CONSENT DECREE — PHASE ONE STUDY
FINAL REPORT

EVALUATION OF THE SOUTH BAY INTERNATIONAL WASTEWATER TREATMENT PLANT RECEIVING WATER QUALITY MONITORING PROGRAM TO DETERMINE ITS ABILITY TO IDENTIFY SOURCE(S) OF RECORDED BACTERIAL EXCEEDANCES

Prepared for U.S. Environmental Protection Agency, Region IX San Francisco, CA

Prepared by
John Largier, Linda Rasmussen, Melissa Carter and Carolyn Scearce
Scripps Institution of Oceanography, University of California, San Diego, CA

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Executive Summary

Introduction

The monitoring of the South Bay Ocean Outfall (SBOO) is reviewed to assess whether this program is sufficient to identify whether the outfall is a cause of bacteria water quality standards being exceeded in beach and kelp waters ("exceedances"). Bacteria-rich wastewater is discharged through the SBOO following treatment of Tijuana sewage flows at the South Bay International Wastewater Treatment Plant (SBIWTP). This review was called for in a Consent Decree between Surfrider Foundation and the California Regional Water Quality Control Board (San Diego), plaintiffs, and the United States Section of the International Boundary and Water Commission (IBWC), defendant, as a result of a suit initiated by Surfrider Foundation. The primary purpose of the existing monitoring program, known as the Receiving Water Quality Monitoring Program (RWQMP), is to ensure compliance with the Coastal Ocean Plan. A related report on the RWQMP has been prepared by SAIC to address compliance issues (*SAIC and R. Smith*, 2004).

This review addresses three specific "phase one" issues: (i) whether the SBIWTP/SBOO is a source of discharges causing the recorded exceedances; (ii) whether discharges from other sources are causing recorded exceedances; and (iii) whether oceanographic conditions and weather events cause onshore transport of the effluent discharged from the SBOO. In order to assess whether RWQMP data is sufficient, analyses of these data (and associated data) are conducted to evaluate the ability to make these determinations based on the available data.

It is concluded that the RWQMP provides insufficient data to make these determinations, even when combined with other available data. Recommendations are made for improved monitoring, through modifying existing strategies and introducing new strategies. However, it is recognized that it is not possible to have a perfect monitoring program in this regard, and that decisions have to be made balancing incremental water quality benefit against increased monitoring costs.

Assessment

Assessment of the RWQMP is built on the review and analysis of regional circulation, plume behavior, and beach/kelp bacteria concentrations.

Coastal ocean circulation:

Both SBOO and land-based discharges are injected into a system of coastal, nearshore and surfzone currents. This underlying circulation pattern is a primary determinant of the destination of plumes of bacteria-rich water.

The coastal waters off Imperial Beach exhibit strong thermal stratification in summer, due to the juxtaposition of sub-surface upwelling with surface warming. In contrast, during winters, these shallow waters are typically well mixed. Alongshore currents are most often southward and these flows likely induce localized upwelling of cold sub-thermocline water that accounts for the colder surface temperatures observed to the south of Point Loma throughout spring-summer-fall. Further, summer thermoclines are observed to slope upward to the coast on many occasions, which may allow intrusions of cold sub-thermocline waters into the nearshore when there is internal tide activity or sea-breeze forcing. These high-frequency processes may enhance the onshore and upward flux of sub-thermocline waters in this region.

Alongshore currents may flow through the Coronado embayment, or, alternatively result in a “gyre” circulation within the embayment - with either clockwise or anti-clockwise circulation. This circulation pattern accounts for about 20% of the variability and may result in either offshore or onshore flows in the vicinity of the SBOO. Onshore/offshore currents resulting from tides are also observed in the region, however, these are short-lived (few hours) and excursion lengths are only 1-2 km. This contrasts to more persistent gyre and alongshore currents with average speeds of about 10 cm/s excursion lengths on the order of 10 km. These flow patterns are evident in CODAR surface current data, with gyre-related off/onshore flows being observed close to the shoreline.

Nearshore waters reflect the effect of these offshore circulation patterns. Tidal currents also account for alongshore transport nearshore, but with shorter duration. Further, alongshore wave-driven currents may be strong in the surfzone. However, little data exists to assess the impact of nearshore circulation on SBOO and land-based plumes.

The foremost limitation of existing data on coastal ocean circulation is the absence of observations at a frequency high enough to resolve the essential temporal variability: tidal, wind-driven, and offshore flow features. The regional coastal circulation is not effectively monitored through existing efforts and the time-dependent direction of plume transport is mostly unknown, for both SBOO and land-based plumes. While providing a regular time-series of ocean properties in the region, the monthly ocean surveys do not provide information on plume behavior owing to inadequate resolution of spatial structure and temporal variability.

Plume behavior:

The SBOO discharges about 25 MGD at 28-m (92 ft) depth, and a distance of 5.6 km (3.4 miles) offshore. The height of plume rise and the level of dilution achieved in the initial mixing zone are primary determinants of the fate of the discharged wastewater, along with current speed and direction.

Monthly monitoring of plume parameters, including temperature, salinity, light transmission and FIB levels, provide snapshots of plume shape and direction. However, the sparse nature of the survey grid, the long time taken to complete surveys, and the infrequent nature of these surveys are problematic in interpreting the data. Thus, although these data function in a regulatory sense to establish compliance, they have minimal value in determining typical plume trajectories or cause and effect relationships between the river, outfall and beach bacterial levels.

Analysis of observed bacteria levels offshore shows that the wastewater plume surfaces frequently in winter and can even do so in mid-summer, during periods of strong upwelling (when the water column becomes isothermal at the 30m isobath).

Models of the outfall discharge using input of monitoring data on stratification and mean currents are consistent with observations from the monitoring program. These results are promising for using real-time data on water properties at the outfall for predicting plume behavior through a combination of near-field modeling and trajectory analysis using CODAR data.

Modeling the initial mixing of the plume is also valuable in obtaining estimates of dilution rates. Direct field observations are not obtained on a scale small enough to map the plume effectively, and thus dilution estimates cannot be properly placed within the context of the discharge plume. The plume model indicates that a dilution of 200-400 is typically achieved in the near-field. Based on estimates of the bacteria concentration in the outfall pipe, and some observations of bacteria concentration in the already-diluted plume, it is estimated that a further 10-100 fold reduction in concentration is needed before this water can enter beach/kelp waters without causing an exceedance. This reduction would have to occur through a combination of mortality and dilution/mixing, and is greater than what is observed at other outfalls.

A review of aerial imagery of plume patterns suggests that the SBOO plume may be narrow (i.e., limited in cross-stream extent), and at times narrower than the distance between stations in the survey grid. This suggests that the offshore survey of FIB levels (and other water properties) may entirely miss the wastewater plume at times. Further, the plume may be limited in vertical extent and, with just 3 FIB samples through the water column, it may be missed at certain stations.

Although water properties that have been used in other cases to track sewage plumes were not successful here, other tracking methods show promise, including satellite and aerial imagery. For these to be used to their best advantage, however, more must be known about the water properties at the time the images are obtained.

The SBOO plume can be transported onshore by a branch of the regional circulation, by wind forcing after surfacing of the plume, and/or by upwelling due to wind forcing or the action of internal tides. Plume surfacing only occurs when the water column is not stratified or has stratification only very near the surface, typically in winter or during strong summer upwelling events. Alternatively, the plume is trapped in or below the thermocline and these waters can be moved onshore during wind-driven upwelling or through the action of internal tides. While existing data provide no direct observation of beach/kelp exceedances associated with these onshore events, onshore flow is evident and cold water is observed repeatedly at nearshore thermistors.

Beach and kelp bacteria concentration:

Data on fecal indicator bacteria at beach and kelp stations is the basis for defining an exceedance. Throughout the report, AB411 standards are used. While the 30-day geometric mean values are also reviewed, the focus is on single-day standards as this allows for investigation of the relation between high bacteria values and specific environmental conditions.

Beach and kelp monitoring data have been analyzed for 1995 through 2003, with 5755 beach samples and 3068 kelp samples. Eleven beach sites and three kelp sites are sampled weekly, with 3 samples at each kelp site. Exceedances occur in 16% of the beach samples and 5% of the kelp samples, on average. Samples obtained during rain are most likely to be contaminated, with 40% and 13% of beach and kelp samples exceeding AB411 standards during rain events. Higher percentages are obtained in wet years, and lower in dry years. While these weekly data do not resolve the day-to-day nor hourly variations in FIB levels caused by regional or tidal currents, it is expected that the samples are frequent enough to provide an aggregated assessment of the probabilities of beach or kelp exceedances during different weather conditions.

Within a day of rain, FIB levels are high at all stations, but less so with distance away from Imperial Beach stations. For some days after rain, or during periods of river flow in the absence of rain, exceedances are tightly clustered around the mouth of Tijuana Estuary, consistent with this a major source. At beach stations, half the observed exceedances are associated with rain events, and a third are associated with river flow (in the absence of rain).

Events related to neither rain nor flow (dry weather events) are less common, accounting for about 1 in 6 exceedances at the beach. Further, the chance of a dry weather sample exceeding standards is only 6%. These events are primarily during summer and they occur mostly at the border station and stations south of the Mexico-US border. There is no direct evidence of an outfall contribution to beach exceedances, but monitoring data is insufficient to be able to determine that there is no contribution. Further, there is an assocation between beach exceedances and wave, wind and tide conditions. This would be consistent with alongshore transport from land sources, suggesting that land runoff dominates exceedance events in dry weather periods as well. Elevated bacteria appears to be associated with south swells, with south winds, and (immediately north of Tijuana Estuary) with tidal outflow and alongshore advection.

At kelp stations, there is a similar association of exceedances with rain and flow events, suggesting that land-based sources also dominate the contamination of nearshore waters.

Only one-in-ten exceedances occur during dry weather conditions, and dry-weather samples only exceed standards 1% of the time. The highest levels of FIB concentration are observed at the kelp stations closest to the shore. At the more offshore kelp station, high FIB concentrations are observed at mid-depth on a few occasions, with concurrent temperature data indicating that this is in the lower thermocline. The pattern of these events suggests that these may be observations of an onshore intrusion of the SBOO plume. This suggestion needs to be verified with additional data.

Highest levels of FIB are observed at beach stations near the mouth of the Tijuana Estuary, indicating that this is a major land-based source. FIB levels to the south of Tijuana Estuary tend to be higher than to the north, specifically during dry-weather conditions, and high levels persist for longer periods following a rain/flow event. This points to the additional sources in the south, including possible effects of Los Buenos Creek.

The dominance of land-based plumes in beach and kelp exceedances suggests that enhanced nearshore monitoring efforts would yield the greatest benefits in terms of water quality improvements and public protection. Further, although the analyses in this report indicate an association between rain/flow and beach contamination, the available data are insufficient to determine the source. The same circulation patterns that transport land-based plumes northward can carry the surfaced SBOO plume onshore and northward.

Recommendations

The three primary issues of concern – coastal ocean circulation, plume behavior, and beach/kelp exceedances – lead to three sets of recommendations, but with substantial overlap. There is also overlap and synergy with priorities of other agencies in the region.

The focus of these recommendations is on improving the skill of monitoring efforts in identifying links of outfall and land-based plumes with exceedance of bacterial standards at beach and kelp stations. Given that most exceedances are related to land sources, some of the recommendations relate more to nearshore problems than to the SBOO.

General recommendations:

1. Coordinate with other agencies;
2. Develop a regional monitoring program;
3. Redesign monitoring locations and times;
4. Allocate resources for data analysis and interpretation;
5. Conduct special studies as a basis for monitoring.

The recommendations given here are not only recommendations for the IBWC as these data are also valuable to other agencies. There is a need for collaboration. Further, it is recommended that regulatory agencies review the compliance monitoring requirements in light of this report and that a dialogue ensues in which the RWQMP pursuant to the NPDES permit is adapted in addition to monitoring that will be supplemental to the NPDES requirements.

In the following listing of specific recommendations, only the highest priority items are noted.

Coastal ocean circulation:

1. It is recommended that time-series observations be obtained through deployment of moorings in the vicinity of the SBOO. These are high priority recommendations, specifically a mooring at the SBOO and a nearshore mooring between the SBOO and the shore. These moorings would provide high-frequency data on currents and temperatures through the water column. Further moorings are also recommended, and it is recommended that these moorings are designed and deployed in coordination with other agencies with interest in circulation in the South Bay region.

2. A second high priority recommendation is to conduct plume mapping (special study) in which the plume would be mapped until a variety of conditions. This should be done at a time when mooring data are available, as this mapping will provide a basis for analysis and interpretation of mooring data.

3. It is recommended that the monthly station-based boat surveys are replaced by tow surveys, allowing a synoptic view of plume and ambient structures. If the station-based surveys are continued, it is highly recommended that the station locations and survey extent be revised to allow for temporally synoptic and spatially coherent surveys. The aims of synopticity and coherence can best be achieved through collaboration with others. Further, it is recommended that bacteria sampling depths are standardized.

4. Aerial data during surveys is highly recommended. Further, it is recommended that a special study be conducted to develop a clearer relation between aerial data and in situ water properties and plume structure. This would provide the basis for proper interpretation of aerial images.

Plume behavior:

1. It is highly recommended that a plume model is run in real-time. In support of this, the mooring at the SBOO is again highly recommended. The combination of mooring data and plume model will yield continuous information on height of plume rise, dilution level achieved, and initial direction of plume trajectory.

2. The strong recommendation for a special plume mapping study is repeated.

3. It is recommended that the radar measurements of surface currents be continued. These data are invaluable during periods when the plume may breaking the surface. Further, this is very valuable input for a multi-agency program defining regional circulation.

Beach and kelp bacteria concentration:

1. The strong recommendation for a nearshore mooring is repeated. In addition to information on coastal circulation patterns, this mooring could provide direct observations of tidal and wind-driven flows that transport land-based contamination alongshore. Further, this mooring can be equipped to obtain local wave observations that can allow for much-improved estimates of wave-driven longshore transport of contamination in the surfzone. These estimates should be validated with a special study of currents in the surfzone.

2. It is highly recommended that a Tijuana plume mapping special study be conducted. This study should address both larger rain-induced plumes and smaller tidal plumes.

3. It is highly recommended that concurrent beach, kelp and offshore bacteria samples are obtained, allowing for links to be identified between surfzone, nearshore and coastal distributions. Further, it is highly recommended that temperature and salinity data are obtained with every sample from beach, kelp or offshore sites.

4. It is recommended that SBOO-related beach sampling is coordinated with sampling by the County of San Diego and other organizations in the US and Mexico.

Further recommendations and details are provided in Chapter 7 of the report.

Chapter 1

Introduction

1.1 Aims and Objectives

This report is a review of the existing monitoring related to the wastewater plume emanating from the South Bay Ocean Outfall (SBOO). It sets out to address the adequacy of the present outfall monitoring program in determining whether fecal bacteria discharged through the outfall are the cause of exceedances of state water quality standards at the beach.

This review fits into a broader context of recurrent water quality concerns in the nearshore waters off Imperial Beach (Figure 1.1). Similar fecal bacterial contamination is observed off other high-density coastal metropolitan areas in southern California (Los Angeles, Orange and San Diego Counties) and worldwide.

The specific focus of this review is to address the problem as it appears through present-day regulatory monitoring. However, this is placed in a broader context, allowing for a better understanding of the more general issue of pathogenic material in coastal waters off Imperial Beach.

Within the overall goal of contributing to the restoration and maintenance of good water quality along our coasts, and of precluding deleterious impacts of pollution on human or ecosystem health, this report is written to achieve two specific aims:

1. Provide a review and assessment of issues raised in the consent decree.
2. Provide a synthetic overview of available oceanographic and monitoring data relevant to questions about the possibility that bacteria-rich wastewater may be transported into beach and kelp waters.

In pursuing these aims, we have set the following objectives:

- Review both offshore and shoreline monitoring data for baseline period (1995-1998) and since commissioning of outfall (1999-2003).
- Review available reports, analyses, and data on circulation of waters in the coastal region between Point Loma and Rosarito.
- Develop a description of the behavior of the SBOO wastewater plume under varying environmental conditions.

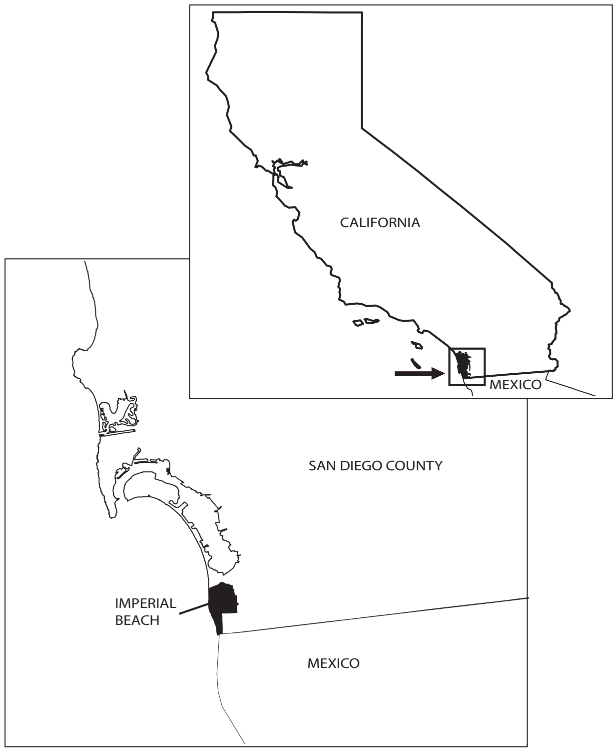


Figure 1.1: Map of study region at Imperial Beach, San Diego, California.

- Develop a description of the location and timing of bacterial contamination of beach and kelp waters off Imperial Beach and neighboring cities.
- Analyze recorded exceedance events in terms of oceanographic and meteorological conditions (to the extent that data allows).
- Assess the adequacy of the SBOO monitoring program in determining whether wastewater discharge is a cause of exceedances of fecal bacterial concentrations at the beach.
- Assess the adequacy of all available data in the region in making this determination.
- Make recommendations on supplementary monitoring, studies and other approaches that would allow for this determination, or improvements in it.

1.2 Beach Water Quality

With the ongoing development of coastal cities the flow of water and water-borne material to the ocean has increased, polluting coastal waters with society's wastes. This pollution has an impact on the ocean ecosystem and on people who derive benefit from it. Recognition of these impacts has led to a concerted effort to reduce the flux of pollutants to coastal waters, with a focus on those constituents that have the greatest impact.

There is no impact that draws more attention than pollution that directly affects public health. Of particular concern are the pathogenic microbes that are contained in wastewater discharged to the ocean and in runoff via natural and constructed channels. The presence of pathogens in coastal waters is routinely monitored through sampling for fecal indicator bacteria (FIB). In California and around the world, such regular bacterial monitoring has demonstrated repeated contamination of coastal waters. Popular beaches such as Imperial Beach are used daily by many people and recurrent water quality problems have the potential of impacting many people. Contact recreation activities include swimming, surfing, kayaking, diving, snorkeling, wading, and fishing - both at the beach and within the kelp beds off Imperial Beach. The impact of fecal contamination goes beyond the possibility of illness as even occasional contamination events will persuade beach users to go elsewhere, leading to a local economic impact that in turn may become a social impact.

The frequent and widespread nature of contamination events in coastal regions worldwide points to large and persistent sources which need to be identified and abated. Several sources of fecal pollution are recognized, including runoff from the land and discharge of wastewater. Once in the ocean, transport, mixing, and biochemical processing determine where these pollutants will be found and at what concentrations. If high concentrations come into contact with key targets (e.g., swimming beaches), then there is significant impact (loss of "beneficial use"). In the case of naturally occurring constituents, such as bacteria and nutrients, the challenge is to mix (dilute) polluted source waters to obtain low concentrations comparable with natural levels.

In any region there are numerous possible sources of fecal bacteria, including wastewater outfalls, stormwater outflows, river/creek outflows, wildlife (birds, mammals) and domestic animals. The flux of fecal bacteria via land runoff (stormwater and rivers) is much greater than was expected prior to regular monitoring. Further, recent studies have shown a tendency for land runoff to remain along the shoreline and spread over distances of a few miles, suggesting that this may be the primary source of beach contamination. Wastewater outfalls are designed to obtain rapid dilution as water enters the ocean at depth, typically sufficient to lower nutrient levels where they no longer pose an ecological threat. However, fecal bacteria concentrations are so high in municipal wastewater that higher levels of dilution are necessary to bring waters into health code compliance before they reach areas of human use. While this additional dilution may be achieved in the "far field" (beyond the initial mixing zone), there is typically inadequate knowledge of local conditions (natural mixing and biochemical degradation) to know if this is achieved and at what radius from the outfall. Recent work in other regions has shown that it is possible that diluted wastewater may enter shallow waters along the shoreline from time to time. Wildlife and domestic animals may also be a significant source of FIB. While pet wastes are increasingly better managed, we do not have that option for wildlife. More attention is needed to differentiate between wildlife and human FIB and, further, to assess the human health risk of wildlife feces in recreational waters. Finally, information on possible groundwater fluxes of FIB is generally lacking, although this is assumed to be a minor source.

There are many other pollutants contained in land runoff and wastewater flows. Some are naturally occurring but excessively concentrated (e.g., nutrients), while others are synthetic compounds (e.g., pesticides). While adequate dilution may be an acceptable approach to the former, this does not effectively mitigate the effects of the latter. Some are a direct threat to human health (e.g., pathogens), while others threaten sustainable use of coastal environments by humans. While the former attracts the hottest attention due to the direct impact on individuals, arguably it is the latter that is a greater threat. In working to identify and address direct human health risks, we should not lose sight of, nor jeopardize, the long-term viability of coastal ecosystems and the myriad of goods and services that they provide us.

1.3 Imperial Beach and The South Bay Ocean Outfall

Recognition of the possibility of contamination of nearshore waters has led to monitoring of many locations along the shores of southern California over the past decades. These data present an unequivocal picture of fecal contamination of these nearshore waters and an urgent challenge to restore their recreational value.

Monitoring of nearshore waters is a combination of County of San Diego DEH weekly monitoring of several sites in accordance with state regulations (AB411) and City of San Diego weekly monitoring of several sites under contract to the International Boundary Water Commission (IBWC), in accordance with federal regulations (NPDES). The County monitoring is used as a basis for action of the Environmental Health Officer in posting the beach as contaminated. The state regulations (AB411: Title 17 of the California Code of Regulations, Group 10) were implemented in 1999. The IBWC data is used as a basis for assessing the impact of the wastewater plume emanating from the offshore outfall. The present outfall-related monitoring program started in July 1995, three and a half years before commissioning of the wastewater treatment plant and outfall in January 1999.

There are multiple potential sources of fecal bacteria along the shores of Coronado embayment (from Coronado to Tijuana, Figure 1.2), including:

- Discharge of wastewater from the South Bay International Wastewater Treatment Plant (SBIWTP) via the South Bay Ocean Outfall (SBOO).
- Contaminated waters from Tijuana River and Estuary (non-point sources and sewer leaks).
- Discharge of wastewater from the San Antonio de los Buenos Wastewater Treatment Plant via Los Buenos Creeek to the surfzone at Punta Banderas, about 5 miles south of the Mexico-US border.
- Contaminated stormwater discharged via local storm drains, runoff and groundwater seepage (non-point sources and sewer leaks).
- Sewer system overflows in Playas/Tijuana, Imperial Beach, Silver Strand or Coronado.
- Discharge of wastewater from the Point Loma Wastewater Treatment Plant via the Point Loma Ocean Outfall (PLOO).
- Shoreline wildlife (most notably birds).
- Other possible minor sources include domestic pets, and contaminated outflow from San Diego Bay.

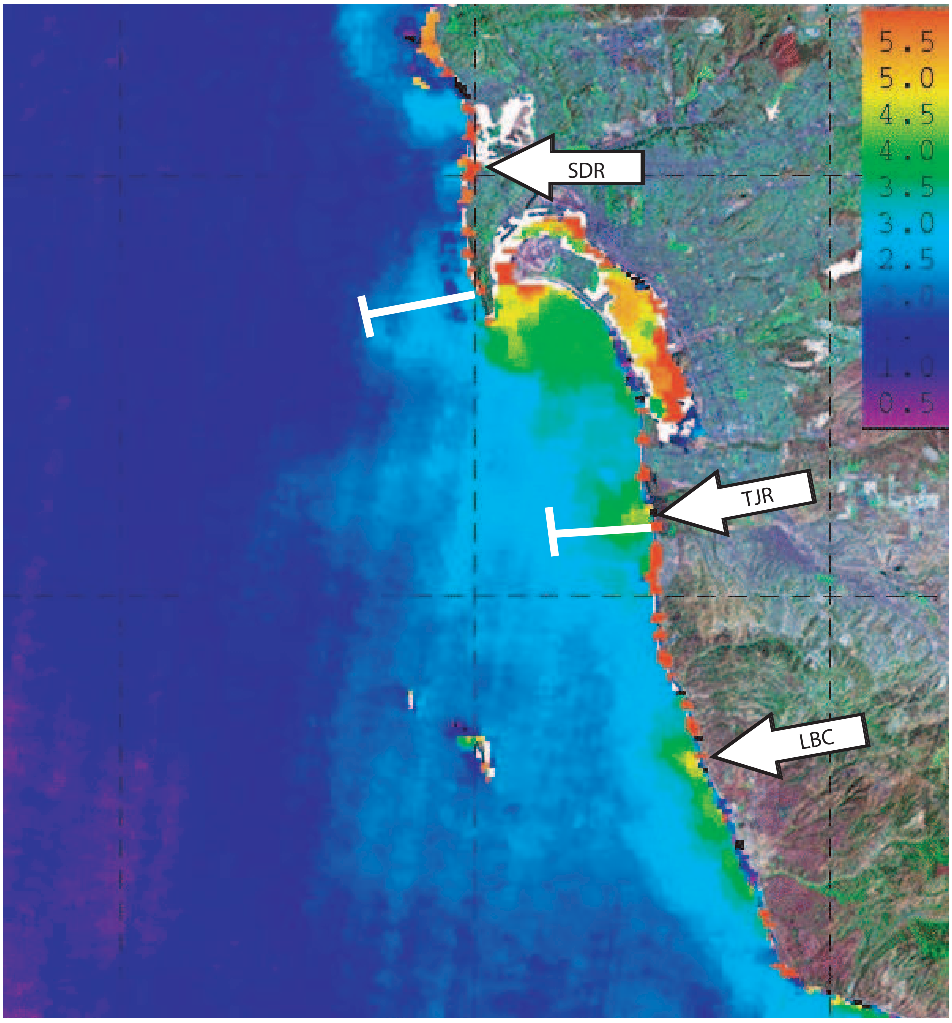


Figure 1.2: Ocean color image of chlorophyll-a with arrows indicating large scale sources of freshwater flux to the San Diego Region. SDR = San Diego River, TJR = Tijuana River, LBC = Los Buenos Creek. Point Loma Ocean Outfall is to north, near SDR and South Bay Ocean Outfall is to south, near TJR. The data are obtained from the Ocean Color Monitor sensor onboard the OceanSat-1 satellite and provided by the San Diego Coastal Ocean Observing System (SDCOOS).

In recent studies of recurrent bacterial contamination of nearshore waters off Huntington Beach (Orange County), *Noble et al.* (2004) identified a similar suite of sources, including major fluxes to the ocean via the Orange County Sanitation District (OCSD) outfall, the Santa Ana River, and multiple smaller conduits for land runoff (e.g., Talbert Marsh). A detailed study of the OCSD wastewater plume could not show that diluted wastewater contacts the beach, but it was shown that this is a possibility. However, in-depth analysis of high-frequency beach FIB data, combined with data from the Santa Ana River, indicates that much of the pattern of high coliform concentrations can be understood as tidal pulses of contaminated water from the river that are subsequently transported alongshore by wave- and tide-driven nearshore currents (*Kim et al.*, In press.).

It is generally accepted that contaminated outflow from the Tijuana River/Estuary will contaminate adjacent beaches and this is shown to be true in Chapter 6, specifically for beaches north of the estuary mouth, consistent with the pattern described for outflow from the Santa Ana River. The focus of the Consent Decree, however, is whether SBOO wastewater may be transported onshore quickly enough and with low enough dilution to result in contamination of beach and kelp waters. In addressing this question, one can start by identifying routes and underlying physical processes by which the wastewater plume, or parts of it, may be transported onshore.

1. Transport of bacteria from outfall to beach involves a sequence of transport stages: To-date studies have tended to focus on a single stage. In linking sources and shore, one needs to give attention to all stages.

2. Plume formation: near-field mixing and plume formation at a level controlled by outfall design and ambient stratification (vertical density structure). These "near-field" processes are the basis of outfall design and they are well represented by existing models. Some monitoring programs track the performance of this near-field mixing and dilution, including determination of whether the plume breaks the surface.

3. Coastal circulation: following formation of the plume, it is transported by the ambient circulation, with little influence of the outfall design and limited further dilution. These "far-field" processes are largely controlled by wind-driven circulation, tidal currents, internal waves, and offshore ocean forcing. The destination of plume waters depends critically on whether they are trapped beneath the thermocline, or whether they are found near-surface.

4. Nearshore circulation: if parts of the plume (diluted wastewater) are transported onshore, this water then needs to be transported through the shallow nearshore waters into the kelp forest or onto the beach. Based on studies off Huntington Beach and Mission Beach, if plume waters are trapped beneath the thermocline then cross-shore transport is primarily due to run-up of internal waves and wind-driven internal motions, as well as occasional widespread subtidal upwelling events. However, if plume waters are near-surface they can be swept into surfzone waters by local wind, tide or wave forcing.

1.3.1 Potential Transport Mechanisms

In addition to analysis of FIB monitoring data, assessment of outfall-beach links can be made through analysis of oceanographic data in terms of evaluating the presence, strength and effectiveness of these transport routes. Towards this end, it is wise to list a full list of transport ideas that have been raised. We have not explored all of these ideas, nor are they all necessarily valid, but they provide a comprehensive framework for our assessment of possible routes for onshore transport of the wastewater plume.

Surface transport mechanisms

Wastewater contaminants can move to the surface either through the buoyancy of the plume water body (inadequate mixing) or through buoyancy of oils and grease contained in the wastewater. Once at the surface, these contaminants can be transported onshore by one of the following processes:

- Onshore surface currents, due to downwelling or a large-scale flow feature, e.g., the anticlockwise gyre found between Point Loma and the Mexico-US border (*Hendricks*, 1990), (Chapter 4).
- Onshore winds and associated surface currents, typically due to the afternoon sea-breeze or on approach of a atmospheric cold front (Chapters 4 and 6).
- Onshore propagating fronts (convergence zones), typically associated with internal waves (*Shanks and Wright*, 1987; *Pineda*, 1993).
- Onshore mixing (eddy diffusion process).

Sub-thermocline transport mechanisms

When the plume and associated contaminants are trapped below stratification (specifically, the thermocline/pycnocline), these contaminants can be transported onshore by one of the following processes:

- Wind-driven upwelling of sub-thermocline waters (*Boehm*, In press).
- Upwelling of sub-thermocline waters associated with remotely forced coastal trapped waves (*Pringle and Riser*, 2003).
- Upwelling associated with alongshore flow past Pt Loma (*Roughan et al.*, in press).
- Tide-driven upwelling and vertical mixing processes associated with San Diego Bay tidal jet (*Chadwick et al.*, 1996).
- Cold swash due to run-up of internal waves or tide or wind-driven setup of thermocline (*Noble et al.*, 2004).
- Vertical mixing and then onshore transport at surface (see above).

In-thermocline transport mechanisms

When the plume collapses within the thermocline, rather than below, contaminants may be transported onshore by:

- Internal wave transport

Bottom-boundary-layer transport mechanisms

Wastewater contaminants can remain at the bottom either through the negative buoyancy of the plume (e.g., desalination brine) or through association with sediment particles (i.e., heavier than water). Sediment associated bacteria may exhibit long-term survival in this dark, cold, and organic-rich environment, allowing for slower onshore transport, which may occur through one of the following processes:

- Onshore transport due to internal waves interacting with the bottom (*Noble et al.*, 2004).
- Resuspension of bacteria-rich fine sediment during onshoreflow events (e.g., in association with upwelling or internal tide pulses).

1.4 The Consent Decree

Ongoing sewage problems in the border region (see Chapter 2) led to a bilateral plan to build the South Bay International Wastewater Treatment Plant. While the outfall may reduce shoreline sources, there is local concern that the plume surfaces and may come back onshore. Recognition that the plant does not currently meet all of the effluent limitations of its NPDES permit led to a suit from the Surfrider Foundation (Surfrider) against the United States Section of the International Boundary and Water Commission, (USIBWC), Case No. 99-CV-2441-BTM(JFS), and a suit from the Regional Water Quality Control Board, San Diego Region (RWQCB) against USIBWC, Case No. 01-CV-0270-BTM(JFS). These were consolidated. The Surfrider suit resulted in Consent Decree No. 99-CV-2442-BTM(JFS), which calls for an evaluation of the Receiving Water Quality Monitoring Program to assess compliance of the publicly owned treatment works (POTW) that is comprised of the South Bay International Wastewater Treatment Plant (SBIWTP) and SBOO. (Text of Consent Decree pages pertaining to this study appear in Appendix A.) This report is directed at an "evaluation of discharges from the POTW as a potential source of bacterial exceedances at the San Diego monitoring stations". This report addresses section C.2.a of the Consent Decree. A related report has been prepared by Science Applications International Corporation (SAIC) to address section C1 of the Consent Decree (*SAIC and R. Smith*, 2004).

In this "Phase One Study", the existing monitoring data are to be evaluated "to determine whether the Receiving Water Quality Monitoring Program generates data sufficient to identify whether discharges from the POTW are a cause of the Recorded Bacterial Exceedances.". Exceedances are occasions when fecal bacteria concentrations exceed compliance standards in the marine environment, notably the State of California AB411 standards. Three specific "Phase One Issues" are identified:

1. To determine whether the SBIWTP is a source of discharges causing recorded exceedances, and if so, the frequency and location of the exceedances caused by those discharges;

2. To determine whether discharges from other sources are causing recorded exceedances, thereby complicating identification of any exceedances caused by discharges from the SBIWTP, and if so, the frequency and location of the exceedances caused by discharges from such other sources;

3. To determine whether oceanographic conditions and weather events cause onshore transport of the effluent discharged from the SBOO, and if so, to what extent.

Further, if this assessment determines that the RWQMP "does not generate data sufficient to determine the Phase One Issues", the report "shall also set forth recommendations for the design of a scope of work for the Phase Two Study". The Phase Two Study will provide recommendations for supplemental monitoring (i.e., monitoring in addition to the RWQMP pursuant to the NPDES Permit).

1.5 Overview and Approach

This report addresses the adequacy of the RWQMP in determining whether exceedances at beach and kelp stations are due to SBOO discharge. The compliance aspects of the RWQMP have been reviewed in a separate study (*SAIC and R. Smith*, 2004). With a focus on beach and kelp water quality, we have conducted analyses of the monitoring data to determine what information it can provide about sources, causes, and patterns of exceedances.

In order to put the Phase One Issues in perspective, we have posed a set of broader questions about how the outfall plume waters may come ashore. This set of fundamental questions, practical questions, and mechanistic questions have been used to inform and guide our review and assessment of Phase One Issues. While this study does not fully answer all of these questions, they form a basis for both the assessment and recommendations called for in the Consent Decree.

Fundamental question: Does wastewater come ashore?

- Do fecal bacteria from the SBOO cause exceedances - either alone or through combination with other sources?

- Do fecal bacteria from the SBOO come ashore, but only at times when large bacteria loads come from elsewhere as well, so that removal of the SBOO source would not remove exceedances?

- Do fecal bacteria from the SBOO come ashore, but only in concentrations below state standards?

Practical question: Can one tell if FIB-rich wastewater comes ashore?

- Can the RWQMP and other existing data tell us when the plume enters kelp and beach waters?
- Can the RWQMP and other existing data tell us when the plume does not enter kelp and beach waters?
- If events can be identified, can we do this in real-time?
- If events cannot be identified, can we assess the probability of the plume entering kelp and beach waters?

Mechanistic question: What transport patterns could bring plume waters ashore?

- If monitoring data shows exceedances due to the plume, can we tell how the plume is transported onshore?
- If monitoring data does not show exceedances due to the plume, can understanding of water motions be used to assess the possibility or probability that exceedances occur at other times or places?

1.6 Assumptions and Limitations

This study is an evaluation of the RWQMP, based on available information and data. The focus on whether monitoring can assess the impact of the SBOO on beach and kelp water quality fits within broader issues of coastal pollution and public health. This study is conducted within the constraints of the objectives and with the limitations as described below. Much of the information presented in this report has been taken as given, with no independent corroboration of facts and figures nor examination of the validity of criteria such as FIB standards. In particular,

- We have taken the numeric AB411 standards as appropriate indicators of acceptable health risk. See Chapter 2.
- In these analyses, we have used the word "exceedance" in the context of AB411 standards, and we primarily use it to refer to a sample that exhibits FIB concentrations exceeding single-day standards, as decribed in Chapter 2.3 (i.e., TC$> 10,000$; FC> 400; Ent> 104). However, it should be noted that the SBOO was designed to meet standards in the California Ocean Plan, which remain the standards for the current NPDES permit for the SBOO. Presently, COP does not include standards for enterococcus.
- We have based our understanding of the functioning of the SBIWTP and the design of the SBOO on published reports, interviews with IBWC personnel, and information available on the IBWC website.
- We have assumed that all reports cited in this study have been professionally prepared and that they are thus credible, valid, and based on professional judgment. We have taken the results of standard culture tests for total coliform, fecal coliform and enterococcus as meaningful and comparable numbers that relate to number of organisms in a given volume of water.

Further, the available data are not exhaustive and there are limitations to these data sets. In particular,

- FIB samples are obtained weekly at pre-determined stations and these data preclude the resolution of FIB variability at the shorter time or space scales that one may expect to see in higher resolution data.

- The infrequent sampling of a highly variable parameter can result in many events not being observed, including some or all of the chronic events. For example, weekly sampling cannot identify events shorter than a week. If the time scales of FIB variability are approximately one day, then weekly sampling catches approximately 14% of events, whereas if variability is dominated by tides then weekly sampling captures 7% of events, and if variability is dominated by rip currents and internal waves with time scale of about an hour, this weekly sampling captures less than 1% of events.

- Covariance between multiple independent parameters is expected, precluding full statistical isolation of different causes of FIB exceedance.

- Statistical distributions of FIB values are not log-normal and this precludes meaningful use of parametric statistics to infer causality in many cases.

- There is incomplete information on the statistical nature of FIB variability so that the percentage of time that events are observed may not be a valid estimate of the percentage of time that events occur.

In addition to limits in sources of information and in data sets, we are limited by the absence of some data and by our own expertise. For example,

- We have limited information on the association between FIB levels and pathogenic microbes in our study region.

- We have limited information on the association between FIB levels and illness in our study region.

- We have no data on the micro-scale distribution of FIB in water, specifically we have no data on the association of FIB with fine particulate organic matter.

- We have little quantitative information on FIB ecology and mortality in coastal waters and we have made no assumptions about decay time scales (T-90 rates) in this assessment of outfall effects.

- Our expertise lies in coastal oceanography, including currents, transport, dynamics, and spatial distributions.

- We have prior experience in the study of oceanographic questions related to FIB transport from ocean outfalls.

In this study, we have endeavored to take a broad approach to the core questions. However many related topics have not been addressed. For example,

- We have not addressed sources, transport or distributions of nutrients, biological oxygen demand (BOD), toxic substances, or other pollutants.

- We have not assessed the adequacy of FIB monitoring as a warning strategy to protect public health.

- We have not assessed the adequacy of the SBOO in terms of compliance (permit obligations).

1.7 Report Outline

This report is based on an analysis of monitoring data from the RWQMP, combined with plume modeling and analysis/review of oceanographic data from a variety of sources. The approach has been to avoid in-depth theoretical discussion or statistical analyses in the report. Further, many of the plots of data are collated in appendices in the interests of presenting a shorter and more readable report.

Following this introductory chapter, further introductory material on the SBIWTP is presented in Chapter 2 and, prior to the core chapters, a brief review of FIB issues and sources is presented in Chapter 3.

The core of the report is in Chapters 4, 5, and 6 where data are analyzed and results obtained. These chapters focus on three key issues: coastal ocean circulation, outfall plume behavior, and FIB levels in beach and kelp recreational waters. Chapter 4 draws on historical data, surface radar images and monthly RWQMP surveys to develop an overview of water motions and circulation in the study region. It is into this circulation that the SBOO plume is injected and the subsequent transport of the plume is largely determined by this regional circulation. Specific attention is given to times and patterns of onshore transport, either at the surface or beneath the thermocline. In Chapter 5, field data is combined with a computer model of plume rise to assess height and dilution obtained in the near-field. This information is linked to FIB surveys conducted as part of the RWQMP and specific conditions are highlighted, specifically showing when the plume can be expected to break the surface. This information is required to determine if plume surfacing may be occuring that would be relevant to plume transport issues raised in the Consent Decree. Finally, in Chapter 6 the weekly beach and kelp FIB station data are analyzed. Two approaches are adopted. Firstly, exceedances are counted and their distribution in space and time is explored - showing associations with rain and with the Tijuana outflow. Secondly, the patterns of FIB concentration are examined without cognizance of standards. This second approach provides much increased insight on transport processes and the resultant FIB distributions.

The report is concluded with recommendations on improved monitoring (Chapter 7). These recommendations are related to the three primary issues: coastal ocean circulation, plume behavior, and nearshore recreational waters.

Chapter 2

Background of South Bay International Wastewater Treatment Plant

2.1 History of Border Sewage Issues

The Tijuana River Valley and the City of Imperial Beach have a long, legally complex history of bacterial contamination dating back to the 1930's. The City of Tijuana, which lies just south of the US-Mexico border, adjacent to the Tijuana Estuary, has historically been unable to keep up with its rapidly growing population and the demands it places on its sewer and septic systems. Tijuana has neither sufficient facilities to process the quantity of sewage produced by the city nor a complete physical infrastructure to collect what sewage is produced. Both treated and untreated sewage eventually make their way into the nearshore ocean waters. Historically, much of it was transported to the ocean via the Tijuana River.

Many steps have been taken by Mexico in an attempt to remedy the problem. The most notable was the construction of new sewage collection, pumping and treatment facilities in Tijuana. The San Antonio de los Buenos Treatment Plant (SALBWTP) was put into operation in June 1987, with an initial capacity of 17 million gallons per day (MGD). However, Tijuana's population growth has continued to grow faster than the sewage infrastructure and raw sewage continues to enter the Tijuana River. The Tijuana River flows through the City of Tijuana before crossing into United States, 8 km (5 miles) east of the mouth of the Tijuana Estuary. Over the last two decades, much has been done to substantially reduce the amount of untreated sewage entering the river and then flowing through the estuary into the ocean near Imperial Beach. However, after heavy rains, nearshore waters are still contaminated and the Tijuana River is generally considered to be the primary mode of delivery of this fecal contamination (see Chapter 6).

A 1983 study prepared for the Regional Water Quality Control Board (RWQCB) recommended the development of an international wastewater treatment plant in the United States to provide secondary treatment of the sewage from Tijuana, with treated sewage then discharged through an ocean outfall. Agreement was reached on the recommendations, and funding of the construction of treatment facilities was authorized when Congress enacted Section 510 of the Water Quality Act of 1987. On July 2, 1990, the Treaty Minute 283, "Conceptual Plan for the International Solution to the Border Sanitation Problem in San

Diego, California/Tijuana, Baja California" was signed between the United States International Boundary and Water Commission (IBWC) and Mexico's Comision Internacional de Limites y Aguas (CILA) agreeing upon the construction of the secondary treatment facility in the United States. Details of the cost sharing were agreed upon in Minute 296, which was signed in April 1997.

In addition to the treatment plant, Minute 283 contained agreement on a river diversion plan. This diversion of contaminated waters from the Tijuana River to the City of San Diego Metropolitan Sewerage System started in 1991, via the Emergency Connection pipeline that had been constructed to allow for emergency treatment of Tijuana sewage at San Diego facilities. Unfortunately, heavy rain and river flow in January 1993 broke the pipeline connection and once again raw sewage flowed down the Tijuana River, resulting in prolonged closure of the southern portion of San Diego's beaches. The pipeline was fixed within seven months and the river diversion was opened again in September 1993.

The SBIWTP was completed in September 1997 and began discharging primary treated sewage from the SBOO in January 1999, thus providing an additional 25 MGD capacity to treat Tijuana's sewage. The total capacity for sewage treatment in Tijuana was 42 MGD (SBIWTP plus SALBWTP). However, Tijuana grew 62% between 1990 and 2000 and this rapid population growth meant that the amount of wastewater generated by the city was already at or beyond the combined capacity of these two facilities (*Bradley and de la Fuente*, 2003). Estimates of the amount of wastewater produced in Tijuana were approximately 60-65 MGD by the end of 2001 (SWRE, 2001). It has been difficult to obtain precise information on the amount of sewage generated in Tijuana. However, discharge information for February 2004 indicates that influent to Los Buenos Creek is between 20 and 32 MGD and that the total Mexican sewage flow is between 42 and 63 MGD (http://www.ibwc.state.gov/). Population statistics indicate a 2004 population in Tijuana that exceeds 1.7 million people, and estimates that 68 MGD of sewage is produced. However, not all sewage is collected or treated (*Bradley and de la Fuente*, 2003).

State Public Service Commission of Tijuana (1997) includes a proposal to build a parallel conveyance system, with the capacity to carry 50 MGD wastewater to the SALBWTP. Also proposed was an expansion of the treatment plant to 25 MGD. The parallel conveyance system was completed in 2004. Nevertheless, discharge to the ocean at Punta Bandera appears to exceed SALBWTP capacity, indicating that some level of untreated sewage is contained in the Los Buenos Creek outflow. However, it has not been possible to verify or more precisely determine the volume and loading of wastewater discharged to the ocean via Los Buenos Creek.

2.2 The South Bay International Wastewater Treatment Plant and the South Bay Ocean Outfall

The SBIWTP is located on a 75-acre site near the international border and provides for advanced primary treatment of 25 MGD of Tijuana sewage. Initially suggested in 1983, proposed in 1988 and formally agreed to in 1990, plant construction was completed in September 1997. The SBIWTP came on-line after completion of the South Bay Ocean Outfall

(SBOO) in January 1999. Upgrading of the SBIWTP to secondary treatment is planned. The SBIWTP is owned and operated by the International Boundary and Water Commission (IBWC) and both the US and Mexico share in the cost of operation and maintenance of the plant. This plant is operated in coordination with the San Antonio de los Buenos Wastewater Treatment Plant (SALBWTP) in Tijuana.

The SBIWTP is connected to the Tijuana sewer collection system by a 72” diameter pipe and also receives sewage flow from collection systems in Smugglers Gulch, Goat Canyon, and Stewarts Drain. Inflows are mechanically screened and then grit is removed and solids are coagulated through addition of ferric chloride and anionic polymer prior to entering the primary sedimentation tanks. Once the solids have been removed the treated wastewater is subject to low-level chlorination (5-8 mg/l is added and detention time is about 15 minutes) during winter months. This partially reduces the bacterial load in the effluent during times when the plume may potentially surface. Effluent FIB loading is sampled after chlorination, with annual averages of order $40\text{-}100\times10^6$ MPN/100ml for total coliform (see further data in Chapter 5). However, chlorination is only done in winter and at these times the total coliform loads are reduced about 10-fold, resulting in effuent loads of less than 10^7 MPN/100ml. Removal of TSS (total suspended solids) is 75% and BOD (biological oxygen demand) is 45%.

The SBIWTP is connected to the SBOO by a 1.4 km (2.3 miles) land based section of 3.7 m (12-foot) diameter pipe. Although average flows are set at 25 MGD, the SBIWTP peak flow is 75 MGD and the outfall has a hydraulic capacity of 250 MGD by gravity (and 334 MGD with the addition of a pump). The U.S. Environmental Protection Agency (EPA) website on Enforcement and Compliance History lists the SBIWTP as non-compliant in terms of NPDES for the 8 most recent quarters January 2002 through December 2003, this non-compliance being due to toxicity and the absence of secondary treatment.

Effluent from the SBIWTP enters the coastal ocean through a series of ports on the SBOO diffuser at a distance of 5.6 km (3.4 miles) offshore and at a depth of 28 m (93 ft). The SBOO consists of a Y-diffuser with 82 risers along each 1981-foot-long arm and one at the junction. Each diffuser has 4 ports directed radially and horizontally outward beneath a large flange. Present operation users 18 diffusers at the end of the southern arm. Visual observations of the discharge indicates that plumes from individual risers do not immediately merge.

2.3 Monitoring Program and Regulations

2.3.1 Regulations

There are several regulations on the federal, state and local level that were created in order to maintain water quality standards and prevent degradation of our water resources. The regulations associated with these plans that are applicable to this study are detailed in the following sections. However, there are instances of overlap and conflicting definitions of standards between these plans. For the most part, federal and state regulations are more specific for dischargers and the receiving body of water, compared to broader regional and local regulations imposed for water quality objectives in areas with specific use requirements. The three main standards applicable to the South Bay region are: 1) the California Ocean

Plan (COP); 2) the Water Quality Control Plan for the San Diego Basin (Basin Plan); and 3) the Health and Safety, California Code of Regulations, Title 17 (AB411). Each of these contains similar standards for two or more fecal indicators (Total Coliform, Fecal Coliform, and Enterococcus) either as a single-sample standard and/or a 30-day mean standard.

The greatest difference in bacteriological standards imposed in this region is between the state COP regulations (used by the City of San Diego's beach monitoring programs, including South Bay) and the Health and Safety code regulations used by the County of San Diego for their beach monitoring program. This is due to the recent updating of the California Code of Regulations AB411 standards to include US EPA recommendations for use of enterococcus as an indicator of sewage or polluted waters (*U.S. Environmental Protection Agency*, 1986). In the forthcoming 2004 revision to the California Ocean Plan, an ammendment is planned to include an enterococcus standard in the COP as well (*State Water Resources Control Board*, 2004). The Basin Plan also includes single day standards for enterococcus, but differs from the other two codes in that standards for total coliform and fecal coliform are based on a 30-day geometric mean only.

The bacteriological standards in regulatory codes generally apply only to beach or nearshore areas deemed "human water contact areas." The California Ocean Plan has defined these areas to include both beaches and kelp beds. The Regional Water Quality Control Board's San Diego Basin Plan designates water contact areas as any coastal waters that are within the 3-mile zone and outside of the zone of initial dilution (ZID) for sewage discharge (Basin Plan Table 2.3). AB411 is designed for protection of "ocean water-contact sports areas" within which is included "waters adjacent to public beaches and public water contact sports areas." However, we have been unable to determine definitively from any of the regional agencies whether or not the AB411 standards apply to non-beach areas such as the kelp beds. According to the California RWQCB, the method of resolving overlapping regulations in California is that the COP takes precedence over all other state and regional regulations. However, one of the key provisions in the Ocean Plan is that where there is a conflict between the COP and another state or regional policy, the more stringent provision will apply unless an exception has been granted by (*State Water Resources Control Board*, 2001).

To take the more conservative approach, and that being adopted by the California Ocean Plan (which regulates the water quality standards around the SBOO), we have chosen to define exceedances based on the AB411 standards. For single sample Total Coliform and Fecal Coliform these are idential to COP standards, but AB411 has an additional standard for enterococcus. We refer to these standards in our discussion of bacterial data for beaches, kelp beds and ocean stations. Since the applicability of enterococcus standards in kelp and ocean areas is somewhat ambiguous and in flux at this time, use of these standards should not be construed as compliance limits but as a benchmark to discuss elevated levels. Where possible, if AB411 and COP standards might produce different conclusions about exceedances, we have shown the data for each indicator and/or each standard.

Clean Water Act

In 1972 amendments were made to the Federal Water Pollution Control Act (Clean Water Act, CWA) to regulate the discharge of pollutants from point sources into waters of the United States in order to protect the nation's waters. The regulations and permit programs set forth in Section 402 of the CWA are known as the National Pollution Discharge Elimination System (NPDES) which is implemented by the State through a program that has been approved and delegated to the State by the the United States Environmental Protection Agency (US EPA).

California Ocean Plan

The 2001 California Ocean Plan (COP) adopted by the State Water Resources Control Board (SWRCB) and approved by the U.S. EPA sets forth water quality objectives for point source discharges into the ocean in order to "maintain the water quality standards of the downstream waters". Chapter II, Section B. defines the areas and bacterial characteristics in which the water contact standards apply as:

> Within a zone bounded by the shoreline and a distance of 1,000 feet from the shoreline or the 30-foot depth contour, whichever is further from the shoreline, and in areas outside this zone used for water contact sports, as determined by the Regional Board, but including all kelp beds, the following bacterial objectives shall be maintained throughout the water column:
>
> 1. Samples of water from each sampling station shall have a density of total coliformorganisms less than 1,000 per 100 ml (10 per ml); provided that not more than 20 percent of the samples at any sampling station, in any 30-day period, may exceed 1,000 per 100 ml (10 per ml), and provided further that no single sample when verified by a repeat sample taken within 48 hours shall exceed 10,000 per 100 ml (100 per ml).
> 2. The fecal coliform density based on a minimum of not less than five samples for any 30-day period, shall not exceed a geometric mean of 200 per 100 ml nor shall more than 10 percent of the total samples during any 60-day period exceed 400 per 100 ml.
>
> The "Initial Dilution Zone" of wastewater outfall shall be excluded from designation as "kelp beds" for purposes of bacterial standards.

Basin Plan

The Water Quality Control Plan for the San Diego Basin was adopted by the California Regional Water Quality Control Board in 1994 in order to "preserve and enhance the quality of water resources in the San Diego region for the benefit of present and future generations." This basin plan supersedes the 1975 Basin Plan and amendments all of which incorporate the COP by reference. Table 2.3 of the Basin Plan designates the coastal waters (up to 3 miles from shore) of the Pacific Ocean as "REC-1," the designation for contact recreation beneficial use. Chapter 3-5 defines the water quality objectives as:

> In waters designated for contact recreation (REC-1), the fecal coliform concentration based on a minimum of not less than five samples for any 30-day period, shall not exceed a log mean of 200/100 ml, nor shall more than 10 percent of the total samples during any 30-day period exceed 400/100 ml.

For Enterococcus the Basin Plan adopts the US EPA criteria for water contact recreation in marine waters for steady state at 35/100 ml and a maximum of 104/100 ml.

Assembly Bill 411

Assembly Bill 411 (AB 411) amended the Health and Safety Code of the State ofdCalifornia specifically the California Code of Regulations, Title 17, which requires the State Department of Health Services to develop statewide ocean water quality criteria and monitoring regulations due to increasing concern of water quality at public beaches and the nearshore waters. From April to October, all beaches with more than 50,000 annual visitors or beaches located in areas adjacent to storm drains that flow during the summer are required to monitor weekly based on the following bacteriological standards:

1. Based on a single sample, the density of the bacteria in water from any sampling station at a public beach or public water contact sports area, shall not exceed:
   (a) 1,000 total coliform bacteria per 100 milliliters (ml), if the ratio of fecal/total coliform bacteria exceeds 0.1; or
   (b) 10,000 total coliform bacteria per 100 ml; or
   (c) 400 fecal coliform bacteria per 100 ml; or
   (d) 104 enterococcus bacteria per 100 ml.
2. Based on the mean of the logarithms of the results of at least five weekly samples during any 30-day sampling period, the density of the bacteria in water from any sampling station at a public beach or public water contact sports area, shall not exceed:
   (a) 1,000 total coliform bacteria per 100 ml; or
   (b) 200 fecal coliform bacteria per 100 ml; or
   (c) 35 enterococcus bacteria per 100ml.

AB 411 also requires any public beaches or water-contact sports area to meet the physical standards: no sewage, sludge, grease, or other physical evidence of sewage discharge shall be visible at any time.

2.3.2 Monitoring Program

The International Boundary and Water Commission (IBWC) is required to monitor the receiving waters surrounding the South Bay Ocean Outfall under the following specifications: NPDES permit No. CA108928 and Cease and Desist Order No. 96-52 in order to determine compliance with water quality standards. The City of San Diego, Ocean Monitoring Group, Metropolitan Wastewater Department (MWWD) has been contracted by IBWC to perform all the regulatory mandated ocean and surf monitoring associated with the NPDES permit. The frequency and type of monitoring conducted by the City of San Diego MWWD is outlined in Tables 2.3.2 and 2.3.2.

Table 2.3 Receiving Waters Monitoring Program Summary

Monitoring Component	Location	Number of Stations	Sample Type	Number Samples/ Station	Sampling Frequency	Sampling Times/ Year	Number Samples/ Year	Parameters	Notes
Water Quality	Shore (n=11)	11	Seawater - Bacti	1	Weekly	52	572	T, F, E [a]	1 Sample/Station
Microbiology &	Kelp (n=3)	3	Seawater - Bacti	3	5x/month	60	540	T, F, E [a]	3 Depths/Station
Oceanographic		3	CTD	1	4x/month	48	144	CTD Profile 1[b]	1 Cast/Station
Conditions		3	CTD	1	1x/month	12	36	CTD Profile 2[c]	1 Cast/Station
	Offshore (n=37)	25	Seawater - Bacti	3	Monthly	12	900	T, F, E [a]	3 Depths/Station
		37	CTD	1	Monthly	12	444	CTD Profile 2[c]	1 Cast/Station
		28	TSS	3	Monthly	12	1008	TSS	3 Depths/Station
		28	Oil & Grease	1	Monthly	12	336	O & G	1 Depth/Station
Sediments	Offshore (n=27)	27	Grab	1	Semiannually (Jan, July)	2	54	Sediment Constituents [d]	1 Grab/Station
Benthic Infauna	Offshore (n=27)	27	Grab	2	Semiannually (Jan, July)	2	108	Infaunal Community	2 Replicate Grabs/Station
Demersal Fishes & Megabenthic Invertebrates	Offshore (n=7)	7	Trawl	1	Quarterly (Jan, Apr, Jul, Oct)	4	28	Fish/Invert Communities	1 Trawl/Station
Bioaccumulation Fish Tissues	Offshore Trawl Sites (n=7)	7	Trawl	3	Semiannually (Apr, Oct)	2	42	Tissue Contaminants [e]	3 Composite Samples/Station (Liver Tissues)
	Rig fishing sites (n=2)	2	Hook & Line/Trap	3	Semiannually (Apr, Oct)	2	12	Tissue Contaminants [e]	3 Composite Samples/Station (Muscle Tissues)

Table 2.3 Continued

Monitoring Component	Location	Number of Stations	Sample Type	Number Samples/ Station	Sampling Frequency	Sampling Times/ Year	Number Samples/ Year	Parameters	Notes
Sediments	Random array (n=40)	40	Grab	1	Annual (July)	1	40	Sediment Constituents [d]	1 Grab/Station
Benthic Infauna	Random array (n=40)	40	Grab	1	Annual (July)	1	80	Infaunal Community	2 Replicate Grabs/Station

[a] T, F. E = total coliform, fecal coliform, and enterococcus bacteria
[b] CTD Profile1 = depth, temperature, transmissivity (light transmission)
[c] CTD Profile 2 = depth, temperature, transmissivity (light transmission), salinity, dissolved oxygen, chlorophyll a, pH
[d] Sediment Constituents = grain size, total organic carbon, total nitrogen, sulfides, metals (see NPDES permit for complete list of chemical constituents)
[e] Fish Tissue Contaminants = total lipids, metals, PCBs, chlorinated pesticides, PAHs (see NPDES permit for complete list of chemical constituents)
* Sampling effort does not include resamples or QA/QC (duplicate/split) samples

Five major monitoring components make up the sampling effort by the City MWWD and are sampled at different frequencies: 1) water quality; 2) sediment characteristics; 3) benthic infauna; 4) demersal fishes and megabenthic invertebrates; 5) bioaccumulation of contaminants in fish tissues. In our analyses we are only considering the monitoring efforts associated with water quality and will therefore only provide detail on this monitoring component.

Three regions within the study area have unique sampling efforts and will be referred to as the following: 1) shoreline (beach) 2); kelp (nearshore); 3) offshore stations. Monitoring efforts began in July 1995 and extend into the present, though there has been some variation to this scheme throughout the data set. Consistent baseline monitoring began in January 1996 through Dec 1998 to allow for comparison of beach FIB levels before and after commission of the outfall in January 1999.

In order to monitor the potential impact of the SBOO on the nearshore recreational water quality, the City MWWD currently performs weekly monitoring for FIB (total coliform, fecal coliform, and enterococcus), weather conditions, visual observations and materials of sewage origin at eleven shoreline stations and three kelp stations, see Figure 2.1 for locations. Eight, of the active shoreline stations are located on the US side of the border. Stations S9, S8, S12, S6, S11, S5, S10, and S4 are found between the border fence and the Hotel del Coronado. The three shoreline stations located on the Mexican side of the border include S3 and S2 north of Punta Bandera and S0 to the south of Punta Bandera. A combination of treated and untreated sewage is discharged directly into the surf zone via Los Buenos Creek. The three kelp stations are clustered together on the United States side of the border between the Imperial Beach Pier and the Tijuana River mouth between 12 and 20 meters (40-66 ft). Water column profiles of temperature and light transmittance (transmissivity) were also measured at the kelp stations on a weekly basis. Variations to the monitoring program will be discussed further in subsequent sections.

Offshore compliance monitoring consists of monthly measurements of the physical, chemical and microbial water parameters at the offshore stations over a two to nine day sampling period in order to characterize the offshore receiving waters. Water column profiles of temperature, conductance (salinity), dissolved oxygen, pH, chlorophyll a, and light transmittance are measured at all 40 offshore stations. Bottle samples are collected at discrete depths on 28 stations for analysis of bacteria (fecal coliform, total coliform, and enterococcus), total suspended solids, and oil and grease concentrations.

The monitoring area thus covers a cross-border region that extends 20 km (12 miles) into the US and more than 10 km (6 miles) into Mexico, with the southernmost shoreline station south of Punta Bandera. North of the study area lies the prominent headland formation of Point Loma west of the mouth of San Diego Bay. The coastline runs roughly in a north-south direction between Punta Bandera in Mexico and Silver Strand, S8, the second most northerly US station. At Silver Strand, the coastline begins to curve substantially to the west and reaches about 45 degree angle by S9, and approximately east-west on approaching the mouth of San Diego Bay. With the exception of S8, which is located along a state beach, the stations between S9 and S6 are urban in character. The final four US shoreline stations are located within a 5 km (3 mile) stretch of undeveloped land that comprises the National Estuarine Research Reserve and Border Field Park. S5 is located on the north bank of the

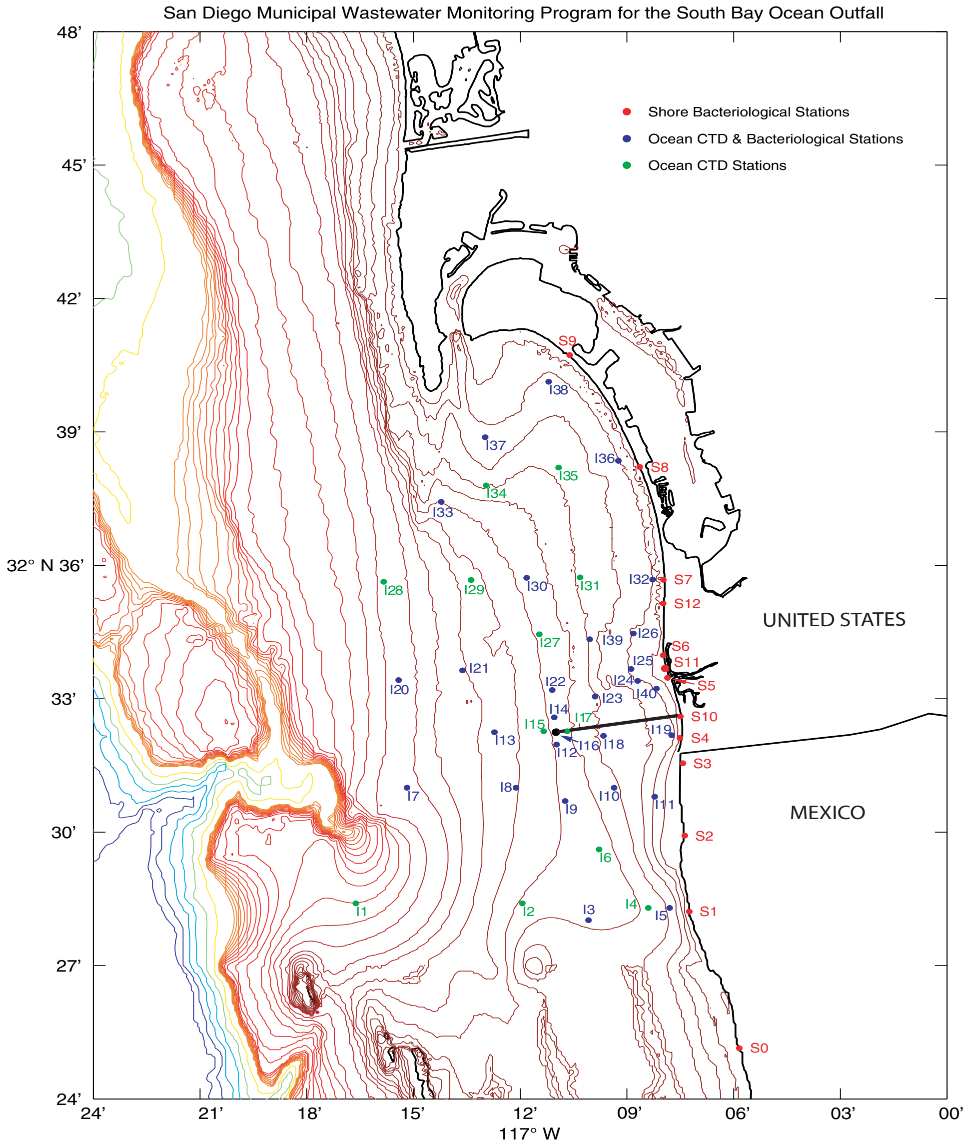


Figure 2.1: Monitoring Stations for the South Bay Ocean Outfall. Depth contours are at 5 m intervals from the shoreline out to 50 m (just inshore of stations I20 and I28), 10 m intervals from 50-200 m, and 100 m intervals from 200-500 m.

Tijuana Estuary, where water from the Tijuana River reaches the ocean. The Tijuana Estuary, located approximately 2.5 km (1.5 miles)north of the border, is a shallow estuary, which typically experiences river flow only during wet winter months.

During the first year of the baseline study, October 1995 - October 1996, all beach stations were typically sampled once a week for all three indicators, with stations S9, S8, and S7 sampled on a different day of the week from stations S6, S5, S4, S3, S2 and S1. In October 1996, a new sampling regime was established, sampling station S7 was discontinued and sampling began at stations S12, S11, and S10, with all stations sampled on a single day of the week for all three indicators . Supplementary sampling also started for additional analysis of total coliform and fecal coliform for all US stations once a week until the end of March 1999. Due to access problems, sampling at station S1 was discontinued in July 2002 and S0 was instated in August 2002, south of Punta Bandera.

Chapter 3

Fecal Indicator Bacteria in Marine Environments

3.1 Basis for Using Fecal Indicator Bacteria

3.1.1 The Fecal Indicator Concept

Originally developed as a method to assess the safety of drinking water the concept of 'indicator organisms' has more recently become the primary method by which recreation waters are tested in order to infer the human risk of exposure to sewage related pathogens. A review by *Griffin et al.* (2001) provides a good overview of the history, utility and associated caveats of the use of indicator organisms employed in microbial water quality monitoring of marine recreational waters. After *Griffin et al.* (2001) the qualities sought in the choice of indicator organisms include:

1. A strong correlation between the presence of indicators and that of other waste related pathogens,
2. The failure of indicators to grow in the marine environment,
3. A higher resistance to disinfection than associated pathogens,
4. Indicators should be easy to isolate and count,
5. Indicators should only occur in the presence of sewage,
6. Indicators should occur in higher numbers than pathogens,
7. Density of indicators correlated with the degree of contamination,
8. Density of indicators correlated to health risk or exposure to pollution.

No single indicator is known to conform exactly to all of these requirements. While researchers continue to search for better indicators, current water quality standards are set by a combination of historical and legal precedents. The indicators required for assessment of microbial water quality in California include total coliform, fecal coliform, and enterococcus. California regulations set thresholds indicating unacceptable bacterial levels for daily measurements and monthly averages (*Noble et al.*, 2000). These groups of indicators are largely defined by response to the culture methods employed to enumerate bacterial levels. Total coliform are gram-negative bacilli that grow at 35 °C after 48 hours (*Griffin et al.*, 2001). Included in the total coliform group are *Escherichia spp*., *Klebsiella spp*., *Shigella spp*., *Salmonella spp*., and *Yersinia spp*. Fecal coliform grow at 45 °C after 48 hours and are considered to be a more selective subset of total coliform that have been shown to be more closely associated in origin with the intestinal tracts of warm-blooded organisms. The fecal coliform group of bacteria is largely composed of the genus *Escherichia spp*. Enterococci are gram-positive cocci that grow at 41 °C after 48 hours and include such bacteria as *Enterococcus faecalis* (*Prescott et al.*, 2002).

3.1.2 Epidemiological Evidence for the Association of Indicators with Health of Bathers

Epidemiological studies have shown increased risk for a number of ailments including gastrointestinal and respiratory illnesses, as well as eye, ear, and skin infections when comparing swimmers to non-swimmers (*Arvanitidou et al.*, 2002). The general approach for epidemiological studies assessing the risk associated with sewage related water borne pathogens involves enumerating indicator microorganisms as proxies for pathogens (*Mugglestone et al.*, 2001). Most studies focus on gastroenteritis, eye infections, skin complaints, ear, nose and throat infections and respiratory complaints. The fecal streptococci and enterococci indicators are most frequently associated with adverse health effects. Health risks have been found to be highest at beaches known to be polluted (*Griffin et al.*, 2001).

Studies by the EPA in the late 1970's and early 1980's set the standards of the acceptable risk model based on the number of swimmers that contracted gastrointestinal illness from marine and freshwater beaches with differing levels of fecal indicator bacteria. The geometric mean standard of 200 fecal coliform per 100 mL relates to 8 illnesses per 1,000 swimmers in freshwater and 19 illnesses per 1,000 swimmers at marine beaches. The acceptable risks model recognizes that every activity entails a certain risk and assumes that most people are willing to accept a low probability of becoming sick from participating in water-related recreation (*U. S. Environmental Protection Agency*, 1986).

3.1.3 FIB Performance for the Prediction of the Presence of Pathogens and Alternative Indicators

Fecal material contains a variety of organisms that are potentially pathogenic to humans including viruses, bacteria, protozoa, and fungi. Researchers and government agencies have been concerned as to how representational existing indicator monitoring standards are in predicting the presence of such pathogenic organisms. Studies have been performed comparing the representational behavior of current indicators with pathogens and alternative indicators.

The risk of human exposure to pathogenic organisms is of most concern when contact is made with untreated or only primary treated sewage. A study by *Payment et al.* (2001)

examined the removal rates of a number of indicator and pathogenic organisms by a facility conducting only primary treatment of waste. Organisms studied included Fecal streptococci, Escherichia coli, Clostridium perfringens, Giardia cysts Cryptosporidium, and human enteric viruses. They found that the process removed no enteric viruses, and that removal rates of the other organisms ranged from 12%-76%.

A number of studies have been conducted comparing how effectively the presence of bacterial indicators correlates with the presence of viruses and comparing the removal rates of indicator bacteria versus enteric viruses. A study by *Beril et al.* (1996) compared the presence of viral and bacterial indicators in cockles. Their aim was to detect enterovirus and hepatitis A. They found that polymerase chain reaction (PCR) was an extremely sensitive technique for virus detection. PCR was significantly more effective than the use of gene probes. Also they found that no correlation could be established between concentrations of fecal coliform and fecal streptococci and virus or viral indicators.

Noble and Fuhrman (2001) performed microbiological assays using reverse transcriptase polmerase chain reaction (RT-PCR) to detect enteroviruses and compare their presence to that of indicator bacteria. They compared 50 coastal seawater samples collected in Santa Monica Bay and found no significant correlation between the presences of enteroviruses and individual standard microbial indicators. However, the correlation increased when the complete set of bacterial indicators were compared to the presence of viruses ($r = 0.71$). They concluded that bacterial indicators were not necessarily good predictors for detecting the presence of viruses in recreational waters.

Wait and Sobsey (2001) conducted both laboratory and field experiments to compare the survival of *Escherichia coli*, *Salmonella typhi*, *Shigella sonnei*, poliovirus type 1 and parvo viruses in seawater. They found that conventional assay methods may often underestimate concentrations of fecal indicator organisms. They used resuscitation and repair plating procedures and found this provided better agreement between survival rates of enteric viruses and bacteria.

Arvanitidou et al. (2002) studied the correlation between the presence of yeasts and filamentous fungi in coastal waters to that of fecal indicator bacteria. They found that the occurence of yeasts significantly correlated with total and fecal coliform, however, they found no correlation between filamentous fungi and bacterial indicators. Yeast and fungi are of particular concern for immuno-compromised individuals.

A study by *Sinton et al.* (1999) compared the rates of sunlight inactivation of fecal bacteriophages with that of bacteria in sewage polluted seawater. They specifically looked at the inactivation of F-specific RNA bacteriophages and fecal coliforms. Their findings showed that the inactivation rates of the bacteriophages were slower than that of fecal coliform and enterococcus. They suggest that bacteriophages may serve as better indicators because of slower inactivation rates.

Another study conducted by *Skanavis and Yanko* (2001) compared *Clostridium perfringens* with traditional indicators in order to determine its efficacy in detecting the presence of sewage solids in marine sediments. They found that C. perfringens spores survive longer than coliforms and are present in higher numbers in the sediment near outfalls. The numbers of standard indicators do not appear to relate well with the amount of sewage solids present. They found minimal differences in the numbers of coliforms and *fecal streptococci* when sediments were only moderately or highly impacted. They concluded that C. perfringes may provide a better indication of the relative volume of sewage solids.

There is evidence that it is possible for fecal indicator bacteria such as E. coli (*Byappanahalli and Fujioka*, 1998) and enterococci (*Desmarais et al.*, 2002) to grow in marine sediments in subtropical and tropical regions. For this reason, other indicators have been sought that will not grow in these conditions. Laboratory and field experiments have compared the regrowth potential of *Clostridium perfringens* with E. coli and enterococci (*Desmarais et al.*, 2002). While E. coli and enterococci did regrow under simulated estuarine conditions, C. perfringens did not. For this reason, it is believed that C. perfringens is a better indicator in subtropical and tropical environments.

3.2 Ecology of Bacteria in Coastal Waters

3.2.1 Survival of Indicator Organisms

The survival rate of fecal indicator bacteria plays an important part in forming the basic assumptions about the fate of sewage in the receiving waters and how long it may persist before physical or biological removal occurs. Fecal indicator bacteria respond to a variety of biotic and abiotic factors affecting decay rates. Furthermore, complex interactions can take place between independent and correlated factors, complicating the process of sorting out the influence any one factor has on bacterial decay rates. Researchers are still trying to determine and model the survival rate of indicator organisms under differing conditions. Ultra violet radiation from sunlight, water temperature, and salinity appear to have significant roles on the inactivation of FIB. However, the issue of understanding decay rates has been complicated by questions regarding the difference between the inactivation, and the ability to culture bacteria. Fecal bacteria can become sufficiently stressed in the marine environment so that they will not culture under standard assays used for enumerating FIB, however, they may maintain cell integrity and a low level of metabolic activity that allow them to become biologically active when more favorable conditions are attained (*KOMEX H20 Science Inc.*, 2003).

3.2.2 Abiotic Factors Affecting Decay Rates

Light

Enteric bacteria, which are adapted to grow within the intestinal tract of vertebrates can be easily damaged by ultraviolet radiation. The short wavelength, high energy portion of the ultraviolet spectrum is most effectively absorbed by DNA (*Prescott et al.*, 2002). DNA is damaged most frequently by the formation of thymine dimmers. If the bacteria are not too stressed, there are a number of mechanisms by which they can subsequently repair the damage inflicted by UV radiation, including photoreactivation and dark reactivation.

Light is considered to be one of the most important stress factors in the removal of fecal indicator bacteria in aquatic conditions (*Kapuscinski and Mitchell*, 1993; *Mayo*, 1995; *Alkan et al.*, 1995; *Burkhardt et al.*, 2000). Sunlight (ultraviolet radiation) was found to have a greater effect on the inactivation of fecal coliform bacteria than potential pathogen indicators, *Clostridium perfringens* and male-specific bacteriophage (MSB), which required 30-50% more light energy for a 50% reduction of initial densities (*Burkhardt et al.*, 2000). The same study found that dark experiments saw no significant change in the densities of fecal and pathogen indicators for up to 34 hours.

Temperature

Temperature affects the metabolic rates of fecal indicator bacteria (*Prescott et al.*, 2002). Survival rates of fecal indicator bacteria do not behave in a uniform manner when exposed to water temperatures above or below those deemed to be optimal for their survival. Furthermore, as water temperatures interact with other conditions, survival rates may increase or decrease at similar temperatures based on these interactions. For this reason it is important to use caution when generalizing from statements made regarding the effect of temperature on survival of indicator organisms. It is important to consider the temperature ranges used in experiments, nutrient and light conditions, and other factors when interpreting the implications from any given study.

A study by *Darakas* (2002) looked at the impact of temperature on of the decay rates of E. coli maintained in suspended media and incubated at constant temperatures. The study found that the optimum temperature for E. coli survival was 10 °C. Bacterial decay rates did not increase quickly for temperatures up to 20 °C, showed moderate increases in decay rates at 30 °C, and had an accelerated decay rate at 37 °C. The length of survival was much shorter for bacteria kept at 4 °C compared to those held at 20 °C.

The study by *Burkhardt et al.* (2000) showed that colder temperatures appeared to make fecal coliforms more susceptible to reduction by sunlight while higher water temperatures require greater amounts of light energy to reduce the initial concentrations, opposite of the conditions required to reduce pathogen indicator, MSB. This experiment looked at indicator microorganisms grown under winter and summer conditions in experimental chambers held in situ at estuarine sites in Alabama and Rhode Island. In Rhode Island, winter temperatures ranged between 1-3 °C, while summer temperatures ranged between 22-25 °C. In Alabama, temperatures ranged between 8-13 °C in winter and 31-32 °C in the summer.

Salinity

The interaction of sunlight and high salinity levels appears to accelerate the rate of bacterial decay for both coliforms and enterococci (*Bordalo et al.*, 2002). Enterococci were found to be more resistant than fecal coliforms to this form of combined environmental stress. Higher levels of fecal indicator bacteria are frequently associated with lower salinity values in marine and estuarine environments (*Pires-Coelho et al.*, 1999; *Lipp et al.*, 2001c; *Bordalo et al.*, 2002). Frequently, however, this association is not indicative of differential survival rates due to the salinity effect so much as indicative of close spatial and temporal associations to sources of fecal contamination or events such as storm induced runoff. It is therefore important to understand the source of a fresh water signature before inferences can be drawn relating to the decay rates of fecal indicator organisms in this environment.

pH

Enteric organisms are adapted for survival in a slightly acidic environment, approximately a pH of 5.0 (*KOMEX H20 Science Inc.*, 2003). A study modeling the mortality of fecal coliforms in waste stabilization ponds found that a pH over 9.3 leads to rapid acceleration in decay rates (*Mayo*, 1995). Seawater generally ranges between 7.5 and 8.5 with a typical pH around 8.0. It is believed that the pH of seawater is high enough to contribute to some extent to increased decay rates of indicator organisms.

Hydrostatic pressure

Fecal indicator bacteria are generally associated with organisms that spend most of their lives on land or in surface waters. These bacteria are usually subjected to pressures close to 1 atm. Hydrostatic pressure in the deep-sea can reach 600 to 1,100 atm. Bacteria are fairly adaptable to extreme hydrostatic pressure (*Prescott et al.*, 2002). Studies of enteric bacteria incubated under simulated deep-sea conditions with hydrostatic pressures up to 1,000 atm showed that highest pressures negatively affected survival rates of these organisms (*KOMEX H20 Science Inc.*, 2003). Both E. coli and S. facalis showed greater survival rates at 250 and 500 atm than at 1,000 atm.

Turbidity

Increased turbidity levels are often associated with detection of higher levels of fecal indicator bacteria (*Alkan et al.*, 1995; *Pires-Coelho et al.*, 1999). An increase in turbidity is can result from storms *Pires-Coelho et al.* (1999) and higher levels of tidal resuspension of sediments (*Streets and Holden*, 2003). The depth of light penetration within the water column is decreased in turbid waters which can slow the rate of UV damage experienced by bacteria during daylight hours (*Alkan et al.*, 1995).

3.2.3 Biological Factors Affecting Decay Rates

Organic material and sediment associated survival

Sediments, particularly those with high organic content and small particle size, provide a more hospitable environment to fecal bacteria and can contribute to their survival (*Craig et al.*, 2002). Enhanced nutrient levels in seawater can increase survival and even lead to growth of fecal indicator organisms (*KOMEX H20 Science Inc.*, 2003). Fecal coliform and enterococci bacteria were found to accumulate in sediments 2 to 4 orders of magnitude higher than in the overlying water column in Boston Harbor, Massachusetts (*Shiaris et al.*, 1987). A recent study in Bodega Bay, California investigating the potential sources of bacteria to Campbell Cove found multi-indicator exceedances in the sediments ranging between 2 and 10 orders of magnitude higher than the overlying water column concentrations.

Predation

Fecal matter contains a combination of organisms including bacteria, protozoas, and viruses (*Jimenez-Cisneros et al.*, 2001). Both protozoa and coliphage viruses can lead to declines in bacterial abundance (*Prescott et al.*, 2002; *KOMEX H20 Science Inc.*, 2003). Protozoa directly prey on bacteria. Coliphages may infect fecal indicators such as E coli, though it is not known how active bacterial phages are in sea water (*KOMEX H20 Science Inc.*, 2003).

3.2.4 Variability of Fecal Indicator Bacteria

Accurate die-off rates are required in order to understand the fate of fecal indicator bacteria in the environment. However, since indicator bacteria respond to a variety of biotic and abiotic controls that interact in complex manners it is impossible to apply a single decay rate or to develop universally effective models for explaining the decay rates of indicators in all systems. Instead, it is important to be aware of the factors that influence the survival of bacteria under different environmental conditions.

Fecal indicator bacteria have been shown to vary on a wide variety of time scales of minutes to hours in the surf zone (*Boehm et al.*, 2002b), on a seasonal basis (*Bagde and Rangari*, 1999; *Lipp et al.*, 2001c), and even on decadal time scales (*Boehm et al.*, 2002b).

High frequency variability: less than a day-daily variability

On very short-term times scales (minutes to hours) bacterial counts can demonstrate fluctuations in concentration. High frequency variability of enterococci in the surf zone was found during two 12 hour studies where samples were collected every 10 minutes at Huntington Beach between 6 stations (*Boehm et al.*, 2002b).

Factors such as the day night cycle and tide cycles also contribute to observed temporal variability at given sites. A number of studies have demonstrated the effect of the day night cycle. Higher concentrations of FIB from water samples in Avalon Bay were found in the evening samples when compared to daylight hour samples (*Boehm et al.*, 2003). Beach water quality samples from Huntington Beach collected from the surf zone in the early morning had total coliform concentrations double the amount of those from the early afternoon (*Boehm et al.*, 2002b). Overnight sampling near the mouth of the Santa Ana River showed an increase in the FIB as the night progressed (*Orange County Sanitation District*, 1999). Twenty-four hour sampling during spring tides showed the highest FIB values were occurring at night with enterococci having a pronounced relationship with sunrise versus sunset (*Noble et al.*, 2003). While this pattern may be due to transport, it is more suggestive of day-night differences in survival.

Mid frequency variability: week to months

Mortality rates for total coliforms and fecal coliforms were not constant over time and were found to decrease faster in the first 7 days (2-log removal) than in the second 7 days (3-log removal), and require a second or third order equation to accurately model die-off. Yet when compared to the mortality rates of *Giardia lamblia*, the fecal indicator bacteria largely under predict the removal times of this pathogen, which requires one month for 3-log removal (*Easton et al.*, 1999).

During summer, cooler than average waters caused by interannual variability in sea surface temperature (SST), synoptic upwelling, and tidal-period cooling are coincident with elevated levels of microbial pollution in the surf zone. This relationship can be explained by the effects of the weakening in stratification on the fate of a wastewater plume and the prolonged persistence of fecal indicator bacteria in colder waters (*Boehm*, In press).

Low frequency variability: year-to-year variability

Changes in population, land use, sewage disposal methods and other such factors can contribute to differences observed in bacterial concentrations over longer time scales (*Boehm et al.*, 2002b). Other factors such as El Ninos and La Ninas and the consequent year-to-year shifting in precipitation patterns also can contribute to year-to-year variability in the frequency and timing of bacterial loading along coastal waters (*Lipp et al.*, 2001a).

3.3 Sources of Fecal Indicator Bacteria

3.3.1 Point Source Pollution

Point source pollution is defined as the release of inadequately treated municipal wastes and other material from a specific location into a body of water such as a stream or river (*Prescott et al.*, 2002).

Ocean outfalls

Ocean outfalls have been developed to alleviate the shoreline pollution that would occur if wastewater from sewage treatment facilities was released closer to the shoreline (*Taylor et al.*, 1998; *Roberts*, 1998; *Smith et al.*, 1999). Typically wastewater from ocean outfalls is released up to 10 kilometers offshore at water depths on the order of 10 to 100 meters. Wastewater is typically released from diffusers allowing for intense initial mixing of effluent. The primary mixing mechanism is buoyancy-induced turbulence in the "near-field area". The vertical boundary of the "near-field" area is generally defined by density stratification or interaction with the free surface of the ocean (*Roberts*, 1998). The area beyond the near field is known as the "far-field". Here the mixing rate is much slower and the waste field is free to drift with the ocean current.

Ocean outfalls are frequently thought to be far enough offshore to prevent contamination of shallow nearshore waters and the shoreline. *Taylor et al.* (1998) looked at the water quality associated with eight outfalls in British Columbia and found that while coliform levels were sometimes elevated directly above the outfalls, the bacterial levels remained lower than those considered unsafe for recreational contact. The study found no indication that wastewater from the outfalls was impacting the shoreline. In a study of modeled water quality conditions associated with outfalls off Oahu, Hawaii (*Roberts*, 1998) found no evidence that the outfall was impacting shoreline water quality. A more recent study examined the outfall from Orange County Sanitation District, located near Huntington Beach, California and could not eliminate the possibility that the outfall was a contributor to poor water quality along the shoreline (*Boehm et al.*, 2002a; *Noble et al.*, 2004). The results of the studies indicate that cold water was regularly being advected in a cross shelf direction under the action of internal tides (see Section 4.4.1). They found that internal tides may serve as a potential mechanism of transport of wastewater from the ocean outfall towards Huntington Beach .

Point Loma Outfall

The Point Loma Wastewater Treatment Plant (PLWTP) opened in 1963. The PLWTP currently treats approximately 180 millions of gallons of water per day for more than 2 million residents of the San Diego area (*http://www.sannet.gov*). Wastewater from the PLWTP is discharged through the Point Loma Ocean Outfall (PLOO). When the PLOO was originally built, it was located 3.5 km (2 miles) offshore in water 60 meters (197 ft) deep (*Stebbins and Byrne*, 1999). In the early 1990s the PLOO was extended 3.8 km (2.4 miles) offshore to prevent the intrusion of the wastewater plume into near shore waters. This was done in order to comply with the California Ocean Plan. The extension of the outfall was completed in November of 1993. The current outfall is located 7.2 km (4.5 miles) offshore in water that is 94 meters (310 ft) deep . Wastewater is released through a Y shaped multiport diffuser system.

Prior to 1994, the outfall monitoring was focused around the original discharge site. Once the extended outfall came on line, monitoring was modified and expanded to accommodate the new deepwater outfall site. Present sampling takes place from La Jolla to Imperial Beach. This monitoring overlaps with some of the monitoring stations for the South Bay Ocean Outfall (SBOO). Factors that are monitored include ocean conditions, microbiology, sediment characteristic, benthic infauna, demersal fishes and mega benthic invertebrates. Microbiological monitoring includes weekly sampling of nine shore stations. Kelp stations are sampled weekly, and 27 offshore stations are sampled on a monthly basis.

South Bay Ocean Outfall

The South Bay Ocean Outfall (SBOO) is described in Section 2.2. Briefly, the SBOO has been in operation since January 1999. It discharges advanced primary treated wastewater from the South Bay International Wastewater Treatment Plant (SBIWTP), which process up to 25 MGD. The City of San Diego Wastewater Department is contracted by IBWC to monitor the recieiving waters for the impacts of releasing effluent from the SBOO on similar spatial and temporal scales as those conducted for the PLOO.

3.3.2 Surf Zone Outfall

Outfalls that release wastewater in rivers or at other sites close to the shoreline are frequently significant sources of coastal pollution (*Taylor et al.*, 1998; *Al-Muzaini et al.*, 1999; *Smith et al.*, 1999). A study in Kuwait showed exceptionally high fecal coliform counts near an outfall that released sewage into Shuwaikh Harbor (*Al-Muzaini et al.*, 1999). Wastewater concentrated near the site of the outfall. Only at high tide was water flow found to be sufficient to advect effluent offshore. A study in Galway, Ireland showed that when transport conditions were favorable, that the river outfall in this area was impacting shoreline sites at least 4.3 km away (*Smith et al.*, 1999).

Punta Bandera

The treatment plant at San Antonio de los Buenos has been in service since 1989. It was built with a capacity to treat 17 MGD of sewage. The components of the system include grit removal channels, an influent pump station, aerated lagoons, and chlorination facilities (*Bradley and de la Fuente*, 2003). As of 1997 the conveyance system had a maximum capacity to bring 35 MGD of sewage to the facility, and at the time was operating at near maximum capacity (*State Public Service Commission of Tijuana*, 1997). This meant that substantially more sewage was arriving at the facility than could be processed. According to the most recent IBWC information, influent at Punta Bandera currently exceeds the San Antonio de los Buenos capacity by between 3-15 MGD. As a result, part of the effluent was treated and the remaining raw sewage was combined with the treated effluent and discharged directly into the sea. The site of discharge is a small river, Los Buenos Creek, located 9 km (5.6 miles) south of the border and just south of Puenta Bandera (Figure 1.2).

3.3.3 Non-point Source Pollution: Land Based Sources

Non-point source pollution includes runoff from urban and agriculture lands (*Brion and Lingireddy*, 1999). Non-point source pollution comes from sources that are not spatially concentrated and are therefore less easy to identify than those from point source pollution.

Urban runoff

Urban runoff contributes a large portion of the pollution that makes its way into coastal oceans (*Leecaster et al.*, 2002). Urban runoff issues are particularly acute in Southern California where the combined factors of high population density and infrequent precipitation lead to large accumulations of pollution in coastal watersheds. These pollutants are transported to the ocean by low-volume flow that do not dilute pollution nor transport pollution offshore. Human use of coastal land and water both alters the landscape and leads to increases in microbial pathogens. Correlations have been observed between fecal coliform counts and the percent coverage of watershed area by impervious surfaces (*Mallin et al.*, 2001). Urban constructions such as road, driveways, sidewalks, parking lots and roof tops contribute to the percentage of impervious surface area in a given watershed. Impervious surface area removes the land's ability to perform natural filtration of rainfall, and consequently leads to increased levels of pollutants found on the land's surface.

A number of studies have looked at the impact of rainfall and urban runoff on estuarine and coastal water quality. A pertinent study to understanding the impact of rainfall in southern California is *Ackerman and Weisberg* (2003). They studied records of rainfall and microbial water quality in Santa Monica Bay. Their results indicated that the period between storm events does not show a correlation with FIB concentrations regardless of the size if the event. In 91% of the storms in the Los Angeles area between 6 mm and 25 mm of rainfall had an increased number of beach closures to high FIB levels in comparison with storm less than 2.5 mm that showed no increase in the number of closures. Concentrations of FIB were found to impact the receiving waters within one day following a rain event greater than 25 mm and on the second day for rainfall less than 6.4 mm. Both FIB concentrations lowered to background levels after 5 days for all rain events.

Further, *Noble et al.* (2003) found that the extent of shoreline exceeding water quality standards in wet weather was nearly 10 times higher than during two dry weather studies, and the magnitude of FIB was also greater. During dry weather, two-thirds of the exceedances were attributable to failure of a single bacteria indicator and most were barely above the threshold. This is contrasted to wet weather where two-thirds of the exceedances were for multiple indicators and at least one indicator was twice the allowable standard.

The idea of large pollutant loads at the start of rain and runoff is known as the "first flush". This has been seen for FIB in the Tijuana Estuary where an initial rise in concentration occurs with the onset of rain and tapers off over time indicating a wash-off effect of accumulated material; this was found to be opposite for metal concentrations (*Langis et al.*, 1991). A study by *Tiefenthaler and Schiff* (2003) found that suspended solids, dissolved trace metals, and total polycyclic aromatic hydrocarbons (PAH) concentrations were on average 2.4 times greater at the beginning than the end of simulated storm events. Further, concentrations of pollutants were inversely correlated with rainfall duration. Storm water capture during the initial portion of the storm water discharge may provide the greatest benefit in reducing constituent concentrations.

A study by *Reeves et al.* (in press) contributed a number of additional observations regarding the impact of urban runoff. Relatively high concentrations of FIB were found in the sediments collected from drainage channels, curbs and gutters. Turbidity was found to be high in wet weather and correlated well with high FIB levels, indicating erosion as a source of the bacteria during storms. In comparison, during dry weather turbidity measurements are low and not correlated with the high FIB concentrations indicating a separate source of bacteria for dry weather, possible wash-off. FIB loading increases nonlinearly with rainfall intensity because both volumetric flow rate and concentration of FIB increase during storms, which is inconsistent with build-up/wash off models that predict pollutant concentration found in runoff should scale with the time between storms and not rainfall intensity.

3.3.4 Local Watersheds: Tijuana and San Diego Bay

The Tijuana River watershed includes 1731 square miles (4483 square kilometers) with 73% of the area of the watershed occurring in Mexico and the remaining 27% of the area occurring in the U.S. (*Zedler et al.*, 1984). The major water bodies within the watershed include the Tijuana River, Cottonwood Creek, and the Tijuana Estuary. Project Clean Water classifies this watershed as impaired, citing major impacts as surface water quality degradation, trash, sedimentation, eutrophication, habitat degradation and loss, flooding, erosion, and invasive species (*http://www.projectcleanwater.org*). The Tijuana River discharges water from this watershed into the Tijuana Estuary, approximately 2.5 km north of Mexico on the U.S. side of the border. The total watershed currently includes approximately one million residents.

The San Diego Bay watershed covers 415 square miles, all of which is located on the U.S. side of the border. The San Diego Bay watershed includes three hydrographic units; the Pueblo San Diego, Sweetwater, and Otay hydrographic units (*http://www.portofsandiego.org*).

Approximately half the population of San Diego resides within the San Diego Bay watershed. The hydrographic unit which includes the northern portion of the shoreline sampling sites for the IBWC is the Otay watershed, which includes approximately 160 square miles of the San Diego Bay watershed. The major impacts to this watershed include surface water quality degradation, reduced ground water recharge, sedimentation, habitat degradation and loss, flood control and invasive species (*http://www.projectcleanwater.org*). Sixty-seven percent of the land use within the watershed is classified as open space, and 20% is classified as urban/residential. Approximately 150,000 people live in this portion of the San Diego Bay watershed.

Interaction of non-point source pollution with the estuarine environment

Input from rivers, marshes and estuaries

Traditionally wetlands have been viewed as providing ecosystem services that include the reduction of eutrophic elements, other chemical pollutants and fecal bacteria. Artificial wetlands have been incorporated into waste management systems to help reduce organic solids and bacterial numbers (*Neralla et al.*, 2000). Within natural wetland systems, a number of factors have been shown to contribute as sources or reservoirs of fecal bacteria. Estuarine processes regulate the rate at which bacteria contained within inland waters are introduced to the coastal environment. Isolated basins within shallow "Mediterranean Climate" estuaries like the Tijuana Estuary, can be subject to very slow ocean exchange (*Hearn and Robson*, 2002). Since as much as 90% of fecal bacteria within such settings may be particle associated, such slow exchange rates may allow bacteria to settle and accumulate within the estuary (*Streets and Holden*, 2003). When exchange rates are slow, the means of bacterial introduction from the estuary to nearby coastal waters may rely primarily on tidal processes (*Mallin et al.*, 1999). Strong flows associated with runoff may move rapidly through the estuary carrying bacteria from external sources and also re-suspend resident bacteria from estuarine sediments. Computer based numerical models with input from field measurements of bacterial levels have been used to explore these processes (*Kashefipour et al.*, 2002; *Streets and Holden*, 2003).

Tijuana River and Estuary

Southern California is an area notable both for the loss and degradation of its wetland area. The Tijuana Estuary stands out as a physically intact wetland setting (*Zedler et al.*, 1992). Nonetheless, the estuary faces problems associated with human encroachment. One of the most prevalent problems exists due to the proximity to the city of Tijuana, situated immediately upstream of the estuary, just across the US/Mexico border. Limited sewage facilities and insufficient drainage infrastructure in Tijuana have placed considerable pressure on the estuary. The worst of this pressure occurred from the mid 1980's to 1991 when as much as 13-20 MGD of sewage regularly flowed down the Tijuana River into the estuary (*Desmond et al.*, 1999). A diverter installed upriver of the estuary in 1991 and the installation of a deepwater outfall in 1999 helped to reduce the amount of sewage that currently flows through the estuary. However, increased bacterial levels continue to be observed within the estuary and in proximity to the mouth.

The coastal region of Southern California displays a Mediterranean type climate, characterized by dry summers and rainy winters (*Zedler et al.*, 1992). The Tijuana Estuary is a shallow body of water, with a small tidal prism. Local meteorological conditions and the physical structure of estuary itself, contribute to profound seasonal and diurnal variability of environmental conditions. During rainfall, the estuary can become substantially freshened, and well-mixed brackish water conditions frequently prevail (*Desmond et al.*, 1999, 2000). Alternatively, during the dry, summer months, the ocean exerts the primary influence on the estuarys water.

Non-human sources

A number of potential non-human sources of fecal indicator bacteria are known to exists within or near the Tijuana Estuary. Within the estuary there are frequently large congregations of birds as the Tijuana Estuary is a stop-over point on the "Pacific Flyway", with bird numbers increasing in winter (*Zedler et al.*, 1992). Large masses of kelp periodically wash up on shore, potentially providing temporary reservoirs for bacteria. Recreational beach users frequently bring dogs onto the beach.

Aquatic birds can contribute substantial quantities of bacteria (*Fogarty et al.*, 2003). Wrack provides both protection from environmental stress and a rich organic substrate and may promote bacterial growth within estuarine systems (*Weiskel et al.*, 1996; *Grant et al.*, 2001). Agricultural runoff is known to contribute nutrients, sediments and bacteria to the watersheds in which they are located (*Tong and Chen*, 2002). Increased bacterial contributions are particularly pronounced in areas where livestock are raised (*Hunter et al.*, 1999).

Groundwater

There are sources of groundwater below the Tijuana Estuary. Since it is possible for fecal pathogens to infiltrate ground water (*Lipp et al.*, 2001b), the connection between the high bacterial concentrations found in the estuary and the quality of underlying ground water is of concern. Groundwater sources, when infiltrated by bacteria, can foster populations from weeks to months (*Conby and Goss*, 2001).

Chapter 4

South Bay Regional Oceanography

This chapter presents a review of oceanographic data available for the South Bay region through studies conducted in preparation for the outfall's design, as well as through other sources such as independent academic studies, new regional observing systems, and remote sensing. Data from the South Bay Ocean Outfall Ocean Monitoring Program has also been analysed.

Although the Tijuana Ocean Engineering Study (TOES) provided much needed information on local currents and water properties, these studies were necessarily limited to finite time frames which may or may not be representative of a ”typical” year or season. Nevertheless, they are one of the few pieces of literature on circulation patterns in this region. More recently, the San Diego Coastal Ocean Observing Program (SDCOOS) has begun collection of ongoing time series data in the South Bay area. A high frequency radar (CODAR) system measures surface currents using high-frequency radar and provides data in real time. In addition, efforts are underway to include continuous water property and subsurface current velocity measurements. Remote sensing systems such as satellite and aerial imagery also provide data (this is covered in detail in the following chapter in relation to outfall plume tracking).

The sampling strategy for the SBOO Ocean Monitoring program was designed with the intent of providing information on bacterial levels at specific locations, rather than with the intent of being used for oceanographic analysis. Therefore, the data analyzed in this chapter provides monthly snapshots of water properties in the South Bay, but its utility for providing information on the oceanographic processes of most interest here, e.g., current velocity and water column stratification, is limited by the frequency of sampling, the duration of sampling, and the irregular positioning of sampling stations. The ocean monitoring hydrographic data does provide information on the stratification conditions on the day each station is sampled, which can tell us about the potential for the plume to surface at that specific time; however ocean conditions can change rapidly in coastal areas. Therefore, no attempt has been made to make conclusions about dynamic oceanographic conditions in this area using the CTD data. Instead, the data is shown to illustrate general seasonal trends and density profiles. This data is then used in the following chapter to demonstrate the possible effects of measured stratification at the outfall on the fate (rise and dilution) of the outfall plume. *It must be emphasized however that in a region where currents and water properties can change hourly, it is not possible to draw conclusions about the probability of occurence of any of these* *scenarios given the available monitoring data.*

Given the limitations described above, recommendations regarding the ocean monitoring program will be given in at the end of this chapter, and in detail in Chapter 7.

4.1 Regional Ocean Circulation: TOES & Other Data

As part of the outfall engineering study, a series of experiments were conducted to observe circulation in the South Bay area from Point Loma to the Coronado Islands. The Tijuana Ocean Engineering Study (TOES) included current meter moorings deployed during three time periods between May 1986 and December 1988. The current meter data were analyzed to identify the dominant flow patterns and model regional circulation pattern probabilities. In addition to the current meter moorings, TOES included a number of other field programs and data analyses over more limited time periods. These included: drifter deployments; analysis of wind, wave and satellite data; and field measurements of 7 different water properties, benthic infauna, sediment chemistry, and kelp characterization.

4.1.1 TOES: Mean Currents

TOES instruments were deployed over three phases of the experiment (Figure 4.1). During Phase I, from May-September 1986, 7 moorings were deployed with 2-3 current meters each at stations C1-C7. During Phase II, September 1986-August 1987, 8 moorings were deployed with 1-3 current meters each at stations C2, C3, and C5-C10 . Phase III consisted of 2 current meter moorings deployed over 12 months at stations near C2 and C5 from Phases I-II. Data was collected from December 1987-December 1988, with the main objective of providing further information on dominant flow direction and variability.

The dominant current direction was alongshore and downcoast, with occasional reversals in direction across the entire region, or reversals in direction between the inshore and offshore meters (*Engineering-Science*, 1988). The findings from Phases I-II are summarized below:

Surface currents were measured at 4 stations at 6-7 m depth (20-23 ft). The dominant direction was downcoast, with currents in this direction 40-50% of the time, at mean velocities of 11-16 cm/s. The next most frequent current direction was upcoast, approximately 30% of the time with mean velocities of 10-13 cm/s, followed by onshore currents 13-19% of the time with current velocities of 9-13 cm/s.

Intermediate level currents measured at 5 stations at 11-16 m depth (36-53 ft) were more evenly distributed between upcoast and downcoast directions (17-31% and 29-47% respectively) with slightly higher current velocities downcoast (9-15 cm/s). Onshore currents were somewhat more frequent than in the surface waters, with a 13-28% occurence, and velocities of 6-14 cm/s.

Deep currents (21-34 m, 69-112 ft) measured at 3 stations were also dominated by alongcoast flow. The outermost station, C5, had predominantly downcoast currents (37-42 % occurence) at 11-15 cm/s. Upcoast and onshore currents were both freqent also, with 21-26% upcoast and 25-26% onshore, both with velocities of approximately 10-12 cm/s.

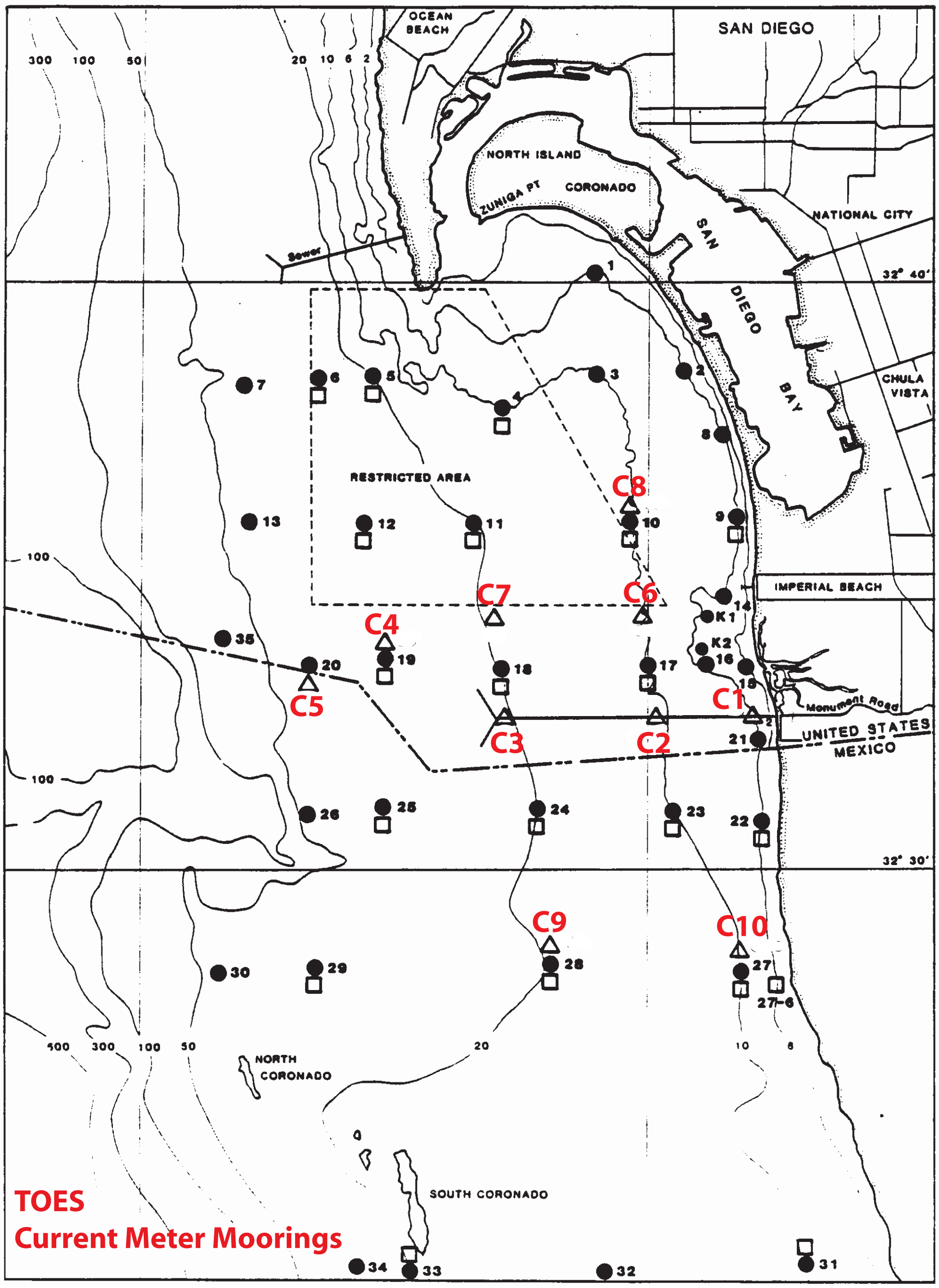


Figure 4.1: Map of TOES current meter stations for Phases I-II (red labels). Circles with small black labels indicate water column sampling stations.

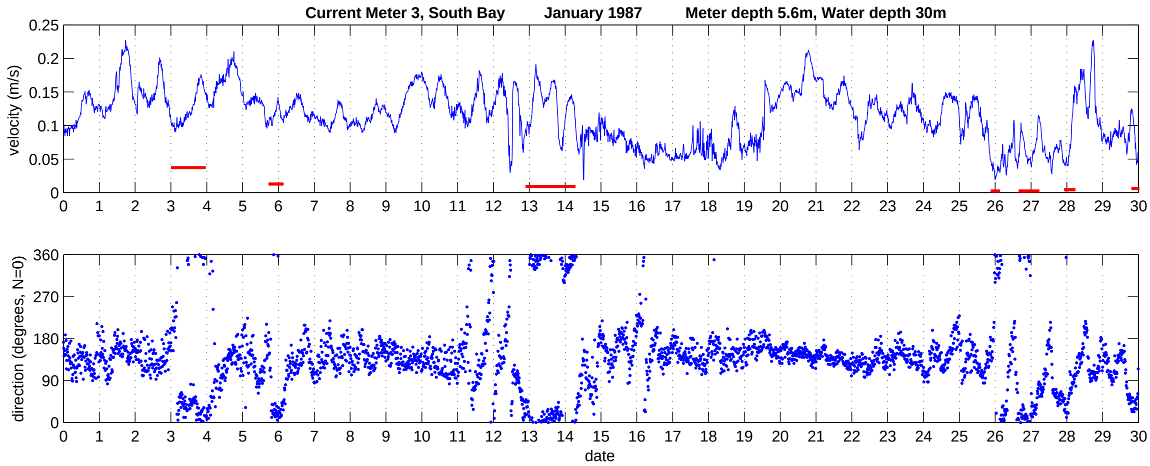
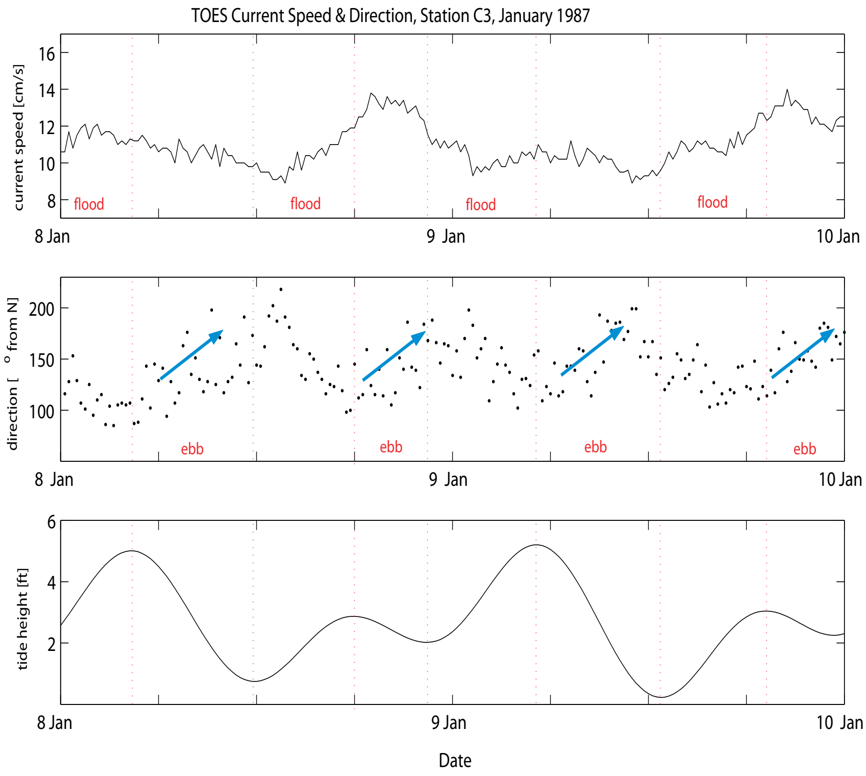


Figure 4.2: TOES current meter data from January 1987 at station C3 in 27 m water depth, 5.6 m current meter depth. Upper panel: current velocity; lower panel: current direction. "Downcoast" is approximately 160°. Red lines indicate periods of flow reversal from downcoast to upcoast.

Figure 4.2 shows a sample of current meter records from a shallow 5-6 m (16-20 ft) current meter in 30 m (98 ft) water depth at station C3 near the present outfall. The example shows the high degree of variablity in both current velocity (top panel) and direction (bottom panel). Current speed routinely changes by 5-10 cm/s over a matter of hours, while current direction can shift rapidly from downcoast to upcoast, or from alongshore to cross-shore. Daily shifts in current direction and speed occur with tidal phase, as seen in Figure 4.3. Currents exhibit a tendency to increase in speed during flood tide, and shift direction between ebb and flood. The shift in direction appears to be inconsistent, and probably depends to a large degree on the prevailing current direction. On January 8-10, for example, current direction shifts back and forth between ebb and flood, moving from a predominantly east flowing current to a more southerly flowing current during ebb tide and returning to the east during flood. On January 12-14 during a spring tide, current direction swings clockwise, completing a full rotation every semi-diurnal tidal cycle.

Of particular importance to plume transport are the onshore currents at all depths. These occur 13-28% of the time with mean velocities of 6-14 cm/s. Plume trapping may occur at any depth (or at the surface) depending on the density profile in the water column; therefore mid-depth and deep currents must be considered as well as surface currents. Onshore flow at mooring C3, nearest the present outfall, occurred 16-19% of the time (increasing frequency with depth). Mean velocity there was 4-11 cm/s, decreasing with depth. Onshore flow was most frequent, with a 25-28% occurence, at the westernmost mooring (C5). However, eastward currents are not persistent, occurring as part of a tidal/diurnal cycle. Typically, an eastward component of 10 cm/s may persist for several hours (or less), resulting in a shoreward excursion of only 1-2 km. More persistent, but weaker onshore currents may be observed at depth during upwelling events.

The dominant alongshore current measured during TOES Phases I-II was in the downcoast direction, opposite of that measured in previous work off Point Loma. However, two



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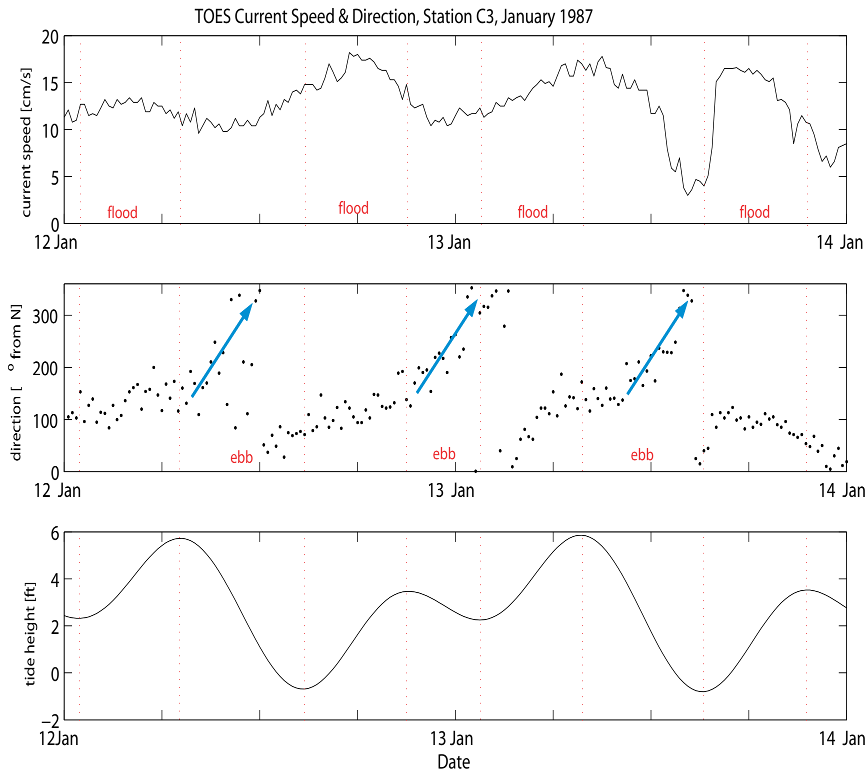

[B]

Figure 4.3: TOES current speed and direction, with tides: A) 8-10 January 1987. B) 12-14 January 1987, during spring tide.

year-long current meters deployed subsequently during TOES Phase III confirmed these results.

4.1.2 TOES Drifter Experiments

Four drifter experiments were conducted during 1986-87, over 10, 17, and 96-hour periods. The drifter paths were generally along the dominant current directions found in the current meter data.

Drifter Deployments, 1986-1987

1. 22-23 May 1986. Seven 3×3 meter, single pane "windowshade drogues" were deployed at ebb tide. Deployment was linear along the proposed outfall, and radially around end of outfall. The drifters were released within the thermocline at a depth of 6 m, and tracked for 17 hours. Movement of all drifters was southward at 7-18 cm/s.

2. 16 July 1986. Three of the windowshade drogues were deployed during flood tide, along a line north of the proposed outfall at 18 m (59 ft), 37 m (121 ft), and 55 m (180 ft) water depths (water column stations 10, 11, and 12). The drifters were released below the thermocline at 12 m (39 ft) depth and tracked for 10 hours. The two inshore drifters followed dominantly upcoast tracks, angled slightly inshore with respect to the bathymetry, while the offshore drifter followed the bathymetry downcoast. Speeds were 3-6 cm/s.

3. 27-31 January 1987. Six four-panel "Davis drifters" were deployed cross-shelf, two along the proposed outfall (near current meter stations C2 and C3) and four to the north (near water column stations 10-13). Release depth varied from 12-24 m (39-79 ft), and was planned to "simulate effluent movement . . . based on bottom topography and thermocline data collected" during CTD surveys. The drifter movements correlated well with current meter data from the same period:

   > "Currents were weakest inshore with flow predominantly downcoast and onshore (0-6 cm/s). Mid-area currents were faster than the inshore currents (5-15 cm/s). Flows were heavily influenced by tides and were upcoast or downcoast, depending on when measured during tidal phase. Offshore currents were strongest (10-30 cm/s) with a predominant upcoast flow. Offshore currents did not appear to be affected by either tides or wind."
   > *(Tijuana Ocean Engineering Study, Vol. 1, D.3-5)*

   Of particular note is the high variability observed, especially with regard to tidal influences on the mid-area drifters; opposing currents between inshore and offshore areas; and vertically variable current speed and direction with observable Ekman spiral. Tidal effects during this experiment were shifts from south to east to north during flood tides, and from north to east to south/southwest during ebb tide. Directional shifts were as much as 270° during a 6 hour period.

The potential for mid-depth transport is especially evident in the drifter deployment near station C3 at 17:30 on 27 January. During this period the 12 m deep drifter travelled from the 36 m isobath (approximately 2 km further offshore than the present outfall) to the north-northeast at approximately 8 cm/s, ending just offshore Silver Strand in about 39 hours. From the speed and frequency distributions published with the current meter data, approximatelly half of the time currents occur in this direction along the drifter path, mid-depth velocities are in the range 10-20 cm/s offshore (C3) and 15-25+ cm/s inshore (C8). So the time required for transport to shore for this drifter may be well below average.

4. 17-22 February 1987. Five multi-drifter experiments were done over these 6 days. All deployments were along a cross-shelf line approximately 2-3 km (1.2-2 mi) south of the U.S.-Mexico border, between the 10 m (33 ft) and 60 m (197 ft) isobaths. Deployments were of 5-10 drifters, with either all surface or a combination of surface and 20 m (66 ft) drifter depths. The dominant flow direction was to the south and east at fairly high speeds (surface drifters often exceeding 20 cm/s.) Surface drifter movement correlated closely with wind data, indicating surface currents were primarily wind-driven during this time.

4.1.3 TOES Modeling and Analysis of Major Current Modes

TOES current meter data was analysed using empirical orthogonal function (EOF) method to determine the major independent modes of circulation in the region (*Hendricks and Christensen*, 1987). The pattern identified as accounting for the largest amount of covariance between current meter records is the Mode 1 circulation. The pattern that accounts for the next greatest amount of the remaining covariance is Mode 2, and so on. In all, 20 patterns (independent modes) were identified from the current meter data. The dominant mode was a uniform, alongcoast flow pattern (Mode 1) which accounted for approximately 68% of the variability (Figure 4.4(a)). Mode 2, a shear flow pattern with opposing alongcoast flow directions on the nearshore and offshore side of the study area, accounted for about 19% of the observed variability (Figure 4.4(b)). The Mode 2 circulation pattern is believed to be responsible for the “gyre-like” circulation frequently observed in this area. Together, these two modes accounted for about 87% of the current variability in this area. Each of these modes occurs independently, and can vary in both strength and direction. The modes also occur simultaneously, such that the strength and direction of each one in combination with the other determines the exact circulation pattern that is observed.

The most frequent combinations of these two major circulation modes were determined statistically. Examples of the most dominant composite patterns are illustrated by the flow maps in Figure 4.5. The other combinations of the two modes give subtle variations on these two patterns.

The current meter data and modeling showed little seasonal variability, except in the Mode 1 flow direction. Downcoast flow was strongest in spring, with a weak upshore pattern more common in fall. Despite this, the variability in the strength and direction of each flow mode within a season tended to dominate any seasonal trends. During the single year of

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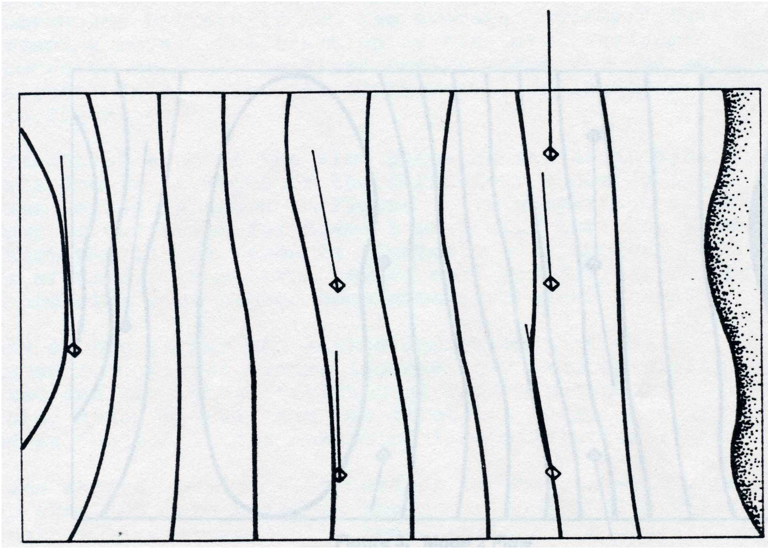

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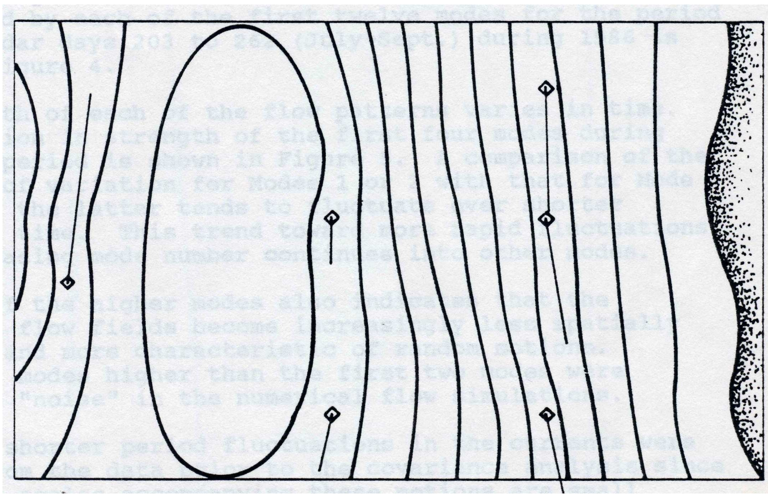


Figure 4.4: Dominant current modes in the South Bay area: A) Mode 1, alongcoast flow. B) Mode 2, shear flow. Vector tails point in direction of flow. Tail lengths proportional to velocity. Flow direction reversals occur with both modes. The dominant direction during the TOES study was downcoast (southwest) for Mode 1, and counter-clockwise for Mode 2. From *Hendricks & Christensen*, 1987.

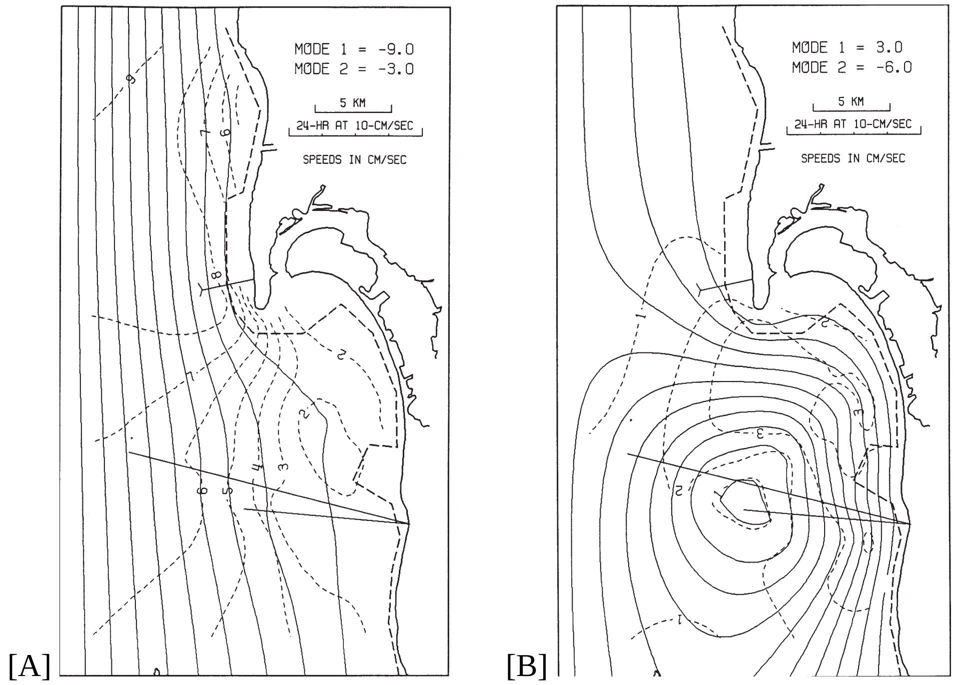


Figure 4.5: Composite model flows with highest probability of occurence. A) Composite flow patter with Mode 1 dominant. B) Composite flow patter with Mode 2 dominant. The magnitude and direction of each mode is shown at the upper left (negative = downcoast/counterclockwise). Solid contours are streamlines, dashed are velocity contours. From *Hendricks & Christensen*, 1987.

observations, the variability in the gyre pattern (Mode 2 flow) was greatest in the winter and spring when direction tended to reverse repeatedly. Short-term temporal variability was high for the lower probability current modes (which also had the slowest velocities), but for the major Modes 1 and 2, variability was normally of the order 1-2 days.

The alongcoast flow pattern (Mode 1) is unlikely to transport discharge from the SBOO toward shore. However, the gyre pattern (Mode 2) can cause flow in a shoreward direction when the circulation is counter-clockwise. The TOES data collected did not show one dominant circulation direction in the gyre; appearance and dissipation of the gyre as well as changes in flow direction were frequent, especially in winter and spring. The best statistics available at this time are the probabilities associated with Mode 1 and Mode 2 flow patterns (i.e., about 70% of variability explained by alongcoast flow mode, and about 20% of variability explained by the gyre flow mode). The most that can be inferred from the TOES data at this time is that the gyre pattern is active *to some degree* about one-fifth of the time; of that roughly half will likely be counter-clockwise flow with varying degrees of intensity.

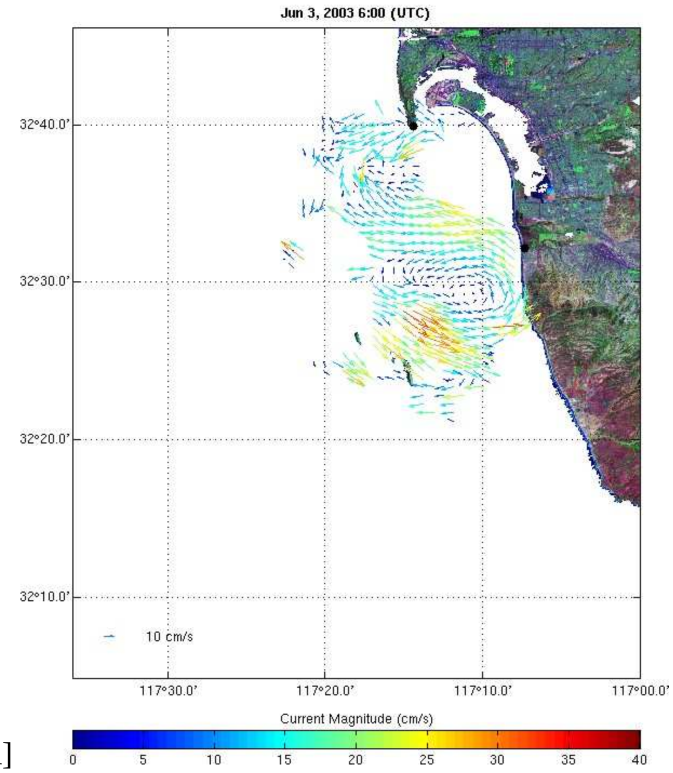
New data being obtained by a regional, high-frequency radar system may eventually provide more information on the probabilities of strong onshore flow associated with the South Bay gyre.

4.1.4 CODAR Surface Currents

Since late 2002, high-frequency radar mapping of surface currents has been provided by the San Diego Coastal Ocean Observing System (SDCOOS). The system uses CODAR (Coastal Ocean Dynamics Applications Radar) equipment and was established through support from the California Clean Beach Initiative provided to the City of Imperial Beach. The principal is that real-time current information will ultimately provide immediate warning of conditions that are typically characterized by fecal indicator bacteria (FIB) exceedances, thus allowing reliable posting of beaches on a more timely basis than the present system, which only provides data 24-72 hours following sampling. Through a collaboration between Scripps Institution of Oceanography and the Universidad Autonoma de Baja California (UABC), funded independently in Mexico, the system provides hourly coverage from Point Loma to Rosarito and offshore about 30 km (19 mi). This region includes the South Bay, the Tijuana outflow, and the Los Buenos Creek south of Punta Bandera. Data obtained by these CODAR units provide information on currents within 0.5 m of the ocean surface - thus, these maps describe surface transport routes, including both mean and tidal currents. With funding from the County of San Diego, this experimental use of radar mapping of surface currents is presently being evaluated in terms of its ability to observe or even forecast times when there is a high probability of elevated FIB levels along the shoreline of Imperial Beach. The San Diego County Department of Environmental Health consults these maps of surface currents on an informal basis to supplement their beach monitoring data and allow for interpretation of conditions that lead to FIB exceedances and the need to post beaches as contaminated. Similar high-frequency radar mapping of surface currents is being proposed for much of the coastline of California as part of the Coastal Ocean Current Mapping Program through the California Coastal Conservancy and is supported with funds from Proposition 40 and 50.

Two major circulation modes identified in the TOES study are evident in CODAR data. Mode 2, the gyre-like circulation, is frequently visible, such as in the hourly image in Figure 4.6(a) from 3 June 2003, 06:00 GMT (counterclockwise). At times there is also evidence of clockwise circulation, for example, off Rosarito on 4 November 2003 (Figure 4.7(a)). On inspection of numerous CODAR maps, it is evident that Mode 2 flow off Imperial Beach may be associated with either a large-scale anti-clockwise gyre extending south from Point Loma, or a small-scale anti-clockwise eddy detached from its likely source at Point Loma. Further, both of these flow patterns will exhibit significant short-term variability, most likely associated with tides or diurnal winds. In both of these cases the circulation shifted soon after to resemble a Mode 1 dominated circulation pattern. Figure 4.6(b), from 3 June 2003, 18:00 GMT and Figure 4.7(b), from 5 November 2003, show the shift to more uniform alongcoast currents within 12-24 hours of the first images.

CODAR images also show the shifting location of the regional gyre over relatively short timescales. Frequently the gyre is located very near the SBOO, either just to the west or directly centered on the diffuser. A gyre centered to the east or northeast of the active diffusers is significant for plume transport since gyre circulation is most often counterclockwise and thus would tend to move outfall water shoreward. There are currently no statistics on the exact frequency of the gyre from CODAR data, although this analysis is planned by SDCOOS.



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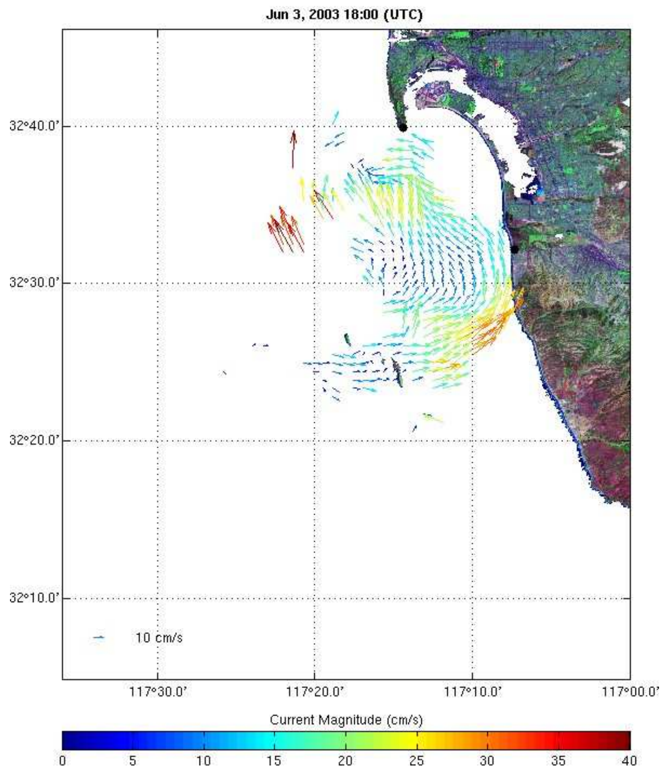

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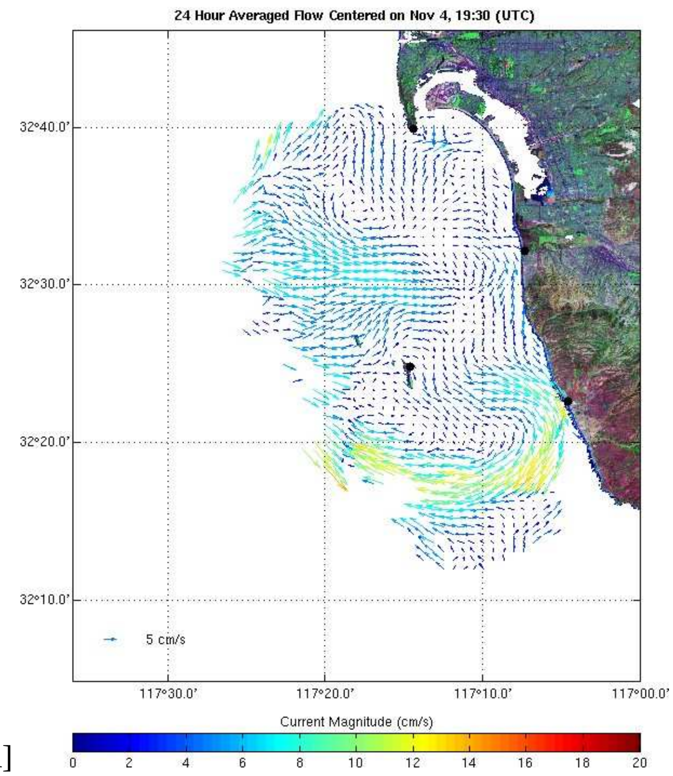
Figure 4.6: Surface currents from CODAR, 2003: A) 3 June, 06:00 GMT. B) 3 June, 18:00 GMT. Images from San Diego Coastal Ocean Observing System.



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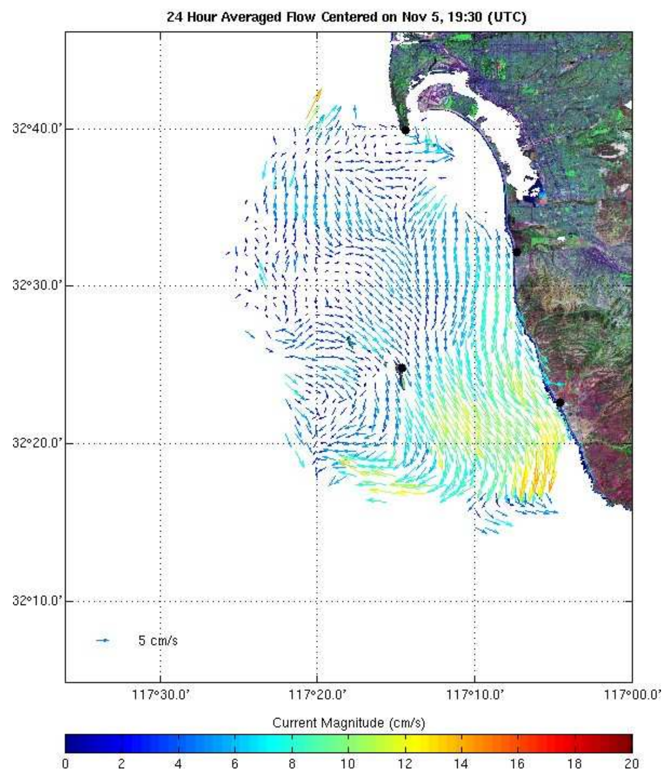

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Figure 4.7: Daily averaged surface currents from CODAR, 2003: A) 4 November, B) 5 November. Images from San Diego Coastal Ocean Observing System.

4.2 Seasonal Variability and Stratification: Ocean Monitoring Program

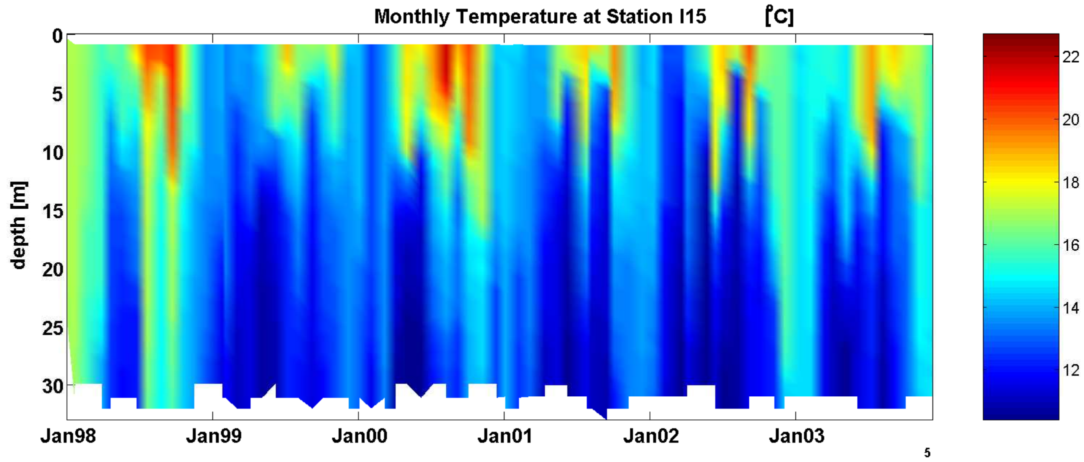


Figure 4.8: Water column temperature at CTD station I15, just offshore of outfall wye. January 1998-December 2003.

The ocean monitoring program conducted by the San Diego Metropolitan Wastewater Department for the IBWC includes a monthly survey of the area between Point Loma and Punta Bandera, extending 24 km (15 mi) alongshore and 14 km (9 mi) offshore (see Figure 2.1). Forty stations are sampled with an electronic conductivity-temperature-depth (CTD) sensor, in addition to other water quality sensors included on the instrument package (see Section 5.1). The vertical CTD profiles record salinity, temperature and depth approximately once per meter, and density is calculated from temperature and salinity. These data describe the structure of the water masses in the region and are used to determine the behavior of the outfall plume. Although these monthly surveys are just a snapshot of continually changing conditions seasonal trends are evident (Figure 4.8).

Not only do monthly surveys miss much of the temporal variability, but surveys are conducted over more than one day. As conditions may change from day to day, interpreting an entire survey as a synoptic picture can be misleading. CTD data are taken concurrently with bacterial samples which have a strict time requirement for returning to the lab for culturing. Thus, each survey must be conducted in segments of less than 6 hours, and one survey spans 3 days. (Some surveys span a 4-7 day period, with three non-consecutive days of sampling.) Regional maps of salinity or temperature from these data must be interpreted with caution because currents and water mass movement in coastal waters may exhibit large differences from day to day (e.g., Figure 4.16). Features that appear to be spatial variations may actually be the result of temporal variations that have occurred over the 3-7 day sampling period. Indeed, this can even be a problem with same-day surveys that have spanned 6-12 hours. Cross-shelf data plots shown in this section are selected to contain only stations that were sampled on the same day.

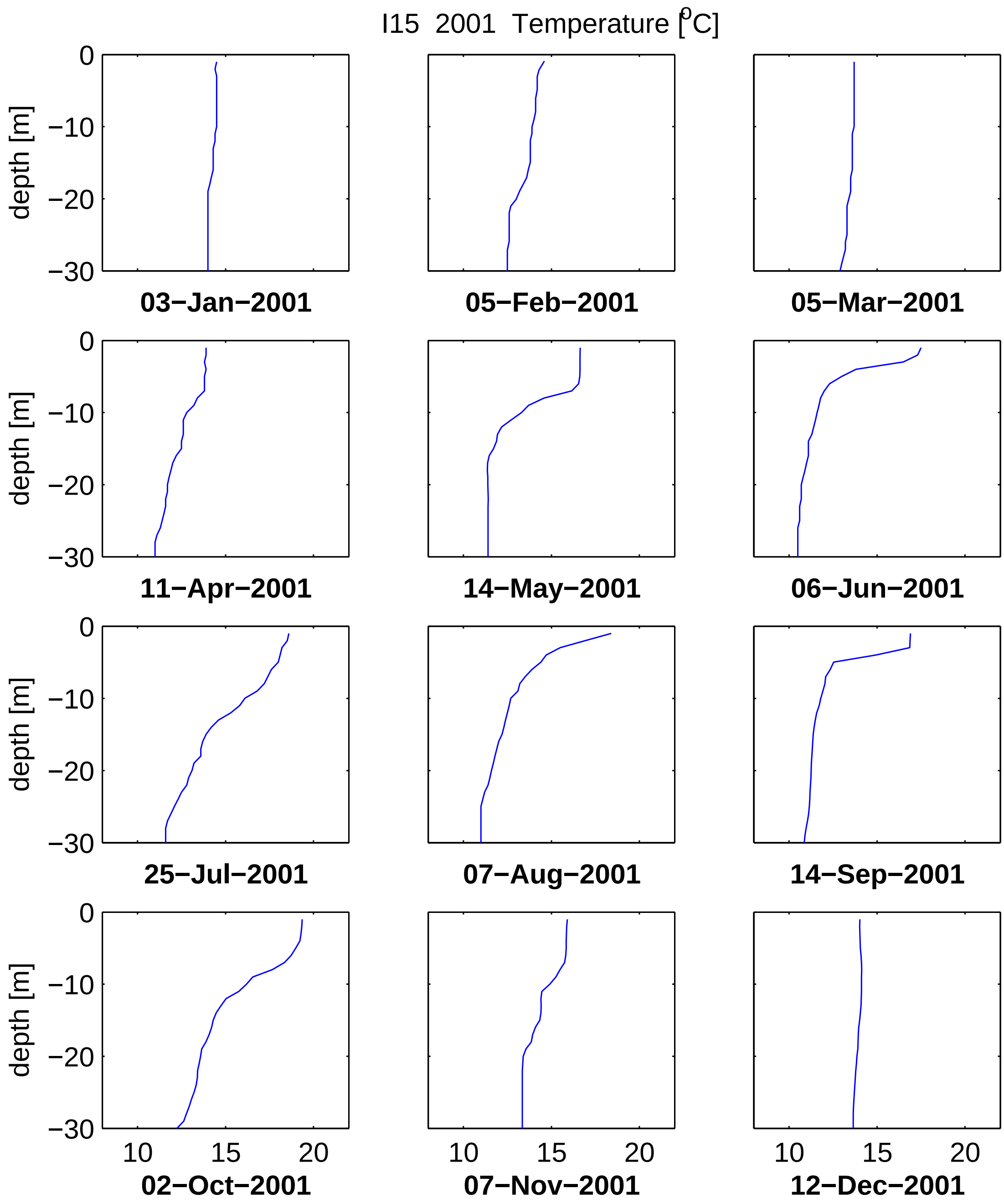


Figure 4.9: Temperature profiles from monthly ocean monitoring CTD surveys, 2001, at station I15 just offshore of the outfall wye.

4.2.1 CTD Density Profiles

CTD profiles taken during the Ocean Monitoring surveys show a high degree of variability in temperature, by season, station, and depth. Salinity, however, varies only slightly. Therefore it is the thermal structure that is primarily responsible for the density differences and stratification.

Figure 4.9 shows the monthly temperature profiles from the 30 m deep ocean monitoring station just west of the outfall wye. Seasonal changes are evident in the degree of stratification from winter conditions when the water column is almost isothermal from top to bottom (December-March), to summer conditions when there is a strong temperature gradient between top and bottom (June-September). During summer, a warm surface mixed layer with a pronounced, steep thermocline is often observed (e.g., June, September). A six year record of ocean temperature at the outfall is shown in Figure 4.8, in which summer surface warming and stratification, and winter cooling and mixing are clearly visible. At this station, coldest bottom temperatures occur during summer stratification (e.g., June-September).

The degree of stratification and response to seasonal effects is somewhat different at stations nearer to shore, such as those near the beaches (e.g., Station I32, Figure 4.10), and in the kelp beds (e.g., Station I25, Figure 4.11). The water column at these sites, much shallower than at the outfall, is more well mixed during all seasons, and can be unstratified during the summer. This could have an effect on plume surfacing if a subsurface plume in a trapped layer penetrated into nearshore waters with similar density.

Studies conducted prior to the construction of the first outfall at Point Loma also addressed the issue of relative stratification and its effects on potential wastewater disposal sites (*San Diego Marine Consultants*, 1958). The average density gradient was found to be greater (i.e., more likely to prevent plume surfacing) at sites off Point Loma than at sites off Imperial Beach. The contrast was greatest at depths of 15-60 m (50-200 ft), where Point Loma density differences between top and bottom were more than three times greater than Imperial Beach (0.65 σ_t vs. 0.20 σ_t). This observation is consistent with the observation of cooler surface temperatures south of Point Loma (Figure 4.16(a)).

4.2.2 Seasonal Water Mass Differences

Two-dimensional cross-shelf sections show the seasonal changes in the water mass structure across the area. Figure 4.12 shows the dramatic difference between winter and summer water masses. The figures shown are cross-shelf sections through CTD stations I28-I32, just north of Imperial Beach. In the summer section (June 2001, Figure 4.12(b)) the lower water mass also appears to be affected by an upwelling event, with cold 10-11°C bottom water approaching a depth of 10 m (33 ft). Figure 4.13(a) shows a relaxation of upwelling conditions in July 2001, and a more evenly stratified water column. By the August survey, Figure 4.13(b), the cold subsurface water mass is again evident. At this time the thermocline has been pushed quite high in the water column and cold water extends even further toward shore than in June. It will be shown in the following chapter that the highly isothermal, cold subsurface water mass associated with strong summer upwelling can allow vertical movement and surfacing of the plume even when there is surface stratification.

Figure 4.14 shows a similar pattern in 2002. In both August 2001 and 2002, the prox-

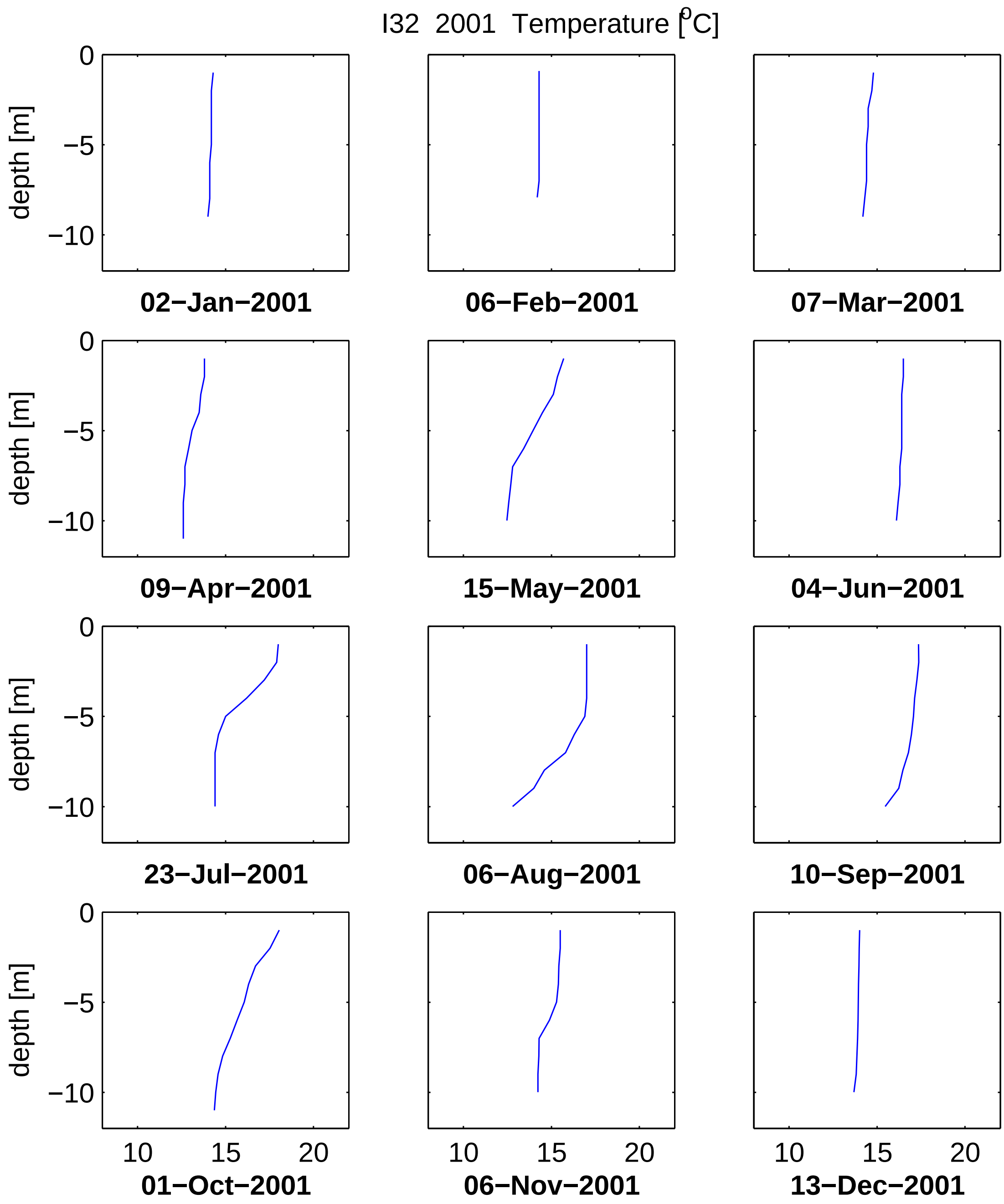


Figure 4.10: Temperature profiles from monthly ocean monitoring CTD surveys, 2001, at station I32 near Imperial Beach .

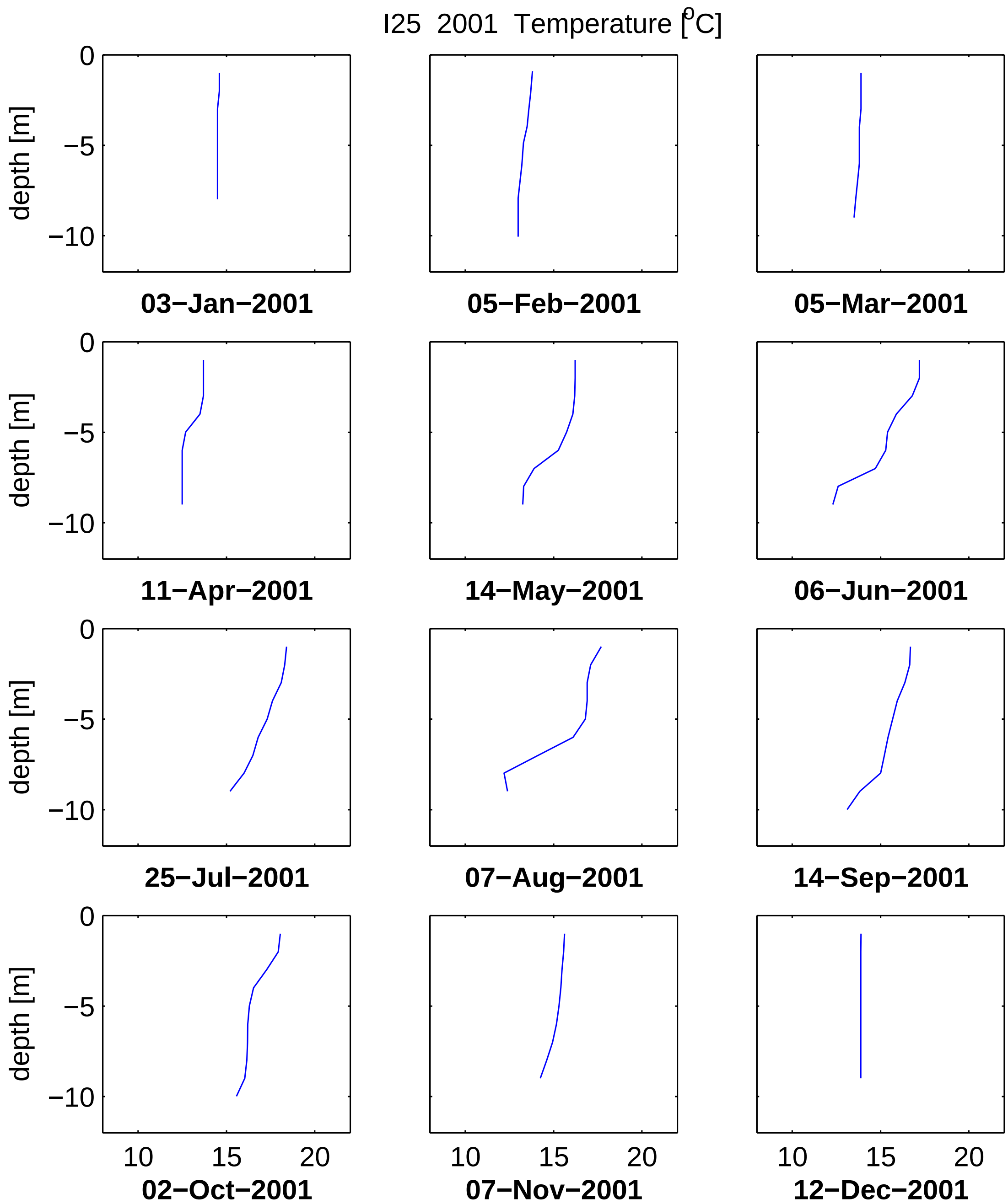


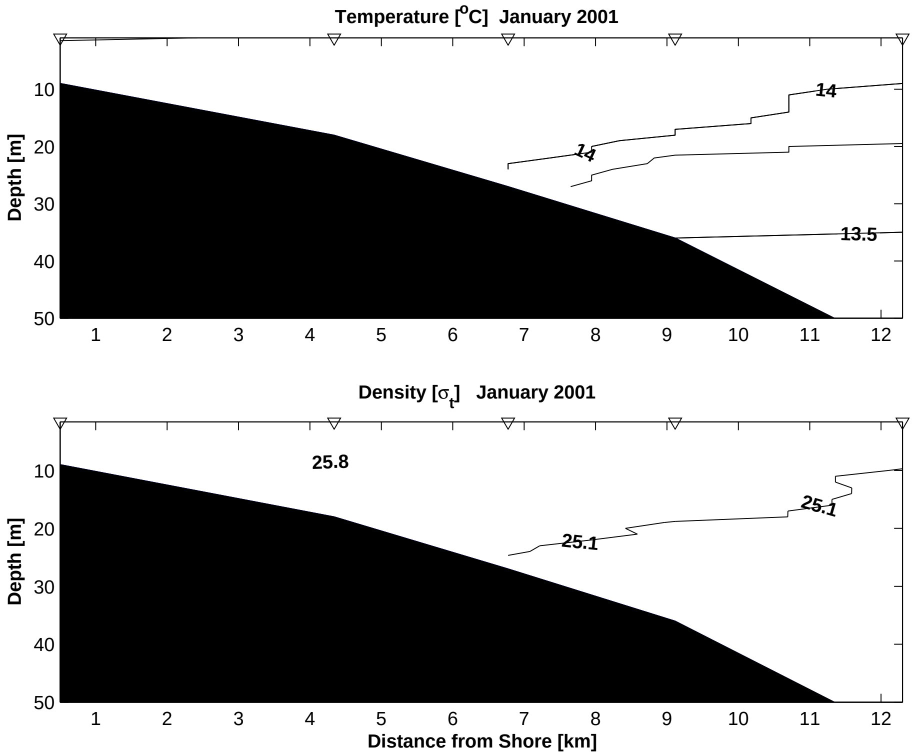
Figure 4.11: Temperature profiles from monthly ocean monitoring CTD surveys, 2001, at station I25 in the Kelp Beds.

imity of sub-thermocline water to the shoreline is apparent. The water column structure in August 2002 also features a broad thermocline which is initially at mid-depth, but shoals upward toward shore. It is possible here that thermocline-trapped plume material could be transported shoreward by upwelling circulation, and then transported into the nearshore and surfzone through internal tide activity (see Section 4.3.2).

4.3 Upwelling & Internal Waves

Of particular relevance to this study are processes that can bring sub-thermocline waters up to the surface with limited mixing and dilution. Two such processes are upwelling and internal waves. Upwelling is associated typically with wind forcing, but also with interaction of currents with topographic features. Internal waves are associated predominantly with tidal forcing, but also diurnal winds. The design of outfalls is based on the idea that wastewater will mix with enough dense sub-thermocline water to achieve a density greater than waters above the thermocline - thus “trapping” the diluted wastewater beneath the thermocline, and preventing it from entering shallow beach and kelp waters. However, if this diluted wastewater plume moves nearshore beneath or within the thermocline, then upwelling or internal waves could transport it into shallow nearshore waters.

In the following, the description of local conditions is based primarily on thermistors (recording thermometers) deployed along this coast in 2001-2002 as part of a project supported by California Sea Grant (Figure 4.15), and partially on TOES data. We focus our comment on existing observation of cold waters (sub-thermocline waters) at nearshore thermistor moorings, rather than providing an in-depth theoretical analysis of upwelling and internal waves. A summary of monthly temperature data from offshore station I15 shows a seasonal warming of surface waters and the presence of cold water at the bottom during summer, resulting in strong and shallow thermal stratification off Imperial Beach (Figures 4.8 and 4.9). The shallow thermocline is typically between 5 and 15 m, so that internal waves and upwelling need only raise the dense cold water a short distance to break the surface nearshore. Sub-thermocline waters may be as warm as 15°C or as cold as 11°C, with month to month variability. This seasonality is also evident in nearshore thermistors moored at multiple locations along the 10 m (33 ft) isobath off San Diego, and specifically in the South Bay region (Figure 4.16). During summer, nearshore surface temperatures may be over 20°C, whereas in winter surface temperatures are about 14°C. At the bottom (10 m depth), however, water as cold as 11°C is observed during spring and summer (Figure 4.16(b)). This collection of thermal records also shows a marked spatial pattern, with colder waters observed south of Point Loma than north of it.



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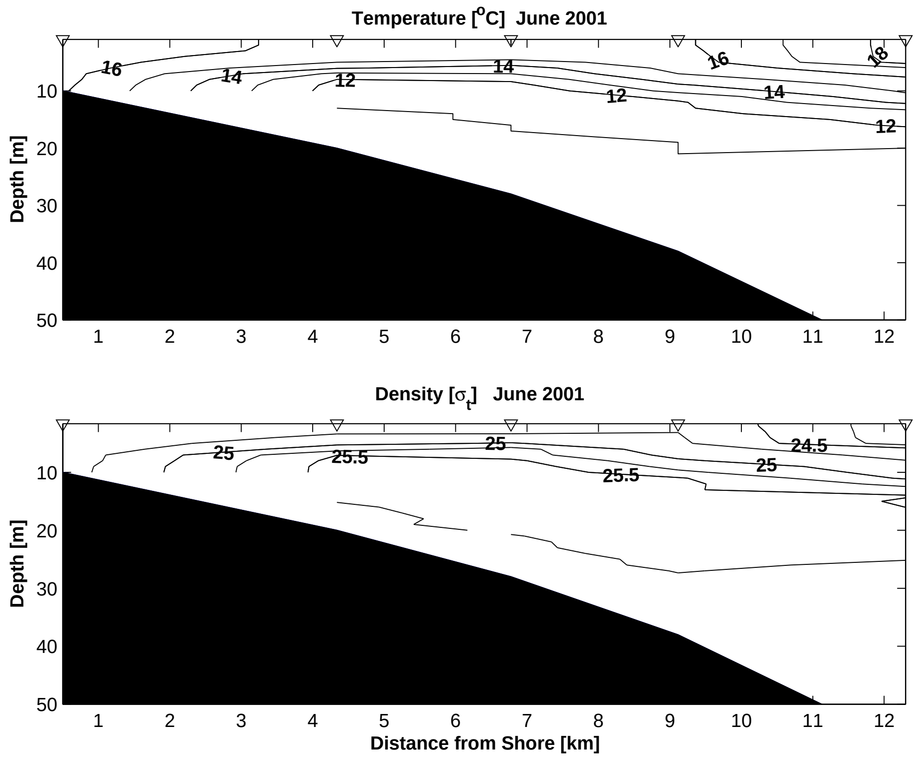


[B]

Figure 4.12: Cross-shelf sections of temperature through CTD stations I28-I32. A) January 2001 survey; B) June 2001 survey. Station locations are marked by triangles at the top of each plot.

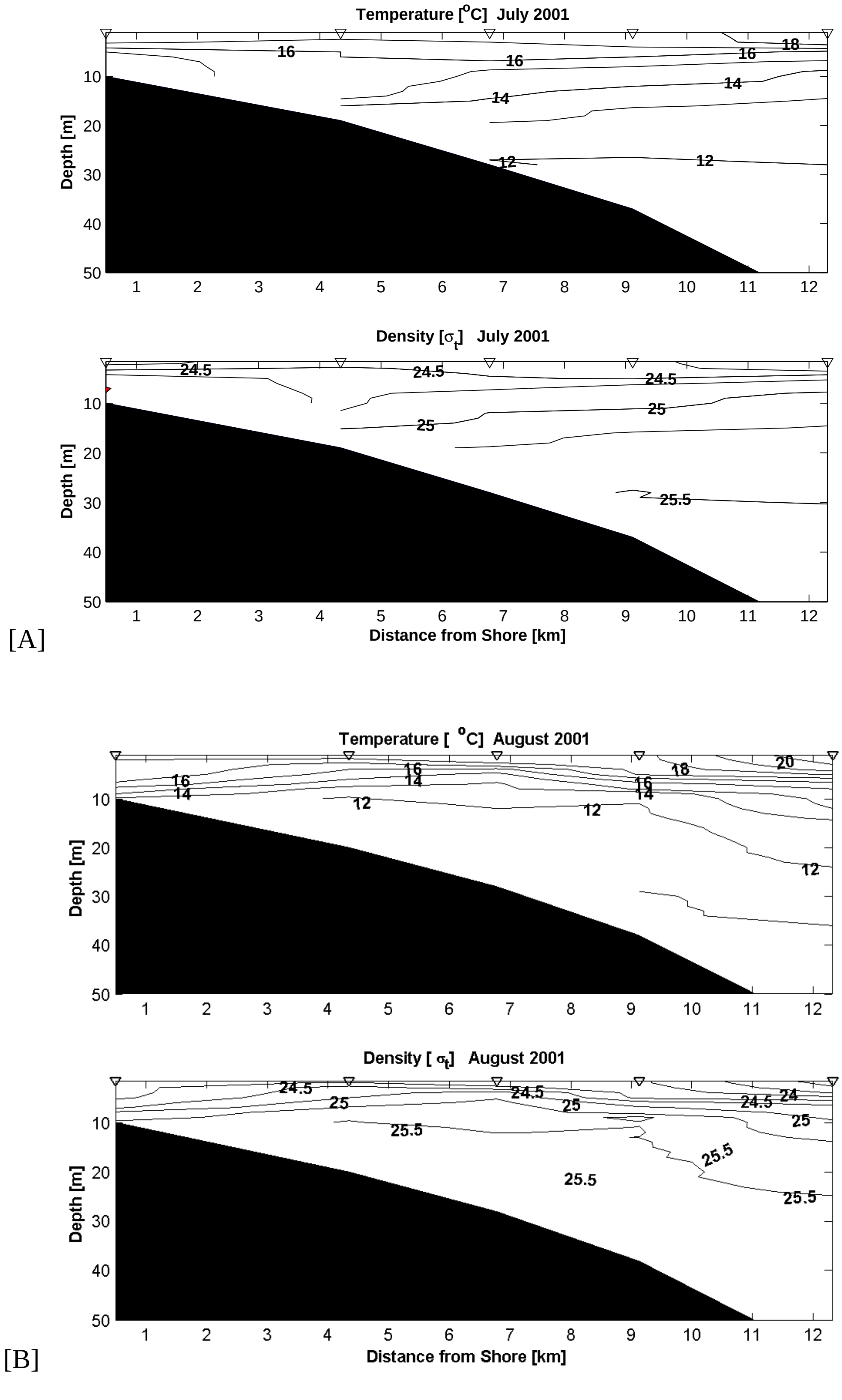


Figure 4.13: Cross-shelf sections of temperature through CTD stations I28-I32. A) July 2001 survey; B) August 2001 survey. Station locations are marked by triangles at the top of each plot.

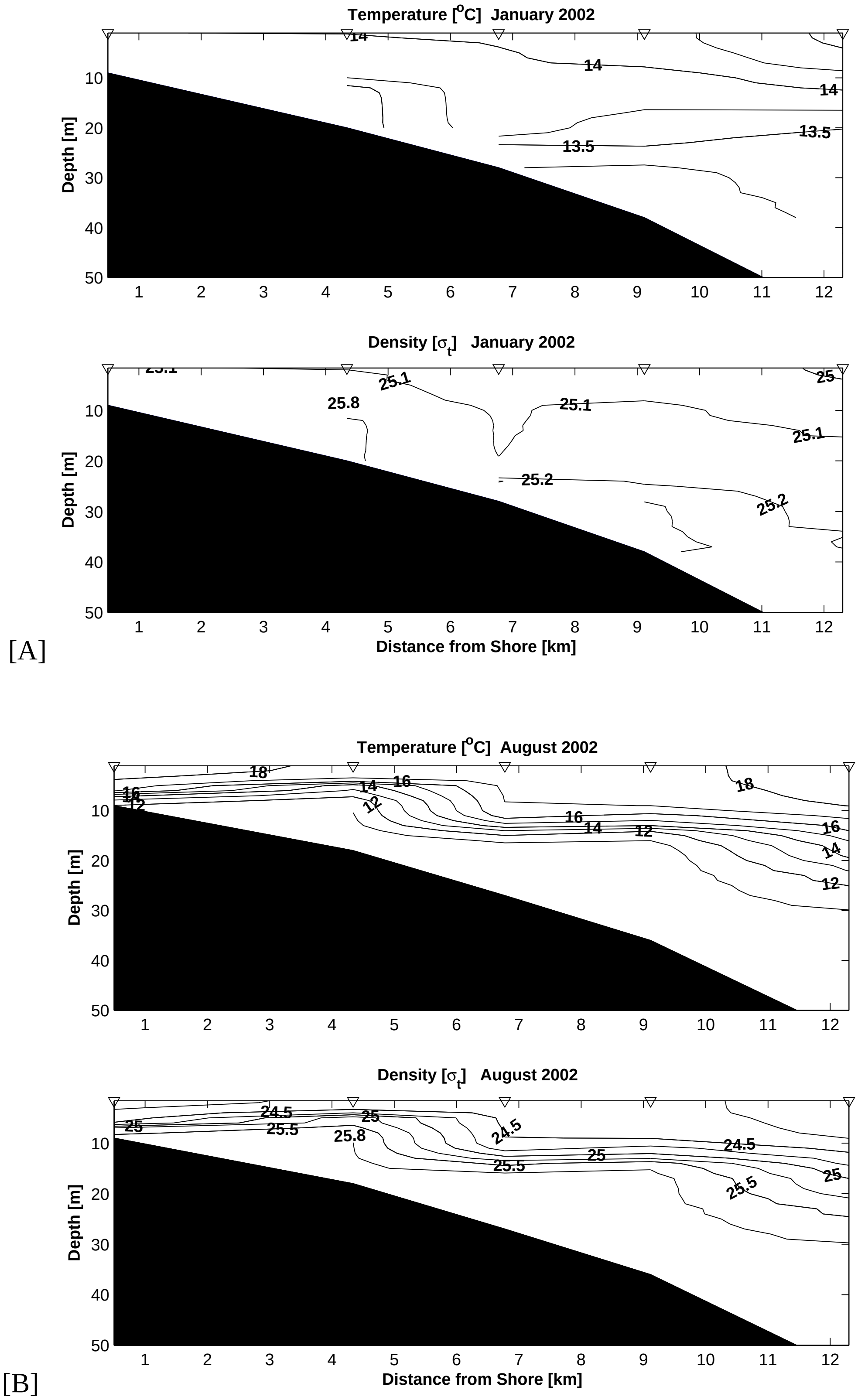


Figure 4.14: Cross-shelf sections of temperature through CTD stations I28-I32. A) January 2002 survey; B) August 2002 survey. Station locations are marked by triangles at the top of each plot.

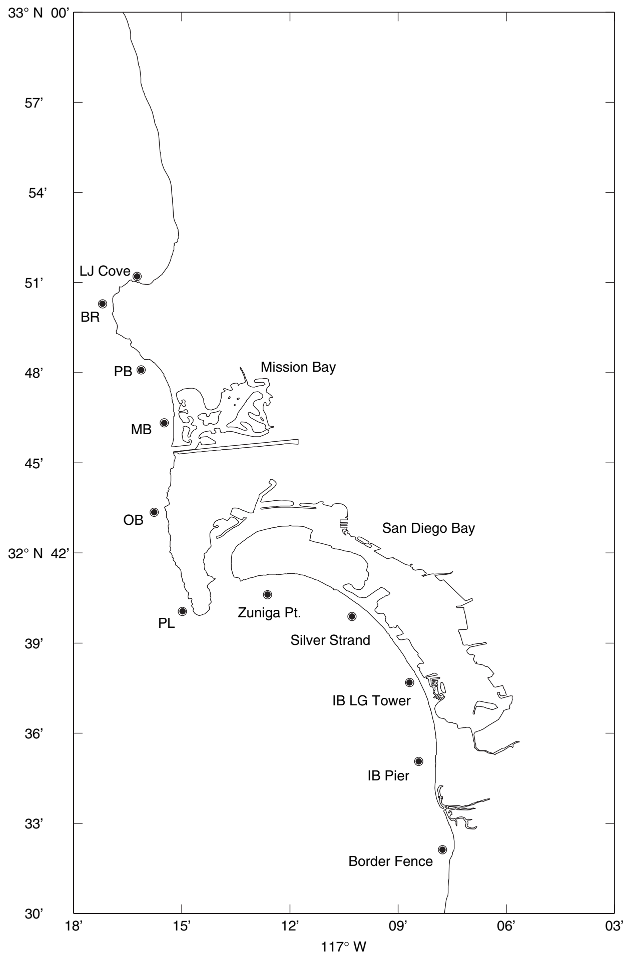


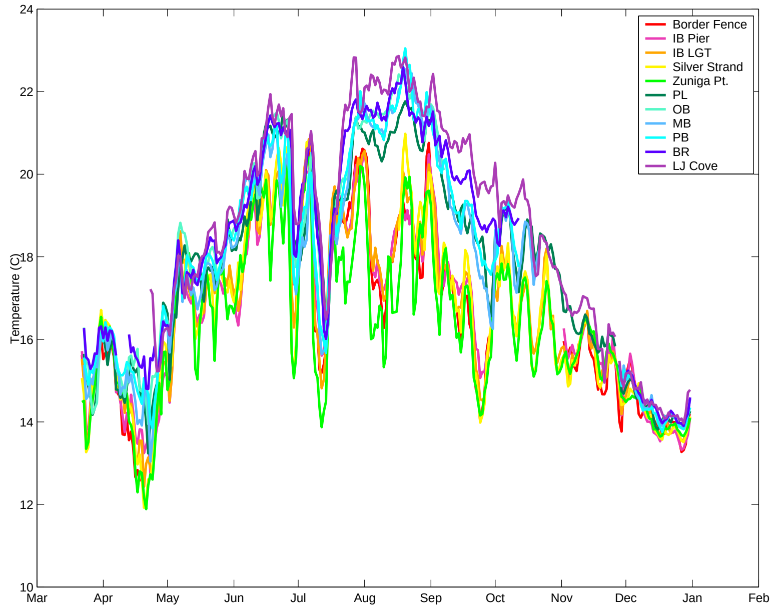
Figure 4.15: Locations of coastal thermistor arrays.

4.3.1 Wind-driven Upwelling

Wind-driven upwelling characterizes coastal waters north of Point Conception (Santa Barbara) and also further south, beyond Punta Banda (Ensenada). While upwelling also occurs in the southern California Bight, it is not a dominant mechanism and not as well studied. However, recent work by *Roughan et al.* (in press) describes localized upwelling evident as cold surface waters south of promontories such Point Loma, Point Dume (Malibu), and Palos Verdes (Los Angeles). They give special attention to Point Loma, recognizing that waters are often colder immediately south of the point than immediately north of it. This localized upwelling appears to be associated with southward flow separating from the coast and crossing isobaths as it passes the end of Point Loma. Following *Pringle and Riser* (2003), the upwelling of cold water at Point Loma correlates with remote wind forcing events off mid-Baja a few days prior, consistent with the well-accepted phenomenon of coastal trapped waves. While not so well supported statistically (due to limited data), this process would likely involve southward flow. Local wind forcing is expected to be of secondary importance. Similar results are reported by *Noble et al.* (2004) and *Hamilton et al.* (In prep.), who see a low level of correlation between local winds and upwelling off Huntington Beach, but an important correlation between southward alongshore flow over the shelf and the upwelling of cold water nearshore. Most recently, *Boehm* (In press) has reported an association of high FIB levels along the Huntington Beach shoreline with periods of colder water (i.e., upwelling). This association may be due to shoreward transport and upwelling of sub-thermocline wastewater or it may be due to surfacing of the wastewater plume during periods when stratification is weak (see later analyses in Section 5.4).

The data in Figure 4.16 are daily averages and thus reflect only subtidal variations in the nearshore temperature (i.e., variability with time scales longer than tidal periods, i.e., >24 hrs). A notable upwelling event occurs around 10 July 2001, with surface temperature below 16.5°C at all moorings, and as low as 14°C at Zuniga Point. In general, coldest temperatures are observed at the Zuniga Point site, near the mouth of San Diego Bay, possibly due to the effects of upwelling and mixing associated with the tidal jet that exits the Bay. A similar broadscale cold event is observed around 28 June 2001. However, events observed later in summer are observed only south of Point Loma. Throughout August and September a temperature difference of about 3°C or more persists between sites north and south of Point Loma. While sub-thermocline waters may only appear transiently at the surface at the 10 m (33 ft) isobath, these cold waters are regularly seen at the bottom at these nearshore locations and it is possible that they upwell inshore of the 10m isobath. In Figure 4.16(b) one can see that 11-15°C water is observed nearshore throughout summer. In late April 2001, 11°C water is observed throughout the region. Similarly during the 10 July 2001 upwelling event, 12°C water is observed at sites both north and south of Point Loma. However, during August and September 2001 (and June 2002), while 12-13°C water is observed repeatedly off Border Fence and Silver Strand, bottom waters off Mission Beach and Bird Rock are no colder than 17°C. In conclusion, then, cold sub-thermocline waters are regularly observed nearshore along South Bay shorelines, extending at least as far as the Mexico-US border.

[A]



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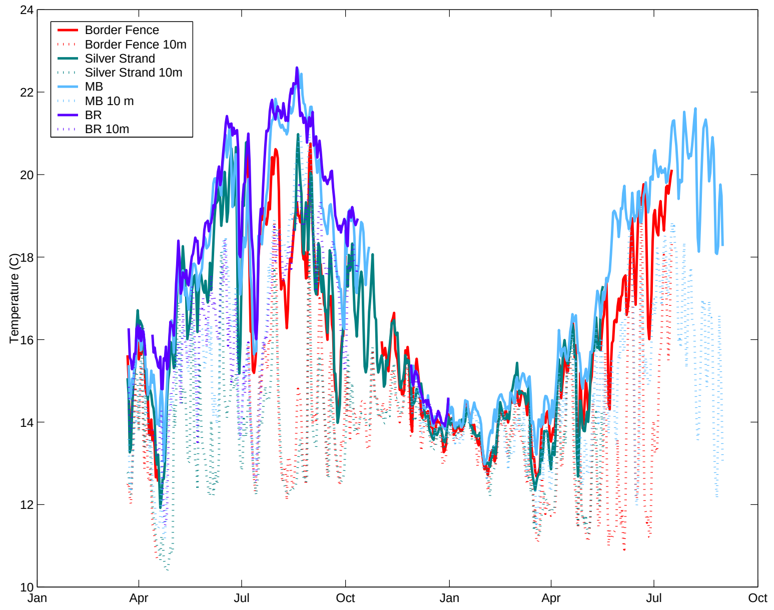


Figure 4.16: Nearshore water temperature from US-Mexico border to La Jolla for 2001/2002 (for mooring locations see Figure 4.15. (A) Daily average surface temperatures for all stations. (B) Surface and bottom daily average temperatures for selected stations (Border, Silver Strand, Mission Beach, Bird Rock).

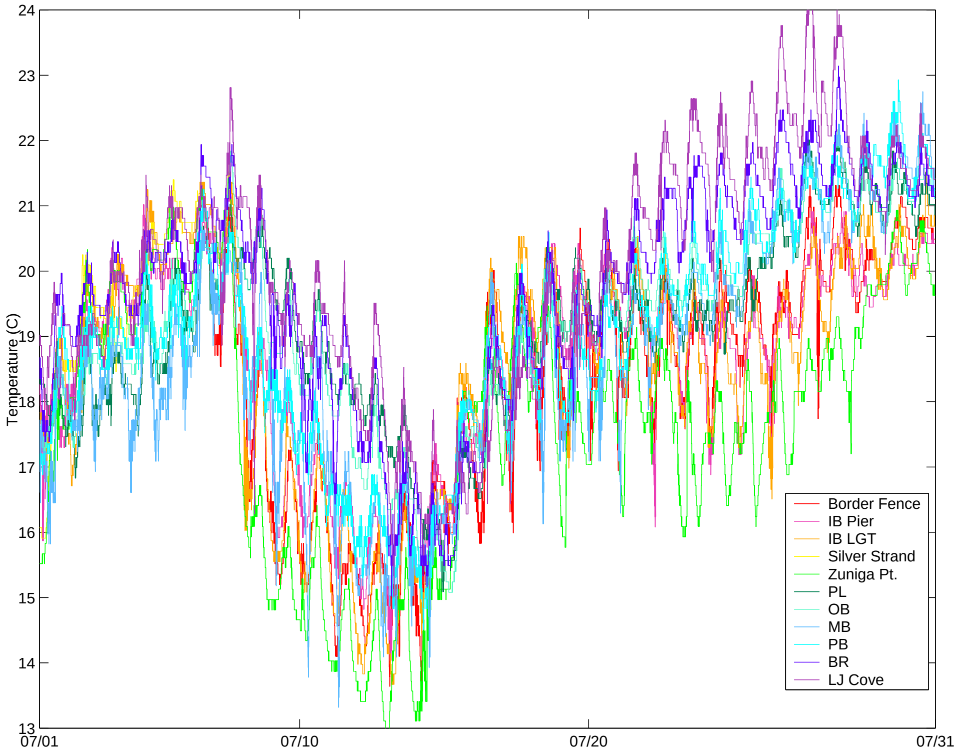


Figure 4.17: High-frequency record of surface temperature at nearshore thermistors in July 2001 (sample interval of 2 minutes).

4.3.2 Tidal and Diurnal Internal Waves

Internal waves are observed along shorelines throughout the world, and in areas of shallow stratification they are an important factor in transporting near-surface and sub-thermocline waters to and/or from the nearshore (*Shanks and Wright*, 1987; *Pineda*, 1993; *Leichter et al.*, 2002). The greatest source of internal waves is tidal forcing which results in internal tides (internal waves with periods of tidal constituents). Typically generated at the shelf edge or other abrupt topography, these internal tides propagate shoreward along the thermocline. On entering shallower waters, these tidal internal waves transfer energy to other internal wave frequencies and one can see a variety of time scales in the nearshore. With the shallow stratification that is typical of southern Californian summers, internal motions on the thermocline are also forced by the day-night variability in winds (*Lerczak et al.*, 2001; *Noble et al.*, 2004). In studies off Huntington Beach (*Noble et al.*, 2004), these two modes of forcing are discussed in more detail and both appear to be capable of bringing sub-thermocline waters into the nearshore during summer months when the thermocline is shallow; at times they may even transport cold waters into the surfzone. While the presence of sub-thermocline waters has been observed off Huntington Beach (*Boehm et al.*, 2002b; *Noble et al.*, 2004), there are no clear observations of high FIB levels in the surfzone coinciding with these events; thus, while this offers a possible route for transport of wastewater into the nearshore and surfzone, it remains a hypothesis as there is no evidence yet that it does so.

In Figure 4.17, high-frequency variability in temperature is shown for the thermistors described in Section 4.3.1. Here one can see the tidal/diurnal nature of temperature variability, with coldest water being observed in nearshore waters for just a few hours a day. For example, the 10 July 2001 upwelling event started with a pulse of cold water into the nearshore on 8 July as the thermocline rose towards the surface and surface temperatures less than 17°C were observed throughout the region south of Point Loma. After an initial rebound in surface temperature, subsequent days brought colder pulses and weaker rebounds until cold water was persistently below 16°C by 14 July. At this time, although daily averages were 14-16°C south of Point Loma, the diurnal pulses of cold water continued and waters colder than 13°C were observed at the surface at Zuniga Point. Off Huntington Beach in 2001, a similar interaction of upwelling-related thermocline shoaling with internal tide and diurnal cold pulses was observed to be responsible for the coldest waters being observed in the nearshore (*Noble et al.*, 2004). These sub-15°C values in the nearshore indicate that sub-thermocline water has intruded and filled the nearshore. The high-frequency variability is dominated by diurnal intrusions of cold water, with both tides and winds being possible forcing mechanisms.

While there are no data in the South Bay surfzone to know if these near-bottom waters continue shoreward and intrude into the surfzone at times, this is quite possible. This was observed off Huntington Beach in 2001 (*Noble et al.*, 2004). Although most sub-thermocline waters are not contaminated by the wastewater plume, recognizing the presence of sub-thermocline waters in the nearshore is to recognize that it is possible for wastewater to be advected into the nearshore and surfzone. If this beach contamination scenario were to occur, it would most likely do so during periods when both internal tides and upwelling occur.

4.4 Nearshore Oceanography

Knowledge and understanding of nearshore currents and dispersion of land runoff is very limited, both for the Imperial Beach region of interest as well as in general. While large river outflow patterns (e.g., Columbia River, Mississippi River) have been reasonably well studied, there are few similar studies of land runoff from arid areas like southern California. During large rainfall events, the Tijuana River flows strongly and produces a large stormwater plume that fills much of our region of interest, and extends beyond the outfall location. Comparable stormwater plumes in Santa Monica Bay have been described by *Washburn et al.* (2003) and further studied during winter 2003 by a collaboration of southern California agencies in the Bight'03 study. Under these conditions, the destination and mixing of land runoff will be determined by coastal circulation, wind forcing, and river plume buoyancy dynamics, in combination with the effects of the Coriolis force. However, typical conditions in southern California involve small-volume land runoff that enters the ocean with little momentum or buoyancy. These inflows occur as tidal pulses from estuaries (e.g., Tijuana Estuary), as continuous discharge from creeks (including wastewater discharge from the San Antonio de los Buenos wastewater treatment plant), and as transient flows from stormdrains. In many water conduits, low-flow diversion gear has been installed to divert contaminated runoff to wastewater treatment plants during periods of low flow. Tijuana River is diverted in this manner between periods of stronger flow.

Nevertheless, significant amounts of land runoff make their way to the ocean between periods of diversion, or via conduits that are not diverted. The destination of such inflow depends on whether these waters are entrained into the surfzone or whether they have sufficient flow speed (momentum) to break through the surf. While some storm water inflow may be entrained completely within the surfzone, many creek and tidal flows are partitioned between dispersion in the surfzone and in the nearshore waters beyond the breakers.

4.4.1 Wave-driven Dispersion in the Surfzone

The surfzone is characterized by breaking waves. As waves break in shallow water they can drive a mean current, so that waves that approach the beach at an angle will drive a longshore current in the surfzone. As is seen later (Section 6.1.2), during periods of south swell (waves approaching from southerly directions), a northward current runs along the Imperial Beach shoreline. North of Imperial Beach, southward longshore currents are rarely observed as the Silver Strand and Coronado beaches are sheltered from northerly swell. The alongshore extent of this transport may be interrupted by headlands, e.g., Point Loma. On the other hand, this alongshore transport is continually mixing with nearshore waters immediately beyond the surf-zone, through the action of rip currents and internal waves (see Section 4.3.2). The rate of loss of a tracer from the surfzone is primarily determined by the dilution rate within a given rip cell and the number of rip cells that a longshore currents passes through (*Inman et al.*, 1969). In the case of water entering the surfzone during tidal outflow from the lower Santa Ana River, plumes of contaminated water are observed to move 4 km (2.5 mi) or more northward along the Huntington beach shoreline. Analysis of these data (*Kim et al.*, 2003) suggests that the mixing of surfzone waters with offshore waters is slower than intuitively expected. *Clarke et al.* (In prep.) have analyzed multiple dye releases off Malibu and find exchange between surfzone and nearshore waters to be characterized by a diffusivity of order 1 m^2/s in the absence of rip currents, and larger ($\approx$ 10-100 m^2/s) in the presence of active rip current exchange, consistent with estimates made by *Smith and Largier* (1995). Surfzone waters may also be flushed by the intrusion of cold near-bottom waters into the surfzone, ejecting warm waters from the surfzone (*Smith and Largier*, 1995; *Pineda*, 1993).

Clearly, more work is required for understanding and quantifying the retention of contaminated land runoff in the surfzone. However, the direction of longshore currents can be estimated from data on wave direction, amplitude and period, which are readily available from the California Data Information Project (*http://cdip.ucsd.edu*). Westerly (onshore) waves are typical of this area, with more north swell being observed during winter and early summers (but sheltered by Point Loma) and southerly swell being observed during summer and fall. The important point for the purposes of tracking plume transport is that swell direction can have an effect on the transport of nearshore contaminants. Outflow from the Tijuana River or Los Buenos Creek appears to move with the northward currents generated during south well, as is shown in Section 6.1.2.

4.4.2 Wind-driven and Tidal Currents in Nearshore Waters

In the nearshore waters beyond the surfzone, wave-driven currents are weak and here tide and wind forcing dominate. Due to the proximity of the coastal boundary, nearshore currents are polarized to run along the shore. Both semi-diurnal tidal currents and diurnal wind-driven

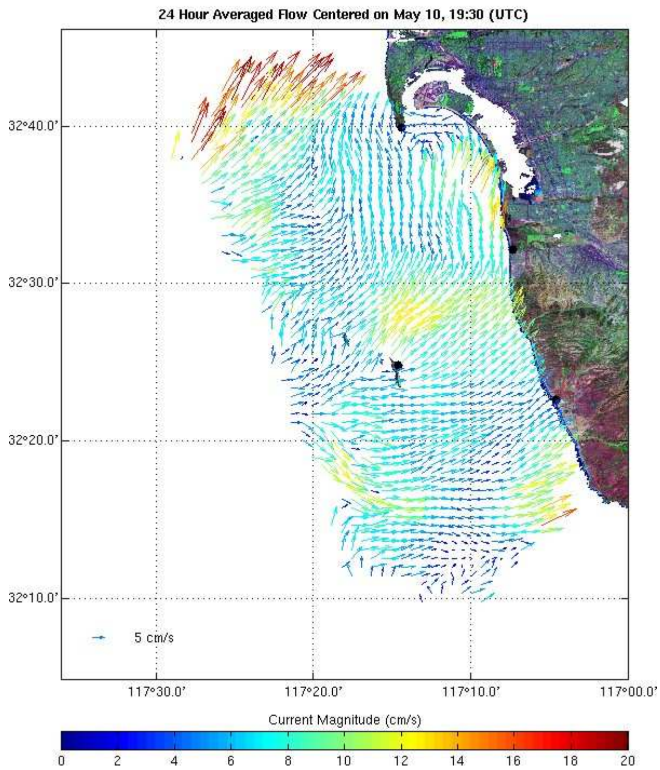


Figure 4.18: CODAR surface currents, daily average for 10 May 2004. Image from San Diego Coastal Ocean Observing System.

currents off Huntington Beach exhibit strong alongshore flows, of the order of 10-30 cm/s. Tides are predominantly semi-diurnal and observed speeds correspond to alongshore displacements of order 1-3 km during a semidiurnal tidal cycle. Further, the phase of these tidal currents is such that up-coast (northward) flow starts sometime around low tide, so that contaminated waters exiting the estuary on the ebb tide are transported northward. In studies of FIB levels along the Huntington Beach shoreline in 2001, this up-coast "zone of impact" is observed by *Kim et al.* (2003) to extend 3 to 4 km northward. Although similar nearshore data are not available off Imperial Beach, these data are now being collected through SDCOOS. TOES data from further offshore suggests that a similar tidal zone of impact should be found north of the Tijuana estuary mouth. Thus, typical tidal currents at Imperial Beach of about 10 cm/s may also advect ebb tide effluent a few kilometers up the beach. (*San Diego Marine Consultants*, 1958).

This alongshore tidal transport of land runoff will be specifically effective during periods when wave-driven mean flow in the surfzone coincides with tidal flows (and when mild onshore breezes keep surface waters onshore). During these conditions, the coincidence of tidal and wave-driven flows result in cross-shore mixing between two plumes of contaminated water and little dilution is observed as contaminated water is transported alongshore.

Local wind forcing is not considered to dominate coastal circulation off southern California (*Hamilton et al.*, In prep.; *Pringle and Riser*, 2003) but there are clearly events in which southerly winds drive strong alongshore currents in the nearshore. An example of such a wind-driven circulation is shown for 10 May 2004 (Figure 4.18) during a day-long southerly wind event with peak wind speeds of approximately 7 m/s (16 mph). Further, daily sea breezes are very regular off Imperial Beach (see Section 6.1). These winds drive transient onshore currents in the afternoon and early evening. In fact, this location is close enough to 30° latitude that diurnal wind forcing may resonate with the inertial period, as discussed by *Lerczak et al.* (2001).

4.5 Summary & Discussion

1. Findings from the original TOES circulation reports on the two major current modes, alongshore and gyre, are corroborated by new surface current data from CODAR. However, subsurface circulation patterns are less well understood. Long-term statistics are also lacking on the frequency, magnitude and direction of each of these major patterns, though review of CODAR data suggests that TOES results are approximately correct (i.e., gyre pattern contributing about 20% of variability, alongshore pattern contributing about 70%). With historical monitoring data however, it is not possible to determine the far-field behavior of the outfall or river plumes.

2. Monthly ocean surveys provide some information on the water column structure in the region. However, the irregular and widely spaced station locations, length of time required for the surveys, and the inherent nature of coastal circulation make interpreting the data challenging. It is not possible to use the surveys for analysis of plume behavior because the plume itself may only be sampled in a few locations, if any, and ocean conditions may change dramatically during the course of the survey. The data is most useful in demonstrating seasonal trends in stratification, and providing historical information for use in plume modeling (see Chapter 5). While limited in use for oceanographic purposes it is nevertheless a commendable effort to provide a regular time series of water properties in the region, both before and after the initiation of outfall discharges.

3. Nearshore processes can contribute to the transport of the outfall plume to the shoreline, as well as to the transport and dispersion of the Tijuana River plume along the shore. Little data exists in the South Bay/Imperial Beach area to assess the impact of processes such as internal wave activity, surfzone wave activity, and tidal currents. These topics may be particularly worthwhile for further study in this area because of the potentially large impact of the river plume that originates in the nearshore zone and has a large effect on bacterial exceedances.

The following recommendations are given to help address the issues summarized above. Further details on oceanographic sampling recommendation are given in Chapter 7.

1. Reorganize the monthly boat-based CTD and bacterial monitoring, to a) coordinate with other agencies to increase the number of sampling boats and personnel and provide truly synoptic sampling, or b) provide more complete and timely sampling of a smaller area;

2. Create a regular grid of CTD/bacteria sampling stations that will facilitate use of the data for analysis of oceangraphic processes and plume tracking.

3. In conjunction with the above, or in place of it, implement monthly towed water column profiling to provide meaningful data on water column structure that can be used to infer the effects of processes such as upwelling, major current patterns and swell conditions.

4. Combine resources with other regional and national agencies (City of San Diego, SDCOOS, State of California, NOAA) to install and maintain a system of moored thermistors and current meters along the San Diego coast, including South Bay, to provide long-term data on coastal current velocity and variability.

5. Coordinate ocean surveys with simultaneous overflights of aerial imaging.

Chapter 5

The South Bay Outfall and Plume

Section 2.a.iii. of the Consent Decree poses the final of three Phase One issues: whether or not oceanographic conditions such as the South Bay Gyre or upwelling "cause onshore transport of the effluent discharged from the POTW, and if so, to what extent," and how sufficient the current monitoring program is in determining this. In order to address this question it is necessary to first determine what the state of the plume is at the source, including the height of the plume and the concentration of the effluent after reaching maximum height. If the effluent can be shown to never surface, or if it can be shown to always be highly diluted upon surfacing, surface transport would no longer be a relevant concern. If on the other hand, certain oceanographic conditions, such as upwelling, can be shown to cause surfacing of the plume at a dilution rate that can potentially cause an exceedance at the shoreline after surface transport, this is directly relevant to Section 2.a.iii. of the Consent Decree.

This chapter will provide a review and analysis of data collected by the Ocean Monitoring program, data collected by other monitoring methods, and results obtained by modeling, with the objective of assessing what can currently be determined about onshore transport of the outfall plume. Included is:

1. A summary of the CTD and bacterial data collected for IBWC by the San Diego Metropolitan Wastewater Department to determine its utility in assessing 1) the state of the plume, and 2) the effects of oceanographic conditions on plume transport;

2. A review of other methods of monitoring outfall plumes, such as remote sensing and water property analysis;

3. A brief summary of plume dynamics and the use of models to predict plume behavior, including work done as part of the outfall design engineering studies;

4. Results of modeling plume behavior based on current SBOO effluent properties, outfall design, and monthly CTD surveys of water properties in South Bay.

The review will focus on the effectiveness of the current monitoring program to determine the path of the outfall plume, the effectiveness of other methods of plume tracking, and the potential for material from the outfall to impact recreational areas in San Diego.

Models were run using actual water property data collected by the Ocean Monitoring program, and effluent data from the IWTP. The models were run to simulate discharge from the outfall (near station I12) and to simulate an outfall located at a depth of 55 m (180 ft, near station I20). The "hyptothetical" model was run to preemptively address the question of the effect of a deeper discharge site. Although this is not strictly a monitoring issue, we believe it is important to consider alternatives that have arisen during public discussion of the SBOO, which was originally designed and sited for discharge of effluent that had undergone secondary treatment.

It should be noted that the ocean sampling data collected for IBWC is not intended primarily for use in physical oceanographic analysis or in dynamic plume tracking. It therefore has many limitations when used for that purpose. In this study, the analysis of the monitoring data has been limited to observing variability in stratification, particularly in the area immediately surrounding the outfall. This data is useful in determining, through the use of models, whether plume surfacing may be occuring under actual oceanographic conditions in the region. As it is currently conducted, however, these determinations could not be used for any practical purposes with respect to plume behavior. By the time CTD surveys (typically 2-3 days in length) are completed, the water column temperature and density profiles that are obtained would be too dated to be used as an indicator of the current potential for the outfall plume to be surfacing.

A summary of recommendations for ocean sampling is included at the end of the chapter, with details in Chapter 7.

5.1 SBOO Ocean Monitoring Program

The stated goals of the Ocean Monitoring program are:

- To ensure that the marine environment is protected
- To document changes in the marine environment over time and space
- To determine the quality of recreational water where citizens swim, dive, and fish
- To differentiate between natural changes and those that may be caused by the sewage discharge
- To measure compliance with state and federal regulations (*http://www.sannet.gov/mwwd/environment/oceanmonitor.shtml*)

The monitoring program collects monthly water column profiles of salinity and temperature using a CTD, with additional instrumentation for measuring dissolved oxygen, transmissivity, and pH during the casts. Data are collected over 40 stations from Coronado to just south of Punta Bandera, Mexico, from near shore to approximately 12 km (7.5 mi) offshore. The sampling station locations were designed by the U.S. EPA and generally follow local bathymetry lines, with additional stations at the outfall diffuser. The spacing of stations ranges from about 500 m (1640 ft) at the outfall to 5 km (3 mi) at the offshore stations, with an average of 2-3 km (1.2-1.9 mi) between adjacent stations running east-west, and 2-5 km (1.2-3.1 mi) north-south. In addition to the CTD data collected, bottle samples are taken for cultures and enumeration of three fecal indicator bacteria: enterococcus, fecal coliforms, and total coliforms. Samples are taken at three depths: surface and near-bottom, plus a sample at approximately two-thirds of the depth of the water column. The CTD surveys have been conducted since mid-1995 and generally span 3 days due to the necessity of transporting bacterial samples back to the laboratory to begin culturing within 6 hours of collection. On occasion, some surveys were conducted over 3 non-consecutive days spanning a 4-7 day period.

The ocean monitoring program provides useful data on ocean water properties (see Section 4.2) and is a valuable time series of conditions in the South Bay area covering nearly a decade. However, several problems were identified with the program that limit its ability to identify and track the effects of the outfall. The major problems that hindered using this data in the most constructive way in this review were:

Station locations While having stations located at similar depths is desirable, the bathymetry-oriented sampling design created a very non-uniform grid that is not conducive to identification or interpretation of features. The optimal spacing would be on a regular grid, with stations close enough to provide similar depths along each cross-shore section. Further, closer spacing would yield a coherent grid with increased confidence that the plume would not pass undetected between stations. If a greater number of stations is not feasible due to time constraints on sampling, it would be better to arrange the bathymetry-oriented stations along a straight line in the cross-shore direction. This would enable viewing truer cross-sections through which the plume might be observed to pass. It is possible that the same number of sampling stations could be arranged in a more regular grid with greater spacing in the north-south direction and increased resolution in the east-west direction, with perhaps one higher resolution along-shore grid line between the outfall and the shoreline. This would allow easier identification of the path of the plume, and distinction between outfall and river plumes. The additional stations clustered at the end of the diffuser occasionally provide useful information on the plume location, but because the plume is often quite narrow near its origin, it can still be easily missed in sampling (see Section 5.2.2).

Sampling duration Coastal regions are characterized by very small-scale physical features such as fronts, jets, and buoyant plumes. In addition, they are notorious for being highly variable on short time scales, from hours to days. Data collected over a span of several days is thus difficult to interpret. Are high levels of contaminants at one side of a sampling area an extension of high levels seen at the other side? Or have the contaminants at the first location been transported by currents to the second location while sampling was underway? Are there still contaminants at the first location? Current velocities in the South Bay range from less than 5 cm/s to over 20 cm/s. This translates into a displacement of 4 to 22 km per day (2.5-14 mi), in a sampling area that is approximately 12×24 km^2 in area (7.5×15 mi^2).

Sampling depths Plume bacteria mapping is complicated by sampling at different depths at different stations. What is mid-depth at one station can be near-surface or near-bottom at another. Plume transport often occurs in one depth range where the plume becomes neutrally buoyant. If mid-depth counts are collected at 20 m at one set of stations, 40

Table 5.1: SBOO Bacterial Sampling Map Color Coding. Red in all cases corresponds to the level for a daily exceedance and green corresponds to the level for a 30-day mean exceedance, as set by California State Ocean Water Quality Standards for human contact areas (AB411, Title 17).

Color	ENT	FEC	TOT
Black	< 5	< 20	< 100
Cyan	5-34	20-200	101-1000
Green	35-60	201-250	1001-5000
Yellow	61-104	251-400	5001-10000
Red	105-300	401-1000	10001-14000
Magenta	> 300	> 1000	> 14000

m at another, and 60 m at a third, it can be impossible to track the plume through a subsurface layer as it moves shoreward.

Appendix C contains maps of bacterial sampling results for each monthly survey. Maps are shown for three depth intervals, corresponding to surface (0-5 m), mid-depth (10-20 m), and bottom (25-35 m) near the outfall. The three types of bacterial counts performed are shown in each column: Enterococcus (left column), Fecal Coliform (middle column), and Total Coliform (right column). Sampled stations are marked with solid filled dots which are color coded by bacterial levels; see Table 5.1 for color coding details. Note that the color coding levels were chosen to correspond to California State Ocean Water Quality (AB411) standards, however these only apply in a regulatory sense to areas near shore designated as regions of "human contact" for recreational purposes. These standards were used to provide a consistent reference point for comparing offshore sites. Selected bacterial maps are shown in the following sections to illustrate seasonal and spatial patterns.

5.1.1 Seasonal and Spatial Patterns in Ocean Bacterial Counts

Maps of bacteria from the monthly CTD surveys show distinct patterns associated with seasonal and physical effects.

Winter, dry conditions: Bacteria surfacing directly above the plume occurs on numerous occasions during winter ocean sampling. Figure 5.1(a) shows one such occurance when plumes from river outflow are not present. Southward flow is evident in the bacterial pattern as well as in Landsat satellite imagery (not shown).

Winter, rainy conditions: Widespread bacterial contamination from river and/or runoff is evident in the pre-outfall survey of January 1997 (Figure 5.1(b)). Similar conditions occur in February 1998, and in March 2000 after the outfall became operational. In the

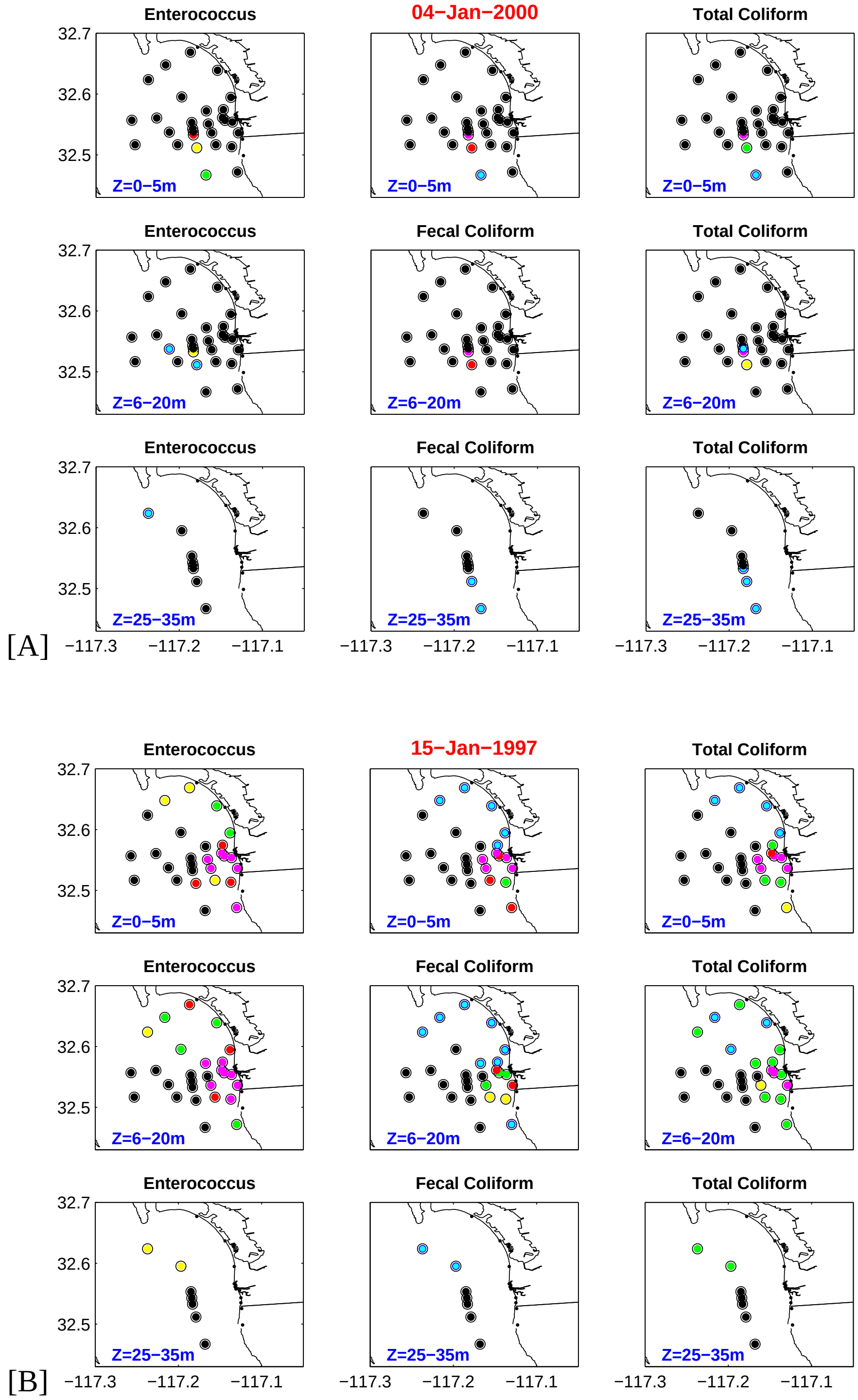


Figure 5.1: A) Bacterial sampling results January 2000 CTD survey showing high counts at the surface. B) January 1997 CTD survey showing strong shore-based source associated with rain.

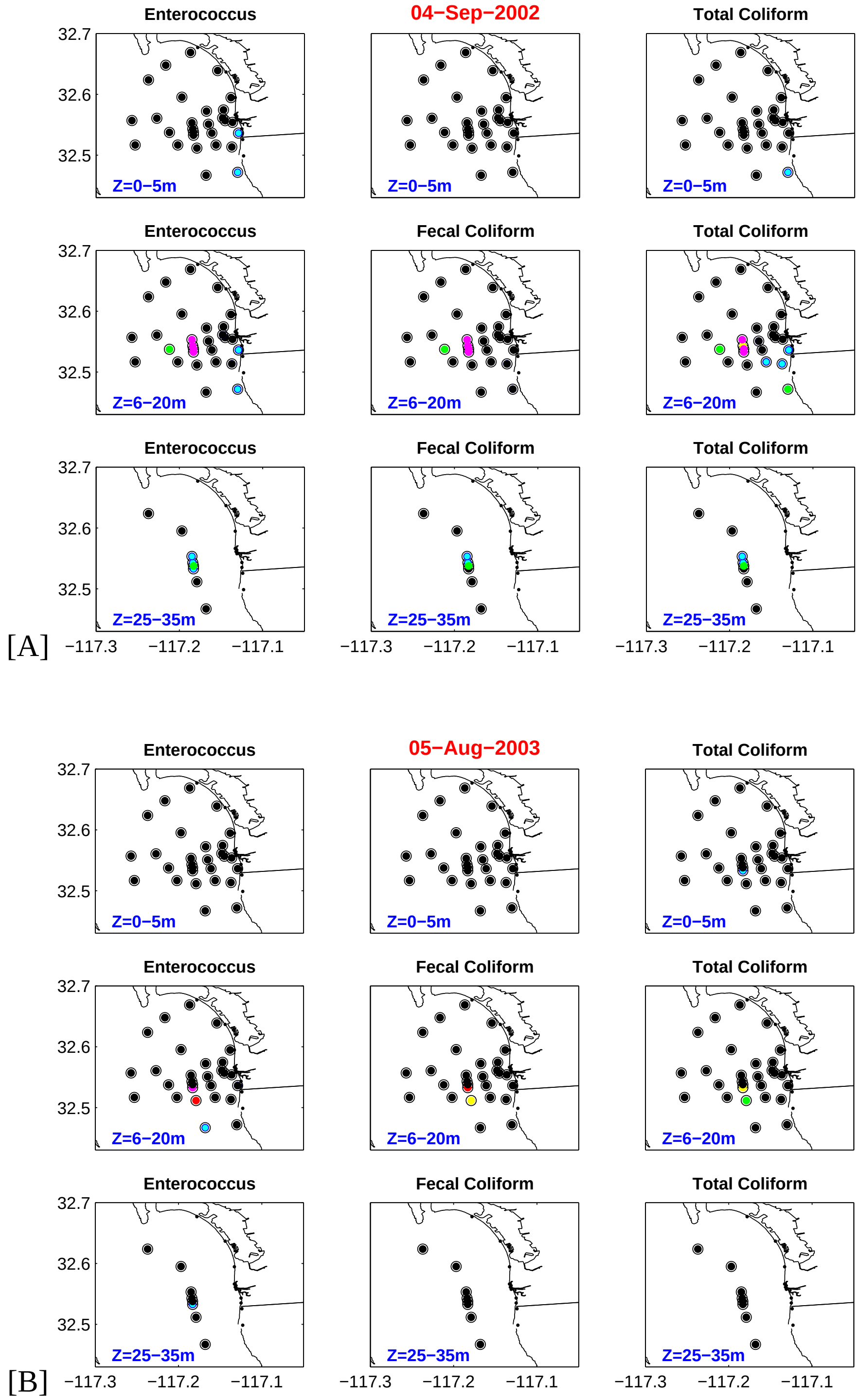


Figure 5.2: A) Bacterial sampling results for September 2002 CTD survey showing plume at mid-depth. B) August 2003 CTD survey showing plume at mid-depth travelling southward from the outfall. See color coding key in Table 5.1.

6-8 March 2000 survey the distinction between land-base sources and the outfall is less distinct, however the highest counts are clustered near shore and the Tijuana River outlet. There are no exceedances in the immediate vicinity of the outfall. At this time (5 March) there was a countywide advisory due to urban runoff and Tijuana River flow, after approximately 0.65 inches of rainfall. One cannot determine whether the plume material from the outfall is travelling shoreward, as it would be indistinguishable from river sources.

Summer: Bacterial patterns in the summer typically show far fewer elevated counts at the surface, and in many summer surveys there are no elevated surface counts at all. Frequently the presence of plume bacteria can be seen deeper in the water column, especially at mid-depth where the rising plume would be trapped by the summer thermocline. This pattern is seen in September 2002 (Figure 5.2(a)) where mid-depth concentrations of enterococcus and fecal coliforms are well above single day exceedance levels over the outfall, but counts at the surface throughout the South Bay area are uniformly low.

In contrast, the maps for 1995-1998 before the outfall was in operation show none of the subsurface bacteria patterns that are seen during the summer months after the outfall is discharging (see figures in Appendix C for 1995-1998).

Movement with currents: The August 2003 survey (Figure 5.2(b)) shows high levels of indicator bacteria at mid-depths at the outfall and directly south, suggesting the trapped plume is being advected southward by currents. Unlike most time periods, the CODAR surface currents at this time are very consistent over a couple of days, with strong southward flow over the entire South Bay area (Figure 5.3). A similar pattern is seen in the January 2000 monitoring data (Figure 5.1(a)).

Blurring between river and outfall effects: As seen in aerial imagery from Ocean Imaging, bacterial surveys also display merging of sources from land and from the outfall. Good examples of this are seen in February 2000 and March 2003 (Figure 5.4). During these surveys it appears that bacterial sources are located at both the shoreline and the outfall. In the February 2000 survey it is unclear whether the elevated counts between the outfall and shore are from the outfall or from well-diluted river input. In March 2003 it appears that there is an outfall source influencing mid-depths, and a river source affecting the surface layers.

5.2 Other Plume Tracking Methods

Various methods have been tried in tracking the path of effluent plumes. The task is complicated by the fact that entrainment of seawater into the plume affects measurable levels of easily monitored water properties more rapidly than it affects bacterial levels. For example, changes in salinity from a 100-fold dilution of effluent with seawater can make plume water indistinguishable from ambient salinity variations. The same dilution would leave typical effluent with exceedance levels of bacteria (for example, effluent with an initial 100,000

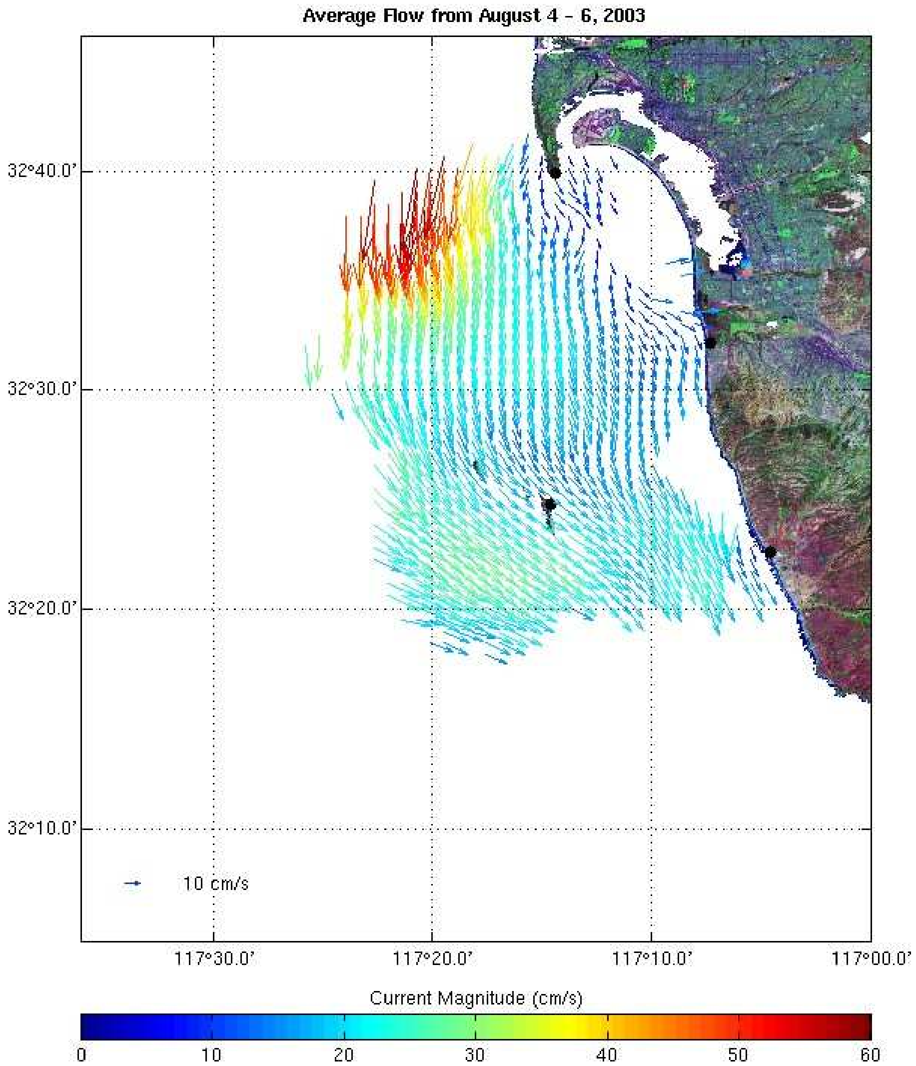
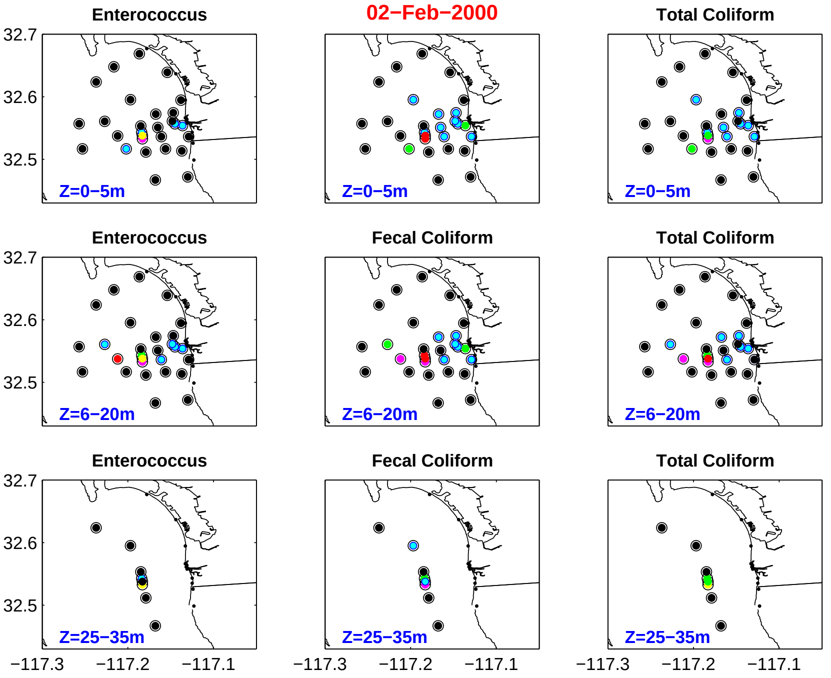
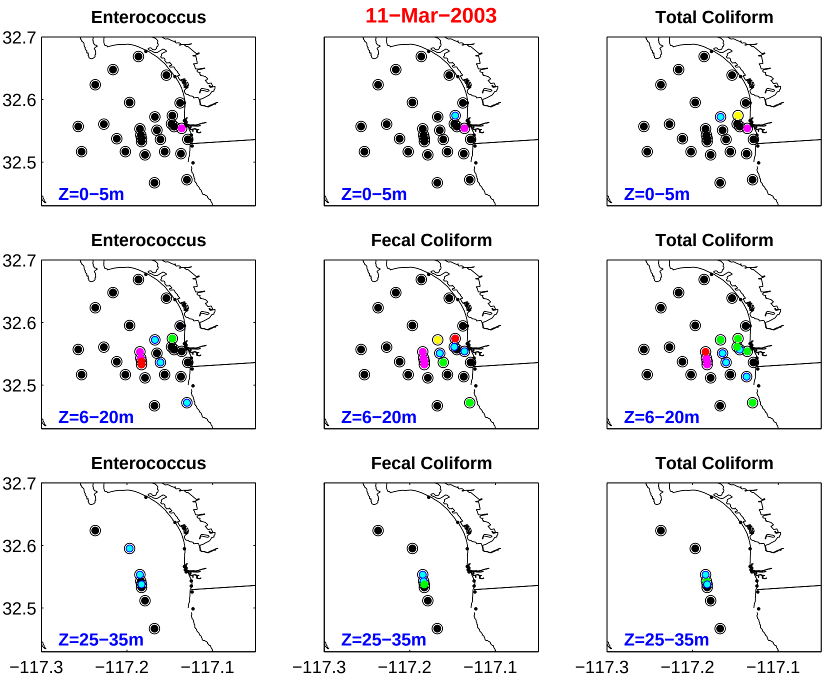


Figure 5.3: CODAR surface currents for 5 August 2003, 0600 GMT. Image from San Diego Coastal Ocean Observing System.



[A]



[B]

Figure 5.4: Bacterial sampling results showing merging between outfall and river sources: A) February 2000 CTD survey, B) March 2003 CTD survey.

CFU/100 mL of fecal coliforms in a hundred-fold dilution with seawater would have a final count of 1000, well in excess of the 200 CFU/100 mL exceedance level.) This can make it impossible to use properties that can be easily monitored by shipboard or remote devices to detect the presence of the effluent plume once it is a short distance from the outfall. In addition, the mechanisms of large scale plume transport and mixing are not understood fully. From aerial imagery it appears that rather than being well dispersed horizontally, plumes may often remain in intact, narrow streamers that can be missed altogether by sampling stations.

Ultimately, tracking a plume with bacterial counts would be the most direct method of determining the exact location of sewage-contaminated waters. However, there are a number of logistical constraints, including the need to process bacteria samples within 6 hours of collection.

5.2.1 Tracking with Multiple Water Properties

Wu et al. (1994) noted in plume monitoring from Huntington Beach that neither temperature, salinity, nor transmissivity were sufficient to distinguish plume water from surrounding seawater. However, they were able to develop a method of discriminating plume water from ambient seawater using a combination of transmissivity, salinity, and fluorescence. First, high fluorescence samples were separated from the data to eliminate low transmissivity samples that were the result of high chlorophyll. The remaining data with low transmissivity fell into two groups with differences in salinity. The higher salinity group was consistent with samples impacted by sediment resuspension, while the lower salinity group was consistent with areas where the plume was expected to be present. These two groups show up as distinct "fingers" on a salinity-transmissivity plot.

The same method applied to SBOO CTD data did not give similar results (Figure5.5). The data do not fall into separate fingers, but instead follow an approximately normal distribution, indicating that there was no distinctive, detectable salinity signature to the SBOO plume after initial mixing at the seafloor, or that turbidity is not restricted to plume and near-bottom waters.

It is likely that the method described here, using temperature, salinity and transmissivity, was not helpful in plume tracking because there is no distinct low salinity–low transmissivity signature to the plume waters in the data that we analysed. There may be several reasons for this: 1) the CTD casts may be missing the plume; 2) the plume may be too well mixed in the water column to still have a distinct low-salinity signature because of entrainment of ambient waters; or 3) the plume itself may have too low a volume (i.e., low volume discharge from the outfall) to maintain a distinct salinity signature. This technique was used previously in Orange County where discharge volumes are significantly higher than at SBOO. It is important to note here that when we address identifiable salinity differences we are talking about factors of about 30:1, whereas when we addresss measurable differences in bacterial levels we are talking about factors of about 1,000,000:1; thus it is possible to lose a salinity signature far sooner than a bacteria signature when discharge water mixes with ambient seawater.

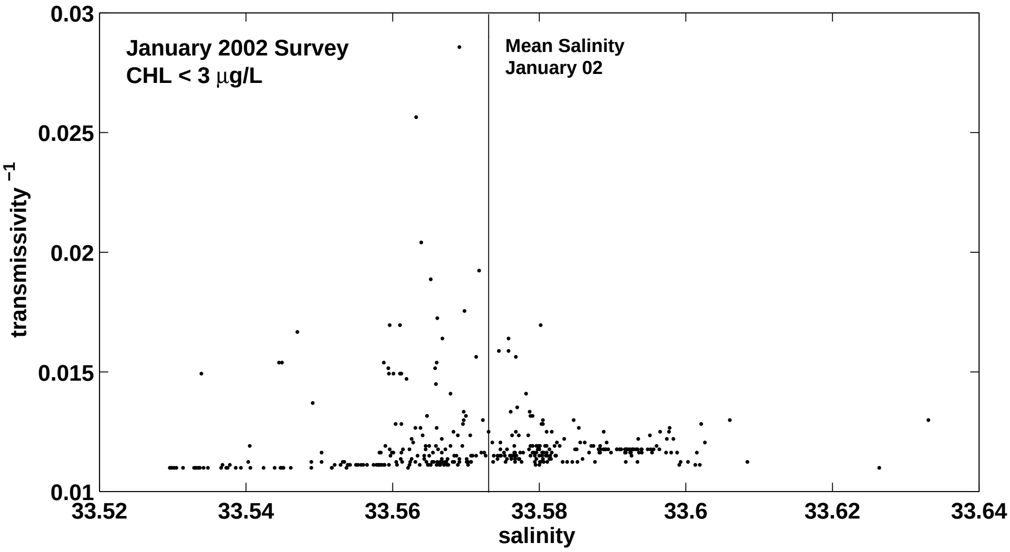


Figure 5.5: Salinity vs. inverse of transmissivity for low chlorophyll data from January 2002 CTD survey.

5.2.2 Remote Sensing

Satellite imagery and aerial photography are additional methods of observing and tracking outfall plumes. While many satellite observing systems do not provide images on a small enough scale to be useful for this purpose, a few do show some utility, although they are limited to the upper few meters of the water column. Ocean Imaging, Inc., has been contracted by State Water Resources Control Board, San Diego Metropolitan Wastewater District, and the International Boundary Water Commission to perform aerial photography and analysis of digital imagery in the San Diego coastal region since October 2002. The imagery that has been used for plume monitoring includes:

- Satellite imagery from Landsat Thematic Mapper (TM): These images have a 20-30 m resolution and are able to resolve moderately detailed features of the outfall plume. Four channels (blue, green, red, and near-IR) are useful for ocean color images, but wide band widths do not allow “fine tuning” of wavelengths observed. However, Landsat data does allow one to distinguish between plumes with differing amounts of suspended sediments, organic matter and chlorphyll. Ocean Imaging found moderate positive correlation between total coliform counts and TM blue/red ratios, probably due to suspended organic matter. The repeat cycle for coverage of the same area is 8 days (through a combination of two satellites).

- Imagery from NASA’s Terra and Aqua satellites’ MODIS (Moderate-resolution Imaging Spectroradiometer): Multi-spectral MODIS images are available in resolutions of 250-1000 m over 36 narrow bandwidths. Images can show the general location of turbidity plumes associated with river, bay, and outfall discharge.

- Imagery from Indian Remote Sensing (IRS) satellites: These multi-spectral images with blue, green, red and near-IR channels have a spatial resolution of 24 m. Capabilities are similar to Landsat TM, and with multiples satellites a repeat cycle of 5-24 days is attained.

- Imagery from Synthetic Aperature Radar: These instruments are based on active radar transmission which can detect variations in the ocean's surface that provide information on surface currents, waves, and surface water properties such as slicks from oil or surfactants. Ocean Imaging has used these images to find areas of surfactants associated with polluted river plumes.

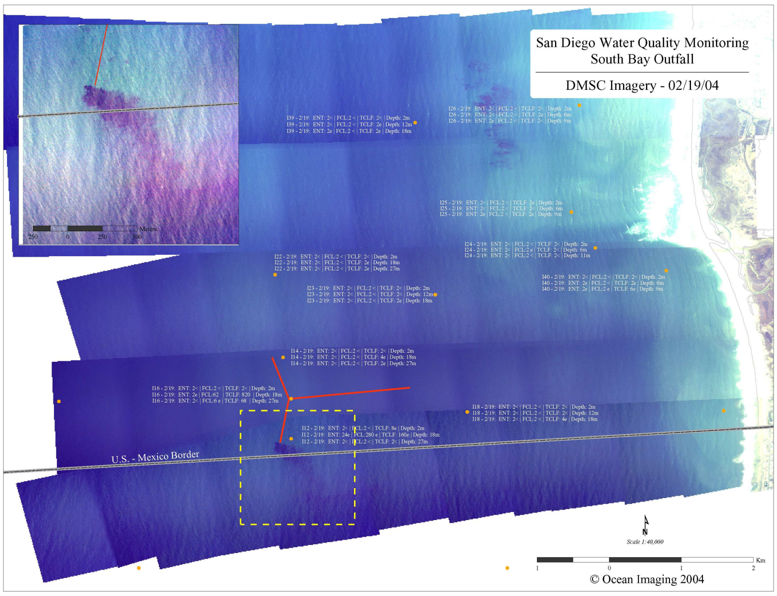
- Satellite imagery from NOAA's AVHRR (Advanced Very High Resolution Radiometry) satellite: This infrared sensor provides low resolution (1.1 km) sea surface temperature images. Its main utility in this area is for discerning large scale currents which might impact the South Bay region. However, these images offer improved temporal resolution, with a repeat cycle of 1/2 day.

- Aerial photographic images: Ocean Imaging creates composite images using a 4-channel DMSC-MK2 optical sensor, flying at low elevations (under cloud level). The resolution of the images is 0.25-2 meters. These images frequently show the location of the Tijuana River and SBOO plumes in significant detail, and sequences of images from consecutive days may be used to infer net flow direction and speed. The bandwidth of the 4 channels is customizable to user-specified wavelengths, allowing imaging of the bandwidths most useful to discrimination of wastewater plumes.

One major advantage of satellite imagery is that the images provide a more or less instantaneous picture of the region, making it easier to interpret the flow patterns and relationship between different features in the image. Major disadvantages are that they are not able to function with cloud cover, they only detect surface features, and repeat imaging of the same area may be infrequent. Further, bacterial concentrations cannot be measured remotely.

Aerial DMSC images frequently show very clear plume boundaries that may be helpful in determining if a surface-breaking plume is moving toward shore, or help guide ocean sampling in progress. Figure 5.6(a) shows a breaking plume surfacing southward of the outfall (*Svejkovsky*, 2004). Taken concurrently with an ocean monitoring survey, this image shows how extremely low bacterial counts can occur in the immediate vicinity of a surfacing plume because of the sharp plume boundaries. An aerial image taken the previous month shows the relationship between the sampling stations at the outfall, the plume boundary, and the ship track during sampling (Figure 5.6(b)). The image was taken the day before the sampling took place, but shows how a) the sampling stations may be entirely outside of the plume boundaries, despite the plume surfacing very close to the outfall, and b) the ship's track may also miss or drift in and out of the plume during sample collection.

The aerial imagery also illustrates the difficulty of distinguishing between the SBO outfall plume and the Tijuana River plume using sparse ocean sampling stations. A DMSC aerial composite taken on 2 March 2003 shows the outlines of the two apparent plumes as they drift to the north-northeast (Figure 5.7). The nearest monitoring stations are labelled in orange. Of these, only one station is located within the boundaries of either of the plumes, so



[A]

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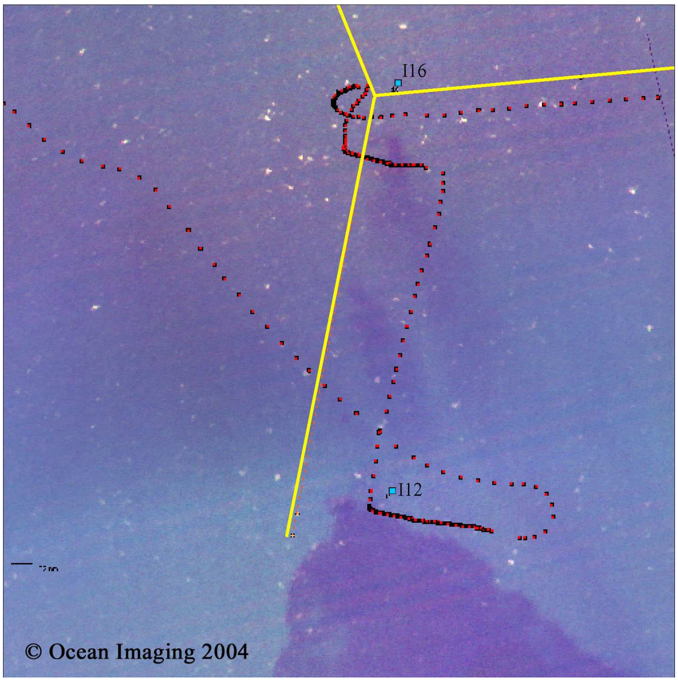


Figure 5.6: Aerial DMSC images showing surfacing plume during winter 2004: A) 19 Feb 2004. B) 5 January 2004 showing relationship between ship's sampling track and plume location on the day after. (Note: Track GPS locations are at equal time intervals, and closer spaced dots near I12 and I-16 indicate ship drift during sampling stops.) Images Copyright *Ocean Imaging*, 2004.

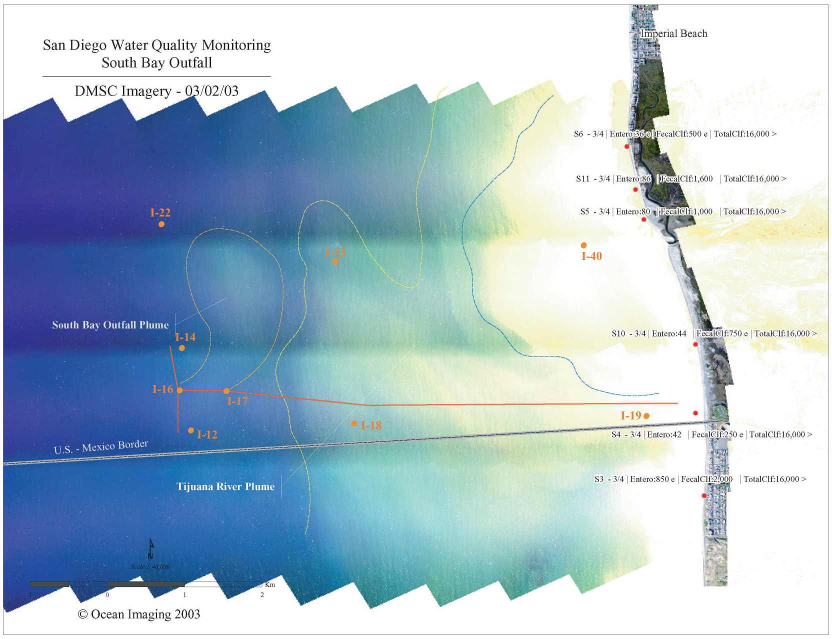


Figure 5.7: Aerial DMSC image from 2 March 2003 showing plumes from both SBOO and Tijuana River. Nearest sampling locations have been overlaid to show relationship between plume boundaries and monitoring stations. Image Copyright *Ocean Imaging*, 2004.

most of the plume activity would not be captured by the ocean sampling program. (Note: the aerial survey does not coincide with the actual sampling dates for this month, which were 10-12 March.) Even if several of the stations did happen to overlap the plumes, it would be difficult to distinguish between water properties and bacterial counts associated with the outfall and those associated with the river plume because of the irregular and wide spacing between stations. For example, if I22 fell within the center of the outfall plume, it would be nearly impossible to exclude the possibility that water at I22 was originating from the Tijuana River plume without satellite imagery. Likewise, it would be nearly impossible to know whether water at I23 was coming from the outfall.

5.3 Plume Dynamics and Mixing Models

Effluent plumes created by submerged wastewater outfalls are subject to a number of influences which determine their height, dilution rates, transport rates, and ability to affect nearby coastal areas. The outfall design controls flow volume, flow velocity, port positioning, and depth of effluent release, all of which can affect the transport and dilution of the plume. In addition, ambient ocean conditions such as temperature, salinity and current speed are also factors in determining plume behavior. Many of these factors have been investigated using empirical field measurements or models, which are themselves often based in part on empirical data.

The design of offshore outfalls for disposing of polluted wastewater is based on three principles: offshore location, sub-thermocline discharge, and high levels of dilution. Questions about the efficacy of outfalls are thus directed at these three criteria: Is the outfall far enough offshore to preclude transport of diluted wastewater back onshore? Is the wastewater discharged deep enough and beneath enough density stratification that the resultant plume does not surface? What level of dilution is achieved through the process of discharge? The "near-field" is the immediate zone around the outfall in which designed dilution is not complete and in which the method of discharge controls the mixing processes. Beyond this initial mixing, the wastewater plume moves into the "far-field," where it is subject to transport and mixing that is primarily controlled by the ambient circulation and stratification. Thus, while the method of discharge and associated near-field processes will determine the dilution and rise of the wastewater plume, the nature of the receiving environment and associated far-field processes will determine the subsequent dilution and destination of the wastewater plume.

5.3.1 Plume Buoyancy and Active Surfacing

For the purposes of determining effects of outfall effluent on nearby beaches and recreational areas, one of the most critical parts of plume dynamics is the effect of buoyancy. Because outfall effluent is relatively "fresh" water, with a much smaller percentage of dissolved material than seawater, and hence a lower density, effluent is much more buoyant than the surrounding seawater upon initial discharge from the diffuser pipe. This buoyant effluent tends to rise toward the surface, and this combined with the momentum of the effluent jet as it discharges from the diffuser causes entrainment of surrounding seawater. While entraining ambient seawater, the effluent concentration decreases while density increases within the plume. Eventually, the plume is well mixed with its surroundings and buoyant effects cease. The zone within which the plume is mixed rapidly by jet momentum and buoyancy is the zone of initial dilution; many regulations specify the minimum dilution factor that must be reached in this zone for a variety of toxic substances.

The height at which neutral density of the plume occurs may be almost anywhere in the water column, depending upon the ambient density and particularly the density gradient. When released at depth in a stratified water column, the wastewater entrains denser waters at depth and attains a final density greater than surface waters, thus precluding further rise of the wastewater plume to the surface. In areas such as South Bay, strong summer surface warming creates a warm, light surface layer with a strong pycnocline (density gradient) below. A strong pycnocline is thought to be one of the most important features that prevents active surfacing of effluent plumes. Winter conditions on the other hand, are characterized by a water column that is less stratified due to surface cooling and increased vertical mixing. Without a strong density gradient to inhibit rise of the buoyant effluent, active plume surfacing is more likely. Near field models (Section 5.3.3) are designed to predict the height of plume rise and potential for active surfacing.

5.3.2 Effects of Outfall Design & Ambient Conditions

The engineering design of an ocean outfall is one of the primary controls on the fate of effluent discharge into the environment. The outfall's flow volume, flow velocity, port spacing, port angle, and port depth are all critical factors in determining the rise of a plume, its thickness, and its dilution. Increased momentum of a discharge jet increases the entrainment of ambient water, and jets that entrain deeper (more dense) water become neutrally buoyant sooner (*Roberts et al.*, 1989b). Designs that encourage high momentum flux near the sea floor are less likely to see plume surfacing at high concentrations. Adequate port spacing is necessary to prevent individual port plumes from merging prematurely which can reduce the entrainment of uncontaminated water and delay dilution and neutral buoyancy. High current velocity tends to increase entrainment and dilution as well, and ambient conditions in general are the other main control of the fate of effluent discharges.

The plume rise and thickness are also affected by local temperature, salinity, and current speed and direction. Temperature and salinity determine seawater density which affects the relative buoyancy of the effluent plume, as discussed above. Greater current speeds normally inhibit the rise of a plume, as well as its vertical thickness (*Roberts et al.*, 1989a). Strong currents also increase the dilution of effluent, more so when they are perpendicular to the discharge. In the case of SBOO, discharge from risers is radial, in 4 directions, so at least 2 ports out of 4 on a riser are always nearly perpendicular to the current.

5.3.3 Plume Mixing and Circulation Models

Numerous models are in use and under development for understanding and predicting ocean currents, coastal zone processes, and buoyant plume behavior. An exhaustive analysis of models with applications to coastal wastewater issues in Southern California can be found in the review prepared for the Orange County Sanitation District (*Tetra Tech, Inc.*, 2003).

Plume models fall into two general categories. Near-field models predict a plume's height of rise, dilution rate and initial boundaries given information on the immediate ambient water properties, currents, and the design and effluent properties of the outfall. Far-field models are larger scale coastal circulation models which attempt to simulate coastal currents, transport and mixing processes. While near-field models would predict the location, dilution, and height of the plume over a scale of hundreds of meters after its initial discharge from an outfall, far-field models would predict the movement of plume water once it has stabilized and entered into the general coastal circulation.

There is some consensus that predictions from near-field models are more robust than that from far-field models at this time. The parameters that are required as input into each type of model differ considerably. While near-field models require input of measureable parameters such as effluent flow rates, ambient water properties, and outfall structure, far-field models are dependent on input of more variable parameters such as wind forcing, current velocities at the model boundaries, and so forth. In addition, near-field models are limited to projecting plume behavior out to a finite point in time, when buoyancy and momentum effects have become negligible and the plume is in relative steady state with its surroundings. In addition, many near-field models that are widely used have also undergone empirical testing, comparing field results of plume behavior to model results, and some have been developed in part using empirical methods. Far-field models, by contrast, attempt to simulate the continuous development of processes that are not only varying with time, but also are affecting many of the other processes that are being modeled. In addition, because many of the physical processes in far-field models are coupled to one another, errors in input parameters can propagate throughout many levels of the model.

Because of the challenges of the physics and computational tasks involved, far-field models for coastal circulation are still considered highly experimental (e.g., coastal versions of the Princeton Ocean Model (POM), MICOM, ROMS, and others) and are in a state of vigorous development in academic settings. Near-field models are also undergoing continuous development and improvement, but versions are available that have been shown to adequately predict small scale plume behavior. Because meeting a minimum level of initial dilution of a sewage plume is the major requirement that must be met in outfall design, near-field models are a valuable tool in planning. The U.S. EPA is involved in the development and distribution of plume modeling tools such as Visual Plumes, which includes a variety of near-field modeling codes. Commercial products such as CORMIX are also available.

Phase IV of the Tijuana Ocean Engineering Studies (TOES) included planning studies to predict plume surfacing, transport and dispersion from the proposed outfall and determine the most efficient length and depth for the outfall and diffuser pipes (*Engineering-Science*, 1990). Plume buoyancy and dilution was tested using UMERGE, a well-tested near-field model that is the precursor to one of the EPA's Visual Plumes models. Effluent characteristics taken from the Point Loma outfall were used in these tests, along with data on ambient water properties and circulation from the TOES Ocean Measurement Program.

Results from the models showed highest dilution rates were obtained with unstratified ambient conditions such as exist during the winter months. Without vertical density gradients to trap the plume at depth, the plume rises higher in the water column and entrains more water. While dilution rates are better, the potential for impact on beaches and other recreational activities is also greater when the plume surfaces. The optimal depth for plume dilution was from an outfall 52 m (170 ft) deep. Deeper water allows the plume more time to mix while rising, and ambient conditions were more conducive to plume rise at this depth than further offshore. During summer stratified conditions, the plume remained trapped below the thermocline at higher concentration.

A computer model called TRACKER was also developed by the TOES team to look into the effects on plume dilution of the gyre circulation and current variability identified in the Ocean Measurement phases of TOES. Objectives were for a minimum initial dilution of 100:1 to meet criteria in the California Ocean Plan for toxic materials, using effluent characteristics of the Point Loma outfall. TRACKER is a simple advection–diffusion model that was used in combination with UMERGE to estimate the effects if the plume was re-entrained back on itself through a current reversal or other flow pattern. The result is an "effective" dilution that compensates for possible irregularities in flow patterns. Using 5 current patterns identified by TOES Phases I-II, they simulated the effects on average monthly dilution for different outfall depths. The minimum depth that could achieve an average dilution of 100:1 under all tested current patterns was 26.5 m (87 ft).

The final design adopted for the SBOO located the outfall diffusers at approximately 28 m depth. The following section presents results of similar near-field modeling using effluent and outfall parameters from the SBOO and ambient water properties from ocean monitoring surveys conducted since the outfall has been operational.

5.4 Modeling the SBOO Plume

Using the monthly CTD and bacterial sampling data provided by the monitoring program, it is now possible to initialize plume models with data from actual water property measurements near the outfall. This allows us to use models to look in more detail at the effects of seasonal changes, variations in stratification, and influences of upwelling on the transport and mixing of the plume. The model results can then be compared to patterns observed in bacterial sampling and other observations of plume fate. Models were run using ambient water properties near the outfall as well as at a hypothetical deeper outfall location.

The model package used for this purpose was the U.S. EPA's Visual Plumes Experimental PVD version ("Plumes60") by *Frick et al.* (2001) which contains several different plume buoyancy and dispersion models. For the modeling described below, the model used was Visual Plumes' UM3. Visual Plumes was selected over CORMIX because it allows input of more detailed water column profiles that can accurately simulate ambient conditions measured in CTD surveys. (Plumes60, for example, can handle 60 levels of ambient water column data.) The UM3 model was set up to simulate the SBOO's 4-port riser construction (*Baumgartner et al.*, 1994; *Isaacson et al.*, 1983) and Frick (personal communication). Details on model configuration are given at the end of this chapter. UM3 is a more recent version of the UMERGE model used in the preliminary engineering studies for the South Bay outfall.

UM3 is also more suitable for multiport diffusers with discrete plumes, as opposed to plumes that merge quickly and which can be modeled as a line source (the other widely used Visual Plumes model, NRFIELD/RSB, treats multiport diffusers in this manner). Experiments on port spacing have shown that while dilution rates may be predicted accurately using line source models, they underestimate plume height on diffusers with widely spaced ports (*Roberts et al.*, 1989b). Visual evidence from the videotaped SBOO underwater ROV inspection shows discrete plumes that are well separated. Merging can also be predicted based on port spacing, volume flow, and ambient density stratification. The ratio s/L_b, where s is the port spacing and L_b is a buoyancy length scale, must be < 0.3 for a series of diffuser ports to be considered effectively a line source (*Roberts et al.*, 1989b). Between 0.3-2 individual plumes may merge below the trap layer when affected by currents, but not under calm conditions. For the SBOO, s/L_b is only less than 0.3 when ambient density stratification is extremely weak (e.g., $\partial\rho/\partial z < 0.01$).

SBOO plume characteristics & model parameters

Effluent properties and flow rates for discharges into the SBOO were obtained from San Diego Metropolitan Wastewater District and IBWC. Annual averages for flow volume and total dissolved solids are in Table 5.3.

Monthly averages for flow volume ranged from 18-25 MGD from IBWC, and 4-5 MGD from MWWD. Between 1999-2003, the range in daily flow volume from IBWC was 4-47 MGD, with approximately 10% of daily flow volumes less than 20 MGD, and 10% over 27 MGD. The daily flow volume from MWWD over 2001-2003 ranged from 0-6.3 MGD.

Table 5.2: Merging and buoyancy parameters for different ambient stratifications.

```
1)  Strong stratification

        Risers       Spacing (ft)    Ports/ris    VolFlow (MGD)
         15.00         24.00          4.00         20.00

        AmbDens      EffDens         d_rho        dz (m)
       1026.00        997.00          2.0        27.43

Reduced gravity = 0.277  m/s2
Buoyancy flux = 0.0022114 m3/s3
Diffuser length   L = 109.728 m   [360 ft]
B-V Freq   N = 0.026389  s-1
Effective port spacing  (RSB) s = 3.6576 m   [12 ft]
Buoyancy length scale  L_b = 4.937 m
s/Lb = 0.74086


2) Very weak stratification

        Risers       Spacing (ft)    Ports/ris    VolFlow (MGD)
         15.00         24.00          4.00         20.00

        AmbDens      EffDens         d_rho        dz (m)
       1025.00        997.00          0.20         27.43

Reduced gravity = 0.26771  m/s2
Buoyancy flux = 0.0021372 m3/s3
Diffuser length   L = 109.728 m   [360 ft]
B-V Freq   N = 0.0083491 s-1
Effective port spacing (RSB) s = 3.6576 m   [12 ft]
Buoyancy length scale  L_b = 15.4281 m
s/Lb = 0.23707
```

Table 5.3: SBOO Effluent, Annual Averages, 1999-2003.

Year		Volume (MGD)	TDS (mg/L)
1999		23	925
2000		24	1224
2001		24	1409
2002	Combined	28	
	IBWC	24	1493
	MWWD	4	n/a
2003	Combined	27	1406
	IBWC	23	1482
	MWWD	4	972

The following parameters and configurations were used in the Visual Plumes model.

Ports and risers: There are 18 risers in operation on the south diffuser pipe: one at the wye, S26 (approximately 624 ft along the south diffuser), S52 (1248 ft), and fifteen from S68-82 (1632-1968 ft). The 15 risers covering the last 336 ft of the south diffuser were used to model the buoyant behavior of the plume because they contribute the majority of the flow and are contiguous. Number of ports = 60 (4 per riser). Port angle settings: 0° vertical, 90° horizontal (north). Port spacing: 6 ft. (equivalent to 4 ports per 24 ft).

Effluent: From 1999-2003, average monthly flow volume of effluent at the ocean outfall has ranged from 23-28 MGD, so the contribution of the 15 contiguous risers at the end of the south diffuser would be 19-23 MGD. Effluent density was based on total dissolved solids (TDS) of 900-1500 mg/L. Slight changes of effluent density within this range have negligible effect on the relative buoyancy of the plume compared to the ambient water. Flow volume was shown to increase the plume height by up to 1 foot per additional 1 MGD of flow volume. An effluent flow volume of 20 MGD was normally used in the models.

Ambient conditions: Ambient salinity and temperature were taken from CTD data collected by the MWWD for the SBOOO monitoring program. As many levels as necessary were included to simulate the major features of the ambient stratification. Data on currents (surface only) was not available until 2003, so most model runs include a range of current velocities from 5-20 cm/s.

5.4.1 SBOO Plume Model Cases

A number of sample cases were modeled, using actual monitoring data for model parameters. The sample cases were chosen to illustrate a typical range of seasonal conditions, as well as the variability that can be expected with less frequent but not atypical events such as strong summer upwellilng. Models were run with a range of current velocities similar to those measured in this area. Two sets of cases were run, one with ambient water profiles taken from station I12 near the active outfall diffuser, and one to simulate a hypothetical deeper outfall with ambient profiles taken from station I20 at a depth of 180 ft. The deeper case was run to pre-emptively address questions of whether a longer outfall could solve potential problems with surfacing of effluent. The shallower runs also include data for current velocities of zero, which is the standard used to establish compliance with dilution requirements for effluent toxicity. Table 5.4 contains a summary of the results for each of the cases, which are discussed in detail below. Plume depth refers to the depth at which maximum plume rise occurs in the nearfield model, average dilution is the dilution at the centerline of the plume, and date is the month of the CTD survey the ambient ocean data is taken from.

SBOO Plume Model: Summer

September 2002 is a representative example of summer water column structure, with very warm surface waters in the upper 10 ft, followed by a steep but not abrupt thermocline

Table 5.4: Plume Model Results

Case		Plume Depth [ft]	Avg. Dilution Factor	Current	Date
SBOO	Summer	16	96	0 cm/s	5 Sep 2002
(I12, 90 ft)		27	175	5 cm/s	
		32	281	10 cm/s	
		40	494	20 cm/s	
	Winter	surface	161	0 cm/s	5 Jan 2000
		surface	252	5 cm/s	
		surface	381	10 cm/s	
		14	625	20 cm/s	
	Mild upwelling	surface	125	0 cm/s	3 Jun 2003
		surface	204	5 cm/s	
		6	338	10 cm/s	
		21	568	20 cm/s	
	Strong upwelling	surface	156	0 cm/s	7 Aug 2001
		surface	247	5 cm/s	
		surface	400	10 cm/s	
		surface	741	20 cm/s	
Deep outfall	Summer	16	313	5 cm/s	4 Sep 2002
(I20, 180 ft)		28	619	10 cm/s	
		43	1305	20 cm/s	
	Winter A	15	367	5 cm/s	4 Jan 2000
		28	758	10 cm/s	
		43	1540	20 cm/s	
	Winter B	surface	436	5 cm/s	9 Jan 2002
		surface	739	10 cm/s	
		40	1324	20 cm/s	
	Strong upwelling	surface	412	5 cm/s	6 Aug 2002
		surface	714	10 cm/s	
		5	1434	15 cm/s	
		24	1727	20 cm/s	

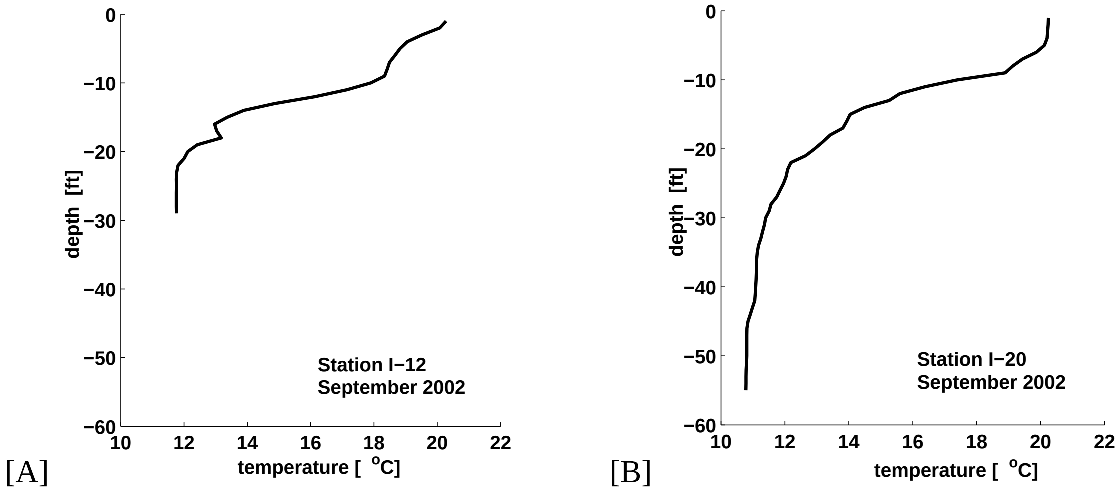


Figure 5.8: Temperature profiles during summer, A)Station I12, September 2002. B) Station I20, September 2002.

after which temperatures gradually approach a minimum of 10-12 ^{o}C (Figure 5.8). Bacterial counts during this month's survey show a plume trapped at mid-depth, with no elevated surface counts (Figure 5.2(a)). In models run to simulate ambient conditions at Station I12 near the outfall, the plume does not reach the surface under any current velocities.

A model run with ambient conditions from station I20 during the same survey gives similar results for plume rise, with higher dilution factors, approximately 300-1300 depending on current velocity, compared to 175-500 at the actual outfall location.

SBOO Plume Model: Winter

An example of plume surfacing occurs in January 2000. Bacterial sampling from January 3-5 shows low counts everywhere in South Bay except immediately over the outfall where levels are in exceedance of the single day standard for enterococcus at the surface (Figure 5.1(a)). Counts are also high to the south of the outfall, decreasing with distance, suggesting the presence of a southward flowing current. Landsat TM imagery from January 3 also shows a pattern in coastal turbidity characteristic of southward flow from north of Point Loma into Mexico; see *Svejkovsky* (2002).

Models using the CTD temperature and salinity profile from near the outfall during this survey (Figure 5.10) show the plume rising to the surface at both low and moderate current velocity, and at 20 cm/s current speed the plume rises to within 14 ft of the surface (Table 5.4, and Figure 5.11(a)).

A plume released at the hypothetical deeper outfall does not surface under any current speeds for temperature profiles like that in January 2000, as seen in Figure 5.11(b). However, in many other winter months temperatur profiles are much more isothermal, as in January 2002. The model results for this structure show the plume surfacing until velocities reach 20 cm/s (Figure 5.12).

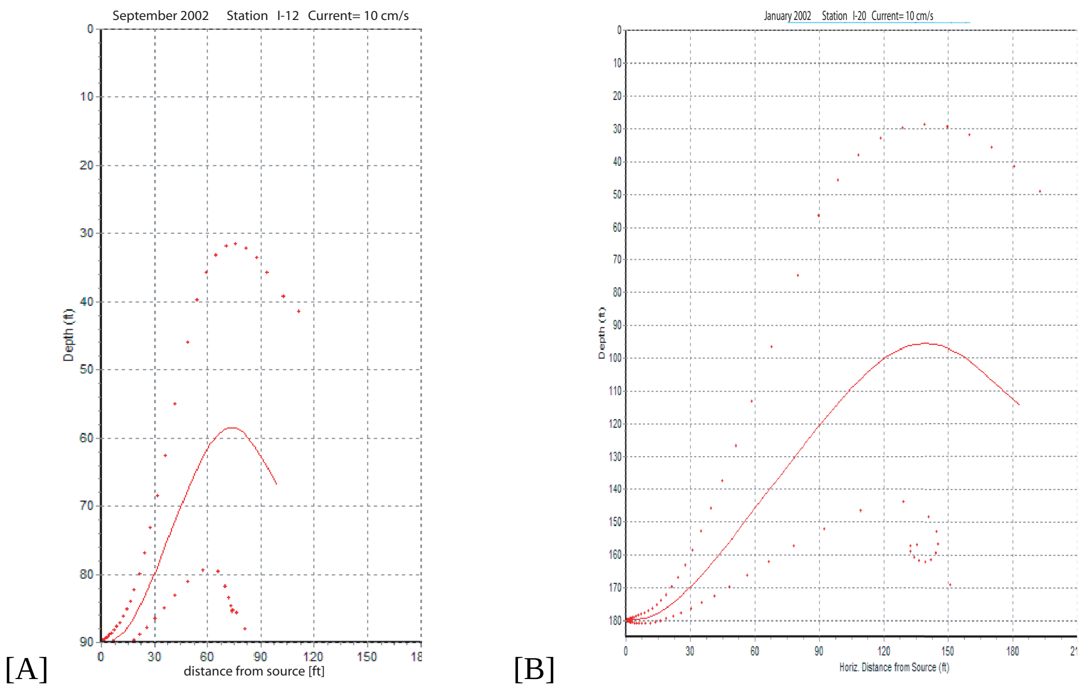


Figure 5.9: Predicted plume heights using CTD profiles for September 2002: A) Station I12, near outfall. B) Station I20, 180 ft depth. Solid red line is plume center, dotted line is boundary.

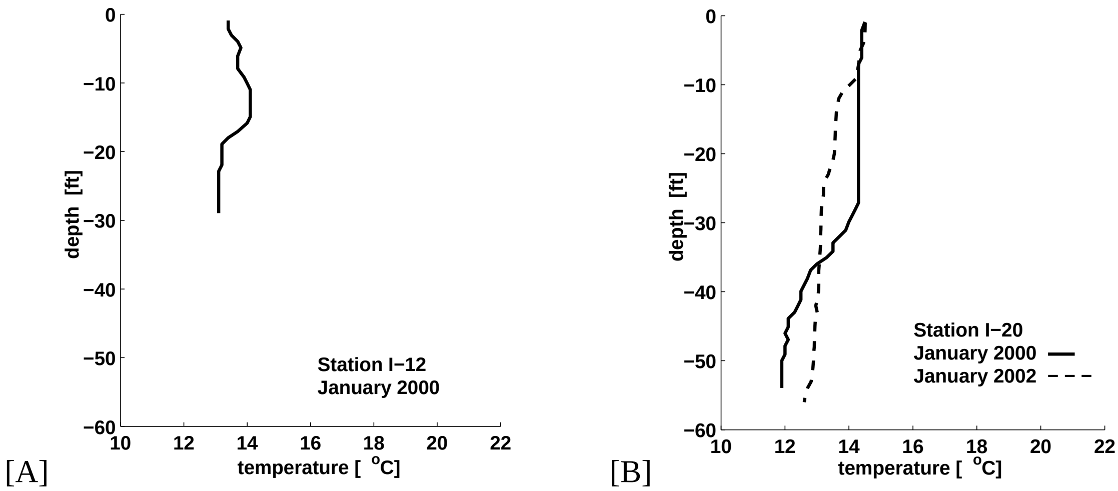


Figure 5.10: Temperature profiles during winter, A) Station I12, January 2000. B) Station I20, January 2000 and January 2002.

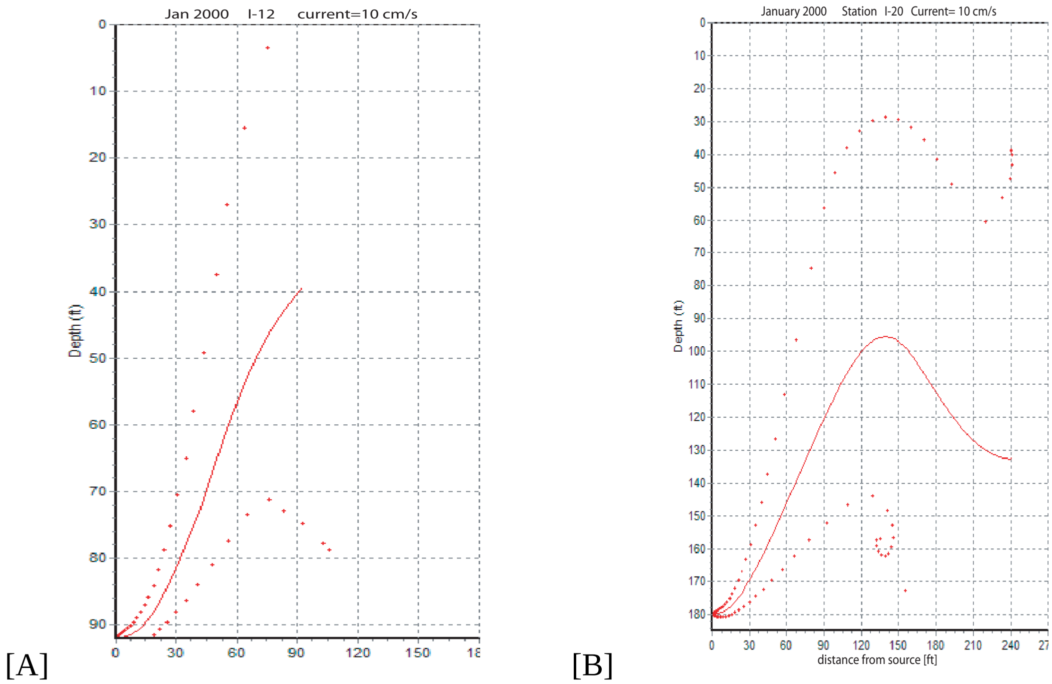


Figure 5.11: Predicted plume rise heights using CTD profiles from 3-5 January 2000, A) Station I12,near outfall. B) Station I20, depth 180 ft. Solid red line is plume center, dotted line is boundary.

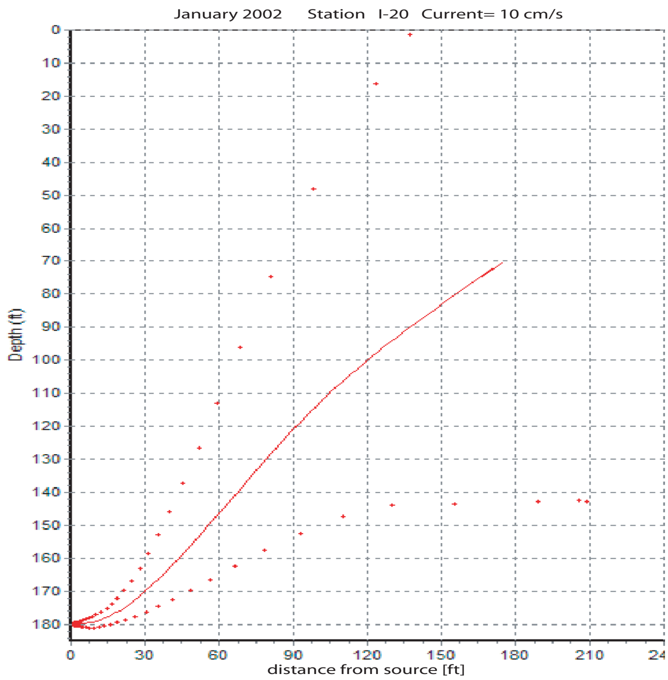


Figure 5.12: Predicted plume rise heights using CTD profiles from January 2002, Station I20, depth 180 ft. Solid red line is plume center, dotted line is boundary.

SBOO Plume Model: Summer Upwelling

It has been assumed that summer stratification will prevent buoyant outfall plumes from surfacing, because the warm surface water is much less dense than subsurface water, and the strong gradient acts as a "cap" on vertical motion. Processes such as internal waves and upwelling have been considered as mechanisms which could bring plume water from a cold subsurface layer to the surface in the nearshore zone. However, high bacterial levels in some summer months in surface water over the outfall have brought to light another mechanism for plume water surfacing, which is also related to upwelling. Models run with the highly isothermal, cold subsurface layer characteristic of strong upwelling events have shown that the plume can rise, and continue to rise, through the dense subsurface layer until a moderate density gradient is reached. If that occurs very high in the water column, the plume may continue and penetrate the surface. In general, models run with a variety of upwelling profiles have shown that strong upwelling resulting in a cold, well-mixed subsurface water mass may allow plume surfacing when the thermocline is sufficiently shallow and compressed. Two sample cases, August 2001 and June 2003, show the effects of different upwelling conditions on plume rise (Table 5.4).

June 2003: Moderate upwelling profile

In June 2003 bacteria was measured at exceedance levels at mid-depth over the outfall and elevated surface counts occur at one outfall station. The temperature profile shows cold water at depth, uniform up to about 15 m, followed by a sharp thermocline and approximately 5 m warm surface mixed layer (Figure 5.14). Models run with this profile show the plume approaching the surface, with height dependent upon current speed. Plume height is 12 m with 20 cm/s current, and less than 4 m from the surface with 5 cm/s current. Surface currents from CODAR during the 3 days of this survey are highly variable, covering this entire range of magnitudes.

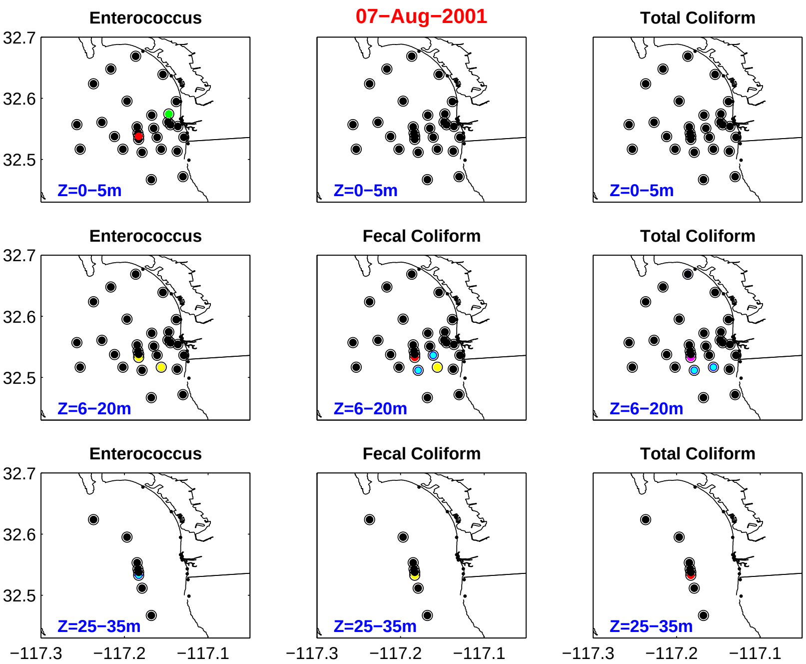
August 2001: Extreme upwelling profile

Bacteria is at exceedance levels at the surface above the outfall, as shown in the map in Figure 5.13(a). The temperature profile shows very cold, upwelled water at depth which is fairly uniform up to 10 m, and with an exceptionally steep thermocline from about 5 m up to the surface (Figures 5.13b and 5.14).

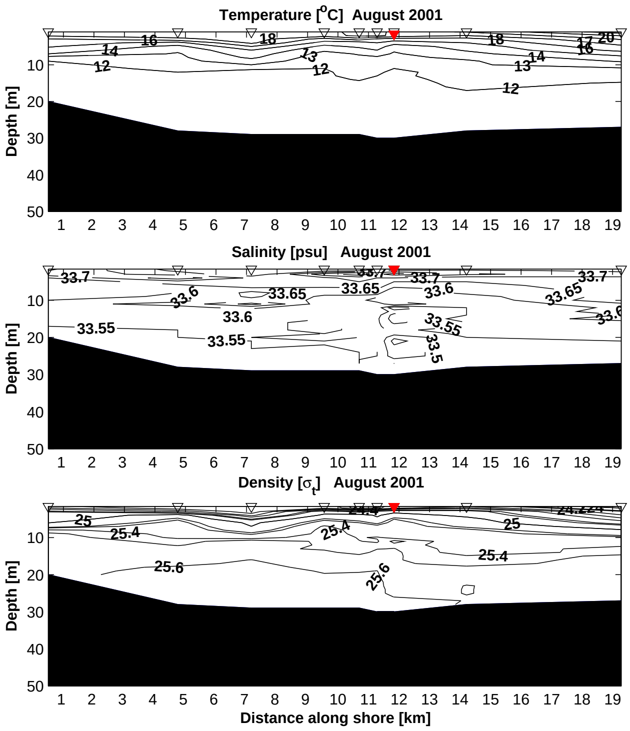
Models run with this profile show the plume reaching the surface over all current magnitudes, from 5 cm/s up to 20 cm/s (Figure 5.15(a)). There is no current data for this time period. At the lower velocities, the plume surfaces almost directly above the outfall, as seen in the bacterial sampling.

Summer upwelling conditions with deeper outfall

The model was also run for water column profiles simulating a deeper outfall location. The first profile is taken from station I20 at 180 ft depth during August 2002 (Figure 5.14b). This temperature and density structure closely approximates that of the shallower site during Au-

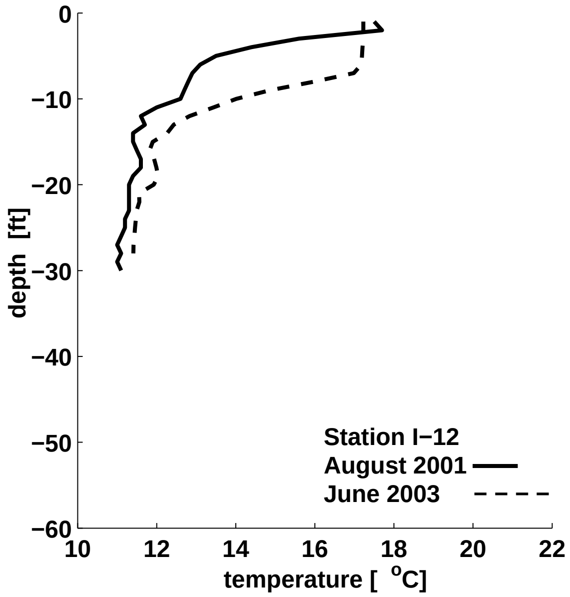


[A]

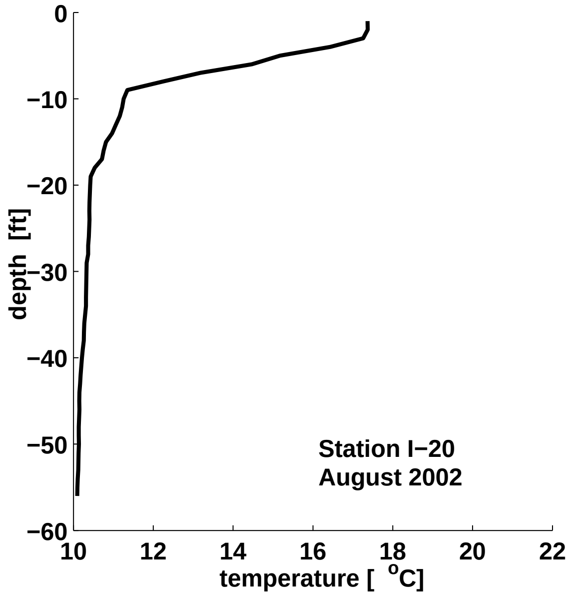


[B]

Figure 5.13: A) Bacterial sampling results for August 2001 CTD survey. See color coding key in Table 5.1. B) Ambient water properties in an alongshelf section through the South Bay Ocean Outfall. Station I12 near active diffuser ports is marked in red.

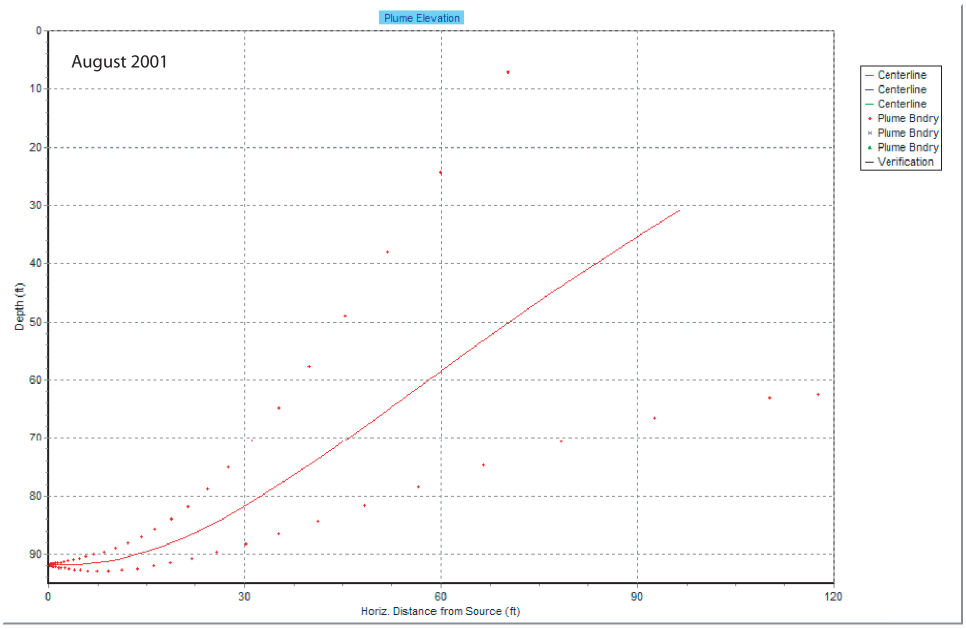


[A]



[B]

Figure 5.14: Temperature profiles during summer upwelling periods, A)Station I12, August 2001 and June 2003. B) Station I20, August 2002.

[A] 

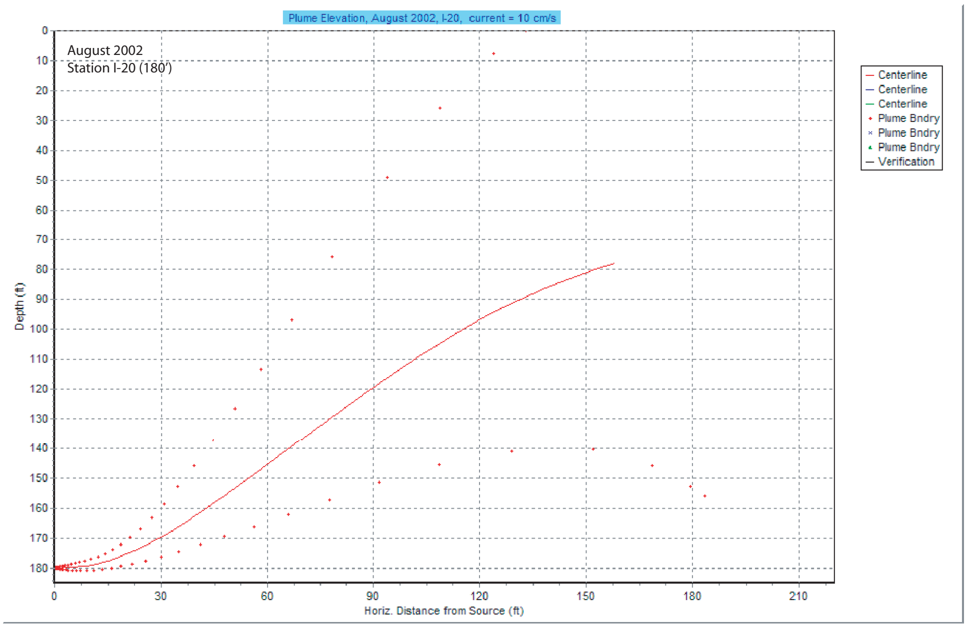
[B] 

Figure 5.15: Predicted plume height during strong upwelling conditions: A) August 2001 CTD survey. Station I12 with 10 cm/s current velocity. B) August 2002 CTD survey, at deeper release site, Station I20 (180’) with 10 cm/s current velocity.

gust 2001, only with a deeper isothermal layer. (The CTD at this station from August 2001 was taken the day after the outfall stations, and the density gradient is much different; it is not possible to determine if this is due to spatial variations, or temporal changes.)

As with the shallower outfall profile, the plume rises directly to the surface when the subsurface has virtuallly no density gradient, even at a depth of 180 ft. (Figure 5.15(b)). Although the plume still surfaces from the deeper site, the dilution factor is much higher. The dilution at the surface is 400 to over 1700, depending on the current velocity (see Table 5.4), compared to 250 to 750 at the actual outfall location. A deeper outfall thus increases the dilution of a surfacing plume by about a factor of two.

5.4.2 Transport by Surface and Subsurface Currents

An important question if the plume surfaces is whether or not it will be transported in a direction and with a velocity that it could impact nearshore recreational areas. At typical surface current velocities of approximately 10 cm/s, surface water could travel 9 km (5 miles) per day, thus reaching the beach in less than a day and before bacterial mortality is significant. The other factor to consider is whether or not the plume would be diluted enough during this transport to reduce bacterial counts below exceedance levels. This depends in large part on large scale plume dynamics which are difficult to predict and not well understood in this environment. Satellite and aerial imagery suggest that the outfall plume may not be as well dispersed as had previously been assumed. Some images show narrow plume streamers and sharp plume boundaries extending away from the outfall source, which may be the result of a regime dominated by stirring rather than mixing. If this were the case, surfacing plume water masses could be transported shoreward with little dilution of bacteria.

Data acquired through the SDCOOS CODAR system should help to provide more information on the potential for surface currents to transport plume waters shoreward, particularly if a system can be developed to monitor water properties and current velocity at the outfall in real time. This type of data could then be used to feed into a near-field plume model, determine the plume height and concentration, and subsequently use the CODAR velocity field to predict the plume direction over time.

5.5 Plume Dilution

Models run with ambient conditions near the outfall (station I12) were also run with zero current to determine compliance with dilution standards set during the planning stages of the outfall. In all cases except one (summer stratification for September 2002) a plume dilution of 100:1 or more was attained, the target minimum dilution of the outfall design. However, the planned minimum dilution for the SBOO was not designed for the type of effluent it has been carrying since it went on line in 1999. During the SBOO planning studies and subsequent studies conducted for the Tijuana Master Plan for Water and Wastewater Infrastructure, the assumption was made that effluent leaving the outfall would be from secondary treatment at the SBIWTP. The modeled effluent is considered to be “100 percent activated sludge secondary effluent, disinfected" (*CDM*, 2003). The difference in effluent type significantly affects the dilution rates required to comply with federal and state regulations. Secondary treatment processes can remove toxins through removal of suspended solids, and disinfection with chlorine, ozone or UV light greatly reduces concentrations of bacteria and similar pathogens.

The South Bay International Wastewater Treatment Plant now uses advanced primary treatment consisting of screening, chemically-assisted sedimentation, and brief chlorination (see Section 2.1). The chlorination procedure is minimal, with no disinfection holding tanks and chlorine levels below a level that would require pre-discharge dechlorination. Further, chlorination is only done during the winter months, December through April, when there is the highest probability of plume surfacing.

5.5.1 Effluent Bacterial Concentrations

The current California Ocean Plan does not contain absolute number standards for the effluent itself, but sets standards for water contact areas within 1000 ft from the shoreline (or 30 ft depth, whichever is greater). The COP standard for total coliform at nearshore sampling stations is:

1. No more than 20% of samples at a single station shall exceed 1000 MPN/100 mL within any 30-day period.
2. No two repeat samples taken within 48 hours at a single station shall exceed 10,000 MPN/100 mL.

Means for bacterial levels in combination primary/secondary treatment effluent without disinfection from the Orange County Sanitation District were approximately 20 million MPN/100 mL for total coliform. After initiating disinfection procedures in late 2002, total coliforms were reduced to approximately 6,000 MPN/100 mL. Mean levels of total coliform in SBIWTP effluent for the last 4 years were:

Mean Total Coliform, SBIWTP Effluent (MPN/100 mL)
Winter:December–April, Summer:May–November

	2000	2001	2002	2003
Annual	94.1×10^6	108.2×10^6	37.4×10^6	35.9×10^6
Winter	78.2×10^6	10.5×10^6	2.5×10^6	1.4×10^6
Summer	118.9×10^6	207.7×10^6	72.7×10^6	65.7×10^6

The winter means are from testing just prior to discharge, after 15 minutes of chlorination.

With an annual average total coliform count of approximately 60 million MPN/100 mL, it is doubtful that even full secondary treatment with disinfection would reduce the concentration to 400 MPN/100 mL, as used in the Tijuana Master Plan modeling. A more more reasonable estimate of 6000 MPN/100 mL is still 10,000 times lower than the average concentration with the current advanced primary treatment at SBIWTP. Monitoring data corroborates these high bacterial loads in the SBOO. Data shown in Figures 5.2 and 5.4 indicate that total coliform values of 10,000 MPN/100ml or higher are frequently observed in the plume. Given that salinities indicate that dilutions of at least 100-fold have already been achieved, these samples point to effluent concentrations of at least 10^6 on discharge. These high concentrations require an additional 100 to 1000-fold dilution before they meet the beach and kelp water quality standards.

It should be noted that required dilution factors for the outfall plume were not determined by modeling bacterial levels. Estimated concentrations of California Ocean Plan "Table B" chemicals were used to determine required initial dilution, based on levels recorded in Point Loma effluent toxicity tests. These tests showed that DDT was the primary chemical of concern, requiring a dilution level of 278:1 by the instantaneous maximum standard, or 1670:1 for the COP 30-day mean standard (see SBOO Preliminary Planning Study, Addendum, Table 4). However, the Preliminary Planning Study recommended that the two highest levels of DDT from the three years of monthly data should not be included to set the initial dilution requirement because DDT is likely introduced in single, illegal dumping events, or through Tijuana sewage. Therefore the third highest instantaneous concentration was used, requiring a 91:1 dilution. An additional toxicity standard, the Chronic Toxicity for marine life (TUc) was also available in preliminary data for the Point Loma effluent. The standard is based on the maximum percent of effluent that causes "no observable effect" on test organisms, as determined by a critical life stage toxicity test. The TUc for Point Loma effluent required an initial dilution level of 100:1, the value used for the final outfall design.

5.5.2 Achieving Minimum Dilution Requirements

The Preliminary Planning Study reports that the IBWC's decision was to rely on agreements with the Mexican government to use "source control" to manage levels in excess of the capabilities of the SWIWTP treatment regimes. Minute No. 283 from July 1990 states that the government of Mexico will "require all industries to provide appropriate pre-treatment of wastewaters" that are discharged into the sewage system and in turn into the SWIWTP. According to the EPA's Tijuana Master Plan (*CDM*, 2003), Mexico's State Department of Ecology regulates maximum allowable limits for industrial contaminants into the sewage system. CESPT, Tijuana's public services commission, is listed as currently working on the development and implementation of a program for industrial pretreatment.

After being in operation for over 5 years, neither secondary treatment nor effective disinfection is in place or planned in the near future for the SBIWTP. The IBWC has filed EPA Environmental Impact Statements since planning began for the treatment plant and outfall to outline options for long-term treatment at the plant; the Final Environmental Impact Statement (FEIS) and Record of Decision (ROD) allowing construction to begin were filed in 1994, and a supplemental statement (SEIS) was filed in 1998, with an additional FEIS and ROD in 1999 approving (but not funding) secondary treatment ponds. The 1998 SEIS lists several areas of "Significant Impact that Cannot be Mitigated," including compliance with California Ocean Plan standards, the problem with toxic spikes in effluent, and compliance with coliform standards. In all three areas, the current advanced primary treatment is considered ineffective or definitely out of compliance. In October 2003 the IBWC announced plans to prepare a second Supplemental Environmental Impact Statement which contains options for long-term treatment similar to the previous SEIS, and several additional options for continuing advanced primary treatment and return flows to Mexico.

Even with optimal initial dilution rates and minimal chlorination, the concentration of bacteria and coliforms in effluent with primary treatment is clearly greater than that assumed during the design of the outfall. Minimum dilution rates for toxins were calculated based on secondary treatment at SWIWTP, as well as pre-treatment in Mexico that is still in the planning stages. With average current speed at the outfall site of 3-4 cm/s (*Engineering-Science*, 1988) the average plume initial dilution would be a factor of 200-400. With initial concentrations of total coliform of order $10^6 - 10^8$ this does little to mitigate the potential effects of the plume should surfacing or subsurface transport occur.

In effect, then, there is a reliance on far-field dilution and bacterial mortality to reduce total coliform concentrations a further 100 times to achieve single-sample standards at the beach or in the kelp. Studies from Orange County indicate that a more realistic far field dilution is a factor of 10 over 10 km. In the event that waters from the wastewater plume are transported into the nearshore and surfzone within a day or two after discharge, it is unlikely that the combination of mixing and mortality could bring about the large reduction in concentration needed for compliance with nearshore standards. However, the question remains as to how frequently plume waters are indeed transported onshore.

5.6 Summary & Discussion

From review of previous studies, analysis of monitoring program data and other oceanographic data, and results of near-field plume models, the following conclusions can be drawn:

1. Ocean monitoring data show several states of the the outfall plume: trapping at mid-depth during summer and fall, surfacing during winter or during strong summer upwelling, transport alongshore, and transport shoreward (though the boundaries are frequently indistinguishable from the Tijuana River plume).

2. Although the water properties that have been used in other cases to track sewage plumes were not successful here, other tracking methods show promise, including satellite and aerial imagery. For these to be used to their best advantage, however, more must be known about the water properties at the time the images are obtained. The relationship between imagable plume, bacterial levels, and plume depth, for example, should be investigated.

3. Models of the outfall discharge using actual ocean conditions are consistent with observations from the monitoring program, and show plume trapping below the surface during stratified conditions, and surfacing occuring during winter and strong upwelling conditions. The results are promising for using real-time data on water properties at the outfall for predicting plume behavior through a combination of near-field modeling and trajectory analysis using CODAR data.

4. The deeper outfall models indicate that surfacing would still occur during unstratified winter conditions and during strong summer upwelling when there is a very narrow

thermocline close to the surface. The dilution factor is higher with a deeper water column, however the benefit of increasing the diltution by a factor of 3-4 may not be significant with effluent initial concentrations on the order of 10^7 MPN/100 mL.

5. Near-field dilution factors of the discharged effluent in the models were approximately 200-400 with average current speeds of 5-10 cm/s (i.e., *not* worst-case scenario). This will give concentrations at the trapping depth (or surface) of $10^4 - 10^6$ MPN/100 mL. Little is known about the mixing behavior of effluent plumes while in transport, but aerial imagery suggests that the plumes can remain coherent ("stirred" as opposed to "mixed") for some distance, and data from other outfalls indicate that a dilution rate of 10:1 or less in the far field is probably realistic. However, more information is needed to determine the fate and dilution of these plumes far-field. Development of coastal models and observing systems should eventually provide more clarity.

To enhance the ability of the data collected to provide information on the state and path of the outfall plume, a set of recommendations for ocean and plume monitoring is presented in detail in Chapter 7. These recommenations include:

- Installing moored thermistors and current meters or ADCP at the outfall site to provide information on stratification, upwelling and current velocity that affects the near-field state of the plume.

- Feeding above data into a real-time near-field plume model to determine plume height and dilution. When models indicates the plume is near the surface, combine data on plume height and concentration with real-time CODAR surface current data for trajectory analysis.

- Making greater use of time-series observations through a system of moored instruments that can provide real-time information on regional circulation patterns and water column stratification. These are the key factors influencing the fate of both outfall and river plumes. This type of system should ideally be part of a wider, regional monitoring program such as that being developed around SDCOOS. Moored observations are initially costly (equipment costs) but are ultimately more cost-effective, efficient from a personnel standpoint, and provide the most useful data.

- Coodinating monthly ocean bacterial monitoring with aerial surveys to provide information on the exact location of the plume and its bacterial concentrations. This data can be used in conjuntion with CODAR surface currents and SDCOOS current meter data to characterize variable states of the plume under different current conditions.

- In general, coordinating and planning monitoring strategies with other regional agencies will increase the effectiveness, both scientifically and financially, of monitoring systems.

Chapter 6

Fecal Bacteria Levels in Beach and Kelp Waters

Contamination of recreational waters is a primary concern in southern California including Imperial Beach. In this chapter, levels of fecal indicator bacteria along South Bay beaches and at kelp forest stations are presented and analyzed with a view to: (i) identify exceedances (locations/occasions when bacteria levels exceed AB 411 water quality standards), (ii) link observed exceedances with specific sources and environmental conditions (transport scenarios), and (iii) explore any possible link between the South Bay Ocean Outfall (SBOO) and beach or kelp exceedances. This analysis allows for an evaluation of the efficacy of the existing Regional Water Quality Monitoring Program (RWQMP) to identify the sources of exceedances and also points to possible relations between bacterial sources and beach/kelp contamination that need to be explored through future studies and monitoring programs.

Exceedances for this report are based on the Health and Safety Code of the Sate of California, specifically the California Code of Regulations, Title 17, which are commonly known as AB411 standards. These standards, as well as standards in the California Ocean Plan (COP) and the Water Quality Control Plan for the San Diego Basin (Basin Plan), are discussed in more detail in Section 2.3. Although the outfall was designed and permitted under COP standards, the focus of this report is on assessing levels of fecal indicator bacteria (FIB) concentrations irrespective of compliance standards therefore, AB 411 standards were used as the common definition of exceedances in beach and kelp waters for this report. However, an “exceedance” can strictly only occur in recreational waters subject to AB411. Although used for contact recreation, kelp bed waters are not always included in AB411 monitoring. Compliance of the SBOO with Ocean Plan and other regulations is addressed in *SAIC and R. Smith* (2004). In general, when water quality meets AB 411 standards it meets Ocean Plan as well. In general, we use single-day standards (Total Coliform (TC) $> 10,000$/100 ml; Fecal Coliform (FC) > 400/100 ml; Enterococcus (Ent) > 104/100 ml) in searching for contamination periods.

These data have been collected as part of the RWQMP associated with the SBOO and conducted by the Municipal Waste Water Department of the City of San Diego (MWWD). Beach FIB data are also collected by the Department of Environmental Health (DEH), County of San Diego (see www.sdcounty.ca.gov/deh/lwq and sdcoos.ucsd.edu), however data are collected from different stations and protocols and stored with a different file format.

Therefore the county data have not been analyzed here. MWWD/SBOO data are available from 1995 (prior to discharge from the SBOO), with intense sampling starting in 1996. Samples are taken every week at 11 beach stations and 3 kelp stations (3 depths at each station). Over the 5 years since the outfall as been in operation (1999-2003) there have been 3098 samples collected at beach stations with 508 exceedances due to one or more indicators. Over the same 5 years, there have been 2726 samples collected at kelp stations with 107 exceedances following Ocean Plan standards (TC and FC only) or 146 exceedances following AB 411 standards (TC, FC and Ent). See Section 2.3 for more detailed information on the monitoring program.

In the following sections, beach data are analyzed first in Section 6.1 and kelp data are analyzed in Section 6.2. For each set of stations, the number of samples and exceedances are given. Thereafter, analyses are based on actual FIB values rather than the binary system of taking a sample as an exceedance or not. This allows more insight to the spatial and interannual patterns of bacteria elevation and how these patterns link with rain, river flow and other effects.

6.1 Bacterial Exceedances at South Bay Beaches

6.1.1 Wet Weather: Exceedances Associated with Rain and River Flow

In southern California a strong association has been observed between shoreline bacterial abundance and runoff events (*Noble et al.*, 2003). Nearshore water quality is most heavily impaired during the winter when rainfall occurs in the region. The data collected for the SBOO bacterial monitoring program shows a similar seasonality.

A key challenge in analyzing wet weather exceedances along the South Bay shoreline is separating the impact of non-point-source pollution (widespread runoff during rain) from the impact of pollution delivered to the ocean via the Tijuana River. Prior to 1999, there were many days when the river flowed into the estuary between rain events, resulting in a characteristic flow-only pattern of bacterial contamination. Since 1999 low flows in the Tijuana River are diverted before reaching the estuary and presently river flow into the estuary tends to occur only following rain when the river flow rate is too large to be handled by the diversion scheme and treatment plant. Thus combining pre-outfall and post-outfall data in a single analysis, the nature of rain/river and river only events can be determined.

Runoff events may contaminate nearshore waters for several days after rain. Public health officials warn people to stay out of the water for 3 days following rainfall events exceeding 2.5 mm (one inch). A study at Santa Monica Bay indicates that while the rain related runoff impact typically lasts for 1-3 days, the impact of runoff near freshwater sources may last closer to 5 days (*Ackerman and Weisberg*, 2003). As seen in analyses presented below, this is also observed in the SBOO shoreline monitoring program where bacterial exceedances near the Tijuana River show a significant correlation with rain that persists up to 4 days after rainfall. This post-rain persistence is considered to be a combination of runoff continuing after the rain has stopped, and retention of contaminated runoff waters in estuaries.

Methods

The first step in data analysis is to determine the criteria by which data should be separated hierarchically between rain events, flow events, and dry events. The methods of *Ackerman and Weisberg* (2003) were used sinceas Santa Monica has similar rainfall and meteorological conditions as San Diego in general, as well as similar patterns of urban development and ground cover. *Ackerman and Weisberg* (2003) note (i) that for rainfall events below 2.5 mm there is no observable rain/runoff effect on water quality, and (ii) mean bacterial concentrations in coastal waters return to background levels within 5 days of rainfall greater than 2.5 mm. For the purpose of this review, a rain event is defined to occur when the 5-day rain total exceeds 2.5 mm (5 days are the day of FIB sampling and the previous 4 days). Lindbergh Field rain data was used for the following analysis as rain gages closer to the Tijuana Estuary do not have continuous over the entire period of the FIB data set. While local rainfall may differ from Lindbergh Field, there is much variation in rainfall over the Tijuana watershed and this gage is likely to be as representative as any other single gage. Data on river flow were obtained from the International Boundary Water Commission (IBWC) Tijuana River gage near the US-Mexico border.

Rain categories Days influenced by rain were categorized as detailed below. First, all days with sample-day rain totals exceeding 2.5 mm were categorized as Day One (D1, days on which the sample was taken on the day of rain) and these days were isolated from the remaining data set. Then, all days with a two-day rain total (sample day and preceding day) exceeding 2.5 mm were categorized as Day Two (D2). Following that, all days with a three-day rain total exceeding 2.5 mm were categorized as Day Three (D3), and so on for Day 4 and Day 5 samples. The median bacterial levels of each of these five subsets are compared with the levels for flow influenced bacteria data (rain less than 2.5 mm) and dry influence bacteria data (rain less than 2.5 mm and flow less than 0.01 m^3/s).

River flow categories River flow events are defined by daily flow of 0.01 m^3/s or more with rainfall less than 2.5 mm. The value of 0.0 m^3/s represents the minimum recorded flow for the Tijuana River at the IBWC gage. Analyses were also conducted in which the flow data are further subdivided into the following flow rate categories: 0.01-0.25 m^3/s, 0.26-0.50 m^3/s, 0.50-0.75 m^3/s, 0.75-1.00 m^3/s, 1.01-2.00 m^3/s, and $>$2.00 m^3/s.

Three divisions of the data set now exist for each station for each bacterial indicator. Bootstrap means and 95% confidence intervals were obtained for each data subset. The bootstrap mean method enables a more robust determination of the mean of a large data set with a non-normal distribution (*Quinn and Keough*, 2002). The Mann-Whitney non-parametric t-test was also performed in order to help define the spatial extent of the impact of rainfall and river flow.

Results

Table of exceedances In Table 6.1, the number of samples collected at beach stations and the number of FIB exceedances at these beach stations are summarized by year and by category (rain, river or dry influence). In each category the exceedances are given as a percentage of the number of days sampled within those respective categories. Between 28 and 53% of rain days exhibit exceedances. Recent years (2001 and 2003) have also shown the highest

Table 6.1: Bacterial Exceedances at South Bay Beaches, 1995-2003. The table is divided by category into samples with rainfall, samples with river flow (rain < 2.5 mm, and samples in dry conditions (rain < 2.5 mm and flow < 0.01 m^3/s). The total number of samples in each category are shown at the top of the table, followed by the number with exceedances of AB 411 standards, and finally the exceedances shown as a percentage of the total number of samples in each category. Each water sample is used for 3 tests (TC, FC, Ent) and an exceedance is obtained for that sample if one or more single-day standards are exceeded (TC $> 10,000$; FC > 400; Ent > 104).

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	Total
# Samples	54	491	1068	1044	704	595	607	585	607	5755
Rain	3	94	196	261	127	113	154	117	132	1197
River Flow	9	191	450	783	215	71	116	0	69	1904
Dry	42	206	422	0	362	411	337	468	406	2654
# Exceed.	4	53	107	251	93	100	138	59	118	923
Rain	1	26	67	108	46	45	81	36	70	481
River Flow	0	18	33	143	31	18	30	n/a	20	293
Dry	3	9	7	n/a	16	37	26	23	28	148
% Exceed.	7%	11%	10%	24%	13%	17%	23%	10%	19%	16%
Rain	33%	28%	34%	42%	36%	40%	53%	31%	52%	40%
River Flow	0%	9%	7%	18%	14%	25%	26%	n/a	29%	15%
Dry	7%	4%	2%	n/a	4%	9%	8%	5%	7%	6%

likelihood of exceedances on rain days, one exceedance in every two days sampled. River flow days and dry days generally have fewer exceedances than rain days. In the absence of either rain or flow influences, less than 1 in 10 days is likely to exhibit exceedances (average of about 1 in 20 over the 9-year record).

Between 25 and 53% of beach exceedances are associated with rain. This rain association rate increases when looking at samples in which multiple indicators exceed standards. During the wet 1998 El Niño year all sample days are associated with rain or river flow and more than half of the exceedances are associated with river flow (Figure 6.1). In other years, however, the flow-association rate is lower (one third or less).

Two trends appear to occur from 2000-2003. First, sampling days associated only with river flow have decreased. Prior to 2000, days associated with river flow typically accounted for about 30-40% of samples, with a high of 75% of samples associated with river flow in 1998. From 2000-2003, days associated with river flow typically accounted for only about 10-20% of samples, with a low of zero samples on flow-only days in 2002 (due to low rainfall during 2002) . Secondly, however, even though flow days appear to be less frequent in recent years, samples taken on these days have exhibited a higher likelihood to have exceedances than in years prior to 2000 (e.g., 25-30% of all flow days have exceedances in recent years,

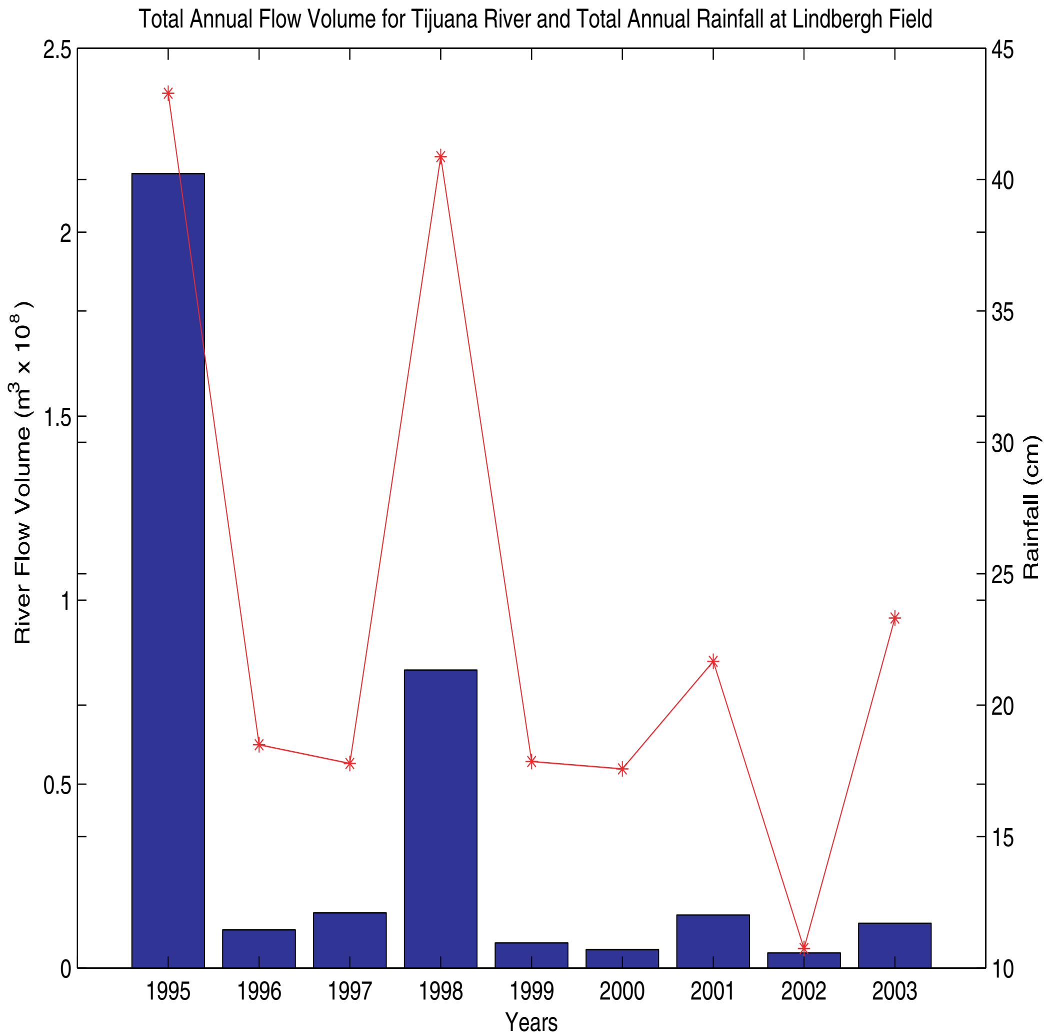


Figure 6.1: Total annual rainfall and river flow for 1995 through 2003. Rain data (red asterisks) are obtained from Lindbergh Field and river data (blue bars) are obtained from IBWC gauge at US-Mexico border.

compared to 9-18% in prior years). This may indicate that although flow-only events are less frequent now, when they do occur they appear to have a greater impact with respect to bacterial loading.

In Figure 6.2, the proportion of days on which exceedances are observed are plotted for different categories, different stations and different years. This extends the information in Table 6.1 to describe the spatial pattern of exceedances. Most notable is the high proportion of exceedances at station S5, at the mouth of the Tijuana Estuary, on flow days as expected. However, data over recent years reflects an increase in the likelihood of contamination on flow influenced days. The likelihood of contamination is greatest on rain-influenced days, specifically at stations S3 and S5 in the late 1990's (rates of over 80%). There is evidently a broad swath of rain impacted stations from the Tijuana Estuary (S5) to southern parts of the city of Tijuana (S2) suggesting a significant source of FIB in this region. During dry weather conditions, exceedances are most likely at stations south of the Mexico-US border, most notably in the last few years (2000-2003). In addition to stations S1-S4, station S12 in Imperial Beach appears to be subject to a recurrent localized problem.

Medians of fecal indicator bacteria The spatial pattern of contamination associated with days of rain events, flow events and dry events are summarized in Figures 6.3, 6.4 and 6.5 of the median values (together with 25 and 75 percentile values) for beach stations. Pre-outfall and post-outfall data are combined in this analysis. Highest median values for rain and flow influenced data are typically found at station S5, although for some categories similar or slightly higher median values may be found at station S1 and other southern stations. Most notably, median TC values are higher for more rain days from the Tijuana River south to Los Buenos Creek. North of S5, FIB median values are lower, with notably lower median values at stations S8 and S9 off Silverstrand and Coronado. Further, while high values may occur on the day of rain, in this northern region, median values fall back to dry weather or flow values a day or two after rain. At station S5 and to the south, rain influence appears to last up to 4 days after rain (see D5 category) and some stations show highest values on D2. This is specifically true for TC concentrations, where median values may remain above or near single day exceedances levels for two to three days after rainfall. There is a decline in indicator levels and shorter persistence with distance from S5, but the decline is less rapid than that observed at the north stations. From the Tijuana River to the border, median fecal coliform values are also at or above exceedance levels for 1-3 days following rain. Enterococcus median values are at or above exceedance levels for 1-3 days from Tijuana River south to Los Buenos Creek. These results are consistent with the general result that between and one third and one half of rain samples in this region exhibit exceedances.

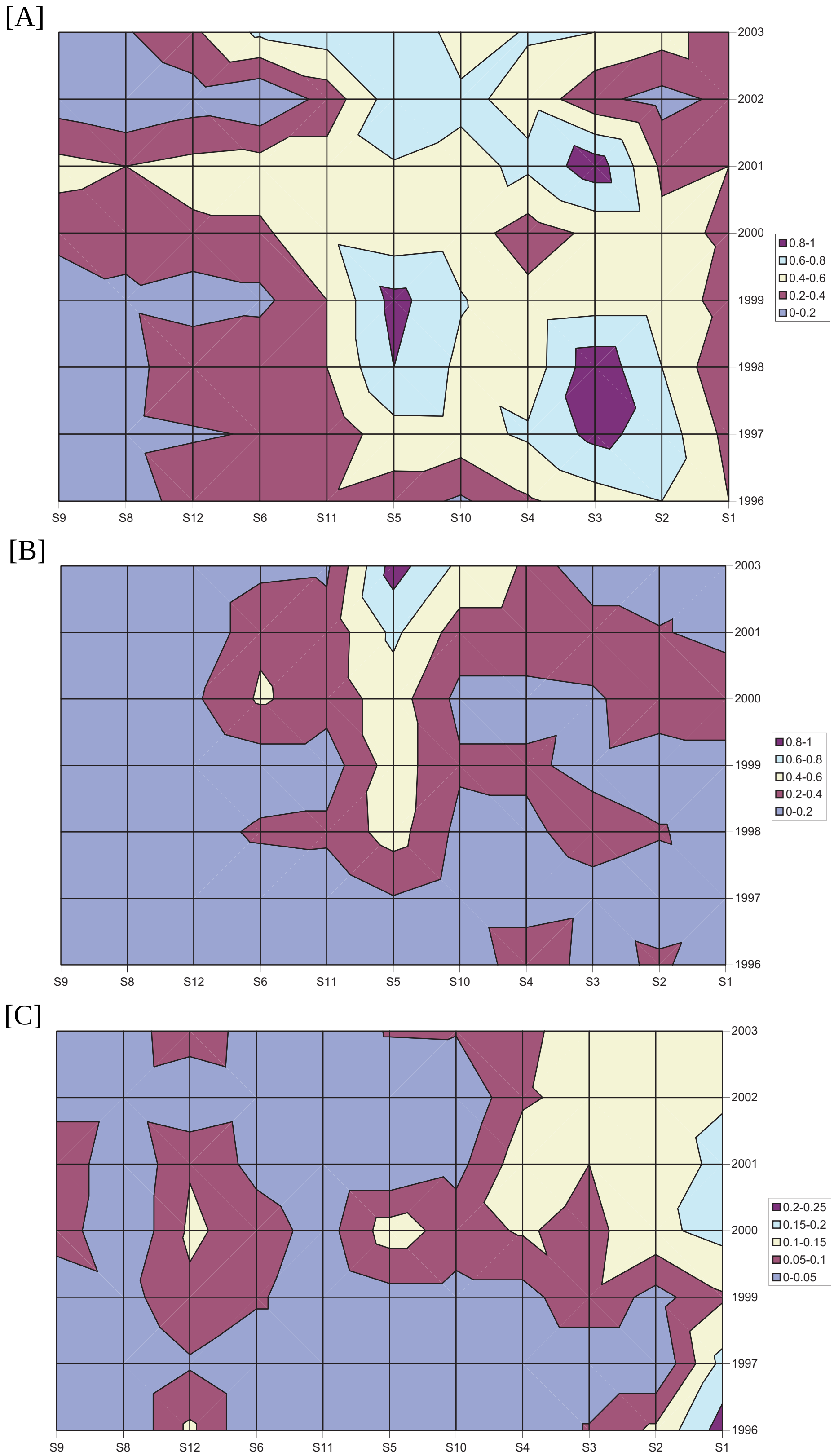


Figure 6.2: Proportion of exceedances (#exceedances/#samples) as a function of year and station, plotted separately for A) rain-influenced days, B) flow-influenced days, and C) dry weather days.

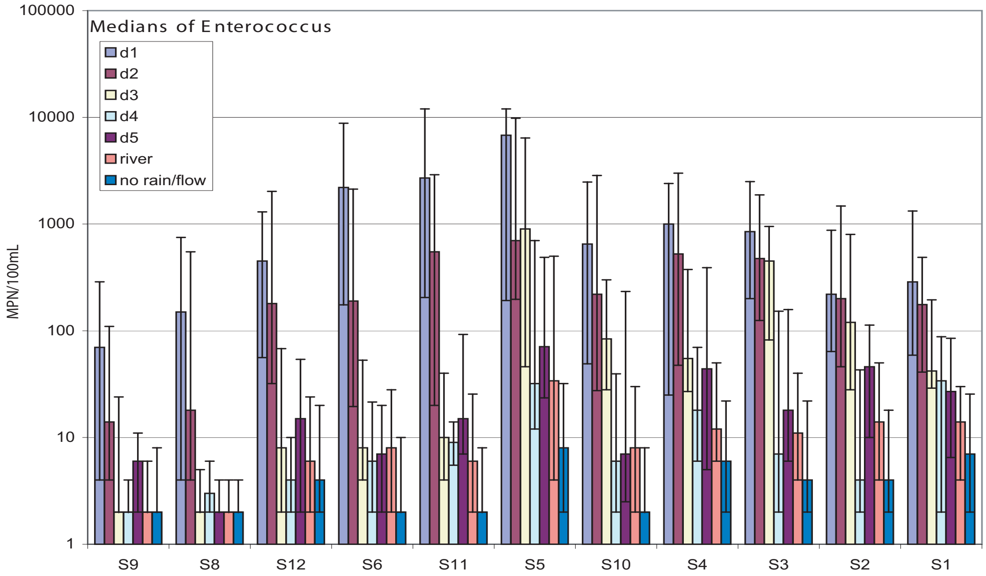


Figure 6.3: Median enterococcus concentrations at beach stations for 5 categories of rain association, flow-influenced days and dry days. Range bars represent the 25 and 75 percentiles. Stations are shown from north to south, with S5 at the mouth of the Tijuana Estuary.

These results indicate that the Tijuana River is the dominant source of contamination during wet weather (rain and flow influenced days). Further, rain days lead to higher loading of nearshore waters than days where there is only loading delivered by way of the Tijuana River. For dry weather data, highest median values are found at station S1, indicating that Los Buenos Creek is the primary source of FIB during these periods. Los Buenos Creek may also be an important secondary source following rain, explaining the more widespread impact and slower recovery of FIB levels south of the Tijuana estuary.

Differences between rain, flow and dry weather categories were also investigated with bootstrap means (Figure 6.6), showing that for all indicators and all stations (other than fecal coliform at S1), the statistical distribution of rain-influenced values is independent of and higher than that for dry weather values. Similarly, rain-influenced data is statistically distinct from flow-influenced data at all stations other than S12, S1 and S2. However, flow-influenced data are statistically distinct and higher than dry weather data only in the vicinity of the Tijuana River (TC between stations S12 and S4; FC between S6 and S4; Ent only at S5). Differences between rain, flow and dry weather categories are also explored using the Mann-Whitney t-test. Categories are compared in pairs: (i) rain versus flow; (ii) rain versus dry; (iii) flow versus dry. Using this test, categories are more distinct and for all stations and all bacterial indicators, rain data is statistically different to data for flow or dry days. This indicates that rain elevates bacterial counts at all stations. Flow categorized data is distinct from dry weather data at most stations, but not at S9, S8, or S1. This indicates that at the two most northerly stations and the most southerly station, river flow does not elevate bacterial

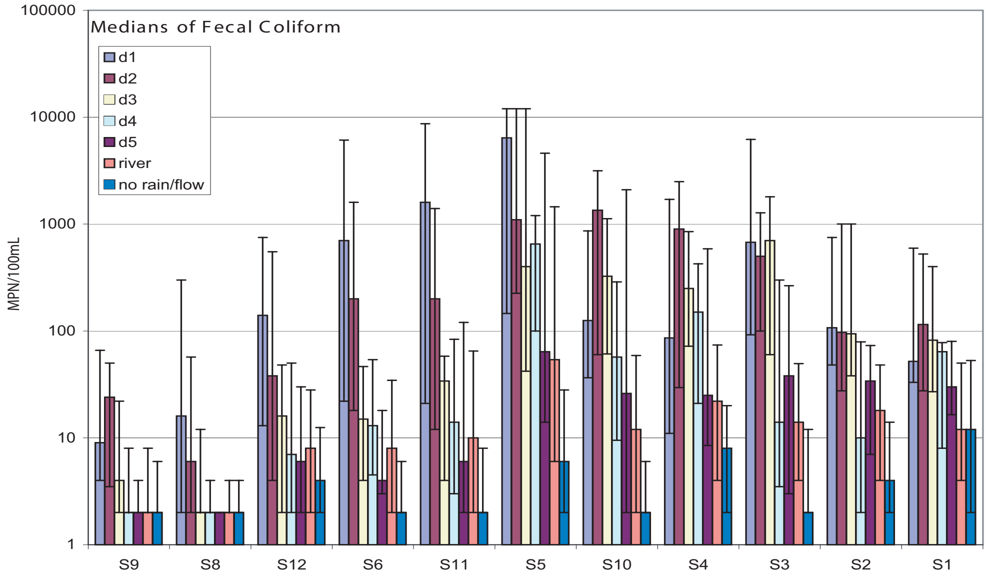


Figure 6.4: Median fecal coliform concentrations at beach stations for 5 categories of rain association, flow-influenced days and dry days. Range bars represent the 25 and 75 percentiles. Stations are shown from north to south, with S5 at the mouth of the Tijuana Estuary.

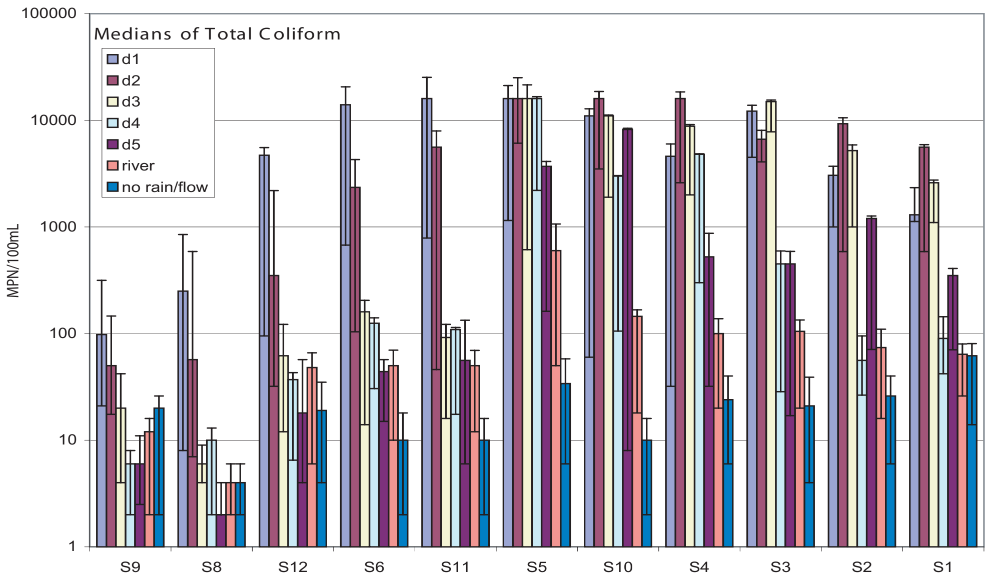


Figure 6.5: Median total coliform concentrations at beach stations for 5 categories of rain association, flow-influenced days and dry days. Range bars represent the 25 and 75 percentiles. Stations are shown from north to south, with S5 at the mouth of the Tijuana Estuary.

counts above background levels with any statistical certainty (results not shown).

6.1.2 Dry Weather: Exceedances Associated with Wave-Driven, Wind-Driven and Tidal Transport

While exceedances associated with rain and/or river flow dominate the number of exceedances and account for the highest levels observed, there are also dry weather exceedances. Exceedances during dry weather are less likely, with no more than 9% of samples in a given year exceeding standards (Table 6.1). However, in recent years (2000-2003) dry weather exceedances have accounted for between 19 and 39% of observed exceedances at beach stations (23 and 37 dry weather exceedances per year), primarily due to increased exceedances at stations S0 to S4. While there is no single source or space-time pattern that appears to account for these events, selected events reflect patterns consistent with transport of known land-based sources by wave-driven surfzone currents, wind-driven nearshore currents, or tidal currents. There are no obvious links between these dry weather beach exceedances and the discharge of wastewater at the SBOO. However, the number of dry weather events are too few to develop any statistical confidence in these patterns and they are described more in the sense of hypotheses to be better evaluated. There are only 12 days in the recent record in which three or more stations show exceedances on the same dry weather day.

Transport patterns associated with south swell

As described in Section 4.4.1, surfzone waters flow alongshore in response to wave forcing. In particular, south swell will result in northward transport along the coast. Consistent with the experience of the County DEH, shoreline water quality is most questionable when swell has a southerly orientation (170-190° at the Point Loma wave buoy, personal communication from Clay Clifton, County DEH). In the following analysis of historical data, it is found that 9 of the 12 multiple-station, dry weather events occur during south swell conditions. Persistent south swell, which originates in distant southern hemisphere storms, is most common from late spring through fall. These events can persist for several days during these dry weather seasons.

Methods In order to explore the association of south swell with shoreline bacterial distributions, wave data from the Coastal Data Information Program (CDIP) buoys are used (see www.cdip.ucsd.edu). Data are available from nearby wave buoys at Point Loma and Point La Jolla. As these buoys are not immediately off Imperial Beach, neither buoy can provide exact information on past waves conditions at Imperial Beach. As waves propagate onshore they develop local conditions due to the complexities of bottom depth nearshore and the sheltering effect of islands and headlands. Although the Point Loma buoy is closer (and thus is used by the County DEH during summer months, when data is available), in this analysis data from the Point La Jolla buoy are used as these data, which start in July 1999, are more continuous for the period over which FIB data are available from SBOO. The Point La Jolla buoy is located 50 km north of the study area and 6km offshore, but it experiences the same south swell events as the surfzone of Imperial Beach and thus it is reasonable to use these data to indicate south swell occurrences off Imperial Beach. For the time both Point La Jolla and Point Loma swell data are available, there is good agreement between the

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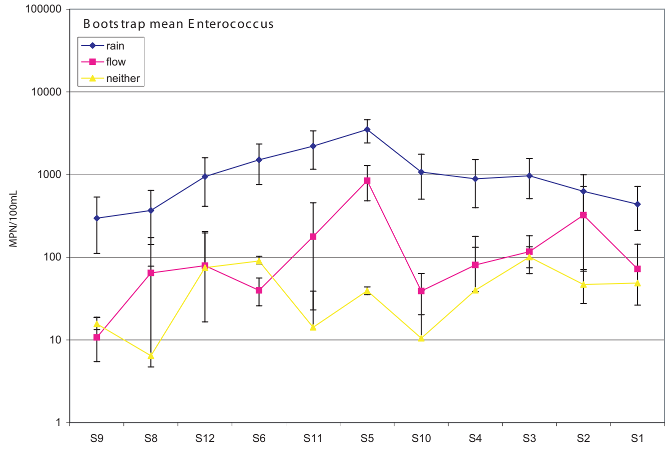

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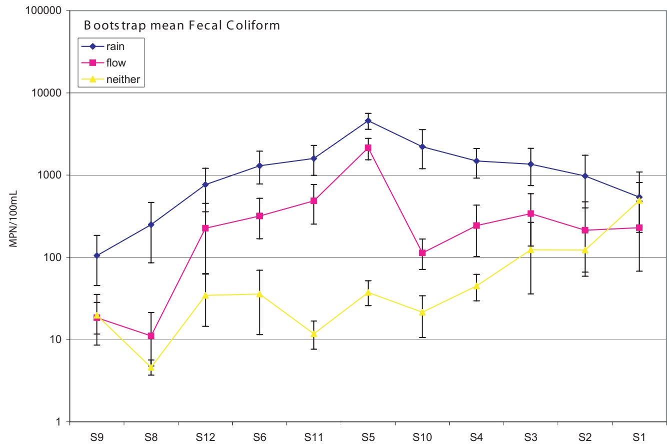

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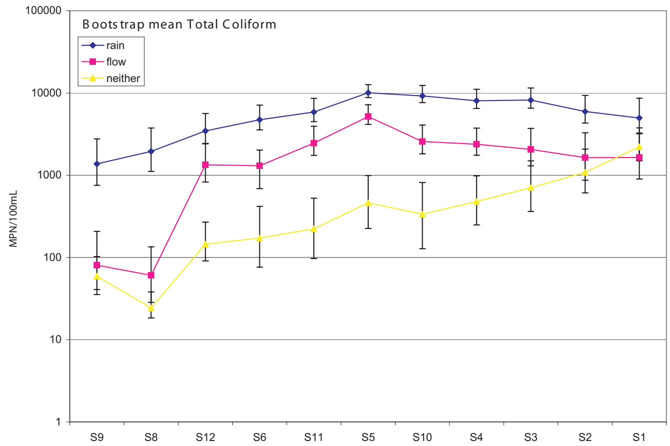


Figure 6.6: Median bacterial levels at each station during rain, flow or neither conditions. Range bars indicate the 95% confidence intervals. A) Enterococcus, B)Fecal Coliform, C) Total Coliform.

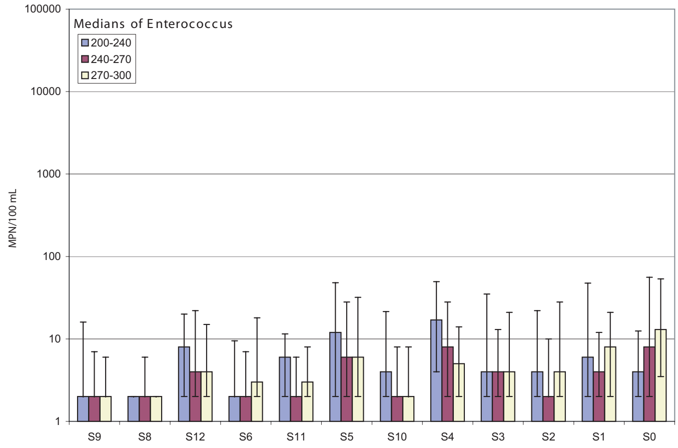
south swell events observed at these two stations, although the exact orientation of waves is different between the two buoys. While all 24-hr means at Point La Jolla are from 203° or more westerly, these same waves have a more southerly orientation at the Point Loma buoy (consistent with the County DEH reference to orientations closer to 180°). These offshore data are not appropriate for detailed models of surfzone transport and one cannot make credible estimates of the strength/speed of longshore currents in the surf zone. This is a topic of active study in the current development of operational coastal ocean observing systems, see Recommendations in 7. Nevertheless, the wave direction information is valid and relevant for the following analysis. Point La Jolla buoy data are available from July 1999.

Eight-hour circular means and standard deviations are determined from CDIP wave direction data. Further, 24- and 48-hour wave direction means are obtained by averaging these 8-hour circular means over a time interval beginning at 08:00 PST the day before, or two days before the day of sampling. These 24-hour means ranged between 203 and 293°. Three categories are defined: 203°-240° = southerly, 240°-270° = southwesterly, and 270°-293° = northwesterly. Thus, in this analysis, southerly swell is defined as directions less than 240° at the Point La Jolla buoy and this is used to indicate oblique surfzone waves at all FIB sampling stations. During these periods, wave orientations at the Point Loma buoy are more southerly.

Results In Figure 6.7, all dry weather FIB data are aggregated and categorized by wave direction. For these dry weather data, where exceedance events occur less than 10% of the time, the 75th percentile is the most meaningful statistic to use in investigating spatial patterns apparent in Figure 6.7. For all stations other than S0 (south of Los Buenos Creek) and S5 (at the mouth of the Tijuana River), 75th percentiles of total coliform levels during dry weather (no-rain/no-flow) show consistently higher values during southerly swell. In contrast, station S0 shows higher levels of FIB for northwesterly waves. Bacterial levels for fecal coliform and enterococcus are low from all sectors, but where 75th percentile values are more than marginally above the detection limits, they follow the same south-swell association as those observed for total coliform.

Case Studies Owing to the rare occurrence of dry weather exceedance events, statistical approaches are limited in their skill. Alternatively, one can explore individual events - case studies that provide insight to what may be happening, but which provide no confidence that such an event will be observed again. In the dry portion of the FIB data, there are 12 days on which three or more stations exceed bacterial standards. These events occurred on 10/1/96, 5/23/00, 8/1/00, 4/3/01, 7/3/01, 9/18/01, 10/8/02, 11/5/02, 1/21/03, 6/17/03, 9/2/03, and 12/16/03. Wave direction data is available for 11 of these events and 7 are found to occur during periods when direction was less than 240° for the 24-hour period prior to sampling. These south-swell influenced patterns of bacterial exceedances generally show highest bacterial levels at stations S2 and S3, with bacterial levels decreasing with distance north. This pattern is always evident in total coliform patterns, but not always clear in distributions of fecal coliform or enterococcus. The event on 6/17/03 is preceded by persistent south swell, but this stops before the FIB sampling and the 24-hour wave direction is not southerly. However, this set of samples exhibits a similar FIB pattern as in other south swell events - indeed, it shows the strongest pattern of up-coast alongshore transport due to southerly wave forcing (Figure 6.8(a)), presumably due to the long period of wave

[A]



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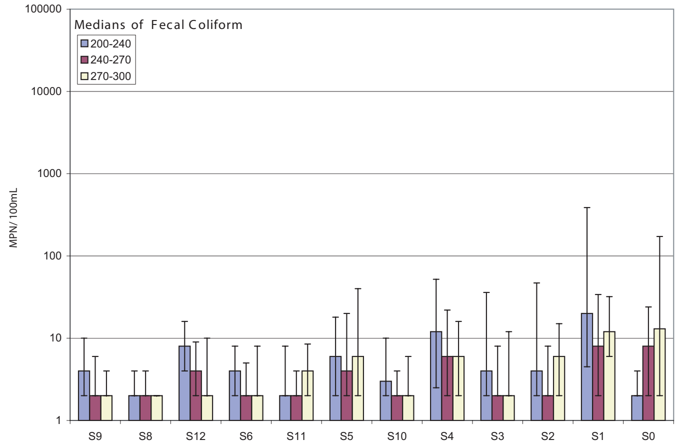

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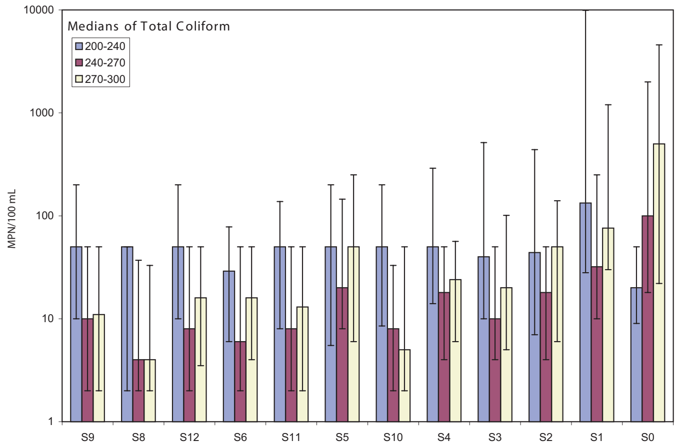

Figure 6.7: Median bacterial levels during differing swell directions: 200-240°, 240-270°, and 270-300°. Range bars indicate the 25 and 75 percentiles. A) Enterococcus, B) Fecal Coliform, C) Total Coliform.

forcing that preceded this sampling (up to less than a day before sampling). Also, bacterial distribution on 10/1/96 fits the pattern observed for other south swell events and a CDIP station in operation at that time shows wave direction approaching from the south (Figure 6.8(b)). Thus, 9 of the 12 dry weather multiple-station events are associated with south swell.

Alternatively, one can look at all days on which south swell is observed. Of the 400 days for which southerly swell was observed between July 1999 and December 2003, shoreline sampling took place on 65 days. Of these 65 days, 11 days are influenced by rain/flow and on 2 days samples are obtained as part the adaptive sampling following rain (one of these also rain-influenced). Examining the 53 dry south swell days sampled, it becomes clear that the occurrence of south swell does not always result in FIB exceedances. Although, there are instances where elevated bacterial levels can be seen throughout the entire data set, there are other days when bacterial levels are elevated only at the more southerly stations, days when bacterial levels are elevated only at S1 and S2, and even days when no elevation of bacterial levels are observed.

These results suggest that long distance transport of bacteria is possible, but that it is necessary to have long-term south swell (i.e., persists for at least 24 hours). Furthermore, transport is more likely to occur within this time frame if peak wave direction has low variability and if the south swell has high energy. However, if south swell persists for several days or more, the chance of long-distance bacterial transport increases for less ideal conditions. Total coliform best reflects the patterns consistent with wave-driven surfzone transport. Fecal coliform and enterococcus data do not always provide a clear pattern of alongshore transport when this is seen for TC, potentially due to lower initial concentration levels. Case studies of northward transport indicate that there is a time lag between the time when south swell commences (or breaks down) and the time when elevated bacterial levels are observed. Because of the multiple interacting factors influencing surfzone transport, analysis of this phenomenon would be strongly enhanced by a substantially larger data set, including data from the Mexican as well as US stations. The primary sources that lead to the observed northward wave-driven transport patterns are not clear, but the volume of outflow from Los Buenos Creek and the strong wave associated patterns at southern stations suggests that FIB from Los Buenos Creek may be transported at least as far as the US-Mexico border. Although elevated FIB levels are observed further north under some south swell conditions, exceedance levels are seldom observed at stations north of the border. Other smaller sources may also contribute to these south-swell patterns (e.g., urban runoff and sewage leaks, tidal outflow from Tijuana Estuary in dry weather).

Transport patterns associated with southerly winds

Given that winds drive surface currents, there may be an association with spatial patterns of FIB with wind direction or strength. Land runoff is freshwater and will tend to form a low-density surface layer at dilutions up to about 100-fold, suggesting the possibility of near-surface plumes of contaminated water that may be responsive to local wind forcing (*Blanton et al.*, 1997). The resultant correlation between wind, low-salinity waters, and down-wind distributions of fecal bacteria has been observed in a study of a shoreline outfall in Galway, Ireland (*Smith et al.*, 1999). Correlations between wind and bacteria levels were observed for stations between 1.9 and 4.3 km (1.1 - 2.6 miles) from the outfall. In addition, it appears that

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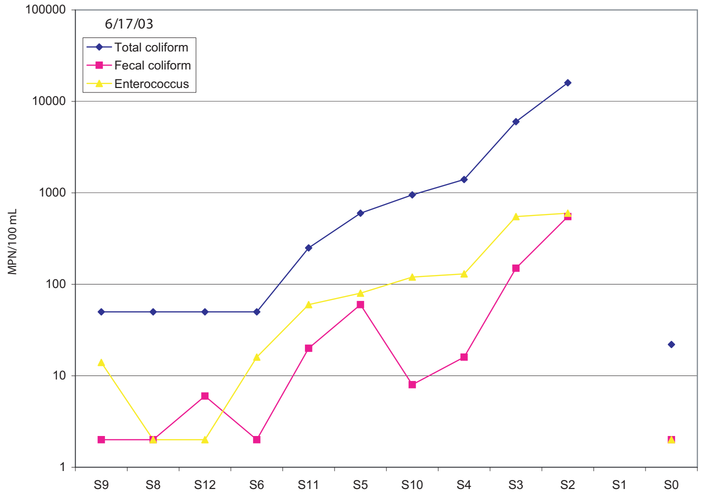

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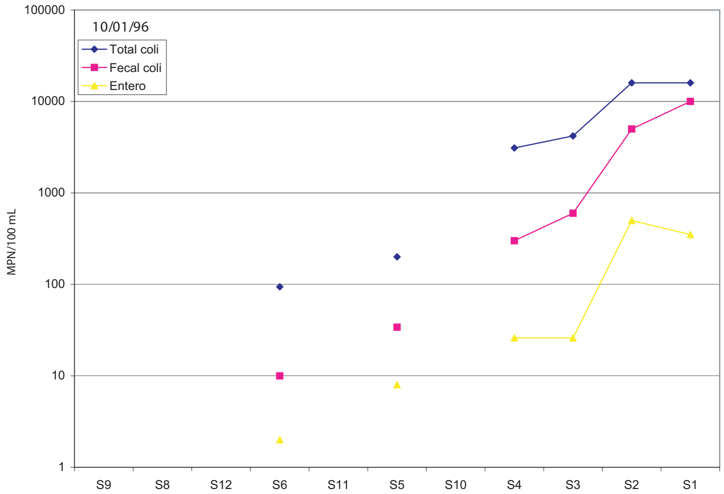

Figure 6.8: Two case studies of south swell events along the Imperial Beach coastline showing the gradual decrease in FIB concentrations with distance north. A) June 17, 2003 B) October 1, 1996. Note: single dots represent gaps in sampling stations along the coast.

there may be rapid, coherent, but short-distance atmospheric transport of fecal bacteria, with distances of 125-175 m (410- 574 ft) being observed in Antarctica (*Hughes*, 2003) and 730 m (2,394 ft) being observed in Israel. This aerial dispersal of FIB is not expected to account for larger scale patterns as described below, but it quite reasonable to expect alongshore transport of low-salinity, contaminated runoff that enters the ocean via Tijuana River or Los Buenos Creek.

Methods Wind effects were investigated through an analysis of hourly wind data available from Brown Field from February 1997 to December 2002. This airfield is immediately east of Tijuana Estuary and it is the closest continuous data available for this analysis. Given that this region is characterized by a strong diurnal wind cycle, with fresh and reliable onshore sea breezes in the afternoon and offshore land breezes pre-dawn, canonical day patterns were determined for wind direction and standard deviations for each month of sampling. Thus, in a given month of a given year, all data between 00:00 and 01:00 were averaged to obtain a typical value for the first hour of the day. Similarly averages were obtained for all hours of the day for the selected month. Comparison between months and between years provides insight on how the strength and pattern of diurnal sea breezes and nocturnal land breezes vary over seasons and between years.

In addition to diurnal patterns, day-to-day variability in winds can be compared with observed bacterial levels. Towards this end, 8-hour circular means of wind direction and arithmetic means of wind speed were calculated. Given that bacterial levels are sampled in the morning, circular means of wind direction for the time interval between 00:00-08:00 PST of the day of sampling were compared with FIB measurements. In contrast to wave analyses, wind is averaged over only the preceding 8 hours as nearshore surface currents are expected to respond more quickly to wind forcing. Wind was split into both 30° and 90° categories and results are given below for the 30° categorization.

Results The canonical day patterns of hourly wind averages follow similar patterns from month to month and year to year (results not shown). During the day a consistent sea breeze develops and wind speeds rise, with a maximum in early afternoon. In the evening and early morning wind speeds are low and there is a much larger degree of variability in direction. The primary seasonal differences are observed in the strength of the midday wind and in the length of the sea-breeze phase. During the winter (December to February), the sea breeze is weak, more variable, and lasts for only 7-8 hours. In mid-summer (July and August) the sea breeze continues for 10 to 12 hours with average wind speeds exceeding 10 knots at midday. However, owing to other strong diurnal effects (e.g., UV mortality effects) and the absence of sampling at different times in the day, it is not possible to discern if these diurnal sea breezes are important in shoreline bacterial levels.

While there is no evident association between bacteria levels and wind strength, there is suggestion of an association between wind direction and bacteria levels. As in other analyses of dry weather data, because exceedances are rare, attention is given to the 75th percentile. Hence, in Figure 6.9 the 75th percentile bacteria abundances are plotted as a function of wind direction over the 8 hours prior to sampling. Data from February 1997 through December 2002 are included in this plot. Wind categories are in 30° increments, centered at 15°, 45°, 75° , etc. At stations nearest to Los Buenos Creek (stations S1 and S2), highest bacteria values are found for southerly winds (roughly 150-200°). This is most notable in

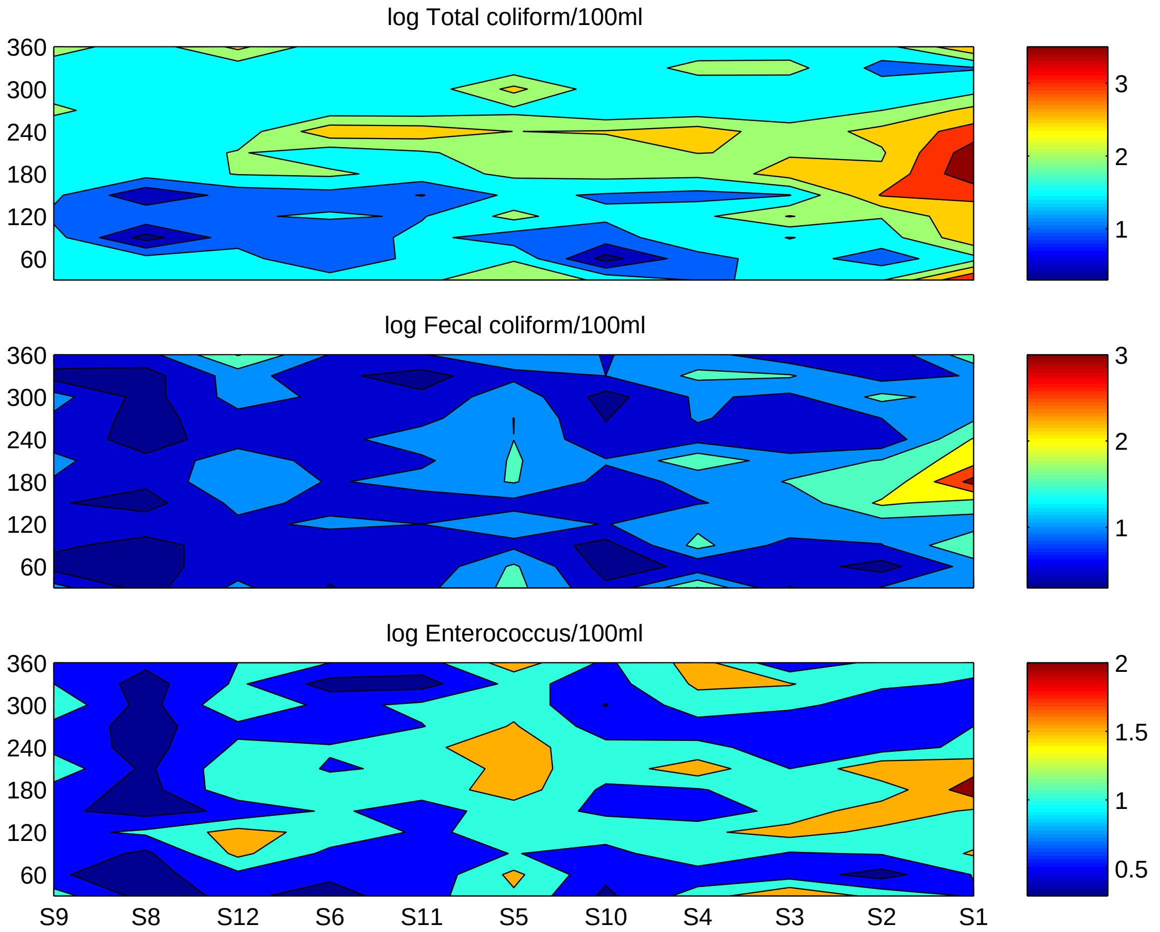

Figure 6.9: Bacteria levels in relation to wind direction for Feb. 1997 - Dec. 2002. Third quartile (75th percentile) levels for FIB concentration as a function of wind direction and station location. Wind direction is categorized in 30-degree bins. FIB concentrations are given as log values and contoured by color (see color bar for values).

TC distributions, and the wind-associated maximum can be seen also at stations stretching up to the Tijuana River mouth (stations S3 to S5), but with the maximum shifting to higher, more westerly winds (about 210°). A similar, but less clear, pattern is seen for FC and Ent.

In summary, there is an apparent association between southerly winds and elevated bacteria levels at stations between the Tijuana River and Los Buenos Creek. The direction of expected wind-driven transport, and the expectation that the Tijuana River is not flowing during these dry days, suggest that the source of FIB to explain these patterns is emanating from Los Buenos Creek or other sources in the south. Highest values at S1 are observed for winds from 150-170°, winds which are blowing up-coast and slightly onshore, thus retaining contaminated waters nearshore through a combination of onshore wind forcing and the onshore component of up-coast wind forcing due to coriolis effects.

Transport patterns associated with tidal currents

Previous studies, specifically off Huntington Beach (Orange County, CA), have found a significant spring-neap tidal cycle in shoreline FIB values (*Boehm et al.*, 2002b) and a clear short-term tidal signal in shoreline FIB values associated with ebb tide outflow from enclosed coastal waters (e.g., Santa Ana River, (*Kim et al.*, 2003)). Likewise, a tidal creek study in North Carolina showed that bacterial concentrations at the mouth were highest near low tide, at the end of the ebb cycle (*Mallin et al.*, 1999). Also within estuaries, one can expect tidal changes in bacteria levels at fixed sites and thus levels can be influenced by the tidal stage at the time of bacterial sampling (*Mallin et al.*, 1999).

Methods Spring-neap tidal changes are related to the lunar cycle and this cycle can be examined by categorizing data according to which day it is collected in the 28-day lunar cycle. The new moon is day 0 and day 28 is the day before the next new moon; for occasional months when there is a day 29 it is included in the 28-day bin. Then for each category one can obtain a median and 75th percentile value from the dry weather FIB data. Due to the smallness of the data set, data from all stations are aggregated in this analysis. While 3-day bins were also formed for individual stations, these results are not shown here.

In a similar way, the high-low/flood-ebb tidal cycle can be examined by categorizing data according to which hour it is collected in a 24-hour tidal cycle (although data are collected on many different days). This looks for an association of FIB levels with tidal phase. These categories are determined by the time of high-high tide (HH), low-low tide (LL), LH (low-high tide) and HL (high-low tide) and the number of hours that have elapsed since the most recent of those tidal extremes. Dry weather bacteria data from stations near the Tijuana mouth were analyzed in this way - stations S6, S11, S5, S10 and S4 were each analyzed separately. NOAA tide data from San Diego Bay is used for this analysis.

Results The sinusoidal pattern observed for 3-day data at individual stations is also seen in the 1-day, all-station analysis of lunar cycle bacteria variations. Peak values occur near spring tide, when tidal ranges are the largest, and lowest values occur close to neap tide, when tidal ranges are the smallest (Figures 6.10, 6.11, and 6.12. All three indicators reflect this spring-neap pattern, though it can be seen most strongly in total coliform. The station-specific 3-day results suggest that this pattern is weakest at stations S5, S10 and S1, near the primary sources of Tijuana River and Los Buenos Creek.

The high-low/flood-ebb tidal cycle is evident in Figures 6.13 and 6.14, but with important differences in the timing of maximum and minimum FIB values. At station S5, median values are low at HH and increase to a maximum 6 hours later (at LL), consistent with outflow of contaminated water from Tijuana estuary during the ebb tide. Then, following LL, median values decrease until shortly after the next high tide (LH), when there is a second modest increase in values during the second ebb tide. Higher values are evident during the HH-to-LL ebb tide, which has a much larger drop in water level and drains water out from deeper in the estuary. During spring tides, the water level drops lowest and much of the estuary water is pulsed out of the estuary basin, resulting in the above-described spring-neap cycle.

For stations north of the Tijuana mouth, this pattern is also evident (primarily in TC), albeit a bit weaker. For these stations, there is an important difference in timing of maxima relative to that seen for S5. At station S11 (immediately north of the mouth), the higher

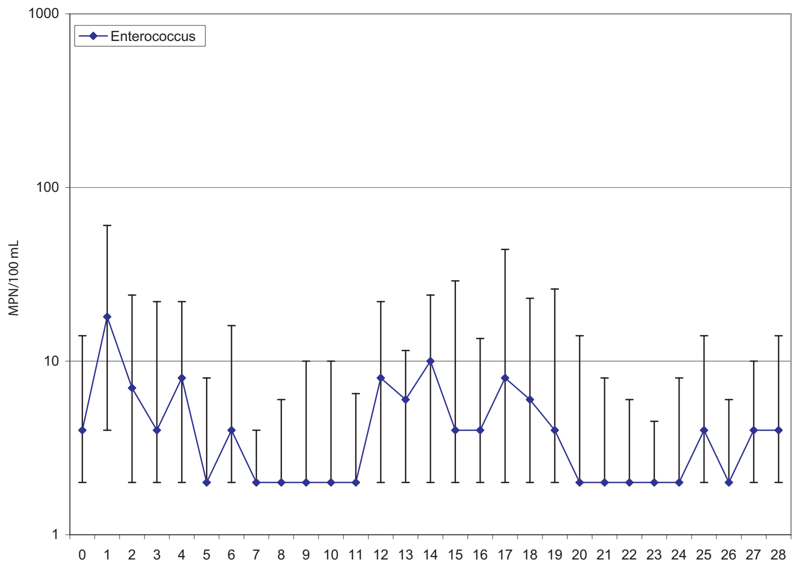

Figure 6.10: Spring-neap tidal cycle in enterococcus values. Median levels for enterococcus counts as a function of day of the lunar cycle (data from all stations combined). Range bars are first and third quartiles (25 and 75 percentile levels).

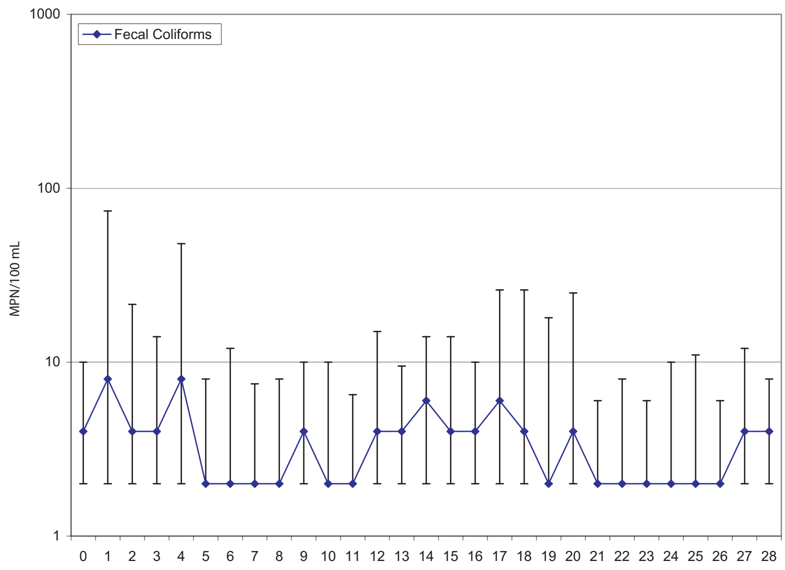

Figure 6.11: Spring-neap tidal cycle in fecal coliform values. Medians for fecal coliform counts as a function of day of the lunar cycle (data from all stations combined). Range bars are first and third quartiles (25 and 75 percentile levels).

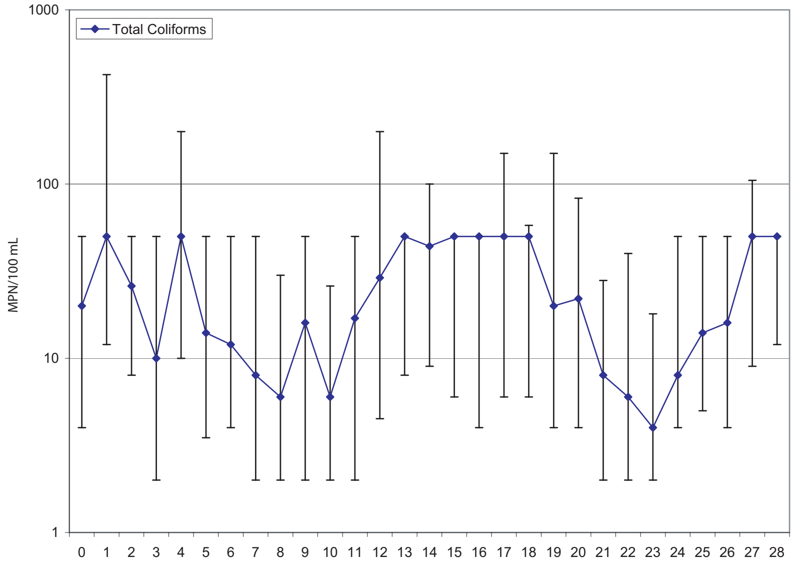

Figure 6.12: Spring-neap tidal cycle in total coliform values. Medians for total coliform counts as a function of day of the lunar cycle (data from all stations combined). Range bars are first and third quartiles (25 and 75 percentile levels).

maximum does not peak at the end of the ebb tide, as for stations 5, but rather occurs about 2-3 hours later. At the next station moving north, station S6, this peak is further delayed and it occurs about 4-5 hours after LL. This is consistent with alongshore tidal transport, as observed off Huntington Beach by (*Kim et al.*, 2003) and as suggested by recent unpublished FIB data collected off Imperial Beach. As this tidal transport is up-coast, the tidal patterns at stations south of the mouth (stations S10 and S4) are not as clear.

These tidal pulses of contaminated water from the Tijuana River may lead to recurrent water quality concerns when samples are taken during the few hours when this tidal "blob" of estuarine water moves past station S5, S11 or S6. This appears to have been the case towards the end of the rainy season in 2000: every second week from late March to early May, sampling happened to be synchronized with the latter part of the main ebb outflow from Tijuana Estuary (samples taken at HH+7:00hrs on 3/28/00, at HH+5:51hrs on 4/11/00, at HH+7:32hrs on 4/25/00, and at HH+7:35hrs on 5/9/00. Although no river flow was recorded and no rain fell within 4 days of sampling, the FIB observations from these four days describe a clear peak in bacterial levels. If on the other hand, sample times become synchronized with tidal inflow of low-FIB offshore waters, a period of low counts will be reported. This calls into question how representative an individual water quality sample may be for stations near tidal sources of indicator bacteria - or, at least, suggests that care must taken in interpreting these data.

This tidal signal is also important in that it suggests that the Tijuana Estuary may continue to pulse out FIB-rich waters some time after rain and inflow have ceased. This suggests either other sources of FIB for the Estuary or persistence of indicator bacteria populations in these estuarine waters. Further, it suggests that stations immediately north of the mouth may

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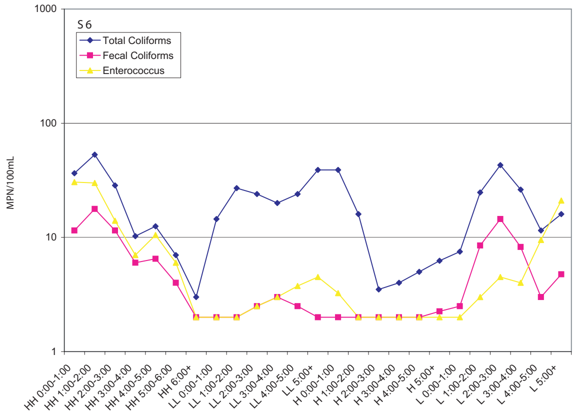

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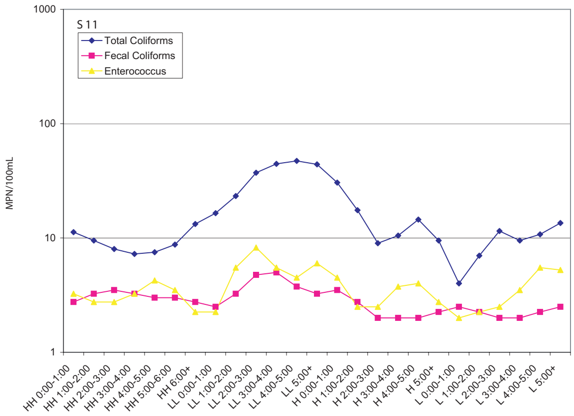

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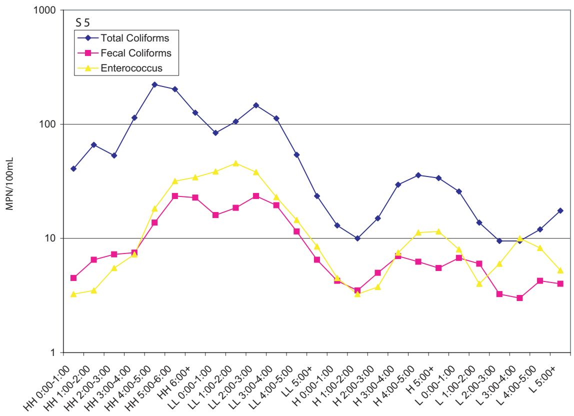
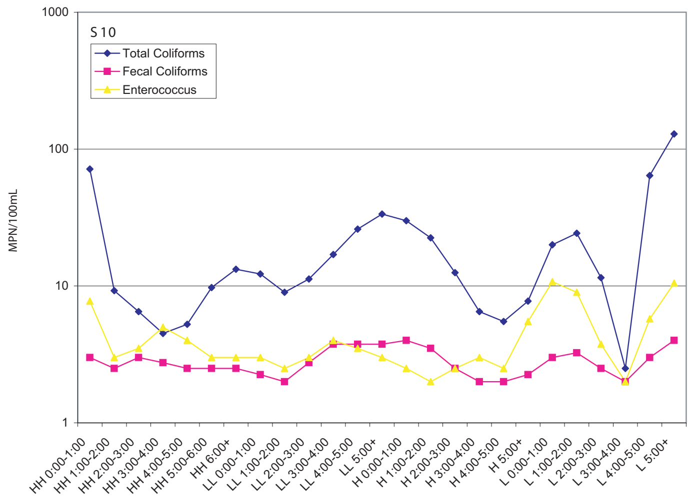


Figure 6.13: Synthesized tidal cycle in bacteria values. Median FIB values (with 3-point running mean smoothing) as a function of the time at which observations were obtained relative to high and low tides. A) Station S6, B) Station S11 and C) Station S5.

[A]



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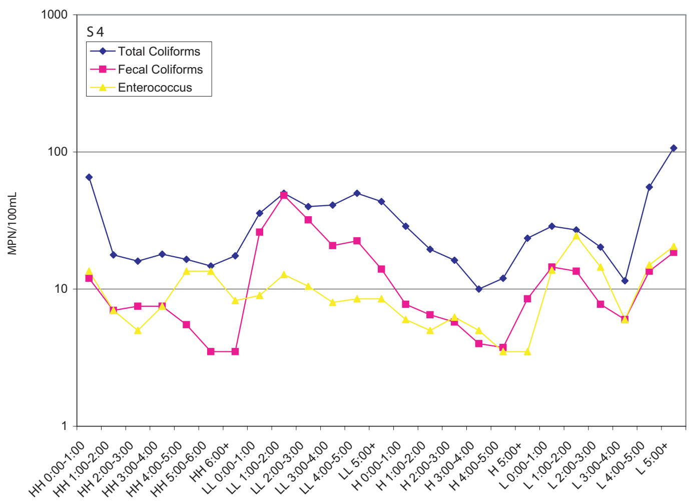


Figure 6.14: Synthesized tidal cycle in bacteria values. Median FIB values (with 3-point running mean smoothing) as a function of the time at which observations were obtained relative to high and low tides. A) Station S10 and B) Station S4.

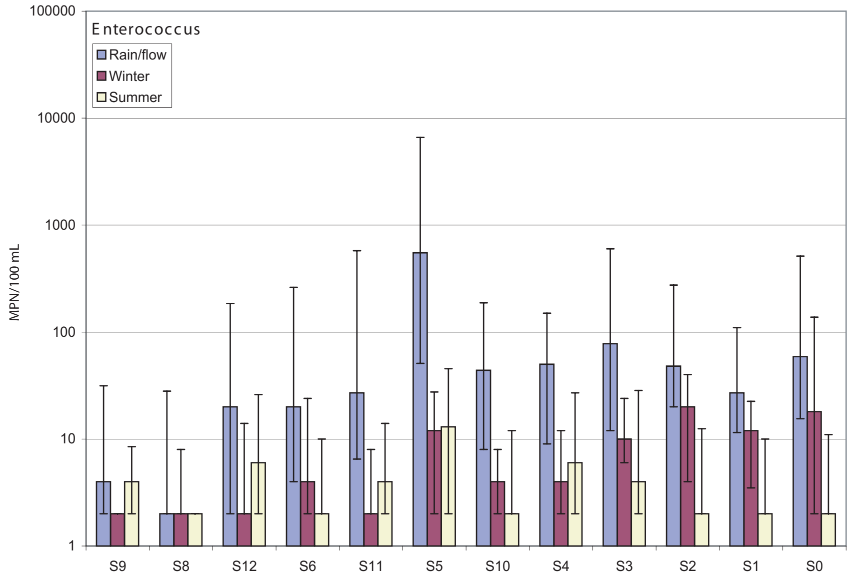


Figure 6.15: Seasonal variability in bacteria levels. Median enterococcus values for rain/flow influenced days, dry weather winter days, and dry weather summer days plotted for all beach stations. Range bars are first and third quartiles (25 and 75 percentile levels).

experience frequent, but short-lived (few hours), episodes of poor water quality following LL tides.

Seasonal variability in beach bacteria levels

Seasonality in beach water quality is well recognized, but it is expected that this seasonality is primarily due to the occurrence of rain events and river flow events in winter months. This is seen clearly in Figures 6.15, 6.16 and 6.17, where median values are plotted for wet weather data (rain and river flow influences) and contrasted with medians for dry weather data in winter (months January-March) and summer (months June-August). In addition to median values, 75 and 25 percentile values are plotted. While very large differences are found between wet and dry data at most stations, there are insignificant differences between winter and summer at many stations.

Although less than the wet-vs-dry differences, notable seasonal differences (once rain and flow influenced data has been removed) are observed at stations in Mexico and at stations north of the Tijuana River. The first set of stations, S0 through S3, exhibit higher median and 75th percentile values in winter, specifically for enterococcus and fecal coliform, but also for total coliform at S1. In contrast, the northerly stations, S11 through S9, exhibit higher median and 75th percentile values in summer, specifically for total coliform.

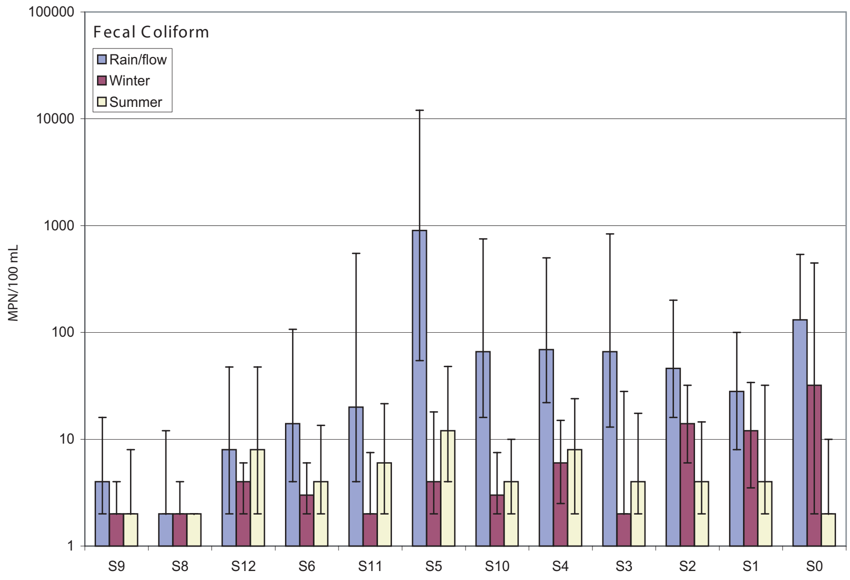


Figure 6.16: Seasonal variability in bacteria levels. Median fecal coliform values for rain/flow influenced days, dry weather winter days, and dry weather summer days plotted for all beach stations. Range bars are first and third quartiles (25 and 75 percentile levels).

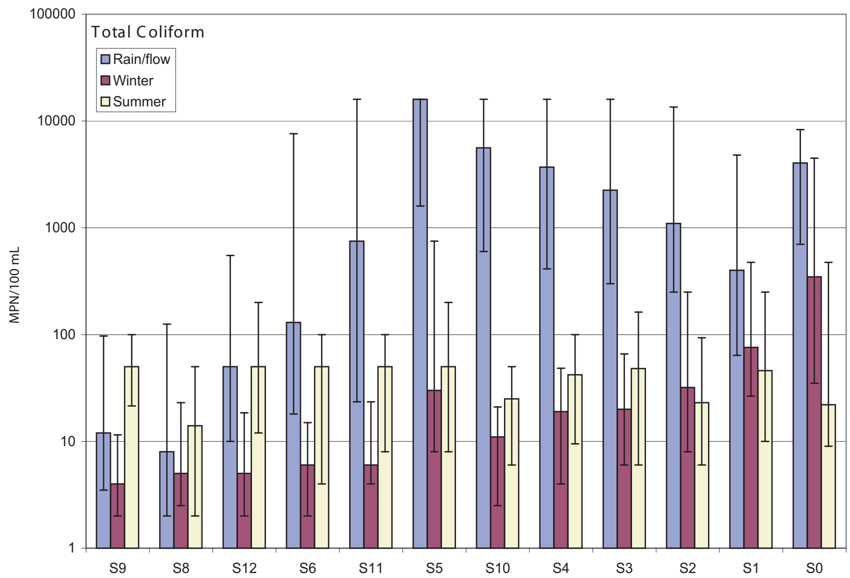


Figure 6.17: Seasonal variability in bacteria levels. Median total coliform values for rain/flow influenced days, dry weather winter days, and dry weather summer days plotted for all beach stations. Range bars are first and third quartiles (25 and 75 percentile levels).

6.2 Bacterial Exceedances at Kelp Stations

Three stations in the vicinity of kelp are sampled weekly to monitor possible exceedance of fecal indicator bacteria (FIB) standards for recreational waters. It is expected that these stations will be subject to contamination during rain and river flow events, as described for beach stations in Section 6.1. However, these stations are some distance offshore and in water depths of about 10-18m, allowing for stratification and near-bottom intrusions of cold sub-thermocline waters (see Section 4.2), as has also been observed in nearshore waters off Huntington Beach (*Noble et al.*, 2004). These factors suggest that the kelp stations are more susceptible to impact from wastewater plumes transported from offshore. In this section, exceedances at the kelp stations are evaluated as a function of time and in comparison with rainfall, river flow, and water temperature, combining approaches used in Chapter 4 and Section 6.1. The aim is to assess whether available data can allow differentiation between contamination originating from land runoff or outfall sources. The approach mostly follows Section 6.1.1 and further information on data sources, methods, exceedance standards, and the hierarchical approach are found in that section.

6.2.1 Overview of Kelp Exceedances

Figures 6.18(a) and 6.18(b) summarize the total number of bacterial exceedances over years, stations and indicator type. No exceedances were recorded for years 1995 and 1996, years in which there was limited sampling. All post-outfall years (1999-2003), except for 2002, have more exceedances than pre-outfall years, however five times more samples were collected in post-outfall years and a direct comparison of total number of exceedances is not appropriate when discussing annual variability. Figure 6.18(b) shows yearly exceedances normalized by the total number of samples collected for that year and can be used to compare between year variability. All post-outfall years except for 2001 have a lower percentage of exceedances in comparison to pre-outfall years, with 2002 having the lowest.

The combined number of exceedances for all years (1995 to 2003) for each station and for each indicator type are shown in Figure 6.19. Station I25, closest to Tijuana Estuary mouth, has the greatest number of exceedances over all indicator types. Station I26 and I25 both show similar trends in the division of exceedances over indicator type. In comparison, the trend over indicators for station I39, furthest offshore and in deeper water, shows the greatest number of exceedances with enterococcus, followed by fecal coliform, which may suggest a different source for the exceedances.

6.2.2 Wet Weather: Exceedances Associated with Rain and River Flow

Percent of exceedances coinciding with rain or flow events: Tables 6.2 and 6.3 summarize the total number of samples taken each year, and the percentage of exceedances that occurred during rain, flow or dry conditions. Also listed are the total number of exceedances of the single day standard, and the percentage that occurred during each type of event. Table 6.2 lists exceedances of the California Ocean Plan standards (Total coliform $> 10,000$ MPN/100 ml; Fecal coliform > 400 MPN/100 ml) which do not include enterococcus. Table 6.3 lists exceedances of the AB 411 standards, which are the same as COP but also include a

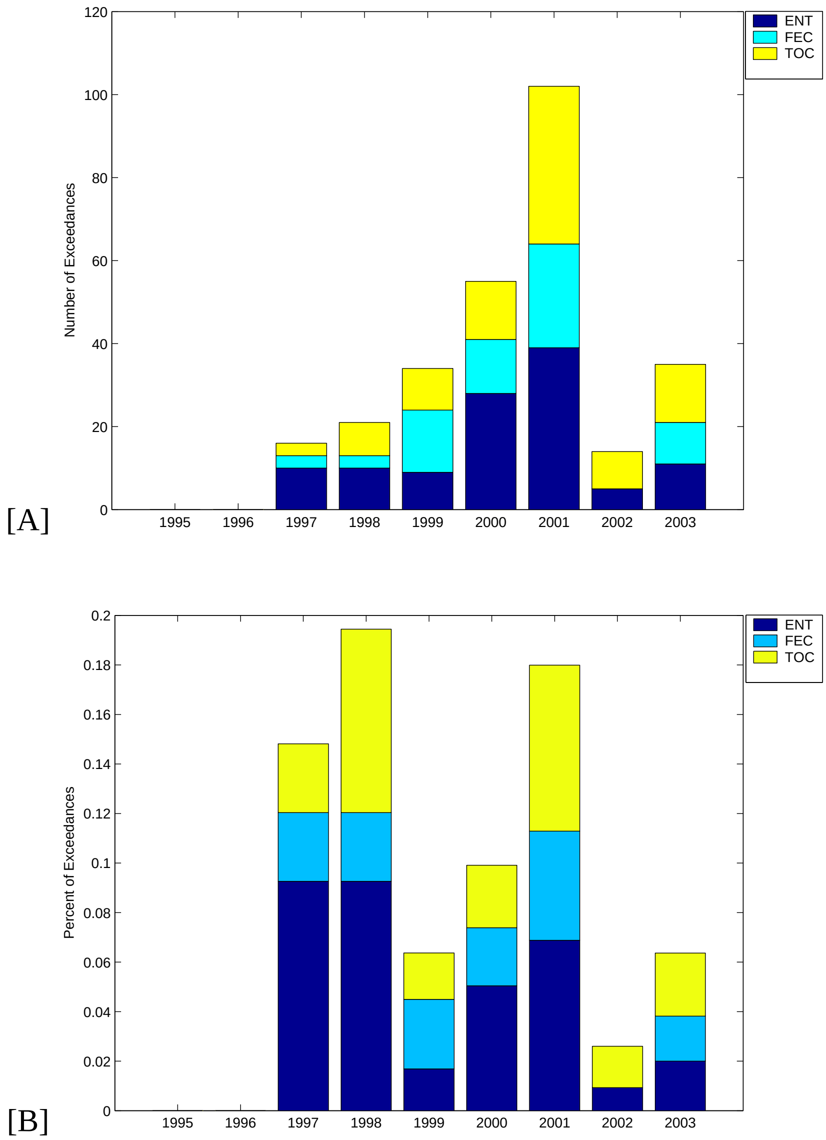


Figure 6.18: Number of bacterial exceedances at kelp stations for each year from 1995 to 2003 divided amongst indicator type: enterococcus (dark blue), fecal coliform (light blue) and total coliform (yellow) A) Combined total number of exceedances, B) Percent of exceedances per number of samples. Exceedances are defined using AB 411 standards.

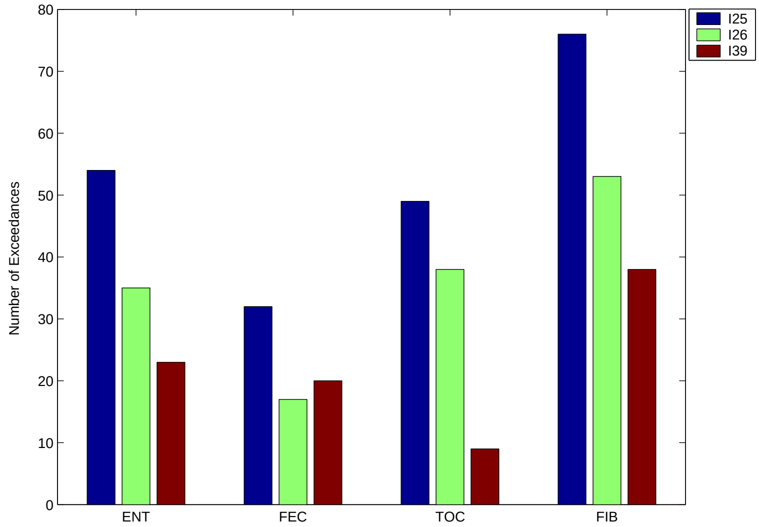


Figure 6.19: Combined total number of FIB exceedances found at each kelp station for each indicator type samples over all years (1995-2003). Colors represent stations: I25 (Blue), I26 (Green) and I39 (Red). Exceedances are defined using AB 411 standards.

standard for enterococcus (Ent > 104 MPN/100 ml). The difference between the two methods in the percent of exceedances is minor, never more than 6% in any given year. Most exceedances occur during rain events (44-95%). Years 1995 and 1996 had no exceedances. Violations during periods of river flow account for 5-30%, with years 1996, 1997, and 2002 experiencing no flow-related exceedances. For all years with exceedances, except for 1999, rain-influenced events have the greatest percentage of violations per event type. Exceedances during 1999 are evenly distributed over all three event types making it the year with the greatest number of exceedances from unknown sources. Note that each water sample is used for 3 tests (total coliform, fecal coliform, and enterococcus) and an exceedance is obtained for that sample if one or more single-day standards are exceeded (TC $> 10,000$ MPN/100 mL; FC > 400 MPN/100 mL; Ent > 104 MPN/100 mL).

Comparison of fecal indicator bacteria with rainfall and river flow: The spatial pattern of contamination in kelp waters associated with rain and flow events is summarized in Figures 6.20, 6.21 and 6.22 of the median values (together with 25 and 75 percentile values) for 5 rain categories (D1 - D5), a flow category (flow > 0.01 m^3/s, rain < 2.5mm) and a dry weather category (flow < 0.01 m^3/s, rain < 2.5mm). Pre-outfall and post-outfall data are combined in this analysis, which is comparable with the analysis for beach stations presented in Figures 6.3, 6.4 and 6.5).

Enterococcus and fecal coliform values are only elevated above exceedance levels on days influenced by rain. Closest to Tijuana Estuary, station I25 is most heavily impacted, with median Ent values exceeding the single-day standard at the surface. Highest values are obtained the day after rain (D2) and they are only elevated that day suggesting that a plume moves past this station following rain. At other times, median Ent and FC values are below 10 MPN/100 ml. Elevated values are also observed at station I26, but only at the surface.

Table 6.2: Bacterial levels in exceedance of California Ocean Plan standards at South Bay Kelp Stations, 1995-2003. Table is divided by category into samples with rainfall, samples with river flow but no rainfall, and samples with neither. Total samples are shown at the top of the table, followed by the number with California Ocean Plan exceedances, and finally the exceedances are shown as a percentage of the total number of samples.

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	Total
# Samples	36	90	108	108	534	555	567	538	550	3068
Rain	0	21	27	39	153	183	188	151	143	905
River Flow	18	27	27	63	72	75	81	0	74	437
Dry	18	42	54	6	309	297	298	387	333	1744
# Exceed.	0	0	3	8	20	20	42	9	16	118
Rain	n/a	0	3	8	6	13	24	9	12	75
River Flow	0	0	0	0	9	4	13	n/a	4	30
Dry	0	0	0	0	5	3	5	0	0	13
% Exceed.	0%	0%	3%	7%	4%	4%	7%	2%	3%	4%
Rain	n/a	0%	11%	21%	4%	7%	13%	6%	8%	83%
River Flow	0%	0%	0%	0%	13%	5%	16%	n/a	5%	7%
Dry	0%	0%	0%	0%	2%	1%	2%	0%	0%	1%

At station I39, furthest offshore and in deepest water, highest Ent and FC values are found near-bottom, suggesting an offshore sub-thermocline source. However, there appears to be a marked association of high values with the day after rain and this suggests that either these events are influenced by rain associated southerly/westerly winds and downwelling of the Tijuana plume or that there may be a rain-associated outflow of groundwater near this station (personal communication, Luciano Peiorin). In the absence of salinity data on I39, it is not possible to make even rough assessments of the source of this curious bottom/mid-depth intrusion. While the groundwater suggestion is speculative and no reports on groundwater seepage in this region could be found, this may bear further investigation. While these patterns are partially reflected in TC plots, the TC levels are more widespread and persistent, with modestly elevated bacteria values at these stations also on flow-related days. On the whole, these kelp station FIB results confirm that the Tijuana River is the dominant source of contamination during wet weather (rain and flow influenced days). Generally, rain days lead to higher loading of nearshore waters than days where there is only loading delivered by way of the Tijuana River.

Table 6.3: Bacterial levels in exceedance of AB 411 standards at South Bay Kelp Stations, 1995-2003. Table is divided by category into samples with rainfall, samples with river flow but no rainfall, and samples with neither. Total samples are shown at the top of the table, followed by the number with AB 411 standard exceedances, and finally the exceedances are shown as a percentage of the total number of samples.

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	Total
# Samples	36	90	108	108	534	555	567	538	550	3068
Rain	0	21	27	39	153	183	188	151	143	905
River Flow	18	27	27	63	72	75	81	0	74	437
Dry	18	42	54	6	309	297	298	387	333	1744
# Exceed.	0	0	10	11	21	36	56	12	21	167
Rain	n/a	0	9	10	7	29	37	12	13	117
River Flow	0	0	0	1	9	4	13	n/a	6	33
Dry	0	0	1	0	8	3	6	0	2	17
% Exceed.	0%	0%	9%	10%	4%	7%	10%	2%	4%	5%
Rain	n/a	0%	33%	26%	5%	16%	20%	8%	9%	13%
River Flow	0%	0%	0%	2%	13%	5%	16%	n/a%	8%	8%
Dry	0%	0%	2%	0%	2%	1%	2%	0%	1%	1%

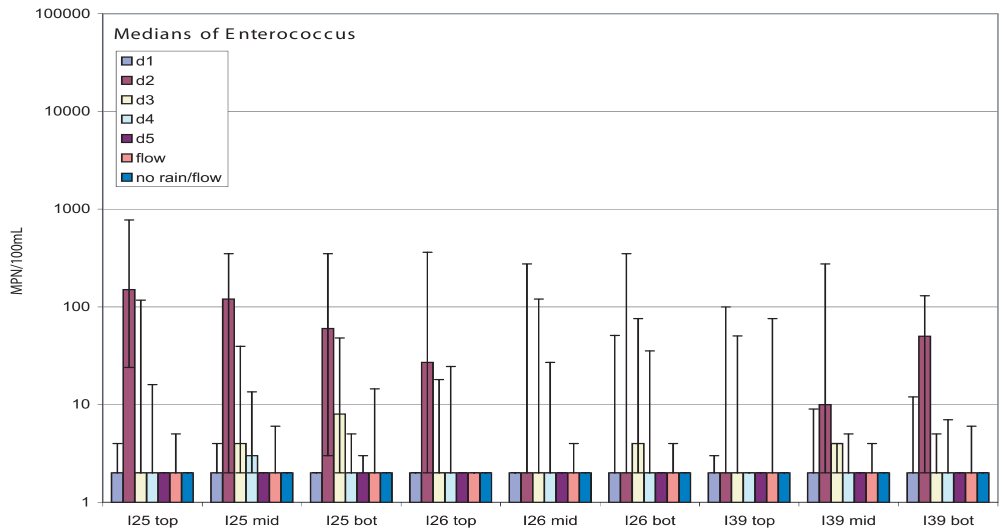


Figure 6.20: Median enterococcus concentrations for kelp samples for Day 1-5 of rain association, flow-influenced days and dry days. Range bars represent the 25 and 75 percentiles. Samples are shown for top (1.5 m), middle (6 m for I25/I26 and 12 m for I39), and bottom (10 m for I25/I26 and 18 m for I39) depth ranges.

Kelp station FIB concentrations during rain- or flow-influenced events are plotted in Figure 6.23 for all depths and stations. The greatest number of exceedances are seen during the rainy season of 2001, although the highest annual rainfall and river flow was in 1998 (Figure 6.1). Although 1995 had even higher rainfall and river flow, monitoring did not begin until July 1995, after the rainy season. Exceedances during 2001 also have the highest concentrations of enterococcus and fecal coliform for all years sampled, yet total coliform concentrations are similar for all years. In contrast 2002 had the lowest number of exceedances for rain and flow influenced events and also had the least total annual amount of rain and river flow for all the years sampled.

FIB have a wide range in concentration over all indicators during rain- and flow-influenced events with total coliform concentrations having similar maximum levels over all the years. For all post-outfall years except 2002, enterococcus and fecal coliform levels are as high or higher than 1997, the highest pre-outfall year.

A comparison of enterococcus, total coliform and fecal coliform versus the daily rainfall, the five day total amount of rainfall, and amount of river flow for the day of sampling is shown in Figure 6.24. Only geometric mean concentration levels and above were selected for comparison with rain and river events. Depth was also plotted in order to determine if there is a correlation for a particular depth range, but it appears that association with station is stronger. In the bottom middle panel it is evident that total coliform values are always high after significant rains, but, this is not true for Ent and FC. However, there is an apparent association between Ent on the day of rain and the amount of rain (see top left panel). This

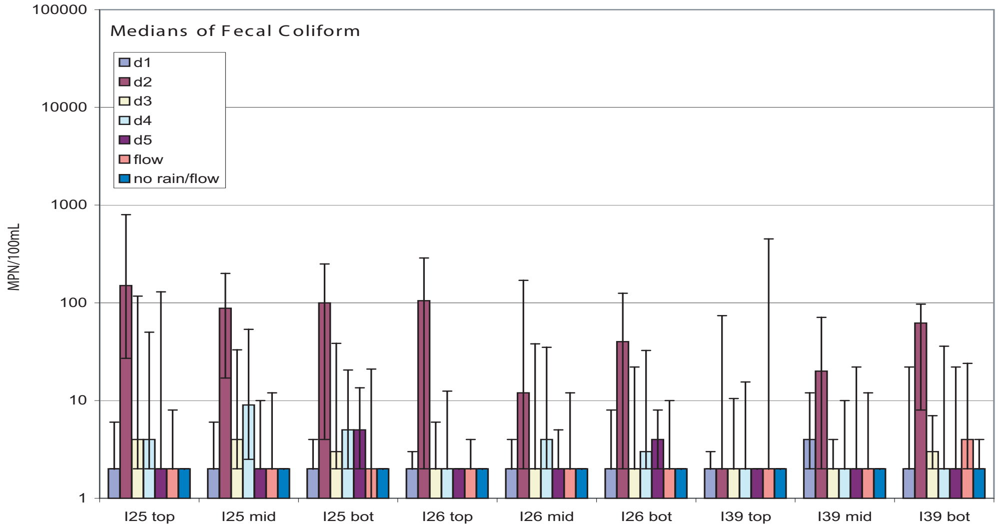


Figure 6.21: Median fecal coliform concentrations for kelp samples for Day 1-5 of rain association, flow-influenced days and dry days. Range bars represent the 25 and 75 percentiles. Samples are shown for top (1.5 m), middle (6 m for I25/I26 and 12 m for I39), and bottom (10 m for I25/I26 and 18 m for I39) depth ranges.

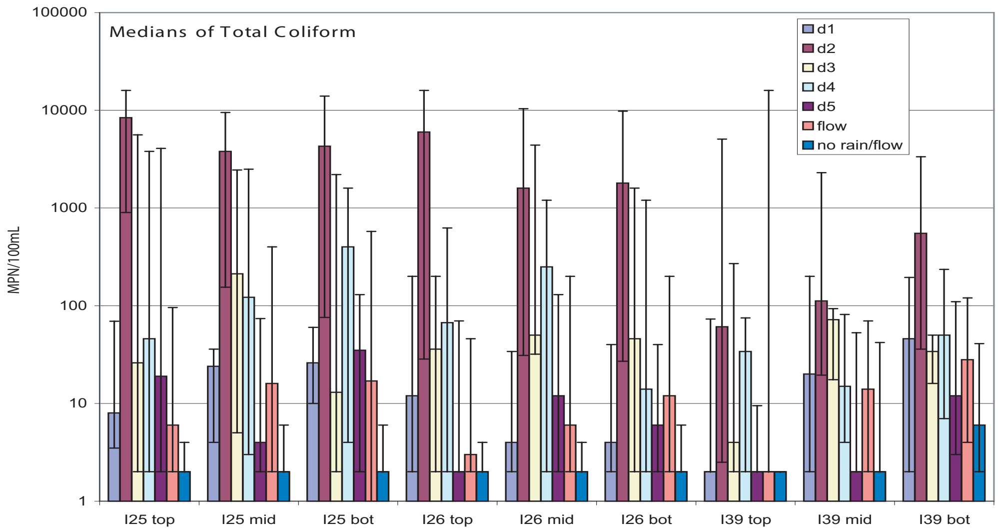


Figure 6.22: Median total coliform concentrations for kelp samples for Day 1-5 of rain association, flow-influenced days and dry days. Range bars represent the 25 and 75 percentiles. Samples are shown for top (1.5 m), middle (6 m for I25/I26 and 12 m for I39), and bottom (10 m for I25/I26 and 18 m for I39) depth ranges.

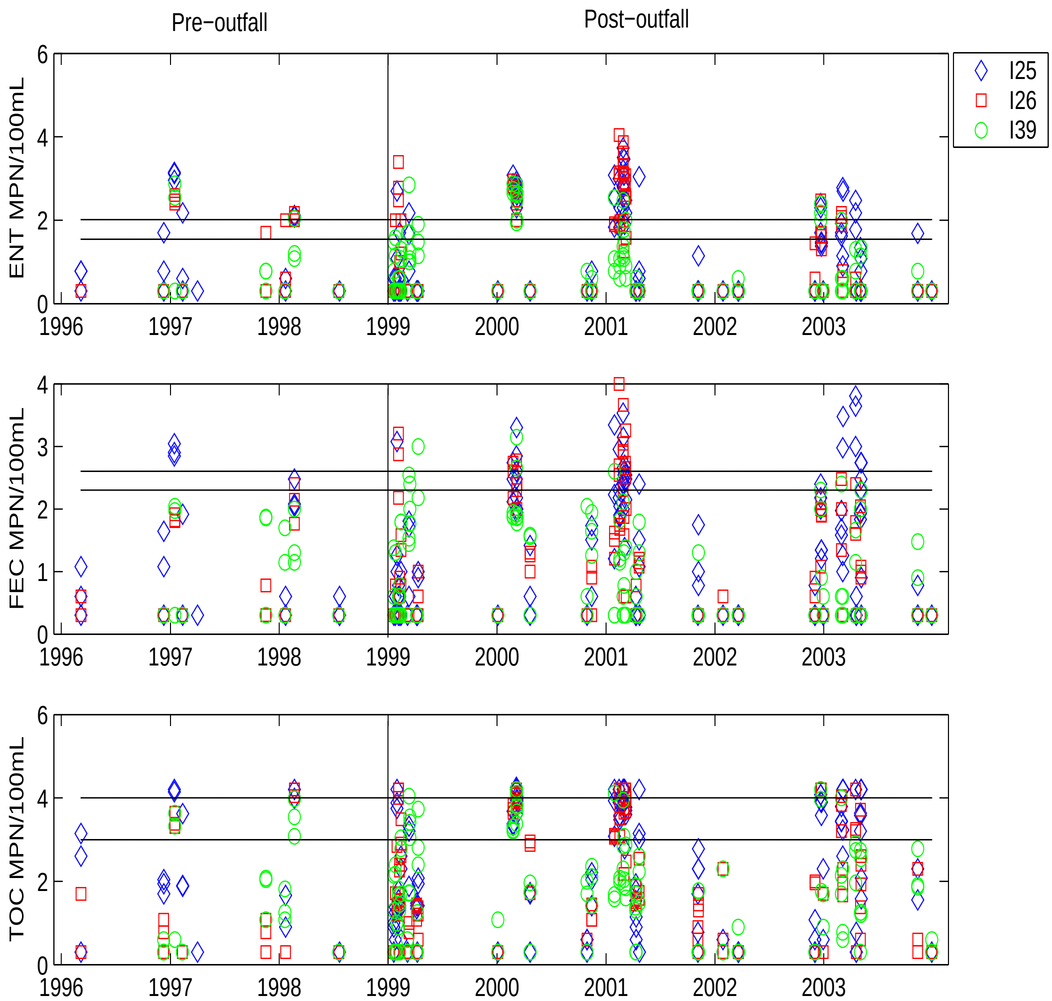


Figure 6.23: Log scale of fecal indicator bacteria concentrations for kelp stations at sampling days with rain $\geq$ 2.54 mm or flow $\geq$ 0.01 m^3/s beginning Jan 1996 to December 31, 2003 for all depths sampled, TOP: Enterococcus, MIDDLE: Fecal Coliform, BOTTOM: Total Coliform. Black lines indicate standard levels for each indicator, top line represents daily standard with bottom line at the 30-day geometric mean level. Note: No rain or flow days were sampled in 1995.

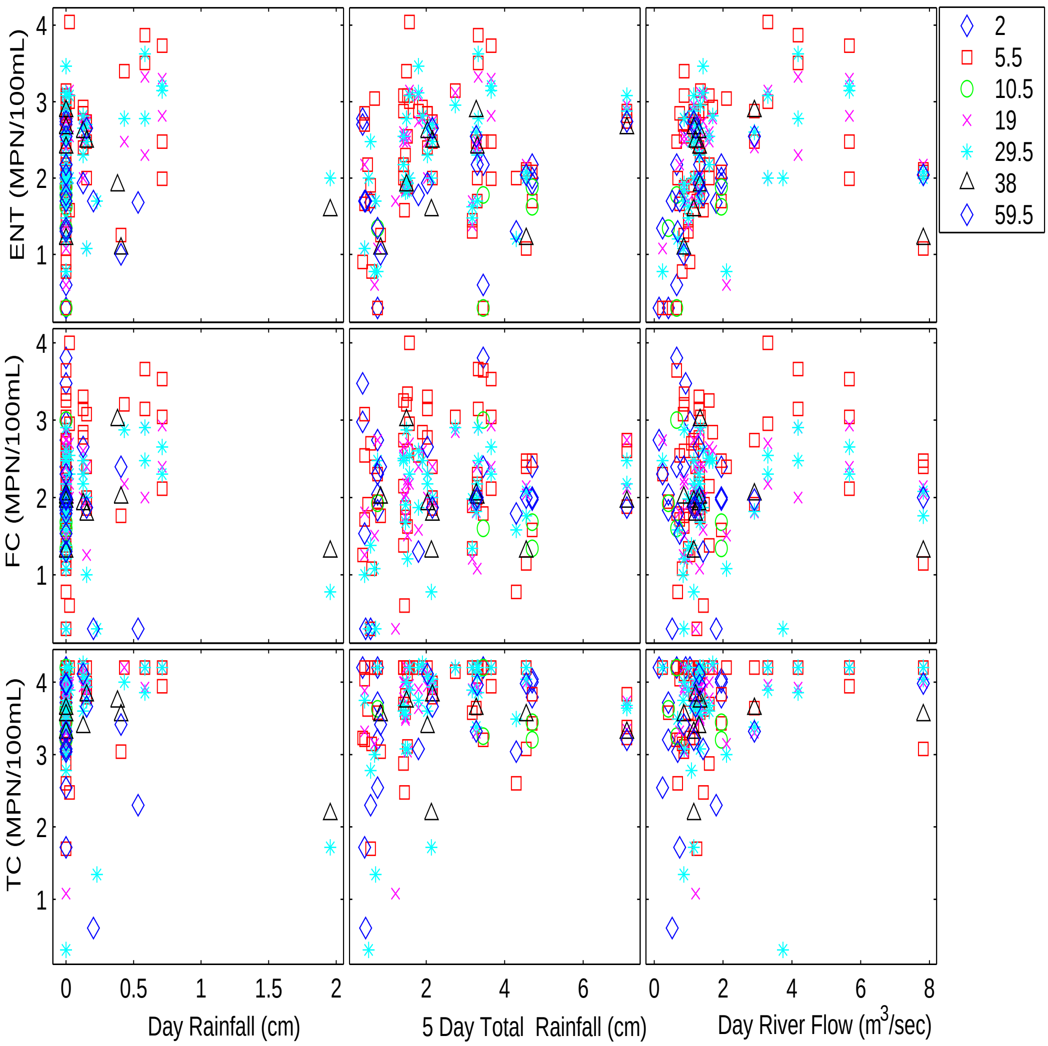


Figure 6.24: Log plot of fecal indicator bacteria versus daily rainfall (left), 5 day rainfall (middle), and river flow (right). Symbols indicate average depth in meters of bottle sample: TOP: Enterococcus, MIDDLE: Fecal Coliform, BOTTOM: Total Coliform.

result and the peak Ent median values on day 2 (Figure 6.3) suggest that Ent may have more of a "first flush" relationship with rain - i.e., the initial runoff in a storm has high values, but then levels drop in later runoff. This would contrast with TC loading, which appears to continue at high levels throughout a rain event. This is speculation, but worth further exploration.

Pre-outfall versus post-outfall differences in kelp contamination are small and not significant given the limited number of samples obtained at kelp stations prior to 1999. For pre-outfall years, 1995-1998, AB411 exceedances occur for 6.1% of samples, whereas for post-outfall years, 1999-2003, AB411 exceedances occur for 5.3% of samples (see Table 6.3). Station I25 has the highest percentage of exceedances and rain associated exceedance events are the most common. While rain days clearly dominate the exceedance record, the association is not always made. Variability in nearshore currents will result in variability in transport and delivery of this contaminated runoff to specific sample locations. Sampling of beach and kelp station on different days makes interpretation of the results difficult and precludes the possibility of observing links between shore and kelp water quality that could verify the presence of a land-based plume impacting the kelp station.

Annual time-series plots of beach and kelp station bacterial concentrations at the 30-day geometric standard levels for all monitoring years can be found in Appendix B, in parallel with data on rainfall, Tijuana River flow, swell direction, and wind direction. These data provide a clear picture of exceedances, with a notable seasonal cycle. However, while 30-day means are a key element of standards and provide an invaluable assessment of the level of contamination, they cannot resolve the scale of temporal variability and thus are limited in their use in developing inference and understanding of associations between environmental conditions and observed FIB levels.

6.2.3 Dry Weather: Exceedances Associated with Sub-Thermocline Sources

Kelp station water quality on dry weather days is generally very good; median and 75th percentile levels are well below exceedance levels (Figures 6.20, 6.21 and 6.22). However, there are infrequent exceedance events at kelp stations during dry weather, with a total of 16 in the period 1999-2003 (see Table 6.3). Although this number seems negligible, it should be remembered that only 1in 7 days are samples, suggesting that there could have been many more events that were not detected. Possible sources are the same as for beach sites and these are discussed more fully in Section 6.1.2.

Geometric standards are exceeded annually at kelp stations (see Appendix B). Underlying these are some observed high values, which are presented here as case studies. Three out of the four events presented have high levels at mid-depth at the outermost kelp station I39, with temperature data indicating that these high values are in the lower thermocline or immediately below it. In some of these case studies values exceed single-day standards, but their importance is that they point to a sub-thermocline source, and hence suggest an offshore source. The forth event at I25 also reflects a single-day exceedance at mid-depth. It is expected that land-based contamination will be associated with a low-salinity plume and be most evident in surface samples. However, there are a number of reasons why the maximum may be found at shallow sub-surface depths and this is not fully addressed here. Note that maps of offshore bacterial levels in the following figures do not show data at kelp stations as these stations are sampled on different days. It is recommended that sampling happen concurrently at kelp and other stations.

September 18, 2000 Kelp station I39 has bacteria levels at the geometric standard at two depths, 12m and 18m (40ft, 60ft). All bacterial indicators are elevated in the 12m bottle sample and only enterococcus in the 18m sample. There is no recent rainfall, river flow or large scale, south swell event to contribute bacteria (Table 6.4 and Figure 6.25(a)). Concurrent water temperatures suggest that these concentrations are below the thermocline, but within a stratified layer separate from the bottom. This is what one may expect to see if the diluted wastewater plume intruded onshore. While it is less likely that this sub-thermocline maximum is due to land-based surface sources or bottom groundwater sources, this is not impossible. In the most recent offshore survey

Table 6.4: Kelp station samples for Sept. 18, 2000 including water temperature and bacterial concentrations (CFU/100ml).

STN	DEPTH (m)	TEMP (°C)	Ent	FC	TC
I25	1.5	19.2	<2	2e	<2
I25	6.1	15.9	<2	<2	<2
I25	9.1	15.7	2e	4e	2e
I26	1.5	19.2	<2	<2	<2
I26	6.1	18.0	<2	<2	<2
I26	9.1	16.0	<2	<2	<2
I39	1.5	18.5	<2	<2	<2
I39	12.1	14.8	64	600e	5,200
I39	18.3	14.2	50e	20e	72

(5-7 September), it appears that the SBOO-discharged FIB plume is transported north at mid-depth. Concentrations are highest at the mid and deep depth ranges at the outfall terminus and decrease in concentration through the northern stations (Figure 6.25(b)).

October 12, 2000 As for the previous event, elevated FIB levels are observed at mid-depth at station I39, with single-day exceedances at 12m depth for enterococcus and fecal coliform, and only FC at 18m. Total coliform is at the geometric standard level for both depths (Table 6.6 and Figure 6.26). Again, the concurrent water temperatures suggest that these concentrations are below the thermocline, but within a stratified layer separate from the bottom. Monthly sampling Oct 2nd through 6th shows the plume at mid and deep depths near the outfall and extending onshore.

May 14, 2001 On May 14, the outer kelp station I39 experiences a single-day exceedance of fecal coliform at 12m and geometric standard exceedances of total coliform at 12m and of fecal coliform at 18m (Table 6.7). This appears similar to the previous two events described - with an intrusion of contaminated water below the thermocline. Monthly offshore sampling on 14-16 May, concurrent with kelp data, indicates the presence of the plume at mid depths near the outfall and extending shoreward.

June 1, 2001 Fecal coliform and total coliform concentrations greatly exceed the daily standards on June 1, 2001 at mid-depth at kelp station I25 (Table 6.8 and Figure 6.27). The 9m (30ft) bottle sample at I25 also has an exceedance above the daily standards for fecal coliform concentrations and a the surface bottle sample at 1.5m (5ft) with mid level enterococcus concentrations. Monthly offshore sampling on 4-6 June indicates the presence of the plume at mid depths and extending well inshore.

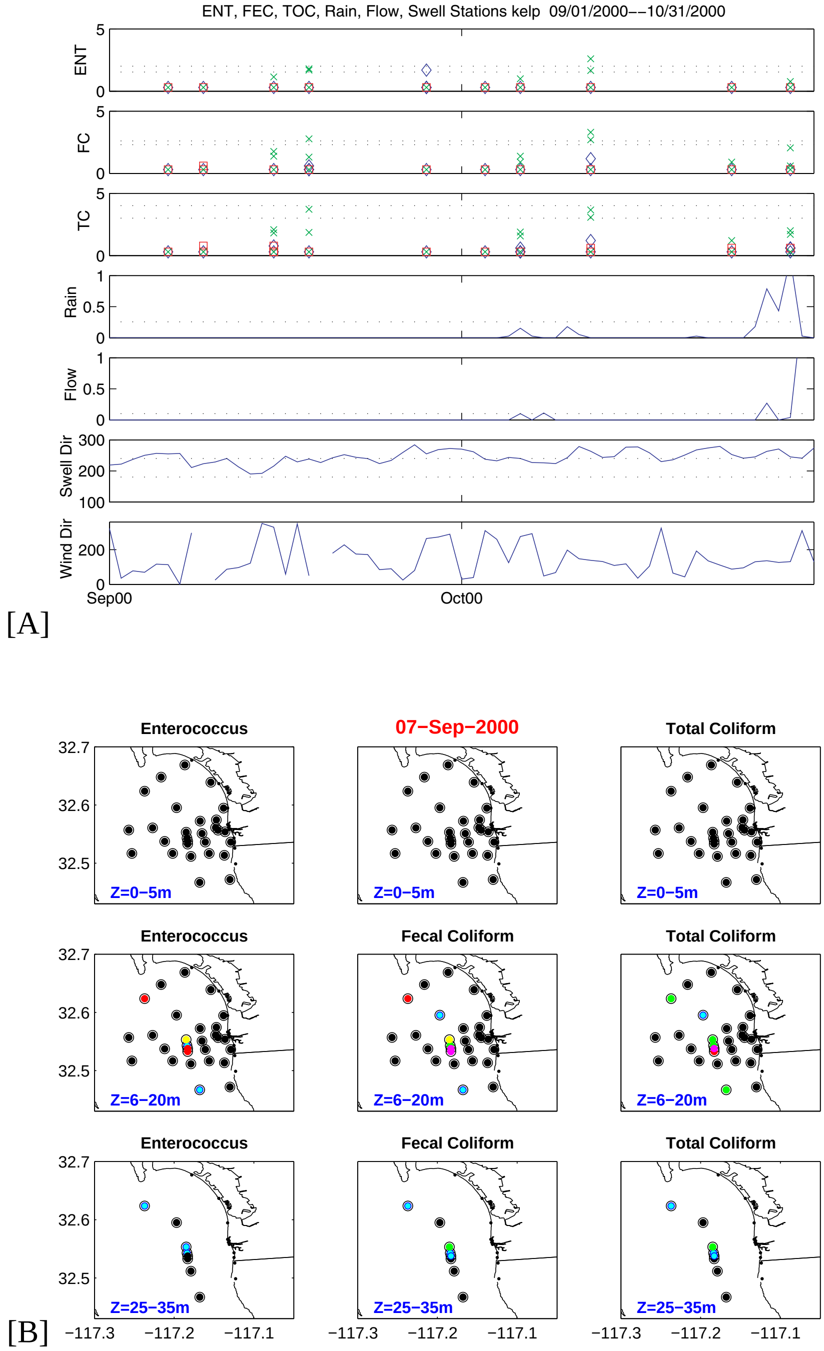


Figure 6.25: A) Log plot of (top to bottom): enterococcus, fecal coliform, total coliform, daily rainfall, Tijuana River flow, swell direction and wind direction from September through October 2002 for kelp stations. I25=blue diamond, I26=red square, I39=green x. B) Bacterial samples for Sept 2000 monthly CTD survey, enterococcus (LEFT), fecal coliform (CENTER), total coliform (RIGHT). See color coding key in Table 6.5

Table 6.5: SBOO Bacterial Sampling Map Color Coding. Red in all cases corresponds to the level for a daily exceedance and green corresponds to the level for a 30-day mean exceedance, as set by California State Ocean Water Quality Standards (Title 17, AB 411).

Color	Ent	FEC	TOT
Black	< 5	< 20	< 100
Cyan	5-34	20-200	101-1000
Green	35-60	201-250	1001-5000
Yellow	61-104	251-400	5001-10000
Red	105-300	401-1000	10001-14000
Magenta	> 300	> 1000	> 14000

Table 6.6: Kelp station samples for Oct. 12, 2000 including water temperature and bacterial concentrations (CFU/100ml).

STN	DEPTH (m)	TEMP (°C)	Ent	FC	TC
I25	1.6	16.8	<2	15e	16e
I25	6.3	14.6	<2	<2	<2
I25	9.3	14.3	<2	<2	<2
I26	1.6	16.3	2e	2e	4e
I26	6.2	15.2	<2	<2	2e
I26	9.4	14.2	<2	<2	<2
I39	1.6	16.6	<2	2e	<2
I39	12.5	13.7	400e	2,000	4,600
I39	18.8	13.7	46	500e	1,200

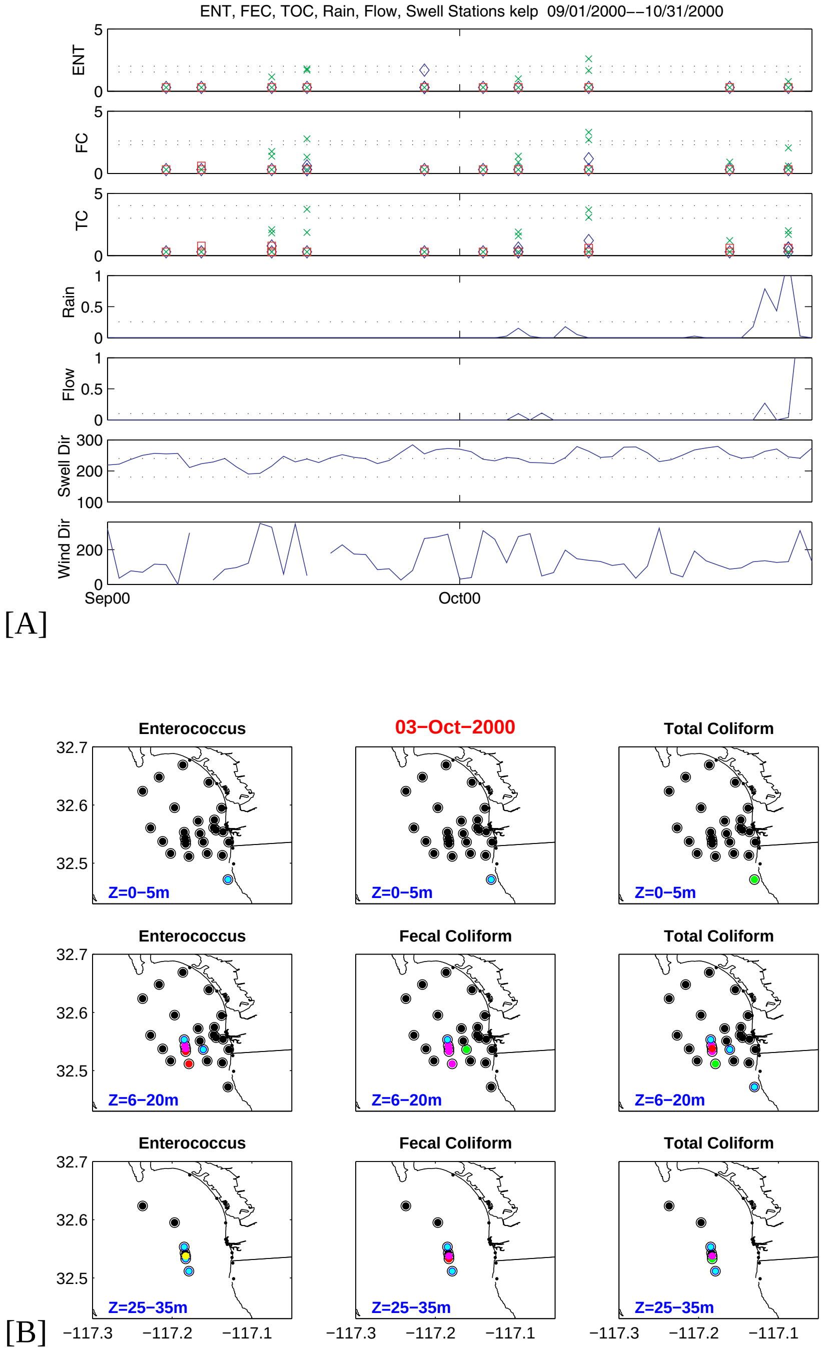


Figure 6.26: A) Log plot of (top to bottom) enterococcus, fecal coliform, total coliform, daily rainfall, Tijuana River flow, swell direction and wind direction from September through October 2002 for kelp stations, I25=blue diamond, I26=red square, I39=green x. B) Bacterial samples for October 2000 monthly CTD survey, enterococcus (LEFT), fecal coliform (CENTER), total coliform (RIGHT). See color coding key in Table 6.5

Table 6.7: Kelp station samples for May 14, 2001 including water temperature and bacterial concentrations (CFU/100ml).

STN	DEPTH (m)	TEMP (°C)	Ent	FC	TC
I25	1.5	16.2	<2	<2	<2
I25	6.1	15.3	<2	<2	<2
I25	9.1	13.3	<2	<2	<2
I26	1.5	16.7	<2	<2	<2
I26	6.1	13.7	<2	<2	<2
I26	9.1	13.0	<2	<2	<2
I39	1.5	15.8	2e	2e	2e
I39	12.2	13.9	20e	450e	1,900
I39	18.3	13.9	10e	260e	600e

Table 6.8: Kelp station samples for June 1, 2001 including water temperature and bacterial concentrations (CFU/100ml).

STN	DEPTH (m)	TEMP (°C)	Ent	FC	TC
I25	1.5	15.5	<50	10e	6e
I25	6.1	13.9	42	>12,000	>16,000
I25	9.1	12.1	<2	450e	750e
I26	1.5	16.4	<2	34e	34e
I26	6.1	13.5	<2	12e	6e
I26	9.1	12.0	<2	24e	28e
I39	1.5	15.6	<2	<2	<2
I39	12.2	11.0	<2	40	38e
I39	18.3	10.7	<2	2e	28e

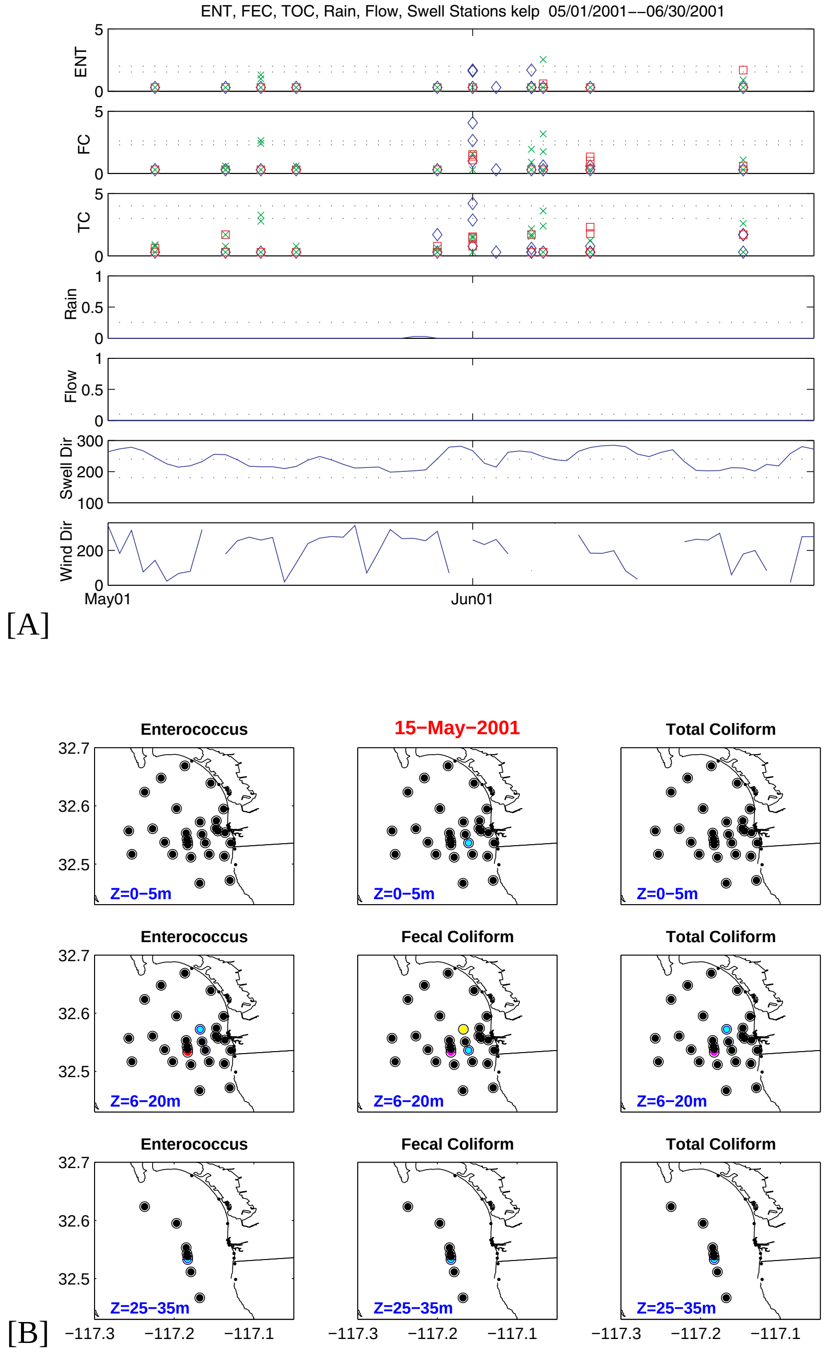


Figure 6.27: A) Log plot of (top to bottom): enterococcus, fecal coliform, total coliform, daily rainfall, Tijuana River flow, swell direction, and wind direction from September through October 2002 for kelp stations. I25=blue diamond, I26=red square, I39=green x. B) Bacterial samples for May 2001 monthly CTD survey, enterococcus (LEFT), fecal coliform (CENTER), total coliform (RIGHT). See color coding key in Table 6.5

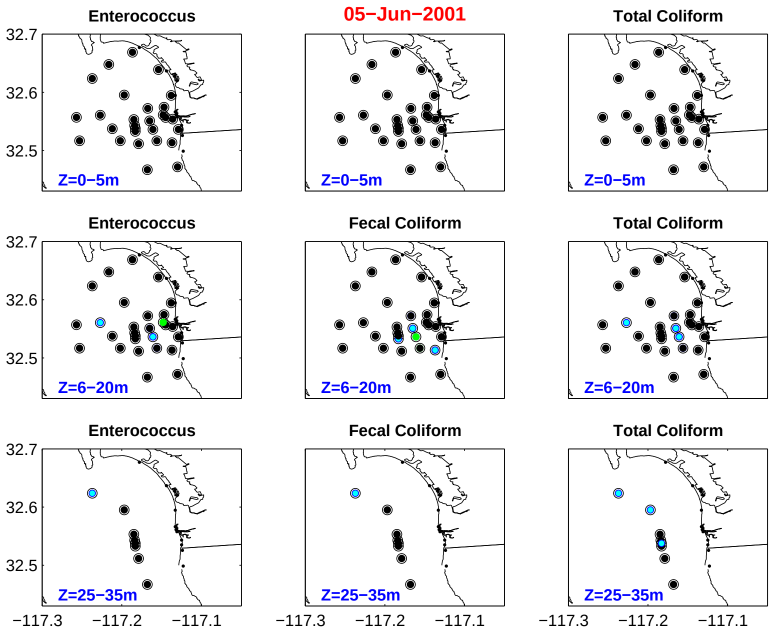


Figure 6.28: Bacterial samples for June 2001 monthly CTD survey, enterococcus (LEFT), fecal coliform (CENTER), total coliform (RIGHT). See color coding key in Table 6.5

6.2.4 Summary

This review of beach and kelp FIB monitoring data indicates the dominance of land runoff during rain and by way of the Tijuana River. Most exceedances are associated with rain and/or flow conditions which suggests that these events are due to these sources of FIB-contaminated waters since no other dominate sources could be characterized from the data set. Wetter seasons and wetter years are thus characterized by higher levels of exceedances for the beach stations, but this does not hold true for all kelp stations. While the direct effect of rain events on exceedances is limited to just a few days (e.g., off Coronado), FIB contamination appears to persist for longer times at beach stations (up to 5 days or perhaps more) in the vicinity of major inflow to the ocean, e.g., near the mouth of the Tijuana River. No evidence is found for exceedances at beach stations being due to the SBOO.

Off Imperial Beach, dry weather events are less frequent and sources are not obvious. There is no direct evidence of an outfall contribution to beach exceedances, but monitoring data is insufficient to be able to determine that there is no contribution. Further, the association of most dry weather events between wave, wind and tide conditions, consistent with alongshore transport from land sources, suggests that land runoff dominates beach exceedance events in dry weather periods as well. Elevated bacteria at the beach stations appears to be associated with south swells, with south winds, and (immediately north of Tijuana Estuary) with tidal outflow and alongshore advection during dry weather events.

Kelp exceedances are similarly dominated during periods of wet weather events, specifically at the station closest to Tijuana Estuary mouth. Dry weather kelp FIB levels are generally low. However, there are a number of curious events where high FIB levels are observed at mid-depth, below the thermocline. This pattern is consistent with that of onshore intrusion of the SBOO plume, but this is no more than a hypothesis at this stage and further study is warranted.

In the final chapter, recommendations are made for enhanced nearshore monitoring of ocean conditions as it is the transport of land-based plumes that will best explain the observed exceedances. Improved monitoring will allow for better protection of the public health and direct efforts in finding sources of exceedances in these coastal recreational waters.

Chapter 7

Recommendations

Based on a review of the existing Regional Water Quality Monitoring Program (RWQMP) and a review of oceanographic studies and plume modeling relevant to the South Bay Ocean Outfall (SBOO), it is concluded that the existing RWQMP is inadequate in terms of determining whether SBOO discharges of bacteria contribute to beach or kelp bed exceedances. Combining RWQMP data with other available environmental data improves the information value of the monitoring, but the program remains inadequate in this sense. In an associated report (*SAIC and R. Smith*, 2004) prepared by SAIC in response to the Consent Decree (see Chapter 1), the adequacy of the RWQMP is addressed in terms of compliance issues.

Nevertheless, the SBOO RWQMP has generated a large volume of valuable data that have been used in this report to assess the nature and likely sources of observed beach and kelp exceedances. The large majority of shoreline and nearshore exceedances are evidently due to land sources as they are strongly associated with rain events and flow in the Tijuana Estuary. However, the sources of dry weather exceedances are less clear. Associations with wave, wind and tidal transport suggest that many dry weather exceedances are also due to land sources, but these associations are weaker and, further, these associations do not account for all events. While it may be thus possible that the SBOO discharge contributes to beach and kelp exceedances, it is not clear whether or not this indeed occurs. In this sense, the RWQMP is inadequate. Nevertheless, it is clear that the SBOO discharge is not the source of recurrent widespread exceedance events at beach or kelp stations. It is our opinion that if the SBOO discharge does make a contribution it is a minor contribution, even during dry weather conditions. It is possible that the SBOO discharge may not be responsible for any events at beach stations. It is only at the outer kelp bed station (I39) that we see an exceedance with characteristics that suggest an outfall source.

As a community, then, the concern for beach and kelp water quality should lead to a focus on monitoring land-based plumes. This is addressed in recommendations in 7.4.3 below. However, the Consent Decree and the objectives of this study are directed at the SBOO plume and this is thus also a focus of recommendations in 7.4.2 below. Further, these plumes are discharged into a coastal circulation that is poorly known. This is a significant limitation on monitoring and management of the SBOO and a number of other water quality concerns in the region. This focus on regional circulation is a third focus of the recommendations, in 7.4.1 below.

The recommendations of effective monitoring strategies are made here with a view to designing an improved RWQMP that will be “sufficient to identify whether discharges from the POTW are a cause of the Recorded Bacterial Exceedances.” Following the Consent Decree, Section 1.4, these recommendations will be the basis for a scope of work for Phase Two. The identification of the causes of events is desired in real-time (“event assessment”), and also through statistical assessment of data aggregated over a year or longer periods (“statistical assessment”).

7.1 The Existing Program

The aspects of the existing monitoring program that are relevant to FIB levels and transport are as follows:

- Monthly offshore surveys, including CTD profiles (with additional sensors) at 40 stations and FIB sampling at 3 levels at 20 stations.
- Monthly sampling of FIB load in effluent stream.
- Weekly sampling of 11 beach stations for FIB.
- Weekly sampling of 3 kelp stations for FIB at 3 depths.

In addition to these SBOO monitoring data, valuable information is available from the following ongoing programs:

- Weekly sampling of 15 beach stations for FIB (County of San Diego).
- Continuous data on tidal levels (San Diego Bay, NOAA).
- Continuous data on winds (Brown Field, Lindbergh Field).
- Continuous data on offshore waves (Point La Jolla, Point Loma, CDIP).
- Continuous data on rainfall (Brown Field, Lindbergh Field).
- Continuous data on flow rate in Tijuana River at Mexico-US border (IBWC).

Further valuable information has been available from the following programs, but continued operation is not assured:

- Weekly multi-spectral aerial surveys (Ocean Imaging).
- Hourly maps of surface circulation from HF radar (SDCOOS, Scripps Institution of Oceanography).
- Continuous data on nearshore currents and thermal stratification (SDCOOS, Scripps Institution of Oceanography).

These data can be used to help assess the impact of the SBOO either statistically or via analysis of specific events. To-date, however, neither analysis appears in monthly or annual reports and the absence of analysis limits the vaue of the monitoring program. Although much has been learnt here from the analysis of the RWQMP data, this information is not a product of the monitoring program in the sense that the required analysis and interpretation is not supported by the RWQMP. In-depth analysis of monitoring data and realization of the benefits of monitoring data requires a concerted effort and commitment of resources to the analysis effort. Analyses need to include non-RWQMP data with existing and potential new RWQMP data. Further, analysis and interpretation is greatly aided by the development and use of computer models of circulation and transport.

7.2 Monitoring Objectives

The analysis of existing data (Chapters 4, 5, and 6) together with a review of outfall studies and monitoring programs elsewhere allow one to identify a set of objectives for monitoring of the SBOO wastewater plume, land-based plumes and the potential association with beach and kelp exceedances. An improved monitoring program would provide more of the following information:

- Times when recreational waters at the beach or in the kelp are contaminated.
- Environmental conditions and water types present at sites of FIB exceedance.
- Source identification of contamination based on distinct properties of the SBOO plume.
- Coherent spatial patterns of contamination, allowing a link to be made between source and beach/kelp stations if/when such an event occurred.
- Direction of SBOO plume transport under different environmental conditions – specifically identifying times when plume extends onshore.
- Times when onshore currents occur.
- Depth of SBOO plume and depth of maximum concentration in the plume.
- Times when SBOO wastewater plume surfaces, whether actively or passively.
- Times when upwelling or internal swash brings sub-thermocline water into nearshore and surfzone waters.
- Extent and timing of the tidal outflow plume from the Tijuana Estuary.
- Extent and timing of northward advection of Los Buenos Creek plume.
- Continuous flow rate and loading for the SBOO source.
- Continuous flow rate and loading for other major sources (Tijuana River and Los Buenos Creek).

- Dilution rates in the far-field as a function of discharge and environment conditions.
- Indices of environmental variability to allow monitoring data to be related to larger scale ocean variability.

Inclusion of all the above components in a comprehensive monitoring program may be precluded by technical or fiscal constraints, but it should be realized that without such a suite of information it may not be possible to assess the record of impact of the SBOO plume on beach and kelp stations. Nor will it be possible to identify times at which the SBOO plume impacts the nearshore and surfzone, if indeed this does occur.

While suggestions are provided in the next section, it is in Phase 2 that supplementary monitoring will be designed. This is recommended. With a careful redesign of SBOO monitoring, it should be possible to develop a much clearer assessment of the extent to which the SBOO discharge impacts beach and kelp FIB levels. Further, this redesign of monitoring should also yield improved information on events as they occur.

In anticipation of this follow-on project, it should be recognized that plume behavior is very variable and exhibits small space and time scales, such that even an enhanced monitoring program may not be able to definitively detect all beach and kelp impacts of the SBOO plume. The incremental increases in cost of increased SBOO monitoring need to be balanced against the incremental increases in water quality benefits, and these need to be compared with the water quality benefits that may be obtained through monitoring and other strategies that address the larger land-based plumes and non-point sources. Given that the majority of observed exceedances are associated with rain and river flow, any improvement in monitoring land-based plumes is likely to lead to a greater reduction in events and also a reduction in the exposure of people to these contaminated waters when they do occur. Nevertheless, it is recommended that the SBOO monitoring plan and objectives are revised within a balance between outfall-oriented and runoff-oriented monitoring.

7.3 General Recommendations

To make monitoring both more efficient and more effective for the purposes of determining the effects of river and outfall plumes on South Bay beaches, several general recommendations can be made.

Coordinate with other agencies. Many monitoring practices could be made more efficient and provide a better set of data if efforts between different agencies and programs were coordinated to complement one another. This includes data collected by San Diego County Department of Environmental Health on beach water quality, data collected as part of the Point Loma Outfall monitoring program, data collected by the San Diego Coastal Ocean Observing System, and data collected by agencies in Mexico.

Develop a regional monitoring program. As plume are discharged into moving coastal waters, information on the structure and variability in coastal circulation is critical to monitoring programs. However, coastal circulation off Imperial Beach is part of larger scale patterns and a better understanding of circulation can be gained by observations that include adjacent areas along the San Diego County coastline, and possibly beyond. This approach is also being recommended by the Orange County Sanitation District in the draft proposal for their NPDES permit, and in a draft report on the Point Loma Outfall monitoring program that has been prepared for the MWWD, City of San Diego, by colleagues at Scripps Institution. This approach not only allows for the best use of limited resources, but also would provide the most comprehensive and useful data set for oceanographic and bacterial transport analysis related to SBOO and South Bay issues.

Redesign ocean and shore monitoring station locations to facilitate use in oceanographic analysis, models and plume tracking. The current design is based on the need to monitor water quality at specific points of interest. Creating more regularly spaced stations and sampling depths conducive to oceanographic analysis is not incompatible with the objectives of compliance monitoring.

Allocate resources for data analysis. Many of the recommendations below are only useful if personnel and funding are available to process, analyze, and interpret the data, including the development and use of computer models. This important component of any monitoring program is often overlooked. Furthermore, data must be made truly accessible to the public, and kept in a format that is compatible with other sources.

Conduct special studies to develop understanding and to validate selected monitoring strategies (e.g., improved validation of aerial imagery of plumes). Further, studies directed at mechanistic understanding often yield great benefits in that diagnostic indices can be identified that can be monitored more effectively and at lesser cost than strategies adopted in the absence of mechanistic understanding.

In addition to recommendations for IBWC, it is recommended that the compliance monitoring requirements for the SBOO be reviewed in light of this report.

7.4 Specific Recommendations

From the analysis of existing data in the previous chapters, and following the above objectives and general comments, we have developed a set of recommendations that fall into three general categories: (1) Coastal Ocean Monitoring, with a more regional perspective; (2) Plume Monitoring at the SBOO; and (3) Beach and Kelp Monitoring, including monitoring of land-based plumes. These recommendations primarily address the issue of FIB exceedances in beach and kelp waters, rather than compliance issues. These recommendations include a mix of field samples, data analysis, computer modeling and special studies designed to provide an improved basis for monitoring decisions and data interpretation.

These recommendations are based on identification of primary gaps in information and knowledge pertaining to the fate of the SBOO and land-based plumes and the causes of beach and kelp exceedances. In particular, the most notable gaps in existing information are: (i) when onshore flow occurs; (ii) direction and extent of SBOO plume; (iii) when plume breaks/approaches surface; (iv) height/dilution of plume; (v) strength and direction of alongshore currents in nearshore and surfzone; and (vi) extent of land-based plumes, e.g., Tijuana outflow.

7.4.1 Coastal Ocean Monitoring

The ocean monitoring recommendations are designed to provide improved data that can be used for oceanographic and transport analysis, as well as provide a more efficient methods of acquiring data.

1. **Moored instruments**

   (a) It is highly recommended that a mooring is deployed at the Y-junction of the outfall. Minimal instumentation would include an ADCP and a string of thermistors (or a profiling thermistor/CTD). In addition to providing key information on currents and thus direction of plume transport, this mooring will provide key information on stratification and thus plume rise (see Plume Monitoring recommendations).

   (b) It is strongly recommended that the IBWC combines resources with other regional and national agencies (e.g., City of San Diego, SCCOOS, State of California, NOAA) to install and maintain a system of moored thermistors and current meters along the San Diego coast, including South Bay. Combined with CODAR data and modeling approaches, these moorings could provide a regional view of circulation patterns in addition to long-term data on coastal current strength and variability at specific sites (e.g., SBOO). The information on regional patterns will allow identification of flow trajectories and lead to a much improved assessment of onshore flow associated with the South Bay gyre and other flow structures. Further, these moorings will provide data on thermal stratification and variability due to upwelling and internal tides.

   (c) It is strongly recommended that 3-4 additional moorings are deployed inshore of the outfall in addition to the SBOO mooring, to define nearshore circulation - both onshore transport from the SBOO to the shore and alongshore transport of land-based plumes. We recommend that these be located near the 20 m isobath at 1) the US-Mexico border, 2) due west of the Tijuana Estuary, and 3) due west of Imperial Beach pier. These additional moorings could form part of a larger, inter-agency regional monitoring program. These moorings should ideally consist of an ADCP, a thermistor string, and a surface conductivity sensor.

2. **Boat-based surveys**

   Boat-based surveys can provide very detailed 3-dimensional data on water properties over a small area at a single point in time. However, these surveys are expensive, both in terms of time, personnel, and facilities. In order for data collected during such surveys to be useful for analysis of bacterial levels, plume trajectories, and other oceanographic processes, it will be necessary to implement changes to the existing monitoring strategy. The data from the moorings (as recommended above) are much more useful than single-day surveys for determining frequency of circulation patterns and other statistics, as well as real-time flow patterns that can be useful in predicting immediate plume behavior or interpreting recent events.

In considering the recommended alternatives, the cost and benefits of moored vs. boat-based surveys should be weighed. Ideally, both are useful in different ways. However, it is strongly recommended that moored time-series data not be sacrificed at the expense of boat-based surveys.

(a) It is highly recommended that the monthly CTD profile surveys are replaced by tow surveys where a tow-fish with CTD and peripheral sensors is towed in an undulating path behind a survey boat. At the same time, water can be pumped on deck from the undulating tow-fish and sampled for FIB and other constituents. This approach gives more spatially coherent data (reduced spatial resolution) and it completes a survey of a given area in much less time. This tow-fish approach has been used by other dischargers. The synopticity that this achieves is essential. These surveys would provide meaningful data on water column structure that can be used to infer current patterns and the effects of processes such as upwelling. Further, the data from these surveys can be used to give detailed characterizations of the water column structure and plume location during the sampling period.

(b) If the tow approach is not used, it is recommended that the station grid is reduced in extent to allow each survey to be completed in one day. These one day surveys could be completed on a more frequent basis (every 2 weeks). The sampling area could be reduced to the area immediately surrounding the outfall and Tijuana River, i.e., an area bounded on the northwest by Imperial Beach pier, on the south by the US-Mexico border, and on the west by the 40 m isobath. A smaller synoptic grid would give better information on transport processes relevant to the outfall and river plumes than broader surveys that cannot be considered synoptic. Further, the station grid should be made regular, to allow for effective use of the data in analysis of oceangraphic processes and plume tracking, and station spacing should be kept within typical coherence length scales (to be assessed through special study).

(c) It is recommended that these surveys be coordinated with other agencies to combine resources and increase the number of sampling boats and personnel on the water at one time. This will allow for a larger spatial extent and station number to be completed in one day. For example, Orange County Sanitation District conducts similar monitoring. The IBWC and City of San Diego MWWD should explore options for combining resources so that monitoring programs throughout southern California can increase the number of boats and personnel on the water in one region at one time. Ideally, the tow-fish approach would be used by a number of boats at one time.

(d) Irrespective of the method of bacteria sampling, it is highly recommended to standardize the depths of water samples for FIB and other analyses. We recommend depth intervals measured from the bottom upward, starting with a bottom sample, and proceeding at intervals of 10 meters, and ending with a surface sample (e.g., at a 22-m site, sample at 21 m, 11 m, and 1 m). If this quantity of samples is unfeasible for the deeper sites, retain as many as possible of the regularly spaced depths (e.g., at a 42-m site, sample at 41 m, 21 m and 1 m).

3. **Surface radar**

   It is recommended that the existing CODAR system is sustained through collaboration with other agencies in the region. The benefits to IBWC are two-fold. Firstly, these real-time data are invaluable in tracking possible onshore movement of plume waters at times when they are observed or estimated to be surfacing (see Plume Modeling recommendations). Secondly, these data are a very valuable input to a system of observing and modeling that can determine the time-dependent regional circulation.

4. **Aerial imagery**

   (a) It is highly recommended that multi-spectral aerial data, as is presently obtained by Ocean Imaging, should be obtained concurrently with all boat-based surveys. These images provide invaluable information on SBOO plume location, as well as very useful information on land-based plumes.

   (b) It is recommended that weekly aerial surveys are flown as part of a regional collaboration between agencies with interest in San Diego County coastal waters. These surveys are motivated primarily by the information gathered on land runoff plume location, size, persistence, and transport patterns.

   (c) It is highly recommended that further study is conducted to relate aerial data to water properties and to better understand the depth of penetration of these optical measurements. Simultaneous data from ocean sampling and aerial imagery will “ground truth” aerial images with respect to plume depth and the bacterial concentrations in the visible plume.

5. **Coastal ocean models**

   It is recommended that ocean monitoring data (e.g., CTD, ADCP, thermistor, bacteria) are made available for use in regional coastal circulation model development, verification, and particle tracking efforts. There are several projects under development at UCSD/SIO, based on the ROMS coastal ocean model. The goal with this type of modeling is to more fully understand and predict the regional circulation that controls transport of river and outfall plumes.

7.4.2 SBOO Plume Monitoring

The plume monitoring recommendations are designed to provide improved data on plume direction, extent and rates of mixing. Further, this improved plume monitoring will allow a clearer definition of SBOO receiving waters - i.e., the spatial extent of plume aggregated over time. The best way to collect data useful for analyzing plume behavior is by moored instruments that can provide a long time series of data, require few human resources to maintain, and that will give detailed information that resolves the high-frequency variability in currents and plume behavior. With this time-based information, one can assess the probabilities of different oceanographic conditions and plume modes. We highly recommend that this type of monitoring is coordinated with modeling efforts that are under development for near-field analysis of plume behavior.

1. It is highly recommended that a mooring is deployed at the outfall, as described above (Coastal Ocean Monitoring). This will provide data on stratification, upwelling and current velocity that affects the near-field state of the plume;

2. It is strongly recommended that a near-field plume model is run operationally to determine plume height and dilution in real-time. This model would receive stratification and current data from the SBOO mooring, daily data on outfall flow volume and bacterial concentration from IWTP, and would provide information on plume behavior, as discussed in Chapter 5. This modeled information will be used to make decisions about adaptive sampling, when to survey and what depths to sample. Further, the plume rise information, specifically when combined with CODAR data, can be used to identify times of high risk for contact recreation.

3. It is strongly recommended that CODAR is sustained and supported in this region, allowing real-time mapping of surface trajectories and thus real-time warning and assessment of onshore movement of plume waters at the surface. The operational benefits of this approach requires an operational data system that can continually receive CODAR data and mooring data, that can run plume model, and that can integrate surface velocities to obtain surface trajectories in real-time.

4. It is recommended that a special study is conducted to map the outfall plume under a variety of ocean conditions. This mapping would provide information on plume behavior, mixing, and the areal extent of plume influence. See Section 7.5 for details on special studies recommendations.

7.4.3 Beach and Kelp Monitoring

The present weekly monitoring of beach and kelp waters is useful for historical assessment of exceedance events over a year or longer periods (as in this report), but it is limited in the level of useful information provided on a real-time basis for protecting the health of the public in areas where there is human contact. By the time samples are processed and results are available, conditions may have already changed and swimmers have gone home. Nearshore monitoring recommendations are designed to improve the public protection benefits of monitoring and to provide information to be used in management and reduction of FIB carried to the ocean by runoff.

1. **Boat surveys**

It is recommended that a special study is conducted to map land-based plumes, specifically the Tijuana Estuary outflow, under dry weather tidal flow and wet-weather river flow conditions. See Section 7.5 for details on special studies recommendations.

2. **Time-series Data**

   (a) It is highly recommended that a nearshore mooring is deployed to obtain information on alongshore tidal currents and local directional wave data off the Tijuana Estuary (see nearshore mooring under Coastal Ocean Monitoring). These data would allow real-time estimates of the zone of impact of the estuary outflow under a variety of conditions. These estimates would be greatly improved by the recommended plume mapping and surfzone current studies.

   (b) It is highly recommended that records of river flow, winds, tide waterlevels and other regional data is included in the database maintained for the South Bay monitoring system, and that this data is analyzed on an ongoing basis for relationships to bacterial exceedances.

   (c) It is recommended that a special study is made of nearshore currents and their effect on alongshore transport of land-based plumes (see Section 7.5).

3. **Bacteria sampling**

   (a) It is highly recommended that any shoreline, kelp, and offshore sampling of bacteria is conducted concurrently - with nearby samples being obtained within an hour of each other. Without this concurrence, it is very difficult to make any links between beach and kelp exceedances, or between nearshore exceedances and elevated concentrations offshore.

   (b) It is recommended that water temperature and salinity data are obtained every time a bacteria sample is obtained. Kelp samples include temperature data, but no salinity data. Beach samples have no associated temperature or salinity data. Without at least these environmental parameters, there is no hope of determining what water mass is passing the observation site at the time of sampling.

   (c) It is recommended that bacterial samples be collected more frequently than the current weekly sampling. Ideally, a study to determine the time scales of variability should be conducted in order to sample at intervals that are statistically meaningful (see Section 7.5). Data reviewed in this report, together with unpublished data collected off Imperial Beach, suggest that daily data may be adequate if one takes account of predictable tidal and diurnal effects. Daily data, if valid, would be much more effective in protecting public at times of contaminated recreational waters. Pending the results of a time-scale study, daily FIB sampling should be considered.

   (d) It is recommended that IBWC sampling is coordinated with sampling by DEH at San Diego County (and others) in order to maximize resources and avoid duplication of efforts. This could enable, for example, thorough sampling of the area twice weekly, instead of two separate agencies collecting less frequent data that is not shared. Further, bacterial monitoring data formats should be coordinated between agencies so that data are accessible for analysis. We recommend agreeing upon a common file format and data reporting conventions so that data from different sources can be combined and analyzed. We also recommend that these data be made available on web or FTP sites so that it can be readily accessed by interested parties.

(e) It is recommended that a special study is conducted on spatial patterns of non-point source pollution (see section 7.5).

7.5 Broader Issues and Further Studies

The following are issues that are important in developing and interpreting a monitoring program, but which probably require additional in-depth research, field experiments, or simply waiting for the results of ongoing studies. However, some of these are sufficiently small-scale and local to be worth considering as adjunct projects for the SBOO monitoring program, or ideally, in collaboration with other regional agencies.

Non-point source pollution This is a very large area of current research about which little is understood. One of the results of our analysis of shoreline bacterial data is that the two stations located in the Imperial Beach urban area experienced different types of exceedances, and at different times, than the rest of the sampling area. (Exceedances frequently occured during the summer season, only at these two stations, and only in enterococcus.) This may be due to effects of non-point source runoff which differs from point source pollution such as the river or outfall. Consideration should be given to additional sampling in this area to characterize this source and possibly differentiate it from point sources such as the outfall or river.

Distinguishing bacterial sources At this time there is no indicator for differentiating between the Tijuana River plume (or other river plumes) and the outfall plume. Funding an analysis of these two discharge sources could help clarify the contributions of each to the bacterial exceedances at the shoreline.

Other methods of differentiating between bacterial sources include characterization through genetic analysis (e.g., ribotyping). It is possible that a large percentage of the bacteria entering South Bay from the Tijuana Estuary is from wildlife such as birds. While this is not practical for use on a regular basis, it could contribute to understanding the nature of the shoreline exceedances and health risks.

Time scales of variability in bacterial levels Studies conducted on bacterial levels in beach sediments suggest that there is a high degree of variability on much shorter time scales than that over which public health monitoring occurs (*Leecaster and Weisberg*, 2001). This can lead to very misleading conclusions if, for example, variability in weekly monitoring data is interpreted as reflecting weekly changes in oceanographic conditions when in fact it is just a ”snapshot” of variability that is occuring over each 6-hour tidal cycle.

To clarify what is actually contributing to high bacterial levels it is absolutely necessary at some point to determine what the time scale of variability in fact is (and there may be more than one). We recommend conducting an experiment that includes sampling over a variety of time scales; for example: 1) beach bacterial samples taken at 30 minute intervals over a 12-hour period, 2) samples taken every 2 hours for a 48-hour period, and 3) beach bacterial samples taken twice daily for a period of two weeks.

Suitability of indicators for public health warnings Following on the bacterial source genetics, another unanswered question that is important to consider is the accuracy of fecal indicator bacteria in general for the purpose of issuing public health warnings. In some areas (e.g., recent studies conducted at Campbell Cove beach in Bodega Bay) it has been found that the dominant source of bacteria is from wildlife such as birds. It is not known at this time if these bacterial sources are a public health hazard for humans. An epidemiology study is being completed in Mission Bay and these results should help confirm or question the link between FIB and public health.

Transport in nearshore currents It is recommended that a special study is made of currents in the surfzone in relation to wave data obtained from a nearshore mooring under different wave conditions. This study may involve moored surfzone current meters, drifters or dye. Further, modeling approaches could be assessed. Either way, this study would lead to greatly improved estimates of alongshore transport of land-based plumes in the surfzone.

Outfall plume mapping It is recommended that a special study is conducted to map the plume under a variety of ocean conditions, including surfacing. This mapping would consist of a combination of special tow-fish surveys at smaller scales with fine-scale aerial surveys. These maps will be used to define plume modes (characteristic forms and mixing rates) and relate these to specific oceanographic conditions as indexed by mooring data. This study will greatly enhance the value of mooring data, aerial imagery and CODAR data in determining plume behavior and mixing. Further, these plume maps will define the extent of the receiving waters for the SBOO and provide information on the spatial extent of plume influence. These plume maps should be obtained under a broad variety of ocean conditions, as defined by tide, wind, season, offshore forcing, etc.

River plume mapping It is recommended that a special study is conducted to map the Tijuana River plume under a variety of ocean conditions. This mapping would provide information on plume behavior, mixing, and the areal extent of plume influence. As in mapping of SBOO plume, this will define plume modes (characteristic forms and mixing rates) and the extent of the plume under a variety of conditions. This study will greatly enhance the value of river flow data, wave data, and nearshore mooring data in determining Tijuana plume behavior and mixing.

Appendix A

Consent Decree Text

CONSENT DECREE [*pages 10-13*]

IN THE UNITED STATES DISTRICT COURT
FOR THE SOUTHERN DISTRICT OF CALIFORNIA

Case No. 99-CV-2441-BTM(JFS) (Consolidated with Case No. 01-CV-0270)
Case No. 01-CV-0270-BTM (JFS)

C. Monitoring Reports

IBWC shall ensure completion of reports that will address the following issues:

1. Evaluation of the Receiving Water Quality Monitoring Program

   [*SAIC tasks*]

2. Evaluation of Discharges from the POTW as a Potential Source of Bacterial Exceedances at the San Diego Monitoring Stations [SIO]

   (a) Evaluation of Existing Monitoring Data (Phase One Study)

   Designation of Expert - Within sixty (60) days of entry of the Consent Decree, the Settling Parties shall designate a qualified expert ("Selected Expert") to evaluate existing monitoring data generated by the Receiving Water Quality Monitoring Program (the "Phase One Study"). In the event that the Settling Parties can not agree within sixty (60) days on the identity of the Selected Expert, the matter shall be subject to the dispute resolution procedures set forth in Section IX below.

   Purpose and Scope of Phase One Study - The purpose of the Phase One Study is to determine whether the Receiving Water Quality Monitoring Program generates data sufficient to identify whether discharges from the POTW are a cause of the Recorded Bacterial Exceedances. The Phase One Study shall assess whether data generated by the Receiving Water Quality Monitoring Program is sufficient to determine:

i. whether the Treatment Plant is a source of discharges causing the Recorded Bacterial Exceedances, and if so, the frequency and location of the Exceedances caused by those discharges;

ii. whether discharges from other sources (such as discharges of partially treated effluent and raw sewage at Punta Banderas, Mexico; sanitary system overflows at Playas, Mexico; discharges into the Tijuana River of raw sewage from Mexico; and sanitary sewer overflows and non-point source pollution in Imperial Beach, Silverstrand and Coronado are causing Recorded Bacterial Exceedances, thereby complicating identification of any Bacterial Exceedances caused by discharges from the POTW, and if so, the frequency and location of the Exceedances caused by discharges from such other sources; and

iii. attendant to the assessments above, whether oceanographic conditions and weather events (such as the South Bay Gyre, the Pacific Decadal Oscillation and upwelling) cause onshore transport of the effluent discharged from the POTW, and if so, to what extent.

The three assessments above are hereafter referred to as the “Phase One Issues.” The findings and/or conclusions reached in the Phase One Study shall be based upon a review of the following recorded materials:

i. Relevant reports on oceanographic conditions in the area of the Outfall prepared by the Scripps Institution of Oceanography; Parson’s Engineering Science, Inc.; Kinnetic Laboratories, Inc.; CWP Geosciences, the Southern California Coastal Water Research Project, and other experts;

ii. Studies addressing the design of the Outfall (e.g., the TOES studies);

iii. Environmental Impact Statements and reports on the Outfall;

iv. Letters commenting on the Outfall by federal agencies, state agencies, and municipalities;

v. Baseline data generated prior to initiation of discharges from the Outfall;

vi. Monitoring data, cover letters, annual reports, and DMRs generated since the initiation of discharges from the Outfall;

vii. Transcripts of depositions taken in these consolidated lawsuits;

viii. Other materials supplied by IBWC, Citizen Plaintiff, the United States Environmental Protection Agency, the Regional Board, the City of Imperial Beach and the City of Coronado;

ix. Existing materials deemed relevant by the Selected Expert; and

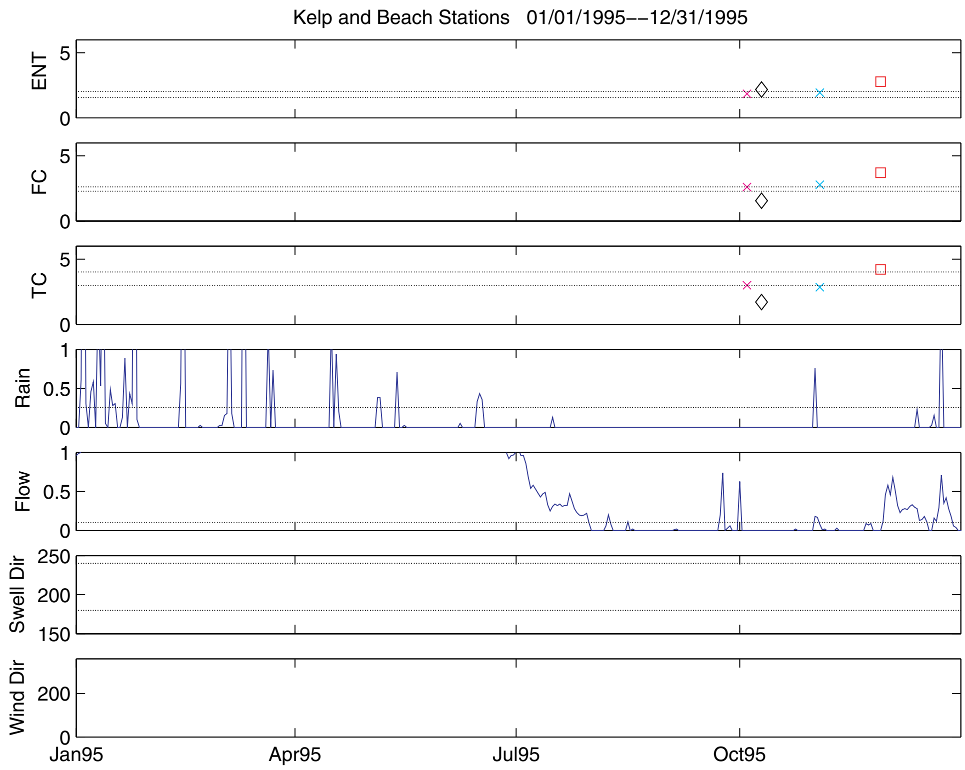
x. Any comments provided by the Settling Parties and the Regional Board.

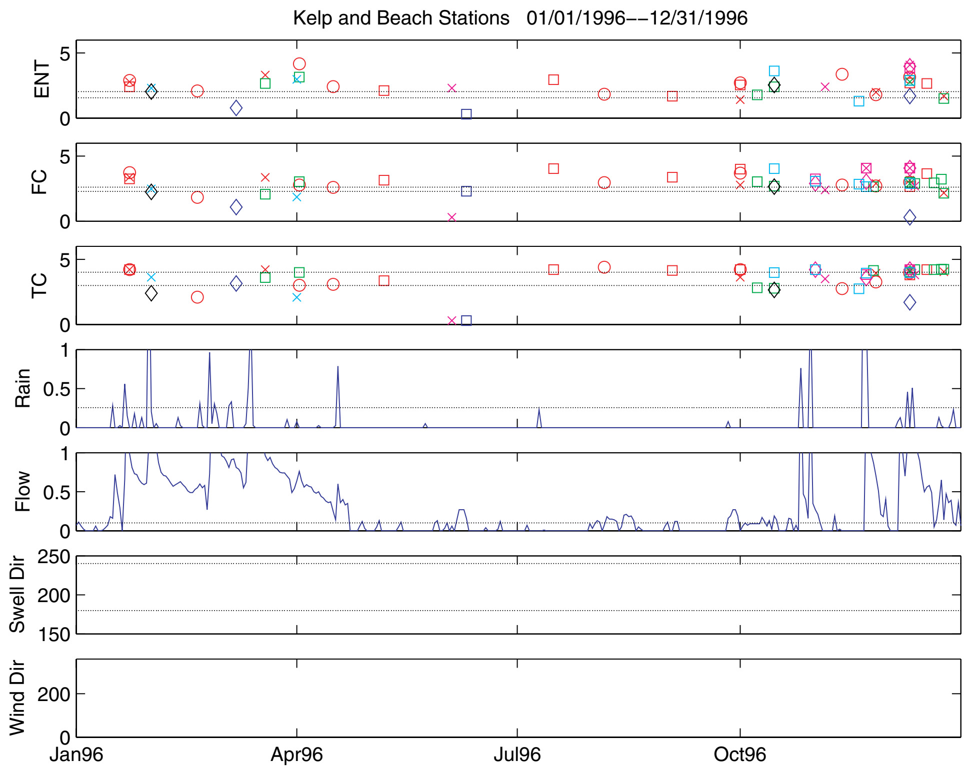
Appendix B

Comparisons Between Beach and Kelp Concentrations and Shore Sources

Yearly time series plots of beach and kelp bacterial concentrations including daily averages for rainfall, flow rate, swell direction and wind direction. Only FIB samples with any single indicator above the geometric standard level are shown. Black lines indicate single standard and geometric concentration levels. Legend of stations locations are as follows:

Station	Color	Shape
S0	Red	Diamond
S1	Red	Square
S2	Red	Circle
S3	Red	X
S4	Green	Square
S10	Green	X
S5	Light Blue	X
S11	Light Blue	Diamond
S6	Light Blue	Square
S12	Pink	Square
S7	Pink	X
S8	Black	Square
S9	Black	Diamond
I25	Dark Blue	Diamond
I26	Dark Blue	Square
I39	Dark Blue	Circle


Kelp and Beach Stations 01/01/1995−−12/31/1995
ENT
FC
TC
Rain
Flow
Swell Dir
Wind Dir
Jan95
Apr95
Jul95
Oct95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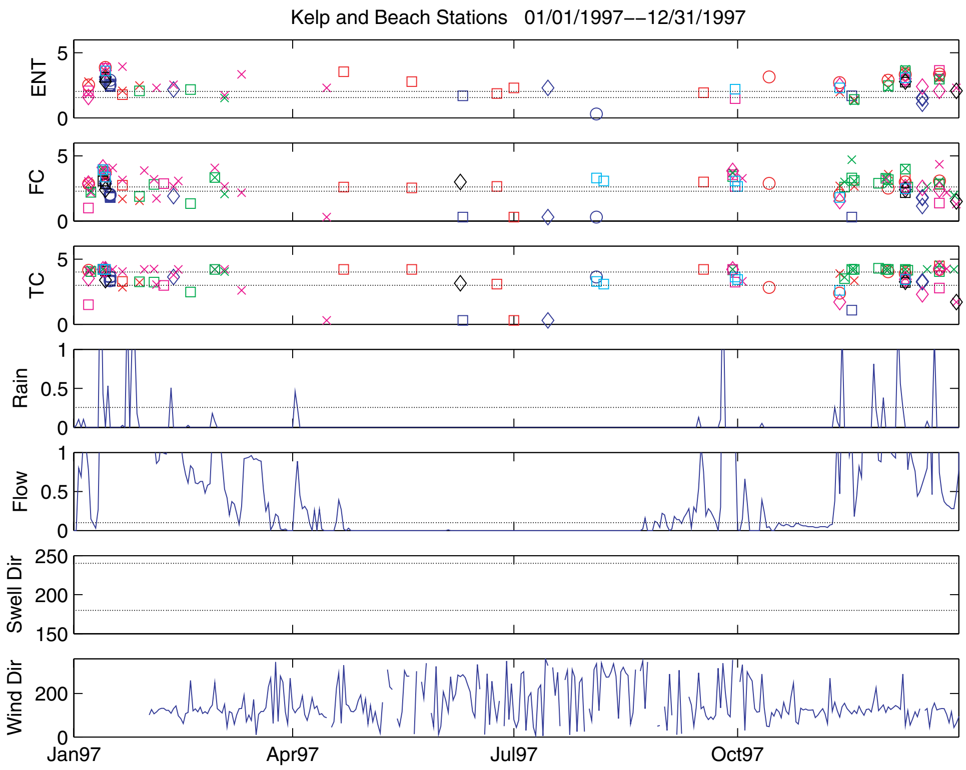
FC
TC
Rain
Flow
Swell Dir
Wind Dir
Jan96
Apr96
Jul96
Oct96



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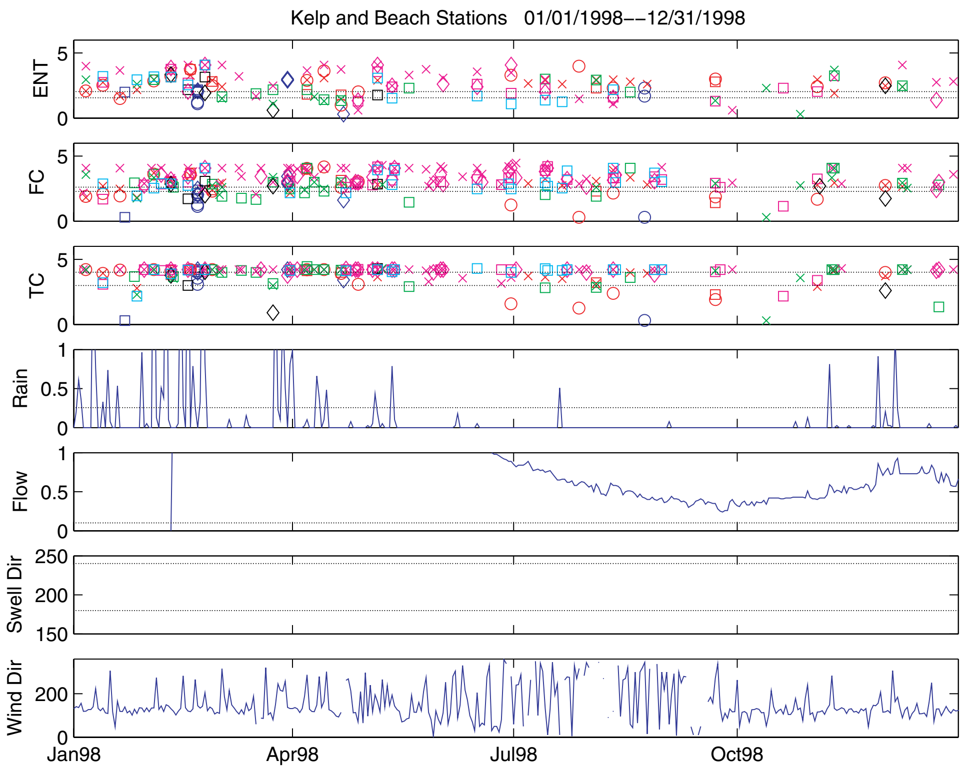
ENT
FC
TC
Rain
Flow
Swell Dir
Wind Dir
Jan97
Apr97
Jul97
Oct97



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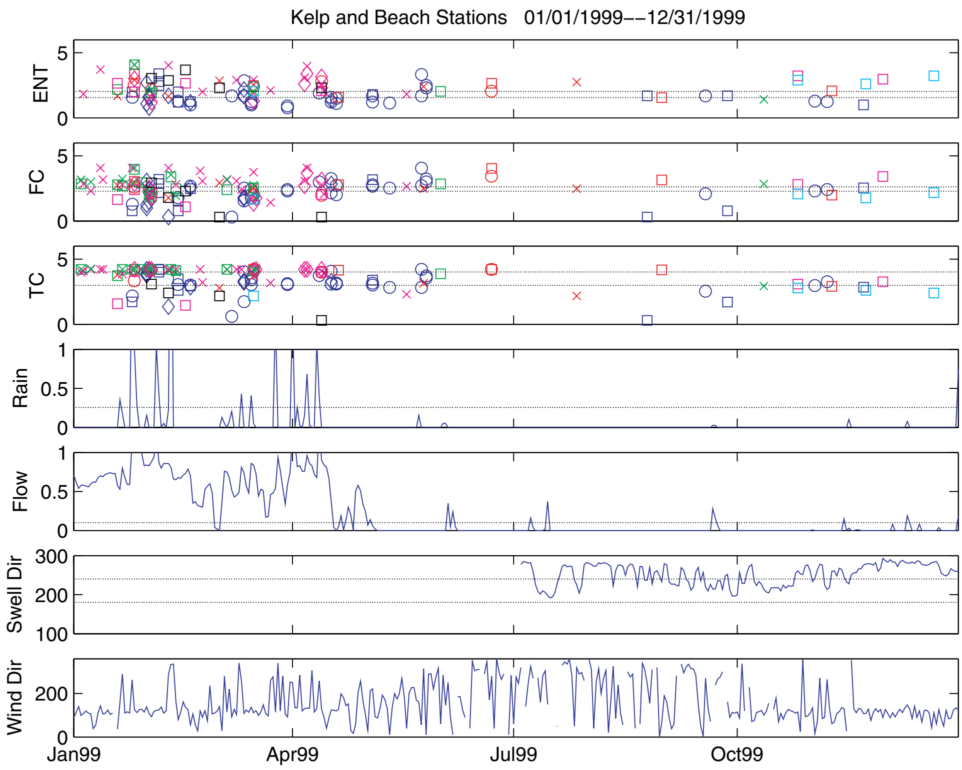
FC
TC
Rain
Flow
Swell Dir
Wind Dir
Jan98
Apr98
Jul98
Oct98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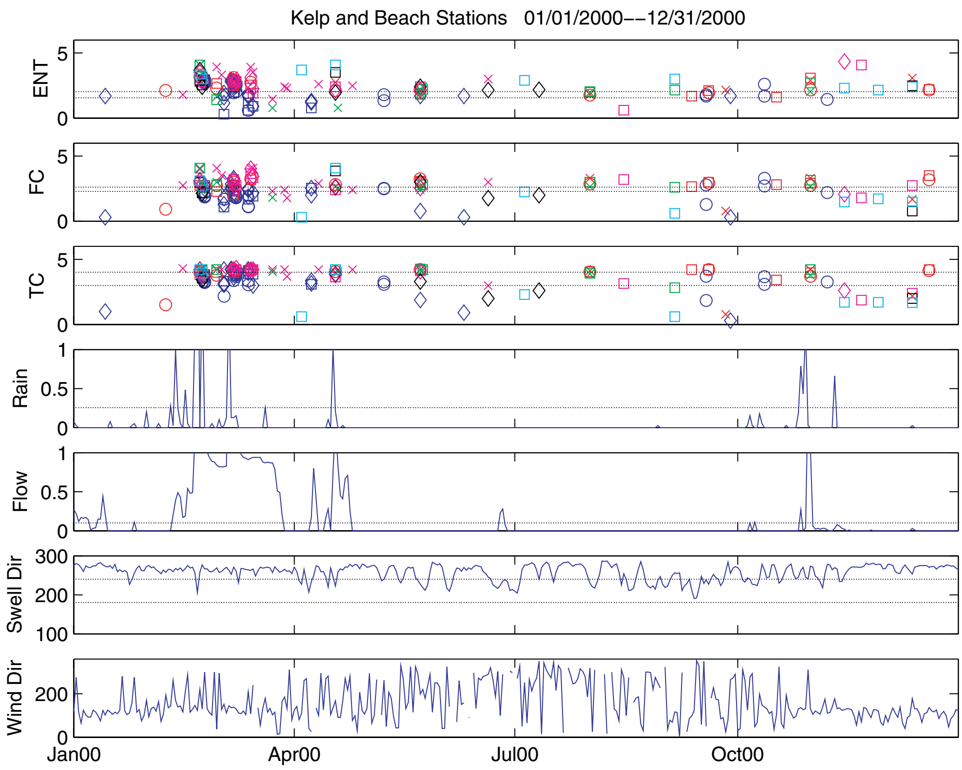
FC
TC
Rain
Flow
Swell Dir
Wind Dir
Jan99
Apr99
Jul99
Oct99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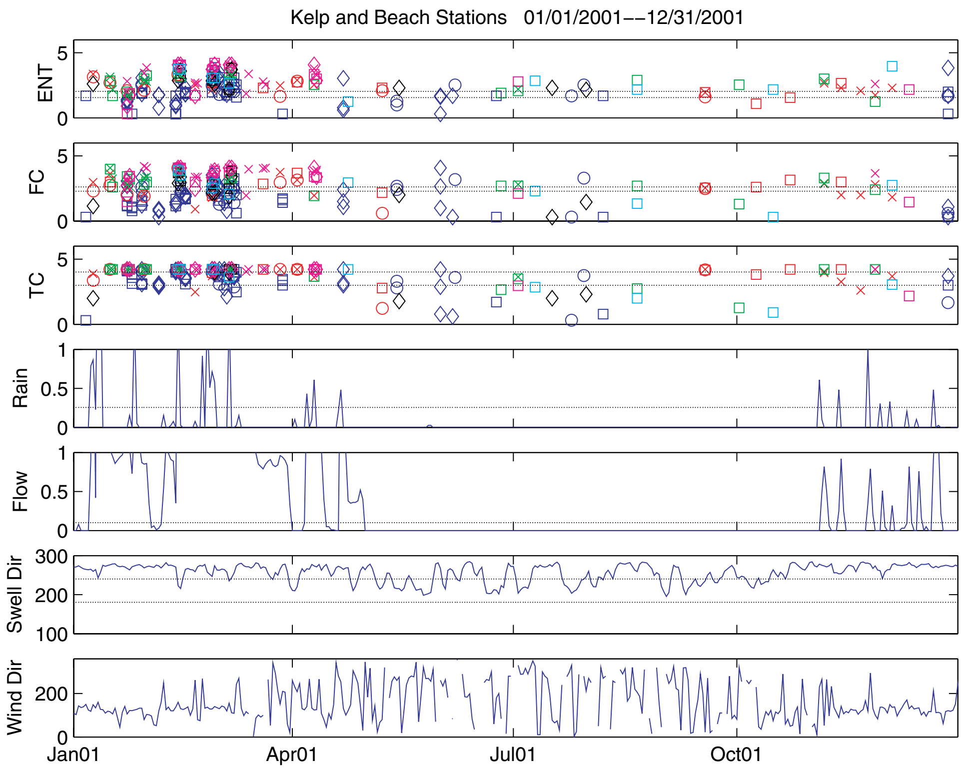
ENT
FC
TC
Rain
Flow
Swell Dir
Wind Dir
Jan00
Apr00
Jul00
Oct00



Kelp and Beach Stations 01/01/2001--12/31/2001
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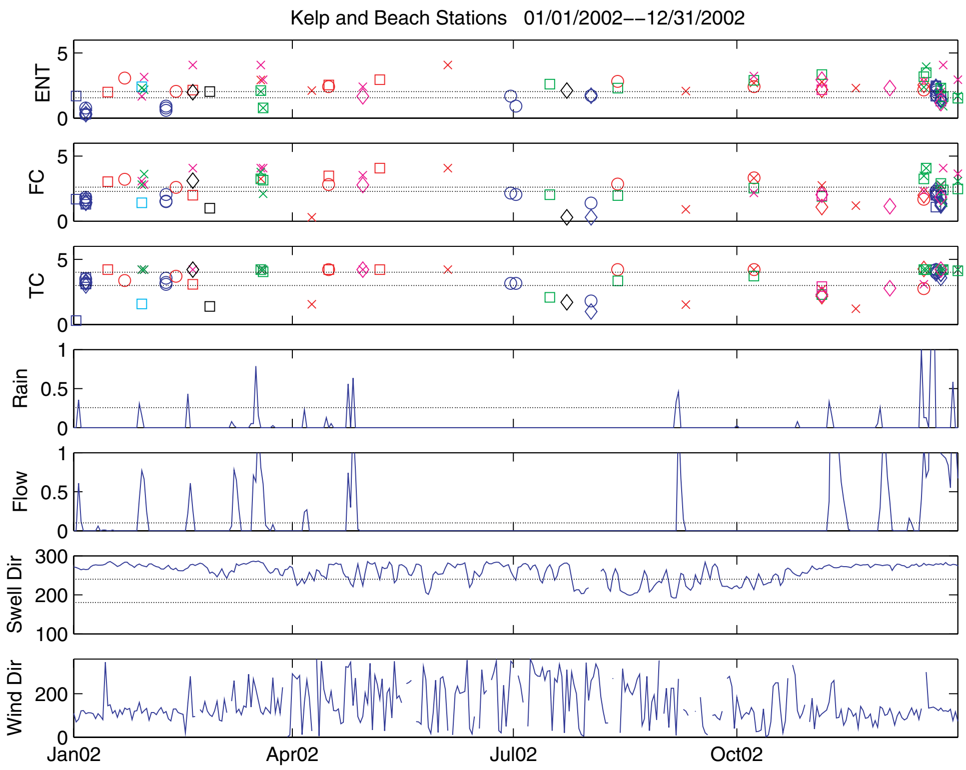
FC
TC
Rain
Flow
Swell Dir
Wind Dir
Jan01
Apr01
Jul01
Oct01



Kelp and Beach Stations 01/01/2002--12/31/2002
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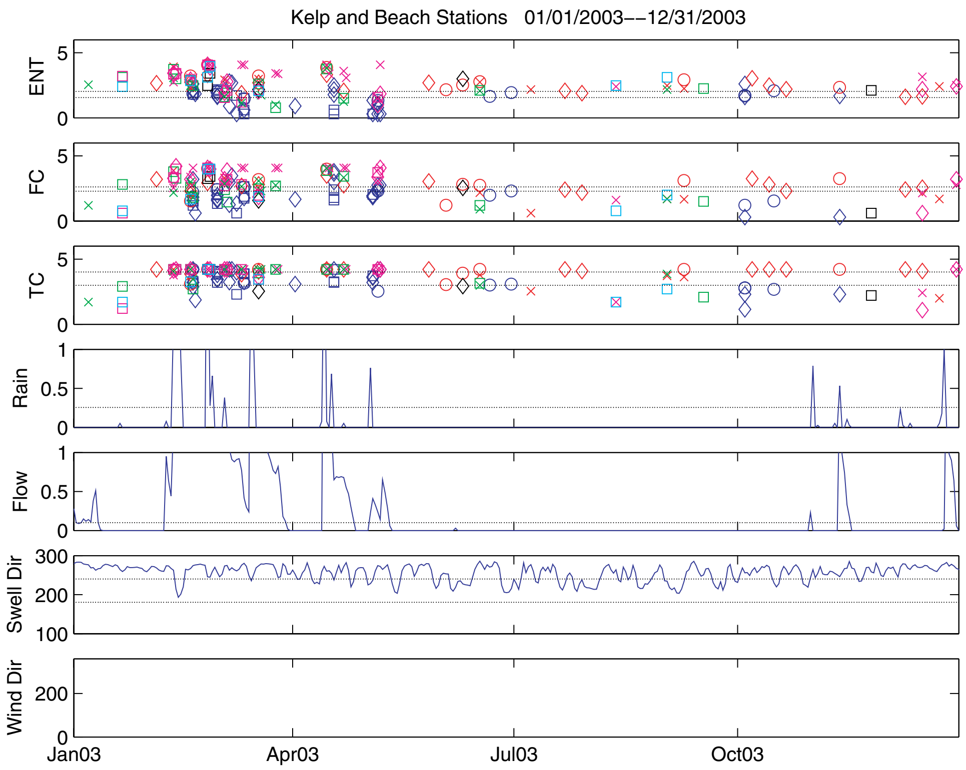
FC
TC
Rain
Flow
Swell Dir
Wind Dir
Jan02
Apr02
Jul02
Oct02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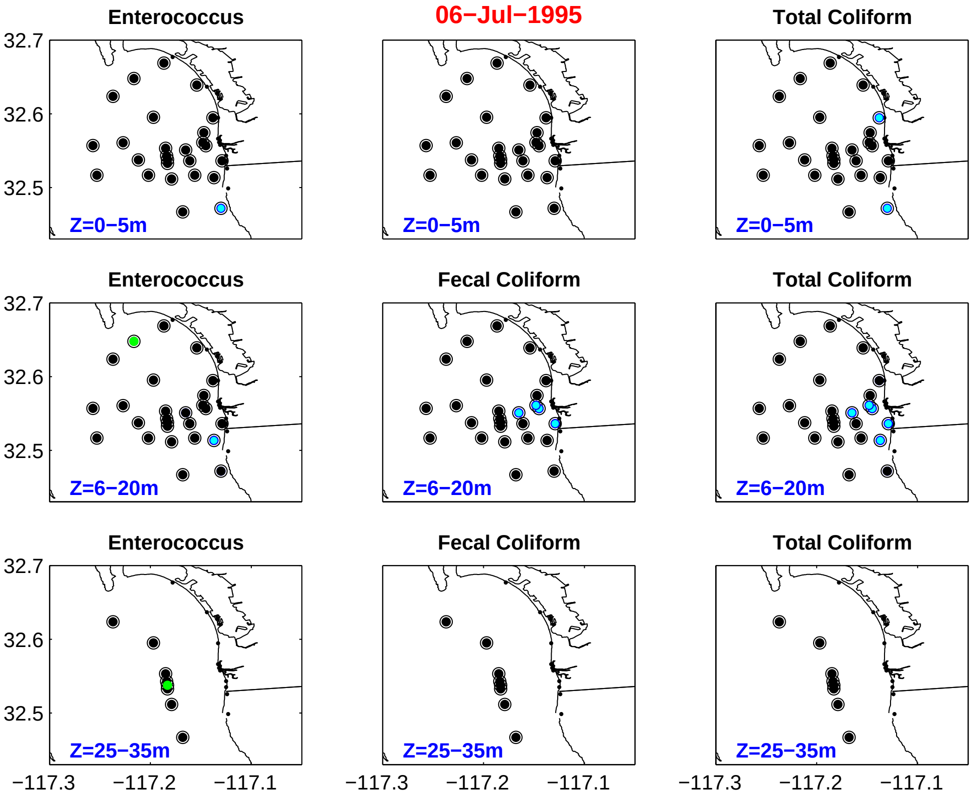
ENT
FC
TC
Rain
Flow
Swell Dir
Wind Dir
Jan03
Apr03
Jul03
Oct03

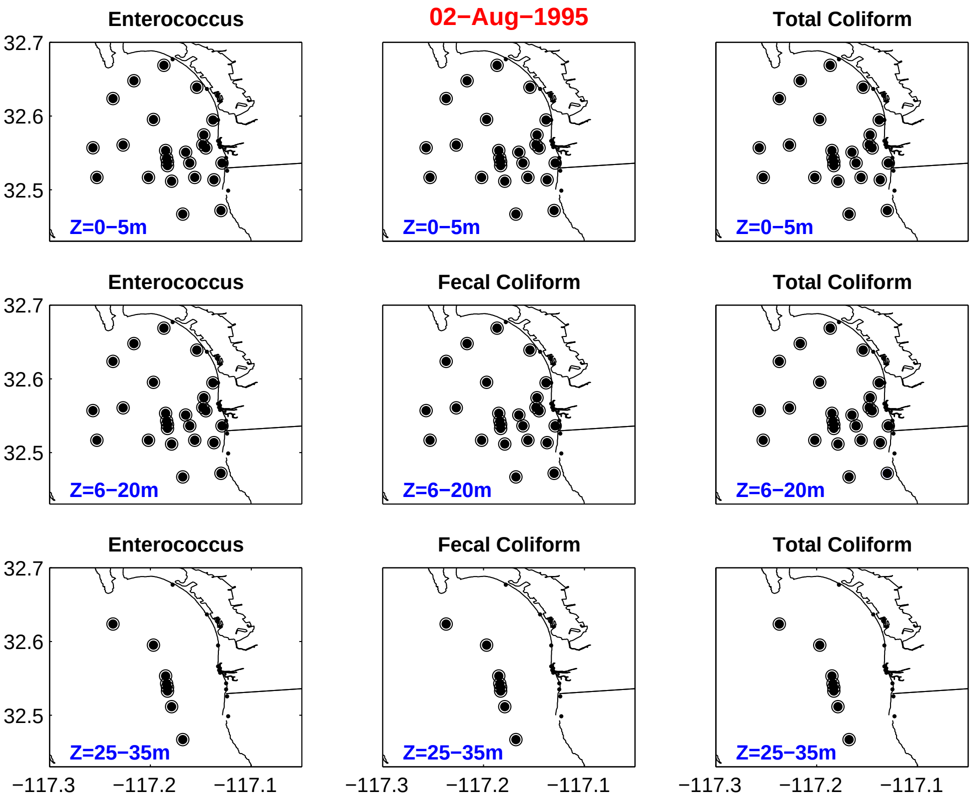
Appendix C

Maps of Monthly Ocean Bacterial Counts, 1995-2003

SBOO Bacterial Sampling Map Color Coding. Red in all cases corresponds to the level for a daily exceedance and green corresponds to the level for a 30-day mean exceedance, as set by California Code of Regulations (Title 17, AB411) for water quality in human contact areas.

Color	ENT	FEC	TOT
Black	< 5	< 20	< 100
Cyan	5-34	20-200	101-1000
Green	35-60	201-250	1001-5000
Yellow	61-104	251-400	5001-10000
Red	105-300	401-1000	10001-14000
Magenta	> 300	> 1000	> 14000


06−Jul−1995
Enterococcus
Total Coliform
Fecal Coliform
Z=0−5m
Z=6−20m
Z=25−35m
32.7
32.6
32.5
−117.3
−117.2
−117.1


02−Aug−1995
Enterococcus
Total Coliform
Fecal Coliform
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Z=6−20m
Z=25−35m
32.7
32.6
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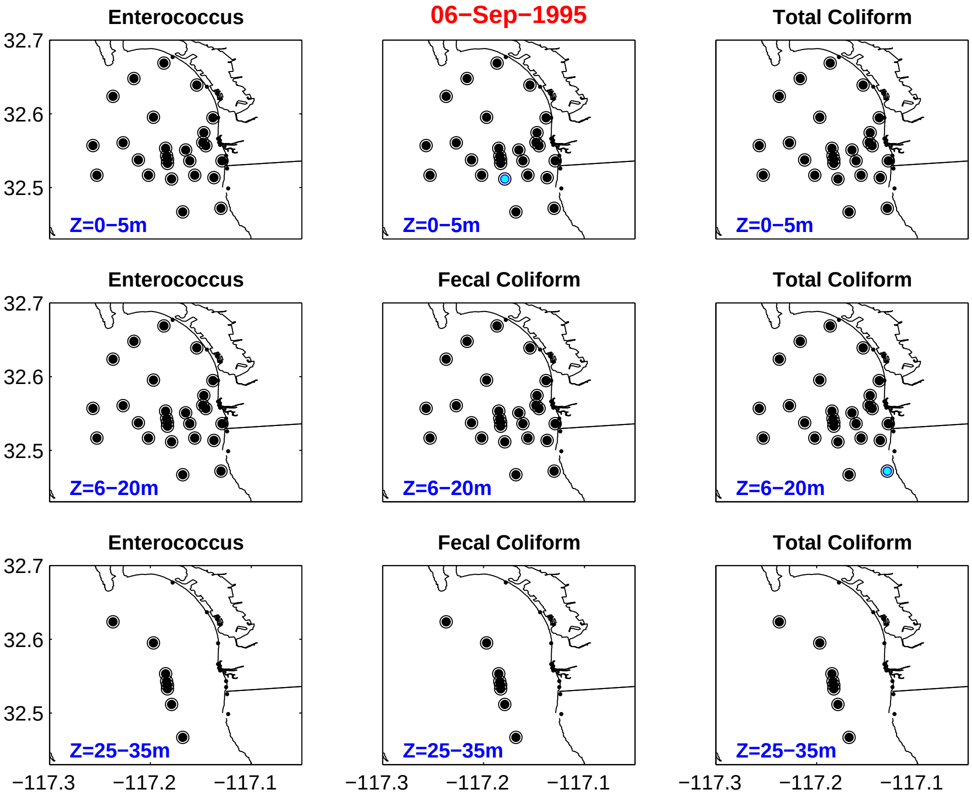
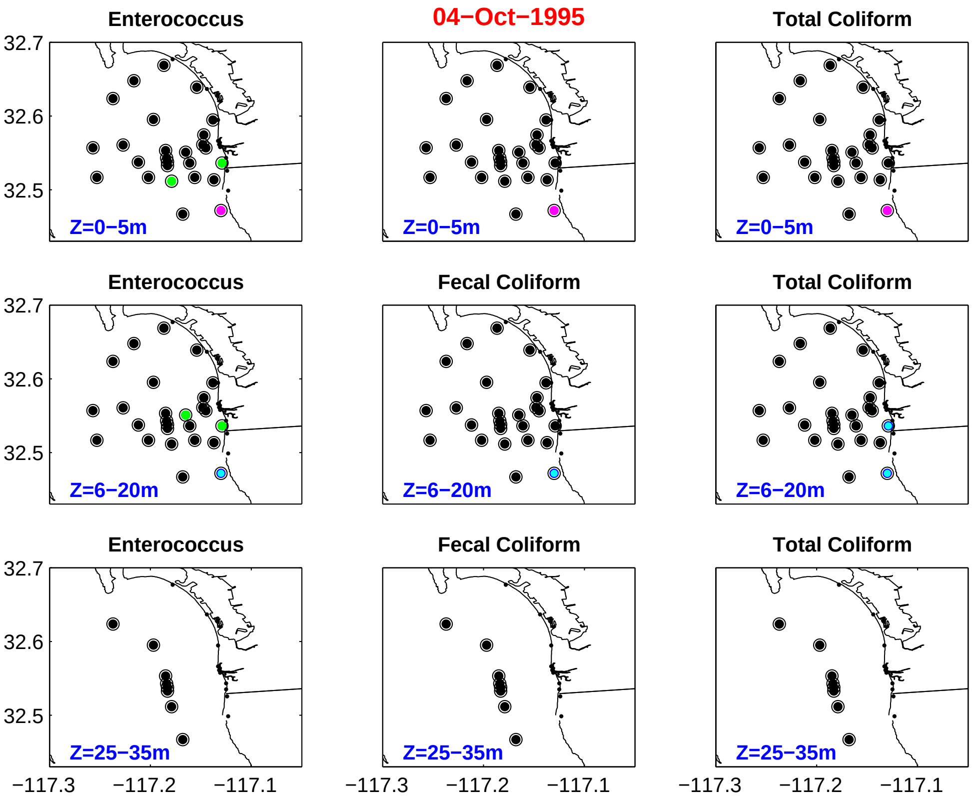
−117.2
−117.1


06−Sep−1995
Enterococcus
Fecal Coliform
Total Coliform
Z=0−5m
Z=6−20m
Z=25−35m
32.7
32.6
32.5
−117.3
−117.2
−117.1


04−Oct−1995
Enterococcus
Fecal Coliform
Total Coliform
Z=0−5m
Z=6−20m
Z=25−35m
32.7
32.6
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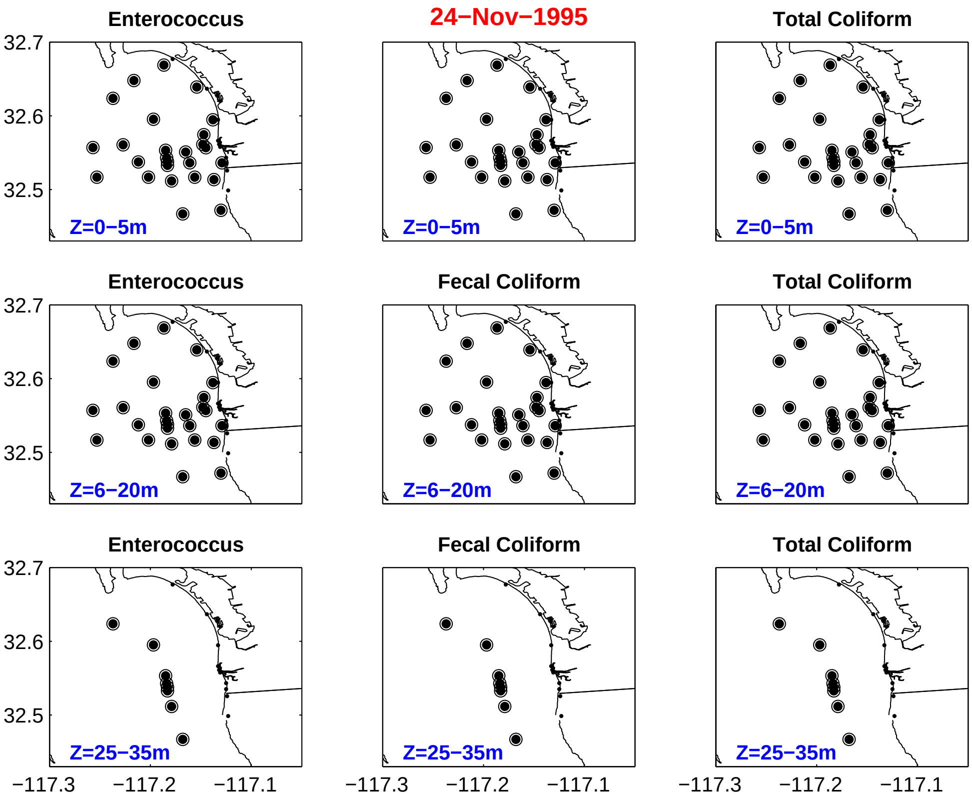
−117.3
−117.2
−117.1


24−Nov−1995
Enterococcus
Fecal Coliform
Total Coliform
Z=0−5m
Z=6−20m
Z=25−35m
32.7
32.6
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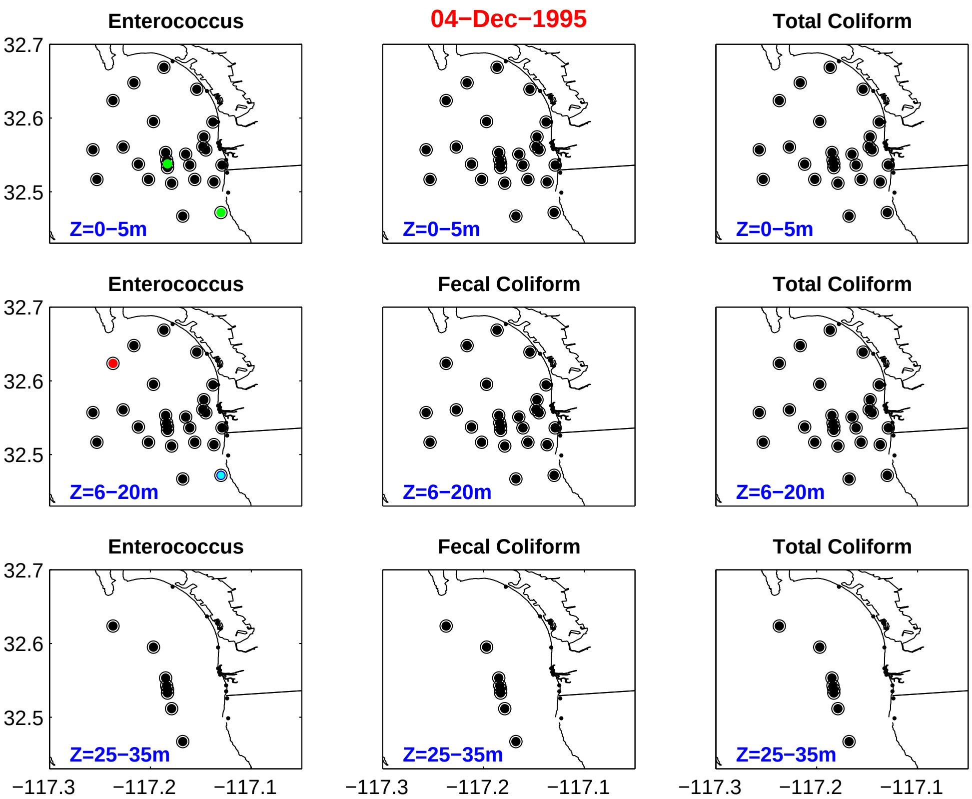
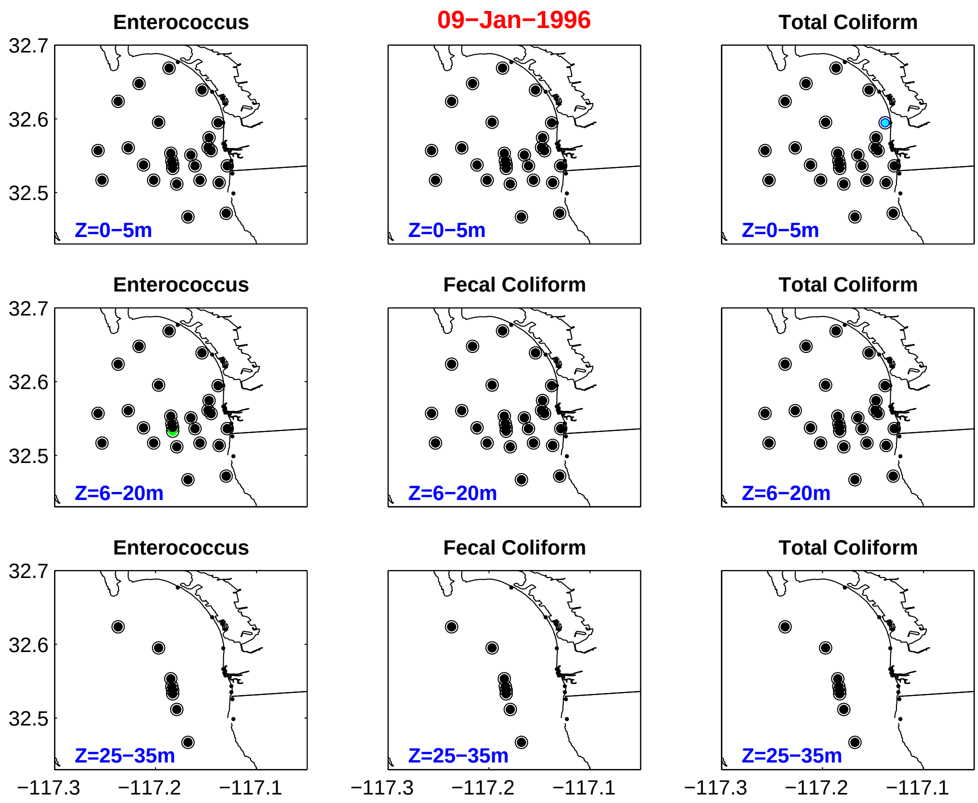
−117.2
−117.1


04−Dec−1995
Enterococcus
Fecal Coliform
Total Coliform
Z=0−5m
Z=6−20m
Z=25−35m
32.7
32.6
32.5
−117.3
−117.2
−117.1


09−Jan−1996
Enterococcus
Fecal Coliform
Total Coliform
Z=0−5m
Z=6−20m
Z=25−35m
32.7
32.6
32.5
−117.3
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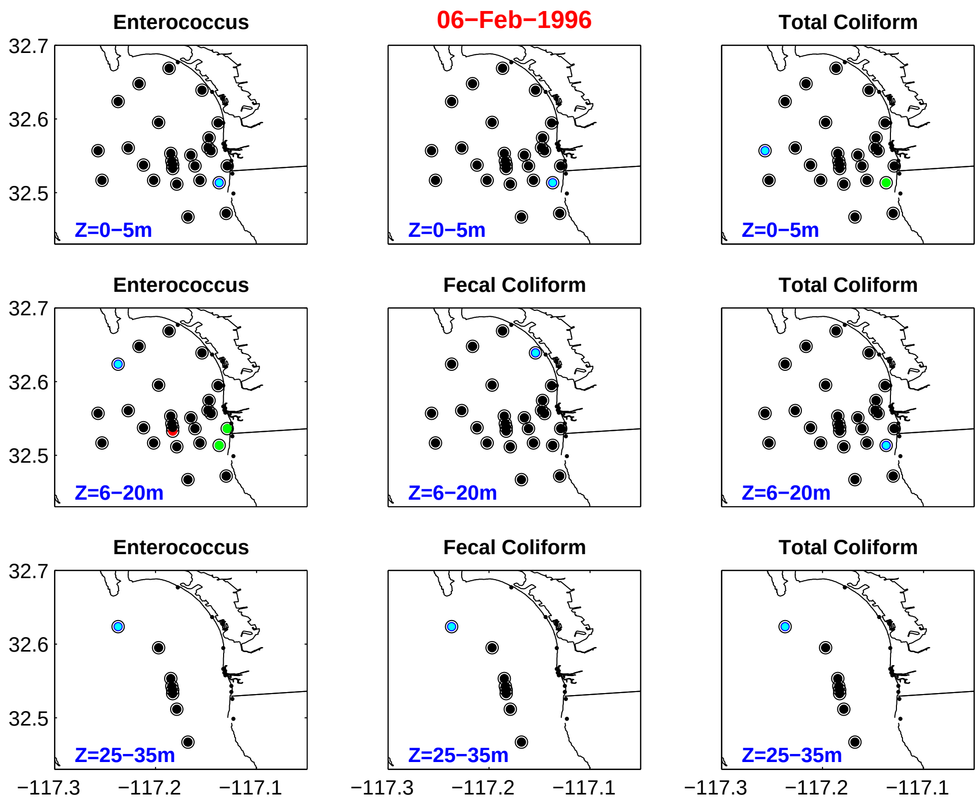
06−Feb−1996
Enterococcus
Fecal Coliform
Total Coliform
Z=0−5m
Z=6−20m
Z=25−35m
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32.5
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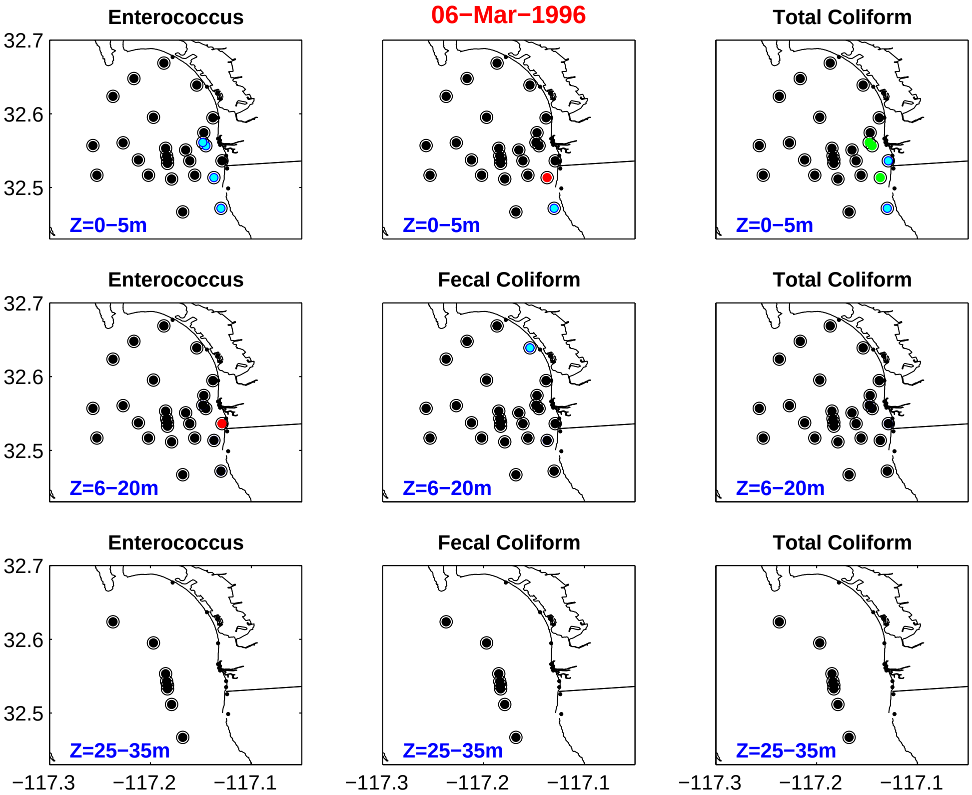
06−Mar−1996
Enterococcus
Total Coliform
Fecal Coliform
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Z=25−35m
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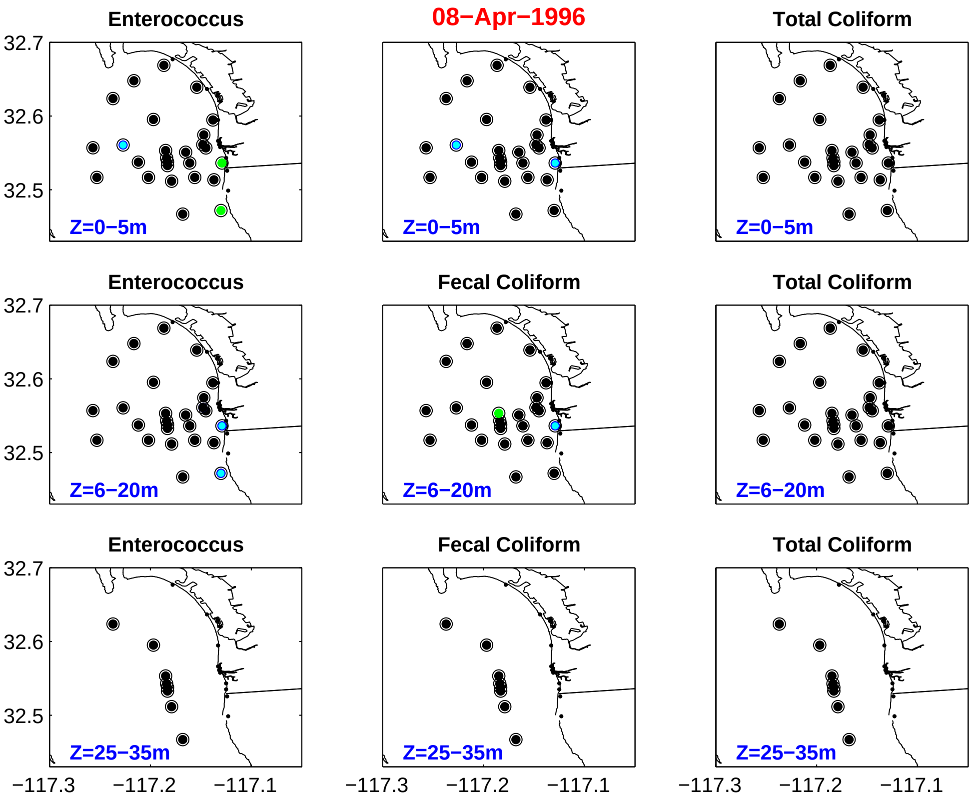
08−Apr−1996
Enterococcus
Total Coliform
Fecal Coliform
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Z=25−35m
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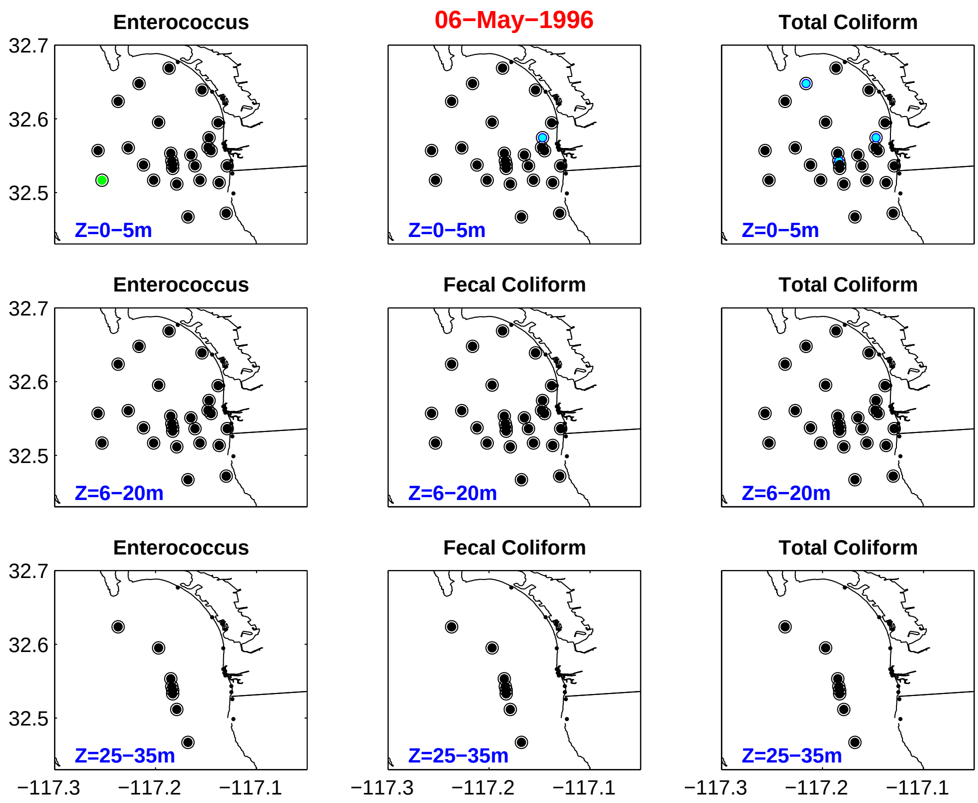
06−May−1996
Enterococcus
Fecal Coliform
Total Coliform
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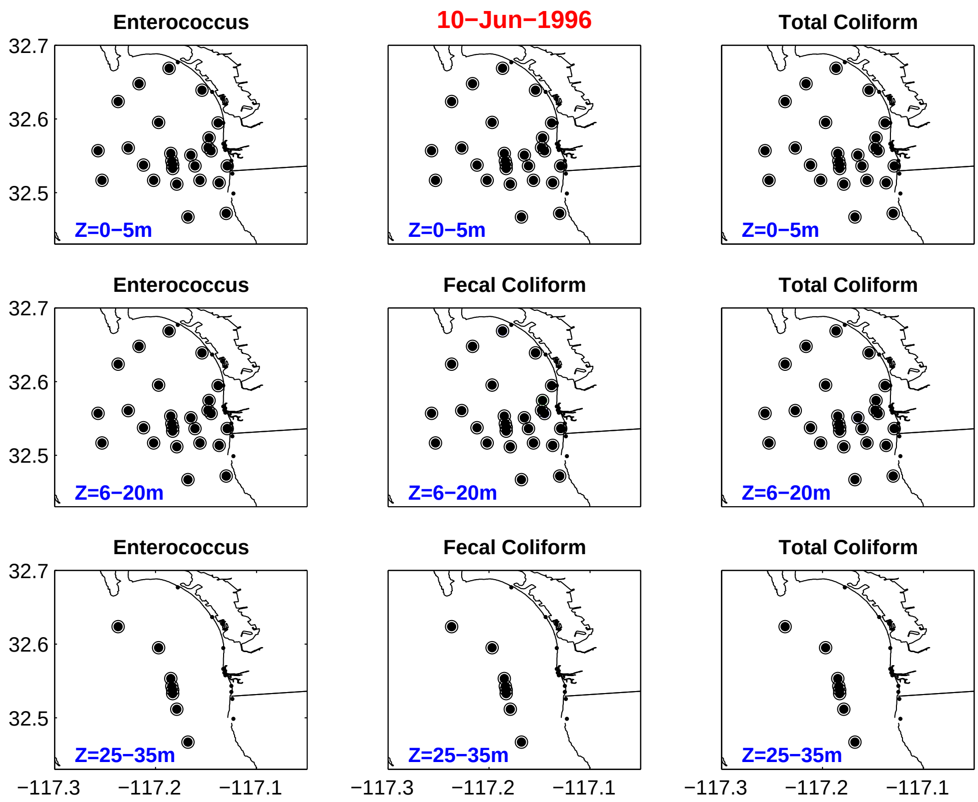
10−Jun−1996
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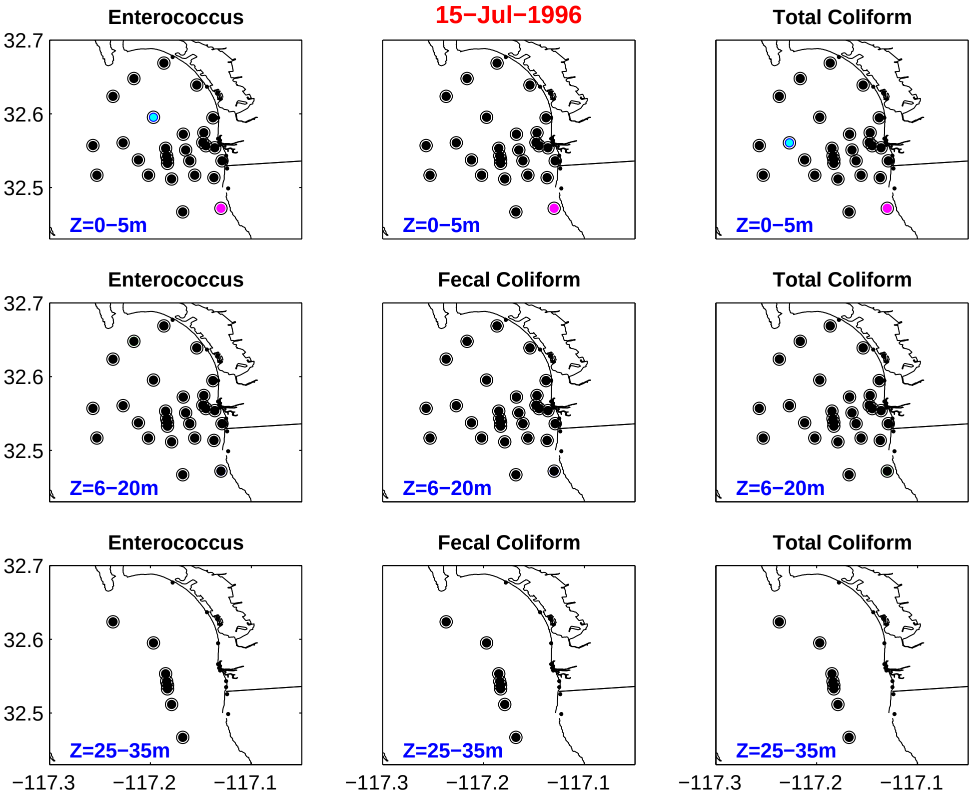
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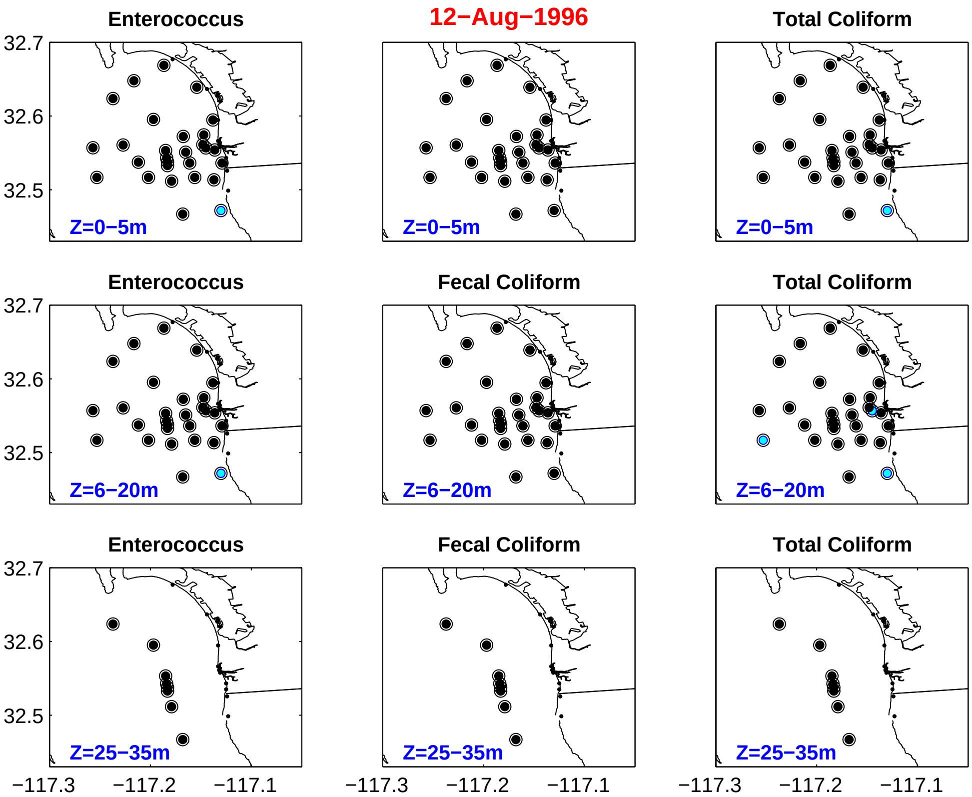
Enterococcus
12−Aug−1996
Total Coliform
Fecal Coliform
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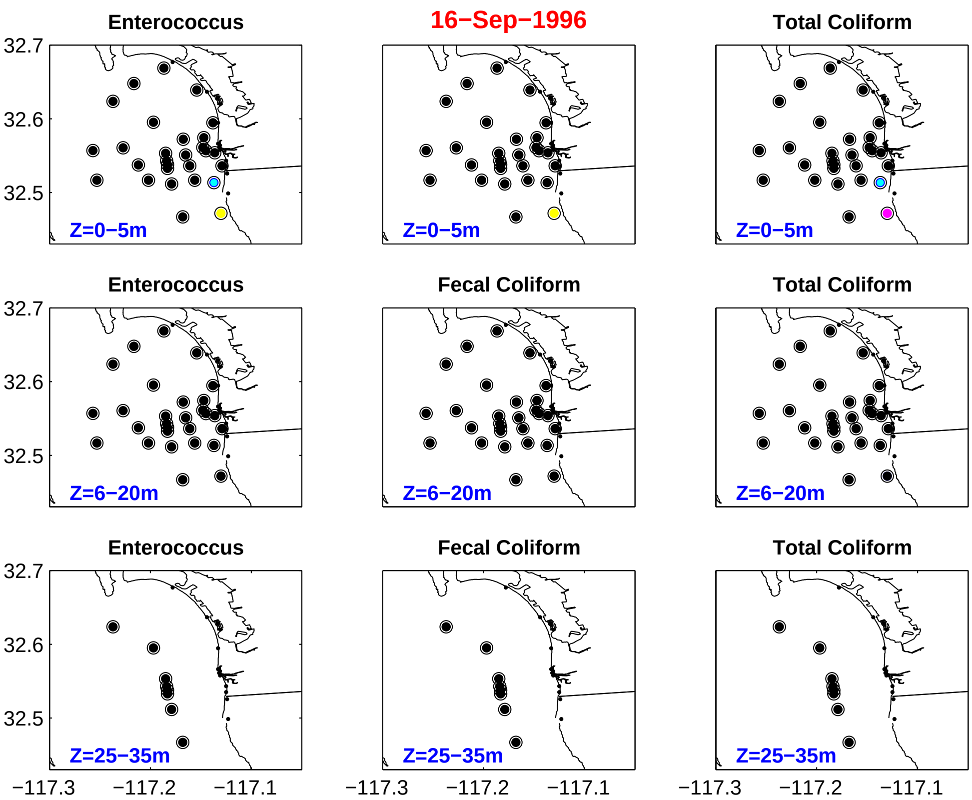
16−Sep−1996
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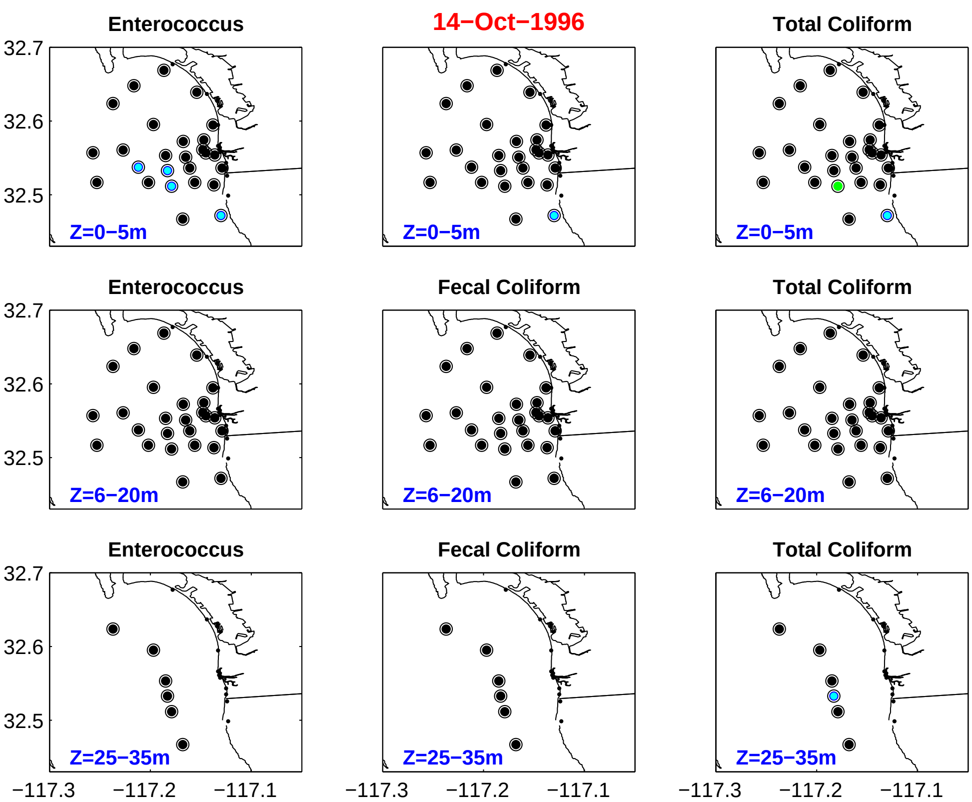
14−Oct−1996
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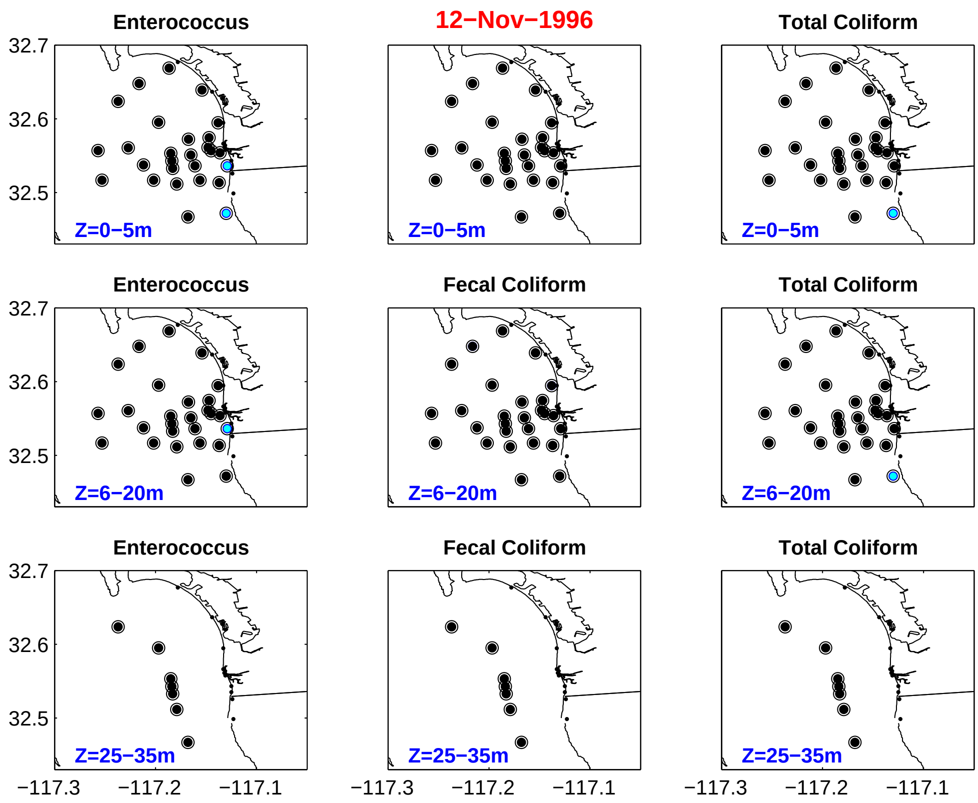
12−Nov−1996
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Total Coliform
Fecal Coliform
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Z=0−5m
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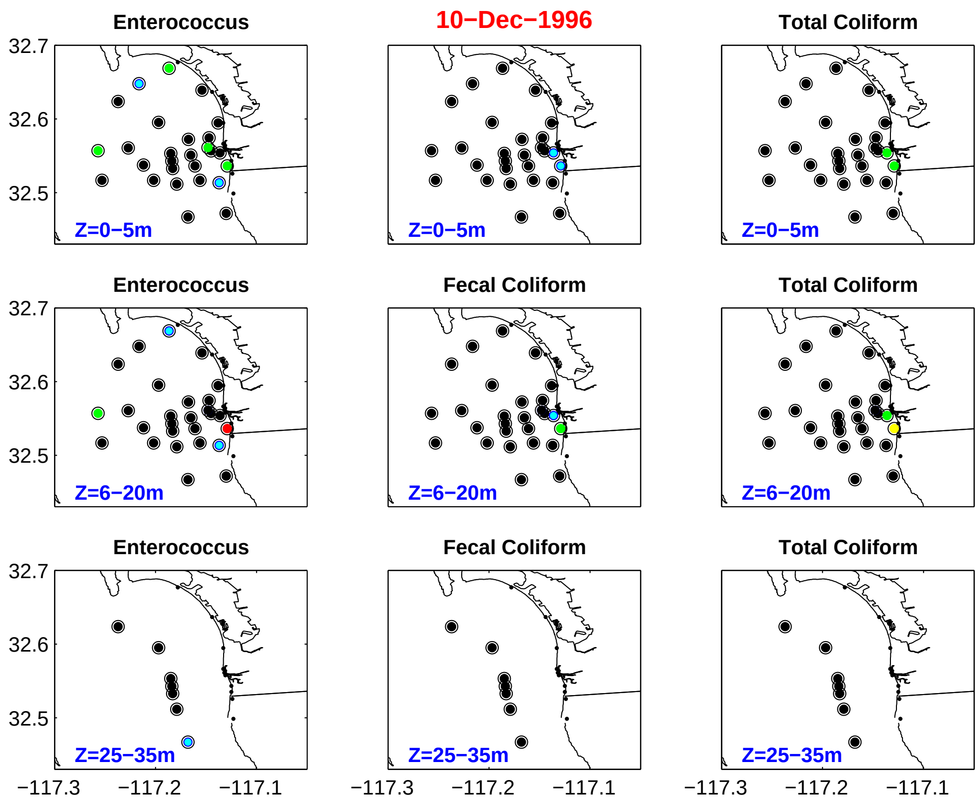
10−Dec−1996
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Total Coliform
Fecal Coliform
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Z=0−5m
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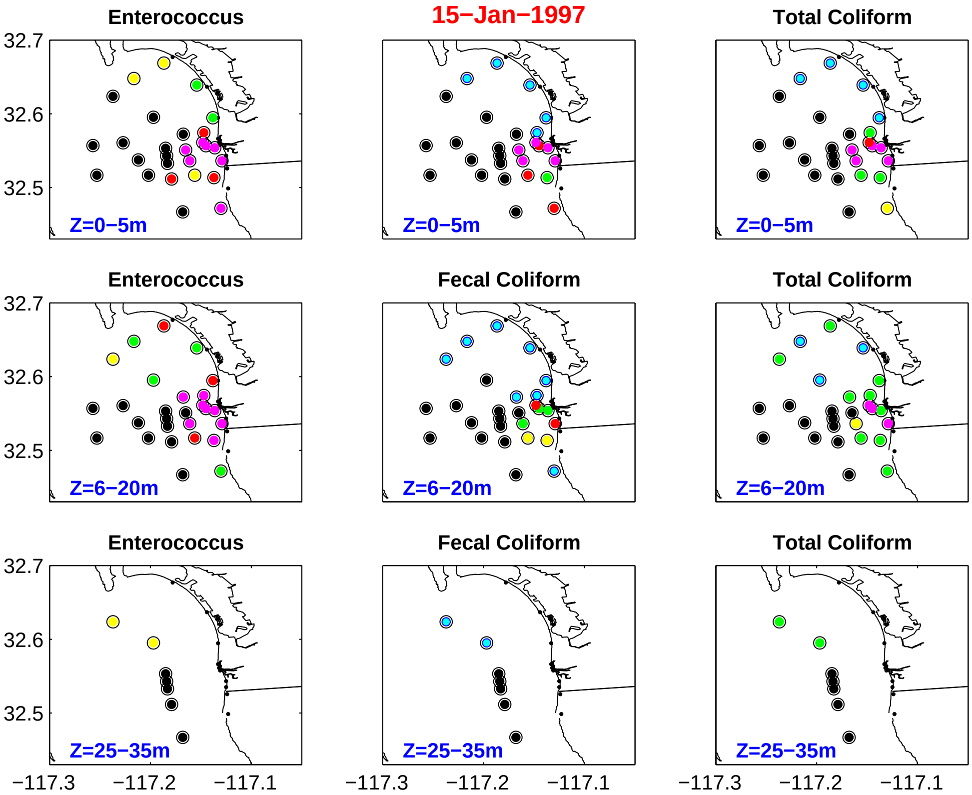
15−Jan−1997
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Total Coliform
Fecal Coliform
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Z=25−35m
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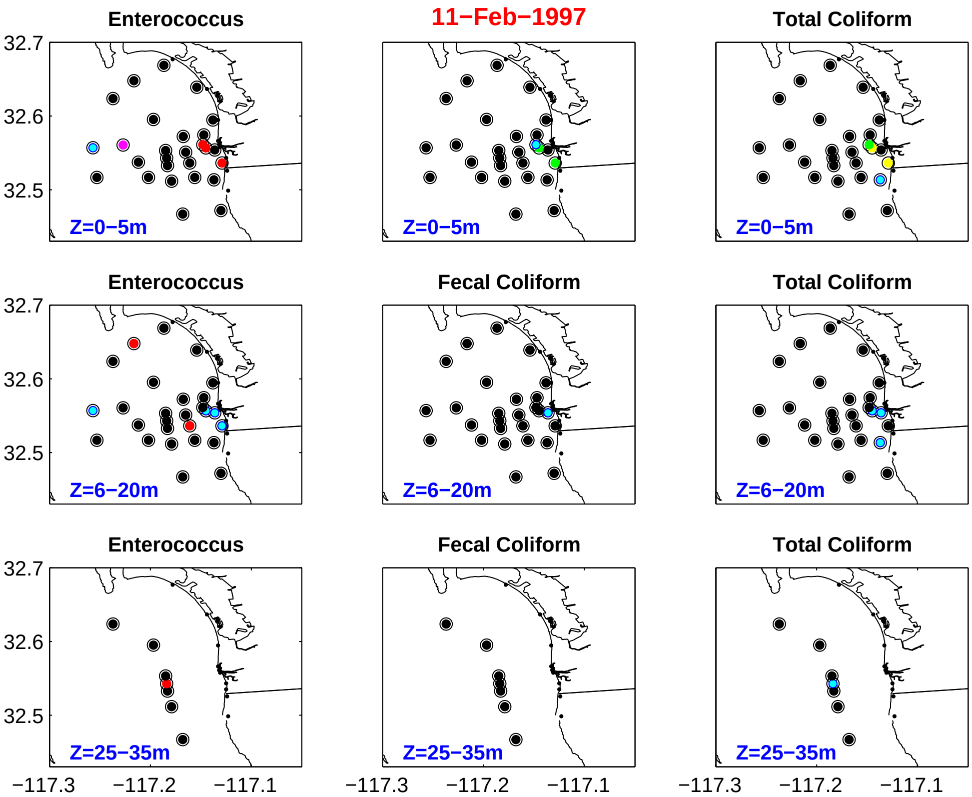
11−Feb−1997
Enterococcus
Total Coliform
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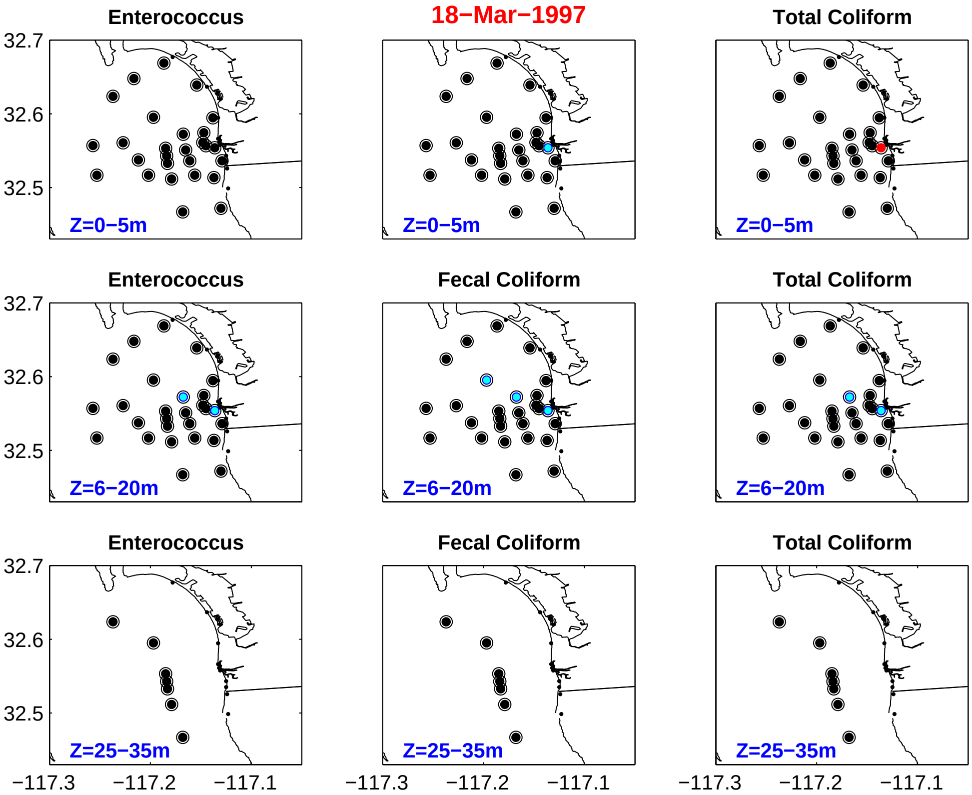
18−Mar−1997
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Total Coliform
Enterococcus
Fecal Coliform
Total Coliform
Enterococcus
Fecal Coliform
Total Coliform
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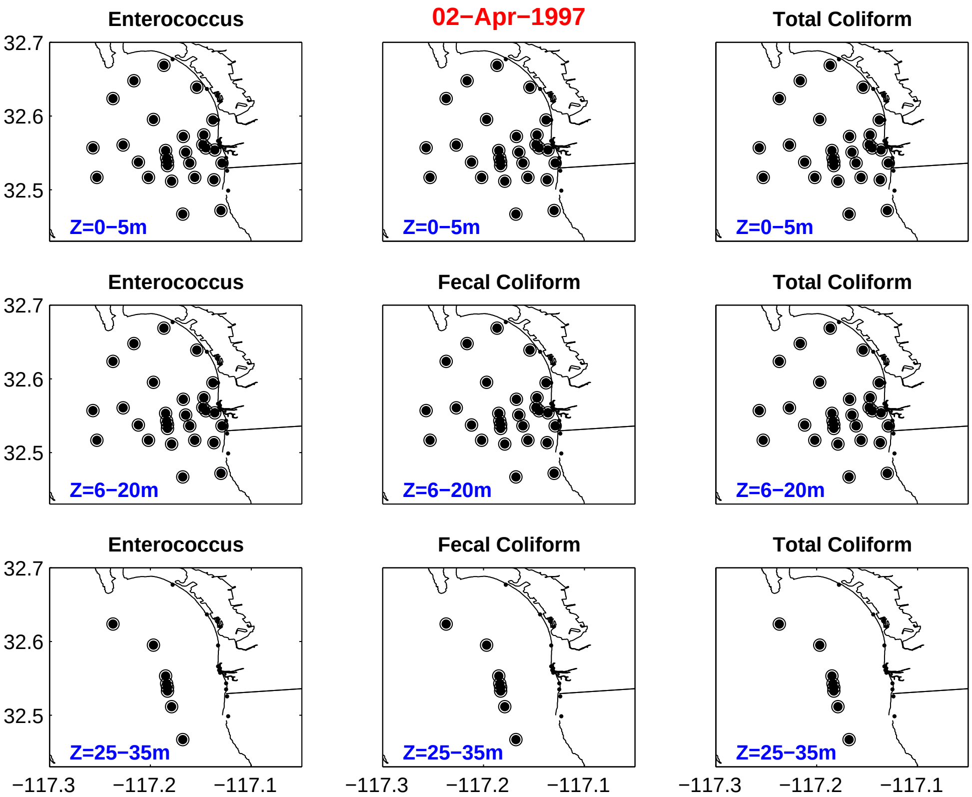
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Enterococcus
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Total Coliform
Enterococcus
Fecal Coliform
Total Coliform
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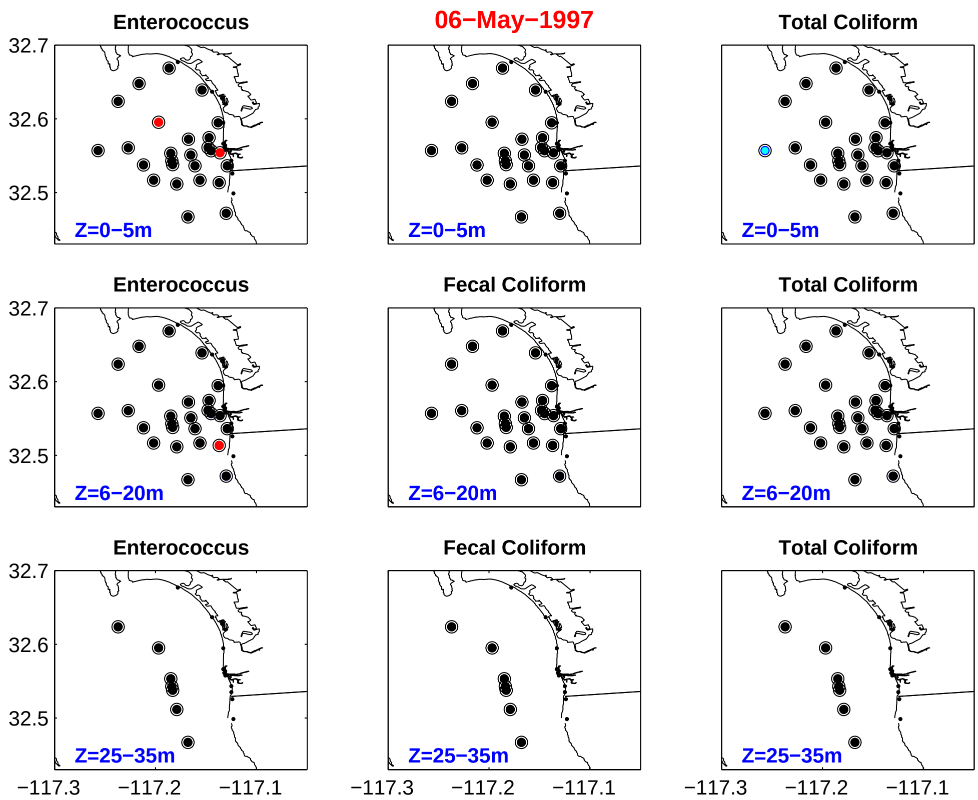
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Enterococcus
Fecal Coliform
Total Coliform
Enterococcus
Fecal Coliform
Total Coliform
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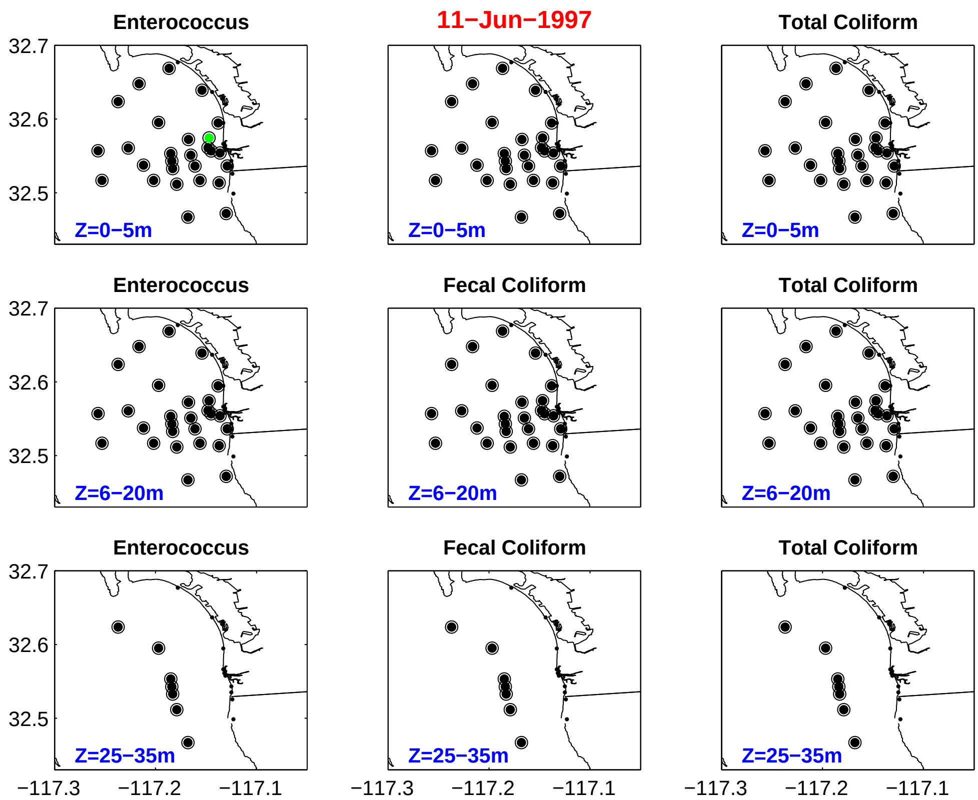
11−Jun−1997
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Total Coliform
Enterococcus
Fecal Coliform
Total Coliform
Enterococcus
Fecal Coliform
Total Coliform
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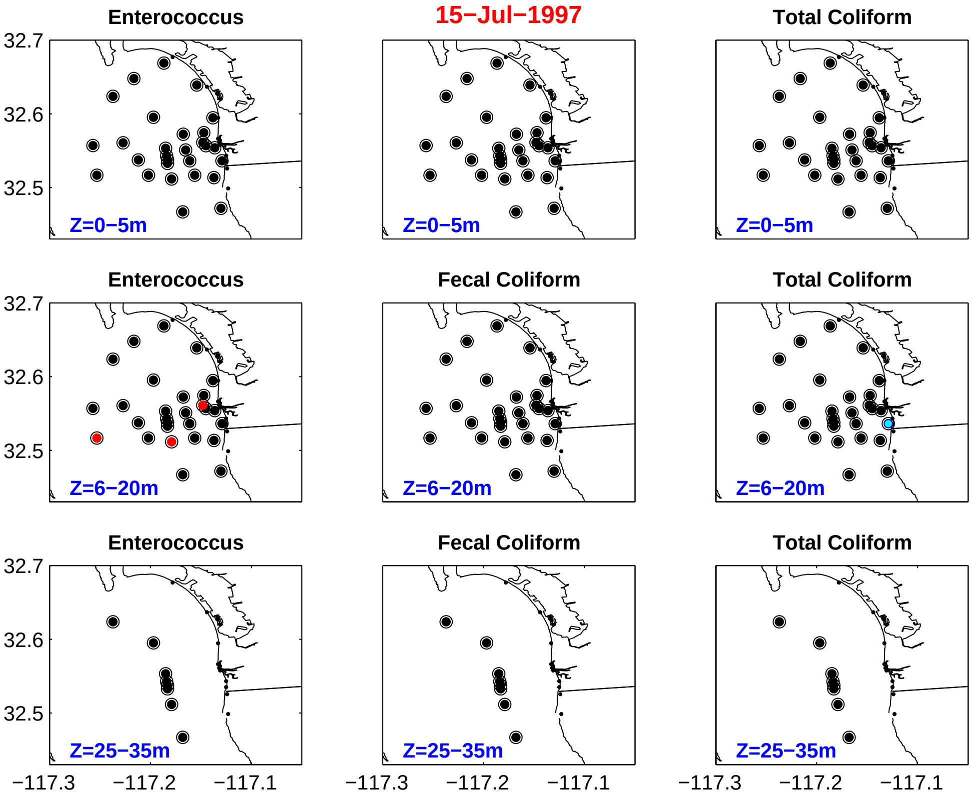
15−Jul−1997
Enterococcus
Fecal Coliform
Total Coliform
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Z=25−35m
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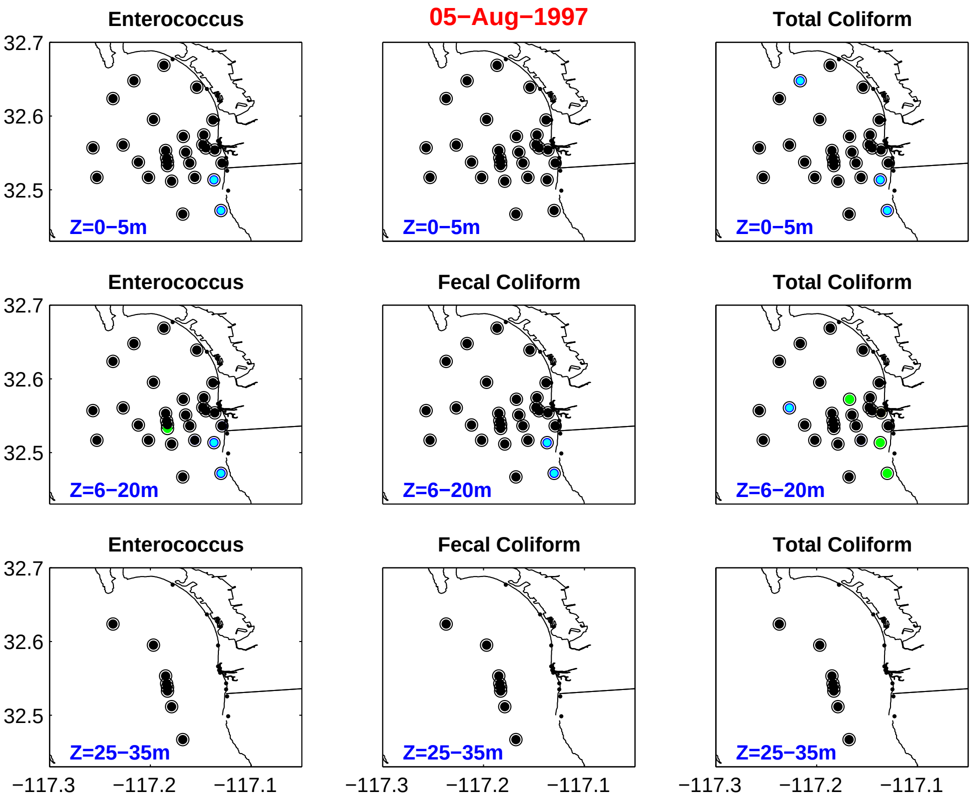
05−Aug−1997
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Fecal Coliform
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Z=25−35m
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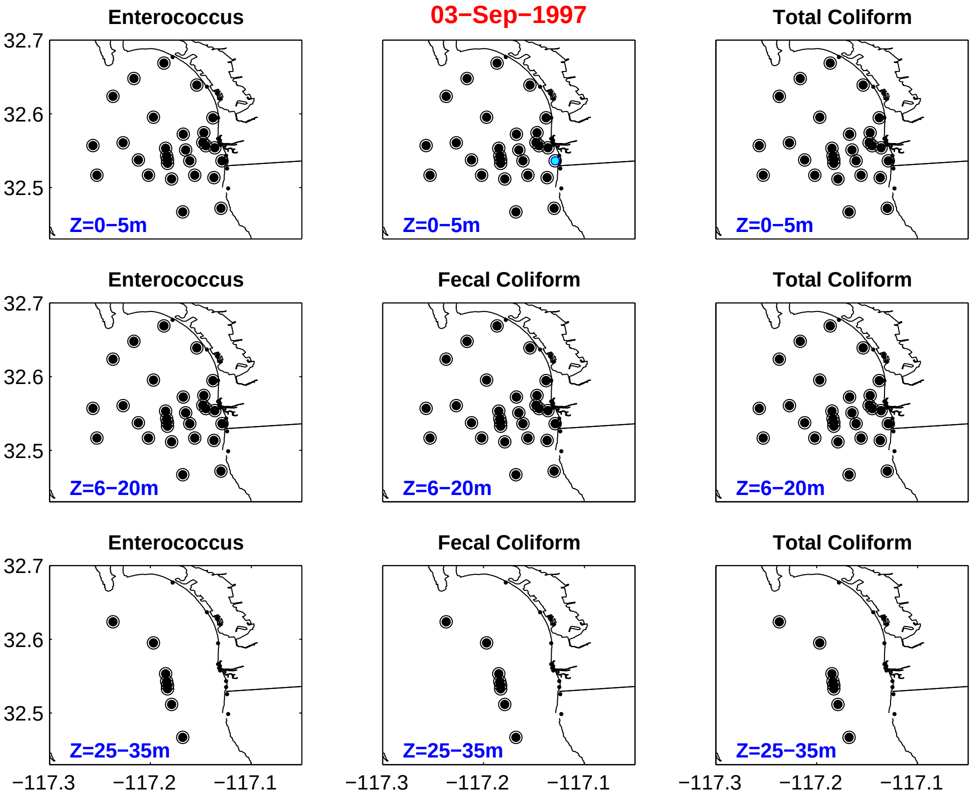
03−Sep−1997
Enterococcus
Fecal Coliform
Total Coliform
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Z=25−35m
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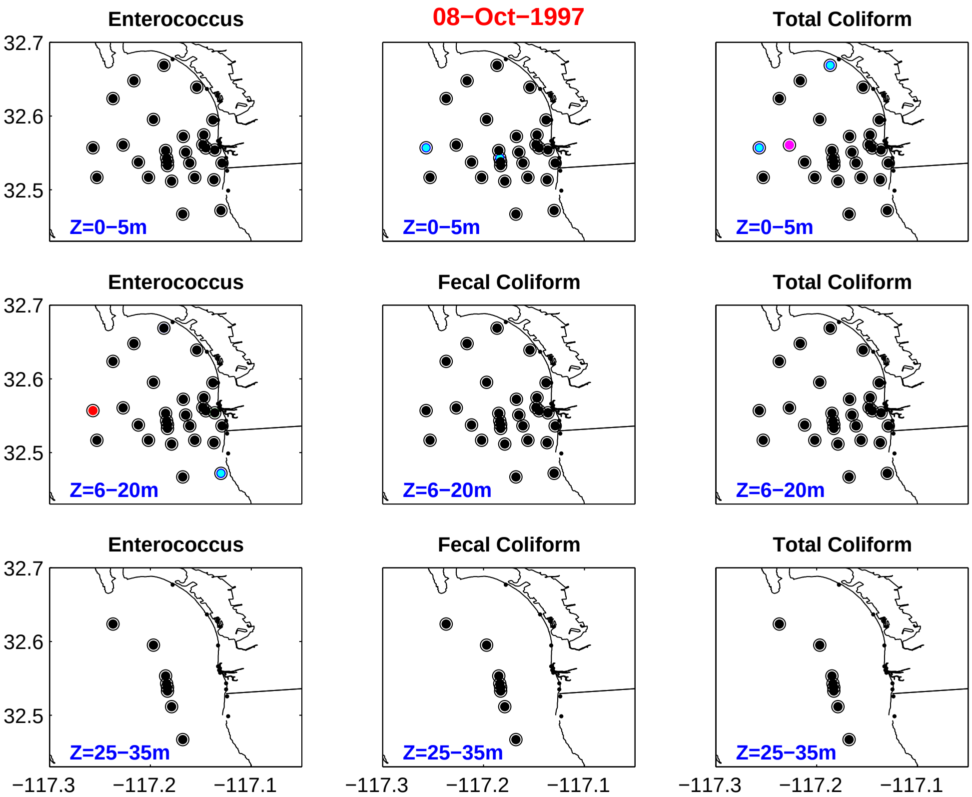
08−Oct−1997
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Fecal Coliform
Total Coliform
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Z=25−35m
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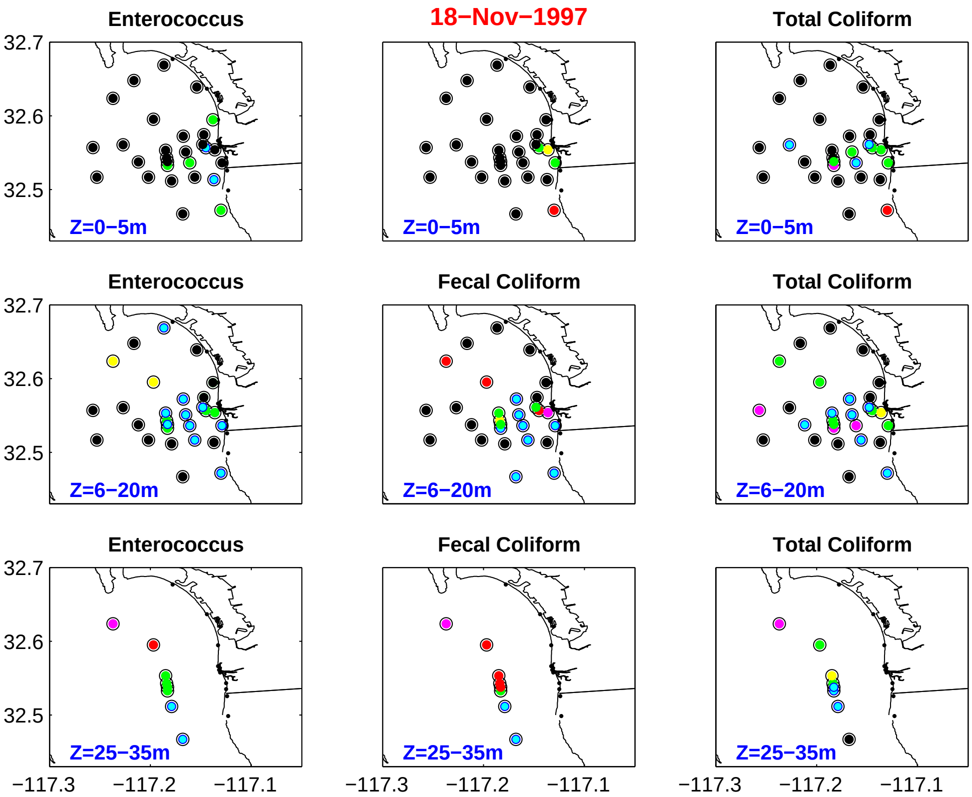
18−Nov−1997
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Fecal Coliform
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Z=0−5m
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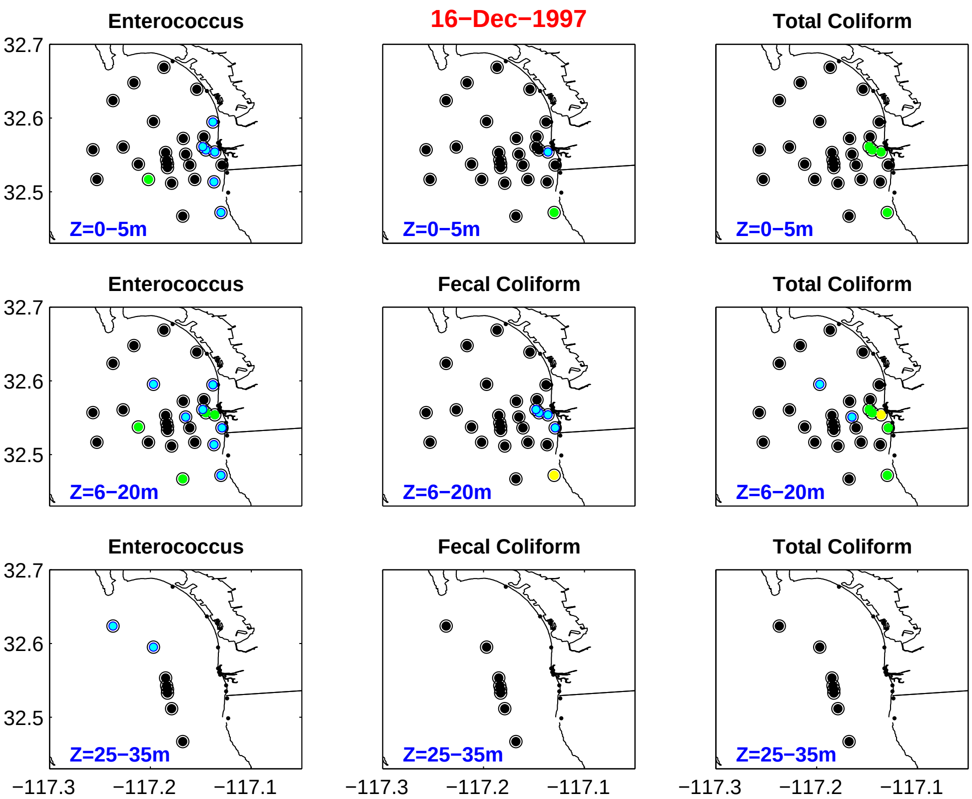
16−Dec−1997
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Fecal Coliform
Total Coliform
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32.5
Z=0−5m
Z=6−20m
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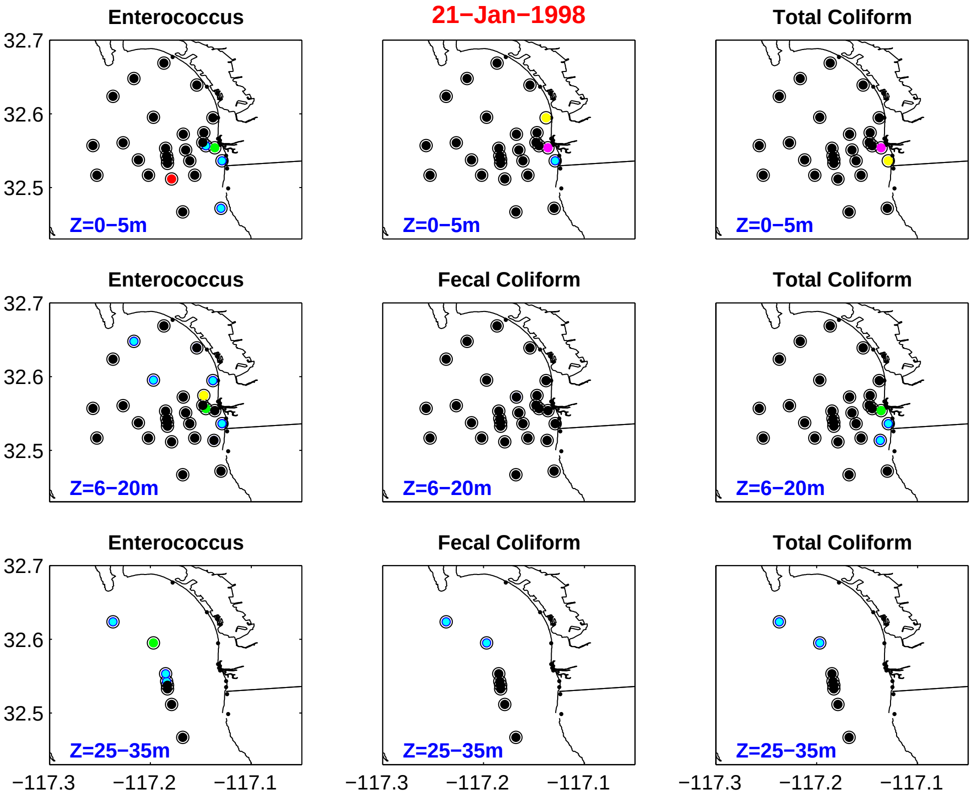
21−Jan−1998
Enterococcus
Fecal Coliform
Total Coliform
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Z=25−35m
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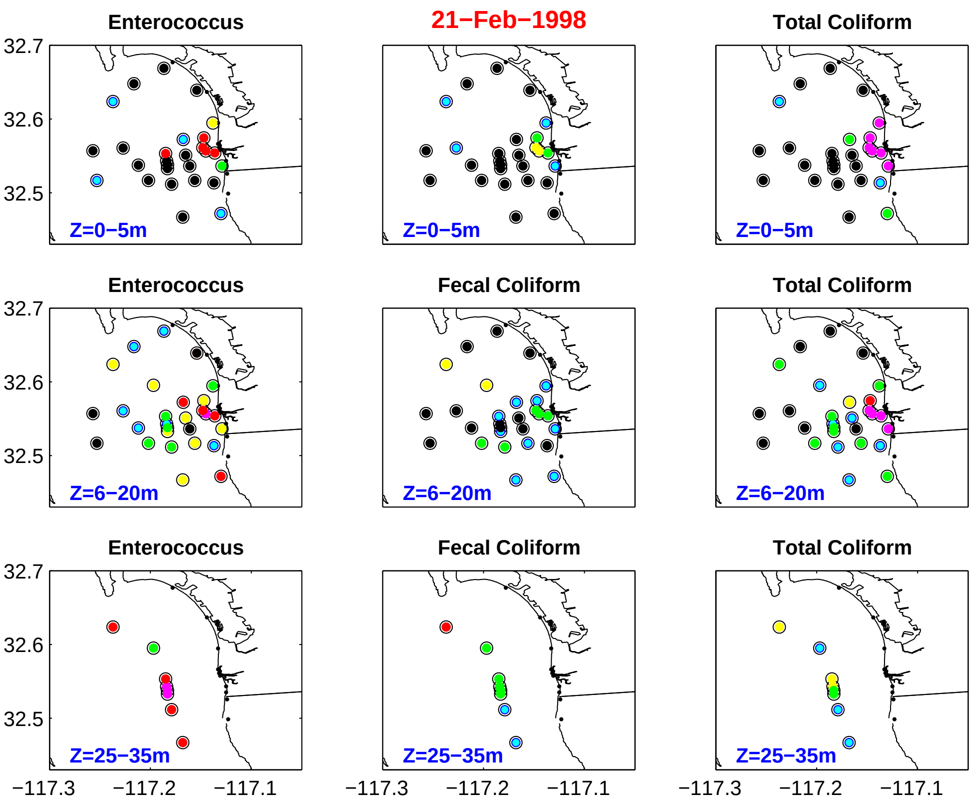
21−Feb−1998
Enterococcus
Fecal Coliform
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Z=25−35m
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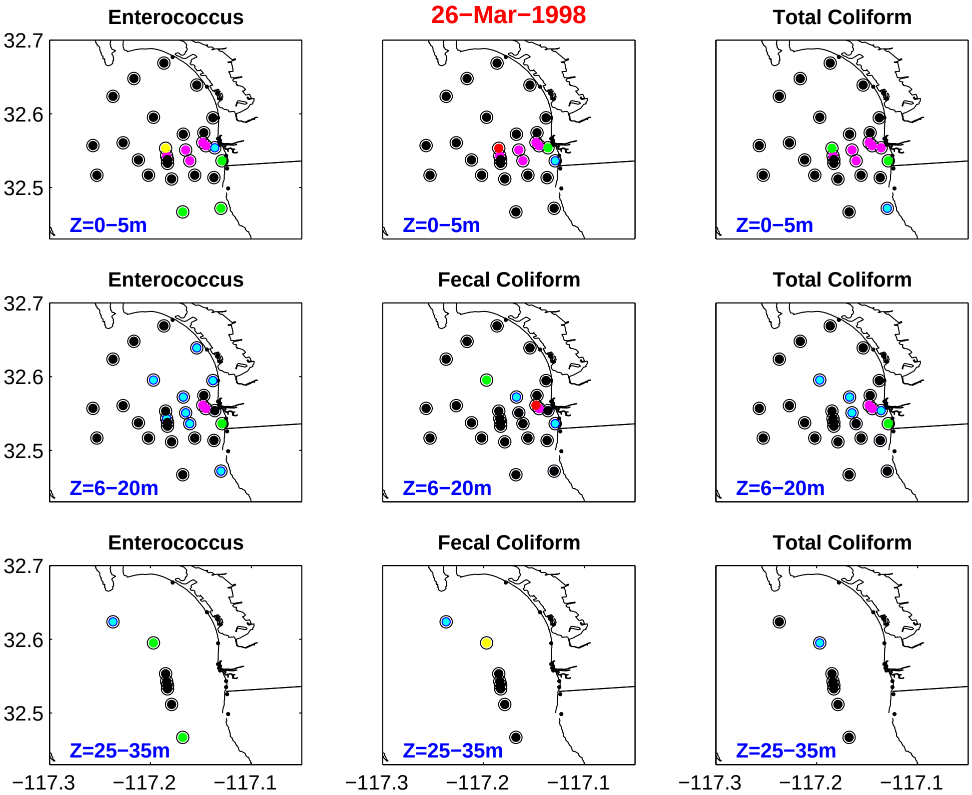
26−Mar−1998
Enterococcus
Total Coliform
Enterococcus
Fecal Coliform
Total Coliform
Enterococcus
Fecal Coliform
Total Coliform
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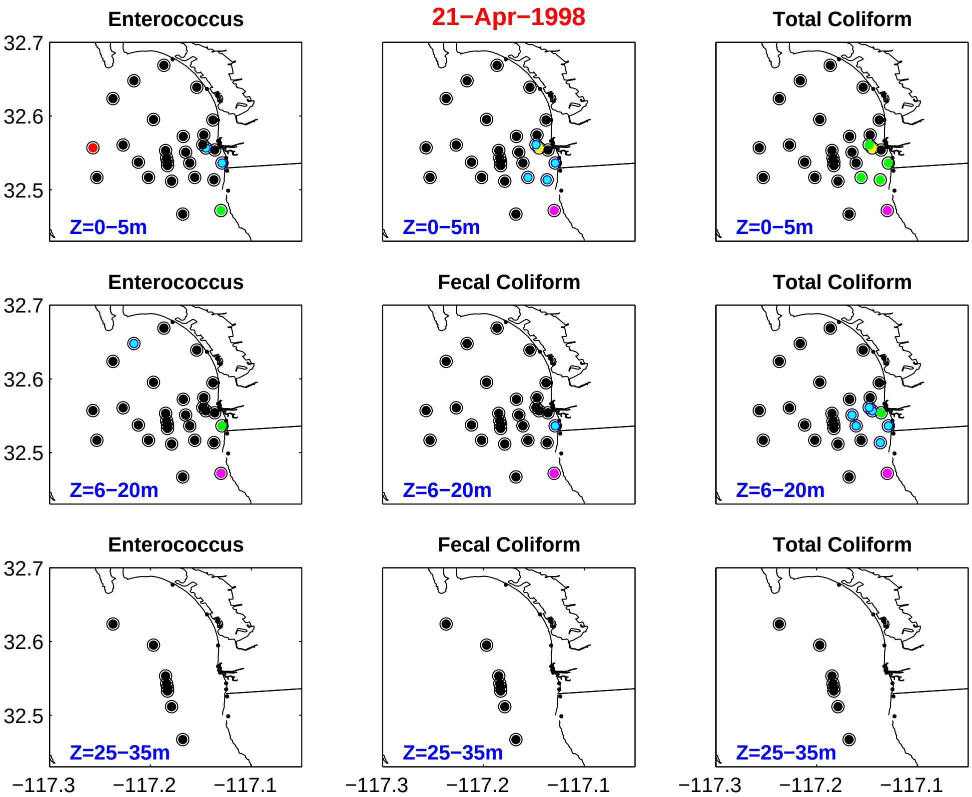
21−Apr−1998
Enterococcus
Total Coliform
Enterococcus
Fecal Coliform
Total Coliform
Enterococcus
Fecal Coliform
Total Coliform
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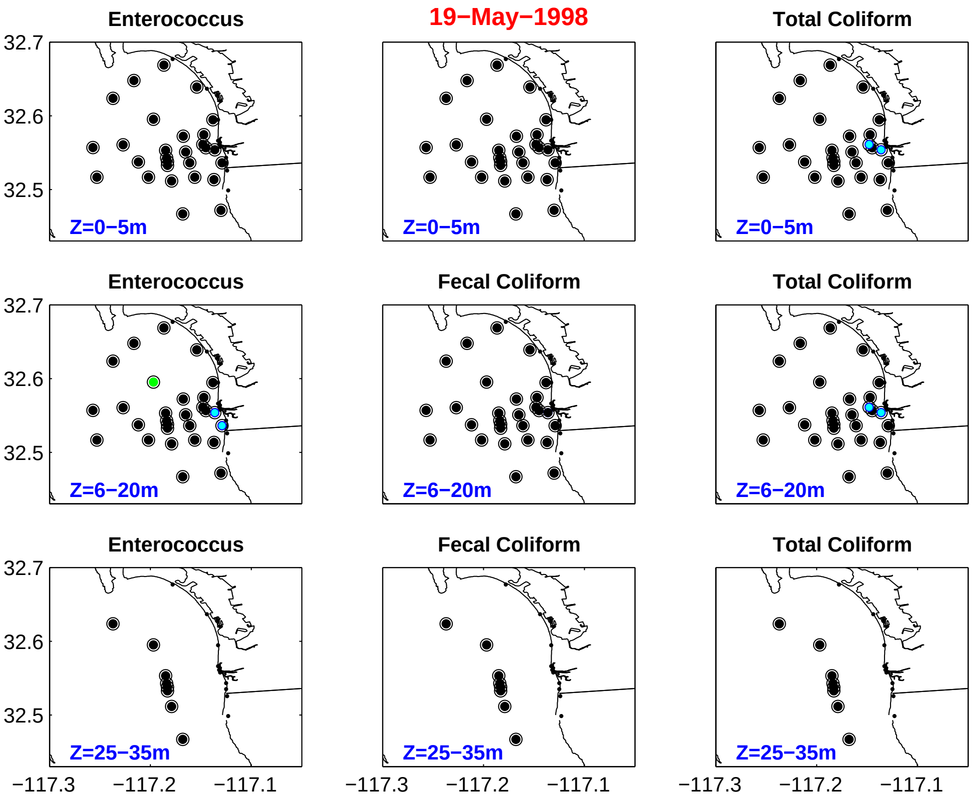
19−May−1998
Enterococcus
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Fecal Coliform
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Z=25−35m
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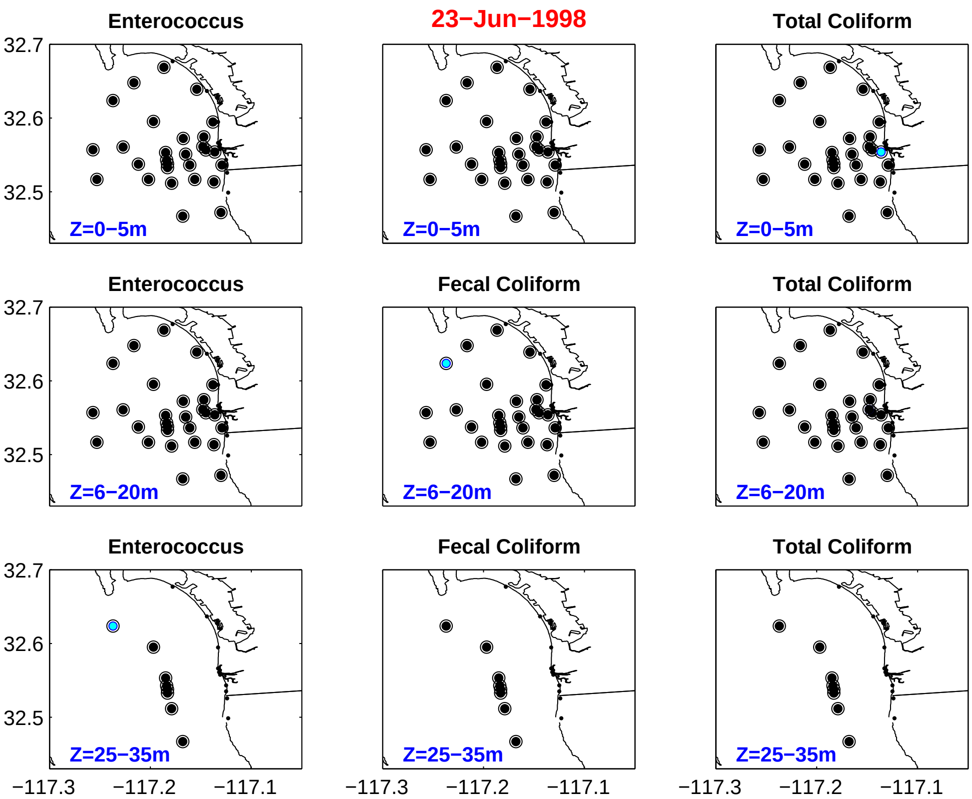
23−Jun−1998
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Total Coliform
Fecal Coliform
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Z=25−35m
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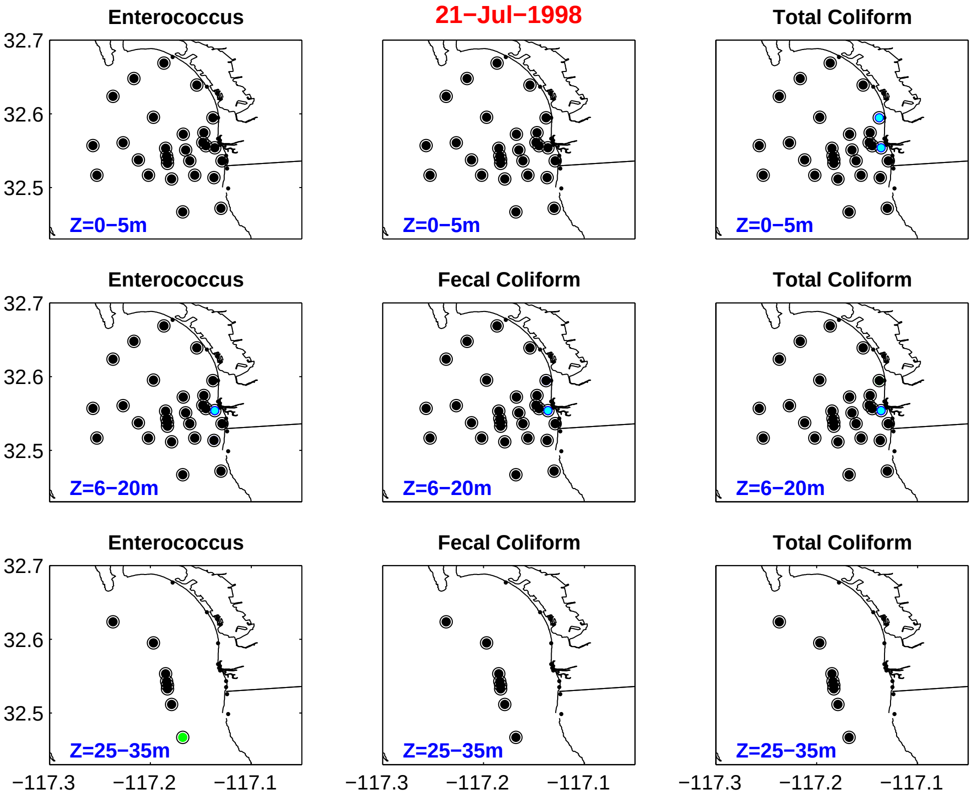
21−Jul−1998
Enterococcus
Fecal Coliform
Total Coliform
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Z=6−20m
Z=25−35m
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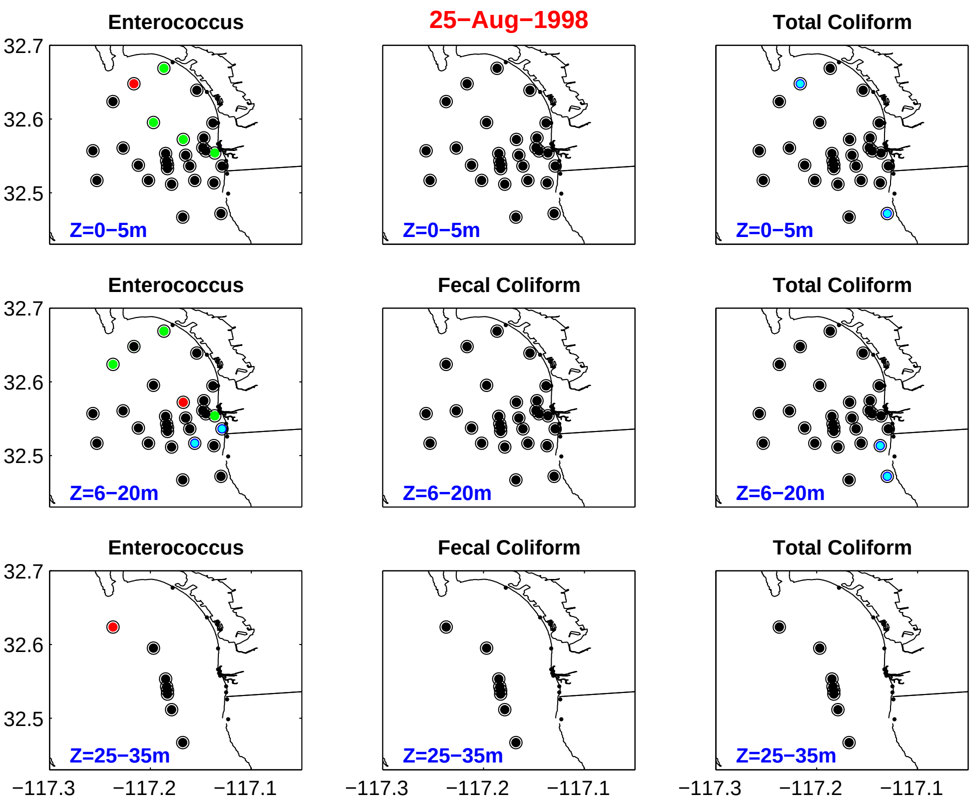
25−Aug−1998
Enterococcus
Fecal Coliform
Total Coliform
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Z=25−35m
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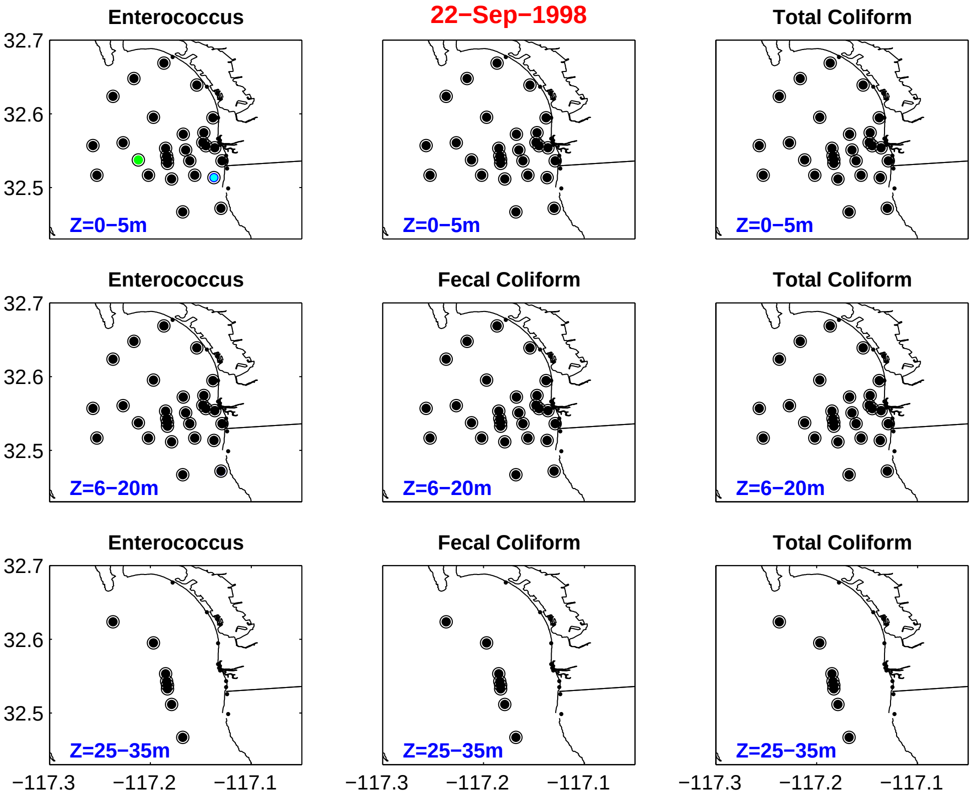
22−Sep−1998
Enterococcus
Fecal Coliform
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Z=25−35m
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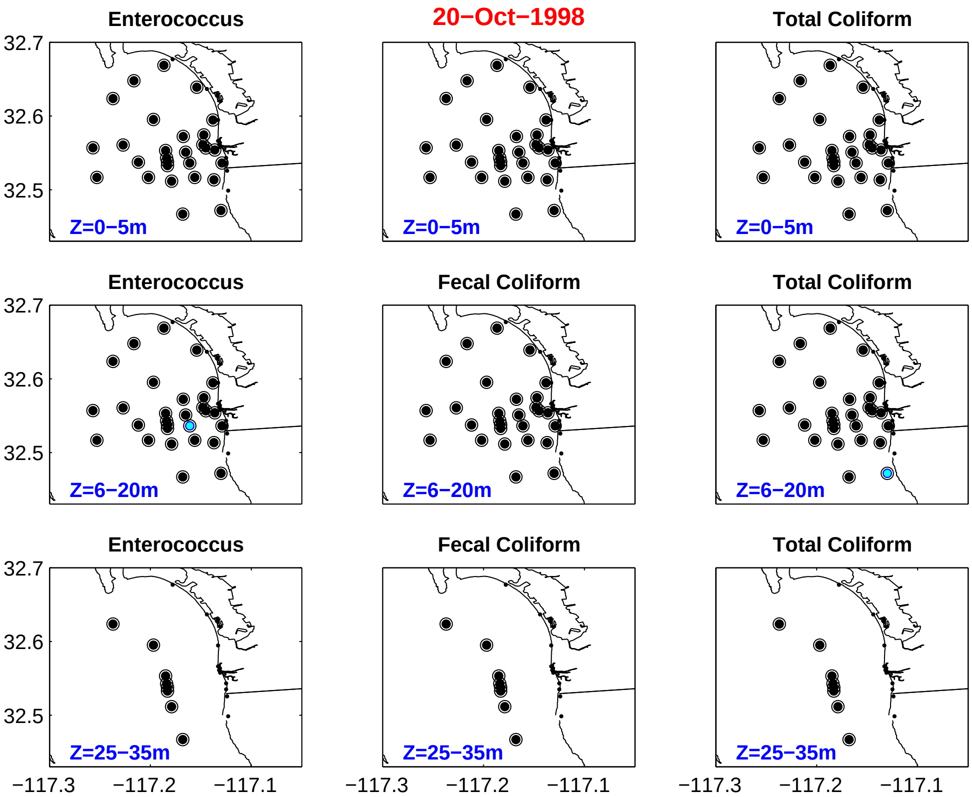
20−Oct−1998
Enterococcus
Fecal Coliform
Total Coliform
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Z=25−35m
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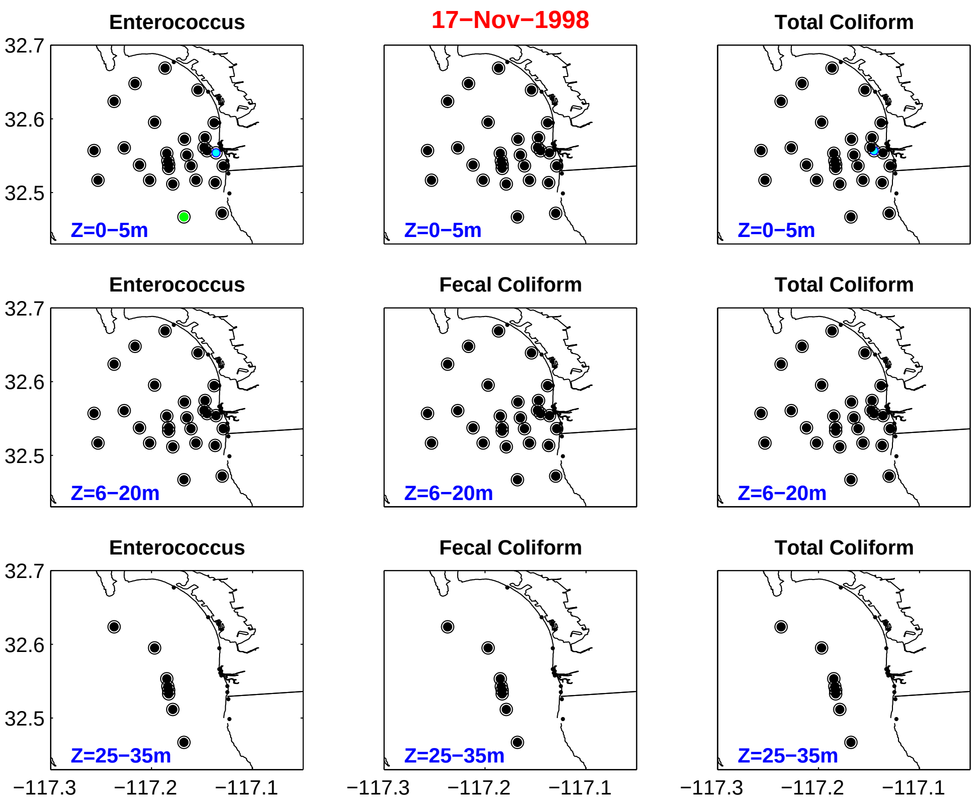
17−Nov−1998
Enterococcus
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Fecal Coliform
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Z=25−35m
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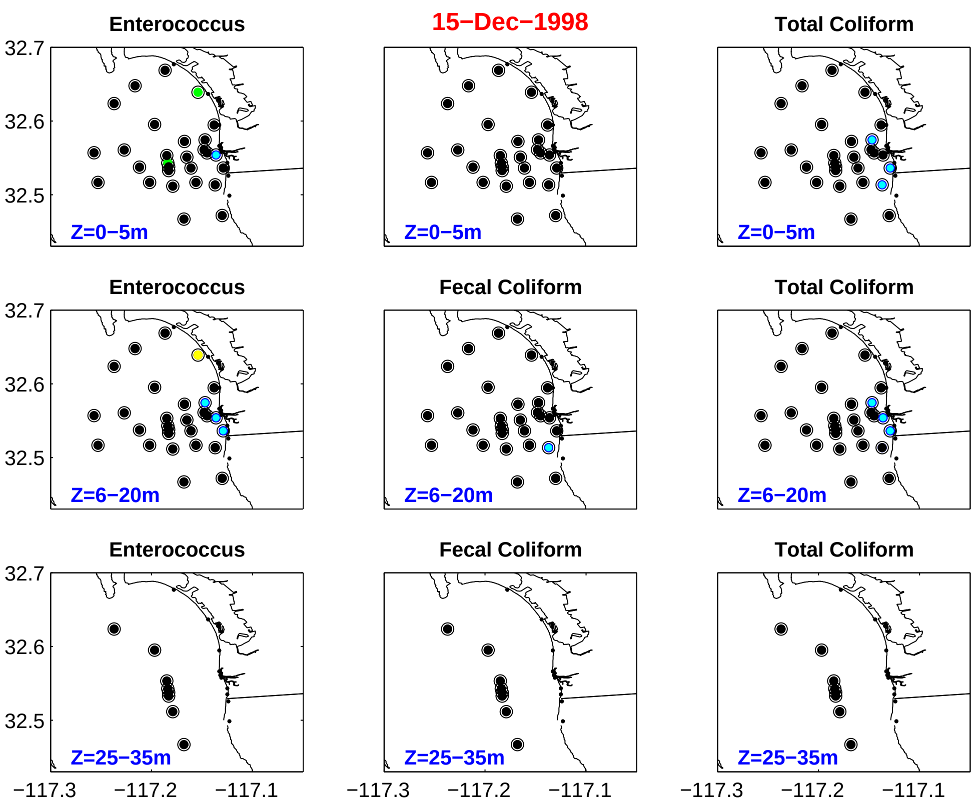
15−Dec−1998
Enterococcus
Total Coliform
Fecal Coliform
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Z=25−35m
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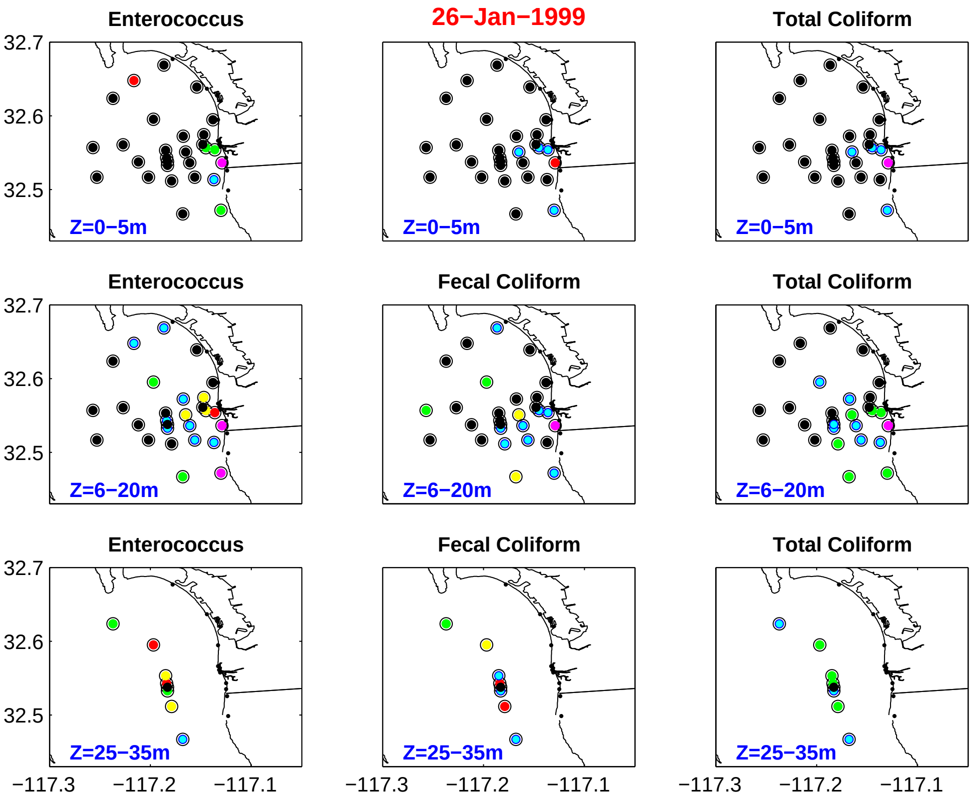
26−Jan−1999
Enterococcus
Total Coliform
Fecal Coliform
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Z=25−35m
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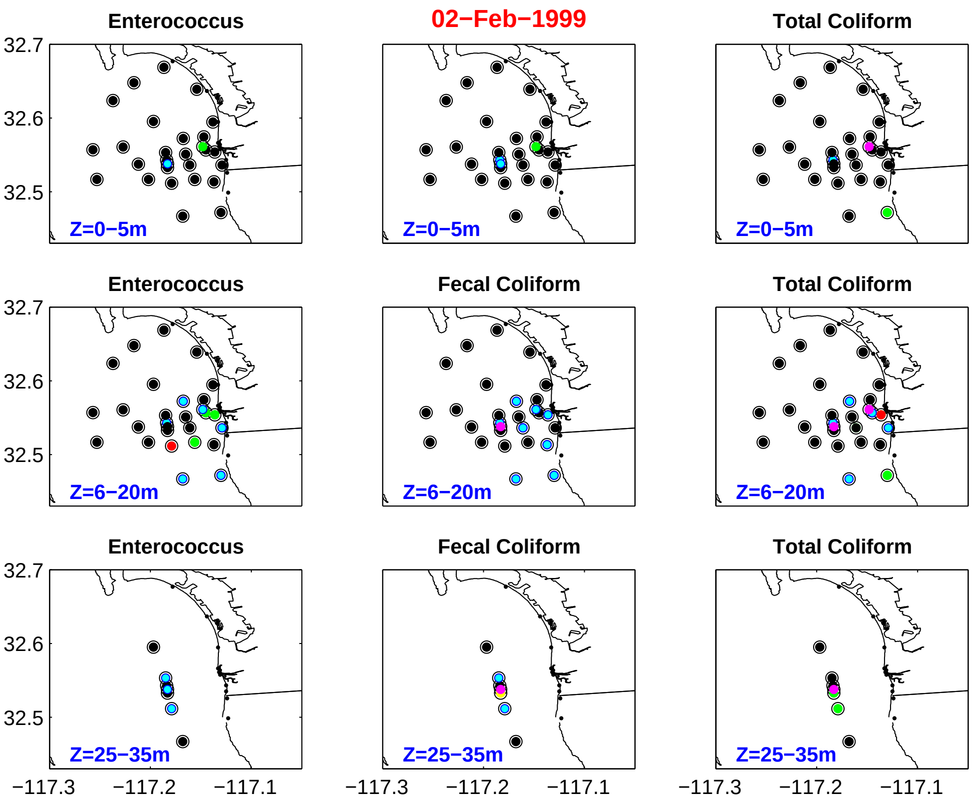
02−Feb−1999
Enterococcus
Total Coliform
Fecal Coliform
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Z=25−35m
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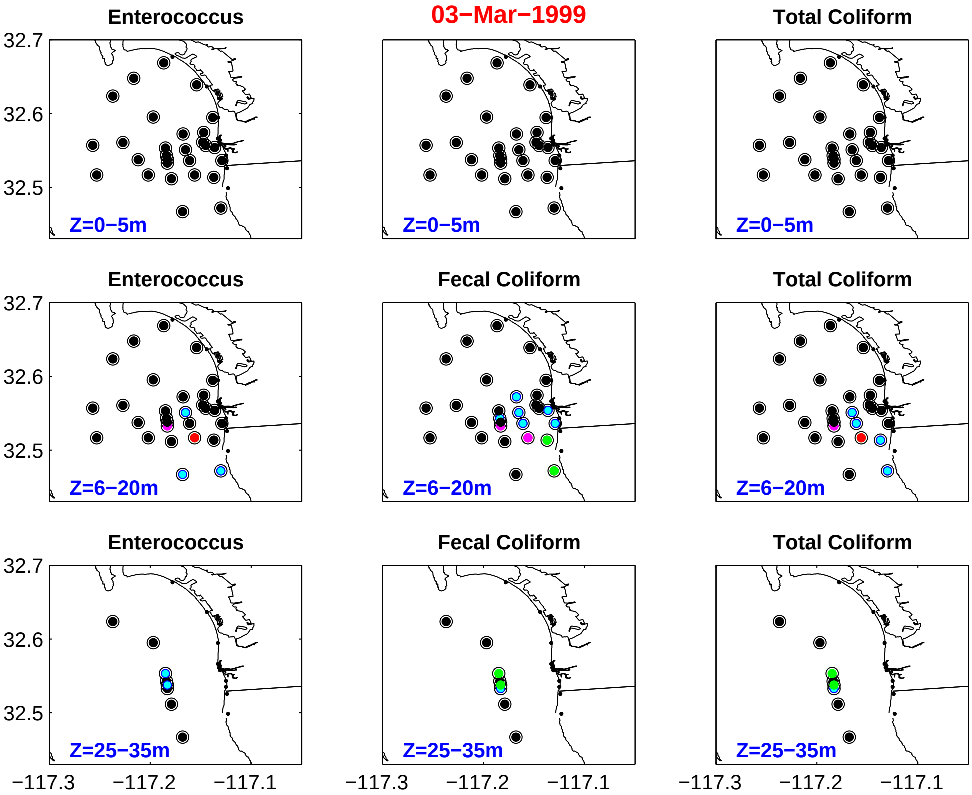
03−Mar−1999
Enterococcus
Fecal Coliform
Total Coliform
Z=0−5m
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Z=25−35m
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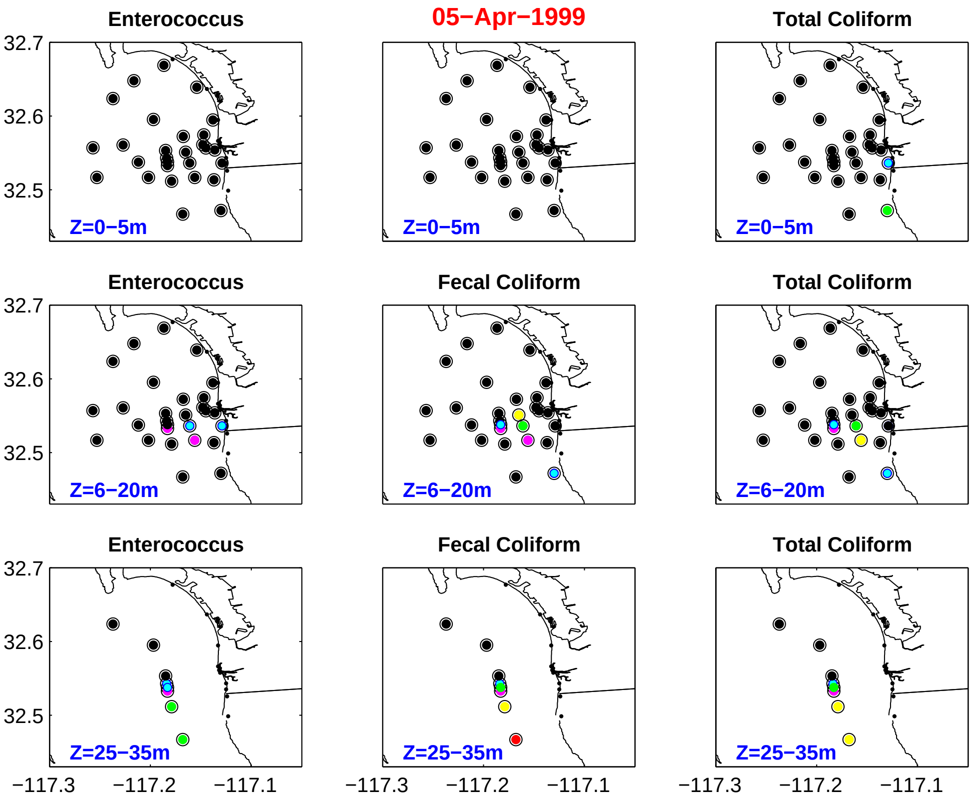
05−Apr−1999
Enterococcus
Fecal Coliform
Total Coliform
Z=0−5m
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Z=25−35m
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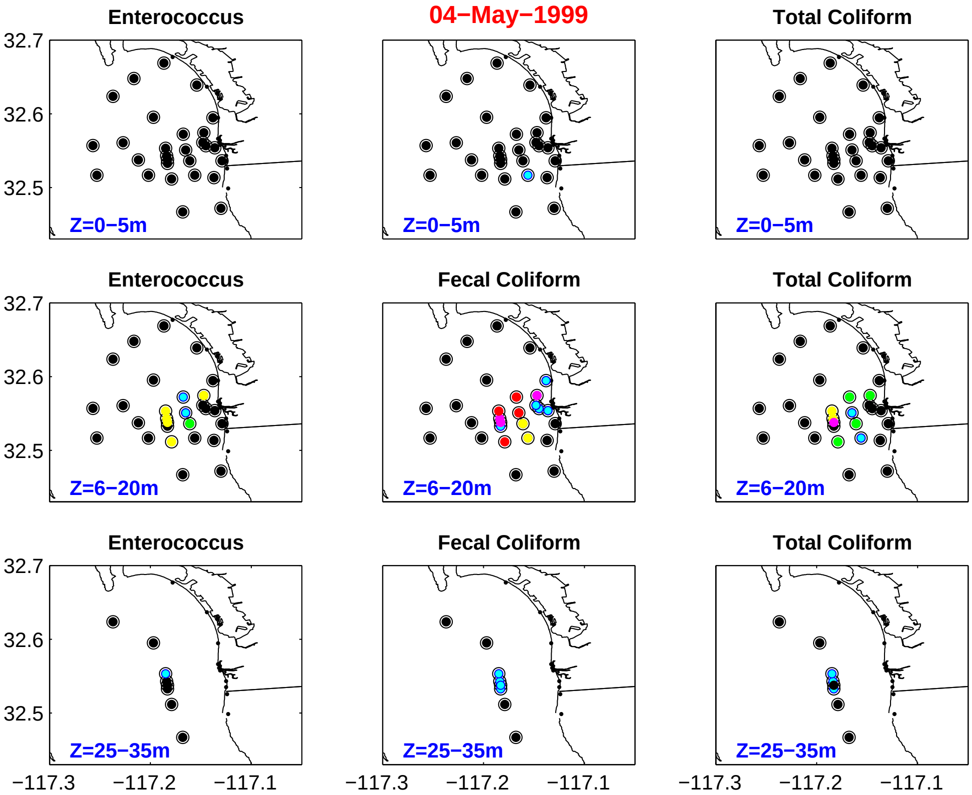
04−May−1999
Enterococcus
Fecal Coliform
Total Coliform
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Z=0−5m
Z=6−20m
Z=25−35m
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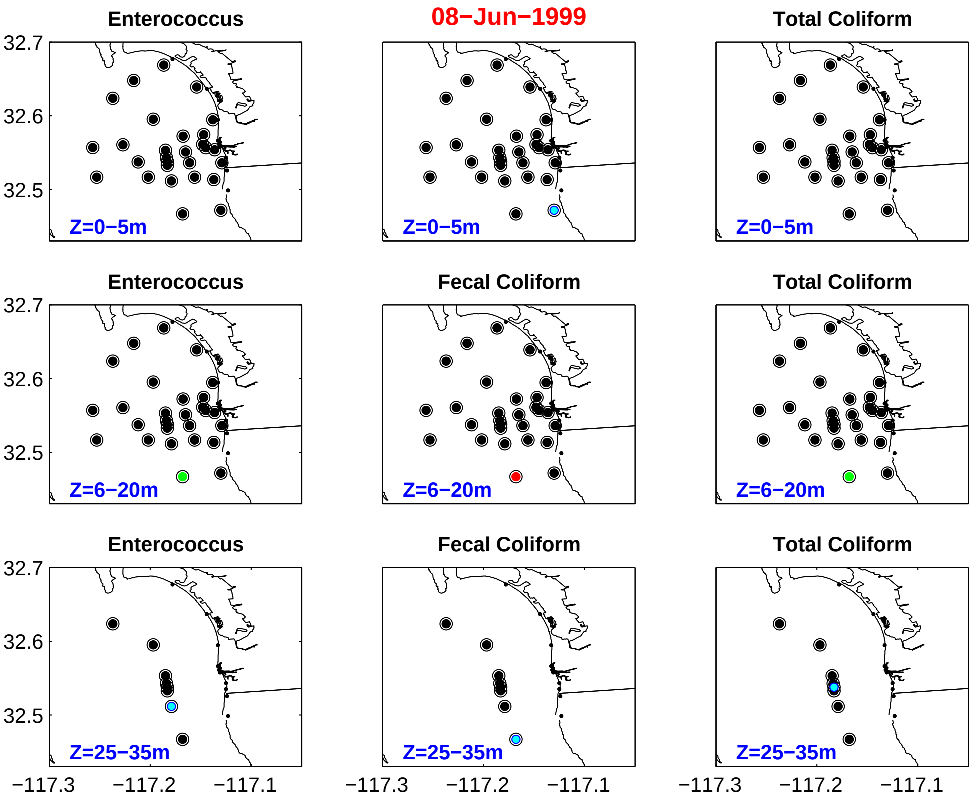
08−Jun−1999
Enterococcus
Fecal Coliform
Total Coliform
32.7
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32.5
Z=0−5m
Z=6−20m
Z=25−35m
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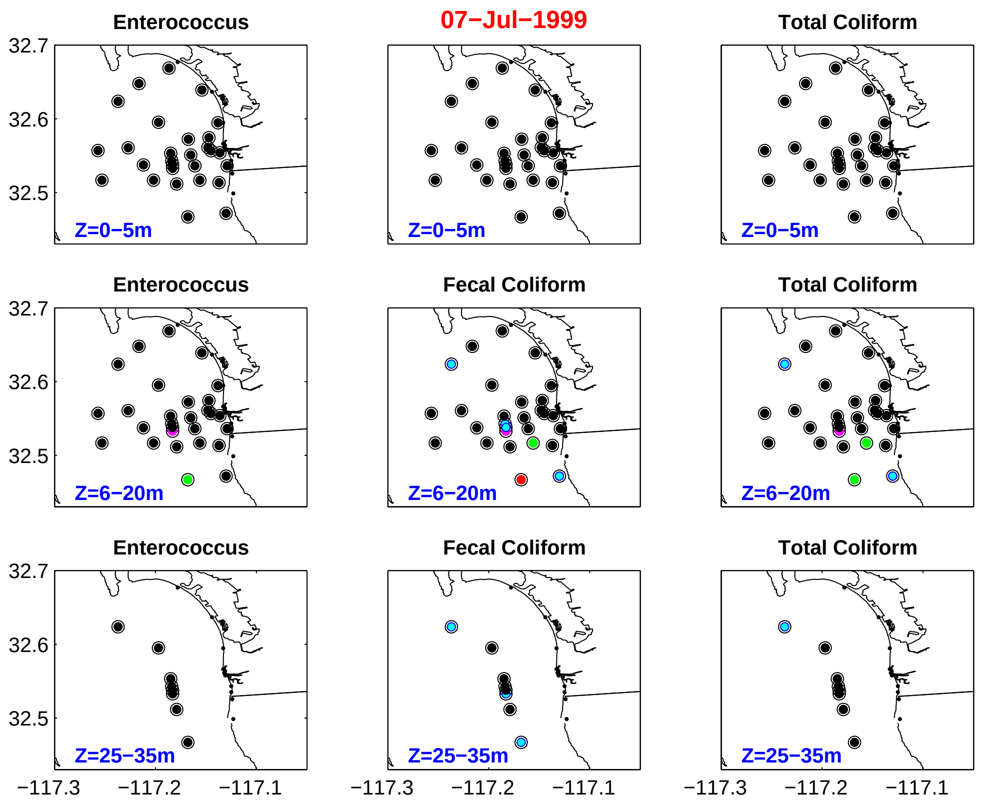

07−Jul−1999
Enterococcus
Fecal Coliform
Total Coliform
Z=0−5m
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Z=25−35m
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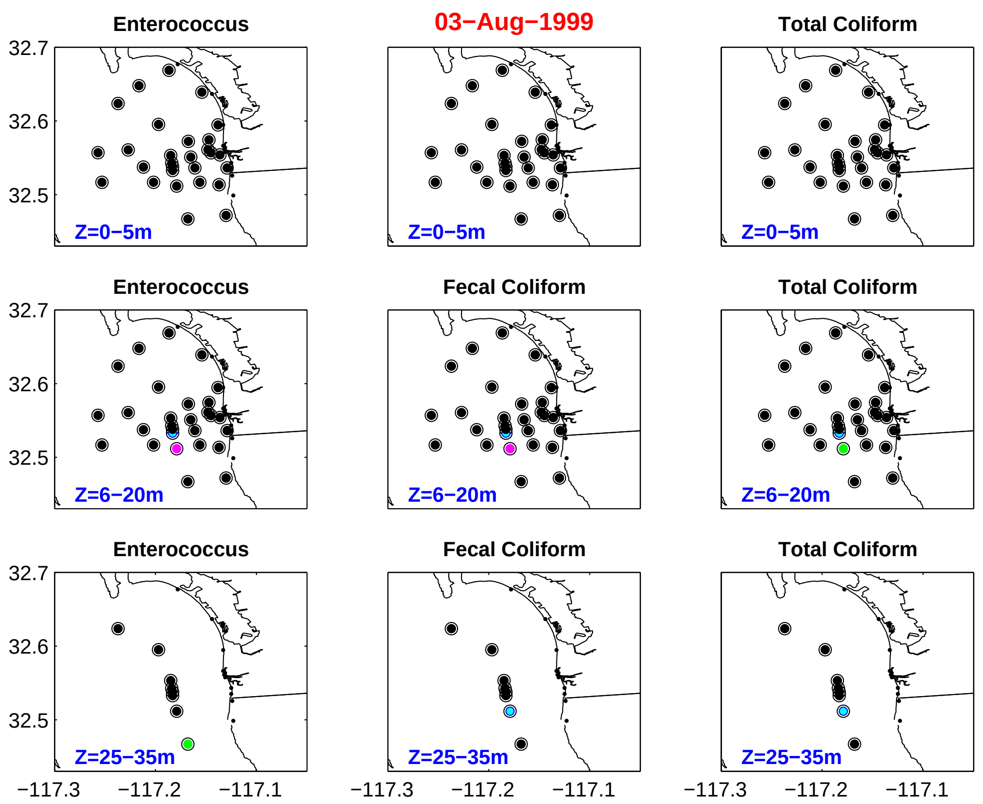

03−Aug−1999
Enterococcus
Fecal Coliform
Total Coliform
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Z=25−35m
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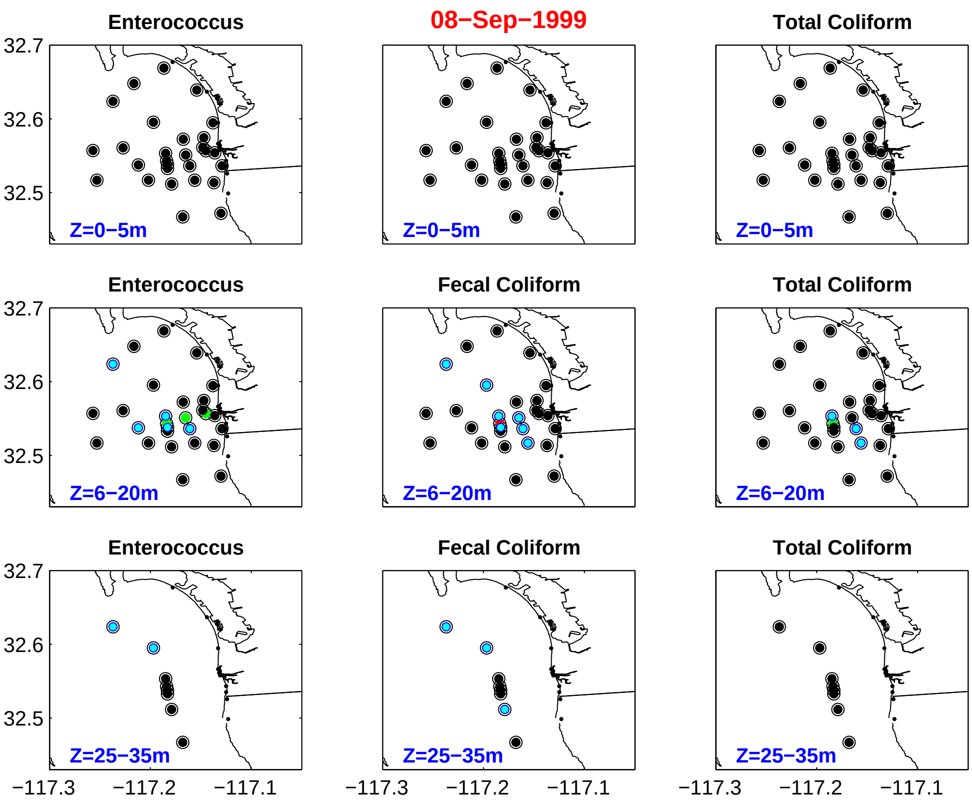
08−Sep−1999
Enterococcus
Fecal Coliform
Total Coliform
Z=0−5m
Z=6−20m
Z=25−35m
32.7
32.6
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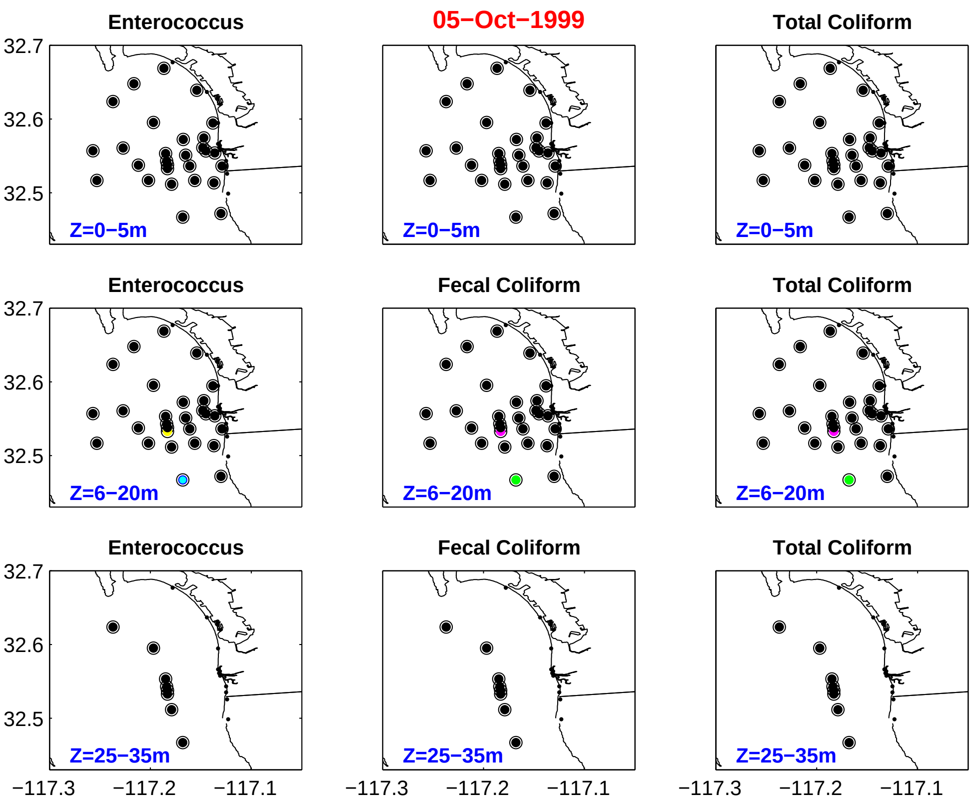
05−Oct−1999
Enterococcus
Fecal Coliform
Total Coliform
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Z=25−35m
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32.5
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−117.2
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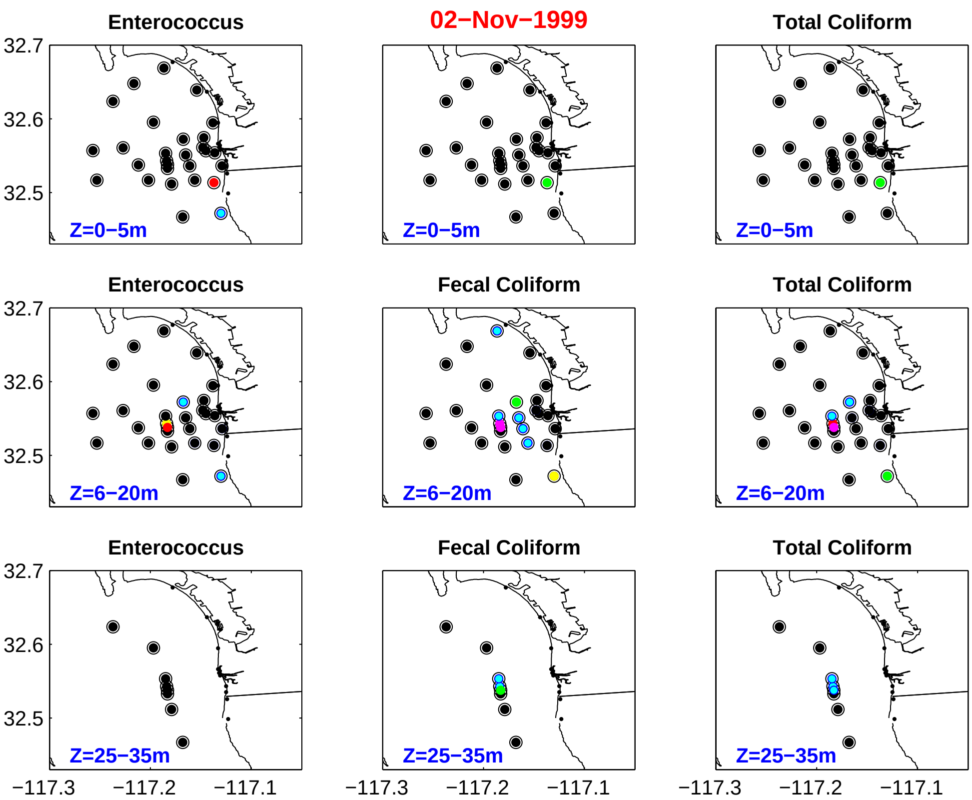
02−Nov−1999
Enterococcus
Fecal Coliform
Total Coliform
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Z=6−20m
Z=25−35m
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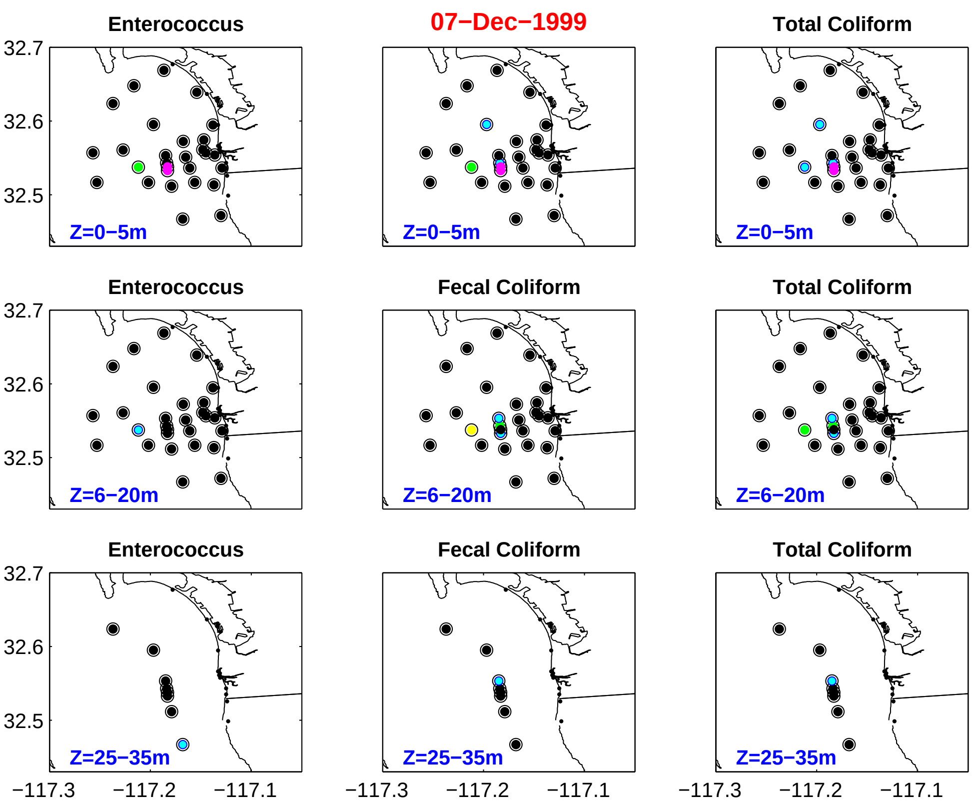
07−Dec−1999
Enterococcus
Fecal Coliform
Total Coliform
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Z=6−20m
Z=25−35m
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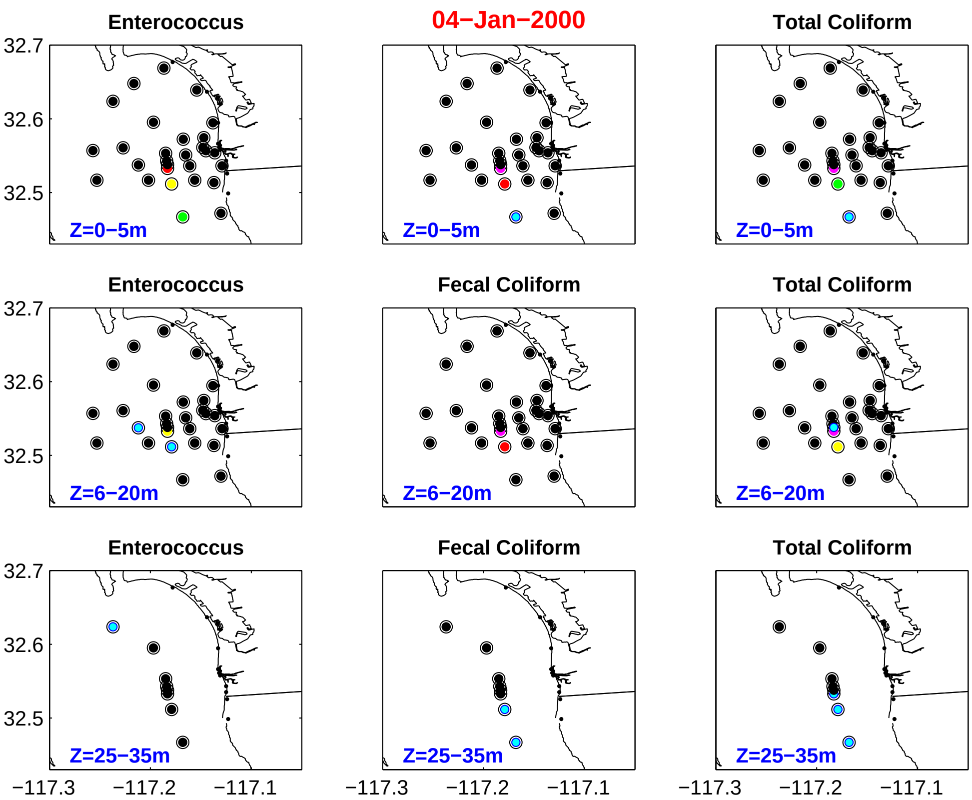
04−Jan−2000
Enterococcus
Total Coliform
Fecal Coliform
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Z=6−20m
Z=25−35m
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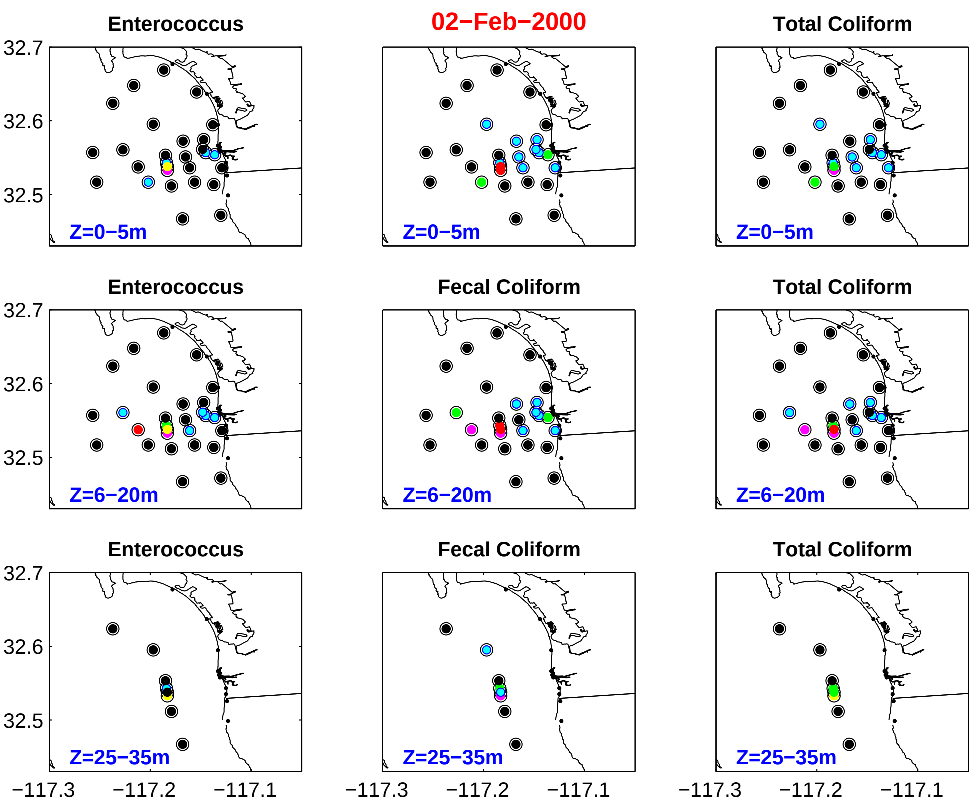
02−Feb−2000
Enterococcus
Total Coliform
Fecal Coliform
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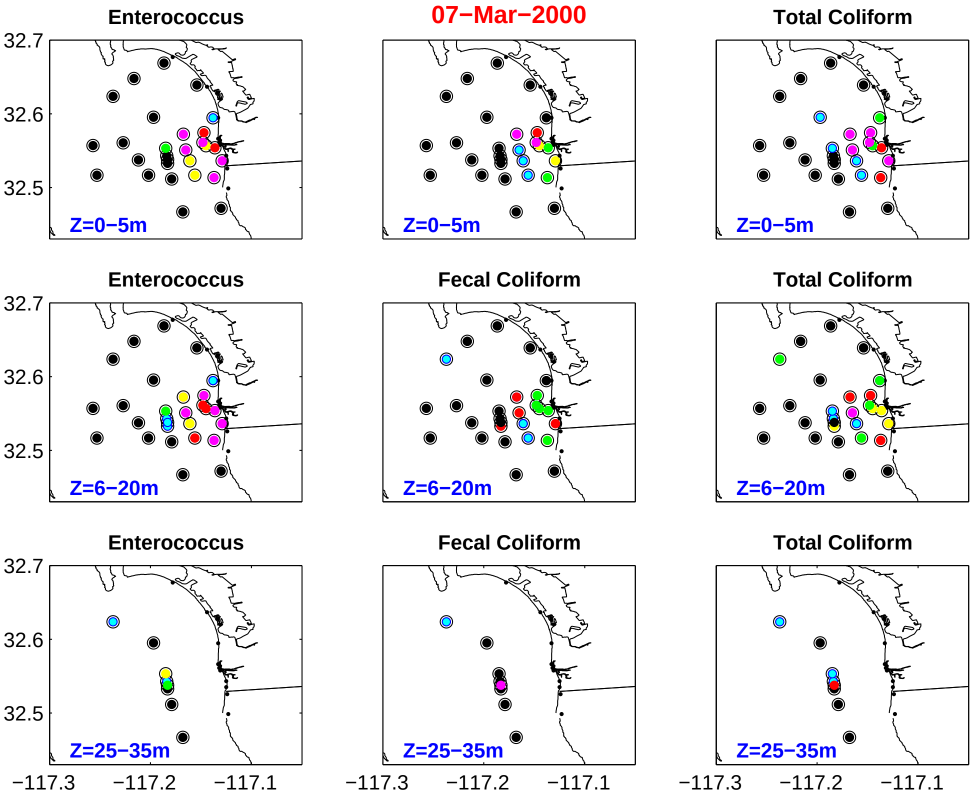
07−Mar−2000
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Z=0−5m
Enterococcus
Fecal Coliform
Total Coliform
Z=6−20m
Z=6−20m
Z=6−20m
Enterococcus
Fecal Coliform
Total Coliform
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Z=25−35m
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32.5
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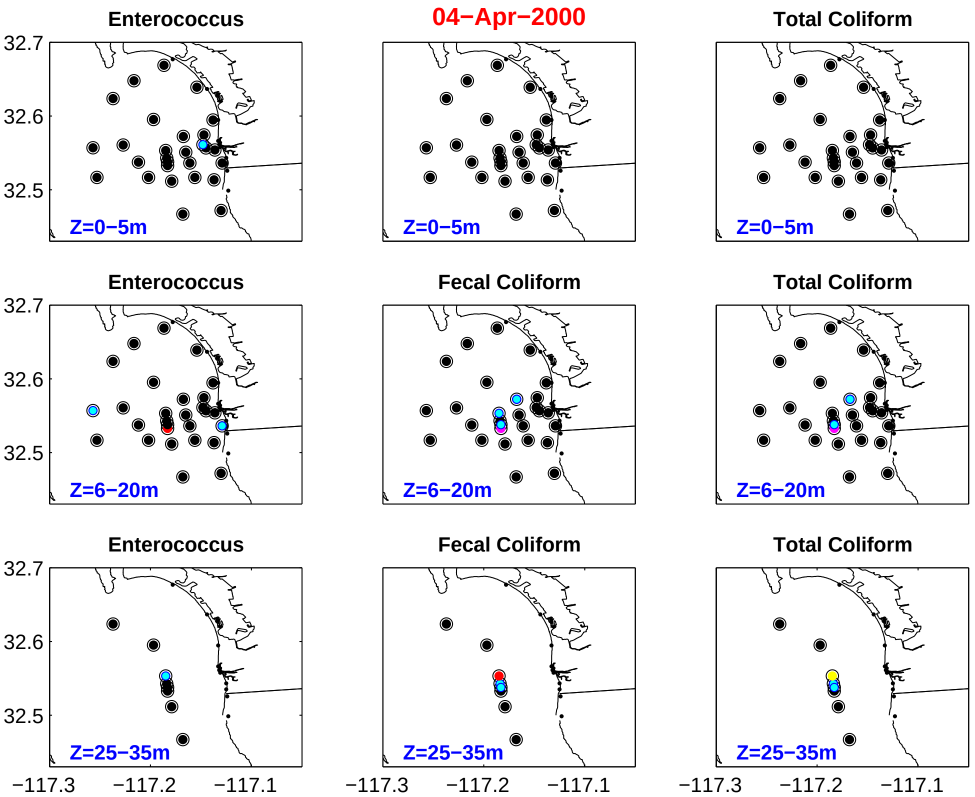
04−Apr−2000
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Total Coliform
Z=0−5m
Z=0−5m
Z=0−5m
Enterococcus
Fecal Coliform
Total Coliform
Z=6−20m
Z=6−20m
Z=6−20m
Enterococcus
Fecal Coliform
Total Coliform
Z=25−35m
Z=25−35m
Z=25−35m
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32.5
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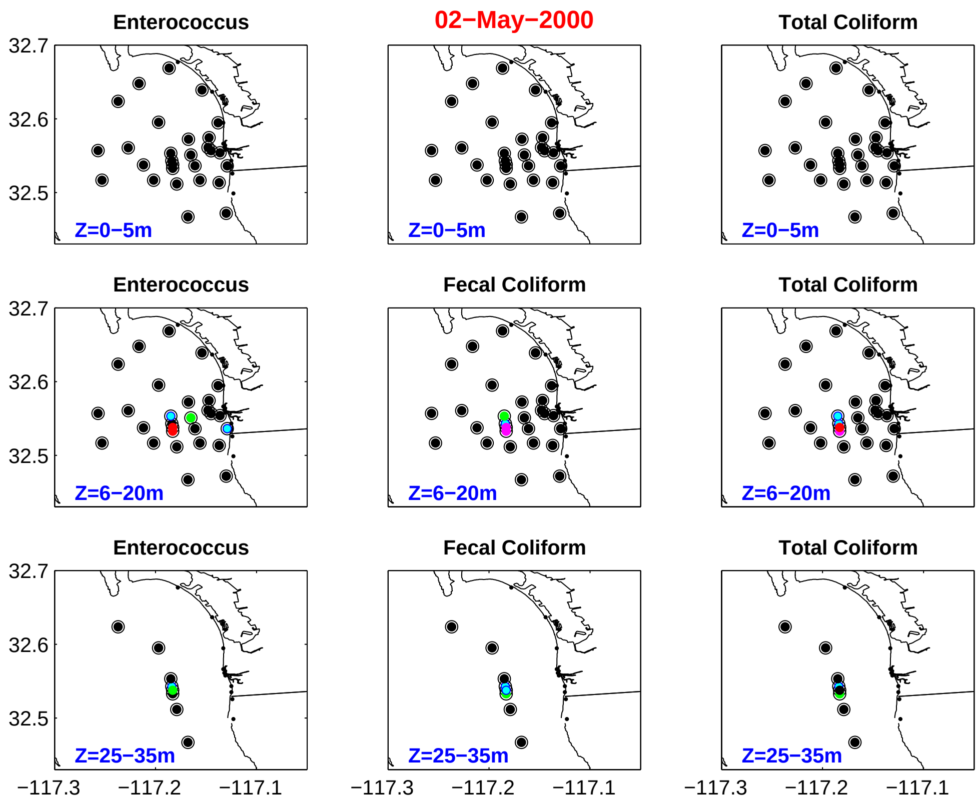
02−May−2000
Enterococcus
Total Coliform
Fecal Coliform
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Z=25−35m
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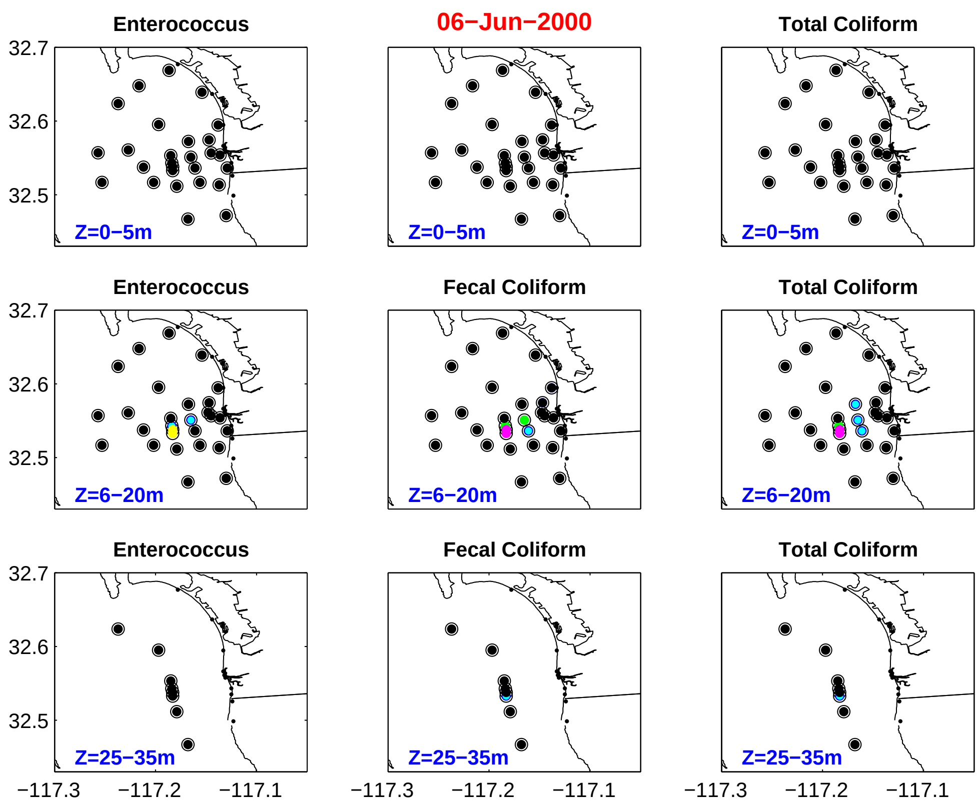
06−Jun−2000
Enterococcus
Total Coliform
Fecal Coliform
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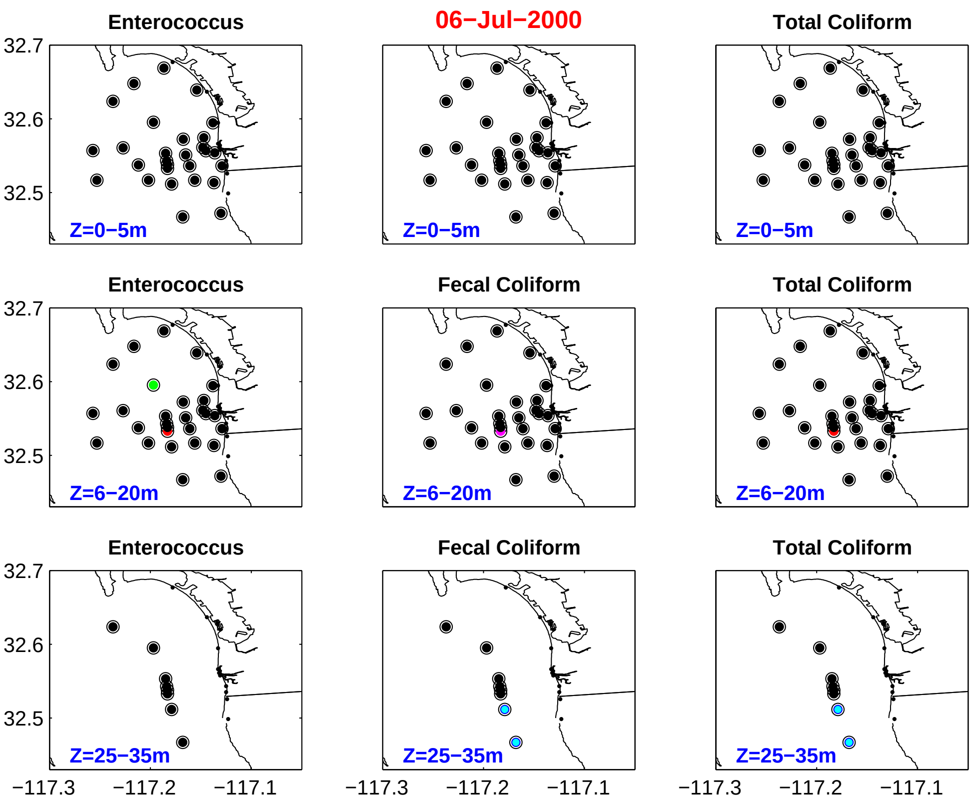
06−Jul−2000
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Total Coliform
Z=0−5m
Z=0−5m
Z=0−5m
Enterococcus
Fecal Coliform
Total Coliform
Z=6−20m
Z=6−20m
Z=6−20m
Enterococcus
Fecal Coliform
Total Coliform
Z=25−35m
Z=25−35m
Z=25−35m
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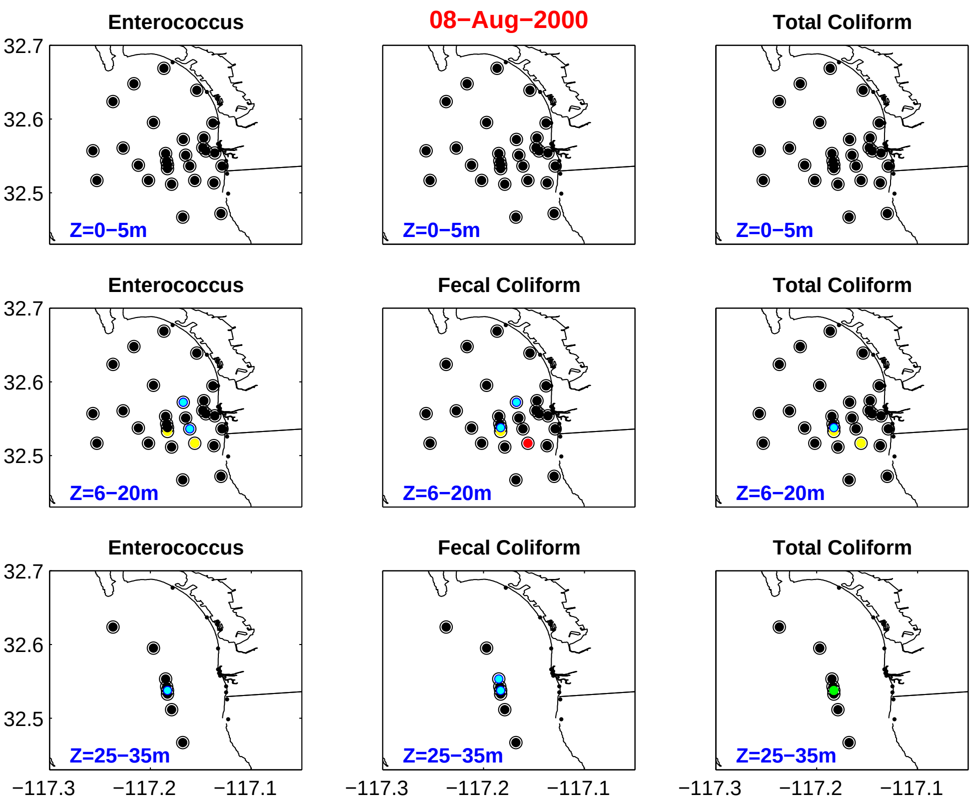
08−Aug−2000
Enterococcus
Total Coliform
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Z=0−5m
Z=0−5m
Enterococcus
Fecal Coliform
Total Coliform
Z=6−20m
Z=6−20m
Z=6−20m
Enterococcus
Fecal Coliform
Total Coliform
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Z=25−35m
Z=25−35m
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32.5
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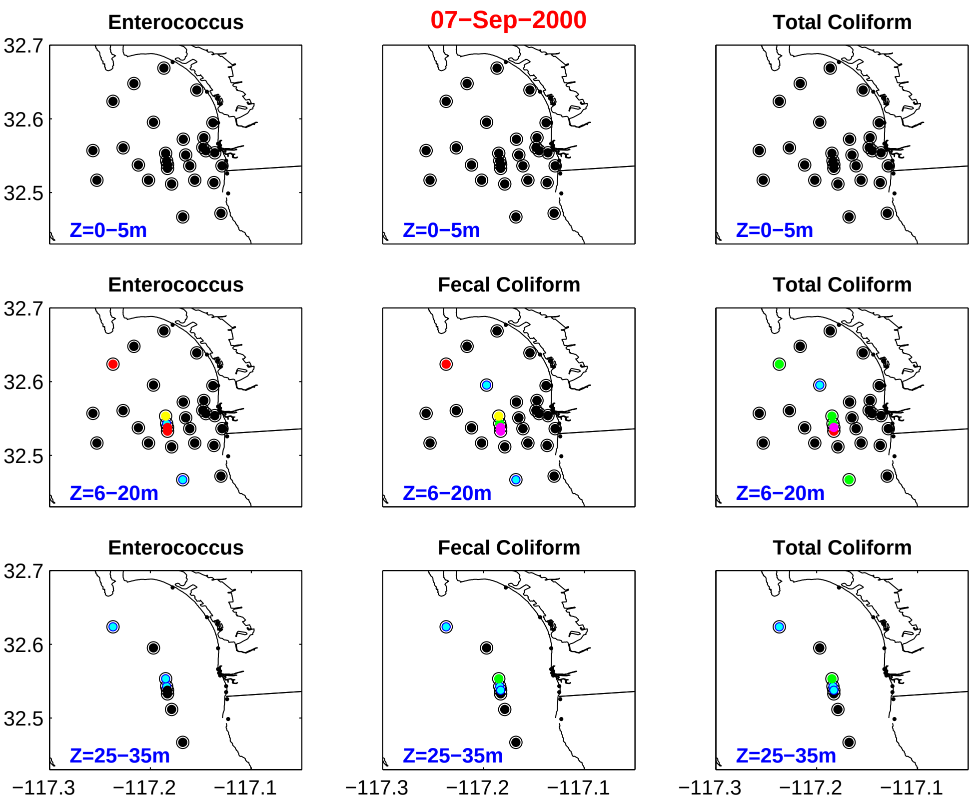
−117.1


07−Sep−2000
Enterococcus
Fecal Coliform
Total Coliform
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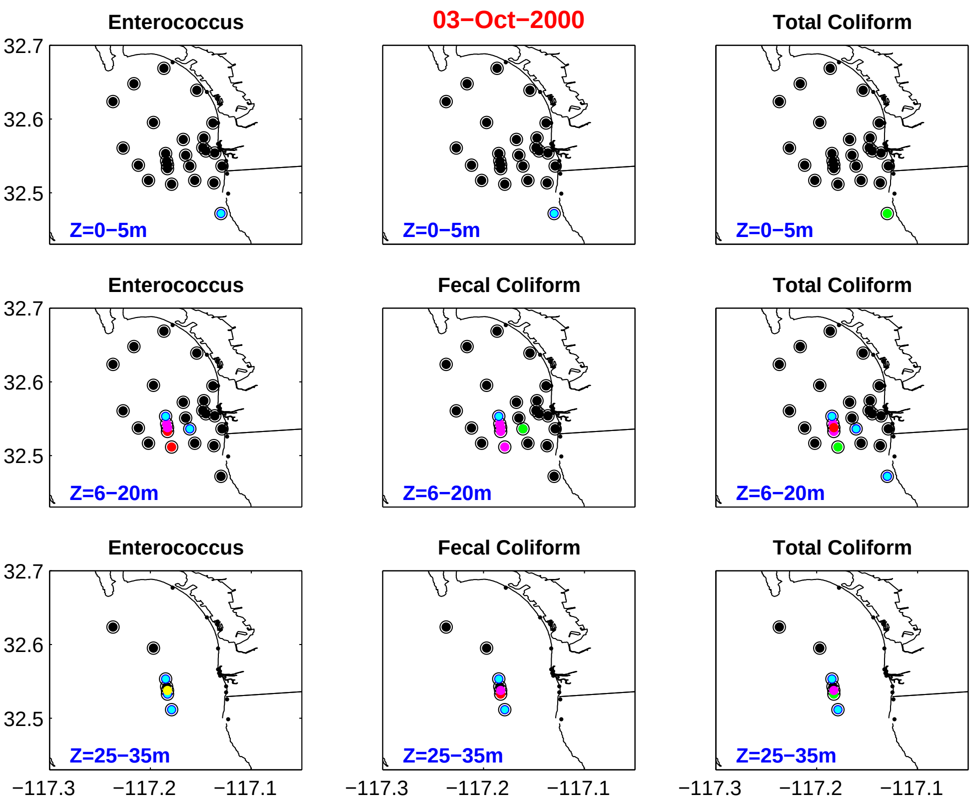
03−Oct−2000
Enterococcus
Fecal Coliform
Total Coliform
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Z=6−20m
Z=25−35m
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32.6
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−117.2
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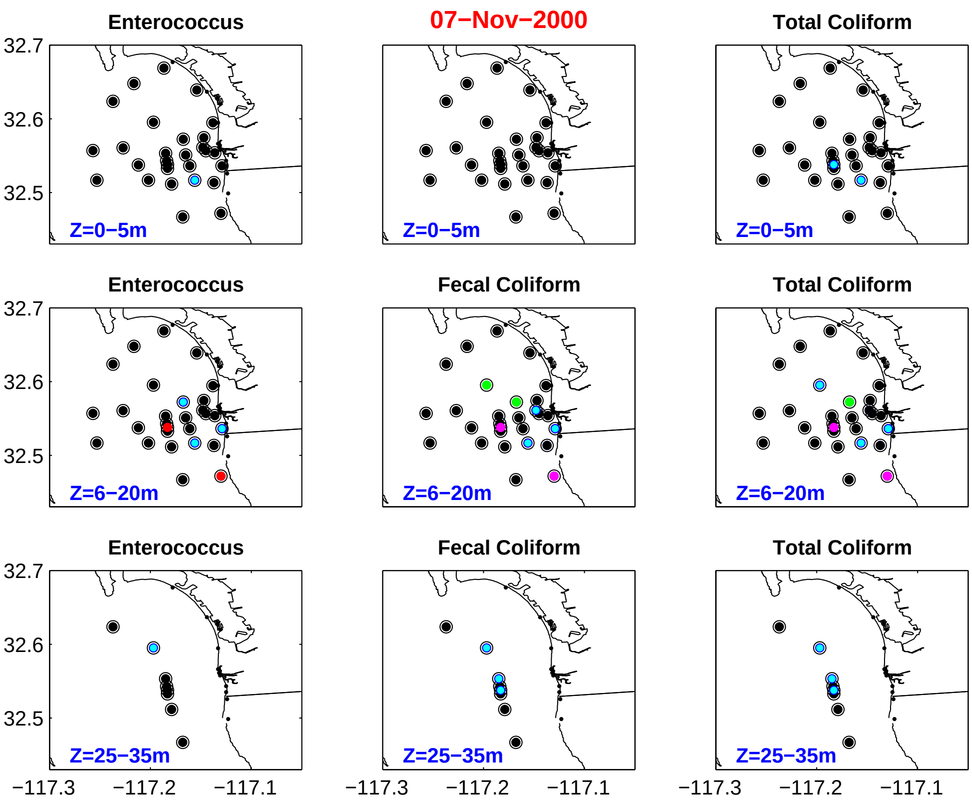
07−Nov−2000
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Total Coliform
Fecal Coliform
Enterococcus
Fecal Coliform
Total Coliform
Z=0−5m
Z=0−5m
Z=0−5m
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Z=6−20m
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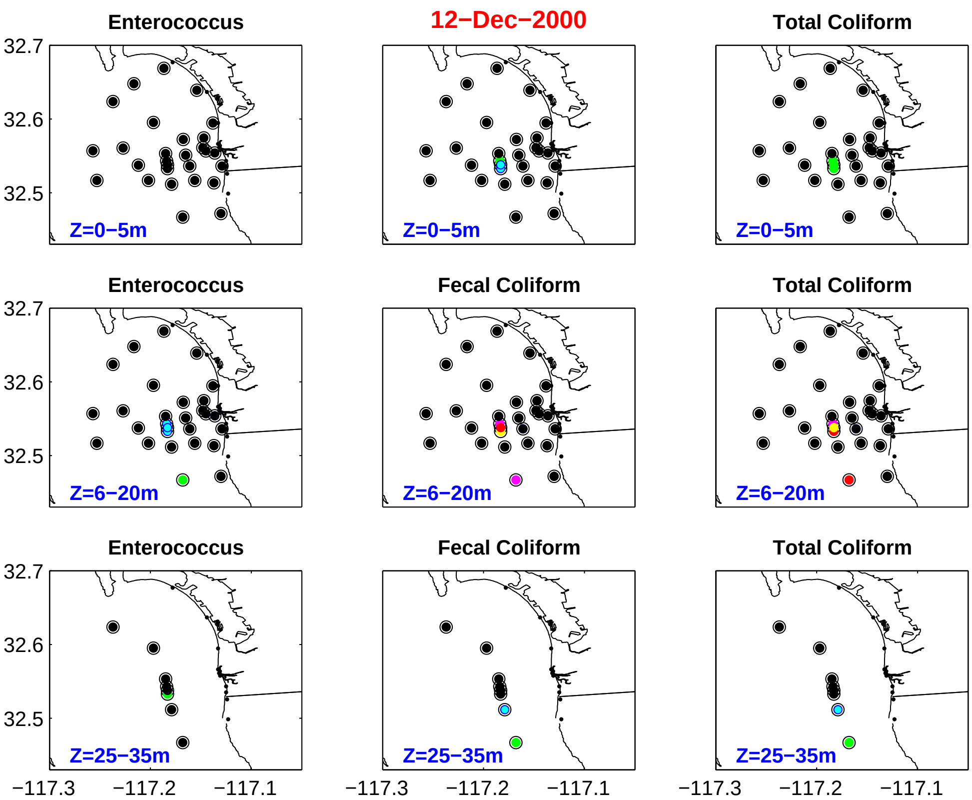
12−Dec−2000
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Total Coliform
Fecal Coliform
Enterococcus
Fecal Coliform
Total Coliform
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Z=0−5m
Z=0−5m
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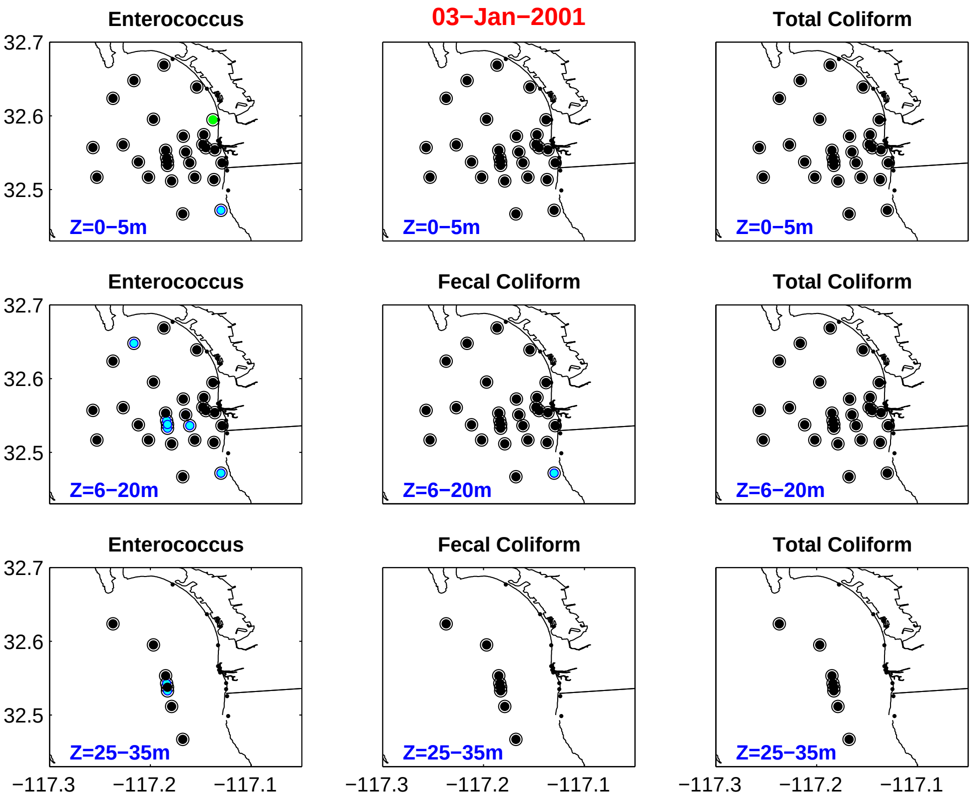
03−Jan−2001
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Fecal Coliform
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Z=25−35m
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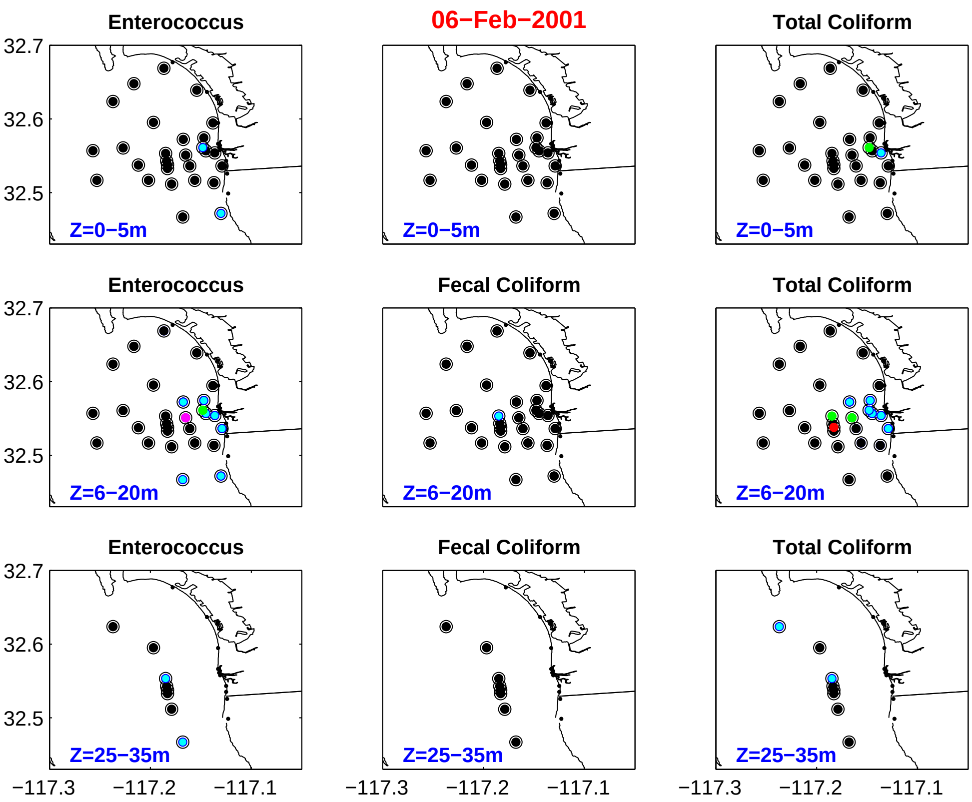
06−Feb−2001
Enterococcus
Total Coliform
Fecal Coliform
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Z=25−35m
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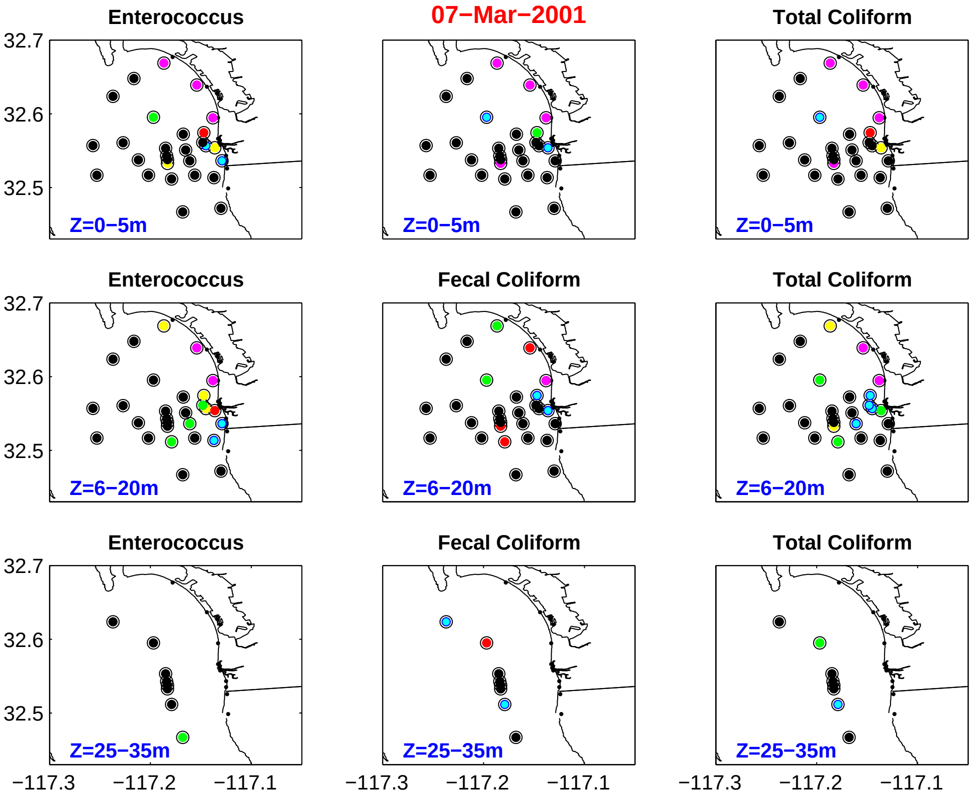
07−Mar−2001
Enterococcus
Total Coliform
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Enterococcus
Fecal Coliform
Total Coliform
Z=6−20m
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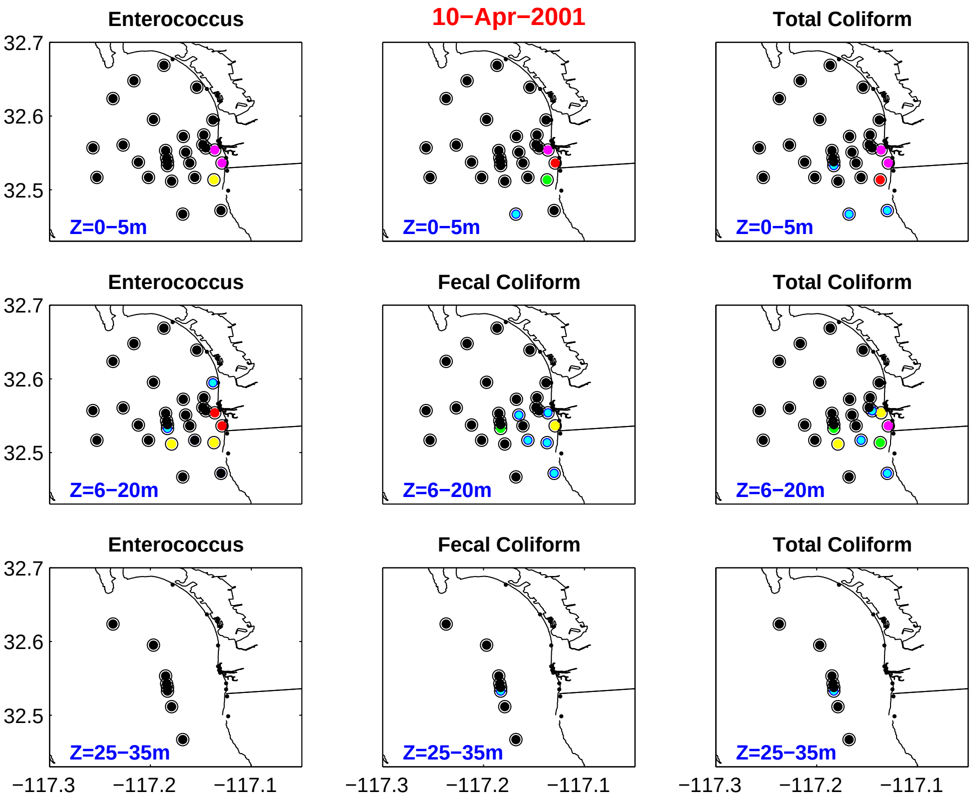
10−Apr−2001
Enterococcus
Total Coliform
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Enterococcus
Fecal Coliform
Total Coliform
Z=6−20m
Enterococcus
Fecal Coliform
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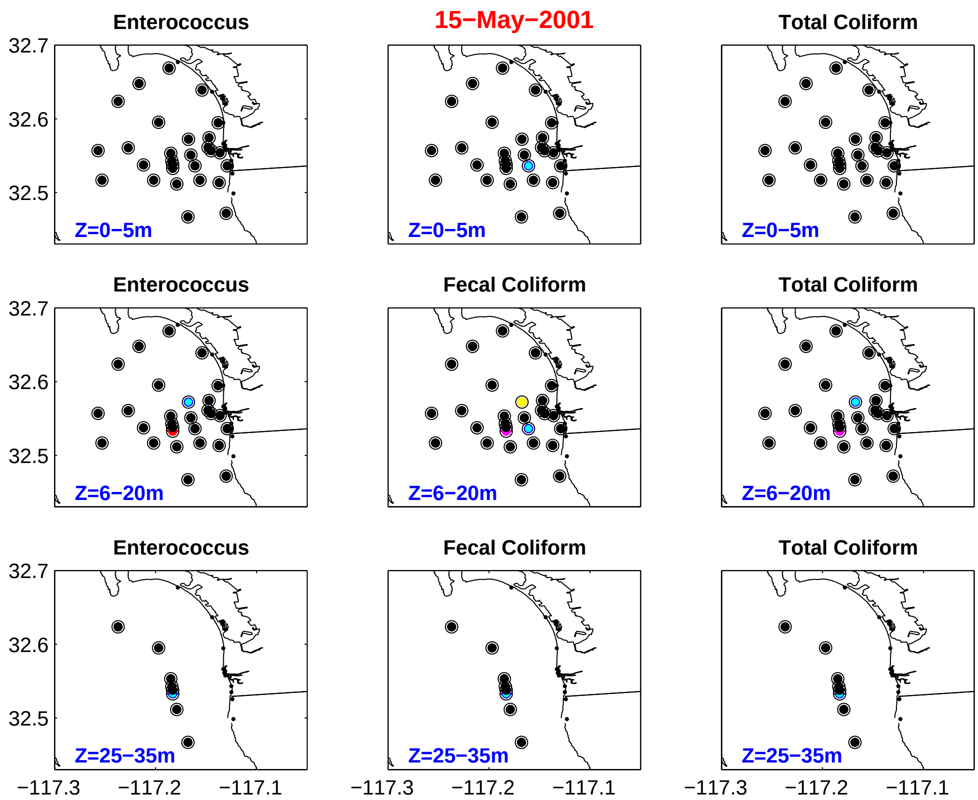
Enterococcus
15−May−2001
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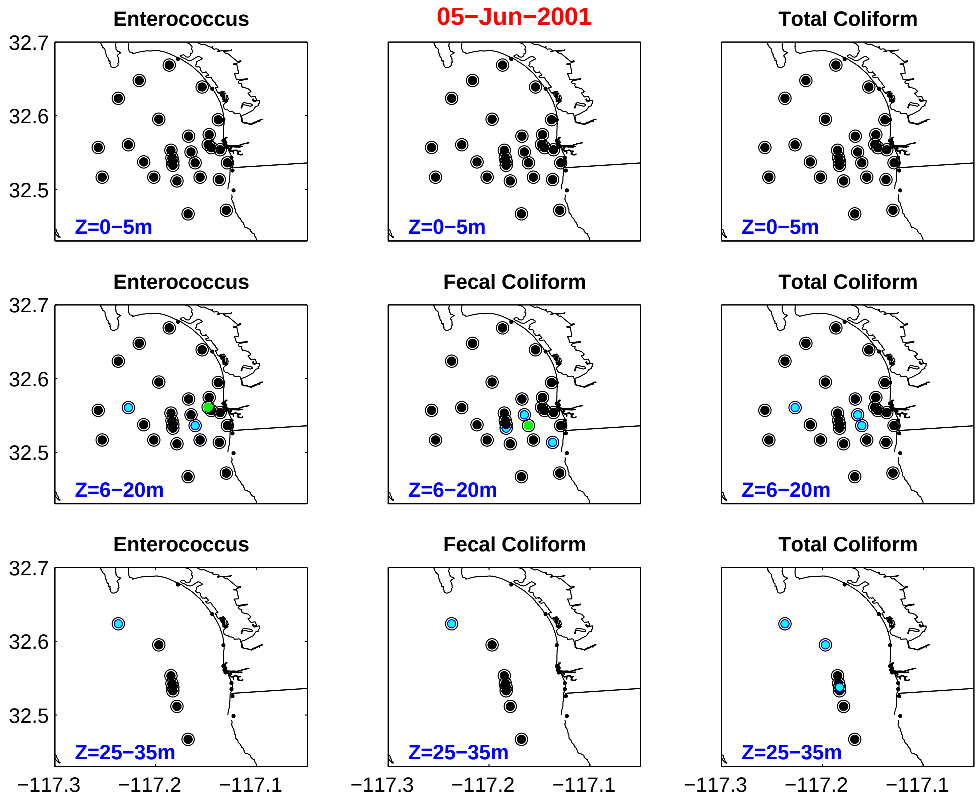
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05−Jun−2001
Total Coliform
Fecal Coliform
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32.5
Z=0−5m
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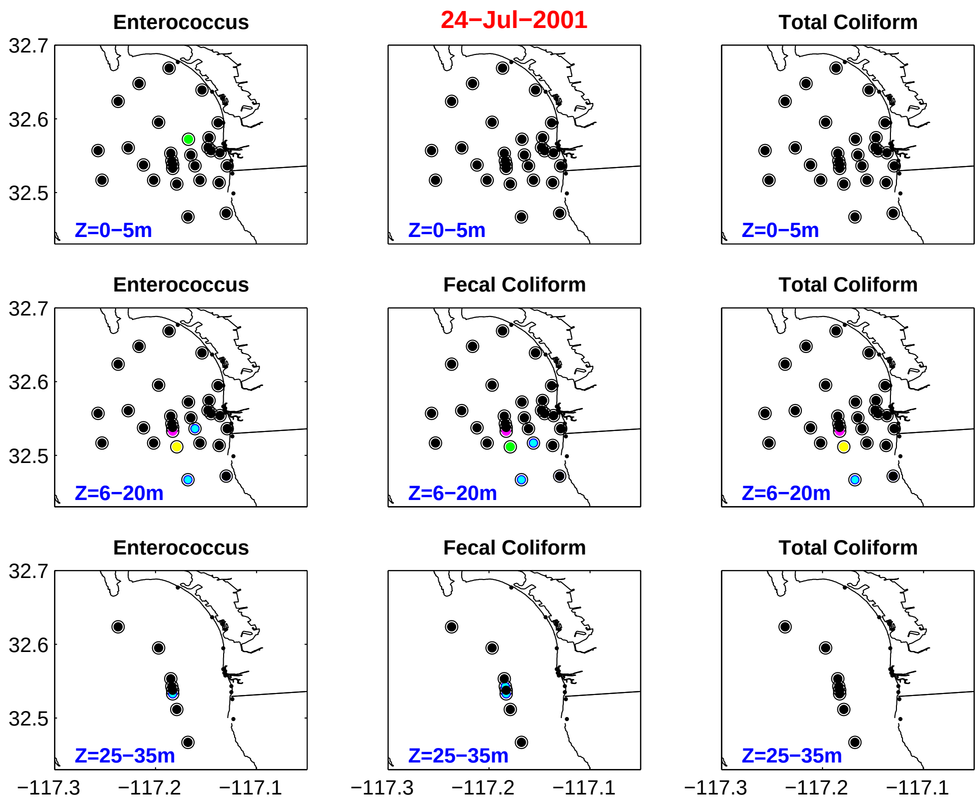
24−Jul−2001
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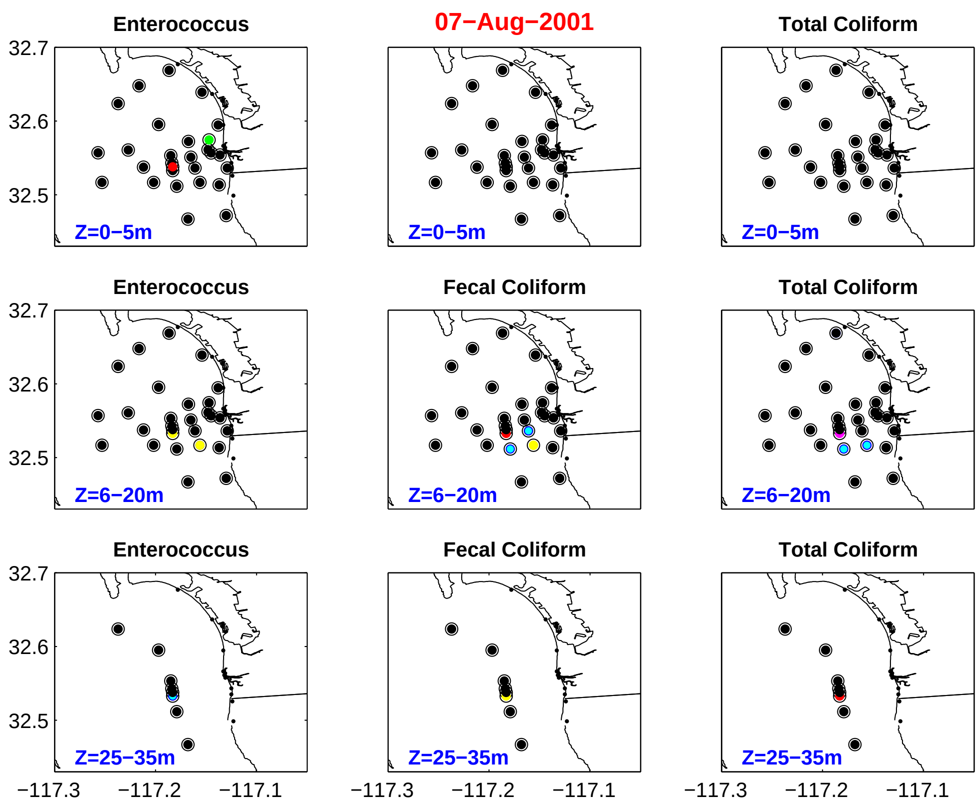
07−Aug−2001
Enterococcus
Fecal Coliform
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Z=25−35m
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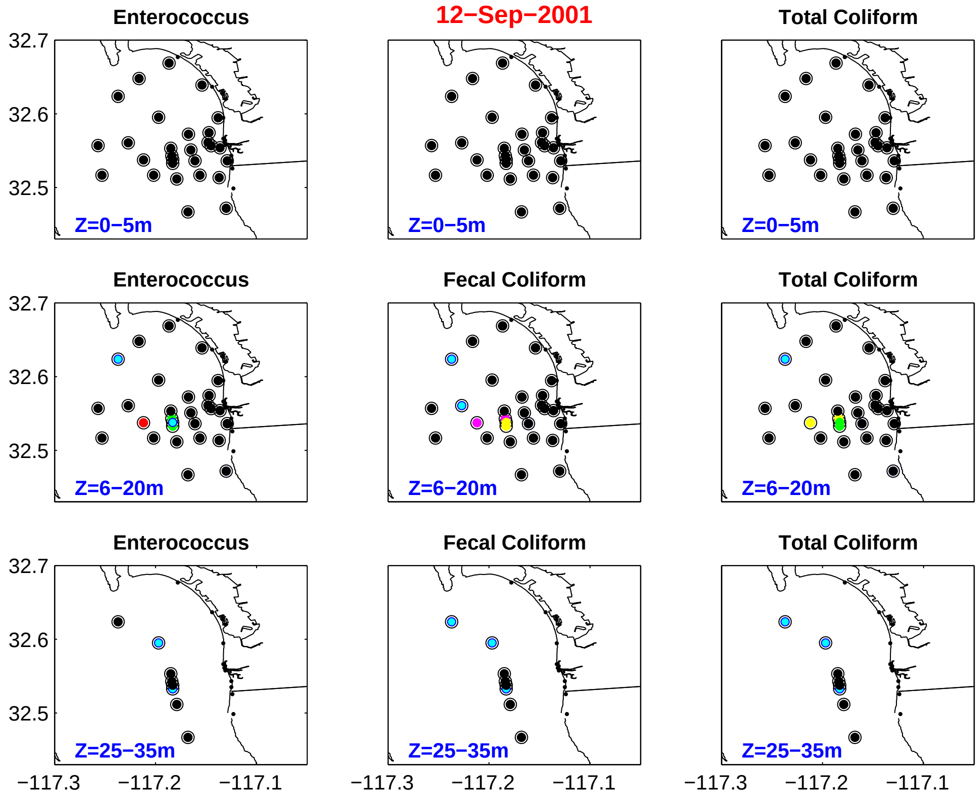
12−Sep−2001
Enterococcus
Fecal Coliform
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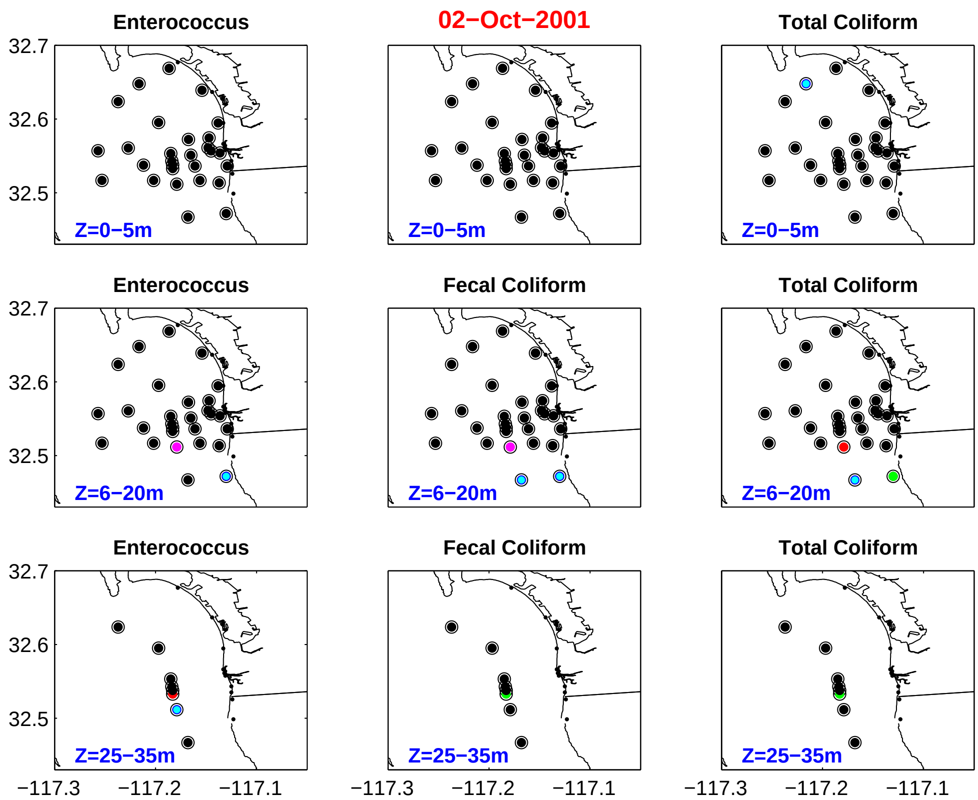
02−Oct−2001
Enterococcus
Fecal Coliform
Total Coliform
Z=0−5m
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Z=25−35m
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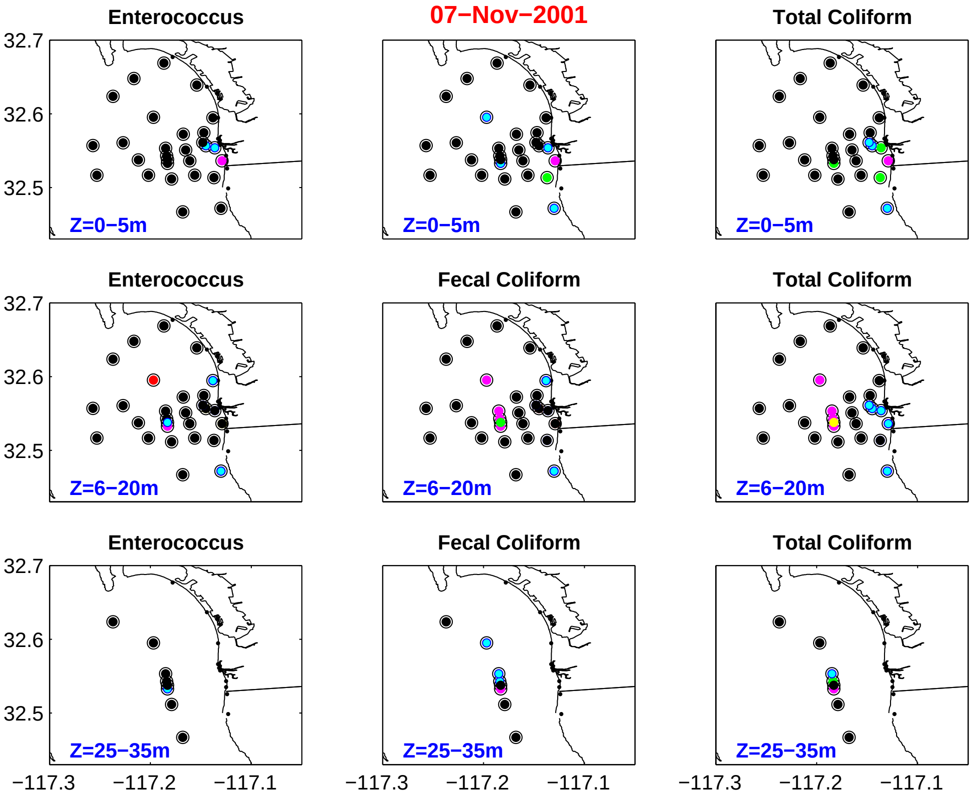
07−Nov−2001
Enterococcus
Total Coliform
Fecal Coliform
Z=0−5m
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Z=25−35m
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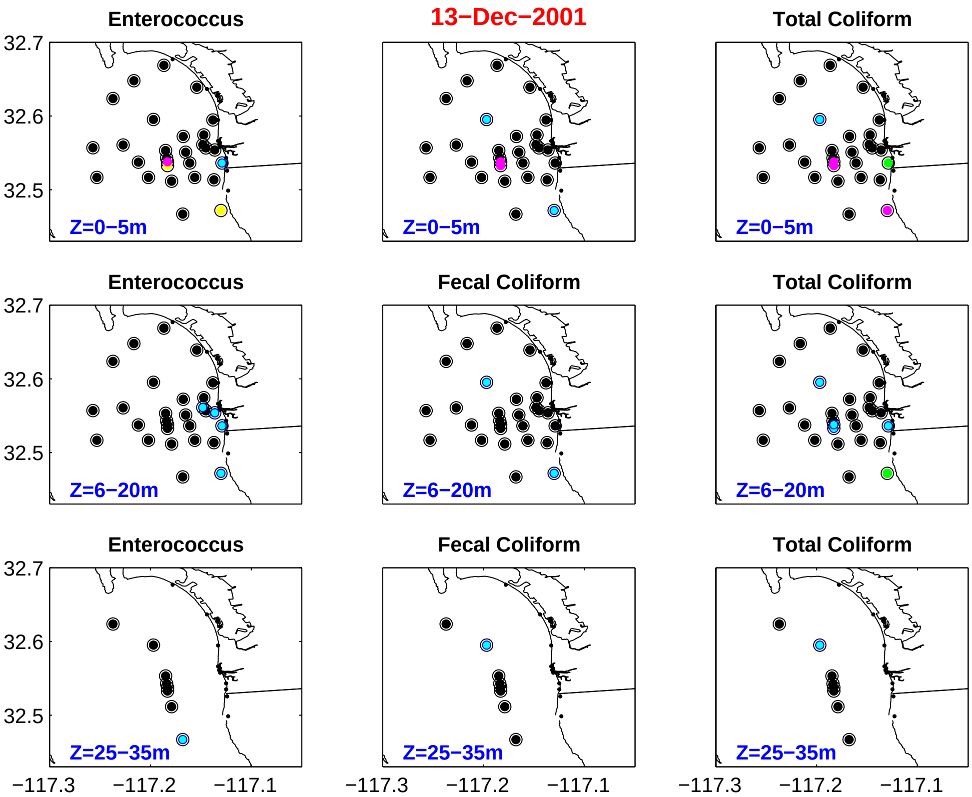
13−Dec−2001
Enterococcus
Total Coliform
Fecal Coliform
Z=0−5m
Z=6−20m
Z=25−35m
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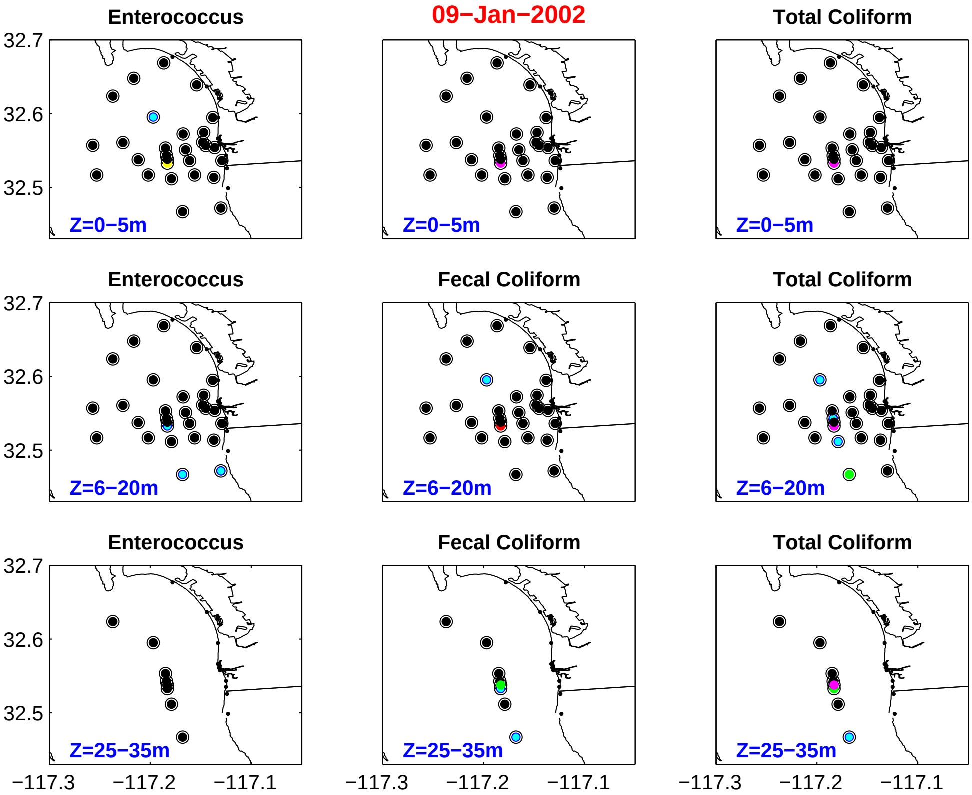
09−Jan−2002
Enterococcus
Fecal Coliform
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Z=25−35m
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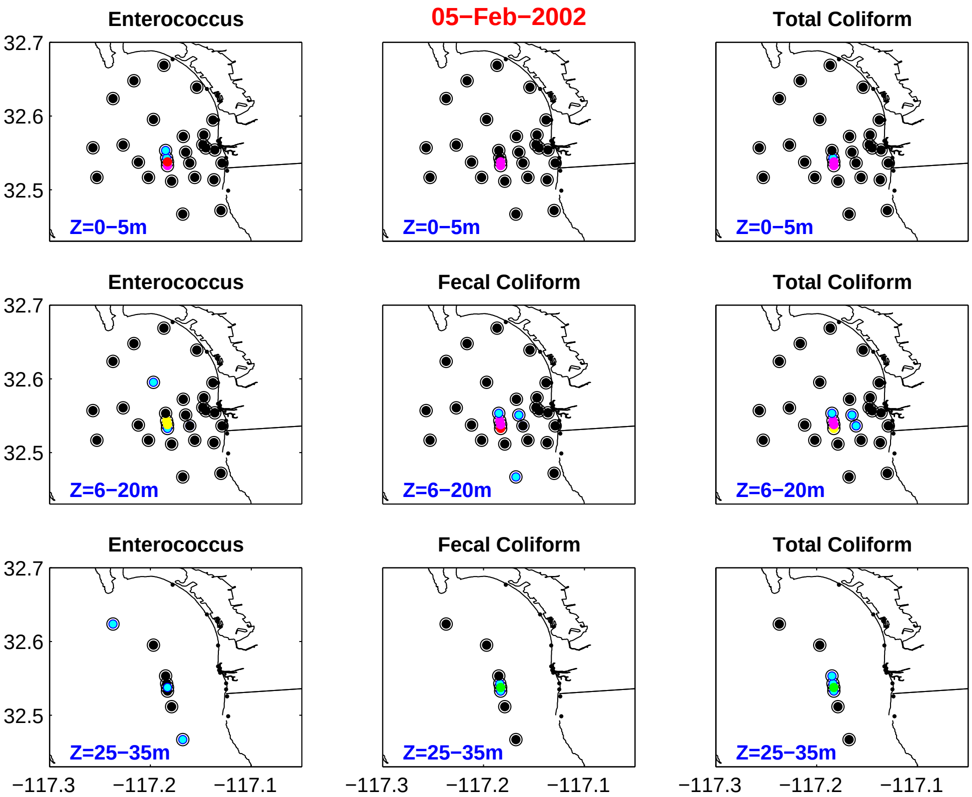
05−Feb−2002
Enterococcus
Fecal Coliform
Total Coliform
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Z=6−20m
Z=25−35m
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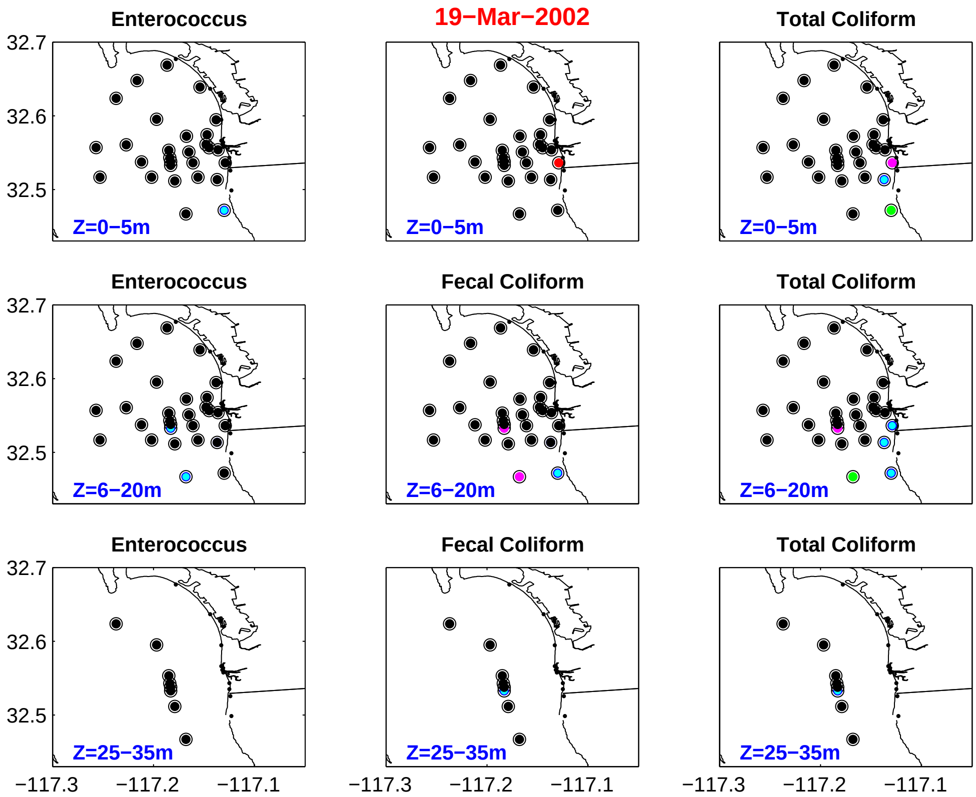
19−Mar−2002
Enterococcus
Total Coliform
Fecal Coliform
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Z=25−35m
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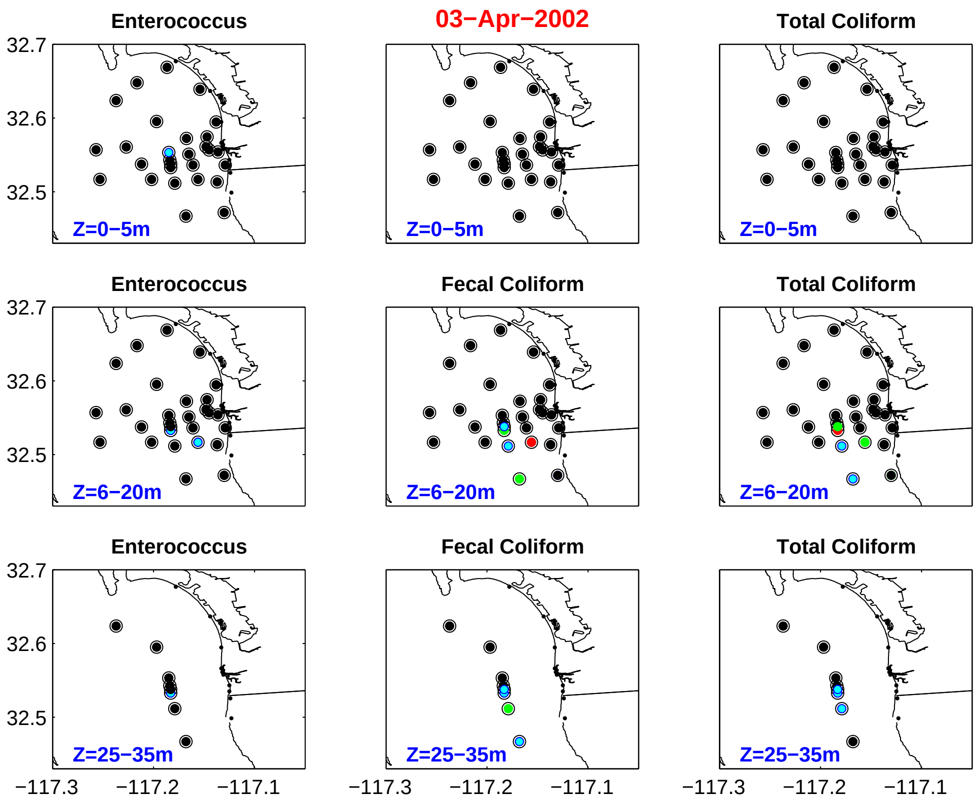
03−Apr−2002
Enterococcus
Total Coliform
Fecal Coliform
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Z=6−20m
Z=25−35m
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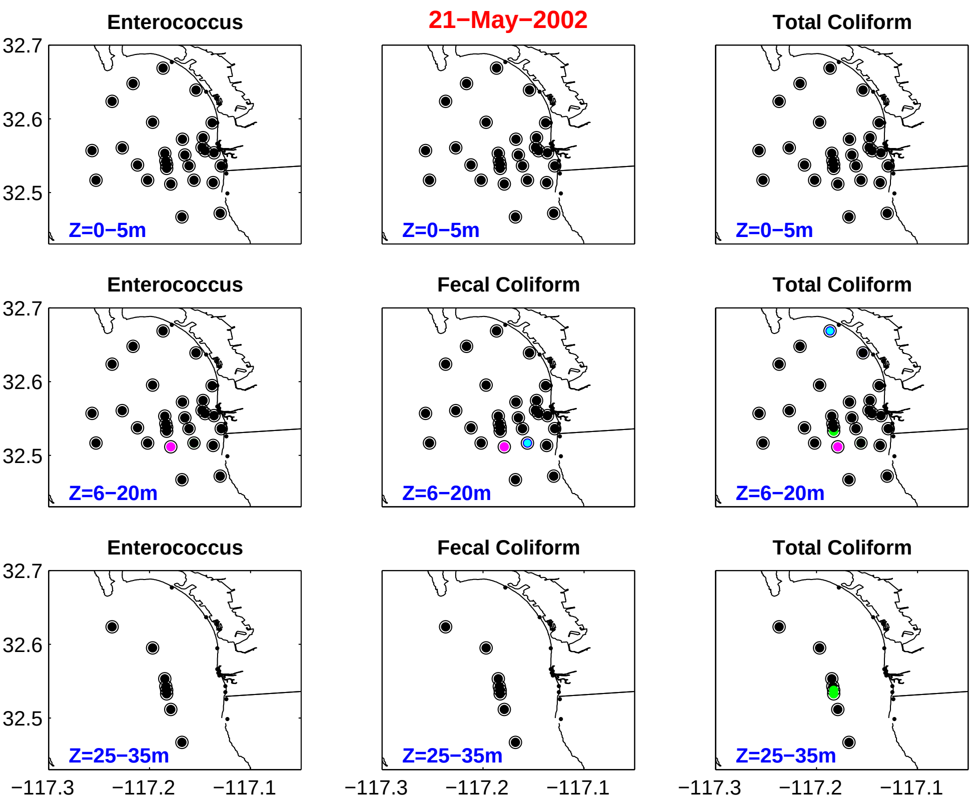
21−May−2002
Enterococcus
Fecal Coliform
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Z=25−35m
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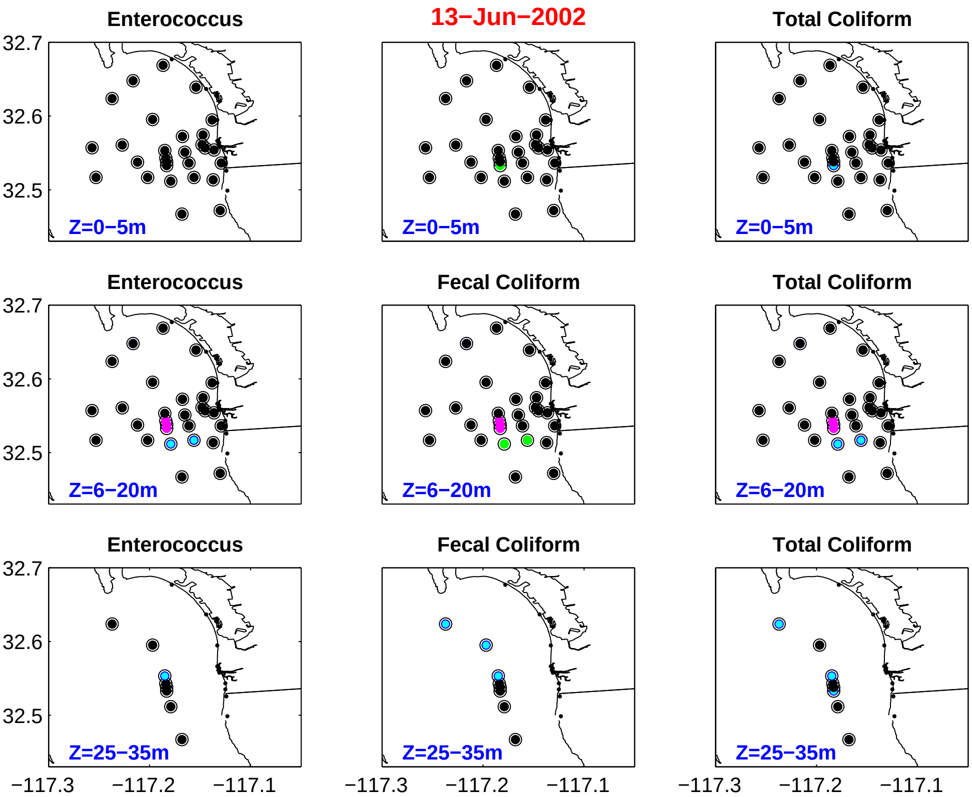
13−Jun−2002
Enterococcus
Fecal Coliform
Total Coliform
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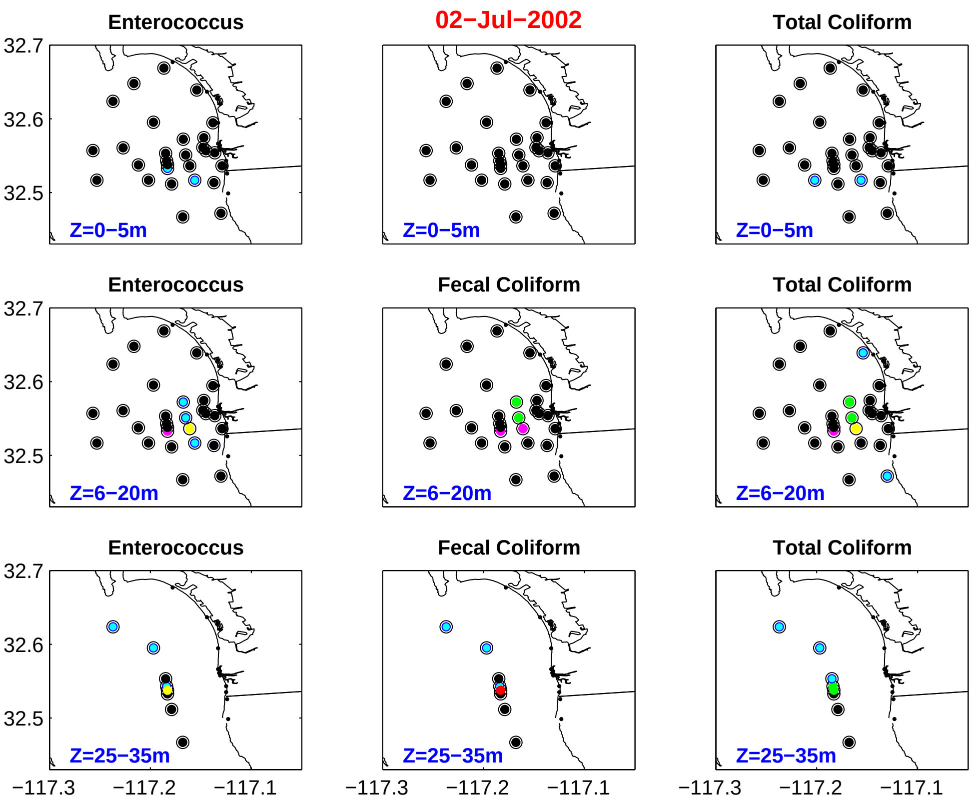
02−Jul−2002
Enterococcus
Fecal Coliform
Total Coliform
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Z=25−35m
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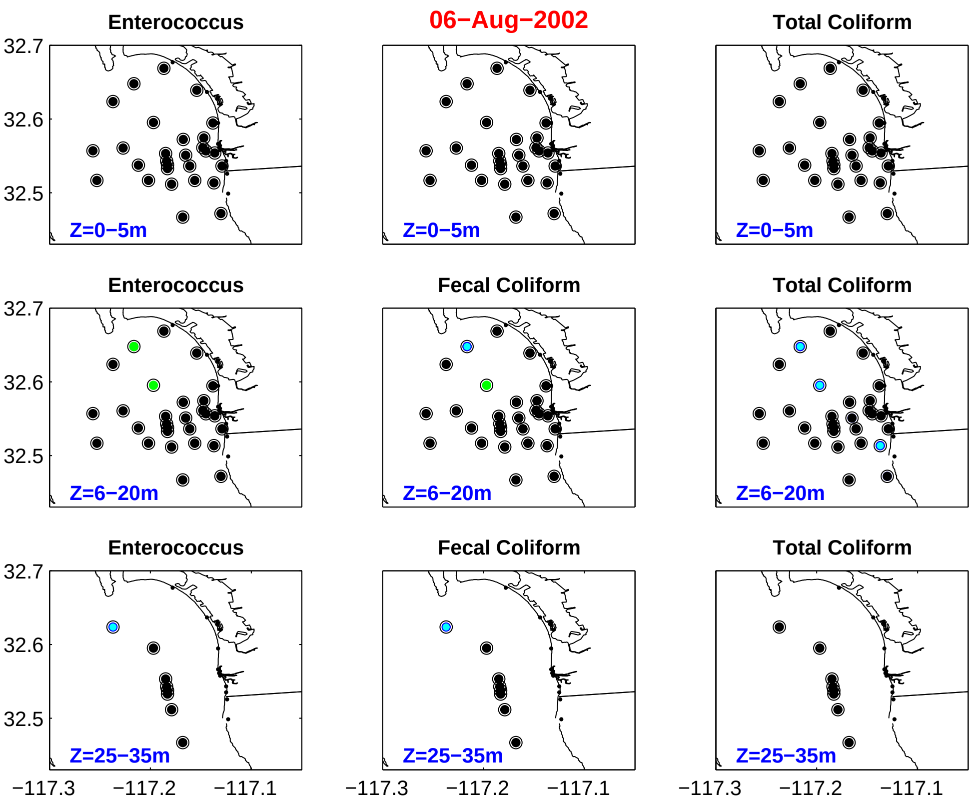
06−Aug−2002
Enterococcus
Fecal Coliform
Total Coliform
Z=0−5m
Z=6−20m
Z=25−35m
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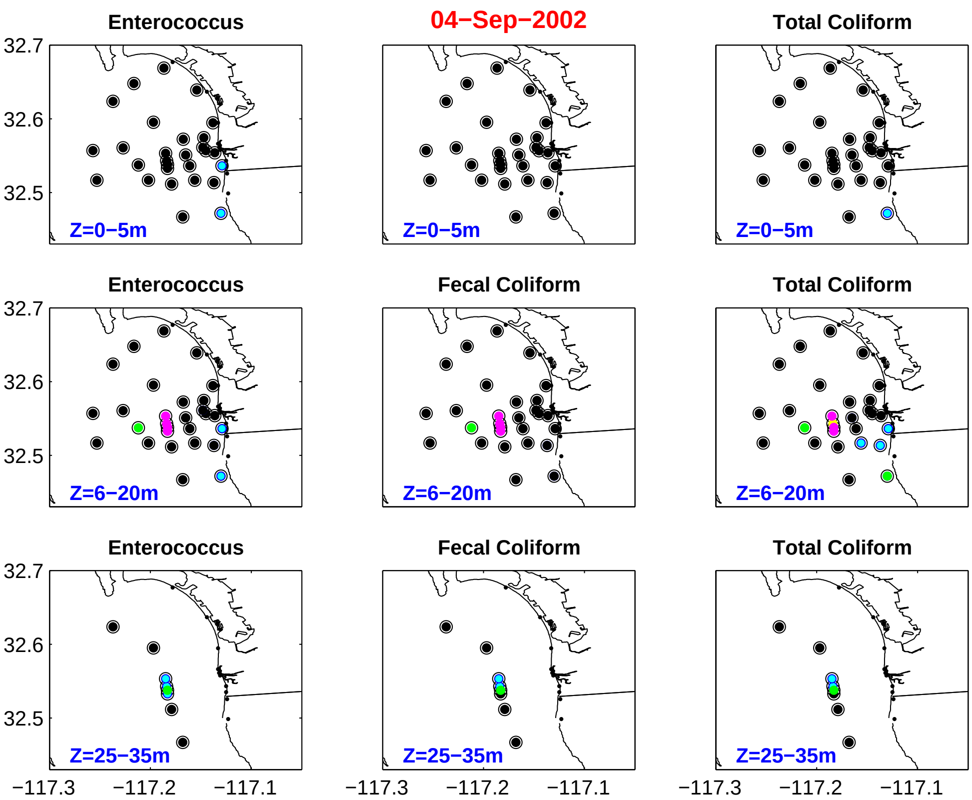
04−Sep−2002
Enterococcus
Fecal Coliform
Total Coliform
Z=0−5m
Z=6−20m
Z=25−35m
32.7
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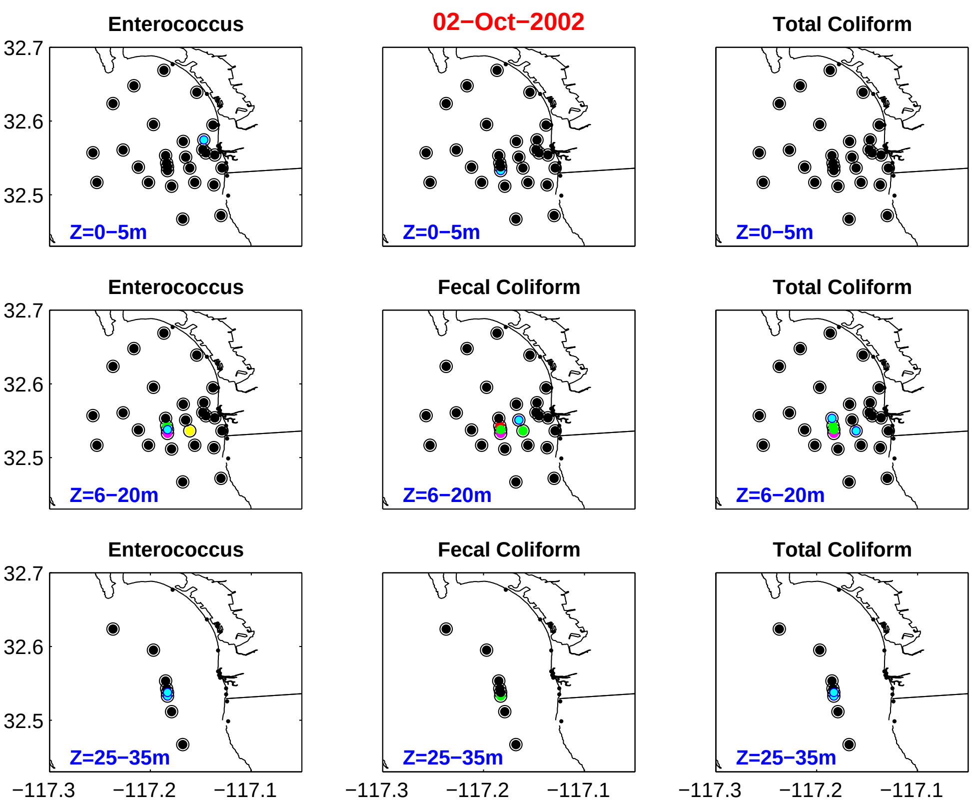
02−Oct−2002
Enterococcus
Fecal Coliform
Total Coliform
Z=0−5m
Z=6−20m
Z=25−35m
32.7
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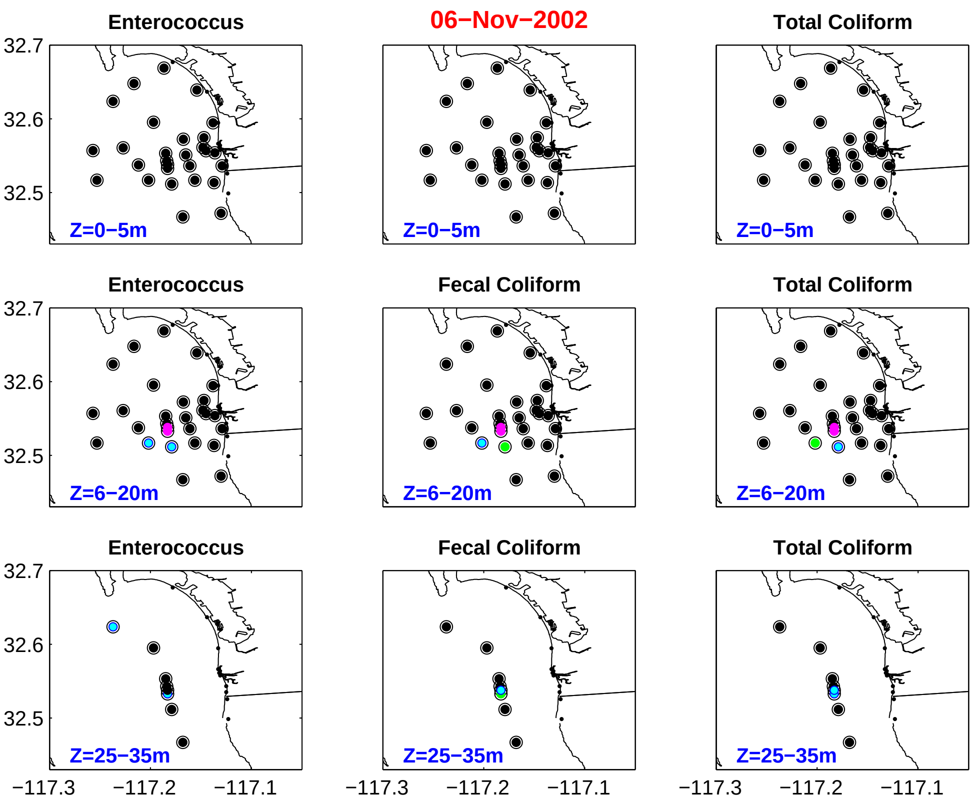

06−Nov−2002
Enterococcus
Fecal Coliform
Total Coliform
Z=0−5m
Z=6−20m
Z=25−35m
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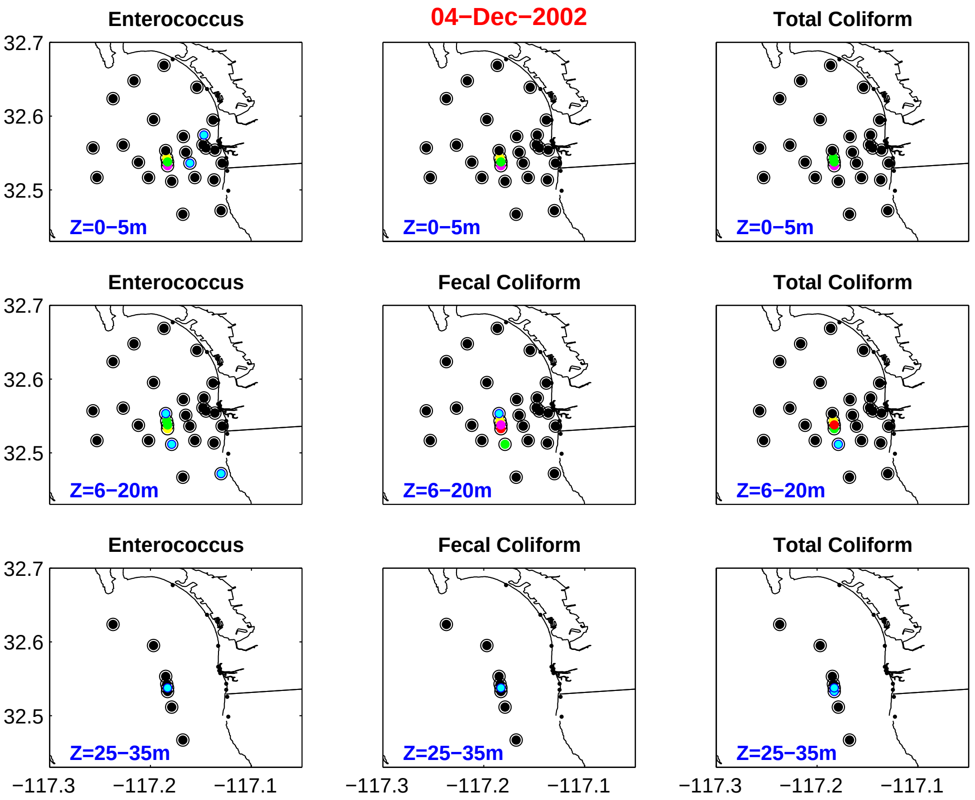

04−Dec−2002
Enterococcus
Fecal Coliform
Total Coliform
Z=0−5m
Z=6−20m
Z=25−35m
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32.5
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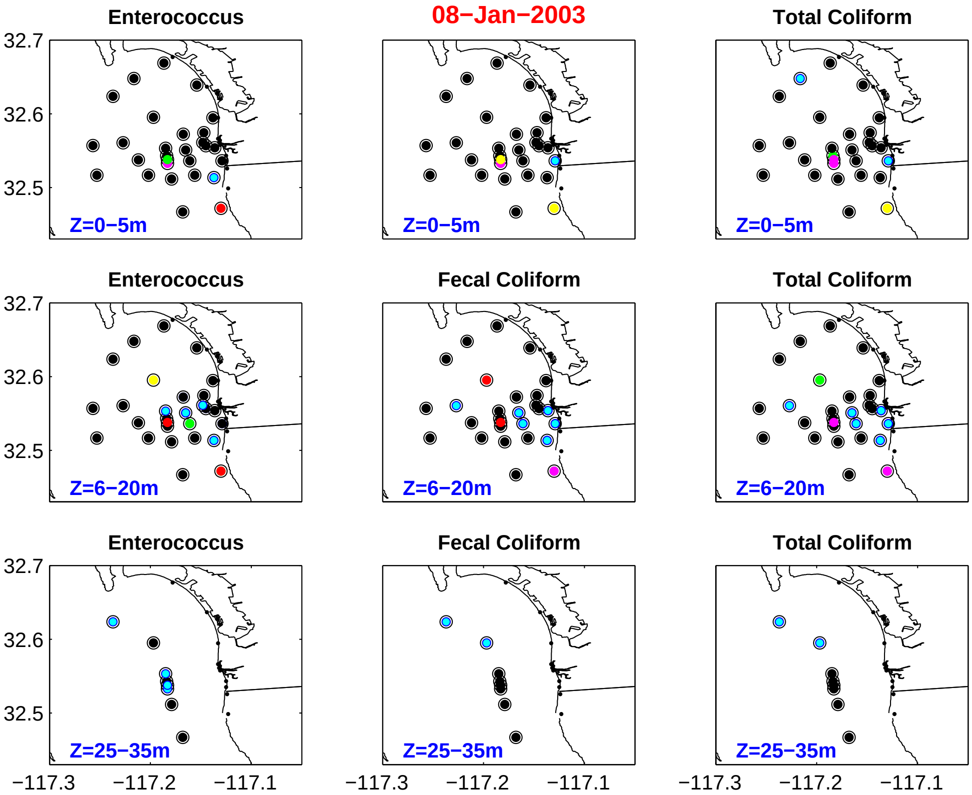
08−Jan−2003
Enterococcus
Total Coliform
Enterococcus
Fecal Coliform
Total Coliform
Enterococcus
Fecal Coliform
Total Coliform
Z=0−5m
Z=6−20m
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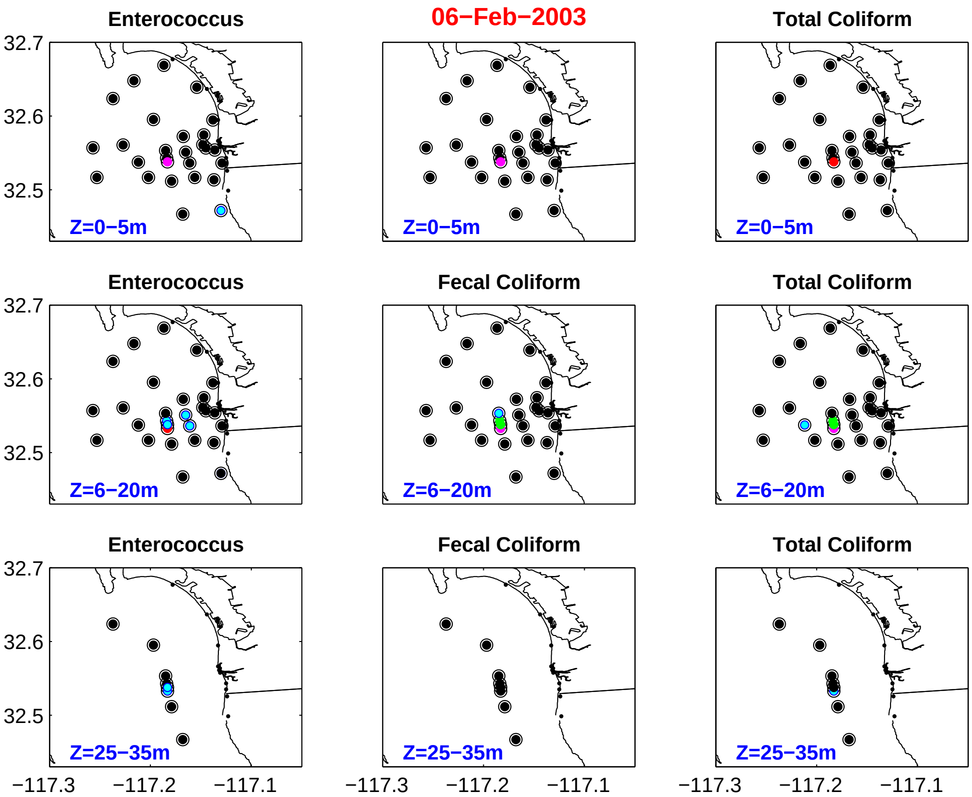
−117.1


06−Feb−2003
Enterococcus
Total Coliform
Enterococcus
Fecal Coliform
Total Coliform
Enterococcus
Fecal Coliform
Total Coliform
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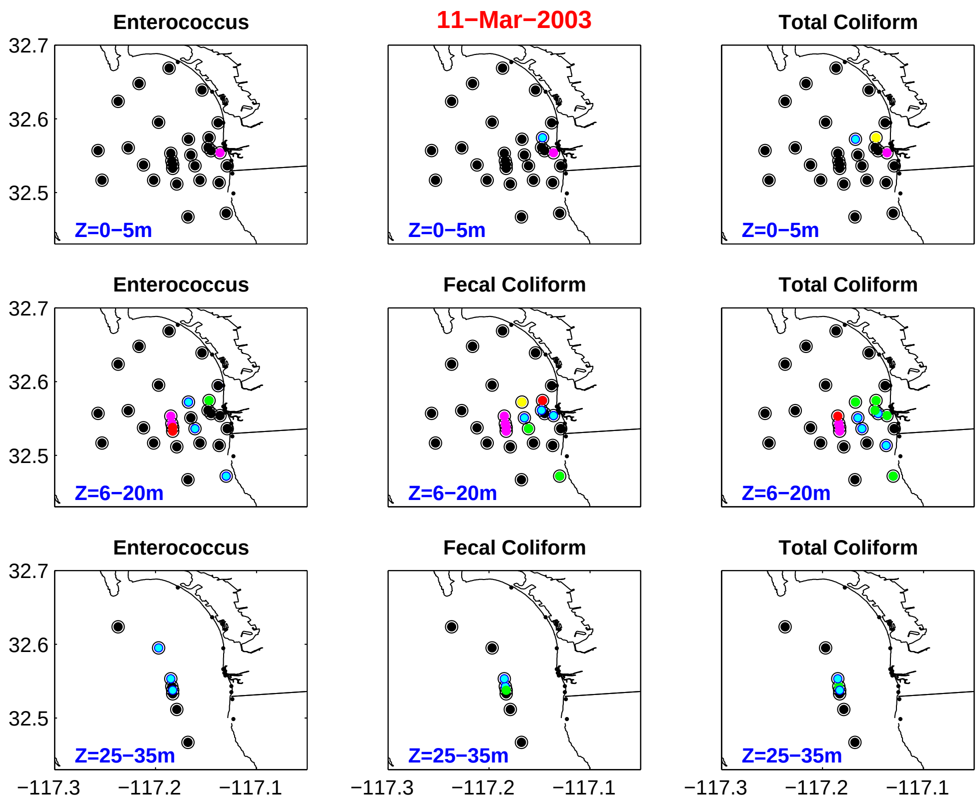
11−Mar−2003
Enterococcus
Fecal Coliform
Total Coliform
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Z=6−20m
Z=25−35m
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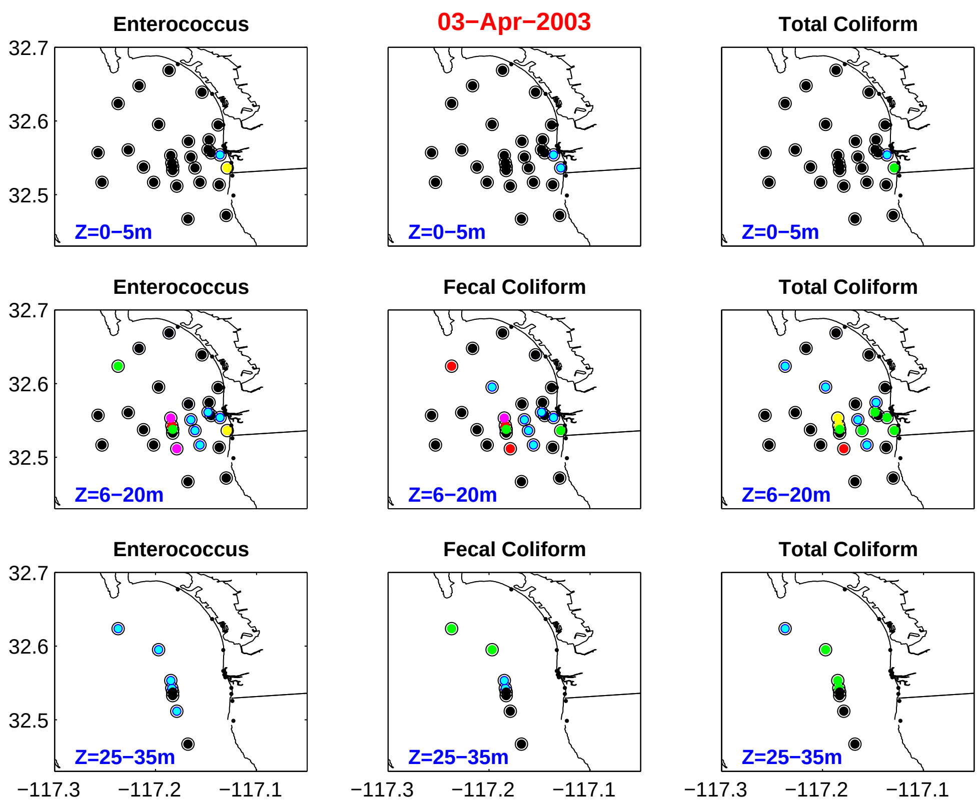
32.6
32.5
−117.3
−117.2
−117.1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Enterococcus
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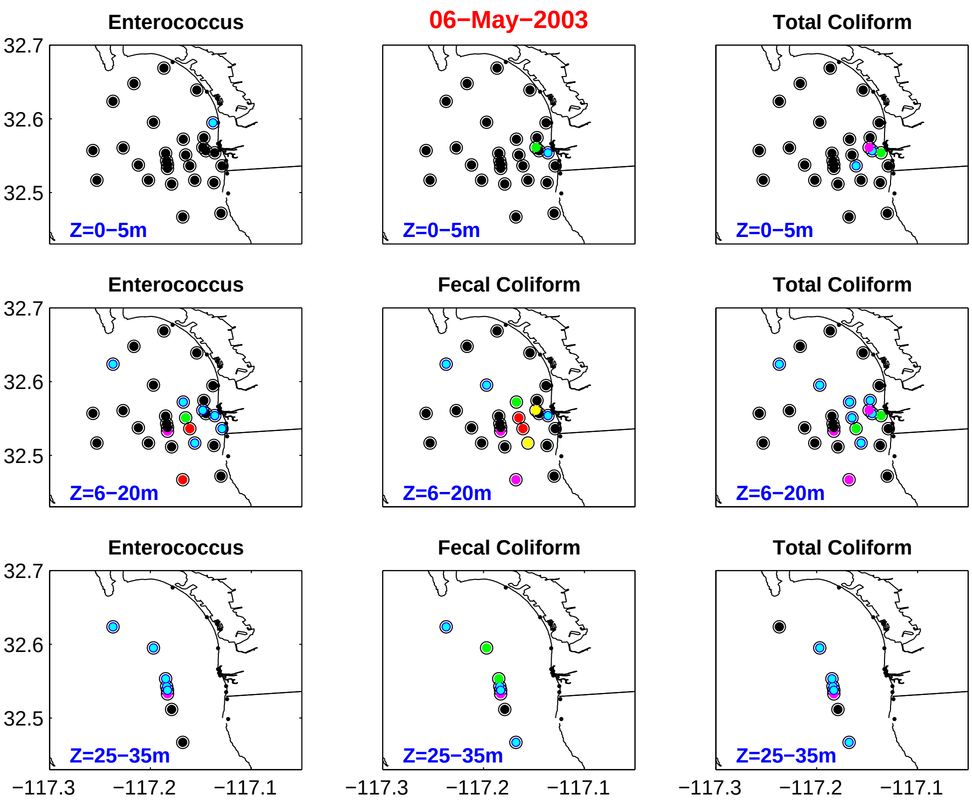
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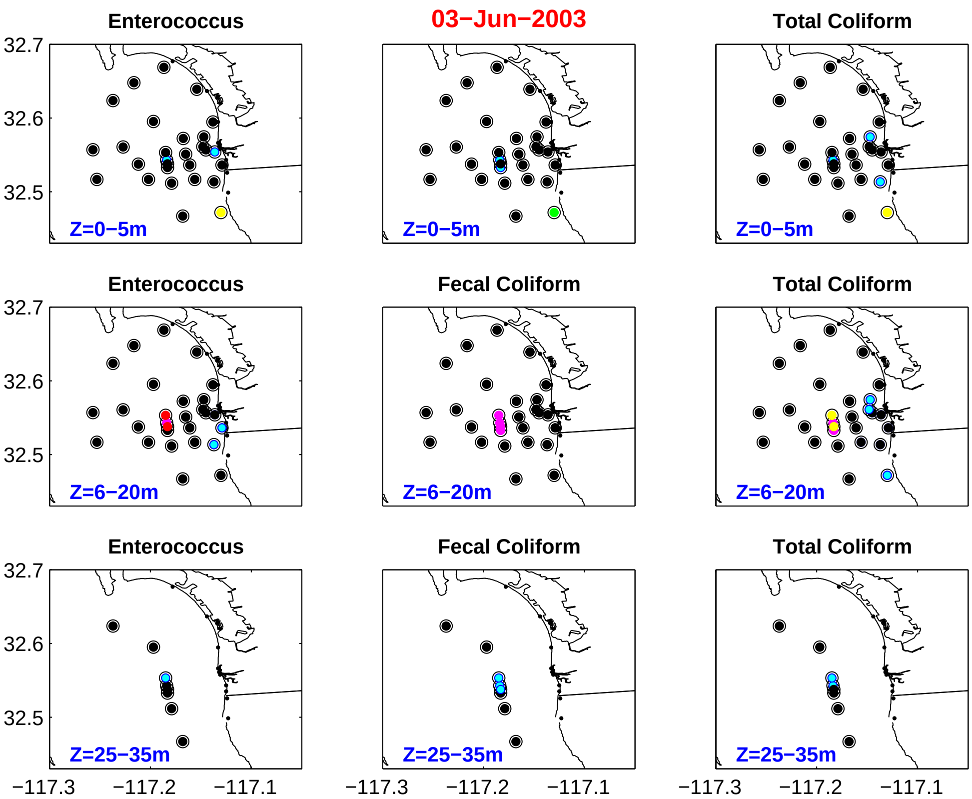
−117.1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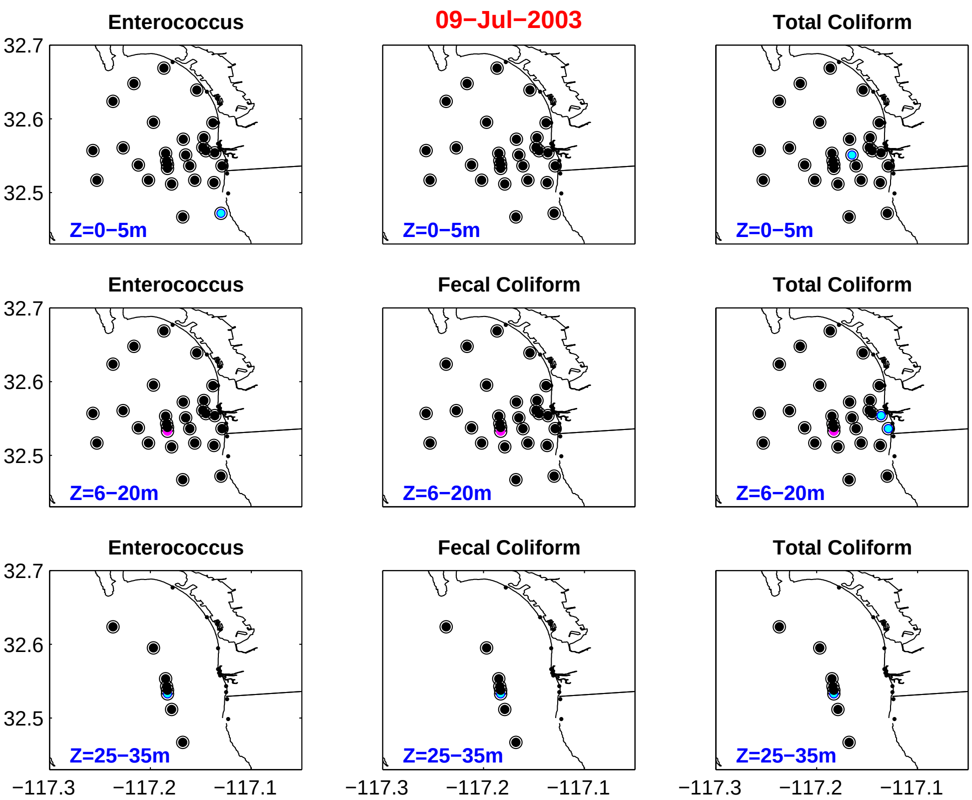
−117.1



09−Jul−2003
Enterococcus
Fecal Coliform
Total Coliform
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Z=6−20m
Z=25−35m
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32.6
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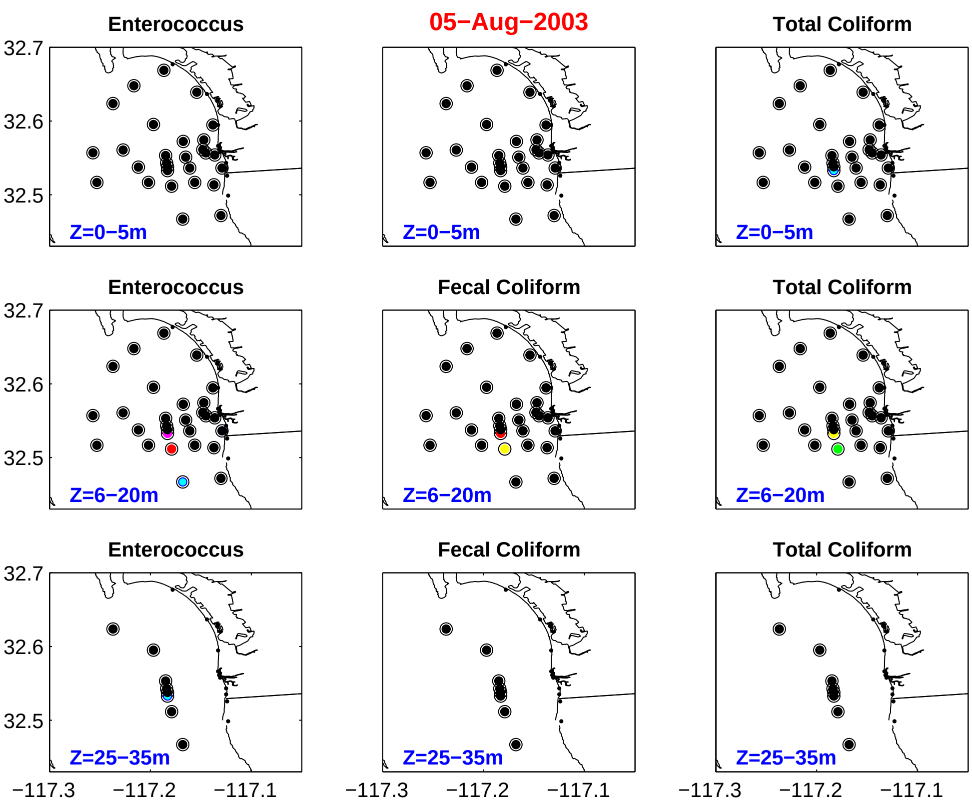
−117.2
−117.1



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Fecal Coliform
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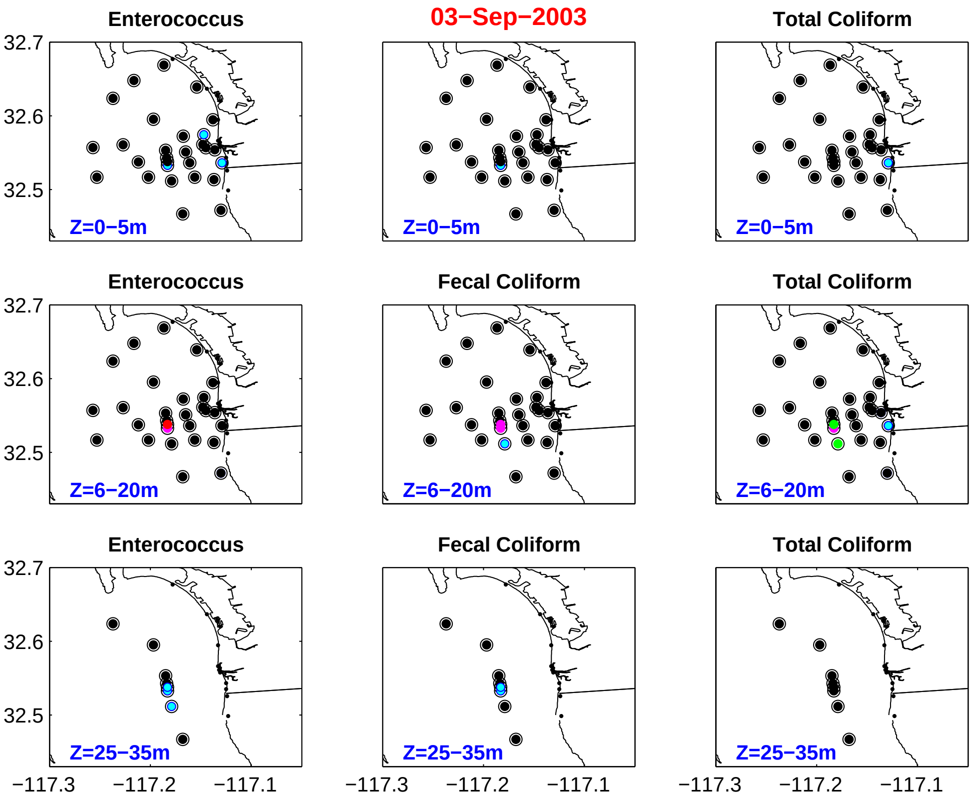
−117.1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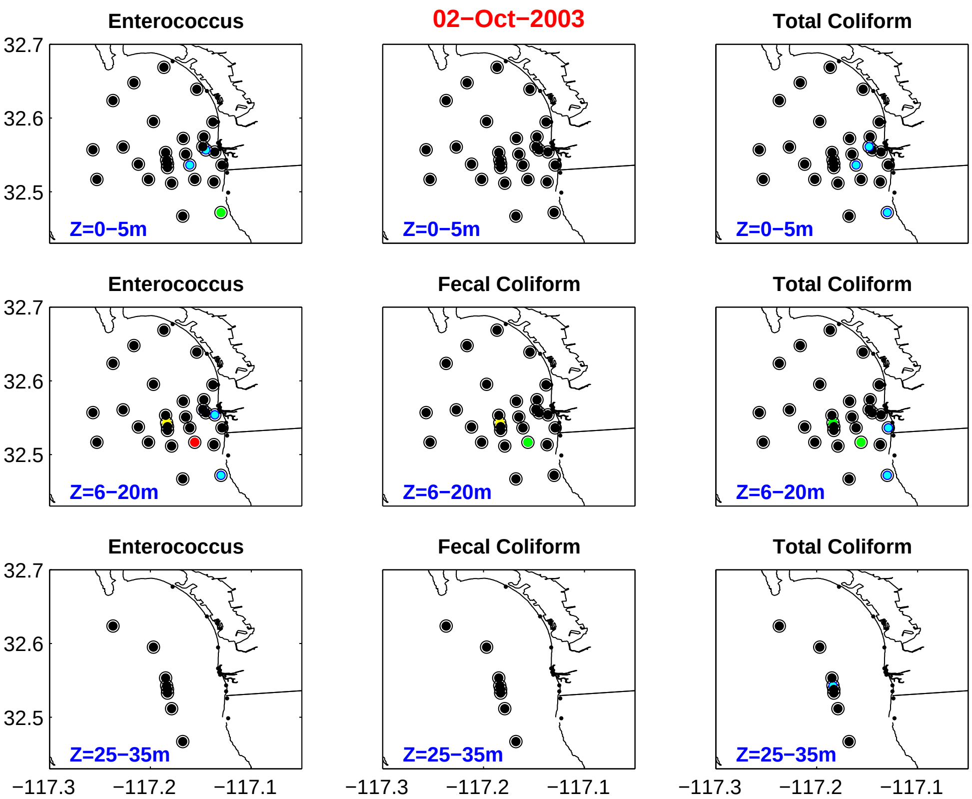
−117.1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Total Coliform
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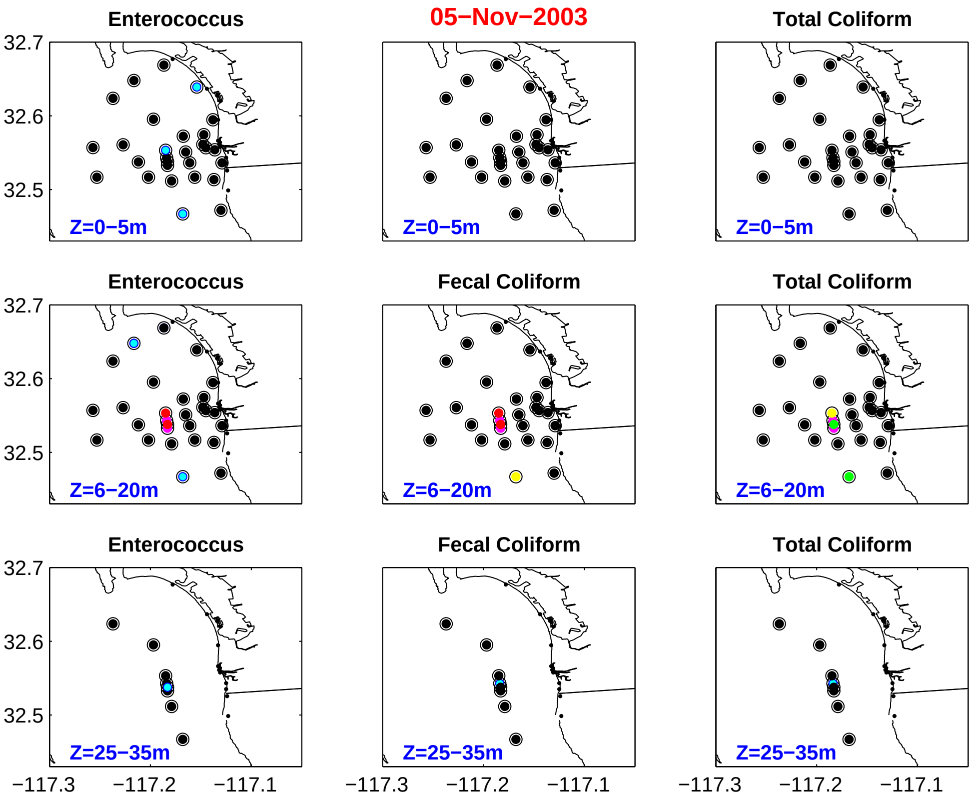
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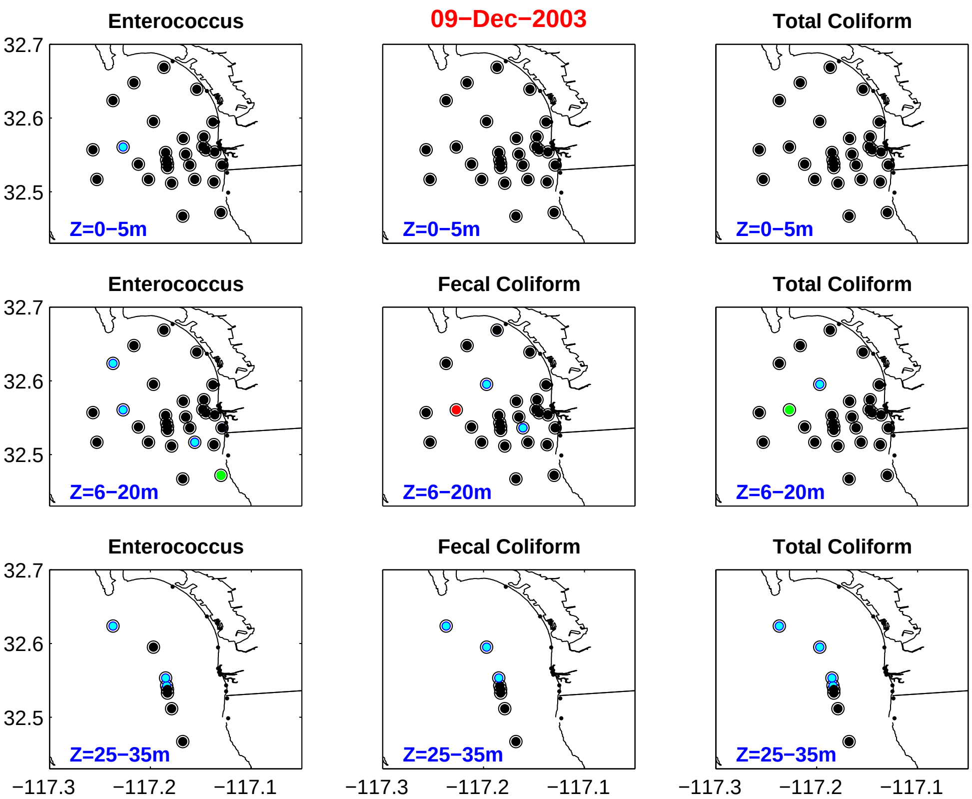
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Total Coliform
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32.7
32.6
32.5
−117.3
−117.2
−117.1

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