, however, we found virtually no difference in the animal source groups between the two sampling periods. Therefore, all the receiving water data were combined for further analysis. An overwhelming majority (75%) of Ribotypes derived from the combined receiving water data set matched Avian Ribotypes in the source library database (Figure 3-4B). Canine and Human Ribotypes each accounted for 7% of the total receiving water-derived Ribotypes at this site. Since no Human Ribotypes were identified in the storm drain-derived Ribotypes, it is feasible that those Human Ribotypes found in the receiving water were conveyed via direct swimmer input.

We next asked whether any of the receiving water-derived Ribotypes were shared with those obtained from storm drain effluent. This analysis is possible since every Ribotype obtained is assigned an identifier code, allowing Ribotypes from one data set to be searched or traced to another data set. Remarkably, results from this tracing analysis (Figure 3-4C) showed that 65% of the receiving water Ribotypes were shared with those obtained from the storm drains. Virtually all of these shared Ribotypes were found to be of Avian origin.

Host-Specific PCR was the second of two MST methods employed. In this assay, unique genetic markers present in the fecal anaerobe *Bacteroides* are amplified using the Polymerase Chain Reaction. If the genetic marker is present, the sample is scored positive for human contamination. Bonita Cove receiving water samples were analyzed by this assay and results indicated that only one sample was positive for human contamination. No storm drain samples were found to be positive for the Human marker, which is in good agreement with the Ribotyping data presented above.

Dry Season Ribotyping Results at Bonita Cove

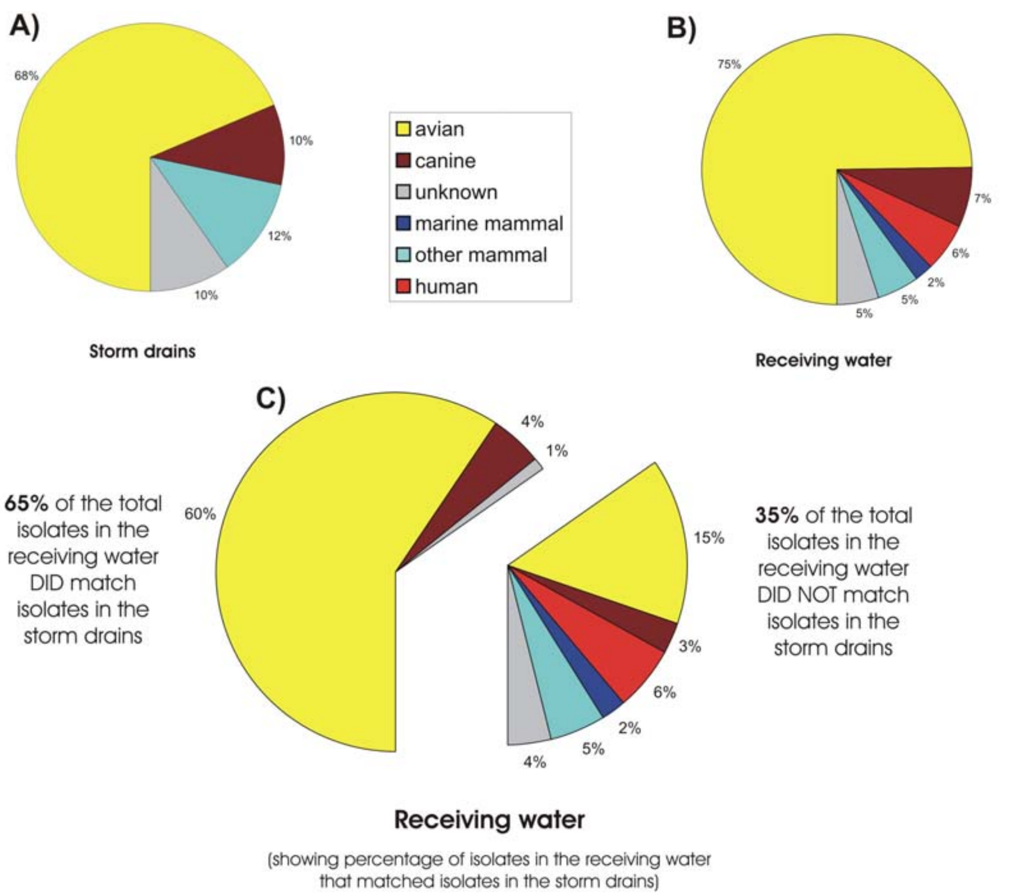


Figure 3-4. Results of Ribotyping analysis at Bonita Cove. The pie charts show the origin of bacterial isolates in storm drains SD1-1 and SD1-2 (A), receiving water (B), and the proportion of isolates in receiving water that matched those in storm drains (C).

Intertidal Sediments

At Bonita Cove, intertidal sediments were assessed to determine the extent to which they may contribute to elevated bacterial densities in the receiving water. Two types of assessments were conducted: a survey of bacterial densities in beach sediments within the intertidal zone and a sediment resuspension study. For the intertidal sediment study, samples of beach sand were collected at different tidal heights from five transects and analyzed for indicator bacteria. The study was conducted on April 14, 2004. The results are presented in detail in Appendix G and summarized in Figure 3-5.

Densities of fecal coliform and enterococcus in sediment were similar at tidal heights of +6, +5, +4, and +2 feet above Mean Lower Low Water (MLLW), with geometric means of the five transects ranging from 32.5 to 101 MPN/g dry sediment. However, at tidal heights of +1 and 0 feet above MLLW, fecal coliform densities dropped dramatically, with geometric means of 1.4 and 2.6 MPN/g, respectively. Mean fecal coliform densities in the upper intertidal sediments (+6, +5, +4, and +2 feet above MLLW) were significantly greater ($p < 0.0001$) than those in the lower intertidal sediments (+1 and 0 feet above MLLW). Similar results were observed for enterococcus densities. These results suggest that sediments in the upper intertidal zone acts as a reservoir for indicator bacteria, but sediments in the lower intertidal zone do not.

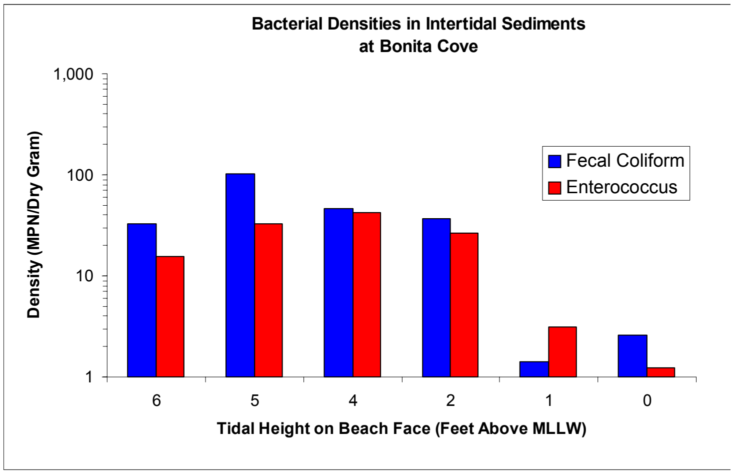


Figure 3-5. Fecal coliform and enterococcus densities in intertidal sediments at Bonita Cove. Bars represent the geometric means of 5 samples.

The second study assessing intertidal sediments was designed to compare bacterial densities before and after sediments were resuspended in the water column. Samples were taken from 15 locations at Bonita Cove centered around the AB411 monitoring site. Two receiving water samples were taken sequentially at each site: 1) a clear water sample, in the absence of suspended sediment; and 2) a resuspended sediment sample, taken after the sediments had been disturbed and kicked up into the water column by the sampler (simulating swimmer activity). Samples were collected in the same way as samples collected for regulatory purposes. The study was conducted twice: once in May 2003 in the lower intertidal zone (only enterococcus was enumerated) and again in April 2004 in the upper intertidal zone (both fecal coliform and enterococcus were enumerated). The enterococcus results are presented in Figure 3-6.

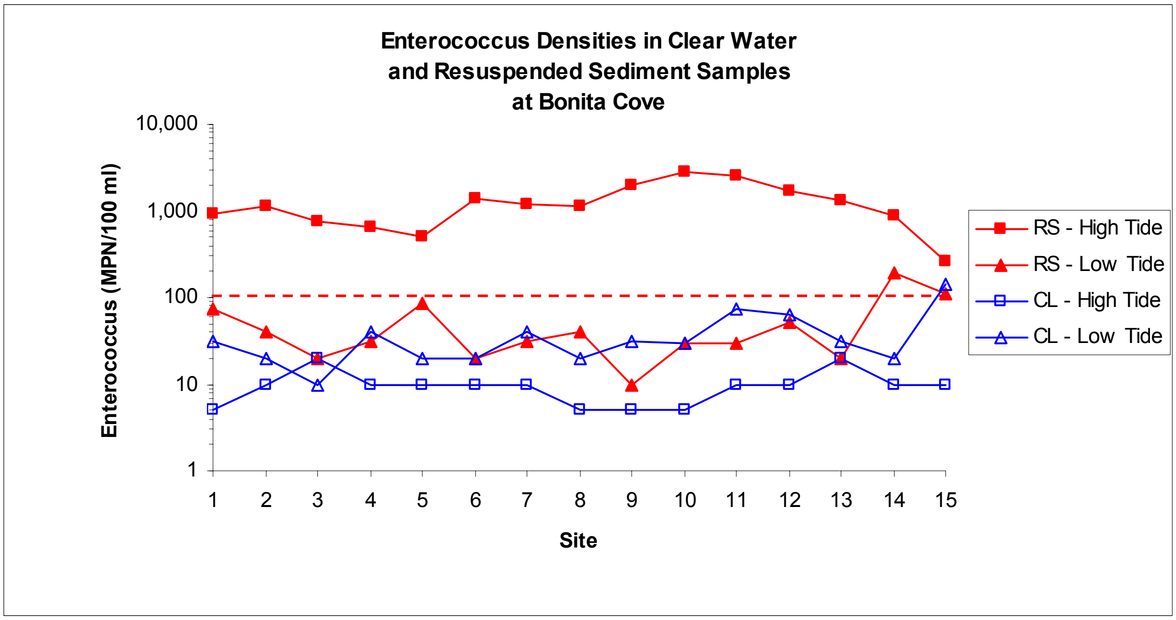


Figure 3-6. Graph of enterococcus densities in receiving water at Bonita Cove. CL refers to clear water samples and RS refers to samples taken after sediment resuspension. The dashed red line represents the AB411 standard for enterococcus of 104 MPN/100 ml.

During the Low Tide study, there was no significant difference ($p > 0.05$) between the mean clear water and resuspended sediment bacterial densities for either fecal coliform or enterococcus. In contrast, when the study was repeated during high tide, there was a marked difference in bacterial densities between the clear water and resuspended sediment samples. For enterococcus, the geometric mean density of the Clear Water samples was low at high tide (9.1 MPN/100 ml), similar to the results observed during low tide. However, after sediment resuspension at high tide, the enterococcus geometric mean density had increased two orders of magnitude to 1,096 MPN/100 ml. At all 15 stations the resuspended sediment samples at high tide were one to two orders of magnitude greater than the corresponding Clear Water samples. The mean enterococcus density of the resuspended sediment sample was significantly greater than that of the clear water samples ($p < 0.0001$).

Fecal coliform bacteria were enumerated at Bonita Cove only in the High Tide resuspension study conducted in April 2004. The results are similar to those seen for enterococcus at high tide. Mean fecal coliform density of the resuspended sediment samples was significantly greater than that of the clear water samples ($p < 0.0001$).

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

The same pattern was not observed in the lower intertidal zone. We believe this can be explained by the fact that the beach face in the upper intertidal zone is exposed (i.e., not inundated by seawater) to a much greater extent than the lower intertidal zone, which allows for a greater period of time for the accumulation of fecal matter. The results of the microbial source tracking study at Bonita Cove indicate that the vast majority of enteric bacteria found in the receiving waters originated from birds. In addition, birds and bird feces were observed frequently on the beach face in the upper intertidal zone. The lower intertidal zone is submerged more frequently than the upper intertidal zone, preventing the accumulation of bird feces. In addition, seawater tends to limit survival of both fecal coliform and, to a lesser extent, enterococcus bacteria. As a result, bacterial densities are lower in the lower intertidal zone sediments and sediment resuspension has a negligible effect on bacterial densities in the water column.

The results of the intertidal sediment study provide the most reasonable explanation for the observed increase in bacterial densities during summer holiday weekends at Bonita Cove. Initially, this increase was thought to be due to a greater number of boats at Bonita Cove on holidays and a greater potential for illicit sewage discharge. However, the results of the Molecular Source Tracking Task indicate that there is very little enteric bacteria from human origin in the receiving waters at this site. In addition, there are no management actions that take place only on holidays that would account for the difference. However, during summer holidays, the number of swimmers at Bonita Cove increases dramatically. As a result, the intertidal sediments on summer holidays may be disturbed by swimmers to a greater extent than on non-holidays, resulting in greater sediment resuspension and subsequent release of the bacteria to the water column.

Conclusions

At the onset of the study, numerous potential sources of indicator bacteria were identified at Bonita Cove. Therefore, this site was the most intensively studied site on the west side of Mission Bay. Investigations conducted as part of Phase I of the study indicated that many of the potential sources initially suspected were unlikely contributors of bacteria to the receiving waters of Bonita Cove. Unlikely sources of indicator bacteria to the receiving waters at this site include comfort station infrastructure, the homeless population, illicit sewage discharge from boats, dog waste, and groundwater. In addition, wrack does not tend to accumulate on the beach at Bonita Cove. Runoff from comfort station washdown was identified as a bacterial source at this site, but was eliminated through effective management actions instituted by the City. The results of the investigations conducted at Bonita Cove are summarized in Table 3-3.

Table 3-3. Sources of indicator bacteria at Bonita Cove. A green N indicates potential sources that are no longer thought to be present or were remediated as part of the study. A red Y indicates potential sources that remain at this site.

Site #	Site Name	Illicit Boat Discharge	Restroom Infrastructure	Birds and Other Wildlife	Irrigation Runoff	Storm Drains	Restroom Washdown	Homeless	Dog Waste	RV Pump Outs	Creek Drainage	Groundwater	Delta Sediment	Intertidal Sediment	Wrack	Other
1	**Bonita Cove**	N	N	Y	Y	Y	N	N	N	N	N	N	N	Y	N	N

Bonita Cove


Birds in the upper intertidal zone at Bonita Cove

The results of investigations conducted as part of Phase II of the study provided the most meaningful information on the sources of indicator bacteria at Bonita Cove. The results of the molecular source tracking and sediment investigations indicate that: 1) the majority of the enteric bacteria in the receiving waters, intertidal sediments, storm drains, and grassy areas of the park originate from birds; 2) excess irrigation and subsequent runoff is conveyed to the receiving waters via the storm drain system; and 3) beach sediments in the upper intertidal zone act as a reservoir for indicator bacteria that is released to the receiving water when the sediments are disturbed (e.g., by swimmers). Sediment resuspension is the most likely reason for the elevated bacterial densities observed during summer holiday weekends at Bonita Cove.

SECTION 4

Bahia Point

Site Overview

Bahia Point is a peninsula located on the western side of Mission Bay (Figure 4-1). It is surrounded by Santa Barbara Cove to the west and Ventura Cove to the southeast. To the south, West Mission Bay Drive separates Bahia Point from Bonita Cove. The Bahia Hotel occupies most of the peninsula. Parking lots and a small strip of grass lie between the hotel and the beach. Although there are no major drainages that discharge in the area, there are two storm drains that discharge on the peninsula and several others that discharge into Santa Barbara Cove and Ventura Cove. Storm drains SD2-4 and SD2-5 drain the parking lots and the grassy areas of the peninsula and they are not part of the MBSIS. The AB411 monitoring site for Bahia Point is located directly in front of storm drain SD2-4. Additional AB411 sites in the area are located in front of storm drains SD2-3 and SD2-7. There is one comfort station at this site located approximately 400 feet south of storm drain SD2-4.

Figure 4-1. Aerial photograph of Bahia Point.

Bahia Point

Temporal Trends

A review of the historical data for Bahia Point suggests that there are no obvious seasonal trends at this site. A graph of the enterococcus densities from 1993 through 2003 is presented in Figure 4-2. Similar to Bonita Cove, the lack of any seasonal trends in the data set at Bahia Point may be due to the relatively small drainage area of the site, as compared with the drainage areas of some sites on the east side of the bay and discussed later in this report. In addition, the bird population is relatively small at this site and does not change much seasonally (Kisner 2002).

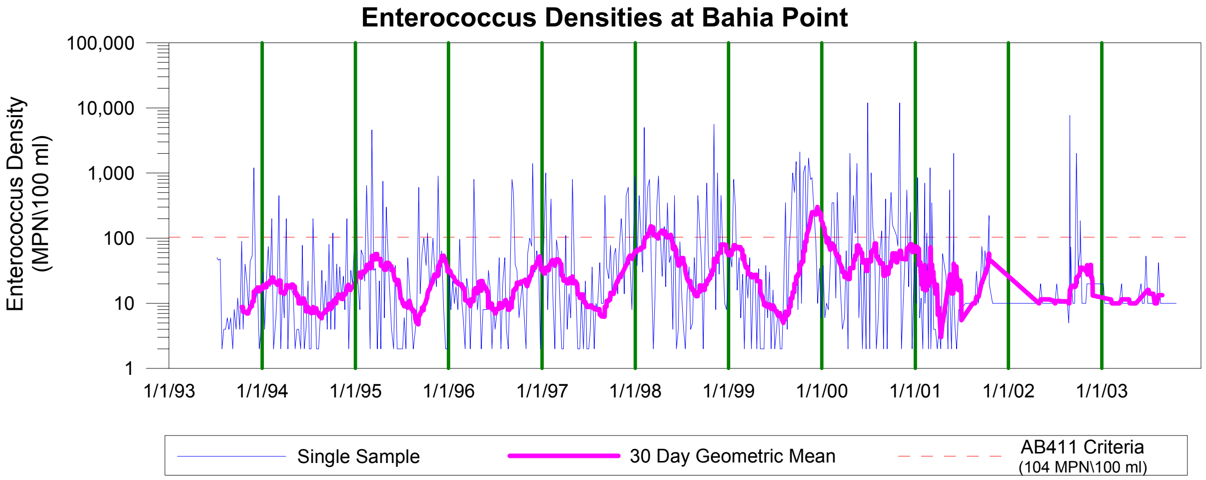


Figure 4-2. Enterococcus densities at Bahia Point from 1993 through 2003. No data were available from November 2001 through March 2002 (source: San Diego County Department of Environmental Health).

Figure 4-2 includes samples collected from the receiving water at Bonita Cove during the Visual Observations Task conducted in the summer of 2002 as well as samples collected during the Weekly Monitoring in the winter of 2002/2003. During the Visual Observations Task, samples were collected three times daily (morning, mid-day, evening) on nine days between August 25 and October 9, 2002. Approximately 30% of the samples for each indicator bacteria had a non-detect result and 55 to 60% of the samples had densities below the AB411 criteria. Only 10 to 15% of the samples had bacterial densities exceeding the AB411 criteria, and these samples appeared temporally random. Elevated bacterial densities do not tend to persist at Bahia Point.

Bacterial Sources – Phase I

Investigations of potential sources of bacterial contamination were completed under each of the tasks outlined in the Phase I scope of work. The sewer lateral lines associated with the comfort station were inspected under Task 1. As part of Task 2, samples were collected around anchored boats in Santa Barbara Cove to determine if boat owners were illicitly discharging sewage. In Task 3, samples were collected and analyzed for bacterial densities in ponded water from excessive irrigation, runoff generated by comfort station washdown, and storm drain runoff from storm drain SD2-4. The complete reports for Tasks 1, 2, and 3 are presented in

Appendices B, C, and D, respectively. The results for each of these studies at Bahia Point are summarized below.

Comfort Stations


Comfort Station 834 at Bahia Point

There is only one comfort station that serves Bahia Point: Comfort Station 834, located at the northern end of the peninsula (Figure 4-1). Although several observations were made of runoff resulting from washdown procedures at this comfort station, only one sample was collected. This sample had extremely high levels of total coliform bacteria (5,000,000 MPN/100 ml). Fecal coliforms were not detected and the enterococcus density was slightly above the AB411 criteria (108 MPN/100 ml). There is no grass buffer strip between the comfort station's concrete foundation and the beach sand at Bahia Point. Therefore, runoff from the washdown procedures drained directly to the sandy beach and was considered a potential source of bacteria to Mission Bay. However, visual observations made during the weekly monitoring conducted during the winter of 2002/2003 confirmed that BMPs initiated to confine runoff from washdown procedures to within the structure were working and had been effective in eliminating this source of bacteria to Mission Bay.

The lateral lines that serve Comfort Station 834 were inspected by closed-circuit television during Task 1 of this study to confirm their structural integrity. These inspections were conducted on September 19, 2002. The results of the inspection showed the lateral line leading from the comfort station to the sewer main was in good condition with the exception of some mild corrosion in a section of cast iron pipe. Thus, the sewer infrastructure is not considered to be a source of bacteria to the area's receiving waters.

Irrigation

Observations made during the Visual Observations Task suggested that excessive irrigation practices resulted in the occurrence of ponded water on the grassy areas and parking lots at Bahia Point. Samples collected for bacterial analyses of this ponded water had high levels of all three indicator bacteria (summarized in Table 4-1). Samples collected from ponded water on the grass contained greater total coliform and enterococcus densities than those collected from paved surfaces. Fecal coliform densities were similar in both areas.

Table 4-1. Indicator bacteria results for samples collected from ponded water on grassy areas and paved surfaces at Bahia Point.

Parameter	Minimum Density (MPN/100 ml)	Maximum Density (MPN/100 ml)	Geometric Mean (MPN/100 ml)
Total Coliform	70	3,000,000	24,940
Fecal Coliform	Non Detect	70,000	2,685
Enterococcus	Non Detect	10,140	176

The indicator bacteria found in the grassy areas at Bahia Point can be transported to the receiving waters via several pathways, including groundwater, direct runoff over the surface of the grass, and through the storm drains. Groundwater transport was determined to be an unlikely means of bacterial migration to Mission Bay (summarized in Section 2). In addition, there was little evidence of erosion at Bahia Point during the Visual Observations Task, suggesting that direct runoff is also unlikely at this site. However, bacteria from the grass can be transported to the receiving waters through the storm drain system at Bahia Point. This potential is discussed further, below.

Recreational Boats in Santa Barbara Cove

Storm Drains

Storm drains were identified as a potential source (and mechanism of transport) of bacterial contamination to the receiving waters surrounding Bahia Point. A total of eight storm drains discharge to the area between Santa Barbara Cove and Ventura Cove. Dry weather flow in half of these is diverted through the MBSIS. Inspections of the diversion structures for these storm drains were conducted on April 3, 2003. Aside from some litter and debris located at the diversion grates of storm drain SD2-6, the infrastructure appeared to be functioning as designed in diverting dry weather flow to the sewer. Appendix I provides a detailed summary of the storm drain inspections.

Four of the storm drains at Bahia Point are not diverted to the sewer system (see Figure 4-1). During the Visual Observations Task, the gutters leading to the storm drains were frequently full of organic debris from lawn maintenance practices. In addition, excess irrigation water was observed flowing through storm drain SD2-4, which discharges in front of the AB411 monitoring site. One sample was collected from storm drain SD2-4 and bacterial densities were very high for all three indicators (2,400,000 MPN/100 ml, 8,000 MPN/100ml and 285,100 MPN/100 ml for total coliform, fecal coliform and enterococcus, respectively). Although only one sample was taken from the storm drains at this site, the presence of high bacterial densities in the grass, organic debris in the gutters, and observations of excess irrigation water suggest that the un-diverted storm drains at Bahia Point, particularly storm drain SD2-4, were likely sources of bacteria to the receiving waters.

In the spring of 2003, the City Park and Recreation Department was made aware of the organic debris that accumulated in the gutters at Bahia Point and the excessive irrigation that helped convey it to the receiving waters of Mission Bay. As a result, management actions were taken to reduce this source of bacteria.

Illicit Discharge from Boats

The potential for bacterial contamination from the illicit discharge of sewage from the boats moored at Santa Barbara Cove (on the west side of Bahia Point) was initially assessed during the boat mooring investigation (Task 2). Samples for bacterial analyses were collected by kayak around the moored boats on each of three days during mid-August, 2002. An additional sample was collected from the beach at the AB411 monitoring site.

Very low levels of all three indicator bacteria were detected throughout the study area. In most cases, the densities were below or just above the detection limits. These results indicated that the illegal discharge of sewage from moored boats was not occurring during the time of sampling at Bahia Point. However, since illicit discharges from anchored boats is likely episodic, there will always be a potential for sewage discharges from boats to be a source of bacterial contamination to area beaches.

Bacterial Sources – Phase II

Bahia Point was not assessed as part of Phase II, but the mechanisms of bacterial transport and amplification identified at other sites in Phase II are unlikely to have a major influence on bacterial densities at Bahia Point.

Conclusions

The results of the Phase I investigations indicate that the beach at Bahia Point is one of the cleanest in Mission Bay. Typically, there is no wrack line present at this site, there are no major creek drainages in the area, and the bird population is low. During the Visual Observations Task, there was no dog waste observed at this site and the number of swimmers was relatively low compared to other sites in Mission Bay. The boat mooring investigation suggested that illicit discharge from boats in Santa Barbara Cove was an unlikely source of bacteria to Bahia Point. The lateral lines from comfort station 834 were in good condition and comfort station runoff, which has been shown to contain high levels of indicator bacteria at this site, has been eliminated as a result of BMPs instituted by the City. In addition, the beach at this site is typically free of organic debris and the bird population is relatively low, which suggests that sediment resuspension is an unlikely bacterial source. A summary of the bacterial sources identified at this site is presented in Table 4-2.

Table 4-2. Sources of indicator bacteria at Bahia Point. A green N indicates potential sources that are no longer thought to be present or were remediated as part of the study. A red Y indicates potential sources that remain at this site.

Site #	Site Name	Illicit Boat Discharge	Restroom Infrastructure	Birds and Other Wildlife	Irrigation Runoff	Storm Drains	Restroom Washdown	Homeless	Dog Waste	RV Pump Outs	Creek Drainage	Groundwater	Delta Sediment	Intertidal Sediment	Wrack	Other
2	**Bahia Point**	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N

Bahia Point

Un-diverted storm drain at Bahia Point

Based on the information collected in Phase I of this study, the most likely source of elevated bacterial densities at Bahia Point appears to be the runoff from the un-diverted storm drains SD2-4 and SD2-5. The drainage area for these storm drains is small, but they convey water from the grassy areas of the park during irrigation, which contain high levels of indicator bacteria. Bacterial densities may also increase as water flows to the storm drains from leaf litter and organic matter in the gutters at Bahia Point. High levels of indicator bacteria were measured from these storm drains during Task 3. In addition, the AB411 monitoring site is located directly in front of the discharge point of storm drain SD2-4. In the spring of 2003, the City Park and Recreation Department was made aware of the organic debris that accumulated in the gutters at Bahia Point and the excessive irrigation that helped convey it to the receiving waters of Mission Bay. As a result, management actions were taken to reduce this source of bacteria. Since that time there have been no exceedances of AB411 criteria at Bahia Point (the enterococcus data is summarized in Figure 4-1), suggesting that the management actions taken by the City have been successful in reducing or eliminating bacterial loads at this site.

Based on the results of the bacterial source tracking analyses conducted at other sites in Mission Bay, the bacteria that are present in the receiving waters at Bahia Point likely originate from birds.

SECTION 5

Fanuel Park

Site Overview

Fanuel Park is located in the northwest corner of Mission Bay at the end of Fanuel Street (Figure 5-1). The site faces the northern end of Sail Bay, which is one of the largest areas of open water in Mission Bay. The area around the Fanuel Park site consists mostly of beach, with a small playground and a volleyball court on the western side of the area. The beach in this area is surrounded by condominiums and apartment buildings and there is only one small grassy area, which lies adjacent to Fanuel Street. A boardwalk around the beach is used year-round by bikers and joggers. In the summer, the beach is used heavily, particularly during holiday weekends. Directly offshore of Fanuel Park, activities such as water-skiing and jet skiing are common. There are four storm drains that discharge directly to the Fanuel Park area. Although all of them are part of the MBSIS, they all convey un-diverted dry weather runoff to Mission Bay downstream of the diversion structures (note red lines in Figure 5-1). There is one comfort station at this site located at the end of Fanuel Street. The Fanuel Park AB411 monitoring site is located in line with storm drain SD3-3, although this storm drain is submerged during even the lowest tides.

Figure 5-1. Aerial photograph of Fanuel Park.

Temporal Trends

A review of the historical data for Fanuel Park suggests that there are no strong seasonal trends in densities of indicator bacteria at this site (Figure 5-2). The magenta line in Figure 5-2 shows that enterococcus levels peak during winter in some years, but high densities are also seen in summer. Exceedances of bacterial standards tend to be sporadic at Fanuel Park.

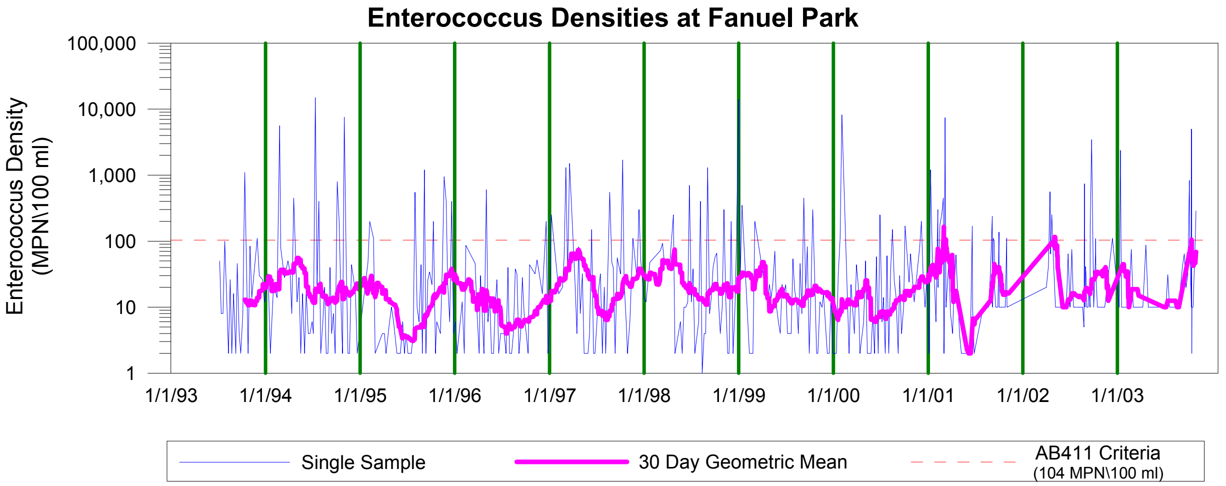


Figure 5-2. Enterococcus densities at Fanuel Park from 1993 through 2003. No data were available from November 2001 through April 2002 (source: San Diego County Department of Environmental Health).

Figure 5-2 includes data from samples collected from receiving water at Fanuel Park during the Visual Observations Task conducted in the summer of 2002 as well as samples collected during the Weekly Monitoring in the winter of 2002/2003. For the Visual Observations Task, samples were collected three times daily on nine days between August 25 and October 9, 2002. In general, indicator bacterial densities were low throughout the study period at Fanuel Park. Nearly 80% of the samples collected had total and fecal coliform densities at or below the detection limit and almost 70% of the samples contained enterococcus densities at or below the detection limit. The maximum density measured was from a single sample taken mid-day on September 24, 2002 (2,300 MPN/100 ml for total and fecal coliform, 3,448 MPN/100 ml for enterococcus).

Bacterial Sources – Phase I

Sources of bacterial contamination to the receiving waters at Fanuel Park were investigated under the Comfort Station Infrastructure Task (Task 1) and the Visual Observations Task (Task 3) developed for Phase I. During the Visual Observations Task, excessive irrigation practices, storm drain infrastructure, and dewatering of groundwater and rainwater from underground parking structures were identified as potential sources of bacterial contamination to Fanuel Park. The complete reports of these investigations are presented in Appendices B and D and summarized below.

Comfort Stations

Comfort Station 9950 at Fanuel Park

One Comfort Station serves Fanuel Park: Comfort Station 9950 at the end of Fanuel Street. Unlike other comfort stations around Mission Bay, the comfort station at Fanuel Park contains several individual toilets, each occupying a private restroom. Cleaning of the comfort station occurred by washing out each individual restroom then sending any residual water to the french drains located adjacent to the comfort station facility. Due to the absence of drains within each restroom, the BMP discussed in Section 3 (Bonita Cove) to contain washdown runoff was not attainable. Therefore, this was the only site where runoff from washdown procedures continued. A total of six samples were collected from the runoff associated with washdown procedures at Comfort Station 9950. Table 5-1 summarizes the results of these samples.

Table 5-1. Summary of bacterial results for wash down samples collected from Fanuel Park Comfort Station 9950.

Parameter	Minimum Density (MPN/100 ml)	Maximum Density (MPN/100 ml)	Geometric Mean (MPN/100 ml)
Total Coliform	2,300	170,000	13,746
Fecal Coliform	Non Detect	13,000	1,030
Enterococcus	10	2,014	152

The lateral line that conveys sewage from Comfort Station 9950 to the sewer main was inspected utilizing closed circuit television on September 26, 2002. This investigation documented that the lateral line was in good condition, with no evidence of structural failures or corrosion. Appendix B details the results of this effort.

Although the bacteria associated with comfort station washdown was identified as a potential source to the bay in Phase I, the results of the Fate and Transport investigation conducted as part of Phase II suggest that bacteria at the surface of Mission Bay Park is not transported to the receiving waters via groundwater (see Appendix F for the complete report). These results, along with those of the comfort station infrastructure investigation, suggest that the Comfort Station 9950 is not a source of indicator bacteria to the receiving waters of Mission Bay.

Irrigation

During the Visual Observations Task, ponded water in the grassy areas of Fanuel Park from excessive irrigation was observed, but no samples were taken. Ponded water was minimal and there was no apparent mechanism of transport (sheet runoff, storm drains, etc.) that would deliver the irrigation water to the receiving waters at this site.

Storm Drains

Plug removed from diversion pipe at Fanuel Park

Four storm drains discharge to Sail Bay in the vicinity of Fanuel Park (Figure 5-1). A detailed inspection of the storm drains and their diversion structures was completed on February 27, 2003. The inspection found a suite of problems associated with the MBSIS diversion structures, including un-diverted flow, missing tide flex or check valves, inflatable plugs inserted into diversion lines, and large volumes of water entering the storm drains downstream of the diversion structures from dewatering activities (see discussion below). Appendix I provides a detailed discussion of the results of the inspection.

Other Sources – Dewatering Activities

A follow-up study to the storm drain inspections was conducted on April 28, 2003 to determine the extent of potential bacterial contamination coming from dewatering activities from underground parking structures near Fanuel Park. These dewatering systems remove groundwater and rainwater from the parking structures and redirect it to the storm drain system downstream of the MBSIS diversion structures. Sixty percent of the samples collected from sumps and drains associated with these operations exceeded AB411 criteria for at least one indicator bacteria. The maximum measured density of bacteria was 160,000 MPN/100 ml for total coliform, 80,000 MPN/100 ml for fecal coliform and 6,131 MPN/100 ml for enterococcus. Appendix K.2 provides a detailed discussion of the dewatering systems at Fanuel Park.

Taken together, the problems associated with the storm drain diversion structures and the dewatering activity at Fanuel Park investigated in Phase I suggest that there is a potential for the storm drains to convey indicator bacteria to the receiving waters of Mission Bay. The complexities of the diversion structures and the unique dewatering activities that occur only at Fanuel Park warrant further investigation at this site.

Bacterial Sources – Phase II

Bacterial Host Origin

The results of Phase I revealed that the storm drains were a potential source of bacteria to the receiving waters. In Phase II of this study, the storm drains and receiving water at Fanuel Park were investigated as part of the Molecular Source Tracking Task to assess the relationship between the indicator bacteria in the storm drain effluent and the receiving waters. The complete report is presented in Appendix E and summarized below.

The results of the Ribotyping analysis (Figure 5-3) show that a majority (60%) of the bacterial isolates collected in the storm drains at Fanuel Park originate from avian sources (Figure 5-3A). However, there was also a large percentage that originated from Canine (20%) and other mammalian (15%) sources (the “other mammal” category includes rodent, raccoon, cat, horse, and squirrel Ribotypes, only a portion of which is represented at each site). In samples collected from the receiving water (Figure 13-3B), 69% of the isolates originated from birds. Interestingly, the second most prevalent host origin in the receiving waters at Fanuel Park was marine mammals (most likely seals). No bacterial isolates originating from human sources were found in the storm drains and only a very small percentage (7%) was found in the receiving waters.

In addition to identifying bacterial host origin, the microbial source tracking results were analyzed to determine the influence of the storm drains as a source of bacteria to the receiving waters. Interestingly, nearly half (53%) of the Ribotypes of bacterial isolates collected in the receiving water matched those found in the storm drains (Figure 5-3C). At Fanuel Park, the storm drain samples were collected from the storm drain diversion boxes, which are largely above the tidal influence of the bay water. Thus, the large percentage of Ribotypes in bacteria collected in the receiving waters that matched the Ribotypes of bacteria collected from the storm drains suggests that dry weather flows from the Fanuel Park storm drains are a significant source of bacteria to the receiving waters at this site.

Other – Intertidal Sediments

Numerous swimmers utilize the beach at Fanuel Park during the summer months and the number of swimmers in the water can be high, particularly during holiday weekends. Thus, resuspension of intertidal sediments during swimming activity is also a potential source of indicator bacteria to the receiving waters at this site.

Other – Wrack Line

As with Riviera Shores, a heavy wrack line consisting of organic material from Sail Bay tends to accumulate on the beach at Fanuel Park. The results of the wrack line study conducted at Riviera Shores, which lies adjacent to Fanuel Park, suggest that the wrack line tends to amplify the bacterial load. In this way, the wrack line found at Fanuel Park is also a likely source of indicator bacteria to the receiving waters at this site.

Dry Season Ribotyping Results at Fanuel Park

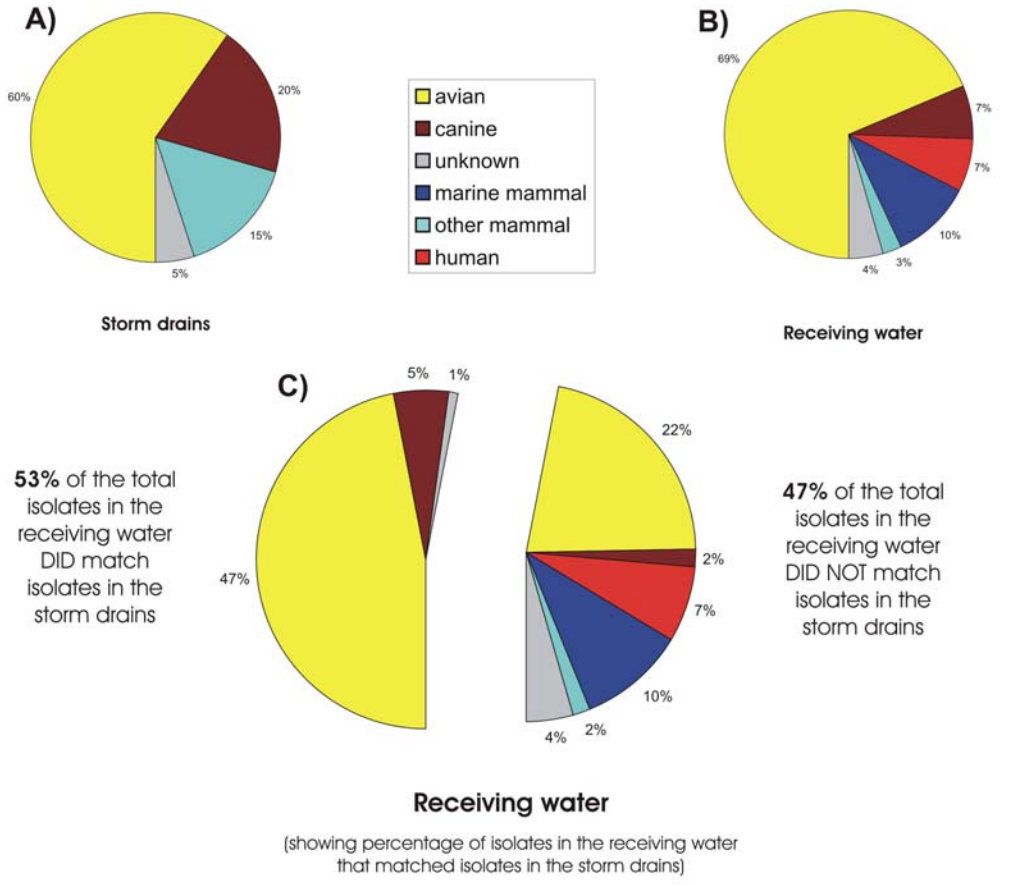


Figure 5-3. Results of Ribotyping analysis at Fanuel Park. The pie charts show the origin of bacterial isolates in the storm drains SD3-1 thru 3-4 (A), receiving water (B), and the proportion of isolates in receiving water that matched those in the storm drains (C).

Conclusions

The results of the Visual Observations Task suggested that comfort station washdown and infrastructure, irrigation, and groundwater are unlikely sources of indicator bacteria to the Mission Bay receiving waters at Fanuel Park. In addition, there is no creek drainage to this part of Mission Bay. However follow-up investigations conducted as part of Phase I revealed several problems with the MBSIS diversion structures at this site. In addition, dewatering operations, which appear to be unique to Fanuel Park, appear to convey bacteria to the receiving waters downstream of the diversion structures. The magnitude of the bacterial load originating from the dewatering operations remains to be determined. However, the problems associated with the diversion structures combined with discharge of the dewatering effluent, suggest that the water conveyed through the storm drains at Fanuel Park is a source of bacteria to the receiving waters at this site. The sources of indicator bacteria identified at Fanuel Park are summarized in Table 5-2.

Table 5-2. Sources of indicator bacteria at Fanuel Park. A green N indicates potential sources that are no longer thought to be present or were remediated as part of the study. A red Y indicates potential sources that remain at this site.

Site #	Site Name	Illicit Boat Discharge	Restroom Infrastructure	Birds and Other Wildlife	Irrigation Runoff	Storm Drains	Restroom Washdown	Homeless	Dog Waste	RV Pump Outs	Creek Drainage	Groundwater	Delta Sediment	Intertidal Sediment	Wrack	Other
3	**Fanuel Park**	N	N	Y	N	Y	N	N	N	N	N	N	N	Y	Y	Y

The results of the microbial source tracking conducted as part of Phase II of this study revealed that the majority of the indicator bacteria in the receiving waters and the storm drains at Fanuel Park originates from birds. In addition, a large proportion of the Ribotypes of the bacterial isolates collected from receiving waters matched those from the storm drains. This suggests that the effluent from storm drains at Fanuel Park is a source of bacteria to the receiving waters. This helps confirm the results of the investigations conducted in Phase I, which found problems with the MBSIS diversion structures and dewatering operations conducted at this site. Additional likely sources of indicator bacteria at Fanuel Park include intertidal sediments through resuspension from swimmers and the wrack line that develops in the upper intertidal zone.

Wrack on beach at Fanuel Park

SECTION 6

Riviera Shores

Site Overview

Figure 6-1. Aerial photograph of Riviera Shores.

The Riviera Shores site is located on the southwestern end of the Crown Point Peninsula directly west of La Cima Drive (Figure 6-1). The site faces Sail Bay to the west, which is one of the largest areas of open water in Mission Bay. The area is used primarily by boaters (kayakers, crew teams, water skiers and jet skis) and joggers on the boardwalk. The beach in this area is not frequented by as many people as other heavy use sites around Mission Bay. There are no large drainages that discharge to Sail Bay in the area around Riviera Shores, but there are four storm drains that discharge to the Riviera Shores beach. All of them are part of the MBSIS. The AB411 monitoring site for Riviera Shores is located directly in front of storm drain SD4-2 at La Cima Drive. There are no public comfort stations at this site and no irrigation. The beach face at Riviera Shores typically contains large amounts of organic debris, which is concentrated in the wrack line located in the upper intertidal zone.

Temporal Trends

A graph of the enterococcus densities in samples collected at Riviera Shores from 1993 through 2003 is shown in Figure 6-2. As with other sites examined on the west side of Mission Bay, there are no obvious seasonal trends in bacterial levels at this site. Exceedances of the AB411 criterion (104 MPN/100 ml) are sporadic and densities in general are low. From November, 2002 through October 2003, there were no exceedances of AB411 criteria for enterococcus or any other indicator bacteria at Riviera Shores.

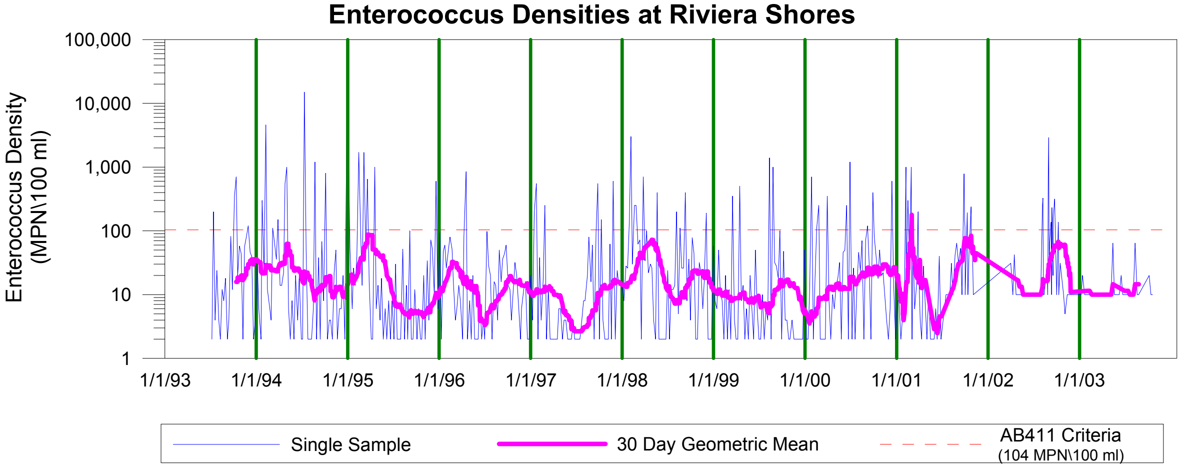


Figure 6-2. Enterococcus densities at Riviera Shores from 1993 through 2003. No data were available from November 2001 through April 2002 (source: San Diego County Department of Environmental Health).

Figure 6-2 includes samples collected from receiving water along Riviera Shores during the Visual Observations Task conducted in the summer of 2002 as well as samples collected during the Weekly Monitoring in the winter of 2002/2003. For the Visual Observations Task, samples were collected three times daily on nine days between August 25 and October 9, 2002. Surprisingly, compared to the other 11 sites monitored during the course of this study, Riviera Shores had the second most exceedances of the AB411 criteria during the Visual Observations Task. No temporal trends were observed in the elevated bacterial densities. Interestingly though, during the weekly observations that continued from November 2002 through April 2003, none of the 19 samples exceeded AB411 criteria for any of the three indicators.

Riviera Shores beach showing accumulation of wrack line

Bacterial Sources – Phase I

The results of the Visual Observations Task suggest that there were very few obvious potential sources of indicator bacteria at Riviera Shores. There are no comfort stations at this site, no irrigation, no flowing storm drains and no grassy park areas for the accumulation of water. Pets were never observed off leash at Riviera Shores and there was no pet waste observed on the beach. In addition, Rivera Shores, along with Fanuel Park and Hidden Anchorage, had the lowest relative number of birds of any of the sites monitored. However, the lack of obvious bacterial sources at Riviera Shores was confounded by the high number of bacterial exceedances recorded during the Visual Observations Task. During this task, there were more exceedances of the enterococcus criterion at Riviera Shores than any other site in the study except De Anza Cove. The high number of bacterial exceedances at Riviera Shores was difficult to explain, however, contamination from sources outside of the area (e.g., transport of bacteria via currents from Fanuel Park) was thought to be a possibility.

Comfort Stations

There are no comfort stations at this site.

Irrigation

Irrigation does not take place at this site.

Storm Drains

At the beginning of this study, storm drains were identified as a potential source (and mechanism of transport) of bacterial contamination to the shoreline at Riviera Shores. Four storm drains have outlets along the Riviera Shores beach, but all of them are diverted during dry weather. These storm drains were inspected on February 27, 2003 and appeared to be in good condition (a complete report is provided in Appendix I). Flow was never observed to emanate from the storm drains, therefore, no samples were collected. Thus, during dry weather, storm drains were determined to be an unlikely source of bacteria at Riviera Shores. During storm events, however, episodic high discharge events may result in localized bacterial contamination that may serve to inoculate the wrack line that is frequently found along the beach face at this site.

Bacterial Sources – Phase II

The results of the Phase I investigative tasks provided no clear indication of the sources of bacteria at Riviera Shores and it was suggested that the bacteria may originate from other areas such as Fanuel Park. However, a more detailed review of the historical bacterial data collected at this site suggested that there was a connection between the bacterial densities and the tidal stage when the sample was collected. Figure 6-3 shows the frequency of enterococcus AB411 exceedances verses tidal height at the time of collection for Riviera Shores. All receiving water samples collected from 2001 through 2003 for which sampling times were available are plotted. The red line in the graph separates the upper intertidal from the lower intertidal zones on the beach face. The graph clearly shows a difference between the samples collected in the upper verses the lower intertidal zones: 92% of the exceedances of the AB411 criterion for enterococcus occurred when samples were collected in the upper intertidal zone (i.e., during higher tides).

Riviera Shores

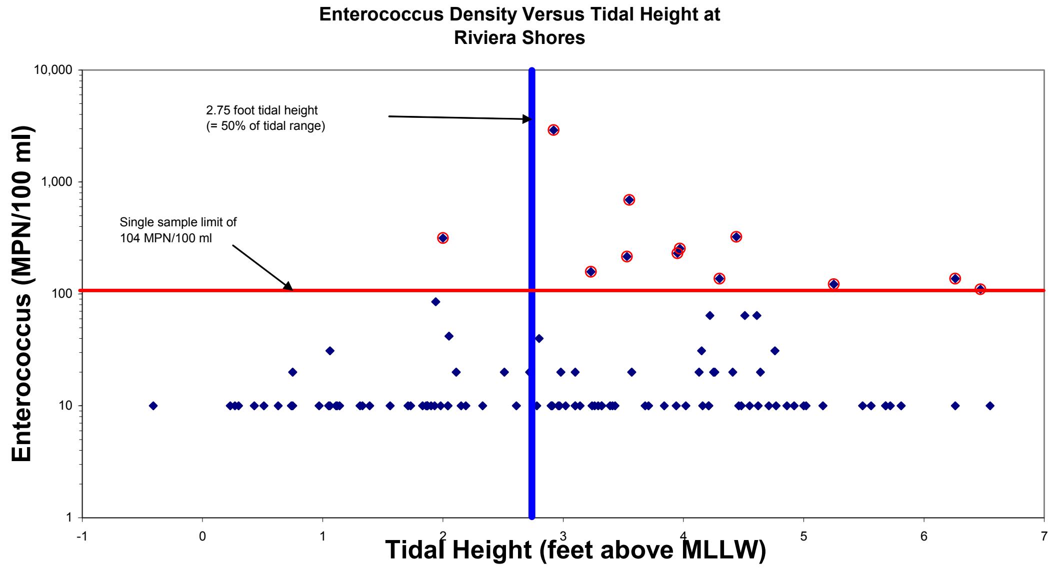


Figure 6-3. Exceedances of the AB411 criterion for enterococcus (104 MPN/100 ml) versus tidal stage at the time of collection for samples collected at Riviera Shores from 2001 through 2003. Samples circled in red exceeded the AB411 criterion.

Based on these results and the observation that a wrack line tends to accumulate along the beach in the upper intertidal zone at Riviera Shores, a follow-up study was conducted to determine the extent to which the wrack line affects bacterial densities in the receiving water. The complete study can be found in Appendix H.

First, samples of the wrack line were collected over time and bacterial densities were enumerated (Figure 6-4). Wrack line samples were collected during a neap tidal stage when the receiving waters did not make contact with the wrack line for a period of 11 days. Bacterial densities in the wrack were maintained during this time, suggesting that the wrack line provides an environment conducive to the maintenance and possibly the growth of both enterococcus and fecal coliform bacteria.

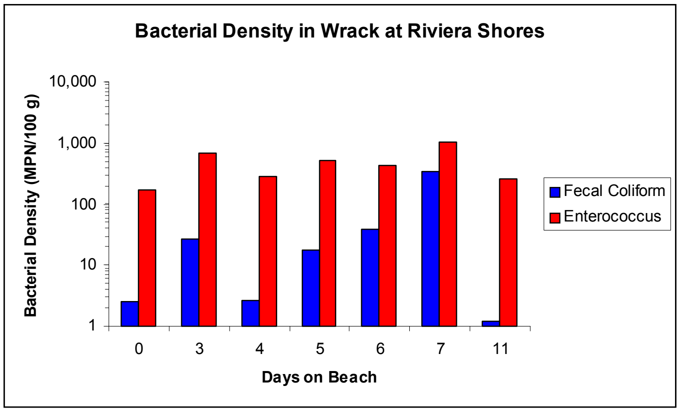


Figure 6-4. Densities of enterococcus and fecal coliforms in wrack line at Riviera Shores. Each bar represents the geometric mean of five samples.

Riviera Shores

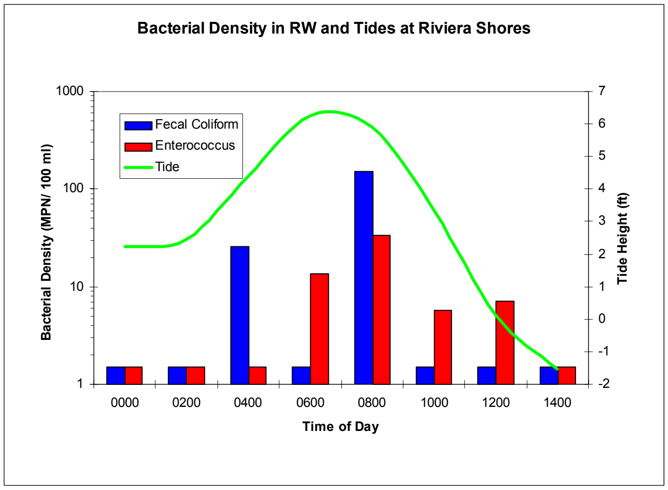


Figure 6-5. Densities of enterococcus and fecal coliform bacteria in receiving water versus tidal height at Riviera Shores. Each bar represents the geometric mean of five samples.

After the bacteria in the wrack line had been enumerated, we took samples of the receiving water during the subsequent spring tide as the water level rose and made contact with the wrack line on the beach. The results of this part of the study are shown in Figure 6-5. Here, bacterial densities were low in the early morning when the edge of the receiving waters were in the lower intertidal zone. Densities increased dramatically at 0600 hours when the receiving waters first made contact with the upper intertidal zone and peaked at 0800 hours when the receiving waters were in contact with the wrack material. As the tide receded into the lower intertidal zone starting at about 1000 hours, bacterial densities decreased. Thus, greater bacterial densities occur in the upper intertidal zone on the beach when the receiving water comes in contact with the wrack line. These results help explain the pattern of greater enterococcus densities in the upper intertidal zone that have been observed at this site (Figure 6-3).

In addition to the receiving water samples collected during this study for indicator bacteria, samples were also collected for assessment of bacterial host origin using the Ribotyping technique (Figure 6-6). A total of 80% of the isolates obtained originated from avian sources. Smaller proportions of other mammals and bacteria from unknown origin were also present. These results suggest that the birds are the primary source of bacteria in the receiving waters at Riviera Shores. Birds are also the likely dominant source of bacteria found in the wrack line.

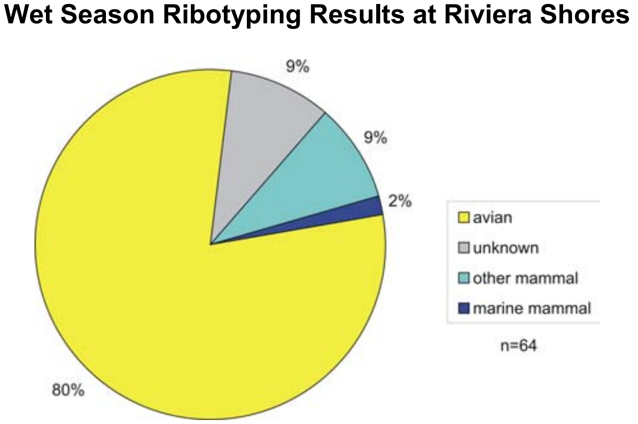


Figure 6-6. Results of wet season Ribotyping analysis of receiving water samples collected at Riviera Shores showing relative percentage of bacterial host origin.

Conclusions

There were very few obvious potential sources of bacteria at Riviera Shores. This site has no irrigation, no comfort stations, no large creek drainage, and relatively small bird population year-round. The site does have four storm drains that discharge to the beach, but the diversion systems appeared to be functioning properly in diverting dry weather flows from entering the bay. The results of the studies conducted at Riviera Shores are presented in Table 6-1.

Table 6-1. Sources of indicator bacteria at Riviera Shores. A green N indicates potential sources that are no longer thought to be present or were remediated as part of the study. A red Y indicates potential sources that remain at this site.

Site #	Site Name	Illicit Boat Discharge	Restroom Infrastructure	Birds and Other Wildlife	Irrigation Runoff	Storm Drains	Restroom Washdown	Homeless	Dog Waste	RV Pump Outs	Creek Drainage	Groundwater	Delta Sediment	Intertidal Sediment	Wrack	Other
4	**Riviera Shores**	N	N	Y	N	N	N	N	N	N	N	N	N	N	Y	N

At the end of the Phase I investigations, the sources of bacteria at this site were unclear. However, the wrack line study conducted in Phase II provided evidence of a mechanism of bacterial amplification at Riviera Shores. The results of the wrack line study suggest that:

1) the majority of the indicator bacteria found at Riviera Shores originates from birds;
2) bacteria from the bird feces inoculates the organic debris in the receiving waters;
3) the wrack line, deposited in the upper intertidal zone, provides an atmosphere that maintains and possibly fosters the growth of indicator bacteria; and
4) bacteria deposited and maintained in the wrack line is released to the receiving waters during high tide.

In this way, the wrack line acts to amplify the initial bacterial load associated with bird feces, maintaining the bacteria over time and possibly allowing the initial bacterial load to increase in magnitude. An extensive wrack line is a common occurrence at Riviera Shores. Although observations on organic debris on the beach was not part of the Visual Observations Task, casual observations made over the course of Phase II suggest that the largest and most persistent wrack lines in Mission Bay develop along the west side of Crown Point (Fanuel Park and Rivera Shores) and the eastern side of the bay at De Anza Cove and Visitor's Center. The results of this study suggest that the wrack line at Riviera Shores is a persistent source of indicator bacteria to the receiving waters of Mission Bay.

Wrack line on the beach at Riviera Shores

SECTION 7

Wildlife Refuge

Site Overview

The Wildlife Refuge site is located on the northeast side of Crown Point, directly south of the Kendall Frost Wildlife Reserve (Figure 7-1). Along with Campland, it is closest of the 12 sites to the Wildlife Reserve. During the summer months this is a popular beach for swimming, jet skiing, and other aquatic activities. Directly behind the beach is a large grass park containing three large parking lots. There are no major creek drainages that discharge to the immediate area around Wildlife Refuge, but the site has two large storm drains that discharge to the beach. Storm drains SD5-1 and SD5-2 are part of the MBSIS and they have diversion structures on the east side of Crown Point Drive. However, downstream of the diversion structure for storm drain SD5-2 are two large inlets that convey excess water from the grass and adjacent parking lot directly to the bay. The AB411 monitoring site is located directly in front of the terminus of storm drain SD5-2. There are two comfort stations at this site, located on either end of the grass park.

Figure 7-1. Aerial photograph of Wildlife Refuge.

Temporal Trends

In contrast to sites on the west side of Mission Bay, a review of the historical data suggests that there are strong seasonal trends in indicator bacterial densities at Wildlife Refuge (Figure 7-2). The moving geometric mean illustrated in Figure 7-2 shows that the enterococcus densities at Wildlife Refuge are typically low in the late spring and summer, increase in the fall, and peak in the winter. In the winter and early spring, enterococcus levels often remain high for extended periods of time. This pattern is typical of most sites on the east side of Mission Bay and is most likely related to 1) the increase in rainfall and associated surface runoff and/or groundwater flow in the winter; 2) fecal matter from the migratory bird population, which also increases dramatically in the winter; or 3) a combination of both. From November of 2002 through October 2003, there were only three exceedances of the enterococcus criterion at this site, a substantial decrease from previous years.

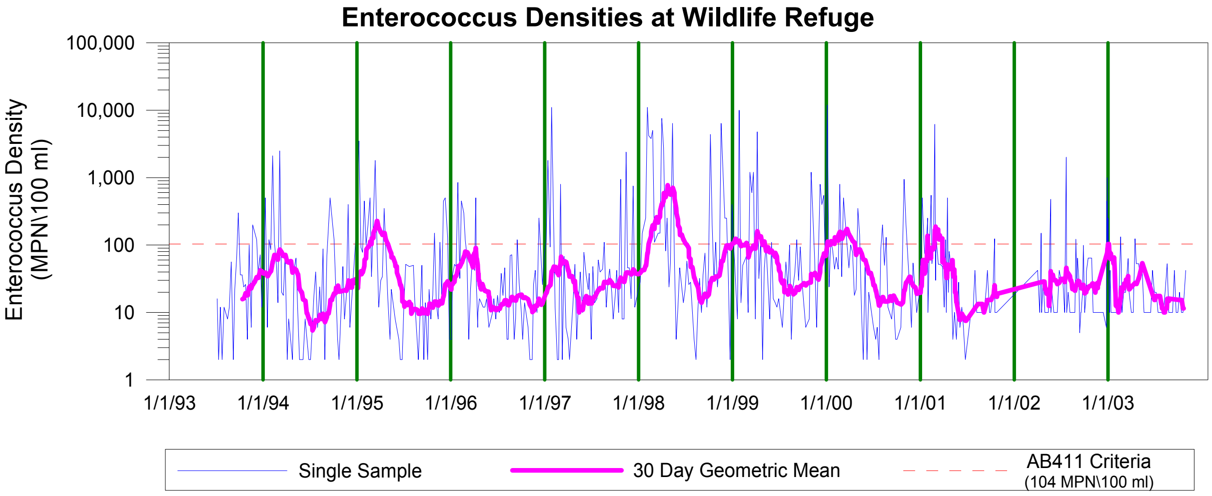


Figure 7-2. Enterococcus densities at Wildlife Refuge from 1993 through 2003. No data were available from November 2001 through March 2002 (source: San Diego County Department of Environmental Health).

Figure 7-2 includes data from samples collected from the receiving water along the shore at Wildlife Refuge during the Visual Observations Task (Task 3) of this study as well as samples collected during the Weekly Monitoring in the winter of 2002/2003. For the Visual Observations Study, samples were collected three times daily (morning, mid-day, afternoon) on nine days between August 25 and October 9, 2002. Total and fecal coliform densities were measured at or below the detection limits in approximately 65% of the samples. Bacterial densities in remaining samples were below AB411 criteria. Only one of the 27 samples collected had an enterococcus level (122 MPN/100 ml) above the AB411 criteria. Over 80% of the samples analyzed for enterococcus had levels at or below the detection limit.

Bacterial Sources – Phase I

Sources of bacterial contamination to the shoreline around the Wildlife Refuge site were investigated as part of Task 1 (Comfort Station Infrastructure Investigation) and Task 3 (Visual Observations Task). Potential sources included comfort station washdown procedures and infrastructure, irrigation practices, storm drain runoff, groundwater, and birds. The results of these investigations are presented in Appendices B and D and are summarized below.

Comfort Stations

There are two comfort stations that serve the area of the Wildlife Refuge, however, only one (Comfort Station 522) was close enough to the receiving waters to be considered a potential source of bacteria. Comfort Station 522 is located on the northern end of the Wildlife Refuge site, 750 feet south of the AB411 monitoring site. A total of four samples were collected from the runoff generated from washdown procedures at this comfort station during the Visual Observations Task. Three of these samples had bacterial densities that exceeded AB411 criteria for all three indicators. The results are summarized in Table 7-1. Observations made during the weekly monitoring conducted from November 2002 through March 2003 indicated that BMPs established to contain runoff generated from washdown procedures within the comfort station were effective, thereby eliminating this source of bacterial contamination to the environment.

Table 7-1. Indicator bacterial densities of wash down samples collected from Wildlife Refuge Comfort Station 522.

Parameter	Minimum Concentration (MPN/100 ml)	Maximum Concentration (MPN/100 ml)	Geometric Mean (MPN/100 ml)
Total Coliform	1,700	3,500,000	172,843
Fecal Coliform	Non Detect	170,000	6,856
Enterococcus	51	177,200	4,412

Comfort Station 522 was inspected by closed circuit television under Task 1 on September 26, 2002. Video of the lateral lines conducted by closed circuit television showed light corrosion in the cast iron portions, however, the lines were documented as being in good condition and were not considered to be a source of bacteria to the site. Appendix B details the results of the comfort station inspection.

Irrigation

During the Visual Observations task, ponded water in the grassy areas of the park and in the parking lot west of the beach area from excessive irrigation was observed. Ten samples were collected from this ponded water and analyzed for indicator bacteria. Bacterial densities were high for all three indicators (Table 7-2). Indicator bacteria were not detected in water samples collected directly from the sprinkler heads, suggesting that the surface of the grass was the source of the bacteria and not the irrigation water itself.

Table 7-2. Bacterial indicator results for samples collected from ponded water on grassy areas and paved surfaces adjacent to the Wildlife Refuge site.

Parameter	Minimum Concentration (MPN/100 ml)	Maximum Concentration (MPN/100 ml)	Geometric Mean (MPN/100 ml)
Total Coliform	500	16,000,000	220,543
Fecal Coliform	20	1,300,000	6,987
Enterococcus	495	238,200	6,966

At Wildlife Refuge, this ponded water is conveyed directly to the receiving water through storm drain SD5-2 as discussed below.

Storm Drains

There are two storm drains that discharge to the eastern shoreline of Crown Point near the Wildlife Refuge site: SD5-1 on the southern end of the site and SD5-2 on the northern end (Figure 7-1). Both of these storm drains are diverted as part of the MBSIS. On April 28, 2003 the storm drain diversion systems were inspected and documented to be functioning properly (see Appendix I for complete report). However, storm drain SD5-2 has two entrances in the grassy area of the park downstream of the diversion structure. Excess irrigation water enters these drains and is conveyed directly to the receiving waters. During the Visual Observations Task, five samples were collected from the discharge of storm drain SD5-2. Four of the samples exceeded the AB411 criteria for each of the indicator bacteria. The fifth sample only exceeded the enterococcus criterion. Table 7-3 summarizes the results.

Storm drain SD5-2 at Wildlife Refuge

Table 7-3. Bacterial indicator results for samples collected from storm drain SD5-2 at Wildlife Refuge.

Parameter	Minimum Concentration (MPN/100 ml)	Maximum Concentration (MPN/100 ml)	Geometric Mean (MPN/100 ml)
Total Coliform	230	16,000,000	43,482
Fecal Coliform	230	240,000	4,754
Enterococcus	122	47,300	3,982

The results of the samples collected from the irrigation water and storm drain effluent suggested that storm drain SD5-2 is a source of bacteria to the receiving waters at the Wildlife Refuge site. This source was thought to be particularly influential at this site because the AB411 monitoring site is directly in front of storm drain SD5-2 and because no other sources were identified during the Phase I investigations.

Groundwater

A groundwater spring discharges along the beach face near the terminus of SD5-2. Bacterial levels were not measured in the effluent from this spring, but it was considered to be a potential bacterial source due to the proximity to the park area where high bacterial densities were measured. Groundwater monitoring was conducted at this site as part of the Phase II Microbial Source Tracking Task. The results are discussed below

Groundwater spring below storm drain SD5-2

Birds

A bird population survey was conducted for Mission Bay Park and the San Diego River from March 2000 to March 2001 (Kisner 2002). The results of the study showed that the bird population increased nearly ten-fold between summer and winter in Mission Bay (Figure 7-3). The increase in the bird population during winter months is consistent with densities of enterococcus at the Wildlife Refuge (Figure 7-1) and other sites on the eastern side of Mission Bay, both peaking in December through February and declining sharply in April.

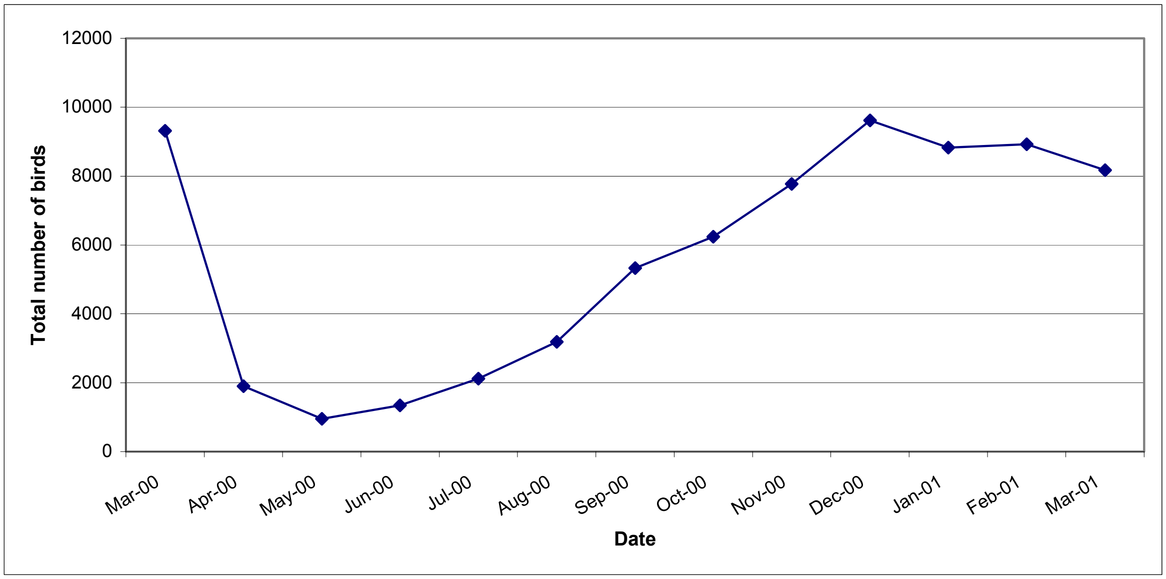


Figure 7-3. Graph of bird population in Mission Bay and San Diego River from March 2000 through March 2001 (reproduced from Kisner 2002).

The Kisner (2002) study segregated the bird population counts into four regions of Mission Bay:

1) Bonita Cove, Quivira Basin, and the entrance to the bay;
2) Bahia Point to Sail Bay;
3) Wildlife Refuge to De Anza Cove; and
4) East Mission Bay from the south end of De Anza Cove to Seaworld.

The temporal patterns of the total bird population in these four areas were very different. For regions 1 and 2 the bird population changed very little over the monitoring period. In contrast, regions 3 and 4 had dramatic changes in the bird populations with temporal patterns very similar to those seen in Figure 7-2. These results may explain the absence of temporal trends in enterococcus levels at Sites 1 through 4 on the west side of the bay and the clear seasonal trends observed at Wildlife Refuge and other sites on the east side of the bay (see below). Thus, the Kisner (2002) study provided strong, albeit indirect, evidence that the levels of enterococcus in some areas of Mission Bay were correlated with the bird population and that the birds may be the source of elevated bacterial levels in the winter.

Bacterial Sources – Phase II

Bacterial Host Origin

The results of the Phase I investigations identified two potential bacterial sources at Wildlife Refuge: 1) storm drain SD5-2 and the irrigation runoff it conveys from the grassy area of the park; and 2) groundwater springs on the beach face, which terminate near storm drain SD5-2. In Phase II, these potential sources were investigated by taking groundwater and receiving water samples near the storm drain. Shallow groundwater samples were taken from the beach face spring four times from July 2003 through October 2003. One sample had an enterococcus density of 30 MPN/100 ml and the rest had densities of < 10 MPN/100 ml. Fecal coliform densities were all < 20 MPN/100 ml. These results suggest that elevated bacterial densities found in the park area at Wildlife Refuge are not transported to the receiving waters via groundwater. These results are consistent with groundwater sampling that took place at several other sites throughout Mission Bay (see Appendix F for the complete results).

The initial design of the Phase II investigation at Wildlife Refuge also included collection of samples from the storm drain SD5-2 and the receiving water in front of it. However, in the spring of 2003 the storm drain terminus became covered over with sand from the beach, preventing water from flowing out of it. The storm drain remained this way throughout the summer of 2003 until early November when the first storms came through the area. The blockage prevented any sample collection from the storm drain. The receiving water samples were collected at this site and analyzed by the HS-PCR technique. Of the 19 samples analyzed, 16 were positive for the General marker, and only one was positive for the Human marker. These results suggest that the enteric bacteria in the receiving waters at Wildlife Refuge are not of human origin and, based on the MST results from other sites in Mission Bay, the most likely origin of the bacteria is birds.

Other – Intertidal Sediments

During the summer months at this site, the swimmer population can be high, particularly during holiday weekends. Thus, resuspension of intertidal sediments during swimming activity, particularly in the area near storm drain SD5-2, is also a potential source of bacteria to the receiving waters at this site.

Conclusions

The results of the investigations conducted at Wildlife Refuge indicate that leaking sewer infrastructure, comfort station washdown, and groundwater are not sources of bacteria to the receiving water at this site. In addition, there is no creek drainage near this site and a wrack line does not tend to accumulate in this area of Mission Bay. However, in contrast to sites on the west side of the bay, seasonal trends in enterococcus densities at Wildlife Refuge and other sites on the east side of the bay appear to be correlated with the migratory bird population, which may explain the elevated bacterial densities during the winter. In summer, irrigation practices also appear to play a role at this site. Several effluent samples taken from the terminus of storm drain SD5-2 had elevated bacterial levels during Task 3. The lower portion of this storm drain conveys excess water from irrigation in the park and very high levels of indicator bacteria were measured in the grassy area surrounding the storm drain entrance during irrigation. The results of the study at Wildlife Refuge are summarized in Table 7-4.

Table 7-4. Sources of indicator bacteria at Wildlife Refuge. A green N indicates potential sources that are no longer thought to be present or were remediated as part of the study. A red Y indicates potential sources that remain at this site.

Site #	Site Name	Illicit Boat Discharge	Restroom Infrastructure	Birds and Other Wildlife	Irrigation Runoff	Storm Drains	Restroom Washdown	Homeless	Dog Waste	RV Pump Outs	Creek Drainage	Groundwater	Delta Sediment	Intertidal Sediment	Wrack	Other
5	Wildlife Refuge	N	N	Y	Y	Y	N	N	N	N	N	N	N	Y	N	N

Wildlife Refuge

Storm Drain SD5-2 conveys irrigation runoff to Wildlife Refuge

Perhaps the most interesting finding of the investigations conducted at Wildlife Refuge was the very low levels of indicator bacteria in the receiving waters from January through October, 2003. During this time there was only one exceedance of AB411 criteria for any of the indicator bacteria, which is much lower than any similar time period in the last ten years (see Figure 7-2 for the enterococcus results). In January, 2003 storm drain SD5-2 was under construction and the terminus of the storm drain was blocked with beach sand, eliminating flow to the receiving waters. The extent to which the effluent from storm drain SD5-2 contributes to elevated bacterial densities in the receiving water at Wildlife Refuge is unclear. However, the high bacterial densities measured in the irrigation water and effluent associated with the storm drain coupled with the very low densities measured in the receiving water when the storm drain was blocked suggest that effluent from storm drain SD5-2 contributes to elevated bacterial densities in the receiving water at this site.

SECTION 8

Campland

Site Overview

Campland is a small recreational destination for campers and RV enthusiasts located on the northeast side of Mission Bay (Figure 8-1). A small beach, approximately 800 feet long is situated on the southern edge of the Campland property. Behind the beach is a large paved area of street, sidewalks, and RV parking spaces and facilities. There is a small grassy area adjacent to the RV facilities. A small jetty forms the western boundary of the facility. This area also contains three boat docks with numerous slips, a boat ramp, and a wash down area. There are no storm drains that impact the Campland site, but the eastern end of the property is bounded by the mouth of Rose Creek. Although this creek drains a fairly large watershed, dry weather flow is diverted to the sewer system as part of the MBSIS approximately one mile from the entrance to Mission Bay. There is one restroom facility located near the beach at Campland, which is operated and maintained by Campland staff (this facility is not part of the comfort station complex throughout the rest of Mission Bay Park). The AB411 monitoring site at Campland is located on the beach directly in front of the restroom.

Figure 8-1. Aerial photograph of Campland.

Temporal Trends

Similar to other sites located in the eastern half of Mission Bay, historical data collected at Campland suggested there are strong seasonal trends in indicator bacterial densities at this site (Figure 8-2). The seasonal trend at Campland appears to be the most defined and consistent of all the Mission Bay monitoring sites, with enterococcus levels that increase annually in October, peak during the winter, and decrease in the spring. As with other sites on the east side of Mission Bay, this pattern appears to correlate well with the observed bird population at this site.

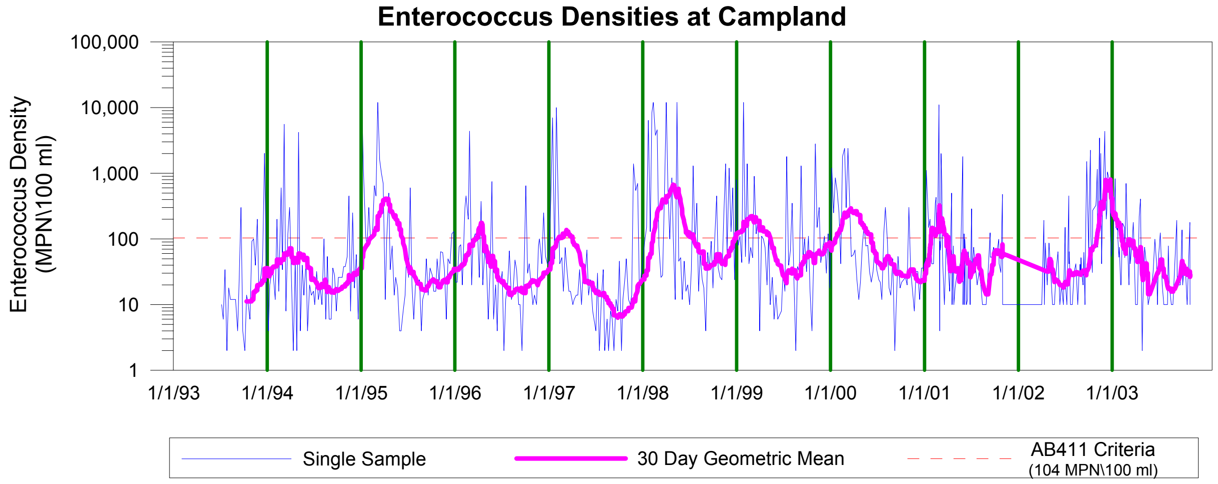


Figure 8-2. Enterococcus densities at Campland from 1993 through 2003. No data were available from January 2001 through March 2002 (source: San Diego County Department of Environmental Health).

Figure 8-2 includes samples collected from the receiving water along the shore at Wildlife Refuge during the Visual Observations Task (Task 3) of this study as well as samples collected during the Weekly Monitoring in the winter of 2002/2003. For the Visual Observations Study, samples were collected three times daily (morning, mid-day, evening) on nine days between August 25 and October 9, 2002. Receiving water samples contained low indicator bacterial densities throughout the study period with the exception of the last three days. During this period densities of all three indicator bacteria increased several fold from the previous sampling dates. The results of the Weekly Monitoring that followed the Visual Observations Task showed that bacterial densities continued to rise at Campland as they had in previous years, peaking in early January (Figure 8-2).

Bacterial Sources – Phase I

Sources of bacterial contamination at Campland were investigated under the Visual Observations Task (Task 3) developed for Phase I. The results of the Task revealed that the common bacterial sources identified at other sites in Mission Bay (ponded water from excessive irrigation, groundwater springs, storm drains, etc.) were not present at Campland. The primary sources of potential bacterial contamination at Campland included bird fecal matter, discharge from Rose Creek, and runoff from a boat and vehicle washdown area on the western end of the site. To further investigate these potential sources, a follow-up study was conducted at

Campland in November, 2003 (detailed in Appendix K). Receiving water and suspected source samples were collected from numerous areas throughout the Campland site, including Rose Creek and the boat dock area. The results suggested that elevated bacterial densities were localized to the beach area between Rose Creek and the boat ramp on the western end of the site. The suspected source of bacteria identified in this area are summarized below.

Rose Creek Discharge

Discharge from Rose Creek was sampled at several stations during the follow-up study. The results suggested that discharge from the creek was not a source of elevated bacterial densities at the Campland beach during dry weather conditions.

Vehicle and Boat Washdown

The largest point source of freshwater to the receiving waters observed during the follow-up study was a 4 inch PVC drainage pipe that delivered runoff from an adjacent boat washdown area to the boat ramp. A total of 17 samples were collected of runoff generated from the washdown area. Over 80% of these samples exceeded AB411 criteria for at least one indicator bacteria. Table 8-1 summarizes these results. In general, the greatest bacterial densities were observed in samples collected from the drainage pipe discharge. Upon further investigation, a dead bird inside this drainage pipe was identified to be the source of bacteria from this area. Indicator bacterial densities in the effluent from this pipe decreased dramatically after the bird was removed and the pipe cleaned.

Table 8-1. Summary of bacterial densities in samples collected from runoff generated from a boat and vehicle washdown area at Campland.

Parameter	Minimum Density (MPN/100 ml)	Maximum Density (MPN/100 ml)	Geometric Mean (MPN/100 ml)
Total coliform	300	9,000,000	2,664
Fecal coliform	40	5,000,000	588
Enterococcus	Non Detect	686,700	89

Birds

Observations made during the follow-up study suggested that the large bird population at the Campland beach and surrounding area was the most obvious source of bacteria to the site. A swim platform used primarily during the summer was frequently populated by a large number of double-crested cormorants (*Phalacrocorax auritus*) and other birds. Large numbers of birds were also observed on the Campland boat docks and beach. Associated with the large bird population was a high density of bird fecal matter on the docks, swim platform, and beach.

Swim platform used by multiple birds

Based on these observations, it was assumed that the high bacterial densities observed in the receiving waters may have been a result of the bird waste in the area. After the results of the follow-up study had been assessed, the City worked with the maintenance crew at Campland to reduce the impact of the large bird population by removing structures where birds congregated. Campland staff also removed bird fecal matter on the beach several times a week to reduce bacterial loading. In addition, Campland management also informed park visitors not to feed the birds. These management actions were initiated in late-December 2002 to mid-January 2003. By the end of January 2003, the enterococcus densities at Campland had decreased dramatically from levels recorded earlier in the winter (Figure 8-3). This pattern is typically seen in the spring at Campland (Figure 8-1), so it was unclear at that time whether or not the management actions were directly responsible for the decline in bacterial densities. Based on the results of Phase I, a similar management program was initiated in November 2003. The results are discussed below.

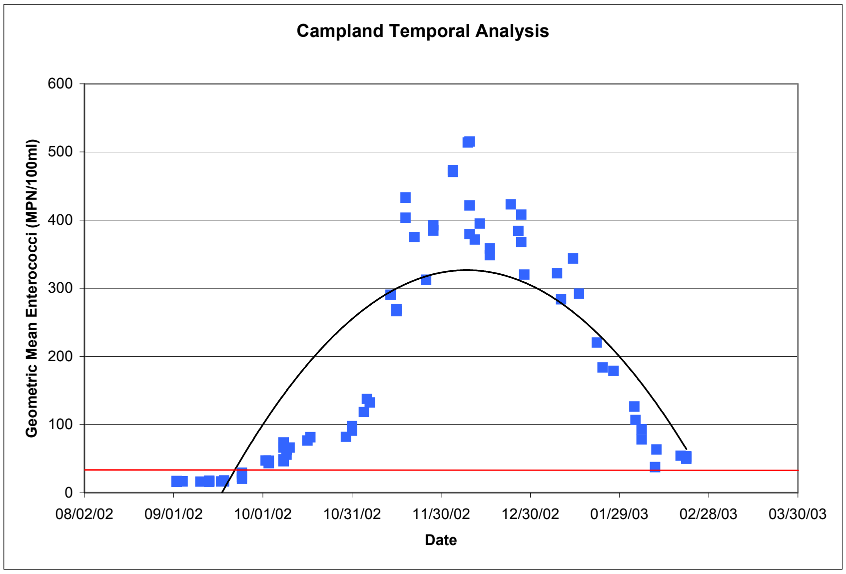


Figure 8-3. Campland temporal analysis, data from 9/2/02 to 2/20/03. Red line indicates the geometric mean standard value of 35 MPN/100ml.

Bacterial Sources – Phase II

Bacterial Host Origin

Ribotyping analysis was the first Microbial Source Tracking (MST) technique employed at Campland and receiving water samples were studied in both Dry and Wet Weather periods (Figure 8-4). The results of the Dry Weather Survey showed that a majority (79%) of the bacteria were of Avian origin (Figure 8-4A). The next largest source groups, canine and other mammals (non-human), were shown to account for 7% each of the total isolates. The results of the Wet Weather Survey (Figure 8-4B) were very similar to those of the Dry Weather Survey with a majority of the receiving water isolates originating from birds (69%). A total of 13% of the Wet Weather Ribotypes could not be identified in the Institute for Environmental Health's Source Ribotype Library Database (Unknown) and 10% were identified as having Canine origin.

HS-PCR was also performed on Campland receiving water samples. While 92% of the Wet Weather samples tested positive for the General *Bacteroides* maker, none of these samples were positive for the Human marker. Dry Weather receiving water samples were analyzed by HS-PCR, and results from these experiments showed that 75% of these samples were positive for the General marker. Interestingly, 33% of the Dry Weather samples were positive for the Human marker. The seasonal pattern suggests that the most likely source of the human input is the large number of swimmers that use this site during the summer.

Wet and Dry Season Ribotyping Results at Campland

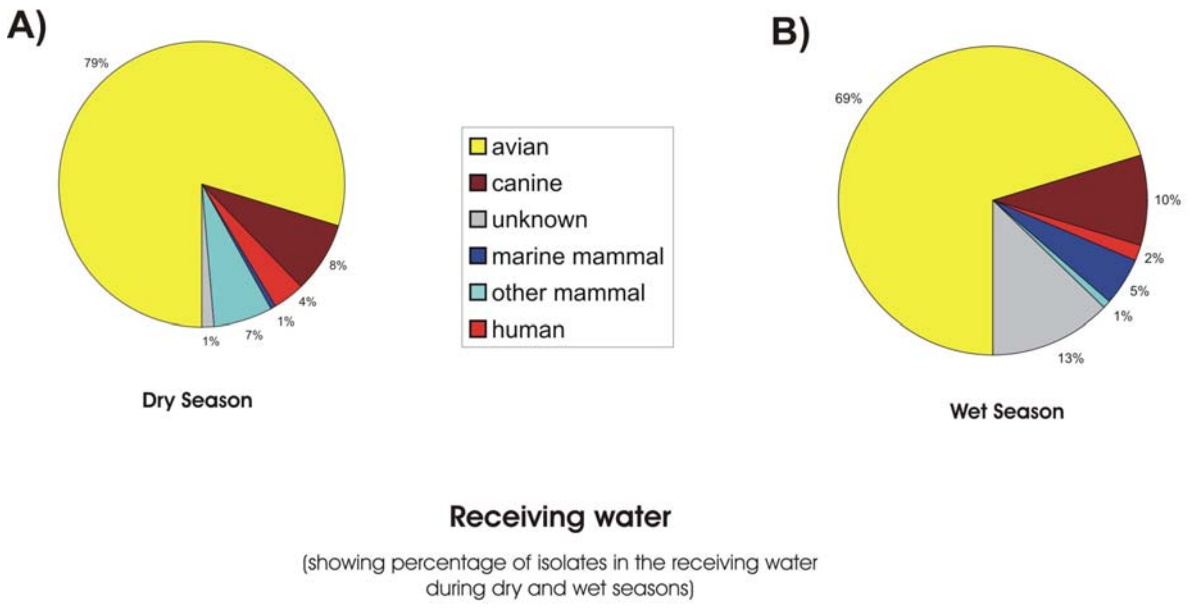


Figure 8-4. Results of Ribotyping analysis from receiving water samples collected at Campland during the dry season (A) and the wet season (B). The pie charts show the origin of bacterial isolates.

The results of the Phase I investigations and the MST results from Phase II strongly suggested that the source of indicator bacteria at Campland during both dry and wet seasons is birds and that the problem is primarily localized to the Campland beach. In October, 2003 staff from MEC and the City met with Campland personnel and designed several BMPs to minimize the impact of the bird feces on indicator bacterial densities in the receiving water. The BMPs included removing sources of freshwater in the area that attract birds, posting signs urging Campland visitors not to feed the birds, and physically removing the fecal matter on the beach face several times a week. The BMPs were initiated at the end of October 2003 and continued through January 2004. During that time, the receiving water at Campland was monitored weekly for enterococcus bacteria.

Removing bird feces from the beach face at Campland

Signage discouraging the feeding of birds

Campland

The impact of the management actions taken by Campland staff (bird waste removal, signage, and winter swim dock relocation) on enterococcus densities in the receiving waters was dramatic. In Figure 8-5, the geometric mean enterococcus densities in the receiving water at Campland collected in winter of 2002/2003 (from October 2002 through January 2003) are compared against those collected from the winter of 2003/2004 (October 2003 through January 2004).

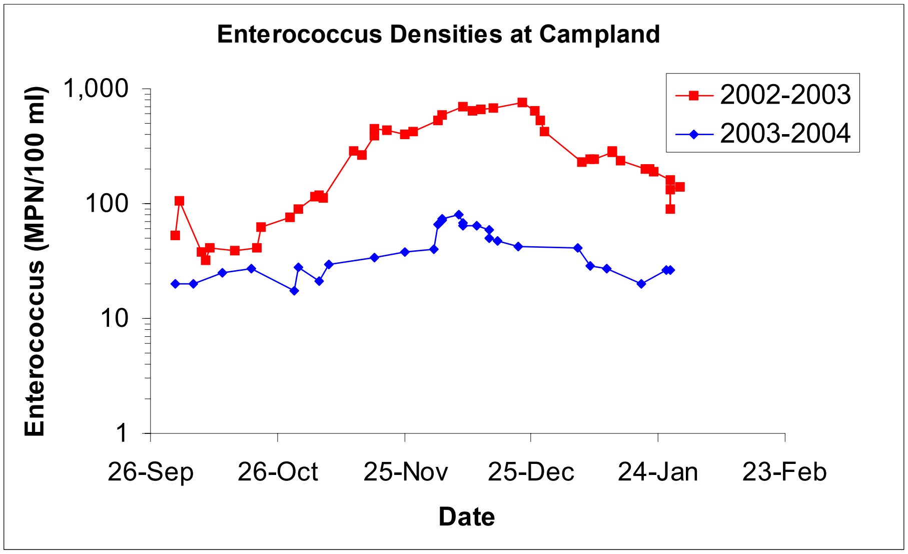


Figure 8-5. Comparison of geometric mean enterococcus densities from receiving water samples collected at Campland from October 2002 through January 2003 to samples collected from October 2003 through January 2004.

The graph shows that samples collected during the 2002/2003 winter were typically an order of magnitude greater than those collected during the same period in the 2003/2004 winter. Bacterial densities in the winter of 2002/2003 are similar to those measured at Campland in previous years (see Figure 8-1). However, the densities measured in the winter of 2003/2004 are among the lowest measured at this site in the last ten years. From October 2003 through January 2004 there were only three exceedances of single sample AB411 criteria for enterococcus at Campland. In contrast, during the same period in the winter of 2002/2003 there were 28 exceedances. The annual rise in enterococcus densities that has been observed at this site since at least 1993 was also seen in the winter of 2003/2004, but the continued rise through the winter that is typically observed was sharply curtailed when management actions were initiated. Thus it appears that the management actions taken at Campland, particularly the removal of bird waste from the beach face, was a very effective means of reducing bacterial densities in the receiving waters of Mission Bay.

Rose Creek Delta Sediments

In addition to the receiving water samples collected at Campland as part of the MST Task, samples of sediment were taken from the Rose Creek delta to determine if bacteria in the sediment act as a source to the receiving waters. The complete report is presented in Appendix G).

Two surveys were conducted: one at the end of the dry season (October 2003) and one during the middle of the wet season (January 2004). Sediments were collected by boat at the surface and from a depth of four inches. During the dry season survey, sediments at the mouth of Rose Creek (i.e., the creek delta) contained very low levels of indicator bacteria (Table 8-2). No fecal coliform bacteria were found and enterococcus was either not present or found in very low densities. Surprisingly, the highest overall densities in the dry weather survey were found at a depth of four inches. These results suggest that the delta sediments during dry weather are not a source of bacteria to the AB411 receiving water monitoring site at Campland.

Table 8-2. Indicator bacteria densities for samples collected from sediments at the mouth of Rose Creek. All values are presented as MPN/gram dry weight. Densities greater than 1,000 MPN/g are highlighted in red.

Indicator	Strata	Minimum Density	Maximum Density	Geometric Mean	Minimum Density	Maximum Density	Geometric Mean
		Dry Weather Survey (10/24/03)			Wet Weather Survey (1/14/04)		
Fecal Coliform	Surface	<1	<1	<1	<1	5	0.7
	Depth	<1	<1	<1	<1	<1	<1
Enterococcus	Surface	<1	35	4.2	<1	55	10.0
	Depth	9	72	22.3	2,496	7,066	4,703

During the wet season survey, after several storms had impacted the area, fecal coliform densities at the surface and at depth remained low at Rose Creek and enterococcus densities at the surface were similar to those observed during the dry weather survey. However, the most remarkable result of the study was the extremely high enterococcus densities at depth during the wet weather survey. Enterococcus densities ranged from 2,496 MPN/g dry weight to over 7,000 MPN/g. These values are extraordinarily high. However, the near absence of fecal coliform bacteria and the low enterococcus densities at the sediment surface suggest that the delta sediments at Rose Creek are not a predominant source of bacteria to the receiving waters at Campland.

In addition to the receiving water monitoring data collected at Campland, receiving water samples are also collected for bacterial analyses from Rose Creek, approximately 2,000 feet north (upstream) of the Campland beach as part of a Supplemental Environmental Program (SEP) conducted by the City. In Figure 8-6, enterococcus densities are plotted over time for receiving water samples collected from Rose Creek and from the Campland beach from October 2002 through January, 2003. Data from the receiving water monitoring support the assertion that indicator bacteria associated with Rose Creek have little impact on the receiving waters at Campland. Enterococcus densities at Campland show periodic spikes throughout the sampling period (Figure 8-6A). However, enterococcus densities in Rose Creek were very low throughout the sampling period except over several days at the end of December (days on 80-100) when enterococcus densities increased dramatically due to a sewage spill that occurred in Rose Creek. Remarkably, during the same time period, enterococcus densities at Campland remained very low. When the data from the Rose Creek sewage spill are removed from the data set and re-plotted (Figure 8-6B), it is apparent that enterococcus densities were very low in Rose Creek throughout the sampling period and there was no apparent correlation between densities measured in Rose Creek and those at Campland. These results combined with other observations at Campland suggest that Rose Creek effluent does not affect indicator bacterial densities in receiving waters at the Campland beach.

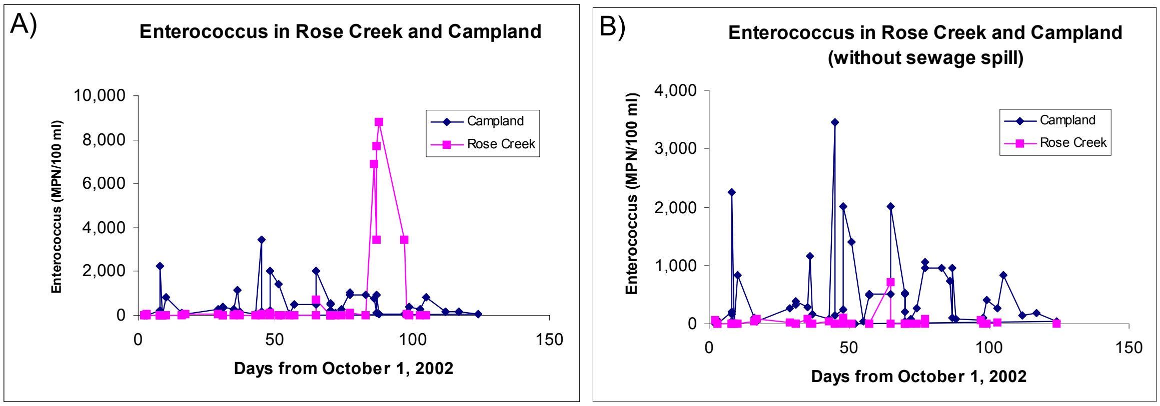


Figure 8-6. Comparison of enterococcus densities in receiving waters collected from Rose Creek and from the Campland AB411 monitoring site with (Graph A) and without (Graph B) data from a sewage spill in Rose Creek in late December 2002.

Other – Intertidal Sediments

Because of the small beach area at Campland and the large number of people that use the facility, the number of swimmers at Campland can be very high, particularly on holiday weekends. Thus, resuspension of intertidal sediments during swimming activity is also a potential source of indicator bacteria to the receiving waters at this site.

Other – Wrack Line

During certain times of the year, the prevailing wind in Mission Bay can drive organic debris onto the beach at Campland, creating a wrack line. As discussed in Appendix H, the wrack line can amplify the bacterial load at a site. In this way, the wrack line that is sometimes found at Campland is also a possible source of indicator bacteria to the receiving waters at this site.

Conclusions

The results of the Phase I investigations and the follow-up study conducted at Campland revealed that the source of elevated bacterial densities at this site were localized to the Campland beach. There are no groundwater springs at this site, no irrigation, no storm drains, and no restroom washdown at this site. Surprisingly, dry weather flow from Rose Creek does not appear to have an impact on the receiving waters at Campland. In addition, sediments at the mouth of Rose Creek were determined to be an unlikely source of bacteria to the Campland receiving waters. Effluent from a boat wash down drainage pipe at the Campland boat ramp was identified as a bacterial source in Phase I, but the pipe was cleaned and the source removed. Visual observations and the results of initial management actions strongly indicated that the source of indicator bacteria at Campland was the bird waste found on the Campland beach. The overall results of the investigations conducted at Campland are presented in Table 8-3.

Campland

Table 8-3. Sources of indicator bacteria at Campland. A green N indicates potential sources that are no longer thought to be present or were remediated as part of the study. A red Y indicates potential sources that remain at this site.

Site #	Site Name	Illicit Boat Discharge	Restroom Infrastructure	Birds and Other Wildlife	Irrigation Runoff	Storm Drains	Restroom Washdown	Homeless	Dog Waste	RV Pump Outs	Creek Drainage	Groundwater	Delta Sediment	Intertidal Sediment	Wrack	Other
6	**Campland**	N	N	Y	N	N	N	N	N	N	N	N	N	Y	Y	N

The results of the Microbial Source Tracking Task conducted In Phase II supported the assertion that the enteric bacteria in the receiving waters at Campland originated from birds. Avian sources accounted for 79% of the bacterial isolates collected in dry weather and 69% of those collected in wet weather. In the winter of 2003/2004, management actions were implemented to reduce the impact of the bacterial load on the beach from bird feces. These actions appeared to have resulted in a dramatic decrease in bacterial densities in the receiving waters at Campland compared to previous years.

SECTION 9

De Anza Cove

Site Conditions

De Anza Cove is a small embayment located in the northeast corner of Mission Bay (Figure 9-1). It is bounded on the east and north by East Mission Bay Drive. There is a grass buffer strip between the road and the bay on the east side and a larger grass park and parking lots on the north side of the cove. This area of Mission Bay Park is used heavily by park visitors, particularly during the summer months. The peninsula that forms the west and south end of De Anza Cove is a mobile home complex known as De Anza Harbor Resort, with numerous individual units. De Anza Cove is also one of the three areas in Mission Bay with boat mooring facilities. Typically, the area is home to 20 to 30 moored boats. There are no major creeks that discharge directly to De Anza Cove, but there are numerous groundwater springs that discharge at the beach along the east side of the cove. In addition, there are eight storm drains that discharge to the area. All but two of these are part of the MBSIS (shown in red in Figure 9-1). The primary AB411 monitoring site is located directly in front of storm drain SD7-2. De Anza Cove has one comfort station, located midway along the northern shoreline.

Figure 9-1. Aerial photograph of De Anza Cove.

Temporal Trends

A review of the historical data for De Anza Cove suggests that there is a strong seasonal pattern in densities of indicator bacteria at this site (Figure 9-2). Similar to the other sites on the east side of the bay, enterococcus densities tend to peak during winter and early spring, then decrease during the late spring and summer. Although the geometric mean enterococcus density tends to decrease in summer, there are also numerous sporadic exceedances of indicator bacterial standards during the summer months.

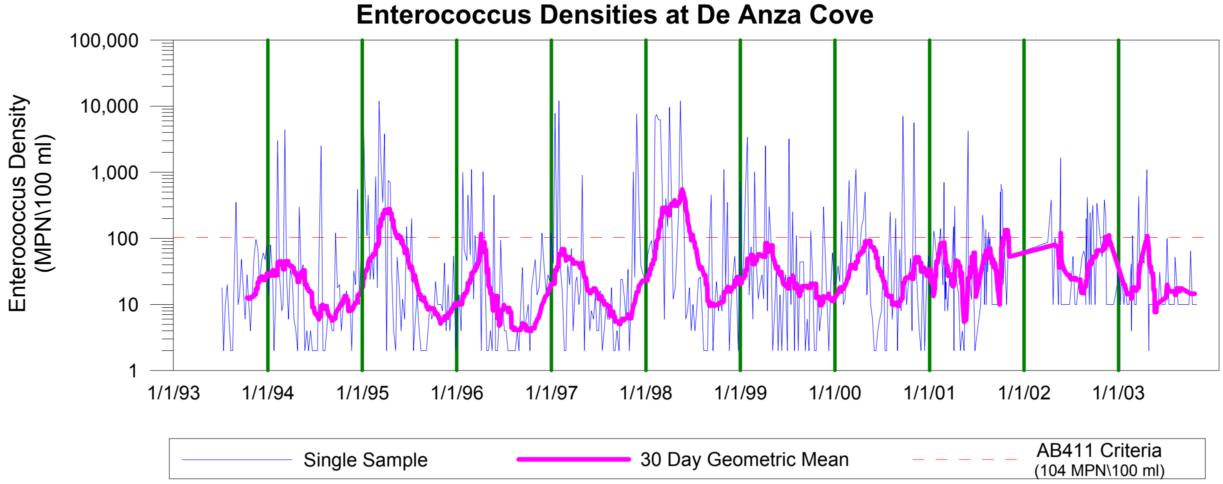


Figure 9-2. Enterococcus densities at Bonita Cove from 1993 through 2003. No data were available from November 2001 through April 2002 (source: San Diego County Department of Environmental Health).

Figure 9-2 includes data from receiving water samples collected at De Anza Cove during the Visual Observations Task (Task 3) of this study conducted in the summer of 2002 as well as samples collected during the Weekly Monitoring in the winter of 2002/2003. For the Visual Observations Task, samples were collected three times daily (morning, mid-day, evening) on nine days between August 25 and October 9, 2002. Samples collected at De Anza Cove had the highest indicator bacterial densities of any site monitored during the study. At least one sample collected from each day, with the exception of August 31, 2002, exceeded AB411 criteria for at least one indicator bacteria. Total and fecal coliform densities ranged from non-detect to 80,000 MPN/100 ml and enterococcus densities ranged from non-detect to 414 MPN/100 ml.

Bacterial Sources – Phase I

Sources of bacterial contamination to De Anza Cove were investigated under all three tasks developed for Phase I. The comfort station's infrastructure was inspected under Task 1. Excessive irrigation practices, storm drain infrastructure, groundwater seepage and birds were all investigated as potential sources of bacterial contamination as part of the Visual

Observations Task (Task 3). Illicit discharges of sewage from anchored boats in De Anza Cove were examined as part of Task 2. The complete reports for these tasks are presented in Appendices B, C, and D, respectively and summarized below.

Comfort Stations

There is one comfort station that serves De Anza Cove. Comfort Station 10087 is located midway along the northern shore of the site (Figure 9-1). Runoff generated from washdown procedures at this comfort station was not observed during the Visual Observations Task and no samples were collected. In addition, during the weekly monitoring conducted from November, 2002 through March, 2003 there were no observations that indicated that comfort station runoff generated from washdown procedures was leaving the comfort station at De Anza Cove.

The structural integrity of the lateral lines that serve this station was inspected on September 26, 2002 utilizing closed circuit television. The results of these inspections showed that the lateral lines were in good condition and were an unlikely source of bacteria to the receiving waters at De Anza Cove.

Irrigation

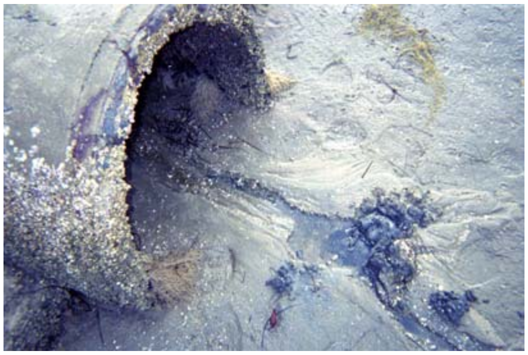
Ponded water in the grassy areas of the park around De Anza Cove occurred from excessive irrigation. Samples of this ponded water had high levels of all three indicator bacterial (Table 9-1). There were no observations of human fecal sources that could account for the high levels of bacteria, however, fecal contamination from the bird population was thought to be likely. Erosion of the banks at De Anza Cove from irrigation was identified as a mechanism of bacterial transport at De Anza Cove. In one instance, the City of San Diego Parks and Recreation Department fixed a broken sprinkler head that caused a large amount of erosion to occur on the beach face. Observations made during the weekly monitoring suggested, in general, erosion problems created by excess irrigation were remediated quickly by City staff.

Erosion caused by a broken sprinkler at De Anza Cove.

Table 9-1. Summary of bacterial densities in samples collected from ponded water on grassy areas surrounding De Anza Cove.

Parameter	Minimum Density (MPN/100 ml)	Maximum Density (MPN/100 ml)	Geometric Mean (MPN/100 ml)
Total Coliform	700	300,000	7,304
Fecal Coliform	90	11,000	1,322
Enterococcus	108	67,600	1,353

Storm Drains



Dry weather flow from De Anza Cove storm drain due to improperly maintained diversion structure

The eight storm drains that discharge to De Anza Cove were identified as a likely source (and mechanism of transport) of bacteria to De Anza Cove during the Visual Observations Task. Inspections of the storm drains and the MBSIS diversion structures were conducted on January 31 and February 5, 2003. Of the six storm drains that are part of the MBSIS, only one (storm drain SD7-2) was functioning properly during the investigation. The malfunctions at the other storm drain diversions were due to sediment and debris that had built up in the diversion structures, which blocked the flow of water to the sewer system. Under these conditions, dry weather flow from the storm drains was being conveyed directly to the receiving waters of Mission Bay. It was clear from the inspections that the diversion structures of these storm drains had not been properly maintained. Appendix I provides a thorough discussion of the results of the inspection.

Twelve samples were collected during the Visual Observations Task of storm drain discharge. Nearly all of them contained bacterial densities much greater than the AB411 criteria for all three indicators. The results are summarized in Table 9-2. The results of the visual observations and storm drain sampling conducted in Task 1 indicate that the storm drains are a potentially large source of bacteria to De Anza Cove during dry and wet weather. In addition, the results of the laboratory eel grass experiment (reviewed in Section 2) indicate that bacterial levels can increase dramatically under conditions that were observed in the storm drains at De Anza Cove: low salinity from freshwater influx, a large amount of organic debris, and UV protection. In this way, the storm drains at De Anza Cove likely amplify the initial bacterial load from the host animal, particularly when organic debris builds up when the storm drains are not properly maintained.

Table 9-2. Summary of bacterial densities in samples collected from storm drains discharging to De Anza Cove (SD7-1 through SD7-6).

Parameter	Minimum Density (MPN/100 ml)	Maximum Density (MPN/100 ml)	Geometric Mean (MPN/100 ml)
Total Coliform	700	300,000	7,304
Fecal Coliform	90	11,000	1,322
Enterococcus	108	67,600	1,353

Illicit Discharge from Moored Boats

Boats moored at De Anza Cove

The potential for bacterial contamination from the illicit discharge of sewage from the boats moored at De Anza Cove was assessed as part of Task 2. This study was designed to determine if illegal dumping of holding tanks from boats moored De Anza Cove was a persistent source of indicator bacteria on the beach. Samples for bacterial analyses were collected by kayak around the moored boats on three days during mid-August, 2002. An additional sample was collected from the beach at the AB411 monitoring site at De Anza Cove. The complete results of the bacterial analyses from the study are presented in Appendix C.

Very low densities of all three bacterial indicators were detected throughout the boat mooring study at De Anza Cove. Over 90% of the samples collected from around the anchored boats were below or equal to the detection limit for all three indicator bacteria. Only one sample collected during the study exceeded AB411 criteria; it was collected from the beach and had a total coliform density of 1,300 MPN/100 ml and a fecal coliform density of 140 MPN/100 ml. However, there was no apparent connection between the high densities at the beach in this single sample and illicit discharge from the boats. The results of the study suggested that illegal sewage dumping from boats moored in De Anza Cove was not a chronic source of bacterial contamination at the beach. However, since the sampling duration was limited, and illegally dumping is likely episodic (if it is occurring), the potential for moored boats as a source of bacterial contamination to adjacent beaches can not be ruled out.

Bacterial Sources – Phase II

De Anza Cove was assessed in all three investigative tasks of Phase II: Microbial Source Tracking, Bacterial Fate and Transport, and the Sediment Investigation. The studies are presented in detail in Appendices E, F, and G, respectively and summarized below.

Bacterial Host Origin

The Microbial Source Tracking Task was conducted at De Anza Cove in both dry and wet weather to determine the origin of the bacteria in the receiving waters and to assess the connection between storm drain effluent and receiving water.

In the dry weather survey, the bacterial isolates collected from storm drains (Figure 9-3A) originated primarily from avian sources (48%), but substantial proportions were found to originate from other mammals (29%), and canine sources (19%). An insignificant percentage of the isolates (4%) originated from humans in the storm drain samples. In the receiving waters at

De Anza Cove a majority of the isolates (64%) were also shown to originate from avian sources (Figure 9-3B). The next largest group (Unknown) accounted for 12% of the dry weather Ribotypes. Interestingly, 9% were found to match Human Ribotypes. We next looked for matches between De Anza Cove Dry Weather receiving water and storm drain Ribotypes. We found that 41% of the Ribotypes collected from the receiving water marched those in the storm drains (Figure 9-3C).

Twenty-five Receiving water and nine storm drain samples were taken during the dry weather survey for HS-PCR analysis. Of these, 14 out of 25 receiving water and 8 out of 9 storm drain samples were positive for the General *Bacteroides* marker, but none of these samples were positive for the Human marker.

Dry Season Ribotyping Results at De Anza Cove

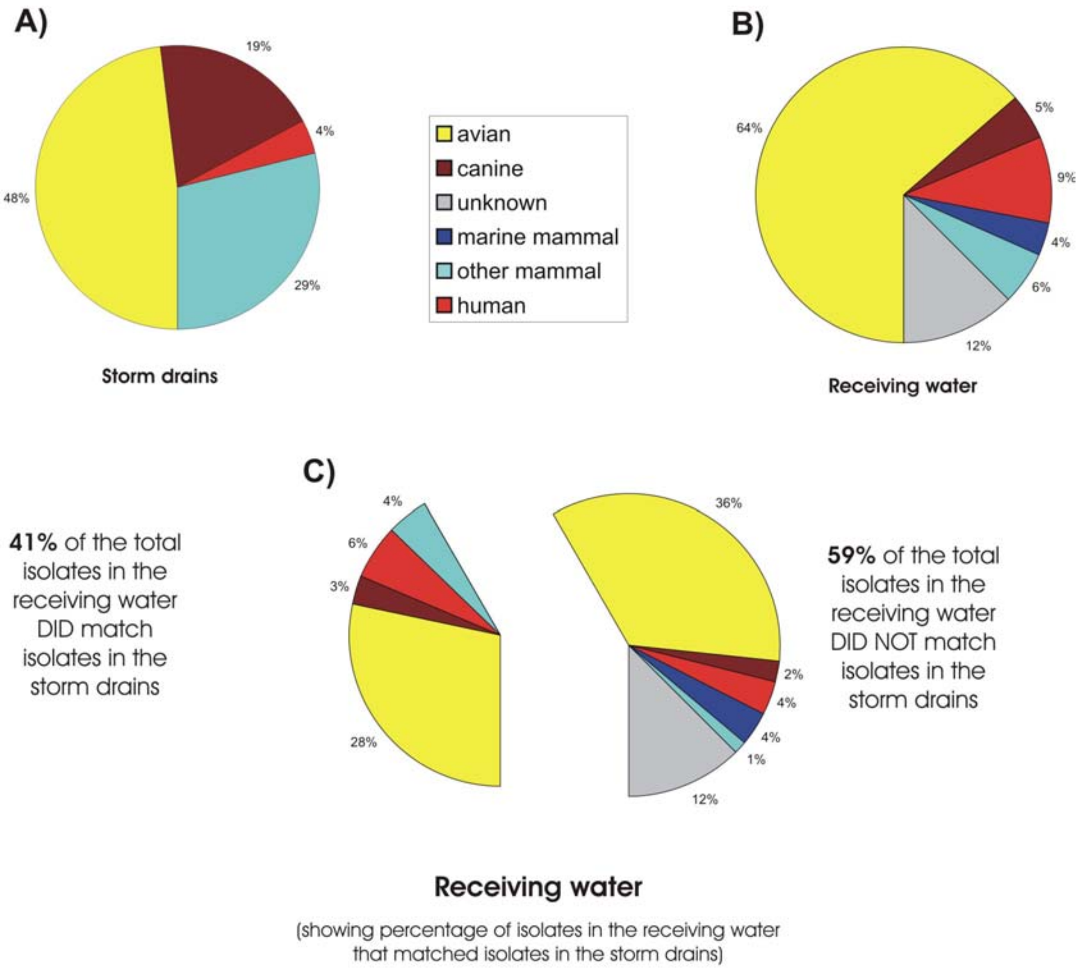


Figure 9-3. Results of Ribotyping analysis at De Anza Cove during dry season. The pie charts show the origin of bacterial isolates in storm drains SD7-2 thru SD7-4 (A), receiving water (B), and the proportion of isolates in receiving water that matched those in storm drains (C).

The Ribotyping results of the wet weather survey conducted at De Anza Cove were very similar to those obtained during the dry weather survey, with birds identified as the major source of enteric bacteria in both storm drains and receiving water (Figure 9-4). However, in the wet weather survey, the percentage of isolates that originated from birds in the receiving water samples (80%) was much higher than that found during the dry weather survey. In addition, there appeared to be a stronger connection between the isolates found in the storm drains and those in the receiving water, with 55% of the isolates common to both areas (Figure 9-4C).

HS-PCR analysis was also performed on samples collected during the wet weather period. All of the receiving water samples (15 out of 15) were positive for the General *Bacteroides* marker, yet none were positive for the Human marker. Likewise, a majority of the storm drain samples analyzed were positive for the General marker (24 out of 28), yet none of these were found to possess the Human marker as well.

Wet Season Ribotyping Results at De Anza Cove

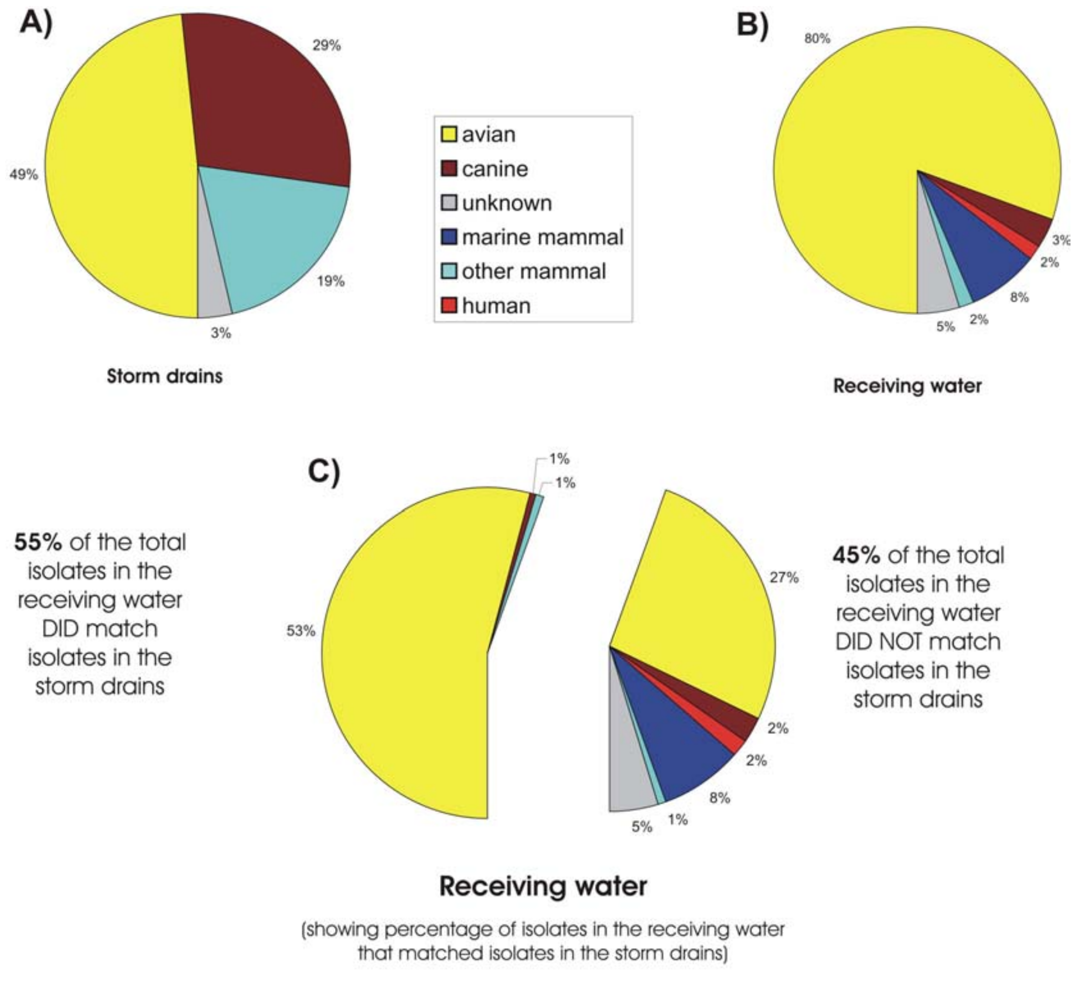


Figure 9-4. Results of Ribotyping analysis at De Anza Cove during wet season. The pie charts show the origin of bacterial isolates in storm drains SD7-2 thru SD7-4 (A), receiving water (B), and the proportion of isolates in receiving water that matched those in storm drains (C).

Taken together, the Ribotyping and HS-PCR results for De Anza Cove suggest that, as with all other sites examined in Mission Bay, the birds are the primary source of enteric bacteria during both dry and wet weather. The relatively large percentage of isolates that were found in both storm drain and receiving water samples suggest that the storm drain effluent at De Anza Cove is a source of enteric bacteria to the receiving waters at this site. Because a similar pattern was observed during both dry and wet weather monitoring periods, this relationship appears to persist year-round.

Fate and Transport

At the end of Phase I, the large number of springs that discharge to the beach at De Anza Cove were thought to be a potential source of bacteria to the receiving waters at this site. This potential was assessed at De Anza Cove in the Fate and Transport Study conducted at this site in March, 2004. In this study, samples were collected from soil cores and groundwater wells in the park, as well as groundwater springs on the beach face at De Anza Cove. The complete results of the study are presented in Appendix F and summarized in Table 9-3.

Drilling groundwater wells at De Anza Cove

Table 9-3. Summary of bacterial densities in samples collected during the fate and transport study at De Anza Cove. Densities are in units of MPN/100 ml for water samples and MPN/100 dry gram for soil samples.

Sample Type	Minimum Density	Maximum Density	Geometric Mean	Minimum Density	Maximum Density	Geometric Mean
	Fecal Coliform			Enterococcus		
Soil cores from park	< 1	4,000	2.40	< 1	14,900	170
Groundwater from park wells	< 20	20	< 20	< 10	< 10	< 10
Groundwater from beach spring	< 20	< 20	< 20	< 10	< 10	< 10

The results of the study revealed that the grassy areas of De Anza Cove, as well as other locations in Mission Bay Park, contain a large reservoir of both fecal coliform and enterococcus bacteria. The origin of the bacteria was determined to be predominantly avian (see Appendix F). However, an analysis of bacterial density with depth from the soil core samples indicated that the migration of bacteria from the park surface to the groundwater is limited to the upper 18 inches of soil by layers of clay and other fine-grained material. Virtually no indicator bacteria were found in the groundwater wells or the beach face springs at De Anza Cove or the other sites investigated in the fate and transport study. In addition, none of the samples collected from groundwater at the beach face springs during the Microbial Source Tracking Task at De Anza Cove contained indictor bacteria. These results indicate that the grassy area of De Anza Cove and the soil directly beneath it contains a large reservoir of indicator bacteria, but the bacteria is not transported to the receiving waters of Mission Bay via groundwater seepage through the beach.

Intertidal Sediments

The intertidal sediments at De Anza Cove were investigated as part of Phase II to determine if the sediments contained bacteria that are released to the water column when the sediments are disturbed (e.g., by swimming activity). Two sequential samples were collected at 15 Stations along the east side of De Anza Cove: a clear water sample (CL) taken without disturbing the sediments, and a resuspended sediment sample (RS) taken after the sediments had been disturbed. At De Anza Cove, the resuspension study was conducted on May 21, 2003 during a very low tide (2 feet below MLLW). Only enterococcus was enumerated. An analysis of the results indicate that the mean resuspended sediment enterococcus density of 38.1 MPN/100 ml was significantly greater than the mean clear water density of 12.3 MPN/100 ml (p = 0.0004). The data are presented graphically in Figure 9-5.

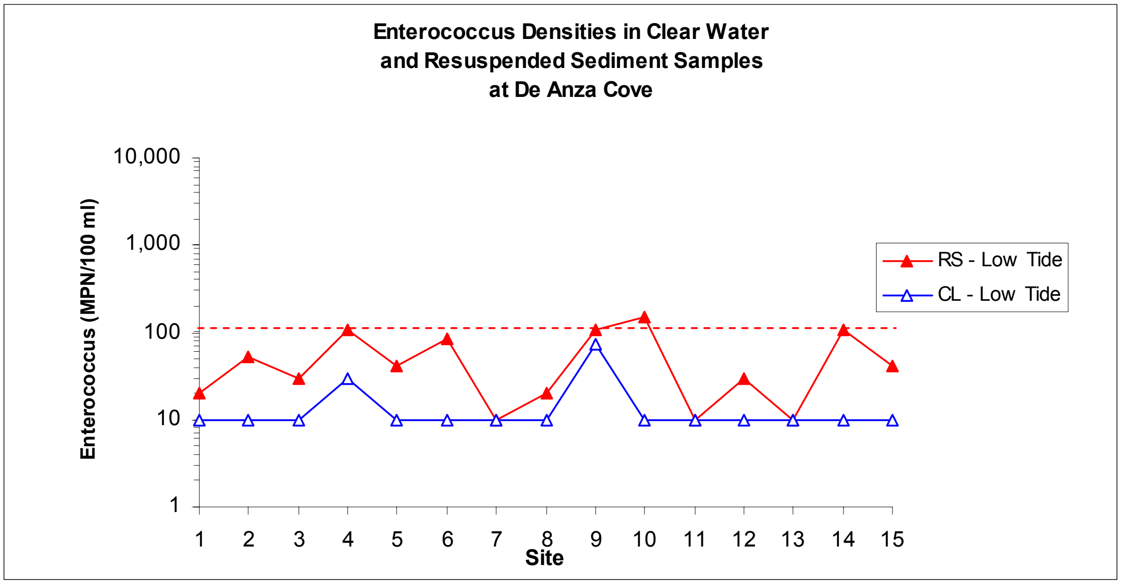


Figure 9-5. Graph of enterococcus densities in receiving water at De Anza Cove. CL refers to clear water samples and RS refers to samples taken after sediment resuspension. The dashed red line represents the AB411 standard for enterococcus of 104 MPN/100 ml.

The results of the sediment resuspension study at De Anza Cove indicate that sediments in the lower intertidal zone at this site act as a reservoir for indicator bacteria. When the sediments are disturbed the bacteria is released to the receiving water resulting in elevated bacterial densities. These results are in contrast to those obtained during the Bonita Cove resuspension study conducted at low tide where there was no difference between clear water and resuspended sediment samples. The likely explanation for this difference is that more storm drains discharge to De Anza Cove than any other site in Mission Bay. The storm drains terminate in the lower intertidal zone at a tidal height of approximately +1 to +2 feet above MLLW. Thus, discharge from the storm drains may inoculate the sediments in the lower intertidal zone at De Anza Cove, which would account for the greater bacterial densities in resuspended sediment samples observed at this site. In addition, sediment grain size was smaller at De Anza Cove than Bonita Cove, which may have accounted for the greater bacterial densities at De Anza Cove.

Other – Wrack Line

A heavy wrack line consisting primarily of organic material tends to accumulate on the beach at De Anza Cove. The results of the wrack line study conducted at Visitor's Center, just south of De Anza Cove, suggest that the wrack line tends to amplify the bacterial load. Although the wrack at De Anza Cove was not assessed in this study, it is also a likely source of indicator bacteria to the receiving waters at this site.

Conclusions

Because of the high frequency of exceedances of AB411 criteria at De Anza Cove, this site was one of the most thoroughly investigated sites in the study. Assessments of bacterial sources were conducted at De Anza Cove as part of all the investigative tasks in Phase I and Phase II. At the onset of the project, numerous potential sources had been identified at this site, including comfort station infrastructure, illicit discharge from moored boats, storm drains, groundwater, the homeless population, and the birds. At the end of Phase I, many of these sources had been removed from the list of potential sources as a result of the investigative tasks or remediation by the City. The results of the investigations conducted at De Anza Cove are summarized in Table 9-4.

Table 9-4. Sources of indicator bacteria at De Anza Cove. A green N indicates potential sources that are no longer thought to be present or were remediated as part of the study. A red Y indicates potential sources that remain at this site.

Site #	Site Name	Illicit Boat Discharge	Restroom Infrastructure	Birds and Other Wildlife	Irrigation Runoff	Storm Drains	Restroom Washdown	Homeless	Dog Waste	RV Pump Outs	Creek Drainage	Groundwater	Delta Sediment	Intertidal Sediment	Wrack	Other
7	**De Anza Cove**	N	N	Y	Y	Y	N	N	N	N	N	N	N	Y	Y	N

The investigative tasks of Phase II focused on the remaining potential bacterial sources. The results of these studies suggest that De Anza Cove suffers from a variety of problems related to sources of indicator bacteria. The bird population at this site can be very high particularly in the winter months along the eastern shore where birds are attracted to freshwater springs on the beach. The eastern shore also receives a large amount of organic debris that accumulates on the beach as a wrack line, which has been shown to amplify the initial bacterial load. Fine-grained intertidal

Storm drain at De Anza Cove

sediments in the lower intertidal zone (likely the upper intertidal as well) act as a reservoir for bacteria that when disturbed, are released to the water column. Finally, and most importantly, there are more storm drains that discharge to De Anza Cove than any other single area in Mission Bay. Numerous lines of evidence from this study indicate that storm drains are a major contributor to elevated bacterial densities in the receiving waters at De Anza Cove, including high indicator bacterial densities in storm drain effluent, clogged diversion structures that allow large amounts of dry weather flow to reach the bay, elevated bacterial densities in intertidal sediments adjacent to the storm drains, a strong connection between storm drains and receiving water as a result of microbial source tracking techniques, and maintenance of an environment conducive to bacterial growth. Although other bacterial sources should be addressed when considering ways to reduce levels of indicator bacteria densities in De Anza Cove, the storm drains and maintenance of the MBSIS diversion structures should be a primary focus.

Site Conditions

Figure 10-1. Aerial photograph of Visitor's Center.

Visitor's Center is located on the eastern side of Mission Bay at the end of Clairemont Drive (Figure 10-1). The site is bounded on the north by the Visitor's Center building, on the east by East Mission Bay Drive and on the west by Cudahy Creek. The site lies within a shallow, triangular shaped invagination of Mission Bay where circulation and tidal flushing is limited. Large areas of irrigated grassy park border three sides of the site. There is an RV pump out station located adjacent to the Visitor's Center building, which attracts numerous tourists to the area, but the beach at Visitor's Center is not as heavily used as other sites in Mission Bay. This site typically contains one of the largest bird populations in the bay, particularly in winter. Three storm drains discharge to this area: storm drains SD8-1 and SD8-2 on the northern end of the site, and SD8-3 approximately 1,000 feet to the south. All three are diverted as part of the MBSIS by diversion structures on the east side of Interstate 5. Storm drain SD8-3 consists of three box culverts that are collectively referred to here as Cudahy Creek. There is a constant flow of water fresh water emanating from Cudahy Creek and storm drain SD8-1. The AB411 monitoring site is located directly in front of storm drain SD8-1. In addition to the restroom inside the visitor's Center building, there is one comfort station at this site, located just east of storm drain SD8-1.

Temporal Trends

As with other sites on the east side of Mission Bay, a review of the historical data for Visitor's Center indicates strong seasonal trends in enterococcus densities at this site (Figure 10-2). Densities typically peak every year in the winter or early spring and tend to be lower in the summer. However, episodic spikes are common throughout the year at this site. The seasonal trend in enterococcus densities correlates well with the changing bird population in Mission Bay. Visitor's Center typically receives a more dramatic influx of migratory birds in the winter than other sites in Mission Bay (Kisner 2000).

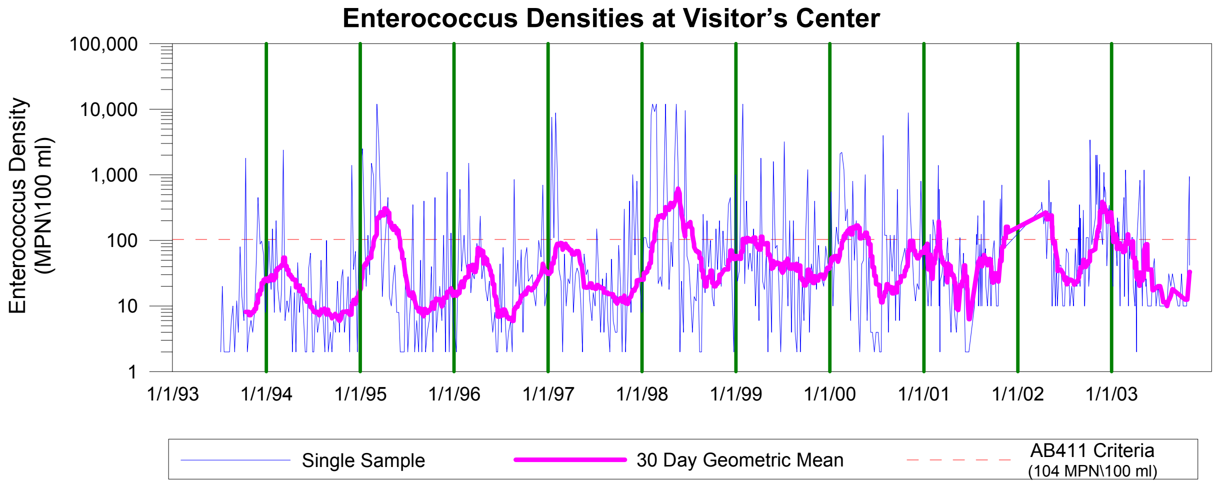


Figure 10-2. Enterococcus densities at Visitor's Center from 1993 through 2003. No data were available from November 2001 through April 2002 (source: San Diego County Department of Environmental Health).

Figure 10-2 includes data from receiving water samples collected at Visitor's Center during the Visual Observations Task (Task 3) of this study conducted in the summer of 2002 as well as samples collected during the Weekly Monitoring in the winter of 2002/2003. For the Visual Observations Task, samples were collected three times daily (morning, mid-day, evening) on nine days between August 25 and October 9, 2002. Visitor's Center was one of the worst sites assessed in the study. Multiple receiving water samples had indicator bacteria levels that exceeded AB411 standards. Elevated densities of all three indicators were detected during various shifts (morning, noon, and evening) on all but two of the visual observation study days.

Bacterial Sources – Phase I

Sources of bacterial contamination at the Visitor's Center were investigated under Tasks 1 and 3 developed for Phase I. The comfort station's infrastructure was inspected under Task 1. Excessive irrigation practices, the RV pump station, storm drain infrastructure and other potential sources of bacteria were investigated as part of the Visual Observations Task (Task 3). A follow-up study was conducted on January 31, 2003 to further identify potential sources of bacterial contamination. This study focused on the two storm drains located near the Visitor's

Center and flow from Cudahy Creek. The complete reports for the investigative tasks and the follow-up study are presented in Appendices B, D, and E, respectively and summarized below.

Comfort Stations

There is one comfort station that serves the Visitor's Center area. Comfort Station 1091 is located approximately 800 feet south of the Visitor Center building, east of storm drain SD8-1. During the Visual Observations Task, runoff generated from washdown procedures at this comfort station was determined not to be impacting surface waters; no samples were collected.

The lateral line of Comfort Station 1091 was inspected utilizing closed circuit television on October 17, 2002. This inspection showed that the lateral line was in good condition and was an unlikely source of bacterial contamination at this site. Appendix B provides a detailed description of this inspection. Taken together, the results of the visual observations and lateral line inspection indicates that Comfort Station 1091 is not a source of bacteria to the bay.

Irrigation

Ponded water in the grassy areas of the park and paved surfaces surrounding Visitor's Center occurred from excessive irrigation. A total of 16 samples were collected from this ponded water. The bacterial densities in these samples were highly variable. Enterococcus densities ranged from 5 MPN/100 ml to over 2 million MPN/100 ml. Table 10-1 summarizes the results of these samples.

Ponded water in the grassy area at Visitor's Center

Table 10-1. Summary of bacterial densities in samples collected from ponded water surrounding Visitor's Center.

Parameter	Minimum Density (MPN/100 ml)	Maximum Density (MPN/100 ml)	Geometric Mean (MPN/100 ml)
Total Coliform	Non Detect	9,000,000	96,951
Fecal Coliform	Non Detect	5,000,000	18,432
Enterococcus	Non Detect	2,419,600	9,568

Erosion of the upper beach face from irrigation runoff at Visitor's Center

Bacteria associated with the irrigation water in the grassy area of the park can reach the receiving waters at this site through street runoff, which is conveyed directly to the bay through storm drain inlets below the diversion structures of storm drains SD8-1, SD8-2, and SD8-3. In addition, erosion of the banks at the Visitor's Center site was a common observation during the Visual Observations Task. This suggests that sheet transport of irrigation water from the grass surface to the bay occurs at this site. Transport of bacteria from the grass to the bay via groundwater was determined to be unlikely at Visitor's Center and other sites in Mission Bay (see Phase II below).

Storm Drains

Storm drains SD8-1 and SD8-2

During Phase I, storm drains were identified as the major potential source (and mechanism of transport) of bacteria at Visitor's Center. Three storm drains discharge to the receiving waters at this site: storm drains SD8-1 and SD8-2 at the northern end of the site and Cudahy Creek (SD8-3) at the southern end (Figure 10-1). The MBSIS diversion structure for storm drains SD8-1 and SD8-2 is located on the east side of Interstate 5 near Morena Drive. During the Visual Observations Task and subsequent monitoring in Phase II, this diversion structure was functioning properly by diverting dry weather flow to the sewer. However, just downstream of the diversion structure is a freshwater spring that is present year-round and flows through storm drain SD8-1. In addition, there is significant groundwater infiltration to the storm drain system in this area. As a result, there is a constant, year-round flow of freshwater flowing to Mission Bay of approximately 5 g.p.m. via storm drain SD8-1. Seven samples were collected from this storm drain during the Visual Observations Task. All of them exceeded AB411 criteria. The results are summarized in Table 10-2. The high bacterial densities and constant freshwater flow associated with storm drain SD8-1 indicate that this storm drain is a significant source of bacteria to the Visitor's Center site.

Table 10-2. Summary of bacteria densities in samples collected from Storm Drain SD8-1 (end of pipe) at Visitor's Center during the Visual Observations Task.

Parameter	Minimum Density (MPN/100 ml)	Maximum Density (MPN/100 ml)	Geometric Mean (MPN/100 ml)
Total Coliform	70	2,400,000	3,611
Fecal Coliform	70	9,000	946
Enterococcus	199	16,310	862

Mouth of Cudahy Creek

The situation at Cudahy Creek is similar to that described for storm drain SD8-1. Observations of the Cudahy Creek diversion structure, located on the west side of Morena Drive, indicate that the diversion structure functions properly in diverting dry weather flows to the sewer. However, groundwater infiltration through the joints in the storm drain downstream of the diversion structure produce a constant flow of freshwater that is conveyed to Mission Bay. In addition, large amounts of organic debris are deposited on the bottom of the Cudahy Creek storm drain from Mission Bay to just downstream of the diversion structure, a distance of approximately 500 feet. The combination of a constant freshwater flow, large amounts of organic debris, and a UV-protected environment inside the storm drain provide conditions conducive to the growth of indicator bacteria. These same conditions, although smaller in magnitude, are also present inside storm drain SD8-1.

The idea that the conditions described above lead to elevated bacterial densities from Cudahy Creek are supported by the monitoring data at that site. Since 2001, flow from the mouth of Cudahy Creek has been monitored for indicator bacteria on a weekly basis as part of Supplemental Environmental Project (SEP) conducted by the City. The results of the bacterial monitoring from July, 2001 through October, 2003 are presented in Table 10-3. Of the 137 samples collected during this time period, 105 (77%), exceeded the single sample AB411 criteria for enterococcus. Clearly, the flow from Cudahy Creek is a significant source of indictor bacteria to the receiving waters at Visitor's Center.

Table 10-3. Summary of AB411 single sample criteria (104 MPN/100 ml) exceedances for enterococcus in samples collected from the mouth of Cudahy Creek at Visitor's Center during the SEP monitoring (both dry and wet season). The table includes the total number of analyses performed, the number that did not exceed AB411 criteria (No), the number that did exceed criteria (Yes), and the percentage of exceedances relative to the total number of analyses (Percent).

Location	Total Analyses	No	Yes	Percent (Yes/Total)
Mouth of Cudahy Creek	137	32	105	77

Bacterial Sources – Phase II

Because of the high frequency of bacterial criteria exceedances at Visitor's Center, this site was studied extensively in Phase II of the study, including investigations in the Microbial Source Tracking Task, Bacterial Fate and Transport Task, and the Sediment Investigation. The studies are presented in detail in Appendices E, F, and G, respectively and summarized below. In addition, processes of bacterial amplification were assessed at the Visitor's Center site in the wrack line investigation and the laboratory eel grass experiment. The results of these studies are presented in Appendix H and summarized briefly below.

Bacterial Host Origin

At Visitor's Center, Microbial Source Tracking was used to assess the relationship between flow from storm drain SD8-1 and Cudahy Creek on the receiving waters at this site and to assess the host origin of the bacteria found there. Samples for this assessment were collected during the 2003/2004 wet season.

Spring east of I-5 that drains to storm drain SD8-1

We first obtained bacterial isolates from the freshwater spring located east of I-5 for Ribotyping. Upon searching the Institute for Environmental Health's Source Ribotype Library Database for matches, we found that 72% of the isolates originated from birds, 13% were Unknown, 8% were Canine, and the remaining 1% originated from other mammalian (non-human) sources. None of the isolates collected originated from human sources. Because flow from the spring is conveyed to Mission Bay via storm drain SD8-1 at Visitor's Center, Ribotype data collected from the spring and the storm drain were combined (a total of 200 Ribotypes) to assess the relationship of that flow on the receiving waters (Figure 10-3A). Of the 200 Ribotypes collected from the Spring/Storm Drain, 49% were of Avian origin, 27% were of Canine origin, 13% were of mixed mammalian sources, and 11% remained unknown. In the receiving water, the majority of the 135 isolates collected (66%) also originated from birds, followed by Canine (14%) and other sources (Figure 10-3B). An insignificant 2% originated from human sources.

We next asked what proportion of the combined Spring/Storm Drain Ribotypes could be traced to the receiving water Ribotype data set (Figure 10-3C). Interestingly, we found that a substantial 64% of the receiving water-derived Ribotypes were shared with those found in the Spring/Storm Drain Ribotype data set. Nearly all of the isolates that were common to both areas originated from Avian or Canine sources.

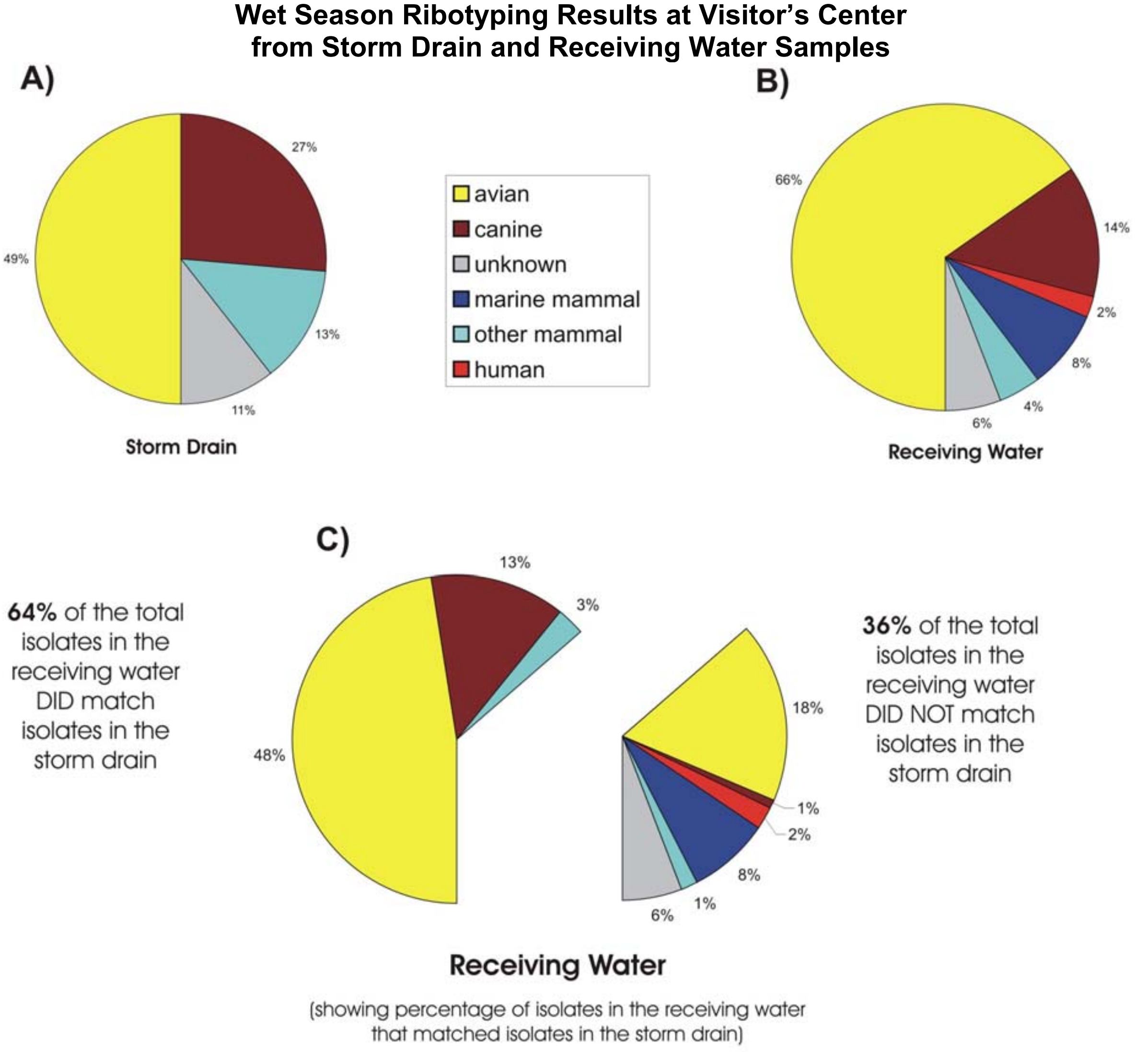


Figure 10-3. Results of Storm Drain SD8-1 and receiving water Ribotyping analysis at Visitor's Center. The pie charts show the origin of bacterial isolates from Storm Drain SD8-1 (A), the receiving water (B), and the proportion of isolates in the storm drain effluent that matched those in receiving water (C).

The second input into Visitor's Center receiving waters, Cudahy Creek, was sampled six times of the course of this task and 96 isolates were obtained for Ribotyping analysis. Similar to the results for the spring, storm drain SD8-1, and the receiving waters, we found that the majority (66%) of the isolates collected from the mouth of Cudahy Creek originated from birds (Figure 10-4A). Canine sources comprised the next largest group, accounting for a substantial 23% of the isolates. As with the other Ribotyping results from Visitor's Center, the percentage of isolates originating from human sources in the Cudahy Creek samples was insignificant (1%).

We next asked what proportion of the Cudahy Creek Ribotypes were in common with those found in the receiving water at this site (Figure 10-4C). We found that 46% of the receiving water-derived Ribotypes were also identified in the Cudahy Creek Ribotype data set. Of these common Ribotypes, the majority were attributed to Avian and Canine sources.

Wet Season Ribotyping Results at Visitor's Center from Cudahy Creek and Receiving Water Samples

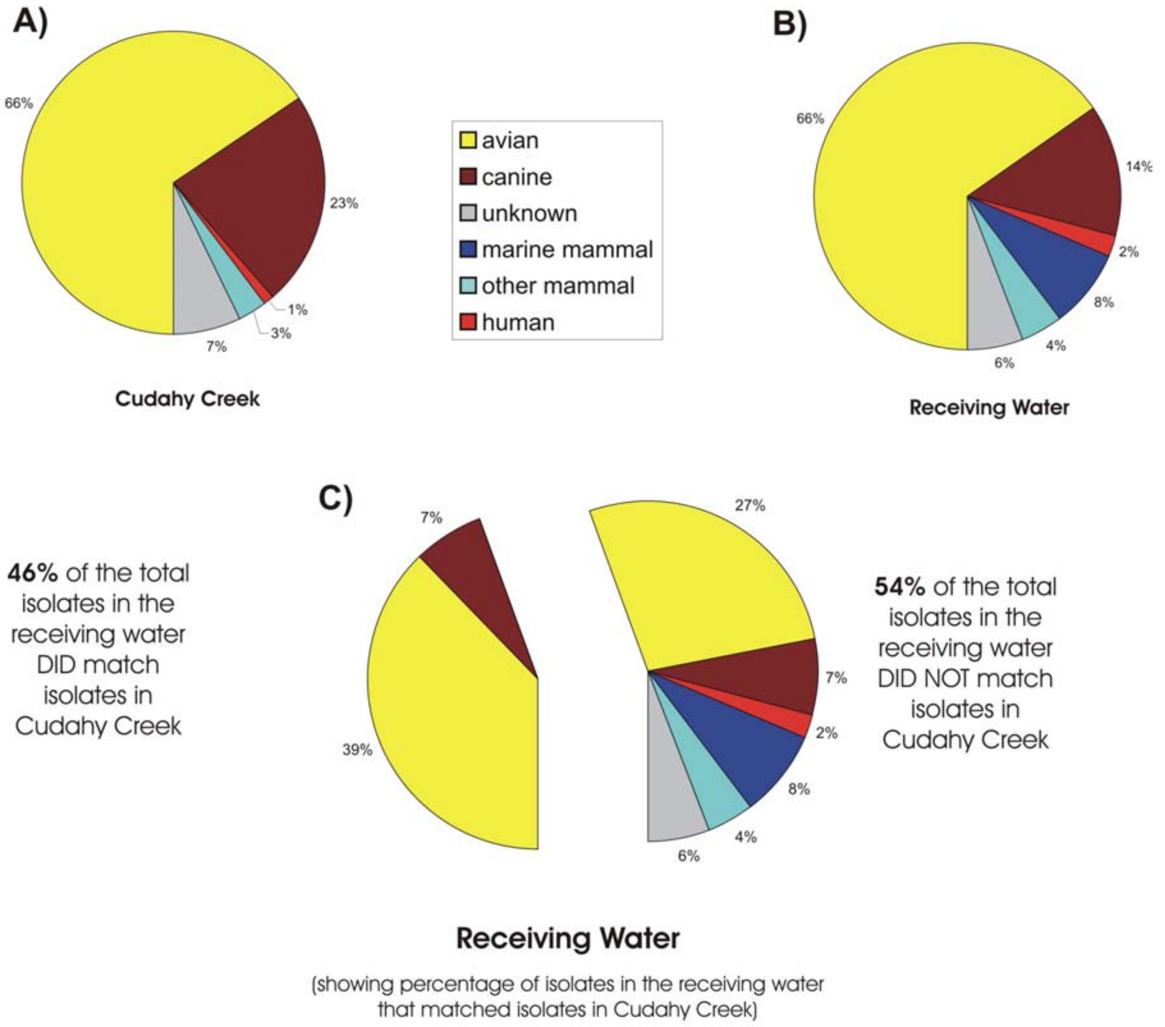


Figure 10-4. Results of Cudahy Creek and receiving water Ribotyping analysis at Visitor's Center. The pie charts show the origin of bacterial isolates from Cudahy Creek (A), the receiving water (B), and the proportion of isolates in Cudahy Creek that matched those in receiving water (C).

In addition to the Ribotyping analyses, the samples collected at Visitor's Center were also analyzed by HS-PCR. A total of 20 samples were analyzed from the receiving water, and eight each from the spring, storm drain SD8-1, and Cudahy Creek. All of these samples were positive for the General *Bacteroides* marker. Importantly, none of these samples were identified to be positive for the Human *Bacteroides* marker. These results agree well with the Ribotyping results, which suggest that enteric bacteria originating from humans is not a significant source of indicator bacteria at Visitor's Center. This was a consistent observation throughout Mission Bay.

The results of the Microbial Source Tracking Task suggest that there is a strong connection between the enteric bacteria found in the receiving waters at Visitor's Center and that found in flows from Storm Drain SD8-1 and, to a lesser extent, Cudahy Creek. As mentioned previously, there is a constant flow to the receiving waters from both these sources that originates downstream of the diversion system and they both provide conditions conducive to bacterial amplification. It is also interesting to note that most of the bacteria identified at this site originated from birds, as elsewhere in Mission Bay, but there was also a substantial percentage of bacteria that originated from Canine sources. One possible explanation for this is that Visitor's Center has an RV pump out facility and this site is a primary initial destination for many tourists. Thus, dog waste from Visitors' pets may be more prominent here than at other sites in Mission Bay. During the Visual Observations Task, dogs were periodically noted on the beach in this area (see Table 2-6). Currently, this area does not contain doggie bag dispensers.

Fate and Transport

In addition to the constant effluent emanating from storm drain SD8-1 and Cudahy Creek at Visitor's Center, this site also has several freshwater springs along the beach face. At the end of Phase I, these springs were identified as a potential source of bacteria to this area. This potential was assessed at Visitor's Center in the Fate and Transport Study conducted at this site in March, 2004. In this study, samples were collected from soil cores and groundwater wells in the park, and groundwater springs on the beach face. The complete results of the study are presented in Appendix F and summarized in Table 10-4.

Sampling groundwater at Visitor's Center

Table 10-4. Summary of bacterial densities in samples collected during the fate and transport study at Visitor's Center. Densities are in units of MPN/100 ml for water samples and MPN/100 dry gram for soil samples.

Sample Type	Minimum Density	Maximum Density	Geometric Mean	Minimum Density	Maximum Density	Geometric Mean
	Fecal Coliform			Enterococcus		
Soil cores from park	< 1	11,200	24.5	< 1	78,900	284
Groundwater from park wells	< 20	20	< 20	< 10	41	< 10
Groundwater from beach spring	< 20	< 20	< 20	< 10	< 10	< 10

The results of the study revealed that the grassy areas of Visitor's Center, as well as other locations in Mission Bay Park, contain a large reservoir of both fecal coliform and enterococcus bacteria. The origin of the bacteria was determined to be avian (see Appendix G). However, an analysis of bacterial density with depth from the soil core samples indicated that the migration of bacteria from the park surface to the groundwater is limited to the upper 18 inches of soil by layers of clay and other fine-grained material. Virtually no indicator bacteria were found in the groundwater wells or the beach face springs at Visitor's Center or the other sites investigated in the fate and transport study. In addition, none of the samples collected from groundwater at the beach face springs during the Microbial Source Tracking Task at Visitor's Center contained indicator bacteria. These results indicate that the grassy area of Visitor's Center and the soil directly beneath it contains a large reservoir of indicator bacteria, but the bacteria is not transported to the receiving waters of Mission Bay via groundwater seepage through the beach.

At Visitor's Center, there are two other mechanisms that can transport bacteria from the grassy area to the receiving waters: irrigation runoff and subsequent flow through storm drains and erosion. Watershed maps produced in Phase I for this site show that excess irrigation water can enter the bay via all three storm drains at this site. Thus, it is important to minimize excess irrigation at Visitor's Center as discussed above in the Irrigation section. In addition, erosion of the banks adjacent to the beach has been determined to be a problem at this site. The results of the fate and transport study suggest that when erosion occurs, the sediment that is transported to the receiving waters contains a significant load of indicator bacteria. Thus, preventing erosion at Visitor's Center is an important element in reducing indicator bacterial densities in the receiving water of Mission Bay.

Delta Sediments

Because there is a large delta built up at the mouth of Cudahy Creek and consistently elevated bacterial densities have been measured in Cudahy Creek effluent, the sediments in the Cudahy Creek delta were assessed as part of the Sediment Investigation Task. The goal of the study was to determine the extent to which bacteria deposited at the mouth of Cudahy Creek impacted the receiving waters at Visitor's Center. The complete report is presented in Appendix G and summarized below.

Cudahy Creek delta exposed at an extreme low tide

Two surveys were conducted: one at the end of the dry season (October, 2003) and one during the middle of the wet season (January, 2004). Sediment cores were collected by boat at the surface and from a depth of four inches. During the dry season survey, sediments at the mouth of Cudahy Creek (i.e., the creek delta) contained very low levels of indicator bacteria (Table 10-5). These results suggest that the delta sediments at Cudahy Creek during the dry season are an unlikely source of bacteria to the AB411 receiving water monitoring site at Visitor's Center. The wet season survey was conducted in January, 2004 after several storms had impacted the area. Fecal coliform densities in surficial sediments were similar to those during the dry season, but the mean enterococcus density during the wet season survey was 38 times greater than the mean dry season density (p 0.0006).

Table 10-5. Summary of indicator bacterial densities in samples collected from delta sediments at the mouth of Cudahy Creek. All values are presented as MPN/gram dry weight.

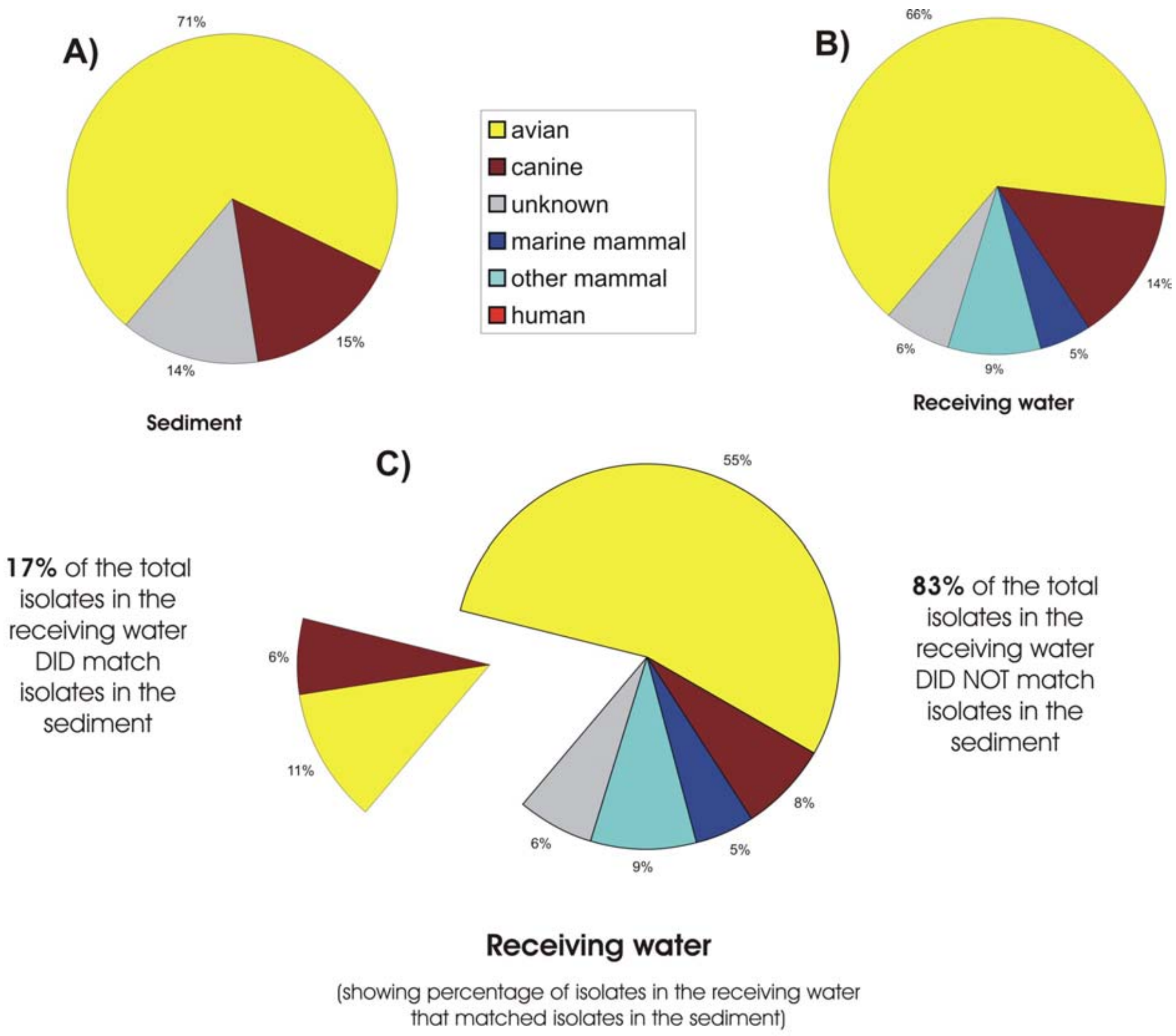
Indicator	Strata	Minimum Density	Maximum Density	Geometric Mean	Minimum Density	Maximum Density	Geometric Mean
		Dry Season Survey (10/24/03)			**Wet Season Survey (1/14/04)**		
Fecal Coliform	Surface	<1	16	3.3	<1	23	2.8
	Depth	<1	2	0.82	<1	<1	<1
Enterococcus	Surface	<1	2	0.82	4	397	35.6
	Depth	<1	3	0.95	1	3,047	176

To determine the host origin of bacteria at Cudahy Creek and to assess the extent to which the sediments act as a bacterial source to the receiving waters, the DNA fingerprints of *E. coli* bacteria in the sediment were compared to those collected in the receiving water using the Ribotyping technique. The comparison was conducted only during the wet season survey. The results of the Ribotyping analysis of the receiving water samples are presented graphically in Figure 10-5.

During the wet season survey, a total of 59 isolates were obtained from Cudahy Creek sediments (Figure 10-5A). Upon querying the Institute for Environmental Health's Source Ribotype Library Database, we found that the majority of isolates in the sediments originated from Avian and (71%) Canine (15%) sources. These results are similar to those found in effluent samples collected from storm drain SD8-1 and Cudahy Creek described above, suggesting that influx from these drainages are a likely source of indicator bacteria in the sediments as well as the receiving waters.

To assess the extent to which sediments act as a source of bacteria to the receiving waters, we next asked what percentage of Ribotypes in the sediments were also found in the receiving waters (Figure 10-5C). The results showed that only 17% of the Ribotypes in the receiving water matched those in the sediment at Cudahy Creek.

Ribotyping Results at Cudahy Creek During the Delta Sediment Investigation



17% of the total isolates in the receiving water DID match isolates in the sediment

83% of the total isolates in the receiving water DID NOT match isolates in the sediment

Receiving water

(showing percentage of isolates in the receiving water that matched isolates in the sediment)

Figure 10-5. Results of Ribotyping analysis at Cudahy Creek during the wet season survey. The pie charts show the origin of bacterial isolates in delta sediments (A), receiving water (B), and the proportion of isolates in receiving water that matched those in sediment (C).

The results of the delta sediment investigation at Cudahy Creek suggest that the sediments at this site act as a reservoir for indicator bacteria during the wet season, but not the dry season. This is likely due to the large influx of bacteria from storm drains SD8-1, SD8-2 and Cudahy Creek watersheds that occurs during storms and the subsequent survival of bacteria in the delta sediments. However, the small percentage of Ribotypes in the receiving waters that matched those in the sediments suggests that the sediments at the mouth of Cudahy Creek act more as a sink for bacteria than a source of bacteria to the receiving waters. The analysis may also have been complicated by the large bacterial load at this site from several sources, which may have overwhelmed the signal from the sediment and reduced the percentage of matching isolates.

Wrack Line

Another potential reservoir of bacteria that was identified at Visitor's Center was the wrack line that accumulates on the beach face at this site. The wrack, or organic debris such as eel grass and algae, tends to accumulate at the high tide mark on the beach and is particularly heavy along the east side of Mission Bay from Visitor's Center to De Anza Cove. As a follow-up study to the investigative tasks conducted in Phase II, the Visitor's Center wrack line was assessed in February, 2004 to determine the extent to which it acted as a reservoir for indicator bacteria. The complete study is presented in Appendix H.

Receiving water at Visitor's Center comes in contact with wrack line

Samples of the wrack that was deposited on the beach during a spring tide were collected over an 11-day period during the subsequent neap tide and analyzed for indicator bacteria. The results of the study, as summarized in Section 2, indicate that the wrack line at Visitor's Center acts as a substantial reservoir of indicator bacteria at this site. Elevated enterococcus and, to a lesser extent, fecal coliform densities appear to be maintained for a prolonged period of time within the wrack matrix. The study also showed that the indicator bacteria maintained within the wrack during neap tides are re-distributed to the receiving waters when subsequent spring tides come in contact with it. In this way, the wrack line acts to amplify the load from the original source by maintaining elevated densities over time and impacting receiving water bacterial densities at Visitor's Center.

Intertidal Sediments

During the Visual Observations Task, swimmers were observed utilizing the beach at Visitor's Center, although swimmer density was not as high at this site as others in Mission Bay. The high densities of indicator bacteria at this site in the receiving water, storm drains, Cudahy Creek, and wrack line suggest that intertidal sediments may also act as a bacterial reservoir at the Visitor's Center beach. Thus, resuspension of intertidal sediments during swimming activity is also a potential source of indicator bacteria to the receiving waters at this site.

Conclusions

The Visitor's Center site has one of the highest rates of bacterial exceedances of any site in Mission Bay. Bacterial densities at Visitor's Center often exceed AB411 criteria, particularly during the winter, and the beach is frequently closed for weeks at a time due to excessive bacterial levels. At the beginning of this study, numerous potential sources of indictor bacteria were identified at Visitor's Center and this was the most intensively investigated site in the study. Potential bacterial sources at Visitor's Center identified at the onset of the project included the birds, excessive irrigation leading to bank erosion, Comfort Station 1091, the RV pump out station, groundwater transport, and dry weather flows from storm drains SD8-1, SD8-2, and Cudahy Creek downstream of the diversion system. As a result of the Phase I investigations, several of these were determined to be unlikely sources of indicator bacteria to the receiving waters of Mission Bay or were eliminated as a result of effective management actions taken by the City. The results of the investigations conducted at Bonita Cove are summarized in Table 10-6.

Table 10-6. Sources of indicator bacteria at Visitor's Center. A green N indicates potential sources that are no longer thought to be present or were remediated as part of the study. A red Y indicates potential sources that remain at this site.

Site #	Site Name	Illicit Boat Discharge	Restroom Infrastructure	Birds and Other Wildlife	Irrigation Runoff	Storm Drains	Restroom Washdown	Homeless	Dog Waste	RV Pump Outs	Creek Drainage	Groundwater	Delta Sediment	Intertidal Sediment	Wrack	Other
8	**Visitor's Center**	N	N	Y	Y	Y	N	N	Y	N	Y	N	Y	Y	Y	N

The results of the investigations conducted in Phase II of this study were important in further identifying bacterial sources and identifying the method of transport that impact the Visitor's Center receiving waters. The results of the Molecular Source Tracking Task helped verify the initial results. The study found: 1) the majority of the enteric bacteria in the grassy area of the site, the spring on the east side of Interstate 5, delta sediments, dry weather flow from storm drain SD8-1 and Cudahy Creek, as well as the receiving waters originates from Avian, and to a lesser extent, Canine sources; 2) enteric bacteria originating from human sources is insignificant; and 3) dry weather flow from storm drain SD8-1 and Cudahy Creek are the primary sources of indicator bacteria to the site's receiving waters.

Birds, storm drains, and wrack line at Visitor's Center

The results of the Fate and Transport study showed that there is a large reservoir of indicator bacteria in the upper 18 inches of soil within the grassy area at Visitor's Center. This bacteria is not transported to the bay via groundwater, but can reach the bay through bank erosion or street runoff to storm drains from excessive irrigation. Sediments within the Cudahy Creek delta act as a reservoir of indicator bacteria that impact the receiving waters to a limited extent. Finally, the wrack that accumulates on the beach at Visitor's Center (and likely the intertidal sediments) acts to amplify the bacterial load over time and is considered a bacterial source to the receiving waters, particularly during high tides.

SECTION 11

Leisure Lagoon

Site Overview

Leisure Lagoon is located on the eastern side of Mission Bay, south of the Visitor's Center. The east side of the Lagoon is bordered by East Mission Bay Drive and the west side is bordered by the open water of North Pacific Passage (Figure 11-1). The beach at Leisure Lagoon is surrounded by a grass buffer strip, parking lots, and a small playground. This site is heavily used by park visitors. During summer holidays, there are typically more swimmers at this site than any other area in Mission Bay. The lagoon itself is fairly small (approximately 500 feet wide by 1,200 feet long) and water circulation is constricted by an island at the lagoon entrance. There are two comfort stations at the site, one located on the northeastern end and one located at the far southern end. There are no major creek drainages in this area, but there are two storm drains that discharge to the Lagoon: SD9-1 and SD9-2. They both drain fairly small drainages within Mission Bay Park and neither of them are part of the MBSIS. The Leisure Lagoon AB411 monitoring site is located directly in front of storm drain SD9-2.

Figure 11-1. Aerial photograph of Leisure Lagoon.

Temporal Trends

Seasonal trends in indicator bacteria densities are apparent at this site (Figure 11-2). Similar to other sites on the east side of Mission Bay, enterococcus densities tend to begin rising in the fall, and peak in early spring. As previously mentioned, this pattern is consistent with the bird population in Mission Bay. In addition, there have been numerous exceedances of the AB411 criterion in the summer months at Leisure Lagoon. Mean enterococcus density (the magenta line in Figure 11-2) showed a strong peak in the spring of 1998. Since that time, the mean enterococcus density and the number of exceedances of AB411 criteria appear to be decreasing.

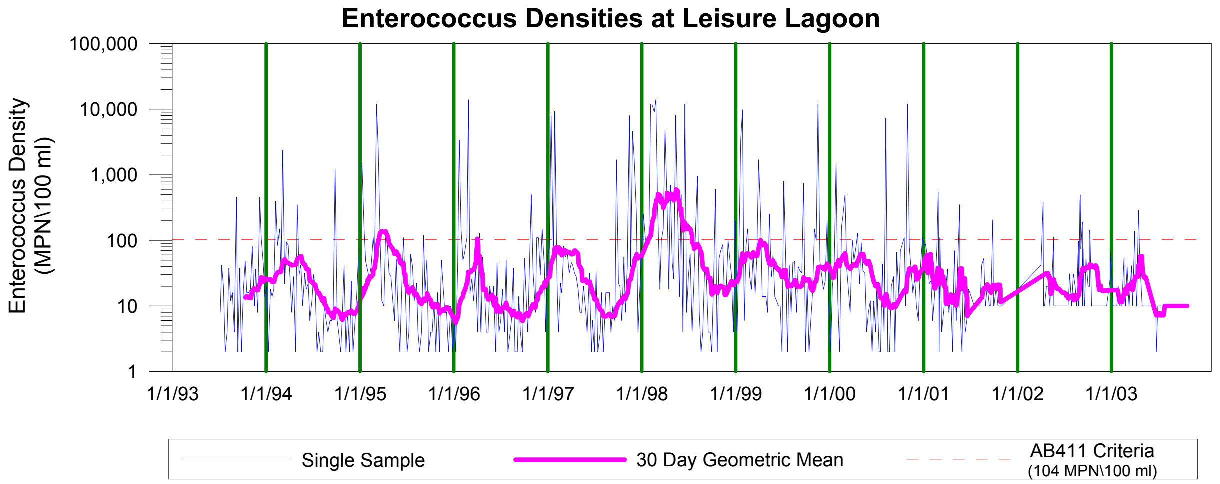


Figure 11-2. Enterococcus densities at Leisure Lagoon from 1993 through 2003. No data were available from January 2001 through March 2002 (source: San Diego County Department of Environmental Health).

Figure 11-2 includes data from samples collected from receiving water at Leisure Lagoon during the Visual Observations Task conducted in the summer of 2002 as well as samples collected during the Weekly Monitoring in the winter of 2002/2003. For the Visual Observations Task, samples were collected three times daily (morning, mid-day, evening) on nine days between August 25 and October 9, 2002. AB411 criteria were exceeded in site samples on four of the nine days of sampling. The highest densities for all three indicators were recorded over Labor Day weekend (3,000 MPN/100 ml for total and fecal coliform and 496 MPN/100 ml for enterococcus).

Bacterial Sources – Phase I

Sources of bacterial contamination to Leisure Lagoon were investigated under the Comfort Station Infrastructure Task (Task 1) and the Visual Observations Task (Task 3) developed for Phase I of the study. In Task 1, the infrastructure of the two comfort stations was inspected for structural integrity. In Task 3, the effects of comfort station washdown procedures, excessive irrigation practices, and storm drain infrastructure were investigated as potential sources of bacterial contamination to the bay at this site. Other potential sources of bacterial contamination that were suspected at Leisure Lagoon included fecal matter from birds, groundwater seepage, and the large number of swimmers, particularly on summer holidays. The complete reports for Tasks 1 and 3 are presented in Appendices B and D, respectively and summarized below.

Comfort Stations

There are two comfort stations that serve Leisure Lagoon. Comfort Station 1092 is located at the northeast end of Leisure Lagoon and Comfort Station 1093 is located on the southern end. During the Visual Observations Task, numerous observations documented that washdown runoff from the comfort stations was being swept out of the facility towards the bay. A total of eight samples were collected from the runoff generated during washdown procedures of both comfort stations. All of the samples exceeded AB411 criteria for at least one indicator and some had extremely high densities. The results are summarized in Table 11-1.

Comfort Station 1092 at Leisure Lagoon

Table 11-1. Bacteria results for samples collected from Leisure Lagoon Comfort Stations 1092 and 1093.

Parameter	Minimum Density (MPN/100 ml)	Maximum Density (MPN/100 ml)	Geometric Mean (MPN/100 ml)
Total Coliform	3,000	16,000,000	534,654
Fecal Coliform	80	5,000,000	63,046
Enterococcus	242	1,553,100	63,861

BMPs instituted by the City Park and Recreation Department in the fall of 2002 eliminated or greatly reduced this source of bacteria to the bay. During the weekly monitoring from November through March, there was only one observation of runoff generated by washdown procedures leaving the comfort stations at Leisure Lagoon (Comfort Station 1092 on December 3, 2002). Thus, this potentially substantial source of bacteria to Mission Bay was greatly reduced. The complete reports for Tasks 1 and 3 are presented in Appendices B and D, respectively.

The structural integrity of the comfort stations' lateral lines at Leisure Lagoon was inspected by closed circuit television as part of Task 1. These inspections were conducted on October 24, 2002. The results of the inspections showed that the lateral lines were in good condition and were an unlikely source of bacterial contamination to the receiving waters at this site. Appendix B provides a detailed description of these inspections.

Irrigation

Early morning irrigation at Leisure Lagoon

During the Visual Observations Task, excessive irrigation was observed to be a common problem at this site, particularly at the southern end of the site. Surface runoff from the grass to the receiving waters at Leisure Lagoon occurred regularly and there was also evidence of erosion associated with the runoff from irrigation practices. Steep slopes in this area likely contributed to the increased runoff. Similar to the Wildlife Refuge site, water collected from the sprinkler head at Leisure Lagoon had non detectable levels of all three indicator bacteria. However, bacterial densities in all of the samples taken from the grass and parking lot areas of the site exceeded AB411 criteria. Table 11-2 summarizes the results of samples collected from ponded water as a result of excessive irrigation. Compared to other sites around Mission Bay, irrigation runoff at Leisure Lagoon (either through sheet flow or through the park storm drains) may be a more important pathway for the conveyance of bacteria from the park to the bay.

Table 11-2. Summary of bacteria densities in samples collected from ponded water in grassy areas and paved surfaces due to excessive irrigation around Leisure Lagoon.

Parameter	Minimum Density (MPN/100 ml)	Maximum Density (MPN/100 ml)	Geometric Mean (MPN/100 ml)
Total Coliform	5,000	16,000,000	541,077
Fecal Coliform	1,300	16,000,000	126,023
Enterococcus	1,100	547,500	49,826

Storm Drains

Storm drain SD9-2 at Leisure Lagoon

Storm drains were identified as a potential source of bacteria to Leisure Lagoon and an important mechanism for the transport of excess irrigation to the receiving waters. Two storm drains discharge directly to Leisure Lagoon: storm drain SD9-1 on the northeastern end of the site and storm drain SD9-2 on the eastern shore (Figure 11-1). A third storm drain discharges into North Pacific Passage approximately 700 feet south of the entrance to Leisure Lagoon, draining the western parking lot of the site. Inspections of these storm drains and their drainage areas were conducted in the spring of 2003. All three of the storm drains are un-diverted (i.e., they are not part of the MBSIS) and they drain small areas within the park. Five samples of dry weather discharge were collected from storm drain SD9-1 during the Visual Observations Task. The source of the discharge was excess irrigation water from the grassy area that surrounds the storm drain inlet. The results are summarized in Table 11-3.

Table 11-3. Summary of bacterial densities in samples collected from storm drains discharging dry weather flow to Leisure Lagoon.

Parameter	Minimum Density (MPN/100 ml)	Maximum Density (MPN/100 ml)	Geometric Mean (MPN/100 ml)
Total Coliform	20	500,000	1,942
Fecal Coliform	Non Detect	11,000	311
Enterococcus	31	68,670	684

Bacterial Sources – Phase II

Leisure Lagoon was assessed as part of all three of the investigative tasks implemented in Phase II of the study. The complete results of each Task are presented in Appendices E, F, and G and summarized for Leisure Lagoon below.

Bacterial Host Origin

A total of 98 bacterial isolates were obtained from storm drain effluent samples at Leisure Lagoon. The majority of the isolates (58%) originated from birds (Figure 11-3A). Other mammalian sources, which consisted primarily of rodent isolates, accounted for 22% of the storm drain Ribotype matches. Canine Ribotypes accounted for 16% of the storm drain-derived Ribotypes.

In samples collected in the receiving water at Leisure Lagoon, the majority of isolates also originated from Avian (45%) and Canine (16%) sources (Figure 11-3B). Most interesting, however, was an unusually large group (29%) of receiving water Ribotypes for which no host animal matches could be found in the Institute for Environmental Health’s Source Ribotype Library Database. Ribotypes from bacterial isolates of human origin accounted for only 5% of the receiving water Ribotypes.

Finally, we asked whether any of the Leisure Lagoon receiving water-derived Ribotypes could be matched to those obtained from storm drain effluent (Figure 11-3C). We found that 27% of the receiving water Ribotypes could be traced to Ribotypes found in the storm drain effluent samples. Nearly all of these isolates originated from birds.

Dry Season Ribotyping Results at Leisure Lagoon

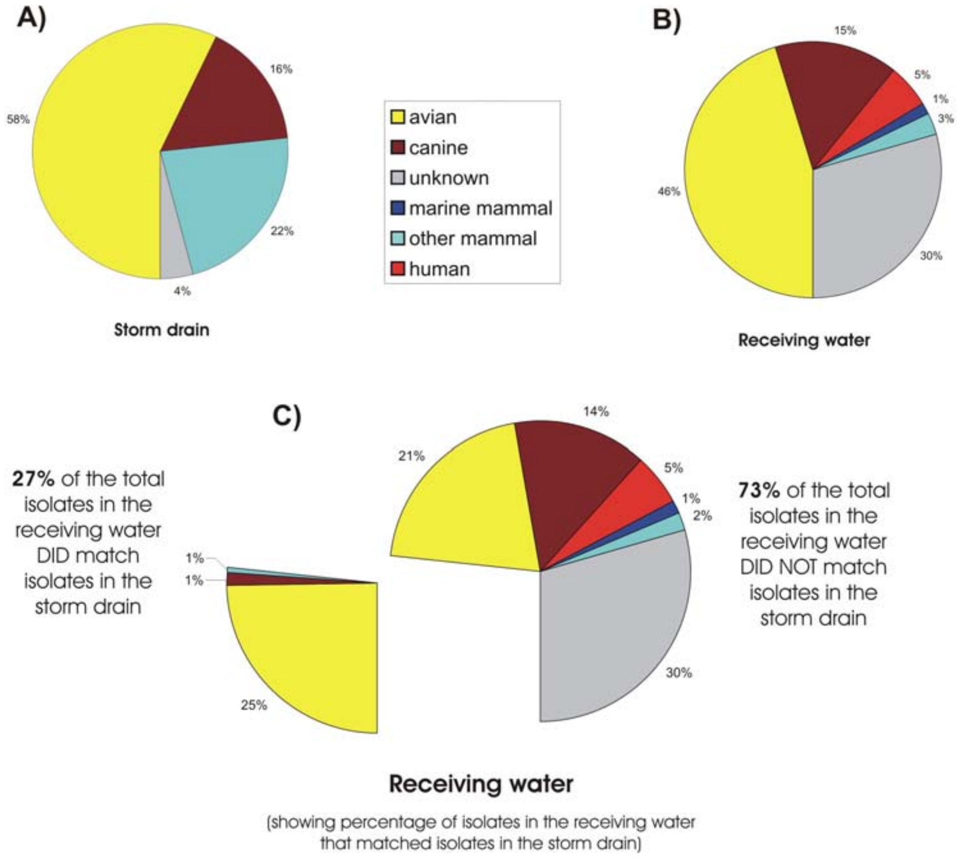


Figure 11-3. Results of Ribotyping analysis at Leisure Lagoon. The pie charts show the origin of bacterial isolates in storm drain SD9-2 (A), receiving water (B), and the proportion of isolates in receiving water that matched those in storm drain (C).

HS-PCR analysis was completed on receiving water and storm drain samples taken at Leisure Lagoon. A total of 15 out of 32 receiving water and 6 out of 8 storm drain samples were positive for the General *Bacteroides* marker. Interestingly, 6 of 32 receiving water samples (19%) were positive for the Human marker, which is greater than any other site sampled. None of the storm drain samples analyzed were positive for the Human marker.

The results of the Microbial Source Tracking Task suggest that, as with other sites investigated in Mission Bay, the birds are the primary source of enteric bacteria in the receiving waters and the storm drain effluent at Leisure Lagoon. The small percentage of Ribotypes from human sources (5%) suggests that there is little input of enteric bacteria to this site from swimmers. However, this site also had the highest percentage of Ribotypes from Unknown origin of any of the sites investigated (30%). The Human Ribotype in the Ribotype Database is more difficult to match than other Ribotypes because of the limited number of contributions from individual humans. Thus, it is possible that the high percentage of Unknown Ribotypes at this site is due to the presence of human enteric bacteria that did not match Ribotypes in the database. This would be supported by the high percentage of HS-PCR samples that tested positive for the Human marker. In addition, the sampling at Leisure Lagoon targeted heavy use weekends when numerous swimmers were in the water. There was no evidence of leaking sewer lines at this site and groundwater samples contained virtually no indicator bacteria.

Fate and Transport

At the end of Phase I, the high levels of indicator bacteria found in the grassy areas of Mission Bay Park combined with the excessive irrigation and groundwater springs observed at Leisure Lagoon suggested that bacteria may be conveyed from the grass to the receiving waters via groundwater transport. This potential mechanism was assessed at Leisure Lagoon in the Fate and Transport Study conducted at this site in March, 2004. In this study, samples were collected from soil cores and groundwater wells in the park, and groundwater springs on the beach face at Leisure Lagoon. The complete results of the study are presented in Appendix F and summarized in Table 11-4.

Full view and close up images of soil cores showing strata

Table 11-4. Summary of bacterial densities in samples collected during the Fate and Transport Study at Leisure Lagoon. Densities are in units of MPN/100 ml for water samples and MPN/100 dry gram for soil samples.

Sample Type	Minimum Density	Maximum Density	Geometric Mean	Minimum Density	Maximum Density	Geometric Mean
	Fecal Coliform			Enterococcus		
Soil cores from park	<1	59,700	8.6	<1	9,000	84
Groundwater from park wells	< 20	20	< 20	< 10	< 10	< 10
Groundwater from beach spring	< 20	20	< 20	< 10	< 10	< 10

The results of the study revealed that the grassy areas of Leisure Lagoon, as well as other locations in Mission Bay Park, contain a large reservoir of both fecal coliform and enterococcus bacteria. The origin of the bacteria was determined to be avian (see Appendix G). However, an analysis of bacterial density with depth from the soil core samples indicated that the migration of bacteria from the park surface to the groundwater is limited to the upper 18 inches of soil by layers of clay and other fine-grained material. Virtually no indicator bacteria were found in the groundwater wells or the beach face springs at Leisure Lagoon or the other sites investigated in the fate and transport study. In addition, none of the samples collected from groundwater at the beach face springs during the Microbial Source Tracking Task at Leisure Lagoon contained indictor bacteria. These results indicate that the grassy area of Leisure Lagoon and the soil directly beneath it contains a large reservoir of indicator bacteria, but the bacteria is not transported to the receiving waters of Mission Bay via groundwater seepage through the beach.

Intertidal Sediments

At Leisure Lagoon, intertidal sediments were assessed to determine the extent to which they may contribute to elevated bacterial densities in the receiving water. As with Bonita Cove, two types of assessments were conducted: a survey of bacterial densities in beach sediments within the intertidal zone and a sediment resuspension study. For the intertidal sediment study, samples of beach sand were collected at different tidal heights from five transects and analyzed for indicator bacteria. The study was conducted on April 29, 2004. The results are presented in detail in Appendix G and summarized below.

At Leisure Lagoon, bacterial densities in intertidal sediments were similar to those found at Bonita Cove. Fecal coliform geometric mean densities in intertidal sediments at Leisure Lagoon ranged from 10.8 to 2.9 MPN/g, and enterococcus geometric mean densities ranged from 5.0 to 10.6 MPN/g. In contrast to Bonita Cove, there were no significant differences for either bacterial indicator between mean sediment densities by tidal height. However, samples taken at Transect C at tidal heights of +2, +1, and 0 feet above MLLW contained bacterial densities that were one to two orders of magnitude greater than samples collected from other transects at the same tidal height. Transect C was located adjacent to storm drain SD9-2 in Leisure Lagoon. The terminus of this storm drain is located at a tidal height of approximately +2 feet above MLLW. Thus, sediment samples collected at tidal heights of 0, +1, and +2 feet above MLLW at Transect C were directly in front of the discharge point of the storm drain outfall, which apparently greatly influenced bacterial densities. The values for these three samples were removed from the data set, and the data were re-plotted, as shown in Figure 11-4. With the storm drain influenced samples removed, it is apparent that the bacterial densities in the upper intertidal sediments at Leisure Lagoon (+6, +5, and +4 feet above MLLW) are greater than those in the lower Intertidal sediments (+2, +1, and 0 feet above MLLW). When data from the upper intertidal sediments were pooled and compared to those in the lower intertidal sediments (without the samples collected in front of the storm drain outfall), there was a significant difference between the two means for both fecal coliform (p = 0.0043) and enterococcus (p = 0.0028).

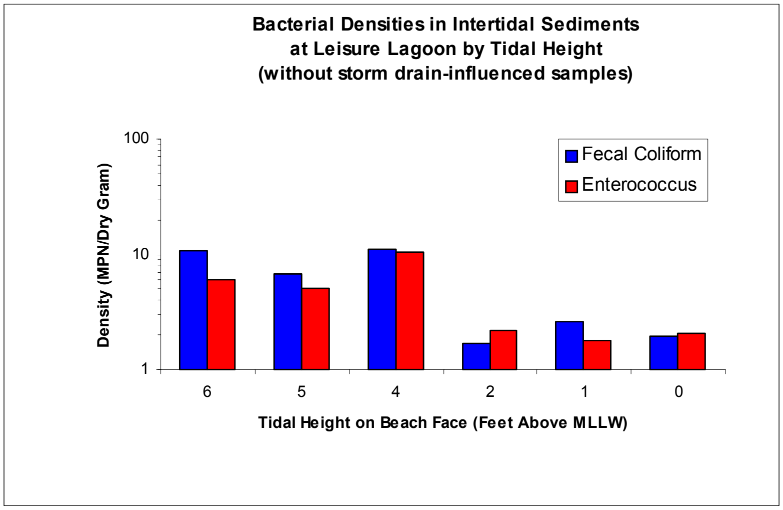


Figure 11-4. Fecal coliform and enterococcus densities in intertidal sediments at Leisure Lagoon by tidal height with storm drain-influenced samples removed. Bars represent the geometric means of 4 to 5 samples.

The second study assessing intertidal sediments was designed to compare bacterial densities before and after sediments were resuspended in the water column. Samples were taken from 15 stations at Leisure Lagoon centered around the AB411 monitoring site. Two receiving water samples were taken sequentially at each station: 1) a clear water sample, in the absence of suspended sediment; and 2) a resuspended sediment sample, taken after the sediments had been disturbed and kicked up into the water column by the sampler (simulating swimmer activity). Samples were collected in the same way as samples collected for regulatory purposes.

The sediment resuspension study was conducted at Leisure Lagoon during a high tide in April 2004. Mean fecal coliform density for resuspended sediment samples (574 MPN/100 ml) was an order of magnitude greater than the mean of clear water samples (21.9 MPN/100 ml). The difference was statistically significant (p < 0.0001). The pattern for enterococcus was similar to that of fecal coliforms. The mean enterococcus density of resuspended sediment samples (384 MPN/100 ml) was significantly greater than the mean of clear water samples (7.9 MPN/100 ml) (p = < 0.0001). Graphical representations of the data (Figure 11-5) clearly demonstrate the difference in bacterial densities in clear water verses water containing resuspended sediment.

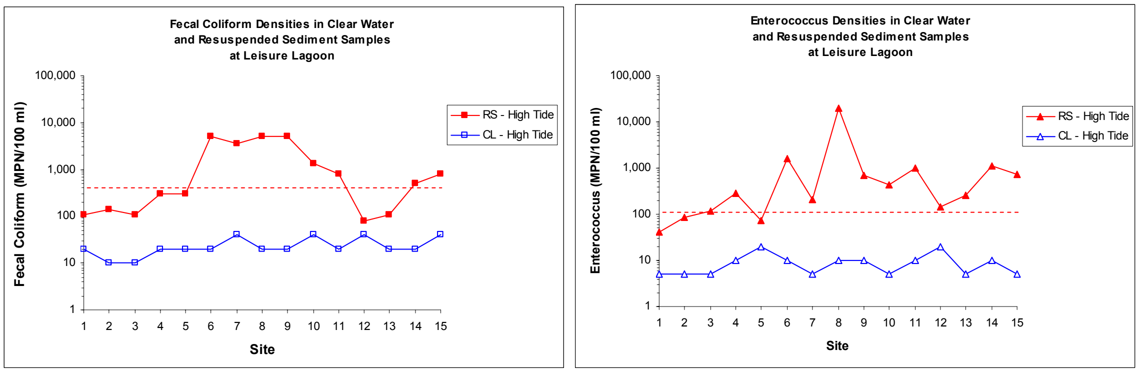


Figure 11-5. Fecal coliform and enterococcus densities in receiving water at Leisure Lagoon. CL refers to clear water samples and RS refers to samples taken after sediment re-suspension. The dashed red lines represent the AB411 standards of 400 MPN/100 ml for fecal coliform and 104 MPN/100 ml for enterococcus.

Similar to Bonita Cove, the results of the sediment resuspension study at Leisure Lagoon clearly indicate that the sediments in the upper intertidal zone act as a reservoir for indicator bacteria. If the sediments are left undisturbed, then the bacteria sorbed to them do not tend to make their way into the water column. However, when these sediments are disturbed and resuspended in the water column, as a result of swimming activity for instance, then bacterial densities in the water column can increase dramatically. Sediments directly in front of storm drain SD9-2 contained the highest densities of indicator bacteria in this study. This is most likely a result of the storm drain effluent originating from irrigation runoff that discharges to this area.

Conclusions

Leisure Lagoon is a semi-enclosed area in Mission Bay with limited tidal circulation. The beach is typically free of organic debris and the bird population fluctuates seasonally. The results of the Phase I investigations at Leisure Lagoon indicate that the comfort station infrastructure is not a source of bacteria to the receiving waters and runoff from comfort station washdown has been eliminated through BMPs instituted by the City Park and Recreation Department. The potential sources of indictor bacteria that were identified at Leisure Lagoon during Phase I included birds, storm drain effluent, irrigation runoff, and possibly the large number of swimmers during the summer months. The County AB411 monitoring site at Leisure Lagoon is located directly in front of the un-diverted storm drain SD9-2. Although the drainage area of the storm drain is small (it encompasses a parking lot and grassy areas of the Park), effluent from the storm drain contained very high densities of indicator bacteria. The most likely source of the high bacterial concentrations from the storm drain is runoff from the grassy areas of the Park during irrigation. This area of the Park is typically heavily irrigated during the summer, from July to late September. Excessive watering appeared to be somewhat problematic at this site, particularly at the south end, and surface runoff to the bay was common during irrigation in the summer. The overall results of the study at Leisure Lagoon are summarized in Table 11-5.

Table 11-5. Sources of indicator bacteria at Leisure Lagoon. A green N indicates potential sources that are no longer thought to be present or were remediated as part of the study. A red Y indicates potential sources that remain at this site.

Site #	Site Name	Illicit Boat Discharge	Restroom Infrastructure	Birds and Other Wildlife	Irrigation Runoff	Storm Drains	Restroom Washdown	Homeless	Dog Waste	RV Pump Outs	Creek Drainage	Groundwater	Delta Sediment	Intertidal Sediment	Wrack	Other
9	**Leisure Lagoon**	N	N	Y	Y	Y	N	N	N	N	N	N	N	Y	N	N

The results of Phase I of the study were used to design Phase II at Leisure Lagoon, which included investigations on microbial source tracking, bacterial fate and transport, and intertidal sediments. Several conclusions can be drawn from the results of these investigations: 1) the majority of the enteric bacteria in the receiving waters, intertidal sediments, storm drains, and grassy areas of the park at Leisure Lagoon originate from birds; 2) the grassy area of the park and soil directly beneath it contain a large reservoir of indicator bacteria, but the bacteria is not transported to the bay via groundwater; 3) excessive irrigation and subsequent runoff does convey bacteria to the receiving waters via storm drains, particularly storm drain SD9-2; and 4) beach sediments in the upper intertidal zone act as a reservoir for indicator bacteria that is released to the receiving water when the sediments are disturbed.


Storm drain SD9-2 at Leisure Lagoon

SECTION 12

North Pacific Passage

Site Overview

North Pacific Passage is located on the eastern side of Mission Bay directly west of the Hilton Hotel property. The sampling site is located on a small stretch of very well-maintained beach north of the Hilton Hotel boat dock (Figure 12-1). Many park visitors use the boardwalk bordering the beach, but in general, beach usage (i.e., swimming and sunbathing) is relatively low at this site throughout the year. There is no irrigation conducted at this site, and no major creek drainages that discharge to the immediate area. However, there are three storm drains that discharge to the beach at North Pacific Passage. Storm drains SD10-1 and SD10-2 drain small areas within the Hilton Hotel complex. The AB411 monitoring site is located directly in front of these storm drains. Storm drain SD10-3 is located just south of the Hilton Hotel and is part of the MBSIS. In addition, there is one comfort station at this site located south of storm drain SD10-3.

Figure 12-1. Aerial photograph of North Pacific Passage.

Temporal Trends

Similar to other sites located on the east side of Mission Bay, seasonal trends of indicator bacterial densities are apparent at North Pacific Passage (Figure 12-2). From 1994 to 2000 the enterococcus levels tended to peak in the winter months and were low during summer. The graph also shows that the number of exceedances of AB411 criteria for enterococcus have decreased in recent years at North Pacific Passage. Since October, 2002 there have been no exceedances of AB411 criteria for enterococcus at this site.

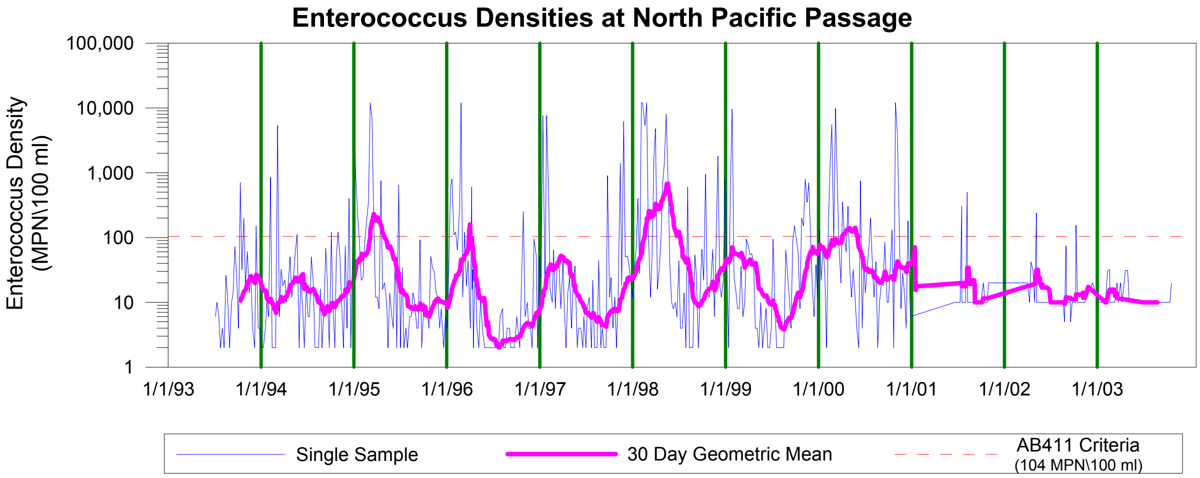


Figure 12-2. Enterococcus densities at North Pacific Passage from 1993 through 2003. No data were available from January through April 2001, nor from November 2001 through March 2002 (source: San Diego County Department of Environmental Health).

Figure 12-2 includes samples collected from the receiving water at North Pacific Passage during the Visual Observations Task conducted in the summer of 2002 as well as samples collected during the Weekly Monitoring in the winter of 2002/2003. During the Visual Observations Task, samples were collected three times daily (morning, mid-day, evening) on nine days between August 25 and October 9, 2002. At North Pacific Passage, approximately 85% of the samples collected had bacterial densities at or below the detection limits for all three indicator bacteria. With the exception of one exceedance of enterococcus (155 MPN/100 ml), the remaining samples had low bacterial indicator densities.

Bacterial Sources – Phase I

Sources of bacterial contamination to receiving waters of North Pacific Passage were investigated during Phase I of this study. The comfort station infrastructure was examined as part of Task 1 (Comfort Station Investigations). Other potential sources, such as excessive irrigation, storm drains, and drainage from a koi pond on the Hilton Hotel property were investigated in Phase I follow-up studies.

Comfort Stations

There is one comfort station that serves the area around North Pacific Passage. Comfort Station 1094 is located approximately 1,000 ft south of the Hilton Hotel. The lateral lines serving this station were examined on October 31, 2002 and found to be in good condition. In addition, there were no observations of runoff from improper comfort station washdown procedures at this site. Thus, the comfort station does not appear to be a source of bacteria to the receiving waters of Mission Bay.

Irrigation

Ponded water on grassy areas and adjacent paved surfaces resulting from excessive irrigation practices were sampled at Riviera Shores as part of the Visual Observations Task. Analyses of these samples showed very high levels of all three indicator bacteria (Table 12-1). Indicator bacteria were not detected in one sample taken directly from the sprinkler flow. These results suggested that the grassy areas at this site act as a reservoir for bacteria that may be transported to the receiving waters of Mission Bay, which is similar to observations made at other sites.

Table 12-1. Bacteria results for samples collected from ponded water around the North Pacific Passage site.

Parameter	Minimum Density (MPN/100 ml)	Maximum Density (MPN/100 ml)	Geometric Mean (MPN/100 ml)
Total Coliform	30,000	3,000,000	240,868
Fecal Coliform	230	110,000	6,392
Enterococcus	957	116,900	12,132

Storm Drains

Three storm drains discharge to the North Pacific Passage site (Figure 12-1). Storm drains SD10-1 and SD10-2 have a small drainage within the Hilton Hotel property and both samples collected during the Visual Observations Task exceeded AB411 criteria. Storm drain SD10-3, located south of the hotel property, was only sampled once and had bacterial densities that were one to two orders of magnitude greater than those measured at SD10-1 and S10-2 (130,000 MPN/100 ml for total coliform, 35,000 MPN/100 ml for fecal coliform, and 14,390 MPN/100 ml for enterococcus). Although the bacterial densities were high, flow from all three storm drains at the time of sampling was very low, suggesting that the magnitude of the bacterial load was small.

The outlets to storm drains SD10-1 and SD10-2 were submerged during most days of the Visual Observations Task, so estimates of flow were minimal. However, they drain a small area within the Hilton Hotel complex and do not appear to convey high loads of indicator bacteria to the bay. Storm drain SD10-3 conveys water from a fairly large drainage within Mission Bay Park. This storm drain is part of the MBSIS and dry weather flow is diverted just south of the Hilton Hotel, approximately 50 feet from the beach. The diversion structure was inspected in the spring of 2003. It was found to be well-maintained and functioning properly in diverting dry weather flows to the sewer system. A complete report of the inspection is provided in Appendix I. Based on these observations, the storm drains at North Pacific Passage, when properly maintained, do not appear to contribute large loads of bacteria to the receiving waters at this site.

Other – Koi Pond Drainage

The majority of the samples collected as part of the Visual Observations Task at this site were from four 6-inch PVC pipes that discharged under the Hilton Hotel boat dock (Figure 12-1). Nearly 70% of the samples collected from these drains exceeded the AB411 criteria for at least one indicator bacteria. Table 12-2 summarizes the results.

Table 12-2. Bacteria results for samples collected from drainage pipes below the Hilton Hotel's boat dock.

Parameter	Minimum Density (MPN/100 ml)	Maximum Density (MPN/100 ml)	Geometric Mean (MPN/100 ml)
Total Coliform	80	9,000,000	4,138
Fecal Coliform	10	50,000	103
Enterococcus	5	290,900	250

A follow-up study was conducted on October 31, 2002 to investigate the source(s) of bacteria discharging from these pipes. Working with the Hilton Hotel's Director of Property Operations, the probable source of the high bacterial counts was traced to a koi pond located near the Hotel's swimming pool. An inspection found that water in the pond had not been properly aerated and sediment and debris had accumulated on the bottom. Pond water was flowing continually from the pond through an overflow drain to a drain box and then directly to the bay receiving waters. The complete results from the follow-up study are presented in Appendix K.

Sampling drain pipes under the Hilton Hotel boat dock

Koi pond at Hilton Hotel

As part of the follow-up study, water samples were collected from the koi pond, drain box, and discharge point for bacterial analyses. The results indicated that levels of all three indicator bacteria were very low in the sample taken from the surface of the koi pond near the drain pipe (Table 12-3). However, very high levels of total coliform (1,300,000 MPN/100 ml) and enterococcus (143,000 MPN/100 ml) were measured in the sample taken from the koi pond drain box, which contained a large amount of debris and organic matter. In addition, the pipe leading from the koi pond to the box was flowing at the time the sample was taken and it was covered with a heavy biofilm. These results reflected the resiliency of the indicator bacteria, particularly enterococcus, to survive in biofilms and drainage systems that are kept continually moist. Similar results were found at a drain pipe at Campland used for boat and vehicle cleaning and in other studies investigating environmental sources of bacteria to recreational waters (Jiang et al. 2001, Solo-Gabriele et al. 2000).

Table 12-3. Bacterial results from Hilton Hotel koi pond follow-up study.

Sample Location	Total Coliform	Fecal Coliform	Enterococcus
Koi pond	170	170	20
Drain box	1,300,000	700	143,000
Beach pipe	1,300	700	63

Maintenance was conducted and BMPs were initiated to properly maintain the koi pond and eliminate discharge from the pond to the bay. During the weekly monitoring conducted from November 2002 through March, 2003, there were no observations of water flowing from any of the pipes at this site. In addition, from November 2002, when the koi pond discharge was eliminated, through October 2003, there have been no exceedances of AB411 criteria at this site (see Figure 12-2 for a graph of the enterococcus data). Thus, the maintenance activities appear to have been effective in eliminating this source of bacteria to the bay.

Bacterial Sources – Phase II

North Pacific Passage was not assessed as part of Phase II, but the mechanisms of bacterial transport and amplification identified at other sites in Phase II are unlikely to have a major influence on bacterial densities at this site.

Conclusions

There were relatively few potential bacterial sources identified in Phase I at North Pacific Passage. The AB411 monitoring site is located in front of two storm drains that drain a portion of the Hilton Hotel property. However, the drainage area is small and flow was minimal during all of the observations of Task 3. There are no grassy areas near the site and the bird population is small. There is one comfort station at North Pacific Passage at the far south end of the site. The lateral line of the comfort station was inspected and found to be in good shape and effluent from restroom washdown was not found to be a problem during the Visual Observations Task. In addition, this site is very well-maintained by the Hilton Hotel staff. A wrack line does not typically persist and bird feces does not tend to accumulate on the beach, suggesting that resuspended intertidal sediments are also an unlikely source of bacteria to the receiving waters. A summary of the bacterial sources identified at this site is presented in Table 12-4.

Table 12-4. Sources of indicator bacteria at North Pacific Passage. A green N indicates potential sources that are no longer thought to be present or were remediated as part of the study. A red Y indicates potential sources that remain at this site.

Site #	Site Name	Illicit Boat Discharge	Restroom Infrastructure	Birds and Other Wildlife	Irrigation Runoff	Storm Drains	Restroom Wash down	Homeless	Dog Waste	RV Pump Outs	Creek Drainage	Groundwater	Delta Sediment	Intertidal Sediment	Wrack	Other
10	North Pacific Passage	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N


Koi pond drainage pipes at North Pacific Passage

The one bacterial source that was identified during the Visual Observations Task was four 6-inch PVC pipes located at the Hilton Hotel boat dock, approximately 100 feet south of theAB411 monitoring site. One or more of the pipes were flowing during nearly all of the observations of Task 3 and densities of indicator bacteria in the effluent were frequently elevated. A follow-up study conducted by the City and subsequent remediation actions taken by the Hotel management eliminated the source of bacteria to the bay.

Based on the results of the bacterial source tracking analyses conducted at other sites in Mission Bay, the bacteria that is present in the receiving waters at North Pacific Passage likely originates from birds.

SECTION 13

Tecolote Creek

Site Overview

Figure 13-1. Aerial photograph of Tecolote Creek.

Tecolote Creek is one of two large freshwater drainages to Mission Bay. The creek is located on the southeastern side of the bay and it drains a large watershed that includes Tecolote Canyon and urban communities such as Linda Vista and Clairemont. The mouth of the creek terminates in a shallow basin approximately 300 feet wide by 600 feet long (Figure 13-1). Water entering Mission Bay from Tecolote Creek is connected to the rest of the bay via a relatively narrow passage on the bay's east side. Water circulation in this area is minimal. Tecolote Creek is part of the MBSIS. Dry weather flows are diverted to the sewer system just east of Morena Boulevard, approximately one half mile from the mouth. There are two other storm drains in the area, but they are connected to a soft bottom swail just west of Interstate 5 and do not impact the bay's receiving waters except during large storm events.

There are two AB411 monitoring sites at Tecolote Creek. One is located at the mouth near the East Mission Bay Drive bridge (called Tecolote Creek) and the other is located on the beach directly in front of the comfort station (called Tecolote Playground). The site at the mouth of the Tecolote Creek was monitored by the County and for this study during Phase I. However, in the spring of 2003 the County discontinued this monitoring site and began monitoring the Tecolote Playground site because a greater number of swimmers use this area.

Temporal Trends

A review of the historical data for Tecolote Creek suggests that there are pronounced seasonal trends in densities of enterococcus at this site (Figure 13-2). Enterococcus densities tend to be low during the dry season (May through October), begin to rise in November or December and peak during the spring. Because the Tecolote Playground site is located adjacent to the mouth of Tecolote Creek, the most likely explanation for this trend is the increased flows from the creek during the wet season, which deliver higher bacterial loads to the area. The bird population also increases dramatically in this area of Mission Bay during the winter months (Kisner 2000).

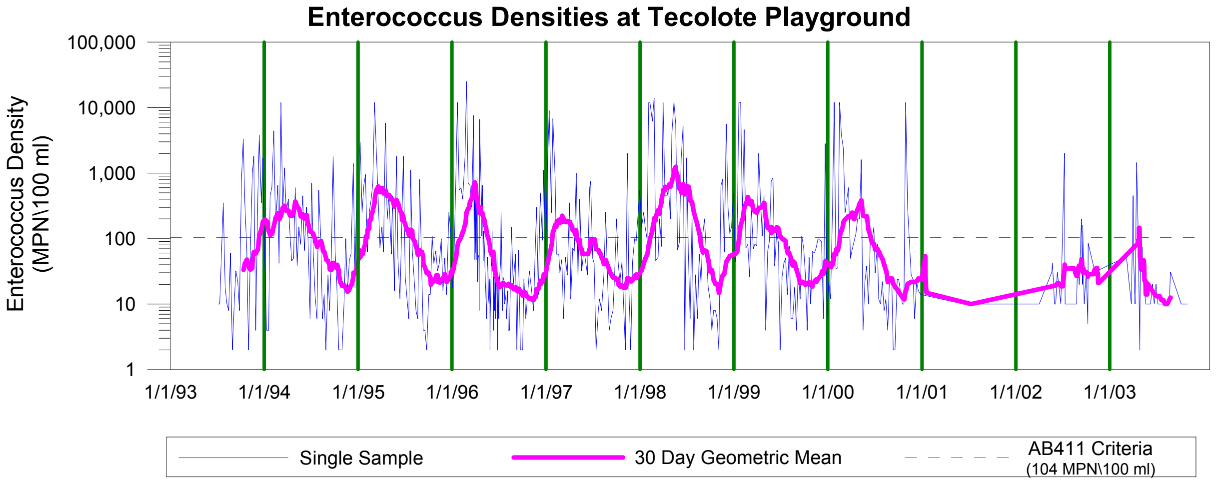


Figure 13-2. Enterococcus densities at Tecolote Playground from 1993 through 2003. No data were available from January 2001 through March 2002 (source: San Diego County Department of Environmental Health).

Results from receiving water samples collected at Tecolote Creek during the Visual Observations Task are not graphed in Figure 13-2 because sampling at that time took place at the mouth of Tecolote Creek. Samples were collected three times daily (morning, mid-day, evening) on nine days between August 25 and October 9, 2002 as part of the Visual Observations Task. In general, these samples had low indicator bacterial densities throughout the study period. AB411 criteria were exceeded on September 13 for total coliform and enterococcus and on September 18 for all three indicators.

Bacterial Sources – Phase I

Sources of bacterial contamination to the area around Tecolote Creek were investigated as part of Task 1 (Comfort Station Infrastructure) and Task 3 (Visual Observations). Potential sources that were initially identified included creek drainage, the comfort station, excessive irrigation practices, birds and other wildlife (including feral pets) and the homeless population. There are no storm drains that impact the receiving waters at Tecolote Creek. The complete reports for Tasks 1 and 3 are presented in Appendices B and D, respectively. The results for each of these studies at Tecolote Creek are summarized below.

Comfort Stations

There is one comfort station that serves the area at Tecolote Creek. Comfort Station 1406 is located approximately 200 feet away from the AB411 monitoring site at Tecolote Playground. This comfort station was inspected on October 3, 2002 with closed circuit television. The lateral lines were documented to be in sound structural condition. In addition, there were no observations of runoff being generated from washdown procedures at this comfort station. Thus, it was determined that Comfort Station 1406 is not a source of bacteria to the receiving waters of Mission Bay.

Irrigation

During the Visual Observations Task, it was observed that excessive irrigation resulted in ponded water in the grassy areas and on paved surfaces around the Tecolote Creek site. Elevated levels of all three bacterial indicators were measured in five samples taken from ponded water in the grass at this site (Table 13-1). As with other sites, bacteria levels in samples taken directly from the sprinklers were very low. However, there was no evidence of bank erosion at this site, so surface flow of irrigation water in the park to receiving waters is unlikely. In addition, there are no storm drains that discharge to the immediate area that could carry bacteria from the grass to the receiving waters and groundwater transport is thought to be minimal in Mission Bay. These observations suggest that the bacteria in the grass at the Tecolote Creek site likely do not impact the receiving waters.

Table 13-1. Indicator bacteria densities for samples collected from ponded water on grassy areas and paved surfaces adjacent to the Tecolote Creek site.

Parameter	Minimum Density (MPN/100 ml)	Maximum Density (MPN/100 ml)	Geometric Mean (MPN/100 ml)
Total Coliform	3,000	16,000,000	202,819
Fecal Coliform	3,000	80,000	14,366
Enterococcus	882	65,000	10,449

Storm Drains

There are no storm drains that discharge to the Tecolote Creek site. It should be noted, however, that Tecolote Creek itself is part of the MBSIS. A detailed discussion of the diversion system for Tecolote Creek is provided in Appendix I.

Other – Homeless Population

Homeless encampment on Tecolote Creek approximately 20 feet from the Tecolote Creek monitoring site

During the Visual Observations Task, homeless people were frequently observed under the Interstate 5 bridge, adjacent to and immediately east of the mouth of Tecolote Creek. Because the AB411 monitoring site was located just downstream of that area during the study, fecal contamination from the homeless population was thought to be more likely here than at other sites. However, samples collected from the delta sediments and receiving water at the mouth of Tecolote Creek during the Sediment Investigation Task of Phase II indicate that there is virtually no bacteria in this area from human origin. The results are discussed in detail in Appendix G and summarized below.

Bacterial Sources – Phase II

Delta Sediments

The results of Phase I revealed no obvious source of bacteria at the Tecolote Creek site except the flow from Tecolote Creek itself. In Phase II of this study, Tecolote Creek was investigated as part of the Sediment Investigation Task to determine the extent to which bacteria deposited at the mouth of Tecolote Creek impacted the receiving waters at the adjacent beach (the complete report is presented in Appendix G).

Two surveys were conducted: one at the end of the dry season (October, 2003) and one during the middle of the wet season (January, 2004). Sediments were collected by boat at the surface and from a depth of four inches. During the dry season survey, sediments at the mouth of Tecolote Creek (i.e., the creek delta) contained very low levels of indicator bacteria (Table 13-2). No fecal coliform bacteria were found and enterococcus was either not present or found in very low densities. These results suggest that the delta sediments during the dry season are not a source of bacteria to the AB411 receiving water monitoring site. During the wet season survey, after several storms had impacted the area, the sediment conditions at the mouth of Tecolote Creek had changed. A layer of fine-grained sediment had been deposited on the surface of the creek delta and bacterial densities were much higher than those observed during the dry season survey.

Table 13-2. Indicator bacteria densities for samples collected from sediments at the mouth of Tecolote Creek. All values are presented as MPN/gram dry weight.

Indicator	Strata	Minimum Density	Maximum Density	Geometric Mean	Minimum Density	Maximum Density	Geometric Mean
		Dry Season Survey (10/24/03)			Wet Season Survey (1/14/04)		
Fecal Coliform	Surface	<1	<1	<1	6	420	20
	Depth	<1	<1	<1	<1	<1	<1
Enterococcus	Surface	<1	1	0.55	8	712	62
	Depth	<1	3	1.1	<1	3	0.95

To determine the host origin of bacteria at Tecolote Creek and to assess the extent to which the sediments act as a bacterial source to the receiving waters, the DNA fingerprints (or Ribotypes) of *E. coli* bacteria in the sediment were compared to those collected in the receiving water using the Ribotyping technique. This comparison was conducted only during the wet season survey since *E. coli* bacteria, a member of the fecal coliform group, were not found during the dry season survey. Samples were collected from the receiving water during the largest tides of the year (January 20 and 21, 2004) when current velocities were maximal. In addition, the samples were collected during an ebbing tide when bacteria in the delta were most likely to be transported to the adjacent receiving water monitoring site. The results of the Ribotyping analysis of the receiving water samples are presented graphically in Figure 13-3.

Wet Season Ribotyping Results at Tecolote Creek

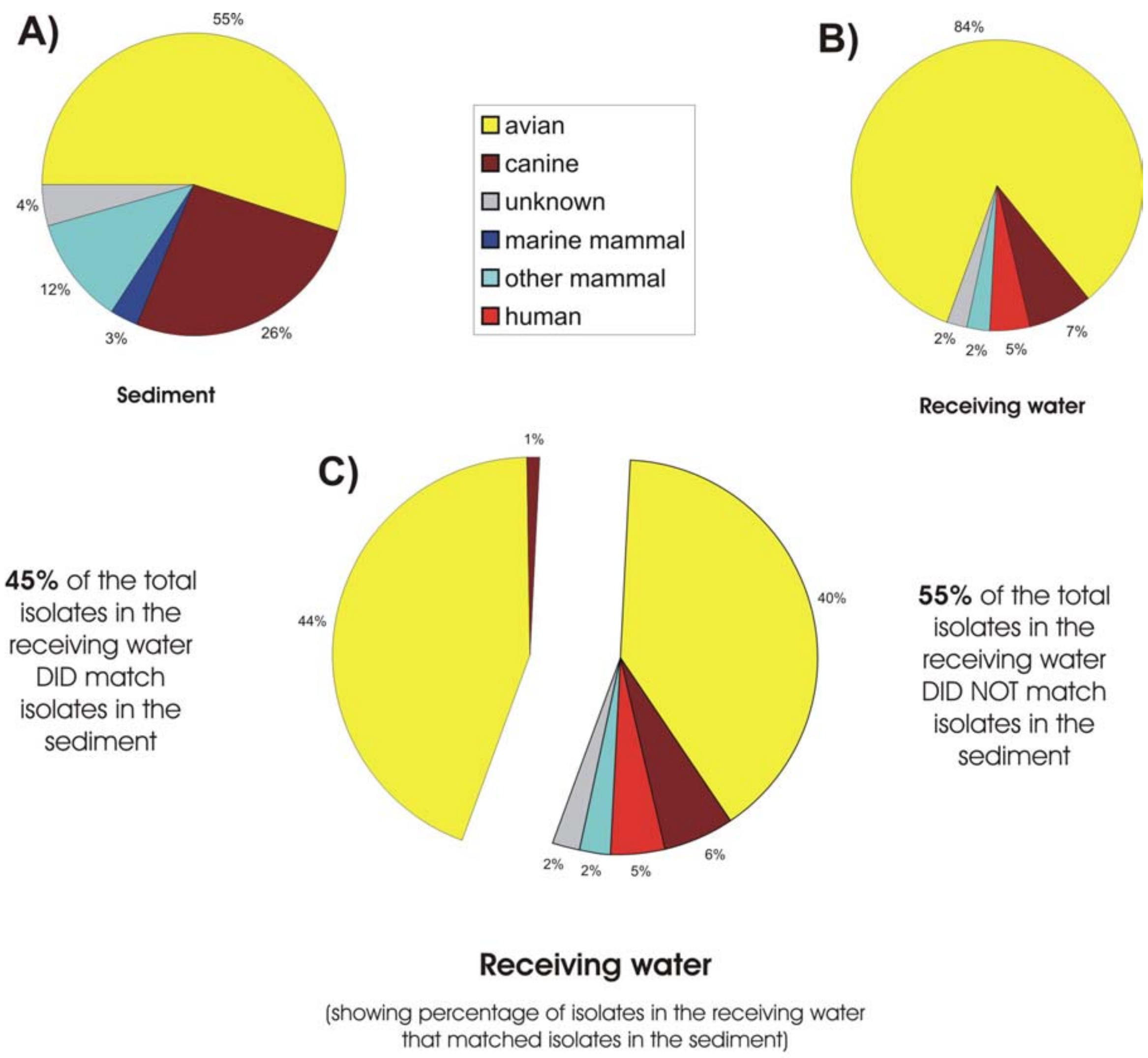


Figure 13-3. Results of Ribotyping analysis at Tecolote Creek during the wet weather survey. The pie charts show the origin of bacterial isolates in delta sediments (A), receiving water (B), and the proportion of isolates in receiving water that matched those in sediment (C).

The results of the Ribotyping analysis (Figure 13-3) show that a majority (55%) of the bacterial isolates collected in the delta sediments at Tecolote Creek originate from Avian and, to a lesser extent, Canine sources (26%) (Figure 13-3A). In samples collected from the receiving water (Figure 13-3B), a much larger proportion of the isolates originated from birds (84%). Interestingly, nearly half (45%) of the Ribotypes of bacteria collected in the receiving water matched those found in the sediment (Figure 13-3C).

These results suggest that a large proportion of the *E. coli* bacteria found in the receiving waters are also found in the delta sediments. However, sediments can only impact the receiving waters if they are lifted from the delta at the mouth of the creek into the water column and transported via currents to the receiving water monitoring site. There are many variables that that affect the extent to which sediment will be transported through a water column. However, two factors play a major role: current velocity and sediment grain size. A recent study on current velocities in Mission Bay suggested that tidally induced current velocities are low in the back portions of Mission Bay near Tecolote Creek, with maximal velocities of approximately of 0.15 m/s (Largier 2003). During the wet season, a large proportion of the surficial sediments in the Tecolote Creek delta were composed of fine-grained particles typical of silts and clays. Sediment grain size is plotted against the current velocities measured at Tecolote Creek in Figure 13-4.

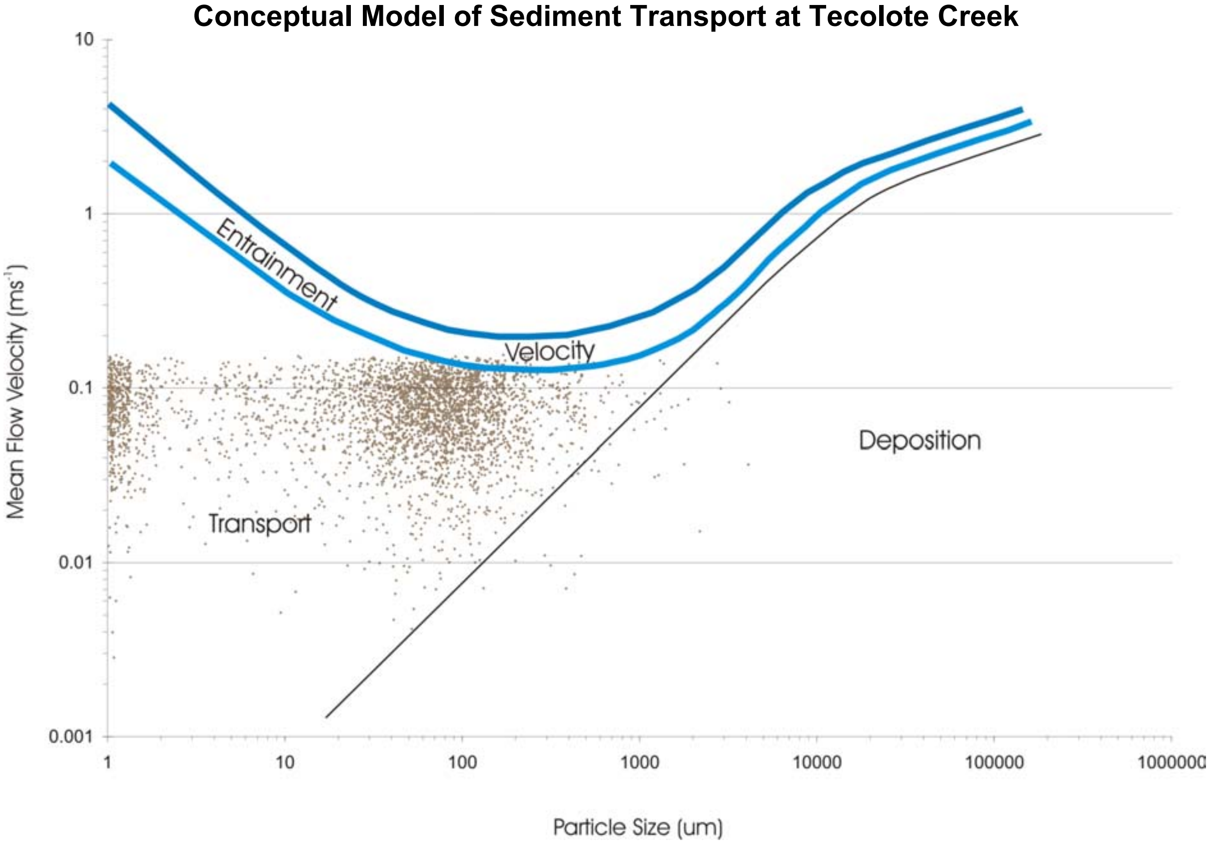

Conceptual Model of Sediment Transport at Tecolote Creek

Figure 13-4. Conceptual model of sediment transport at Tecolote Creek showing grain size distribution of delta sediments plotted against current velocities at this site.

In this figure, the wet season sediment grain size and current velocity data collected at Tecolote Creek were entered into a model of sediment transport proposed by Summerfield (1991). The model is based on over 30 empirical studies on sediment transport with a wide range of physical characteristics. In this simplified conceptual model, the Entrainment Velocity is the current speed needed to lift a particle of a given size off a horizontal surface into the water column. Largier et al. (2003) found that current velocities at Tecolote Creek typically average approximately 0.15 m/s, which is well below the entrainment velocity used in the model. However, during the largest spring tides, maximal current velocities can reach up to 0.15 m/s at Tecolote Creek. Under these conditions, the velocity is sufficient to lift particles of a grain size measured in the Tecolote Creek sediments into the water column. Bacteria adhered to these sediment particles can be transported from the delta to the receiving waters. In this way the reservoir of bacteria contained in the delta sediments at Tecolote Creek during the wet season can act as a source of bacteria to the receiving water monitoring site.

However, it is important to remember that the vast majority of the tidally-induced current velocities at Tecolote Creek are below the entrainment velocity used in this model. Thus, under the majority of conditions, bacteria adhered to the sediments deposited at the mouth of Tecolote Creek are unlikely to have a large impact on the receiving waters at the AB411 monitoring site.

Conclusions

The results of the investigation at Tecolote Creek indicate that there are few easily identifiable sources of indicator bacteria at this site. The restroom infrastructure is intact and comfort station washdown procedures do not impact the site. There are no storm drains that affect the area and irrigation runoff does not appear to be problematic. In general, the beach is fairly clean at this site and a wrack line is unlikely to have a large impact on bacterial densities at this site. The Visual Observations Task indicated that the homeless population does not appear to affect bacterial densities in the receiving waters. This observation was verified by the results of the Microbial Source Tracking study, which found that a very small percentage of the enteric bacteria in the receiving waters originated from human sources. The results of the study at Tecolote Creek are summarized in Table 13-3.

Table 13-3. Sources of indicator bacteria at Tecolote Creek. A green N indicates potential sources that are no longer thought to be present or were remediated as part of the study. A red Y indicates potential sources that remain at this site.

Site #	Site Name	Illicit Boat Discharge	Restroom Infrastructure	Birds and Other Wildlife	Irrigation Runoff	Storm Drains	Restroom Washdown	Homeless	Dog Waste	RV Pump Outs	Creek Drainage	Groundwater	Delta Sediment	Intertidal Sediment	Wrack	Other
11	**Tecolote Creek**	N	N	Y	N	N	N	N	N	N	Y	N	Y	N	N	N

Tecolote Creek

Birds and sediment at the mouth of Tecolote Creek

The sediment investigation conducted in Phase II provided the most valuable information in identifying sources of the bacteria at Tecolote Creek. The results of the study suggested that, during the dry season, the delta sediments at the mouth of Tecolote Creek are an unlikely source of bacteria to the receiving waters. During the wet season, a large majority of the bacteria in the receiving waters (84%) and the sediment (55%) at this site originate from birds. In addition, the delta sediments act as a reservoir of indicator bacteria during the wet season. The vast majority of time at this site, tidally-induced current velocities are insufficient to entrain sediment-sorbed bacteria from the delta and transport them to the receiving waters. However, during the largest ebbing tides, bacteria contained in the delta sediments can act as a source to the receiving waters.

SECTION 14

Hidden Anchorage

Site Overview

Hidden Anchorage is located in the southeastern corner of Mission Bay within a cove on the south side of Fiesta Island. There is a water ski jump ramp near the middle of the cove and the area is used frequently by water skiers and recreational boaters. The eastern side of the cove has several fire pits that are also frequently used by park visitors. The west side of the cove is heavily used by pet owners and their dogs because Hidden Anchorage is one of only a few leash-free dog parks in San Diego County. There are no comfort stations, grassy park areas, nor irrigation at this site. There are no major creek drainages that impact Hidden Anchorage, but the site does have four storm drains that discharge to the area (Figure 14-1). All four drain an impoundment on the other side of a berm that contains open land frequently used by dogs. None of the storm drains are diverted, but dry weather flow is non-existent from these storm drains. Exceedances of indicator bacterial standards have been sporadic at Hidden Anchorage and have not previously been attributed to any known source.

Figure 14-1. Aerial photograph of Hidden Anchorage.

Temporal Trends

There are no meaningful long-term bacteria data available for Hidden Anchorage. In general, samples taken of the receiving water at Hidden Anchorage during the Visual Observations Task had low indicator bacteria densities throughout the study period. However, on September 13 and October 8, 2002 AB411 criteria for all three indicators were exceeded. On October 9, 2002 standards for fecal coliform and enterococcus were exceeded. These dates corresponded with extreme high tides, suggesting a correlation between tidal heights and bacterial exceedances.

Bacterial Sources – Phase I

During the Visual Observations Task, very few potential sources of indicator bacteria were identified at Hidden Anchorage. There are no comfort stations or sewer lines at this site, no irrigation, and no dry weather discharge from storm drains or creeks. In addition, Hidden Anchorage has a very small bird population and organic debris does not tend to accumulate in this area of the bay. Due to the low amount of potential sources at this site, no spot samples were taken during the Visual Observations Task. However, the one likely potential source of elevated bacteria that was identified at this site was dog waste. During the Visual Observations task (Appendix D), there were more observations of dogs and dog waste on the beach at Hidden Anchorage than any other site assessed in the study.

Comfort Stations

There are no comfort stations at this site.

Irrigation

Irrigation does not occur at this site.

Storm Drains

Four storm drains discharge to the receiving waters at Hidden Anchorage (Figure 14-1). During the Visual Observations Task and subsequent weekly monitoring activities, none of these storm drains were flowing, therefore, no samples were collected. The inlets to the storm drains are imbedded in the soil (as opposed to impervious surfaces typical of other storm drains in the park). This, combined with the lack of irrigation at this site, effectively eliminate dry weather flows to the receiving waters.

Other – Dog Waste

Due to the lack of potential bacterial sources identified during the Visual Observations Task, it was hypothesized that the elevated bacterial levels were associated with the dog waste on the upper beach face that had been washed into the water column by the extreme high tides. There was not enough data at this site to test for a statistical correlation between tidal height and bacterial densities, but the results of the Visual Observations monitoring suggested that elevated bacterial densities may be related to samples collected in the upper intertidal area of the beach where dog waste was frequently observed. The results of samples collected during different tidal stages on October 8 and 9, 2002 as part of the Visual Observations Task are presented in Table 14-1. The results suggest that higher bacterial densities are associated with higher tides.

Table 14-1. Tidal height, stage, and indicator bacterial densities (in MPN/100 ml) at Hidden Anchorage on October 8 and October 9, 2002.

Date	Time	Tidal Height (feet.)	Tidal Stage	Total Coliform	Fecal Coliform	Enterococcus
10/8/2002	0715	2.49	Flooding	10	10	5
10/8/2002	1130	**6.53**	Ebbing	**2,400**	**2,400**	**609**
10/8/2002	1600	0.73	Ebbing	170	170	**109**
10/9/2002	0730	2.47	Flooding	10	10	5
10/9/2002	1130	**6.47**	Flooding	500	300	**4,884**
10/9/2002	1700	0.71	Ebbing	500	**500**	**122**

Based on the presumed connection between tidal height, dog waste on the beach, and elevated bacterial levels in the water column, BMPs were initiated to reduce the dog waste on the beach at Hidden Anchorage. As a result, additional trash cans, baggie dispensers, and signs were placed around the Hidden Anchorage beach during the first and third weeks of December, 2002. Park rangers from the City Park and Recreation Department implemented additional enforcement activities to further ensure proper disposal of dog fecal matter by park goers.

Signs posted at Hidden Anchorage to encourage proper removal of dog waste

Observations made during the weekly monitoring efforts showed that the amount of dog waste on the beach decreased after the management actions were taken. Of the 21 days of observation between November 2002 and March 2003, pet waste was observed on the beach only twice. Since the management actions were initiated, there have been only three exceedances of AB411 criteria at Hidden Anchorage. All three were attributed to extremely turbid water at the time of sampling, apparently due to recreational boating activities. Thus, the management actions are thought to have been effective in reducing bacterial levels at Hidden Anchorage.

High turbidity caused from recreational boating activities

Hidden Anchorage

Bacterial Sources – Phase II

Hidden Anchorage was not assessed as part of Phase II. However, mechanisms of bacterial transport and amplification related to the intertidal sediment and resuspension studies identified at other sites in Phase II may also influence bacterial densities at Hidden Anchorage.

Conclusions

There were very few potential sources of fecal indicator bacteria identified during Phase I at Hidden Anchorage. There was no irrigation of grassy park areas for the accumulation of bacteria, no comfort stations or sewer lines, and no groundwater springs or creek drainages at this site. None of the storm drains that discharge to the area were flowing during dry weather sampling. In addition, Hidden Anchorage had a very small bird population during the Visual Observations Task and the Weekly Monitoring from November 2002 through March 2003. A summary of the bacterial sources identified at this site is presented in Table 14-2.

Table 14-2. Sources of indicator bacteria at Hidden Anchorage. A green N indicates potential sources that are no longer thought to be present or were remediated as part of the study. A red Y indicates potential sources that remain at this site.

Site #	Site Name	Illicit Boat Discharge	Restroom Infrastructure	Birds and Other Wildlife	Irrigation Runoff	Storm Drains	Restroom Washdown	Homeless	Dog Waste	RV Pump Outs	Creek Drainage	Groundwater	Delta Sediment	Intertidal Sediment	Wrack	Other
12	Hidden Anchorage	N	N	Y	N	N	N	N	N	N	N	N	N	Y	N	N

The most likely cause of elevated bacterial indicator densities at this site was the dog waste on the beach. Hidden Anchorage is a favored spot by many dog owners because dogs are allowed to run off leash. During the Visual Observations Task, there were more observations of dogs and dog waste on the beach at this site than any other location in Mission Bay. A follow-up study conducted at this site also suggested that dog waste was the likely source of fecal indicator bacteria to the receiving waters. Subsequent management action taken by the City of San Diego Park and Recreation Department, which consisted of the installation of dog waste baggie dispensers and additional trash cans, appeared to have been effective in reducing bacterial exceedances at this site.

Bird waste and sediment resuspension remain potential sources of indicator bacteria at Hidden Anchorage.

Summary of Findings

SECTION 15

The purpose of this study was to plan, design, and implement a bacterial source identification study to identify sources of bacterial contamination in Mission Bay and recommend appropriate actions and activities to eliminate the input of those sources to Mission Bay. This section provides a brief summary of the findings from each of the six investigative tasks conducted in the two-year study.

Task 1 – Investigate sources of human sewage from restroom infrastructure within Mission Bay Park;

Task 2 – Investigate sources of human sewage from illicit discharge of sewage from moored or anchored boats;

Task 3 – Conduct visual observations and bacterial assessments of other potential bacterial sources within Mission Bay Park;

Task 4 – Identify the origins of enteric bacteria in the bay using microbial source tracking (MST) techniques;

Task 5 – Investigate the transport mechanisms of bacteria from the surface of Mission Bay Park to the bay receiving waters (i.e., fate and transport study);

Task 6 – Investigate the extent to which sediment acts as a source of bacteria to bay receiving waters.

The major findings from each of these tasks are discussed below. The major findings for each of the individual sites can be found at the end of Sections 3 through 14.

Task 1 – Restroom Infrastructure

In Task 1, the comfort stations at 12 locations within Mission Bay Park (Figure 15-1) were evaluated to determine if leaking infrastructure from these facilities was a source of bacteria to the bay. The lateral lines of the comfort stations, which carry sewage to the sewer mains, were visually inspected with a closed-circuit television system to assess the conditions of the lateral lines. The inspections revealed that the integrity of the lateral lines of all of the comfort stations investigated was intact. These results suggest that the infrastructure of comfort stations within Mission Bay Park is not a likely source of fecal pollution to the bay.

Figure 15-1. Site map of Mission Bay showing the twelve sites investigated in this study.

Task 2 – Illicit Discharge From Boats

In Task 2, illicit discharge of sewage from boat holding tanks was investigated as a potential source of bacteria at three locations in Mission Bay where boats moor or anchor: Bonita Cove, Santa Barbara Cove, and De Anza Cove. At each site, samples were collected for bacterial analyses in surface waters surrounding the moored or anchored boats and from a beach location where routine monitoring is conducted. The samples near the boats were collected by kayak. Each site was sampled in this way on three separate days. Very low densities of all three bacterial indicators were detected throughout the study at all three sites. In most cases, the densities were below or just above the detection limits. The lack of elevated levels of indicator bacteria from any of the samples collected indicates that illegal discharge of sewage from moored and anchored boats was not occurring during the time of sampling. The results also suggest that illegal sewage dumping from moored and anchored boats is not a likely chronic source of bacterial contamination at the beach. However, the illegal discharge of sewage holding tanks from moored boats is inherently episodic and the results of the study do not rule out the potential for isolated events.

Task 3 – Visual Observations

Task 3 was designed to assess the numerous potential sources of bacteria to Mission Bay other than leaking comfort station infrastructure and illicit discharge from moored and anchored boats. The potential sources assessed in this task included fecal matter from birds and feral and wild animals that inhabit the park, the homeless population, the behavior of some park visitors, and park management practices, such as comfort station cleaning and irrigation procedures. To determine the extent to which these potential sources may be contributing to the bacterial contamination of Mission Bay, a comprehensive visual observation program was implemented at 12 sites throughout Mission Bay.

A total of approximately 1,300 man-hours of visual observations were made during the nine days of the study (over 100 hours per site). In addition, over 500 samples from receiving waters of the bay and suspected sources were collected and analyzed for fecal indicator bacteria. The results from the observations and bacterial monitoring suggested that several potential bacterial sources identified at the beginning of the study were not likely to be contributing bacteria to the bay. These included rodents and wildlife other than birds, leaking garbage cans, trash or food in the park, illicit boat discharge, improper use of recreational vehicle pump-outs, the homeless population, and pet waste (except at one site). The results also indicated that each site examined in the study was unique in terms of potential bacterial sources. The potential sources identified throughout the bay that remained at the end of Phase I included:

1. birds,
2. storm drain effluent,
3. groundwater,
4. creek drainage,
5. irrigation runoff,
6. restroom washdown practices,
7. pet waste (Hidden Anchorage),
8. other pipe drainage (North Pacific Passage)
9. and boat cleaning (Campland).

Bacterial sources from restroom washdown practices, pet waste at Hidden Anchorage, other pipe drainage at North Pacific Passage, and boat cleaning at Campland were eliminated as potential sources of bacteria to the bay through effective management actions instituted by the City.

Task 4 – Microbial Source Tracking

The molecular genetic techniques employed throughout the Microbial Source Tracking Task provide us with the most direct and accurate insight as to the host origin of enteric bacteria found in the many water types sampled at Mission Bay. Results from both MST methods utilized in Phase II confirmed that the large majority of the enteric bacteria in Mission Bay originates from birds and contributions from human sources are insignificant (Figure 15-2 and 15-3). The wealth of data generated from the MST portion of the study, however, allows us to draw unique conclusions for each site examined as presented below.

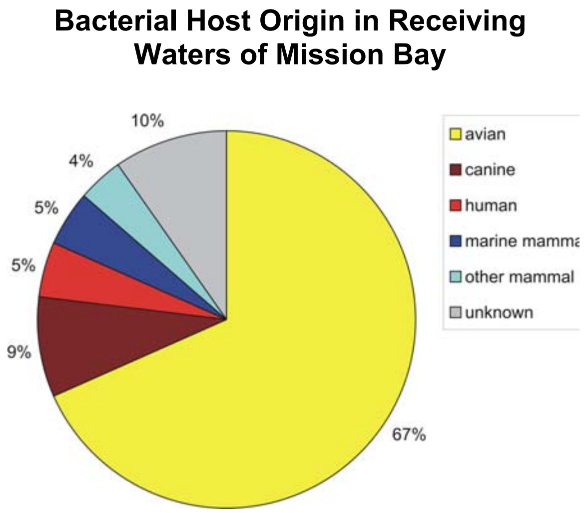


Figure 15-2. Results of Ribotyping analysis of receiving water samples collected at all sites studied in Mission Bay between July 2003 and April 2004.

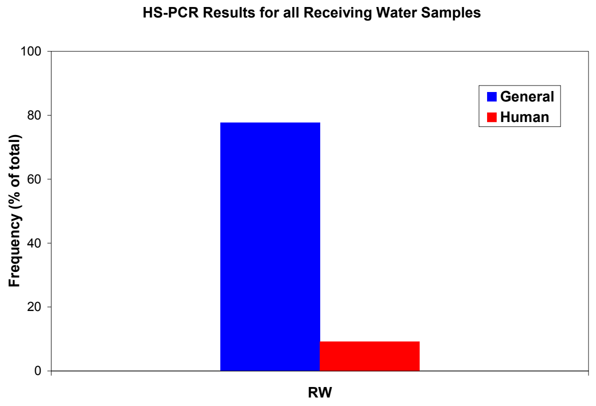


Figure 15-3. Results of HS-PCR analysis of receiving water samples collected at all sites studied in Mission Bay between July 2003 and April 2004.

Bonita Cove – We found no difference in the origin of the bacteria at this site between holiday and non-holiday periods that would explain the discrepancy in bacterial densities observed during these two periods at Bonita Cove. However, we did determine that a large percentage of the bacteria isolated from the storm drains at this site matched the bacteria isolated in the receiving water, suggesting that the storm drains convey these bacterial strains to the bay in addition to direct deposition from birds themselves.

Fanuel Park – Given the unique characteristics of the storm drain system at Fanuel Park, the connection between the bacteria in the receiving water and the bacteria in the storm drain is much more direct than other sites; therefore, the storm drains are believed to be a direct source of bacteria to the receiving waters.

Wildlife Refuge – While receiving water samples at Wildlife Refuge were found to be contaminated with fecal bacteria, they were not found to contain a significant proportion of human contamination.

Campland –The bacterial host-origin proportions were similar between the dry season and wet season surveys at Campland. While the Ribotyping technique did not implicate human sources during the wet season or dry season surveys, human contamination was detected during dry the season by the HS-PCR assay. Therefore, human sources remain a possibility at the receiving water at Campland, most likely originating from the swimmers themselves.

De Anza Cove – A strong connection between the storm drain bacteria and the receiving water was made at De Anza Cove, and this connection was observed to be slightly higher during the wet season survey. The connection suggests that the storm drains at De Anza Cove are a bacterial source to the receiving waters.

Visitor's Center – Two drainage sources sampled at Visitor's Center were found to be contaminated with a large percentage of avian-derived bacteria: storm drain effluent and the Cudahy Creek effluent. A significant proportion of the bacteria from the receiving water at Visitor's Center matched bacteria from these sources, suggesting that effluent from them impacts bacterial densities in the receiving waters.

Leisure Lagoon – A majority of the receiving water was contaminated with avian-derived bacteria at this site, but the host origin of a significant percentage of the bacteria could not be identified due to suspected limitations of the Ribotyping assay. However, the HS-PCR method suggests that a significant proportion of the receiving water samples were contaminated with human bacteria. Only a modest connection between the receiving water bacteria and the bacteria present in the storm drain at Leisure Lagoon was observed. Since sampling at this site took place during heavy use periods, we believe the most likely source of the human bacteria at this site at the time of sampling was from the swimmers themselves.

Task 5 – Bacterial Fate and Transport

The Fate and Transport Study revealed several important factors about the migration of indicator bacteria from the grassy areas of Mission Bay Park to the bay's receiving waters. The conclusions of the study are summarized below.

- The grassy areas of Mission Bay Park contain a large reservoir of indicator bacteria. Samples collected in Phase I and Phase II from irrigated portions of the park contained fecal coliform densities ranging from 40 to 16,000,000 MPN/100 ml. Enterococcus densities ranged from 5 to 2,500,000 MPN/100 ml. High levels were observed throughout the park during both dry and wet seasons.

- Molecular analyses of the bacteria in the grassy areas of the park reveal that the majority of the identified isolates originated primarily from birds.

- Data from soil cores from three areas in the park, De Anza Cove, Visitor's Center, and Leisure Lagoon, revealed high bacterial densities near the ground surface. Densities of both indicators decreased with depth and appeared to be negligible at a maximal depth of approximately 18 inches.

- Bacterial densities appear to be related to soil grain size, with the highest levels associated with the silt and clay soil fractions. Soil strata with a silt and clay fraction of between approximately 10 and 34% appeared to act as a barrier to the vertical migration of bacteria from the grassy areas of the park.

- The saturated zone is though to be at a depth of approximately 5 to 6 feet below ground surface. At depths of seven and 12 feet below ground surface, levels of indicator bacteria in groundwater were below the detection limit in nearly all cases.

- Groundwater samples collected from beach face springs also contained negligible levels of indicator bacteria suggesting that groundwater is not a source of enteric bacteria to Mission Bay.

- Overall, the results of this study indicate that the bacteria associated with the grassy areas of the park are trapped within the top 18 inches of soil and are not likely to be transported via groundwater to the receiving waters of Mission Bay.

Task 6 – Sediment Investigation

The results of the sediment investigation allowed us to reach several conclusions about the extent to which sediments influence bacterial densities in the receiving water of Mission Bay. The results of both the delta sediment investigation and the sediment resuspension study suggest that the relationship between sediments and receiving water is dependent on the specific characteristics of each site. The conclusions of the two studies are summarized by site below.

Rose Creek – Sediments in the Rose Creek delta do not appear to have an impact on bacterial densities in the receiving waters at Campland in either dry or wet season periods.

Cudahy Creek – Sediments in the Cudahy Creek delta act as a reservoir for indicator bacteria, particularly during the wet season. However, the extent to which bacteria in the sediment impact the receiving waters appears to be relatively minor.

Tecolote Creek – Sediments in the Tecolote Creek delta contain low bacterial densities in the dry season and high bacterial densities in the wet season. During the wet season, it is likely that bacteria in the sediment are transported to the receiving waters only during periods of maximal tidal currents. The majority of time, the sediments are not a source of bacteria to the receiving waters.

Bonita Cove – Sediments in the upper intertidal zone at Bonita Cove act as a reservoir for indicator bacteria. When the sediments are disturbed (e.g., through swimmer activity), the bacteria is released to the water column resulting in elevated bacterial densities. Sediments in the lower intertidal zone do not act as a reservoir for indicator bacteria.

Leisure Lagoon – As with Bonita Cove, sediments in the upper intertidal zone at Leisure Lagoon act as a reservoir for indicator bacteria that can be released to the water column when the sediments are disturbed. In addition, effluent from storm drain SD9-2 appears to have elevated the bacterial densities in the nearby sediments.

De Anza Cove – Sediments in the lower intertidal zone at De Anza Cove act as a reservoir for indicator bacteria that can be released to the water column when the sediments are disturbed. In addition, it is likely that sediments in the upper intertidal zone at De Anza Cove play the same role.

Recommendations

Following the completion of each of the major tasks conducted in this study, recommendations were made to the City regarding suggested actions that could be taken to reduce potential bacteria sources to the bay. In addition, other recommendations were made following the completion of follow-up studies, the weekly monitoring, and as other information pertinent to potential bacteria sources in the bay was discussed at monthly meetings between the City and MEC. This section summarizes the recommendations submitted to the City over the course of the study. Recommendations resulting from the investigative tasks of Phase II are presented first because the Phase II results provided the most pertinent information on reducing bacterial loads to Mission Bay overall.

The most important result of the Mission Bay Bacterial Source Identification Study is that the majority of the enteric bacteria in Mission Bay originates from birds and that contributions of bacteria from human origin are insignificant. Because little can be done about the number of birds in Mission Bay, we believe that the most effective management solutions in reducing indicator bacterial densities should focus on four areas where we believe the initial load generated from avian sources can be amplified:

1. intertidal sediments,
2. the wrack line,
3. irrigation runoff, and
4. storm drains.

Recommendations focusing on each of these areas are presented below.

Intertidal Sediments

There are relatively few management actions related to intertidal sediments that have been implemented to reduce loading of indicator bacteria on the beach. At Campland, simply removing the bird fecal matter from the beach face proved to be a very effective means of reducing indicator bacterial densities in the receiving waters. However, this type of program is very labor intensive and likely impractical on a large scale. In addition, replacing the sand on the beach is likely impractical, as studies have shown that bacterial densities can return to initial levels within two weeks of sand replacement. Since we know of no BMPs that have been applied specifically to reducing bacterial densities in intertidal sediments, we believe that creative BMPs should be designed and tested to determine their ability to reduce bacterial loading in this area. For instance, grooming practices should be evaluated to assess their effectiveness in reducing bacterial loads on the beach. Initial work conducted on beaches in the Great Lakes region suggests that bacterial densities in beach sediments increase after certain types of grooming.

The results of the MST study in Mission Bay, the sediment investigation, and the laboratory study suggest that sediments in the lower intertidal zone are less likely to contain elevated indicator bacterial densities partially because bacterial survival is limited by the effects of seawater. Thus, one possible way to reduce bacterial densities in the upper intertidal sediments is to periodically spray that area with seawater during the grooming process. This procedure is likely to be most effective during neap tides when the upper intertidal zone is exposed to bird feces for the greatest period of time. To our knowledge, this type of BMP has never been initiated and would thus require monitoring to assess its effectiveness.

In addition to intertidal sediments, delta sediments were also investigated as part of Phase II. Overall, the sediments that form the deltas of the three major drainages to Mission Bay do not appear to impact bacterial densities in the receiving waters. However, they can act as a reservoir for indicator bacteria and should be studied thoroughly before any management actions that could disturb them are initiated.

Wrack Line

Accumulation of organic debris that forms the wrack line is a persistent phenomenon in Mission Bay. The results of the wrack line study suggested that the wrack acts as a bacterial reservoir that maintains the initial load for prolonged periods of time before releasing it back to the receiving waters. This process is likely to be most problematic on the east side of Sail Bay (Fanuel Park and Riviera Shores) and the east side of Mission Bay (primarily De Anza Cove to Visitor's Center), although wrack accumulates at all sites to a limited extent. Since the origin of the bacteria in the wrack is predominantly Avian, it is possible that this process had some influence on the results from the receiving water samples collected as part of the MST study. Thus, removal of the wrack from the beach face in Mission Bay would likely be an effective means of reducing indicator bacterial densities in the receiving water. We believe removal of the wrack during neap tides would be the most efficient way to manage this problem. However, as with the recommendations made for the intertidal sediments above, beach grooming practices utilized by the City should be evaluated to determine their effectiveness in reducing bacterial densities in the intertidal zone. For instance, one grooming practice currently in place utilizes a rake structure that tends to grind the wrack into the sediment rather than removing it, thus leaving the source of the bacteria on the beach. Other, more effective means of removing the wrack line should be considered and evaluated.

Irrigation Runoff

The results of the Fate and Transport study indicate that there is a large reservoir of bacteria in the upper soil strata within the grassy areas of Mission Bay Park. MST techniques established that the origin of that bacteria is Avian. Although the Fate and Transport study indicates that the bacteria are not impacting the receiving waters via groundwater transport, the potential exists for other transport mechanisms, such as soil erosion and excess irrigation. In Phase I of the Mission Bay Bacterial Source Identification Study, excessive irrigation at several sites was shown to be a potential bacterial transport pathway from the park to the bay receiving waters. The excess irrigation water transported bacteria to the bay through storm drains (downstream of the Mission Bay Sewage Interceptor System) and via overland transport, which results in erosion of the banks. To prevent bacterial transport via these mechanisms, the following actions are recommended to the City.

To the extent possible, reduce excessive irrigation throughout the park to eliminate or minimize flow to the bay from the storm drains. This might be accomplished through a variety of turf management techniques, such as redirecting sprinklers to prevent overflow to the gutters, installing sensors to assess the water content of the soil, and automating the sprinkler system to increase watering efficiency.

Minimize erosion by maintaining stable banks. This could be accomplished by reducing excessive irrigation as mentioned above, fixing and maintaining sprinkler heads near banks where erosion occurs, and eliminating flow from concrete ramps associated with park comfort stations. In areas where bank erosion is particularly problematic, permanent edge structures could be installed to further prevent erosion.

Storm Drains

The most common conveyance of indicator bacteria to the receiving waters of Mission Bay identified in this two-year study was storm drain effluent during dry and wet weather. The storm drains were determined to be a potential source of bacteria at several sites examined, although at some sites such as Bahia Point their impact has been minimized. Storm drain effluent during dry weather was found to exist at Bonita Cove, Fanuel Park, Wildlife Refuge, De Anza Cove, Visitor's Center, and Leisure Lagoon. This is of particular interest because all of these sites, except Leisure Lagoon, are part of the low flow interceptor system around Mission Bay. Based upon this study, the dry weather flow from storm drains and associated indicator bacteria that is conveyed to the receiving water is the result of several mechanisms:

1. The storm drains are an open system that accept significant amounts of sediment and debris from inlet points throughout the drainage basins,

2. The storm drain interceptors are periodically ineffective in redirecting flow to the sewer due to the accumulation of sediment and debris within diversion structures during dry weather,

3. Bacterial amplification occurs within the storm drains,

4. There is bacterial influx to the storm drains downstream of the diversion points, primarily from irrigation runoff.

The bacterial problems can be further increased based on the elevation of the storm drain in relationship to tidal levels and the low flow diversion system. A worst case scenario would be represented by a tidally influenced storm drain that had a low flow diversion system that was positioned above the high tide level. This would provide for a length of storm drain not protected by the low flow diversion system that was subject to tidal influences that would wash contamination back out into the bay. This problem is made worse if the storm drains are closed conduits instead of open channels, which is typical in Mission Bay.

Proper maintenance and cleaning of the storm drains and diversion structures is extremely important in minimizing bacterial loads from storm drains to the receiving waters of Mission Bay. The maintenance of the storm drain system is separate from the maintenance of the low flow interceptor system. The storm drain system is the responsibility of the Street Division and low flow interceptor system is the responsibility of the Metropolitan Wastewater Department. The cleaning of the storm drain system (i.e. removal of sediment and debris) is conducted primarily in known problems areas. The City also has a street sweeping program, which regularly removes particulates and trash from streets that would otherwise end up in the storm drains. A more extensive preventive maintenance program to specifically address water quality concerns citywide is not in place due to the limited resources available for system maintenance. The City's Urban Runoff Management Plan adopted by City Council on January 28, 2002 included a storm water conveyance system component (Section 2.1.11) that outlines key maintenance elements to address water quality concerns that would be implemented in phases as funding becomes available. These key areas include increased inspection and cleaning of storm drain inlets and catch basins, inspection and cleaning of storm drain lines, and removal of trash and debris from open channels. Increased resources to remove sediment and debris from the storm drains would decrease the accumulation of sediment and debris at the diversion point.

The City's Urban Runoff Management Plan also has a low flow diversion component (Section 2.1.10). To optimize the low flow diversion system, the City has conducted and continues to conduct monthly coordination meetings between operations and engineering staff to discuss operational challenges (e.g., failure of check valves) and develop system enhancements for implementation. As a result of these efforts, the Engineering & Capital Projects Department intends to make modifications to the existing low flow diversion system to improve the system effectiveness and reduce maintenance expenses of the Metropolitan Wastewater Department that currently maintains the systems. The proposed Mission Bay Sewage Interceptor System Repair and Improvement Project is funded in part by an Environmental Protection Agency (EPA) grant. The project will proceed to construction pending receipt of a NEPA exemption. The project includes the replacement of the failed or ineffective check values, which were identified as attributing to the bacterial amplification within the storm drain.

It is recommended that steps be taken to minimize bacterial amplification that currently occurs within the tidally influenced storm drains. The monitoring results of Phase I and the results of the laboratory follow-up study conducted as part of Phase II showed that even storm drains that are not part of the MBSIS (such as SD9-2 at Leisure Lagoon) can act as bacterial amplifiers. The influx of organic debris and water from the bay combined with the environmental conditions inside the storm drains can produce dramatic growth of indicator bacteria. Preventing the influx of organic debris to the storm drains would likely be an effective means of minimizing this process. Tide gates are in place at some sites on the west side of Mission Bay and are to be installed in the lower San Diego River channel as part of the San Diego River – Ocean Beach Water Quality Improvement Project, which is funded in part by the Governor's Clean Beaches Initiative. We recommend that the San Diego River channel devices be assessed as potential models to be used for storm drains in Mission Bay.

The results of the two-year study and on-going monitoring conducted by the City indicate that the storm drains that convey the most indicator bacteria to Mission Bay are storm drain SD8-1 and Cudahy Creek culvert at Visitor's Center. Both these storm drain systems have continual flow of freshwater, which contain high densities of indicator bacteria. The results of the MST task indicate that dry weather flow from these storm drains impact the bacteria densities in the receiving water at Visitor's Center. These drains are part of the low flow diversion system, however, the diversion points are located on the east side of Interstate 5. Although inspections of the low flow diversion systems indicate that they typically divert dry weather flow to the sewer, there is an influx of freshwater that enters the storm drain downstream of the diversion point. In addition, organic material from the bay enters the storm drain with the high tide. This combination produces a significant amount of bacteria that is subsequently conveyed to the bay.

Due to the complexity of the engineering issues related to SD8-1 and Cudahy Creek, a report should be developed recommending alternatives that could help minimize the bacteria contamination from these drains. This report should quantify the daily bacterial load that is conveyed from these locations to the bay as well as analyze a number of alternative methods of reducing bacterial contamination. Alternatives could include circulation and flushing of water through the storm drains, elimination of fresh water sources downstream of the dry weather diversions, installation of tide gates on the ends of the pipes, screens or other methods to prevent debris accumulation in the storm drains and, opening up the storm drains to allow for disinfection by sunlight and maintenance practices. It may take a combination of alternatives to deal with these drains since they represent a near worst case situation.

In addition to addressing the storm drains in Mission Bay, the sampling location for the AB411 monitoring should also be addressed. At coastal beaches throughout southern California, the AB411 monitoring site is located 25 yards away from a storm drain terminus. However, in Mission Bay, the AB411 monitoring sites are located directly in front of storm drains at many locations. To be consistent with the AB411 monitoring conducted throughout southern California, we recommend that the City consider moving the AB411 sampling locations 25 yards away from the end of a storm drain.

At the end of Phase I, several recommendations were made to the City to reduce the bacterial densities in Mission Bay. The recommendations from Phase I are presented below. Many of these recommendations have already been implemented or are ongoing. In these cases, actions taken by the City are also noted.

Infrastructure

The infrastructure investigation indicated that the lateral lines of the Mission Bay Park restrooms were an unlikely source of sewage to the bay. However, it was recommended that the City investigate two restrooms that appeared to have some potential problems: Facility 10096 on Ventura Point and Facility 9939 at Santa Clara Point. Although neither facility is a likely source of sewage to the bay, the following recommendations were presented to the City to verify the integrity of these lines:

Recommendation:

Facility 10096 – Ventura Point. During the CCTV investigations, a root mass was identified in the line from this comfort station. The simplest way to determine if the root mass is acting as a potential conveyance of sewage to the surrounding area is to remove it with a snake and visualize the area of intrusion using a CCTV system. If a hole or separation of the pipe is evident, the pipe should be replaced or patched.

Facility 9939 – Santa Clara Point. The CCTV report for the comfort station at the end of Santa Clara Point noted “severe corrosion” along one section in the lateral line. The corrosion observed suggests that the integrity of the cast iron wall of the pipe may have been compromised. Unfortunately, the only way to positively determine if sewage is escaping from the pipe is to view it externally. Excavating the pipe for visual inspection and subsequent replacement if necessary is recommended.

Action:

No action has yet been taken on these recommendations.

Boats

The results of the boat mooring study suggest that the illegal dumping of sewage from moored boats was not a source of bacteria at the sites monitored during the sampling period. However, since the sampling duration was limited, and illegal dumping is likely episodic (if it is occurring), the potential for moored boats as a source of bacterial contamination to adjacent beaches cannot be ruled out. The following actions were recommended to the City.

Recommendation:

Re-sample during a high use time period. It is reasonable to assume that the most likely time for illegal discharges from boat holding tanks will be when the greatest number of boats are using the anchorages and moorings. Therefore, repeating the sampling protocol during a high use weekend (e.g., Memorial Day, 2003) would have the greatest likelihood of collecting a sample during a discharge event. Sampling at night or early morning when illegal discharges are most likely to occur would also increase the chances of capturing an illegal discharge.

Action:

A follow-up study was conducted in response to this recommendation over Memorial Day weekend 2003. The results of both studies were similar and did not suggest any evidence of illicit discharge from moored or anchored boats at Bonita Cove during the sampling period of either investigation.

Recommendation:

Follow up on anecdotal information. There is some information that suggests that individuals may be using some boats moored in Mission Bay as semi-permanent residences. For instance, results of the 2000 census suggested that some individuals may be using moored boats in Mission Bay as a permanent residence. If some boats are being lived on for extended periods of time, there is a greater likelihood that there is illegal discharge coming from these boats. Reducing this potential source of sewage to the bay may help in reducing some high bacterial levels on adjacent beaches.

Action:

Any information related to this issue is investigated and relayed to the appropriate City authority.

Visual Observations

Numerous observations were made during the Visual Observations Task of the project regarding potential bacterial sources.

Recommendation:

Investigate the potential for bacterial contamination of the bay receiving waters through de-watering at Fanuel Park and Riviera Shores.

Action:

The de-watering and pumping activities at Fanuel Park and Riviera Shores were thoroughly investigated in a follow-up study conducted in the spring of 2003. All potential de-watering sources were documented and mapped as part of the follow-up study. In addition, problems (primarily maintenance issues) associated with the storm drain diversion system were documented and, in some cases, corrected. The study found that some de-watering operations were a source of large volumes of water to Mission Bay. Bacterial levels associated with these and other sources in the area were also documented in the study.

Recommendation:

Contact the City's Real Estate Assets Department (or appropriate group) regarding boat and car washdown areas at Campland and investigate the causes of the elevated bacteria levels in this area.

Action:

This recommendation resulted in a follow-up study conducted at Campland with the cooperation of the City's Real Estate Assets Division and Campland management and staff. During the investigation, a dead bird was found to be the source of the contamination at the boat washdown area. The carcass was removed and the drain pipe was cleaned. Subsequent monitoring showed a dramatic decrease in bacterial levels in effluent from this pipe after the management actions had been taken.

Recommendation:

Develop a program to reduce the potential for bacterial contamination from birds at Campland. Possible actions include: remove the swim platform in front of the swimming beach during low use periods; encourage Campland residents and guests to stop feeding the birds; and remove the bird waste from the intertidal area of the Campland beach.

Action:

This recommendation also resulted in the follow-up study at Campland mentioned above. Campland management and staff were extremely cooperative in initiating all of the recommendations during the winter of 2002/2003. Soon after the recommendations were instituted, bacterial levels decreased dramatically at Campland, suggesting that they may have been effective in decreasing bacterial exceedances at this site.

Recommendation:

Throughout the study there was a steady flow of water emanating from storm drain SD8-1 at Visitor's Center. The source of the flow was suspected to be a combination of groundwater influx and a spring on the east side of Interstate 5. However, there were no maps of this storm drain available to the City and it is unclear if there are other potential sources of water in the area. Therefore, we recommend that the City investigate the source(s) of the water discharged from the Visitor's Center storm drain and remediate where possible.

Action:

No action has yet been taken on this recommendation.

Recommendation:

Post signs directing park visitors not to feed the birds at Visitor's Center.

Action:

Signs have been posted at Visitor's Center as a result of this recommendation.

Recommendation:

Contact the City's Real Estate Assets Department (or appropriate group) about the four PVC pipes that are contributing bacteria to the bay at the Hilton Hotel boat dock and investigate the source(s) of the drainage to these pipes as appropriate.

Action:

This recommendation resulted in a follow-up study to assess the source of bacteria from the pipes at Hilton Hotel in conjunction with the Real Estate Assets Department and Hilton Hotel management and staff. The source of the bacteria was identified as a koi pond on the Hotel property that had not been well-maintained. The Hotel management was very pro-active in draining and cleaning the pond, fixing a drain pipe that was not functioning properly, and replacing aeration pumps. Following these actions, flow from the pipes that drained to the beach and the associated bacterial load to Mission Bay was eliminated. In addition, a management plan was instituted to continue routine maintenance and monitoring of the pond.

Recommendation:

Investigate the extent of the homeless population and potential for fecal contamination at suspected sites, particularly Tecolote Creek.

Action:

The City has a homeless assistance team that deals with the homeless population on an on-going basis.

Recommendation:

Investigate the possibility of additional trash cans, signs, and bags etc. at Hidden Anchorage to reduce bacterial loading from pet waste.

Action:

This recommendation resulted in additional trash cans, baggie dispensers, and signs placed at Hidden Anchorage in addition to increased enforcement by the City Park and Recreation Department. The results of routine monitoring at this site suggested that dog waste on the beach and bacterial exceedances decreased substantially at this site following the actions taken by the City.

Recommendation

Contact the City of San Diego Park and Recreation Department about the irrigation procedures in Mission Bay Park and determine the appropriate procedures that could help reduce irrigation flow to the bay.

Action:

Following this recommendation, the City Park and Recreation Department fixed broken sprinkler heads and corrected erosion problems at De Anza Cove, Visitor's Center, and other areas identified in the Visual Observations Task. The City is currently pursuing an automated computer system to help manage irrigation issues in Mission Bay Park. The project is scheduled to be initiated in May 2005.

Recommendation:

Contact the City of San Diego Park and Recreation Department regarding the washdown of the Mission Bay Park comfort stations and possible procedures to reduce runoff from the restrooms during cleaning.

Action:

Following this recommendation, the City Park and Recreation Department instituted a program to change the way comfort stations were cleaned. City staff were instructed to keep the water from the washdown procedures contained within the comfort station, directed towards internal drains that are connected to the sanitary sewer. Observations made during the weekly monitoring (November 2002 through March 2003), suggested that these changes had been adopted by City staff, thus reducing this potential source of bacteria to the bay.

Recommendation:

Where possible, determine the drainage area of all storm drains in Mission Bay where high bacterial levels in storm drains were measured or suspected (Sites 1, 2, 3, 4, 7, 8, 9, 10,and 11) and assess the effectiveness of the interceptor system in these areas.

Action:

This recommendation resulted in an inspection of the storm drains and the diversion system at all of the 12 sites investigated in this study as well as mapping of the diverted and un-diverted areas of Mission Bay Park. At some locations, the diversion system appeared to be effective in diverting dry weather flows to the sewer system. In other areas, accumulation of sediment and debris at the diversion structure may limit the effectiveness of the diversion system.

During follow-up studies of Phase I, several storm drains were investigated during dry weather (at least 72 hours after a rain event) upstream of their outfalls before they enter Mission Bay. These storm drains were found to have relatively high indicator bacteria densities, which may contribute to beach water quality standard exceedances. These include the storm drain systems at the following locations: Fanuel Park, Visitor's Center, De Anza Cove, Wildlife Refuge, Bonita Cove, and Santa Barbara Cove. The following recommendations were submitted to the City.

Recommendation:

The storm drains at all these locations would benefit from more frequent routine maintenance to prevent any bacteria associated with debris from entering Mission Bay.

Action:

Several of the storm drain diversion structures identified in the storm drain inspections were cleaned as a result of this recommendation.

Recommendation:

One of the two tide flexes in the culvert behind Campland and near the wildlife refuge needs to be replaced with a tidal exclusion device.

Action:

No action has yet been taken on this recommendation.

Recommendations

Recommendation:

The Metropolitan Wastewater Department receives information regarding the MBSIS, however, this information does not always accurately represent the effectiveness of the system in diverting dry weather flows to the sewer system. We recommend that the City develop a process to communicate specific problems and approximate down time of the diversion system promptly to the City Storm Water Pollution Prevention Program. Further, we understand that both the City Streets Division and the Metropolitan Wastewater Department manage the Mission Bay Sewage Interceptor System. Both groups need to continue providing accurate and prompt information to the City Storm Water Pollution Prevention Program regarding scheduled cleaning and maintenance.

Action:

Communication between the various division and departments involved with water quality in Mission Bay has increased as a result of the regular meetings conducted on the Mission Bay Source Identification Study. The processes and connections developed during this study will enhance communications between the City departments and divisions after the project has been completed. In addition, there is a monthly coordination meeting to discuss the MBSIS. It may be helpful if a member of the Storm Water Pollution Prevention Program attended these meetings.

Recommendation:

Information gathered during the project investigation at one site, Hidden Anchorage on the south side of Fiesta Island, indicated that pet waste on the beach at Hidden Anchorage was a persistent problem. That area of Fiesta Island is a common area for pet owners to let their dogs run leash free. During routine observations made during the study, dogs were frequently observed on the beach and in the fenced-in area on the west side of Hidden Anchorage. In November, 2002 pet waste baggie dispensers and additional trash cans were placed along the west shore of Hidden Anchorage in response to the large amount of pet waste on the beach. Subsequent observations in the area suggested that the trash cans and baggies had been somewhat effective in reducing the number of dog waste piles on the beach. However, the problem has not been eliminated and several pet owners have been observed ignoring their pet's waste in the area. Because the chain link fence at Hidden Anchorage provides a safe haven for dogs, this area is extremely attractive to pet owners. Therefore, to further reduce the amount of fecal material from pets at Hidden Anchorage, the following recommendation was made: Remove the chain link fence at Hidden Anchorage on Fiesta Island to help reduce the number of dogs (and dog waste) in the area.

Action:

No action has yet been taken on this recommendation.

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