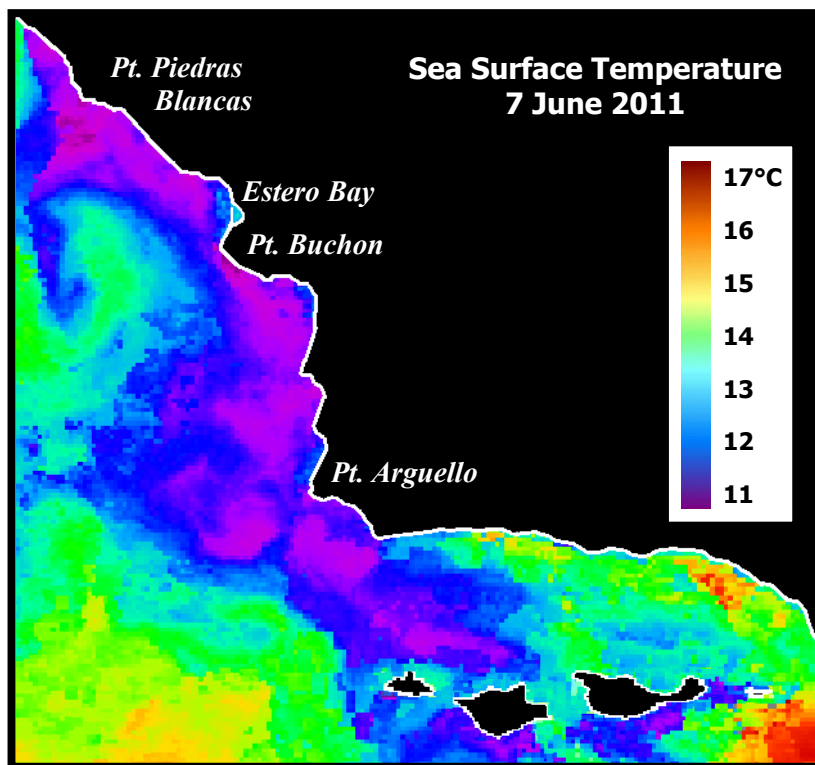


**City of Morro Bay and
Cayucos Sanitary District**

OFFSHORE MONITORING AND REPORTING PROGRAM

2011 ANNUAL REPORT



Marine Research Specialists

**3140 Telegraph Rd., Suite A
Ventura, California 93003**

**Report to the
City of Morro Bay and
Cayucos Sanitary District**

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Morro Bay, California 93442
(805) 772-6272

**OFFSHORE MONITORING
AND REPORTING PROGRAM**

2011 ANNUAL REPORT

Prepared by

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April 2012

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Mr. Bruce Keogh
Wastewater Division Manager
City of Morro Bay
955 Shasta Avenue
Morro Bay, CA 93442

2 April 2012

Reference: 2011 Annual Monitoring Report

Dear Mr. Keogh:

Enclosed is the referenced report. It documents the continued effectiveness of the treatment process, the absence of marine impacts, and compliance with the discharge limitations and reporting requirements specified in the NPDES discharge permit.

Please contact the undersigned if you have any questions regarding this report.

Sincerely,

Bonnie Luke
Project Manager

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is to the best of my knowledge and belief, true, accurate and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Mr. Rob Livick
Acting Director of Public Services
City of Morro Bay

Date

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LIST OF ACRONYMS AND DEFINITIONS

ACOE	U.S. Army Corps of Engineers
Anomaly	An anomaly is a deviation or departure from ambient (mean) conditions in one of the six measured seawater properties: salinity, temperature, density, dissolved oxygen, alkalinity, or transmissivity. The amplitude of the anomaly is quantified as the difference between the measured seawater property at a given station and the mean of that property measured at all other stations at the same depth level or distance above the bottom.
Anthropogenic	Changes to the environment induced by human activities
ASP	Amnesic Shellfish Poisoning
BCCE	Brown and Caldwell Consulting Engineers
BEHP	Bis 2-Ethyl Hexyl Phthalate is a compound that leaches out of plastics and is ubiquitous in the environment.
BIP	A Balanced Indigenous Population is as an ecological community that exhibits characteristics similar to those of nearby, healthy communities existing under comparable but unpolluted environmental conditions.
BBL	A benthic boundary layer is often synonymous with a bottom nepheloid layer (<i>see below</i> BNL) and is associated with increased turbulence and mixing caused by the decrease in current flow immediately above the seafloor that is required to meet the zero-velocity boundary condition at the seafloor.
BNL	The bottom nepheloid layer is a common phenomenon on continental shelves where increased turbidity near the seafloor is caused by the presence of naturally occurring particulates formed from light-weight flocs of detritus. Oscillatory bottom currents generated by passing surface gravity waves easily suspend these flocs.
BMP	Best Management Practices
BOD₅	Five-day biochemical oxygen demand
BTEX	Benzene, toluene, ethyl benzene, and xylene
Cal/OSHA	California Department of Industrial Relations, Division of Occupational Safety and Health
CAM-17	CAM is the California Administrative Manual and CAM-17 refers to the list of 17 heavy metals identified in the California Code of Regulations (CCR 2003), Title 22, Chapter 11: Identification and Listing of Hazardous Waste.
CCLEAN	<u>Central Coast Long-term Environmental Assessment Network</u>
CEQA	California Environmental Quality Act
CCR	California Code of Regulations (CCR 2003)
CDFG	California Department of Fish and Game
CDP	Coastal Development Permit
Coordinate Datum	All coordinates cited in this report are referenced to the WGS84 datum

LIST OF ACRONYMS AND DEFINITIONS

(Continued)

COP	The California Ocean Plan (SWRCB 2005), which is regularly revised but the 2005 edition was in force when the current NPDES discharge permit was issued to MBCSD.
CTD	A CTD is an instrument package that continuously records conductivity, temperature, and depth, in addition to a number of other physical oceanographic parameters in the water column.
CV	A coefficient of variation is used to compare the relative amounts of variation in populations having different means. It is the standard deviation expressed as a percentage of the mean.
DDT	Dichloro Diphenyl Trichloroethane, a chlorinated pesticide
DEHP	Di(2-ethylhexyl) phthalate synonymous with Bis(2-ethylhexyl) phthalate
dEIR	Draft Environmental Impact Report
DHS	California Department of Health Services
DMR	Discharge Monitoring Report
DMR-QA	Discharge Monitoring Report Quality Assurance (DMR-QA) Study administered by the United States Environmental Protection Agency
DO	Dissolved Oxygen
EIR	Environmental Impact Report
ELAP	California Department of Health Services, Environmental Laboratory Accreditation Program
EQ	Exceptional Quality is a standard for compost that meets the Federal and State requirements for beneficial reuse as a soil amendment in the local community.
ERL	Effects Range Low is a sediment toxicity concentration below which adverse biological effects are not expected to occur.
ERM	Effects Range Median is a sediment toxicity concentration above which adverse biological effects are expected to occur.
GPM	Gallons per Minute
HAB	Harmful Algal Bloom
Hazwopper	Hazardous Waste Operations and Emergency Response
HCl	Hydrochloric Acid
HCH	Isomers of hexachlorocyclohexane including alpha, beta, gamma (lindane), and delta
I&I	Inflow and Infiltration
Isopycnal	A surface of constant seawater density
JPA	The Joint Powers Agreement between the City of Morro Bay and the Cayucos Sanitary District (MBCSD) outlines the contractual agreement between the two agencies for the operation of the WWTP

LIST OF ACRONYMS AND DEFINITIONS

(Continued)

Leachate	A solution formed by leaching, especially a solution containing contaminants picked up through the leaching of soil
LC₅₀	Lethal 50% Concentration is a toxicity endpoint where 50% of the specimens will die after a 96-hour exposure period.
LOE	Line of Evidence used to evaluate whether a receiving-water measurement complied with permit limits
MANOVA	Multivariate Analysis of Variance
MBAS	Monterey Bay Analytical Services
MBCSD	The City of Morro Bay and Cayucos Sanitary District
MCC	A Motor Control Center manages the speed and torque of electric motors connected to the Center
MTBE	Methyl Tertiary Butyl Ether is an additive to gasoline that boosts octane to reduce air emissions but has contaminated groundwater in many regions after accidentally leaking from underground storage tanks.
MDL	Method Detection Limit is the lowest concentration that can be reported under ideal conditions where the sample contains only the compound of interest with a concentration in an optimal calibration range and in a medium that does not interfere with the performance of the analytical instrument.
MGD	Million Gallons per Day
mg/Kg	Milligrams per Kilogram = $\mu\text{g/g}$ dry weight = parts per million
mg/L	Milligrams per Liter = aqueous parts per million
Mixed liquor	A mixture of activated sludge, wastewater, and oxygen where organic sewage constituents are biologically assimilated
ML	The Minimum Level is the method-specific minimum concentration of a substance that can be quantitatively measured in a sample given the current analytical performance used by most certified laboratories within California, as specified in the 2005 Ocean Plan.
MLLW	Mean Lower Low Water
MMS	Minerals Management Service
MPN	Most Probable Number
MRS	Marine Research Specialists
MT	Metric Ton = 1,000 kg
MWH	Montgomery, Watson, Harza is the engineering firm selected for the design of the MBCSD treatment-plant upgrade.
NEP	National Estuary Program
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration

LIST OF ACRONYMS AND DEFINITIONS

(Continued)

NOEC	No Observable Effect Concentration
NORM	Naturally Occurring Radioactive Material
NPDES	National Pollutant Discharge Elimination System
NTU	Nephelometric Turbidity Units
O&G	Oil and Grease
O&M	Operations and Maintenance
OIT	Operator-in-Training
PAH	Polynuclear Aromatic Hydrocarbons
PCA	Principal Component Analysis is a multivariate technique that arranges samples along an axis based on species composition. This arrangement is conducted independently along a number of dimensions (usually 2 or 3) that approximate some pattern of response of the intertidal community to underlying environmental gradients. PCA condenses the complex species-abundance database to a few factors responsible for observed variability within the intertidal community structure, while retaining ecologically meaningful biological information.
PCB	Polychlorinated Biphenyl
PCi/L	Pico-Curies per liter is a measure of aqueous radioactivity.
Perturbation	A perturbation is a small but detectable variation (anomaly) in one or more seawater properties caused by the presence of dilute effluent within the receiving waters. Individual Perturbations identified in this report are designated P1 through P12.
PG&E	Pacific Gas and Electric
POTW	Publicly Owned Treatment Works
Power (1-β)	The probability correctly rejecting the null hypothesis depending on the significance criterion, the variability of the sample results, and the size of the impact
ppm	Parts per million = mg/L in solution , or mg/Kg = µg/g dry weight
PQL	Practical Quantification Limit is the lowest concentration that can be measured with statistical reliability given the sample size and analytical method.
PSDWF	Peak seasonal dry-weather flow
PSP	Paralytic Shellfish Poisoning
<i>p</i>-value	Low <i>p</i>-values (<0.05) indicate a high degree of confidence that the computed quantity is statistically significant.
PWWF	Peak wet-weather flow
Pycnocline	A region of rapid vertical change in the density field of the seawater column
QA/QC	Quality Assurance and Quality Control

LIST OF ACRONYMS AND DEFINITIONS

(Continued)

RAS	Return Activated Sludge is continuously returned to the aeration tank to provide a seed of developed bacteria for rapid digestion of incoming wastewater. Some sludge is wasted (WAS) to prevent excessive solids buildup.
RFP	Request for Proposal
ROV	Remotely Operated Vehicle
RPA	The Reasonable Potential Analysis procedures in Appendix IV of the California Ocean Plan provide a quantitative methodology for statistically analyzing historical effluent data to determine the likelihood of exceeding permit limits in the future, and thus, whether continued monitoring is warranted.
RWQCB	State of California Regional Water Quality Control Board - Central Coast Region
SAIC	Science Applications International Corporation
SBE	Sea-Bird Electronics, Inc.
SCBPPFCT	Southern California Bight Pilot Project Field Coordination Team
SCCWRP	Southern California Coastal Water Research Project
SEP	Supplemental Environmental Project
Sigma-T	σ_t units are a measure of the density of water equal to the 1000 times the specific gravity minus one.
SJCF	San Joaquin Composting Facility located in Kern County California and owned by McCarthy Family Farms, Inc.
STLC	Soluble Threshold Limit Concentration applies to the measured concentration in the liquid extract from a biosolid sample, as determined by a Waste Extraction Test. The State of California classified biosolids with leachate concentrations exceeding the STLC as hazardous.
SWRCB	State Water Resources Control Board
Thermocline	A region of rapid vertical change in the temperature field of the seawater column
TIC	Tentatively Identified Compound is a compound that can be seen by the analytical testing method, but its identity and concentration cannot be confirmed without further analytical investigation. Many analytical methods can report TICs but the analysis is not targeted specifically for their detection.
TKN	Total Kjeldahl Nitrogen
TRC	Total Residual Chlorine in effluent is determined from grab samples collected beyond the chlorine contact chamber.
TSS	Total Suspended Solids

LIST OF ACRONYMS AND DEFINITIONS

(Continued)

TTLC	Total Threshold Limit Concentration applies to the total wet-weight concentration of a contaminant within a bulk biosolid sample consisting of the entire millable solid matrix rather than just the leachate. Biosolids are designated as hazardous wastes in the State of California if measured bulk concentrations exceed the TTLC.
TUa	Acute Toxicity Units
TUc	Chronic Toxicity Units
TVS	Total Volatile Solids
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGPO	United States Government Printing Office
USMMS	United States Minerals Management Service
VFD	Variable-Frequency Drives are electronic-motor-speed controllers used at the MBCSD WWTP to precisely control the influent pumping rate at the plant headworks by adjusting the frequency of electrical power sent to the pump motors.
WAS	Waste Activated Sludge is removed from the treatment process to prevent excessive solids buildup.
WERF	The Water Environment Research Foundation is a nonprofit organization that helps utilities and corporations manage water resources.
WET	Waste Extraction Tests measure the soluble leachate or the extractable amount of a substance contained within a bulk sample of biosolids. A WET is indicated if the bulk wet-weight concentration of a contaminant in a biosolids sample exceeds ten times the STLCL.
WWTP	City of Morro Bay-Cayucos Sanitary District Waste Water Treatment Plant
ZID	The Zone of Initial Dilution is a limited volume of water surrounding the outfall where wastewater rapidly mixes with receiving waters. Most receiving-water objectives of the Ocean Plan do not apply within the ZID.

EXECUTIVE SUMMARY

The City of Morro Bay and the Cayucos Sanitary District (MBCSD) jointly own the wastewater treatment plant operated by the City of Morro Bay. The treatment plant discharges effluent to the open ocean environment of northern Estero Bay under the authority of National Pollutant Discharge Elimination System (NPDES) permit No. CA0047881. The current permit was issued in January 2009. The permit allows discharge of blended primary- and secondary-treated wastewater, although the vast majority of the wastewater receives secondary treatment. The discharge permit requires a monitoring and reporting program that evaluates short- and long-term effects of the effluent discharge on receiving waters, benthic sediments, and infaunal communities. This 2011 Annual Report partially satisfies those reporting requirements.

This document presents a comprehensive analysis of the extensive monitoring data collected over the last 26 years. Virtually every aspect of the treatment process, receiving waters, and seafloor sediments is monitored. An exhaustive quantitative analysis of all measured parameters demonstrates that the effluent discharge consistently meets the permit requirements and has no discernible effect on the ocean environment. A comparison of the properties of the influent and effluent affirms the treatment plant's proficiency at removing contaminants and reducing organic loads within the wastewater stream. All offshore water-quality measurements indicate that the effluent plume was largely restricted to a narrow 15-m zone of initial dilution (ZID) around the outfall. Measurements within the effluent plume collected a few feet from a diffuser port quantified the plume's rapid dispersion, and demonstrated that the structure was operating better than predicted by modeling. Finally, the absence of adverse discharge-related impacts to the physics, chemistry, and biology of benthic sediments verified the effectiveness of the treatment process, the high dilution of effluent within receiving waters, and the low toxicity of the discharged effluent. The additional data presented in this report are consistent with conclusions based on historical data insofar as the treatment plant's continued low emission of contaminants, low toxicity of the effluent stream, and absence of impacts to the marine environment.

The plant operates under a 301(h)-permit that modifies the general NPDES requirements on suspended-solid and biochemical oxygen demand (BOD) emissions. All other NPDES limits, including restrictions on the discharge of toxic substances, apply to the MBCSD discharge without exception. Regardless, the partial-secondary treatment currently performed by the plant routinely achieves reductions in suspended solids and BOD that are close to, and often exceed, secondary treatment requirements. In fact, the effluent usually consists almost entirely of wastewater that has received secondary treatment.

Effluent monitoring during 2011 documented another year of high operational performance by the treatment plant. Major effluent constituents, including suspended solids (TSS), BOD, and oil and grease (O&G), all had much lower concentrations and mass emissions than the permitted maximums, as has consistently been the case throughout the history of the monitoring program. The plant performed well in 2011 in spite of an increase in the flow compared to recent years. Although the treatment process efficiently removed major organic wastewater constituents such as suspended solids, BOD, O&G, and coliform bacteria, the general lack of other chemical contaminants within effluent was largely due to their absence within the influent stream. Like most publicly owned treatment works, the MBCSD plant is not designed to extract heavy metals and synthetic organic compounds from wastewater. Instead, the MBCSD effluent's low toxicity is primarily due to the lack of heavy industry within its service area. The few businesses that discharge to the sewer system produce wastewater that is similar to that of domestic sources, only on a larger scale. A comprehensive industrial waste survey, maintained and periodically updated by collections system personnel, documents these sources. In addition, an ongoing public-outreach program and the convenience of an onsite household hazardous waste recycling facility further reduced the introduction of pollutants into the waste stream.

Throughout the more than two decades of operation, the treatment plant has consistently outperformed expectations for wastewater treatment based on regulatory standards. During this time, there has been no indication of deterioration in plant performance, and effluent quality has consistently exceeded the performance criteria anticipated in the original design. On rare occasions where exceptions to standards or criteria have occurred, they have been the direct result of unforeseen external events, or the brief, unavoidable mechanical failure of a treatment-system component. In light of their diligent adherence to a program of preventative maintenance, the main challenge for plant personnel has been to respond quickly to unanticipated failures in system components or unforeseeable events.

Among the thousands of samples and measurements collected as part of the monitoring program during 2011, there were no exceptions to the waste-discharge requirements specified in the NPDES permit. This level of compliance is laudable and represents the culmination of many years of hard work by dedicated and experienced MBCSD personnel. Their knowledge and experience regularly enables them to enact appropriate proactive measures that ensure the smooth operation of this facility.

Quarterly offshore water-column surveys evaluated receiving-water quality. The high-precision measurements collected during the surveys were capable of resolving minute changes in ambient water properties. These measurements detected and delineated effluent as it mixed with receiving waters upon discharge from the diffuser. Slight anomalies in water properties associated with the presence of dilute effluent were observed very close to the diffuser structure within the ZID. These highly localized anomalies were still within the limits specified in the NPDES permit, even those collected well within the ZID, where such limits do not apply. The high degree of effluent dilution observed close to a diffuser port attested to the continued effectiveness of the diffuser structure in rapidly mixing the wastewater within receiving waters.

The physics, chemistry, and biology of benthic sediments around the outfall have also been monitored for 26 years. As has been the case throughout the two and a half decades of monitoring, all measurements fully complied with requirements of the discharge permit and the objectives of the California Ocean Plan. Benthic environments are important indicators of the presence of marine pollution because they act as a major reservoir for most contaminants that enter the ocean. The lack of perceptible impacts to the benthic environment around the diffuser structure during 2011 confirmed that the treatment process effectively removed contaminants from the influent stream and that the diffuser structure efficiently diluted wastewater upon its discharge into receiving waters.

Three sediment-chemistry analyses document the absence of discharge-related benthic impacts. First, chemical concentrations measured within Estero Bay sediments during 2011, and in prior years of monitoring, were below thresholds identified as toxic to marine organisms. This includes samples collected close to the diffuser structure, as well as those collected more than 1 km away. In fact, measured concentrations were comparable to those found in benthic sediments collected throughout the region, but they were generally much less than those found within the Southern California Bight. Second, benthic samples collected during 2011 did not exhibit significant gradients of increasing contaminant concentration with increasing proximity to the outfall. Finally, there is no evidence of a buildup of wastewater constituents near the outfall over time, based on a comparison of the long record of measurements collected near and far from the discharge.

Infauna residing within seafloor sediments also serve as indicators of marine contamination because of their limited mobility and well-defined responses to pollution. Numbers of species, abundance, biomass and other parameters describing infaunal communities can indicate the presence of contaminant-induced stresses if, for example, gradients extending from a pollutant source to distant, unaffected areas are observed. More than 241,000 infaunal organisms have been collected and examined since the beginning

of the benthic monitoring program 26 years ago. Throughout the monitoring program, there has never been any indication of outfall-related impacts to benthic biota. Instead, the data have revealed a consistently healthy indigenous infaunal community, with uniformly high diversity that does not decline with proximity to the diffuser. These observations hold true despite widespread and significant temporal variation in the abundance of individual organisms. The analyses continue to demonstrate that the sediments surrounding the outfall support an extraordinarily healthy marine community dominated by suspension-feeding organisms living in clean sediments.

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1.0 INTRODUCTION

The City of Morro Bay and the Cayucos Sanitary District (MBCSD) jointly own the wastewater treatment plant operated by the City of Morro Bay. A 301(h)-modified National Pollutant Discharge Elimination System (NPDES) permit was originally issued to the MBCSD in March 1985 (Permit Number CA0047881). Region IX of the U.S. Environmental Protection Agency (USEPA) and the Central Coast California Regional Water Quality Control Board (RWQCB) jointly issued the permit. Following extensive evaluation processes, the USEPA and the RWQCB reissued the permit three times: March 1993 (RWQCB-USEPA 1993ab), December 1998 (RWQCB-USEPA 1998ab), and January 2009 (RWQCB-USEPA 2009ab). This report addresses compliance with the provisions of the most recent permit.

Marine Research Specialists (MRS) began conducting the Offshore Monitoring and Reporting Program for the MBCSD in July 1993. Since then, the treatment plant staff, MRS, and subcontracted laboratories, which include BC Laboratories and Aquatic Testing Laboratories, have collected and analyzed samples as part of the monitoring program.

1.1 REPORT ORGANIZATION

This 2011 annual report summarizes results from the four major monitoring components that analyze the treatment plant, receiving waters, marine sediments, and benthic biota. The organization of this document is similar to that of previous annual reports for continuity with these four reporting aspects of the monitoring program. Other than this brief introductory chapter, the major sections include the following:

Chapter 2	Treatment Plant Performance
Chapter 3	Receiving Water Quality
Chapter 4	Bottom Sediments and Biota
Chapter 5	Conclusions and Recommendations

Chapter 2 details all aspects of the onshore portion of the monitoring program, including the operation and performance of the treatment plant and the disposition of biosolids during 2011. Chapter 3 documents the four offshore surveys that were conducted during 2011 to assess the quality of ocean waters where the effluent is discharged. Chapter 4 documents the analysis of sediment samples collected during an offshore survey in October 2011. It places the chemical and biological measurements in historical context by incorporating time-series analyses of the entire 26-year database. Finally, Chapter 5 reiterates the major conclusions of this report, and presents recommendations for future actions concerning the monitoring program and operation of the treatment plant.

In addition to these chapters, a large set of appendices provides detailed supporting documentation for the analyses in the body of this report. Appendix A lists the design specifications of the wastewater treatment plant. Appendix B details the biological analysis of the offshore sediment samples and contains information about the taxonomists who performed the species-level identification of the specimens. Appendix C contains sample descriptions, including the location, depth, and grain-size characteristics of sediment samples. Appendix D contains the annual outfall inspection report. The original benthic chemistry report and quality assessment and quality control (QA/QC) analyses performed by BC Laboratories are provided in Appendix E. QA/QC procedures for the analytical laboratories are provided in Appendix F. It also contains a summary of the analytical methods used by BC Laboratories in their chemical analyses of the samples.

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CHAPTER 2

Treatment Plant Performance

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2.0 TREATMENT PLANT PERFORMANCE

During 2011, the treatment plant efficiently removed nearly all organics and other solids from the wastewater stream. Analyses of key diagnostic constituents, including suspended solids, biochemical oxygen demand (BOD), and oil and grease (O&G), demonstrated the high operational performance of the plant. Similarly, periodic analyses of effluent for trace metals, pesticides, priority pollutants, and toxicity demonstrated the benign environmental character of the effluent. A proactive operation and maintenance program ensured that there were no avoidable exceptions to the limits specified in the NPDES discharge permit during 2011. The sections below use these analyses to evaluate regulatory compliance through a comparison of measured wastewater characteristics with the limits cited in the NPDES discharge permit issued to the City of Morro Bay and Cayucos Sanitary District in January 2009 (RWQCB-USEPA 2009).

Data collected during 2011 augment 25 years of prior monitoring information, chronicling the high level of performance achieved by the treatment process over the last two decades. As in previous years, removal of suspended solids and oxygen-demanding materials during 2011 exceeded permit-required minimum limits. In many instances, the treatment plant's performance approached and exceeded the requirements for full secondary treatment.

Despite processing a large volume of sewage during 2011, the plant discharged only 22% of the allowed solids, while still attaining removal rates 17% higher than the permitted minimum. Throughout the year, the treatment plant removed solids at a rate significantly exceeding the 85% requirement for full secondary treatment. Additionally, the average effluent suspended solids concentrations during eight months of the year remained below or met the 30-mg/L criterion for full secondary treatment. The annual average effluent suspended-solids concentration (27 mg/L) was less than half of the permitted maximum (70 mg/L), and the total solids emission (45 MT¹) was only 22% of the allowed solids discharge (199 MT).

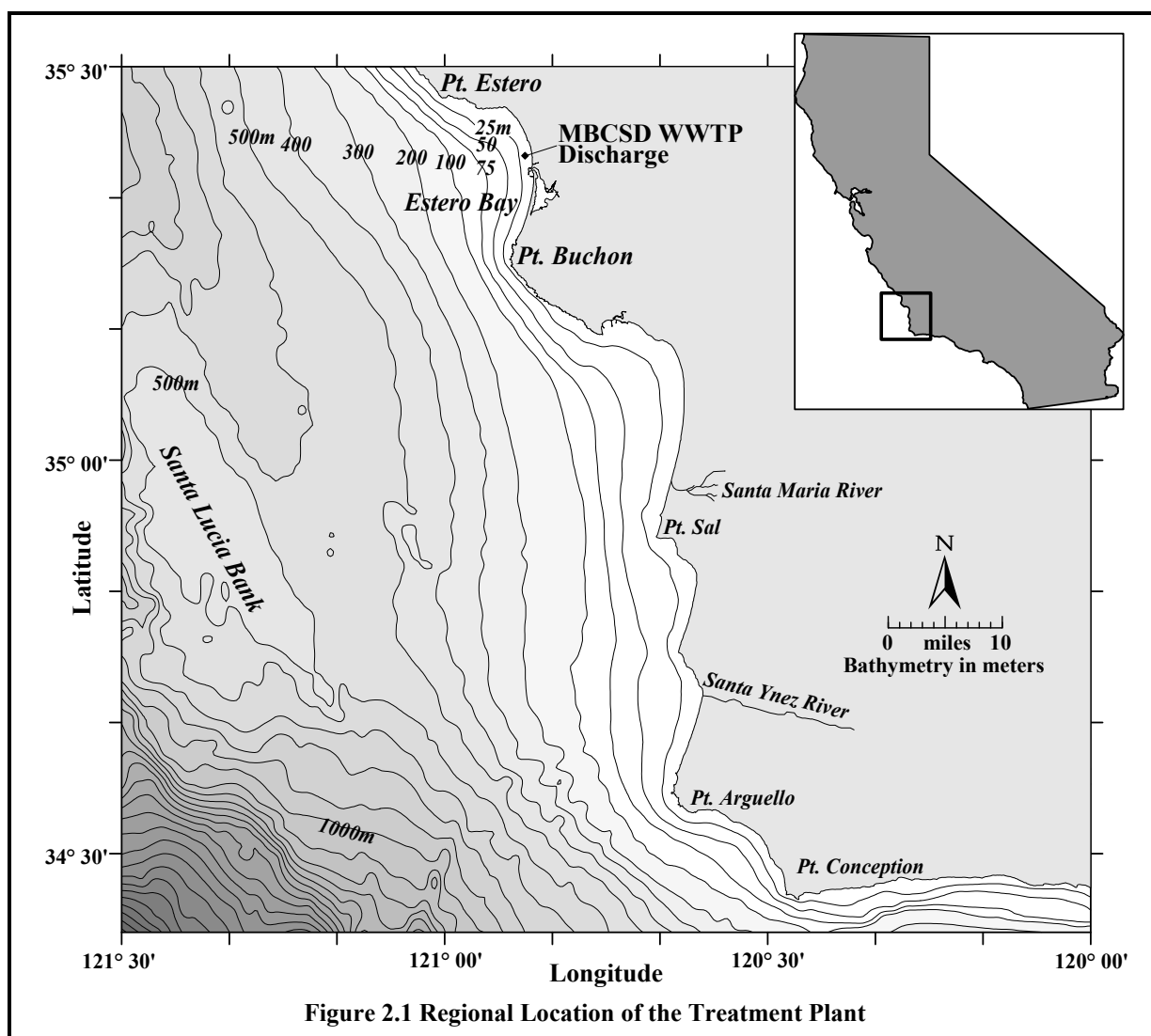
During 2011, the treatment plant also removed the vast majority (83%) of oxygen-demanding material from the influent stream. Technology-based requirements on BOD are generally unimportant for marine discharges because oxygen depletion is of little concern in the open ocean (Page 6 in National Academy of Sciences 1993). Nevertheless, the average BOD removal rate exceeded the 85% monthly standard for full secondary treatment during four months of the year, while the lowest monthly removal rate of 72% was still nearly two and a half times greater than the minimum permitted rate of 30%. Additionally, the annual average effluent BOD concentration (52 mg/L) was well less than half of the permitted maximum (120 mg/L), and the total mass emission (89 MT) was only about one-fourth of the allowed BOD discharge (342 MT).

The general absence of industrial contaminants in the wastestream attests to the benign nature of the influent, which is almost entirely generated by nonindustrial residential sources. Chemical analyses for 78 chemical compounds quantified low-level concentrations of only five common wastewater constituents and three naturally occurring trace minerals. All measured concentrations were well below permit limitations. Chronic bioassays conducted on effluent samples that were collected during 2011 determined that the discharge had a very low toxicity to marine organisms, results that were consistent with the prior 17-year record of testing.

¹ Metric tons or 1,000 Kg (1.1 short tons)

2.1 WASTEWATER TREATMENT PLANT

The Morro Bay/Cayucos Wastewater Treatment Plant (WWTP) is publicly owned and operated by the City of Morro Bay and the Cayucos Sanitary District (MBCSD). The WWTP is located in the City of Morro Bay, within San Luis Obispo County, along the central coast of California (Figure 2.1). The plant serves the Morro Bay and Cayucos communities, which, according to the 2010 census, have a combined population of approximately 12,835 (10,243 in Morro Bay and 2,592 in Cayucos). The WWTP discharged, on average, 1.24 million gallons per day (MGD) during 2011. The plant was designed to accommodate an average dry-weather flow of 2.06 MGD, a peak seasonal dry-weather flow (PSDWF) of 2.36 MGD, and a peak wet-weather flow (PWWF) of 6.64 MGD. The plant's flow did not surpass any of these design limits during 2011.



2.1.1 Operations

During 2011, eight trained personnel operated the WWTP (Table 2.1). Bruce Keogh served as both the Wastewater Division Manager and the Laboratory Director; Les Girvin continued to serve as WWTP Supervisor.

WWTP personnel provided laboratory workspace to the National Estuary Program (NEP), which is dedicated to protecting and restoring the natural resources of Morro Bay and its watershed. NEP volunteers used the WWTP laboratory to analyze bacterial samples collected throughout the Morro Bay watershed.

WWTP personnel attended a number of workshops, seminars, and continuing education classes throughout 2011. Course topics included CPR and first aid, calibration and bump testing of the plant's handheld atmospheric monitors, and Grade II & IV operator certification reviews.

Additionally, WWTP personnel attended a storm water training seminar sponsored by the City of Morro Bay, the California Water Environment Association (CWEA) Tri Counties Workshop, and a demonstration of a solids dewatering performance with a PWT screw press.

WWTP personnel also conducted plant tours for the public, members of other agencies (including the California Coastal Commission, the CalRecycle – Compliance and Enforcement Division, and the City of Morro Bay Public Works Advisory Board), and Morro Bay High School students.

In addition to performing the periodic effluent analyses required by the NPDES Permit, during 2011 the laboratories involved in the analyses of the MBCSD WWTP samples participated in laboratory performance evaluations intended to evaluate the accuracy of effluent measurements and assure the overall quality of the monitoring reports. For example, State and Federal laboratory performance evaluations that were successfully completed during 2011 included:

- Water Pollution 196 Performance Test (WP-196), which assessed analytical chemistry capabilities; and
- The California Department of Health Services Environmental Laboratory Accreditation Program (ELAP) review of general laboratory protocols.

The regulatory agencies found the results from these studies to be within acceptable ranges.

The MBCSD WWTP laboratory analyzed effluent parameters reported on a daily and weekly basis, including residual chlorine, suspended solids, turbidity, coliform, pH, and biochemical oxygen demand. Aquatic Testing Laboratories evaluated the toxicity of effluent to marine organisms with semiannual bioassay tests. BC Laboratories, Weck Laboratories, and Monterey Bay Analytical Services (MBAS) determined the concentrations of a wide range of chemical compounds within effluent on a semiannual basis. BC Laboratories also performed the annual chemical analysis of biosolid and benthic-sediment samples, as described in Section 2.3 of this chapter and in Chapter 4. Each laboratory's quality assurance and control plan is included in Appendix F of this report.

In recent years, both the City of Morro Bay and the Cayucos Sanitary District have actively sought to identify and eliminate sources of inflow (rainwater runoff) and infiltration (of groundwater), known as I&I, within their respective collection systems. Reducing the volume of I&I entering the collection system minimizes the amount of non-wastewater unnecessarily processed by the WWTP. Meanwhile, at the WWTP itself, personnel have maintained a diligent and proactive preventative maintenance program that

Table 2.1 Morro Bay/Cayucos WWTP Personnel During 2011

Name	Grade and Certification No.
Bruce Keogh	IV – 8978
John Gunderlock	IV – 10500
Les Girvin	III – 8499
Steven Aschenbrenner	II – 7548
David Williams	II – 9601
George Helms	II – 28158
David Bierman	II – 28745
Steve Sibley	I – 8005

includes major preemptive repairs of various components of the treatment process and the outfall. During 2011, WWTP staff documented these activities in monthly operations summaries submitted to the RWQCB (MBCSD 2011a-l).

To assist WWTP staff in the operation and maintenance (O&M) of major plant components, an O&M manual (dated November 1987) was completed following the plant upgrade in 1986. The O&M manual includes standard operating procedures as well as preventative and contingency plans for controlling and minimizing the effects of accidental discharges. The manual is reviewed and updated as new major equipment is placed on-line or when procedures are changed.

Revisions to the O&M manual that were completed in 2011 included updates to the Laboratory Quality Assurance and Quality Control Manual (May 2011), and various safety programs, including: the Electrical Lockout/Tagout Procedures (July 2011); Confined Space Entry Procedures (July 2011); and the Emergency Evacuation, Tsunami Preparedness, and Fire Prevention Program (August 2011). Specifically, the tsunami plan was revised to include lessons learned from the March 2011 tsunami generated by the Tohoku earthquake in Japan.

Standard Operating Procedures for the following equipment were also updated during 2011: boiler setpoints (Nov 2011); gas flow meters on the digester gas lines (Oct 2011); and operational modes for the influent VFD's (Oct 2011).

As part of routine maintenance procedures, SCUBA divers inspect the ocean outfall's exterior and the diffuser structure for signs of damage annually. On 8 and 9 December 2011 the outfall was found to be in good condition, with no broken or plugged diffuser ports. The divers conducting the inspection replaced the bolts on 12 of the diffusers and collected video of the outfall and its surroundings. Based on the condition of the bolts that were removed, they recommended that all the diffuser bolts be replaced in the near future. Plant staff requested and received approval for the additional funds necessary to complete the bolt replacement project from the MBCSD at its 12 January 2012 meeting. The replacement of the remaining bolts is scheduled to be completed in the first quarter of 2012. The outfall inspection report is included herein as Appendix D.

Figure 2.2 is a photograph of a diffuser port taken during a previous outfall inspection. It shows a dense cover of marine epifaunal organisms thriving on the outer surface of the diffuser port. A large colony of club-tipped anemones (*Corynactis californica*), bright pinkish-red in color, covers the top surface of the port. The continued presence of these filter-feeding organisms attests to the benign nature of the effluent discharge, and to the outfall's value as an artificial reef. Quantitative biological surveys conducted within the region found that these anemones are only occasionally observed on high-relief rock surfaces within Estero Bay, and then only in deeper water (>85 m) (Morro Group, Inc. 1999). Ostensibly, their susceptibility to elevated suspended-sediment loads explains their rarity on nearshore, lower-relief rocks. The preponderance of anemones on the diffuser confirms the minimal negative impact of the outfall's particulate discharge on marine organisms.

Other routine maintenance and minor repairs were regularly conducted on various treatment-plant components. For example, the emergency standby generator was regularly tested under full load. Every quarter, the standby generator was inspected, and a certified contractor performed scheduled maintenance.

In addition, the WWTP staff instituted several major repairs and preventative-maintenance measures during 2011. Typically, there are only one or two large-scale repair and maintenance events each year; however, during 2011 there were five major undertakings.

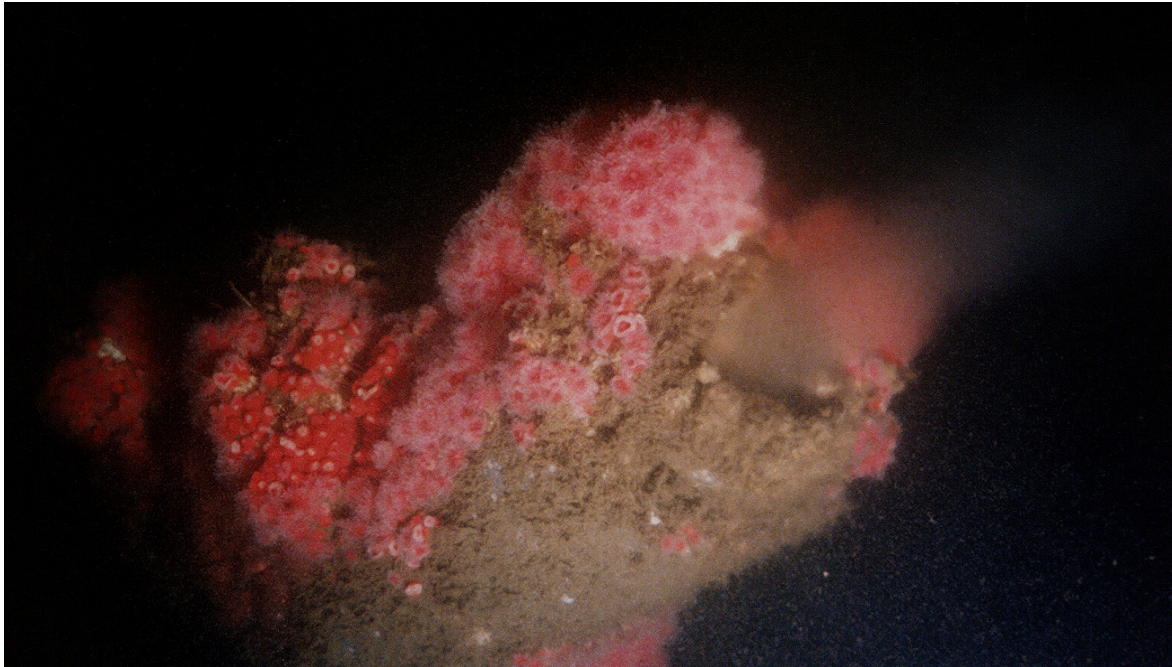


Figure 2.2 Photograph of a Diffuser Port Discharging Effluent

First, beginning in February and continuing through the remainder of 2011, plant staff investigated possible solutions to address struvite (ammonium magnesium phosphate, $\text{NH}_4\text{MgPO}_4 \cdot 6\text{H}_2\text{O}$) buildup that had been discovered within the discharge piping of the digesters. Struvite accumulation is a common problem in wastewater treatment systems and can create problems in process pipes, pumps and other equipment due to crystal formation (scaling) on critical surfaces. Continued buildup within the pipes could eventually impact their hydraulic capacity. The formation of struvite deposits also reduces efficiency in heat exchangers, and restricts flow in surface aerators. Therefore, plant staff contacted various vendors and other treatment facilities in an attempt to address the problem. Following consultation with these sources, as well as with staff at the State Water Resources Control Board (SWRCB), the WWTP staff instituted weekly sampling of the digester supernatant for the formative components of struvite: magnesium, phosphate, and ammonia.

The formation of struvite typically occurs when concentrations of soluble magnesium (Mg^{+2}), ammonium (NH_4^{+}), and orthophosphate (PO_4^{-3}) become super-saturated. Minimizing the concentration levels of any of these three main soluble ions is one of the primary means of controlling struvite formation. Other measures include using the proper pump design and size, pipe diameter and material of construction, and design of pipe connections with an emphasis on minimizing the turbulence in the flow systems. The investigation into appropriate preventative measures applicable for minimizing struvite buildup at the MBCSD WWTP remains ongoing at the time this report was written.

The second major maintenance event began at 2:30 a.m. on 11 March when plant staff was notified that the United States West Coast and Alaska Tsunami Warning Center had issued a tsunami warning for the coastal areas of most of California, all of Oregon, and the western part of Alaska. The tsunami warning was generated in response to the 9.0-magnitude (M_w) Tohoku earthquake that was centered offshore of the Japanese island of Honshu. This earthquake was one of the most powerful quakes to occur since

modern record keeping began in 1900, and triggered powerful tsunami waves that reached heights of up to 40.5 metres (133 ft) along the nearby coastline of Miyako.

In response to the tsunami warning, staff mobilized and arrived at the plant at approximately 5:30 a.m. They ensured that the plant was both operating as designed, moved vehicles and other equipment to higher ground, and communicated with the Emergency Operations Center (EOC) throughout the event.. Meanwhile, residents in the coastal areas of the communities of Oceano, Cayucos, Port San Luis, Grover Beach, Avila Beach, and Morro Bay, and were also encouraged to evacuate and seek higher ground as a precautionary measure.

The tsunami produced a 6.3-foot sea-level surge at 9:21 a.m. and another 6.6 foot surge at 11:25 a.m. at nearby Port San Luis. Fortunately, although this was the largest tsunami event ever recorded at the Port, the treatment plant was not impacted by the event. Nevertheless, plant staff drew on lessons learned during the event to update the tsunami preparedness program in the O&M manual, and to guide their ongoing efforts to protect critical plant facilities (buildings and equipment) against similar types of flooding events.

The third major maintenance event at the WWTP also occurred in March 2011. From 19 to 22 March, an intense storm event resulted in high creek flows, large surf, and extreme tides that diverted the path of Morro Creek northward from its usual discharge point along Atascadero Beach. Over the following week, flow from the creek removed a large volume of sand from the beach due west of the plant, eventually exposing approximately 100 ft of the outfall pipe. Staff inspected the exposed section, confirmed that there was no indication of structural damage to the pipe, and made preparations to rebury the pipe, a process that included applying for and receiving emergency permits from the following agencies: the Army Corp of Engineers, the California Coastal Commission, and the RWQCB. The MBCSD contracted with Associated Pacific Divers to cut a new channel across the beach to divert creek flow several hundred yards south of the outfall. The work was completed on 2 April. Once the creek was diverted, the tides and waves naturally reburied the pipe.

The fourth major maintenance event to occur during 2011 took place beginning on 31 March, when staff discovered a problem with the effluent flow meter used to pace the dosing pumps for sodium hypochlorite (for disinfection) and sodium bisulfite (for dechlorination). Staff subsequently shipped the meter to the manufacturer for repairs and maintenance. While the effluent flow meter was off line (from 4 April onward), the influent flow meter provided pacing signals for both the plant's disinfection and dechlorination processes.

Repairs were made to the effluent flow meter, including the rebuilding of the lower end of the propeller unit and the installation of a new and upgraded flow totalizer. During the repair process, however, the manufacturer removed the mounting brackets that hold the meter's tube frame to the wall of the metering vault. As a result, the meter could not be positioned properly relative to the vault's inlet pipe, which is critical for accurate flow measurement. Additionally, because the lower mounting bracket is normally submerged, WWTP staff had to drain the metering vault in order to determine the precise location for the mounting brackets. Draining the vault required diversion of all flow into the vault and the chlorine contact tank for a minimum of three hours.

A system for stopping flow to the metering vault and chlorine contact tank was devised wherein the grit chamber and primary clarifier #2 were drained, then subsequently refilled. On the morning of 28 April, plant flow was diverted into the two empty tanks, thereby causing flow to the metering vault to temporarily cease. The metering vault was then drained using a large hydraulic pump, and confined-space-entry protocols were implemented to measure and install mounting brackets. However, straightening vanes located within the thirty-inch pipe then interfered with the flow meter propeller. After

grinding the straightening vanes to allow propeller clearance, the flow-meter installation was completed. Once flow was restored to the meter vault, the effluent meter was reconnected and it reassumed pacing the sodium hypochlorite and sodium bisulfite pacing pumps.

The fifth major maintenance event to take place during 2011 involved the construction of flood walls at the motor control centers (MCC), the maintenance shop, and the administration building. The flood walls will protect the buildings while still allowing access into the MCCs and other critical control areas in the event of an inundation. Staff also installed flood gates on some of the MCC doors, and raised equipment above a projected flood elevation of thirty inches.

The sixth and final major maintenance event to take place during 2011 involved the collaborative efforts of WWTP staff and Ballard Diving and Salvage in a detailed internal video inspection of the outfall using a remotely operated vehicle (ROV) equipped with both video cameras and sonar imaging capabilities. The inspection assessed the outfall's structural integrity and the levels of debris buildup within the outfall pipe. Because of the outfall's 1,600-m length, the inspection process was conducted in two parts.

The first phase of the inspection was conducted on 18 and 19 May. The ROV was inserted into the air relief structure within the plant, whereupon it proceeded downstream 600 m toward the diffuser structure. The second phase of the inspection, which encompassed the review of the final 1,000 m of the outfall, was completed on 30 September.

The logistics associated with the outfall inspection were particularly complex. The first phase of the inspection required a sufficient wastewater flow to push the ROV 250 m down the outfall until it became completely submerged and could proceed under its own propeller power. At that point, wastewater flow to the outfall was stopped for five hours. Stopping plant discharge for this extended period of time could only be accomplished during the early morning hours, just after midnight, when inflow to the plant is lowest. In addition, flow diversion required preparation of several major plant components, including draining of the grit chamber and one primary clarifier to act as temporary storage during the inspection. Wastewater within the chlorine contact tank was also pumped to a sludge drying bed to create further storage capacity. As the majority of plant outflow was diverted into these improvised storage tanks and the inspection commenced, precisely controlled flow amounts were occasionally re-diverted back to the outfall to assist the ROV's transport, and recovery from the outfall pipe.

The second phase of the inspection initially attempted to utilize professional divers to remove the diffuser's end flange, insert the ROV, and guide it upstream to inspect the final 1,000 m of the outfall. The ROV's offshore entry into the outfall during this second phase required the conjunction of calm seas and high tides between the hours of midnight and 2 a.m. On 13 and 14 June, divers from Ballard Diving and Salvage were deployed. The divers excavated sand from around the partially buried end flange of the diffuser and began removing the flange's attachment bolts. However, deteriorating sea conditions and shifting sand near the flange exhausted the divers' limited bottom time, and the operation was aborted. After further assessment, it was determined that the inspection could be successfully conducted entirely from onshore using the same technique applied during the first phase of the inspection. The video inspection was eventually completed on 30 September.

In conjunction with these major maintenance efforts, WWTP staff also performed the following routine maintenance activities in 2011:

- Installed new control circuitry at the headworks (January);
- Installed a rebuilt sump pump located in the lower headworks pump room (January);

- Replaced a portion of the main air manifold that feeds the aeration system in the solids contact channel, and replaced the drive motor on the grit aeration blower for the aerated grit chamber (January);
- Replaced the time clocks used to control the sparking unit and replaced the spark plug unit used to keep the waste gas burner lit (February);
- Replaced the batteries for the emergency auxiliary generator (March);
- Performed repairs to the end gates of the two grit bins used to collect grit (March);
- Installed a new rotating brush contactor on the jib crane at the headworks, and serviced all the fire extinguishers at the plant (April);
- Performed minor adjustments to the dosing pumps, and calibrated the chlorine residual analyzers following activation of the high residual chlorine alarm during several large rainfall events (May);
- Replaced the 3-way valve used to control the heat exchanger on the hot water loop used to regulate the temperature of digester #2 (May);
- Installed a new video chart recorder to monitor and record plant flow and chlorine residual levels (June);
- Repaired main influent pump #3 (July);
- Installed a new oxygen sensor on the atmospheric monitoring system used to monitor the headworks influent channel screening area (July);
- Replaced a faulty sump pump used to supply samples to the total chlorine residual analyzer and replaced the ferric chloride chemical dosing pump (July);
- Replaced the sight glass and associated piping and valves for the sodium hypochlorite chemical storage tank (July);
- Replaced the water trap on the digester gas system for digester #2 (July);
- Installed a backflow preventer on the water line used to supply water to the seals for the biofilter recirculation pumps at the interstage pumping station (July);
- Installed a float system in the main influent channel that can be used as a backup system to control the main influent pumps (August);
- Installed new wiring and control circuits for the gas monitors at the headworks (August);
- Replaced the amperage and volt meters on the control panel of the switch gear for utility power and the emergency auxiliary generator (August);
- Installed two new oil pressure sending units on the emergency auxiliary generator and replaced the laboratory oven used to dry samples (August);
- Replaced the sight glass and associated piping and valves on the ferric chloride and sodium bisulfite storage tanks (August);
- Replaced the pressure and vacuum relief valves on all three digesters (August);
- Installed new pressure switches on instrument air compressors #1 and #2 (August);
- Removed and performed repairs to the discharge piping for the sludge recirculation pump in digester #2, and rebuilt scum pump #2 (September);
- Installed a new drive belt on the drive motor and pump for the sludge recirculation pump on digester #3 (September);
- Replaced the hose on the sample head of the 24-hour influent and effluent composite sampler (September);
- Installed a new section of gas piping on digester #2 (October);
- Completed major repairs to the headworks transfer fan, including the installation of new bearing pillow blocks and drive sheaves (November);

- Installed a new sodium bisulfite chemical dosing pump and replaced the sump pump and 120V outlet within electrical pull vault #6 (November);
- Installed new hydraulic hoses on the trailer-mounted submersible hydraulic pump (November); and
- Installed a new sodium bisulfite chemical dosing pump, and performed repairs to the check valve on Grit Pump #P2502 (December).

2.1.2 Plant History

The original WWTP, built in 1954, had a nominal capacity of 0.7 MGD and a 1-MGD maximum throughput. The original plant included a headworks structure, primary and secondary clarifiers, a biofilter, a single-stage digester, chlorination facilities, biosolids drying beds, and a short ocean outfall.

In 1964, the plant upgraded to a nominal capacity of 1 MGD and a 1.3-MGD maximum throughput to meet the demands of the growing coastal community. This upgrade added a pump station, a splitter box, a primary clarifier, a secondary clarifier, a biofilter, chlorination facilities, biosolids beds, and another primary digester, which allowed conversion of the existing digester to a secondary capacity. A new office and laboratory were also constructed during this upgrade.

During the 1970s, the City of Morro Bay developed a plan for additional upgrades to the WWTP facilities intended to further augment the plant's capacity. In 1980, the City began designing these planned improvements, including the construction of a new outfall to better protect the marine environment, and a facilities upgrade to provide full secondary treatment.

Following a yearlong study of oceanographic conditions within Estero Bay, design of the new outfall was completed in April 1981. The new outfall and diffuser system extended the discharge from the surfzone to a point far offshore. The deeper discharge increased dilution of wastewater within the open-ocean environment. The new outfall was completed and placed in service in June 1982.

The design of the facility improvements, completed in September 1981, called for a final effluent suspended-solids concentration of 30 mg/L and an equivalent limit on BOD. However, aid from state or federal agencies to finance the construction to meet these full-secondary treatment levels was not available. Since discharge through the new outfall was not causing any apparent adverse environmental impacts and the projected future throughput was low, the State determined that additional financial aid for upgrading the MBCSD WWTP to full secondary was not warranted. Instead, the City modified the design to provide secondary treatment to a majority (1 MGD) of the projected flow to comply with the state water-quality standards set forth in the California Ocean Plan (COP) (SWRCB 1990). State officials agreed with this level of treatment, provided that the USEPA approved a 301(h)-modified NPDES discharge permit that adjusted secondary-treatment requirements on suspended-solid and BOD emissions.

In a 16 March 1983 letter, RWQCB staff determined that the proposed discharge would comply with applicable state laws, including water-quality standards, and would not require additional treatment, pollution control, or other requirements on any other point or nonpoint source. This tentative determination was pursuant to Title 40 of the Code of Federal Regulations, Section 125.60(b)(2) [40 CFR 125.60(b)(2)] (USGPO 1982a) and 40 CFR 125.63(b) of the 301(h) regulations dated November 1982 (USGPO 1982b).

The treatment-plant upgrades completed between 1983 and 1985 increased the plant's capacity to a 2.06-MGD average dry-weather flow and a peak flow of 6.6 MGD. The plant now includes primary treatment of all influent by screening, grit removal, and primary sedimentation. Additionally, depending on the hydraulic conditions within the plant, up to 1 MGD of the flow can be diverted through a secondary

treatment process of trickling filters, clarifiers, and a solids contact chamber. The secondary-treatment process utilizes two trickling filters, an aerated solids contact channel, and a secondary sedimentation tank. The original 1954 sedimentation tank was converted into a chlorination system where the primary- and secondary-treated effluents are mixed and disinfected prior to dechlorination and discharge through the ocean outfall.

On 29 March 1985, an NPDES permit based on the previously approved Section-301(h) modification established water-quality standards for the MBCSD WWTP. The permit required treated effluent to achieve a suspended solids content of no more than 70 mg/L (75% removal) and a maximum BOD of 120 mg/L (30% removal). The permit also required an extensive monitoring program to assure maintenance of environmental quality. The permit was valid for five years and expired on 8 March 1990. After an evaluation process, the permit was reissued in December 1992. During this evaluation period, improvements to the treatment facilities included the installation of a sludge removal system in the mixing chamber of the chlorine contact tank.

The MBCSD again applied for renewal of the permit in May 1997, supporting its application with an extensive technical review of more than ten years of monitoring data (MRS 1997a). An administrative extension until 11 December 1998 allowed regulatory agencies additional time to review and issue the new permit (RWQCB 1998). In July 1998, RWQCB staff determined that the discharge described in the MBCSD application “*would comply with applicable state laws, including water quality standards, and would not result in additional treatment, pollution control, or other requirements on any other point or nonpoint source.*” This permit was finalized and issued by USEPA on 26 January 1999, with an effective date of 1 March 1999.

Based on discussions between RWQCB, USEPA, and MBCSD staff and their consultants, the following revisions were also implemented in the 1999 permit:

- A 12.7% reduction in the allowed mass emission of suspended solids, BOD, and O&G;
- More extensive reporting requirements for biosolids;
- Elimination of shellfish monitoring;
- A revised benthic sampling pattern eliminating seasonal sampling and increasing the number of stations close to the diffuser structure;
- A revised receiving-water sampling program eliminating bottle casts and doubling the number of vertical profiles close to the diffuser structure; and
- Specification of mass emission goals for toxic chemicals.

Based on the historical absence of perceptible impacts and projection of consistently high effluent quality, on 3 July 2003 the MBCSD again applied for a renewal of the discharge permit (MBCSD 2003). As with the previous permits, the application requested continued discharge under the 301(h) provision with minor modifications to the BOD and suspended solids requirements. On 4 February 2004, the RWQCB (2004) administratively extended the existing permit to allow time for further review. On 10 September 2005, the USEPA Region IX (2005) issued a tentative decision concurring with issuance of a permit to the MBCSD in accordance with Section 301(h) of the Clean Water Act. On 6 April 2006, the USEPA and RWQCB staff issued a joint notice for a proposed action to reissue the 301(h) modified NPDES discharge permit to the MBCSD. However, on 11 May 2006 the RWQCB and the USEPA conducted a joint public hearing on reissuing the MBCSD permit wherein the RWQCB voted to continue the hearing pursuant to the issuance of a biological evaluation by the USEPA (2007).

In 2008, the USEPA issued an Endangered Species Act (ESA) biological evaluation of continued discharge under a 301(h) modified discharge permit wherein they determined:

...that the continued wastewater discharge from the Morro Bay/Cayucos facility is not likely to adversely affect the brown pelican or southern sea otter, both of which occur in the vicinity of the subject discharge. EPA finds that any potential direct or indirect effects of the continued wastewater discharge would be insignificant to the brown pelican and southern sea otter.

Pursuant to Section 7 of the ESA, the proposed action of the USEPA required consultation with the U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS), which protect federally listed endangered species and designate critical habitat that may be affected by the proposed action. On 21 December 2007, the USFWS concurred with the USEPA “*determination that the proposed project is not likely to adversely affect the brown pelican or southern sea otter.*”

Nevertheless, the USEPA incorporated three conservation measures into the new NPDES discharge permit to address concerns about potential contributions to otter morbidity by cat litter and domoic acid poisoning. First, the MBCSD would implement a public outreach program to minimize the input of cat litter-box waste into the municipal sewer system. Second, the MBCSD would regularly monitor nutrient loading from the WWTP. Third, the facility would upgrade to at least full secondary treatment levels by 2014.

Based on the foregoing findings and the incorporated conservation measures, the RWQCB unanimously adopted the new discharge permit on 4 December 2008. Subsequently, on 9 January 2009 the California Coastal Commission unanimously determined that the new discharge permit complied with the California Coastal Zone Management Act. On 14 January 2009, the USEPA issued the new NPDES permit, effective 1 March 2009. In addition to the conservation measures noted above, the following revisions were also implemented in the 2009 permit:

- Elimination of acute toxicity testing;
- Implementation of triggered shoreline coliform monitoring;
- Revision of benthic sampling pattern eliminating cross-shore stations and shifting from grab- to composite-sediment chemistry samples; and
- Revision of receiving-water sampling program reducing the number of vertical profiles and implementing a tow-survey component.

Although the current NPDES permit was not finalized until January 2009, the MBCSD had actually begun to implement several of the proposed conservation measures years before. For example, in April 2006, the MBCSD, working to address the concerns of the USEPA and RWQCB, adopted an eight-year time schedule to rehabilitate and upgrade the treatment plant to tertiary treatment, including onsite composting, as the preferred alternative for upgrading the WWTP by 2014. The MBCSD subsequently adopted a draft facilities master plan that outlined the facilities necessary for a tertiary treatment capacity of 1.5 MGD in September 2007. Meanwhile, in August 2007 the City of Morro Bay and the Cayucos Sanitary District individually adopted revenue programs that identified increases in sewer-rate fees necessary for each community to finance the proposed plant upgrade and to provide revenue for needed sewer-system capital improvement projects. In July 2008, the City of Morro Bay implemented new residential and commercial water-use rates that increased the existing fees by 50%. Subsequent annual increases of 5% for residents, and 7.25% for non-residents and commercial businesses will continue through 2014.

During 2009, following completion of a flood hazard analysis, the City and District voted to relocate the treatment plant site to an elevated area adjacent to the existing treatment plant. In October 2009, the MBCSD public noticed a Request for Proposal (RFP) for Engineering Design Services for the upgrade, and the City of Morro Bay released a Revised Notice of Preparation (NOP) for the project, reflecting

changes to the project description involving construction of treatment-plant components in the new location, and the demolition of the existing plant after the relocated treatment-plant components were constructed and brought on-line. Based on the proposals received, the City and District awarded a contract to Montgomery, Watson, Harza (MWH) at the February 2010 JPA meeting. The design process was expected to take 15 months.

Throughout 2010, the City of Morro Bay and District staff continued work with MWH, on the design process for the plant upgrade, as well as staff from Environmental Science Associates, on the environmental review process for the proposed upgrade. As part of these efforts, treatment plant staff conducted a weekly sampling program designed to verify influent loading parameters during high flow periods. In June 2010, the City and District also voted to consider a separate proposal from PERC Water Corporation (PERC) to design, build, operate, and finance an alternative treatment plant project. However, PERC subsequently withdrew from the process in early October 2010.

Meanwhile, in September 2010, a draft Environmental Impact Report (dEIR) for the upgrade project was released for review and public comment. The comment period for this document closed in November 2010, and the final EIR was released in December 2010. The Morro Bay City Council certified the EIR and approved the Conditional Use Permit and Coastal Development Permit (CDP) for the upgrade project on 11 January 2011. However, the decision to issue the CDP was subsequently appealed to the California Coastal Commission. At the time of the writing of this report, the design process remains on hold pending resolution of the Commission's review and permitting decision via a de novo hearing.

2.1.3 Regulatory Setting

The 1972 Federal Clean Water Act and its 1977 amendments established national water-quality goals and created a national permit system (NPDES) of minimum standards for the quality of discharged waters (USGPO 1997a). Pursuant to the new system, states established standards specific to water bodies and designated the types of pollutants to be regulated. Since 1973 the California State Water Resources Control Board and its nine Regional Water Quality Control Boards have been delegated the responsibility of administering permitted discharges into the coastal marine waters of California. The State Board prepares and adopts the COP, which incorporates the state water-quality standards that apply to all NPDES permits. The RWQCB established a Water Quality Control Plan for the basin containing San Luis Obispo County waters ("The Basin Plan" RWQCB 1994). The basin standards incorporate the applicable portions of the COP and specifically address the beneficial uses of marine waters adjacent to the outfall site. Water-quality objectives and toxic material limitations in the basin plan are designed to protect the beneficial uses of ocean waters within specific coastal areas. The basin plan identifies the following existing beneficial uses for the waters of Estero Bay:

- **Water Contact Recreation (REC-1).** Uses of water for recreational activities involving body contact with water, where ingestion of water is reasonably possible. These uses include, but are not limited to, swimming, wading, water skiing, skin and scuba diving, surfing, and fishing.
- **Noncontact Water Recreation (REC-2).** Uses of water for recreational activities involving proximity to water but not normally involving body contact with water, where ingestion of water is reasonably possible. These uses include, but are not limited to, picnicking, sunbathing, hiking, beachcombing, camping, boating, tidepool and marine life studies, hunting, sightseeing, and aesthetic enjoyment in conjunction with the above activities.

- **Industrial Service Supply (IND).** Uses of water for industrial activities that do not depend primarily on water quality, including, mining, cooling water supply, hydraulic conveyance, gravel washing, fire protection, and oil well repressurization.
- **Navigation (NAV).** Uses of water for shipping, travel, or other transportation by private, military, or commercial vessels. The RWQCB interprets NAV as being present within any natural body of water that has sufficient capacity to float watercraft for the purposes of commerce, trade, transportation, and pleasure.
- **Marine Habitat (MAR).** Uses of water that support marine ecosystems including, but not limited to, preservation or enhancement of marine habitats, fish, shellfish, and vegetation such as kelp, or wildlife such as marine mammals and shorebirds.
- **Shellfish Harvesting (SHELL).** Uses of water that support habitats suitable for the collection of filter-feeding shellfish such as clams, oysters, and mussels, for human consumption, commercial, or sport purposes. This includes waters that have in the past, or may in the future, contain significant shellfisheries.
- **Ocean Commercial and Sport Fishing (COMM).** Uses of water for commercial or recreational collection of fish, shellfish, or other organisms, including uses involving organisms intended for human consumption or bait purposes.
- **Preservation of Rare, Threatened, or Endangered Species (RARE).** Uses of water that support habitats necessary, at least in part, for the survival and successful maintenance of plant or animal species established under state or federal law as rare, threatened, or endangered.
- **Wildlife Habitat (WILD).** Uses of water that support terrestrial ecosystems including, but not limited to, preservation and enhancement of terrestrial habitats, vegetation, wildlife (e.g., mammals, birds, reptiles, amphibians, invertebrates), or wildlife water and food sources.

Section 301(b) of the Clean Water Act requires publicly owned treatment works to meet effluent limitations based on secondary treatment, which is defined in terms of limits on three technology-based effluent parameters (40 CFR 133; USGPO 1997a). These limitations are:

- Total suspended solids (TSS) concentrations not exceeding 30 mg/L as a 30-day average and removal rates not less than 85%;
- BOD concentrations not exceeding 30 mg/L as a 30-day average and removal rates not less than 85%; and
- Hydrogen-ion concentration (pH) between 6.0 and 9.0.

Section 301(h) of the Act allows an NPDES permit to modify some or all of these full secondary treatment requirements, if certain conditions are met. The MBCSD WWTP is a combined primary and secondary treatment facility that has operated under a Section 301(h)-modified NPDES permit (number CA0047881) since March 1985. The modifications in this NPDES permit apply only to the TSS and BOD requirements, so all other NPDES limitations apply without exception, including those for wastewater pH

and toxic compounds. The modification was issued only after the MBCSD satisfied the following additional conditions:

- Demonstrate the existence of a water-quality standard specific to the pollutant for which the modification is requested (40 CFR 125.61; USGPO 1997a). The COP specifies limits on TSS and dissolved-oxygen (DO) depression (SWRCB 2005). In January 1999, the California Coastal Commission determined that the discharge complies with the State Coastal Zone Program that incorporates COP standards.
- Demonstrate that the discharge does not adversely impact public water supplies or interfere with the protection and propagation of balanced, indigenous biological populations (40 CFR 125.62). The USFWS (1998 2007) and the NMFS (1998 2004) determined that the discharge will not adversely impact threatened or endangered species, or critical habitats, pursuant to the ESA.
- Conduct a monitoring and reporting program capable of evaluating the effects of the discharge (40 CFR 125.63). The monitoring program described in this report satisfies this requirement.
- Demonstrate that the discharge will not result in any additional treatment requirements on any other point or nonpoint source (40 CFR 125.64). The footprint of the MBCSD discharge does not overlap other discharges.
- Determine whether the WWTP is subject to pretreatment requirements. Since there are no known sources of toxic pollutants or pesticides in the influent, the WWTP is exempt from general pretreatment requirements in lieu of a pollution prevention program. And since the discharge is considered small, it is also exempt from the urban pretreatment requirement (40 CFR 125.65).
- Demonstrate whether the pollution-prevention program meets the requirement for a nonindustrial source control program (40 CFR 125.66). The MBCSD pollution prevention program implements public education and source reduction programs to limit the entrance of toxic pollutants or pesticides into the treatment plant.
- Demonstrate that there will be no new, substantially increased discharges of BOD and TSS beyond those specified in the permit (40 CFR 125.67). The historically high performance of the plant process and the limited projected growth in population and industry within the service area, and the analyses provided in this report demonstrate this.
- Ensure that the WWTP exceeds the minimum requirements for primary treatment (40 CFR 125.60). The WWTP performs “*treatment by screening, sedimentation, and skimming adequate to remove at least 30 percent of the biochemical oxygen demanding material and of the suspended solids in the treatment works influent, and disinfection, where appropriate*” (40 CFR 125.58(r); USGPO 1997a).

The MBCSD WWTP is currently categorized as a Class III wastewater treatment facility by the Office of Operator Certification within the California State Water Resources Control Board. The Board reclassified the facility in 2001 from a Class IV facility based on the advanced treatment process and the plant’s low flow volume. A typical Class IV facility treats more than 20 MGD in the primary process, while the MBCSD plant processes a total flow of less than 2 MGD and carries out partial-secondary treatment of a portion of the flow.

2.1.4 Description of the Treatment and Outfall System

The WWTP operating characteristics are listed in Appendix A. All wastewater is treated through a primary treatment process, which includes screening, grit removal, and primary sedimentation, as shown in Figure 2.3. Typically, a portion of the flow is diverted for an additional secondary treatment process using biofilters, a solids-contact chamber, and a secondary clarifier. The secondary process consists of parallel single-stage, high-rate, trickling filters whose combined outflow goes to a solids contact channel and then to a secondary sedimentation tank. When flows exceed 1 MGD, secondary-treated effluent can be subsequently blended with primary-treated effluent, before the entire blend is chlorinated for disinfection and then dechlorinated. The disinfected and dechlorinated effluent is discharged into Estero Bay through a 4,400-ft (1,341-m) outfall terminating in a multi-port diffuser system. Waste biosolids are anaerobically digested, dried, composted and used as soil conditioner and fertilizer. A schematic of the biosolid process is shown in Figure 2.15 on Page 2-36.

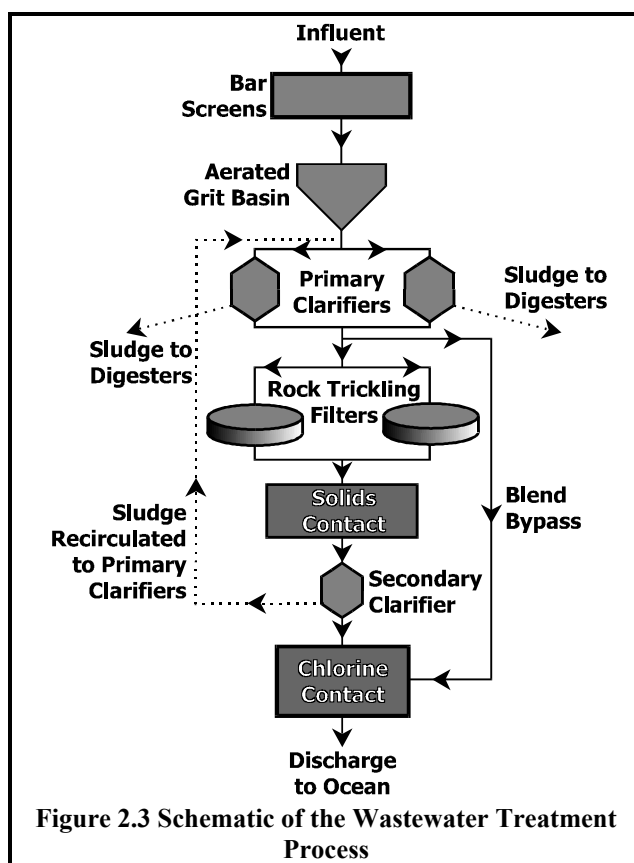


Figure 2.3 Schematic of the Wastewater Treatment Process

The location of the Morro Bay-Cayucos WWTP and outfall within Estero Bay is shown in Figure 2.4. The discharge is released into unstressed, open-ocean waters at 35°23'11"N latitude and 120°52'29"W longitude. Treated effluent flows through a 27-in (0.69-m) diameter outfall that extends approximately 4,400 ft (1,341 m) in a northwesterly direction. The outfall terminates in a multi-port diffuser approximately 2,700 ft (827 m) from shore. The 170-ft (51.8 m) long diffuser lies at a water depth of 50 ft (15.2 m), measured relative to the mean lower low-water (MLLW) datum. Twenty-eight of the 34 available diffuser ports are currently open. The remaining six ports can be made operational if the sustained discharge exceeds 6.60 MGD.

Because of its location, the MBCSD discharge does not interfere with maintenance of water quality and designated beneficial uses within Estero Bay (listed in Section 2.1.3 on Page 2-12). The discharge occurs in well-flushed, open coastal waters where re-entrainment or accumulation of effluent will not violate applicable water-quality standards, even if combined with pollutants from other sources. Intakes and outfalls from other publicly owned treatment works are distant from the MBCSD outfall. For example, water intake for the Morro Bay desalinization plant is from saltwater wells and not from the open ocean where the MBCSD discharge occurs. Similarly, surface discharge of water from the desalination plant, when it does occur, is far south of the MBCSD discharge point and does not add chemical loads to the ocean environment.

2.1.5 Pollution Prevention Program

The MBCSD's Pollution Prevention Program aims to minimize the introduction of incompatible contaminants, such as pollutants and pesticides, into the treatment process. The NPDES permit requires an annual status report detailing efforts to comply with the requirements for a Pollution Prevention Program. This section serves as that report. Additionally, the current permit includes a specific requirement to document educational and outreach efforts regarding proper cat waste disposal.

As in previous years, three aspects of pollution prevention were emphasized during 2011: public outreach, industrial waste source control and identification, and diligent monitoring of influent and effluent for industrial contaminants.

Industrial Waste Survey

During 2011, as in previous years, elevated levels of industrial pollutants were not detected within the MBCSD wastewater stream. Instead, the comprehensive monitoring conducted for more than 25 years indicates that effluent discharged from the MBCSD treatment plant consists primarily of benign constituents typical of wastewater generated from domestic sources. This is because the local economy within the MBCSD service area relies primarily on tourism and commercial fishing, with no heavy industry or manufacturing of any environmental significance. Accordingly, slightly more than 50 restaurants, and an approximately equal number of hotels are found in the service area during any given year.

Since 1999, industrial waste surveys have been used to quantify the comparatively low volume of influent derived from light industrial sources within the service area. The survey activities are based on a digital database that is used to catalogue business names, addresses, contact information, inventories of chemicals, and discharge volumes for all of the potential industrial users within the service area.

The list of businesses in the database is adapted and updated regularly based on business license applications filed with the City of Morro Bay and input provided by the CSD. Businesses with no potential for industrial discharges, such as offices and retail stores, are classified separately from those with the potential for industrial waste discharge. All businesses with potential industrial discharges are either interviewed in person, or are asked to complete a Commercial User Questionnaire. Based on their responses, businesses that either do not generate wastewater at all, or discharge only domestic wastewater (e.g., theaters, beauty shops, and barbershops) may be excluded from the industrial-discharge



Figure 2.4 Location of the MBCSD Outfall and Monitoring Stations within Estero Bay

classification. For the remaining businesses, waste discharge volumes are estimated from water usage history obtained from City Water Department billing records. Follow-up activities for these businesses include scheduled return visits, surprise onsite inspections, and formal tours of the facilities. Based on this phase of the survey, certain dischargers are identified for continued close monitoring with scheduled, annual future site visits. These include commercial laundries, car washes, dry cleaners, print shops, and the oil-water separator maintained by the City of Morro Bay. Businesses are also targeted with unannounced inspections. For example, in 2011 impromptu grease trap inspections were conducted at 23 food service establishments (restaurants and markets).

Although domestic sources contributed the majority (>80%) of the wastewater processed by the plant in 2011, commercial businesses and government agencies contributed approximately 0.19 MGD, or about 17% of the influent. However, a substantial portion of the water use attributed to the government agencies, including the City of Morro Bay, Morro Bay High School, the San Luis Coastal School District (Del Mar Elementary School), and the State Department of Parks (Morro Bay State Park), is utilized for the irrigation of landscaping, sports fields, and agricultural uses, which would not be expected to flow into the collection system. Additionally, the compounds added to the wastestream by both the large commercial and government users are not particularly toxic to humans or aquatic organisms, and do not generally interfere with the treatment process.

Mission Linen is the most industrial of the large dischargers located within the service district. This commercial laundry facility uses several industrial-grade detergents, bleaches, surfactants, and brighteners that can potentially harm the bacteria within the secondary treatment system. In addition, solvents, oils, and other substances removed from soiled laundry have the potential to release contaminants into the wastestream. Although Mission Linen's discharge constitutes only a small percentage (1.0%, or 0.013 MGD in 2011) of the wastewater processed by the treatment plant, MBCSD staff actively work with this discharger to minimize potential risks from their wastestream. For example, in 2002 Mission Linen installed a pretreatment system that includes pH buffering with phosphoric acid to neutralize excessive increases in wastewater alkalinity that can potentially interfere with the plant's treatment process.

Other users with light industrial discharges include the Bayshore Care Center and the Inn at Morro Bay (both of which operate in-house laundering facilities), Hay printing, several dry cleaners, and various local car washes. Car-wash discharges are considered industrial in nature because of the volume of solids, oils, and grease that are washed from vehicles. As mitigation, the car washes pretreat their wastewater with grease separators before discharging it into the collection system. The sewer-use ordinance within the City of Morro Bay municipal code also prohibits smaller contributors, like gas stations and repair garages, from disposing known contaminants into the collection system. Similarly, the municipal code requires restaurants and self-service car washes to install and maintain grease traps within their sewer line connections.

In addition to chemical inputs from industrial users, the WWTP itself intentionally introduces three chemicals (ferric chloride, sodium hypochlorite, and sodium bisulfate) into the treatment process. Ferric chloride is used primarily to control odor in the collection system, although it also reduces hydrogen sulfide emissions during flaring of digester gas and heating of the digesters at the WWTP, as required by the Air Pollution Control Board. Wastewater facilities commonly disinfect effluent prior to discharge with some form of chlorine; the WWTP uses sodium hypochlorite. However, because even low concentrations of residual chlorine can be hazardous to aquatic life, the MBCSD treatment plant adds sodium bisulfite to the wastestream to remove excess free and combined chlorine ions once disinfection is complete.

Not surprisingly, the sodium bisulfate added to the MBCSD treatment process for dechlorination generally tracks the monthly sodium hypochlorite dose used by the plant. Dosage also tracks seasonal changes in the fraction of organic matter entering the plant, which typically increases during the summer due to increased tourist population within the service area and decreased I&I. For example, in 2011 both hypochlorite (2,628 gallons) and bisulfate (1,974 gallons) usage were lowest during the month of February and highest (3,701 gallons and 2,760 gallons respectively) in July, representing a 41% seasonal increase for both chemical compounds.

Public Outreach

The MBCSD's public outreach program educates consumers and local businesses about the organization and operation of the treatment plant, as well as best management practices and techniques for the proper disposal of a variety of household wastes, including pharmaceuticals, fats, oils, and grease.

The MBCSD reaches out to the public through online and written literature, as well as direct communication through presentations, talks, and plant tours. Online outreach efforts center around the City's website where a series of pages is devoted to an overview of the wastewater treatment plant and collection-system operations. The web pages contain links to pertinent information on current topics of interest, including: the status and history of the pending treatment plant upgrade, collection system do's and don'ts, the onsite household hazardous waste facility, the County's pharmaceutical take-back program, *Toxoplasma gondii* and cat litter disposal, and the status of the on-site biosolids composting program. In addition, searchable copies of each of the treatment plant's self-monitoring reports from 2005 onward, as well as a copy of the current NPDES permit, are also available online.

The website provides links to the USEPA website and other outside sources of information on relevant topics, and presents information on specific disposal concerns, like the appropriate disposal methods for pharmaceuticals and personal care products, biomedical wastes, oils and grease, explosives, and pet wastes. Pursuant to the conservation measures recommended by the USEPA (2007) in their biological evaluation conducted in preparation for issuance of the current NPDES discharge permit, the City's website also incorporates updated information on best management practices for cat litter disposal and avoiding its introduction into the collection system. During the most recent permit renewal process USEPA staff had postulated that minimizing the input of cat-litter-box wastes into the municipal sewer system would help reduce the introduction of the parasite *T. gondii* into the marine environment, thereby mitigating a known disease vector affecting southern sea otters. RWQCB staff incorporated the USEPA's concerns into a special provision within the plant's final NPDES permit requiring the creation of a cat-litter public-outreach program.

Shortly following the finalization of the permit, on 21 January 2009 however, Johnson et al. (2009) published the results of a detailed field study of southern sea otter exposure to *T. gondii*, which effectively refuted claims that the incidental disposal of cat litter to the MBCSD system contributed to the observed impacts on otter morbidity from *T. gondii* infection. The authors of the 2009 study not only confirmed that the epicenter of *T. gondii* exposure in otters was not located within Estero Bay as erroneously asserted by NRDC (2006) and Miller et al (2002), but also hypothesized that, based in part on the new epicenter location, "a more important source of infection might be bobcats and mountain lions" instead of housecats. In fact, the world's largest reported outbreak of human toxoplasmosis was linked to a municipal drinking-water reservoir in British Columbia that had been contaminated by cougar feces (Bowie et al. 1997; Aramini et al. 1998).

Nevertheless, during 2011, MBCSD staff continued existing public outreach and education efforts on the proper disposal of cat litter. The MBCSD cat litter outreach program was incorporated into the Public Services Utility newsletters that were circulated to water users in both January and August 2011. A “*don’t flush the mush*” insert was also included in the September 2011 water bills. Additionally, discussions of best management practices were included in presentations made to local realtor groups as well as to members of the public during tours of the treatment plant.

MBCSD does not anticipate any changes to the cat litter public outreach program in the coming year. They will continue to use “*don’t flush the mush*” mailers, newsletters, public outreach presentations, and plant tours to communicate with the general public on the topic of cat litter and waste disposal. In addition, MBCSD staff will continue to make periodic visits to specific commercial and professional establishments to encourage them to establish and implement appropriate policies and procedures to properly dispose of feline wastes.

Among its other public outreach endeavors, in August 2000 the MBCSD partnered with the Integrated Waste Management Authority to establish a permanent household hazardous-waste collection facility at the treatment plant. The WWTP continues to offer free waste-disposal to all residents of San Luis Obispo County every Saturday from 11:00 a.m. to 3:00 p.m., except holiday weekends.

Over the last decade this household hazardous-waste disposal facility has been one of the top sites in the county, in terms of the volume of material collected, with between 20 and 50 individuals utilizing the facility each weekend. Between July 2010 and June 2011, the WWTP disposal facility processed more than 103 tons (206,504 pounds) of household hazardous waste, a large portion of which was recycled.

Well over half (122,374 pounds) of the collected material was comprised of electronic waste (e-waste), which the facility started accepting in 2004. E-waste includes computer monitors and hardware, television screens, cellular phones and digital cameras. These items have components (e.g. screens, batteries) that may contain substantial amounts of cadmium, mercury, chromium, lead, or phosphorous.

Additional materials collected at the facility during 2011 included: more than 16,800 pounds of oil-based paint; 33,000 pounds of latex paint; 2,900 pounds of flammable liquids and solids; 2,650 pounds of aerosol containers; 1,000 pounds of antifreeze; 3,247 pounds of car batteries; 5,000 pounds of motor oil products; 2,300 pounds of poisons; 600 pounds of acids and bases; 7,650 pounds of light bulbs and lamps, 12,434 pounds of rechargeable and other batteries, and 4,000 pounds of compressed gas cylinders. Without the permanent hazardous waste facility, much of this material would have gone to a landfill or would have passed through the treatment plant and into the ocean.

Beginning in 2010, the MBCSD broadened their partnership with the Integrated Waste Management Authority and local law enforcement agencies by participating in the development and implementation of Operation Medicine Cabinet, a county-wide pharmaceutical take-back program. This program allows the public to drop off unused pharmaceuticals and medications in secure drop boxes located at ten different police and Sheriff Stations throughout the county, including one in the lobby of the Morro Bay Police Station. Under Operation Medicine Cabinet, the public is able to drop off unwanted medications 24 hours a day, seven days a week. Encouraging awareness and utilization of the drop boxes helps remove unwanted or unused prescription and over-the-counter medicines from storage, and prevents potential abuse of these compounds. Additionally, offering proper disposal options for these products rather than discarding them in the garbage or down the drain keeps them from winding up in landfills or being passed through the treatment plant and discharged into the ocean. During 2011 approximately 2,900 pounds of pharmaceutical wastes were collected throughout the county, 500 pounds of which were deposited at the Morro Bay Police Station drop box.

Source Identification

Efforts to eliminate or reduce contaminant loads entering the WWTP's wastestream have been successful; elevated contaminant concentrations within effluent samples are rarely detected during the periodic chemical assays. Although no unusual contaminants were detected within the wastestream during 2011, anomalous concentrations of individual chemicals have been reported in the past. On those occasions, MBCSD personnel successfully traced the contaminants to the source, and worked with the source owner to eliminate the contamination.

In 2006, the State Water Resources Control Board adopted new statewide waste-discharge requirements for sanitary sewer systems, which transferred responsibility for managing the introduction of fats, oils, grease, and other components from the WWTP to the Collections Department under the City of Morro Bay's Sewage System Management Plan¹. Ongoing source identification and resolution efforts conducted by the City in 2011 included a grease-trap inspection program. During 2011, approximately 50 businesses were subject to the requirements. The MBCSD conducted scheduled inspections as well as spot checks at approximately 23 businesses throughout the year. During these inspections, MBCSD staff discussed best management practices (BMPs) with kitchen staff and provided the businesses with a BMP handbook. They also handed out "no grease" stickers to put above sinks in order to raise awareness and to use as reminders of the proper disposal methods.

2.2 WASTEWATER CHARACTERIZATION

Monthly wastewater characterizations documented a number of different aspects of the treatment plant's performance in 2011 (Table 2.2). Removal rates quantified the plant's ability to reduce major organic

Table 2.2 Monthly Averages of Influent and Effluent Parameters

Month	Flow (MGD)	Suspended Solids				Biochemical Oxygen Demand			
		Influent (mg/L)	Effluent (mg/L)	Removal (percent)	Emission (kg/day)	Influent (mg/L)	Effluent (mg/L)	Removal (percent)	Emission (kg/day)
January	1.366	372	17	95.9	82	283	27	90.5	130
February	1.271	370	21	93.9	101	324	46	85.7	201
March	1.545	275	25	91.7	128	256	44	83.2	218
April	1.298	262	30	87.8	142	302	88	71.7	473
May	1.197	317	37	89.4	161	320	57	81.5	259
June	1.259	333	22	92.6	103	318	45	85.7	208
July	1.408	359	33	91.2	174	341	52	84.4	288
August	1.243	358	32	92.7	150	332	57	82.8	264
September	1.109	369	32	92.2	129	293	52	82.3	228
October	1.079	425	27	94.4	107	334	45	86.4	176
November	1.108	350	24	93.7	101	309	50	83.9	217
December	1.044	322	21	93.1	85	328	56	82.8	238
Average	1.244	343	27	92.4	122	312	52	83.2	245
Monthly Limitation	≤2.36²		≤70	≥75.0	≤546		≤120	≥30.0	≤936
Annual Total (MT)					45				89
Nominal Annual (MT/year)					≤199				≤342

¹ City of Morro Bay Sewer System Management Plan, approved June, 2009. City of Morro Bay Public Services Department, Wastewater Collections Division

² Peak Seasonal Dry-Weather Flow (PSDWF)

Table 2.2 (continued) Monthly Averages of Influent and Effluent Parameters

Month	pH		Turbidity (NTU)	Settleable Solids (ml/L)	Median ¹ Total Coliform (MPN/100ml)	Oil and Grease		
	Influent	Effluent				Influent (mg/L)	Effluent (mg/L)	Emission (kg/day)
January	7.8	7.5	23	<0.1 ²	<2	53	≈2.4 ³	12
February	7.8	7.5	26	<0.1	<2	100	≈3.8	21
March	7.7	7.5	29	<0.1	<2	12	≈2.9	22
April	7.7	7.5	28	<0.1	<2	140	≈4.1	21
May	7.7	7.5	32	<0.1	<2	13	≈4.8	20
June	7.8	7.6	25	<0.1	<2	140	≈4.7	23
July	7.8	7.6	31	<0.1	<2	81	≈3.7	20
August	7.8	7.6	25	<0.1	2	52	5.0	22
September	7.8	7.6	23	<0.1	3	68	≈4.6	18
October	7.8	7.6	23	<0.1	<2	110	≈3.9	23
November	7.8	7.7	20	<0.1	<2	60	≈3.4	15
December	7.8	7.6	20	<0.1	<2	68	≈5.0	22
Average	7.8	7.6	26	<0.1	<2	75	≈4.0	20
Monthly Limitation		6-9	≤75	≤1.0	≤23		≤25.0	≤195

constituents within the wastestream. Effluent concentrations characterized the overall quality of effluent discharged through the ocean outfall, while mass emissions quantified the cumulative load of wastewater constituents introduced into the marine environment.

Treatment-plant personnel collected and analyzed samples throughout 2011; those samples were then used to compute the monthly averages of the principal influent and effluent characteristics listed in Table 2.2. WWTP personnel regularly determined the principal physicochemical properties of the effluent, including suspended solids, BOD, pH, total residual chlorine (TRC), turbidity, settleable solids, and total coliform bacteria. The frequency and the duration of individual sampling and testing events varied among the parameters. For example, average reductions in suspended solids and BOD were determined from 24-hour composite samples of influent and effluent that were collected and analyzed at least weekly. Analyses for the concentrations of most of the remaining constituents were conducted only on effluent samples. Discrete effluent grab samples were analyzed for pH, TRC, temperature, turbidity, and settleable solids on a daily basis. Effluent grab samples were also analyzed for total coliform five times per week, whereas O&G concentrations were determined from weekly samples. Effluent ammonia was determined from monthly grab samples.

Detailed analyses of these measurements confirm that, during 2011, the plant exceeded wastewater treatment expectations based on the regulatory standards. Over the plant's long history, there has never been an indication of deteriorating plant performance, and effluent quality has consistently exceeded expectations based on the original design criteria. Rare exceptions to standards or criteria have been direct

¹ Computed from samples collected in the 30 days prior to the last day of the month (MBCSD 1997a).

² The “less-than” symbol (<) indicates that the substance was not detected at a concentration above the method detection limit (MDL), which is listed after the “<” symbol.

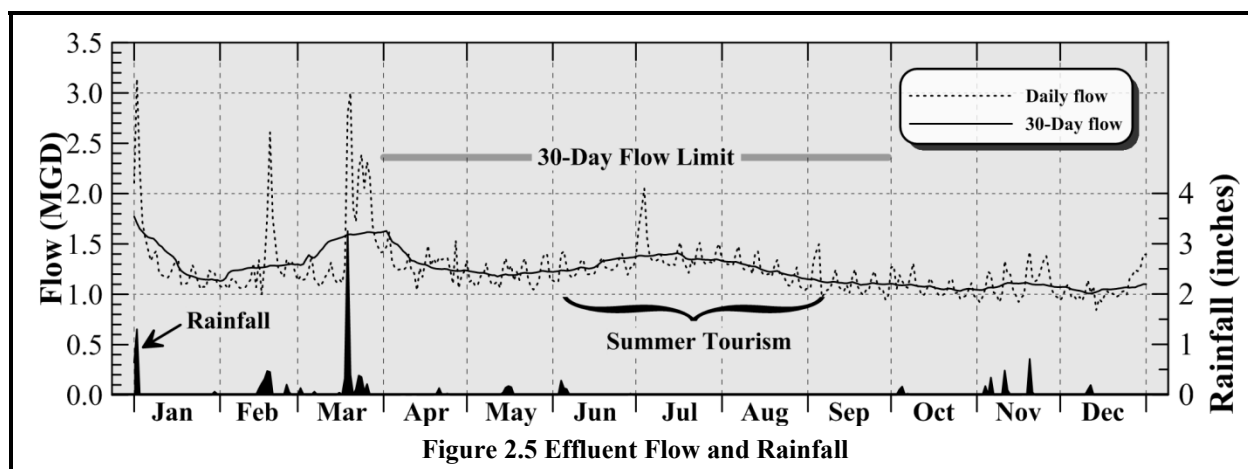
³ The monthly median O&G concentration is used to evaluate plant performance because it provides a more robust measure of central tendency when one or more individual concentrations are not reliably quantified (see Section IV.C.8.C of the COP). O&G concentrations measured in two-thirds of the 52 weekly effluent samples were below the 5-mg/L practical quantification limit (PQL), as shown by the light-gray shading in Figure 2.10c on Page 2-27. The “approximation” symbol (≈) indicates that the median concentration for the month was also too low to be reliably quantified; namely, it was below the PQL. Compliance with the monthly O&G limitation is evaluated in Discharge Monitoring Reports (DMRs) using an arithmetic-average where unquantifiable concentrations are treated as zero (see Item Numbers 15 and 23 in SWRCB 2006).

results of brief, unavoidable mechanical failures of a treatment-system component or the external introduction of a contaminant within the influent stream. As a byproduct of a diligent preventative maintenance program, the plant has operated at a high level of efficiency with little equipment down time. The primary challenge for plant personnel is to respond quickly to unanticipated failures in system components and to external events that impact the treatment process.

2.2.1 Flow Rate

Flow through the plant in 2011 remained below the plant's design capacity and the limit in the NPDES discharge permit. The waste discharge requirements (RWQCB-USEPA 2009) state that the "*peak seasonal dry weather flow shall not exceed a monthly average of 2.36 MGD.*" Plant throughput never approached this flow limitation during 2011 (Table 2.2), not even during winter when the limitation does not apply due to increased flows from precipitation events.

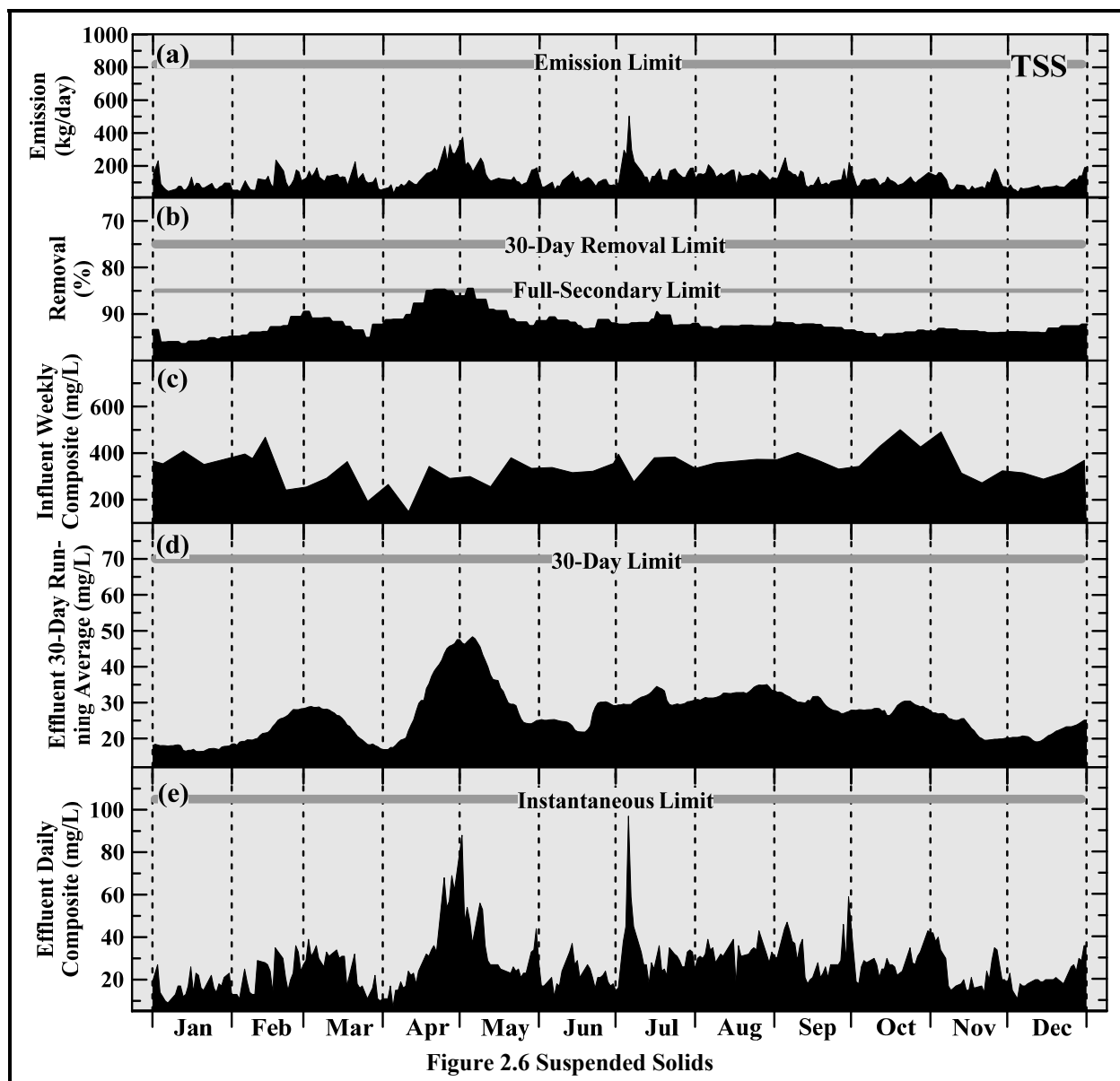
The highest average monthly flow (1.545 MGD) of 2011 occurred in the month of March. It was associated with a series of rainstorms that brought more than 5 inches of rain to the area, and produced a succession of daily flow volumes in excess of 2 MGD. Similar, though less dramatic peaks in daily flow coincided with significant rainfall events in the months of January, February, and November (Figure 2.5). Overall, however, only 12.8 inches of rain fell at the treatment plant during 2011. For comparison, this is slightly below the average amount of precipitation (13.7 inches) measured at the plant over the last decade.



The influence of summer tourism is also apparent in Figure 2.5 as a slight increase in the 30-day running average flow between mid-May and the end of August (solid line in Figure 2.5). However, at 1.41 MGD, the mid-July peak of this 30-day running average flow still represented only 60% of the monthly permit limit for peak dry-season flow, which is indicated by the thick shaded line that spans the 'dry' season (April through September) in Figure 2.5. Smaller peaks can also be observed in the figure that coincide with key holiday weekends throughout the year. The most prominent of these are associated with the Independence Day (4 July) and Labor Day (5 September) weekends.

2.2.2 Suspended Solids, Turbidity, and Settleable Solids

Suspended solids, turbidity, and settleable solids measure the particulate load within the wastewater stream. One of the primary functions of the treatment process is to remove organic particulates from the wastestream. The treatment plant's removal of nearly all (92%) solids from influent (Figure 2.6b; Table



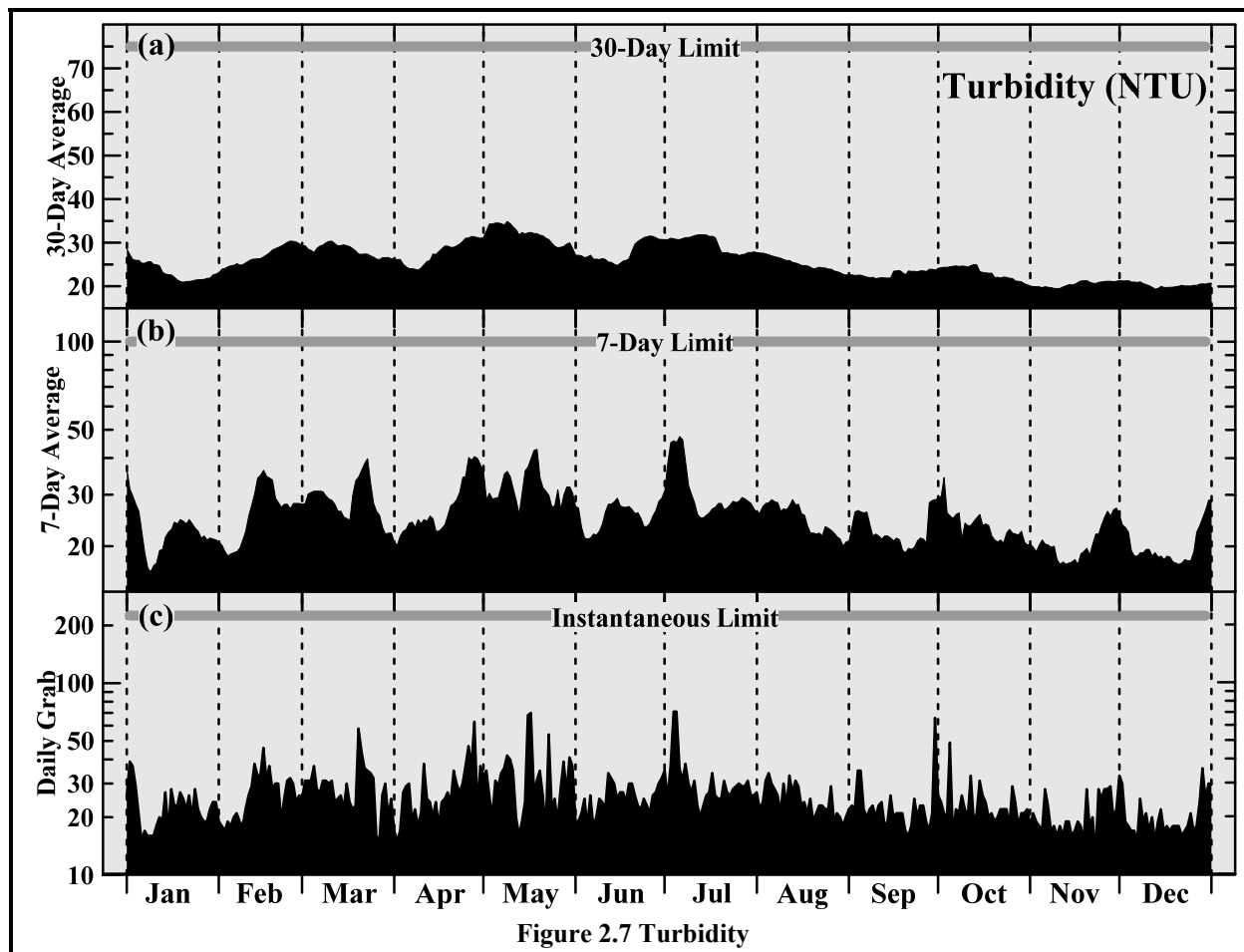
2.2) indicates an exceptionally high overall performance during 2011. As such, the plant's solids removal rate far exceeded the minimum required by the NPDES permit, which specifies removal of only 75% of the suspended solids on a monthly basis. In fact, during every month in 2011, the plant's removal rate exceeded the 85% removal rate established for full secondary treatment.

The TSS data collected in 2011 demonstrate that the treatment plant's performance levels routinely exceed secondary treatment standards. The low average TSS concentration (27 mg/L) within the effluent discharged in 2011 measured less than half of the monthly permit limit of 70 mg/L, and was a direct consequence of the plant's high solids removal rate. Benchmark monthly TSS concentrations during eight months of the year were also at or below the 30-mg/L maximum concentration required to meet full-secondary standards, even though the average influent TSS concentration was 343 mg/L.

Despite the high influent solids load in 2011, the average monthly effluent TSS concentrations were so low (≤ 37 mg/L) that the permit-required removal rate technically did not even apply. Regulators recognize that the imposition of a high removal rate is unnecessary when effluent TSS concentrations are low to begin with. Consequently, the NPDES discharge permit imposes the 75% monthly removal rate only when effluent TSS concentrations exceed 60 mg/L (RWQCB-USEPA 2009, SWRCB 2005). Regardless, during 2011, the treatment process exceeded performance expectations by removing, on average, an additional 17% of the influent TSS above the nominal 75% removal rate.

The diffuse particulate cloud in the photograph of the diffuser in Figure 2.2 on Page 2-5 reflects the light sediment loads in discharged wastewater and its low turbidity (Figure 2.7). Over the entire year, the WWTP discharged approximately 45 metric tons of suspended solids to the ocean. This mass emission is only 23% of the projected 199 metric tons that would have been discharged if effluent had contained the permitted TSS concentration of 70 mg/L and the throughput reached the nominal average dry-weather flow of 2.06 MGD.

The consistently low monthly averages for TSS, turbidity, and settleable solids demonstrate the overall effectiveness of the treatment plant's screening, grit removal, sedimentation, filtration, and clarifying processes (Table 2.2). The monthly averages all remained well below the permitted limits, and despite a low detection limit of 0.1 mL/L, only one of the 365 daily effluent samples contained a detectable amount of settleable solids.



2.2.3 Biochemical Oxygen Demand

BOD measures organic loading within the wastewater stream. Organic loading is indirectly determined from the amount of oxygen required for aerobic bacteria to decompose organic matter in a sample of wastewater. Organic material, which supports bacterial degradation and demands oxygen, can harm the environment if its decomposition severely depletes DO within receiving waters. Specifically, prolonged oxygen depletion can disrupt benthic and demersal communities and can also cause mass mortalities of aquatic life (Diaz and Rosenberg, 1995).

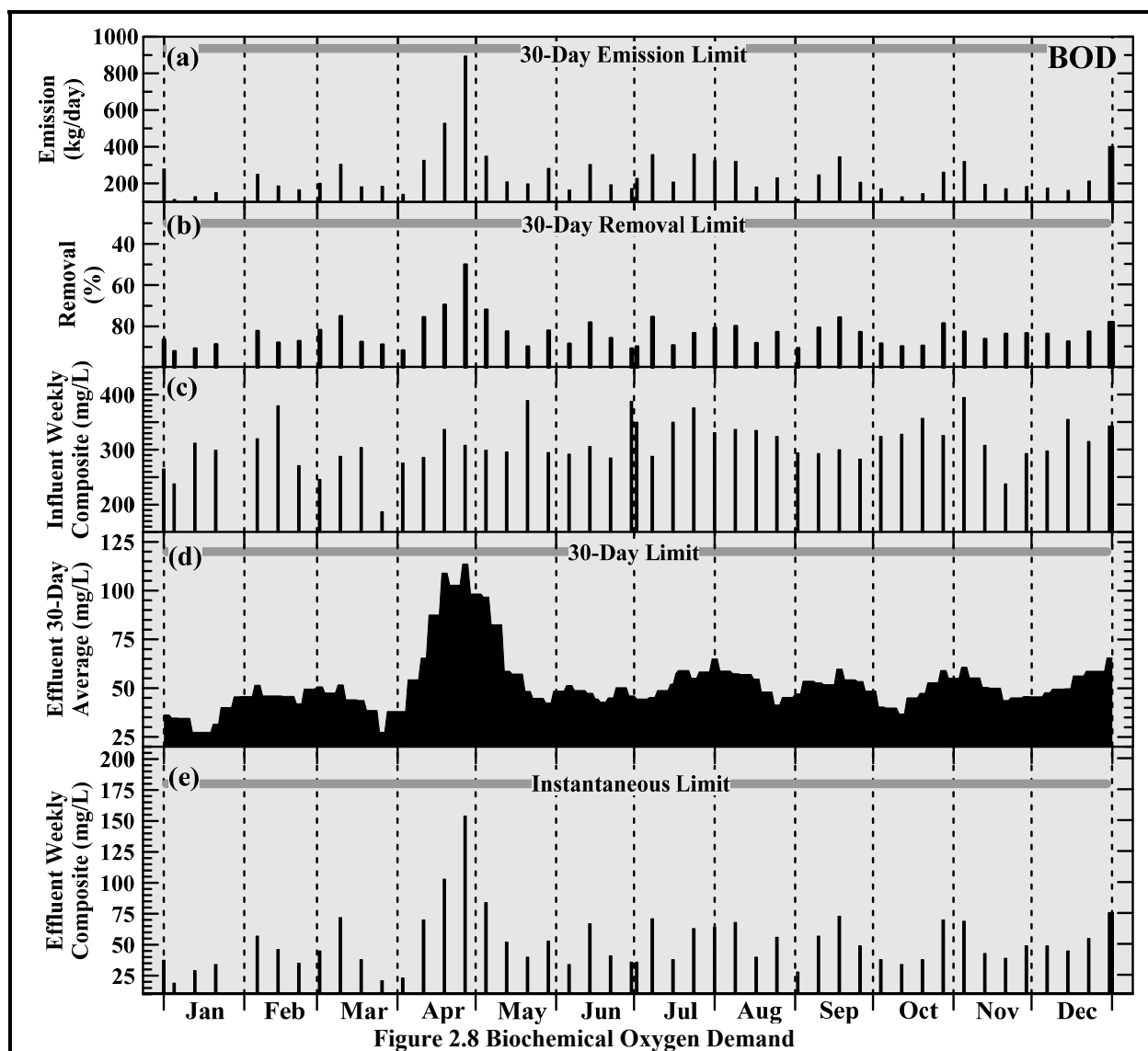
However, DO depletion is typically only of concern in semi-enclosed water bodies, such as bays and estuaries, which are environments that differ vastly from the highly oxygenated open-coastal marine environment of Estero Bay. In fact, because of higher oxygen-replenishment capabilities, an evaluation by the National Academy of Sciences (1993) questioned the environmental benefits of imposing technology-based BOD limits on open-ocean dischargers, namely, requiring secondary treatment standards for BOD.

Nevertheless, during 2011 the WWTP reduced influent organics by more than 83% on average, as determined by the weekly composite samples analyzed for BOD (Table 2.2; Figure 2.8). Thus, the WWTP removed more than two and a half times the minimum amount of organic material that is required for removal (30%) by the NPDES discharge permit. Additionally, as with TSS removal, regulators recognize that high BOD removal rates are not necessary when effluent has a low BOD concentration. Consequently, the NPDES discharge permit imposes the 30% minimum monthly removal rate only when effluent BOD levels exceed 60 mg/L.

During 2011, the treatment process maintained monthly effluent BOD concentrations at or below 57 mg/L during every month of the year except April. Although the plant was only subject to the 30% removal rate during this one month, it consistently achieved far higher rates of BOD removal throughout the year. Specifically, monthly removal rates exceeded the 85% removal rate requirement for full secondary treatment during four months of the year and achieved rates of 81% or higher during every other month except April.

During the month of April, the secondary treatment process suffered an upset of unknown origin that caused marked declines in both BOD and TSS removal rates (Figure 2.8b and Figure 2.6b). At the peak of the event, near the end of April, the effluent BOD concentration of 154 mg/L approached, but did not exceed, the permitted instantaneous maximum of 180 mg/L (Figure 2.8e). Because this and the prior week's measurement were elevated, the April monthly average BOD of 88 mg/L was much higher than for the other months (Table 2.2). Although the reported monthly average was well below the 30-day limit of 120 mg/L, the running 30-day mean peaked at 114 mg/L three days prior to the end of April (Figure 2.8d).

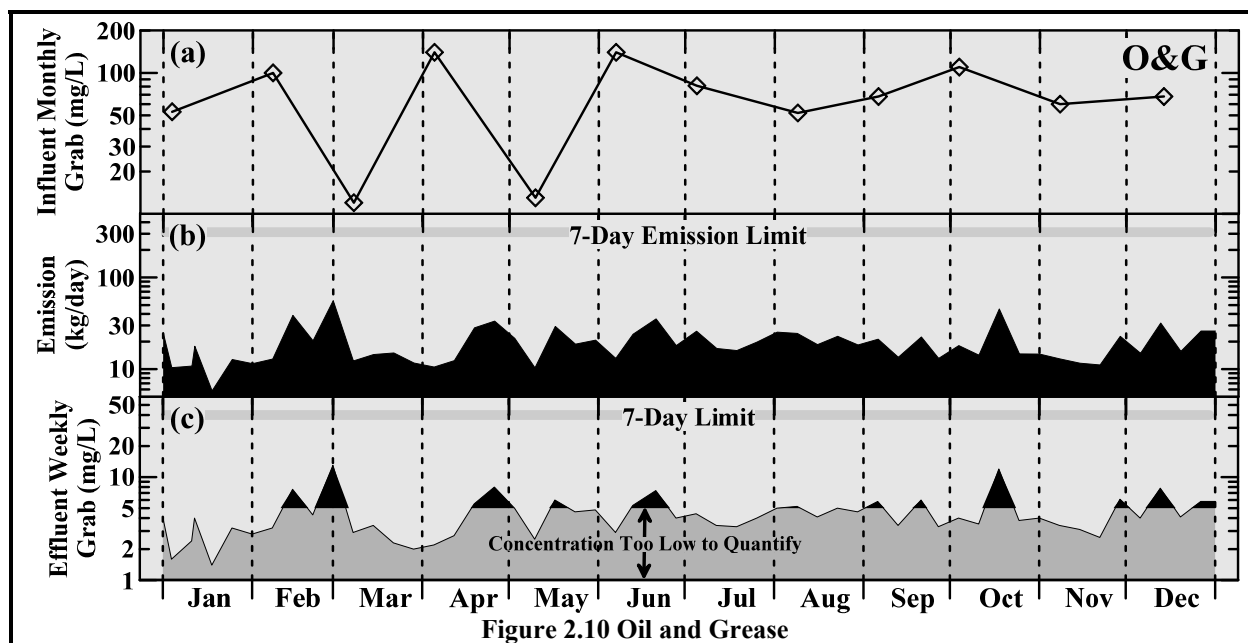
Relative to monthly limits, the decline in plant performance was less apparent in the TSS time history (Figure 2.6d). However, it is clear from the decline in both the BOD and TSS removal rates during this event (Figure 2.8b and Figure 2.6b), and the absence of an obvious increase in the influent loading (Figure 2.8c and Figure 2.6c), that the increased effluent concentrations were directly related to a decline in plant performance rather than an increase in influent loading caused by some external event. Although the cause of the decline was not determined, the event was temporary, and treatment plant performance returned to nominal levels by mid-May. Because of the event's short duration, and because of the plant's high performance throughout the rest of the year, the 89 MT of oxygen-demanding organic material discharged during 2011 was only one-quarter of the 342 MT allowed by the discharge permit.



2.2.4 Oil and Grease

During 2011, the treatment process reduced average O&G concentrations within the influent stream by 18-fold (Table 2.2). In fact, only 32% of the effluent samples contained quantifiable concentrations of oil and grease (≥ 5.0 mg/L). As a result, individual weekly effluent O&G concentrations remained low (≤ 13.0 mg/L) throughout the year (Figure 2.10c), and the associated emissions were well below the 312-kg/day limit on 7-day averages (Figure 2.10b), and only a fraction of the permitted maximum daily emission of 585 kg/day.

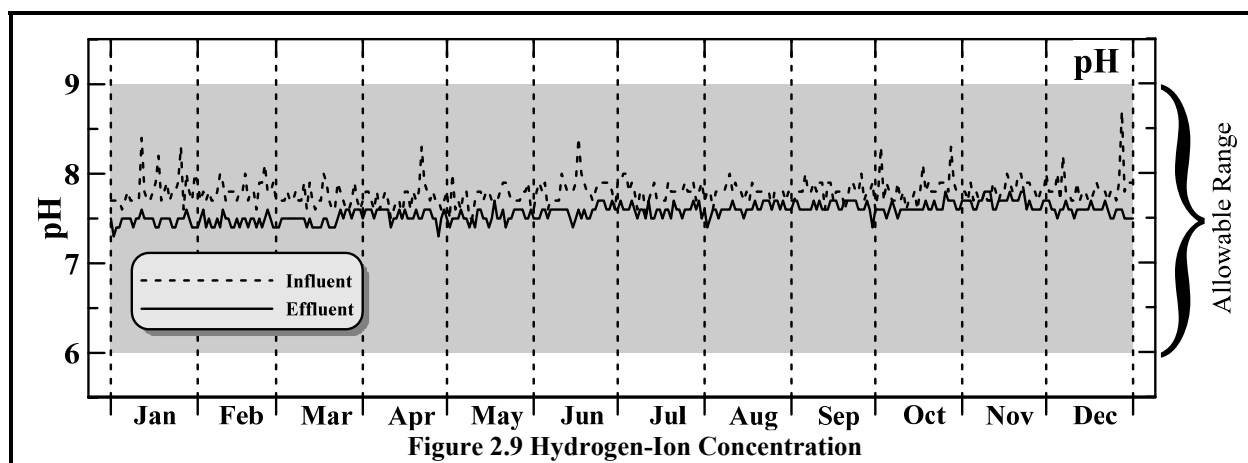
The majority (>90%) of O&G found in the MBCSD influent is comprised of polar hydrocarbons (Table 2.3 in MRS 2011a). Hydrocarbon composition can help indicate whether the source of an O&G sample is industrial in nature, and therefore represents a new or potentially hazardous discharge for the treatment process. For example, polar hydrocarbons are associated with animal and vegetable-based O&G, such as



that used in restaurant cooking, while non-polar hydrocarbons are usually associated with more industrial sources, specifically fuels and motor oils. The predominately polar composition of the MBCSD influent O&G is a testament to the region's tourism-based economy and the lack of heavy industry within the MBCSD service area.

2.2.5 pH

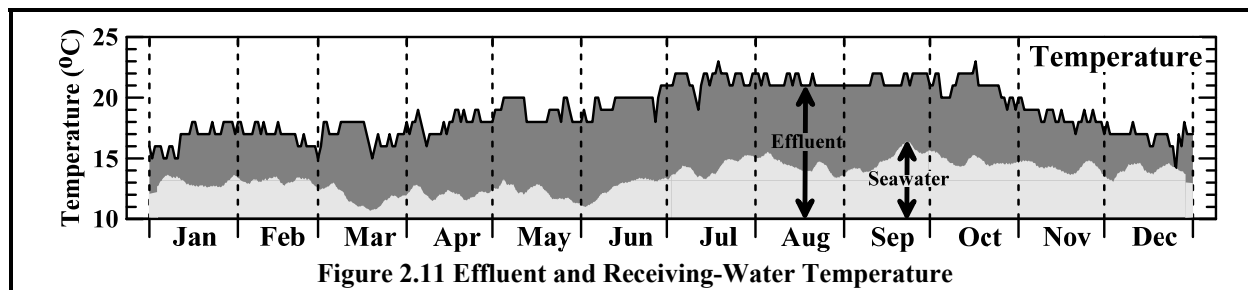
The MBCSD discharge permit requires that the hydrogen-ion concentration (pH) of the effluent remains within 6 to 9 at all times. Section 301(h) of the Clean Water Act allows an NPDES discharge permit to be issued that exceeds these pH limitations. However, because the plant's partial secondary treatment can routinely treat wastewater to comply with the pH standards for full secondary treatment, the MBCSD discharge permit does not allow this exception. Moreover, the general absence of heavy industrial input into the collection system creates an influent stream with a nominal pH that would meet the discharge requirement even without treatment.



Because influent pH (dashed line in Figure 2.9) remained within the discharge limits (shaded area), effluent pH measurements also remained within the allowable range by default (solid line). Comparison of the two time histories demonstrates that the treatment process significantly moderated short-term pH fluctuations within the influent.

2.2.6 Temperature

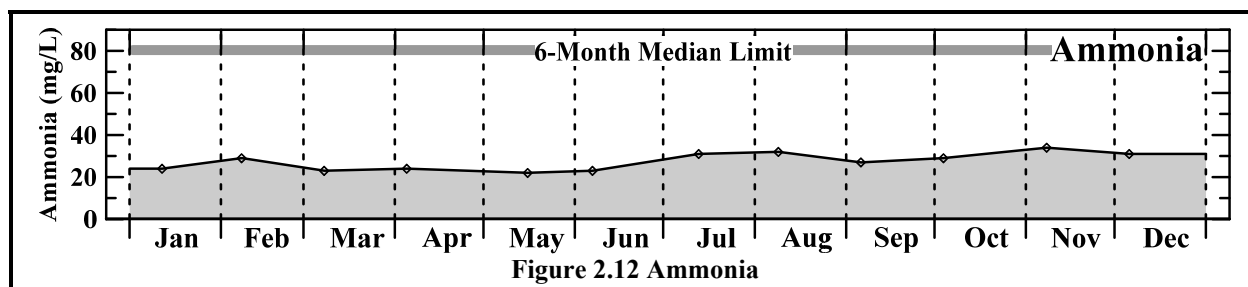
Although the NPDES permit does not limit effluent temperature, it is an important physical property to document because the difference between effluent and receiving-water temperature dictates the amount of mixing that occurs shortly after the wastewater is discharged into the ocean. The warmer the effluent compared to seawater, the greater the buoyancy of the plume and the more turbulence generated by its rise within the water column (see Section 3.2 on Plume Dispersion). Effluent temperature, shown by the dark shading in Figure 2.11, exhibits a distinct semi-annual cycle that tracks seasonal insolation, as does air temperature. Effluent temperatures begin gradually increasing in early spring (April), peak in mid-to-late summer (July through mid-October), and then decline during the fall (mid-October through December).



Because of the strong and sustained influence of upwelling in 2011, seawater temperatures, shown by the light shading, did not track seasonal-insolation trends in effluent temperature. In response to intense southeastward winds, seawater temperatures dropped in March and remained low until June (see Section 3.2.3). The resulting low seawater temperatures from mid-March through May provided a greater thermal contrast with effluent than in late fall and winter (November and December). Upwelling winds continued throughout the summer of 2011 and maintained the large thermal contrast between seawater and effluent. As a result, the period of maximum thermal contrast, which exceeded 5°C, persisted throughout the period between March and October. Although this large thermal contrast would normally enhance buoyancy-induced dispersion of the effluent plume, water-column stratification, caused by upwelling, limits the vertical motion of the rising plume, largely offsetting the dispersion benefits of the thermal contrast during upwelling season.

2.2.7 Ammonia

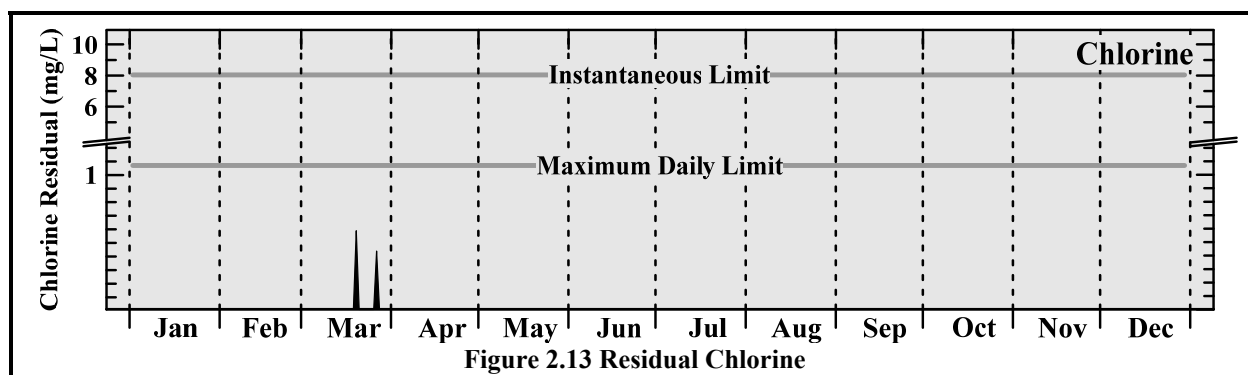
The concentration of ammonia as nitrogen (NH₃-N) was uniformly low throughout 2011. Grab samples analyzed for ammonia on a monthly basis had concentrations at or below 34 mg/L, which is less than half of the 6-month median limit of 80.4 mg/L (Figure 2.12). This peak concentration was also 23-times lower than the permitted instantaneous limit of 804 mg/L, which is imposed to protect marine aquatic life.



2.2.8 Residual Chlorine

Total residual chlorine (TRC) measures the level of chlorine remaining in the effluent after disinfection with sodium hypochlorite and subsequent dechlorination or buffering with sodium bisulfite. Daily grab samples for residual chlorine are collected when concentrations of effluent constituents are expected to be at their highest levels, during peak flow periods. Balancing chlorination and dechlorination to obtain adequate disinfection (coliform reduction) without dosing the marine environment with high levels of chlorine can be challenging because the chlorine demand is constantly changing due to continuous variations in flow and organic loading within the wastestream. Consequently, the disinfection process occasionally requires direct operator intervention. If sodium hypochlorite beyond what is needed to meet the coliform demand is added, then dechlorination may be complicated and TRC levels in the effluent may increase.

Throughout 2011, treatment plant personnel maintained careful control over the disinfection and dechlorination processes. As a result, only two of the 365 grab samples had detectable concentrations of TRC (Figure 2.13). Both detects were associated with the tail end of a significant rainfall event where substantial variations in flow complicated the disinfection process.



The first instance of a detectable TRC occurred on 20 March following an intense three-day storm event that deposited four inches of rain at the plant. The second detection occurred a week later following a more-prolonged rainy period that deposited an additional inch of rain at the plant. Nevertheless, both measured concentrations (0.59 and 0.44 mg/L) were less than half of the daily limit (1.07 mg/L) and remained well below the permitted instantaneous limit (8.04 mg/L). TRC in the remaining samples collected during 2011 never exceeded the 0.05-mg/L detection limit, which is five-times lower than the 6-month median limit of 0.27 mg/L specified in the discharge permit. Because detectable TRC

concentrations were so rare, the monthly averages for all months, including March, remained at or below the 0.05 mg/L detection limit, and well below the 6-month median specified in the permit.

2.2.9 Coliform Bacteria

Effluent samples collected on five consecutive days each week were analyzed for the most probable number of total coliform organisms per 100 ml (MPN/100ml). Figure 2.14b shows that the highest measured daily coliform density (500 MPN/100ml) was still less than one-quarter of the permitted instantaneous maximum of 2,400 MPN/100ml; all other measured daily coliform densities were less than 6% of the permitted limit. In fact, 60% of the 282 effluent samples analyzed in 2011 had no measurable coliform density. As a result, the highest monthly median coliform density (3 MPN in Table 2.2 and Figure 2.14a) remained well below the 30-day median limit of 23 MPN/100ml specified in the NPDES permit. For the most part, increased coliform densities were randomly scattered throughout the year, although increased occurrences of small but detectable densities in September and October resulted in an extended period of measurable 30-day medians (Figure 2.14a).

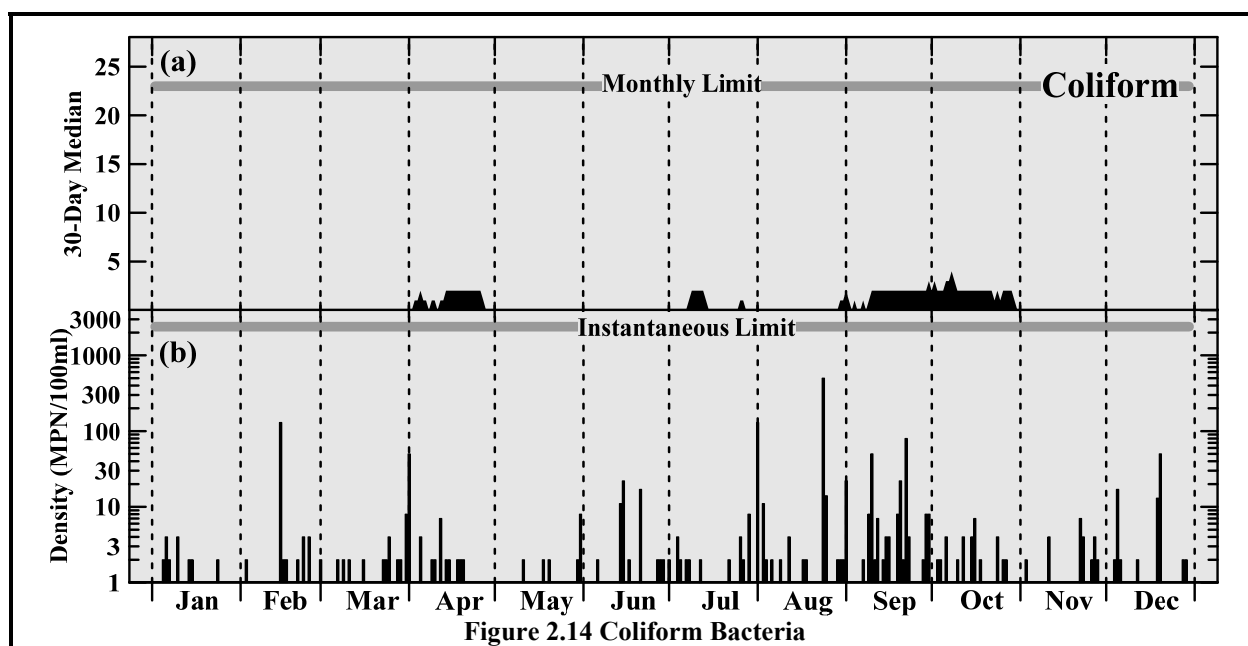


Figure 2.14 Coliform Bacteria

2.2.10 Toxicity

In 2011, effluent samples were tested semiannually, in January and July (Table 2.3), for toxicity using chronic bioassays¹ of composite effluent samples. The chronic bioassays found consistently low effluent toxicity, with levels much less than the discharge permit limits.

Chronic bioassays have historically been conducted on giant kelp (*Macrocystis pyrifera*). Toxic screening studies conducted in 1993 indicated that giant kelp was more sensitive to MBCSD effluent than other species typically used in bioassays at that time, such as the larvae of the inland silverside (*Menidia beryllina*) and the bay mussel (*Mytilus edulis*) (MRS 1994). Over the last twenty years, the bioassays

¹ Acute bioassay testing requirements were eliminated in the current MBCSD discharge permit, in accordance with previous updates to the California Ocean Plan.

Table 2.3 Comparison of Measured Toxicity Levels with Permit Limitations

Sample Date	Bioassay Test	End Point (%)	Concentration (TU)	Limit (TU)
11 January	Red Abalone (<i>Haliotis Rufescens</i>) Larval Development	10.0	10.0	134
12 July	Red Abalone (<i>Haliotis Rufescens</i>) Larval Development	5.6	17.9	134

have repeatedly demonstrated that giant kelp are only minimally affected by exposure to the treatment plant effluent. As required by the current discharge permit, however, a new screening study was conducted on the July 2009 and January 2010 effluent samples that included an assessment of the effluent's effect on the development of larval red abalone (*Haliotis rufescens*) in addition to that of giant kelp. The bioassays indicated larval abalone are slightly more sensitive to effluent than kelp zoospores, therefore, all subsequent bioassays have been conducted on larval abalone.

The chronic toxicity tests conducted in January and July 2011 measured spore germination and growth response in larval red abalone after exposure to a range of effluent dilutions.¹ The results of the 2011 abalone bioassays confirm the effluent's continued low chronic toxicity. All chronic-toxicity endpoints were more than seven-times lower than the applicable permit limitation of 134 chronic toxic units (TUC) for the daily maximum toxicity. The reported TUC were based on a "No Observable Effects Concentration" (NOEC), which is the highest effluent concentration that does not cause an adverse effect statistically different from a control sample. They indicate that the chronic bioassays did not find adverse effects when abalone were exposed to effluent concentrations as high as 5.6%, whereas the permit allows adverse effects in concentrations as low as 0.75%.

2.2.11 Nutrients

During the review process for the current MBCSD discharge permit (USEPA 2007), concerns were raised regarding the relative contribution of nutrients discharged to the ocean by coastal treatment plants, such as the MBCSD WWTP, and their potential role in the promotion of harmful algal blooms (HABs). HABs occur when periodic explosions of growth in naturally occurring algae, which form the base of the marine food web, result in extensive monocultures (blooms) of particular species that are harmful to humans or other life through the production of toxins, or simply from their accumulated biomass.

Offshore central California, most HABs are caused by recurring blooms of two algal genera (*Pseudo-nitzschia* and *Alexandrium*). Both algae produce potent neurotoxins that accumulate in fish and shellfish, causing paralytic amnesic shellfish poisoning (commonly known as domoic acid poisoning), and shellfish poisoning (PSP), respectively. *Pseudo-nitzschia* is a genera of diatoms common along the west coast of the United States that are known to produce domoic acid. When ingested, this toxin can cause neurological damage, including dizziness, headaches, seizures, disorientation, difficulty breathing, and coma. Domoic acid poisoning resulting from algal blooms has been documented in a wide variety of both marine mammals and seabirds. Meanwhile, the exceptionally high potency of the saxitoxin produced by *Alexandrium* species means that even low density populations of this algae can cause severe problems, even though blooms of this algae are may not be visible on the water surface.

Considerable research has been conducted in an effort to understand the environmental factors that promote HABs. Through these studies, processes such as coastal upwelling and river runoff have been implicated as factors that may create physical and chemical conditions (e.g., high nutrient concentrations)

¹ The semiannual effluent reports contain raw test data, pertinent quality assurance/quality control (QA/QC) data, and chains of custody for the chronic bioassays (MRS 2011gh).

conducive to the development of phytoplankton blooms (Trainer et al. 2002, Kudela et al. 2004). Upwelling conditions, which are discussed in Chapter 3 of this report, have been particularly implicated in the generation of HABs along the central California coastline (Trainer et al. 2000, Kudela et al. 2005). In addition to these natural processes, increased human activity and pollution are also thought to be contributing factors to the recent observed higher frequency and intensity of HABs.

Therefore, the USEPA proposed a conservation measure for “*Regular monitoring of nutrient loading from the [MBCSD] facility’s ocean outfall*” in their biological evaluation, and a request for concurrence with their finding of “*no likely adverse effects*” from the USFWS. The USEPA’s recommendation was subsequently incorporated into the current discharge permit’s receiving-water limitations as follows: “*Wastewater constituents within the discharge shall not cause objectionable aquatic growths or degradation of indigenous biota resulting from the discharge of nutrients.*”

Open-ocean dischargers, such as the MBCSD treatment plant, are not normally required to monitor for bio-stimulatory nutrients because energetic, well-flushed marine environments rapidly dilute and disperse discharged nutrients, preventing their accumulation to deleterious levels. For this reason, there are no numerical objectives for nutrient compounds (except ammonia) within receiving waters promulgated in the COP. However, in response to the concerns regarding nutrient loading and HABs, MRS (2008b) designed and instituted a nutrient-monitoring requirement for the MBCSD effluent monitoring program that includes the semiannual analyses of nitrate [NO_3^-], urea [$\text{CO}(\text{NH}_2)_2$], ortho-phosphate [$(\text{PO}_4)^{3-}$], and dissolved silica [SiO_2] concentrations.

These particular compounds were selected because they represent limiting macronutrients for phytoplankton growth within the euphotic zone of the ocean. The ocean bio-stimulatory nutrients, in order of decreasing importance, are nitrogen, phosphorus, and silica. Meanwhile, nitrate and urea are nitrogen compounds found in measurable concentrations within wastewater, and have been associated with the stimulation of phytoplankton growth (Kudela and Cochlan 2000). Ammonia [NH_3] is another nitrogen compound typically associated with phytoplankton growth. However, ammonia concentrations are already regularly measured as part of the MBCSD discharge permit’s waste discharge requirements.

In fulfillment of the new permit requirement, nutrient assays of MBCSD effluent were conducted on grab samples collected in January and July 2011. The assay results demonstrate that nutrient concentrations within the MBCSD effluent and mass loading to the marine environment from its discharge, are small compared to both other central-coast dischargers and the contribution from regional streams and rivers (Table 2.4). Specifically, concentrations of nitrate, phosphate, and silica within MBCSD effluent were substantially lower than those of the three large central-coast WWTPs to the north, while concentrations of urea were comparable to those of the other dischargers. With concentrations near or below the 0.05-

Table 2.4 Nutrient Concentrations and Loading from Central-Coast Ocean Discharges

Source		Concentration (mg/L)				Mass Emission (kg)			
		Nitrate	Urea	Phosphate	Silica	Nitrate	Urea	Phosphate	Silica
MBCSD	January	<0.05	0.091	1.6	16.0	<100.	160.	2,870.	27,200.
	July	0.06	0.085	1.56	14.0				
Santa Cruz		9.52	0.087	7.7	30.2	139,000.	1,360.	117,000.	489,000.
Watsonville		10.52	0.110	13.6	35.6	105,000.	1,250.	154,000.	364,000.
Monterey		4.82	0.084	3.4	41.0	85,600.	1,100.	30,300.	488,000.
Streams and Rivers ¹		3.58	0.021	0.14	25.6	1,660,000.	33,500.	340,000.	25,200,000.

¹ Average concentrations and total emissions from fourteen streams and rivers discharging to the northern central coast from July 2005 and June 2006 (CClean 2007).

mg/L detection limit, the MBCSD nitrate levels, in particular, were two orders of magnitude lower than those of the other WWTPs within the central-coast region. Although nitrate and silica concentrations within MBCSD effluent were also less than the average concentrations found within central-coast rivers and streams, urea and phosphate concentrations were higher, as was the case for the other central-coast WWTPs.

Notwithstanding the slightly higher urea and phosphate concentrations within effluent, potential environmental effects from nutrient discharge are dictated by the total mass emissions contributed by the various sources (right side of Table 2.4). When the relatively small volume of the MBCSD discharge is considered, its total nutrient loading to the marine environment is one- to three-orders-of-magnitude less than each of the three large WWTPs, all of which discharge into the waters of the Monterey Bay National Marine Sanctuary (Table 2.4). Similarly, nutrient loading from the MBCSD discharge is up to four-orders-of-magnitude (10,000-times) less than the average contribution of runoff from the central-coast region.

2.2.12 Chemical Compounds

In addition to the effluent properties and bioassay results described above, there are 78 chemical properties that are regulated by the COP whose effluent concentrations are limited in the discharge permit. Effluent composite samples were analyzed in January and July 2011 for the presence of these chemical compounds, which include trace metals, chlorinated and nonchlorinated phenolic compounds, volatile organic compounds, organochlorine pesticides, PCBs, cyanide, base-neutral compounds, and radionuclides. The COP regulates the discharge of these compounds for the protection of marine life and the protection of human health from exposure to both carcinogenic and non-carcinogenic substances.

As has been the case in the historical record of 2,962 chemical assays spanning 19 years of MBCSD effluent monitoring, the 2011 analyses detected concentrations of only a few ubiquitous compounds at levels well below the regulatory limits (Table 2.5). Those detected compounds are discussed below, while detailed discussions of effluent chemistry, along with the corresponding concentration limits, minimum reporting levels, laboratory data sheets, pertinent QA/QC data, and chains of custody for all the chemical constituents were provided in the semiannual self-monitoring reports (MRS 2011gh).

The chemical assays found only eight of the 78 chemical compounds present in quantifiable amounts within the 2011 effluent samples.¹ The measured concentrations for all eight compounds were significantly less than the permitted limits. Annual mass emissions of these compounds also met the goals in the discharge permit's reporting provisions. The compounds with quantifiable concentrations included three trace metals (copper, lead, and zinc), two radionuclides, cyanide, selenium, and low-level congeners of dioxin.

The analyses also detected nine additional compounds in the semiannual effluent samples, but at concentrations that were too low for reliable quantification. Specifically, the concentrations of these compounds were more than the method detection limit (MDL)² but less than the minimum level (ML). Reporting of these detected-but-not-quantified concentrations is required under the current NPDES discharge permit, although they are not compared to effluent limitations for compliance assessments.

¹ Quantifiable concentrations of the eight compounds are listed in bold typeface in Table 2.5.

² The method detection limit is the lowest concentration that can be reported under ideal conditions, when the sample contains only the compound of interest in a concentration within an optimal calibration range and within a medium that does not interfere with the performance of the analytical instrument.

Table 2.5 Chemical Compounds Detected within Effluent Samples

Compound	Concentration (µg/L)			Mass Emission (kg/vr)	
	Limit	January	July	Goal	Measured
Protection of Marine Aquatic Life					
Arsenic	670.	≈0.62 ¹	≈1.0	17.	≈1.47
Chromium VI	270.	≈1.8	≈1.7	93.	≈3.18
Copper	140.	16.	14.	690.	27.2
Lead	270.	0.97 ²	0.90 ²	465	2.3
Mercury	5.29	<0.017 ³	≈0.088	1.4	≈.095
Nickel	670.	≈4.3	≈3.8	142.	≈7.35
Selenium	2,010.	2.5	≈1.9	65.	≈3.99
Zinc	1,620.	50.	≈48.	244.	≈88.9
Cyanide	130.	≈2.7	6.1	71.	≈7.98
Phenolics (Non-Cl ₂)	4,020.	— ⁴	≈2.6	—	≈4.47
Radionuclides (pCi/L)	α	15.	3.79	—	—
	β	50.	7.2	—	—
Protection of Human Health (Non-Carcinogens)					
Chromium III	25,500,000.	≈1.8	≈1.7	—	≈3.18
Toluene	11,400,000.	—	≈0.22	4.	≈0.378
Protection of Human Health (Carcinogens)					
Bis(2-ethylhexyl)phthalate	469.	—	≈4.9	320.	≈8.43
Chloroform	17,400.	—	≈0.86	5.	≈1.48
Dioxin (pg/L)	0.52	—	0.123	1.48 mg	0.21 mg

Trace Metals

Three of the quantifiable concentrations were associated with commonly occurring metals: copper, lead, and zinc. Unlike synthetic organic compounds, trace metals occur naturally within the mineralogy of sediments along the central California coast and are ubiquitous in the local sedimentary environment. All three of the metals were detected in quantifiable amounts within seafloor sediment samples collected at all the benthic survey stations, including the distant reference station B1 (see Section 4.2). These metals enter the wastewater collection system through erosion of natural mineral deposits along the central California coast, as well as through corrosion of household plumbing systems. Regardless of their source, the effluent metal concentrations were only one-eighth of levels deemed deleterious to marine organisms, and the highest metal mass emission was more than 2.5 times lower than the emission goal recommended in the discharge permit.

These three metals have been detected at quantifiable levels in over half of the effluent samples collected during the last 19 years, and therefore, do not represent a new or increased source of contaminants entering the collection system. Moreover, the long monitoring history unequivocally demonstrates that

¹ The “approximation” symbol (≈) indicates that the detected concentration was too low to be reliably quantified, namely, it was below the Minimum Level (ML). Consequently, the number listed after the symbol represents an estimated concentration. Accurately quantified concentrations are indicated by bold typeface.

² The reported concentration was below the practical quantification limit (PQL) and was flagged “as estimated” by the chemistry laboratory. However, in accordance with the guidance from the COP and the NPDES permit, the reported value is listed “as measured” herein, because the value exceeded the ML.

³ The “less-than” symbol (<) indicates that the compound was not detected at a concentration above the method detection limit (MDL), which is listed after the “<” symbol.

⁴ The “dash” symbol (—) indicates that analysis of the compound was not required as part of the monitoring program, or that a mass-emission goal was not specified in the discharge permit.

there is no reasonable potential for these metal concentrations to exceed the discharge permit limits in the future (Refer to the recommendation concerning reductions in monitoring frequency in Section 5.4).

Radionuclides

As with the trace metals described above, the presence of measurable radioactivity within the 2011 effluent sample was not unusual. Radionuclides have regularly been detected within MBCSD effluent samples, largely because naturally occurring radioactive material (NORM) is present throughout the earth's crust, and because radioactive decay can be quantified at extraordinarily low levels. Consequently, the permit limits specified for radionuclides are not derived in the same manner as for other chemical constituents. Permit limits for other constituents are based on their potential for adverse impacts after discharge and include an allowance for the 133-fold minimum dilution that occurs immediately after discharge. Limits on radioactivity, however, are based on the California Code of Regulations, Title 22, §64441 and §64443, and are the same as those established for drinking water; they do not account for post-discharge dilution. Regardless of their origin, the levels of radioactivity measured within the July 2011 effluent sample were well below drinking-water standards.

The low alpha (α) and beta (β) decay levels measured within the July 2011 effluent samples were typical of most prior effluent samples and of naturally occurring sediments of the region. Beta particle activity arises from radioactive decay in both natural and man-made materials, while alpha particle activity arises from natural mineral deposits that enter the collection system through erosion.

Selenium

Selenium, another naturally occurring element within the mineralogy of the central California coast, was detected at quantifiable levels within the January 2011 effluent sample. Low-level concentrations of selenium in MBCSD effluent have typically been associated with the mobilization of naturally occurring selenium in surficial soils following heavy rainfall events. However, as with the other detected elements, selenium's measured concentration was low compared to its permit limit and therefore, not of ecological concern.

Cyanide

Cyanide was detected at low concentrations in the July 2011 effluent sample. As with the other detected compounds, cyanide's measured concentration was low compared to its permit limitation and therefore, not of ecological concern. Cyanide has been detected at quantifiable levels within approximately 20% of the effluent samples collected over the past decade and a half.

Although cyanide occurs naturally, it can also form in the treatment process as a byproduct of the disinfection process. Additionally, it is frequently used in pigments and can be introduced into the collection system during photo processing, newspaper printing, jewelry making, electroplating, and metal cleaning. Cyanide is also a component in many insecticides.

Dioxin

Dioxin was the only other chemical compound quantified in the 2011 effluent samples. The toxic-equivalent concentration of the combined concentrations of dioxin congeners was only about one-quarter of the level considered a potential threat to human health. Similarly, the dioxin mass emission in 2011 was well below the goal identified in the discharge permit. Low concentrations of dioxin congeners have been detected in nearly all of the MBCSD effluent samples collected during the last decade, although the toxic-equivalents rarely approach the permitted limit. Dioxin is pervasive in the modern environment because it was introduced historically by incineration of municipal and chemical wastes, exhaust from

automobiles using leaded gasoline, and improper disposal of chlorinated chemical wastes. Dioxins do not readily decompose and, once introduced into the environment, they persist for long periods. Although relic dioxin introduced in the past accounts for much of the concentrations currently measured within the environment, small concentrations of various dioxin congeners can also be formed during chlorination of municipal drinking water and wastewater effluent.

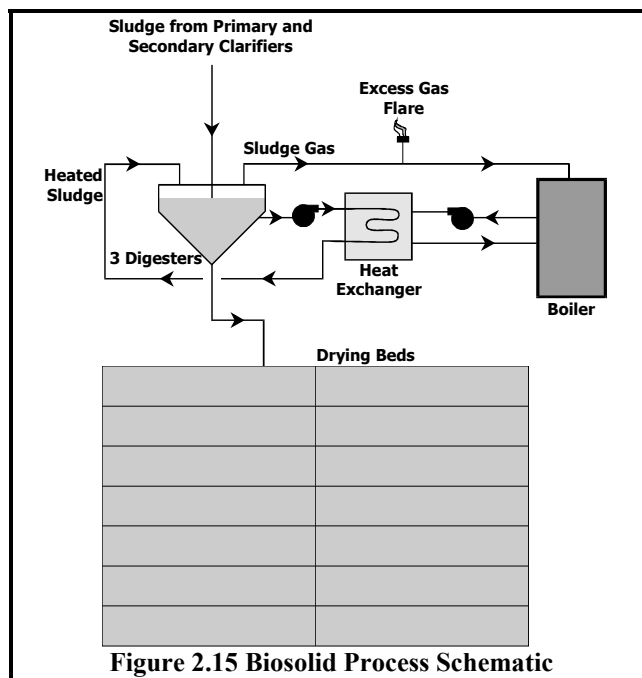
2.3 BIOSOLIDS

The monitoring and reporting requirements of the NPDES permit (RWQCB-USEPA 2009) stipulate characterization of biosolids in accordance with 40 CFR 503 (USGPO 1997b). To that end, this section describes the disposition of the approximately 144.2 dry metric tons of biosolids generated by the WWTP during 2011, as well as the final 72.6 dry metric tons of compost that were generated by the plant in 2010 and distributed to the public as part of the WWTP's now discontinued onsite composting program. The discussion also addresses the major compounds within the sludge produced by the plant, because they determine the suitability of biosolids for future composting and land application. The complete biosolids report¹ was submitted to the USEPA, RWQCB, and San Luis County Environmental Health Services on 12 January 2012 and is incorporated herein by reference.

2.3.1 Composting Process

Solids removed by the primary clarifiers (Figure 2.3 on Page 2-15) were processed as shown in the schematic of Figure 2.15. Sludge was stabilized using two mixed-primary digesters heated to 97°F (36°C). Heated sludge was then transferred to a secondary digester with heat exchange from the primary digesters. Solids settled in the secondary digester and the supernate was returned to the wastewater treatment process. The primary digesters' capacities are 192,000 gallons and 170,544 gallons, and the secondary digester's capacity is 166,000 gallons, giving a total capacity of 528,000 gallons (2 megaL). The clarifiers pumped an average of 9,250 gallons of sludge per day to the primary digesters. Average detention times were 57 days. Digester temperature and flow were recorded daily.

Stabilized sludge drawn from the secondary digester was transferred to one of 12 sludge-drying beds. Each of these 5,200 ft² (483 m²) beds had an under-drain and decanting system that recirculated runoff through the treatment process. Twelve to 14 inches (33 cm) of sludge were applied to the beds. Drying times typically ranged from two to four months depending on the weather conditions. Once dried, the biosolids were removed from the beds and stored in a concrete containment area that also drained rainfall runoff through the treatment system. Biosolids were stored in this area until they were



¹ Morro Bay/ Cayucos Wastewater Treatment Plant 2011 Annual Sewage Sludge Report, January 2012.

removed from the WWTP for composting and eventual use as a soil amendment. Biosolids storage times were generally less than one year.

On 11, 12, 14, and 15 November 2011, the treatment plant sent a total of 144.2 dry metric tons of stored, dried biosolids to the 162-acre San Joaquin Composting Facility (SJCF) owned by McCarthy Family Farms, Inc. The SJCF is located in Kern County, California, and operates under Solid Waste Facility Permit No. 15-AA-0287 (Permit Resolution No. 1999-96 adopted by the California Integrated Waste Management Board). The SJCF uses windrow and aerated static pile composting to further reduce pathogens and limit vector attraction. Windrows are divided into three temperature-recording stations. A windrow passes the high-temperature phase after all three stations maintain a temperature of 55°C for 15 days and the windrow has been turned at least five times. Six temperature stations are monitored for aerated static pile composting. All six stations must maintain a temperature of 55°C for three days before pathogen reduction is considered complete. After maintaining 40°C for 14 days, reduction of vector attraction is also considered complete. Prior to shipping biosolids to the SJCF, the MBCSD provided a Class-B biosolid certification statement based on chemical analyses performed on biosolid samples collected at the treatment plant.

In previous years, a significant portion of the biosolids generated by the WWTP process, rather than being shipped offsite, was composted on-site and made available to the local public for use as a high-quality soil amendment. This successful beneficial-reuse program, developed by WWTP personnel and operated over the past decade, utilized a windrow composting similar to that of the SJCF. The program produced exceptional-quality (EQ) compost that met the Federal and State Class-A standards for low metal concentrations, pathogen reduction, and vector-attraction reduction.

Due to the planned upgrades to the WWTP facility, however, the on-site biosolids composting operation was discontinued in late 2010. The final windrow was constructed by plant staff in August 2010, and composting for this windrow was completed in April 2011. The distribution of the resulting 72.6 dry metric tons of compost to members of the local public took place over the following weeks.

2.3.2 Chemical Compounds

Complying with the Monitoring and Reporting Program, the analyses were conducted on a composite of biosolid samples collected from the drying beds. Chemical analyses were conducted on a composite sample collected on 6 September 2011 from the biosolids that were ready for shipment from the WWTP at the time. The full laboratory results, including chains of custody, instrument calibration reports, and analyses of method blanks and spikes, were reported by MRS (2011b). They are compared with regulatory limits in Table 2.6.

The data in the table shows that biosolid contaminant concentrations were significantly less than regulatory criteria that would designate them as hazardous, or limit their use for land application or composting. The analyses tested for the presence of more than 150 potential contaminants and measured seven other properties and nutrients within the biosolid sample. Nevertheless, only a few compounds were detected, primarily naturally-occurring trace metals.

All trace-metal concentrations were below the total threshold limit concentrations (TTLC) that would designate the biosolids as hazardous. One metal, copper, had a bulk wet-weight concentration that exceeded ten-times the soluble threshold limit concentration (STLC). Accordingly, a waste extraction test (WET) assessed its water solubility. This elutriate test demonstrated that the copper within the biosolids sample had very low solubility with a 6.9-mg/L dissolved concentration that was three and a half times lower than the 25-mg/L STLC level where leaching into groundwater may be of concern. The low solubility shows that the copper was tightly bound into a mineral matrix, with little bioavailability.

Table 2.6. Comparison between Measured Biosolid Concentrations and State and Federal Limits

Constituent	Units	Wet Weight				Dry Weight		
		Measured		Limit		Measured	Limit	
		Bulk	WET ¹	STLC ²	TTLC ³	Bulk	Monthly ⁴	Ceiling ⁵
Solids	%	82.7	— ⁶	—	—	—	—	—
Cyanide	ppm	2.6	—	—	—	3.1	—	—
Antimony	ppm	≈1.9 ⁷	—	15.	500.	≈2.3	—	—
Arsenic	ppm	3.4	—	5.	500.	4.1	41.	75.
Barium	ppm	290.	—	100.	10,000.	350.	—	—
Beryllium	ppm	≈0.18	—	0.75	75.	≈0.22	—	—
Boron	ppm	15.	—	—	—	18.	—	—
Cadmium	ppm	2.7	—	1.	100.	3.3	39.	85.
Chromium (Total)	ppm	38.	—	560.	2500.	45.	—	—
Chromium (Hexavalent)	ppm	≈0.30	<0.07 ⁸	5.	500.	≈0.36	—	—
Cobalt	ppm	3.4	—	80.	8,000.	4.2	1,500.	4,300.
Copper	ppm	480. ⁹	6.9	25.	2,500.	580.	1,500.	4,300.
Lead	ppm	36.	—	5.	1,000.	44.	300.	840.
Mercury	ppm	1.1	—	0.20	20.	1.3	17.	57.
Molybdenum	ppm	19.	—	350.	3,500.	23.	—	—
Nickel	ppm	36.	—	20.	2,000.	43.	420.	420.
Selenium	ppm	6.7	—	1.	100.	8.0	100.	100.
Silver	ppm	3.0	—	5.	500.	3.7	—	—
Thallium	ppm	<0.73	—	7.	700.	<0.88	—	—
Vanadium	ppm	20.	—	24.	2,400.	24.	—	—
Zinc	ppm	1,100.	—	250.	5,000.	1,300.	2,800.	7,500.
Bis(2-ethylhexyl) phthalate	ppm	35.	—	—	—	43.	—	—
Benzoic Acid	ppm	20.	—	—	—	25.	—	—
Hydrogen-Ion	pH	6.28	—	—	—	—	—	—
Phosphate	ppm	68,000.	—	—	—	82,000.	—	—
Ammonia	ppm	8,100.	—	—	—	9,800.	—	—
TKN	ppm	34,000.	—	—	—	41,000.	—	—
Organic Nitrogen	ppm	25,900.	—	—	—	31,200.	—	—
Nitrate as NO ₃	ppm	130.	—	—	—	150.	—	—
Oil & Grease	ppm	15,000.	—	—	—	18,000.	—	—
Total Dissolve Solids	ppm	—	6,100.	—	—	—	—	—

¹ Waste Extraction Tests (WET) measure the soluble leachate or the extractable amount of a substance contained within a bulk sample of biosolids. A WET is indicated if the bulk wet-weight concentration of a contaminant exceeds ten times the STLC.

² Soluble Threshold Limit Concentrations (STLC) apply to the measured concentration in the liquid extract from a biosolid sample, as determined by a WET. Biosolids with leachate concentrations exceeding the STLC are classified as hazardous in the State of California, as described in the California Code of Regulations (CCR 2003).

³ Total Threshold Limit Concentrations (TTLC) apply to the total wet-weight concentration of a contaminant within a bulk biosolid sample consisting of the entire millable solid matrix, rather than just the leachate. Biosolids are designated as hazardous wastes in the State of California if measured bulk concentrations exceed the TTLC, as described in the CCR (2003).

⁴ Federally mandated dry-weight limits imposed on biosolids suitable for application on agricultural land apply to monthly average concentrations as defined in Table 3 of the Code of Federal Regulations (USGPO 1997b). [40 CFR §503.13(b)(1)].

⁵ Federally mandated dry-weight ceiling concentrations above which biosolids are considered hazardous waste as defined in Table 1 USGPO (1997b).

⁶ “—” indicates that the measurement was not required or its limit was not specified.

⁷ Concentrations preceded by an “approximation” symbol (≈) were too low to be reliably quantified and represent estimated concentrations because they were reported below the minimum level (ML) but above the method detection limit (MDL).

⁸ A “less-than” symbol (<) indicates that the substance was not detected at a concentration above the MDL, which is listed after the “<” symbol.

⁹ Bulk concentrations shown in bold were greater than ten times the STLC and a WET was conducted.

The insolubility of copper is further confirmed by the low concentrations found in the plant's semiannual effluent samples (16 µg/L and 14 µg/L in Table 2.5). Copper occurs naturally in the mineralogy of ambient sediments in the central coast region and, as a result, its presence in biosolids is not unexpected. Additionally, copper enters the collection system through the internal corrosion of household plumbing systems. Nevertheless, the dry-weight concentrations for all detected metals in the biosolid sample, including copper, were well below the federally mandated limits, including the monthly limit for materials suitable for agricultural land application (as represented in the three right-most columns of Table 2.6).

In addition to trace metals, two organic compounds were also detected at quantifiable concentrations within the biosolids sample: benzoic acid and bis(2-ethylhexyl)phthalate (DEHP). Benzoic acid is a common food preservative while DEHP is added to plastic resins to soften them. DEHP has been consistently detected at low levels in effluent and biosolids samples collected throughout the past decade. Because of its mobility, high vapor pressure, and the massive scale of its production, DEHP has become pervasive in the environment. There are no limits on either of these compounds in State and Federal regulations governing biosolids.

The other compounds listed in Table 2.6 further characterize the biosolids, as required in the waste discharge requirements. Additionally, a modified WET test (STLC) for total dissolved solids was conducted in response to a request from the composter.

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CHAPTER 3

Receiving Water Quality

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3.0 RECEIVING WATER QUALITY

This chapter describes environmental conditions within the ocean waters immediately adjacent to the MBCSD wastewater discharge during 2011. The first section details the monitoring program that assesses compliance with the water-quality objectives of the California Ocean Plan (COP; SWRCB 2005) as embodied in the NPDES permit covering the MBCSD discharge (hereinafter referred to as “*the NPDES permit*,” RWQCB–USEPA 2009). The second section discusses the disposition of the effluent plume within the receiving waters and how it is influenced by the hydraulic design of the outfall and stratification of the receiving waters. The final section of this chapter provides a synopsis of the offshore measurements collected during the four water column surveys conducted in 2011 (MRS 2011cdef) and compares them with the waste discharge requirements specified in the NPDES permit. Quantitative analyses of continuous instrumental measurements and the qualitative visual observations are also both addressed in the last section. The observations demonstrate that the diffuser structure was operating as designed by efficiently diluting treated wastewater within the zone of initial dilution (ZID) that surrounds the outfall.

During all four of the 2011 offshore receiving-water surveys, dilute wastewater was detected within the receiving waters. The weak discharge-related perturbations in the water-property fields indicated that the treated wastewater was rapidly mixed upon discharge, and all of the observed perturbations were small compared to the natural variability in seawater properties observed along this portion of the central California coast. Projected contaminant concentrations were far below the receiving-water limitations specified in the NPDES permit, and the discharge fully complied with the objectives of the COP. In summary, the highly localized, transient seawater perturbations associated with the effluent discharge were too small to be of environmental significance.

3.1 MONITORING PROGRAM

Wastewater chemistry (Chapter 2), receiving waters (this chapter), and the biology and physicochemistry of seafloor sediments (Chapter 4) constitute the three major components of the MBCSD monitoring program. During 2011, and for the past 25 years, receiving-water monitoring has included quarterly offshore surveys conducted near the wastewater discharge within northern Estero Bay and periodic surfzone coliform sampling along the adjacent shoreline. Measurements collected during the offshore surveys include instrumentally recorded seawater-properties, flow velocity determined from drifter trajectories, qualitative observations of general oceanographic and meteorological conditions, and visual observations of beneficial uses.

3.1.1 Objectives of Sampling

Receiving-water monitoring is required under provisions of a 301(h)-modified NPDES permit to determine compliance with the water-quality objectives of the COP (SWRCB 2005) and the Central Coast Basin Plan (RWQCB 1994). The monitoring program also satisfies the provisions of the Clean Water Act (40 CFR 125.63c), which require a receiving-water monitoring program that “*provide[s] adequate data for evaluating compliance with water quality standards or water quality criteria.*” In addition, water column measurements provide background information on the vertical structure of ambient marine waters near the discharge location. This information aids in estimating minimum initial dilution rates, which occur when the receiving waters are strongly stratified, as described in Section 3.2.2.

3.1.2 Scope of Monitoring

One goal of the monitoring program is to assess whether the discharge meets the water-quality objectives of the COP. These objectives, summarized in Table 3.1, ensure the reasonable protection of beneficial uses and prevention of nuisance. They apply to samples collected within the discharge's wastefield after initial dilution has been completed. Initial dilution is the rapid, turbulent mixing of wastewater and seawater in the area immediately surrounding the point of discharge.

Ambient seawater is forcibly entrained into the discharge plume by two physical processes. Close to the diffuser ports, the momentum of the wastewater jet induces turbulent shear that rapidly entrains near-bottom seawater, thereby diluting the effluent. Additional turbulent mixing occurs as the warm, buoyant effluent-seawater mixture rises through the water column. This buoyancy-induced entrainment causes the density of the effluent plume to approach that of ambient seawater (neutral buoyancy) at some point in the water column. Depending on ambient stratification at the time of the discharge, the plume either can reach the surface or become trapped at some intermediate depth level. Thus, initial dilution, where a majority of effluent dilution is achieved shortly after discharge, is complete when the diluting wastewater ceases to rise in the water column and begins to spread horizontally.

To better assess compliance with the COP standards, the receiving-water monitoring program was extensively modified when the previous NPDES permit was issued in 1999 (RWQCB–USEPA 1998b). Prior to 1999, the effluent plume was rarely observed in the instrumental measurements and its lateral extent was largely indeterminate when it was observed. This was partially due to the wide spacing of water-sampling stations that, at the time, coincided with the benthic sampling pattern. Additionally, the earlier permit required collection of discrete water samples to be analyzed for suspended solids, coliform, and oil and grease. This water-bottle sampling was time-consuming and compromised the synoptic nature of the instrumental measurements. Beginning with the 1999 surveys, bottle casts were eliminated and the lateral extent of the survey was reduced from 1000 m to 100 m, while the number of sampling stations was doubled from eight to sixteen. Rapid instrumental sampling within this tighter sampling pattern consistently provided high-resolution synoptic snapshots of the ocean waters immediately surrounding the outfall. As a result, the disposition of the effluent plume has been accurately delineated in all 52 surveys conducted since the beginning of 1999.

Further improvements in the receiving-water monitoring program were implemented in 2009 as part of the current NPDES permit (RWQCB–USEPA 2009). For example, the navigational accuracy of positioning systems had advanced to the point where the location of individual measurements could be precisely determined relative to the discharge point. This precise determination of the plume's spatial extent is important for assessing compliance with water-quality objectives that only apply beyond the ZID. With that in mind, the receiving-water monitoring program in the current permit added a requirement for a tow survey, where the instrumentation package is towed horizontally across and around the diffuser structure at two different depth levels. Collection and analysis of this tow data began with the second-quarter receiving-water survey conducted in 2009. Additionally, all surveys since that time have included vertical profiles of seawater properties at six sampling stations aligned along a north-south transect, and spanning an alongshore-distance of 100 m on either side of the diffuser structure.

Table 3.1 Water-Quality Objectives of the California Ocean Plan

B. Bacterial Characteristics

1. Water-Contact Standards

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 [sic] 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:

- a. The 30-day geometric mean of the five most-recent seawater samples from each site shall not exceed a total coliform density of 1,000 per 100 ml; a fecal coliform density of 200 per 100 ml; or an enterococcus density of 35 per 100 ml.
- b. A single seawater sample shall not exceed a total coliform density of 10,000 per 100 ml; a fecal coliform density of 400 per 100 ml; an enterococcus density of 104 per 100 ml, or a total coliform density of 1,000 per 100 ml when the fecal to total coliform ratio exceeds 0.1.

The "Initial Dilution Zone" of wastewater outfalls shall be excluded from designation as "kelp beds" for purposes of bacterial standards and Regional Boards should recommend extension of such exclusion zone where warranted to the State Board. Adventitious assemblages of kelp plants on waste discharge structures (e.g., outfall pipes and diffusers) do not constitute kelp beds for purposes of bacterial standards.

2. Shellfish Harvesting Standards

Throughout the water column in all areas where shellfish may be harvested for human consumption, as determined by the Regional Board, the median total coliform density shall not exceed 70 per 100 ml and not more than 10 percent of the samples shall exceed 230 per 100 ml.

C. Physical Characteristics

1. Floating particulates and grease and oil shall not be visible.
2. The discharge of the waste shall not cause aesthetically undesirable discoloration of the ocean surface.
3. Natural light shall not be significantly reduced at any point outside the initial dilution zone as a result of the discharge of waste.
4. The rate of deposition of inert solids and the characteristics of inert solids in ocean sediments shall not be changed such that benthic communities are degraded.

D. Chemical Characteristics

1. The dissolved oxygen concentration shall not at any time be depressed more than 10 percent from which occurs naturally, as a result of the discharge of oxygen demanding waste materials.
2. The pH shall not be changed at any time more than 0.2 units from that which occurs naturally.
3. The dissolved sulfide concentration of waters in and near sediments shall not be significantly increased above that present under natural conditions.
4. The concentration of substances set forth in Chapter II, Table B in marine sediments shall not be increased to levels which would degrade indigenous biota.
5. The concentration of organic materials in marine sediments shall not be increased to levels which would degrade marine life.
6. Nutrient materials shall not cause objectionable aquatic growths or degrade indigenous biota.
7. Numerical water quality objectives in Table B apply to all discharges within the jurisdiction of this plan.

E. Biological Characteristics

1. Marine communities, including vertebrate, invertebrate and plant species, shall not be degraded.
2. The natural taste, odor and color of fish, shellfish, or other marine resources used for human consumption shall not be altered.
3. The concentration of organic materials in fish, shellfish or other marine resources used for human consumption shall not be bioaccumulated to levels that are harmful to human health.

F. Radioactivity

1. Discharge of radioactive waste shall not degrade marine life.

An automated probe system was used to collect precise *in situ* measurements of seawater properties during each of the four quarterly receiving-water surveys of 2011. Measured seawater parameters consisted of temperature, salinity, dissolved oxygen (DO), acidity/alkalinity (pH), and light transmittance (water clarity). Qualitative visual observations made during the offshore surveys provided information on any potential wastewater contributions to levels of floating particulates, seawater discoloration, odors,

algal blooms, and surface water clarity. Wildlife and recreational use, as well as general weather and sea conditions, were also noted.

In addition to the quarterly sampling used to delineate the discharge plume offshore, monitoring of the adjacent surfzone along Atascadero State Beach has historically been conducted to assess aesthetic conditions for the beneficial uses described in Section 2.1.2. Bacteriological conditions along the shoreline are of particular interest for shellfish harvesting and for water-contact recreation, namely swimming and surfing. However, disinfection of MBCSD effluent routinely reduces bacterial densities to levels well below receiving-water standards prior to discharge, and the more than 100-fold dilution that occurs shortly after discharge renders the plant's bacterial loading imperceptible. Consequently, surfzone bacterial samples are too distant to be materially affected by the discharge, and are instead dominated exclusively by onshore sources and runoff (MRS 1994 – 2010). Because of this, the current permit no longer requires regular monitoring of surfzone bacteria, but triggers monitoring at eight surfzone locations along Atascadero State Beach when there is an upset in the WWTP's disinfection process that causes total coliform density in the effluent to exceed 2400 MPN/100 ml. The surfzone stations are located at gradient distances upcoast and downcoast relative to Station C, which is positioned at the onshore site closest to the offshore discharge location (See Table 3.2 and Figure 3.1). During 2011, however, there were no instances of elevated effluent coliform that triggered the requirement for surfzone sampling.

Table 3.2 Target Locations of Surfzone Sampling Stations

Station	Description	Along-Shore Distance¹ (m)	Latitude²	Longitude
A1	Upcoast Reference	1330 N	35° 23.967' N	120° 52.116' W
A	Upcoast Midfield	912 N	35° 23.750' N	120° 52.067' W
B	Upcoast Nearfield	488 N	35° 23.517' N	120° 52.000' W
C	Onshore of Diffuser	0	35° 23.250' N	120° 51.950' W
D	Downcoast Nearfield	426 S	35° 23.033' N	120° 51.917' W
E	Downcoast Midfield	922 S	35° 22.767' N	120° 51.900' W
F	Downcoast Reference	1602 S	35° 22.400' N	120° 51.883' W
G	Morro Creek ³	— ⁴	—	—

Other beneficial uses, such as fishing and non-water-contact recreation, including beachcombing, boating, and picnicking, were addressed by visual observations of aesthetic conditions noted during the offshore surveys conducted in 2011. These auxiliary observations included weather conditions, ocean currents, tides, and any evidence of water discoloration, floating oil and grease, turbidity, odor, or materials of sewage origin on the beach or in the water.

3.1.3 Sampling Station Design

Offshore receiving-water sampling focuses on the water column close to the discharge location (Figure 3.1). During 2011, water sampling was conducted at six offshore stations situated at three gradient distances upcoast and downcoast from the ZID (Figure 3.2).

¹ Along-shore distance and direction from Station C

² As described in the glossary, all coordinates cited in this report are referenced to the WGS84 datum

³ Immediately before flowing to the ocean

⁴ Location varies with the along-shore migration of the mouth of Morro Creek

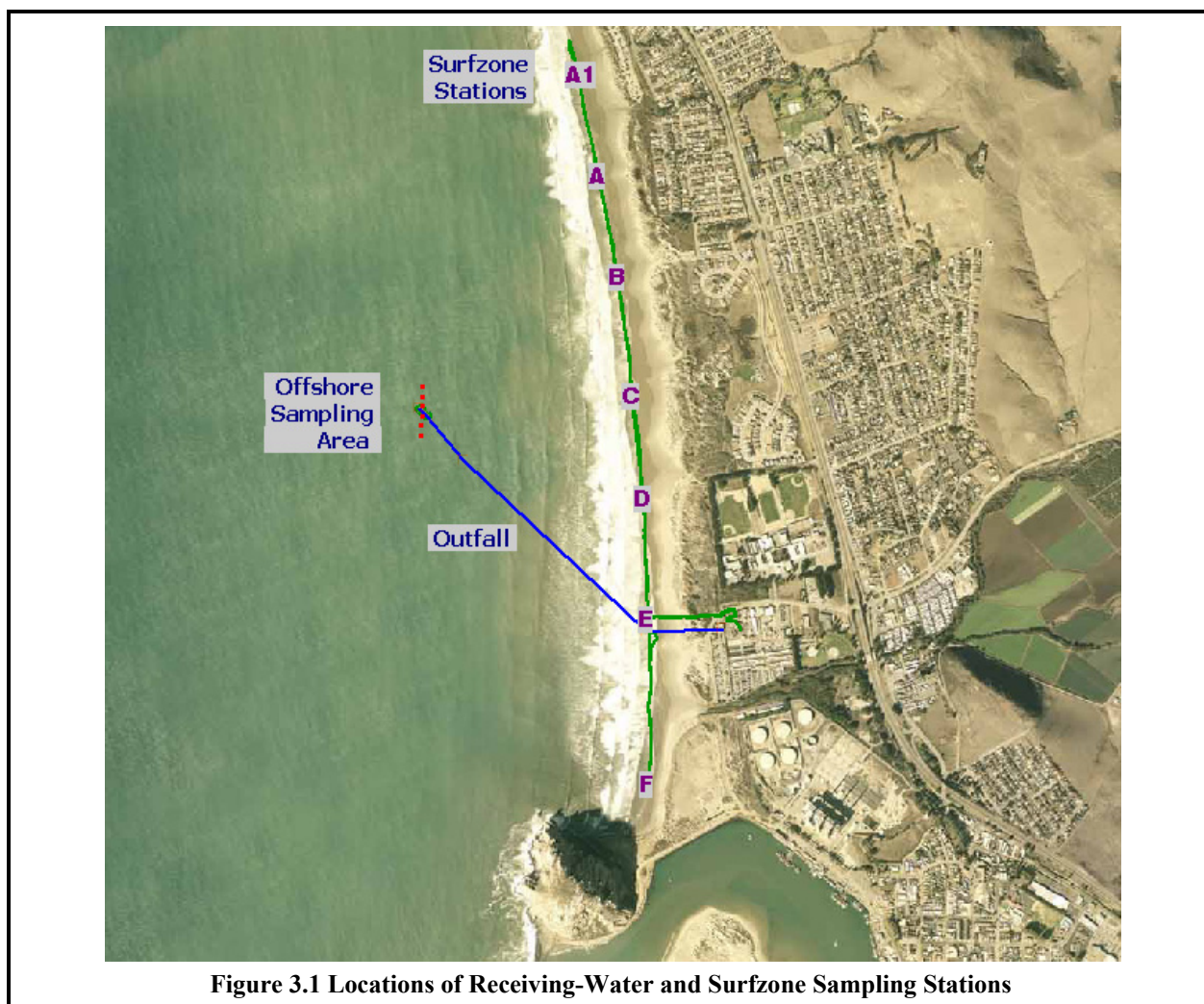


Figure 3.1 Locations of Receiving-Water and Surfzone Sampling Stations

The closest portion of the diffuser structure lies 827 m from the shoreline, while the diffuser structure itself extends an additional 52 m toward the northwest along the seafloor (Figure 3.1).

Twenty-eight of the 34 available ports discharge effluent along a 42 m section of the diffuser structure. The diffuser ports were hydraulically designed to rapidly dilute effluent within the receiving seawater immediately upon discharge. Most of this turbulent mixing occurs within a zone of initial dilution (ZID), which extends laterally to a distance of approximately 15 m from the center of the diffuser structure.

Over longer periods, energetic waves, tides, and coastal currents within Estero Bay further disperse the effluent plume within open-ocean receiving waters beyond the ZID. Areas of special concern, such as sanctuaries and estuaries are too distant to be materially affected by the treated wastewater discharge. For example, the southern boundary of the Monterey Bay National Marine Sanctuary is located 38 km to the north, while the entrance to Morro Bay lies 2,800 m to the south of the discharge. In 1995, Morro Bay was included in the National Estuary Program; however, because of its distance from the discharge, incursion of unmixed wastewater into the Bay is highly unlikely. Direct seawater exchange between the discharge point and Morro Bay is restricted by Morro Rock, which lies between the outfall and the south-

facing entrance to the Bay. Morro Rock is the largest physiographic feature along the adjacent coastline and extends into Estero Bay approximately 2,000 m south of the point of discharge (Figure 3.1).

During 2011, the discharge's region of influence was evaluated quarterly using water-quality data collected at the six offshore stations situated at three gradient distances upcoast and downcoast from the ZID (Figure 3.2). The two closest stations, which are on the outer margin of the ZID, were located 15 m from the closest point on the diffuser structure rather than its center point. The remaining more-distant stations were located relative to the center point of the diffuser structure.

It is important to consider the “closest-approach” distance when evaluating impacts at stations near the wastewater discharge. Although the discharge has historically been considered a “point source” for most large-scale modeling purposes, it does not occur at a single location of infinitesimal size. Because the discharge is distributed along a 42 m section of the seafloor, its finite size affects assessments of wastewater dispersion at sites close to the discharge. Specifically, the amount of wastewater dispersion at a given point in the water column is determined more by its distance to the closest diffuser port rather than its distance to the center point of the diffuser structure. Near the source, this “closest-approach” distance can be much less than the actual distance to the center of the diffuser structure (Table 3.3, Figure 3.2). As such, it would be unsuitable to design a nearfield sampling pattern based solely on center-point distances rather than closest-approach distances.

With the closest-approach distances in mind, the six receiving-water monitoring stations were aligned along a north-south axis at the same isobath (15.2 m) as the diffuser center point. Stations RW3 and RW4 were positioned at the boundary of the ZID at a distance of 15 m upcoast and downcoast of the closest diffuser ports (Table 3.3). Stations RW2 and RW5 were located at nearfield distances (60 m) from the diffuser center point. Midfield Stations RW1 and RW6 represent reference stations situated 100 m upcoast and downcoast of the center point. Depending on the direction of the local oceanic currents at the time of sampling, one or more of these near and midfield stations could conceivably be influenced by

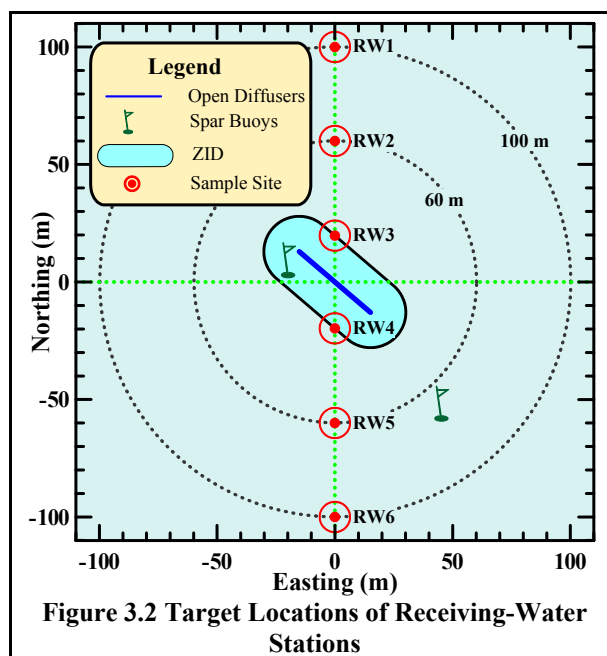


Figure 3.2 Target Locations of Receiving-Water Stations

Table 3.3 Target Locations of Receiving-Water Stations

Station	Description	Latitude	Longitude	Closest Approach Distance ¹ (m)	Center Distance ² (m)
RW1	Upcoast Midfield	35° 23.253' N	120° 52.504' W	88.4	100
RW2	Upcoast Nearfield	35° 23.231' N	120° 52.504' W	49.4	60
RW3	Upcoast ZID	35° 23.210' N	120° 52.504' W	15.0	20
RW4	Downcoast ZID	35° 23.188' N	120° 52.504' W	15.0	20
RW5	Downcoast Nearfield	35° 23.167' N	120° 52.504' W	49.4	60
RW6	Downcoast Midfield	35° 23.145' N	120° 52.504' W	88.4	100

¹ Distance from the closest open diffuser port

² Distance to the center of the open diffuser section

wastewater discharge. Under those circumstances, the midfield station on the opposite side of the diffuser acts as a reference station. Comparisons of water properties at these antipodal stations quantify the departures from ambient seawater properties that are used in the evaluation of compliance with the NPDES discharge permit.

3.1.4 Navigation

Vessel positioning within the compact offshore sampling pattern has improved with the availability of Differential Global Positioning Systems (DGPS). DGPS, with typical position errors of less than 4 m, significantly enhances the accuracy of traditional GPS navigation systems, which have position errors as large as ± 15 m, a span half the width of the ZID itself. At the beginning of 1998, the survey vessel F/V *Bonnie Marietta* was fitted with a Furuno™ GPS 30 and FBX2 differential beacon receiver. This navigational system was used on 29 July 1998 to precisely locate the position of the open section of the diffuser structure (MRS 1998b) and to establish the new target locations for the offshore monitoring stations listed in Table 3.3.

Specifying the precise location of each measurement relative to the diffuser is crucial for accurate interpretation of the water property fields. For example, during vertical profiling, the actual sampling locations do not coincide with the exact target coordinates listed in Table 3.3. The combined influences of winds, waves, and currents induce vessel offsets of tens of meters within the minute or so it takes to complete the water-property profile at each station. Even during quiescent periods, drift is induced by residual vessel momentum remaining after station approach. Prior to the use of DGPS, these offsets could not be resolved by the available navigation, but, during the 2011 surveys, the sampling locations were precisely determined throughout the vertical profiling conducted at each station.

Determination of vessel drift during vertical profiling is an important consideration because it caused some of the measurements in 2011 to be collected within the ZID, where the water-quality objectives in the COP do not apply (see shaded entries in Table 3.4). The average closest-approach distances in Table 3.4 can be compared with the target offsets listed in Table 3.3 to assess the fidelity of the sampling locations with respect to diffuser-structure proximity. From the standpoint of an ideal compliance evaluation, all measurements would be made at or beyond the ZID boundary, namely, at distances of more than 15 m from the diffuser structure. However, measurements collected well within the ZID, and close to the diffuser structure, are also valuable because they capture the dynamics of the plume while it is still undergoing rapid initial mixing, and lend timely insight into the dispersive capabilities of the diffuser structure. These close-in measurements have demonstrated that the MBCSD discharge routinely meets the COP receiving-water objectives well within the ZID.

Table 3.4 Station Proximity to the Discharge

Station	Description	Closest-Approach Distance ¹ (m)				
		Target	March	June	August	October
RW3	Upcoast ZID	15.0	28.8²	22.6	19.3	23.1
RW4	Downcoast ZID	15.0	18.5	5.8	10.6	16.0
RW2	Upcoast Nearfield	49.4	31.0	51.9	47.8	45.1
RW5	Downcoast Nearfield	49.4	50.5	45.2	48.7	40.9
RW1	Upcoast Midfield	88.4	69.3	97.7	80.6	84.1
RW6	Downcoast Midfield	88.4	92.6	84.8	89.5	91.6

¹ Distance from the closest open diffuser port to the average station position

² All or portions of the profiles highlighted in bold typeface with shading were sampled within the ZID

3.1.5 Sampling Equipment and Methodology

The 38-ft F/V *Bonnie Marietta*, owned and operated by Captain Mark Tognazzini of Morro Bay, provided vessel support for the four offshore surveys conducted in 2011. Bonnie Luke of Marine Research Specialists (MRS) oversaw deployment of the CTD and collected auxiliary measurements of biological, meteorological, and oceanographic conditions. Douglas Coats, also of MRS, provided navigational support during the survey. William Skok assisted with deployment and recovery of the CTD and drifter. During the June 2011 survey, Mr. Bruce Keogh, the MBCSD Wastewater Division Manager, monitored operations onboard the vessel as client inspector.

Standard observations for weather, seas, water clarity/coloration, Secchi depth, and the presence of any odors and floating debris were recorded during each of the surveys. Wind speeds and air temperatures were measured with a Kestrel® 2000 Thermo-Anemometer. These observations were collected during the vertical profiling conducted at each of the six stations.

Auxiliary Measurements

As vertical profiles were collected at each station, a Secchi disk was lowered through the water column to determine its depth of disappearance. This provided a visual measure of the water clarity within the upper water column. The depth of disappearance is inversely proportional to the average amount of organic and inorganic suspended material along a line of sight immediately below the sea surface. As such, Secchi depth is a measure of ambient light penetration, which can be limited during upwelling when plankton density increases within the near-surface euphotic zone. The depth of the euphotic zone, where most oceanic photosynthesis occurs, extends to approximately twice the Secchi depth. Because Secchi depths are less precise than measurements collected with electronic sensors, these and the other qualitative observations described above, were ancillary to the digital measurements of seawater parameters collected throughout the water column.

At the beginning of each survey, a drifter was deployed at the center of the open section of the diffuser structure. The drifter was drogued at mid-depth (7 m) using the curtain shade design of Davis et al. (1982). In this configuration, the drifter trajectory was largely determined by the oceanic flow field rather than surface winds. Satellite navigation onboard the drifter allowed continuous recording of the precise position of the drifter throughout its deployment. Additionally, the vessel's locations during deployment and recovery of the drifter were recorded for navigational comparison. These trajectory measurements established the ambient flow velocity throughout each survey, and indicated the path of plume transport for use in the interpretation of seawater property distributions.

Instrumental Measurements

A Sea Bird Electronics SBE-19 Seacat CTD¹ instrument package was used in the first two surveys of 2011, while a newer model SBE-19plusV2 was used in the August and October 2011 surveys. Both instruments were deployed in both a vertical water-profiling mode, as well as a horizontal-tow configuration. They collected measurements of conductivity, temperature, light transmittance, dissolved oxygen (DO), pH, and pressure at sampling rates of 2 and 4 Hz (0.5- and 0.25-second intervals). Submersible pumps on the CTDs continuously flushed water through the conductivity cells and oxygen plenums at a constant rate, independent of the CTD's motion through the water column.

The six seawater properties used to assess receiving-water quality in this report were derived from the continuously recorded output of the CTDs' probes and sensors. Pressure housing limitations on the

¹ Conductivity, temperature, and depth (CTD)

combination oxygen/pH sensor confine the CTDs to depths less than 200 m (Table 3.5), which is well beyond the maximum depth of the deepest station in the outfall survey. The precision and accuracy of the various probes, as reported in manufacturer's specifications are also listed in the Table. Salinity (‰, parts-per-thousand) was calculated from conductivity measurements reported in units of Siemens/m. Density was derived from contemporaneous temperature (°C) and salinity data, and was expressed as 1000 times the specific gravity minus one, which is a unit of sigma-T (σ_t).

Table 3.5 Specifications for the Two CTD Instruments

Component	Instrument	Depth ¹	Units	Range	Accuracy	Resolution
Housing	Both	600	—	—	—	—
Pump	Both	3400	—	—	—	—
Pressure	Both	680	Psia	0 to 1000	± 5.0	± 0.5
Depth	19	—	Meters	0 to 600	± 3.0	± 0.3
	19plusV2	—	Meters	0 to 600	± 1.7	± 0.1
Conductivity	19	600	Siemens/m	0 to 6.5	± 0.001	± 0.0001
	19plusV2			0 to 9.0	± 0.0005	± 0.00005
Salinity	19	600	‰	0 to 38	± 0.006	± 0.0006
	19plusV2			0 to 58	± 0.004	± 0.0004
Temperature	19	600	° C	-5 to 35	± 0.01	± 0.001
	19plusV2			-5 to 35	± 0.005	± 0.0001
Transmissivity	19	2000	%	0 to 100	± 0.1	± 0.025
	19plusV2			0 to 100	± 0.3	± 0.03
Dissolved Oxygen	19	200	mg/L	0 to 21.5	± 0.14	± 0.014
	19plusV2		%Saturation	0 to 120	± 2	—
Acidity/Alkalinity	Both	200	pH	0 to 14	± 0.1	± 0.006

All three of the physical parameters (salinity, temperature, and density) helped determine the lateral extent of the effluent plume during the towing phase of the survey. Additionally, during the vertical-profiling phase, they quantified layering, or vertical stratification and stability of the water column, which determines the behavior and dynamics of the effluent as it mixes with seawater within the ZID. Data on the three remaining seawater properties, light transmittance (water clarity), hydrogen-ion concentration (acidity/alkalinity – pH), and dissolved oxygen (DO), further characterized receiving waters and were used to assess compliance with water-quality criteria. Light transmittance was measured as a percentage of the initial intensity of a transmitted beam of light detected at the opposite end of a 0.25-m path. Increased transmittance indicates increased water clarity and decreased turbidity.

The Sea Bird Electronics SBE-19 Seacat CTD instrument package was calibrated in the MRS laboratory prior to both the March and June surveys. The upper-bound DO calibration point at full saturation was established by immersing the CTD in an aerated, temperature-controlled calibration tank. Similarly, a zero-oxygen calibration point was determined by filling the oxygen-sensor plenum with an 8% solution of sodium sulfite (Na_2SO_3). Oxygen calibration coefficients were determined by regression analysis of sensor-membrane current and temperature, as recommended by the manufacturer (SBE 1993).

¹ Maximum depth limit in meters

Because of difficulty in obtaining a reliable zero-oxygen calibration point during the June 2011 pre-cruise calibration, the DO and pH probe assembly was shipped to the manufacturer for inspection and repair. The assembly was returned at the end of May 2011, and recalibrated in the MRS laboratory prior to deployment. This time, the pre-cruise calibration coefficients determined by MRS closely corresponded with prior factory calibrations. However, given the age of the CTD, which had been in service for nearly two decades, a new CTD package, the SBE-19plusV2 CTD, was commissioned for use in future surveys.

The new SBE-19plusV2 CTD system offers many advantages over the older unit. For example, the 4 Hz sampling rate on the new instrument collects data at twice the rate of the older unit, allowing much higher spatial resolution for a given tow, or descent rate. Additionally, the probes and sensors on the new CTD have a much faster response time, further enhancing the spatial resolution of seawater properties. Lastly, the probes and sensors on the new CTD are more stable and exhibit negligible long-term drift. As a result, and in accordance with the manufacturer's recommendations, the new CTD package does not require regular recalibration of the sensors prior to each field survey. Nevertheless, the accuracy of the pH and DO sensors was confirmed in the MRS laboratory prior to its deployment during the August 2011 survey.

In contrast, coefficients for the pH sensor on the older CTD package were determined from a linear regression of output voltage after immersion in six separate buffered solutions of known pH. Buffering solutions with a pH of 4 ± 0.01 , 6 ± 0.01 , 7 ± 0.01 , 8 ± 0.01 , 9 ± 0.02 , and 10 ± 0.02 were used to bracket the range of in situ measurements. The SeaTech transmissometer was air calibrated by fitting the voltages recorded with and without blocking of the light transmission path in air, as recommended by the manufacturer (SBE 1989). Algorithms that converted sensor voltage to engineering units during processing of the field data relied on calibration coefficients determined before the survey.

Comparison with the factory calibration of the older CTD package conducted in December 2001, and the June 2006 and June 2011 replacement and calibration of the DO probe, confirmed the continued accuracy and stability of the temperature, pressure, and conductivity sensors, as well as the operational integrity of the oxygen and pH probes. To correct for a slight drift in the pressure strain gauge since its calibration in 2001, a -0.25 Psia offset was incorporated in the conversion to depth measurements. In addition, slight temporal trends in pH and DO arose from the ongoing equilibration of these sensors during the first two surveys of 2011. The trends were removed by fitting smooth orthogonal polynomials to the sensor time series. Maximum adjustments were small, and on the order of sensor accuracy.

The CTDs were held below the sea surface for several minutes prior to vertical profiling to allow the sensors to equilibrate. Subsequently, the CTDs were raised to within 0.5 m of the sea surface and vertical profiling commenced. The CTDs were lowered at a continuous rate of speed to the seafloor. Measurements at all six stations were recorded during a single deployment of the CTD packages by towing them below the water surface while transiting between adjacent stations. Upon retrieval of the CTDs, the data were downloaded to a portable computer and examined for completeness and range acceptability. Data recorded during vertical profiling were processed in accordance with standard analysis procedures (SCBFMC 2002), which resulted in bin-averaged data across 0.5-m standard depth intervals. The profile data were collated in individual survey reports (MRS 2011cdef), and digitally archived within the USEPA STORET database.

Following collection of the vertical profiles, the CTDs were redeployed and continuously towed around and across the ZID at two separate depths in accordance with the receiving-water monitoring requirements of the current NPDES discharge permit. An example of the tow pattern, from the third-quarter survey, is shown in Figure 3.3. Prior to the tow survey, the CTD instrument packages were fitted with a depth-suppressor and horizontal stabilizer to achieve constant-depth tows with forward-looking sensor probes. In contrast to the old CTD, the new CTD was deployed utilizing a clump weight on the main towline to help achieve the proper initial tow depth, and uses a broader, but lighter horizontal wing attached to the CTD to assist with stability while the package is towed. The appropriate length of towline was deployed for each type of setup, and the reconfigured CTD packages were towed near the sea surface, passing close to the diffuser structure at least five times. Subsequently, an additional length of towline was paid-out, and at least five additional passes were made at mid-depth.

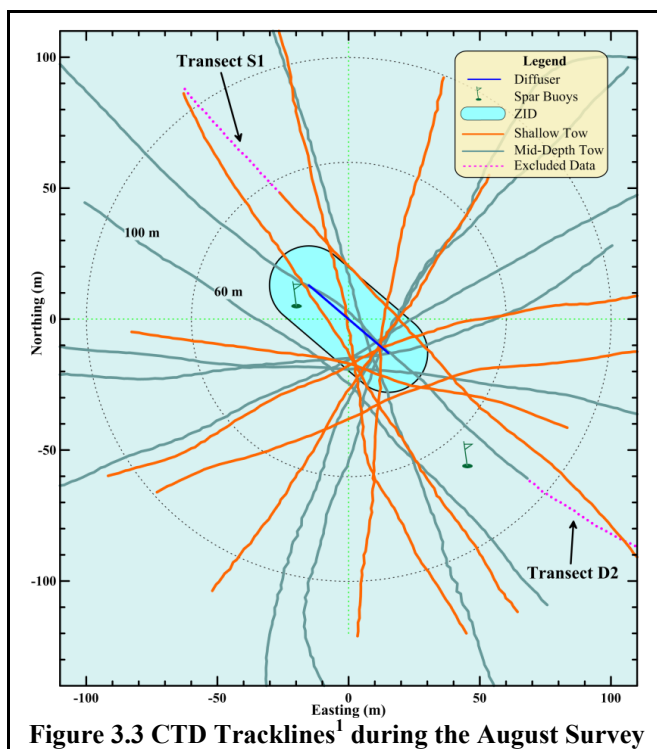


Figure 3.3 CTD Tracklines¹ during the August Survey

3.2 PLUME DISPERSION

Offshore monitoring is conducted to determine whether the wastewater discharge is causing significant impacts on the receiving waters of Estero Bay beyond the ZID. Section 3.3.1 makes this determination by comparing the water quality at the boundary of the ZID, and gradient areas beyond the ZID, with background water properties. However, the complex interaction between physical oceanographic processes and ambient seawater properties near the outfall makes detection of the relatively minor discharge-related changes challenging. The significance of potential water-quality impacts is assessed through a comparison between the amplitude of discharge-related anomalies and the inherent variability in ambient seawater properties. Statistically speaking, if the amplitude of the effluent anomaly is small compared to the inherent variability in ambient seawater properties, then the impact cannot be deemed significant.

The following two subsections describe the nature of wastewater dispersion from the MBCSD diffuser structure. The first subsection discusses the configuration of the multiport diffuser structure and describes how its hydraulic design determines the dimensions of the ZID. The second subsection describes the dynamics of the rapid mixing that occurs within the ZID immediately after discharge from the diffuser.

The final two subsections describe oceanographic processes that affect ambient seawater properties within northern Estero Bay, and quantify ranges in natural variability caused by these processes. These measures of natural-variability are used to establish thresholds for determining whether discharge-induced changes are significant. Regional processes cause major fluctuations in the character of the receiving waters near

¹ Data from the first part of Transect S1 and last part of Transect D2 (dashed lines in the figure) because slight differences in vessel speed resulted in small differences in tow depth compared to the average tow depths of the other transects.

the diffuser, and large seasonal changes in the vertical structure directly affect the dispersive capability of the outfall.

3.2.1 Zone of Initial Dilution

Treated wastewater from the MBCSD WWTP is discharged into northern Estero Bay through a 1,450-m outfall-diffuser system (Table 3.6). The existing outfall was constructed in 1982 with an upgraded 0.686-m diameter steel pipe lined and coated with cement mortar. The outfall extends to a water depth of about 15.2 m (50 ft), approximately 0.5 nautical miles offshore of Atascadero State Beach. At its terminus is a multiport linear diffuser consisting of 34 ports, each 5.08 cm in diameter. The ports are spaced 1.52 m apart on alternating sides of the pipe. The current discharge volume from the WWTP only requires the use of 28 of the 34 available ports.

For regulatory and modeling purposes, an idealized ZID is envisioned around the diffuser structure, where the most intense turbulent mixing of effluent is thought to take place shortly after discharge. The ZID is assumed to extend beyond the dimensions of the diffuser structure to a horizontal distance equal to the water depth (USEPA 1994). The water depth at the center point of the diffuser structure is 15.24 m (50 ft) measured relative to the MLLW tidal datum. Consequently, the ZID forms a vertical cylinder whose horizontal cross-section is an elongated ellipse as shown in Figure 3.2 on Page 3-7. Based on the diffuser specifications, the dimensions of the ZID are 73.15 m (240 ft) in length, 31.2 m (102.4 ft) in width, and 15.24 m (50 ft) in height. The length is twice the water depth (15.24 m) added to the 42.67 m (140 ft) long diffuser section where ports are open. The width of the ZID is twice the water depth added to the inside diameter (0.68 m) of the diffuser pipe. Coatings, which add 0.2 m to the outside diameter of the pipe, and the angled diffuser ports, which extend beyond the edge of the pipe, were neglected for the purposes of determining ZID dimensions. The ZID covers an ocean surface area of approximately 3000 m².

In reality, at any given time, the actual initial dilution zone departs markedly from the idealized vertical cylinder described above. On a regular basis, the prevailing current flow carries the effluent plume well beyond the boundaries of the idealized ZID long before it achieves buoyant equilibrium and before initial mixing is complete. Nevertheless, because wastewater is rapidly diluted upon discharge, the water-quality objectives of the COP are consistently met, even within the boundary of the ZID.

3.2.2 Critical Initial Dilution Ratio

Shortly after discharge, wastewater dilution is determined by the physical characteristics of the diffuser system and stratification within the receiving waters. The most rapid mixing occurs within the ZID, close to the diffuser structure. There, the turbulent processes associated with the high-velocity discharge jets emanating from the diffuser ports, and the buoyant rise of the effluent plume through the water column,

Table 3.6 Hydraulic Characteristics of the Outfall

Parameter	Measurement
Outfall diameter (m)	0.686
Outfall length (m)	
Land	207
Ocean	1,449
Diffuser diameter (m)	0.686
Diffuser length (m)	51.8
Port orientation (° from horizontal)	0
Port diameter (m)	0.0508
Orifice contraction coefficient	0.89
Center point depth of outfall ports (m MLLW)	15.2
Number of ports open	28 ¹
Port spacing ² (m)	1.52
Design flow rate for each port (m ³ /s)	0.01 ³

¹ 28 of 34 ports available

² Ports are located on alternating sides of the diffuser. Distance between ports on the same side of the diffuser is 3.04 m.

³ Flow rate assuming 34 ports open in a total flow of 0.340 m³/s (7.76 MGD). The outfall design capacity is 0.358 m³/s (8.17 MGD).

result in the rapid dilution of discharged wastewater. Subsequent transport and dispersion by regional oceanographic processes further dissipate the effluent, albeit at a slower rate. The dispersion associated with these oceanographic processes is not considered part of initial dilution.

The limiting concentrations for wastewater constituents specified in the NPDES permit (see Chapter 2) were determined by applying the critical initial dilution ratio for the MBCSD outfall to the open-ocean water-quality objectives specified in the COP for individual contaminants (Table B of SWRCB 2005). The critical initial dilution applicable to the MBCSD outfall was conservatively estimated to be 133:1 (Tetra Tech 1992). The following example shows how this dilution factor was applied to determine the wastewater limits that were established for cadmium in the NPDES permit. The COP's water-quality objective for cadmium in receiving waters has an instantaneous maximum concentration of 0.01 mg/L or less (SWRCB 2005). Based on modeling under extremely stratified conditions, there will be at least 133 parts of ambient water mixed with each part of wastewater after completion of initial mixing. From the definition of dilution (Fischer et al. 1979), the concentration of a particular contaminant in wastewater is given by:

$$C_e \equiv C_o + D (C_o - C_s) \quad \text{Equation 3.1}$$

where: C_e = the concentration of a constituent in the wastewater effluent,
 C_o = the concentration of the constituent in the ocean after dilution by D ,
 D = the dilution ratio of the volume of seawater mixed with wastewater, and
 C_s = the background concentration of the constituent in ambient seawater.

The background concentration (C_s) for cadmium in seawater is negligible so the wastewater limit is $(D+1)$ times the COP objective (C_o). Thus for cadmium, the instantaneous maximum concentration in wastewater should be no more than 1.34 mg/L, or 134 times the seawater objective of 0.01 mg/L. Thus, under the worst-case scenario, wastewater containing 1.34 mg/L of cadmium will dilute to a concentration of 0.01 mg/L upon reaching the boundary of the ZID, and the receiving water objective will be met. This is how the maximum effluent limit on cadmium concentration (1.34 mg/L) was established in the NPDES discharge permit granted to the MBCSD.

The foregoing calculation demonstrates how strongly the assumed initial dilution influences the wastewater limitations that are specified in the discharge permit. Because a low value (133:1) was specified for the critical initial dilution, conservative wastewater limitations have been established for the MBCSD discharge. As discussed in Section 3.3.1, however, direct observations recorded close to the diffuser during the 2011 surveys indicate that dilutions much higher than 133:1 were achieved well within the ZID and below the assumed plume-trapping depth of 6.4 m. In fact, the original plume modeling that established the 133:1 critical dilution (Tetra Tech 1992) included 34 open diffuser ports instead of the 28 ports that are currently in use, thereby underestimating the flow rate and mixing from individual diffuser ports.

Additionally, the model assumed that the receiving waters at the point of discharge were highly stratified. However, the stringent vertical stratification profile used in the modeling is not typical of the receiving-water conditions close surrounding the outfall. Specifically, the critical initial dilution computed by the original modeling was overly conservative because the density profile used to establish the MBCSD critical initial dilution was collected 1 km south of the diffuser structure, where the water column was

highly stratified due to the influence of the thermal discharge from the Morro Bay power plant¹. At the time the “critical” density profile was measured, the power plant was discharging heated water to the ocean near Station F, next to Morro Rock (see Figure 3.1 on Page 3-6).

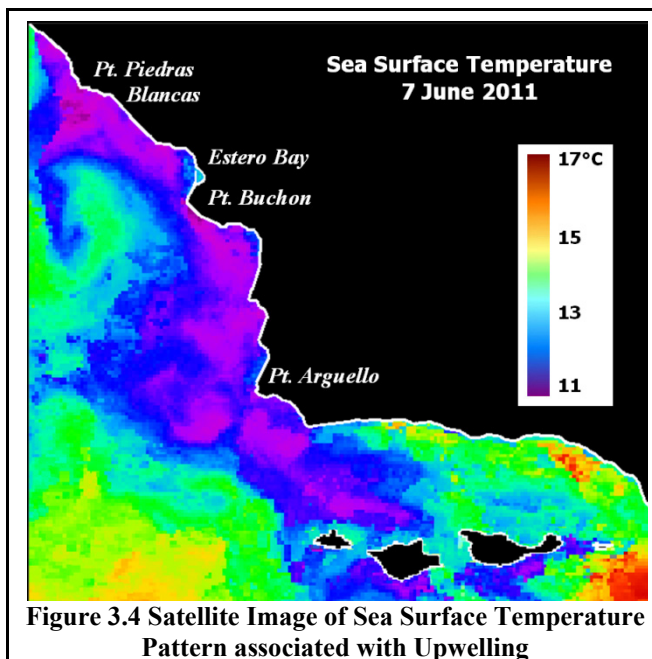
Because this southerly monitoring station consistently exhibited anomalous water properties relative to the ambient conditions near the MBCSD outfall, it was discarded when the receiving-water monitoring program was revised in 1999. Nevertheless, the original plume modeling, which established both the critical initial dilution ratio currently applied to the outfall and the present effluent discharge limits, incorporated a heavily stratified profile from this station. The model predicted that the receiving waters would trap the effluent plume 6.4 m below the sea surface. More recent dilution modeling, however, demonstrates that with the weaker vertical stratification typical of the water column near the diffuser, a critical initial dilution of approximately 200:1 with a plume trapping depth of 1.4 m is more representative of the worst-case outfall performance (Lindstrom 1998).

Nevertheless, even with dilutions of only 133:1, the highly sensitive CTD instrumentation would have a difficult time detecting the signature of the wastewater discharge, except very close to diffuser ports. Accordingly, most wastewater-induced perturbations in water quality are imperceptible beyond the ZID, particularly in the presence of the large, natural oceanic variability that exists within northern Estero Bay.

3.2.3 Regional Oceanographic Processes

A broad suite of complex oceanographic processes determines the disposition of coastal marine waters within northern Estero Bay. Close to shore, an energetic wave field occasionally dominates the oceanographic conditions along this section of the central California coast. This wave energy increases the turbulence within nearshore waters, and causes significant sediment resuspension and sand transport along the outfall corridor. Farther offshore, bands of counter currents move ocean waters in alternating directions along the continental shelf.

This large-scale, along-shore current flow is interrupted by cross-shore tidal currents and by turbulent jets that occasionally form at major promontories, such as Point Piedras Blancas, Point Buchon, and Point Arguello (Figure 3.4). These narrow, energetic jets transport materials far from the coast, and are repeatedly observed extending from upwelling centers located south of major coastal headlands in satellite imagery. In addition to these processes, wind-driven upwelling alters the vertical distribution of water properties within Estero Bay and contributes to the remarkably high productivity of the marine waters there.

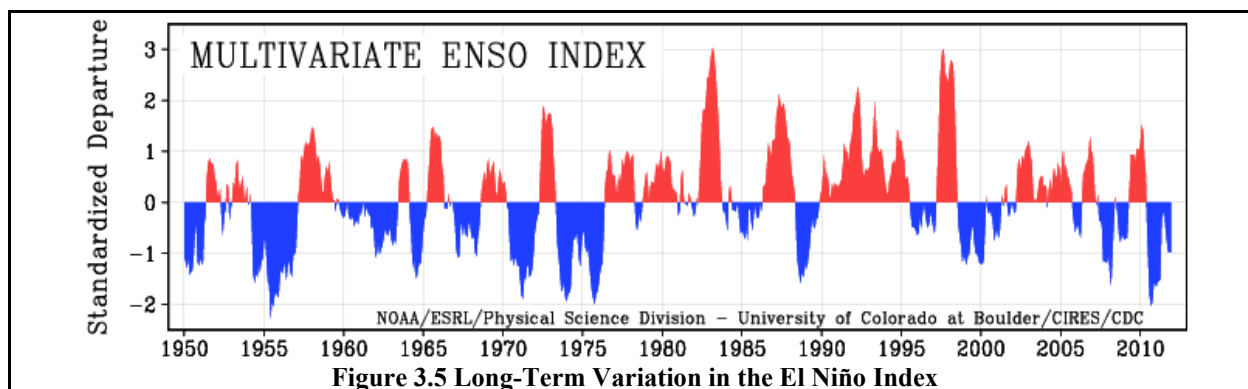


¹ The plant is not currently operating. It is owned by NRG Energy, but has formerly been owned by the following entities: Pacific Gas and Electric, Duke Energy, LS Power Group, the Dynegy Corporation, and Icahn Enterprises.

The open-ocean flow field largely controls ambient seawater properties within Estero Bay. Beyond the continental slope (>50 miles offshore), the diffuse, southward-flowing California Current represents the eastern limb of the clockwise-flowing gyre that covers much of the North Pacific Ocean. Before turning south to form the California Current, subarctic water is carried along at high latitudes where it is exposed to atmospheric cooling, nutrient regeneration, and precipitation. As a result, the waters of the California Current are characterized by a seasonably stable low salinity (32‰ to 34‰), low temperature (13°C to 20°C), and high nutrient concentrations. Because of this stabilizing effect, seawater off the central coast undergoes less seasonal variation than surface waters at similar latitudes along the eastern seaboard.

Immediately shoreward of the California Current, along the continental slope and shelf, is the northward flowing Davidson countercurrent, which carries warmer, more saline, and less oxygenated waters from the Southern California Bight. The Davidson Current exhibits a strong seasonal variability in intensity that coincides with large-scale changes in coastal winds. Specifically, throughout much of the year, winds along the central coast blow from the northwest, parallel to the coast and in opposition to the northward-flowing Davidson Current. These strong northwesterly winds induce upwelling near Points Estero, Buchon, and Sal. During the upwelling season, surface water near the coast is transported offshore by the prevailing winds, and is replaced by deep cool, nutrient-rich seawater near the coast as shown in Figure 3.4. When these northwesterly winds relax, usually between December and February, the Davidson Current strengthens. A spring transition back to strong southwestward winds typically occurs fairly rapidly between March and June. Despite reversals observed elsewhere along the California Coast, however, the Davidson current maintains a sustained northward flow near Estero Bay (Coats et al. 1991).

Significant inter-annual variations in oceanographic and marine biological properties also occur along the central California coast, and have strongly influenced the waters of Estero Bay throughout the last half century (Figure 3.5). These large amplitude variations are associated with the El Niño–Southern Oscillation (ENSO), which cycles at a period of 3 to 5 years (Graham and White 1988). El Niño and its counterpart, La Niña, are oscillations of the ocean-atmosphere system in the tropical Pacific. El Niño is characterized by unusually warm sea surface temperatures and La Niña by unusually cool temperatures in the equatorial Pacific Ocean. For example, the dark blue areas in the center of the satellite image in Figure 3.6 depict abnormally cool sea surface temperatures present in the Central and Eastern Tropical Pacific during an unusually strong La Niña event.

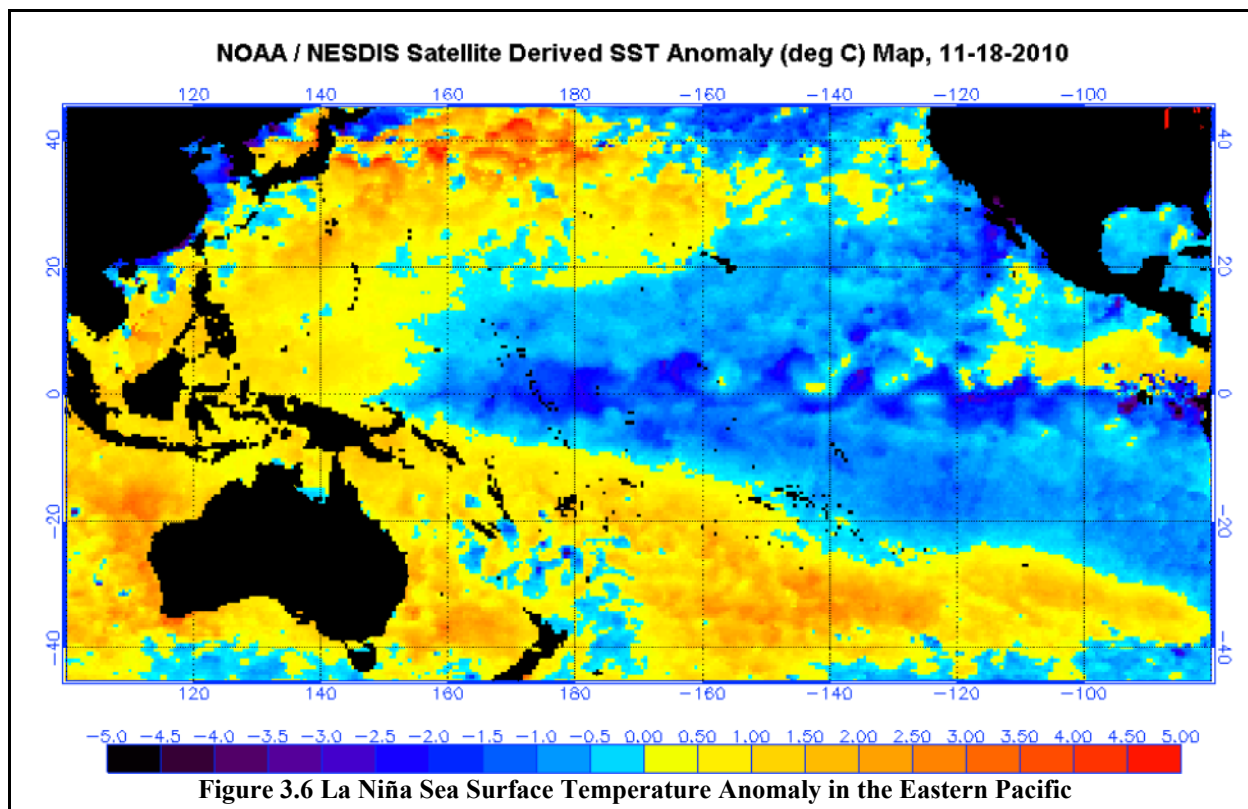


Typically, each period in the cycle lasts approximately 12 months (Figure 3.5). During strong El Niño periods, such as between 1982 and 1983, and between 1997 and 1998, basin-wide changes in the dynamic balance of wind-driven currents result in modified flow patterns along the coastline of western North and

South America (Chelton et al. 1982). Changes in the study region include an anomalous strengthening of Davidson Current outflow from the Southern California Bight. El Niño events also generally coincide with increased winter storm activity, reductions in zooplankton biomass, and the introduction of marine organisms typically found far to the south. For example, the relatively strong El Niño condition that was present during the latter half of 1997 and the beginning of 1998, resulted in a substantial increase in rainfall during the early part of 1998, and heavily impacted central-coast ocean waters and associated biota.

The most recent El Niño oscillation began in the summer of 2009, and grew substantially in strength during the fall of 2009. However, this moderate to strong El Niño (NOAA 2010) ended abruptly in May 2010 and was followed by a rapid transition to a very pronounced La Niña phase, the like of which has not been seen in over 35 years (Figure 3.5). This relatively strong La Niña event opened 2011, and then dissipated in the spring before re-emerging in October and continuing through the end of the year.

During La Niña events, high pressure builds in the eastern equatorial Pacific while low pressure develops to the west, producing a stronger equatorial pressure gradient. The easterly trade winds strengthen, causing upwelling off the coastlines of Peru and Ecuador to intensify, and lowering sea surface temperatures throughout the Eastern Pacific Ocean (dark blue areas in center of Figure 3.6), including along California's central coast. The low sea surface temperatures along the equator also cause the Pacific storm track to shift northward, typically resulting in drier conditions throughout the southern United States. In fact, in 2011, San Luis Obispo County had its driest December since rain records were first kept in 1869. The stronger-than-normal winds associated with the current La Niña event measurably increased the persistence and strength of upwelling events along the central coast throughout the last half of 2010 and all of 2011.



In addition to, and superimposed on these large-scale oceanic flows are a variety of transient phenomena including intense eddies, swirls, filaments, meanders, and narrow jets of flow. Many of these cross-shore turbulent features are evident in the complex surface flow pattern depicted in satellite images. For example, in Figure 3.4, an upwelling-induced cold-water jet, delineated in shades of purple and dark blue, emanates from Pt. Piedras Blancas. The jet forms a recirculating eddy-like feature offshore of Estero Bay. Embedded in these large-scale features are smaller filaments of flow that add further complexity to the surface flow pattern. All of these cross-shore flow features are capable of transporting significant quantities of coastal heat, nutrients, and pollutants to offshore waters (Savoie et al. 1991).

Tidal currents provide another mixing mechanism for ocean waters in the study region, although they are not responsible for significant net transport. Estero Bay experiences astronomical tides of diurnal inequality, meaning that the two daily sets of tidal extrema are of unequal amplitude. Tidal fluctuations of as much as 2.1 m can combine with storm surges of up to 0.3 m. Typically, however, the tidal range near the outfall site is approximately 1 m between mean high and low water.

At shorter periods, shoaling internal waves and surface gravity waves also serve to mix coastal water properties in both the horizontal and vertical directions within the receiving waters. This region of the central coast is relatively unprotected and experiences a comparatively high flux of wave energy, especially in winter when intense storm events are prevalent. Under certain conditions, this wave energy impinges on Atascadero State Beach at oblique angles, generating substantial alongshore transport within the coastal littoral cell between Point Estero and Morro Rock (Figure 3.7). The wave-generated littoral cell can extend well offshore into Estero Bay, encompassing the MBCSD discharge location. Four primary meteorological sources generate waves in this region: 1) extratropical winter cyclones in the northern hemisphere, 2) northwesterly winds after the spring transition to upwelling conditions, 3) tropical disturbances off shore of Mexico, and 4) extratropical storm swells generated in the southern hemisphere during summer. The first two are the dominant influences on the wave climate along this section of the central California coast, while the last two generate swells from the south, which are diminished near the outfall site by the sheltering effects of Point Buchon (Figure 3.7).

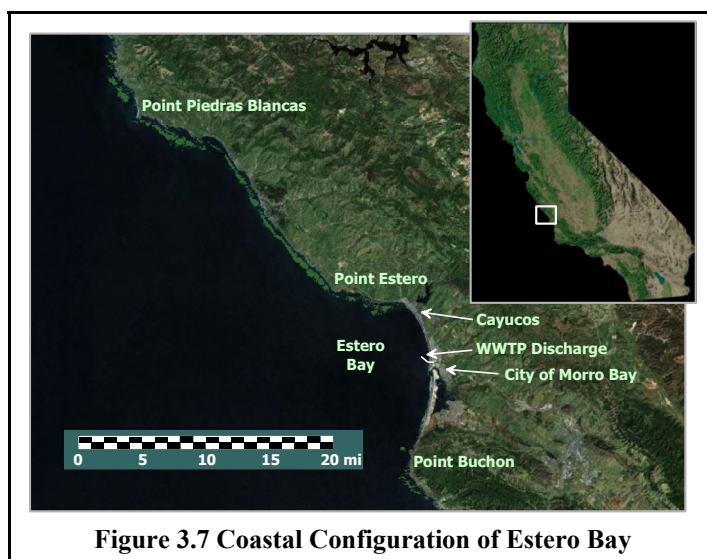


Figure 3.7 Coastal Configuration of Estero Bay

Winter storm waves generated by extratropical winter cyclones are often accompanied by locally severe weather along the south-central coast. These extratropical storms are associated with low-pressure systems that develop along the polar front in the North Pacific Ocean, and that propagate westward toward the central coast. Thus, major wave events often coincide with an increased discharge from the outfall due to heavy rainfall and increased I&I. These storms occur predominantly from December through March. In fact, more than 95% of all major deepwater wave events ($H_s > 4$ m) occur between the months of November and April (Everts Coastal 1996).

With the exception of major storm events, prevailing northwesterly winds are the predominant mechanism for generating waves near the outfall. These winds dominate during the spring and summer when a high-pressure system is established over the eastern North Pacific Ocean. The winds are highly coherent over this section of the central coast and, consequently, can generate wind waves over a large fetch (Chelton et al. 1987). However, these locally generated waves tend to be of shorter period and smaller height than those generated by major winter storms.

3.2.4 Ambient Seawater Properties

A detailed understanding of ambient seawater properties, and their natural variation within the region surrounding the outfall, is an integral part of compliance evaluation. The receiving-water limitations in the NPDES permit echo the objectives listed in the COP (Table 3.1 on Page 3-4), and the Central Coast Basin Plan (RWQCB 1994). The offshore receiving-water surveys are designed to assess compliance with objectives dealing with undesirable alterations to six physical and chemical characteristics of seawater. Other components of the monitoring program, described in other chapters of this report, address the remaining permit limits.

For the receiving waters, the permit states that wastewater constituents within the discharge shall not cause the limits listed in Table 3.7 to be exceeded (See Sections V.E through V.K of the permit). The first two receiving-water limits, P1 and P2, rely on qualitative visual observations for compliance evaluation. Compliance with the remaining four receiving-water limitations can be quantitatively evaluated by comparing instrumental measurements with the specific numerical limits listed in the NPDES permit. For example, the numeric limits on absolute values of DO (>5 mg/L) and pH (7.0 to 8.3), which reflect Basin Plan objectives, can be directly compared with field measurements within the dilute wastewater plume.

Table 3.7 Permit Provisions Addressed by the Offshore Receiving-Water Surveys

Limit#	Provision	Source	Limit
P1	V.E	COP C.1	Floating particles or oil and grease to be visible on the ocean surface
P2	V.F	COP C.2	Aesthetically undesirable discoloration of the ocean surface
P3	V.I	Basin Plan	Temperature of the receiving water to adversely affect beneficial uses
P4	V.G	COP C.3	Significant reduction in the transmittance of natural light at any point outside the initial dilution zone
P5	V.J	Basin Plan COP D.1	The DO concentration outside the zone of initial dilution to fall below 5.0 mg/L or to be depressed more than 10 percent from that which occurs naturally
P6	V.K	Basin Plan COP D.2	The pH outside the zone of initial dilution to be depressed below 7.0, raised above 8.3, or changed more than 0.2 units from that which occurs naturally

However, both P5 and P6 also contain narrative statements, which originate in the COP and define unacceptable water-quality impacts as “*significant*” excursions beyond those that occur “*naturally*.” Quantitative evaluation of these limits requires a further comparison of field measurements with numerical thresholds that reflect the natural variation in transmissivity, DO, and pH within the receiving waters surrounding the outfall. The 25-year record of quarterly receiving-water surveys conducted as part of the MBCSD monitoring program provides the necessary insight into this natural temporal and spatial variation in ambient seawater properties close to the outfall.

Natural variation in seawater properties is driven by a varying combination of the oceanographic processes described in the previous section. These processes determine the range in ambient seawater properties caused by natural spatial variation within the survey region at a given time (e.g., vertical

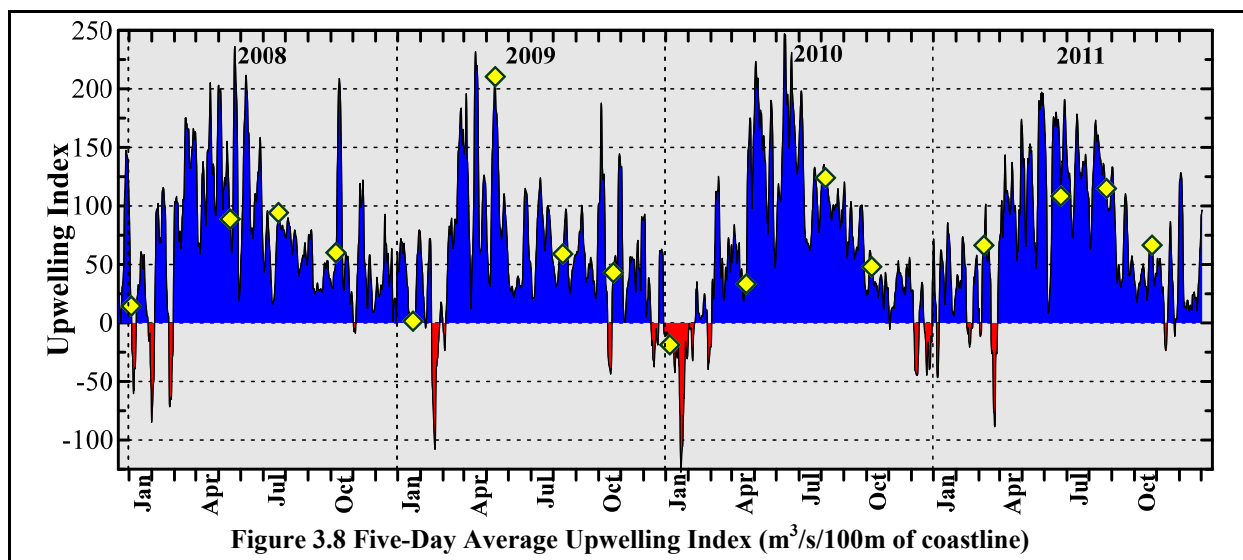
stratification), and by temporal variations caused by seasonal and interannual influences (e.g. El Niño and La Niña). Of particular interest are upwelling and downwelling processes that not only determine average properties at a given time, but also the degree of water-column stratification, or spatial variability, present during any given survey. An accurate characterization of stratification helps distinguish discharge-related changes, that arise from the presence of wastewater constituents and are subject to the compliance evaluation, from changes that arise because of the upward movement of ambient seawater, which are specifically excluded from the compliance evaluation.

Most of the variability in the ambient seawater database arises from temporal changes in average seawater properties among surveys. Within individual surveys, vertical differences in seawater properties far exceed lateral differences, except during winter surveys when downwelling events typically create a very uniform water column. The dominating influence of seasonal variability on receiving-water properties, in terms of differences in both vertical stratification and average properties, is reflected in the conditions observed during the four offshore surveys conducted in 2011 (Table 3.8). As noted in the table, the strength of upwelling that prevailed at the time of each survey tended to influence the degree of stratification.

Table 3.8 Oceanographic Conditions during the Quarterly Receiving-Water Surveys

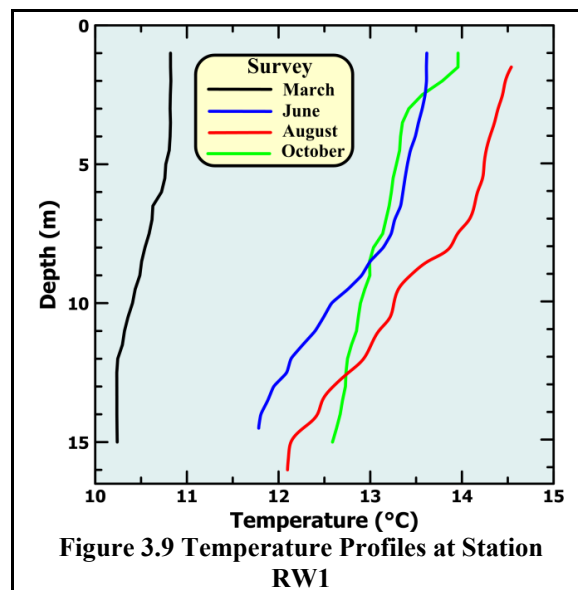
Conditions	March (winter)	June (spring)	August (summer)	October (fall)
Tide	Flood	Ebb	Slack	Slack
Wave Height (from)	4 NW	3 NW	2 NW	3 NW
Flow Direction (toward)	SW	ESE	SE	SSE
Stratification	Weak	Strong	Strong	Moderate
Water Clarity	Moderate	Moderate	Low	High
Upwelling	Moderate	Intense	Intense	Moderate
Plume Visible	No	No	No	No
Plume Signature	Yes	Yes	Yes	Yes

All four of the 2011 surveys were conducted when some degree of upwelling and water-column stratification prevailed. Blue shaded areas in Figure 3.8 represent times when northwesterly winds prevailed near Estero Bay, driving surface waters offshore, and inducing upwelling near the coast, while

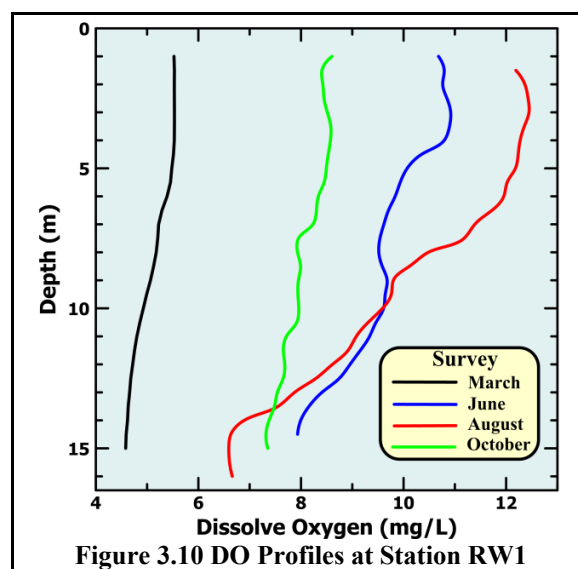


the yellow diamonds identify the individual receiving water surveys. As seen in the figure, the second, third and fourth-quarter receiving-water surveys have consistently been conducted during periods of upwelling. The first-quarter 2011 survey was unusual in that it was also associated with a brief but moderately intense upwelling event. Most other first-quarter surveys were conducted when little or no upwelling was occurring, and when downwelling from successive winter storms had produced a nearly uniform water column. Downwelling displaces deep watermasses offshore, where they no longer provide a nearshore vertical contrast in seawater properties, thereby producing a uniform (unstratified) water column within the survey area.

The relative influence of upwelling can also be seen in the temperature profiles collected at Station RW1 during each of the quarterly surveys in 2011, both in the degree of stratification and in the range of average temperatures (Figure 3.9). For example, profiles from the surveys conducted in June, August, and October 2011 exhibit broad thermoclines that extend through the entire water column. These profiles are typical of upwelling conditions when northwesterly winds along the central California coast drive surface waters offshore, allowing cooler, denser, saltier, and oxygen-poor water at depth to “upwell” near the coast to replace it. The degree of stratification observed during a given survey also depends on the intensity and duration of the upwelling winds prior to the survey. For example, the temperature profiles indicate that upwelling was more sustained during the June (blue) and August (red) surveys, as compared with the October (green) survey. Although it was also associated with an upwelling event, the March (black) profile exhibits less vertical variation than the other surveys because it was immediately preceded by a downwelling event. During winter, relaxation of upwelling winds and passing storms generally serve to thoroughly mix nearshore waters, resulting in a fairly uniform temperature throughout the water column.



Although upwelling is recognized as the primary driver behind the productive fisheries of the central California coast, the persistence and strength of the upwelling that occurred during much of 2010 and into early 2011 eventually depleted oxygen within the nearshore waters of Estero Bay (Figure 3.10). The upwelling conditions initially facilitated phytoplankton blooms that produced oxygen and consumed carbon dioxide. However, as phytoplankton died and fell to the seafloor, their decomposition consumed more of the available oxygen in the nearshore waters than they contributed. Normally, the northwesterly winds that promote upwelling are not constant and during periods when they intermittently relax, mixing of the waters on the continental shelf takes place, replenishing the subsurface waters with oxygen. Without this periodic relaxation of the winds,



however, DO levels begin to drop, as they did during the summer of 2010, when DO concentrations below 3 mg/L were measured near the seafloor (MRS 2011a). In fact, most DO levels measured near the seafloor during both the August and October 2010 surveys were below the Basin Plan limit of 5 mg/L. As seen in Figure 3.10, ambient DO levels were still significantly depressed at the time of the March 2011 survey. Fortunately, these conditions did not persist beyond March 2011; a significant downwelling event took place shortly after the first-quarter survey that replenished nearshore oxygen levels, as reflected in the DO profiles of the other three surveys.

3.3 COMPLIANCE EVALUATION

This section evaluates the compliance of the MBCSD discharge in 2011 with the six permit limits listed in Table 3.7. The water-quality limitations are based on criteria in the COP (Table 3.1), the Central Coast Basin Plan, and other state and federal policies that were designed to protect marine life and beneficial uses of ocean waters. Because the limits only pertain to changes in water properties that are caused by the presence of wastewater constituents beyond the ZID, instrumental measurements undergo a series of screening procedures prior to numeric comparison with the permit thresholds.

The quantitative analyses described in this section focus on water-property excursions caused by the presence of wastewater constituents beyond the ZID, and whose amplitudes can be reliably discerned against the backdrop of ambient fluctuations. A detailed understanding of ambient seawater properties, and their natural variability within the region surrounding the outfall, is therefore, an integral part of the compliance evaluation presented in this section.

The results of these analyses applied to data collected during 2011 demonstrate that the MBCSD discharge complied with the NPDES discharge permit, as has been the case for the prior quarter century of monitoring. Moreover, although observations within the ZID are not subject to compliance evaluations, they often meet the prescribed limits because dilution levels exceed the conservative design specifications assumed in the discharge permit. Thus, the quantitative evaluation described in this section documents an outfall and treatment process that was continuing to perform at a high level during 2011.

3.3.1 Screening for Applicability

Evaluating whether any of the 31,456 receiving-water measurements collected during 2011 exceeds a permit limit is a complex process. For example, apparently significant excursions in an individual seawater property may be unrelated to the presence of wastewater constituents, and may instead be due to any number of confounding factors. These confounding factors include natural processes, statistical uncertainty, instrumental error, entrainment of ambient bottom waters within the rising effluent plume, ongoing initial mixing within and beyond the ZID, and other anthropogenic influences unrelated to the discharge, such as dredging discharges or oil spills.

Because of this complexity, prior to comparison with Basin-Plan numerical limits and COP objectives, measurements are sequentially screened to restrict attention to: 1) the oceanic area where permit provisions apply; 2) changes due to the presence of wastewater particulates; and 3) changes large enough to be reliably detected against the backdrop of natural variation (Table 3.9).

Measurement Location

The COP states that compliance with its receiving-water objectives “shall be determined from samples collected at stations representative of the area within the waste field where initial dilution is completed.” Initial dilution includes the mixing that occurs from the turbulence associated with both the ejection jet, and the buoyant plume’s subsequent rise through the water column. Although currents often transport the plume beyond the ZID before the initial dilution process is complete, the COP states that dilution estimates shall be based on “the assumption that no currents, of sufficient strength to influence the initial

Table 3.9 Receiving-Water Measurements screened for Compliance Evaluation

Topic Addressed	Screening Question	Answer		Parameter
		No	Yes ¹	
Location	1. Was the measurement collected beyond the 15.2-m ZID boundary where modeling assumes that initial dilution is complete?	4,040	27,416	All
Wastewater Constituents	2. Did the beyond-ZID measurement coincide with a quantifiable salinity anomaly ($\leq 550:1$ dilution level) indicating the presence of detectable wastewater constituents?	25,999	1,417	All
Natural Variation	3. Did seawater properties associated with a quantifiable salinity anomaly depart significantly from the expected range in ambient seawater properties present at the time of the survey?	1,417	0	Temperature
		1,417	0	Transmissivity
		1,417	0	DO
		1,370	47	pH

dilution process, flow across the discharge structure.” Because of this, the regulatory mixing distance, which is equal to the 15.2-m water depth of the discharge, provides a conservative boundary to screen receiving-water data for subsequent compliance evaluation. Application of this initial screening question to the 2011 dataset eliminated 4,040 of the original receiving-water observations from further consideration because they were recorded within the ZID (Table 3.9, Question 1).

Presence of Wastewater Constituents

The MBCSD discharge permit restricts application of the numerical receiving-water limits to excursions caused by the presence of wastewater constituents. This confines the compliance analysis to changes caused “*as the result of the discharge of waste*,” as specified in the COP, rather than anomalies that arise from the movement of ambient seawater that becomes entrained in the rising effluent plume. Analyses of data collected during quarterly receiving-water surveys over the past decade have demonstrated that the direct influence of dilute wastewater is almost never observed in any seawater property other than salinity, except very close (<1 m) to a diffuser port and within its ejection jet.

In fact, negative salinity anomalies are the only consistent indicator of the presence of wastewater constituents within receiving water. Wastewater salinity is negligible compared to that of the receiving seawater, so the presence of a distinct salinity minimum provides *de facto* evidence of the presence of wastewater constituents. Because of the large contrast between the nearly fresh wastewater and the salty receiving water, salinity provides a powerful tracer of dilute wastewater that is unrivaled by other seawater properties. The contrast between effluent and seawater temperature, DO, pH, and transmissivity is much smaller, and as such, their wastewater signatures dissipate rapidly upon discharge with very little mixing. Wastewater’s near lack of salinity, however, allows the presence of effluent constituents to be identified even after dilution that is substantially greater than the 133-fold critical initial dilution assumed in the discharge permit.

The association between negative salinity anomalies and wastewater constituents is so robust that the dilution achieved at a given point within the effluent plume can be determined directly from the amplitude of the salinity anomalies. By rearranging Equation 3.1, the dilution ratio (D) can be computed from the salinity anomaly ($A = C_o - C_s$) as follows:

$$D \equiv \frac{(C_e - C_o)}{(C_o - C_s)} \approx \frac{-C_o}{(C_o - C_s)} \propto A^{-1} \quad \text{Equation 3.2}$$

¹ Number of remaining CTD observations of potential compliance interest based on this screening question

where:

D = the dilution ratio of the volume of seawater mixed with wastewater,
 C_o = the salinity of the wastewater-seawater mixture after dilution by D ,
 C_s = the background seawater salinity, and
 $A = C_o - C_s$ = the salinity anomaly.

The salinity concentration measured within MBCSD effluent (C_e) is small compared to that of both the receiving seawater (C_s) and, after dilution by more than 100-fold, the effluent-seawater mixture (C_o). Consequently, it can be neglected in the equation. Additionally, to a close approximation; dilution levels are directly proportional to the inverse of the salinity anomaly. Thus, increased effluent dilution at a given location within receiving waters is reflected by smaller amplitude salinity anomalies.

The smallest reduction in salinity that can be reliably detected within receiving waters is 0.062‰, which reflects a dilution level of at least 542-fold when substituted into Equation 3.2. This plume-detection threshold was determined from a statistical analysis of the natural variability in salinity readings measured near the outfall over a five-year period between 2004 and 2008. Thus, wastewater that has mixed with 542 parts of seawater no longer has a salinity signature that can be reliably discerned against the backdrop of natural variation. This dilution threshold was rounded up to 550-fold for added conservatism in the screening analysis (Table 3.9, Question 2).

The 550:1 plume-detection threshold is more than four-times higher than the 133:1 minimum initial dilution ascribed to the worst-case outfall performance, and upon which compliance with the Table B receiving-water objectives of the COP is ensured through specification of end-of-pipe limits on effluent contaminant concentrations in the NPDES discharge permit. Consequently, discernible salinity anomalies are more than capable of detecting out-of-compliance measurements within receiving waters, while measurements with anomaly amplitudes below the plume-detection threshold have wastewater concentrations far too dilute to be of compliance interest.

Application of this screening question to the 27,416 observations that were measured outside the ZID during 2011 surveys determined that only 1,417 measurements had reductions in salinity that could potentially be related to the presence of dilute wastewater constituents (Table 3.9, Question 2)..

Natural Variation

Another integral part of the compliance evaluation is determining whether a particular measurement differed from other observations at the same depth level because of naturally occurring variations in seawater properties at the time of the survey or whether it was perceptibly altered by the presence of wastewater constituents (Table 3.9, Question 3). Thus, natural variability must be accurately quantified for each survey as part of the compliance evaluation.

The natural range in ambient seawater properties differs among surveys, largely because of differences in upwelling-induced vertical stratification. It is important to consider this vertical variation when evaluating whether a particular measurement extends beyond its natural range. Departures (anomalies) from background conditions are traditionally defined as the difference between a given measurement and the average of seawater properties measured at the same depth level, but at locations beyond the discharge's influence. However, when the water column is highly stratified, ambient seawater properties near the seafloor differ from those within the rest of the water column, and their juxtaposition within the rising effluent plume can appear as a lateral anomaly at mid-depth. These entrainment-generated anomalies regularly appear within the rising effluent plume when the water column is strongly stratified by upwelling. However, the amplitudes of these entrainment-generated anomalies are unrelated to both the

concentration of wastewater constituents within a given measurement and the quality of the effluent that is being discharged at that particular time.

As described in Section 3.2.4, only significant departures in temperature, light transmittance, DO, and pH are relevant for evaluating compliance with receiving-water limits. Thresholds for evaluating whether any of these measured properties extended beyond the natural conditions were determined for each receiving-water survey conducted during 2011 (Table 3.10). Excursions beyond the thresholds identify measurements that warrant comparison with the specific numeric thresholds identified in permit provisions (Table 3.7).

Table 3.10 Thresholds for Significant Departures from Natural Conditions

Water Property	March	June	August	October
Temperature (°C)	>11.64	>14.45	>15.39	>14.60
Transmissivity (%)	<65.6	<58.6	<50.7	<70.0
DO (mg/L)	<3.27	<6.37	<5.24	<6.01
pH (minimum)	<7.434	<7.915	<7.942	<7.975
pH (maximum)	>7.682	>8.273	>8.525	>8.244

The thresholds of natural variation for each water property were established using a two-step process in a manner analogous to COP Appendix VI. First, one-sided 95% confidence bounds on transmissivity (-10.2%), temperature (+0.82°C), DO (-1.4 mg/L), and pH (± 0.94) were determined from an analysis of the same five-year database used to characterize within-survey salinity variation. These bounds quantify the spatial variability inherent in the ambient receiving waters surrounding the outfall at any given time. Second, the confidence bounds were combined with 95th percentiles determined from background seawater properties for each survey, thereby capturing seasonal differences among surveys, including the degree of vertical stratification. The percentiles were determined from vertical profiles excluding measurements potentially affected by the discharge. The resulting set of thresholds quantifies significant departures from natural conditions that prevailed at the time of each survey. Because the thresholds incorporate ambient vertical variability, many of the entrainment-generated anomalies artificially created by the upward movement of the plume during stratified conditions are excluded from further compliance consideration, and attention is focused on potentially significant anomalies caused by the presence of wastewater constituents.

Of the 1,417 measurements that were potentially related to the presence of wastewater constituents beyond the ZID, 47 measurements had a water property that extended outside the expected range in ambient seawater properties listed in Table 3.10. Forty-seven anomalously low pH measurements were consecutively recorded along a mid-depth tow transect as it traversed the northeast boundary of the ZID during the June 2011 survey (Figure 3.11). The treatment plant's effluent had a pH of 7.8, which is below that of the receiving water on the day of the survey, so it is conceivable that wastewater constituents could have contributed to the reductions observed within the mid-depth plume.

However, the deviation of these pH measurements from the expected range was extremely small; at ≤ 0.076 they were well below the reported accuracy

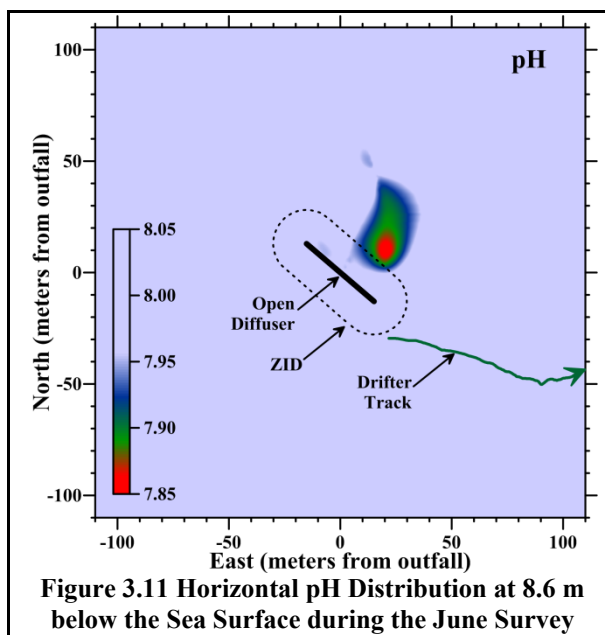


Figure 3.11 Horizontal pH Distribution at 8.6 m below the Sea Surface during the June Survey

of the sensor (± 0.1 pH units, Table 3.5). Additionally, high dilution levels coincided with the very small reductions in pH (Figure 3.12), and after a dilution of more than 200-fold, the 0.4 difference between wastewater pH (7.6) and ambient seawater pH (8.0) would have been imperceptible. Lastly, wastewater-induced anomalies tend to co-occur, yet temperature, density, DO, and transmissivity were all within the ranges expected for ambient seawater. A number of very small jellyfish (Medusozoa) were present in the survey area during the June survey. Some lodged on the CTD package and impeded the transmissometer's light path, resulting in the loss of a small amount of data. It is plausible that jellies may have also briefly adhered to the pH probe and were responsible for the slight, but temporary drop in pH that was measured. Nevertheless, the potential validity of these 47 measurements cannot be unequivocally ruled out. Consequently, these 47 pH values were carried forward in the compliance analysis.

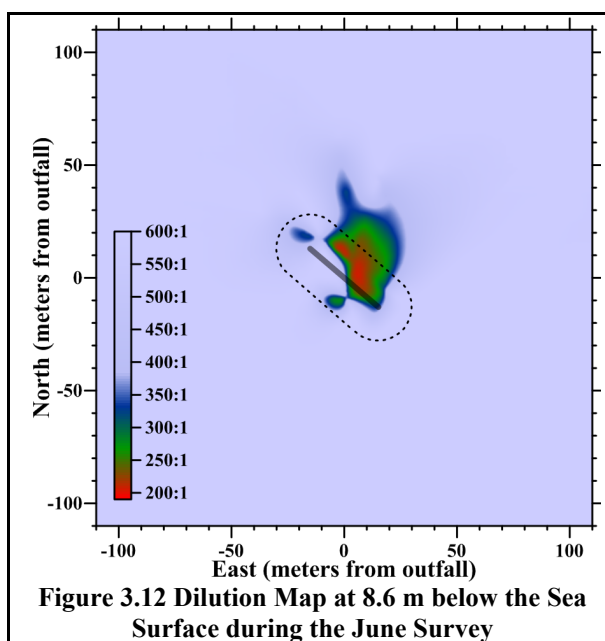


Figure 3.12 Dilution Map at 8.6 m below the Sea Surface during the June Survey

3.3.2 Numerical Limits

The last four permit provisions (P3 through P6 in Table 3.7) provide numerical limits that identify unacceptable changes in receiving-water properties. The provisions are derived from three regulatory documents: the Central Coast Basin Plan, the COP, and by reference, the California Thermal Plan. In addition, Secchi depth measurements collected during the four quarterly surveys are compared with the permit limit on the transmission of natural light (P4 in Table 3.7).

COP Objectives

The COP allows DO to be depressed 10% below “that which occurs naturally” due to the presence of oxygen-demanding material within effluent (COP §II.D.1; Permit Provision P5 in Table 3.7). Likewise, pH is allowed to extend 0.2 units beyond natural ranges (COP §II.D.2; Permit Provision P6 in Table 3.7). Numerical permit limits are therefore determined by applying COP allowances to the thresholds of natural conditions listed in Table 3.10.

After applying the 0.2 unit COP allowance for pH, all of the 47 low pH measurements left after the screening analysis in the previous section were found to be in compliance with the permit's receiving-water limits. Specifically, the lowest anomalous pH measurement (7.839) was well above the minimum allowable pH applicable to the June survey (7.715 in Table 3.11).

Table 3.11 COP Limits on Discharge-Related Changes to Seawater

Water Property	March	June	August	October
Temperature (°C)	>13.86	>16.67	>17.61	>16.82
Transmissivity (%)*	<65.6	<58.6	<50.7	<70.0
*Applicable Depth (m)	<13	<12	<6	<12
DO (mg/L)	<2.94	<5.73	<4.72	<5.41
pH (minimum)	<7.234	<7.715	<7.742	<7.775
pH (maximum)	>7.882	>8.473	>8.725	>8.444

The COP objective limiting significant reductions in the transmission of natural light can also be translated into a numerical permit limit. Because the COP does not specify an allowance beyond natural conditions, the permitted minimum transmissivities (Table 3.11) match the lower bound of the natural transmissivity range applicable to each survey (Table 3.10). However, natural light is restricted to the euphotic zone, which extends to twice the Secchi depth. Thus, the limit on transmissivity reductions only applies above the euphotic-zone depths listed after the asterisk in Table 3.11. Regardless, the screening analysis in the previous section demonstrated that all transmissivity measurements, irrespective of their depth, fell within their natural range and therefore, complied with the permitted minimum transmissivity limits listed in Table 3.11.

In addition to determining the extent of the euphotic zone, Secchi depth measurements also provide an independent measure of the penetration of natural light (Table 3.12). However, the Secchi depth's measure of light transmission is far less precise than the instrumentally-recorded transmissivities used in the screening analysis. Secchi depths are determined by lowering a standard-sized disk into the water column, and noting the depth at which it disappears. Because of the subjective nature of the measurement, Secchi depths are generally only reported to the nearest 0.5 m. In addition, artificial differences in the reported depth among stations can be introduced, for example, from changes in ambient light arising from changes in cloud cover as the survey progresses, or from collecting measurements taken inside or outside of the survey vessel's shadow.

Table 3.12 Average Secchi Depths (m) measured near the Diffuser and at Distant Locations

Survey	Nearfield ¹	Reference
March	7.5	6.0
May	5.5	6.0
August	3.0	3.0
October	4.5	5.9

As with the transmissivity measurements, no significant reduction in the transmission of natural light near the diffuser structure was found among the Secchi depth measurements. Apparent reductions in average nearfield Secchi depths during the May and August surveys (Table 3.12) were too small to be resolved given the inherent measurement error in the Secchi depth measurements. Specifically, a one-sided two-sample t-test assuming unequal variances found no statistically significant reduction in the nearfield mean depths at the 95% confidence level ($p > 0.11$). The 1.4 m reduction in the October nearfield mean was also small compared to the scatter in data.

Finally, although the COP remains silent regarding thermal changes, it incorporates the California Thermal Plan (SWRCB 1972) requirements by reference (COP Introduction §C.3). The Thermal Plan limits temperature increases in coastal waters from new discharges to less than 2.2°C (4°F). At no time during any of the 2011 surveys was this temperature limit exceeded.

Basin Plan Limits

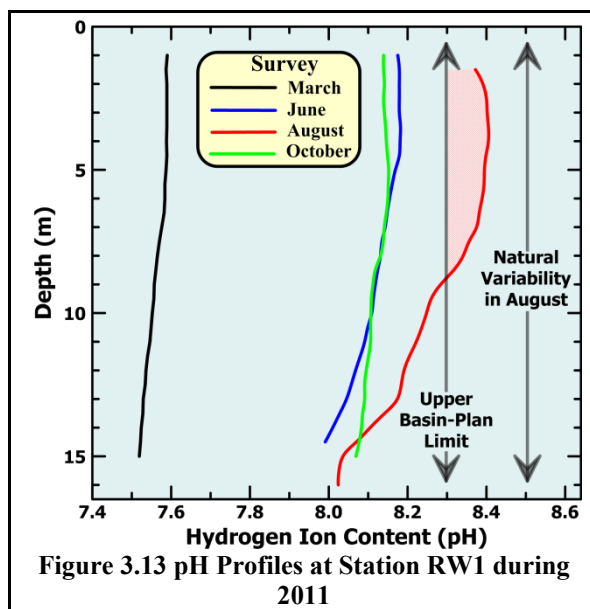
As demonstrated in the screening analysis (Table 3.9), there were only 47 (pH) measurements recorded beyond the ZID during the 2011 that could be associated with dilute wastewater constituents with statistical confidence. The Basin Plan restricts pH levels to a range of 7.0-to-8.3 units (P6). However, with a minimum pH of 7.839, all 47 of the anomalous measurements complied with the Basin Plan's lower pH limit (7.0). The Basin Plan also limits temperature excursions to those that will not adversely affect beneficial uses (P3). As documented in Table 3.9, however, the presence of dilute wastewater particulates beyond the ZID exerted no perceptible thermal influence and thus, could not have affected any of the beneficial uses designated for the receiving waters surrounding the outfall.

¹ Stations RW3 and RW4 within 28 m of the diffuser structure

In contrast to the COP limits, which are referenced to “*that which occurs naturally*,” and allow adaption to seasonal and interannual changes in the ambient marine environment surrounding the outfall, the Basin Plan contains fixed numerical limits restricting DO concentrations to no less than 5 mg/L (P5 in Table 3.7), and pH levels to a range of 7.0-to-8.3 pH units (P6). As such, the Basin Plan’s inflexible DO and pH limits fail to account for natural oceanographic processes, like upwelling, that often cause excursions beyond those limits. For example, nearly half of the measurements recorded during the August 2011 survey had pH levels exceeding the Basin Plan’s upper bound threshold of 8.3 units. Similar circumstances occurred during the January and April 2010 surveys, when all 9,235 instrumental observations exceeded the Basin Plan pH limit (MRS 2011a). Although the NPDES permit only imposes these Basin-Plan limits when excursions are caused by the presence of wastewater constituents beyond the ZID, the inflexibility of the Basin Plan limits unduly complicates the compliance assessment when fluctuations in ambient oceanic conditions routinely exceed those limits. Because the COP receiving-water objectives are adequately protective of the marine environment, application of the fixed Basin Plan limits to receiving-water characteristics already covered by the COP is not only inappropriate but redundant (see the recommendation for their removal from the NPDES discharge permit in Chapter 5).

The high ambient pH levels surrounding the outfall in 2011 were clearly related to natural oceanographic processes along the central coast. Specifically, the high pH measured in the upper water column during the August 2011 survey were the direct result of a period of enhanced, upwelling-induced primary productivity. Phytoplankton blooms undergoing photosynthesis produced oxygen and consumed carbon dioxide (carbonic acid) in large amounts, thereby increasing pH (lower acidity) within the upper water column. The elevated pH could not be attributed to the presence of dilute wastewater constituents because the pH (7.7 units) measured in an effluent sample collected on the day of the survey was much lower than that of the receiving waters. In fact, the plant’s effluent pH levels remained between 7.3 and 7.8 throughout the year (Section 2.2.5, Figure 2.10), so they could not have contributed to an increased pH within receiving waters.

The upwelling-induced increase in pH that occurred during the August survey is apparent in the profile measured at Station RW1 (red line in Figure 3.13). Station RW1 was located upstream of the direction of plume transport during all four of the receiving water surveys conducted in 2011, and therefore could not have been influenced by the discharge. Because its location was well beyond the discharge’s influence, all of the pH profiles shown in Figure 3.13 were entirely the result of natural processes. In contrast to the Basin-Plan limit, the upper-bound estimate of natural pH variability determined from the August survey data (8.525 in Table 3.10) appropriately encompassed the highest pH levels at Station RW1 (Figure 3.13). In addition, the field operations manual for data collection within the southern California bight provides data-screening limits on “reasonable” pH ranges that also range well beyond the Basin Plan limits and encompass the August 2011 measurements (Table 3 in SCBFMC 2002).



As with the high ambient pH levels during the August survey, it is similarly inappropriate to assess compliance with the Basin Plan limit on DO concentrations of no less than 5 mg/L, when background concentrations are already below that limit. Naturally occurring DO concentrations below 5 mg/L were not envisioned within coastal waters when the Basin Plan limit on DO was promulgated in 1972. However, as described in Section 3.2.4, a period of sustained upwelling that extended from mid-2010 through the first quarter of 2011 resulted in ambient DO concentrations that were below 5 mg/L during the August and October surveys of 2010 (MRS 2011a), as well as the March 2011 survey (black line in Figure 3.10). As a result of the naturally occurring depletion of DO at depth, the lower-bound DO threshold for the March 2011 survey was appropriately determined to be 3.27-mg/L (Table 3.10). However, as with the pH thresholds, this lower bound DO threshold fell within the 3 mg/L to 12 mg/L range considered typical of the regional coastal environment offshore southern California (Table 3 in SCBFMC 2002).

3.3.3 Other Lines of Evidence

The screening analysis described in Section 3.3.1 serves to restrict attention to the oceanic area where the permit provisions apply, and to eliminate excursions that were either unrelated to the discharge, or too small to be of consequence given the natural variability in the receiving waters. As a result, nearly all of the 2011 observations were summarily eliminated from further compliance analysis. However, within the eliminated measurements lies a body of additional evidence which further substantiates the finding that the receiving-water measurements recorded during the 2011 surveys complied with the limitations specified in the NPDES discharge permit.

Abductive inference (Suter 2007) is a process for analyzing these varied sources of information. It emphasizes a pattern of reasoning which accounts for both the discrepancies among multiple lines of evidence as well as concurrences. It has been used to implement sediment-quality guidelines for California estuaries (SWRCB 2009). A “best explanation” approach serves to limit the uncertainty associated with each individual CTD measurement and provide a more robust compliance assessment. Together, these lines of evidence significantly strengthen the conclusion that the discharge fully complied with the permit during 2011. In particular, dilute wastewater constituents had no tangible effect on the ocean environment surrounding the outfall, and instead, receiving-water anomalies observed within the discharge plume were largely the result of entrainment and upward displacement of ambient seawater within a stratified water column.

Mixing Performance

The high-spatial-resolution tow measurements recorded during 2011 demonstrated that even well within the ZID, wastewater was being diluted to levels far higher than expected from the dilution modeling. Although compliance screening eliminates observations within the ZID because the permit limits do not apply there, these close-in observations foretell whether the outfall is capable of meeting the 133-fold dilution necessary to achieve COP objectives at the completion of the initial dilution process.

Close to the diffuser structure, only slight salinity and density anomalies showed any indication of the presence of the discharged effluent during 2011. The absence of other plume signatures is a direct result of high dilutions that exceeded 150-fold within a few meters of a diffuser port. This demonstrated that the effluent was undergoing rapid dilution immediately after discharge, and that the diffuser structure was consistently performing at a higher level than originally designed. As a result, the discharge routinely met numerical receiving-water limits even within the 15-m-wide ZID.

Effluent Quality

Because of its high quality, the MBCSD effluent could not have materially contributed to observed fluctuations in TSS and DO within receiving waters, including the substantial DO depletion observed throughout the water column during the March 2011 survey (Sections 3.2.4 and 3.3.2, and Figure 3.10). Not only does the treatment process effectively eliminate the vast majority of suspended solids and oxygen-demanding material from the wastestream prior to discharge (Section 2.2.2 and 2.2.3), but as discussed previously, the small amount of residual material is then rapidly dispersed into the particularly well-flushed, open-ocean environment of Estero Bay. For example, effluent discharge at the time of the March survey had a biochemical oxygen demand (BOD) of 72 mg/L (MRS 2011c), which would have induced a minuscule DO depression of no more than 0.023 mg/L after dilution (MRS 2003a).

Moreover, the MBCSD treatment process routinely removes more than 80% of the organic material from the wastestream (Table 2.2). In fact, because of the absence of a tangible BOD influence, wastewater usually increases DO within subsurface receiving waters, rather than decreasing it. This is because effluent is oxygenated by recent contact with the atmosphere during the treatment process, whereas receiving waters at depth are typically depleted in DO, particularly during periods of pronounced upwelling such as occurred throughout most of 2011. In general, DO depletion from the discharge of municipal effluent is “not of ecological concern in the ocean or open coastal waters,” and when it is of concern, such as in estuaries, it is “more likely to result from eutrophication by nutrients rather than point source inputs of BOD” (Page 9 of National Academy of Sciences 1993).

Similarly, reductions in transmissivity due to wastewater particulates are rarely observed within receiving waters except very close to the discharge, where permit limits do not apply. As with DO, wastewater-induced turbidity is imperceptible beyond the ZID because of both the low suspended-solid concentrations within the MBCSD effluent (27 mg/L during 2011), and the exceptionally high dilution levels achieved close to the outfall (>150:1). For example, during 2011, reductions in ambient transmissivity caused by wastewater particulates within the least dilute seawater measurements (i.e. those taken within the ZID, shortly after discharge) varied between 0.4% and 1.3%. (Table 3.13). These reductions are an order of magnitude smaller than the range in naturally-occurring transmissivity fluctuations observed during the receiving water surveys (Table 3.9, Question 3).

Table 3.13 Comparison between Projected Transmissivity Reductions caused by Wastewater Particulates and the Lower Bound of Background Seawater Fluctuations

Parameter	March	June	August	October
Lowest Dilution	492	193	153	193
Effluent TSS (mg/L)	26.0	20.6	34.0	35.0
Transmissivity (%)				
Projected Reduction	0.4	0.6	1.1	1.3
Natural Range ¹	13.3	13.4	16.3	13.8

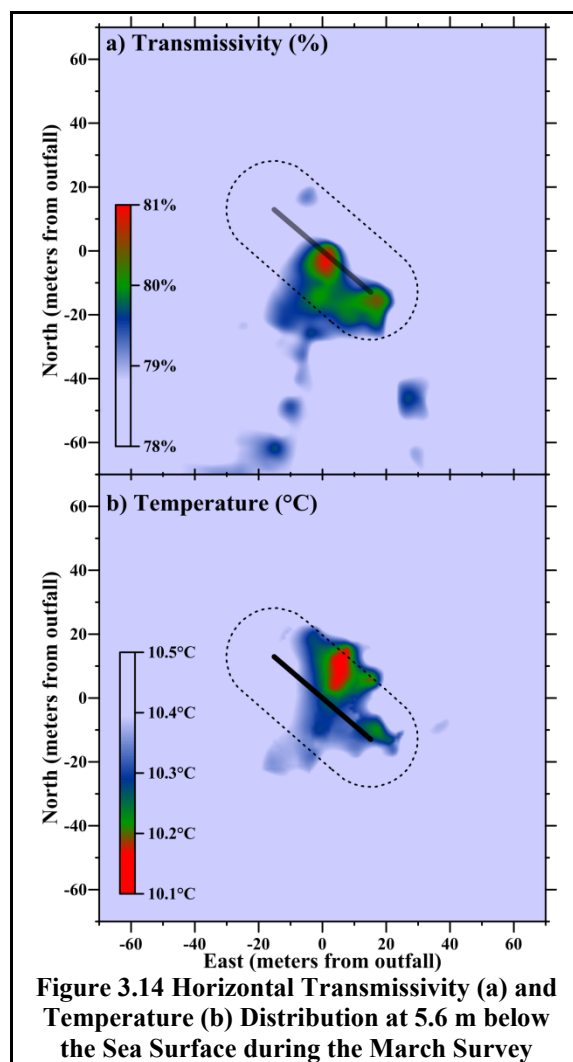
Entrainment Signature

During the March 2011 survey, a slight increase in transmissivity and a decrease in temperature were observed during the shallow tow survey (Figure 3.14ab). The anomalies were clearly associated with the discharge plume because of their proximity to the diffuser structure, and because they coincided with anomalies in other water properties, including a localized reduction in salinity. However, only the salinity anomaly ranged beyond ambient water properties at depth. The properties within all other anomalies matched ambient seawater properties at depth, including increased transmissivity (water clarity) and cooler temperatures.

¹ Difference between average transmissivity and the lower threshold of natural variability (Table 3.10)

These discharge-related anomalies in water properties (other than salinity) arose because the ejection jet from the diffuser ports rapidly entrained comparatively large volumes of near-bottom seawater. As a result, the buoyant effluent plume acquired the properties of ambient seawater at depth and carried them upward as the plume dispersed within the water column. If the ambient seawater characteristics within the upper water column differ from those near the seafloor, for example, when upwelling causes vertical stratification, then the juxtaposition of the differing seawater properties creates a lateral contrast (anomaly) within the discharge plume at mid-depth. This entrainment signature is only observed when the water column is stratified because, without a vertical gradient in ambient seawater properties, no lateral contrast is produced within the rising effluent plume. Thus, the anomalies observed during the March 2011 survey were consistent with upward transport of near-bottom seawater via the process of entrainment.

Evidence for this entrainment signature is conclusive because the temperature and transmissivity anomalies observed during the tow could not have been generated by the presence of wastewater constituents. When discharged, effluent is warmer and more turbid than the receiving waters, yet the anomalies were cooler and less-turbid. If the presence of wastewater particulates within the plume were to have any influence, it would be to decrease transmissivity, not increase it. As such, entrainment of clear bottom waters within the plume also offers the best explanation for the 1.5 m increase in nearfield Secchi depth that was observed during the March survey (Table 3.12).



Consequently, in addition to the rigorous quantitative compliance evaluation (Sections 3.3.1 and 3.3.2), abductive reasoning applied to the 2011 data supports the conclusion that the receiving-water measurements recorded during the 2011 surveys complied with the limitations specified in the NPDES discharge permit. Although discharge-related changes in seawater properties were observed, they were not directly caused by the presence of wastewater constituents within the water column.

3.3.4 Visual Observations

There are two remaining permit provisions (P1 and P2 in Table 3.7) that are not addressed by the foregoing analysis of instrumental observations. These provisions assess whether floating particulates, oil and grease, or any aesthetically undesirable discoloration of the ocean surface was present during the receiving-water surveys conducted in 2011. These permit provisions are instead addressed by visual observations made during each of the surveys. The visual observations during 2011 confirmed that there

was no visual evidence of these discharge-related impacts to the ocean surface during any of the receiving water surveys.

3.4 BENEFICIAL USE

Visual observations during the 2011 receiving-water surveys demonstrated that the coastal waters near the outfall and along adjacent shoreline continued to be beneficially utilized by humans and wildlife. There was no evidence indicating that the discharge detracted from the beneficial uses that were identified for northern Estero Bay in the Basin Plan (see Section 2.1.2). Specifically, fish, marine mammals, and seabirds were observed utilizing the area within and around the ZID area as marine habitat (*viz.*, the *MAR* beneficial-use identified for the waters of Estero Bay in the Central-Coast Basin Plan, as outlined in Section 2.1.2). The presence of surfers, kayakers, beachcombers, and commercial and recreational fishing boats attested to the use of the waters for water recreation (*REC-1* and *REC-2*), transportation (*NAV*), and fishing (*COMM*).

Wildlife sightings during the 2011 receiving-water surveys were dominated by Pelagic and Brandt's cormorants (*Phalacrocorax*), which nest on Morro Rock, and were observed during each of the four surveys. Smaller numbers of California brown pelicans (*Pelecanus occidentalis californicus*) and western gulls (*Larus occidentalis*) were also observed transiting the survey area during each of the surveys. During the March 2011 survey, a large body of several hundred sooty shearwaters (*Puffinus griseus*) was also present in the survey area. Every year, millions of these migratory seabirds arrive from distant breeding grounds in New Zealand and Chile to forage in the highly productive waters of the California Current. They generally begin to arrive in California waters in March and stay throughout the summer. A common murre (*Uria aalge*) and several western grebes (*Aechmophorus occidentalis*) were also observed within the confines of the harbor during the March 2011 survey.

Marine mammal sightings during the receiving-water surveys are typically dominated by southern sea otters (*Enhydra lutris nereis*) and California sea lions (*Zalophus californianus*) (Figure 3.15). For example, small numbers of sea otters were observed during three of the four quarterly surveys of 2011, while a lone sea lion was observed transiting the survey area during the October survey. Higher numbers of sea lions and otters are typically observed near the Morro Bay harbor entrance and during transit to and from the survey



Figure 3.15 Southern Sea Otter within Morro Bay

site, than at the survey site itself; during the March 2011 survey, several rafts of sea otters were observed within the confines of the harbor channel, but only one otter was actually observed near the survey area.

A number of small, unidentified jellyfish (Medusozoa) were observed at mid-depth in the water column near the ZID during the June survey. Additionally, a few large pieces of detached bull kelp holdfasts (*Nereocystis luetkeana*) were noted in the survey area during both the June and October surveys.

Recreational (*REC*) beneficial uses were also in evidence during the 2011 surveys. For example, non-contact water recreational activities, designated as *REC-2* in the Basin Plan, including walking, jogging, and beachcombing were observed along Atascadero Beach. Water-contact recreation, designated *REC-1* in the Basin Plan, also occurs frequently along the beach adjacent to the outfall. This typically includes activities such as surfing, swimming, body surfing, kayaking, stand-up paddle boarding, kite surfing, and wind surfing.

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CHAPTER 4

Marine Sediments and Benthic Biota

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4.0 MARINE SEDIMENTS AND BENTHIC BIOTA

This chapter describes the coastal benthos within Estero Bay where the MBCSD effluent is discharged. The MBCSD Offshore Monitoring Program includes benthic observations to assess potential impacts of wastewater discharge on marine sediments and the infaunal community near the outfall. Benthic environments are important indicators of the presence of marine pollution because they are the major reservoir for most contaminants that enter the ocean. Deleterious changes in the benthic environment, resulting from the deposition of effluent particulates, have been observed around other coastal outfalls (e.g., Stull et al. 1986a); however, no such impacts have been found after 26 years of benthic monitoring around the MBCSD outfall. This includes the October 2011 survey described in this chapter.

In the marine ecosystem, organic and inorganic matter are dynamically interrelated, and the quality of the material deposited on the seafloor directly affects the health of infaunal communities. Therefore, both the physicochemical and biological properties of the benthos are described in this chapter. Infauna residing within sedimentary environments serve as indicators of contaminated sediments because of their limited mobility and well-defined responses to pollution. Numbers of species, abundance, biomass, and other parameters of community composition can indicate contaminant-caused stresses if, for example, gradients are observed extending from a pollutant source to more distant, unaffected areas.

This chapter presents the full results of the benthic survey conducted on 24 October 2011. Physical properties of sediments are tabulated in Appendix C and chemical data from the survey are tabulated in Appendix E of this report, while benthic biological data are provided in Appendix B. BC Laboratories conducted the relevant chemical analyses following methods described by Tetra Tech (1986ab). Marine Research Specialists performed the infaunal community analyses and data synthesis.

The following section describes the benthic-monitoring program, including collection methods and station design. The second section of this chapter presents the findings related to the physicochemical analysis of the sediments. The third section describes the health of the benthic infaunal community residing within Estero Bay during 2011.

4.1 MONITORING PROGRAM

As with the marine receiving-water monitoring described in Chapter 3, sediment samples were collected at reference and outfall stations to investigate any potential discharge-related impacts to the benthos. The samples were analyzed for physicochemical properties and infaunal community composition in order to compare the benthic environment at these two sets of stations, as well as at gradient stations in between.

4.1.1 Scope of Monitoring

On 24 October 2011, offshore sediment samples were collected at seven stations within Estero Bay (Figure 4.1). The field sampling and laboratory procedures adhered to the requirements of the Monitoring and Reporting Program described in the discharge permit (RWQCB-USEPA 2009). During the 26 years of offshore monitoring, the benthic-monitoring program has undergone a number of major modifications. The original permit, issued in 1985, required semiannual sediment collection at six stations with physicochemical analysis of a composite of three replicate grab samples collected at each station. The stations were distributed around the outfall along a north-south isobath. Five of these original stations have continued to be sampled throughout the monitoring program. The sixth station, a “reference” station, located 1 km to the south, was dropped when the permit was reissued in 1993 because it was found to be unrepresentative of the benthic environment near the outfall.

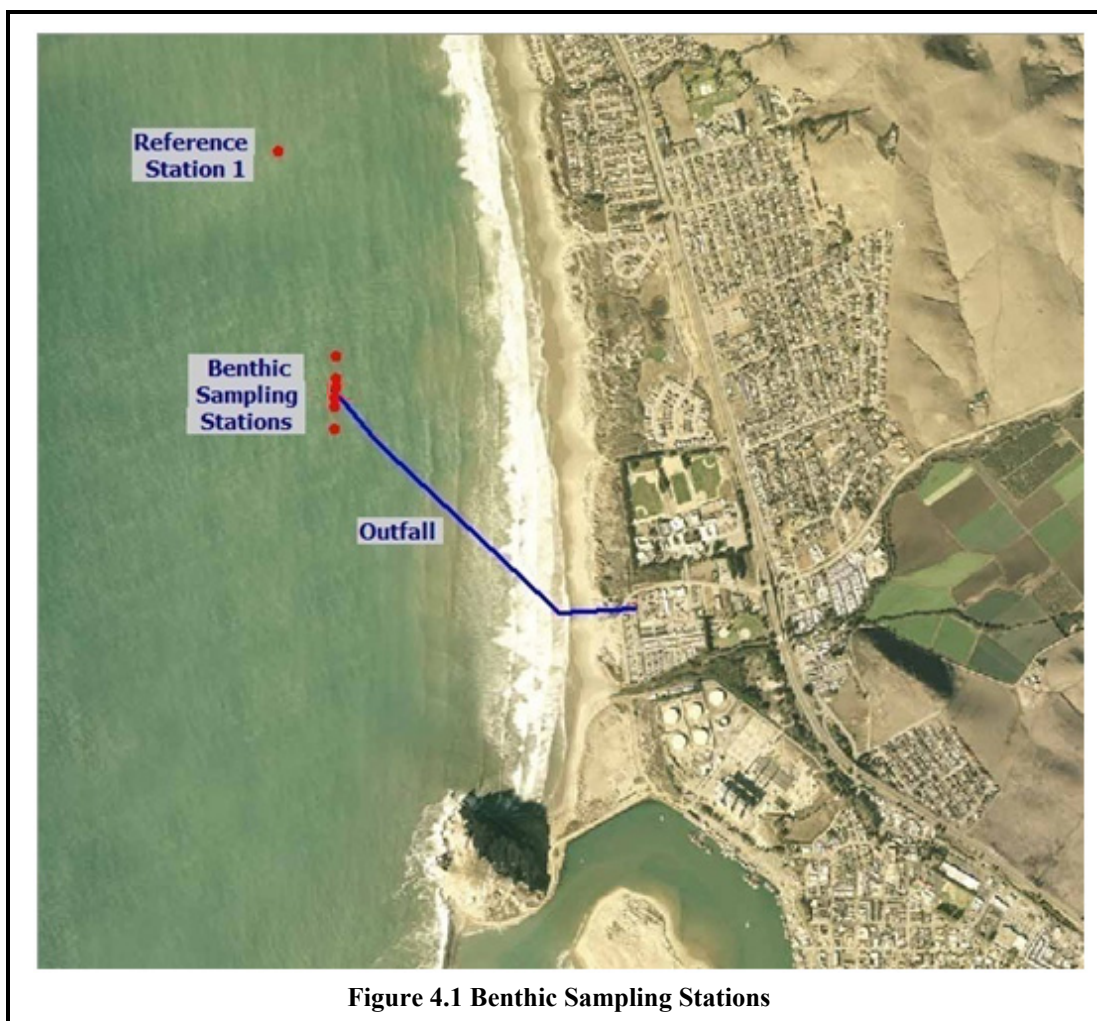


Figure 4.1 Benthic Sampling Stations

The discharge permit that was reissued in 1993 (RWQCB-USEPA 1993ab) also changed laboratory protocols. It required separate chemical analysis of each of the replicate samples collected at the five Stations. Statistical analysis of the scatter in chemical concentrations for the replicate samples at each individual station quantified the within-station variability and lent insight into the significance of spatial differences among stations. In particular, this report uses the replicate chemical analyses conducted in 1993 and 1994 to establish confidence intervals around concentrations measured at each station. If the observed differences in chemical concentrations among stations are less than the inherent uncertainty in the concentration at a given station, as defined by variability in replicate samples, then the spatial differences between stations cannot be considered meaningful. In 1995, after the within-station variability had been quantified, chemical analysis reverted to a composite protocol where aliquots from each of the three replicates collected from a station were homogenized into a single composite sample in the laboratory before extraction.

Further modifications were implemented when the NPDES permit was issued in 1998 (RWQCB-EPA 1998ab). After 13 years of monitoring, the amplitude of seasonal fluctuations had been adequately determined, eliminating the need for a post-winter survey. As a result, the focus of monitoring shifted to the determination of interannual changes in spatial patterns. To that end, four additional benthic sampling

stations, located 60 m from the outfall, were added to the five historical stations. The cross-shore configuration of two of these new stations (Stations 8 and 9) provided a more spatially balanced sampling pattern capable of detecting potential impacts that might not be restricted to along-shore directions. Finally, chemical analyses were performed on a single grab sample collected at each of the nine stations.

Based on an analysis of the previous 23 years of benthic data, the current permit (RWQCB-EPA 2009), adopted in January 2009, also instituted several changes to the program. First, chemical analysis protocols reverted to those utilized prior to 1998, where aliquots from each of three replicates collected at a station are homogenized into a single composite sample prior to analysis. This reduces uncertainty in the reported station concentrations by reducing within-station variability. Second, the permit eliminated the analyses of sulfides within benthic porewater samples. High-resolution analyses conducted over the previous six years had definitively demonstrated that the Estero Bay sediments do not contain measureable levels of dissolved sulfides. Finally, the cross-shore benthic monitoring stations (Stations 8 and 9) were eliminated from the sampling pattern because the inherent differences in the benthic environments caused by their difference in water depth confounded the interpretation of trends at the remaining stations.

The current permit also eliminated the sampling requirement at the northern reference station (Station B1); because of its physical separation (1 km) from the outfall, the reference station has a measurably different infaunal community composition (MRS 1998bi), and sediment physicochemistry from the remaining stations. However, as one of the six original sampling stations in the program, the long record of grain size, infaunal, and metal-concentration data acquired at Station B1 has immeasurable value for the insight it provides into the larger scale processes working within Estero Bay as a whole. Therefore, sampling for these parameters at Station B1 was continued during 2009, 2010, and 2011.

4.1.2 Sampling Station Design

Benthic sampling in 2011 was conducted at the seven stations shown in Figure 4.1 on Page 4-2 and in Figure 4.2 on Page 4-6. The target positions for sample collection are specified in the current NPDES permit and are summarized in Table 4.1. The stations lie along a north-south isobath (15.2 m) that intersects the center of the diffuser structure. Two stations (B4 and B5) are located within 20 m of the center of the diffuser structure, at the edge of the “zone of initial dilution” (ZID). Two additional stations (B3 and B6) are located at nearfield distances (60 m) from the diffuser structure. Finally, the midfield stations (B2 and B7) are separated by three diffuser lengths from the discharge (150 m). The seventh, reference station (B1) is located 1 km north of the outfall, well beyond the discharge’s sphere of influence.

Table 4.1 Target Locations of Benthic-Sediment Sampling Stations

Station	Description	Latitude	Longitude	Distance (m)	
				Closest ¹	Center ²
B1	Upcoast Reference	35° 23.730' N	120° 52.677' W	1,000	1,016
B2	Upcoast Midfield	35° 23.280' N	120° 52.504' W	138	150
B3	Upcoast Nearfield	35° 23.231' N	120° 52.504' W	49	60
B4	Upcoast ZID	35° 23.210' N	120° 52.504' W	15	20
B5	Downcoast ZID	35° 23.188' N	120° 52.504' W	15	20
B6	Downcoast Nearfield	35° 23.167' N	120° 52.504' W	49	60
B7	Downcoast Midfield	35° 23.118' N	120° 52.504' W	138	150

¹ Distance from the closest open diffuser port

² Distance to the center of the open diffuser section

As described in Section 3.1.3, the finite length of the diffuser structure creates ambiguity in the distance measured from the outfall. For discussion purposes, station separations are usually referenced to the center of the diffuser. However, in terms of contaminant dispersion, the closest-approach distance is the controlling parameter.

The upcoast reference station (B1), midfield stations (B2 and B7), and ZID stations (B4 and B5) have all been regularly sampled throughout the 26 years of benthic monitoring. The two nearfield stations (B3 and B6) were incorporated into the program in 1999, and improved the program's ability to resolve potential benthic impacts related to effluent discharge. Although sampling is no longer required at Station B1 under the current permit, samples were voluntarily collected at the station and analyzed for grain size, infaunal composition, and trace-metal concentrations.

The extraordinarily long record of infauna, grain size, and trace metals has provided valuable insights into previously unknown trends in Estero Bay's regional benthic conditions. Therefore, although those trends are unrelated to the MBCSD discharge, the lengthy time history at Station B1 was deemed of enough scientific value to warrant continued sampling there. However, although required for compliance evaluation at the other stations, sediment oil and grease concentrations have not been found to be diagnostic of the seafloor environment, or the effects of the MBCSD discharge, so the voluntary sampling at Station B1 did not include these constituents.

4.1.3 Benthic Sample Collection and Processing

Field sampling and laboratory procedures adhered to the requirements of MBCSD Monitoring and Reporting specified in the permit (RWQCB-USEPA 2009). The 38-ft F/V *Bonnie Marietta*, owned and operated by Mr. Mark M. Tognazzini of Morro Bay, provided vessel support during the offshore survey. Dr. Douglas Coats of Marine Research Specialists (MRS) logged navigation fixes, assisted in benthic grab deployment and retrieval, and collected sediment subsamples for chemical assay. Ms. Bonnie Luke, also of MRS, sieved and processed infaunal samples. Mr. William Skok was the marine-equipment technician responsible for benthic grab operations.

Equipment

Sediment chemistry and benthic infaunal samples were collected using a chain-rigged Young grab whose design was modified from that of a Van Veen sediment sampler. The pair of jaws on the grab acquires sediments from a 0.1-m² area of the seafloor. The stainless-steel grab is coated with Dykor[®] and is equipped with a frame that enhances its penetration, stability, and proficiency in collecting a level, undisturbed sample. Dykor[®] has properties similar to Teflon[®]; it improves the chemical inertness of the grab sampler, limiting contamination of the sediment chemistry samples by the grab itself, particularly from trace metals. The grab was completely refurbished by sandblasting and recoating with Dykor[®] in 1999. At that time, a stainless steel lip was also welded to the mouth of the jaw to improve the seal, which aids in sample retention during ascent.

At each of the seven monitoring stations, three replicate grab samples were collected and composited for analyses of sediment chemical composition and bulk properties, and five replicate grab samples were collected for benthic infaunal analyses (Table C.1).

Offshore navigation aboard the survey vessel was supplied by a Furuno[™] GPS 30 coupled to an FBX2 differential beacon receiver. Global positioning satellite (GPS) navigational fixes were recorded digitally at 1-second intervals. Electronic recordings of waypoints were used to mark the trip-time of the grab sampler and other pertinent information. Navigational errors inherent in standard GPS readings were greatly reduced with the use of a Differential GPS (DGPS) system that was first implemented by the U.S.

Coast Guard. DGPS incorporates a second signal from a nearby land-based beacon. Because the beacon is fixed at a known location, the position error in the reading from the GPS satellites can be precisely calculated. This correction is continuously transmitted to the DGPS receiver and results in extremely accurate offshore navigation, typically with position errors of less than 2 m.

Physicochemical Samples

Prior to and during the survey, the sampling equipment was thoroughly cleaned to eliminate the introduction of non-sediment contaminants into the samples, and to prevent cross-contamination between stations. Before the survey, the grab sampler and sediment scoops were washed with Alconox®, deionized water, and 10% Hydrochloric Acid (HCl). During the survey, the grab and sampling utensils were washed with Alconox®, rinsed with seawater, and subsequently decontaminated with deionized water, methanol, and 1% HCl prior to sampling at each station.

Surficial sediments were collected from the upper 2 cm of the single grab sample recovered from each of seven benthic stations. Sufficient sample volumes were collected to provide material for QA/QC analyses. Samples were stored in the appropriate glass or plastic containers and refrigerated at approximately 4°C prior to analysis. Chain of custody forms accompanied all sample shipments from the field and between laboratories. Appendix E contains the chains of custody, laboratory QA/QC analysis, and the chemical results as reported by the laboratory, while Appendix C includes a physical description of the samples.

The sediments from each of the seven benthic-monitoring stations were separately analyzed for the analytes listed in Table 4.2. A summary of the analytical methods used and their authority is provided in Appendix E.

Table 4.2. List of Analytes in Sediment Samples

• Sediment particle size	• Biochemical oxygen demand	• Total Kjeldahl nitrogen (TKN)
• Moisture content	• Oil and grease ¹	• Total volatile solids (TVS)
• 11 trace metals		

Infaunal Samples

In addition to samples collected for sediment chemistry, five replicate grab samples were collected at each of seven benthic-monitoring stations for infaunal analyses. Upon retrieval of the grab, each sample was inspected for acceptability. Acceptance criteria are based on penetration depth, surface condition, and overall sample integrity and are reported in Table C.1 in Appendix C of this report. Sediment samples that met the acceptability criteria were lightly washed, and elutriated onto a 1.0-mm mesh sieve. The extracted material was then washed into a labeled 16-oz. jar and preserved with 10% buffered formalin. After a minimum fixation period of 48 hours, the formalin was rinsed from the samples on a 0.5-mm mesh sieve and the samples were transferred to 70% alcohol for processing, preservation, and storage. After transfer to alcohol, the infaunal samples were stained with a Rose Bengal solution to aid in sorting of the organisms into the following major taxonomic groups: annelida and nemertea, mollusca, crustacea, echinodermata, and miscellaneous phyla.

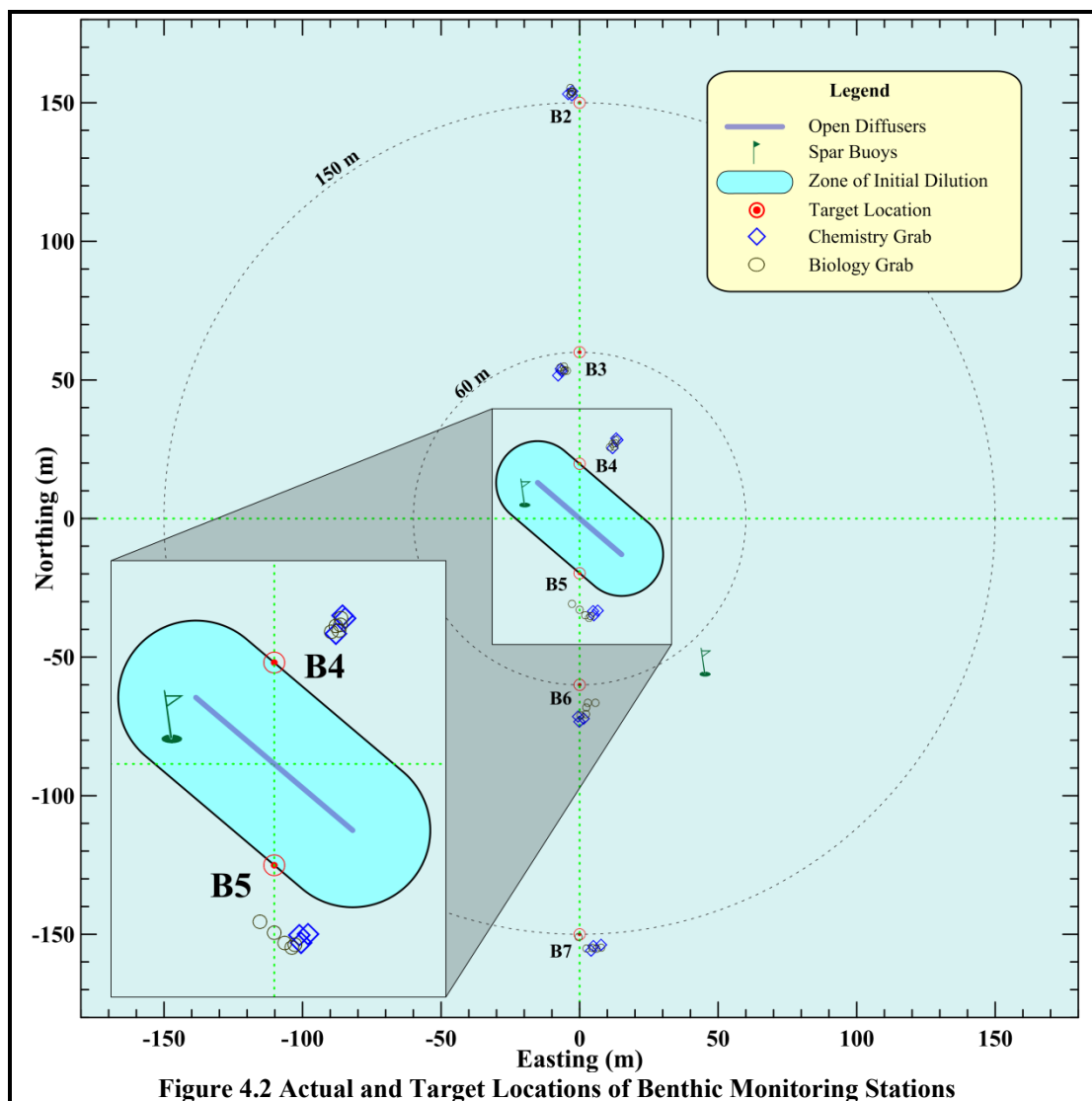
All individual organisms were enumerated and identified to species level where possible. Voucher collections have aided in the consistent identification of organisms collected throughout the 26-year benthic-monitoring program. The voucher collections contain specimens representative of each species

¹ As discussed previously, the sediments from the voluntary sampling conducted at B1 were not analyzed for oil and grease.

identified, and are augmented as new taxa are collected. The qualifications and experience of the taxonomic specialists responsible for species identification are presented at the end of Appendix B.

Sampling Location Offsets

Figure 4.2 shows the position of the chemistry (blue) and infaunal (green) grabs, relative to each target location (red) that were recorded for Stations B2 through B7 during the October survey. As described in Chapter 3, a number of factors influence the offset of the actual grab locations from the target locations listed in Table 4.1. Because the vessel is anchored during the benthic survey, differences between the sampling and target positions arise because the vessel swings about the anchor location along a scope of approximately 20 m. How the vessel will set relative to its anchor position is difficult to predict based on the constantly changing wind, wave, and current conditions. Changes in position during sampling at an individual station arise because of these changing conditions, in addition to movement from anchor drag. The within-station position changes during the October 2011 survey are apparent in Figure 4.2 by the



spatial dispersion among the three sediment-chemistry grab samples and five infaunal grab samples collected at each station.

Table 4.3 lists the average position of the eight grabs collected at each station. Despite the many unavoidable factors affecting vessel offset, differences between the target position and average grab location were less than half the 30-m width of the ZID at all stations except the reference station (Station B1). Although it was not possible to collect samples at the precise target locations, knowledge of the actual location where samples were collected allowed the spatial offsets to be factored into the gradient analysis. Without the benefit of differential GPS navigation, most of these offsets would never have been resolved. The enhanced resolution provided by differential GPS also lent insight into minute spatial differences between individual grab samples that could not have been resolved otherwise.

Table 4.3 Average Location of Benthic-Sediment Grab Samples at each Station

Station	Description	Latitude	Longitude	Distance (m)		
				Closest ¹	Center ²	Offset ³
B1	Upcoast Reference	35° 23.741' N	120° 52.694' W	1,027	1,043	27
B2	Upcoast Midfield	35° 23.282' N	120° 52.506' W	141	154	5
B3	Upcoast Nearfield	35° 23.228' N	120° 52.508' W	42	54	9
B4	Upcoast ZID	35° 23.214' N	120° 52.496' W	29	30	15
B5	Downcoast ZID	35° 23.181' N	120° 52.502' W	24	34	14
B6	Downcoast Nearfield	35° 23.161' N	120° 52.503' W	59	70	10
B7	Downcoast Midfield	35° 23.116' N	120° 52.501' W	142	154	6

4.1.4 Benthic Analysis

A wide variety of physical, chemical, and biological parameters were determined from the 56 sediment samples collected during the October 2011 survey. This report examines these parameters for any potential discharge-related spatial patterns. They are also compared to historical measurements to reveal any potential temporal trends that could be associated with a buildup of contaminants. Finally, the interrelation between biological and physicochemical parameters is evaluated for possible toxicological effects.

Organic-Loading Properties

Sediment samples collected at the seven benthic-monitoring stations during the October 2011 survey were analyzed for moisture content, grain size, organic properties, and eleven trace metals. The organic-loading parameters, oil and grease (O&G), total volatile solids (TVS), total Kjeldahl nitrogen (TKN), and biochemical oxygen demand (BOD), are considered relevant for sewage-outfall monitoring. If the volume of organic solids discharged by the outfall is not adequately dispersed, then a buildup of O&G, TVS, TKN, and BOD can occur, and can impact areas beyond the ZID.

BOD measures the depletion of dissolved oxygen caused by aerobic microorganisms during decomposition of organic material. Excessive BOD can be deleterious to marine organisms if

¹ Distance from the closest open diffuser port

² Distance to the center of the open diffuser section

³ Average offset from Target Locations listed in Table 4.1

decomposition significantly depletes dissolved oxygen levels. This can occur when aerobes metabolize excess organic matter deposited by wastewater discharge.

The TVS concentration quantifies the amount of organic matter in the solid fraction of bottom sediments. It is reported as percentage of dry-sample weight. TKN measures the amount of organic nitrogen present as ammonia, as well as that bound into organic compounds in the aqueous phase of the benthic samples. However, natural TKN levels vary widely among seafloor sediment samples, so anthropogenic (human-induced) impacts are difficult to discern from TKN measurements alone. Similarly, other properties that can indicate organic loading from effluent discharge, including dissolved sulfides, O&G, and BOD, are problematic to sample, analyze, and interpret.

For example, O&G concentrations are often below detection limits, even close to the discharge. Similarly, BOD is difficult to accurately measure in sediment samples, and interference from errant pieces of organic material has resulted in erroneously high levels both during 2011 (Station B5) and in previous surveys. Specifically, Station B9 in 2000, and various stations prior to 1995 (Figure 4.9b on Page 4-26) exhibited anomalously elevated BOD concentrations. Because of persistent interference during BOD determinations, overall confidence in BOD results for benthic sediment samples remains low.

Trace Metals

In contrast to synthetic chemicals, the presence of trace metals within seafloor sediments is not necessarily indicative of anthropogenic input. Most trace metals are found in detectable concentrations within naturally occurring mineral deposits. Some metals provide essential minerals needed by marine organisms to survive. However, elevated levels of certain trace metals can be indicative of anthropogenic input, and excessive levels can cause deleterious effects in marine organisms.

Nine trace metals have been measured in seafloor sediments since the inception of the monitoring program. They are arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc. The toxicity of these metals to marine organisms has been examined in numerous laboratory bioassays and field experiments (Long and Morgan 1991, Long et al. 1995). These studies have been summarized in the form of biological effects levels, most notably an effects-range low (ERL), below which toxic effects are not expected, and an effects-range median (ERM), above which adverse biological effects can be expected. The potential for impacts from concentrations in the range between these thresholds cannot be reliably predicted.

In 1998, the analysis of aluminum and iron within benthic sediments was added to the monitoring program. Unlike the other nine metals, aluminum and iron are not particularly toxic to marine organisms, and their naturally occurring concentrations are relatively insensitive to anthropogenic input. This latter attribute makes them ideal tracers of natural variations in all the trace metals. Consequently, they have been used to normalize observed concentrations in the other nine metals so that background variation is reduced and anthropogenic trends can be revealed. In particular, iron has been used as a reference element for determining anthropogenic enrichment of trace metals within the Southern California Bight (Schiff and Weisberg 1997) and in many other offshore regions (Daskalakis and O'Conner 1995).

Physical Properties

Moisture content and grain-size distribution are two important physical properties of marine sediments. Moisture content is a measure of the volume of pore water present in the sediment samples. While not an indicator of discharge effects, it is an important parameter used to convert chemical concentrations measured in the wet sediment sample to a dry-weight basis. Dry-weight concentrations allow a more direct comparison of chemical concentrations associated with bulk sediments by eliminating variations in

sample mass that arise from arbitrary differences in water content. Moisture content is also used, along with salinity measurements, to eliminate the bias introduced by salt content in grain-size determinations.

Grain-size distribution is important to quantify because an increase in fine sediments near a municipal ocean outfall can be indicative of excessive effluent-solids deposition. In addition, the amount of fine sediment directly affects the composition of the infaunal community that resides within the sediments; although the precise mechanism for this relationship is rarely clear (Snelgrove and Butman 1994). Finally, natural variation in trace-metal concentrations has been correlated with the fine-sediment (mud) fraction and, like aluminum and iron, has been used to normalize metal concentrations (Dossis and Warren 1980, Ackerman et al. 1983, Horowitz and Elrick 1987).

Accurate measurement of the fine sediment fraction is particularly important for use in the interpretation of the marine biological data. Otherwise, variability in a benthic community's composition could be erroneously ascribed to effluent discharge, when instead it may be the result of natural variation in the distribution of fine particulates. One of the major difficulties in the accurate measurement of the fine fraction in marine sediments is that the standard pipette method described by Plumb (1981) and Folk (1980) overestimates the finest (clay) fraction. This occurs because the procedure incorrectly includes the weight of the dissolved solids (salt) when weighing the dried pipette extraction. This often generates an artificial bimodal grain-size distribution, where the smallest (clay) fraction exceeds the next largest (silt) fraction.

In 1994, the anomalous character of the bimodal size distribution in the MBCSD database led to a number of internal investigations and confirmatory grain-size analyses by outside laboratories (MRS 1995). The refined analysis method that is now in use accounts for the presence of dissolved solids by correcting for the measured salinity in the pipette fractions (MRS 1998i and Coats et al. 1999). This refined particle-size analysis method was instituted in the MBCSD monitoring program beginning in 1998. As a result, the finest size fractions determined in sediment samples collected after October 1997 are far more accurate than those determined in prior surveys. Thus, some of the long-term trends in the MBCSD grain-size database can be ascribed to improvements in methodology, rather than actual changes in the benthic environment.

Biological Parameters

Determining whether the discharge is causing adverse biological effects involves assessing whether a balanced indigenous population (BIP) of shellfish, fish, and wildlife exists in areas potentially affected by the discharge. A BIP is an ecological community, which exhibits characteristics similar to those of nearby, healthy communities existing under comparable environmental conditions beyond the influence of the discharge. Certain biological characteristics of the community are examined in a BIP evaluation, including spatial and temporal distributions of species composition, abundance, biomass, dominance, and diversity. Other overall biological indicators of a BIP include trophic (feeding-habit) structure and the presence or absence of sensitive indicator species. Most marine monitoring programs determine the presence of a BIP using data on the infaunal organisms that live with sediments surrounding a potential pollutant source.

When assessing a BIP, infauna have many advantages over other marine organisms, such as marine mammals or finfish. First, infauna are relatively easy to collect in numbers large enough for reliable statistical testing. Second, they have limited mobility and cannot easily escape exposure to pollutants. Finally, decades of monitoring studies have established well-defined responses of infaunal taxa to pollutant stress.

In the earliest MBCSD monitoring surveys, analysis of biological samples produced two types of data on infaunal organisms: the number of organisms for each taxon, and the biomass of major taxonomic groups within each sample. Biomass is difficult to interpret, however, because the erratic presence of large, undersampled organisms severely skews the results. Also, in practice, the heavy calcareous shells and exoskeletons of mollusks and crustaceans are troublesome to remove, and alcohol evaporation during weighing affects the determination of wet-weight biomass. Because of these problems, the USEPA does not recommend biomass for inclusion in 301(h) monitoring programs (USEPA 1987). Therefore, beginning in 1998, the NPDES permit no longer required this analysis.

Pollution affects marine ecosystems by changing the number and type of benthic organisms found in the sediments. However, subtle changes in community composition are not always readily apparent in the large volume of raw data generated by a long-term monitoring program. Over the 26 years of MBCSD monitoring, 241,000 individual organisms representing 386 individual taxa have been collected. To assess whether the infaunal community has been impacted, these data must be summarized into concise parameters that are indicative of pollutant stresses.

Biodiversity is a common indicator of the well-being of ecological systems, and forms the cornerstone of most impact assessment studies. Unfortunately, biodiversity is difficult to define quantitatively, in part because it has two major components: species richness and evenness. Species richness measures the variety (number) of species, while evenness measures the distribution of individuals (abundance) among the species (Magurran 1988). Healthy ecosystems are thought to be both rich in species and have an even distribution of individuals among those species.

Although no single measure can accurately represent changes in both evenness and richness along a pollution gradient, many indices attempt to do so. The Shannon Diversity Index (H') is the most widely used diversity index because it exhibits some degree of sensitivity to both evenness and richness. In addition, most diversity indices only measure the diversity within a local area at a particular time, *viz.*, among replicate samples from a single station (α -diversity). In contrast, pollutant stresses tend to induce marked changes in community composition between samples separated spatially and temporally (β -diversity; Smith et al. 1979). Multivariate analysis techniques are better suited to the evaluation of β -diversity than are individual indices.

Most diversity indices are also poorly suited for describing potential impacts to infaunal communities because they lack biological meaning, show little correlation with environmental quality, and are difficult to interpret ecologically (Goodman 1975, Washington 1984, Green 1979). As a result, ambiguous or biased estimates of diversity often occur. Therefore, many indices are not recommended for routine inclusion in 301(h) monitoring programs (USEPA 1987). Nevertheless, the current NPDES permit requires that a number of infaunal community indices be reported and examined for temporal trends (RWQCB-USEPA 2009). However, because of limitations associated with the indices, spatial differences with respect to outfall proximity, which are evaluated using standard statistical hypothesis tests, must be interpreted carefully. Table 4.4 lists the infaunal indices computed in this report. The associated algorithms and guidance on how to interpret them are presented in Appendix B.1.

Table 4.4 List of Infaunal Parameters

• Number of individuals • Number of individuals per species • Margalef species richness (d) (Margalef 1951) • Simpson dominance (C') (Simpson 1949, Wittaker 1965) • Pielou evenness index (J') (Pielou 1977) • Infaunal Trophic Index (ITI)	• Number of species • Species richness (S) (Magurran 1988) • Shannon-Wiener index (H') • Brillouin index (h) • Swartz dominance (S_w)
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4.2 MARINE SEDIMENT QUALITY

The quality of marine sediments surrounding the MBCSD outfall provides a definitive measure of potential marine impacts caused by wastewater discharge. Specifically, discharge-related impacts have been demonstrated in outfall monitoring programs offshore both central and southern California, wherein marked changes in the benthic environment have been observed surrounding the discharge locations (Phillips and Hershelman 1996, Stull et al. 1986b). Discharge-related impacts have also been observed on the continental shelf south of Estero Bay, where sediments were found to exhibit small but statistically significant chemical signatures indicative of drilling mud discharges over widespread areas (Hyland et al. 1994, Coats et al. 1991, Coats 1994). If the MBCSD effluent discharge were causing significant impacts to the marine environment, similar changes in sediment properties would be evident near the diffuser structure. The challenge is to distinguish changes that are caused by naturally occurring processes from changes that result from human activities.

Physicochemical changes in sediments provide a good indication of marine impacts for four main reasons. First, because outfalls are located on the seafloor, sediments are proximal to the source of potential contamination. Second, many contaminants are hydrophobic and tend to preferentially adhere to the fine particulates as they settle out of the effluent plume. Third, contaminants incorporated into seafloor sediments tend to have a long residence time because of the slow dispersive processes that prevail within pore waters. Finally, infaunal organisms that live within seafloor sediments are continuously exposed to contaminants because they cannot easily escape the source of pollution. If seafloor sediments or pore waters become polluted, infaunal organisms can be impacted. Sedentary infaunal organisms provide a food source for other, more mobile organisms, such as finfish and shellfish. These trophic relationships can lead to bioaccumulation of contaminants within the marine food chain.

Despite the sensitivity of the benthos to effluent discharge, there has never been any indication of deleterious impacts to seafloor sediments resulting from the MBCSD discharge. This remained true during 2011, as it has in the previous 25 years of monitoring. The lack of negative benthic impacts is largely due to the comparatively low mass-emission of anthropogenic chemicals from the outfall. There has never been a large industrial contributor to the MBCSD influent stream, and the total discharge volume is small compared to ocean dischargers to the south, where discharge volumes can be over 100-times greater (e.g., SCCWRP 2006).

The lack of benthic impacts is evident from three sets of analyses performed on the chemical properties of sediment samples collected around the MBCSD outfall during the October 2011 survey. Each of these analyses is discussed in the following subsections. First, concentrations of potential contaminants measured in sediment samples were below levels that have been empirically linked to toxicity in marine organisms. Second, the spatial pattern of sediment concentrations near the outfall during 2011 bore no consistent relation to outfall proximity. Third, sediment concentrations do not exhibit any significant long-term trends that would suggest a buildup of contaminants close to the outfall.

4.2.1 Concentrations below Toxic Levels

In keeping with the COP, narrative receiving-water limitations contained within MBCSD's NPDES discharge permit (RWQCB-USEPA 2009) state that the discharge should not cause chemical substances in marine sediments "*to be increased above levels which would degrade indigenous biota.*" This requirement was established because contaminants that reside in sediments for long periods have the potential to exert acute and chronic effects on resident marine organisms (NOAA 1991ab, Finney and Huh 1989, Bertine and Goldberg 1977).

Over the 26 years of continuous benthic monitoring, there has never been any indication of an effluent-related degradation of marine organisms within Estero Bay. In large part, this is due to the consistently low chemical concentrations within the discharged effluent (see Chapter 2). As a result, contaminant concentrations measured within Estero Bay sediments, both near and distant to the outfall, have been below thresholds reliably determined to be harmful to marine biota. In fact, the comparatively pristine marine environment of Estero Bay is reflected in benthic contaminant levels that are well below concentrations measured in sediments offshore southern California.

Thresholds of Biological Effect

Over the years, marine monitoring programs have placed considerable emphasis on benthic contamination. This experience has resulted in a set of thresholds of biological concern that can be used to screen chemical concentrations measured within marine sediment samples at any location. Specifically, these biological benchmarks can be used to assess whether the chemical concentrations measured in sediments have the potential for adverse biological effects. Although the thresholds are not regulatory criteria, they provide toxicological guidelines that help assess the potential environmental significance of specific chemical concentrations measured in the field.

The toxicological benchmarks advanced by NOAA (Long and Morgan 1991) are used in this report to evaluate sediment chemical concentrations measured during 2011. These guidelines are based on a correlation between chemical concentrations and observed biological effects in numerous modeling, laboratory, and field studies (Long et al. 1995). The studies identify two toxicological endpoints, an Effects-Range Low (ERL) and an Effects-Range Median (ERM) concentration. The lower toxicological endpoint (ERL) is associated with the concentration of a particular compound that produced an adverse biological effect in only 10% of the data. Below the ERL, adverse biological effects are unlikely. Above the ERM, which is based on the median of the toxicological data, adverse effects are considered likely to occur. The most conservative benchmark (ERL) was used in this report to determine the potential for marine biological impacts from most of the chemical concentrations that were measured within Estero Bay during 2011. These benchmarks provide a reliable screening tool for most, but not all sediment contaminants. For example, the relationship between nickel concentrations and the incidence of effects in the toxicological database is very weak. Consequently, even the upper (ERM) benchmark for nickel is a poor predictor of levels where biological effects might be expected.

Both trace-metals and organic contaminants are of concern in the benthic environment. However, their natural occurrence differs markedly. Synthetic compounds, such as PAHs, PCBs, and pesticides, are organic constituents that can have the most significant anthropogenic impact if found in sufficient concentrations. However, in this and many other marine sediment studies, their concentrations are below detection levels. In contrast, trace metals occur naturally in the marine environment and are commonly detected in sediment samples. Because of this, trace metals serve as a powerful surrogate for evaluating the regional transport and fate of a host of other particulate contaminants.

Grain-Size Distribution

Within deep offshore basins, sediment trace metals accurately record the history of contaminant accumulation because they are ubiquitous and long-lived. However, these deep benthic sediments often contain significant fractions of fine-grained sediments, which support an increased number of trace-metal bonding sites per unit of volume. Thus, large differences in trace metal concentrations among sediment samples can be caused by natural differences in mud fractions that are unrelated to human activities. Because of this, many marine benthic studies divide (normalize) trace metal concentrations by the mud fraction. Normalization is intended to reduce inherent natural variability, revealing anthropogenic

contaminant patterns normally masked by the natural association between metals and fine particulates (Dossis and Warren 1980).

While this approach works well in deep quiescent basins, it is not as applicable in nearshore environments where energetic oceanographic processes erode fine particles, leaving behind coarser, more transport-resistant sandy sediments. Sandy sediments usually have comparatively low metal concentrations. Also, metals tend to be incorporated into the mineralogy of the sand grains themselves, rather than adsorbed onto their surfaces, as is the case with silts and clays. Therefore, metals are less likely to dissolve and become assimilated by marine organisms residing within sandy sediments. Because of the lower bioavailability of metals in sands, NOAA does not recommend mud fraction normalization of trace-metals for samples with less than 20% fine-grained material (Long and Morgan 1991). Because the Estero Bay sediments consist almost entirely of sand (>99%, Table 4.5), iron- and aluminum-normalized concentrations are assessed instead.

Table 4.5 Grain-Size Distribution (%) within Seafloor Sediment Samples Collected on 24 October 2011

	Clay (9 to 12 ϕ)	Silt (5 to 8 ϕ)	Fine to Medium Sand (1 to 4 ϕ)	Coarse Sand (1 ϕ)	Very Coarse Sand (0 ϕ)	Gravel (-1 ϕ to -3 ϕ)
Station B1	0.24	0.69	97.93	0.06	0.99	0.09
Station B1 ¹	0.26	0.79	97.08	0.86	0.65	0.36
Station B2	0.12	0.56	98.68	0.62	0.02	0.00
Station B3	0.17	0.36	97.18	0.60	0.52	1.18
Station B4	0.21	0.31	96.85	0.53	0.43	1.67
Station B5	0.11	0.55	97.67	0.83	0.52	0.31
Station B6	0.10	0.47	98.52	0.77	0.14	0.00
Station B6 ¹	0.01	0.51	97.49	1.56	0.43	0.00
Station B7	0.19	0.20	98.17	1.01	0.43	0.00
Mean ²	0.14	0.48	97.77	0.70	0.40	0.18

Irrespective of trace-metal normalization, grain-size distributions can be indicative of a buildup of effluent particulates within the surficial sediments if, for example, there is an increase in fine fractions close to the discharge point. Although this was not the case around the MBCSD outfall, the overall character of the grain-size distribution reflects the dynamics within a particular benthic environment. Higher mud fractions reflect more-quiescent depositional environments, while well-sorted sands result from energetic wave environments that winnow fine particulates as they constantly rework the surficial sediments.

Accordingly, statistical analyses of grain-size distributions within the 2011 sediment samples reflect the high-energy environment near the outfall. The samples consisted of well-sorted fine sands with a distribution skewed slightly toward the finer fractions (Table 4.5; Appendix Table C.4). During 2011, mean particle diameters ranged from 149 to 164 μ m, lying in the middle of the fine-sand portion of the grain-size distribution. The high degree of sorting is reflected by low standard deviations ($\sigma < 0.5$). The small, but consistently positive skew to the distribution reflects a slight excess in the finer fractions relative to larger fractions in the tails of the distributions. Together, these properties point to a highly energetic flow regime that tends to winnow fines from the surficial sediments. The contribution of larger-diameter fractions was negligible in that the combined coarse sand and gravel fractions ($\leq 1\phi$) represented less than 3% of the total sample weight (Table 4.5). These largest fractions consisted mainly of fragments of shell hash that are randomly distributed on the surface of sediments in many shallow subtidal coastal areas.

¹ Duplicate analysis of sediment sample

² Mean computed after arc-sine transformation

Undetected and Nontoxic Metals

In 2011, trace-metal concentrations within sediment samples were either not detected or were below levels that are potentially toxic to marine organisms (*cf.* mean, ERL, and ERM concentrations in Table 4.6). The only exception was nickel, which is described in more detail below. Cadmium was not detected within the 2011 sediment samples, as has been the case in most prior monitoring surveys. Similarly, although mercury and silver were detected at a few stations, their concentrations were too low to be reliably quantified. Their respective highest estimated concentrations, 0.07, 0.06, and 0.04 mg/Kg, were well below the lowest toxic-effects levels (ERLs) of 1.2, 0.15, and 1.0 mg/Kg where biological effects first become noticeable, and far below median effects levels (ERMs) where biological impacts are expected. Thus, even if these three metallic elements are present in Estero Bay sediments at concentrations approaching their detection limits, they would be unlikely to affect marine organisms.

Table 4.6 Metal Concentrations (mg/Kg-dry) within Seafloor Sediment Samples Collected on 24 October 2011

Station	Aluminum	Arsenic	Cadmium	Chromium	Copper	Iron	Lead	Mercury	Nickel	Silver	Zinc
B1	6,300	3.2	<0.06 ¹	61	3.2	10,400	2.2	≈0.06 ²	42	<0.03	19
B2	5,500	4.1	<0.07	47	3.3	9,700	2.2	≈0.04	47	≈0.04	17
B3	5,500	3.3	<0.06	46	3.1	9,300	1.9	≈0.03	45	<0.03	17
B4	6,000	4.2	<0.06	49	3.2	9,700	2.2	<0.03	44	<0.03	17
B5	5,600	3.7	<0.07	47	3.3	9,300	2.1	≈0.03	46	<0.04	16
B6	5,800	3.5	<0.06	52	3.3	9,500	2.1	≈0.04	48	<0.03	16
B7	5,800	3.5	<0.06	52	3.1	9,500	2.0	<0.03	41	<0.03	16
Mean³	5,800	3.6	<0.05	50	3.2	9,600	2.1	≈0.04	44	<0.04	17
ERL	— ⁴	8.2	1.2	81	34.0	—	46.7	0.15	20.9	1.0	150
ERM	—	70.0	9.6	370	270.0	—	218.0	0.71	51.6	3.7	410
SCB⁵	—	6.1	0.2	27	11.6	—	10.2	—	29	0.2	44

Two of the remaining eight metals, namely aluminum and iron, are not toxic to marine organisms. As described previously, these two metals were added to the monitoring program in 1998 to track natural variations in concentrations of other trace metals that occur because of inherent differences in mineralogy. The other six metals (arsenic, chromium, copper, nickel, lead, and zinc) have been consistently detected within Estero Bay sediments throughout the history of the benthic-monitoring program. Although they each have the potential for anthropogenic enrichment, their mean concentrations have remained comparable to ambient levels for the region. In 2011, as in previous years, five of these six metals had concentrations well below the ERL where biological effects can begin to become apparent. Only the mean

¹ “<” indicates that the metal was not detected above the method detection limit (MDL).

² “≈” indicates that the reported concentration exceeded the MDL but was not quantified because it was below the practical quantification limit (PQL).

³ After logarithmic transformation

⁴ Guideline not specified

⁵ Concentration that would be considered enriched (99th percentile) relative to background concentrations in the Southern California Bight after normalization by iron (Schiff and Weisberg 1997)

nickel concentration was above the ERL; however, it was still below the ERM where biological impacts to marine organisms would be expected to occur. Each of the six detected metals is described below.

Arsenic

Although present in measurable amounts (≤ 4.2 mg/Kg), the mean arsenic concentration in Estero Bay sediments was less than half of the lowest toxicity level (8.2 mg/Kg) where adverse biological impacts would first begin to appear, and an order of magnitude smaller than the ERM (70 mg/Kg) where biological impacts become probable. For comparison, approximately 75% of the area within the Southern California Bight (SCB) has arsenic concentrations exceeding the mean level measured in Estero Bay during 2011 (Schiff and Gossett 1998). After adjustment for the mean iron concentration, average arsenic levels would have to be 2.5 mg/Kg higher to be considered enriched relative to background concentrations in marine sediments to the south (SCB = 6.1 mg/Kg in Table 4.6).

Although arsenic is widely distributed throughout nature, pure arsenic is a highly poisonous metallic element used in insecticides, herbicides, solid-state doping agents, and various alloys. However, these anthropogenic sources of arsenic do not constitute a significant component of the wastewater processed by the MBCSD. Instead, most of the arsenic present in the Estero Bay sediments derives from erosion of enriched onshore mineral deposits. Although arsenic occurs naturally in central-coast sediments, mine tailings may contain higher residual levels due to the increased presence of arsenopyrites in the ore, overburden, and soil. Arsenic from mine tailings may be released into surface and ground waters through erosion, and reach Estero Bay through runoff within the adjacent watershed (MRS 2000b).

Chromium

Chromium is also enriched within the sediments throughout Estero Bay, and within the entire south central-coast region. This enrichment is reflected in the 50-mg/Kg mean chromium concentration within samples collected near the outfall in 2011, which is almost double the 27-mg/Kg that would be considered impaired for sediments within the SCB (Table 4.6). However, chromium concentrations within all the 2011 sediment samples remained below the lowest toxicity benchmark where biological effects might first be observed. The highest concentration (61 mg/Kg-dry) was measured at reference Station B1, and was still well below the ERL of 81 mg/Kg. More importantly, the maximum concentration was only one-sixth of the level where biological effects become probable (ERM=370 mg/Kg). Even at that concentration, the potential for marine effects is probably overstated, given that the incidence of effects in the toxicological studies used to establish the levels for chromium were “*greatly influenced and exaggerated by data from multiple tests conducted in only two field surveys*” (Long et al. 1995).

The ambiguity in chromium’s toxic effects levels partially arises from the fact chromium has several oxidation states, each of which has a vastly different toxicity. The presence of hexavalent and metallic oxidation states of chromium generally arises from anthropogenic sources, particularly industrial processes; however, the relatively non-toxic trivalent form of chromium found within the Estero Bay sediment samples occurs naturally in chromite ore. This is evident from the lack of measurable levels of hexavalent forms in sediment samples collected prior to 1999, when chromium speciation was performed (MRS 1996, 1997c, 1998bi, and 1999b). The elevated chromium levels within Estero Bay sediments originate in naturally occurring chromite minerals that are introduced to the Central Coast’s waters by fluvial transport of eroded ultrabasic minerals found in the Franciscan formation. The Franciscan formation outcrops along the headlands north of Point Estero and in the Santa Ynez Mountains. Thus, although chromite ore is a widely distributed mineral deposit, it is more prevalent along the south-central coast of California than in most other areas (SAIC 1986).

Nevertheless, the presence of higher chromium concentrations within central-coast sediments often leads to misinterpretation by regulators and scientists unfamiliar with the local mineralogy. Only around 25% of the SCB had sediments with chromium concentrations higher than those of Estero Bay. Most of this area was within Santa Monica Bay, where a high mass-emission of contaminants from publicly-owned treatment works occurred before 1988. Similarly, elevated chromium levels were observed within the Santa Barbara Basin in the northern reaches of the SCB, which led to speculation that those sediments were impaired as well, even though they can be also be ascribed to the presence of naturally occurring chromite ore in the region (Chow and Earl 1978). The erroneous characterization of an impaired condition in the northern SCB was prompted by an incorrect assertion by Schiff and Gossett (1998) that the elevated chromium concentrations were “*highly predictive of adverse biological effects*” in their review of contaminant concentrations within the SCB. That assertion was in direct conflict with published findings by the developers of the biological-effects levels, who stated that the chromium effect levels were exaggerated (Long et al. 1995).

While erosion of naturally occurring chromite ore along the central coast explains its overall enrichment within the marine sediments of northern Estero Bay, ordinary erosional processes may not be able to account for the trend of increasing chromium concentrations that has been observed in the decade prior to 2000. During that time, long-term increases in chromium, arsenic, copper, and nickel were documented throughout the Estero Bay region, but were unrelated to the MBCSD discharge (MRS 2010a). Although these metals are naturally enriched in onshore mineral deposits, nearshore depositional sediments should have reached equilibrium with onshore sediments that have been eroding within the adjacent watershed throughout geologic time. Instead, the observed increases in marine sediment concentrations that were observed in the monitoring program prior to 2000 suggest that the erosion of these mineral deposits has been accelerated by human activities, such as mining. As described by MRS (2000b, 2001), sediment samples collected in conjunction with a supplementary environmental project indicate that erosion around abandoned chromite mines is the likely cause for the observed trends in metal concentrations within the marine sediments of Estero Bay.

Copper

As with arsenic and chromium, copper commonly occurs within the minerals found along the central coast. However, the 3.2-mg/Kg average copper concentration within marine sediments collected at the seven benthic-monitoring stations in 2011 is well below the 11.5-mg/Kg concentration considered enriched relative to background levels within the SCB sediments. Approximately 90% of the SCB sediments have higher copper concentrations than those measured in Estero Bay. All of the sediment samples collected within Estero Bay during 2011 had copper concentrations that were also far below levels that would begin to affect marine organisms (ERL=34 mg/Kg). In contrast to chromium, the biological effect levels of copper are well defined by toxicological studies. Consequently, biological impacts from the observed copper levels within Estero Bay sediments are highly unlikely given that the highest measured copper concentration (3.3 mg/Kg) was 80-times lower than the ERM level where adverse effects become probable.

Lead and Zinc

Lead and zinc concentrations in Estero Bay sediments are also low compared to ERL levels where adverse biological effects first become noticeable. Additionally, they are low compared to concentrations within the SCB, where approximately 95% of the area has higher concentrations. Most of the elevated lead and zinc concentrations offshore southern California were measured within Santa Monica Bay and

on the Palos Verdes Shelf, where large wastewater treatment plants have discharged for many decades. However, most of the metal emissions from these treatment plants occurred prior to the substantial improvements in effluent quality that were realized in 1988. Unfortunately, the historical discharges from these outfalls accumulated within adjacent sediments and have persisted for decades (Stull et al. 1986b). In contrast, the historically low emission of chemicals from the MBCSD treatment plant has had no measurable effect on the high sediment quality within Estero Bay.

Nickel

Although unrelated to wastewater discharge, nickel was the only metal whose concentration in Estero Bay sediments consistently exceeded its ERL level (Table 4.6). In fact, in the more than two decades of benthic monitoring, only one sample contained nickel in concentrations less than the ERL of 20.9 mg/Kg. Despite measured nickel concentrations that consistently exceed marine-toxicological benchmarks, no apparent deleterious impacts to infaunal organisms living within northern Estero Bay sediments have been observed. There are two reasons for this.

First, nickel exhibits a very weak relationship between the incidence of effects and concentrations in the database used to establish the toxic-effect ranges (Long et al. 1995). Because of this weak toxicological relationship, specification of bulk nickel concentrations that induce adverse reactions in marine biota is highly uncertain. Much of this uncertainty arises from wide variability in nickel bioavailability. When nickel is in a dissolved form, or adheres to surfaces of fine-grained sediments, it is much more likely to impact organisms that ingest or come into contact with the sediments. Conversely, nickel that is bound into the mineralogy of larger sand grains has little influence on marine organisms. The sandy sediments within the MBCSD benthic monitoring area fall into the latter category.

The second reason for the lack of impacts from elevated nickel concentrations stems from the fact that nickel occurs naturally in the mineralogy of the southern portion of the central California coast (Steinhauer et al. 1994). Because nickel and chromium often co-occur in mineral deposits, it is likely that the increased nickel concentrations found offshore also derive from the Franciscan geologic formation that outcrops at Point Estero. Thus, much of the measured nickel is bound into the mineral matrix of the sand grains themselves, where marine fauna cannot readily metabolize it. Additionally, if there is a slightly higher dissolved-phase nickel concentration within the pore waters of Estero Bay, it has probably been present for epochs, and benthic organisms in the region may have adapted accordingly.

Nickel and chromium are the only metals whose measured bulk concentrations in Estero Bay sediments consistently exhibit “*anthropogenic enrichment*” relative to background concentrations in the SCB (Schiff and Weisberg 1997). However, this designation is not correct because much of the regional enrichment along the central California coast arises from natural erosional processes, rather than from accelerated erosion of contaminated mine tailings. In fact, the influence of regional mineralogy is also plainly evident in the SCB database where “*background*” nickel concentrations steadily increase from south to north. As with chromium, Schiff and Gossett (1998) did not account for this natural variability in ore deposits and erroneously ascribed observed nickel gradients to anthropogenic contamination within the SCB.

Organic Loading

There are no well-established biological effects levels for organic-loading parameters such as TKN, BOD, TVS, and O&G (Table 4.7). However, the moisture content, mud fraction, TKN, BOD, and TVS measured in the sediment samples collected in 2011 were comparable to levels measured over the last decade.

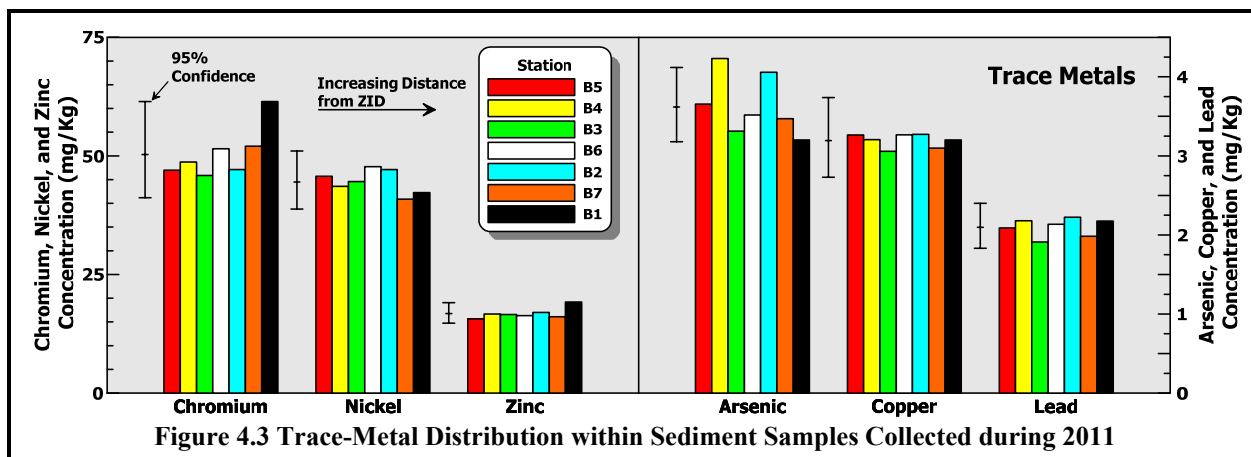
4.2.2 Spatial Distribution Unrelated to Outfall Proximity

In 2011, as in previous years, the spatial distribution of sediment chemicals did not exhibit a pattern indicative of a benthic environment impaired by wastewater discharge. Specifically, there was no consistent evidence that sediment chemical concentrations near the diffuser structure were elevated relative to distant sites. A gradient of steadily increasing contaminant concentrations with increasing outfall proximity would provide *prima facie* evidence of discharge-related impacts to the marine environment. This pattern of impairment has been observed around larger outfalls servicing more industrialized locales (Phillips and Hershelman 1996, Stull et al. 1986b, Stull 1995, Diener et al. 1995). The lack of contaminant loading around the MBCSD outfall was confirmed through application of rigorous statistical hypothesis tests, and by qualitative visual comparisons of concentrations ranked by distance from the diffuser structure.

The bar graphs in Figure 4.3 show trace-metal concentrations ranked by distance from the diffuser. Potential outfall-related impacts would appear as bar heights decreasing from left to right in many, if not all of the trace metals. On the contrary, none of the metals exhibited a clear spatial trend except chromium and zinc, which appear to increase with distance from the outfall, suggesting that any perceived spatial distribution of metals was unrelated to the MBCSD discharge.

Table 4.7 Non-metal Concentrations (mg/Kg-dry)¹ within Seafloor Sediment Samples Collected on 24 October 2011

Station	Moisture (%)	BOD	Oil & Grease	TKN	Volatile Solids (%)
B1	21.9	26	— ²	141	1.66
B2	23.6	30	<21	144	2.00
B3	21.5	18	<20	121	2.10
B4	22.0	18	<21	110	1.87
B5	23.4	40	<21	131	2.06
B6	20.4	20	<20	138	1.95
B7	19.3	19	<20	123	1.71
Mean ³	21.7	23	<21	129	1.91



¹ Unless otherwise indicated as “%”

² Sample not analyzed for O&G

³ Arc-sine transformation for % and logarithmic transformation for mg/Kg

The general increase in iron and aluminum concentrations with increasing distance from the outfall (Figure 4.4) demonstrate that the perceived increases in chromium and zinc concentrations (Figure 4.3) were naturally occurring. As described previously, normalization of raw trace-metal concentrations by aluminum, iron, or mud concentrations is common practice in impact-assessment studies because it can reveal anthropogenic patterns that are otherwise masked by variability in background concentrations. Similarly, they can eliminate spatial differences perceived to be related to an impact when they are in fact due to natural variability. When the raw concentrations in Figure 4.3 are normalized by aluminum and iron (Figure 4.4), the perceived gradients are reduced or disappear entirely (Figure 4.5).

Additionally, normalization by iron and aluminum reduces perceived differences in concentrations between individual stations. The uncertainty in the concentration measured at any given station is reflected by the 95% confidence intervals shown to the left of each bar graph. They were determined from the range in concentrations found among replicate samples collected at each individual station.¹ Perceived differences between stations that are smaller than this inherent sampling error, have, by definition, a low degree of confidence.

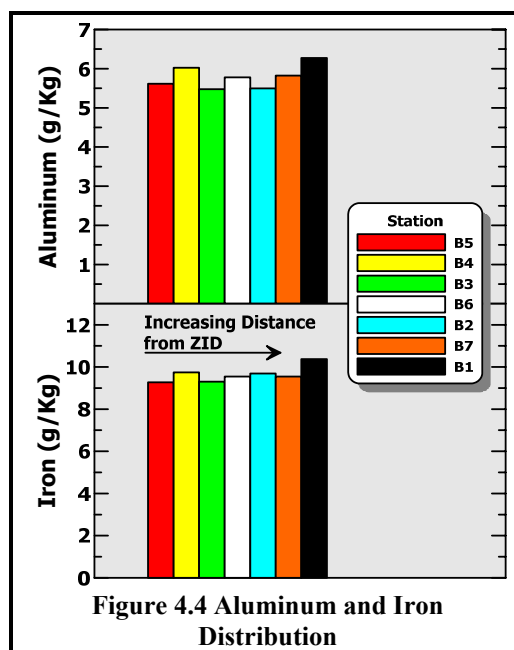


Figure 4.4 Aluminum and Iron Distribution

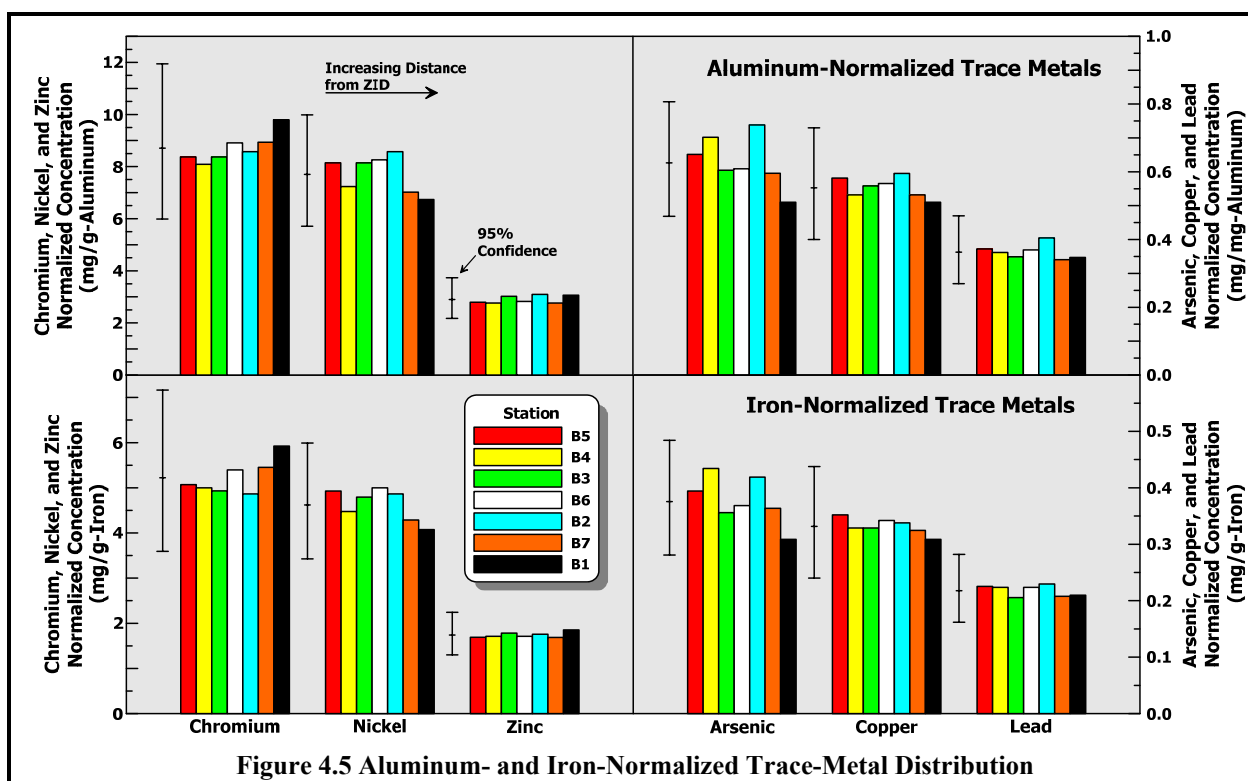


Figure 4.5 Aluminum- and Iron-Normalized Trace-Metal Distribution

¹ The confidence intervals were determined from three replicate chemistry samples that were collected and separately analyzed at each station in 1993 and 1994.

A few raw concentrations, namely the high chromium concentration at reference Station B1 and the high arsenic concentration at Station B4, range outside the confidence interval and may be incorrectly interpreted as a statistically significant spatial difference (Figure 4.3). However, normalization by aluminum and iron substantially reduced the overall variability observed in the raw concentrations. In particular, both iron and aluminum concentrations were higher in the samples collected at Stations B1 and B4 (black and yellow bars in Figure 4.4). Consequently, normalization reduced raw metal concentrations at these two stations to a greater extent than at other stations. As a result, the spatial distribution for all metals was encompassed entirely within their respective confidence bounds, including the chromium and arsenic concentrations at Stations B1 and B4 (Figure 4.5).

These qualitative observations indicate that the perceived spatial patterns in raw metal concentrations were not related to MBCSD effluent discharge because they were in the wrong direction, namely, decreasing concentrations with proximity to the discharge (Figure 4.3), and were instead the result of a naturally occurring spatial differences that prevailed in Estero Bay at the time of the survey (Figure 4.4). However, statistical hypothesis tests provide a more rigorous, quantitative method for assessing whether the MBCSD discharge is causing an increase in metal concentrations close to the outfall compared to distant stations. Two types of spatial tests were performed (Table 4.8). First, a test for the presence of a spatial gradient was performed by fitting a line to the concentration versus distance data. If the

Table 4.8 Tests for Significantly Higher Contaminant Concentrations near the Diffuser

Parameter	Linear Trend		Difference in Means (mg/Kg)				Iron-normalized ¹ <i>p</i>	Aluminum-normalized <i>p</i>
	Slope	<i>p</i> ²	Near ³	Distant ⁴	<i>t</i> ⁵	<i>p</i> ²		
Aluminum (g/Kg)	0.021	[0.20]	5.72	5.86	-0.54	[0.31]	0.28	NA
Arsenic	-0.035	0.30	3.66	3.56	0.33	0.38	0.27	0.37
Chromium	0.063	[0.02]	48.2	53.2	-1.21	[0.18]	[0.22]	[0.12]
Copper	-0.001	0.95	3.20	3.19	0.10	0.46	0.13	0.34
Iron (g/Kg)	0.024	[0.02]	9.5	9.9	-1.45	[0.14]	NA	[0.28]
Lead	0.011	[0.55]	2.08	2.13	-0.51	[0.32]	0.34	[0.48]
Nickel	-0.017	0.36	45.4	43.3	0.97	0.22	0.14	0.25
Zinc	0.042	[0.01]	16.3	17.4	-1.21	[0.18]	[0.25]	[0.19]
BOD	0.001	[0.99]	22.6	24.3	-0.30	[0.39]		
TKN	0.040	[0.20]	125	135	-1.20	[0.15]		
TVS (%)	-0.016	0.05	1.99	1.79	1.72	0.11		
Mud (%)	0.023	[0.18]	0.56	0.66	-0.56	[0.32]		

¹ Results of hypothesis tests performed on trace-metal concentrations normalized by the iron and aluminum concentration to reduce the potential influence of inherent variability in background metal concentrations.

² *p*-value or probability that a linear gradient is not significant or that a higher nearfield mean concentration is not significant (null hypotheses). In this study, *p*-values less than 0.05 (95% confidence) indicate that there is a linear gradient or that nearfield means are significantly higher, and the null hypothesis can be rejected (shown in bold font). Note, however, that a “one-sided” *t*-test was performed, in which only higher, rather than lower, nearfield concentrations are meaningful. Consequently, *p*-values for negative *t*-values are not pertinent and are indicated with brackets.

³ Mean concentration computed among Stations B3, B4, B5, and B6, which lie within 60 m of a diffuser port (the largest closest-approach of chemistry grabs in Figure 4.2). For percent concentrations, an arc-sine transform was applied to the concentrations prior to hypothesis testing. For other units, a logarithmic transform was applied.

⁴ Mean concentration computed among Stations B1, B2, and B7, which lie more than 138 m from a diffuser port.

⁵ *t*-value computed from the difference in near and far mean concentrations relative to measurement variability. A negative *t*-value indicates that the computed mean concentration was lower at stations near the diffuser, opposite of that expected in an environment impacted by effluent discharge.

concentrations consistently decrease with distance, then the negative slope of the line will be statistically significant and possibly indicative of outfall-related impacts. The second statistical test evaluated whether mean concentrations at the four stations within 60 m of the discharge differed significantly from average of the three distant stations (Stations B1, B2, and B7), which are located more than 138 m away. In contrast to the first type of test for spatial gradients, the second hypothesis test did not evaluate whether the concentrations steadily changed along a gradient; instead, it assessed whether the average concentration in the group of stations close to the outfall was significantly lower than that of distant stations, which would again be indicative of outfall-related impacts.

The “*p*-value” determines the significance of any perceived spatial trend by testing it against a null hypothesis of no trend. It quantifies the probability that a perceived spatial gradient could have occurred by chance. When $p < 0.05$, there is less than a 5% risk that the observed spatial gradient was happenstance due to random fluctuations. This threshold for designating potentially significant spatial gradients is consistent with the 95% confidence levels promulgated by the COP and used throughout this report. However, it is important to keep in mind that during any given year, a sediment constituent may exhibit an anomalous concentration at one or more stations that results in a spatial gradient that appears to be related to outfall proximity. Occasionally, that gradient is determined to be statistically “*significant*” at the 95% confidence level. Nonetheless, by the very definition of the 95% confidence level, one in twenty tests would be expected to reveal a “*significant*” gradient when, in fact, none exists. Over the years, many constituents have been tested for spatial gradients, and occasionally the analysis identifies one that appears to be statistically significant at some particular time. Upon further analysis, however, the gradient has always been found to be unrelated to the discharge. Additionally, approximately half of the time, the statistically “*significant*” gradients reflect decreasing concentrations with increasing proximity to the outfall, which is opposite the spatial gradient expected from impacts associated with effluent discharge.

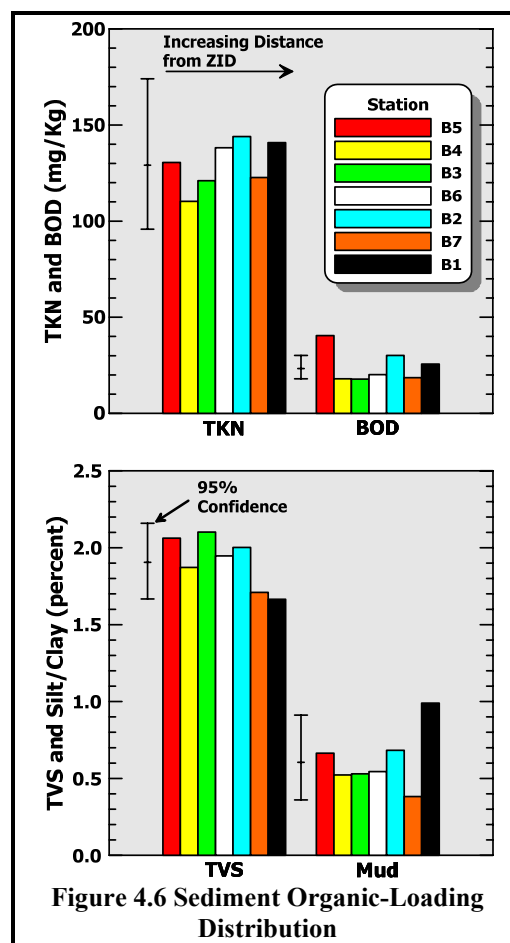
Such was the case for the two trace metals (chromium and zinc) that exhibited a possibly significant spatial trend of increasing concentration with increasing distance from the diffuser (Figure 4.3). Accordingly, the statistical test for linear trends (Table 4.8) found positive gradients (slope column in the table) that were large enough to be statistically significant (*p*-values less than 0.05, which are highlighted in bold in the table). However, because those gradients are opposite of what would be produced by contaminant buildup around the outfall, the statistical test is irrelevant for the compliance analysis, and their associated *p*-values are enclosed in brackets. The statistically significant gradient in iron concentrations ($p = 0.02$) demonstrates that although a perceptible spatial trend may be present, it was related to natural processes rather than effluent discharge.

In addition, the spatial trends were so slight that when average concentrations at groups of stations near and far from the outfall were tested for significant differences, none was found. The results of tests for significant differences in mean concentrations are shown in the remaining columns of Table 4.8. None of the differences in raw concentrations were statistically significant ($p \geq 0.11$ in the “*Difference in Means*” column of Table 4.8) even after accounting for normalization by iron and aluminum ($p \geq 0.12$ in the last two columns of Table 4.8).

Table 4.8 also provides the results of statistical tests for significant differences in near- and far-field concentrations for the four organic loading parameters. As with trace-metal concentrations, none of the organic properties exhibited a significant spatial difference in average concentrations ($p \geq 0.11$), although three of the four parameters had slightly lower concentrations near the outfall (*p*-values enclosed in brackets).

TVS was the only sediment property that exhibited a spatial gradient with a trend (negative slope) consistent with an effluent-discharge signature. Although a gradient of decreasing concentrations with decreasing distance from the outfall is visually apparent (lower left bar graph in Figure 4.6), differences in concentrations were small compared to the scatter in data (viz. they were encompassed by the 95% confidence interval), and the slope of trend was not statistically significant, although only marginally so ($p=0.054$). Moreover, the perceived trend in TVS concentration was largely due to a low concentration at Station B1 rather than a high concentration immediately adjacent to the outfall. Because of its much greater distance from the outfall, the concentration at this station had an inordinately large influence on the linear regression. Nevertheless, the remaining six stations showed no evidence of a significant trend ($p=0.31$).

As has been the case with past surveys, the sediment sample from Station B1 also contained a substantially higher amount of fine sediments (black bar in the lower right graph of Figure 4.6) compared to the other stations. At close-to 1%, the mud fraction at Station B1 was nearly double of that at the other six stations. A duplicate analysis of a subsample from the Station B1 sediments confirmed the accuracy of the increased silt and clay (mud) fractions at that station (Table 4.5), and demonstrated that the difference at that station was not due to measurement or analysis error. As with the other sediment properties, the difference in fine fractions at Station B1 was unrelated to effluent discharge because increased fine fractions far from the outfall is opposite of the trend that would be produced by the accumulation of fine wastewater particulates from deposition near the outfall. Instead, as mentioned previously, the sedimentary environment at Station B1 has been found to be fundamentally different from that of the other monitoring stations. This is primarily due to Station B1's large 1-km distance from the outfall compared to all other stations, which are located 150 m or less, from the outfall.



4.2.3 No Buildup over Time Related to Wastewater Discharge

The previous section examined the spatial distribution of constituents at a single point in time, namely, during the October 2011 survey. However, the characteristics of ambient sediments at individual stations can be inherently different because of slight differences in their water depth, or because of differences in the depositional characteristics of their geographic location. For example, Station B1 lies in a more quiescent area north of the outfall, which probably accounts for the consistently higher mud fraction found there.¹ These factors complicate the interpretation of any perceived spatial gradients with respect to

¹ The prevailing wave field is from the northwest and much of northern Estero Bay is in the wave shadow of Point Piedras Blanca and Point Estero (Figure 3.7). Station B1's northerly location is more protected from swell arriving from the northwest.

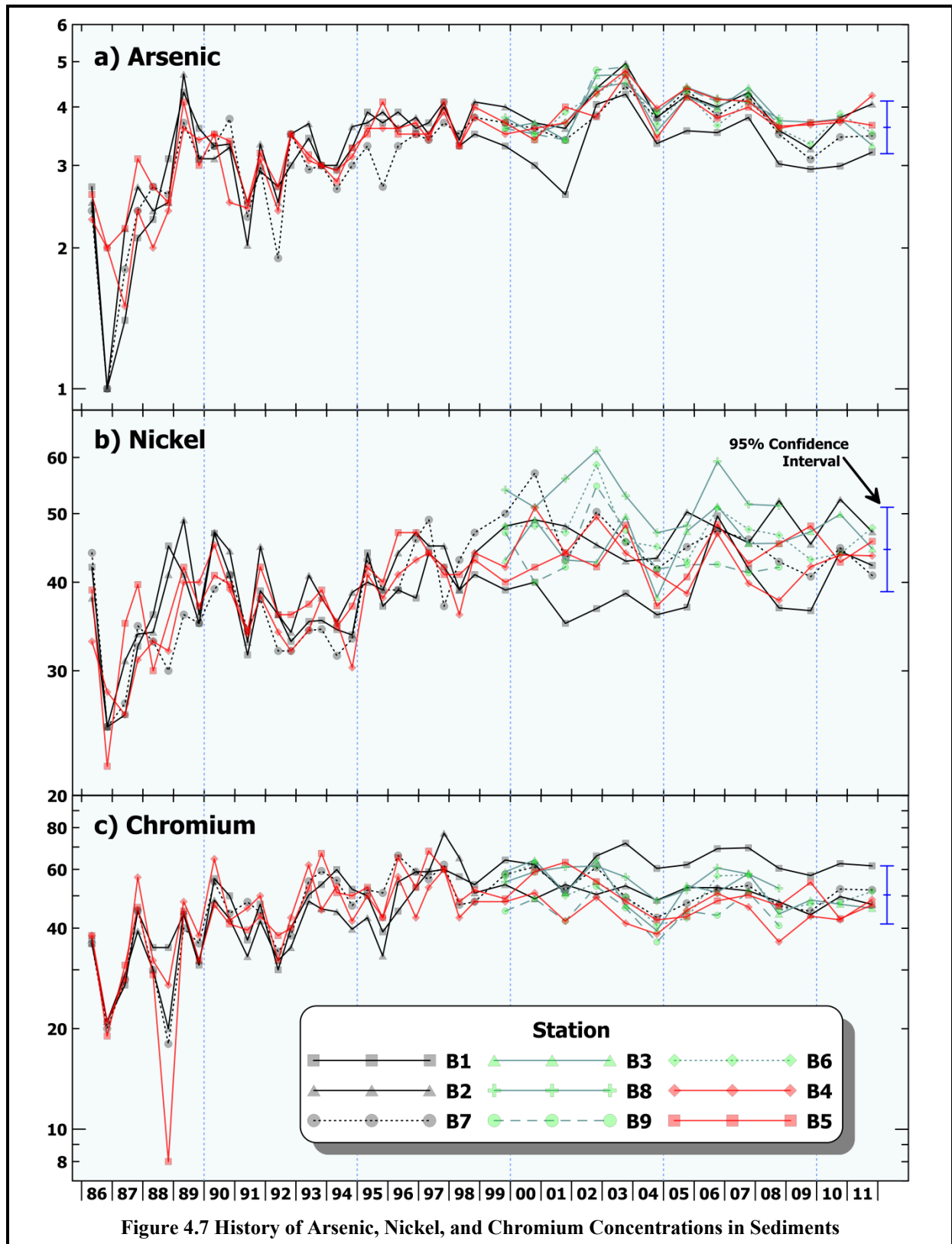
effluent discharge. Examining changes in spatial distributions over time, however, significantly improves the power to detect potential discharge-related impacts. Specifically, if there were any measurable marine impacts from wastewater discharge, they would be revealed by a long-term buildup of contaminants in sediments surrounding the outfall, as compared to distant stations. Consequently, examining spatial trends in contaminant concentrations over time can reveal discharge-related trends that may be masked in a spatial analysis applied to a single survey.

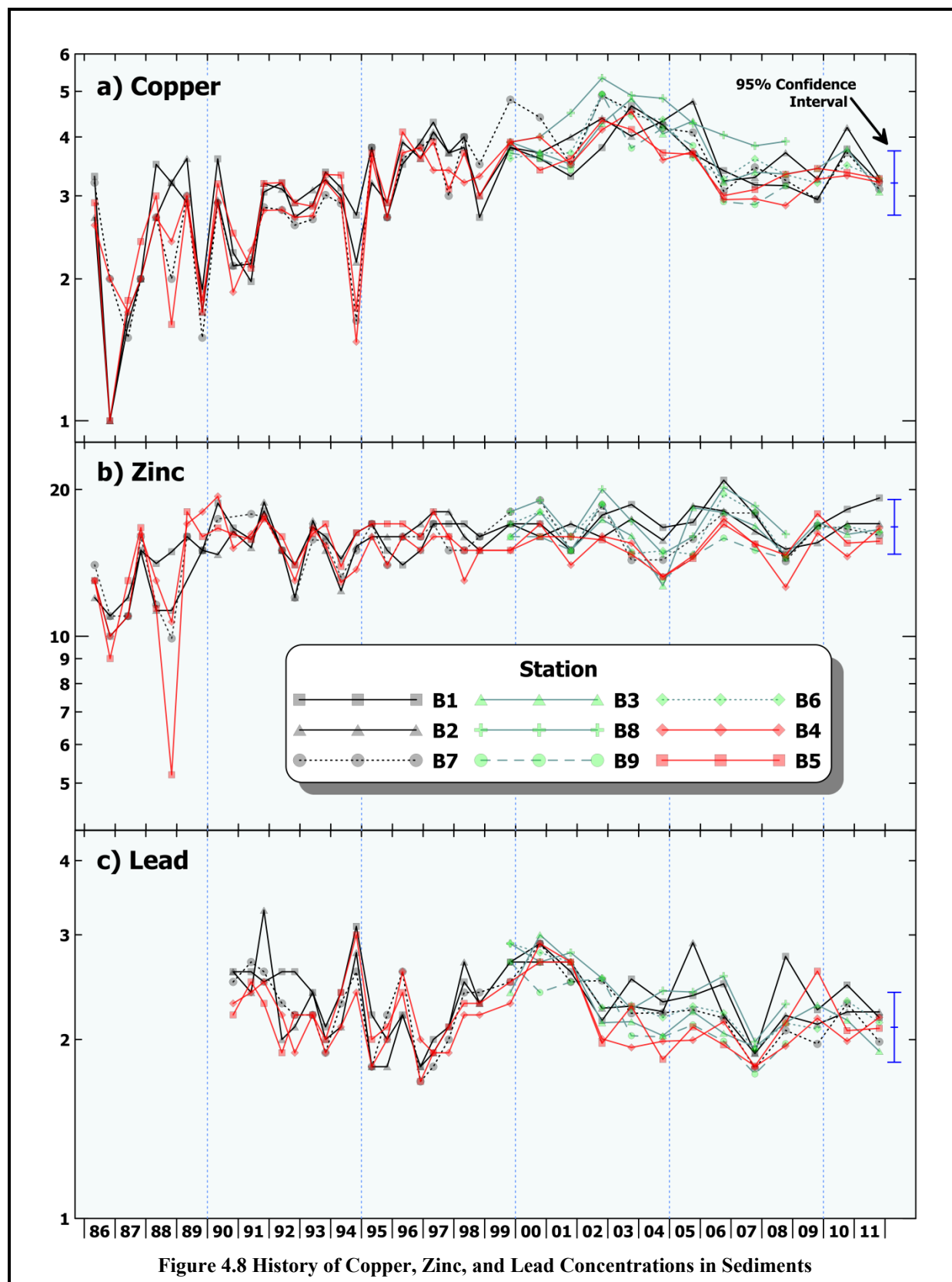
However, perceived temporal trends in contaminant concentrations must be interpreted carefully because natural and anthropogenic processes unrelated to the effluent discharge can also cause large and widespread changes in chemical concentrations within sediments. These regional influences are apparent in the time series of sediment chemical concentrations shown in Figure 4.7, Figure 4.8, and Figure 4.9. Large-amplitude fluctuations occur over periods of a few years and a long-term increase in the concentrations of five sediment constituents are apparent in the decade-and-a-half prior to 2000 (Figure 4.7abc, Figure 4.8a, and Figure 4.9c).

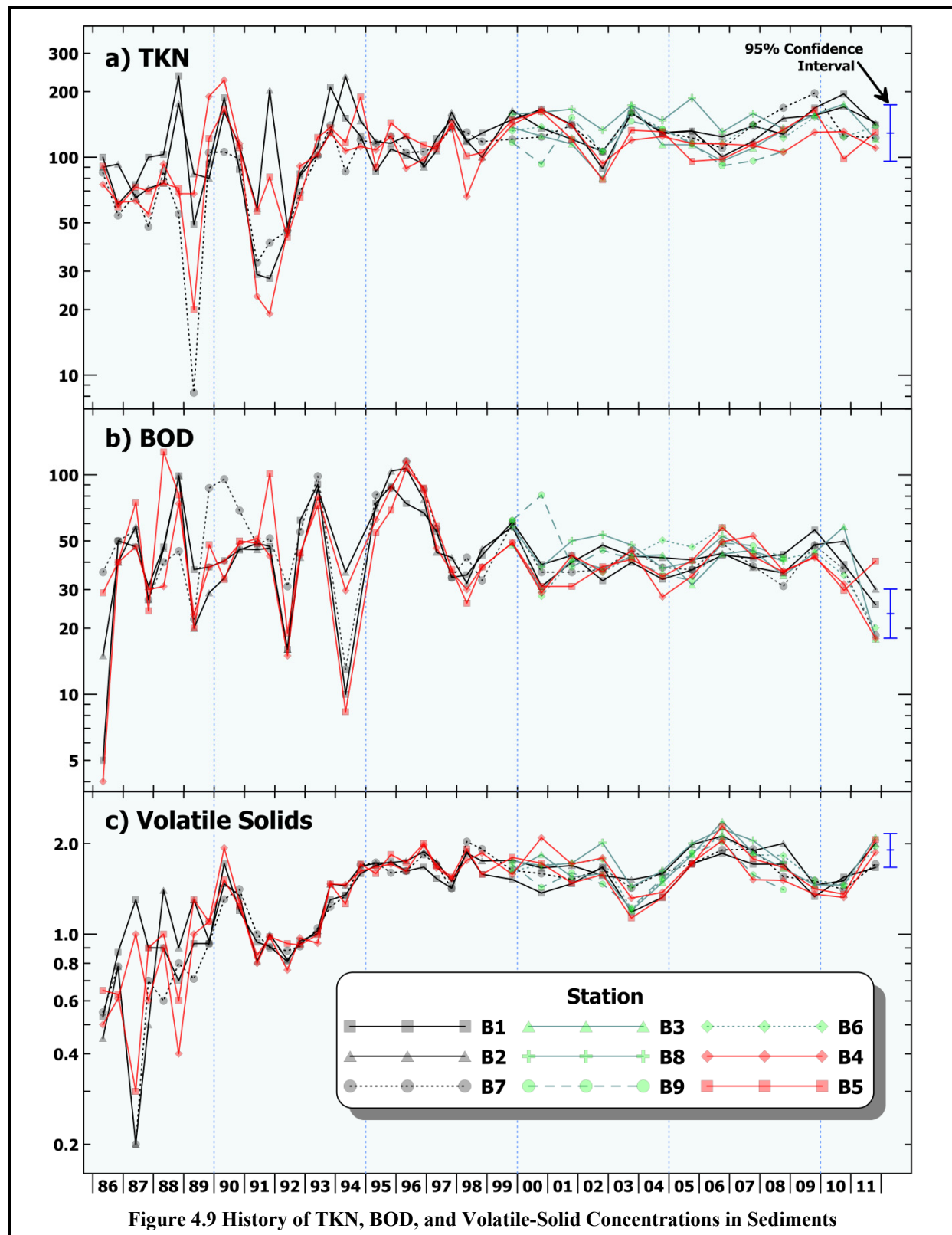
Nevertheless, these large interannual fluctuations and long-term increases tend to occur in unison at all stations, so the spatial differences among samples collected at a given time (i.e., within a given survey) are comparatively small. In other words, the fluctuations in concentrations generally tracked one another through time. This indicates that changes in sediment concentrations that arise because from regional influences throughout Estero Bay are far larger than those induced by any localized effects. During a given survey, spatial differences in sediment concentrations tend to remain within the 95% confidence interval (shown to the right of each time series in the figures) that quantifies the uncertainty in individual measurements. As described in the previous section, these confidence bounds indicate that most spatial differences within a given survey are not statistically significant, while interannual fluctuations and long-term trends are large enough to be reliably quantified in the presence of sampling uncertainty. Any subtle spatiotemporal trends in sediment chemical composition that may be related to the MBCSD discharge are difficult to discern in the presence of these large regional excursions in sediment chemistry.

The pre-2000 long-term increase in some sediment metal concentrations was the subject of intensive investigation in prior annual reports (MBCSD 2010) and in an independent, separate field study (MRS 2000b). Those analyses unequivocally demonstrate that the observed increase could not be caused by the MBCSD discharge because: 1) the accumulation occurred at all stations, including stations distant from the outfall, 2) the MBCSD metal emission was far too small to account for the widespread increase, and 3) the discharge remained unchanged while the trend in average concentrations leveled out after 2000. Instead, the steady increase in sediment metal concentrations prior to 2000 was ascribed to accelerated erosion of contaminated mine tailings at abandoned chromite mines within the adjacent watershed. After 2000, sediment concentrations appear to have reached equilibrium with the metal loading from runoff into Estero Bay.

Discerning subtle localized impacts within the backdrop of large interannual fluctuations and long-term trends requires a special statistical technique that overcomes limitations associated with purely spatial or purely temporal approaches to impact evaluation (Coats et al. 1999, Skalski et al. 2001). The parallelism technique assumes that the large temporal excursions in concentrations occur in unison at all stations and represent a simultaneous response to regional influences unrelated to the MBCSD discharge. Under those circumstances, discharge-related spatiotemporal changes would appear as a gradual separation of the colors in Figure 4.7, Figure 4.8, and Figure 4.9, as contaminants preferentially accumulate near the outfall over time. Concentrations at nearfield stations (shown in red) would slowly increase relative to concen-



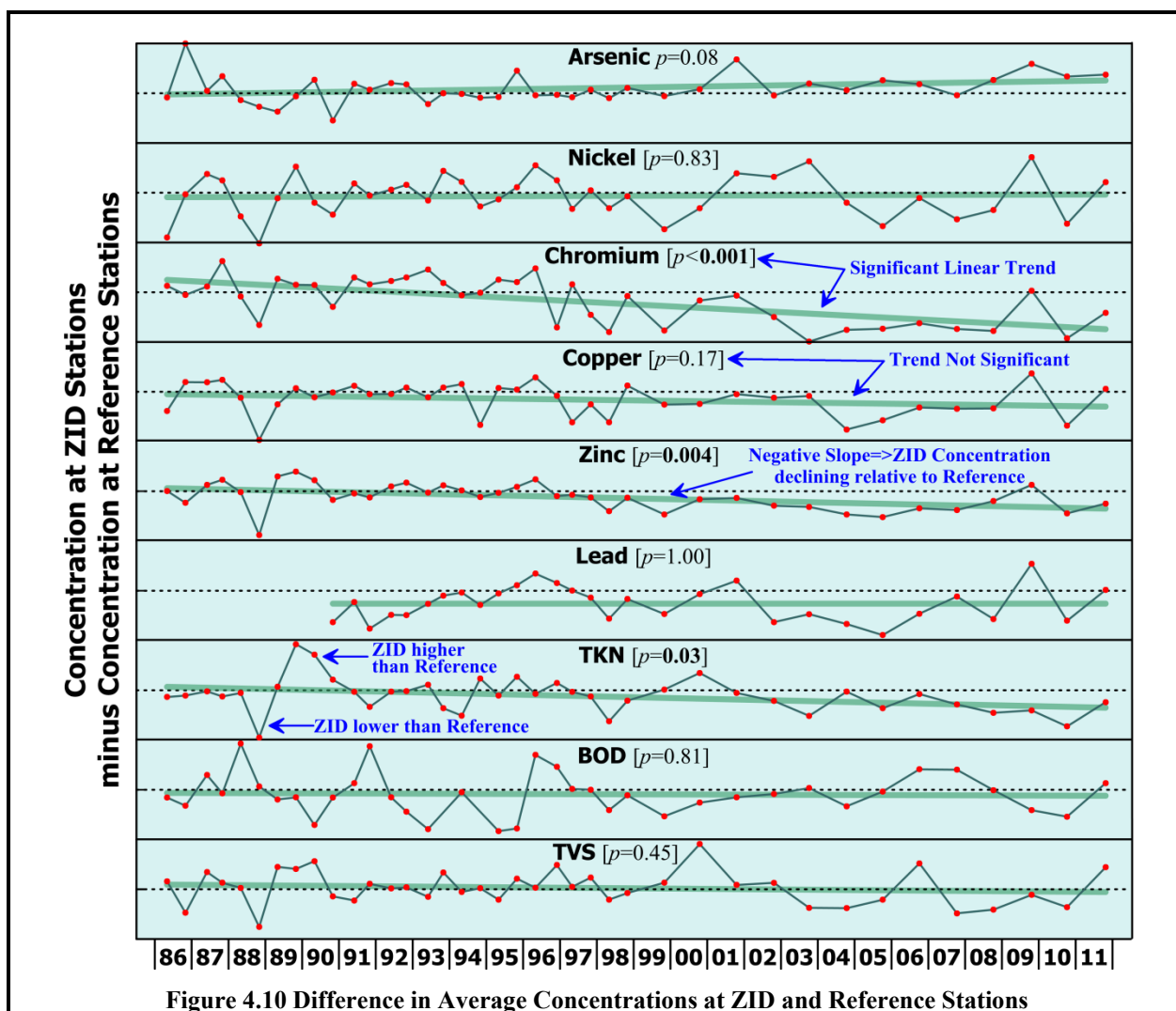




trations at mid-field (green) and distant reference stations (black). However, because of the large coherent fluctuations that occur over time, subtle spatiotemporal changes may be present but not visually apparent in the time series.

Analysis of the difference between average concentrations at stations located near the outfall, and those that are distant from the outfall, effectively removes the temporal oscillations that occur on a seasonal and interannual basis. Specifically, if the time series of average concentrations near the outfall parallel those of distant stations, then there is little evidence of a discharge-related accumulation. A parallelism test is also insensitive to inherent differences in the sedimentary environment at the two groups of stations, as was previously described for reference Station B1, for example. Distant stations may have consistently higher (or lower) average concentrations because of natural spatial differences in the benthic environment, but because the parallelism test only deals with trends in the difference between the two groups of stations, rather than their absolute values, such natural spatial variations are appropriately eliminated from the compliance evaluation.

Time series of differences in sediment concentrations at ZID and distant stations are presented in Figure 4.10. If contaminants discharged by the MBCSD discharge were accumulating in sediments near the



outfall, then concentrations at stations near the outfall (B4 and B5) would slowly increase relative to distant stations (B1, B2, and B7). These increases would appear as positive slopes in the average difference shown in Figure 4.10. A regression test for a statistically significant trend (slope) in the difference is equivalent to a test of the null hypothesis that the contaminant concentrations at impacted and non-impacted sites remain constant (parallel) over time.

Arsenic was the only chemical constituent that exhibited a positive slope, suggesting the possibility of a buildup of wastewater contaminants close to the discharge compared to reference stations. However, the associated p -value (0.08), which measures confidence in the slope of the line, indicates that this perceived trend was not statistically significant.

All of the other chemicals exhibited negative slopes indicating that ZID concentrations generally decreased over time relative to reference stations (Figure 4.10). Because this trend is opposite of that expected from a buildup of contaminants near the discharge, the parallelism hypothesis test is irrelevant for a compliance evaluation, so the associated p -values for the parallelism test are listed with brackets surrounding them. Nevertheless, significant negative slopes are of interest because they can indicate large-scale trends within the sediments of Estero Bay, albeit unrelated to the outfall.

For example, chromium exhibited the strongest case for rejecting parallelism ($p < 0.001$), and accepting the alternative hypothesis that chromium concentrations actually decreased near the outfall compared to distant stations. Although this trend is clearly unrelated to contaminant buildup around the discharge, it appears to be confirmed by the individual time series shown in Figure 4.7c. Early in the record, chromium concentrations at the most-distant reference station (B1), shown by the black squares, were comparable to those of other monitoring stations. In the latter half of the record, however, chromium concentrations at Station B1 began to diverge from rest of the group. Specifically, in each of the last eight years, concentrations of chromium have been significantly higher at Station B1 than any of the other stations. This probably results from its large geographic separation from the rest of the group. As described previously, Station B1 is located in a more quiescent depositional regime, which is reflected in a much-higher mud fraction. Although trace-metal concentrations tend to be naturally higher in fine-grained sediments, this does not adequately explain why the same trend is not observed in the other metals. Instead, the slowly increasing chromium concentrations at Station B1 may be the result of its proximity to the mouth of a creek whose watershed encompasses a relict chromite mine, and where contaminants from this mine are preferentially deposited.

Zinc ($p < 0.004$) and TKN ($p = 0.032$) also exhibit similar, statistically significant trends, where concentrations distant from the outfall have been steadily increasing relative to nearfield monitoring stations. In both of those cases, however, the subtle divergence in the (non-parallel) time series is not readily apparent in the individual time series (Figure 4.8b and Figure 4.9a). This demonstrates the value of parallelism tests, which eliminate large coherent fluctuations and allow the more relevant long-term trends to be revealed. Another attribute of parallelism is that it only addresses trends, and masks inherent differences in overall concentrations within the two groups of stations. This attribute is apparent in the lead time series (Figure 4.10). Although the average lead concentrations at ZID and reference stations closely tracked one another, and there was strong evidence that the trends were parallel ($p > 0.99$), the average ZID concentrations were almost always lower than the reference station averages. This difference is apparent in the negative offset of the green regression line. Thus, parallelism tests focus only on long-term trends in the difference in contaminant concentrations. They appropriately disregard absolute concentration values that may be inherently different between the two groups of stations due to natural causes.

In contrast to chromium, zinc, and TKN, which showed strong, statistically significant trends over time, nickel concentrations were almost perfectly parallel over the record of measurements, as demonstrated by the negligible slope of the linear regression that leaves little reason to reject the null hypothesis of parallelism ($p > 0.83$).

Thus, the parallelism analysis reveals some interesting insights into the distribution of contaminants within the ambient sediments of northern Estero Bay. In particular, lead concentrations tend to increase toward the north, but that spatial gradient does not change over time. In contrast, chromium, zinc and TKN concentrations at more northerly locations have been steadily increasing relative to sites to the south. Arsenic, nickel, copper, BOD, and TVS concentrations are spatially uniform, and have remained so over the past quarter century. Although these unusual and unexplained aspects of the sedimentary environment of Estero Bay are unrelated to the discharge, they suggest extreme care is warranted when assessing potential impacts to the seafloor from human activities in the region.

4.3 BENTHIC INFAUNAL COMMUNITY

The infauna living within the surficial sediments of northern Estero Bay provide additional insights into the ambient seafloor environment in the region. They are also particularly effective for compliance determinations that assess the presence of a BIP surrounding the outfall because they act as sensitive sentinels for possible impacts caused by wastewater discharge that may be too minor to be revealed in the analysis of chemical constituents alone. Infauna are the best biological indicators of marine pollution because they have limited mobility and cannot easily escape exposure to contaminants in their immediate environment. Other organisms, such as marine mammals and finfish, range more widely, making it impossible to determine where the organisms were exposed to contaminants.

The diffuser structure lies on the seafloor, where particulate contaminants discharged into marine waters ultimately settle and accumulate. Because infauna reside within seafloor sediments, they are close to the potential source of pollution. Additionally, infaunal species vary in their sensitivity to pollutant stressors. As such, changes in relative abundance among species can signal the presence of subtle alterations in their environment. Infauna are also important organisms to monitor because of their low trophic level within the marine food web. They are a major food source for more-mobile epifaunal and pelagic marine organisms, such as crabs, finfish, and marine mammals.

In recognition of infauna's role as an early detector of marine pollution, the MBCSD discharge permit requires regular monitoring of the overall health of the benthic community within Estero Bay. Infaunal monitoring also addresses the COP requirement that the discharge not degrade indigenous marine biota (see Objective E.1 in Table 3.1 on Page 3-3). The benthic monitoring has now amassed 26 years of infaunal data. During that time, 241,000 specimens representing more than 386 individual taxa have been collected and examined. Throughout the monitoring program, there has never been any indication of deleterious discharge-related impacts to the benthic community. Instead, the data have revealed a consistently healthy indigenous infaunal community with uniformly high diversity beyond the ZID, and no evidence of spatial changes in the infaunal assemblages in relation to ZID proximity.

These observations hold true despite widespread variations in the abundance of individual organisms. Over the years, the dominance of individual taxa have waxed and waned in response to natural changes in the environment. Additionally, for many taxa, distinct differences in abundance are evident between the winter and summer sampling seasons. Other species come and go in response to powerful long-term variations in the oceanographic environment. One such variation is the El Niño – Southern Oscillation, whose impact has been evident in benthic sediment samples collected within Estero Bay on at least four occasions during the last two decades of MBCSD monitoring (NOAA 2010). The first event was in 1988,

and the second began at the end of 1997 and extended into 1998. Its influence on benthic organisms was still evident during 1999. Another minor event may have occurred in 1991, however, the event with the largest influence on faunal populations around the outfall occurred in 2009 when the faunal density was 100-times higher than average due to a huge explosion in the sand-dollar population. The effects of this population boom continued to be apparent in the 2011 data.

Almost 5,000 individual organisms were enumerated in the 35 sediment samples that were collected during the benthic survey conducted in October 2011. A compendium of the taxonomic identifications and enumerations conducted on year-2011 sediment samples is provided in Tables B.1 through B.8 in Appendix B at the back of this report. Tables B.9 and B.10 list infaunal indices that were computed from infaunal data, as required by the NPDES monitoring and reporting program. This section of the annual report combines these data with biological data collected over the prior 25 years to determine whether there have been discharge-related impacts to the benthic biota.

Three analyses demonstrate that there have been no deleterious impacts to benthic organisms as a result of the discharge. First, the organisms that inhabit the sediments around the outfall are indicative of an indigenous community of filter feeders that thrive only in clean sediments. Second, infaunal data collected during 2011 show no evidence of spatial gradients indicative of biotic degradation attributable to effluent discharge. Third, despite wide fluctuations in community parameters over time, there were no long-term trends indicative of an increasingly degraded benthic environment around the outfall. All the stations tended to respond in unison to large interannual and seasonal influences on the infaunal community. To date, the indigenous benthic community remains healthy, with no perceptible influence from ambient contaminant levels, including the previously discussed long-term trends in trace-metal concentrations that have occurred throughout Estero Bay.

4.3.1 Indigenous Infaunal Community

The type and abundance of benthic organisms directly reflect the quality of the marine sediments where they live. Infaunal communities residing in degraded sediments tend to exhibit low species richness and diversity because they are populated by only a few opportunistic taxa that feed on detritus and thrive in sediments that are high in subsurface organics. In contrast, clean sediments are populated by diverse assemblages of organisms that include filter feeders, which extract nutrients from suspended particulates. These suspension feeders are sensitive to excessive particulate loads such as those that can be discharged from low-performance treatment works. The widespread presence of suspension feeders around the MBCSD outfall clearly indicates that the discharge is not adversely affecting them. One such suspension feeder is the club-tipped anemone (*C. californica*) that carpets the diffuser ports (see the photograph in Figure 2.2 on Page 2-4). Their presence is indicative of the benign nature of the suspended sediments discharged by the treatment plant.

Excluded Organisms

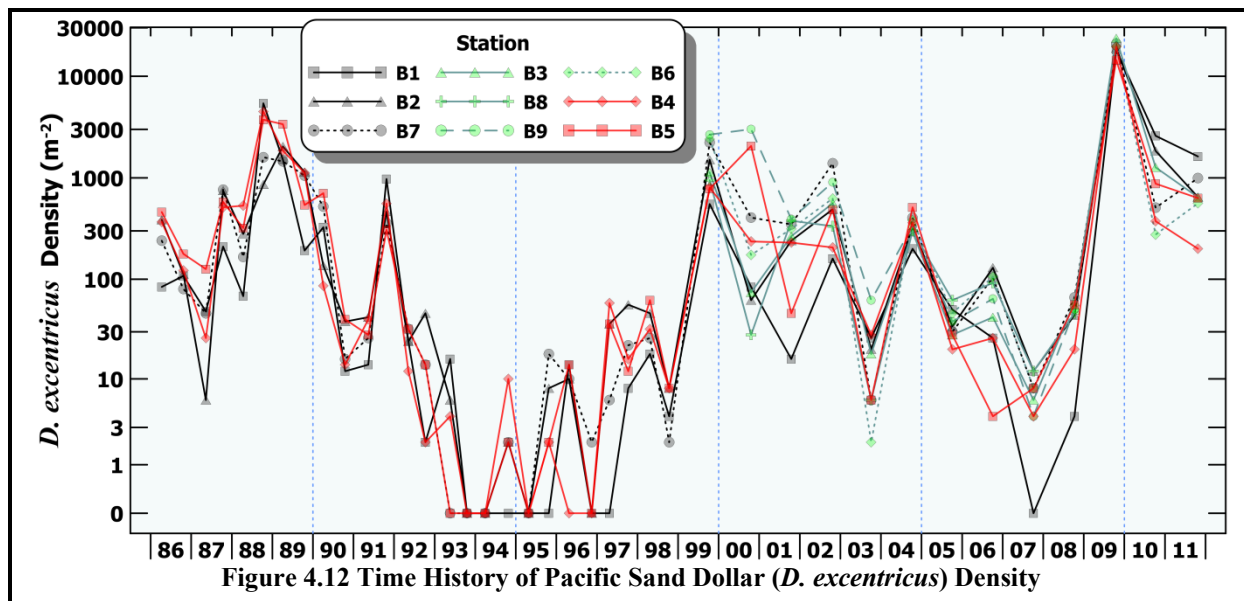
The populations of two organisms, *Diopatra ornata* and *Dendraster exentricus*, have a profound effect on the MBCSD infaunal database. However, these organisms and their attached taxa are not particularly sensitive to changes in sediment quality, and their presence frequently confounds impact assessments. Consequently, their populations were removed from the database prior to the impact assessments described in this section.

Since 2000, the parchment tubes of the Ornate Tubeworm (*Diopatra ornata*) have routinely been separated in the field prior to sieving of the infauna. Ornate tubeworms are so called for the elaborate layering of pieces of shells, algae, sticks, and other debris on the outside of their large parchment tubes (Figure 4.11). Large numbers of nestling epiphytes reside on the microhabitats created by these tube casings, including small crabs and other crustaceans. Inclusion of these epiphytes in the infaunal database can dramatically skew the enumeration of marine infaunal organisms in samples where they are present. Because epifauna live on the surface of marine substrates, they tend to be more mobile and less susceptible to sediment pollutants than infauna, which live in the interstices between sand grains. Removal of the parchment tubes in the field, prior to sieving, avoids sample contamination with large populations of epiphytes. The tubeworms themselves, however, are included in the enumerations because they tend to congregate in higher densities close to both natural reefs and manmade structures, such as outfalls (Davis et al. 1982). During the October 2011 survey, *D. ornata* tube casings were separated from samples, although only one casing collected at Station B3, contained a live adult that was included in the enumeration.



Figure 4.11 Photograph of a Tubeworm (*Diopatra* sp.)

Statistical analyses performed on the 2011 benthic samples also excluded Pacific sand dollar (*Dendraster excentricus*) populations. Although sand dollars are filter feeders and can be sensitive to pollution, they are removed from the database prior to statistical analysis because they exhibit extreme population fluctuations from year to year (Figure 4.12) which can potentially mask discharge-related impacts on less-dominant taxa.



Sand dollars form dense beds just seaward of the wave break, which acts as a barrier for predacious sea stars. At that location, predation is limited because sea stars can move over the sand-dollar bed only at

significant risk of tumbling into the surf zone with a passing wave (Morin et al. 1985). Consequently, sand-dollar beds migrate shoreward in the summer and seaward in the winter in response to seasonal wave action (Oliver et al. 1980). A winter of strong wave action, usually associated with El Niño, reduces predation, permitting enhanced recruitment of juvenile sand dollars. Specifically, the increased sand-dollar recruitment that occurred in late 1988, 1991, 1999, and 2009 was associated with high-waves generated by El Niño events in 1988, 1998, 2009 and the weaker one in 1991.

Similarly, the sand-dollar population drop documented in 2003 may have been linked to a predation event in late 2002. On numerous occasions during the October 2002 survey, short-spined sea stars (*Pisaster brevispinus*) became jammed in the jaws of the grab sampler, resulting in an unusually high number of repeated grab-sampling attempts at several stations. Accordingly, sand dollar populations in the following year 2003 were markedly diminished, suggesting that predation may have played a significant role in the reduction observed between 2002 and 2003.

Because their large numbers overwhelmingly dominate the population statistics during high-recruitment years, sand dollars have the potential to mask any influence from the discharge on less-dominant taxa, whose populations are more consistent and sensitive to potential discharge impacts. For example, average sand dollar densities have ranged from a historical high of 19,000 m⁻² in October of 2009 to less than 50 m⁻² between May 1992 and October 1998. During 1999, however, recruitment peaked slightly before experiencing a general decline through 2007 when a total of only 31 sand dollars were collected. During those years, removal of the few *D. excentricus* specimens from the database had little impact on the statistical analyses.

In 2009, however, an extremely successful recruitment event took place, and more than 67,000 individual sand dollars were enumerated within the 35 infaunal samples collected during the annual benthic survey. Surviving individuals from this recruitment event were encountered in both 2010 and 2011. During 2010, a total of 3,869 individuals were enumerated, while 2,652 individual sand dollars were enumerated in 2011. These three populations clearly belonged to the same age group (cohort) of sand dollars because the individuals within each year were of uniform size, but their size progressively increased (Figure 4.13). Although not as populous as in 2009 or 2010, the 2011 population was among the largest recorded in the course of the monitoring program, with 812 specimens collected at Station B1 alone. In comparison, the amassed total of all other benthic organisms collected during 2011 sampling came to only 2,317 individuals.



Figure 4.13 Comparison of the Sand Dollar cohort in 2009 (left), 2010 (center), and 2011 (right)

Because their populations were comparatively large, community indices computed with the 2011 *D. excentricus* population (Table B.9) were vastly different from indices computed without their inclusion (Table B.10). Most of the indices, such as dominance and diversity, measure the uniformity in abundance

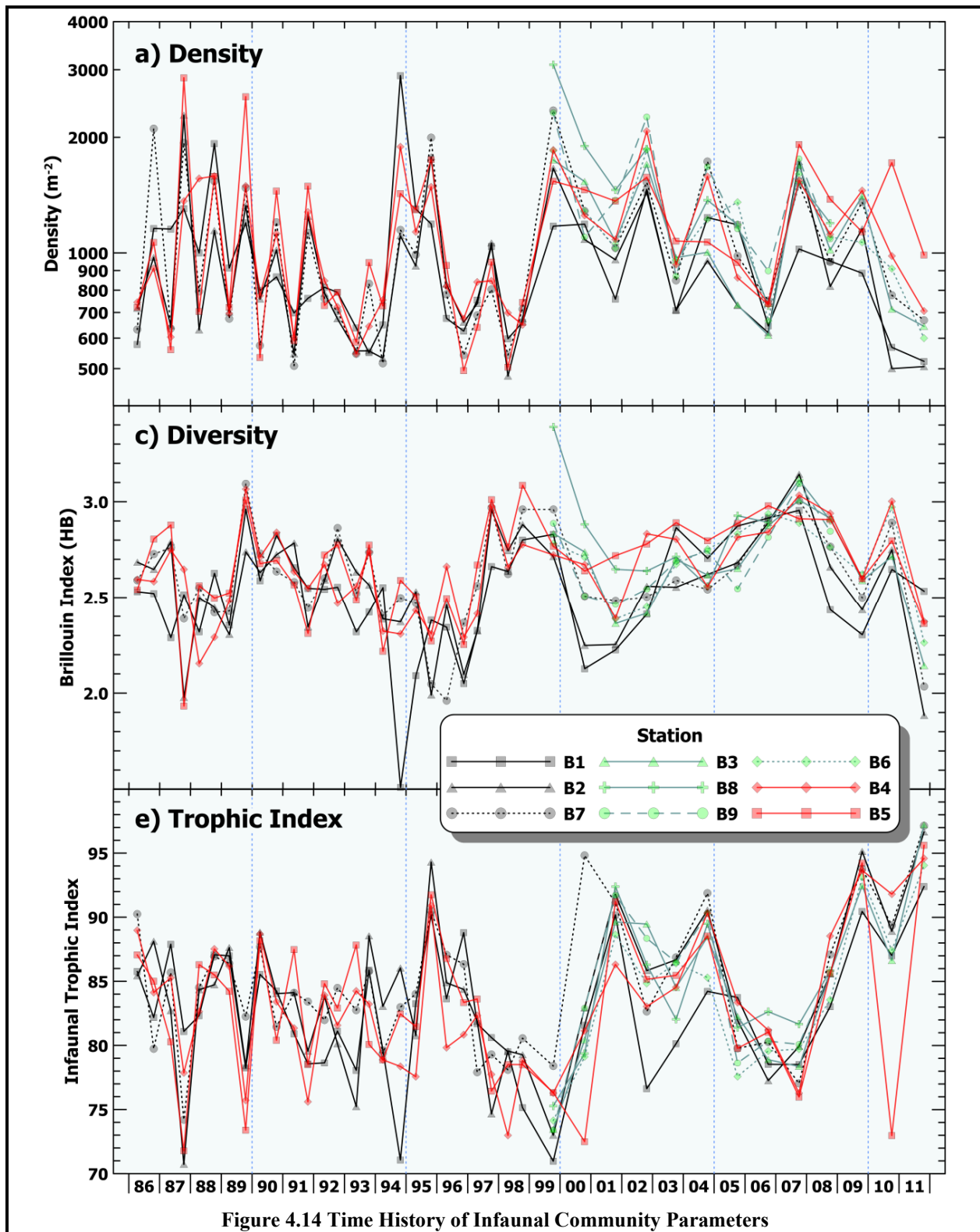
among species. When the overwhelmingly dominant sand-dollar population is included in the indices, trends in the diversity due to population differences in other taxa are completely masked. For example, the Swartz dominance index (S_w , see Section B.1.2) is normally a relatively diagnostic and stable measure of the overall health of the infaunal community. However, because sand dollars represented more than 78% of the population in three of the five replicate samples collected at Station B1, the index remained at unity (See the S_w column in Table B.9) and provided no information about the relative abundances of other taxa. Exclusion of sand dollars from the computation of indices (Table B.10) allows differences in other taxa to be discerned. Note that the infaunal trophic index (ITI) is unaffected by the presence of sand dollars because they are not included in the feeding guilds quantified by that index.

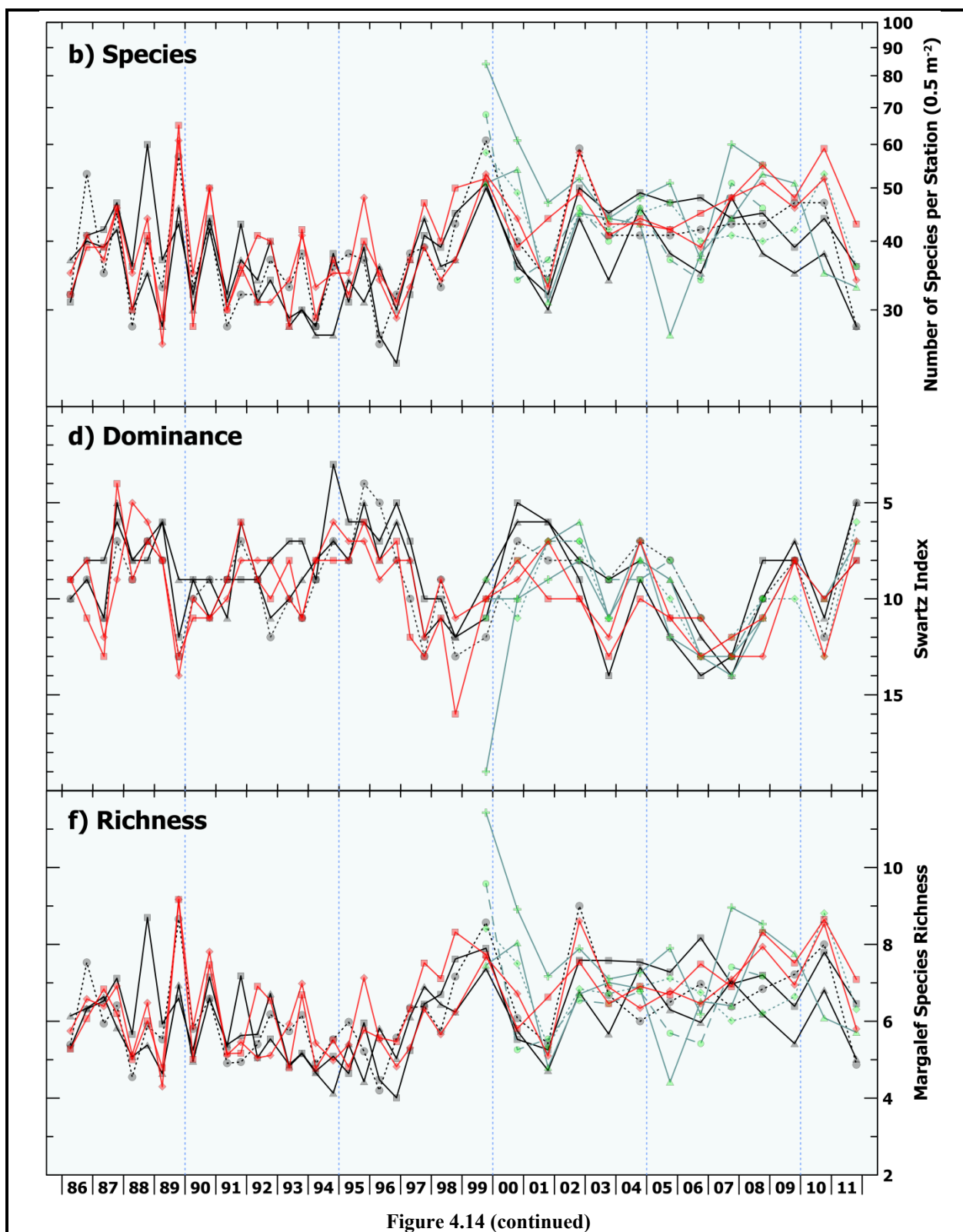
Exclusion of the transient sand-dollar population enhances, but does not detract from the impact evaluation, because their distribution is clearly unrelated to effluent discharge. As with the chemical constituent time histories, spatial distributions of sand-dollar populations related to outfall proximity would be evident in the sand-dollar population history (Figure 4.12) as a separation between the time histories for the ZID stations (red), for midfield stations (green), and for stations well away from the diffuser structure (black). Instead, the large fluctuations in sand-dollar abundance tend to occur equally at all stations. The consistently low density of fully-grown adult sand dollars, even during the high-population periods, demonstrates that their presence is transient; no permanent sand dollar beds exist in the region (Brown and Caldwell 1989, 1993). It is well established that sand-dollar beds are often dominated by a single age cohort, suggesting that recruitment is episodic and only occasionally successful (Cameron 1980, Oliver et al. 1980, Morin et al. 1985, Cameron and Rumrill 1982). Figure 4.13 confirms that the sand dollars collected during the MBCSD benthic surveys tend to be composed of small juveniles of the same cohort.

Although exclusion of sand dollar counts eliminates their undue influence on the population statistics described below, it is likely that the extensive sand-dollar bed that has been developing since 2009 affected other infauna through competition for food and space during 2011. Although their numbers were comparable to 2010, their increase size in 2011 (Figure 4.13) resulted in a much greater volume of sand dollars residing on, and within, surficial sediments. For example, the grab volume in some sediment samples collected in 2011 consisted almost entirely of sand dollars, with very little sediment (and other taxa) present. The increased presence of sand dollars may have impacted the ability of certain surface-deposit and subsurface-detritus feeders to move about and forage for food. As described below, the large sand-dollar volumes indirectly affected benthic population parameters in 2011 compared to prior years, even though the sand-dollar counts were specifically excluded from those population parameters.

Abundance

In this report, the overall health of the benthic community within Estero Bay is reflected by the principal population parameters computed from samples collected at each station over the duration of the monitoring program. For the reasons described above, sand dollars (*D. excentricus*) were excluded from the population statistics to better evaluate the overall health of the benthic community. The resulting non-*Dendraster* community parameters then provide a succinct description of the abundance, diversity, richness, and trophic (feeding) structure of benthic biota. Figure 4.14 shows the temporal variability in mean community parameters that were computed for each of the nine historic benthic monitoring stations, seven of which have been monitored continuously, including in 2011. Each major category of community parameter is discussed in the sections that follow.





Population density, shown in Figure 4.14a, measures the total abundance, or number of organisms, within a 1-m² area of the seafloor. It is the most basic single measure of a community of organisms, but lacks valuable insight as to how the abundance is distributed among the differing taxa. Because of this deficiency, it is not a useful ecological measure by itself. Nonetheless, major declines in organism density can occur after a rapid increase in sediment contamination. This initial decline is often followed by a marked increase in total abundance as opportunistic species repopulate the degraded environment.

Throughout the monitoring program, the number of organisms collected at each station has fluctuated enormously. Although the range in abundance covers almost an order of magnitude, differences in abundance among individual stations within any given survey were much smaller. Namely, all the stations tend to track the temporal fluctuations as a group, and spatial differences among stations within a given survey are generally small compared to the wide temporal fluctuations between surveys.

The largest population changes occur on a seasonal basis. Post-summer populations (those sampled during the October survey) are generally a factor of three higher than the post-winter populations. The reduced winter population, which was only measured prior to 1999, is a response to harsher oceanographic conditions when storms generate intense wave-induced currents that scour the bottom near the 15-m water depth of the outfall. Post-summer populations reflect recruitment of the more delicate annelid worms that can only survive during quiescent benthic-flow regimes. The absence of winter surveys after 1998 accounts for the uniform increase in density that is apparent in the last decade of the monitoring record.

Any spatial gradients in density are completely masked by the large temporal fluctuations. In particular, abundances at stations near the outfall (shown in red) were not consistently lower (or higher) than the density at distant stations (shown in black), and that lack of spatial distinction has remained constant throughout the monitoring program. This demonstrates that any accumulation of sediment chemicals from the effluent discharge over the last two decades has had no discernible impact on infaunal abundance, particularly when compared to large seasonal and interannual population fluctuations.

In 2010 and 2011, overall infaunal density (excluding sand dollars) reached the lowest levels since winter surveys were discontinued in 1999. Densities at some stations dropped below 600 m⁻² and were comparable to the lowest densities measured prior to 1999 after winter storms had culled large numbers of delicate taxa from the infaunal community. This overall drop in abundance in 2010 and 2011 coincides with the establishment of the sand dollar bed. Now that the sand dollars are maturing and are substantially larger in size, their presence may be physically impacting the infaunal community structure and availability of resources (e.g. surface area for tube feeders; competition for food).

Number of Species

The total number of species is another measure of the overall health of benthic communities (Figure 4.14b). Everything else being equal, infaunal communities respond to environmental stresses by becoming less diverse, as reflected by a substantial reduction in the number of species. However, the number of species encountered in a sample is directly related to the number of organisms in the sample, i.e., it is inherently related to sample abundance. Because rare species are generally undersampled, the number of species automatically increases in samples with more organisms. Thus, it is difficult to tell if a decreased number of species is due to an actual decline in biodiversity, or simply due to decreased sample sizes (abundance). Irrespective of the influence of sample size, reductions in species counts would suggest a decline in diversity and degradation in the marine environment.

No obvious long-term trend in numbers of species is apparent, suggesting that sedimentary conditions near the outfall have not been preferentially degraded (Figure 4.14b). Specifically, there was no obvious

divergence in the colors over time, where species counts at stations distant from the outfall, shown in black, steadily increase relative to stations near the outfall. As with abundance, any spatial differences in the 2011 data were minor when compared to seasonal and interannual fluctuations.

Beginning in 1996, there was a steady increase in the number of species encountered in samples. This trend culminated in 1999, when 84 species were collected at Station B8 alone (green line with crosses). However, this increase was largely due to the increased prevalence of ornate tubeworms (*D. ornata*) within some of the samples. For example, between 1990 and 1996, only one, and usually no *D. ornata* specimens were collected during any given survey. However, in the post-winter surveys of both 1997 and 1998, two ornate tubeworms were encountered. In 1999, four of these tubeworms were found at Station B8 alone. These tubes were not removed prior to sieving as they are now, and as discussed previously, the inclusion of numerous epiphytic taxa associated with their tube casings resulted in the unusually large number of species recorded in 1999.

The other temporal fluctuations in species counts tended to track the fluctuations in abundance. Consequently, at least some of the variability in the numbers of species is an artifact of the sample size (abundance) rather than purely an increase in species richness or diversity. As with the density time histories, species counts were low in 2011 compared to the prior decade. Only 28 species were found at some stations, which is comparable to the limited species counts found in post-winter surveys conducted prior to 1999. Again, the reduced numbers of species in 2011 probably arose because the more delicate organisms were eliminated through competition from the sand dollars, just as they were eliminated by mechanical disturbance during storms as reflected in post-winter surveys conducted prior to 1999.

Diversity

A large number of interrelated diversity indices have been developed in an attempt to account for the inherent relationship between the number of species and sample size or abundance. Two common indices are the Shannon Diversity (H') and the Brillouin index (HB) (Appendix B.1.1). Both exhibit nearly identical time histories in the MBCSD database, so only the Brillouin index is shown in Figure 4.14c.

Ostensibly, diversity should decrease in a degraded benthos, although significant reductions can also occur in the absence of anthropogenic stresses. Nevertheless, temporal trends in diversity did not exhibit any evidence of a deteriorating benthic environment near the outfall. On the contrary, in recent years the highest diversity was typically observed at one of the two stations located closest to the outfall (shown in red). Higher diversity at the two ZID stations indicates a healthy infaunal community close to the outfall rather than a community impaired by the discharge of effluent.

Nevertheless, two large historical outliers in diversity warrant discussion. First, the markedly high diversity (3.39) that was measured at nearfield Station B8 in 1999 was an artifact of the enumeration of additional epiphytes residing on the casings of ornate tubeworms. As discussed previously, the presence of a large number of epiphytic species heavily influenced both the overall abundance, and number of species counted at this station during the 1999 survey (Figure 4.14ab).

The second unusual outlier was the very low diversity (1.51) that was found at Reference Station B1 during the October 1994 survey (black square ■ in Figure 4.14c). As with outlier described above, there were an unusually high number of organisms enumerated in the samples collected at this station in 1994 (Figure 4.14a). However, in this case, the increased abundance was associated with a single species, the spioniform polychaete worm *Magelona sacculata*. Nearly 1,000 specimens were collected at Station B1 during the October 1994 survey. As a result of the numeric dominance of this one taxon, the computed diversity at this station was low.

M. sacculata is often one of the numerically dominant taxa found in northern Estero Bay, but on average, only approximately 50 specimens are typically collected at each station. Although magelonids are common in sandy bottom sediments, their distribution is patchy, so a few replicate samples typically contain most of the specimens, while other grab samples from the same station contain none. Nevertheless, the presence of this surface detritus feeder can be considered marginally indicative of degraded sediment conditions. However, the abnormally increased abundance in 1994 occurred at the reference station, and thus bore no relationship to effluent discharge.

Interestingly, during the 2011 survey, only two *M. sacculata* specimens were collected among the seven sampling stations, and their general absence was partially responsible for some of the highest trophic indices ever measured during the 26-year monitoring program (see the discussion of the trophic index below). Competition with large volumes of sand dollars could explain the general absence of this delicate marine worm, as well as the overall reduction in biodiversity observed during the 2011 survey.

Dominance

The Swartz species dominance index differs from the community indices discussed previously because it does not make an *a priori* assumption concerning how individuals are distributed among species. Because it is non-parametric, it is less sensitive to the limitations that plague other community indices. It is defined as the total number of species accounting for 75% of the individual organisms collected. As such, it represents an inverted measure, in which increased dominance is associated with lower values of the Swartz index.¹ Increased dominance is expected in degraded benthic communities where a few opportunistic, pollution-tolerant taxa abound in the absence of a wider array of pollution-sensitive organisms. As with the other community parameters, Figure 4.14d shows that differences in dominance among stations in a given survey were generally small compared to temporal fluctuations. Overall dominance was generally low during 2011, with five or more species typically sharing numerical superiority. In fact, in most surveys, organisms were more evenly distributed among taxa at the outfall stations (shown in red) than at more distant stations. This is opposite of the pattern expected if effluent discharge had degraded the benthic environment.

By far the lowest historical dominance occurred in samples collected at Station B8 during 1999. During that survey, nineteen species accounted for 75% of the specimens collected. Judging from a Swartz index that normally is near eight species, up to 10 of the 19 dominant species that were found at Station B8 during 1999 were epiphytic organisms associated with the presence of ornate tubeworms. The exclusion of these tubeworms from subsequent surveys has resulted in more stable and representative values of the Swartz index.

As with the other indices, species dominance during the October - 2011 benthic survey was unusual. At some stations, only 5 species encompassed 75% of the specimens in the benthic samples collected. This is the highest dominance observed in nearly a decade, and although it is consistent with, and mirrors the drop observed in density, species counts, and diversity, it represents a somewhat independent community measure because of its non-parametric computational basis. Nevertheless, all of these community measurements indicate that the infaunal population in 2011 had lower abundance and fewer taxa compared to other recent surveys, including those of the last two years when large numbers of sand dollars were also present. However, at the time of both those surveys, the average size of the individual sand dollars was substantially smaller.

¹ Note that the vertical axis of the Swartz index plot is inverted in Figure 4.14d so that values that are located higher in the plot represent increased dominance.

Clean-Sediment Feeding Guilds

The Infaunal Trophic Index (*ITI*) (Word 1978, 1980, 1990) compares the abundance of four soft-bottom assemblages that are distinguished by their feeding behavior. Because sensitivity or tolerance to organic enrichment differs among the four groups, shifts in the dominance of the individual feeding groups, as reflected by a change in the Trophic Index, can be indicative of a benthic environment degraded by organic material. The *ITI* ranges between 0 and 100. When species in Group I (suspension feeders) and Group II (surface-detritus feeders) dominate, index values are above 58, indicating that sediments are relatively clean, or at least devoid of organic material. Lower infaunal indices occur when populations of species in Group III (surface deposit feeders) and Group IV (subsurface detritus feeders) are prevalent. Their increased presence results when sediments are rich in the organic material that acts as a food source for these organisms.

The *ITI* has been exceptionally high throughout the monitoring program, typically exceeding 80 (Figure 4.14e). This reflects a community dominated by suspension-feeding organisms, with few organisms that depend on organic material to survive. The exceptionally clean sediments of Estero Bay have always been documented with a trophic index well above the critical *ITI* of 58, below which organically altered benthic conditions are thought to exist. In fact, trophic indices have always exceeded 70 at the MBCSD benthic stations, confirming the consistent dominance of suspension and surface-detritus feeders in the relatively clean sedimentary environment offshore Morro Bay and Cayucos.

Moreover, there is no consistent pattern of organic degradation close to the outfall evident in the *ITI* time series. Effluent-related degradation would appear as a gradual separation in colors over time, with stations closest to the diffuser structure (shown in red) eventually having the lowest *ITI*. This would be followed by a slightly higher *ITI* at nearfield stations, shown in green. Instead, as with the other community indices, and with the chemical concentrations, there is no consistent pattern of color separation from year to year.

Occasionally, however, an outlier *ITI* will occur within a given survey. For example, there have been two anomalously low *ITIs* associated with ZID Station B5: one in the year-2000 survey, and the other in 2010 (red squares in Figure 4.14e). Although they were not particularly low compared to *ITIs* reported in some other years, they stand well apart from the other *ITIs* reported in the same year at other stations. Detailed analysis in Section 4.4 of MRS (2011a) identified the outfall as the source of organic material that caused a marked increase in subsurface detritus feeders at that particular sampling station. However, instead of wastewater discharge, the source of the organics was the debris field that exists immediately adjacent to the outfall structure. These two instances of anomalously low *ITIs* arose because Station-B5 grab samples were inadvertently collected extremely close to the diffuser structure. In addition to their low *ITIs*, the sediment samples contained significant amounts of shell hash and surficial debris that made them visually and volumetrically distinguishable from other samples collected farther from the diffuser. Significant amounts of organic debris accumulate in the sediments next to seafloor structures like the outfall pipe, as epifauna die and slough off the structure. In the case of the outfall, debris is also purposely dislodged by divers cleaning the diffusers, or accidentally dislodged by collisions by the grab. Like the shell mounds below offshore platforms, the accumulation of organic debris can be quite large but is localized very close to the structure. Consequently, the structure's debris field never encountered when grab samples are collected more than a few meters away. In addition to the organic enrichment, these structural debris fields support a unique community of benthic organisms with an affinity for high concentrations of organic material, and which weighs heavily in the reduction of the *ITI*.

With the exception of the anomalously low *ITI* measured next to the diffuser structure at Station B5 in 2010, *ITIs* in the last three years have been among the highest ever observed in the entire 26-year benthic

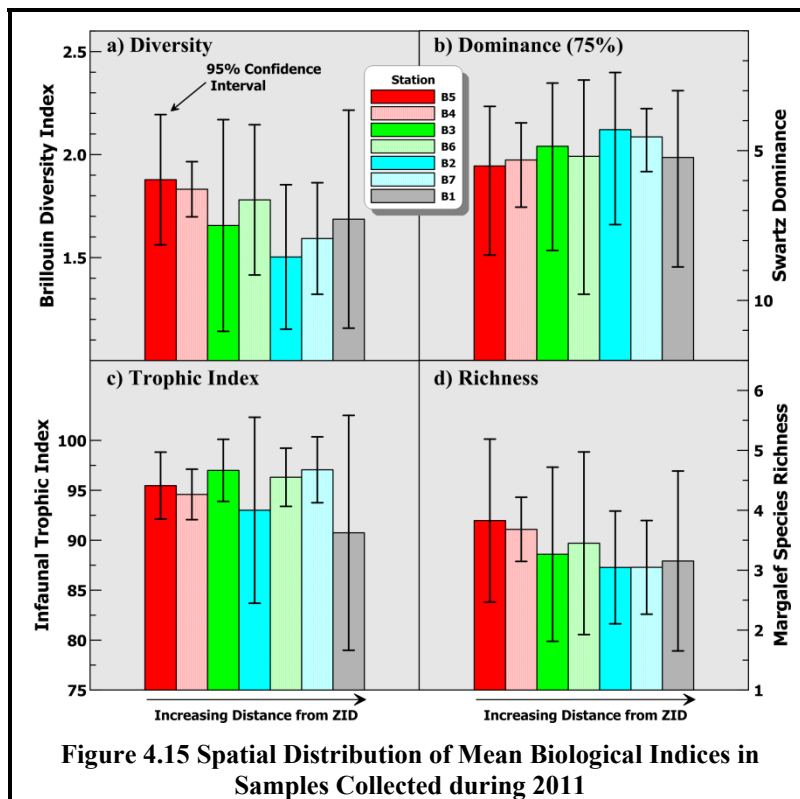
monitoring program. With *ITIs* as high as 97, the infaunal community consists almost entirely of suspension feeders (Group I) residing in sediments with reduced organic content. This finding is confirmed by the steady decrease in sediment BOD concentrations that occurred in the last two years, culminating in 2011 with the lowest concentration recorded in the last decade (Figure 4.9b). As discussed previously, the establishment of a maturing sand dollar bed provides the most plausible explanation for the observed changes in the infaunal community parameters. However, the associated *ITI* increase and BOD decrease suggests that the mechanism for the infaunal change was primarily trophic, rather than predation or competition for space. Apparently, the large community of filter-feeding sand dollars reduces the amount of detritus and other organic material that is normally deposited and incorporated within the sediments of northern Estero Bay, leaving little food available for other infauna except those that also survive on organics suspended in the water column (Group I suspension feeders).

4.3.2 Infaunal Diversity Unrelated to Outfall Proximity

The previous section documented the overall health of the infaunal community surrounding the outfall using a 26-year record of infaunal community indices. This section investigates whether spatial trends related to outfall proximity exist in the infaunal data collected in 2011. As described in Appendix B.1, four of the biological indices are more informative than the other indices. They include the Brillouin Diversity Index, the Swartz Dominance Index, the Margalef Richness Index, and the Infaunal Trophic Index (*ITI*). The 2011 spatial distribution of average values for these four indices is shown in Figure 4.15.¹

The bars shown in Figure 4.15 are arranged in order of increasing distance from the diffuser structure. The red-colored bars on the left are associated with the ZID stations located closest to the diffuser, while the two green bars in the middle represent the nearfield stations. Finally, the blue and gray bars that are farthest to the right represent the three distant stations, which lie 140 m or more from the outfall.

Impacts to infaunal communities from the discharge would be reflected in the bar chart as a spatial trend of steadily increasing diversity, *ITI*, or richness from left to right (Figure 4.15acd). In contrast, dominance would be expected to decrease with increasing distance from the outfall (Figure 4.15b). However, none of these spatial trends is visually apparent in the Figure. If anything, the opposite appears to be the case.



¹ Note that the values plotted in the time histories of Figure 4.14 are station totals, and differ from the averages among replicate samples plotted in Figure 4.15.

Another way of evaluating whether significant spatial differences exist among the infaunal indices is to test whether any of the average values are significantly different from those of other stations, irrespective of their distance from the outfall.¹ The height of the bars in Figure 4.15 reflects the average index computed from the five replicate samples collected at each station. The 95% confidence intervals surrounding those averages quantify the variability among replicate samples collected at each individual station. As such, the confidence intervals reflect the inherent uncertainty in the determination of average station values. Thus, if the mean at one station is encompassed within the confidence interval at another station (or vice versa), then no statistical significance can be ascribed to any perceived difference between the averages at those two stations, at least with any degree of confidence (viz., a 95% confidence level, $\alpha \leq 0.05$). Visual inspection of Figure 4.15 indicates that the differences in average indices between all but one pair of stations were encompassed by the associated confidence intervals.

The only exception is the difference between the average diversity at Stations B5 and B2 (solid red and blue bars in Figure 4.15). The lower confidence bound on the higher average diversity at Station B1 does not quite encompass the lower average diversity at Station B2. Similarly, the upper bound interval at Station B2 is slightly below average density at Station B5. However, the average diversity at the ZID station (B5) is higher than at the distant station (B2). Higher diversity near the outfall is opposite of what would be expected if the MBCSD discharge was having a deleterious impact on the local infaunal community. Consequently, the null hypothesis test is irrelevant to the compliance analysis, regardless of its marginal statistical significance. The purely spatial analysis shows that if any potential spatial differences in infaunal community indices existed in the 2011 database, they were either too small to be reliably quantified or were in direction opposite of what would be expected from a negative discharge impact.

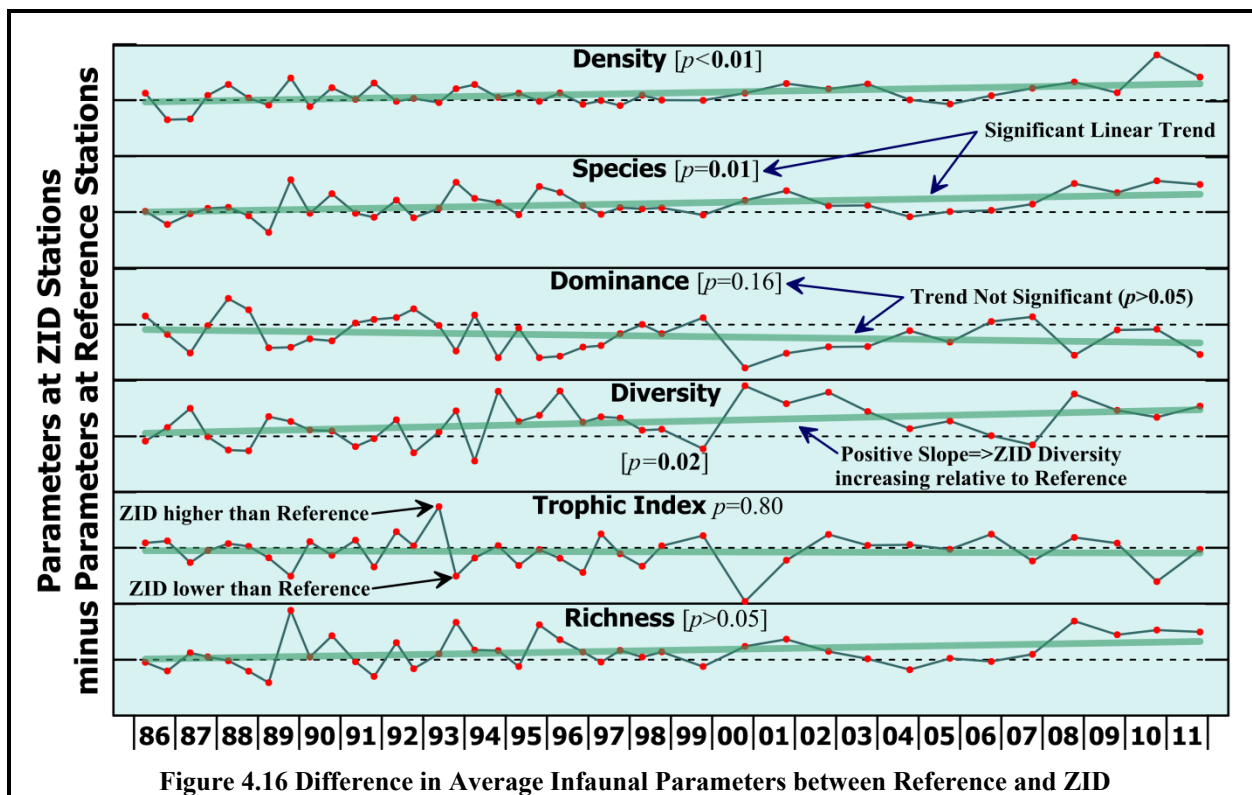
4.3.3 Spatiotemporal Infaunal Trends Unrelated to Outfall Proximity

As with the chemical constituents within northern Estero Bay sediments, subtle spatiotemporal trends in the infaunal community can be difficult to discern in the time series shown in Figure 4.14. The parameters exhibit wide fluctuations between seasons and years. Compared to these large temporal oscillations, the spatial differences among samples collected at a given time (i.e., within a given survey) were comparatively small. In other words, the stations generally tracked one another through time. This indicates that changes in infaunal communities that arise because from regional influences throughout Estero Bay are far larger than those induced by any localized effects. Therefore, within a given survey, spatial differences in infaunal parameters can be difficult to differentiate, and are likely to be confounded by larger natural differences in the sedimentary environment and other zoogeographic influences.

The limitations associated with purely spatial or purely temporal approaches to impact evaluation are largely eliminated through the use of the same statistical analysis technique used in Section 4.2.3. It is based on tests for nonparallel trends at impact and reference sites (Coats et al. 1999, Skalski et al. 2001). In this application, these parallelism statistical tests are capable of discerning subtle temporal trends in the difference between average indices at stations located near the outfall, and those that are distant from the outfall, even though the indices as a whole widely fluctuate from survey to survey. As described previously, discharge-related spatiotemporal changes would appear in Figure 4.14 as a gradual separation of the colors as contaminants accumulate near the outfall and affect the resident organisms. However, because of the large coherent fluctuations that occur over time, subtle spatiotemporal changes in community structure may be present but not visually apparent in that kind of presentation. Taking the

¹ This is equivalent to an unpaired two-sample Student *t*-test of the null hypothesis that there is no difference in mean values between stations at the 95% confidence level assuming unequal variances and a two-tailed distribution.

difference in average values at distant and near sites removes the temporal oscillations that occur on a seasonal and interannual basis. In effect, parallelism assumes that the large temporal excursions in indices occur in unison at all stations and represent a simultaneous response to regional influences. Time series of differences in parameters at ZID and distant stations are presented in Figure 4.16.



If the MBCSD discharge were negatively affecting the benthic community over time, the infaunal properties of populations at stations near the outfall (4 and 5) would slowly diverge from those of the distant stations (1, 2, and 7). This would appear as a trend or slope in the difference average indices shown in Figure 4.16. A regression test for a statistically significant trend (slope) in the difference is equivalent to a test of the null hypothesis that the population responses at impacted and non-impacted sites are parallel over time.

Parallelism tests applied to the 26-year time series found slight, but statistically significant, positive linear trends in three infaunal indices: density ($p = 0.004$), number of species ($p = 0.010$), and diversity ($p = 0.025$). The slight increases in the difference between these indices at ZID and reference stations are apparent as a small slope in the linear regression lines shown in Figure 4.16. The trends arose because, in recent years, the ZID stations have exhibited increasingly greater density, species counts, and diversity compared to reference stations. This is opposite of the temporal trend one would expect if the effluent discharge was having a deleterious impact on the benthos near the outfall. Higher abundance and diversity at stations close to the outfall reflects a healthier infaunal community compared to the distant reference stations.

Although parallelism could not be rejected for species richness ($p = 0.054$), the significance test was marginal. However, as with other indices, a trend where the variety of species is increasing over time near the outfall is opposite of what would be expected from a community that was being negatively impacted

by the MBCSD discharge. Parallelism tests for trends that are opposite of that expected from an increasing impaired infaunal community near the outfall are irrelevant to the impact assessment, and their p -values are enclosed in brackets in Figure 4.16. This was the case for all of the infaunal community indices except the nearly imperceptible negative trend in the ITI, which was so small that parallelism was strongly indicated ($p=0.80$).

4.3.4 Infaunal Community Structure

As described above, determining whether adverse biological conditions exist near the MBCSD outfall involves assessing whether the existing benthic environment supports a balanced indigenous population (BIP). A BIP is an ecological community that exhibits characteristics similar to those of nearby, healthy communities existing under comparable, but unpolluted, environmental conditions. In evaluating a BIP, infauna have an important advantage over other marine organisms, such as marine mammals or finfish. Infauna are relatively easy to collect in numbers large enough for reliable statistical testing, and they do not move about over large areas, so their response is site specific. Benthic pollution affects marine ecosystems by changing the infaunal community structure, namely, the number and type of benthic organisms found in the sediments. However, evaluating the well-being of the infaunal community, and testing its variation over time and space is complicated by the multitude of individual taxa collected within each replicate grab sample. Subtle changes in community composition are not always readily apparent in the large volume of raw data generated by field surveys.

The multivariate complexity of infaunal abundance data makes a BIP analysis challenging because it is difficult to quantify the health of the community into a concise parameter that is indicative of existing environmental conditions. Biodiversity is a common indicator of the well-being of ecological systems, and forms the cornerstone of most impact-assessment studies. It was the basis for the impact assessment described in the previous two sections. However, as described in Section 4.1.4 and Appendix B.1, diversity and other univariate parameters can miss subtle changes in community structure that are reflected by differences in the abundance of individual taxa, but not in the individual indices. For example, two grab samples can have identical infaunal indices, without having a single species in common.

Despite the univariate parameter's inability to capture potential changes in community structure, most benthic monitoring studies routinely report standard infaunal community indices, and rely on them in their examinations of temporal and spatial trends. As described in previous sections, the historical record of univariate analyses provides a useful backdrop for evaluating the large infaunal dataset, but the potential for changes at the species level must also be examined. One of the difficulties with infaunal indices is that they only reflect the diversity within a local area at a particular time (α -diversity). In contrast, pollution and other stresses tend to induce major changes in community composition where completely different (pollution-tolerant taxa) communities begin to inhabit an impacted area, and result in infaunal assemblages that differ widely across the samples collected through time at widely separated locations. That kind of diversity is measured by β -diversity (Smith et al. 1979). Thus, analysis of individual measures of α -diversity within samples is not well suited to an infaunal dataset containing moderate levels of β -diversity (heterogeneity), such as in the 2011 infaunal dataset. Compositional differences among the 35 samples collected in 2011 were moderately large, as demonstrated by a Whittaker (1972) β -diversity of 4.5.¹

¹ β_w measures the ratio of the total number of species in the dataset to the average number species in the samples, minus one. If $\beta_w=0$, then all the samples have the same number of species. $\beta_w=4.5$ indicates that the entire database had over five distinct communities, with 5.5-times as many species (79) as the average individual sample (14).

Multivariate techniques are much better suited to the evaluation of datasets with high β -diversity. The 2011 dataset used in this multivariate analysis consisted of a matrix of counts for 95 taxa¹ in the 35 samples. Analyzing this complex matrix for potential differences among samples by comparing differences in each individual species is intractable, not just because of the number of species, but because many pairs of samples have few species in common. In response to these challenges, ecologists have, over the last 50 years, developed specialized multivariate analysis tools. These analysis techniques are highly effective at extracting the dominant patterns from complex species-sample databases. The multivariate techniques employed here exploit redundancies (correlations) in the abundance of individual species among the samples, and compress the data into the most meaningful patterns.

Inherent Sampling Variability

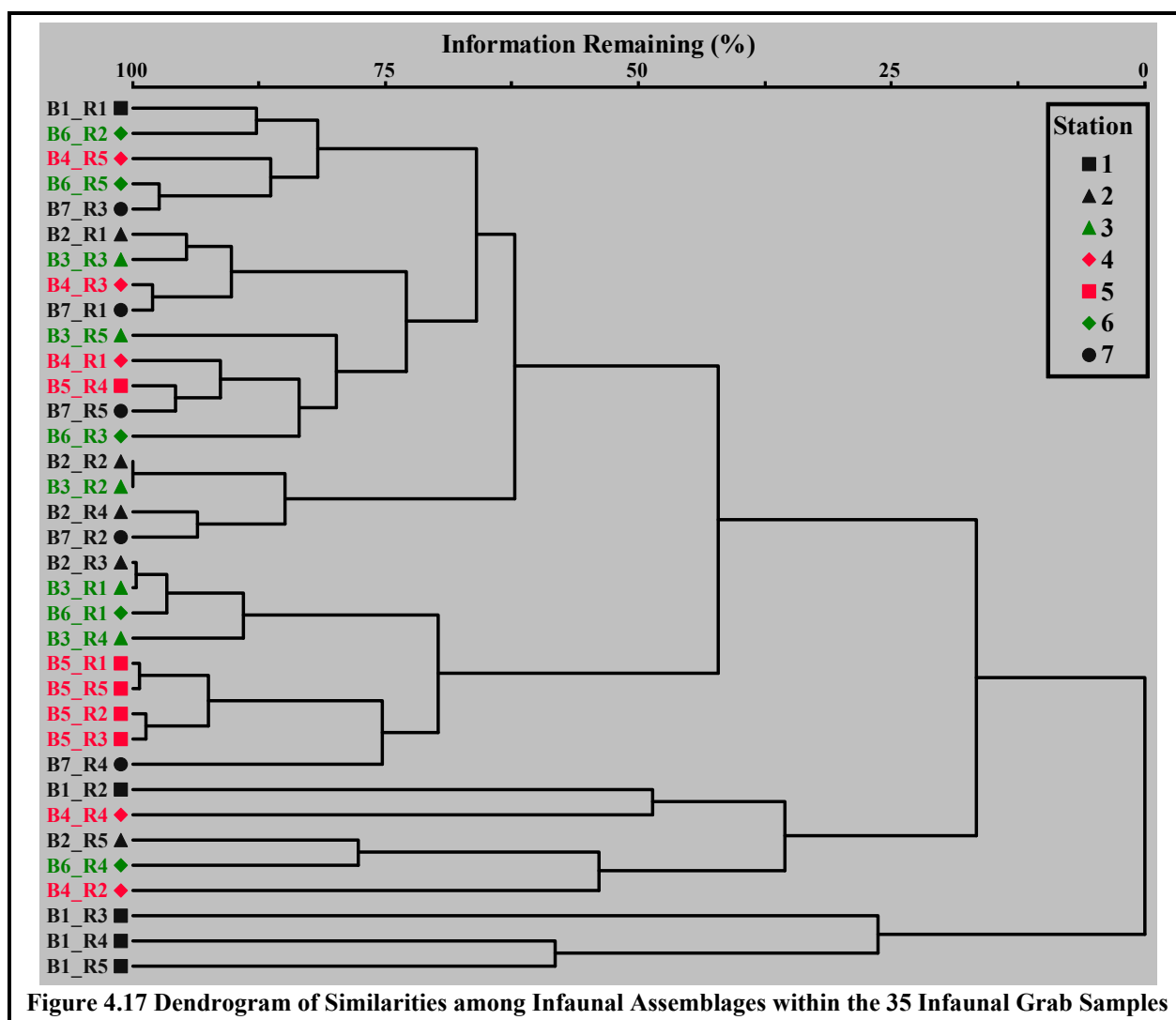
As with the other field measurements, it is crucial to determine the inherent variability associated with estimating the infaunal community at a given station. Variability among repeated replicate grab samples collected from an individual station at a particular time lends insight into the inherent uncertainty in average values reported for each station. This within-station variability is fundamental for testing hypotheses concerning the significance of perceived differences between samples collected at different locations. If the inherent sampling variability is statistically larger than the observed difference between the two stations, then the spatial difference cannot be considered significant.

A dendrogram (tree diagram) produced from the multivariate species database provides a convenient graphical means for determining the relative magnitudes of within-station and between-station infaunal variability among the samples (Figure 4.17). Testing the relative variability among the 35 individual grab samples collected during 2011 indicates whether differences among replicates collected at a station are smaller than the differences between the stations, indicating that spatial differences are large enough to be reliably resolved, even in the presence of inherent sampling uncertainty associated with station averages.

Dendrograms display the relative similarity in the infaunal assemblages among samples, or groups of samples, using a branched diagram similar to the branches on a tree. Sample pairs that have the most similar assemblages coalesce into a branch toward the left on the percent-information-remaining axis. The horizontal axis at the top of the dendrogram reflects the amount of information (variability) that is left in the sample-species matrix after two samples are combined. Combining samples with relatively similar species composition results in a minimal loss of information (variability) in the original species-sample matrix. For example, Figure 4.17 shows that the infaunal assemblages within Replicates R1, R2, R3, and R5 from Station B5 were nearly identical, and considering them as a single combined assemblage results in a minimal (9%) loss of multivariate information. As more samples, or other groups, are added to each branch, the differences in the assemblages associated with each group become increasingly larger, and as each group is combined into a new group, more overall information about the differences in the assemblages is lost.

The dendrogram for the 2011 database shows that replicate grab samples collected from an individual station only occasionally contained assemblages that were more similar to one another than to the assemblages present within sediment samples collected at other stations. Individual replicates are color- and symbol-coded by station. For example, only the previously mentioned four replicate samples from Station B5, and Replicates R3, R4, and B5 from Station B1 contained infaunal assemblages that were similar to one another, and distinguishable from the communities at other stations. The infauna within all

¹ Because the multivariate analysis examined differences in community structure among the samples, and not specifically diversity, additional specimens could be included in the database. These additional specimens were not identified to species level, usually because they were juveniles and too small for reliable taxonomic identification.



of the other replicate samples did not cluster first with other samples from the same station. The absence of within-station clustering is very different from the samples collected in 2010 (MRS 2011a) when infauna within replicate samples from the same station often exhibited a greater similarity to each other than to replicates from other stations. Inherently high infaunal variability within the 2011 database, however, resulted in a multivariate analysis that was generally incapable of clearly distinguishing spatial differences in the infaunal communities among most stations.

A statistical analysis of multivariate variance (MANOVA) confirmed that the within-station similarity of replicate samples from five Stations B2, B3, B4, B6, and B7 was no greater than that expected by chance ($p=0.35$). The p -value cited here, and throughout this section, is the probability that the measured difference between stations could have occurred by chance alone. It is determined by comparing the magnitude of the difference between stations, with the scatter in the replicate samples collected at a particular station. If the scatter in replicate samples is large compared to the difference in sites, then the station difference is more likely to be an artifact of chance alone, rather than a real spatial difference. Generally, differences in groups are considered statistically significant when p -values are less than 0.05,

which corresponds to a 5% (1-in-20) probability that the difference occurred by chance alone. Thus, any perceived infaunal differences among the five similar stations was likely (35% chance) to have been due to random sampling uncertainty.

In contrast, when the strong replicate groupings in samples from reference Station B1 (black squares in Figure 4.17) and ZID Station B5 (red squares) are included in the MANOVA, the overall within-station fidelity was found to be highly significant ($p=0.0002$). However, the character of the replicate clustering at Station B1 differed greatly from that of Station B5. As reflected in the dendrogram, the infaunal assemblages among the four replicates at Station B5 were very similar to one another, and in combination, their assemblage began to appear similar to the combined assemblages from other stations with about 75% of the information remaining. The three replicates samples (R3, R4, and R5) at Station B1, on the other hand, had a very different type of within-station fidelity. Their infaunal assemblages were very different from each other, and only appeared similar after nearly all other replicates were combined (27% of the information remaining). Moreover, their combined infaunal assemblage was vastly different from the infauna within the 32 other sediment samples collected in 2011.

As a whole, this analysis of replicate samples demonstrates that infaunal differences among the stations were generally less than the variability within replicate grabs collected at individual stations. Thus, the statistical analyses indicate that spatial gradients were not large enough to be easily discerned within the 2011, except perhaps at Station B1 and B5.

Spatial Variability

The dendrogram revealed that the most distinct suite of infauna assemblage resided within the four replicate samples collected south of the diffuser structure at Station B5. Samples collected at the distant reference Station B1 also contained taxa that were different from most other samples collected in 2011, although they were also quite different from one another. The absence of discernible spatial differences among the infaunal communities at other stations was due to high overall variability caused by the patchy distribution of large numbers of sand dollars. Although the sand-dollar enumerations were not included in the multivariate analysis, their presence indirectly influenced the type and number of infauna that coexisted with them. As a result, those co-occurring taxa exhibited wide variability.

As described previously, the presence (volume) of a maturing sand dollar bed within the survey area during 2011 was readily apparent in the infaunal indices of community structure compared to those of prior years. Specifically, the infaunal community in 2011 was less abundant and less diverse compared to prior years. Multivariate analyses demonstrate that these declines were largely due to the general reduction in populations of organisms that feed on surficial and subsurface organic material. Their absence coincided with a reduction in their food source, as reflected by the decline in sediment BOD concentrations in 2011.

The declines in organic deposits, and their associated infauna, were undoubtedly related to the increased size of high numbers of sand dollars in 2011. However, the sand-dollar bed in 2011 was also extremely patchy, and this heterogeneity occurred over very small spatial scales of less than the 1.4-m average distance between grab samples at a given station. This is apparent in the wide variation in sand-dollar counts among replicates at a given station; for example, at Station B1, Replicate R2 only had four sand dollars while Replicate R3 had 275. In one instance during the 2011 field survey, the grab encountered the sharply defined edge of a patch of sand dollars wherein half of the grab was completely filled with sand dollars throughout the entire depth of the sample, while the other half was filled with normal-looking sediment without a single sand dollar present.

Given the patchy nature of the sand-dollar distribution and their influence on resident infauna, it is not surprising that replicate grab samples exhibited widely different infaunal assemblages at the same station.

The differences were so large that they overwhelmed any small spatial differences in infaunal communities among most stations. This was apparent in the cluster analysis described previously. However, a related multivariate technique lends further insight into the nature of the spatial differences in the 2011 infaunal database.

A two-dimensional ordination¹ plot provides a visual interpretation of the differences in the infaunal communities found in the 35 samples collected during the 2011 benthic survey (Figure 4.18). It distills the major infaunal differences among samples as a distance between sample points in the multivariate

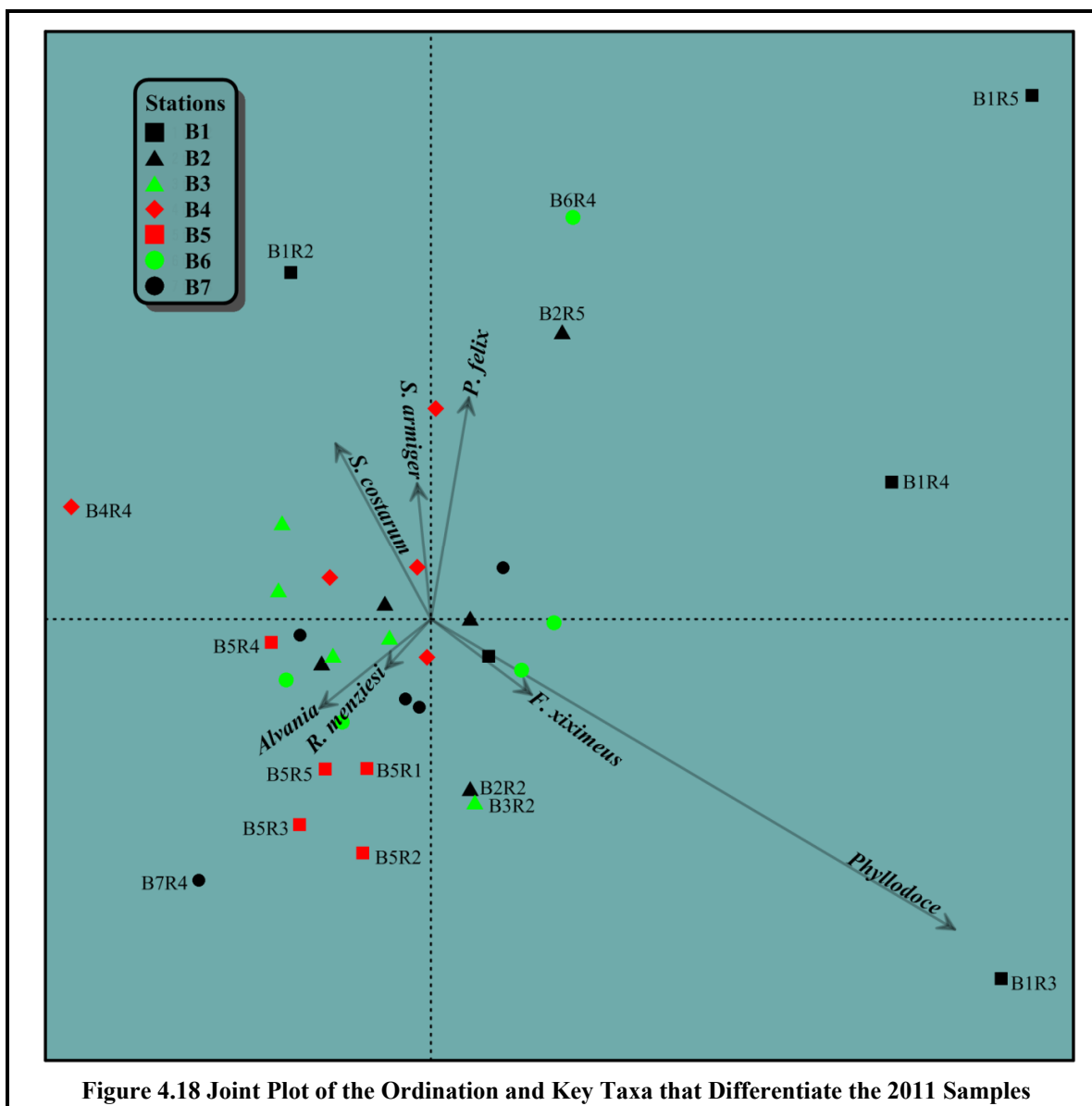


Figure 4.18 Joint Plot of the Ordination and Key Taxa that Differentiate the 2011 Samples

¹ The multivariate ordination was derived from a non-metric multidimensional scaling (Mather 1976, Kruskal, 1964) of Sørensen (Bray-Curtis) distance (Sørensen, 1948), the same multivariate distance measure used in the dendrogram. There was less than a 0.4-percent chance ($p=0.004$) that the stress measure of the final solution's fit could have occurred by chance based on Monte Carlo randomization tests.

hyperspace. As such, the diagram's axes do not represent distances in physical dimensions. Instead, the locations of the points within the diagram characterize the composition of the assemblage within individual benthic samples. The distance between a pair of points measures the degree of difference in the species compositions contained within those samples. Widely separated points have very dissimilar infaunal assemblages, namely, few species in common, and large differences in the abundance of those species that are common between the samples. In contrast, points that lie close to one another have assemblages with many common species and similar abundances between those common species.

In addition, separations in sample points along the horizontal axis of the ordination plot characterize a difference in species composition that fundamentally departs from differences in community composition along the vertical axis. Often, changes along the one axis may reflect large-scale zoogeographic differences while the other axis coincides with a local environmental gradient in the samples, such as a pollution gradient. For the 2011 data, however, the ordination plot failed to exhibit a consistent spatial pattern among stations (consistent with the dendrogram previously discussed). For example, the five replicates from the distant reference Station B1 did not all cluster together at the limit of one of the axes, as would be expected from a zoogeographic influence on the infaunal community. Although the three replicates with unusual assemblages identified in the dendrogram (B1R3, B1R4, and B1R5 in Figure 4.17) had positive X-axis values, and were well separated from the cloud of other replicate samples (near the origin), the other Station-B1 replicates were lost in the cloud of other sample points. In addition, the three unusual Station B1 replicates were widely separated along the Y-axis, indicating that the range in their assemblages was at least as large as the difference in the assemblage associated with all the other samples. Thus, the ordination plot further confirms that the variation in the infaunal assemblages among samples in 2011 was large, and that there was no discernible zoogeographic difference as had been observed in the past (MRS 2011a).

Similarly, the ordination plot does not exhibit a pattern that would be indicative of an infaunal community impacted by the effluent discharge. A discharge-related environmental gradient that was influencing the infauna surrounding the outfall would appear as a cluster of red symbols that was isolated from the other sample points, and that reflected an impacted infaunal assemblage close to outfall. Although the four very similar replicate samples from ZID Station B5 had ordination points located close to one another (red squares), they were not widely separated from the cloud of other ordination points. This indicates that the infaunal community at Station B5 was not particularly different from other stations, although the assemblages within those four replicates were unusually similar.

Influential Taxa

The abundances of individual species within a given replicate sample, as compared to that of another sample, are difficult to discern and interpret when an investigator is faced with the enormous amount of information contained in the 2011 infaunal database listed in Table B.1. Although perusal of the table may reveal patterns for specific taxa, it is difficult to decide how important the differences in counts of one taxon are, relative to another. Additionally, many species co-occur and yield the same distribution among samples, further confusing the interpretation. Finally, the most abundant taxa are often not the most diagnostic of potential impacts because they are present in substantial numbers within all the samples.

Multivariate community analysis was designed to quantitatively distill this complex set of information, to eliminate redundant or marginal patterns, and to produce most important information concerning how the communities within individual samples relate to one another. The analysis described in the previous subsections identifies a few of the key differences among replicate samples at Stations B1 and B5 during 2011 that stood out against the scatter due to sampling variability. While this is the primary goal of the

multivariate analysis, it also identifies which taxa primarily influence the community differences among replicate samples. Those influential taxa often have life-history information, such as a tolerance or sensitivity to pollution and organic loading, which can lend further insight into the potential impacts from effluent discharge.

An indicator species analysis compliments the multivariate sample analysis described above, and is graphically overlain on Figure 4.18. The degree of influence of individual, highly influential taxa is represented by arrows (vectors) is superimposed on the ordination plot discussed previously. The length of an arrow for an individual taxon reflects how strongly it participated in differentiating the samples, and its direction points toward samples that have a comparatively elevated abundance of that taxon. Conversely, arrows pointing away from samples reflect a comparatively low abundance of an indicator taxon.

The elevated presence of two taxa in the unusual replicate samples collected at Station B1 was particularly indicative of their infaunal assemblage. The most influential, at least for Replicate R3, were the annelid worms within the genus *Phyllodoce* spp. Sixteen of the 18 specimens collected during the 2011 survey were found in this one replicate sample (Tables B.1 and B.2 in Appendix B). Similarly, the gammarid amphipod, *Foxiphalus xiximeus*, was prevalent in all three replicate samples, and accounted for one-third of the specimens collected during the entire survey. Neither species has a life history that is particularly diagnostic of unusual environmental conditions. However, it is noteworthy that the sand-dollar counts within these three replicate samples were among the highest found within the 2011 survey. In fact, two of the replicates (R3 and R5) had sand dollar counts exceeding 270 specimens; the replicate with the next highest count only contained 201 specimens. It is therefore reasonable to assume that the two indicator species identified in the ordination plot were associated with the unusually dense sand-dollar bed sampled by the three replicate grabs at Station B1.

In contrast, the tightly clustered group of replicate samples from Station B5 (red squares labeled B1R1, B1R2, B1R3, and B1R5 in Figure 4.17 and Figure 4.18) were not associated with an unusual sand-dollar abundance. Instead, their separation along the negative Y-axis was caused by a relatively increased abundance of a genus of small sea snails (*Alvania* spp.) and the phoxocephalid amphipod *Rhepoxynius menziesi* (arrows that point down toward the Station-B5 sample points in Figure 4.18). The B5 samples were also distinguished by a relatively low abundance of the marine worm *Scoloplos armiger* (one specimen) and the absence of the *Phylofelia* worms that were present in other samples (arrows that point up along the positive Y-axis of Figure 4.18). Based on the life histories of these key differentiating taxa, the infaunal assemblage within the unusually similar replicate samples at Station B5 was not indicative of degraded benthic conditions at this ZID location.

On the contrary, the indicator taxa characterize a healthy infaunal community with an abundance of pollution-sensitive suspension feeders and a general lack of opportunistic taxa that feed on organic material. Normally, opportunistic, pollution-tolerant polychaetes, such as *S. armiger* and *P. felix* increase in abundance in response to excessive organic loading around municipal wastewater outfalls. Their increased abundance comes at the expense of more pollution-sensitive phoxocephalid amphipods, such as *R. menziesi*. Phoxocephalids are active suspension feeders known to be extremely sensitive to pollution (Pearson and Rosenberg, 1978) and because of this, they are routinely used in bioassay testing of marine sediments (ASTM, 1991; USEPA-USACOE, 1991, 1993). However, the population of phoxocephalids at Station B5 exceeded that of most other stations, while there was a general absence of the pollution-tolerant polychaetes.

Thus, the results of the multivariate analysis were consistent with the findings from the analyses of infaunal community indices and sediment chemistry. Together, the weight of quantitative evidence

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CHAPTER 5

Conclusions and Recommendations

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5.0 CONCLUSIONS AND RECOMMENDATIONS

The MBCSD monitoring program was designed to evaluate the performance of the wastewater treatment plant and to monitor the quality of effluent discharged to the ocean. This annual report evaluated compliance with the NPDES discharge permit and documented potential discharge impacts through quantitative analyses of an extensive data set of effluent constituents, receiving-water measurements, sediment chemistry analyses, and marine biological enumerations. Of the thousands of measurements collected as part of the monitoring program during 2011, none exceeded the discharge limitations.

5.1 TREATMENT PLANT

The MBCSD Wastewater Treatment Plant (WWTP) has been operating under the provisions of a 301(h)-modified NPDES permit since 1986, with 2011 marking the 26th year of high performance by this treatment facility. In fact, many of the best measures of treatment performance have been achieved during the past eight years of operation (Table 5.1). For example, the low average effluent Total Suspended Solids (TSS) concentration in 2011 (27 mg/L) was the direct result of the treatment process's exceptional efficiency, which removed 92% of the influent solids. As a result, the 2011 solids emission was only 21% of that allowed under the NPDES permit.

Reductions in the discharge of oil and grease (O&G) and biochemical oxygen demand (BOD) also attest to the plant's overall high standard of performance. As with TSS, the discharge of O&G and BOD over the past several years has been exceptionally low, while their corresponding removal rates were high compared to the average rates achieved over the entire 26 years of monitoring (Table 5.1).

5.1.1 Overall Performance

Measurements of wastewater characteristics acquired throughout 2011 demonstrate that the treatment process exceeded expectations based on the original plant design, the NPDES discharge permit, and federal regulatory standards. For example, during 2011, the plant removed 17% more suspended solids than the minimum permitted, and the BOD removal rate was more than two and a half times greater than the minimum permitted rate of 30%. During eleven months of the year, effluent BOD concentrations remained at or below the 60-mg/L threshold, below which removal-rate requirements are not even applicable, while effluent TSS concentrations remained well below that concentration threshold throughout the entire year. Moreover, the plant routinely achieved treatment levels that exceeded the removal requirements for full secondary treatment. For example, monthly solids-removal rates substantially surpassed the 85% full secondary criterion throughout 2011, while BOD removal rates achieved full secondary levels during four months of the year. Other effluent constituents were also correspondingly low during 2011. The discharge of settleable solids was imperceptible, and monthly averages of effluent turbidity, pH, ammonia, and coliform density remained far below the applicable permit limitations.

The continued high overall performance of the treatment process during 2011 was the direct result of vigilant control of the process, and a proactive program of preventative maintenance. Plant personnel actively sought out and corrected potential mechanical problems with plant components before they occurred, and quickly responded to the occasional unforeseen failure. The benefits of past efforts to reduce rainwater inflow and groundwater infiltration (I&I), and to more accurately measure plant flow, are also evident in the record of annual average flow rates listed in (Table 5.1).

5.1.2 Flow Rate

Historically, the most influential factor affecting flow rate was a metering inaccuracy that resulted in flow overtotalization. A study conducted in 2002 found that rates reported by the effluent flow meter were consistently overestimated by as much as 25%. Without this overtotalization, average flow over the 26-year record would be closer to 1.19 MGD rather than the reported 1.39 MGD. Because of overestimated flow prior to 2002, the annual mass emissions were also overestimated. Consequently, the average emissions, shown in bold at the bottom of Table 5.1, are slightly inflated. Specifically, the reported average annual TSS emission of 63 MT is actually closer to 53 MT. Similarly, the average annual BOD emission reported at 96 MT is, in reality, closer to 83 MT, and the reported 11 MT of O&G discharged on average is closer to 9 MT.

Table 5.1 Average Annual Wastewater Parameters

Year	Flow (MGD)	Suspended Solids				Biochemical Oxygen Demand			
		Influent (mg/L)	Effluent (mg/L)	Removal (percent)	Emission (MT)	Influent (mg/L)	Effluent (mg/L)	Removal (percent)	Emission (MT)
1986	1.42	332	32.8	89.8	64	235	77.0	67.2	151
1987	1.51	274	21.8	92.0	45	257	52.0	79.8	108
1988	1.51	397	29.8	90.0	62	242	43.9	81.9	92
1989	1.46	321	37.3	88.4	75	259	69.8	73.1	141
1990	1.38	345	36.0	89.6	69	261	75.7	71.0	144
1991	1.28	280	30.5	89.1	54	236	66.9	71.6	118
1992	1.41	310	43.0	86.3	84	224	59.3	73.5	116
1993	1.54	339	33.0	89.6	70	222	39.0	81.9	83
1994	1.38	310	32.0	89.4	61	249	33.0	86.4	63
1995	1.55	270	30.6	87.6	69	208	31.4	83.9	67
1996	1.55	344	33.1	89.9	70	241	35.7	85.0	73
1997	1.64	283	36.0	86.6	79	231	38.6	83.0	85
1998	1.95	236	38.8	83.9	101	216	39.1	81.5	99
1999	1.68	386	44.0	86.7	102	287	49.5	82.5	118
2000	1.77	337	37.4	87.5	91	271	50.3	81.1	125
2001	1.48	450	37.6	89.5	74	396	62.7	83.1	127
2002	1.14	374	49.2	86.0	77	386	67.5	82.4	101
2003	1.06	314	39.2	86.7	56	311	56.3	81.3	81
2004	1.09	354	28.9	91.3	44	336	53.3	83.8	81
2005	1.25	373	24.3	93.3	42	303	49.8	83.0	88
2006	1.19	335	20.5	93.2	34	291	45.3	83.8	75
2007	1.09	381	20.9	94.1	31	330	44.4	86.0	68
2008	1.10	337	20.0	94.1	30	331	38.4	88.3	58
2009	1.09	328	25.3	92.3	38	311	37.6	87.4	56
2010	1.19	383	26.6	92.1	42	350	49.4	85.2	85
2011	1.24	343	26.8	92.4	45	312	52.2	83.2	89
Average	1.39	336	32.3	89.6	63	279	50.6	81.1	96
Limitation	2.06		70.0	75.0	199		120.0	30.0	342

Table 5.1 Average Annual Wastewater Parameters (continued)

Year	Oil and Grease			Mass Emission (MT)	Turbidity (NTU)	pH	Chronic Toxicity (TUC)	Ammonia as NH ₃ -N (mg/L)
	Influent (mg/L)	Effluent (mg/L)	Removal (percent)					
1986	64	13.8	78.4	27	26	7.7		18
1987	44	6.2	85.9	13	23	7.5		
1988	38	6.3	83.4	13	40	7.5		
1989	28	6.1	78.2	12	49	7.4		26
1990	34	8.5	75.0	16	55	7.4		26
1991	73	6.9	90.5	12	50	7.3		18
1992	33	5.3	83.9	10	56	7.3		9
1993	26	6.0	76.9	13	43	7.4	19.42 ¹	20
1994	60	4.1	93.2	8	36	7.5	4.37	27
1995	63	5.1	91.9	11	32	7.5	4.35	23
1996	52	7.9	84.8	17	34	7.7	4.83	23
1997	49	5.3	89.2	12	32	7.7	7.80	23
1998	51	5.4	89.4	15	34	7.6	7.80	19
1999	52	6.2	88.1	14	48	7.5	5.00	25
2000	74	5.5	92.6	13	39	7.5	5.60	24
2001	47	4.6	90.2	9	41	7.4	5.60	28
2002	39	4.4	88.7	7	41	7.5	4.98	31
2003	44	5.3	87.9	7	34	7.5	7.80	27
2004	47	3.7	92.0	6	26	7.5	5.60	29
2005	62	4.4	92.9	8	23	7.6	5.60	27
2006	44	4.1	90.6	7	26	7.6	4.36	28
2007	52	4.0	92.4	6	27	7.6	4.36	28
2008	84	4.4	94.8	7	30	7.5	5.56	27
2009	93	4.5	95.1	7	29	7.5	15.82 ²	32
2010	76	4.7	93.8	9	31	7.6	10.88 ²	34
2011	75	4.0	94.1	7	26	7.6	13.95	27
Average	53	5.7	88.0	11	36	7.5	7.56	25
Limitation		25.0			75	6-9	134.00	322

In 2002, overtotalization was largely eliminated after the more accurate influent flow meter was commissioned, and flow began to be reported based on its measurements. However, on occasion, flow is still overtotalized due to aberrant influent-flow readings, for example, when the influent flume becomes temporarily surcharged after water backs up from the wetwell at the plant headworks. Nevertheless, judicious use of corrected effluent flow totals, based on an adjustment determined in the flow-meter study conducted in 2002, effectively eliminated flow overtotalization during 2011.

5.1.3 Effluent Constituents

The treatment process was designed to remove organic particulates from the wastewater stream and disinfect effluent. It was not designed to eliminate chemical contaminants dissolved in wastewater. Instead, a vigorous pollution-prevention program is in place, which aims to limit the introduction of

¹ Screening bioassay of three marine species

² Screening bioassay of two marine species

chemical contaminants at the source, before they enter the collection system. The multifaceted pollution-prevention program includes public education, an onsite hazardous waste collection facility, source identification, a pharmaceutical take-back program, and inspections of industrial users. Domestic users generate more than 80% of the sewage processed at the WWTP; non-industrial users or light industry, which generate wastewater similar to that of domestic sources but on a larger scale, contribute the remaining portion of the WWTP's influent. Without heavy industry within the service area, there is a concomitant lack of industrial pollutants within the MBCSD wastewater.

As in prior years, a few common metals and ubiquitous chemical compounds appeared in low concentrations within the effluent and biosolid samples collected during 2011. Of the 78 chemical compounds tested in semi-annual effluent samples, only a few were present in quantifiable amounts. Additionally, the measured concentrations of these compounds were all well below applicable NPDES discharge limits. In most cases, the concentrations were orders of magnitude lower than their respective limits. The associated mass emissions were also well below the limits identified in the discharge permit.

Quantified compounds within the effluent included three commonly occurring trace metals (copper, lead, and zinc), two radionuclides, cyanide, selenium, and low-level congeners of dioxin. The trace metals and selenium all occur naturally within the mineralogy of sediments along the central California coast. Additionally copper, lead, and zinc also enter the collection system through internal corrosion of household plumbing systems.

Dioxins are ubiquitous in the environment, have been regularly detected within effluent samples at low levels, and do not indicate a new or elevated source within the collection system. Additionally, some level of radioactivity in effluent samples is expected because of naturally occurring radionuclides. Nonetheless, radiation levels were still well within the limits established for drinking water standards and were similar to historical levels. Low levels of cyanide form as a byproduct of the plant's disinfection processes.

Bioassays conducted over the past decade have consistently demonstrated the MBCSD effluent's low toxicity to marine organisms. The chronic bioassays conducted in 2011 again confirmed the benign nature of MBCSD effluent. Average toxicity levels in 2011 were an order-of-magnitude less than the permitted limits.

As with effluent samples, chemical analyses of biosolid samples quantified only very low concentrations of some commonly occurring wastewater constituents. In addition to the bulk organic compounds, the only constituents with quantifiable concentrations included 16 ubiquitous trace metals, benzoic acid (a food preservative), and DEHP (a common phthalate compound). All measured concentrations were well below regulatory limits that would make the biosolids hazardous or unsuitable for composting and land application.

5.2 RECEIVING WATERS

The receiving-water environment was monitored on a quarterly basis to evaluate the oceanographic conditions near the outfall, particularly with respect to any adverse impacts from wastewater discharge. Comparisons of water quality at the boundary of the zone of initial dilution (ZID) with gradient areas beyond the dilution zone documented compliance with the receiving-water objectives of the California Ocean Plan (COP) as specified in the NPDES discharge permit. Extremely sensitive electronic probes provided a detailed picture of water quality during the four surveys conducted in 2011. Precise navigation and high-resolution data on light transmittance, density, temperature, salinity, pH, and dissolved oxygen assessed the limited spatial extent of the dilute effluent plume within receiving waters.

During all four surveys, small anomalies in water properties associated with the submerged wastewater plume were detected. In all cases, the water-quality fluctuations were restricted to the ZID, were generated by the upward displacement of ambient seawater and not the presence of wastewater constituents, or were insignificant compared to the larger ambient variations resulting from natural oceanographic processes. Several of these plume measurements captured the signature of wastewater while it was undergoing rapid initial mixing within the ejection jet emanating from a diffuser port. Dilution rates determined from these close-in measurements were compared with expected critical initial dilution ratios based on modeling during the outfall design. They demonstrated that the diffuser structure had dispersed the wastewater to a much greater extent than predicted by the modeling.

Because tests for compliance with the receiving-water limitations in the discharge permit only apply outside the ZID, these close-in measurements were not subject to the standards in the COP. Nevertheless, plume observations collected within the ZID were routinely below the permit limits applicable to observations collected outside this narrow 15-m mixing zone. None of the observed conditions suggested that unmixed wastewater was tangibly affecting receiving waters within or beyond the ZID. As with prior monitoring, water quality parameters measured in the 2011 surveys confirmed that the diffuser was operating efficiently and that wastewater was diluted 150-fold immediately following discharge from the diffuser ports.

5.3 SEAFLOOR SEDIMENTS

The monitoring program has evaluated physical, chemical, and biological conditions within the benthic sediments around the outfall for 26 years. Temporal fluctuations in these factors have been directly related to natural influences, the largest of which occur on seasonal and interannual time scales. The more notable faunal variations have typically involved interannual population fluxes within individual taxa. For example, substantial increases in the abundance of the Pacific sand dollar (*Dendraster excentricus*) were documented in 1989, 1991, 1999, and 2009. During these episodic recruitment events, sand dollar populations overwhelmingly dominated the infaunal community, with the residual effects of successful recruitment persisting into following years, as was the case in 2011. The marked population increases in sand dollars all coincided with the well-recognized global climate fluctuation known as El Niño. These major changes affect all of the benthic monitoring stations, including reference sites, and are related to inherent oceanographic variability rather than the discharge of effluent.

To test for outfall-related effects, a large number of biological indices and parameters were computed from an enumeration of the more than 241,000 specimens collected over 26 years of benthic monitoring. None of these parameters exhibited statistically significant spatial distributions related to the effluent discharge or long-term spatiotemporal trends indicative of an increasingly degraded benthic habitat near the outfall. Not only were the spatial differences in 2011 small compared to inherent sampling variability, but also seasonal and interannual changes in community structure from natural environmental oscillations, such as El Niño, were substantially larger. Despite large temporal fluctuations in the infaunal community, its health has remained uniformly high throughout the 26 years of monitoring. The benthic environment surrounding the outfall continues to be populated by an infaunal community dominated by pollution-sensitive suspension-feeding organisms.

Spatiotemporal analyses were also conducted on the large dataset of sediment physicochemistry spanning the 26 years since benthic monitoring began in 1986. Those analyses demonstrated that there was no buildup of sediment contaminants surrounding the outfall. In addition, trace-metal and organic concentrations collected both near and far from the outfall in 2011 remained below thresholds considered harmful to marine biota. In fact, sediment trace-metal concentrations within Estero Bay were well below concentrations found in the vast majority of samples collected offshore Southern California. This attests

to the pristine nature of the ocean environment in northern Estero Bay. Nickel and chromium are the only trace metals with comparatively elevated concentrations within Estero Bay sediments. However, these metals occur naturally in the mineralogy of the region. As a result, the Estero Bay sediment metal concentrations are comparable to those in nearby benthic environments, such as Port San Luis (NOAA 1991a), and the Morro Bay Estuary (Tenera and Marine Research Specialists 1997).

These sediment-chemistry analyses, in conjunction with analyses of infaunal community structure, provide strong empirical evidence that the sediments surrounding the outfall, along with the organisms within them, have not been perceptibly impacted by the discharge, even after more than two-and-a-half decades of operation and monitoring.

5.4 RECOMMENDATIONS

The 26 years of monitoring data summarized in this annual report demonstrate that the MBCSD WWTP has been operating as designed and that the discharge of effluent has not adversely impacted the marine environment within Estero Bay. Occasional adjustments made to the monitoring program have substantially increased its capacity to detect minute environmental impacts, yet conclusions regarding the lack of impacts have continued to hold true into 2011.

Recent adjustments made to the monitoring program have typically dealt with potential improvements to the monitoring program rather than with improvements to plant performance. As in recent past reports, most of the following recommendations pertain to proposed adjustments to the monitoring program:

- **Reduce the monitoring frequency for effluent chemical parameters.** Pursuant to the provisions within the current NPDES permit, a reduction in the monitoring frequency of effluent chemical concentrations is warranted (MBCSD 2004; MRS 2004b, 2009b). The MBCSD discharge permit allows a change in monitoring frequency to once-in-the-life of the permit for those compounds that are undetected in the first year of monitoring. During 2009 sampling, which was the first year of sampling under the current permit, there were 73 chemical constituents which met this criterion. Additionally, application of the SWRCB's (2005) statistical methodology to two decades of MBCSD effluent measurements unequivocally demonstrates that there is no reasonable potential for exceedance of permit limits for those 73 compounds, or for the remaining compounds currently monitored on an annual basis. As a result, the COP does not require continued annual monitoring of any of the compounds. Concentrations measured within 2009, 2010, and 2011 effluent samples, which were collected after the reasonable-potential analysis was conducted, only serve to strengthen those conclusions. The reduction in monitoring frequency is further justified by the historically high level of compliance, a proposed monitoring frequency that is consistent with other similar-sized dischargers, and an ongoing bioassay program that provides a more sensitive all-inclusive evaluation of effluent quality.
- **Reinstate analysis for trace metals, grain size, and infauna at benthic Station B1.** Although the physical environment at Station B1 departs from that at the outfall stations, its 1 km distance from the outfall provides valuable insight into large-scale environmental processes within Estero Bay that are independent of the discharge. Additionally, Station B1 has been continuously sampled throughout the 26-year monitoring program. Even though benthic monitoring at this location is no longer required by the current discharge permit, voluntary collection and analysis of sediment samples has been conducted in 2009, 2010, and 2011. Continued sampling at this location is recommended to maintain historical consistency with the long-term time-series analyses, and to provide insight into regional processes affecting Estero Bay as a whole.

- **Eliminate the Cat-Litter Public-Outreach Program.** The current discharge permit requires an annual reevaluation of the implementation goals of the Cat-Litter Public-Outreach work plan. A requirement for development and submittal of a work plan was included in the current permit as a conservation measure because concerns were raised that Estero Bay was a “hot-spot” for otter mortality associated with *T. gondii* infection. Disposal of cat litter into the MBCSD collection system was thought by some to be a contributing factor to the high exposure and infection rates found in live animals and carcasses tested from the Estero Bay area. However, shortly after final approval of the current MBCSD permit in 2009, results from a comprehensive field study (Johnson et al. 2009) were published that confirmed that disease vectors unrelated to WWTP discharge are responsible for the observed *T. gondii* exposure in otters, and that the epicenter for infection is not within Estero Bay. As such, there is little scientific rationale for the continuation of a dedicated outreach program specific to cat-litter disposal in the MBCSD collection system.

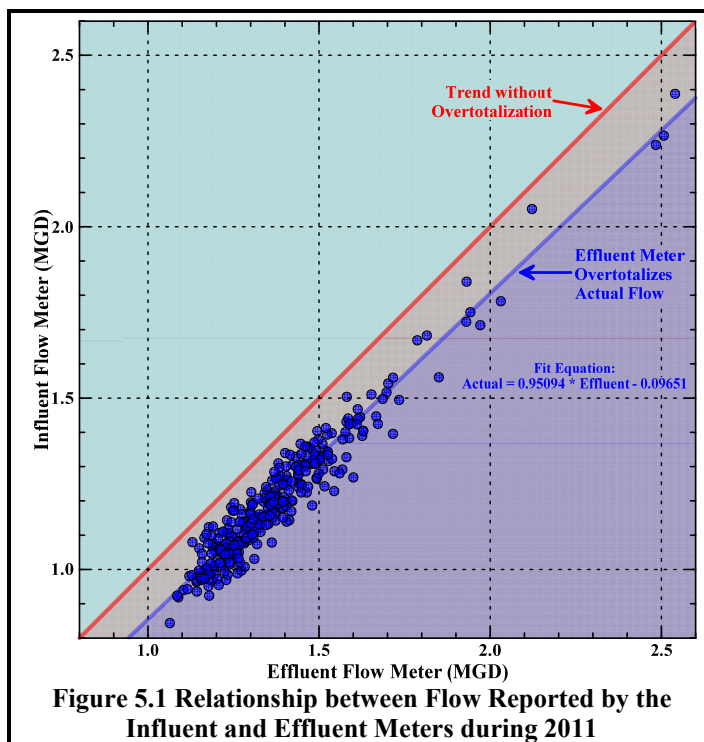
Instead, existing public-outreach efforts required under the permit should continue to incorporate efforts to keep regulatory agencies and the general public abreast of the latest scientific findings in order to reduce existing misconceptions about the MBCSD discharge’s effects on otter health and the significance of *T. gondii* within the watershed. Nevertheless, although the current MBCSD efforts at public education and outreach regarding cat litter disposal are comprehensive, and include the use of the internet, posters, newsletters, and public talks and tours, they remain uncodedified by a formal work plan, as required in the current NPDES permit. Therefore, until such time as the RWQCB revisits the validity of the concerns underlying the inclusion and necessity of this conservation measure, the MBCSD should continue to work towards finalizing a cat-litter public-outreach work plan in accordance with the permit requirements.

- **Remove Basin-Plan receiving-water limits on pH and DO from the NPDES discharge permit.** As discussed in Section 3.3.2, the Basin Plan limits on pH and DO that are incorporated into the current NPDES discharge permit issued to the MBCSD are inappropriate for open ocean dischargers. The fixed Basin Plan limits were largely designed for discharges to onshore surface waters, where there is little natural variation in pH and DO within the receiving waters. Conversely, natural oceanographic processes, such as upwelling, regularly cause the DO and pH of the ambient receiving water surrounding the MBCSD outfall to range beyond the Basin Plan limits. In contrast to the Basin Plan limits, the COP recognizes the potential for inherent variation in the receiving-water characteristics and specifies limits on excursions in these two water properties relative to background levels present at the time of the survey. Because the COP receiving-water objectives are designed to be adequately protective of the marine environment, application of the fixed Basin Plan limits to the same receiving-water characteristics already covered by the COP is not only inappropriate but redundant.
- **Remove the effluent nutrient-monitoring requirement.** A provision for nutrient monitoring was incorporated into the current discharge permit to address concerns regarding the MBCSD’s potential nutrient contribution to the generation of harmful algal blooms offshore central California. As discussed in Section 2.2.11, however, chemical analyses conducted to date demonstrate that nutrient concentrations within the MBCSD effluent, and mass loading to the marine environment from its discharge, are insignificant compared to both other central-coast dischargers, and the contribution from regional streams and rivers. Specifically, nutrient loading from the MBCSD WWTP is several orders-of-magnitude lower than both runoff and discharge from other central-coast WWTPs, and far smaller than the nutrient loading from naturally occurring processes such as upwelling. Additionally, it is clear that nutrient loads from the MBCSD discharge are unrelated to the frequency or intensity of the algal bloom occurring along this stretch of coastline. Consequently, continued nutrient monitoring

provides no scientifically valid or usable information relevant to the prediction or management of algal blooms, and should be discontinued.

- **Apply an updated correction formula when reporting daily flow using effluent flow-meter measurements.** Daily plant throughput is normally determined by totalizing the readings from the influent flow meter. The influent flow-meter readings are used because they more accurately measure the volume of wastewater processed by the treatment plant. On rare occasions, however, the influent flow meter reports are erroneously high values. Typically, these outliers are obvious in the flow record and result from easily identifiable causes such as surcharging of the influent trunk line during major rain events, or when equipment malfunctions occur at the headworks. On those occasions, daily flow is reported using measurements from the effluent flow meter that have been adjusted downward to account for that meter's overttotalization.

Historically, the effluent flow meter has been found to overttotalize the actual flow by 25% [MRS 2003b]. However, a comparison of daily flow totals reported by the influent and effluent meters during 2011 (Figure 4.4) provides an updated formula for adjusting the effluent flow-meter readings:



$$A = 0.9509 \times E - 0.0965 \quad \text{Equation 5.1}$$

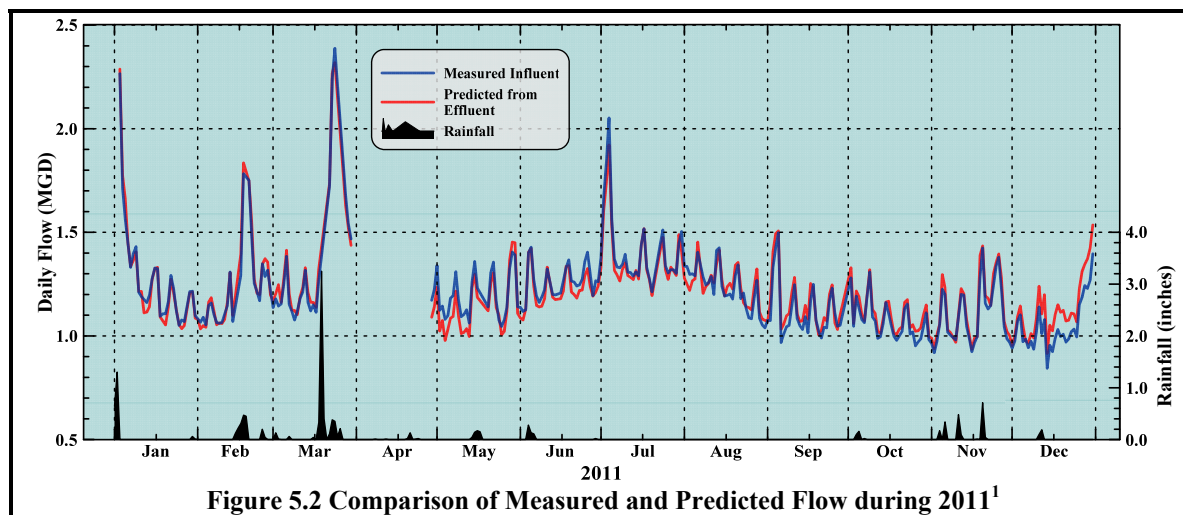
where: A = the actual (estimated) plant flow in MGD, and
 E = the flow measured by the effluent meter.

Equation 5.1 was determined from a linear regression of the 285 pairs of daily flow observations that the influent and effluent meters measured in 2011. Anomalous influent measurements, for example, those caused by surcharging of the influent flume, were excluded from the regression. Additionally, effluent flow measurements were unavailable during certain portions of the year. Specifically, during most of April 2011, the effluent flow meter was offline while repair and maintenance efforts were underway, thereby precluding any comparison with the influent data during that time.

The 285 measurements analyzed exhibited a highly consistent linear relationship (Equation 5.1) that explains 95% of the variation in the influent measurements (Figure 4.4). In the middle of the observations, near a flow of 1.2 MGD, the uncertainty¹ in the predicted flow is ± 0.093 MGD. Extrapolating beyond the data range increases the uncertainty in the predicted flow. Assuming the linear relationship between the meter readings is still valid at 6 MGD, the uncertainty in the flow

¹ 95% confidence interval around the predicted actual flow

predicted from the effluent meter increases to ± 0.154 MGD. These uncertainties are small compared to flow fluctuations, and flow predicted from the effluent meter using Equation 5.1 (red line in Figure 5.2) closely tracks the flow measured by the influent meter (blue line).



When influent flow measurements are unavailable or obviously compromised, daily flow should be reported from effluent meter readings adjusted by Equation 5.1. To ensure that adjustments to effluent flow readings continue to be as accurate and timely as possible, the coefficients in Equation 5.1 should be recomputed on a semiannual basis. The availability of precise and closely matching measurements from both the influent meter and the adjusted effluent meter provides valuable system redundancy in the event that one of the meters is taken offline for repairs or calibration.

- **Initiate a source-detection investigation at the onset of significant declines in plant performance.** Throughout more than a quarter century of monitoring, the MBCSD treatment plant's effluent quality has consistently exceeded expectations based on the original design criteria, and there has never been an indication of deteriorating plant performance. Although rare, exceptions to standards or criteria have occurred, but have always been the direct results of brief, unavoidable mechanical failures of a treatment-system component or the external introduction of a contaminant within the influent stream.

Although the plant's overall performance during 2011 was, in many ways, comparable to previous years, a marked, month-long decline in secondary-treatment performance began in mid-April and continued through the first week of May. During that time, TSS and BOD removal rates were significantly impacted, resulting in effluent BOD concentrations which closely approached several permit limits (see Section 2.2.3). Review and analysis by WWTP staff, both during and following the event,² suggests that the upset was unrelated to ongoing plant repairs and activities, and that an outside event or influent source may have negatively affected plant performance instead. However, a detailed source-identification investigation was not initiated. Implementation of the WWTP's existing source-detection program, at the first sign of a significant anomaly or decline in plant performance, would improve plant personnel's ability to identify the source of the upset, and allow them to take timely and appropriate actions to prevent potential exceedances of permit limits.

¹ Replacement and repairs to the effluent flow meter precluded comparison of the flow data during April 2011.

² Personal communication with Bruce Keogh on February 24, 2012

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CHAPTER 6
Literature Cited

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6.0 LITERATURE CITED

- Ackerman, R., Bergmann, M. and G. Schleichert. 1983. Monitoring heavy metals in coastal and estuarine sediments – a question of grain size: < 20µm versus < 60 µm. *Environmental Technology Letters*. 4:317-328.
- Agg, A.R., G. Stanfield, and D.J. Gould. 1978: Indicators of pollution. In: Investigations of sewage discharges to some British coastal waters. Water Research Centre Technical Report TR67: 9-96.
- American Public Health Association, American Water Works Association, Water Environment Federation. (APHA) 1998. Standard Methods for the Examination of Water and Wastewater. 20th Edition. Washington, DC. 1200 pp.
- American Society for Testing and Materials (ASTM). 1992. Standard guide for conducting 10-day static sediment toxicity tests with marine and estuarine amphipods, E1367-92. In: Annual Book of ASTM Standards, Vol. 11.04. American Society of Testing and Materials, Philadelphia, PA.
- Anderson, M.J. 2001. A new method for non-parametric multivariate analysis of variance. *Austral Ecology* 26:32-46.
- Aramini, J. J., C. Stephen, and J. P. Dubey. 1998. *Toxoplasma gondii* in Vancouver Island cougars (*Felis concolor vancouverensis*): Serology and oocyst shedding. *Journal of Parasitology* 84:438–440.
- Barclays Law Publishers (Barclay). 1997. California Code of Regulations (CCR), Environmental Health. Title 22, §64441 and §64443. Barclays, P. O. Box 3066, South San Francisco, CA 94083.
- Bertine, K. and E. Goldberg. 1977. History of heavy metal pollution in the southern California coastal zone – Reprise. *Environmental Science and Technology*. 11:297-299.
- Bowie, W.R., A.S. King, D.H. Werker, J.L. Isaac-Renton, A. Bell, S. B. Eng, and S. A. Marion. 1997. Outbreak of toxoplasmosis associated with municipal drinking water. *The Lancet* 350:173–177.
- Brown and Caldwell Consulting Engineers. 1989. City of Morro Bay, 301(h) Receiving Water Monitoring Program, 1988 Annual Analysis Report. January 1989.
- Brown and Caldwell Consulting Engineers. 1993. City of Morro Bay and Cayucos Sanitary District, NPDES permit monitoring and reporting program, 1992 annual report (January 1993). Prepared for the City of Morro Bay, Morro Bay.
- California Code of Regulations (CCR). 2003. Title 22, Chapter 11: *Identification and Listing of Hazardous Waste*. California Code of Regulations Updated on February 10, 2004. Current as of Register 2004, No. 5 Dated January 30, 2004.
- California Department of Fish and Game (CDFG). 2003. Proposal: Expanded Monitoring Of Threatened California Sea Otters and Their Prey For Terrestrial-Origin Parasitic And Bacterial Pathogens. Submitted by David A. Jessup and Melissa A. Miller, Marine Wildlife Veterinary Care and Research Center, California Department of Fish and Game, 1451 Shaffer Road, Santa Cruz, CA 95060. Submitted on March 25, 2003.
- Cameron, R.A. 1980. Elements of recruitment in a population of the sand-dollar *Dendraster excentricus*; *Am. Zool.* - 20(4): 928.
- Cameron, R.A. and S.S. Rumrill. 1982. Larval abundance and recruitment of the sand dollar *Dendraster excentricus* in Monterey Bay, California; *Mar. Biol.* - 71(2): 197-202.

- Carignan, R., Rapin, F., and A. Tessier. 1985. A Sediment Porewater Sampling for Metal Analysis - A Comparison of Techniques. *Geochimica Et Cosmochimica Acta* 49 (11): 2493-2497.
- Carollo Engineers. 1999. Cayucos/Morro Bay Comprehensive Recycled Water Study. City of Morro Bay Cayucos Sanitary District. Draft. October 1999.
- Carr, R.S. and D.C. Chapman. 1995. Comparison of methods for conducting marine and estuarine sediment porewater toxicity tests - Extraction, storage, and handling techniques. *Arch. Environ. Contam. Toxicol.* 28:69-77.
- Central Coast Long-term Environmental Assessment Network (CClean). 2007. 2001–2006 Program Overview: Central Coast Long-term Environmental Assessment Network, Regional Monitoring Program. Submitted to: California Regional Water Quality Control Board, Region 3, 895 Aerovista Place, Suite 101. San Luis Obispo, CA 93401. [Overview.PDF](#) [Accessed 11 February 2010].
- Central Coast Water Authority. 2009. Comprehensive Annual Financial Report. Year Ended June 30, 2009. [Statistical Section.pdf](#) [Accessed 9 February 2010].
- Chelton, D.B., P.A. Bernal, and J.A. McGowan. 1982. Large-scale interannual physical and biological interaction in the California Current. *Journal of Marine Research.* 40:1095-1125.
- Chelton, D.B., R.L. Bernstein, A. Bratkovich, and P.M. Kosro. 1987. The Central California Coastal Circulation Study, *EOS Trans. AGU*, 68(1), 12-13.
- Chow, T.J. and J. Earl. 1978. Trace Metal in Sediments. Southern California Baseline Study. Final Report. Volume III. Report 4.1.1 submitted to the Bureau of Land Management, Washington D.C.
- Coats, D.A. 1994. Deposition of Drilling Particulates Offshore Point Conception California, *Marine Environmental Research.* Vol. 37(1994): 95-127.
- Coats, D.A. 1995. 1994 Annual Soft-Bottom Benthic Monitoring: Massachusetts Bay Outfall Studies. MWRA Enviro. Quality Dept. Tech. Rpt. Series No. 95 20 Massachusetts Water Resources Authority, Boston MA. 174 pp.
- Coats, D.A., M.A. Savoie, and D.D. Hardin. 1991. Poleward flow on the Point Conception Continental Shelf and its relation to the distribution of oil-drilling particulates and biological impacts, *EOS Trans. AGU* 72(44):254.
- Coats, D.A., Imamura, E., Fukuyama, A.K., Skalski, J.R., Kimura, S., and J. Steinbeck. 1999. Monitoring of Biological Recovery of Prince William Sound Intertidal Sites Impacted by the Exxon Valdez Oil Spill: 1997 Biological Monitoring Survey. Edited By: G. Shigenaka, R. Hoff, and A. Mearns. NOAA Technical Memorandum NOS OR&R 1. NOAA Hazardous Materials Response and Assessment Division, 7600 Sand Point Way NE, Seattle, WA 98115.
- Coats, D.A., Imamura, E., Fukuyama, A.K., Skalski, J.R., Kimura, S., and J. Steinbeck. 2003. Monitoring of Biological Recovery of Prince William Sound Intertidal Sites Impacted by the Exxon Valdez Oil Spill: Sampling Effort in Assessments of Oil-Spill Impacts to Intertidal Organisms Edited By: G. Shigenaka and R. Hoff. NOAA Technical Memorandum Administrative Draft, January 2003. NOAA Hazardous Materials Response and Assessment Division, 7600 Sand Point Way NE, Seattle, WA 98115.
- Cohen, J. 1988. *Statistical Power Analysis for the Behavioral Sciences*. Second Edition. Lawrence Erlbaum Associates, Publishers. New Jersey.

- Conrad, P.A. 2003. Personal communication via telephone on 4 April 2003 between Mr. Bruce Keogh, MBCSD Wastewater Division Manager, and Dr. P.A. Conrad, Department of Pathology, Microbiology, and Immunology, University of California, Davis.
- Conrad, P.A. 2004a. Letter from Patricia Conrad DVM, Ph.D., Professor of Parasitology, University of California, Davis, to Bruce Keogh, Wastewater Division Manager, City of Morro Bay, dated December 13, 2004.
- Conrad, P.A. 2004b. Subject: Bivalve Results. Personal communication via email on 9 February 2004 at 15:09 from Dr. P.A. Conrad, Department of Pathology, Microbiology, and Immunology, University of California, Davis to Mr. Bruce Keogh, MBCSD Wastewater Division Manager.
- Crecelius, E. and V. Cullinan. 1998. Differences in the Concentrations of Priority Pollutant Metals in Seawater Samples from Puget Sound and the Strait of Georgia. In: Toxic Contaminants Session of the 1998 Conference on Puget Sound Research. http://www.psat.wa.gov/Publications/98_proceedings/sessions/toxic_contaminants.html
- Daskalakis, K. and T. O'Conner. 1995. Normalization and elemental sediment contamination in the coastal United States. *Environmental Science and Technology* 29:470-477.
- Davis, N., G.R. Van Blaricom, and P.K. Dayton. 1982. Man-made structures on marine sediments: effects on adjacent benthic communities. *Marine Biology* 70: 295-303.
- Davis, R.E., J.E. Dufour, G.J. Parks, and M.R. Perkins. 1982. Two Inexpensive Current-Following Drifters. Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California. SIO Reference No. 82-28. December 1982.
- DeWitt, T.H., G.R. Ditsworth, and R.C. Swartz. 1988. Effects of natural sediment features on survival of the phoxocephalid amphipod *Rhepoxynius abronius*. *Mar. Environ. Res.* 25:99-124.
- Diaz, R.J. and R. Rosenberg. 1995. Marine benthic hypoxia: A review of its ecological effects and the behavioural responses of benthic macrofauna. *Oceanography and Marine Biology Annual Review* 33:245-303.
- Diener, D.R. and S.C. Fuller. 1995. Infaunal Patterns in the Vicinity of a Small Coastal Wastewater Outfall and the Lack of Infaunal Community Response to Secondary Treatment. *Bulletin of the Southern California Academy of Sciences*. 94(1):5-20.
- Diener, D., S. Fuller, A. Lissner, C. Haydock, D. Maurer, G. Robertson and T. Gerlinger. 1995. Spatial and temporal patterns of the infaunal community near a major ocean outfall in southern California. *Marine Pollution Bulletin*. 30:861-878.
- Dossis, P. and L.J. Warren. 1980. Distribution of heavy metals between the minerals and organic debris in a contaminated marine sediment. Pages 119-139 In: Baker, R.A. (Ed) *Contaminants and Sediments*, Vol. 1: Fate and transport, case studies, modeling toxicity. Ann Arbor Science, Ann Arbor Michigan. 558 pp.
- Earth-Wise. 2003. Biosolids and Green Waste Compost Project. Final Report Submitted to the City of Morro Bay & Cayucos Sanitary District, San Luis Obispo County, California to the City of Morro Bay & Cayucos; by Tim Bolander and Ted Peterson, Earth-Wise/Spirit of the Earth, P.O.Box 6741, Los Osos, CA 93412, Phone: (805) 534-9605; March 2003.
- Ebert, E.E. 1968. A food-habits study of the southern sea otter, *Enhydra lutris nereis*. *Calif. Fish and Game* 54:33-42.

- Estes, J.A., R.J. Jameson, and A.M. Johnson. 1981. Food selection and some foraging tactics of sea otters. In: D.A. Chapman and D. Pursley (eds.). Worldwide furbearer conference proceedings, August 3-11, 1980. Frostburg, MD. Pp. 606-636.
- Everts Coastal. 1996. Evaluation: Artificial Beach Enhancement to Reduce the Potential for Daylighting and Improve Beach Conditions at Avila Beach, California. Appendix C of the Addendum to Alternative Analysis and Proposed Remedial Action Study for the Beach Areas Avila Beach, California, Volume 2. Fluor Daniel GTI Report Prepared for UNOCAL. November 4, 1996. 50pp+appendices.
- Fischer, H.B., E.J. List, R.C.Y. Koh, J. Imberger and N.H. Brooks. 1979. Mixing in Inland and Coastal Waters. Academic Press, New York. 483 pp.
- Finney, B. and C. Huh. 1989. History of metal pollution in the Southern California Bight: An Update.. Environmental Science and Technology. 23:294-303.
- Folk, R.L. 1980. Petrology of Sedimentary Rocks. Herpmill Publishing Co., Austin, Tx.
- Goodman, E. 1975. The theory of diversity-stability relationships in ecology. Q. Rev. Biol. 50:237-266.
- Gotshall, D.W., L.L. Laurent, S.L. Owen, J. Grant, and P. Law. 1984. A Quantitative Ecological Study of Selected Nearshore Marine Plants and Animals at the Diablo Canyon Power Plant Site: A Pre-Operational Baseline, 1973-1978. California Department of Fish and Game, Marine Resources Technical Report No. 48.726 pp.
- Gotshall, D.W., J.R.R. Ally, D.L. Vaughan, B.B. Hatfield, and P. Law. 1986. Pre-Operational Baseline Studies of Selected Nearshore Marine Biota at the Diablo Canyon Power Plant Site: 1979-1982. California Department of Fish and Game, Marine Resources Technical Report No. 50.369-70 pp.
- Graham, N.E. and W.B. White. 1988. The El Niño cycle: a natural oscillator of the Pacific Ocean atmosphere system. Science. 240 1293-1302.
- Grassle, J.F. and W. Smith. 1976. A similarity measure sensitive to the contribution of rare species and its use in investigation of variation in marine benthic communities. Oecologia 25: 13-22.
- Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley & Sons, Inc., New York, NY. 257p.
- Green, E.J., and D. Schnitker. 1974. The direct titration of water soluble sulfide in estuarine muds of Montsweag Bay, Maine. Marine Chemistry 2(1974):111-124.
- Hoenig, J.M. and D.M. Heisey. 2001. The Abuse of Power: The Pervasive Fallacy of Power Calculations for Data Analysis. The American Statistician, 55:19-24.
- Horowitz, A. and K. Elick. 1987. The relation of stream sediment surface area, grain size, and trace element chemistry. Applied Geochemistry. 2:437-445.
- Hyland, J., D. Hardin, M. Steinhauer, D. Coats, R. Green, and J. Neff, 1994. Environmental Impact of Offshore Oil Development on the Outer Continental Shelf and Slope off Point Arguello, California, Marine Environmental Research. Vol. 37(1994): 195-229.
- Johnson, C.K., M.T. Tinker, J.A. Estes, P.A. Conrad, M. Staedler, M.A. Miller, D.A. Jessup, and J.A. K. Mazet. 2009. Prey choice and habitat use drive sea otter pathogen exposure in a resource-limited coastal system. PNAS published online before print January 21, 2009. doi:10.1073/pnas.0806449106. [PNAS Otter](#)

- Keith, J.O., L.A. Woods, Jr., and E.G. Hunt. 1971. Reproductive failure in brown pelicans on the Pacific coast. *Trans. N. Amer. Wildl. and Nat. Res. Conf.* 35:56-63.
- Khoury, J.; Pang, M.; Young, C.; Pandit, A.; Carr, S.; and D. Fischer. 2005. Cyanide generation during preservation of chlorinated wastewater effluent samples for total cyanide analysis. *Water Environment Research*, Submitted Nov 07, 2005.
- Kopperdahl, F. 1976. Guidelines for Performing Static Acute Toxicity Fish Bioassays in Municipal and Industrial Wastewaters. Calif. Dept. of Fish and Game.
- Kruskal, J. 1964. Non-metric multidimensional scaling: a numerical method. *Psychometrika* , 29, 1-27.
- Kudela, R.M. and W.P. Cochlan. 2000. Nitrogen and Carbon Uptake Kinetics and the Influence of Irradiance for a Red Tide Bloom off Southern California. *Aquat. Microb. Ecol.* 21: 31-47.
- Kudela, R.M., Pitcher, G., Probyn, T., Figueiras, F., Moita, T., Trainer, V.L., 2005. Harmful algae blooms in coastal upwelling systems. *Oceanography* 18, 184–197.
- Kudela, R.W., Chochlan, W., Roberts, A., 2004. Spatial and temporal patterns of Pseudo-nitzschia spp. in central California related to regional oceanography. In: Steidinger, K.A., Landsberg, J.H., Tomas, C.R., Vargo, G.A. (Eds.), Harmful Algae 2002. Florida and Wildlife Conservation Commission, Florida Institute of Oceanography, and Intergovernmental Oceanographic Commission of UNESCO, pp. 347–349.
- Lenihan, H.S., C.H. Peterson, S.L. Kim, K.E. Conlan, R. Fairey, C. McDonald, J.H. Grabowski and J. S. Oliver. 2003. How variation in marine benthic community composition allows discrimination of multiple stressors. *Marine Ecology Progress Series* 206:63-73.
- Lenth, R.V. 2001. Some Practical Guidelines for Effective Sample Size Determination. *The American Statistician*, 55:187-193.
- Levin, L.A., Ekau, W., Gooday, A.J., Jorissen, F., Middelburg, J.J., Naqvi, S.W.A., Neira, C., Rabalais, N.N., and Zhang, J. 2009. Effects of natural and human-induced hypoxia on coastal benthos. *Biogeosciences* 6:2063–2098. [Hypoxia.PDF](#) [Accessed 29 March 2011].
- Lindstrom, K. 1998. Report on Evaluation of February 1998 Sampling Results: AERA Energy LLC (Aera) Produced Water Discharge Proposal. K.P. Lindstrom, Inc. P.O. Box 51008, Pacific Grove Ca. In association with Carollo Engineers, 4200 Truxtun Ave, Suite 200, Bakersfield, CA 93309.
- Lindsey, J. 2008. April and May are the coldest seawater months. The San Luis Obispo Tribune. 22 November 2008. <http://www.sanluisobispo.com/news/local/story/537286.html>
- Long, E.R., and Lee G. Morgan. 1991. The potential for biological effects of sediment-sorbed contaminants tested in the National Status and Trends Program. U.S. Dept. Commerce, Nat. Oceanic Atmos. Admin., Off. Oceanogr. Mar. Assess., Rockville, MD. NOAA Tech. Mem. NOS OMA 52 175 pp. plus appendices.
- Long, E.R., D.D. MacDonald, S.L. Smith and F.D. Calder. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environmental Management* 19(1):81-97.
- Magurran, A.E. 1988. Ecological diversity and its measurement. University Press, Cambridge.
- Margalef, R. 1951. Diversidad de especies en las comunidades naturales. *Publ. Inst. Biol. Aplic.* Barcelona 9:5-27.

- Margalef, R. 1972. Homage to Evelyn Hutchinson, or why is there an upper limit to diversity. *Trans Connect. Acad. Arts Sci.* 44: 211-235. (Non consulté.)
- Marine Research Specialists (MRS). 1994. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 1993 Annual Report. Submitted February 1994 to the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA.
- Marine Research Specialists (MRS). 1995. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 1994 Annual Report. Submitted February 1995 to the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA.
- Marine Research Specialists (MRS). 1996. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 1995 Annual Report. Submitted February 1996 to the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA.
- Marine Research Specialists (MRS). 1997a. City of Morro Bay and Cayucos Sanitary District, Supplement to the 1997 Renewal Application for Ocean Discharge under NPDES Permit No. CA0047881. Prepared for the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA. May 1997.
- Marine Research Specialists (MRS). 1997b. Recommended Changes to NPDES Permit No. CA0047881. Letter from Dr. D. A. Coats, Senior Oceanographer at Marine Research Specialists, to Mr. W. T. Boucher, Director, Public Works Department of the City of Morro Bay, dated 25 June 1997.
- Marine Research Specialists (MRS). 1997c. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 1996 Annual Report. Submitted February 1997 to the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA.
- Marine Research Specialists (MRS). 1998a. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, Water Column Sampling, March 1998 Survey. Prepared for the City of Morro Bay, Morro Bay, CA. April 1998.
- Marine Research Specialists (MRS). 1998b. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, Semiannual Benthic Sampling Report, April 1998 Survey. Prepared for the City of Morro Bay, Morro Bay, CA. July 1998.
- Marine Research Specialists (MRS). 1998c. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, Water Column Sampling, July 1998 Survey. Prepared for the City of Morro Bay, Morro Bay, CA. August 1998.
- Marine Research Specialists (MRS). 1998d. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 1997 Annual Report. Submitted February 1998 to the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA.
- Marine Research Specialists (MRS). 1998e. Review of USEPA Tentative Decision Document, Regional Board Staff Report, Draft Waste Discharge Requirements, and Draft Monitoring and Reporting Program for Reissuance of a Modified NPDES Permit. Letter from Dr. D. A. Coats, Senior Oceanographer at Marine Research Specialists, to Mr. Bruce Keogh, Wastewater Division Manager, City of Morro Bay, dated 10 September 1998.
- Marine Research Specialists (MRS). 1998f. Modifications to Draft Waste Discharge Requirements and Draft Monitoring and Reporting Program for Reissuance of NPDES Permit CA0047881 Letter from Dr. D. A. Coats, Senior Oceanographer at Marine Research Specialists, to Mr. Bruce Keogh, Wastewater Division Manager, City of Morro Bay, dated 23 October 1998.

- Marine Research Specialists (MRS). 1998g. Further Modifications to Draft Waste Discharge Requirements and Draft Monitoring and Reporting Program for Reissuance of NPDES Permit CA0047881 Letter from Dr. D. A. Coats, Senior Oceanographer at Marine Research Specialists, to Ms. Sorrel Marks, Central Coast Regional Water Quality Control Board, dated 2 November 1998.
- Marine Research Specialists (MRS). 1998h. Additional Benthic Data Supporting the 1997 NPDES Permit Renewal Application for the City of Morro Bay/Cayucos Sanitary District. Letter from Dr. D. A. Coats, Senior Oceanographer at Marine Research Specialists, to Dr. T. Fleming, U.S. Environmental Protection Agency, Region 9; dated 7 April 1998.
- Marine Research Specialists (MRS). 1998i. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, Semiannual Benthic Sampling, October 1997. Prepared for the City of Morro Bay, Morro Bay, CA.
- Marine Research Specialists (MRS). 1998h. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 1997 Annual Report. Submitted February 1998 to the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA.
- Marine Research Specialists (MRS). 1999a. MTBE Analysis Results for Effluent Samples Collected in January and July 1998. Letter from Dr. Douglas A. Coats, Program Manager for Marine Research Specialists, to Mr. Bruce Keogh, Wastewater Division Manager, City of Morro Bay; dated 18 October 1999.
- Marine Research Specialists (MRS). 1999b. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 1998 Annual Report. Submitted March 1999 to the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA.
- Marine Research Specialists (MRS). 2000a. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 1999 Annual Report. Submitted February 2000 to the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA.
- Marine Research Specialists (MRS). 2000b. Supplemental Environmental Report: Source of Metal Contamination within the Seafloor Sediments of Northern Estero Bay, October 2000. City of Morro Bay and Cayucos Sanitary District Offshore Monitoring and Reporting Program. December 2000.
- Marine Research Specialists (MRS). 2001. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2000 Annual Report. Submitted February 2001 to the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA.
- Marine Research Specialists (MRS). 2002. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2001 Annual Report. Submitted February 2002 to the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA.
- Marine Research Specialists (MRS). 2003a. City of Morro Bay and Cayucos Sanitary District, Supplement to the 2003 Renewal Application For Ocean Discharge Under NPDES Permit No. CA0047881. Prepared for the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA. July 2003.
- Marine Research Specialists (MRS). 2003b. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2002 Annual Report. Submitted February 2003 to the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA.

- Marine Research Specialists (MRS). 2004a. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2003 Annual Report. Submitted February 2004 to the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA.
- Marine Research Specialists (MRS). 2004b. Letter report from Dr. Douglas A. Coats, Senior Oceanographer, Marine Research Specialists, to Mr. Bruce Keogh, Wastewater Division Manager, City of Morro Bay, dated 12 July 2004. Reference: Quantitative Analysis in Support of Reduction in Monitoring Frequency.
- Marine Research Specialists (MRS). 2005. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2004 Annual Report. Submitted February 2005 to the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA.
- [Marine Research Specialists \(MRS\). 2006a. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2005 Annual Report. Submitted February 2006 to the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA.](#)
- Marine Research Specialists (MRS). 2006b. Response to the Natural Resources Defense Council document, Time is of the Essence: The Legal and Technical Reasons Why EPA and the Regional Board Must Deny the 301(h) Waiver and Require Upgrade of the Morro Bay-Cayucos Sewage Plant “As Fast as Possible.”
- [Marine Research Specialists \(MRS\). 2007. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2006 Annual Report. Submitted 27 February 2007 to the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA.](#)
- [Marine Research Specialists \(MRS\). 2008a. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2007 Annual Report. Submitted 26 February 2008 to the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA.](#)
- Marine Research Specialists (MRS). 2008b. Proposed Nutrient Monitoring Requirement for MBCSD’s Draft NPDES Discharge Permit. Letter from Dr. D. A. Coats, Senior Scientist at Marine Research Specialists, to Mr. B. Keogh, Wastewater Division Manager, City of Morro Bay, dated 7 May 2008.
- [Marine Research Specialists \(MRS\). 2009a. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2008 Annual Report. Submitted 26 February 2009 to the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA.](#)
- Marine Research Specialists (MRS). 2009b. Request for Reduction in the MBCSD WWTP Effluent monitoring Frequency and Correction to Heptachlor Units. Draft Letter from Dr. D. A. Coats, Senior Oceanographer at Marine Research Specialists, to Mr. Bruce Keogh, Wastewater Division Manager, City of Morro Bay, dated 7 December 2009.
- [Marine Research Specialists \(MRS\). 2010. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2009 Annual Report. Submitted 31 March 2010 to the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA.](#)
- [Marine Research Specialists \(MRS\). 2011a. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, 2010 Annual Report. Submitted 31 March 2011 to the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA.](#)

- Marine Research Specialists (MRS). 2011b. Monitoring and Reporting Program Annual Biosolids Report: Chemical Analysis Results, September 2011. Prepared for the City of Morro Bay and Cayucos Sanitary District, Morro Bay, CA. 14 October 2011.
- [Marine Research Specialists \(MRS\). 2011c. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, First Quarter Receiving-Water Survey, March 2011. Prepared for the City of Morro Bay, Morro Bay, CA. 29 April 2011.](#)
- [Marine Research Specialists \(MRS\). 2011d. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, Second Quarter Receiving-Water Survey, June 2011. Prepared for the City of Morro Bay, Morro Bay, CA. 19 July 2011.](#)
- [Marine Research Specialists \(MRS\). 2011e. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, Third Quarter Receiving-Water Survey, August 2011. Prepared for the City of Morro Bay, Morro Bay, CA. 31 October 2011.](#)
- [Marine Research Specialists \(MRS\). 2011f. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, Fourth Quarter Receiving-Water Survey, October 2011 Survey. Prepared for the City of Morro Bay, Morro Bay, CA. 22 December 2011.](#)
- [Marine Research Specialists \(MRS\). 2011g. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, Semiannual Effluent Sampling: Chemical and Bioassay Analysis Results, January 2011. Prepared for the City of Morro Bay, Morro Bay, CA. 24 January 2011.](#)
- [Marine Research Specialists \(MRS\). 2011h. C City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, Semiannual Effluent Sampling: Chemical and Bioassay Analysis Results, July 2011. Prepared for the City of Morro Bay, Morro Bay, CA. 2 August 2011.](#)
- Mather, P. 1976. *Computational Methods of Multivariate Analysis in Physical Geography*. London: J. Wiley and Sons.
- Maurer, D., H. Nguyen, G. Robertson and T. Gerlinger, 1999. The infaunal trophic index (ITI): its suitability for marine environmental monitoring. *Ecological Application* 9: 699-713.
- McConnaughey, B.H. and E. McConnaughey. 1985. *National Audubon Society Nature Guides: Pacific Coast*. Alfred Knopf, New York.
- McMurray, G. 2007. Wave Energy Ecological Effects Workshop. Hatfield Marine Science Center, Oregon State University. October 11-12, 2007.
- Meador, J.P., R.C. Clark, Jr., P.A. Robisch, D.W. Ernest, J.T. Landahl, U. Varanasi, S. Chan, and B.B. McCain. 1994. Analyses of Elements in Sediment and Tissue Cycles I to V (1984-88). National Status and Trends Program, National Benthic Surveillance Project: Pacific Coast. National Marine Fisheries Service, Northwest Fisheries Science Center, Coastal Zone and Estuarine Studies Division Technical Memorandum NMFS-NWFSC-16. 2725 Montlake Blvd. E., Seattle WA 98112. August 1994.
- Miller, M.A., I.A. Gardner, C. Kreuder, D.M. Paradies, K.R. Worcester, D.A. Jessup, E. Dodd, M.D. Harris, J.A. Ames, A.E. Packham, and P.A. Conrad. 2002. Coastal freshwater runoff is a risk factor for *Toxoplasma gondii* infection of southern sea otters (*Enhydra lutris nereis*). *International Journal for Parasitology* 32(2002) 997-1066.
- Morin, J.G., J.E. Kastendiek, A. Harrington, and N. Davis. 1985. Organization and patterns of interaction in a subtidal sand community on an exposed coast. *Mar. Ecol. Prog. Ser.* 27: 163-185.

- Morris, R., D. Abbott, and E. Haderlie. 1980. *Intertidal Invertebrates of California*. Stanford University Press. Stanford, California. 690pp.
- [City of] Morro Bay and Cayucos Sanitary District (MBCSD). 1997a. Sampling and Analyses of Samples. Letter to Ms. Sorrel Marks of the Regional Water Quality Control Board, Central Coast Region from Mr. B. Keogh, Acting Wastewater Division Manager. 10 June 1997.
- [City of] Morro Bay and Cayucos Sanitary District (MBCSD). 1997b. Draft of NPDES Permit for Morro Bay – Cayucos Wastewater Treatment Plant: Permit NO. 92-67. Letter from Mr. B. Keogh, Interim Wastewater Division Manager for the City of Morro Bay, to Mr. R. W. Briggs, Executive Director of the Regional Water Quality Control Board Central Coast Region, dated 24 July 1997.
- [City of] Morro Bay and Cayucos Sanitary District (MBCSD). 1998. Letter from Mr. Bruce Keogh, Wastewater Division Manager for the MBCSD, to Ms. Sorrel Marks, Regional Water Quality Control Board, dated 1 October 1998.
- [City of] Morro Bay and Cayucos Sanitary District (MBCSD). 2003. Letter from Mr. Bruce Ambo, Public Services Director to Mr. Roger Briggs, Executive Officer, California Regional Water Quality Control Board. Subject: Notice of submittal of application and supplemental documentation for the renewal of National Pollution Discharge Elimination System Permit No. CA0047881, dated July 3, 2003.
- [City of] Morro Bay and Cayucos Sanitary District (MBCSD). 2004. Letter to Mr. Matt Thompson of the Regional Water Quality Control Board, Central Coast Region from Mr. B. Keogh, Wastewater Division Manager, dated 19 July 2004. Reference: Submittal of Quantitative Documentation in Support of Reductions in the Monitoring Frequency for the Morro Bay/Cayucos Sanitary District Effluent.
- [City of] Morro Bay and Cayucos Sanitary District (MBCSD). 2011a. The City of Morro Bay-Cayucos Wastewater Treatment Plant Monthly Operations Summary, January 2011.
- [City of] Morro Bay and Cayucos Sanitary District (MBCSD). 2011b. The City of Morro Bay-Cayucos Wastewater Treatment Plant Monthly Operations Summary, February 2011.
- [City of] Morro Bay and Cayucos Sanitary District (MBCSD). 2011c. The City of Morro Bay-Cayucos Wastewater Treatment Plant Monthly Operations Summary, March 2011.
- [City of] Morro Bay and Cayucos Sanitary District (MBCSD). 2011d. The City of Morro Bay-Cayucos Wastewater Treatment Plant Monthly Operations Summary, April 2011.
- [City of] Morro Bay and Cayucos Sanitary District (MBCSD). 2011e. The City of Morro Bay-Cayucos Wastewater Treatment Plant Monthly Operations Summary, May 2011.
- [City of] Morro Bay and Cayucos Sanitary District (MBCSD). 2011f. The City of Morro Bay-Cayucos Wastewater Treatment Plant Monthly Operations Summary, June 2011.
- [City of] Morro Bay and Cayucos Sanitary District (MBCSD). 2011g. The City of Morro Bay-Cayucos Wastewater Treatment Plant Monthly Operations Summary, July 2011.
- [City of] Morro Bay and Cayucos Sanitary District (MBCSD). 2011h. The City of Morro Bay-Cayucos Wastewater Treatment Plant Monthly Operations Summary, August 2011.
- [City of] Morro Bay and Cayucos Sanitary District (MBCSD). 2011i. The City of Morro Bay-Cayucos Wastewater Treatment Plant Monthly Operations Summary, September 2011.

- [City of] Morro Bay and Cayucos Sanitary District (MBCSD). 2011j. The City of Morro Bay-Cayucos Wastewater Treatment Plant Monthly Operations Summary, October 2011.
- [City of] Morro Bay and Cayucos Sanitary District (MBCSD). 2011k. The City of Morro Bay-Cayucos Wastewater Treatment Plant Monthly Operations Summary, November 2011.
- [City of] Morro Bay and Cayucos Sanitary District (MBCSD). 2011l. The City of Morro Bay-Cayucos Wastewater Treatment Plant Monthly Operations Summary, December 2011.
- Morro Group, Inc. 1999. MFS Globenet Corp./WorldCom Network Services Fiber Optic Cable Project Draft Environmental Impact Report. SCH No. 98091053. Submitted to: County of San Luis Obispo Department of Planning and Building. Prepared in association with Arthur D. Little, Inc. and Marine Research Specialists. October 1999.
- Musick, Peeler & Garrett, LLP (MP&G). 2004. Response to RWQCB Staff “Findings” dated August 7, 2004. Letter from Mr. Steven J. Elie, Attorney at Law and counsel for the City of Morro Bay, to Mr. Roger Briggs, Executive Officer, California Regional Water Quality Control Board; dated September 5, 2004.
- Natural Resources Defense Council (NRDC). 2006. Time is of the Essence: The Legal and Technical Reasons Why EPA and the Regional Board Must Deny the 301(h) Waiver and Require Upgrade of the Morro Bay-Cayucos Sewage Plant “As Fast as Possible.”
- National Oceanic and Atmospheric Administration (NOAA). 1991a. Progress Report on the National Status and Trends Program. Second summary of data on chemical contaminants in sediments from the National Status and Trends Program. U.S. Dept. Commerce, Nat. Oceanic Atmos. Admin., Off. Oceanogr. Mar. Assess., Rockville, MD. NOAA Tech. Mem. NOS OMA 59 29 pp. plus appendices
- National Oceanic and Atmospheric Administration (NOAA). 1991b. Contaminant trends in the southern California Bight: Inventory and assessment. NOAA Tech, Memo. NOS ORCA 62. Seattle WA.
- National Oceanic and Atmospheric Administration (NOAA). 1998. Letter from Dr. William T. Hogarth, Regional Administrator of the National Marine Fisheries Service to Mr. Bruce Keogh, Wastewater Division Manager for the City of Morro Bay; dated 30 July 1998.
- National Oceanic and Atmospheric Administration (NOAA). 2004. Letter from Ms. Valerie L. Chambers, Assistant Regional Administrator for Habitat Conservation of the National Marine Fisheries Service, to Mr. Bruce Keogh, Wastewater Division Manager for the City of Morro Bay; dated 12 August 2004.
- National Oceanic and Atmospheric Administration (NOAA). 2010. El Nino/Southern Oscillation (ENSO) Diagnostic Discussion. Climate Prediction Center: National Centers for Environmental Protection, National Weather Service, National Oceanic and Atmospheric Administration; Camp Springs MD. Updated March 10, 2010. Available at ensodisc.html. [Accessed 31 March 2010].
- National Academy of Sciences. 1993. Managing Wastewater in Coastal Urban Areas. National Research Council Committee on Wastewater Management for Coastal Urban Areas, Water Science and Technology Board, Commission on Engineering and Technical Systems. 477 pp.
- North Carolina Division of Water Quality. 2008. Use of EPA Method 1664, Environmental Testing & Analysis Article. <http://h2o.enr.state.nc.us/lab/files/epa1664.pdf>

- Oliver, J.S., P.N. Slattery, L.W. Hulberg, and J.W. Nybakken. 1980. Relationships between wave disturbance and zonation of benthic invertebrate communities along a subtidal high-energy beach in Monterey Bay, California. *Fish. Bull.*, U.S. 78:437-454.
- Ott, F. S. 1986. Amphipod sediment bioassays: effects on response of methodology, grain size, organic content, and cadmium. Ph.D. Dissertation. University of Washington. Seattle, Washington. 285pp.
- Pearson, T.H., and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanogr. Mar. Biol. Annu. Rev.* 16:229-311.
- Phillips, C. and G. Hershelman. 1996. Recent temporal trends in sediment metal concentrations near a large wastewater outfall off Orange County, California. *Water Environment Research.* 68:105-114.
- Pielou, E.C. 1977. *Mathematical ecology*. John Wiley and Sons, New York, NY. 384 pp.
- Plumb, R.H., Jr. 1981. Procedures for handling and chemical analysis of sediment and water samples. U.S. Army Corps of Engineer Waterway Experiment Stations, Vicksburg, Miss.
- Puget Sound Estuary Program (PSEP). 1997. Recommended Guidelines For Measuring Metals In Puget Sound Marine Water, Sediment and Tissue Samples. In: Recommended Protocols for Measuring Selected Environmental Variables in Puget Sound. Prepared for U. S. Environmental Protection Agency Region 10, and the Puget Sound Water Quality Action Team, April 1997. <http://www.psat.wa.gov/Publications/protocols/protocol.html>.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region. 1994. Water Quality Control Plan (Basin Plan) Central Coast Region. Available from the RWQCB at 81 Higuera Street, Suite 200, San Luis Obispo, California. 148pp+appendicies.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region. 1998. Administrative Extension of Waste Discharge Requirements/National Pollution Discharge Elimination System (NPDES) CA0047881, Order 92-67. Letter to Mr. William Boucher, Director of Public Works, City of Morro Bay from Roger W. Briggs, Executive Officer. 10 April 1998.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region. 1999. Special Request for Methyl Tertiary Butyl Ether (MTBE) Waste Discharge Data. Letter to Mr. Bruce Keogh, Morro Bay/Cayucos WWTP from Roger W. Briggs, Executive Officer. 3 May 1999.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region. 2003a. 2002 Annual Offshore Monitoring Report, City of Morro Bay and Cayucos Sanitary District Wastewater Treatment Plant, San Luis Obispo County. Letter from Roger W. Briggs, Executive Officer of the RWQCB to Mr. Bruce Keogh, City of Morro Bay WWTP; dated 14 March 2003.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region. 2003b. Effluent Toxicity and Toxoplasma Monitoring, City of Morro Bay and Cayucos Sanitary District Wastewater Treatment Plant, San Luis Obispo County. Letter from Mr. Roger Briggs, Executive Officer of the California Regional Water Quality Control Board Central Coast Region, to Mr. Bruce Keogh, City of Morro Bay WWTP; dated 11 June 2003.

- Regional Water Quality Control Board (RWQCB) - Central Coast Region. 2004. Continuance of National Pollutant Discharge Elimination System (NPDES) Permit No. CA 0047881, Morro Bay/Cayucos WWTP. Letter from Mr. Roger Briggs, Executive Officer of the California Regional Water Quality Control Board Central Coast Region, to Mr. Bruce Keogh, City of Morro Bay; dated 4 February 2004.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – Region IX. 1993a. Waste Discharge Requirements (Order No. 92-67) and Authorization to Discharge under the National Pollutant Discharge Elimination System (Permit No. CA0047881) for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – Region IX. 1993b. Monitoring and Reporting Program No. 92-67 for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County (Permit No. CA0047881).
- Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – Region IX. 1998a. Waste Discharge Requirements (Order No. 98-15) and National Pollutant Discharge Elimination System (Permit No. CA0047881) for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County. 11 December 1998.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – Region IX. 1998b. Monitoring and Reporting Program No. 98-15 for City of Morro Bay and Cayucos Sanitary District, San Luis Obispo County. 11 December 1998.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – Region IX. 1998c. Staff Report for Regular Meeting of 11 December 1998 (prepared on 2 September 1998). Subject: Reissuance of modified National Pollutant Discharge Elimination System Permit No. CA0047881, Waste Discharge Requirements for the City of Morro Bay and Cayucos Sanitary District Wastewater Treatment Facility, San Luis Obispo County—Order No 98-15.
- Regional Water Quality Control Board (RWQCB) - Central Coast Region and the Environmental Protection Agency (USEPA) – Region IX. 2009. Waste Discharge Requirements (Order No. R3-2008-0065) and National Pollutant Discharge Elimination System (Permit No. CA0047881) for the Morro Bay and Cayucos Wastewater Treatment Plant Discharges to the Pacific Ocean, Morro Bay, San Luis Obispo County. Effective 1 March 2009.
- Riedman, M.L. and J.A. Estes. 1990. The sea otter, *Enhydra lutris*: behavior, ecology and natural history. Biological report 90(14). Washington, DC: USDO, FWS, 127 pp.
- Roper, D.S. 1990. Benthos associated with an estuarine outfall, Tauranga Harbour, New Zealand. New Zealand Journal of Marine and Freshwater Research. 24: 487-498.
- Roper, D.S., D.G. Smith, and G.B. Read. 1989. Benthos associated with two New Zealand coastal outfalls. New Zealand Journal of Marine and Freshwater Research 23: 295-309.
- Sarda, N. and G.A. Burton. 1995. Ammonia variation in sediments: spatial, temporal and method-related effects. Environ. Toxicol. Chem., 14: 1499-1506.

- Savoie, M.A., D.A. Coats, P. Wilde, and P. Kinney. 1991. "Low-Frequency Flow Variability on the Continental Shelf Offshore Point Conception." In: Minerals Management Service. 1991. California OCS Phase II Monitoring Program Final Report. U.S. Department of the Interior, Minerals Management Service, Pacific OCS Region, Los Angeles, California. OCS Study MMS 91-0083. 41pp.
- Science Applications International Corporation (SAIC). 1986. Assessment of Long-Term Changes in Biological Communities in the Santa Maria Basin and Western Santa Barbara Channel – Phase I. Volume II Synthesis of Findings. Prepared for the United States Department of the Interior, Minerals Management Service, Pacific OCS Region, Los Angeles, California. OCS Study MMS 86-0012.
- Schiff, K.C. and R.W. Gossett. 1998. Southern California Bight 1994 Pilot Project: III. Sediment chemistry. Southern California Coastal Water Research Project. Westminster, CA.
- Schiff, K. and S. Weisberg. 1997. Iron as a reference element for determining trace metal enrichment in California coastal shelf sediments. pp 68-78 in : S. Weisberg, C. Francisco and D. Hallock (eds.), Southern California Coastal Water Research Project Annual Report 1995-96. Westminster, CA.
- Schreiber, R.W. and R.W. Risebrough. 1972. Studies of the brown pelican. *Wilson Bull.*:84:119-135.
- Sea-Bird Electronics, Inc. (SBE). 1989. Calculation of M and B Coefficients for the Sea-Tech Transmissometer. Application Note No. 7, Revised September 1989.
- Sea-Bird Electronics, Inc. (SBE). 1993. SBE 13/22/23/30 Dissolved Oxygen Sensor Calibration and Deployment. Application Note No. 13-1, rev B, Revised April 1993.
- Shannon, C.H., and W. Weaver. 1949. The mathematical theory of communication. Univ. of Illinois Press, Urbana, IL. 117 pp.
- Simpson, E.H. 1949. Measurement of diversity. *Nature*. 163:688.
- Skalski, J. R., D.A. Coats, and A.K. Fukuyama. 2001. Criteria for oil spill recovery: A case study of the intertidal community of Prince William Sound, Alaska, following the *Exxon Valdez* oil spill. *Environmental Management*, Vol. 28, pp 9-18.
- Skalski, J.R., J.J. Millspaugh, C. Cooper, and D.A. Coats. 2004. A Statistical Test and Sample Size Calculations for Differences in Ecological Community Composition Based on Analysis of Distance (ANODIS). Submitted to: *Journal of Agricultural, Biological and Environmental Statistics*, February 2004.
- Smith, W., V.R. Gibson, L.S. Brown-Leger and J.F. Grassle. 1979. Diversity as an indicator of pollution: cautionary results from microcosm experiments. Pp. 269-277 in J. F. Grassle, G. P. Patil, W. Smith, and C. Tallie, eds, *Ecological diversity in theory and practice*. International Cooperative Publishing House, Fairland, MD.
- Snelgrove, P.V.R. and C.A. Butman. 1994. Animal-Sediment Relationships Revisited: Cause Versus Effect. *Oceanography and Marine Biology: an Annual Review*. UCL Press. 32:111-177.
- Sokal, R.R. and F.J. Rohlf. 1997. *Biometry: the Principals and Practice of Statistics in Biological Research*, 3rd ed. W.H. Freeman and Company, New York. 850 pp.
- Sørensen, T. 1948. A method of establishing groups of equal amplitude in plant sociology based on similarity of species content. *Biologiske Skrifter*, 5, 1-34.

- Southern California Bight Field Methods Committee (SCBFMC). 2002. Field Operation Manual for Marine Water-Column, Benthic, and Trawl monitoring in Southern California. Technical Report 359. Southern California Coastal Water Research Project. Westminster, CA. March 2002. [359_field_methods_manual.pdf](#) [Accessed 1 April 2012].
- Southern California Coastal Water Research Project (SCCWRP). 2006. Effluent discharges to the Southern California Bight from large municipal wastewater treatment facilities in 2003 and 2004. Pp.1-15,in: Southern California Coastal Water Research Project [Annual Report 2005-2006](#). Westminster, CA.
- State Water Resources Control Board (SWRCB). 1972. Water Quality Control Plan for Control of Temperature in the Coastal and Interstate Waters and Enclosed Bays and Estuaries of California. Revises and supersedes the policy adopted by the State Board on January 7, 1971, and revised October 13, 1971, and June 5, 1972. California Division of Water Quality, Water Quality Planning Unit.
- State Water Resources Control Board (SWRCB). 1990. California Ocean Plan, Water Quality Control Plan Ocean Waters of California. Corrected Copy (Table B, Radioactivity). October 18, 1990.
- State Water Resources Control Board (SWRCB). 1997. Water quality control plan, ocean waters of California, California Ocean Plan. California Environmental Protection Agency. Effective July 23, 1997.
- State Water Resources Control Board (SWRCB). 2001. Water quality control plan, ocean waters of California, California Ocean Plan. California Environmental Protection Agency. Effective December 3, 2001.
- State Water Resources Control Board (SWRCB). 2005. Water Quality Control Plan, Ocean Waters of California, California Ocean Plan. California Environmental Protection Agency. Effective February 14, 2006.
- State Water Resources Control Board (SWRCB). 2006. Completing Pre-Printed Discharge Monitoring Reports (EPA Form 3320-1). Last Revision Date: July 7, 2006. [dmr_instructions.pdf](#) [Accessed 1 April 2012].
- State Water Resources Control Board (SWRCB). 2009. Water Quality Control Plan for Enclosed Bays and Estuaries – Part 1 Sediment Quality. California Environmental Protection Agency. Effective August 23, 2009. [sed_qlty_part1.pdf](#) [Accessed 26 March 2010].
- Steinhauer, M., E. Crecelius, and W. Steinhauer. 1994. Temporal and spatial changes in the concentrations of hydrocarbons and trace metals in the vicinity of an offshore production platform. *Mar. Environ. Res.*, 37, 129-163.
- Stull, J. 1995. Two decades of marine biological monitoring, Palos Verdes, California, 1972 to 1992. *Bulletin of the Southern California Academy of Sciences*. 94:21-45.
- Stull, J.K., C.I. Haydock, R.W. Smith, and D.E. Montagne. 1986a. Long-term changes in the benthic community on the coastal shelf of Palos Verdes, Southern California. *Marine Biology* 91: 539-551.
- Stull, J., R. Baird, and T. Heesen. 1986b. Marine sediment core profiles of trace constituents offshore a deep wastewater outfall. *Journal of the Water Pollution Control Federation*. 58:985-991.

- Swartz, R.C., D.W. Schultz, G.R. Ditsworth, W.A. DeBen, and F.A. Cole. 1985. Sediment toxicity, contamination, and macrobenthic communities near a large sewage outfall. Pages 152-75 in *Validation and Predictability of Laboratory Methods for Assessing the Fate and Effects of Contaminants in Aquatic Ecosystems*. T.T. Boyle (ed.). American Society for Testing and Materials. STP 865. Philadelphia, PA.
- Tenera and Marine Research Specialists. 1997. Analysis of sediments from the City of Morro Bay mooring area A-1 maintenance dredging project. Report to the City of Morro Bay, Harbor Department, Morro Bay, CA. 11 pp. plus appendices.
- Tetra Tech. 1986a. Analytical methods for EPA priority pollutants and 301(h) pesticides in estuarine and marine sediments. Final program document prepared for the Marine Operations Division, Office of Marine and Estuarine Protection, U.S. Environmental Protection Agency. EPA Contract No. 68-01-6938. Tetra Tech, Inc., Bellevue, WA.
- Tetra Tech. 1986b. Quality assurance and quality control (QA/QC) for 301(h) monitoring programs: Guidance on field and laboratory methods. Final program document prepared for the Marine Operations Division, Office of Marine and Estuarine Protection, U.S. Environmental Protection Agency. EPA Contract No. 68-01-6938. Tetra Tech, Inc., Bellevue, WA.
- Tetra Tech. 1992. Technical Review City of Morro Bay, CA Section 301(h) Application for Modification of Secondary Treatment Requirements for a Discharge into Marine Waters. Prepared for the U.S. Environmental Protection Agency, Region IX, San Francisco, CA by Tetra Tech, Inc., Lafayette, CA. February 1992.
- Trainer, V.L., Adams, N.G., Bill, B.D., Stehr, C.M., Wekell, J.C., Moeller, P., Busman, M., Woodruff, D., 2000. Domoic acid production near California coastal upwelling zones, June 1998. *Limnol. Oceanogr.* 45, 1818–1833.
- Trainer, V.L., Hickery, B.M., Horner, R.A., 2002. Biological and physical dynamics of domoic acid production off the Washington coast. *Limnol. Oceanogr.* 47, 1438–1446.
- Trueblood, D. D., E. D. Gallagher, and D. M. Gould. 1994. The three stages of seasonal succession on the Savin Hill Cove mudflat, Boston Harbor. *Limnol. Oceanogr.* 39: 1440-1454.
- U.S. Department of the Interior (USDOI). 1998. Morro-Bay Cayucos Wastewater Treatment Plant NPDES Permit Renewal Application. Letter from Ms. Diane K. Noda, Field Supervisor of the Fish and Wildlife Service to Mr. Bruce Keogh, Wastewater Division Manager for the City of Morro Bay; dated 18 September 1998.
- U.S. Environmental Protection Agency (USEPA). 1983. Methods for chemical analysis of water and wastes. EPA 600/4-79-020. Environmental Monitoring and Support Laboratory, Cincinnati, OH.
- U.S. Environmental Protection Agency (USEPA). 1987. Recommended Biological Indices for 301(h) Monitoring Programs. EPA 430/9-86-002. September 1987.
- U.S. Environmental Protection Agency (USEPA). 1993. Technical Information Review. Methyl tertiary Butyl Ether (CAS No. 1634-04-4). Office of Pollution Prevention and Toxics, U.S. EPA, Washington, D.C.
- U.S. Environmental Protection Agency (USEPA). 1994. Amended Section 301(h) Technical Support Document. Oceans and Coastal Protection Division (4504F), Office of Wetlands, Oceans and Watersheds, United States Environmental Protection Agency, Washington DC 20460. EPA 842-B-94-007. September 1994.

- U.S. Environmental Protection Agency (USEPA). 1998. Letter from F. Marcus, Regional Administrator of the USEPA Region IX in regard to the City of Morro Bay/Cayucos Sanitary Districts application for a modified NPDES permit under Section 301(h) of the Clean Water Act. Tentative Decision of the Regional Administrator Pursuant to 40 CFR Part 125, Subpart G; dated 3 September 1998.
- U.S. Environmental Protection Agency (USEPA). 2002. Methods for Measuring the Acute Toxicity of Effluents and Receiving Water to Freshwater and Marine Organisms, Fifth Edition. October 2002. U.S. Environmental Protection Agency, Office of Water (4303T). 1200 Pennsylvania Avenue, NW Washington, DC 20460. EPA-821-R-02-012.
- U.S. Environmental Protection Agency (USEPA). 2005. Letter from Wayne Nastri, Regional Administrator of the USEPA Region IX in regard to the City of Morro Bay/Cayucos Sanitary Districts application for a modified NPDES permit under Section 301(h) of the Clean Water Act. Tentative Decision of the Regional Administrator Pursuant to 40 CFR Part 125, Subpart G; dated 10 September 2005.
- U.S. Environmental Protection Agency (USEPA). 2007. Request for Concurrence with EPA Finding of "No Likely Adverse Effect" Pursuant to Section 7 of the Federal Endangered Species Act for the Continued Ocean Discharge from the Morro Bay/Cayucos Wastewater Treatment Plant. Letter dated 6 September 2007 from Ms. Alexis Strauss, Director, USEPA Water Division to Ms. Diane Noda, Field Supervisor, U.S. Fish and Wildlife Service, transmitting an Endangered Species Act Biological Evaluation for the Morro Bay/Cayucos Wastewater Treatment Plant prepared by the U.S. EPA Region IX, September 2007.
- U.S. Environmental Protection Agency (USEPA) and the U.S. Army Corps of Engineers (USACOE). 1991. Evaluation of Dredged Material Proposed for Ocean Disposal (Testing Manual). Prepared by the Environmental Protection Agency, Office of Marine and Estuarine Protection, Washington, D.C., and Department of the Army, U.S. Army Corps of Engineers, Washington, D.C. EPA-503/8-91/001, 280 pp.
- U.S. Environmental Protection Agency (USEPA) and the U.S. Army Corps of Engineers (USACOE). 1993. Draft Inland Testing Manual. Prepared by the Environmental Protection Agency, Office of Water, Washington, D.C., and Department of the Army, U.S. Army Corps of Engineers, Washington, D.C.
- U.S. Fish and Wildlife Service (USFWS). 1982. California brown pelican recovery plan. Portland, OR.
- U.S. Government Printing Office (USGPO). 1997a. Code of Federal Regulations. Protection of the Environment. Criteria And Standards For The National Pollutant Discharge Elimination System, Criteria for Modifying the Secondary Treatment Requirements Under Section 301(h) of the Clean Water Act, Definitions. Chapter 40, Part 125, Subpart G.
- U.S. Government Printing Office (USGPO). 1997b. Code of Federal Regulations. Environmental Protection. Standards for the use or disposal of Sewage Sludge, Land Application, Pollutant Limits. Chapter 40, Part 503, Subpart B. 1 July 1997 edition.
- U.S. Government Printing Office (USGPO). 1982a. Code of Federal Regulations. Protection of the Environment. Criteria And Standards For The National Pollutant Discharge Elimination System, Criteria for Modifying the Secondary Treatment Requirements Under Section 301(h) of the Clean Water Act, Primary or equivalent treatment requirements. Chapter 40, Part 125, Subpart G.

- U.S. Government Printing Office (USGPO). 1982b. Code of Federal Regulations. Protection of the Environment. Criteria And Standards For The National Pollutant Discharge Elimination System, Criteria for Modifying the Secondary Treatment Requirements Under Section 301(h) of the Clean Water Act, Establishment of a monitoring program. Chapter 40, Part 125, Subpart G.
- U.S. Minerals Management Service (USMMS). 1996. Outer continental shelf oil and gas leasing program: 1997-2002, final environmental impact statement. U.S. Department of the Interior, Minerals Management Service, Herndon, VA. OCS EIS/EA MMS 96-0043.
- Washington, H.G. 1984. Diversity, biotic and similarity indices. A review with special relevance to aquatic ecosystems. *Water Res.* 18:653-694.
- Water Environment Research Foundation (WERF). 2003. Cyanide formation and fate in complex effluents and its relation to water quality criteria. WERF publication No. 98-HHE-5. Water Environment Research Foundation, Alexandria, Va. Co-published by IWA Publishing, London, United Kingdom.
- Winger P.V. and P.J. Lasier. 1991. A Vacuum-Operated Pore Water Extractor for Estuarine and Freshwater Sediments. *Archives of Environmental Contamination and Toxicology*, v.21, p. 321-324; Aug 1991.
- Whittaker, R.H. 1965. Dominance and diversity in land plant communities. *Science* 147:250-260.
- Whittaker, R.H. 1972. Evolution and measurement of species diversity. *Taxon* 21:213-251.
- Word, J.Q. 1978. The infaunal trophic index. Pages 19-39 In: Bascom (Ed.) Southern California Coastal Water Research Project, Annual report for the year 1978. El Segundo, CA.
- Word, J.Q. 1980. Classification of Benthic Invertebrates into Infaunal Trophic Index Feeding Groups. Pages 103-121 In: Bascom (Ed.) Southern California Coastal Water Research Project, Annual report for the years 1979-1980. El Segundo, CA.
- Word, J.Q. 1990. The infaunal trophic index, a functional approach to benthic community analyses. Dissertation. University of Washington, Seattle, Washington, USA.
- Zheng A., Dzombak DA, Luthy, R.G., Kavanaugh, M.C., and R.A. Deeb. 2004a. The occurrence of cyanide formation in six full-scale publicly owned treatment works. *Water Environment Research* 2004 Mar-Apr;76(2):101-12.
- Zheng, A., Dzombak, D.A., and R.G. Zheng, R.G. 2004b. Effects of Nitrosation on the Formation of Cyanide in Publicly Owned Treatment Works Secondary Effluent. *Water Environment Research*, 2004 May-Jun: 76(3): 197-204(8).

APPENDIX A

Wastewater Treatment Plant Specifications

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Table A.1 WWTP Specifications

Parameter	Quantity	Parameter	Quantity
Waste Loading		Tank 1	2.74
Flow (MGD)		Tank 2	2.74
Average dry-weather flow	2.06	Surface loading rate PSDWF (10 ³ L/m ² /day)	29.74
PSDWF	2.36	Detention time at PWWF (hr.)	2.2
Peak dry-weather flow	6.64	Total Treatment	
PWWF	6.60	Overall treatment efficiencies (%)	
Strength		BOD ₅	57
BOD ₅ (mg/L)	280	Suspended solids	75
Suspended solids (mg/L)	280	Expected effluent quality (mg/L)	
Grit (ft ³ /mg)	10	BOD ₅	120
Waste quantities at PSDWF		Suspended solids	70
BOD ₅ (mt/day)	2.5	Solids stabilization	
Suspended Solids (mt/day)	2.5	Anaerobic digester loading (mt/day)	
Grit (ft ³ /day)	23.6	Primary solids	1.6
Preliminary Treatment		Secondary solids	0.4
Mechanically cleaned bar screen		Assumed sludge volatile content (%)	
Number	1	Primary solids	70
Capacity (MGD)	8.2	Secondary solids	82
Channel Monster		Sludge volume (m ³ /day)	50.7
Number	1	Digester 1 (existing, fixed cover)	
Capacity (MGD)	7.0	Diameter (m)	12.2
Influent pumps (variable speed)		Side water depth (m)	4.9
Number	3	Volume (m ³)	629
Capacity each (MGD)	3.3	Digester 2 (existing, fixed cover)	
Total head (m)	9.6	Diameter (m)	12.2
Aerated grit removal tanks		Side water depth (m)	5.8
Number	1	Volume (m ³)	725
Length (m)	9.1	Digester 3 (new, floating cover)	
Width (m)	4.9	Diameter (m)	10.7
Depth (m)	2.4	Side water depth (m)	6.9
Detention time at PWWF (min)	6.3	Volume (m ³)	646
Grit Pumps		Hydraulic detention time based on net volume of digesters 2 and 3 (days)	23
Number	2	Assumed volatile solids reduction (%)	55
Capacity (gpm)	250	Expected sludge gas production (m ³ /day)	804
Primary Treatment			
Sedimentation tanks			
Number	2		
Diameter (m)			
Tank 1	15.2		
Tank 2	12.2		
Average side water depth (m)			

Parameter	Quantity
Sludge drying beds	
Number	12
Length each (m)	49.4
Width each (m)	9.8
Solids Loadings (kg ft ⁻¹ yr ⁻¹)	78.3
Assumed removal efficiency (%)	
BOD ₅	35
Suspended solids	65
Primary effluent quality (mg/L)	
BOD ₅	182
Suspended solids	98
Secondary treatment	
Biofilters (existing, in partial secondary treatment mode of operation)	
Flow distribution at PSDWF (MGD)	
Biofilter 1	0.39
Biofilter 2	0.58
Diameter (m)	
Biofilter 1	18.3
Biofilter 2	21.3
Net media surface area (m ²)	
Biofilter 1	262
Biofilter 2	350
Average media height (m)	
Biofilter 1	1.4
Biofilter 2	1.5
Media Volume (m ³)	
Biofilter 1	360
Biofilter 2	532
Specific organic loading rate (lbs BOD ₅ /day/1000 ft ³)	47
Circulated flow (MGD)	
Biofilter 1	1.37
Biofilter 2	2.04
Hydraulic loading rate (gpm/ft ² media surface)	
Biofilter 1	0.34
Biofilter 2	0.38
Circulation pumps	
Biofilter 1	
Capacity (gpm)	950
Total head (m)	3.4
Biofilter 2	
Capacity (gpm)	1420
Total head (m)	4.3

Parameter	Quantity
Stand-by (2-speed)	
Capacity (gpm)	960
	1660
Total head (m)	3.4
	4.4
Interstage pumping	
Biofilter effluent pumps (variable speed)	
Number	2
Capacity each (gpm)	2300
Total head (m)	8.2
Secondary sedimentation tanks	
Number	1
Diameter (m)	16.8
Tank surface area (m ²)	221
Tank volume (m ³)	3125
Average water depth (m)	4.6
Overflow rate at PSDWF (10 ³ L/m ² /day)	16.6
Expected secondary treatment effluent quality (mg/L)	
BOD ₅	30
Suspended Solids	30
Chlorination	
Chlorine contact tank (existing)	
Number of passes	2
Length (m)	
Pass 1	16.8
Pass 2	22.9
Width each pass (m)	4.6
Average depth (m)	2.3
Total volume (m ³)	413
Detention time at PDWF (min)	24
Chlorinators	
Pre-chlorinator	
Number	1
Initial capacity (kg/day)	227.3
Ultimate capacity (kg/day)	909.1
RAS chlorinator	
Number	1
Capacity (kg/day)	227.3
Ultimate capacity (kg/day)	90.9
Sodium Hypochlorite Post Chlorinator	
Chemical feed pumps	3
Combined Capacity (kg/day)	5450
Dechlorination	
Sodium Bisulfite System	
Chemical feed pumps	3
Combined Capacity (kg/day)	1226

APPENDIX B
Infaunal Biology

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INFAUNAL INDICES

B.1.1 Species Diversity

The Shannon diversity index (H') (Shannon and Weaver 1949) is the most common diversity index used in 301(h) programs. It measures the relative distribution of individual organisms among the species present in the sample. H' increases for broader distributions of individuals among species. If all individuals are of one species then H' is 0.00. If each individual organism is a separate species then H' is determined by the logarithm of the total number of organisms collected. For other distributions, the

diversity index is given by: $H' = - \sum_{j=1}^S \left[\left(\frac{n_j}{N} \right) \ln \left(\frac{n_j}{N} \right) \right]$; where: S = total number of species, n_j = number of

individuals in the j^{th} species, N = total number of individuals, and $\ln$ = natural logarithm (base e). The value of the Shannon index usually falls between 1.5 and 3.5 and only rarely surpasses 4.5 (Margalef 1972).

Some studies have found a decrease in this index in response to pollutant stress in benthic communities. However, this index is ambiguous because it depends on how evenly the organisms are distributed among the species. Consequently, a statistically significant reduction in this index can occur in the absence of anthropogenic (human-induced) stresses.

When randomness in the sample cannot be guaranteed, then the Brillouin index (h) is a more appropriate

measure of diversity (Pielou 1977). It is calculated using the formula: $h = \frac{\ln(N!) - \sum_{j=1}^S [\ln(n_j!)]}{N}$. It gives a

similar measure of diversity although it produces a slightly lower value than the Shannon index when applied to the same data. In contrast to the Shannon index, the Brillouin will vary between samples although the number of species and their proportional abundance remain the same. Because of its dependence on sample size and the increased complexity of its computation, the Brillouin index is more rarely used than the Shannon index.

B.1.2 Evenness

The Pielou evenness index (J') (Pielou 1977) measures how evenly the individual organisms are distributed among the species present in the sample. J' increases for more even distributions of individuals among species. If all individuals belong to a single species, then J' is indeterminate. If each species is represented by a single organism, then J' will be equal to 1.00. For other distributions, the evenness index is given by: $J' = \frac{H'}{\ln S}$; where: S = total number of species, and H' = Shannon-Wiener diversity index.

Because this index is derived from the Shannon-Wiener diversity index (H'), it is subject to the same limitations.

B.1.3 Species Dominance

Dominance indices increase with decreasing diversity and are heavily weighted toward the most common species in a sample. The best known of these measures is Simpson's index (C') (Simpson 1949; Wittaker 1965). It is related to other diversity and evenness indices but increases with increasing proportions of individuals associated with a few species. If all individuals are of one species, then C' is maximum and equal to the maximum dominance of 1.00. If individual organisms are evenly distributed among species

($J'=1.00$), then C' asymptotically approaches 0.00 with increasing numbers of individuals. The Simpson dominance measure is given by: $C' = \sum_{j=1}^S \left(\frac{n_j}{N} \right)^2$ but for finite communities, the unbiased form is:

$$C' = \sum_{j=1}^S \left(\frac{n_j(n_j - 1)}{N(N - 1)} \right) \text{ (Magurran 1988).}$$

An unrelated measure of dominance has been ascribed to Swartz et al. (1985). The Swartz dominance index (Sw) is defined as the minimum number of species that account for 75% of all individual organisms collected in a sample. In this dominance measure, species are first ranked by the number of individual organisms before establishing the cumulative percent equal to or exceeding 75%. This is an inverse measure because higher dominance is reflected in a lower number of species accounting for 75% of the individual organisms. Despite this, it is not subject to many of the limitations that plague the other univariate indices. It is a non-parametric measure that does not assume an underlying distribution of individuals among species.

B.1.4 Infaunal Trophic Index

The Infaunal Trophic Index (ITI) (Word 1978) compares the abundance of four soft-bottom benthic assemblages distinguished by feeding behavior. Because the sensitivity or tolerance to organic enrichment in particulate matter differs among the four groups, shifts in group dominance, as reflected in a changing infaunal index, can be indicative of changed or degraded environmental conditions. The ITI ranges between 0 and 100. When species in Group I (suspension feeders) and Group II (surface-detritus feeders) dominate, index values are above 58 and sediments are relatively clean. Lower infaunal indices occur when species in Group III (surface deposit feeders) and Group IV (sub-surface detritus feeders) dominate and sediments are high in organics. The ITI is computed from: $ITI = 100 - 33.3 \left[\frac{G_2 + 2G_3 + 3G_4}{G_1 + G_2 + G_3 + G_4} \right]$; where:

G_i = number of individual organisms within the i^{th} trophic group.

B.1.5 Species Richness

The Margalef species richness index (d) (Margalef 1951) measures the number of species in a sample relative to the number of individual organisms. d strongly increases for increasing number of species and increases only logarithmically for decreasing number of individuals. If only one species is present then d is 0.00. For other distributions, the richness index is given by: $d = \frac{S - 1}{\ln N}$. Its applicability to biological communities is dependent on whether specimens are log-normally distributed among the species in a given sample. Such an assumption is not globally applicable to benthic marine communities, and without testing each data set, the richness index is of questionable value.

Table B.1 Station Abundance by Taxa during October 2011

Taxonomic Group	Taxon	Station							Station Total	Percent of Total	Cumulative %
		B1	B2	B3	B4	B5	B6	B7			
Echinodermata	<i>Dendraster excentricus</i>	812	323	323	100	316	281	497	2652	—	—
Crustacea	<i>Rhepoxynius menziesi</i>	34	108	110	82	146	83	110	673	29.05	29.05
Mollusca	<i>Alvania</i>	12	32	46	41	111	40	75	357	15.41	44.45
Nemertea	<i>Carinoma mutabilis</i>	23	27	42	54	27	50	26	249	10.75	55.20
Crustacea	<i>Rhepoxynius abronius</i>	48	16	18	28	43	22	35	210	9.06	64.26
Crustacea	<i>Foxiphalus xiximeus</i>	23	2	2	6	22	18	6	79	3.41	67.67
Crustacea	<i>Cancer gracilis</i>	20	6	5	2	14	14	11	72	3.11	70.78
Crustacea	<i>Majoxiphalus major</i>	2	2	15	24	9	5	13	70	3.02	73.80
Nemertea	<i>Carinomella lactea</i>	—	3	7	23	12	1	—	46	1.99	75.79
Bivalvia	<i>Tellina modesta</i>	3	5	8	4	11	5	4	40	1.73	77.51
Bivalvia	<i>Tellina bodegensis</i>	4	8	8	6	5	3	3	37	1.60	79.11
Crustacea	<i>Americhilidium shoemakeri</i>	5	6	4	4	6	6	3	34	1.47	80.58
Mollusca	<i>Nassarius perpinguis</i>	1	3	3	6	7	7	5	32	1.38	81.96
Annelida	<i>Lumbrineris californiensis</i>	5	1	3	8	2	5	5	29	1.25	83.21
Annelida	<i>Sigalion spinosa</i>	1	1	7	7	9	—	4	29	1.25	84.46
Crustacea	<i>Pacifoculodes spinipes</i>	1	3	5	6	1	5	6	27	1.17	85.63
Annelida	<i>Lumbrineris</i>	2	3	2	9	6	3	1	26	1.12	86.75
Annelida	<i>Spiochaetopterus costarum</i>	10	4	1	1	6	1	—	23	0.99	87.74
Crustacea	<i>Eohaustorius sencillus</i>	—	7	10	—	2	2	1	22	0.95	88.69
Annelida	<i>Phyllodoce</i>	17	—	1	—	—	—	—	18	0.78	89.47
Annelida	<i>Notomastus lineatus</i>	1	1	6	2	3	3	2	18	0.78	90.25
Annelida	<i>Scoloplos armiger</i>	3	2	1	8	1	1	—	16	0.69	90.94
Crustacea	<i>Tecticeps convexus</i>	—	1	—	4	2	—	5	12	0.52	91.45
Crustacea	<i>Gibberosus myersi</i>	1	—	1	—	4	2	1	9	0.39	91.84
Nemertea	<i>Cerebratulus californiensis</i>	4	1	—	1	1	1	—	8	0.35	92.19
Crustacea	<i>Aoroides intermedius</i>	—	—	—	—	8	—	—	8	0.35	92.53
Mollusca	<i>Mitrella aurantiaca</i>	7	—	—	—	—	—	—	7	0.30	92.84
Crustacea	<i>Gnathopleustes pugettensis</i>	3	—	—	—	—	—	4	7	0.30	93.14
Crustacea	<i>Anchicolurus occidentalis</i>	—	—	—	2	3	—	2	7	0.30	93.44
Annelida	<i>Chaetozone setosa</i>	—	—	—	2	2	2	1	7	0.30	93.74
Bivalvia	<i>Clinocardium nuttallii</i>	2	—	1	1	1	—	1	6	0.26	94.00
Annelida	<i>Nephtys caecoides</i>	2	—	—	1	1	2	—	6	0.26	94.26
Crustacea	<i>Isocheles pilosus</i>	1	—	—	1	1	2	1	6	0.26	94.52
Annelida	<i>Sthenelais verruculosa</i>	—	—	1	1	2	1	1	6	0.26	94.78
Annelida	<i>Armandia bioculata</i>	4	—	—	—	1	—	—	5	0.22	94.99
Crustacea	Hippolytidae	2	1	—	—	1	—	1	5	0.22	95.21
Annelida	<i>Glycera convoluta</i>	—	1	1	1	1	1	—	5	0.22	95.43
Annelida	<i>Apoprionospio pygmaea</i>	4	—	—	—	—	—	—	4	0.17	95.60
Annelida	<i>Glycinde armigera</i>	2	—	—	1	—	—	1	4	0.17	95.77
Mollusca	<i>Olivella pedroana</i>	—	—	1	—	1	—	2	4	0.17	95.94
Mollusca	<i>Odostomia</i>	—	—	—	4	—	—	—	4	0.17	96.12
Crustacea	<i>Photis brevipes</i>	—	—	—	—	4	—	—	4	0.17	96.29
Annelida	<i>Gyptis brevipalpa</i>	2	—	—	—	—	1	—	3	0.13	96.42
Crustacea	<i>Leuroleberis sharpei</i>	1	—	2	—	—	—	—	3	0.13	96.55
Annelida	<i>Goniada brunnea</i>	—	2	1	—	—	—	—	3	0.13	96.68

Table B.1 Station Abundance by Taxa during October 2011

Taxonomic Group	Taxon	Station							Station Total	Percent of Total	Cumulative %
		B1	B2	B3	B4	B5	B6	B7			
Mollusca	<i>Nassarius fossatus</i>	–	1	1	–	1	–	–	3	0.13	96.81
Annelida	<i>Phylo felix</i>	–	1	–	–	1	1	–	3	0.13	96.94
Bivalvia	<i>Chione</i>	–	–	1	2	–	–	–	3	0.13	97.07
Annelida	<i>Onuphis iridescens</i>	–	–	–	2	–	1	–	3	0.13	97.19
Crustacea	Majidae	–	–	–	1	1	–	1	3	0.13	97.32
Crustacea	<i>Erichthonius brasiliensis</i>	–	–	–	–	3	–	–	3	0.13	97.45
Crustacea	<i>Crangon</i>	1	–	–	–	1	–	–	2	0.09	97.54
Annelida	<i>Magelona sacculata</i>	1	–	–	–	–	1	–	2	0.09	97.63
Bivalvia	<i>Rochefortia tumida</i>	1	–	–	–	–	1	–	2	0.09	97.71
Annelida	<i>Travisia gigas</i>	1	–	–	–	–	–	1	2	0.09	97.80
Nemertea	<i>Lineus bilineatus</i>	–	2	–	–	–	–	–	2	0.09	97.89
Crustacea	Gammaridea	–	1	–	–	1	–	–	2	0.09	97.97
Echinodermata	<i>Amphiodia digitata</i>	–	1	–	–	–	–	1	2	0.09	98.06
Crustacea	<i>Mesolamprops dillonensis</i>	–	–	1	–	–	1	–	2	0.09	98.14
Crustacea	<i>Synidotea bicuspidata</i>	–	–	–	–	2	–	–	2	0.09	98.23
Mollusca	<i>Amphissa undata</i>	–	–	–	–	2	–	–	2	0.09	98.32
Mollusca	<i>Kurtziella beta</i>	–	–	–	–	2	–	–	2	0.09	98.40
Crustacea	<i>Blepharipoda occidentalis</i>	–	–	–	–	1	1	–	2	0.09	98.49
Bivalvia	<i>Siliqua lucida</i>	–	–	–	–	–	2	–	2	0.09	98.58
Annelida	<i>Leitoscoloplos pugettensis</i>	–	–	–	–	–	2	–	2	0.09	98.66
Phoronida	<i>Phoronis</i>	1	–	–	–	–	–	–	1	0.04	98.71
Annelida	<i>Typosyllis farallonensis</i>	1	–	–	–	–	–	–	1	0.04	98.75
Annelida	<i>Goniada maculata</i>	1	–	–	–	–	–	–	1	0.04	98.79
Annelida	<i>Magelona hartmanae</i>	1	–	–	–	–	–	–	1	0.04	98.83
Mollusca	<i>Polinices lewisii</i>	1	–	–	–	–	–	–	1	0.04	98.88
Platyhelminthes	Polycladida	1	–	–	–	–	–	–	1	0.04	98.92
Crustacea	<i>Callinassa</i>	1	–	–	–	–	–	–	1	0.04	98.96
Annelida	<i>Notomastus tenuis</i>	–	1	–	–	–	–	–	1	0.04	99.01
Annelida	<i>Ampharete labrops</i>	–	–	1	–	–	–	–	1	0.04	99.05
Nemertea	<i>Paranemertes sp. A</i>	–	–	1	–	–	–	–	1	0.04	99.09
Echinodermata	<i>Leptosynapta</i>	–	–	1	–	–	–	–	1	0.04	99.14
Crustacea	<i>Bathycopea daltonae</i>	–	–	1	–	–	–	–	1	0.04	99.18
Bivalvia	<i>Pandora punctata</i>	–	–	1	–	–	–	–	1	0.04	99.22
Other	<i>Halosydna brevisetosa</i>	–	–	1	–	–	–	–	1	0.04	99.27
Annelida	<i>Cirriformia spirabranchia</i>	–	–	1	–	–	–	–	1	0.04	99.31
Annelida	<i>Diopatra ornata</i>	–	–	–	1	–	–	–	1	0.04	99.35
Annelida	<i>Chone mollis</i>	–	–	–	1	–	–	–	1	0.04	99.40
Echinodermata	<i>Amphiodia</i>	–	–	–	1	–	–	–	1	0.04	99.44
Mollusca	<i>Turbonilla</i>	–	–	–	1	–	–	–	1	0.04	99.48
Bivalvia	<i>Cooperella subdiaphana</i>	–	–	–	1	–	–	–	1	0.04	99.53
Crustacea	<i>Euphilomedes carcharodonta</i>	–	–	–	1	–	–	–	1	0.04	99.57
Annelida	<i>Mesochaetopterus</i>	–	–	–	1	–	–	–	1	0.04	99.61
Bivalvia	<i>Pandora bilirata</i>	–	–	–	1	–	–	–	1	0.04	99.65
Annelida	<i>Platynereis bicanaliculata</i>	–	–	–	–	1	–	–	1	0.04	99.70
Annelida	<i>Tenonia priops</i>	–	–	–	–	1	–	–	1	0.04	99.74

Table B.1 Station Abundance by Taxa during October 2011

Taxonomic Group	Taxon	Station							Station Total	Percent of Total	Cumulative %
		B1	B2	B3	B4	B5	B6	B7			
Annelida	<i>Eupolymnia heterobranchia</i>	–	–	–	–	1	–	–	1	0.04	99.78
Crustacea	<i>Photis macinerneyi</i>	–	–	–	–	–	1	–	1	0.04	99.83
Annelida	<i>Axiothella rubrocincta</i>	–	–	–	–	–	1	–	1	0.04	99.87
Crustacea	<i>Mandibulophoxus gilesi</i>	–	–	–	–	–	1	–	1	0.04	99.91
Crustacea	Paguridae	–	–	–	–	–	1	–	1	0.04	99.96
Crustacea	Idotea	–	–	–	–	–	–	1	1	0.04	100.00
Total Number of Individuals		1073	576	645	453	810	581	831	4969		
Total Number of Individuals Excluding <i>D. Excentricus</i>		261	253	322	353	494	300	334	2317		

Table B.2 Replicate Sample Abundance by Taxa at Station B1 during October 2011

Taxonomic Group	Taxon	Replicate					Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Echinodermata	<i>Dendraster excentricus</i>	100	4	275	162	271	812	–	–
Crustacea	<i>Rhepoxynius abronius</i>	11	28	6	2	1	48	18.39	18.39
Crustacea	<i>Rhepoxynius menziesi</i>	16	9	–	7	2	34	13.03	31.42
Nemertea	<i>Carinoma mutabilis</i>	6	9	2	3	3	23	8.81	40.23
Crustacea	<i>Foxiphalus xiximeus</i>	5	–	7	10	1	23	8.81	49.04
Crustacea	<i>Cancer gracilis</i>	3	4	13	–	–	20	7.66	56.70
Annelida	<i>Phyllodoce</i>	–	–	16	1	–	17	6.51	63.22
Mollusca	<i>Alvania</i>	6	4	2	–	–	12	4.60	67.82
Annelida	<i>Spiochaetopterus costarum</i>	–	10	–	–	–	10	3.83	71.65
Mollusca	<i>Mitrella aurantiaca</i>	–	1	6	–	–	7	2.68	74.33
Crustacea	<i>Americhilidium shoemakeri</i>	1	4	–	–	–	5	1.92	76.25
Annelida	<i>Lumbrineris californiensis</i>	–	1	2	1	1	5	1.92	78.16
Nemertea	<i>Cerebratulus californiensis</i>	2	–	2	–	–	4	1.53	79.69
Annelida	<i>Apoprionospio pygmaea</i>	–	4	–	–	–	4	1.53	81.23
Bivalvia	<i>Tellina bodegensis</i>	–	2	2	–	–	4	1.53	82.76
Annelida	<i>Armandia bioculata</i>	–	–	4	–	–	4	1.53	84.29
Bivalvia	<i>Tellina modesta</i>	1	–	1	1	–	3	1.15	85.44
Annelida	<i>Scoloplos armiger</i>	–	2	1	–	–	3	1.15	86.59
Crustacea	<i>Gnathopleustes pugettensis</i>	–	–	3	–	–	3	1.15	87.74
Annelida	<i>Glycinde armigera</i>	–	2	–	–	–	2	0.77	88.51
Annelida	<i>Lumbrineris</i>	–	2	–	–	–	2	0.77	89.27
Annelida	<i>Nephtys caecoides</i>	–	2	–	–	–	2	0.77	90.04
Crustacea	<i>Majoxiphalus major</i>	–	1	1	–	–	2	0.77	90.80
Bivalvia	<i>Clinocardium nuttallii</i>	–	1	1	–	–	2	0.77	91.57
Crustacea	Hippolytidae	–	–	2	–	–	2	0.77	92.34

Table B.2 Replicate Sample Abundance by Taxa at Station B1 during October 2011

Taxonomic Group	Taxon	Replicate					Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Annelida	<i>Gyptis brevipalpa</i>	–	–	2	–	–	2	0.77	93.10
Crustacea	<i>Crangon</i>	1	–	–	–	–	1	0.38	93.49
Annelida	<i>Notomastus lineatus</i>	1	–	–	–	–	1	0.38	93.87
Phoronida	<i>Phoronis</i>	–	1	–	–	–	1	0.38	94.25
Crustacea	<i>Gibberosus myersi</i>	–	1	–	–	–	1	0.38	94.64
Crustacea	<i>Leuroleberis sharpei</i>	–	1	–	–	–	1	0.38	95.02
Crustacea	<i>Pacifoculodes spinipes</i>	–	1	–	–	–	1	0.38	95.40
Annelida	<i>Magelona sacculata</i>	–	1	–	–	–	1	0.38	95.79
Annelida	<i>Goniada maculata</i>	–	1	–	–	–	1	0.38	96.17
Mollusca	<i>Nassarius perpinguis</i>	–	1	–	–	–	1	0.38	96.55
Crustacea	<i>Callianassa</i>	–	1	–	–	–	1	0.38	96.93
Annelida	<i>Magelona hartmanae</i>	–	–	1	–	–	1	0.38	97.32
Mollusca	<i>Polinices lewisii</i>	–	–	1	–	–	1	0.38	97.70
Annelida	<i>Typosyllis farallonensis</i>	–	–	1	–	–	1	0.38	98.08
Platyhelminthes	Polycladida	–	–	1	–	–	1	0.38	98.47
Bivalvia	<i>Rocheportia tumida</i>	–	–	–	1	–	1	0.38	98.85
Crustacea	<i>Isocheles pilosus</i>	–	–	–	1	–	1	0.38	99.23
Annelida	<i>Sigalion spinosa</i>	–	–	–	–	1	1	0.38	99.62
Annelida	<i>Travisia gigas</i>	–	–	–	–	1	1	0.38	100.00
Total Number of Individuals		153	98	352	189	281	1073		
Total Number of Individuals Excluding <i>D. Excentricus</i>		53	94	77	27	10	261		

Table B.3 Replicate Sample Abundance by Taxa at Station B2 during October 2011

Taxonomic Group	Taxon	Replicate					Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Echinodermata	<i>Dendraster excentricus</i>	29	3	173	74	44	323	–	–
Crustacea	<i>Rhepoxynius menziesi</i>	20	34	21	22	11	108	42.69	42.69
Mollusca	<i>Alvania</i>	8	2	18	2	2	32	12.65	55.34
Nemertea	<i>Carinoma mutabilis</i>	6	5	7	6	3	27	10.67	66.01
Crustacea	<i>Rhepoxynius abronius</i>	4	3	4	3	2	16	6.32	72.33
Bivalvia	<i>Tellina bodegensis</i>	3	1	2	1	1	8	3.16	75.49
Crustacea	<i>Eohaustorius sencillus</i>	–	–	1	4	2	7	2.77	78.26
Crustacea	<i>Americhilidium shoemakeri</i>	1	–	2	1	2	6	2.37	80.63
Crustacea	<i>Cancer gracilis</i>	–	2	–	4	–	6	2.37	83.00
Bivalvia	<i>Tellina modesta</i>	1	2	1	–	1	5	1.98	84.98
Annelida	<i>Spiochaetopterus costarum</i>	1	–	1	–	2	4	1.58	86.56
Nemertea	<i>Carinomella lactea</i>	2	–	–	–	1	3	1.19	87.75
Mollusca	<i>Nassarius perpinguis</i>	–	1	1	1	–	3	1.19	88.93
Annelida	<i>Lumbrineris</i>	–	–	2	1	–	3	1.19	90.12
Crustacea	<i>Pacifoculodes spinipes</i>	–	–	2	1	–	3	1.19	91.30

Table B.3 Replicate Sample Abundance by Taxa at Station B2 during October 2011

Taxonomic Group	Taxon	Replicate					Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Annelida	<i>Goniada brunnea</i>	2	–	–	–	–	2	0.79	92.09
Crustacea	<i>Majoxiphalus major</i>	1	–	1	–	–	2	0.79	92.89
Crustacea	<i>Foxiphalus xiximeus</i>	–	1	–	1	–	2	0.79	93.68
Nemertea	<i>Lineus bilineatus</i>	–	–	–	1	1	2	0.79	94.47
Annelida	<i>Scoloplos armiger</i>	–	–	–	–	2	2	0.79	95.26
Annelida	<i>Lumbrineris californiensis</i>	–	–	–	1	–	1	0.40	95.65
Mollusca	<i>Nassarius fossatus</i>	–	1	–	–	–	1	0.40	96.05
Crustacea	<i>Tecticeps convexus</i>	–	–	1	–	–	1	0.40	96.44
Nemertea	<i>Cerebratulus californiensis</i>	–	–	1	–	–	1	0.40	96.84
Annelida	<i>Notomastus lineatus</i>	–	–	1	–	–	1	0.40	97.23
Annelida	<i>Notomastus tenuis</i>	–	–	1	–	–	1	0.40	97.63
Annelida	<i>Sigalion spinosa</i>	–	–	–	1	–	1	0.40	98.02
Crustacea	Gammaridea	–	–	–	1	–	1	0.40	98.42
Echinodermata	<i>Amphiodia digitata</i>	–	–	–	1	–	1	0.40	98.81
Crustacea	Hippolytidae	–	–	–	1	–	1	0.40	99.21
Annelida	<i>Glycera convoluta</i>	–	–	–	–	1	1	0.40	99.60
Annelida	<i>Phylo felix</i>	–	–	–	–	1	1	0.40	100.00
Total Number of Individuals		78	55	240	127	76	576		
Total Number of Individuals Excluding <i>D. Excentricus</i>		49	52	67	53	32	253		

Table B.4 Replicate Sample Abundance by Taxa at Station B3 during October 2011

Taxonomic Group	Taxon	Replicate					Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Echinodermata	<i>Dendraster excentricus</i>	192	100	–	19	12	323	–	–
Crustacea	<i>Rhepoxynius menziesi</i>	17	34	24	15	20	110	34.16	34.16
Mollusca	<i>Alvania</i>	18	–	6	17	5	46	14.29	48.45
Nemertea	<i>Carinoma mutabilis</i>	6	6	5	7	18	42	13.04	61.49
Crustacea	<i>Rhepoxynius abronius</i>	3	3	5	2	5	18	5.59	67.08
Crustacea	<i>Majoxiphalus major</i>	1	3	2	1	8	15	4.66	71.74
Crustacea	<i>Eohaustorius sencillus</i>	–	–	3	1	6	10	3.11	74.84
Bivalvia	<i>Tellina modesta</i>	1	1	2	–	4	8	2.48	77.33
Bivalvia	<i>Tellina bodegensis</i>	1	–	2	2	3	8	2.48	79.81
Annelida	<i>Sigalion spinosa</i>	1	–	1	2	3	7	2.17	81.99
Nemertea	<i>Carinomella lactea</i>	–	–	–	4	3	7	2.17	84.16
Annelida	<i>Notomastus lineatus</i>	–	–	4	1	1	6	1.86	86.02
Crustacea	<i>Cancer gracilis</i>	–	4	–	–	1	5	1.55	87.58
Crustacea	<i>Pacifoculodes spinipes</i>	–	1	3	–	1	5	1.55	89.13
Crustacea	<i>Americhilidium shoemakeri</i>	1	2	–	1	–	4	1.24	90.37

Table B.4 Replicate Sample Abundance by Taxa at Station B3 during October 2011

Taxonomic Group	Taxon	Replicate					Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Mollusca	<i>Nassarius perpinguis</i>	1	–	–	–	2	3	0.93	91.30
Annelida	<i>Lumbrineris californiensis</i>	–	–	2	–	1	3	0.93	92.24
Annelida	<i>Lumbrineris</i>	1	–	1	–	–	2	0.62	92.86
Crustacea	<i>Foxiphalus xiximeus</i>	–	–	–	2	–	2	0.62	93.48
Crustacea	<i>Leuroleberis sharpei</i>	–	–	–	2	–	2	0.62	94.10
Echinodermata	<i>Leptosynapta</i>	1	–	–	–	–	1	0.31	94.41
Mollusca	<i>Olivella pedroana</i>	1	–	–	–	–	1	0.31	94.72
Nemertea	<i>Paranemertes sp. A</i>	–	–	1	–	–	1	0.31	95.03
Annelida	<i>Sthenelais verruculosa</i>	–	–	1	–	–	1	0.31	95.34
Annelida	<i>Goniada brunnea</i>	–	–	1	–	–	1	0.31	95.65
Annelida	<i>Phyllodoce</i>	–	–	–	1	–	1	0.31	95.96
Annelida	<i>Ampharete labrops</i>	–	–	–	1	–	1	0.31	96.27
Bivalvia	<i>Chione</i>	–	–	–	1	–	1	0.31	96.58
Bivalvia	<i>Clinocardium nuttallii</i>	–	–	–	1	–	1	0.31	96.89
Annelida	<i>Glycera convoluta</i>	–	–	–	1	–	1	0.31	97.20
Mollusca	<i>Nassarius fossatus</i>	–	–	–	1	–	1	0.31	97.52
Other	<i>Halosydna brevisetosa</i>	–	–	–	1	–	1	0.31	97.83
Annelida	<i>Cirriformia spirabranca</i>	–	–	–	1	–	1	0.31	98.14
Annelida	<i>Spiochaetopterus costarum</i>	–	–	–	1	–	1	0.31	98.45
Annelida	<i>Scoloplos armiger</i>	–	–	–	–	1	1	0.31	98.76
Crustacea	<i>Gibberosus myersi</i>	–	–	–	–	1	1	0.31	99.07
Crustacea	<i>Bathycopea daltonae</i>	–	–	–	–	1	1	0.31	99.38
Crustacea	<i>Mesolamprops dillonensis</i>	–	–	–	–	1	1	0.31	99.69
Bivalvia	<i>Pandora punctata</i>	–	–	–	–	1	1	0.31	100.00
Total Number of Individuals		245	154	63	85	98	645		
Total Number of Individuals Excluding <i>D. Excentricus</i>		53	54	63	66	86	322		

Table B.5 Replicate Sample Abundance by Taxa at Station B4 during October 2011

Taxonomic Group	Taxon	Replicate					Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Echinodermata	<i>Dendraster excentricus</i>	–	29	70	–	1	100	–	–
Crustacea	<i>Rhepoxynius menziesi</i>	18	15	22	8	19	82	23.23	23.23
Nemertea	<i>Carinoma mutabilis</i>	11	2	3	31	7	54	15.30	38.53
Mollusca	<i>Alvania</i>	10	3	7	16	5	41	11.61	50.14
Crustacea	<i>Rhepoxynius abronius</i>	7	7	5	4	5	28	7.93	58.07
Crustacea	<i>Majoxiphalus major</i>	4	–	2	13	5	24	6.80	64.87
Nemertea	<i>Carinomella lactea</i>	–	15	8	–	–	23	6.52	71.39
Annelida	<i>Lumbrineris</i>	2	–	2	3	2	9	2.55	73.94
Annelida	<i>Scoloplos armiger</i>	3	3	–	1	1	8	2.27	76.20
Annelida	<i>Lumbrineris californiensis</i>	–	2	3	–	3	8	2.27	78.47

Table B.5 Replicate Sample Abundance by Taxa at Station B4 during October 2011

Taxonomic Group	Taxon	Replicate					Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Annelida	<i>Sigalion spinosa</i>	2	1	1	3	–	7	1.98	80.45
Mollusca	<i>Nassarius perpinguis</i>	2	1	1	1	1	6	1.70	82.15
Crustacea	<i>Pacifoculodes spinipes</i>	–	2	1	3	–	6	1.70	83.85
Bivalvia	<i>Tellina bodegensis</i>	–	2	1	2	1	6	1.70	85.55
Crustacea	<i>Foxiphalus xiximeus</i>	–	1	3	–	2	6	1.70	87.25
Crustacea	<i>Americhilidium shoemakeri</i>	1	1	2	–	–	4	1.13	88.39
Mollusca	<i>Odostomia</i>	1	1	2	–	–	4	1.13	89.52
Bivalvia	<i>Tellina modesta</i>	1	1	1	1	–	4	1.13	90.65
Crustacea	<i>Tecticeps convexus</i>	–	2	–	2	–	4	1.13	91.78
Annelida	<i>Onuphis iridescens</i>	2	–	–	–	–	2	0.57	92.35
Annelida	<i>Chaetozone setosa</i>	1	–	1	–	–	2	0.57	92.92
Annelida	<i>Notomastus lineatus</i>	–	1	–	–	1	2	0.57	93.48
Crustacea	<i>Cancer gracilis</i>	–	–	2	–	–	2	0.57	94.05
Crustacea	<i>Anchicolurus occidentalis</i>	–	–	–	1	1	2	0.57	94.62
Bivalvia	<i>Chione</i>	–	–	–	1	1	2	0.57	95.18
Mollusca	<i>Turbonilla</i>	1	–	–	–	–	1	0.28	95.47
Annelida	<i>Glycinde armigera</i>	1	–	–	–	–	1	0.28	95.75
Annelida	<i>Nephtys caecoides</i>	1	–	–	–	–	1	0.28	96.03
Crustacea	<i>Isocheles pilosus</i>	1	–	–	–	–	1	0.28	96.32
Nemertea	<i>Cerebratulus californiensis</i>	–	–	–	–	1	1	0.28	96.60
Annelida	<i>Chone mollis</i>	–	1	–	–	–	1	0.28	96.88
Annelida	<i>Diopatra ornata</i>	–	1	–	–	–	1	0.28	97.17
Crustacea	<i>Euphilomedes carcharodonta</i>	–	1	–	–	–	1	0.28	97.45
Echinodermata	<i>Amphiodia</i>	–	–	1	–	–	1	0.28	97.73
Crustacea	Majidae	–	–	1	–	–	1	0.28	98.02
Bivalvia	<i>Cooperella subdiaphana</i>	–	–	–	1	–	1	0.28	98.30
Annelida	<i>Glycera convoluta</i>	–	–	–	1	–	1	0.28	98.58
Bivalvia	<i>Pandora bilirata</i>	–	–	–	1	–	1	0.28	98.87
Bivalvia	<i>Clinocardium nuttallii</i>	–	–	–	–	1	1	0.28	99.15
Annelida	<i>Sthenelais verruculosa</i>	–	–	–	–	1	1	0.28	99.43
Annelida	<i>Mesochaetopterus</i>	–	–	–	–	1	1	0.28	99.72
Annelida	<i>Spiochaetopterus costarum</i>	–	–	–	–	1	1	0.28	100.00
Total Number of Individuals		69	92	139	93	60	453		
Total Number of Individuals Excluding <i>D. Excentricus</i>		69	63	69	93	59	353		

Table B.6 Replicate Sample Abundance by Taxa at Station B5 during October 2011

Taxonomic Group	Taxon	Replicate					Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Echinodermata	<i>Dendraster excentricus</i>	125	93	63	35	—	316	—	—
Crustacea	<i>Rhepoxynius menziesi</i>	32	34	30	22	28	146	29.55	29.55
Mollusca	<i>Alvania</i>	18	28	28	14	23	111	22.47	52.02
Crustacea	<i>Rhepoxynius abronius</i>	10	5	7	10	11	43	8.70	60.73
Nemertea	<i>Carinoma mutabilis</i>	5	5	2	10	5	27	5.47	66.19
Crustacea	<i>Foxiphalus xiximeus</i>	6	8	4	—	4	22	4.45	70.65
Crustacea	<i>Cancer gracilis</i>	3	7	1	—	3	14	2.83	73.48
Nemertea	<i>Carinomella lactea</i>	—	5	7	—	—	12	2.43	75.91
Bivalvia	<i>Tellina modesta</i>	1	2	4	2	2	11	2.23	78.14
Crustacea	<i>Majoxiphalus major</i>	2	1	—	2	4	9	1.82	79.96
Annelida	<i>Sigalion spinosa</i>	2	—	—	5	2	9	1.82	81.78
Crustacea	<i>Aoroides intermedius</i>	—	—	—	—	8	8	1.62	83.40
Mollusca	<i>Nassarius perpinguis</i>	1	—	2	2	2	7	1.42	84.82
Crustacea	<i>Americhilidium shoemakeri</i>	1	1	2	—	2	6	1.21	86.03
Annelida	<i>Lumbrineris</i>	—	2	—	3	1	6	1.21	87.25
Annelida	<i>Spiochaetopterus costarum</i>	—	—	1	4	1	6	1.21	88.46
Bivalvia	<i>Tellina bodegensis</i>	—	2	2	1	—	5	1.01	89.47
Crustacea	<i>Photis brevipes</i>	4	—	—	—	—	4	0.81	90.28
Crustacea	<i>Gibberosus myersi</i>	1	—	1	—	2	4	0.81	91.09
Annelida	<i>Notomastus lineatus</i>	—	—	2	—	1	3	0.61	91.70
Crustacea	<i>Anchicolurus occidentalis</i>	—	—	—	3	—	3	0.61	92.31
Crustacea	<i>Erichthonius brasiliensis</i>	—	—	—	—	3	3	0.61	92.91
Annelida	<i>Lumbrineris californiensis</i>	—	—	1	1	—	2	0.40	93.32
Annelida	<i>Chaetozone setosa</i>	—	2	—	—	—	2	0.40	93.72
Crustacea	<i>Eohaustorius sencillus</i>	—	1	—	—	1	2	0.40	94.13
Annelida	<i>Sthenelais verruculosa</i>	—	—	1	—	1	2	0.40	94.53
Crustacea	<i>Tecticeps convexus</i>	—	—	—	2	—	2	0.40	94.94
Mollusca	<i>Kurtziella beta</i>	—	—	—	1	1	2	0.40	95.34
Crustacea	<i>Synidotea bicuspidata</i>	—	—	—	—	2	2	0.40	95.75
Mollusca	<i>Amphissa undata</i>	—	—	—	—	2	2	0.40	96.15
Annelida	<i>Platynereis bicanaliculata</i>	1	—	—	—	—	1	0.20	96.36
Crustacea	<i>Pacifoculodes spinipes</i>	1	—	—	—	—	1	0.20	96.56
Annelida	<i>Glycera convoluta</i>	—	1	—	—	—	1	0.20	96.76
Mollusca	<i>Olivella pedroana</i>	—	1	—	—	—	1	0.20	96.96
Crustacea	<i>Isocheles pilosus</i>	—	1	—	—	—	1	0.20	97.17
Bivalvia	<i>Clinocardium nuttallii</i>	—	—	1	—	—	1	0.20	97.37
Crustacea	Gammaridea	—	—	1	—	—	1	0.20	97.57
Nemertea	<i>Cerebratulus californiensis</i>	—	—	—	1	—	1	0.20	97.77
Annelida	<i>Armandia bioculata</i>	—	—	—	1	—	1	0.20	97.98
Crustacea	<i>Crangon</i>	—	—	—	1	—	1	0.20	98.18
Annelida	<i>Phylo felix</i>	—	—	—	1	—	1	0.20	98.38
Annelida	<i>Scoloplos armiger</i>	—	—	—	—	1	1	0.20	98.58
Annelida	<i>Tenonia priops</i>	—	—	—	—	1	1	0.20	98.79
Mollusca	<i>Nassarius fossatus</i>	—	—	—	—	1	1	0.20	98.99
Annelida	<i>Nephtys caecoides</i>	—	—	—	—	1	1	0.20	99.19

Table B.6 Replicate Sample Abundance by Taxa at Station B5 during October 2011

Taxonomic Group	Taxon	Replicate					Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Annelida	<i>Eupolymnia heterobranchia</i>	–	–	–	–	1	1	0.20	99.39
Crustacea	Majidae	–	–	–	–	1	1	0.20	99.60
Crustacea	Hippolytidae	–	–	–	–	1	1	0.20	99.80
Crustacea	<i>Blepharipoda occidentalis</i>	–	–	–	–	1	1	0.20	100.00
Total Number of Individuals		213	199	160	121	117	810		
Total Number of Individuals Excluding <i>D. Excentricus</i>		88	106	97	86	117	494		

Table B.7 Replicate Sample Abundance by Taxa at Station B6 during October 2011

Taxonomic Group	Taxon	Replicate					Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Echinodermata	<i>Dendraster excentricus</i>	87	97	1	1	95	281	–	–
Crustacea	<i>Rhepoxynius menziesi</i>	21	16	22	8	16	83	27.67	27.67
Nemertea	<i>Carinoma mutabilis</i>	10	12	17	3	8	50	16.67	44.33
Mollusca	<i>Alvania</i>	22	–	14	–	4	40	13.33	57.67
Crustacea	<i>Rhepoxynius abronius</i>	3	6	5	2	6	22	7.33	65.00
Crustacea	<i>Foxiphalus xiximeus</i>	6	8	1	–	3	18	6.00	71.00
Crustacea	<i>Cancer gracilis</i>	1	3	–	–	10	14	4.67	75.67
Mollusca	<i>Nassarius perpinguis</i>	2	1	–	3	1	7	2.33	78.00
Crustacea	<i>Americhilidium shoemakeri</i>	3	2	–	1	–	6	2.00	80.00
Bivalvia	<i>Tellina modesta</i>	2	–	–	3	–	5	1.67	81.67
Annelida	<i>Lumbrineris californiensis</i>	1	2	1	1	–	5	1.67	83.33
Crustacea	<i>Majoxiphalus major</i>	–	1	1	–	3	5	1.67	85.00
Crustacea	<i>Pacifoculodes spinipes</i>	–	–	4	1	–	5	1.67	86.67
Bivalvia	<i>Tellina bodegensis</i>	1	–	–	2	–	3	1.00	87.67
Annelida	<i>Lumbrineris</i>	–	1	–	1	1	3	1.00	88.67
Annelida	<i>Notomastus lineatus</i>	–	–	–	3	–	3	1.00	89.67
Crustacea	<i>Eohaustorius sencillus</i>	1	–	–	–	1	2	0.67	90.33
Crustacea	<i>Isocheles pilosus</i>	1	–	–	–	1	2	0.67	91.00
Annelida	<i>Leitoscoloplos pugettensis</i>	1	–	–	–	1	2	0.67	91.67
Crustacea	<i>Gibberosus myersi</i>	–	1	–	1	–	2	0.67	92.33
Annelida	<i>Chaetozone setosa</i>	–	1	–	1	–	2	0.67	93.00
Bivalvia	<i>Siliqua lucida</i>	–	–	–	1	1	2	0.67	93.67
Annelida	<i>Nephtys caecoides</i>	–	–	–	–	2	2	0.67	94.33
Annelida	<i>Onuphis iridescens</i>	1	–	–	–	–	1	0.33	94.67
Annelida	<i>Gyptis brevipalpa</i>	1	–	–	–	–	1	0.33	95.00
Crustacea	Paguridae	1	–	–	–	–	1	0.33	95.33
Nemertea	<i>Carinomella lactea</i>	–	1	–	–	–	1	0.33	95.67
Crustacea	<i>Mandibulophoxus gilesi</i>	–	1	–	–	–	1	0.33	96.00
Crustacea	<i>Photis macinerneyi</i>	–	–	1	–	–	1	0.33	96.33
Annelida	<i>Sthenelais verruculosa</i>	–	–	1	–	–	1	0.33	96.67

Table B.7 Replicate Sample Abundance by Taxa at Station B6 during October 2011

Taxonomic Group	Taxon	Replicate					Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Crustacea	<i>Blepharipoda occidentalis</i>	–	–	1	–	–	1	0.33	97.00
Annelida	<i>Glycera convoluta</i>	–	–	–	1	–	1	0.33	97.33
Annelida	<i>Scoloplos armiger</i>	–	–	–	1	–	1	0.33	97.67
Nemertea	<i>Cerebratulus californiensis</i>	–	–	–	1	–	1	0.33	98.00
Crustacea	<i>Mesolamprops dillonensis</i>	–	–	–	1	–	1	0.33	98.33
Bivalvia	<i>Rocheftoria tumida</i>	–	–	–	1	–	1	0.33	98.67
Annelida	<i>Axiobella rubrocincta</i>	–	–	–	1	–	1	0.33	99.00
Annelida	<i>Phylo felix</i>	–	–	–	1	–	1	0.33	99.33
Annelida	<i>Spiochaetopterus costarum</i>	–	–	–	1	–	1	0.33	99.67
Annelida	<i>Magelona sacculata</i>	–	–	–	–	1	1	0.33	100.00
Total Number of Individuals		165	153	69	40	154	581		
Total Number of Individuals Excluding <i>D. Excentricus</i>		78	56	68	39	59	300		

Table B.8 Replicate Sample Abundance by Taxa at Station B7 during October 2011

Taxonomic Group	Taxon	Replicate					Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Echinodermata	<i>Dendraster excentricus</i>	100	77	201	119	–	497	–	–
Crustacea	<i>Rhepoxynius menziesi</i>	24	27	13	24	22	110	32.93	32.93
Mollusca	<i>Alvania</i>	11	6	4	44	10	75	22.46	55.39
Crustacea	<i>Rhepoxynius abronius</i>	5	8	7	2	13	35	10.48	65.87
Nemertea	<i>Carinoma mutabilis</i>	3	7	8	1	7	26	7.78	73.65
Crustacea	<i>Majoxiphalus major</i>	2	–	6	1	4	13	3.89	77.54
Crustacea	<i>Pacifoculodes spinipes</i>	–	1	–	2	3	6	1.80	79.34
Crustacea	<i>Foxiphalus xiximeus</i>	4	–	2	–	–	6	1.80	81.14
Crustacea	<i>Cancer gracilis</i>	2	4	3	2	–	11	3.29	84.43
Annelida	<i>Lumbrineris californiensis</i>	1	1	–	–	3	5	1.50	85.93
Mollusca	<i>Nassarius perpinguis</i>	–	1	1	2	1	5	1.50	87.43
Annelida	<i>Sigalion spinosa</i>	1	–	–	1	2	4	1.20	88.62
Crustacea	<i>Tecticeps convexus</i>	–	1	–	–	4	5	1.50	90.12
Crustacea	<i>Gnathopleustes pugettensis</i>	–	–	3	1	–	4	1.20	91.32
Bivalvia	<i>Tellina modesta</i>	1	–	–	1	2	4	1.20	92.51
Bivalvia	<i>Tellina bodegensis</i>	2	–	1	–	–	3	0.90	93.41
Crustacea	<i>Americhilidium shoemakeri</i>	–	2	–	–	1	3	0.90	94.31
Crustacea	<i>Anchicolurus occidentalis</i>	–	1	–	–	1	2	0.60	94.91
Crustacea	<i>Majidae</i>	1	–	–	–	–	1	0.30	95.21
Mollusca	<i>Olivella pedroana</i>	–	1	–	–	1	2	0.60	95.81
Annelida	<i>Notomastus lineatus</i>	–	1	–	–	1	2	0.60	96.41
Crustacea	<i>Gibberosus myersi</i>	–	1	–	–	–	1	0.30	96.71
Annelida	<i>Glycinde armigera</i>	–	1	–	–	–	1	0.30	97.01
Annelida	<i>Sthenelais verruculosa</i>	–	1	–	–	–	1	0.30	97.31
Annelida	<i>Lumbrineris</i>	–	–	1	–	–	1	0.30	97.60

Table B.8 Replicate Sample Abundance by Taxa at Station B7 during October 2011

Taxonomic Group	Taxon	Replicate					Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Crustacea	Hippolytidae	–	–	1	–	–	1	0.30	97.90
Crustacea	Eohaustorius sencillus	–	–	–	–	1	1	0.30	98.20
Crustacea	Idotea	–	–	1	–	–	1	0.30	98.50
Annelida	Chaetozone setosa	–	–	–	1	–	1	0.30	98.80
Annelida	Travisia gigas	–	–	–	1	–	1	0.30	99.10
Echinodermata	Amphiodia digitata	–	–	–	1	–	1	0.30	99.40
Crustacea	Isocheles pilosus	–	–	–	1	–	1	0.30	99.70
Bivalvia	Clinocardium nuttallii	–	–	–	–	1	1	0.30	100.00
Total Number of Individuals		157	141	252	204	77	831		
Total Number of Individuals Excluding <i>D. Excentricus</i>		57	64	51	85	77	334		

Table B.9 Infaunal Indices in Sediment Samples Collected in October 2011

Parameter ^a		Total Organisms	Identified Organisms	Number of Species	Organisms per Species	Diversity (H')	Brillouin Index (h)	Dominance (C')	Dominance (S _w)	Species Richness (d)	Evenness (J')	Infaunal Index (ITI)
Station B1	Replicate 1	153	146	10	15	1.18	1.09	0.49	2	1.81	0.51	100
	Replicate 2	98	90	22	4	2.46	2.16	0.14	7	4.67	0.80	92
	Replicate 3	352	333	20	17	0.91	0.84	0.69	1	3.27	0.31	77
	Replicate 4	189	188	9	21	0.63	0.58	0.75	1	1.53	0.29	98
	Replicate 5	281	281	8	35	0.22	0.19	0.93	1	1.24	0.11	87
Station B2	Replicate 1	78	70	11	6	1.68	1.48	0.27	3	2.35	0.70	98
	Replicate 2	55	53	10	5	1.38	1.17	0.43	3	2.27	0.60	97
	Replicate 3	240	220	16	14	0.95	0.86	0.63	1	2.78	0.34	98
	Replicate 4	127	123	16	8	1.47	1.31	0.40	2	3.12	0.53	98
	Replicate 5	76	74	14	5	1.56	1.35	0.38	3	3.02	0.59	92
Station B3	Replicate 1	245	225	11	20	0.65	0.60	0.74	1	1.85	0.27	97
	Replicate 2	154	154	9	17	1.11	1.03	0.47	2	1.59	0.51	100
	Replicate 3	63	56	14	4	2.06	1.76	0.22	6	3.23	0.78	99
	Replicate 4	85	66	20	3	2.33	1.99	0.16	7	4.53	0.78	94
	Replicate 5	98	93	20	5	2.45	2.17	0.12	7	4.19	0.82	95
Station B4	Replicate 1	69	56	15	4	2.15	1.84	0.17	5	3.48	0.79	92
	Replicate 2	92	89	20	4	2.21	1.94	0.17	5	4.23	0.74	93
	Replicate 3	139	128	17	8	1.68	1.52	0.34	3	3.30	0.59	97
	Replicate 4	93	73	15	5	1.94	1.70	0.23	4	3.26	0.72	94
	Replicate 5	60	51	16	3	2.16	1.81	0.19	5	3.82	0.78	96
Station B5	Replicate 1	213	195	15	13	1.34	1.23	0.44	2	2.66	0.49	96
	Replicate 2	199	169	16	11	1.58	1.45	0.35	2	2.92	0.57	98
	Replicate 3	160	131	17	8	1.76	1.59	0.29	3	3.28	0.62	97
	Replicate 4	121	103	17	6	2.10	1.89	0.19	5	3.45	0.74	91
	Replicate 5	117	92	27	3	2.66	2.30	0.13	10	5.75	0.81	95
Station B6	Replicate 1	165	142	16	9	1.47	1.33	0.41	2	3.03	0.53	95
	Replicate 2	153	152	14	11	1.40	1.28	0.43	3	2.59	0.53	97
	Replicate 3	69	55	11	5	1.65	1.43	0.27	3	2.50	0.69	99
	Replicate 4	40	39	22	2	2.83	2.24	0.08	13	5.73	0.92	80
	Replicate 5	154	149	14	11	1.41	1.29	0.43	3	2.60	0.54	94
Station B7	Replicate 1	157	145	11	13	1.13	1.03	0.51	2	2.01	0.47	100
	Replicate 2	141	135	16	8	1.49	1.35	0.37	2	3.06	0.54	97
	Replicate 3	252	246	11	22	0.84	0.78	0.67	1	1.82	0.35	98
	Replicate 4	204	160	15	11	1.01	0.91	0.58	2	2.76	0.37	93
	Replicate 5	77	67	16	4	2.18	1.89	0.17	6	3.57	0.79	98
Mean	Station B1	215	208	13.8	18.3	1.08	0.97	0.60	2.4	2.50	0.40	91
	Station B2	115	108	13.4	7.7	1.41	1.23	0.42	2.4	2.71	0.55	96
	Station B3	129	119	14.8	9.9	1.72	1.51	0.34	4.6	3.08	0.63	97
	Station B4	91	79	16.6	4.8	2.03	1.76	0.22	4.4	3.62	0.72	95
	Station B5	162	138	18.4	8.1	1.89	1.69	0.28	4.4	3.61	0.65	95
	Station B6	116	107	15.4	7.4	1.75	1.51	0.32	4.8	3.29	0.64	93
	Station B7	166	151	13.8	11.8	1.33	1.19	0.46	2.6	2.64	0.50	97
Standard Deviation	Station B1	102	99	6.6	11.3	0.85	0.74	0.30	2.6	1.44	0.26	9.5
	Station B2	75	68	2.8	3.5	0.28	0.24	0.13	0.9	0.38	0.13	2.3
	Station B3	73	71	5.1	8.2	0.79	0.67	0.26	2.9	1.33	0.24	2.5
	Station B4	31	31	2.1	1.7	0.22	0.16	0.07	0.9	0.41	0.08	2.0
	Station B5	44	44	4.9	3.8	0.51	0.41	0.13	3.4	1.23	0.13	2.7
	Station B6	57	56	4.1	3.9	0.61	0.41	0.15	4.6	1.38	0.17	7.5
	Station B7	66	64	2.6	6.8	0.53	0.45	0.20	1.9	0.73	0.18	2.7

Table B.9 Infaunal Indices in Sediment Samples Collected in October 2011

Parameter ^a		Total Organisms	Identified Organisms	Number of Species	Organisms per Species	Diversity (H')	Brillouin Index (h)	Dominance (C')	Dominance (S _w)	Species Richness (d)	Evenness (J')	Infaunal Index (ITI)
Station Total	Station B1	1073	1038	37	28	1.12	1.07	0.62	1	5.18	0.31	92
	Station B2	576	540	29	19	1.50	1.43	0.40	2	4.45	0.45	97
	Station B3	645	594	34	17	1.74	1.66	0.34	3	5.17	0.49	97
	Station B4	453	397	35	11	2.46	2.33	0.14	6	5.68	0.69	95
	Station B5	810	690	44	16	2.06	1.97	0.26	4	6.58	0.54	96
	Station B6	581	537	37	15	1.86	1.76	0.31	3	5.73	0.52	94
	Station B7	831	753	29	26	1.39	1.33	0.46	2	4.23	0.41	97
Survey	Total	4969	4549	80	57	1.78	1.75	0.37	3	9.38	0.41	95

Table B.10 Infaunal Indices excluding *D. excentricus* in Sediment Samples Collected in October 2011

Parameter ^a		Total Organisms	Identified Organisms	Number of Species	Organisms per Species	Diversity (H')	Brillouin Index (h)	Dominance (C')	Dominance (S _w)	Species Richness (d)	Evenness (J')	Infaunal Index (ITI)
Station B1	Replicate 1	53	46	9	5.11	1.78	1.54	0.22	4	2.09	0.81	100
	Replicate 2	94	86	21	4.10	2.38	2.09	0.15	7	4.49	0.78	92
	Replicate 3	77	58	19	3.05	2.58	2.19	0.10	9	4.43	0.88	77
	Replicate 4	27	26	8	3.25	1.67	1.35	0.25	3	2.15	0.80	98
	Replicate 5	10	10	7	1.43	1.83	1.26	0.18	5	2.61	0.94	87
Station B2	Replicate 1	49	41	10	4.10	1.71	1.43	0.28	4	2.42	0.74	98
	Replicate 2	52	50	9	5.56	1.23	1.04	0.48	2	2.04	0.56	97
	Replicate 3	67	47	15	3.13	1.99	1.65	0.24	5	3.64	0.74	98
	Replicate 4	53	49	15	3.27	1.99	1.66	0.24	5	3.60	0.74	98
	Replicate 5	32	30	13	2.31	2.18	1.73	0.17	7	3.53	0.85	92
Station B3	Replicate 1	53	33	10	3.30	1.61	1.31	0.31	3	2.57	0.70	97
	Replicate 2	54	54	8	6.75	1.32	1.14	0.42	3	1.75	0.63	100
	Replicate 3	63	56	14	4.00	2.06	1.76	0.22	6	3.23	0.78	99
	Replicate 4	66	47	19	2.47	2.43	1.99	0.15	8	4.68	0.83	94
	Replicate 5	86	81	19	4.26	2.37	2.08	0.14	6	4.10	0.80	95
Station B4	Replicate 1	69	56	15	3.73	2.15	1.84	0.17	5	3.48	0.79	92
	Replicate 2	63	60	19	3.16	2.34	1.98	0.15	7	4.40	0.80	93
	Replicate 3	69	58	16	3.63	2.20	1.87	0.19	6	3.69	0.79	97
	Replicate 4	93	73	15	4.87	1.94	1.70	0.23	4	3.26	0.72	94
	Replicate 5	59	50	15	3.33	2.11	1.77	0.19	5	3.58	0.78	96
Station B5	Replicate 1	88	70	14	5.00	1.90	1.66	0.25	4	3.06	0.72	96
	Replicate 2	106	76	15	5.07	1.98	1.74	0.24	5	3.23	0.73	98
	Replicate 3	97	68	16	4.25	2.05	1.77	0.23	5	3.55	0.74	97
	Replicate 4	86	68	16	4.25	2.21	1.92	0.16	5	3.55	0.80	91
	Replicate 5	117	92	27	3.41	2.66	2.30	0.13	10	5.75	0.81	95
Station B6	Replicate 1	78	55	15	3.67	2.06	1.75	0.20	5	3.49	0.76	95
	Replicate 2	56	55	13	4.23	2.05	1.77	0.17	4	2.99	0.80	97
	Replicate 3	68	54	10	5.40	1.59	1.38	0.28	3	2.26	0.69	99
	Replicate 4	39	38	21	1.81	2.78	2.21	0.08	12	5.50	0.91	80
	Replicate 5	59	54	13	4.15	2.09	1.80	0.17	5	3.01	0.81	94
Station B7	Replicate 1	57	45	10	4.50	1.64	1.39	0.32	4	2.36	0.71	100
	Replicate 2	64	58	15	3.87	1.89	1.60	0.26	4	3.45	0.70	97
	Replicate 3	51	45	10	4.50	1.98	1.70	0.17	4	2.36	0.86	98
	Replicate 4	85	41	14	2.93	1.72	1.38	0.36	5	3.50	0.65	93
	Replicate 5	77	67	16	4.19	2.18	1.89	0.17	6	3.57	0.79	98

Table B.10 Infaunal Indices excluding *D. excentricus* in Sediment Samples Collected in October 2011

	Parameter ^a	Total Organisms	Identified Organisms	Number of Species	Organisms per Species	Diversity (H')	Brillouin Index (h)	Dominance (C')	Dominance (S _w)	Species Richness (d)	Evenness (J')	Infaunal Index (ITI)
Mean	Station B1	52	45	12.8	3.4	2.05	1.69	0.18	5.6	3.15	0.84	91
	Station B2	51	43	12.4	3.7	1.82	1.50	0.28	4.6	3.05	0.72	96
	Station B3	64	54	14.0	4.2	1.96	1.66	0.25	5.2	3.27	0.75	97
	Station B4	71	59	16.0	3.7	2.15	1.83	0.19	5.4	3.68	0.78	95
	Station B5	99	75	17.6	4.4	2.16	1.88	0.20	5.8	3.83	0.76	95
	Station B6	60	51	14.4	3.9	2.11	1.78	0.18	5.8	3.45	0.80	93
	Station B7	67	51	13.0	4.0	1.88	1.59	0.25	4.6	3.05	0.74	97
Standard Deviation	Station B1	35	29	6.6	1.36	0.41	0.43	0.06	2.4	1.21	0.07	9.5
	Station B2	13	8	2.8	1.23	0.37	0.28	0.12	1.8	0.76	0.10	2.3
	Station B3	13	17	5.0	1.61	0.48	0.41	0.12	2.2	1.17	0.08	2.5
	Station B4	13	8	1.7	0.67	0.15	0.11	0.03	1.1	0.43	0.03	2.0
	Station B5	13	10	5.3	0.68	0.30	0.25	0.05	2.4	1.09	0.04	2.7
	Station B6	15	7	4.1	1.31	0.43	0.29	0.07	3.6	1.23	0.08	7.5
	Station B7	14	11	2.8	0.65	0.21	0.22	0.09	0.9	0.63	0.08	2.7
Station Total	Station B1	261	226	36	6.28	2.75	2.53	0.10	8	6.46	0.77	92
	Station B2	253	217	28	7.75	2.06	1.88	0.28	5	5.02	0.62	97
	Station B3	322	271	33	8.21	2.31	2.14	0.20	7	5.71	0.66	97
	Station B4	353	297	34	8.74	2.54	2.37	0.14	7	5.80	0.72	95
	Station B5	494	374	43	8.70	2.53	2.36	0.18	8	7.09	0.67	96
	Station B6	300	256	36	7.11	2.45	2.26	0.16	6	6.31	0.68	94
	Station B7	334	256	28	9.14	2.19	2.03	0.22	5	4.87	0.66	97
Survey	Total	2317	1897	79	24.01	2.64	2.57	0.16	8	10.33	0.60	95

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Education

B.S.	Marine Biology, California State University, Long Beach
Certificate	Environmental Studies, California State University, Long Beach
M.S.	Biology, California State University, Long Beach

Credential

Instructor, California Community Colleges
Subjects: Biological Sciences, Marine Sciences, Ecology

Qualifications

Susan Williams is an environmental scientist with over thirty years experience in ecological monitoring and assessment. She has a strong background in natural history and an excellent working knowledge of such varied communities as coastal sage scrub, coastal dunes, wetlands, and marine benthos. Ms. Williams also has training in hazardous materials management, including courses and seminars in CEQA, environmental auditing, and the fate of toxins in the environment. She has an extensive background in biological survey techniques and laboratory methodology.

The postgraduate Environmental Studies Certificate provided interdisciplinary training in economics, public health issues, environmental toxicology, and assessing human impacts on terrestrial and marine environments.

Professional Employment

- 1989-present. Consultant and Contract Employee. Projects include Shoreline Recovery Study of the Exxon Valdez spill, terrestrial ecological survey of a Superfund site, and various benthic surveys, and environmental education.
- 1990-present. Interpretive Specialist, City of Ventura (Community Services). As part of the Interpretive Outreach Program, deliver classroom and field presentations on a variety of natural and cultural history topics; program development.
- 1993 - 1994. Park Ranger (Interpretive Division), Channel Islands National Park. Staff Visitor Center, present programs to school groups and general public, develop public programs (Tidepools, Island Ethnobotany).
- 1989 - 1994. Part-time Instructor, Oxnard College. Topics taught include Microbiology, Marine Biology, Biology, and Environmental Sciences.
- 1986 - 1989. Researcher, Battelle Ocean Sciences, Ventura. Laboratory supervisor, task leader for monitoring program, taxonomist, safety officer.
- 1984 - 1986. Research Scientist, Harbors Environmental Project, University of Southern California. Assessment of the marine environment of Marina Del Rey; monitoring offshore disposal of cannery waste.
- 1980 - 1986. Assistant Curator, Allan Hancock Foundation, University of Southern California. Responsible for maintaining museum collection of marine animals, processing loans, conducting independent research.

- 1979 - 1981. Research Associate, Applied Ecology Program, Institute for Marine and Coastal Studies. Investigated impacts of storms on sandy beaches, monitored benthic impacts of electrical generating stations, supervised laboratory.
- 1975 - 1978. Associate Research Scientist, Department of Biological Sciences, University of Southern California. As part of the Outer Continental Shelf Program, collected and analyzed benthic samples prior to offshore oil exploration.

Miscellaneous

Charter Member, Southern California Association of Marine Invertebrate Taxonomists

Participant, Boys & Girls Club of Ventura Career Fair

Judge, Ventura County Science Fair (2004-present). Assigned categories included Zoology, Botany, and Human Biology, junior division (grades 6-8)

Publications and Technical Reports

Ms. Williams has published 13 papers, ranging from taxonomic works and ecological analyses to articles on environmental issues for the general public.

Detailed list available upon request.

ROY K. KROPP

Senior Research Scientist
Pacific Northwest National Laboratory
Battelle Marine Sciences Laboratory
Sequim, Washington

Education

Ph.D.	Zoology, University of Maryland, 1988
M.S.	Biology, University of Guam, 1982
B.S.	Zoology, San Diego State University, 1978

Qualifications

Dr. Kropp is a specialist in benthic marine ecology, toxicology, and the systematics of crustaceans and mollusks with 21 years of experience. He has served as the principal investigator for or participated in marine environmental surveys in the tropical and boreal Pacific, off California, the Gulf of Mexico, along the Atlantic Coast of the United States, and in the Mediterranean. Currently, Dr. Kropp is the Senior Scientist for Benthic Biology for the Massachusetts Water Resources Authority Monitoring Program. Since matriculating to the Marine Sciences Laboratory from Battelle's Duxbury facility, Dr. Kropp has continued benthic ecological studies, recently completing studies of infaunal communities associated with dredged material disposal sites in Rhode Island Sound and Long Island Sound. He was the technical project manager for the preparation of the Final Environmental Impact Statement being prepared for the Providence River dredging project by the U.S. Army Corps of Engineers and is participating as a benthic ecologist on similar EISs for the designation of disposal sites in Rhode Island Sound and Long Island Sound. Dr. Kropp designed and directed a study to examine the effects of increased summer nutrient loads on nearshore seagrass beds in NW Sardinia by examining changes in plant phenology, motile epifaunal communities, and plant epiphyte loads. Dr. Kropp is a recognized authority on crustacean systematics. He was the crustacean taxonomist for the Sardinian study and served as the crustacean and mollusk taxonomist for studies conducted off California and New England. He was the crustacean taxonomist for the Gulf of Thailand and Sea of Okhotsk programs and has extensive experience in the systematics of Indo-Pacific crustaceans. Dr. Kropp is a Research Associate with the Smithsonian Institution and a Research Affiliate of the University of Guam Marine Laboratory. He has authored or coauthored many journal publications and technical reports.

Project Experience

- **Soft-Bottom Monitoring Study conducted for Massachusetts Water Resources Authority (MWRA).** Senior Scientist responsible for technical oversight of benthic monitoring tasks, including directing data analyses and report preparation for study of the response of the Boston Harbor benthos to the abatement of sludge discharge, and for the eventual diversion of effluent to Massachusetts Bay. Assisted in the design and performance of the rapid assessment technique used in the study. Co-principal Investigator of a study to determine the importance of the new outfall site as a recruitment area for juvenile lobsters.
- **Piscataqua River, New Hampshire 301(h) waiver Water Quality and Benthic Community Study.** Principal investigator for the study performed to fulfill requirements of a 301(h) waiver application. Designed the sampling scheme for the study, analyzed ecological and water-quality data, and prepared the interpretive report.
- **Rhode Island Sound and Long Island Sound Infaunal Community Analyses.** Co-Principal Investigator for two studies of infaunal communities in and near dredged material disposal sites for the U.S. Army Corps of Engineers. Performed benthic data analyses and coauthored the technical reports.
- **Effect of Water-Column Nutrients on Seagrass Epifaunal Communities in NW Sardinia, Italy.** Principle Investigator responsible for study design, staff training, study implementation, data analysis and interpretation, and preparation of interpretive report. Study examining the effects of increased summer nutrient loads (related to increased tourism) on nearshore seagrass beds by examining changes in plant phenology, motile epifaunal communities, and epiphyte loads.
- **Environmental Studies in the Gulf of Thailand, Phase I and II** Biology Task Leader for project that investigated the impacts of drilling activities on the benthos. Performed ecological data analysis, wrote biological characterization chapters of the resulting reports.

Roy K. Kropp (Continued)

Other Experience

Monitoring Studies.

Task Leader for a study to determine the abundance of ocean quahogs (*Arctica islandica*) at proposed dredged material disposal sites in Rhode Island Sound. Designed and directed the study. Analyzed quahog abundance and size-frequency data, and prepared an interpretive report.

Biology Task Leader for the Sediment Survey at the (New York) Mud Dump Site and Environs. Responsible for analysis and interpretation of infaunal data collected during 1994. Prepared sections on the benthic community for the draft final report. Contributed sections on the infaunal community and trophic relationships for the draft SEIS.

Task Leader. Statistical design of field sampling and data analysis, interpretation, and write-up for program involving lead shot remediation at Remington Gun Club site.

Biology Task Leader for Environmental Studies in the Sea of Okhotsk. Analyzed infaunal data collected from proposed drilling platform sites. Prepared an interpretive report on the infaunal communities in the study area.

Biology Task Leader for the Region VI (EPA) contaminated sediment study. Analyzed infaunal data from seven ocean dredged material disposal sites in the Gulf of Mexico. Prepared interpretive reports on the communities at each site and provided recommendations for improving the study design.

Scientist for the New York Bight Rapid Benthic Assessment project that concerned the selection of a new site for the disposal of dredge spoils. Conducted epibenthic trawls and sediment grab sampling. Analyzed trawl catches, fish stomach contents, and infauna collected in sediment grabs.

Assistant Program Manager for California OCS Phase II Monitoring Program (CAMP) that established baseline conditions in the Santa Maria Basin prior to the installation of a drilling platform. Principal Investigator studying the life histories of several key infaunal species. Conducted independent study on the incidence of repaired shell damage to gastropods and scaphopods in the study area.

Beach Replenishment Dredging Studies. Principal Investigator for three USACE sand borrow area studies. Responsible for design and ecological analysis for three projects establishing baseline conditions or investigating the effects of dredging in sand borrow areas at Broadkill Beach in Delaware Bay and off Absecon Inlet and Great Egg Harbor, New Jersey.

Toxicological Studies. Project Manager or Senior Scientist for toxicological testing of sediments from the Providence River, New Haven, and Boston Harbor/Weymouth Fore River. These tests were conducted from the New England Division, Army Corps of Engineers and involved marine species, including *Americamysis bahia* and *Ampelisca abdita*. Responsibilities included overall test planning and supervision, data analyses, and report preparation.

Project Manager for toxicological testing of sediments from Pistol Point Bar, CT. These tests were conducted from the New England Division, Army Corps of Engineers and involved freshwater species including *Hyalella azteca*, *Chironomus tentans*, and *Lumbriculus variegatus*.

Project Manager for toxicological testing of synthetic-based drilling muds from the Gulf of Mexico. These tests were conducted from the American Petroleum Institute and involved a marine species, *Leptocheirus plumulosus*.

Environmental Impact Statements. Project Manager for the preparation of the Final Environmental Impact Statement being prepared for the Providence River dredging project by the US Army Corps of Engineers. Coordinator for activities including response to public comments, re-analysis of fish trawl data to evaluate fishery value of potential disposal sites, directed the development of a statistically valid design of study on lobster populations at disposal sites, directing implementation of the study, designed a dredge survey to sample northern quahog populations in the area to be dredged and wrote the interpretive report, monitored project budgets and tracked deliverable preparation. Information will be used to assist the government in deciding the most appropriate disposal alternative.

Artificial Reef Studies. Benthic Infauna/Epifauna Task Leader for 5-year study for U.S. Army Corps of Engineers (USACE) and Environmental Protection Agency (EPA) Delaware Artificial Reef Study that investigated the feasibility of using artificial reef as compensation for shallow- and deep-water habitat loss. Performed ecological data analysis of epifaunal communities on the reefs and infaunal communities surrounding the reefs, wrote sections

Roy K. Kropp (Continued)

of the report. Designed portions of a study to examine the effects of artificial reef units on the infauna.

NOAA Hydrolab Aquanaut and field assistant for study of artificial reef colonization at Salt River Canyon, St. Croix, U.S. Virgin Islands.

Taxonomist. Crustacean taxonomist for benthic studies conducted in NW Sardinia, Italy.

Identified crustaceans and mollusks collected from Boston Harbor, Massachusetts Bay, and Cape Cod Bay for the MWRA Harbor and Outfall Monitoring Program.

Chief taxonomist for the Environmental Studies in the Gulf of Thailand, Phase I and II project. Identified the crustaceans collected during the study. Directed the establishment of a project-specific voucher collection and edited the documentation for the voucher collection.

Identified crustaceans and mollusks collected from off California for the CAMP program and the Morro Bay/Cayucos Sanitation District 301(h) monitoring program.

Specialist on benthic invertebrates for several baseline monitoring studies conducted in the western Pacific (Micronesia).

Professional Affiliations

Biological Society of Washington
Crustacean Society
Estuarine Research Federation
Pacific Science Association

Technical Reports

Kropp RK, Diaz RJ, Dahlen DT, Boyle JD. 2002. *2001 Harbor Benthic Monitoring Report*. MWRA Environmental Quality Department Technical Report Series 2002-19. Prepared for the Massachusetts Water Resources Authority, Boston, Massachusetts.

Kropp R, Diaz R, Hecker B, Dahlen D, Boyle J, Abramson S, Emsbo-Mattingly S. 2002. *2001 Outfall Benthic Monitoring Report*. MWRA Environmental Quality Department Technical Report Series 2002-15. Prepared for the Massachusetts Water Resources Authority, Boston, Massachusetts.

Kohn NP, and RK Kropp. 2002. *Year 5 Post-Remediation Biomonitoring of Pesticides and other Contaminants in Marine Waters near the United Heckathorn Superfund Site, Richmond, California*. Prepared for the U.S. Environmental Protection Agency, Region 9.

Kropp RK, Diaz RJ, Dahlen DT, Boyle JD, Hunt, CD. 2002. *2000 Harbor Benthic Monitoring Report*. MWRA Environmental Quality Department Technical Report Series 2002-02. Prepared for the Massachusetts Water Resources Authority, Boston, Massachusetts.

Kropp R, Diaz R, Hecker B, Dahlen D, Boyle J, Abramson S, Emsbo-Mattingly S. 2002. *2000 Outfall Benthic Monitoring Report*. MWRA Environmental Quality Department Technical Report Series 2001-11. Prepared for the Massachusetts Water Resources Authority, Boston, Massachusetts.

Kohn, NP, and RK Kropp. 2001. *Year 4 Postremediation Biomonitoring of Pesticides and Other Contaminants in Marine Waters Near the United Heckathorn Superfund Site, Richmond, California*. PNNL-13632. Prepared for the U.S. Environmental Protection Agency, Region 9.

Kropp RK, RJ Diaz, D Dahlen, JD Boyle, CD Hunt. 2001. *1999 Harbor Benthic Monitoring Report*. MWRA Environmental Quality Department Technical Report Series 01-03. Prepared for the Massachusetts Water Resources Authority, Boston, Massachusetts.

Williams, G. D., R. M. Thom, J. E. Starks, J. S. Brennan, J. P. Houghton, D. Woodruff, P. L. Striplin, M. Miller, M. Pedersen, A. Skillman, R. Kropp, A. Borde, C. Freeland, K. McArthur, V. Fagerness, S. Blanton, and L. Blackmore. 2001. *Reconnaissance Assessment of the State of the Nearshore Ecosystem: Eastern Shore of Central Puget Sound, Including Vashon and Maury Islands (WRIAs 8 and 9)*. Ed., J. S. Brennan. PNNL-14055. Report prepared for King County Department of Natural Resources, Seattle, Washington. 353 pp.
<http://dnr.metrokc.gov/wlr/watersheds/puget/nearshore/sonr.htm>.

Roy K. Kropp (Continued)

Williams, GD, RM Thom, DL Woodruff, MC Miller, RK Kropp, AB Borde, AD Skillman, SL Blanton, J Brennan, and L Blackmore. 2001. A Comprehensive Assessment of the Central Puget Sound (King County) Nearshore Ecosystem: Historic Changes, Data Gaps, and Pending Threats. PNNL-SA-34562. In *Puget Sound Research 2001 Proceedings--The Puget Sound/Georgia Basin Ecosystem: Status, Stressors, and the Road to Recovery*. Bellevue, Washington, February 12-14, 2001.

Kohn, NP, and RK Kropp. 2000. *Year 3 Post-Remedial Monitoring of Pesticides and Other Contaminants in Marine Waters Near the United Heckathorn Superfund Site, Richmond, California*. PNNL-13286. (Final Draft Report October 2000. Prepared for the U.S. Environmental Protection Agency, Region 9, San Francisco, California.

Kropp, R.K., V.I. Cullinan, J.D. Boyle, and C.D. Hunt. April 2000. "Stratford Point Benthic Analysis September 1999 Survey." Prepared for Sporting Goods Properties, Inc..

Kropp, R.K., R. Diaz, D. Dahlen, J.D. Boyle, D. Shull, and E.D. Gallagher. 2000. *1998 Boston Harbor Benthic Monitoring Report*. MWRA Environmental Quality Department Technical Report Series 00-06. Prepared for the Massachusetts Water Resources Authority, Boston, Massachusetts.

Kropp RK, RJ Diaz, B Hecker, D Dahlen, JD Boyle, KE Keay, CD Hunt. 2000. *1999 Outfall Benthic Monitoring Report*. MWRA Environmental Quality Department Technical Report Series 00-16. 230 pp. Prepared for the Massachusetts Water Resources Authority, Boston, Massachusetts..

Pinza, M.R., J.Q. Word, J.A. Ward, and R.K. Kropp. 2000. Ecotoxicological Testing to Address Confounding Factors for Hong Kong Contaminated Sediments. PNWD-3020. Prepared for ERM-Hong Kong, Ltd..

Kropp, R.K., R. Diaz, D. Dahlen, J.D. Boyle, D. Shull, and E.D. Gallagher. 2000. 1998 Boston Harbor benthic monitoring report. MWRA Environmental Quality Department Technical Report Series 00-06. Prepared for the Massachusetts Water Resources Authority, Boston, Massachusetts.

Kropp, R.K., D. Dahlen, J.D. Boyle, R. Diaz, B. Hecker, and E.D. Gallagher. 1999. 1998 Outfall benthic monitoring report. MWRA Environmental Quality Department Technical Report Series 99-15.

Lavalli, K. and R.K. Kropp. 1998. Abundance Of Juvenile Lobsters At The New Outfall Site: Comparisons With Inshore Abundances And Discussion of Potential Outfall Impacts On Lobster Populations. MWRA Environmental Quality Department Technical Report Series 98-14. 31 pp.

Battelle [Kropp, R.K.]. 1998. Shellfish sampling and site characterizations: Narragansett Bay and Rhode Island Sound Proposed Disposal Sites. Final Report to U.S. Army Corps of Engineers, North Atlantic Division, New England District. 28 pp.

Battelle. 1996. Region VI contaminated sediment study phase III. Draft Final Report to U.S.E.P.A. Region VI. [wrote sections on infaunal communities at seven ODMDS sites in the Gulf of Mexico].

Battelle. 1996. Sediment survey at the Mud Dump Site and environs. Draft Final Report to U.S.E.P.A. Region II. [wrote sections on infaunal communities].

Kropp, R.K. and R.J. Diaz. 1995. Infaunal community changes in Boston Harbor, 1991-1994: The 1994 annual soft-bottom benthic monitoring report: Boston Harbor studies. MWRA Environmental Quality Department Technical Report Series 95-21. 41 pp.

Kropp, R.K. and R.J. Diaz. 1995. 1993 annual soft-bottom benthic monitoring report: Boston Harbor studies. MWRA Environmental Quality Department Technical Report Series 94-10. 78 pp.

Kropp, R.K. 1995. Environmental post-dredge monitoring, Great Egg Harbor Inlet and Peck Beach Ocean City, New Jersey. Final report to U.S. Army Corps of Engineers, Philadelphia District. 44 pp.

Kropp, R.K. 1995. Brigantine Inlet to Great Egg Harbor Inlet feasibility study, Atlantic County, New Jersey: Benthic animal assessment of potential borrow source. Final report to U.S. Army Corps of Engineers, Philadelphia District. 40 pp.

Foster, K.L., R.K. Kropp, A.M. Spellacy, F. Querzoli, and R. Lordo. 1995. Delaware Bay Artificial Reef Study Year 5. Draft Summary Report to [U.S.] EPA and U.S. Army Corps of Engineers. 132 pp.

Kropp, R.K. 1994. Delaware Bay Coastline Broadkill Beach interim feasibility study, Sussex County Delaware: Benthic animal assessment of potential borrow source. Final report to U.S. Army Corps of Engineers, Philadelphia

Roy K. Kropp (Continued)

District. 40 pp.

Kropp, R.K. 1994. Piscataqua River, New Hampshire water quality and benthic community study. Final report to U.S. EPA Region I. 30 pp.

Kropp, R.K. (ed.). 1994. Voucher collection documentation sheets. *In*: Battelle, Environmental Studies in the Gulf of Thailand, Phase II. Final Report to Unocal Thailand, Ltd.

Kropp, R.K. 1994. Biological characterization studies. *In*: Battelle, Environmental Studies in the Gulf of Thailand, Phase II: Impact of processing activities and produced water discharges at Platong Central Processing Platform. Final Report to Unocal Thailand, Ltd.

Kropp, R.K. 1994. Biological characterization studies. *In*: Battelle, Environmental Studies in the Gulf of Thailand Phase II: Impact of drilling fluids and cuttings discharges. Final Report to Unocal Thailand, Ltd.

Foster, K.L., R.K. Kropp, A.M. Spellacy, F. Querzoli, and R. Lordo. 1994. Delaware Bay Artificial Reef Study Year 4. Final Summary Report to [U.S.] EPA and U.S. Army Corps of Engineers. 89 pp.

Foster, K.L., R.K. Kropp, A.M. Spellacy, F. Querzoli, R. Lordo, and J. Ryther, Jr. 1993. Delaware Bay Artificial Reef Study Year 3. Draft Final Report to [U.S.] EPA and U.S. Army Corps of Engineers. 126 pp.

Foster, K.L., R.K. Kropp, J.H. Ryther, and A.M. Spellacy. 1992. Delaware Artificial Reef Study Year 2. Final Report to [U.S.] EPA and U.S. Army Corps of Engineers. 92 pp.

Kelly, J.R., and R.K. Kropp. 1992. Benthic recovery following sludge abatement in Boston Harbor: Part I Baseline survey 1991 and Part II Spring 1992 Survey. Final Report to the Massachusetts Water Resources Authority.

Kropp, R.K. 1991. Biological characterization. *In*: Battelle, Funan Field Background Monitoring Study. Final Report to Unocal Thailand, Ltd.

Kropp, R.K. 1991. Biological characterization studies. *In*: Battelle, Environmental Studies in the Gulf of Thailand. Final Report to Unocal Thailand, Ltd.

Foster, K.L., R.K. Kropp, and T.L. Burch. 1991. Delaware Bay Artificial Reef Study Year 1. Final Report to [U.S.] EPA and U.S. Army Corps of Engineers. 67 pp.

Hyland, J., E. Baptiste, J. Campbell, J. Kennedy, R. Kropp, C. Robinson, and S. Williams. 1990. Macroinfaunal assemblages in the Santa Maria Basin off the coast of southern California. Chapter 7 *In*: M. Steinhauer and E. Imamura, eds., California OCS Phase II Monitoring Program. Year-Three annual Report. Report to U.S. Department of Interior, Minerals Management Service, Pacific OCS Office, Los Angeles, CA. Contract No. 14-12-0001-30262. Two volumes.

Kropp, R.K., and D.G. Carroll. 1990. Life-history studies of selected macroinfaunal invertebrates from the Santa Maria Basin, California. Chapter 8 *In*: M. Steinhauer and E. Imamura, eds., California OCS Phase II Monitoring Program. Year-Three annual Report. Report to U.S. Department of Interior, Minerals Management Service, Pacific OCS Office, Los Angeles, CA. Contract No. 14-12-0001-30262. Two volumes.

Kropp, R.K., and L.G. Eldredge. 1982. Macroinvertebrates. *In*: R.H. Randall and L.G. Eldredge, eds., Assessment of shoalwater environments in the vicinity of the proposed Ocean Thermal Energy Conversion development at Cabras Island, Guam. University of Guam Marine Lab Technical Report, 79 pp. 107-131.

Amesbury, S.S., M.W. Colgan, R.F. Myers, R.K. Kropp, and F.A. Cushing. 1981. Biological monitoring study of airport runway expansion site, Moen, Truk, eastern Caroline Islands. Part B: Construction phase. University of Guam Marine Lab Technical Report 74:1-125.

Eldredge, L.G., and R.K. Kropp. 1981. Selected bibliography of the physical, chemical, and biological oceanographic literature for the waters surrounding Guam. Lawrence Berkeley Laboratory Earth Sciences Division Report LBL-13443, 22 pp.

Journal Publications

Steimle, F., K. Foster, R. Kropp, and B. Conlin. 2002. Benthic macrofauna productivity enhancement by an artificial reef in Delaware Bay, USA. *ICES Journal of Marine Science* 59:S100-S105.

Roy K. Kropp (Continued)

- Paulay G, R Kropp, PK Ng, and LG Eldredge. In press. "The crustaceans and pycnogonids of the Mariana Islands." *Micronesia* in press.
- Lavalli, K.L., R.K. Kropp, and K.E. Keay. 2000. Anticipated effects of the discharge of secondary effluent on lobster fisheries in Massachusetts Bay: Perception and reality. Submitted to *Environmental Management*.
- Kropp, R.K., K.L. Foster, F.W. Steimle, W.C. Muir, and B.E. Conlin. 1999. A mussel-based epifaunal community on artificial reefs in Delaware Bay, USA: early development and variation. Proceedings of the 7th International Conference on Artificial Reefs and Related Aquatic Habitats, San Remo, Italy, October 1999. Abstract .
- Kelly, J.R., R.K. Kropp, A.D. Uhler, M.B. Zielinski, and S. Tawatchai. 1998. Environmental response and recovery at drilling platforms in the Gulf of Thailand. Proceedings of the 1998 SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production. Caracas, Venezuela. 21 pp.
- Trulli, W.R., R.K. Kropp, H.K. Trulli, D.P. Redford. 1997. Comparison of the results of two EPA marine debris studies. Pp 307-325 In Coe, J.M. and D.B. Rogers (eds) *Marine Debris: Sources, Impacts, and Solutions*. Springer. New York.
- Kropp, R.K. and R.B. Manning. 1996. Two new genera and species of deep-water gall crabs from the Indo-West pacific (Crustacea: Decapoda: Cryptochiridae). In: A. Crosnier (ed.), *Résultats des Campagnes MUSORSTOM*, Volume 15. *Mémoires Museum National D'Histoire Naturelle* 168:531-539.
- Foster, K.L., R.K. Kropp, F.W. Steimle, W.C. Muir, and B.E. Conlin. 1995. Fish community and feeding habitats at a pre-fabricated concrete artificial reef in Delaware Bay, U.S.A. *Ecoseet '95, Proceedings of the International Conference on Ecological System Enhancement Technology for Aquatic Habitats*, Tokyo 1:266-271.
- Steimle, F., W. Muir, K. Foster, R. Kropp, and B. Conlin. 1995. Benthic community enhancement by a prefabricated concrete artificial reef in lower Delaware Bay. *Ecoseet '95, Proceedings of the International Conference on Ecological System Enhancement Technology for Aquatic Habitats*, Tokyo, 2:581-586.
- Kropp, R.K. 1995. *Lithoscaptus pardalotus*, a new species of coral-dwelling gall crab (Brachyura, Cryptochiridae) from Belau. *Proceedings of the Biological Society of Washington*, 108(4):637-642.
- Vermeij, G.J. and R.K. Kropp. 1995. A note on the muricid gastropod *Muricodrupa jacobsoni* in the Palau Islands. *The Festivus* 27(7):84-85.
- Foster, K.L., F.W. Steimle, W.C. Muir, R.K. Kropp, and B.E. Conlin. 1994. Mitigation potential of habitat replacement: Concrete artificial reef in Delaware Bay—Preliminary results. *Bulletin of Marine Science* 55:783-795.
- Kropp, R.K. and J. Haig. 1994. *Petrolisthes extremus*, a new porcelain crab (Decapoda: Porcellanidae) from the Indo-West Pacific. *Proceedings of the Biological Society of Washington* 107:312-317.
- Kropp, R.K. 1994. The gall crabs (Decapoda: Cryptochiridae) of the Rumphius Expeditions revisited and the description of three new species. *Raffles Bulletin of Zoology* 42:521-538.
- Kropp, R.K. 1992. Repaired shell damage among soft-bottom mollusks on the continental shelf and upper slope north of Point Conception, California. *The Veliger* 35:36-51.
- Hyland, J., E. Baptiste, J. Campbell, J. Kennedy, R. Kropp, and S. Williams. 1991. The infaunal benthos of the outer continental shelf and slope north of Point Conception, California. *Marine Ecology Progress Series* 78:147-161.
- Kropp, R.K. and J.H. Dominguez. 1990. *Mesacturus dicrurus*, an unusual new stomatopod crustacean from Micronesia. *Proceedings of the Biological Society of Washington* 103:372-375.
- Manning, R.B., R.K. Kropp, and J. Dominguez. 1990. Distribution patterns of deep-sea stomatopod crustaceans, Family Bathysquillidae. *Progress in Oceanography* 24:311-316.
- Kropp, R.K. 1990. Revision of the genera of gall crabs occurring in the Pacific Ocean (Crustacea: Cryptochiridae). *Pacific Science* 44:417-448.
- Kropp, R.K. 1989. A revision of the Pacific species of gall crabs, genus *Opecarcinus* (Crustacea: Cryptochiridae). *Bulletin of Marine Science* 45:98-129.

Roy K. Kropp (Continued)

Haig, J. and R.K. Kropp. 1988. *Petrolisthes eldredgei*, a new porcellanid crab from the Indo-West Pacific, with redescription of two related species. *Micronesica* 20:171-186. [issue date 1987]

Kropp, R.K. 1988. The status of *Cryptochirus hongkongensis* Shen, 1936 (Brachyura: Cryptochiridae). *Proceedings of the Biological Society of Washington* 101:866-871.

Kropp, R.K. 1988. The status of *Cryptochirus coralliodytes* Heller and *Lithoscaptus paradoxus* Milne Edwards (Brachyura: Cryptochiridae). *Proceedings of the Biological Society of Washington* 101:872-882.

Kropp, R.K. 1988. Case 2636. *Fizesereneia* Takeda and Tamura, 1908 (Crustacea: Decapoda): proposed confirmation of *Troglocarcinus heimi* Fize and Serène, 1956 as the type species. *Bulletin of Zoological Nomenclature* 45:262-263.

Kropp, R.K. and M. Takeda. 1988. *Utinomiella*, a replacement name for *Utinomia* Takeda and Tamura, 1981 (Crustacea, Decapoda), *non* Tomlinson, 1963 (Crustacea, Acrothoracica). *Bulletin of the Biogeographical Society of Japan* 43:29.

Kropp, R.K. and R.B. Manning. 1987. The Atlantic gall crabs, family Cryptochiridae (Crustacea: Decapoda: Brachyura). *Smithsonian Contributions to Zoology* 462:1-21.

Kropp, R.K. 1987. Descriptions of some endolithic habitats for snapping shrimp (Alpheidae) in Micronesia. *Bulletin of Marine Science* 41:204-213.

Kropp, R.K. 1986. Feeding biology and mouthpart morphology of three species of coral gall crabs (Decapoda: Cryptochiridae). *Journal of Crustacean Biology* 6:377-384.

Kropp, R.K. 1986. A neotype designation for *Petrolisthes tomentosus* (Dana), and the description of two new species of *Petrolisthes* from the Mariana Islands (Anomura, Porcellanidae). *Proceedings of the Biological Society of Washington* 99:452-463.

Nelson, S.G. and R.K. Kropp. 1985. Ammonia excretion and nitrogen assimilation by the tropical freshwater prawn *Macrobrachium lar* (Crustacea, Palaemonidae). *Comparative Biochemistry and Physiology* 81A:699-704.

Kropp, R.K. and R.B. Manning. 1985. Cryptochiridae, the correct name for the family containing the gall crabs (Crustacea, Decapoda, Brachyura). *Proceedings of the Biological Society of Washington* 98:954-955.

Eldredge, L.G. and R.K. Kropp. 1985. Volcanic ashfall effects on intertidal and shallow-water coral reef zones at Pagan, Mariana Islands. *Proceedings of the Fifth Coral Reef Congress, Tahiti* 4:189-194.

Kropp, R.K. 1984. *Tanaocheles stenochilus*, a new genus and species of crab from Guam, Mariana Islands (Brachyura, Xanthidae). *Proceedings of the Biological Society of Washington* 97:744-747.

Kropp, R.K. 1983. Three new species of Porcellanidae (Crustacea, Anomura) from the Mariana Islands and a discussion of Borradaile's *Petrolisthes lamarckii* complex. *Micronesica* 19:91-106.

Kropp, R.K. 1982. Responses of five holothurian species to attacks by a predatory gastropod, *Tonna perdx*. *Pacific Science* 36:445-452.

Eldredge, L.G. and R.K. Kropp. 1981. Crustacean-induced skeletal modification in *Acropora*. *Proceedings of the Fourth International Coral Reef Symposium, Manila* 2:115-119. [published 1982]

Kropp, R.K. and C. Birkeland. 1981. Comparison of crustacean associates of *Pocillopora* from high islands and atolls. *Proceedings of the Fourth International Coral Reef Symposium, Manila* 2:627-632. [published 1982]

Kropp, R.K. 1981. Additional porcelain crab feeding methods (Decapoda, Porcellanidae). *Crustaceana* 40:307-310.

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APPENDIX C

Sediment Properties: October 2011 Survey

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APPENDIX C
Properties of Sediment Samples Collected during October 2011 Offshore Survey

Table C.1 Sediment Grab-Sample Collection Record

Station	Sample	Date	Time ¹	Penetration Depth (cm)	Latitude	Longitude	Sediment Type	Sediment ² Color	Comment
1	Bio 1	10/24/2011	7:47:15	9.0	35° 23.7442' N	120° 52.6816' W	Sand	Lt. Brown	Many sand dollars
	Bio 2	10/24/2011	7:51:00	8.0	35° 23.7443' N	120° 52.6807' W	Sand	Lt. Brown	
	Bio 3	10/24/2011	7:53:26	8.0	35° 23.7443' N	120° 52.6797' W	Sand	Lt. Brown	
	Bio 4	10/24/2011	7:55:54	9.0	35° 23.7444' N	120° 52.6803' W	Sand	Lt. Brown	
	Bio 5	10/24/2011	7:58:05	9.0	35° 23.7444' N	120° 52.6806' W	Sand	Lt. Brown	
	Chem 1	10/24/2011	8:00:42	N/A	35° 23.7445' N	120° 52.6803' W	Sand	Lt. Brown	
	Chem 2	10/24/2011	8:05:01	N/A	35° 23.7444' N	120° 52.6802' W	Sand	Lt. Brown	
	Chem 3	10/24/2011	8:10:24	N/A	35° 23.7450' N	120° 52.6803' W	Sand	Lt. Brown	
2	Bio 1	10/24/2011	8:47:33	9.0	35° 23.2830' N	120° 52.5042' W	Sand	Lt. Brown	Many sand dollars
	Bio 2	10/24/2011	8:50:06	10.0	35° 23.2822' N	120° 52.5040' W	Sand	Lt. Brown	
	Bio 3	10/24/2011	8:52:20	9.0	35° 23.2818' N	120° 52.5042' W	Sand	Lt. Brown	
	Bio 4	10/24/2011	8:54:33	10.0	35° 23.2823' N	120° 52.5039' W	Sand	Lt. Brown	
	Bio 5	10/24/2011	8:56:59	8.0	35° 23.2822' N	120° 52.5037' W	Sand	Lt. Brown	
	Chem 1	10/24/2011	8:59:27	N/A	35° 23.2824' N	120° 52.5038' W	Sand	Lt. Brown	
	Chem 2	10/24/2011	9:03:34	N/A	35° 23.2819' N	120° 52.5048' W	Sand	Lt. Brown	
	Chem 3	10/24/2011	9:06:46	N/A	35° 23.2816' N	120° 52.5039' W	Sand	Lt. Brown	
3	Bio 1	10/24/2011	9:25:04	8.0	35° 23.2279' N	120° 52.5065' W	Sand	Lt. Brown	Few sand dollars
	Bio 2	10/24/2011	9:27:30	9.0	35° 23.2278' N	120° 52.5072' W	Sand	Lt. Brown	
	Bio 3	10/24/2011	9:29:47	8.0	35° 23.2280' N	120° 52.5070' W	Sand	Lt. Brown	
	Bio 4	10/24/2011	9:32:02	9.0	35° 23.2287' N	120° 52.5072' W	Sand	Lt. Brown	
	Bio 5	10/24/2011	9:37:09	8.0	35° 23.2285' N	120° 52.5081' W	Sand	Lt. Brown	
	Chem 1	10/24/2011	9:39:27	N/A	35° 23.2283' N	120° 52.5080' W	Sand	Lt. Brown	
	Chem 2	10/24/2011	9:43:05	N/A	35° 23.2279' N	120° 52.5078' W	Sand	Lt. Brown	
	Chem 3	10/24/2011	9:46:33	N/A	35° 23.2270' N	120° 52.5086' W	Sand	Lt. Brown	
4	Bio 1	10/24/2011	10:07:53	7.5	35° 23.2128' N	120° 52.4966' W	Sand	Lt. Brown	
	Bio 2	10/24/2011	10:10:20	8.0	35° 23.2135' N	120° 52.4954' W	Sand	Lt. Brown	
	Bio 3	10/24/2011	10:13:08	8.0	35° 23.2142' N	120° 52.4953' W	Sand	Lt. Brown	
	Bio 4	10/24/2011	10:15:34	8.0	35° 23.2129' N	120° 52.4956' W	Sand	Lt. Brown	
	Bio 5	10/24/2011	10:18:07	8.0	35° 23.2134' N	120° 52.4960' W	Sand	Lt. Brown	
	Chem 1	10/24/2011	10:20:17	N/A	35° 23.2126' N	120° 52.4960' W	Sand	Lt. Brown	
	Chem 2	10/24/2011	10:23:42	N/A	35° 23.2145' N	120° 52.4951' W	Sand	Lt. Brown	
	Chem 3	10/24/2011	10:26:49	N/A	35° 23.2142' N	120° 52.4948' W	Sand	Lt. Brown	
5	Bio 1	10/24/2011	10:55:38	7.0	35° 23.1824' N	120° 52.5065' W	Sand	Lt. Brown	
	Bio 2	10/24/2011	10:58:14	8.0	35° 23.1812' N	120° 52.5047' W	Sand	Lt. Brown	
	Bio 3	10/24/2011	11:00:53	8.0	35° 23.1801' N	120° 52.5034' W	Sand	Lt. Brown	
	Bio 4	10/24/2011	11:03:32	9.0	35° 23.1796' N	120° 52.5025' W	Sand	Lt. Brown	
	Bio 5	10/24/2011	11:06:10	9.0	35° 23.1799' N	120° 52.5021' W	Sand	Lt. Brown	
	Chem 1	10/24/2011	11:08:39	N/A	35° 23.1801' N	120° 52.5013' W	Sand	Lt. Brown	
	Chem 2	10/24/2011	11:14:58	N/A	35° 23.1810' N	120° 52.5004' W	Sand	Lt. Brown	
	Chem 3	10/24/2011	11:18:41	N/A	35° 23.1809' N	120° 52.5015' W	Sand	Lt. Brown	

¹ Time when the sediment grab was collected (trip time of the grab)

² No odors emanating from the sediment samples were noted at any station

Table C.1 Sediment Grab-Sample Collection Record

Station	Sample	Date	Time ¹	Penetration Depth (cm)	Latitude	Longitude	Sediment Type	Sediment ² Color	Comment
6	Bio 1	10/24/2011	11:34:48	7.0	35° 23.1630' N	120° 52.5014' W	Sand	Lt. Brown	
	Bio 2	10/24/2011	11:37:05	10.0	35° 23.1630' N	120° 52.5032' W	Sand	Lt. Brown	
	Bio 3	10/24/2011	11:39:25	8.5	35° 23.1621' N	120° 52.5036' W	Sand	Lt. Brown	
	Bio 4	10/24/2011	11:41:38	9.5	35° 23.1608' N	120° 52.5037' W	Sand	Lt. Brown	
	Bio 5	10/24/2011	11:44:08	8.5	35° 23.1606' N	120° 52.5050' W	Sand	Lt. Brown	
	Chem 1	10/24/2011	11:46:18	N/A	35° 23.1600' N	120° 52.5043' W	Sand	Lt. Brown	
	Chem 2	10/24/2011	11:51:51	N/A	35° 23.1594' N	120° 52.5053' W	Sand	Lt. Brown	
	Chem 3	10/24/2011	11:55:11	N/A	35° 23.1604' N	120° 52.5056' W	Sand	Lt. Brown	
7	Bio 1	10/24/2011	12:17:10	9.5	35° 23.1174' N	120° 52.5066' W	Sand	Lt. Brown	
	Bio 2	10/24/2011	12:19:36	9.0	35° 23.1151' N	120° 52.5048' W	Sand	Lt. Brown	
	Bio 3	10/24/2011	12:21:56	8.0	35° 23.1152' N	120° 52.5034' W	Sand	Lt. Brown	
	Bio 4	10/24/2011	12:24:31	8.0	35° 23.1150' N	120° 52.5024' W	Sand	Lt. Brown	
	Bio 5	10/24/2011	12:26:36	8.0	35° 23.1152' N	120° 52.5013' W	Sand	Lt. Brown	
	Chem 1	10/24/2011	12:29:14	N/A	35° 23.1158' N	120° 52.5013' W	Sand	Lt. Brown	
	Chem 2	10/24/2011	12:32:37	N/A	35° 23.1156' N	120° 52.5031' W	Sand	Lt. Brown	
	Chem 3	10/24/2011	12:35:29	N/A	35° 23.1147' N	120° 52.5037' W	Sand	Lt. Brown	

Table C.2 Grain-Size Class Distribution in October 2011 Sediment Samples

Phi	-2 to -1	-1 to 0	0 to 1	1 to 2	2 to 3	3 to 4	4 to 9	>9
Size (µm)	2000	1000	500	250	125	62.5	62.5 to 2	<2
Class	Gravel	Vry Crs Snd	Crs Sand	Med Snd	Fine Snd	Vry Fine Snd	Silt	Clay
Station 1	0.086%	0.993%	0.063%	3.237%	69.713%	24.983%	0.686%	0.238%
Station 1(d)	0.362%	0.646%	0.855%	3.540%	69.081%	24.461%	0.793%	0.262%
Station 2	0.000%	0.017%	0.616%	1.939%	76.718%	20.027%	0.562%	0.120%
Station 3	1.175%	0.520%	0.598%	2.376%	79.370%	15.430%	0.359%	0.171%
Station 4	1.670%	0.432%	0.529%	3.410%	79.986%	13.451%	0.310%	0.213%
Station 5	0.314%	0.518%	0.835%	2.702%	76.273%	18.694%	0.551%	0.113%
Station 6	0.000%	0.144%	0.772%	2.840%	76.119%	19.557%	0.473%	0.096%
Station 6(d)	0.000%	0.430%	1.564%	2.970%	76.457%	18.061%	0.505%	0.014%
Station 7	0.000%	0.434%	1.010%	2.160%	75.630%	20.384%	0.196%	0.187%

Table C.3 Grain-Size Weight Distribution in October 2011 Sediment Samples

Phi Size (µm) Class	Dry Weight (grams)			Percentage Summary		
	<-1 to 4 2000 to 62.5	>4 <62.5	Total	-2 to -1 2000	-1 to 4 1000 to 62.5	4 to >9 <62.5
	Coarse	Fine		Gravel	Sand	Mud
Station 1	109.707	1.024	110.731	0.086%	98.989%	0.925%
Station 1(d)	99.862	1.064	100.926	0.362%	98.584%	1.054%
Station 2	98.917	0.680	99.597	0.000%	99.317%	0.683%
Station 3	99.623	0.531	100.154	1.175%	98.295%	0.530%
Station 4	102.753	0.540	103.293	1.670%	97.807%	0.523%
Station 5	100.913	0.675	101.588	0.314%	99.022%	0.664%
Station 6	100.989	0.578	101.567	0.000%	99.431%	0.569%
Station 6(d)	102.362	0.534	102.896	0.000%	99.481%	0.519%
Station 7	101.907	0.391	102.298	0.000%	99.618%	0.382%

Table C.4 Grain-Size Statistics for October 2011 Sediment Samples

Station	Percent Coarser than Listed Diameter (µm)								
	Mean (φ)	σ (φ)	Skewness (φ)	Mean (µm)	5%	16%	50%	84%	95%
B1	2.75	0.440	0.09	149	243	197	151	110	85
B1(d)	2.74	0.461	0.07	150	256	201	152	110	84
B2	2.73	0.371	0.12	151	224	191	153	118	91
B3	2.65	0.378	0.07	159	246	202	160	125	96
B4	2.61	0.392	0.02	164	267	208	165	128	99
B5	2.69	0.398	0.08	155	242	200	157	120	92
B6	2.70	0.389	0.09	154	236	197	155	119	92
B6(d)	2.67	0.399	0.06	157	249	202	158	121	94
B7	2.68	0.345	0.06	156	232	194	157	125	100

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APPENDIX D
Outfall Inspection Report

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Morro Bay/Cayucos Wastewater Treatment Plant
Outfall/Diffuser Annual Report

Name of Discharger: MBLSD
NPDES Permit Number: CA0047881

Name of Diver/Inspector: Craig Porter / Porter Diving.
Firm & Address: 15730 Morro Road

Telephone Number: (805) 466 - 0566

Outfall Length: 5160 Feet Depth of Water: 50 Feet

Design of Diffuser (physical dimensions, shape, include sketch):

Number of Ports: 34 Number Ports Open: 28 Diffuser Level? 1'-6"

End of Diffuser Open? _____ Closed? ☒

Outfall Marked by Bouys? Yes: ☒ No: _____ Type: SPAR

Diffusers Operating as Designed? Yes: ☒ No: _____

Breaks in Outfall Line Noted? Yes: _____ No: ☒ if yes, describe

Describe Problems Noted: _____

Corrected Action Needed: Changed Bolting on 12 Diffusers
was starting rusting of Diffuser string

Physical Description of Environment Around Outfall (i.e. fish noted, debris, sediment, etc.):

Direction of Plume in Relationship to Shoreline: set to north

Pictures Taken? Yes: ☒ No: _____ (Include copies if taken)

Craig Porter
Signature of Diver/Inspection

12/9/2011
Date

Signature of Diver/Inspection

Date

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APPENDIX E

Sediment Chemistry: October 2011 Survey Methods, Results, and QA/QC

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Methods

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**Table E.1 Summary of Analytical Methods Used for
Physicochemical Determinations of Sediment**

Parameter	Method	Description	Reference
Biochemical Oxygen Demand 5-Day	5210B	Dissolved Oxygen Probe	6
Total Kjeldahl Nitrogen (TKN)	351.2	Block Digestion/Colorimetry	1
Total Volatile Solids	160.4	Dry ashing/Gravimetry	1
Moisture	160.3	Evaporation/Gravimetry	1
Sediment Grain Size	MRS, 1998	Sieve/Pipette without salt	2,3,4
Aluminum	6010	ICP	5
Arsenic	7060	GFAAS	5
Cadmium	6010	ICP	5
Chromium	6010	ICP	5
Copper	6010	ICP	5
Iron	6010	ICP	5
Lead	7421	CVAAS	5
Mercury	7471	CVAAS	5
Nickel	6010	ICP	5
Silver	272.2	GFAAS	1
Zinc	6010	ICP	5
Oil and Grease	1664	Extraction/Gravimetry	7

CVAAS = Cold Vapor Atomic Absorption Spectrometry

ICP/MS = Inductively Coupled Plasma/Mass Spectrometry

GC = Gas Chromatography

GC/MS = Gas Chromatography/Mass Spectrometry

GFAAS = Graphite Furnace Atomic Absorption Spectrometry

References:

1. U.S. Environmental Protection Agency. 1983. Methods for chemical analysis of water and wastes. EPA-600/4-79-020.
2. Plumb, R.H., Jr. 1981. Procedures for Handling and chemical analysis of sediment and water samples. U.S. Army Corps of Engineer Waterway Experiment Stations, Vicksburg, Miss.
3. Marine Research Specialists. 1998. City of Morro Bay and Cayucos Sanitary District, Offshore Monitoring and Reporting Program, Semiannual Benthic Sampling, October 1997. Prepared for the City of Morro Bay, Morro Bay, CA
4. Coats, D.A., Imamura, E., Fukuyama, A.K., Skalski, J.R., Kimura, S., and J. Steinbeck. 1998. Monitoring of Biological Recovery of Prince William Sound Intertidal Sites Impacted by the *Exxon Valdez* Oil Spill. 1997 Biological Monitoring Survey. NOAA Technical Memorandum NOS ORCA NOS OR&R 1.
5. U.S. Environmental Protection Agency. 1986. Test methods for evaluating solid wastes physical/chemical methods. EPA SW-846. 3rd ed., revised.
6. American Public Health Association, American Water Works Association, and Water Pollution Control Federation. 1998. Standard methods for the examination of water and wastewater (20th Ed.). Washington, DC.
7. U.S. Environmental Protection Agency. 1999. Method 1664 Revision A: N-Hexane Extractable Material (HEM; Oil and Grease) and Silica Gel Treated N-Hexane Extractable Material (SGT-HEM; Non-polar Material) by Extraction and Gravimetry. February 1999. EPA-821-R-98-002.

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Analytical Results

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Date of Report: 11/17/2011

Bonnie Luke

Marine Research Specialists
3140 Telegraph Road, Suite A
Suite A
Ventura, CA 93003-3238

Project: Annual Benthic Sediment Sampling for MBTP
BC Work Order: 1117519
Invoice ID: B111493

Enclosed are the results of analyses for samples received by the laboratory on 10/24/2011. If you have any questions concerning this report, please feel free to contact me.

Sincerely,



Contact Person: Tina Green
Client Services Manager



Authorized Signature

Certifications: CA ELAP #1186; NV #CA00014

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Case Narratives

Case Narrative for Work Order 1117519

Due to a laboratory error the BOD holding time was missed and analyzed outside of the 48 hour holding time.



Laboratories, Inc.

Environmental Testing Laboratory Since 1949

Chain of Custody Form

Report To: Client: Marine Research Specialists		Project #: Morro Bay Benthic		Analysis Requested																	
Attn: Bonnie Luke		Project Name: Offshore Sediment Sampling																			
Street Address: 3140 Telegraph Rd STE A		Global ID #:																			
City, State, Zip: Ventura CA 93003		Sampler(s): Doug Coats																			
Telephone: (805) 289-3926																					
Email: Bonnie.Luke@MRSEnv.com																					
Work Order #: 11-17519																					
Sample #	Description	Date Sampled	Time Sampled	Moisture 160.3 or BC	Total Volatile Solids 160.4 or 2540G	Biochemical Oxygen Demand 405d	Total Kjeldahl Nitrogen 351.2	Oil and Grease 413.2 or 1664/HBM	Al, Fe, As, Cd, Cr (total), Cu, Pb, Hg, Ni	Ag, Zn	Pesticides and PCBs 8080	Base Neutral and Extractables 8270	Soil	Sludge	Drinking Water	Ground Water	Waste Water	Other	TAI Days	Notes	
1 B1	Station B1	10/24/2011	0805	X	X	X	X	X	X	X	X	X	X							X	No O&G, 8080, or 8270 at Station B1
2 B2	Station B2	10/24/2011	0903	X	X	X	X	X	X	X	X	X	X							X	
3 B3	Station B3	10/24/2011	0943	X	X	X	X	X	X	X	X	X	X							X	
4 B4	Station B4	10/24/2011	1024	X	X	X	X	X	X	X	X	X	X							X	
5 B5	Station B5	10/24/2011	1115	X	X	X	X	X	X	X	X	X	X							X	
6 B6	Station B6	10/24/2011	1152	X	X	X	X	X	X	X	X	X	X							X	
7 B7	Station B7	10/24/2011	1233	X	X	X	X	X	X	X	X	X	X							X	
CHK BY [Signature] DISTRIBUTION [Signature]																					
SUB-OUT ☐																					
Billing		☒ Same as Above		EDF Required?		Sample Disposal										Special Reporting					
Client: _____				☐ Yes ☒ No		☐ Return to Client ☒ Disposal by lab ☐ Archive Months _____										☐ QC ☐ EDF ☐ Raw Data					
Address: _____				Send Copy to State of CA?		1. Relinquish By: Bonnie Luke Date: 10/24/11 Time: 17:30										1. Received by: Jerry M... Date: 10-24-11 Time: 1730					
City: _____ State: _____ Zip: _____				☐ Yes ☒ No		2. Relinquish By: Jerry M... Date: 10-24-11 Time: 2055										2. Received by: [Signature] Date: 10-24-11 Time: 2055					
Attn: _____						3. Relinquish by: _____ Date: _____ Time: _____										3. Received by: _____ Date: _____ Time: _____					
PO#: _____																					

BC Laboratories, Inc. 4100 Atlas Court Bakersfield, Ca. 93308 Tel: 800.878.4911 Fax: 661.327.4911

Page 1 of 2

11-17519

marine research specialists

3140 Telegraph Road., Suite A • Ventura, CA 93003 • (805) 644-1180

Attachment (Page 2 of 2) to Chain of Custody Form Morro Bay Benthic Sediment Sampling at 7 Stations on Monday, 24 October 2011

The following analyses should be conducted on the **composited** soil matrix using procedures and a QC Level similar to the analyses conducted in 2010 on BC Laboratory Sample Number **10-14100**. Prior to analysis, macrofauna and large remnants greater than 0.25 inches should be removed, taking care to avoid contamination. **Additionally, prior to analysis, homogenize the composite sample in the laboratory to ensure uniform distribution of multiple subsamples in sample container(s).** All results should be reported on an as-received (raw) basis and where appropriate, on a **dry-weight basis**. The required analyses are:

Constituent	Samples	Method
Moisture	7	160.3 or BC
Total Volatile Solids	7	160.4 or SM-2540G
Biochemical Oxygen Demand	7	405.1 or SM17-5210B
Total Kjeldahl Nitrogen	7	351.2
Oil and Grease	6	413.2 or EPA-1664/HEM
Metals (11)		
Aluminum	7	SW-6010
Iron	7	SW-6010
Arsenic	7	SW-7060
Cadmium	7	SW-6010
Total Chromium	7	SW-6010
Copper	7	SW-6010
Lead	7	SW-7421
Mercury	7	SW-7471
Nickel	7	SW-6010
Silver	7	EPA-272.2
Zinc	7	SW-6010

Questions can be directed to Bonnie Luke at Marine Research Specialists at (805) 289-3926.

Chain of Custody and Cooler Receipt Form for 1117519 Page 3 of 3

BC LABORATORIES INC.		SAMPLE RECEIPT FORM		Rev. No. 12	06/24/08	Page 1 Of 1	
Submission #: 1117519							
SHIPPING INFORMATION Federal Express ☐ UPS ☐ Hand Delivery ☐ BC Lab Field Service ☒ Other ☐ (Specify) _____				SHIPPING CONTAINER Ice Chest ☒ None ☐ Box ☐ Other ☐ (Specify) _____			
Refrigerant: Ice ☒ Blue Ice ☐ None ☐ Other ☐ Comments: _____							
Custody Seals Ice Chest ☐ Containers ☐ None ☒ Comments: _____ Intact? Yes ☐ No ☐ Intact? Yes ☐ No ☐							
All samples received? Yes ☒ No ☐ All samples containers intact? Yes ☒ No ☐ Description(s) match COC? Yes ☒ No ☐							
COC Received ☒ YES ☐ NO		Emissivity: 0.98		Container: 32oz jar		Thermometer ID: 177	
		Temperature: A 0.7 °C / C 0.8 °C				Date/Time 10-24-11	
						Analyst Init JWW 2102	

SAMPLE CONTAINERS	SAMPLE NUMBERS									
	1	2	3	4	5	6	7	8	9	10
QT GENERAL MINERAL/ GENERAL PHYSICAL										
PT PE UNPRESERVED										
QT INORGANIC CHEMICAL METALS										
PT INORGANIC CHEMICAL METALS										
PT CYANIDE										
PT NITROGEN FORMS										
PT TOTAL SULFIDE										
2oz. NITRATE / NITRITE										
PT TOTAL ORGANIC CARBON										
PT TOX										
PT CHEMICAL OXYGEN DEMAND										
PTA PHENOLICS										
40ml VOA VIAL TRAVEL BLANK										
40ml VOA VIAL	(	)	(	)	(	)	(	)	(	)
QT EPA 413.1, 413.2, 418.1										
PT ODOR										
RADIOLOGICAL										
BACTERIOLOGICAL										
40 ml VOA VIAL- 504										
QT EPA 508/608/8080										
QT EPA 515.1/8150										
QT EPA 525										
QT EPA 525 TRAVEL BLANK										
100ml EPA 547										
100ml EPA 531.1										
QT EPA 548										
QT EPA 549										
QT EPA 632										
QT EPA 8015M										
QT AMBER										
8 OZ. JAR	A	A	A	A	A	A	A			
32 OZ. JAR										
SOIL SLEEVE										
PCB VIAL										
PLASTIC BAG										
FERROUS IRON										
ENCORE										

Comments:

Sample Numbering Completed By: JWW Date/Time: 11/24/11 2102

A = Actual / C = Corrected

[H:\DOCS\WP80\LAB_DOCS\FORMS\SAMREC2.WPD]

Marine Research Specialists
3140 Telegraph Road, Suite A
Suite A
Ventura, CA 93003-3238

Reported: 11/17/2011 16:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: [none]
Project Manager: Bonnie Luke

Laboratory / Client Sample Cross Reference

Laboratory	Client Sample Information			
1117519-01	COC Number:	---	Receive Date:	10/24/2011 20:55
	Project Number:	---	Sampling Date:	10/24/2011 08:05
	Sampling Location:	---	Sample Depth:	---
	Sampling Point:	Station B1	Lab Matrix:	Solids
	Sampled By:	Doug Coats	Sample Type:	Soil
1117519-02	COC Number:	---	Receive Date:	10/24/2011 20:55
	Project Number:	---	Sampling Date:	10/24/2011 09:03
	Sampling Location:	---	Sample Depth:	---
	Sampling Point:	Station B2	Lab Matrix:	Solids
	Sampled By:	Doug Coats	Sample Type:	Soil
1117519-03	COC Number:	---	Receive Date:	10/24/2011 20:55
	Project Number:	---	Sampling Date:	10/24/2011 09:43
	Sampling Location:	---	Sample Depth:	---
	Sampling Point:	Station B3	Lab Matrix:	Solids
	Sampled By:	Doug Coats	Sample Type:	Soil
1117519-04	COC Number:	---	Receive Date:	10/24/2011 20:55
	Project Number:	---	Sampling Date:	10/24/2011 10:24
	Sampling Location:	---	Sample Depth:	---
	Sampling Point:	Station B4	Lab Matrix:	Solids
	Sampled By:	Doug Coats	Sample Type:	Soil
1117519-05	COC Number:	---	Receive Date:	10/24/2011 20:55
	Project Number:	---	Sampling Date:	10/24/2011 11:15
	Sampling Location:	---	Sample Depth:	---
	Sampling Point:	Station B5	Lab Matrix:	Solids
	Sampled By:	Doug Coats	Sample Type:	Soil
1117519-06	COC Number:	---	Receive Date:	10/24/2011 20:55
	Project Number:	---	Sampling Date:	10/24/2011 11:52
	Sampling Location:	---	Sample Depth:	---
	Sampling Point:	Station B6	Lab Matrix:	Solids
	Sampled By:	Doug Coats	Sample Type:	Soil
1117519-07	COC Number:	---	Receive Date:	10/24/2011 20:55
	Project Number:	---	Sampling Date:	10/24/2011 12:33
	Sampling Location:	---	Sample Depth:	---
	Sampling Point:	Station B7	Lab Matrix:	Solids
	Sampled By:	Doug Coats	Sample Type:	Soil

Marine Research Specialists
3140 Telegraph Road, Suite A
Suite A
Ventura, CA 93003-3238

Reported: 11/17/2011 16:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: [none]
Project Manager: Bonnie Luke

Chemical Analysis

BCL Sample ID:	1117519-01	Client Sample Name:	Station B1, 10/24/2011 8:05:00AM, Doug Coats						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Moisture	0	21.9	%	0.05	0.05	Calc	ND		1
Total Kjeldahl Nitrogen	140	110	mg/kg	40	15	EPA-351.2	ND		2
Volatile Solids	1.67	1.30	%	0.200	0.200	SM-2540G			3
Biochemical Oxygen Demand	25	20	mg O/kg	7.5	7.5	SM17-5210B		S05	4
Solids	100	78.1	%	0.05	0.05	SM-2540G			5

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	Calc	10/25/11	11/04/11 16:39	TMS	Calc	1	BUJ1750
2	EPA-351.2	11/03/11	11/07/11 10:33	SDU	SC-1	0.962	BUK0265
3	SM-2540G	10/26/11	10/26/11 12:00	MSA	MANUAL	1	BUK0785
4	SM17-5210B	10/27/11	10/27/11 11:30	HPR	YSI-57	0.250	BUK0287
5	SM-2540G	10/25/11	10/25/11 16:00	DIW	MANUAL	1	BUJ1825

Marine Research Specialists
3140 Telegraph Road, Suite A
Suite A
Ventura, CA 93003-3238

Reported: 11/17/2011 16:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: [none]
Project Manager: Bonnie Luke

Total Concentrations (TTLc)

BCL Sample ID: 1117519-01		Client Sample Name: Station B1, 10/24/2011 8:05:00AM, Doug Coats							
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Arsenic	3.2	2.5	mg/kg	0.50	0.37	EPA-6020	ND		1
Cadmium	ND	ND	mg/kg	0.50	0.050	EPA-6010B	ND		2
Chromium	61	48	mg/kg	0.50	0.060	EPA-6010B	ND		2
Copper	3.2	2.5	mg/kg	1.0	0.12	EPA-6010B	ND		2
Lead	2.2	1.7	mg/kg	0.25	0.047	EPA-6020	ND		1
Mercury	0.064	0.050	mg/kg	0.16	0.024	EPA-7471A	ND	J	3
Nickel	42	33	mg/kg	0.50	0.058	EPA-6010B	ND		2
Silver	ND	ND	mg/kg	0.25	0.027	EPA-6020	ND		1
Zinc	20	15	mg/kg	2.5	0.25	EPA-6010B	0.58		2
Aluminum	6300	4900	mg/kg	5.0	1.3	EPA-6010B	1.6		2
Iron	10000	8100	mg/kg	5.0	3.7	EPA-6010B	ND		2

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-6020	10/28/11	11/16/11 20:44	PPS	PE-EL1	1	BUJ2010
2	EPA-6010B	10/28/11	10/31/11 06:10	ARD	PE-OP1	1	BUJ1999
3	EPA-7471A	10/26/11	10/27/11 12:40	MEV	CETAC1	0.962	BUJ1858

Marine Research Specialists
3140 Telegraph Road, Suite A
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Reported: 11/17/2011 16:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: [none]
Project Manager: Bonnie Luke

EPA Method 1664

BCL Sample ID:	1117519-02	Client Sample Name:	Station B2, 10/24/2011 9:03:00AM, Doug Coats						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Oil and Grease	ND	ND	mg/kg	50	16	EPA-1664HEM	ND		1

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-1664HEM	10/27/11	10/27/11 09:00	JAK	MAN-SV	1	BUJ2062

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Reported: 11/17/2011 16:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: [none]
Project Manager: Bonnie Luke

Chemical Analysis

BCL Sample ID:	1117519-02	Client Sample Name:	Station B2, 10/24/2011 9:03:00AM, Doug Coats						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Moisture	0	23.6	%	0.05	0.05	Calc	ND		1
Total Kjeldahl Nitrogen	140	110	mg/kg	40	15	EPA-351.2	ND		2
Volatile Solids	2.00	1.53	%	0.200	0.200	SM-2540G			3
Biochemical Oxygen Demand	30	23	mg O/kg	10	10	SM17-5210B		S05	4
Solids	100	76.4	%	0.05	0.05	SM-2540G			5

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	Calc	10/25/11	11/04/11 16:39	TMS	Calc	1	BUJ1750
2	EPA-351.2	11/03/11	11/07/11 10:35	SDU	SC-1	1	BUK0265
3	SM-2540G	10/26/11	10/26/11 12:00	MSA	MANUAL	1	BUK0785
4	SM17-5210B	10/27/11	10/27/11 11:30	HPR	YSI-57	0.333	BUK0287
5	SM-2540G	10/25/11	10/25/11 16:00	DIW	MANUAL	1	BUJ1825

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Reported: 11/17/2011 16:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: [none]
Project Manager: Bonnie Luke

Total Concentrations (TTLC)

BCL Sample ID: 1117519-02		Client Sample Name: Station B2, 10/24/2011 9:03:00AM, Doug Coats							
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Arsenic	4.0	3.1	mg/kg	0.50	0.37	EPA-6020	ND		1
Cadmium	ND	ND	mg/kg	0.50	0.050	EPA-6010B	ND		2
Chromium	48	36	mg/kg	0.50	0.060	EPA-6010B	ND		2
Copper	3.3	2.5	mg/kg	1.0	0.12	EPA-6010B	ND		2
Lead	2.2	1.7	mg/kg	0.25	0.047	EPA-6020	ND		1
Mercury	0.037	0.028	mg/kg	0.16	0.024	EPA-7471A	ND	J	3
Nickel	47	36	mg/kg	0.50	0.058	EPA-6010B	ND		2
Silver	0.045	0.034	mg/kg	0.25	0.027	EPA-6020	ND	J	1
Zinc	17	13	mg/kg	2.5	0.25	EPA-6010B	0.58		2
Aluminum	5600	4200	mg/kg	5.0	1.3	EPA-6010B	1.6		2
Iron	9600	7400	mg/kg	5.0	3.7	EPA-6010B	ND		2

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-6020	10/28/11	11/16/11 21:02	PPS	PE-EL1	1	BUJ2010
2	EPA-6010B	10/28/11	10/31/11 06:11	ARD	PE-OP1	1	BUJ1999
3	EPA-7471A	10/26/11	10/27/11 12:42	MEV	CETAC1	0.977	BUJ1858

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Reported: 11/17/2011 16:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: [none]
Project Manager: Bonnie Luke

EPA Method 1664

BCL Sample ID:	1117519-03	Client Sample Name:	Station B3, 10/24/2011 9:43:00AM, Doug Coats						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Oil and Grease	ND	ND	mg/kg	50	16	EPA-1664HEM	ND		1

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-1664HEM	10/27/11	10/27/11 09:00	JAK	MAN-SV	1	BUJ2062

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Reported: 11/17/2011 16:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: [none]
Project Manager: Bonnie Luke

Chemical Analysis

BCL Sample ID:	1117519-03	Client Sample Name:	Station B3, 10/24/2011 9:43:00AM, Doug Coats						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Moisture	0	21.5	%	0.05	0.05	Calc	ND		1
Total Kjeldahl Nitrogen	120	95	mg/kg	40	15	EPA-351.2	ND		2
Volatile Solids	2.10	1.65	%	0.200	0.200	SM-2540G			3
Biochemical Oxygen Demand	18	14	mg O/kg	6.0	6.0	SM17-5210B		S05	4
Solids	100	78.5	%	0.05	0.05	SM-2540G			5

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	Calc	10/25/11	11/04/11 16:39	TMS	Calc	1	BUJ1750
2	EPA-351.2	11/03/11	11/07/11 10:35	SDU	SC-1	1	BUK0265
3	SM-2540G	10/26/11	10/26/11 12:00	MSA	MANUAL	1	BUK0785
4	SM17-5210B	10/27/11	10/27/11 11:30	HPR	YSI-57	0.200	BUK0287
5	SM-2540G	10/25/11	10/25/11 16:00	DIW	MANUAL	1	BUJ1825

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Reported: 11/17/2011 16:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: [none]
Project Manager: Bonnie Luke

Total Concentrations (TTLc)

BCL Sample ID:	1117519-03	Client Sample Name:	Station B3, 10/24/2011 9:43:00AM, Doug Coats						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Arsenic	3.3	2.6	mg/kg	0.50	0.37	EPA-6020	ND		1
Cadmium	ND	ND	mg/kg	0.50	0.050	EPA-6010B	ND		2
Chromium	46	36	mg/kg	0.50	0.060	EPA-6010B	ND		2
Copper	3.1	2.4	mg/kg	1.0	0.12	EPA-6010B	ND		2
Lead	1.9	1.5	mg/kg	0.25	0.047	EPA-6020	ND		1
Mercury	0.031	0.025	mg/kg	0.16	0.024	EPA-7471A	ND	J	3
Nickel	44	35	mg/kg	0.50	0.058	EPA-6010B	ND		2
Silver	ND	ND	mg/kg	0.25	0.027	EPA-6020	ND		1
Zinc	16	13	mg/kg	2.5	0.25	EPA-6010B	0.58		2
Aluminum	5500	4300	mg/kg	5.0	1.3	EPA-6010B	1.6		2
Iron	9300	7300	mg/kg	5.0	3.7	EPA-6010B	ND		2

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-6020	10/28/11	11/16/11 21:05	PPS	PE-EL1	1	BUJ2010
2	EPA-6010B	10/28/11	10/31/11 06:13	ARD	PE-OP1	1	BUJ1999
3	EPA-7471A	10/26/11	10/27/11 12:44	MEV	CETAC1	0.962	BUJ1858

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Reported: 11/17/2011 16:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: [none]
Project Manager: Bonnie Luke

EPA Method 1664

BCL Sample ID:	1117519-04	Client Sample Name:	Station B4, 10/24/2011 10:24:00AM, Doug Coats						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Oil and Grease	ND	ND	mg/kg	50	16	EPA-1664HEM	ND		1

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-1664HEM	10/27/11	10/27/11 09:00	JAK	MAN-SV	1	BUJ2062

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Reported: 11/17/2011 16:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: [none]
Project Manager: Bonnie Luke

Chemical Analysis

BCL Sample ID:	1117519-04	Client Sample Name:	Station B4, 10/24/2011 10:24:00AM, Doug Coats						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Moisture	0	22.0	%	0.05	0.05	Calc	ND		1
Total Kjeldahl Nitrogen	110	86	mg/kg	40	15	EPA-351.2	ND		2
Volatile Solids	1.87	1.46	%	0.200	0.200	SM-2540G			3
Biochemical Oxygen Demand	18	14	mg O/kg	6.0	6.0	SM17-5210B		S05	4
Solids	100	78.0	%	0.05	0.05	SM-2540G			5

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	Calc	10/25/11	11/04/11 16:39	TMS	Calc	1	BUJ1750
2	EPA-351.2	11/03/11	11/07/11 10:37	SDU	SC-1	1	BUK0265
3	SM-2540G	10/26/11	10/26/11 12:00	MSA	MANUAL	1	BUK0785
4	SM17-5210B	10/27/11	10/27/11 11:30	HPR	YSI-57	0.200	BUK0287
5	SM-2540G	10/25/11	10/25/11 16:00	DIW	MANUAL	1	BUJ1825

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Reported: 11/17/2011 16:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: [none]
Project Manager: Bonnie Luke

Total Concentrations (TTLIC)

BCL Sample ID:	1117519-04	Client Sample Name:	Station B4, 10/24/2011 10:24:00AM, Doug Coats						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Arsenic	4.3	3.3	mg/kg	0.50	0.37	EPA-6020	ND		1
Cadmium	ND	ND	mg/kg	0.50	0.050	EPA-6010B	ND		2
Chromium	49	38	mg/kg	0.50	0.060	EPA-6010B	ND		2
Copper	3.2	2.5	mg/kg	1.0	0.12	EPA-6010B	ND		2
Lead	2.2	1.7	mg/kg	0.25	0.047	EPA-6020	ND		1
Mercury	ND	ND	mg/kg	0.16	0.024	EPA-7471A	ND		3
Nickel	44	34	mg/kg	0.50	0.058	EPA-6010B	ND		2
Silver	ND	ND	mg/kg	0.25	0.027	EPA-6020	ND		1
Zinc	17	13	mg/kg	2.5	0.25	EPA-6010B	0.58		2
Aluminum	6000	4700	mg/kg	5.0	1.3	EPA-6010B	1.6		2
Iron	9800	7600	mg/kg	5.0	3.7	EPA-6010B	ND		2

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-6020	10/28/11	11/16/11 21:14	PPS	PE-EL1	1	BUJ2010
2	EPA-6010B	10/28/11	10/31/11 06:14	ARD	PE-OP1	1	BUJ1999
3	EPA-7471A	10/26/11	10/27/11 12:46	MEV	CETAC1	0.962	BUJ1858

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Reported: 11/17/2011 16:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: [none]
Project Manager: Bonnie Luke

EPA Method 1664

BCL Sample ID:	1117519-05	Client Sample Name:	Station B5, 10/24/2011 11:15:00AM, Doug Coats						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Oil and Grease	ND	ND	mg/kg	50	16	EPA-1664HEM	ND		1

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-1664HEM	10/27/11	10/27/11 09:00	JAK	MAN-SV	1	BUJ2062

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Reported: 11/17/2011 16:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: [none]
Project Manager: Bonnie Luke

Chemical Analysis

BCL Sample ID:	1117519-05	Client Sample Name:	Station B5, 10/24/2011 11:15:00AM, Doug Coats						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Moisture	0	23.4	%	0.05	0.05	Calc	ND		1
Total Kjeldahl Nitrogen	130	100	mg/kg	40	15	EPA-351.2	ND		2
Volatile Solids	2.06	1.58	%	0.200	0.200	SM-2540G			3
Biochemical Oxygen Demand	41	31	mg O/kg	7.5	7.5	SM17-5210B		S05	4
Solids	100	76.6	%	0.05	0.05	SM-2540G			5

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	Calc	10/25/11	11/04/11 16:39	TMS	Calc	1	BUJ1750
2	EPA-351.2	11/03/11	11/07/11 10:37	SDU	SC-1	0.962	BUK0265
3	SM-2540G	10/26/11	10/26/11 12:00	MSA	MANUAL	1	BUK0785
4	SM17-5210B	10/27/11	10/27/11 11:30	HPR	YSI-57	0.250	BUK0287
5	SM-2540G	10/25/11	10/25/11 16:00	DIW	MANUAL	1	BUJ1825

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Reported: 11/17/2011 16:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: [none]
Project Manager: Bonnie Luke

Total Concentrations (TTLc)

BCL Sample ID: 1117519-05		Client Sample Name: Station B5, 10/24/2011 11:15:00AM, Doug Coats							
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Arsenic	3.7	2.8	mg/kg	0.50	0.37	EPA-6020	ND		1
Cadmium	ND	ND	mg/kg	0.50	0.050	EPA-6010B	ND		2
Chromium	47	36	mg/kg	0.50	0.060	EPA-6010B	ND		2
Copper	3.3	2.5	mg/kg	1.0	0.12	EPA-6010B	ND		2
Lead	2.1	1.6	mg/kg	0.25	0.047	EPA-6020	ND		1
Mercury	0.033	0.025	mg/kg	0.16	0.024	EPA-7471A	ND	J	3
Nickel	46	35	mg/kg	0.50	0.058	EPA-6010B	ND		2
Silver	ND	ND	mg/kg	0.25	0.027	EPA-6020	ND		1
Zinc	16	12	mg/kg	2.5	0.25	EPA-6010B	0.53		2
Aluminum	5600	4300	mg/kg	5.0	1.3	EPA-6010B	1.5		2
Iron	9200	7100	mg/kg	5.0	3.7	EPA-6010B	ND		2

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-6020	10/28/11	11/16/11 21:17	PPS	PE-EL1	1	BUJ2010
2	EPA-6010B	10/28/11	10/31/11 06:16	ARD	PE-OP1	0.909	BUJ1999
3	EPA-7471A	10/26/11	10/27/11 12:49	MEV	CETAC1	0.992	BUJ1858

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Reported: 11/17/2011 16:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: [none]
Project Manager: Bonnie Luke

EPA Method 1664

BCL Sample ID:	1117519-06	Client Sample Name:	Station B6, 10/24/2011 11:52:00AM, Doug Coats						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Oil and Grease	ND	ND	mg/kg	50	16	EPA-1664HEM	ND		1

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-1664HEM	10/27/11	10/27/11 09:00	JAK	MAN-SV	1	BUJ2062

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Reported: 11/17/2011 16:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: [none]
Project Manager: Bonnie Luke

Chemical Analysis

BCL Sample ID:	1117519-06	Client Sample Name:	Station B6, 10/24/2011 11:52:00AM, Doug Coats						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Moisture	0	20.4	%	0.05	0.05	Calc	ND		1
Total Kjeldahl Nitrogen	140	110	mg/kg	40	15	EPA-351.2	ND		2
Volatile Solids	1.95	1.55	%	0.200	0.200	SM-2540G			3
Biochemical Oxygen Demand	20	16	mg O/kg	7.5	7.5	SM17-5210B		S05	4
Solids	100	79.6	%	0.05	0.05	SM-2540G			5

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	Calc	10/25/11	11/04/11 16:39	TMS	Calc	1	BUJ1750
2	EPA-351.2	11/03/11	11/07/11 10:38	SDU	SC-1	1	BUK0265
3	SM-2540G	10/26/11	10/26/11 12:00	MSA	MANUAL	1	BUK0785
4	SM17-5210B	10/27/11	10/27/11 11:30	HPR	YSI-57	0.250	BUK0287
5	SM-2540G	10/25/11	10/25/11 16:00	DIW	MANUAL	1	BUJ1825

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Reported: 11/17/2011 16:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: [none]
Project Manager: Bonnie Luke

Total Concentrations (TTLC)

BCL Sample ID:	1117519-06	Client Sample Name:	Station B6, 10/24/2011 11:52:00AM, Doug Coats						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Arsenic	3.5	2.8	mg/kg	0.50	0.37	EPA-6020	ND		1
Cadmium	ND	ND	mg/kg	0.50	0.050	EPA-6010B	ND		2
Chromium	51	41	mg/kg	0.50	0.060	EPA-6010B	ND		2
Copper	3.3	2.6	mg/kg	1.0	0.12	EPA-6010B	ND		2
Lead	2.1	1.7	mg/kg	0.25	0.047	EPA-6020	ND		1
Mercury	0.040	0.032	mg/kg	0.16	0.024	EPA-7471A	ND	J	3
Nickel	47	38	mg/kg	0.50	0.058	EPA-6010B	ND		2
Silver	ND	ND	mg/kg	0.25	0.027	EPA-6020	ND		1
Zinc	16	13	mg/kg	2.5	0.25	EPA-6010B	0.56		2
Aluminum	5700	4600	mg/kg	5.0	1.3	EPA-6010B	1.5		2
Iron	9500	7600	mg/kg	5.0	3.7	EPA-6010B	ND		2

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-6020	10/28/11	11/16/11 21:20	PPS	PE-EL1	1	BUJ2010
2	EPA-6010B	10/28/11	10/31/11 06:17	ARD	PE-OP1	0.952	BUJ1999
3	EPA-7471A	10/26/11	10/27/11 12:51	MEV	CETAC1	0.977	BUJ1858

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Reported: 11/17/2011 16:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: [none]
Project Manager: Bonnie Luke

EPA Method 1664

BCL Sample ID:	1117519-07	Client Sample Name:	Station B7, 10/24/2011 12:33:00PM, Doug Coats						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Oil and Grease	ND	ND	mg/kg	50	16	EPA-1664HEM	ND		1

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-1664HEM	10/27/11	10/27/11 09:00	JAK	MAN-SV	1	BUJ2062

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Reported: 11/17/2011 16:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: [none]
Project Manager: Bonnie Luke

Chemical Analysis

BCL Sample ID:	1117519-07	Client Sample Name:	Station B7, 10/24/2011 12:33:00PM, Doug Coats						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Moisture	0	19.3	%	0.05	0.05	Calc	ND		1
Total Kjeldahl Nitrogen	120	99	mg/kg	40	15	EPA-351.2	ND		2
Volatile Solids	1.71	1.38	%	0.200	0.200	SM-2540G			3
Biochemical Oxygen Demand	19	15	mg O/kg	6.0	6.0	SM17-5210B		S05	4
Solids	100	80.7	%	0.05	0.05	SM-2540G			5

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	Calc	10/25/11	11/04/11 16:39	TMS	Calc	1	BUJ1750
2	EPA-351.2	11/03/11	11/07/11 10:39	SDU	SC-1	1	BUK0265
3	SM-2540G	10/26/11	10/26/11 12:00	MSA	MANUAL	1	BUK0785
4	SM17-5210B	10/27/11	10/27/11 11:30	HPR	YSI-57	0.200	BUK0287
5	SM-2540G	10/25/11	10/25/11 16:00	DIW	MANUAL	1	BUJ1825

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Project Manager: Bonnie Luke

Total Concentrations (TTLIC)

BCL Sample ID: 1117519-07		Client Sample Name: Station B7, 10/24/2011 12:33:00PM, Doug Coats							
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Arsenic	3.5	2.8	mg/kg	0.50	0.37	EPA-6020	ND		1
Cadmium	ND	ND	mg/kg	0.50	0.050	EPA-6010B	ND		2
Chromium	52	42	mg/kg	0.50	0.060	EPA-6010B	ND		2
Copper	3.1	2.5	mg/kg	1.0	0.12	EPA-6010B	ND		2
Lead	2.0	1.6	mg/kg	0.25	0.047	EPA-6020	ND		1
Mercury	ND	ND	mg/kg	0.16	0.024	EPA-7471A	ND		3
Nickel	41	33	mg/kg	0.50	0.058	EPA-6010B	ND		2
Silver	ND	ND	mg/kg	0.25	0.027	EPA-6020	ND		1
Zinc	17	13	mg/kg	2.5	0.25	EPA-6010B	0.58		2
Aluminum	5800	4700	mg/kg	5.0	1.3	EPA-6010B	1.6		2
Iron	9600	7700	mg/kg	5.0	3.7	EPA-6010B	ND		2

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-6020	10/28/11	11/16/11 21:23	PPS	PE-EL1	1	BUJ2010
2	EPA-6010B	10/28/11	10/31/11 06:18	ARD	PE-OP1	1	BUJ1999
3	EPA-7471A	10/26/11	10/27/11 12:53	MEV	CETAC1	0.992	BUJ1858

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EPA Method 1664

Quality Control Report - Method Blank Analysis

Constituent	QC Sample ID	MB Result	Units	PQL	MDL	Lab Quals
QC Batch ID: BUJ2062						
Oil and Grease	BUJ2062-BLK1	ND	mg/kg	50	16	

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EPA Method 1664

Quality Control Report - Laboratory Control Sample

								<u>Control Limits</u>		
Constituent	QC Sample ID	Type	Result	Spike Level	Units	Percent Recovery	RPD	Percent Recovery	RPD	Lab Quals
Oil and Grease	QC Batch ID: BUJ2062									
	BUJ2062-BS1	LCS	571.00	780.00	mg/kg	73.2		59 - 117		

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Project Manager: Bonnie Luke

EPA Method 1664

Quality Control Report - Precision & Accuracy

									Control Limits		
Constituent	Type	Source Sample ID	Source Result	Result	Spike Added	Units	RPD	Percent Recovery	RPD	Percent Recovery	Lab Quals
QC Batch ID: BUJ2062		Used client sample: Y - Description: Station B2, 10/24/2011 09:03									
Oil and Grease	DUP	1117519-02	ND	ND		mg/kg			30		
	MS	1115418-85	ND	542.00	780.00	mg/kg		69.5		56 - 111	
	MSD	1115418-85	ND	324.00	780.00	mg/kg	50.3	41.5	30	56 - 111	Q03

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Project Manager: Bonnie Luke

Chemical Analysis

Quality Control Report - Method Blank Analysis

Constituent	QC Sample ID	MB Result	Units	PQL	MDL	Lab Quals
QC Batch ID: BUJ1750						
Moisture	BUJ1750-BLK1	ND	%	0.05	0.05	
QC Batch ID: BUK0265						
Total Kjeldahl Nitrogen	BUK0265-BLK1	ND	mg/kg	40	15	
QC Batch ID: BUK0287						
Biochemical Oxygen Demand	BUK0287-BLK1	ND	mg O/kg	0.98	0.98	

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Chemical Analysis

Quality Control Report - Laboratory Control Sample

Constituent	QC Sample ID	Type	Result	Spike Level	Units	Percent Recovery	RPD	Control Limits		Lab
								Percent Recovery	RPD	
QC Batch ID: BUK0265										
Total Kjeldahl Nitrogen	BUK0265-BS1	LCS	384.70	400.00	mg/kg	96.2		85 - 115		
QC Batch ID: BUK0287										
Biochemical Oxygen Demand	BUK0287-BS1	LCS	192.15	198.00	mg O/kg	97.0		85 - 115		

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Project Manager: Bonnie Luke

Chemical Analysis

Quality Control Report - Precision & Accuracy

									<u>Control Limits</u>		
Constituent	Type	Source Sample ID	Source Result	Result	Spike Added	Units	RPD	Percent Recovery	RPD	Percent Recovery	Lab Quals
QC Batch ID: BUJ1825		Used client sample: Y - Description: Station B1, 10/24/2011 08:05									
Solids	DUP	1117519-01	78.100	78.000		%	0.1		20		
QC Batch ID: BUK0265		Used client sample: N									
Total Kjeldahl Nitrogen	DUP	1117752-01	803.50	799.90		mg/kg	0.4		20		
	MS	1117752-01	803.50	1170.1	400.00	mg/kg		91.6		80 - 120	
	MSD	1117752-01	803.50	1178.2	400.00	mg/kg	0.7	93.7	20	80 - 120	
QC Batch ID: BUK0287		Used client sample: Y - Description: Station B1, 10/24/2011 08:05									
Biochemical Oxygen Demand	DUP	1117519-01	19.825	22.367		mg O/kg	12.0		20		
QC Batch ID: BUK0785		Used client sample: Y - Description: Station B1, 10/24/2011 08:05									
Volatile Solids	DUP	1117519-01	1.3040	1.2890		%	1.2		20		

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Project Manager: Bonnie Luke

Total Concentrations (TTLC)

Quality Control Report - Method Blank Analysis

Constituent	QC Sample ID	MB Result	Units	PQL	MDL	Lab Quals
QC Batch ID: BUJ1858						
Mercury	BUJ1858-BLK1	ND	mg/kg	0.16	0.024	
QC Batch ID: BUJ1999						
Cadmium	BUJ1999-BLK1	ND	mg/kg	0.50	0.050	
Chromium	BUJ1999-BLK1	ND	mg/kg	0.50	0.060	
Copper	BUJ1999-BLK1	ND	mg/kg	1.0	0.12	
Nickel	BUJ1999-BLK1	ND	mg/kg	0.50	0.058	
Zinc	BUJ1999-BLK1	0.58477	mg/kg	2.5	0.25	J
Aluminum	BUJ1999-BLK1	1.6089	mg/kg	5.0	1.3	J
Iron	BUJ1999-BLK1	ND	mg/kg	5.0	3.7	
QC Batch ID: BUJ2010						
Arsenic	BUJ2010-BLK1	ND	mg/kg	0.50	0.37	
Lead	BUJ2010-BLK1	ND	mg/kg	0.25	0.047	
Silver	BUJ2010-BLK1	ND	mg/kg	0.25	0.027	

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Total Concentrations (TTLC)

Quality Control Report - Laboratory Control Sample

Constituent	QC Sample ID	Type	Result	Spike Level	Units	Percent Recovery	RPD	Control Limits		Lab
								Percent Recovery	RPD	Quals
QC Batch ID: BUJ1858										
Mercury	BUJ1858-BS1	LCS	0.75328	0.80000	mg/kg	94.2		80 - 120		
QC Batch ID: BUJ1999										
Cadmium	BUJ1999-BS1	LCS	10.646	10.000	mg/kg	106		75 - 125		
Chromium	BUJ1999-BS1	LCS	107.25	100.00	mg/kg	107		75 - 125		
Copper	BUJ1999-BS1	LCS	103.85	100.00	mg/kg	104		75 - 125		
Nickel	BUJ1999-BS1	LCS	112.09	100.00	mg/kg	112		75 - 125		
Zinc	BUJ1999-BS1	LCS	110.76	100.00	mg/kg	111		75 - 125		
Aluminum	BUJ1999-BS1	LCS	541.32	500.00	mg/kg	108		75 - 125		
Iron	BUJ1999-BS1	LCS	550.41	500.00	mg/kg	110		75 - 125		
QC Batch ID: BUJ2010										
Arsenic	BUJ2010-BS1	LCS	24.601	25.000	mg/kg	98.4		75 - 125		
Lead	BUJ2010-BS1	LCS	25.050	25.000	mg/kg	100		75 - 125		
Silver	BUJ2010-BS1	LCS	9.9940	10.000	mg/kg	99.9		75 - 125		

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Project Manager: Bonnie Luke

Total Concentrations (TTLC)

Quality Control Report - Precision & Accuracy

									Control Limits		
Constituent	Type	Source Sample ID	Source Result	Result	Spike Added	Units	RPD	Percent Recovery	RPD	Percent Recovery	Lab Quals
QC Batch ID: BUJ1858		Used client sample: N									
Mercury	DUP	1117360-01	0.23571	0.29381		mg/kg	21.9		20		A02
	MS	1117360-01	0.23571	1.0160	0.79365	mg/kg		98.3		80 - 120	
	MSD	1117360-01	0.23571	1.0140	0.79365	mg/kg	0.2	98.1	20	80 - 120	
QC Batch ID: BUJ1999		Used client sample: N									
Cadmium	DUP	1117561-01	0.057797	ND		mg/kg			20		
	MS	1117561-01	0.057797	10.636	10.000	mg/kg		106		75 - 125	
	MSD	1117561-01	0.057797	10.487	10.000	mg/kg	1.4	104	20	75 - 125	
Chromium	DUP	1117561-01	7.2225	7.3151		mg/kg	1.3		20		
	MS	1117561-01	7.2225	114.44	100.00	mg/kg		107		75 - 125	
	MSD	1117561-01	7.2225	112.71	100.00	mg/kg	1.5	105	20	75 - 125	
Copper	DUP	1117561-01	9.0172	9.0429		mg/kg	0.3		20		
	MS	1117561-01	9.0172	117.80	100.00	mg/kg		109		75 - 125	
	MSD	1117561-01	9.0172	116.26	100.00	mg/kg	1.3	107	20	75 - 125	
Nickel	DUP	1117561-01	7.6959	7.8162		mg/kg	1.6		20		
	MS	1117561-01	7.6959	116.79	100.00	mg/kg		109		75 - 125	
	MSD	1117561-01	7.6959	114.07	100.00	mg/kg	2.4	106	20	75 - 125	
Zinc	DUP	1117561-01	34.885	35.198		mg/kg	0.9		20		
	MS	1117561-01	34.885	141.72	100.00	mg/kg		107		75 - 125	
	MSD	1117561-01	34.885	137.61	100.00	mg/kg	2.9	103	20	75 - 125	
Aluminum	DUP	1117561-01	6601.4	6606.9		mg/kg	0.1		20		
	MS	1117561-01	6601.4	7424.9	500.00	mg/kg		165		75 - 125	A03
	MSD	1117561-01	6601.4	7105.6	500.00	mg/kg	4.4	101	20	75 - 125	
Iron	DUP	1117561-01	11820	11638		mg/kg	1.6		20		
	MS	1117561-01	11820	12250	500.00	mg/kg		86.0		75 - 125	
	MSD	1117561-01	11820	11832	500.00	mg/kg	3.5	2.5	20	75 - 125	A03
QC Batch ID: BUJ2010		Used client sample: Y - Description: Station B1, 10/24/2011 08:05									
Arsenic	DUP	1117519-01	2.4692	2.4732		mg/kg	0.2		20		
	MS	1117519-01	2.4692	27.921	25.000	mg/kg		102		75 - 125	
	MSD	1117519-01	2.4692	27.703	25.000	mg/kg	0.8	101	20	75 - 125	
Lead	DUP	1117519-01	1.7350	1.6938		mg/kg	2.4		20		
	MS	1117519-01	1.7350	26.723	25.000	mg/kg		100		75 - 125	
	MSD	1117519-01	1.7350	26.552	25.000	mg/kg	0.6	99.3	20	75 - 125	
Silver	DUP	1117519-01	ND	ND		mg/kg			20		
	MS	1117519-01	ND	10.236	10.000	mg/kg		102		75 - 125	
	MSD	1117519-01	ND	9.9462	10.000	mg/kg	2.9	99.5	20	75 - 125	

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Project Manager: Bonnie Luke

Notes And Definitions

J	Estimated Value (CLP Flag)
MDL	Method Detection Limit
ND	Analyte Not Detected at or above the reporting limit
PQL	Practical Quantitation Limit
RPD	Relative Percent Difference
A02	The difference between duplicate readings is less than the PQL.
A03	The sample concentration is more than 4 times the spike level.
Q03	Matrix spike recovery(s) is(are) not within the control limits.
S05	The sample holding time was exceeded.

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APPENDIX F
Laboratory Quality Assurance and Quality Control Plans

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APPENDIX F

Quality Assurance/Quality Control

Government organizations and respected contract research facilities now require specific Quality Assurance Programs and Plans for all scientific research efforts. Marine Research Specialists (MRS), without exception, abides by these requirements and has integrated Quality Assurance procedures in their normal course of scientific investigations. We pride ourselves on excellence and objectivity in research, and we support that pride with Quality Assurance and Quality Control procedures, which are documented by SOP's. These procedures have been developed through the years in support of major environmental programs for clients such as the U.S. Environmental Protection Agency, U.S. Department of Commerce (NOAA), and the U.S. Department of the Interior (Minerals Management Service).

The quality assurance procedures for work undertaken in this program meet all MRS requirements for assuring the reliability of monitoring and measurement data. This level of QA/QC is also applicable to all subcontractors working on this monitoring program under the direction of MRS. The procedures form an integrated program for assuring complete, accurate, precise, and representative data under defined requirements. Our general quality assurance requirements are discussed below.

Program Management. The basis of any sound QA/QC program resides with the Program Manager, Ms. Bonnie Luke. She ensures that monitoring program activities, client-approved changes in scope, and progress are well documented throughout the duration of the monitoring program. She also ensures that specific QA/QC documentation such as field observation logs, sampling logs (separate logs are maintained for water, sediment and infauna samples), and sample transfer forms are properly and accurately recorded and maintained. It is important to note that each and all samples maintain unique sample codes throughout the sample collection, analyses, and reporting phases of the monitoring program.

Ms. Luke, also conducts QA/QC reviews of our subcontractors, BC Laboratories and Aquatic Testing Laboratories, to ensure that their QA/QC procedures, described on the following pages are adhered to. They are promptly notified of any deviation and the need for corrective action.

Field Sampling. All field sampling equipment is calibrated according to manufacturer's specifications. Logs are maintained for the Sea-Bird SBE-19 Seacat CTD Profiler with the number of casts and cast locations recorded. Calibration results are also recorded into the log. Periodically, the CTD is returned to the manufacturer for a complete bench testing and calibration. The CTD was factory calibrated and fully tested at the Sea Bird Testing Facility in November 1999 and again in October 2001.

The Van Veen sediment grab sampler and subsamplers are cleaned with noncontaminating solvents between all collections of sediment chemistry samples. The solvents include methanol for the removal of organics and de-ionized water and HCl for the removal of metals. The grab sampler and sediment subsamplers such as scoops, are coated with noncontaminating Dykor® to limit contamination of chemistry samples from the sampling equipment. Similarly, all sediment sample containers are pre-cleaned and acid washed according to USEPA specifications. The grab sampler was recoated with Dykor® in September 1999.

Laboratory Analysis. QA/QC procedures are also used in the laboratory for grain-size analysis and sorting benthic infauna samples. A minimum of 10 percent of all samples sorted by any one technician are resorted by another technician. The level of sorting error must not exceed five percent (i.e. the sample residue that is resorted by another technician must not contain more than five percent of the total number of organisms contained in the original sample). Additionally, all samples sorted by a technician who is in the process of being trained are subject to quality control inspection. A technician is considered a trained

sorter if they pass quality control inspection in five consecutive samples. Ms. Bonnie Luke is currently the lead technician for MRS for both grain-size analysis and benthic sample sorting.

Independent QA/QC Audit. In addition to the QA/QC auditing performed by the Program Manager, an independent semi-random audit on project performance is conducted by Dr. Douglas A. Coats. Dr. Coats reviews all reports for completeness, thoroughness, accurateness, and errors. He also performs periodic unannounced audits on monitoring program status and additionally, calls or meets independently with the Public Works Department's project officer for an evaluation of our performance.

Subcontracted Laboratories. The following Quality Assurance guidelines and methods for subcontractor laboratories are excerpts from the full Quality Assurance Manuals of BC Laboratories and Aquatic Testing Laboratories. The full QA documents are too voluminous to provide in complete form in this annual report but are on file at MRS. BC Laboratories of Bakersfield California, performed the chemical analyses for treatment plant effluent and sludge and the offshore sediments. Aquatic Testing Laboratories of Ventura analyzed the effluent for acute and chronic toxicity levels.