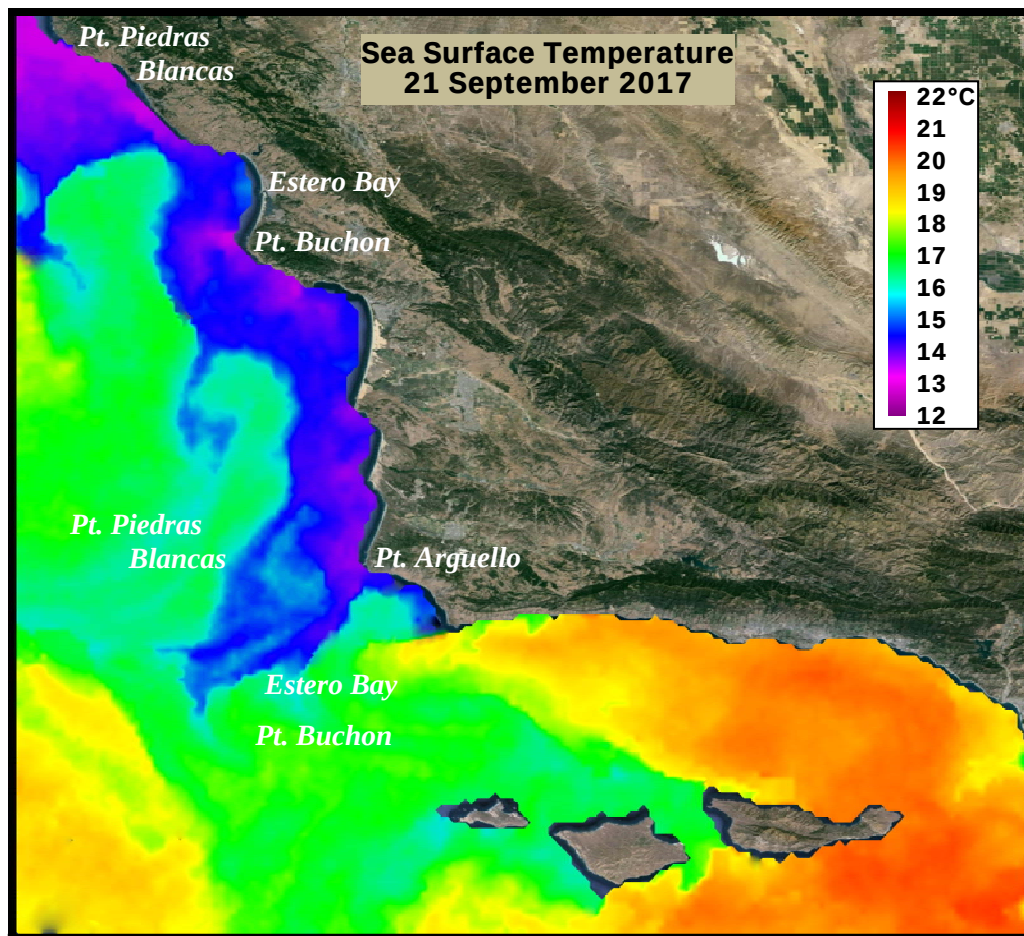


**City of Morro Bay and
Cayucos Sanitary District**

OFFSHORE MONITORING AND REPORTING PROGRAM

2017 ANNUAL REPORT



Marine Research Specialists

4744 Telephone Rd Ste 3 PMB 315
Ventura, California 93003

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

**955 Shasta Avenue
Morro Bay, California 93442
(805) 772-6272**

**OFFSHORE MONITORING
AND REPORTING PROGRAM**

2017 ANNUAL REPORT

**Prepared by
Douglas A. Coats**

**Submitted by
Marine Research Specialists**

**4744 Telephone Rd., Suite 3 PMB 315
Ventura, California 93003**

**Telephone: (805) 644-1180
E-mail: Marine@Rain.org**

March 2018

marine research specialists

4744 Telephone Rd., Suite 3 PMB 315 • Ventura, CA 93003 • 805-644-1180

John Gunderlock
Wastewater & Collection Systems Supervisor
City of Morro Bay/Cayucos Sanitary District
955 Shasta Avenue
Morro Bay, CA 93442

30 March 2018

Reference: 2017 Annual Monitoring Report

Dear Mr. Gunderlock:

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.

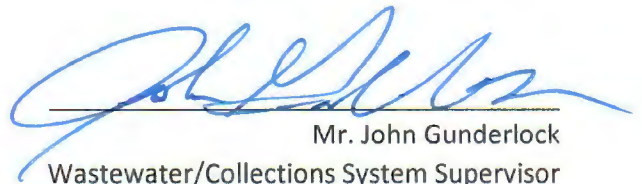
Sincerely,

 **MARINE RESEARCH SPECIALISTS**
Vice President

2018.03.30 12:20:39 -07'00'

Douglas A Coats
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. John Gunderlock

Wastewater/Collections System Supervisor
City of Morro Bay/Cayucos CSD Wastewater Treatment Plant

Date: 3/30/18

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LIST OF ACRONYMS AND DEFINITIONS

ACOE	U.S. Army Corps of Engineers
AHA	Activity Hazard Analyses investigate potential facility hazards
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
APCD	San Luis Obispo County Air Pollution Control District
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 lightweight flocs of detritus. Oscillatory bottom currents generated by passing surface gravity waves easily suspend these flocs.
BMPs	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

LIST OF ACRONYMS AND DEFINITIONS

(Continued)

CIWQS	<u>California Integrated Water Quality System Project</u>
CDP	Coastal Development Permit
CMAR	Construction Manager at Risk: A project delivery method wherein the Construction Manager (CM) is required to deliver a project within a guaranteed maximum price
Coordinate Datum	All coordinates cited in this report are referenced to the WGS84 datum
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.
CSWP	Cayucos Sustainable Water Project
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.
CWSRF	Clean Water State Revolving Fund (CWSRF) that includes a Water Recycling Funding Program administered by the SWRCB Division of Financial Assistance
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
ENSO	El Niño–Southern Oscillation
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.

LIST OF ACRONYMS AND DEFINITIONS

(Continued)

ESA	Endangered Species Act
FOG	Fats, Oils, and Greases
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
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

LIST OF ACRONYMS AND DEFINITIONS

(Continued)

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
MMRP	Major Maintenance and Repair Plan
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
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
OSHA	Occupational Safety and Health Administration
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.

LIST OF ACRONYMS AND DEFINITIONS

(Continued)

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 = μ g/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
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
RFQ	Request for Qualifications
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.
SCBFMC	Southern California Bight Field Methods Committee
SCBPPFCT	Southern California Bight Pilot Project Field Coordination Team
SCCWRP	Southern California Coastal Water Research Project

LIST OF ACRONYMS AND DEFINITIONS

(Continued)

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.
SLO EHS	<u>San Luis Obispo County Environmental Health Services</u>
SOP	Standard Operating Procedure
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.
STORET	STORage and RETrieval electronic data system for water quality monitoring data developed and administered by the USEPA
SWRCB	State Water Resources Control Board of the California Environmental Protection Agency
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 downstream of the chlorine contact chamber.
TSS	Total Suspended Solids
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 Toxic Unit
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

LIST OF ACRONYMS AND DEFINITIONS

(Continued)

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 STLC.
WQX	Water Quality Exchange framework providing the main mechanism for submitting data to the USEPA STORET Data Warehouse
WRRF	Water Resource Recovery Facility
WRF	City of Morro Bay Water Reclamation Facility
WRFCAC	City of Morro Bay Water Reclamation Facility Citizen Advisory Committee
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 2017 Annual Report partially satisfies those reporting requirements.

This document presents a comprehensive analysis of the extensive monitoring data collected over the last three decades. 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 shortly after discharge 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 alone. All other NPDES limits, including restrictions on the discharge of toxic substances, apply to the MBCSD discharge without exception. Regardless, the partial-secondary level of treatment currently performed by the plant routinely achieves reductions in suspended solids and BOD that are close to, and often exceed, secondary treatment requirements.

Effluent monitoring throughout 2017 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 entire operational history of the plant. 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 digital database, maintained 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 potential introduction of pollutants into the waste stream.

Throughout more than three decades of operation, the treatment plant has consistently outperformed expectations for wastewater treatment based on regulatory standards. During that 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 2017, there was only one exception to the waste-discharge requirements specified in the NPDES permit. This near-perfect 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 close to the diffuser structure within the ZID. These highly localized anomalies were still within the limits specified in the NPDES permit, even though they were collected close to the discharge where such limits do not apply.

The physics, chemistry, and biology of benthic sediments around the outfall have been monitored for 32 years. As has been the case throughout this 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 2017 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 2017, 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 2017 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 is observed. More than 266,000 infaunal organisms have been collected and examined since the beginning of the benthic monitoring program 32 years ago. Throughout the monitoring program, there has never been an indication of discharge-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.

In the 29 years prior to 2015, analyses demonstrated that the sediments surrounding the outfall supported an extraordinarily healthy marine community dominated by suspension-feeding organisms living in pristine sediments. These observations held true despite widespread and significant temporal variation in the abundance of individual organisms. However, a major change in the benthic environment occurred in 2015, when numerous large sand dollars dominated the benthic environment throughout the survey area. They displaced most of the resident suspension-feeding infauna and introduced opportunistic detritus feeders that also happen to have an affinity to sand-dollar beds. Most measures of the health of the infaunal community declined as a result, including density, diversity, species counts, and richness. The concomitant decline in feeding indices were reminiscent of organic enrichment that had been observed within seafloor sediments immediately surrounding large ocean discharges in other regions prior to improvements in wastewater treatment during the 1980s.

However, the declines in the measures of infaunal wellbeing that were observed during surveys since 2014 were unrelated to benthic degradation caused by the discharge of organic constituents from the MBCSD outfall. First, organic loading within wastewater discharged from the MBCSD outfall during this period was among the lowest on record. Second, the declines occurred uniformly throughout the offshore survey area with no evidence of a spatial gradient related to ZID proximity. Third, the concentrations of organic constituents measured within sediment samples collected at the infaunal sampling sites were comparable to those of prior years. Instead, the observed decline was directly associated with the establishment of a mature sand dollar bed. The resulting disturbance of surficial sediments displaced nearly all of the suspension-feeding organisms that had characterized the survey area for the prior 29 years. The small amount of sediment not occupied by the numerous large sand dollars was quickly populated by a few opportunistic organisms directly associated with sand dollars, principally, a sand-dollar parasitic snail and a detritus-feeding lugworm with a strong documented affinity for sand-dollar beds. These organisms marked a profound change in the overall health and diversity of the infaunal community within northern Estero bay; one that was unparalleled in the prior three-decade-long benthic monitoring record.

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 2009 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 various subcontracted laboratories, have collected and analyzed samples as part of the monitoring program.

1.1 REPORT ORGANIZATION

This 2017 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	Marine Sediments and Benthic 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 2017. Chapter 3 documents the four offshore surveys that were conducted during 2017 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 2017. It places the chemical and biological measurements in historical context by incorporating time-series analyses of the entire 32-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 benthic sample descriptions, including the location, depth, and grain-size characteristics of sediment samples. Appendix D contains a report of the annual outfall inspection that was conducted by diver. The original benthic chemistry report and quality assessment and quality control (QA/QC) analyses performed are provided in Appendix E.

2.0 TREATMENT PLANT PERFORMANCE

During 2017, the treatment plant removed nearly all organic materials 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), documented 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 (O&M) program minimized the number of avoidable exceptions to the limits specified in the NPDES discharge permit during 2017. The sections below use these analyses to evaluate regulatory compliance through a comparison between the measured wastewater characteristics and 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 2017 augment 31 years of prior monitoring information that chronicle a treatment process that consistently achieves a high level of performance. Despite processing an unusually large fraction of sewage within the wastestream during 2017, the plant discharged only 26% of the allowed solids, while still attaining an annual removal rate 13% higher than the permitted minimum. The treatment plant removed solids at a rate exceeding the 85% standard for full secondary treatment in all months except January and June. Additionally, the average effluent suspended-solids concentrations during two months of the year remained at or below the 30-mg/L criterion for full secondary treatment. The annual average effluent suspended-solids concentration (38 mg/L) was only about half of the permitted maximum (70 mg/L), and the total solids emission (52 MT¹) was only about one-quarter of the allowed solids discharge (199 MT).

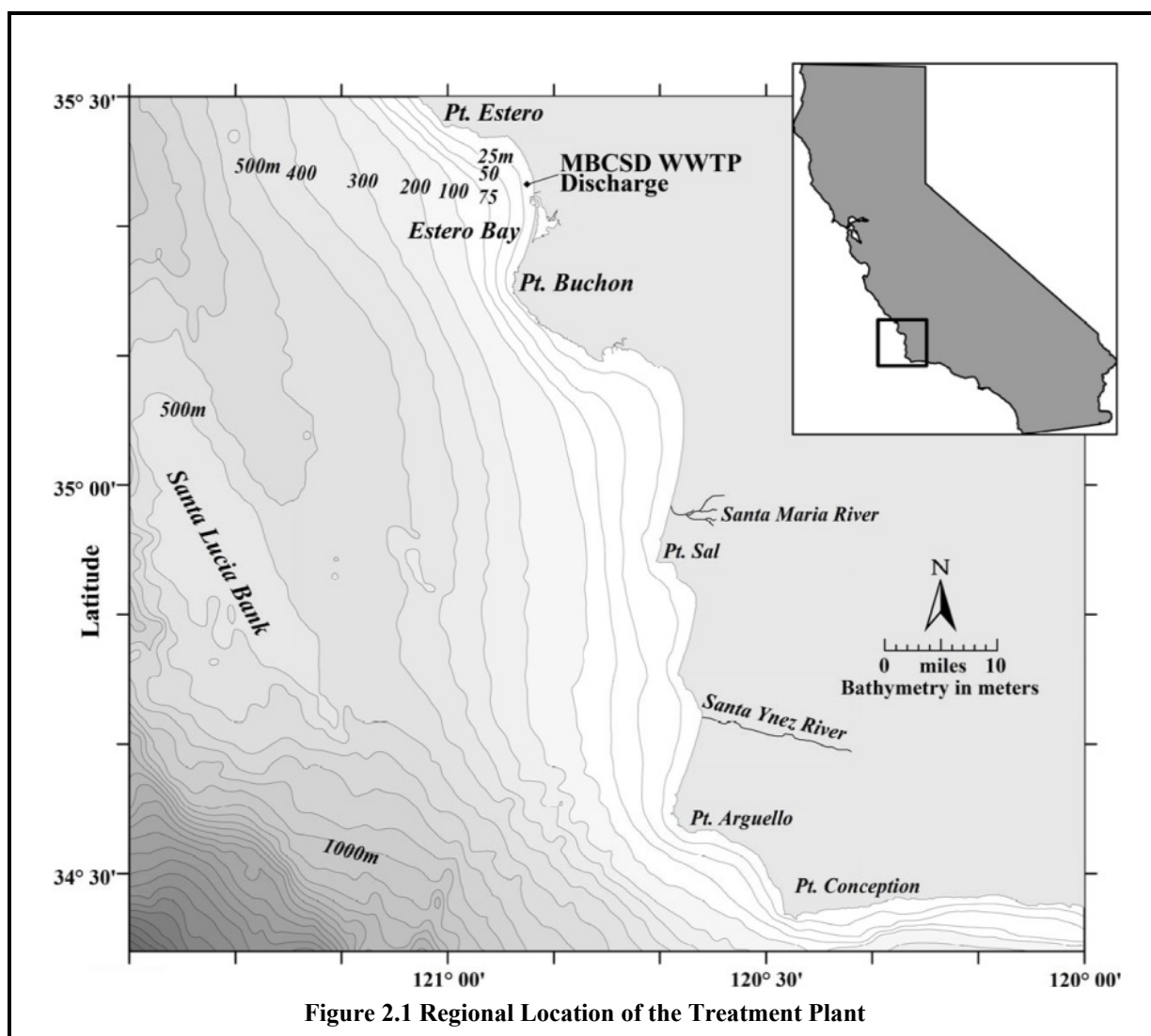
During 2017, the treatment plant also removed the vast majority (84%) of oxygen-demanding material from the influent stream. Technology-based requirements for BOD are generally unimportant for open-ocean discharges because they are unlikely to result in oxygen depletion (Page 6 in National Academy of Sciences 1993). Nevertheless, the average BOD removal rate met or exceeded the 85% monthly standard for full secondary treatment during five months of the year, while the lowest monthly removal rate of 75% was 2½ times greater than the minimum permitted rate of 30%. Additionally, the annual average effluent BOD concentration (52 mg/L) was less than half of the permitted maximum (120 mg/L), and the total mass emission (70 MT) was about one-fifth 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 of only two common wastewater constituents and three naturally occurring trace metals. All measured concentrations were well below permit limitations. Chronic bioassays conducted on effluent samples that were collected twice during 2017 determined that the discharge had very low toxicity to marine organisms, a result consistent with the prior 24-year record of toxicity 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, 1.02 million gallons per day (MGD) during 2017. The plant was designed to accommodate an average dry-weather flow of 2.06 MGD, a peak seasonal dry-weather flow (PSDF) of 2.36 MGD, and a peak wet-weather flow (PWWF) of 6.64 MGD. The plant's flow did not even approach, much less surpass, any of these design limits during 2017.



2.1.1 Operations

Throughout most of 2017, thirteen trained personnel operated the WWTP (Table 2.1). On 3 January, staff within the City of Morro Bay Wastewater Collection Division merged with the WWTP operators. John Gunderlock then served as both the WWTP and Collections System Supervisor. Joe Mueller was hired on 9 January to provide additional WWTP oversight as the City's Utilities Division Manager. 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 workshops, seminars, and continuing education classes throughout 2017. Training courses and seminars covered topics such as Environmental Safety Training, Confined Space Entry, Trench Shoring Safety, Lockout/Tagout Electrical Hazard Control, and OSHA¹ Construction Safety Training. Laboratory personnel training included refresher coursework in Basic Water Analysis, Laboratory Exam Review, and Distribution System Field Monitoring and Chlorine Testing for Small Systems. Other education-related efforts included a microorganism class and tour of the Paso Robles Wastewater Treatment Plant Laboratory. The City's Utilities Division Manager attended The Water Environment Federation annual seminar in Chicago.

Throughout 2017, WWTP staff conducted plant tours for the public, students from local schools, members of various local agencies, staff from other treatment plants, and candidates for employment at the WWTP. During several plant tours, concerned citizens and members of the Morro Bay Chamber of Commerce learned about treatment-plant processes and the City's plans for the new Water Reclamation Facility.

During a visit by staff from the California Rural Water Association, discussions focused on best management practices (BMPs) and testing procedures used by the WWTP laboratory. A local college student toured the facility and as part of an environmental studies course report, compared actual WWTP specifications with calculated treatment-performance metrics. As part of the Plant's annual permit requirements, APCD² staff conducted a regulatory-based tour and inspection.

Plant operations during 2017 included ongoing maintenance of an overall health and safety plan. The WWTP passed an annual inspection by SLO EHS³ in conjunction with the WWTP Hazardous Waste Business Plan on file with that county agency. The WWTP's chemical response plan was reviewed with SLO EHS representative during a tour of the WWTP.

**Table 2.1 Morro Bay/Cayucos WWTP
Personnel During 2017**

Name	Term	Grade and Certification No.
John Gunderlock	1/1–12/31	V – 10500
Joe Mueller	1/9–12/31	V – 8495
Richard Fernandez	1/1–12/31	III – 41341
Steven Aschenbrener	1/1–12/31	II – 7548
Dane Lundy	1/1–12/31	II – 36547
Matt Mathews	1/3–12/31	II – 42473
Landon Mortimer	1/9–12/31	II – 42800
Adam Hegg	1/9–7/5	I – OIT
Kyle Quaglino	1/3–12/31	I – OIT
Robert Victor	1/3–12/31	I – OIT
Chad Rocha	1/3–12/31	I – OIT
Dave Zevely	1/3–12/31	I – OIT
Alex Tapia	1/3–12/31	I – OIT

¹ Occupational Safety and Health Administration

² San Luis Obispo County Air Pollution Control District

³ San Luis Obispo County Environmental Health Services

In addition to performing the periodic effluent analyses required by the NPDES Permit during 2017, the laboratories involved in the analyses of the MBCSD WWTP samples participated in laboratory performance evaluations intended to assess the accuracy of effluent measurements and ensure the overall quality of the monitoring reports. In particular, the adequacy of each laboratory's analytical chemistry capabilities was demonstrated during 2017 when acceptable results were achieved in a Water Pollution Proficiency Testing Study, which is an annual requirement of laboratories certified by the State of California Environmental Lab Accreditation Program (ELAP) and is sponsored by the State Water Resources Control Board and the USEPA. Successful completion of the federally mandated Discharge Monitoring Report Quality Assurance Study 37 (DMR-QA 37) satisfied this state regulatory requirement.

The MBCSD WWTP laboratory analyzed wastewater parameters reported on a daily basis, including residual chlorine, turbidity, and pH. Abalone Coast Analytical performed suspended solids, BOD, and total coliform analyses on samples collected at least weekly. Aquatic Testing Laboratories evaluated the toxicity of effluent to marine organisms with semiannual bioassays. BC Laboratories, Weck Laboratories, Vista Analytical Services, and Monterey Bay Analytical Services 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.

To assist WWTP staff in the operations and maintenance (O&M) of major plant components, an O&M Manual (dated November 1987) was completed following the plant upgrade in 1986. The WWTP's O&M Manual has since been reviewed and updated on a regular basis. It is currently complete and valid for the operation and maintenance of the existing facility. The Manual was last reviewed and updated on 29 December 2017. For example, an SOP describing procedures for producing SOPs, along with a template, was created in 2017 to assist operators in writing appropriately detailed and comprehensive SOPs. Additionally, twenty Activity Hazard Analyses (AHAs) and Standard Operating Procedures (SOPs) were completed in 2017 by operations staff. AHAs investigated potential facility hazards and informed the development of associated SOPs.

Updates also included revisions or additions to SOPs as new major equipment was placed online or when procedures for existing equipment were changed or improved. For example, the SOPs include procedures to archive project records for tasks completed on individual plant components to expedite future review of prior actions taken. Additionally, contingency plans are embedded within the O&M Manual that address response to chemical spills, high flow and flood response, fire prevention and suppression, emergency evacuation, and comprehensive hazard communication procedures. Safety updates address procedures for heat illness identification and prevention, detailed lockout-tagout, confined space entry, and emergency notifications.

As part of routine maintenance procedures, divers inspect the ocean outfall's exterior and the diffuser structure for signs of damage annually. The outfall was inspected on 7 December, and the written inspection report is included herein as Appendix D. The outfall and diffuser system was found to be in good condition, with no broken or plugged diffuser ports. The divers provided photodocumentation of the outfall's condition in the form of digital video recorded throughout their inspection.

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 a 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 1999). Ostensibly, their susceptibility to elevated suspended-sediment loads explains their rarity on nearshore, lower-relief rocky substrates.

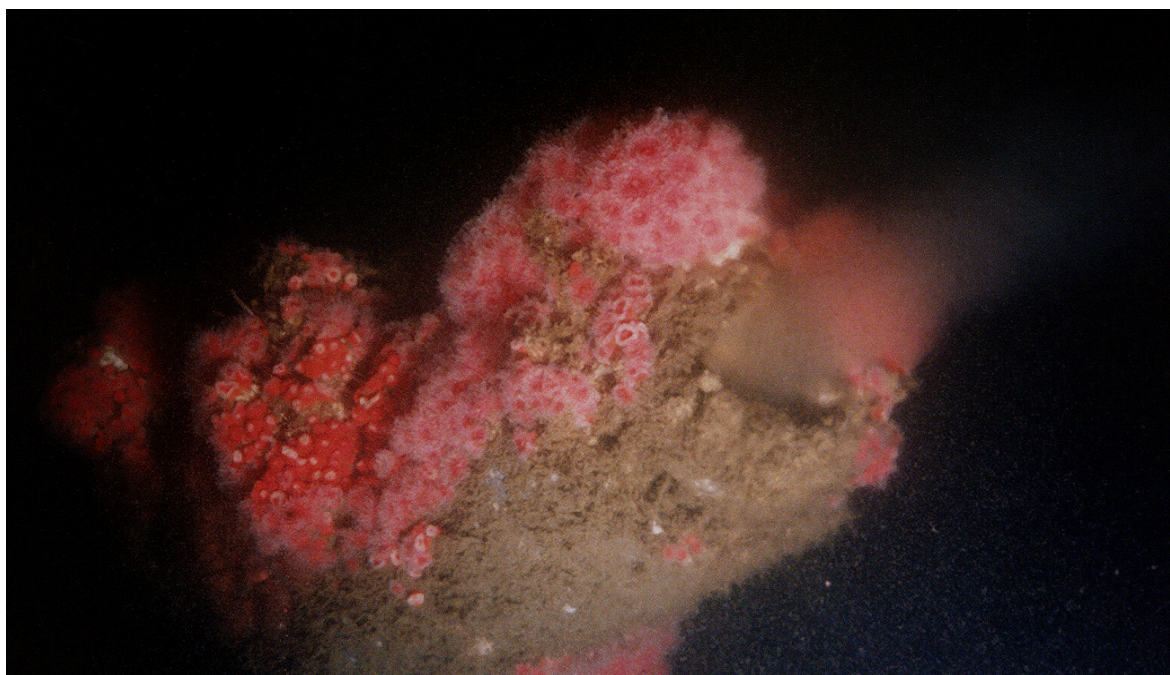


Figure 2.2 Photograph of a Diffuser Port Discharging Effluent

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 process secondary sludge. The existing office building 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 augment the plant's capacity further. In 1980, the City began designing these planned improvements, including the construction of a new outfall to protect the marine environment, and an upgrade of processing equipment 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 much farther offshore. This deeper discharge significantly increased the effluent mixing rate 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, monetary aid from state or federal agencies to finance the construction of a full-secondary-treatment facility 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 ensure full compliance with the state water-quality standards set forth in the California Ocean Plan (COP) (SWRCB¹ 1990).

State officials concurred with this partial-secondary level of treatment, provided that the USEPA approve a 301(h)-modified NPDES discharge permit that adjusted secondary-treatment requirements on suspended-solids and BOD emissions. In a March 1983 letter, RWQCB staff formally determined that the proposed discharge would comply with state water-quality standards pursuant to Subsection 301(h) of Title 40 of the Code of Federal Regulations.²

Upgrades to the treatment plant, 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 consisting 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.

In 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 in 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 within 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 10 years of monitoring data (MRS 1997a). An administrative extension until 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.

¹ State Water Resources Control Board of the California Environmental Protection Agency

² 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)

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 program, increasing the number of stations close to the diffuser structure and eliminating seasonal sampling;
- A revised receiving-water sampling program, doubling the number of vertical profiles close to the diffuser structure and eliminating bottle casts; and
- Specification of mass emission goals for toxic chemicals.

Based on the historical absence of perceptible impacts from the discharge, and the projected continuation of consistently high effluent quality, the MBCSD again applied for a renewal of the discharge permit in July 2003 (MBCSD 2003). As with the previous permits, the application requested continued discharge under the 301(h) provision that allows minor modifications to the BOD and suspended-solids requirements. In February 2004, the RWQCB (2004) administratively extended the existing permit to allow time for further review. In 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. In 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, in May 2006, the RWQCB and the USEPA conducted a joint public hearing addressing the reissuance of 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. In December 2007, the USFWS concurred with the USEPA's "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 be required to monitor nutrient loading from the WWTP on a regular basis. Third, the facility would upgrade to a minimum of full secondary-treatment levels by 2014.

Based on the foregoing findings and the incorporation of conservation measures, the RWQCB unanimously adopted the new discharge permit in 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%.

During 2009, based on the findings of 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 for the project, reflecting changes to the project description involving construction of treatment-plant components adjacent to the current ones. Demolition of the existing plant was to occur after the relocated treatment-plant components were constructed and brought online. The engineering design contract was awarded at the February 2010 Joint Powers (JPA) meeting with a projected completion in 15 months.

The final Environmental Impact Report for the upgrade project was released in December 2010. The Morro Bay City Council certified the EIR¹ and approved the Conditional Use Permit and Coastal Development Permit (CDP) for the upgrade project in January 2011; however, the decision to issue the CDP was subsequently appealed to the California Coastal Commission. A *de novo* hearing was held in January 2013 at which the proposed upgrade project at its current location was terminated.

Subsequently, at the February 2013 JPA meeting, the MBCSD approved development of an MMRP. The Plan was instituted to ensure uninterrupted operation of the existing WWTP in compliance with regulatory requirements during the extended operational period required for the development and construction of a new treatment facility at a different site. In August 2013, the MBCSD submitted an application to the RWQCB for a new discharge permit to replace the current 301(h) modified permit due to expire on 28 February 2014. Based on direction from the MBCSD and RWQCB staff, an application was submitted for a full secondary discharge permit.

During 2013 and 2014, the MBCSD explored various sites and treatment alternatives for a new facility to process wastewater currently treated by the existing WWTP. In early 2015, the City of Morro Bay identified a Water Reclamation Facility (WRF) as the preferred design, and initially selected a location east of the City and north of Highway 41. On April 30, the Cayucos Sanitary District suspended

¹ Environmental Impact Report

participation with the City in their WRF and began planning a separate Water Resource Recovery Facility (WRRF). The District began independently evaluating wastewater treatment alternatives, characterizing flow rates and mass loadings specific to the District's collection system, identifying beneficial uses for recycled water, evaluating potential facility locations, and developing a funding and financing strategy.

The WRRF is now encompassed in the Cayucos Sustainable Water Project (CSWP) that also incorporates the necessary conveyance infrastructure. During 2016, the Cayucos Sanitary District selected a membrane bioreactor as the WRRF treatment process, identified a CMAR¹ as the construction delivery method for the CSWP, selected the CMAR contractor, began preparing a dEIR,² and purchased a property for the WRRF site along Toro Creek Road. During early 2017, the District published the dEIR and subsequently completed a final EIR, consisting of response to comments on the dEIR. The CSWP is scheduled for completion in 2018.

At the same time, the City of Morro Bay staff and their consultants made significant progress on developing the new WRF to replace the existing WWTP. A Memorandum of Understanding was executed for the future purchase of a property near the South Bay Boulevard exit from Highway 1, after site-selection studies were performed to identify a preferred location for the new WRF. A draft Facility Master Plan, Master Water Reclamation Plan, and Draft Rate Study were also completed. Based on recommendations in the Master Water Reclamation Plan, full advanced treatment, a recycled water pipeline, and injection wells to facilitate indirect potable reuse are anticipated as part of the project. The City of Morro Bay received approval for a \$10.3M loan from the SWRCB CWSRF³ for the design and planning of a recycled water project. During October and November 2017, an RFQ was issued for the design and construction of WRF onsite improvements, and the design of WRF offsite improvements, including a lift station and pipelines. The WRF is scheduled for completion by December 2022.

On 7 December 2017, the RWQCB adopted a new permit for the MBCSD discharge with an effective date of 1 March 2018 (RWQCB 2018). In contrast to the current and prior permits, the new permit is not Section 301(h) modified, but will consider interim TSS and BOD effluent limits identical to those of a 301(h)-modified permit to allow the MBCSD time to bring the CSWP and WRF online. The RWQCB staff anticipates no more than five years will be required before these facilities can be commissioned, and will not make additional time extensions available to meet the final effluent discharge limitations contained within new permit.

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 Plan's standards incorporate the

¹ A Construction Manager at Risk (CMAR) is a project delivery method wherein the Construction Manager (CM) is required to deliver a project within a guaranteed maximum price.

² Draft Environmental Impact Report. The CSWP dEIR was completed in January 2017 and is available at: <http://www.cayucossd.org/cswp-draft-eir>. The final EIR is also available on the website link, and was certified in April 2017.

³ The Clean Water State Revolving Fund (CWSRF) includes a Water Recycling Funding Program administered by the SWRCB Division of Financial Assistance.

applicable portions of the COP, and promulgate water-quality objectives and toxic material limitations that are designed to protect the beneficial uses of receiving waters within individual basins. The Basin Plan identified the following the beneficial uses specific to the marine waters of Estero Bay, including those adjacent to the MBCSD outfall site.

- **Water Contact Recreation (REC-1)** water uses include recreational activities involving body contact with water, where ingestion of water is reasonably possible. Specific uses include, but are not limited to, swimming, wading, water skiing, skin and scuba diving, surfing, and fishing.
- **Noncontact Water Recreation (REC-2)** water uses include recreational activities involving proximity to water but not normally involving body contact with water, where ingestion of water is reasonably possible. Specific uses include, but are not limited to, picnicking, sunbathing, hiking, beachcombing, camping, boating, tide pool and marine life studies, hunting, sightseeing, and aesthetic enjoyment in conjunction with the above activities.
- **Industrial Service Supply (IND)** water uses include industrial activities that do not depend primarily on water quality, such as, mining, cooling water supply, hydraulic conveyance, gravel washing, fire protection, and oil well repressurization.
- **Navigation (NAV)** water uses include those 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 that has sufficient capacity to float watercraft for the purposes of commerce, trade, transportation, and pleasure.
- **Marine Habitat (MAR)** water uses 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)** water uses support habitats suitable for the collection of filter-feeding shellfish such as clams, oysters, and mussels, for human consumption, commercial, or sport purposes. Specific uses include waters that have in the past, or may in the future, contain significant shellfisheries.
- **Ocean Commercial and Sport Fishing (COMM)** water uses encompass 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)** water uses 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)** water uses 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 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.

These limits were based on the treatment capabilities of the best available technology at the time, rather than an evaluation of the treatment necessary to reduce potential environmental impacts to an acceptable level within receiving waters. Recognizing that this level of treatment may not be necessary within ocean waters, Section 301(h) was added to the Act to allow an NPDES discharge 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 requirements:

- 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, thereby establishing the relevant standards (SWRCB 2005). In January 2009, the California Coastal Commission determined that the 301(h)-modified discharge permit issued to the MBCSD 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 would 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 highly localized footprint of the MBCSD discharge does not overlap that of 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. In addition, because the discharge is considered small, it is 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, 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 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 on a large portion of the flow.

During 2015, the California Department of Public Health developed a Management Plan for Commercial Shell Fishing within Morro Bay. The Plan provides reporting guidelines in the event of a sewage spill to the Bay or adjacent ocean. WWTP staff provided comments on the Plan, and signed a Statement of Agreement concerning its implementation.

2.1.4 Description of the Treatment and Outfall System

The WWTP operating characteristics are listed in Table A.1 of 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 biosolids process is shown in Figure 2.14 on Page 2-36.

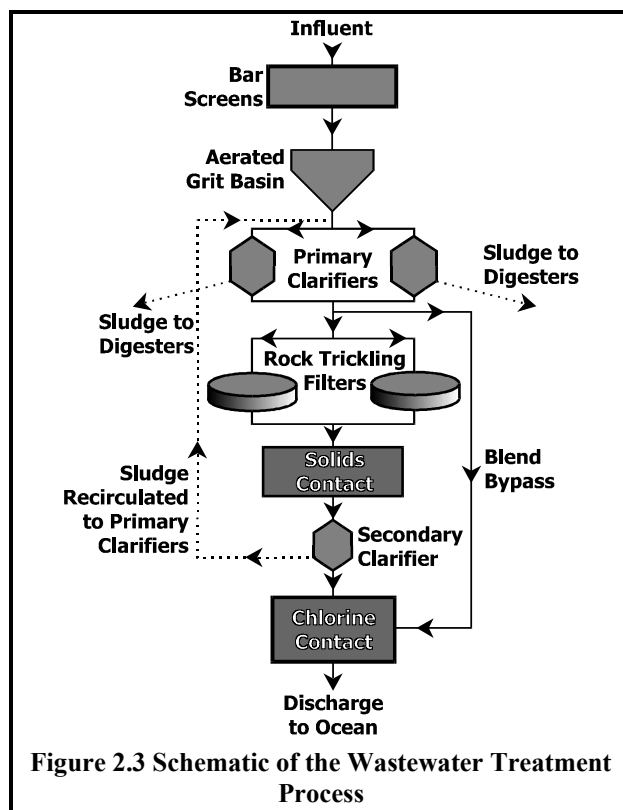


Figure 2.3 Schematic of the Wastewater Treatment Process

The location of the Morro Bay-Cayucos WWTP and outfall within Estero Bay is shown in Figure 2.4. The treated wastewater is released into unstressed, open-ocean waters at 35°23'11"N latitude and 120°52'29"W longitude. The 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 the maintenance of water quality and beneficial uses designated for Estero Bay (listed in Section 2.1.3 on Page 2-9). 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 2017: public outreach, industrial-waste source control and identification, and monitoring of influent and effluent for industrial contaminants.

Industrial Waste Survey

During 2017, as in previous years, elevated levels of industrial pollutants were not found within the MBCSD wastewater stream. Instead, three decades of comprehensive monitoring demonstrates that effluent discharged from the MBCSD treatment plant consists of benign constituents typical of wastewater generated from domestic sources. In fact, based on analyses of past water usage, domestic sources contributed approximately 80% of the wastewater processed by the plant, with commercial businesses and government agencies contributing the remaining amount.

However, this usage-based approach overestimates the influence of nondomestic sources on the treatment process. For example, a substantial portion of the water-use attributed to the government agencies is utilized for the irrigation of landscaping, sports fields, and agricultural uses and thus, would not be expected to flow into the collection system. These agencies include the City of Morro Bay, Morro Bay High School, the San Luis Coastal School District, Morro Elementary School, and the State Department of Parks (Morro Bay State Park). Additionally, the compounds added to the wastestream by both large commercial and government users are not particularly toxic to humans or aquatic organisms and do not generally interfere with the treatment process.

This general lack of chemical contaminants within the wastestream arises because the local economy within the MBCSD service area relies largely on tourism and commercial fishing, with no heavy industry or manufacturing of any environmental significance. Nevertheless, beginning in 1999, a digital database has been used to catalogue business names, addresses, and contact information for all of the potential industrial users within the service area. This database has been used to quantify the comparatively low volume of influent derived from light industrial sources within the service area. For example, slightly more than 50 restaurants and an approximately equal number of hotels are found in the service area during any given year.

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 Cayucos Sanitary District. Businesses with no potential for industrial discharges, such as offices and retail stores, are classified separately from those with the potential for light-industrial discharge. Businesses that either do not generate wastewater at all, or discharge only domestic wastewater (e.g., theaters, beauty shops, and barbershops), are excluded from the industrial-discharge classification.

The City of Morro Bay's Source Control Program divides facility inspections into two classes: Class I light-industrial facilities and Class II food-service establishments, which constitute the majority of commercial businesses discharging to the collection system. During 2017, six Class I and sixty-one Class II facilities were inspected. Class I inspections emphasized compliance with the discharge requirements set out in the City's Municipal Code, such as pre-treatment to maintain an acceptable pH range. Class II inspections emphasized BMPs for the disposal of fats, oils, and greases (FOG). During the Class II inspections, a FOG BMP handout was distributed along with "No Grease" stickers to be displayed above kitchen sinks to raise awareness and serve as a reminder of proper FOG disposal methods. The inspections themselves focused on determining the presence of grease traps or interceptors, and if present, whether they were properly cleaned and maintained. For establishments with fryers, the method and frequency of oil disposal was documented.

Class 1 facilities consist of light industrial businesses such as commercial laundries, car washes, dry cleaners, print shops, and the oil-water separator maintained by the City of Morro Bay. Collections personnel perform scheduled visits, surprise onsite inspections, and formal tours of these facilities. Car-

wash discharges are considered industrial in nature because of the volume of solids, oils, and grease that are washed from vehicles. As with restaurants, the sewer-use ordinance within the City of Morro Bay municipal code requires self-service car washes to install and maintain grease traps within their sewer line connections. The municipal code also prohibits smaller contributors, like gas stations and repair garages, from disposing known contaminants into the collection system.

As part of the City's pretreatment program, samples from a commercial laundry's discharge are occasionally collected and analyzed. One routine inspection during 2017 found that the discharge pH had extended beyond the 5.5-to-9.0 range allowed in the municipal code. Shortly thereafter, City staff discussed strategies with the launderer's staff to improve pH stability within the launderer's discharge and to achieve compliance municipal discharge requirements. The laundry staff agreed to install a new pH probe and to calibrate it following the manufacturer's recommendations. As a further recommendation to ensure compliance, the City Staff recommended that the laundry service develop written SOPs for the chemical dosing equipment and associated processes. The laundry service subsequently commissioned the new pH probe and upgraded the mixing and chemical dosing equipment as well.

In addition to chemical input from light industry, the WWTP itself intentionally introduces three chemicals (ferrous chloride, sodium hypochlorite, and sodium bisulfite) into the treatment process. Ferrous chloride is used primarily to control hydrogen sulfide emissions during flaring of digester gas and heating of the digesters at the WWTP, as required by the APCD. 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 total chlorine residual once disinfection is complete.

Public Outreach

The MBCSD utilizes online and written literature as well as direct communication through multiple workshops, presentations, talks, and plant tours in order to educate consumers and local businesses about the organization and operation of the treatment plant; sewer-system BMPs; and techniques for the proper disposal of a variety of household wastes.

The Cayucos Sanitary District maintains a website¹ with status updates and other information relating to the CSWP, along with Town Hall Meeting notices, responses to FAQs,² and links to other resources. The City's website³ includes a series of pages devoted to an overview of the wastewater treatment plant and collection-system operations. The web pages contain pertinent information on current topics of interest. These include the status and history of the pending transition to an offsite WRF, the availability of an onsite Household Hazardous Waste Facility, and Collection System Do's & Don'ts. In addition, digital copies of all of the treatment plant's self-monitoring reports from 2005 onward, including, for example, this annual monitoring report are also available online.

The Collection System Do's & Don'ts section of the City's website also provides current BMPs for cat-litter disposal and the importance of avoiding its introduction into the collection system.⁴ This outreach program was one of the conservation measures recommended in the USEPA's (2007) biological evaluation that was conducted in preparation for issuance of the current NPDES discharge permit. During

¹ <http://www.cayucossd.org/>

² Frequently Asked Questions

³ <http://www.morro-bay.ca.us/342/Wastewater-Treatment-Plant-Operations>

⁴ <http://www.morro-bay.ca.us/documentcenter/view/1201>

the permit-renewal process, USEPA staff postulated that minimizing the input of cat-litter-box wastes into the municipal sewer system could limit the number of *Toxoplasma gondii* parasites introduced 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.

However, immediately following the finalization of the current permit, on 21 January 2009, Johnson et al. (2009) published the results of a detailed field study of southern sea otter exposure to *T. gondii*. That study unequivocally demonstrated that the incidental disposal of cat litter into the MBCSD collection system was not the cause of the observed impacts on otter morbidity from *T. gondii* infection. The authors of the 2009 study 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). More importantly, Johnson et al. (2009) 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). Based on these recent findings, the requirement for a cat-litter outreach program was eliminated in the new MBCSD discharge permit, which will become effective on 1 March 2018 (RWQCB 2018).

Nevertheless, prior to and throughout the term of the current permit, the MBCSD has maintained an ongoing public outreach and education effort for the proper disposal of cat litter. Irrespective of the lack of a nexus with otter *T. gondii* infections, cat litter, even the "disposable" kind, can lead to sewer line blockages. As part of the outreach program, the MBCSD occasionally includes newsletters with collection-system BMPs in monthly water bills. The inserts also provide information on the newly implemented water-conservation requirements, proper disposal of pet wastes, and emergency contact information for sewer emergencies. Additionally, cat litter BMPs were discussed with members of the public during tours of the treatment plant.

Other public-outreach endeavors by the MBCSD include its involvement in the collection of household hazardous wastes. Beginning in August 2000, the MBCSD collaborated with the Integrated Waste Management Authority to establish a permanent household hazardous-waste collection facility located at the WWTP. The collection facility offers 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. The facility remains one of the top waste-disposal sites in the county in terms of the volume of material collected. Between 20 and 50 individuals utilize the facility each weekend. From July 2016 to June 2017, the disposal facility processed nearly 20 tons of household hazardous waste, a large portion of which was recycled. Collected material is sorted, packaged, and labeled before transport to the appropriate offsite recycling and disposal facilities.

Source Identification

Past and ongoing efforts to eliminate or reduce contaminants entering the WWTP's wastestream have been successful, and as evidence of that success, elevated contaminant concentrations within effluent samples are rarely detected during the periodic chemical assays. Although nothing unusual was detected within the wastestream during 2017, anomalous concentrations of individual chemicals have been sporadically 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 FOG, and other components from the WWTP to the Collections Department under the City of Morro Bay's Sewer

System Management Plan¹ and the Cayucos Sanitary District.² Ongoing source identification and resolution efforts conducted by the City and District include a grease-trap inspection program for businesses subject to the requirements. Collections personnel regularly conduct scheduled inspections as well as spot checks as described in the *Industrial Waste Survey* subsection above. During inspections, personnel discuss BMPs with restaurant staff, provided educational materials such as a BMP handbook and make recommendations for grease trap maintenance as necessary.

Known light-industrial dischargers were also inspected for compliance with source control processes and procedures. One of the most important of the Class 1 facilities is the commercial laundry that operates within the City of Morro Bay. Although this facility only contributes approximately 1.6% to plant flow, commercial laundries use industrial-grade detergents, bleaches, surfactants, and brighteners that can potentially harm the bacteria within the WWTP's secondary-treatment system. In addition, solvents, oils, and other substances removed from soiled laundry have the potential to release contaminants into the wastestream. To minimize this potential, the laundry installed a pretreatment system during 2002 that included pH buffering with acid to neutralize excessive increases in wastewater alkalinity that can potentially interfere with the plant's treatment process.

2.2 WASTEWATER CHARACTERIZATION

Monthly wastewater characterizations documented a number of different aspects of the treatment plant's performance during 2017 (Table 2.2). Removal rates quantified the plant's ability to reduce major organic 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.

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	1.450	212 ³	35	83.8 ³	191	191	47	75.4	258
February	1.475	346	28	92.1	154	318	37	88.4	201
March	1.057	325	37	86.0	145	315	51	83.9	195
April	1.006	308	29	89.3	104	344	58	83.2	211
May	0.911	388	46	88.1	152	345	57	83.6	187
June	0.954	329	76 ⁴	76.8	279	334	80	75.9	291
July	1.095	415	43	91.1	170	401	55	86.3	225
August	0.965	454	35	91.6	125	365	48	86.8	167
September	0.918	332	31	90.3	103	323	40	87.8	127
October	0.843	442	39	89.5	120	305	47	84.5	149

¹ City of Morro Bay Sewer System Management Plan, originally approved June, 2009, reapproved June, 2014. City of Morro Bay Public Services Department, Wastewater Collections Division

² [CSD Ordinances.pdf](#)

³ The January average influent TSS concentration (212 mg/L) was below the 240 mg/L threshold where the TSS removal rate is deemed to be a relevant measure of plant performance and subject to the 75% monthly limitation.

⁴ The June average effluent TSS concentration was determined with a relatively low degree of confidence because only four measurements were included in the average. By comparison, averages for most other months were determined from more than 20 measurements. The much greater uncertainty in the June average that arose from its reduced sample size undoubtedly contributed to its excursion above the monthly limitation. Similarly, the comparatively low June removal rate (76.8%) was also an artifact of the small sample size.

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)
November	0.798	352	41	88.9	121	331	47	85.8	133
December	0.781	393	45	86.8	132	331	61	81.6	181
Average	1.018	357	38	88.1	142	324	52	83.8	193
Monthly Limit	≤2.36¹		≤70	≥75.0	≤546		≤120	≥30.0	≤936
Annual Total (MT)					52	70			
Nominal Annual (MT/year)					≤199	≤342			

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

Month	pH		Turbidity (NTU)	Settleable Solids (ml/L)	Median ² Total Coliform (MPN/100ml)	Oil and Grease		
	Influent	Effluent				Influent (mg/L)	Effluent (mg/L)	Emission (kg/day)
January	7.6	7.4	39	<0.1 ³	2	47	≈3.4 ^{4,5}	≈11
February	7.6	7.5	23	<0.1	2	22	≈1.2	<5
March	7.7	7.4	29	<0.1	<2	32	≈1.5	≈5
April	7.6	7.4	42	<0.1	<2	63	≈3.6	≈11
May	7.5	7.4	35	<0.1	<2	8.6	≈4.0	≈12
June	7.5	7.3	54	<0.1	<2	84	≈3.0	≈10
July	7.5	7.3	35	<0.1	<2	19	≈2.8	≈10
August	7.6	7.3	28	<0.1	<2	49	<0.86	<5
September	7.5	7.3	30	<0.1	2	40	<0.86	≈5
October	7.6	7.3	31	<0.1	2	66	≈2.2	≈9
November	7.6	7.3	34	<0.1	5	16	<0.86	≈4
December	7.6	7.3	39	<0.1	15 ²	12	<0.86	<3
Average	7.6	7.4	35	<0.1	<2	38	<1.8	<7
Monthly Limit		6-9	≤75	≤1.0	≤23		≤25.0	≤195

Treatment-plant personnel periodically collected wastewater samples throughout 2017. Results from the analyses of those samples were used to compute the monthly averages of the principal influent and effluent characteristics listed in Table 2.2. WWTP personnel performed the laboratory analyses to determine the principal physicochemical properties of the effluent, including concentrations of suspended solids, BOD, pH, total residual chlorine (TRC), turbidity, and settleable solids. 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

¹ Peak Seasonal Dry-Weather Flow (PSDWF)

² The 30-day median coliform density is computed from samples collected in the 30 days prior to the last day of the month in accordance with guidance from the RWQCB (MBCSD 1997a). Because of the 30-day look-back period, the December 30-day median determined herein (15 MPN/100 ml) differs from the median reported to CIWQS (17 MPN/100 ml), which includes the entire 31-day calendar month.

³ 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.

⁴ 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 all but six of the 52 weekly effluent samples were below the 5-mg/L practical quantification limit (PQL), as shown by the gray shading in Figure 2.9c on Page 2-27.

⁵ The “approximation” symbol (≈) indicates that the median concentration for the month was also too low to be reliably quantified; namely, it was below the practical quantification limit (PQL).

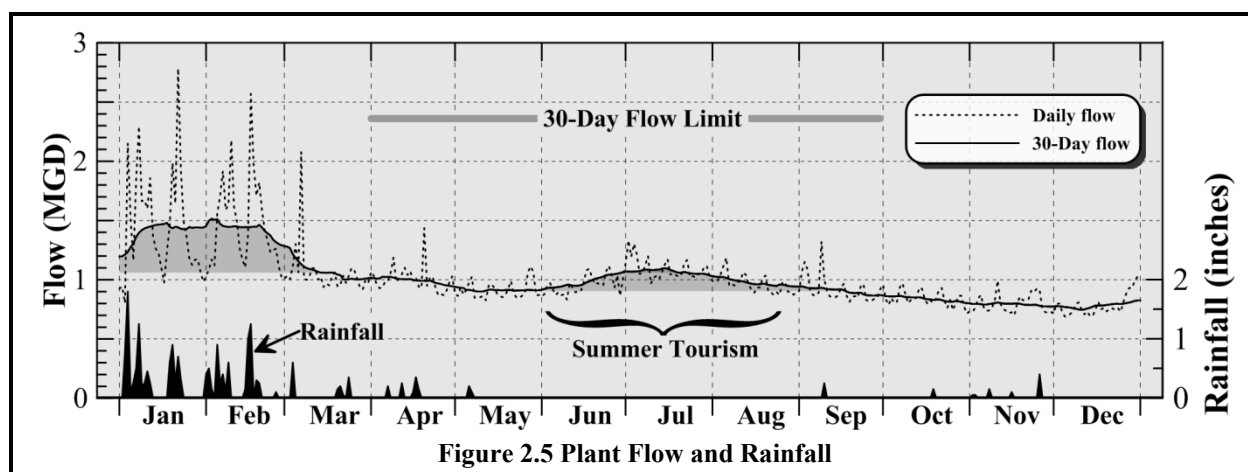
and effluent that were collected and analyzed at least weekly. Analyses for the concentrations of most of the remaining constituents were conducted only on effluent samples. Discrete effluent grab samples were analyzed for pH, TRC, temperature, turbidity, and settleable solids on a daily basis. Effluent grab samples were also analyzed by Abalone Coast Analytical for total coliform five times per week, whereas O&G concentrations were determined by BC Laboratories from weekly samples. Effluent ammonia was determined from monthly grab samples.

Detailed analyses of these measurements confirm that, during 2017, the plant regularly exceeded wastewater treatment expectations established in regulatory standards and the original WWTP design criteria. Moreover, the plant has consistently discharged exceptionally high quality effluent over its long history, and there has never been an indication of deteriorating plant performance. Rare exceptions to standards or criteria have been brief, and have often resulted from unavoidable repairs to, or mechanical failures of a treatment-system component. However, as a byproduct of a diligent preventative maintenance program, the plant has operated at a high level of efficiency with little equipment down time.

2.2.1 Flow Rate

Flow through the plant in 2017 remained far below both the plant's design capacity and the limits established 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 limit during 2017 (Table 2.2), not even during winter (October through March) when the limit does not apply because increased inflow from precipitation events is expected. In fact, the highest average monthly flow, 1.475 MGD in February, was only 68% of peak dry weather limit.

Additionally, this peak monthly flow occurred during the wet-weather season, when I&I¹ associated with a series of intense rainstorms that occurred throughout January and February (solid black spikes at the bottom of Figure 2.5) demonstrably contributed to the long-term average WWTP throughput (solid black line in the Figure). This storm series brought 14.8 inches of rain to the area over a seven-week period, and generated 24 of the 26 daily flows that exceeded 1.5 MGD (dashed line in Figure 2.5).



¹ Inflow (of rainwater) and Infiltration (of groundwater)

The first storm was the most intense, and deposited 2.6 inches of rainfall over the collection area from late January 3rd into January 4th. It resulted in one of the highest daily flows (3.95 MGD) ever reported by the WWTP. However, this abnormally high reported flow was partially an artifact of gaps and overttotalization in the instrumental flow readings that were available during the rain event. As described in the January Monthly Operations Summary (MBCSD 2017a), the heavy rain event surcharged the influent line and caused the water-level-based influent flow-meter to overttotalize the flow. In the absence of other valid direct measurements of flow, the influent flow-meter data was reported in the CIWQS¹ database for compliance-evaluation purposes. Normally, when the influent-meter data is compromised by flume surcharging, effluent flow-meter data is used to report flow. However, during portions of the day, flow through the WWTP was so high that it maxed-out the impeller-based effluent flow meter, thereby underestimating daily plant throughput. In contrast to the flow reported by direct meter readings, a more-realistic estimate of daily flow (2.152 MGD) was determined from past inflow data that found 0.633 MG of rainwater enters the WWTP for each inch of rain that falls within the collection-system's watershed. That estimated flow was used in the plant-performance evaluation described in this report (Figure 2.5, Table 2.2).

Other rainwater inflow events are evident in Figure 2.5 as sharp upward excursions in the dashed line that coincide with rainfall events. In addition to these short-term plant-flow responses to the individual rainstorms, longer-term flow through the WWTP also increased in response to the repeated storm events (solid line). These longer-term flow contributions represent increased groundwater infiltration into the collection system that arose from an elevated water table. Infiltration contributed an additional 22 MG of plant throughput over the seven-week period of elevated water-table levels. As shown by the shaded area beneath the solid line in Figure 2.5, winter infiltration added approximately 0.4 MGD to the daily flow rate during most of January and February.

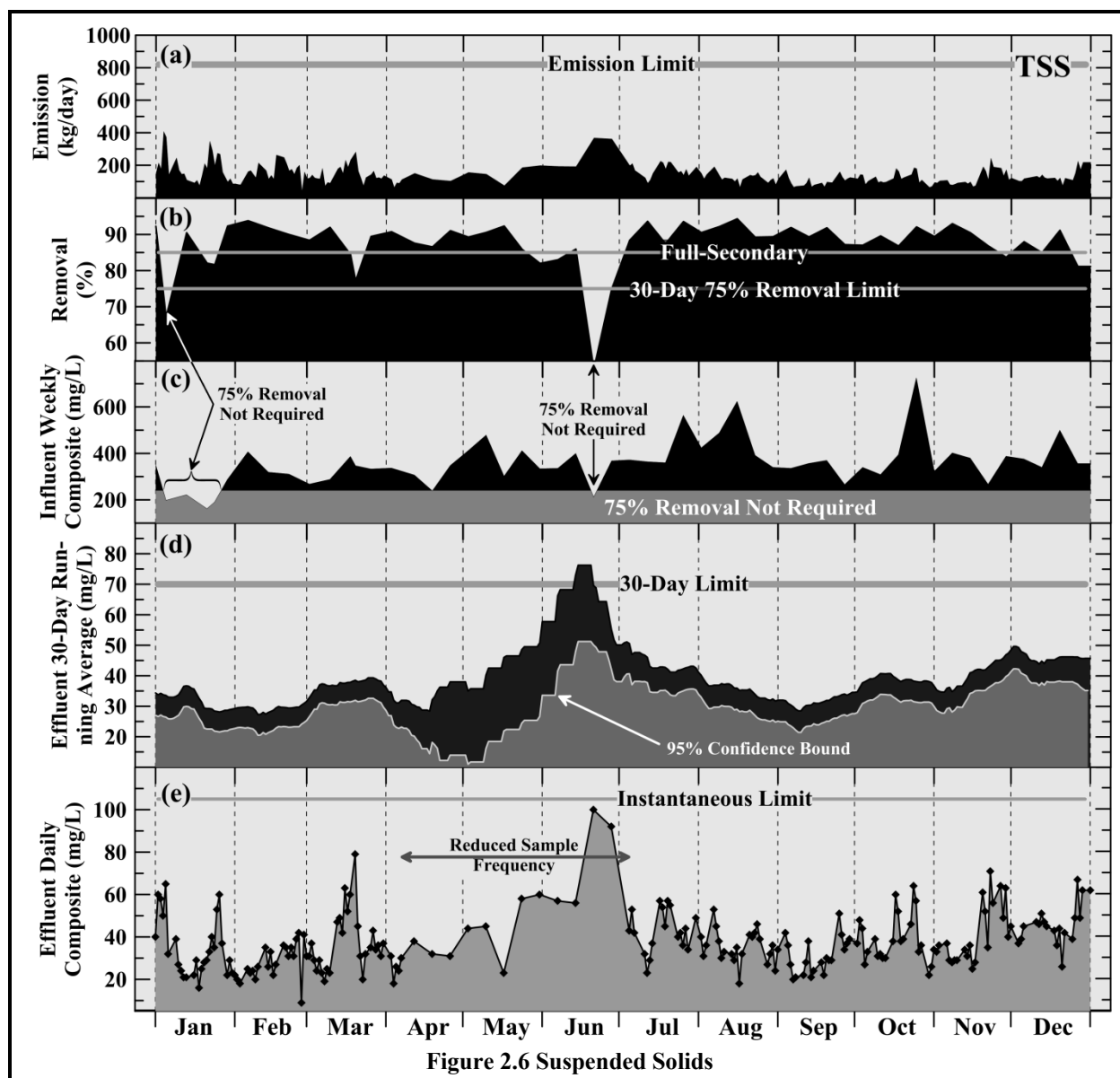
Population increases related to summer tourism also resulted in a perceptible increase in the 30-day moving average flow (upward bow in the solid line from June through August in Figure 2.5). However, the additional 10 MG of plant throughput that resulted from population increases during the dry season was less than half of that associated with infiltration. Moreover, at its 1.1 MGD peak around the Independence Day Holiday, the 30-day flow was only 47% of the monthly allowance for peak dry-season flow shown by the thick shaded line that spans the 'dry' season (April through September) in Figure 2.5. Short-term increases in flow due to tourism are also apparent around the Independence Day and Labor Day holidays at the beginning of July and September.

2.2.2 Suspended Solids, Turbidity, and Settleable Solids

Suspended solids, turbidity, and settleable solids measure the particulate load within wastewater. One of the principal functions of the treatment process is to remove organic particulates from the wastestream. The treatment plant's removal of nearly all (88%) of the solids from influent (Figure 2.6b; Table 2.2) documents a high overall performance during 2017. In particular, the plant's annual solids removal rate exceeded the minimum required by the NPDES permit, which specifies removal of only 75% of the suspended solids on a monthly basis.

In fact, the plant's 88% annual removal rate exceeded the 85% monthly removal rate established for full-secondary treatment. Moreover, the WWTP achieved removal rates equivalent to full secondary treatment consistently throughout the year, with monthly averages exceeding the standard in every month except January and June, when the removal rate was immaterial because influent solid concentrations were already low (refer to the co-occurring downward excursions in Figure 2.6bc). The removal-rate limit

¹ California Integrated Water Quality System Project



specified in the COP and NPDES discharge permit is a technology-based requirement rather than one that reflects the actual potential for environmental impacts within receiving waters. As such, its application is conditional on the presence of high TSS concentrations within influent, as described below.

Sharp reductions in influent TSS concentration, such as those shown in Figure 2.6c, arise from external events unrelated to the treatment process. They often occur when rainwater inflow from intense winter storms dilute the suspended solids load within the collection system. Although these low-influent TSS events are clearly unrelated to the efficacy of the treatment process, they weigh heavily in computation of removal rate. Because of this, removal rates are considered an irrelevant measure of plant performance when influent TSS concentrations are low. From a process standpoint, the same fraction of suspended solids cannot be removed from the influent stream when there is less material available to remove. From

an environmental standpoint, only the solids loading within the discharged wastestream is of concern, not the influent loading or the fraction of material removed.

Regulators recognize that requiring a high removal rate is unnecessary when effluent TSS concentrations are low to begin with. Consequently, the NPDES discharge permit does not impose the 75% monthly removal rate when the requirement would result in an effluent TSS concentration of less than 60 mg/L (RWQCB-USEPA 2009, SWRCB 2005). Thus, the 75% removal-rate requirement does not apply when average influent TSS concentrations fall below 240 mg/L,¹ which occurred during most of January, and briefly during June.

In contrast to removal rate, the overall solids load released to the ocean more directly measures the discharge's potential for environmental effects. Daily mass emissions of solids were uniformly low throughout 2017 and only on maximum-emission days did they reach even half of the allowed amount (Figure 2.6a). Low overall effluent TSS concentrations, combined with low flow rate during 2017, resulted in an annual total solids emission that was well below the allowable solids emission (Table 2.2). Over the entire year, the WWTP only discharged 52 metric tons of suspended solids to the ocean. That solids emission was only 26% of the projected 199 metric tons that would have been discharged if effluent had contained the permitted TSS concentration of 70 mg/L and throughput reached the nominal average dry-weather flow of 2.06 MGD.

Similarly, the long-term record of effluent TSS concentrations normally provides a good indication overall plant performance for any given period during 2017 (Figure 2.6d). Except for the June, averages for each calendar month were well below the monthly limit of 70 mg/L (Table 2.2), as was the 30-day moving average (Figure 2.6d). However, the average TSS concentration reported for June was noticeably higher, both because of a brief decline in TSS-removal performance, and because of uncertainty in the determination of the long-term average TSS during that period of time. Because of these influences, the computed 76-mg/L TSS concentration for June slightly exceeded the 70-mg/L monthly discharge limit (Table 2.2).

As described in the June Monthly Operations Summary (MBCSD 2017b), the temporary performance decline in TSS removal arose because of a reduction in Return Activated Sludge (RAS) from the secondary clarifier. Effluent TSS concentrations quickly returned to normal after a second RAS airlift was employed and back flushing of the RAS piping helped clear accumulated solids. The entire RAS system was rehabilitated later in the year.

Although the June TSS event was brief, it unduly influenced the calculation of the June monthly average because of the reduced number of effluent TSS measurements collected during that month. During a three-month period from April through June, effluent TSS was measured on a weekly basis to match the minimum sampling requirement promulgated in the discharge permit. Prior to that, effluent TSS was determined much more frequently (refer to the spacing of the individual sample points in Figure 2.6e).

The higher historical sampling frequency provided a more reliable estimate of central tendency namely, a more representative measure of the overall monthly plant performance. For example, at the historical effluent-TSS sampling rate, more than 20 data points typically contributed to the calculation of the monthly average. However, in June 2017, only four measurements were available to determine the average, and two of those occurred during the period of reduced RAS flow (June data points in Figure

¹ 240 mg/L is four-times the 60-mg/L threshold on effluent concentration that determines the applicability of removal rate for compliance evaluations. This applicability threshold derives from the first note to Table A of the COP (SWRCB 2005), which states: "...the discharger shall remove 75% of suspended solids from the influent stream at any time the influent concentration exceeds four times [the lower effluent concentration limit]."

2.6e). To improve the accuracy of monthly averages, collection of effluent TSS samples reverted to the historical schedule after the June event.

The uncertainty introduced by the markedly reduced sampling rate can be discerned in the moving average shown in Figure 2.6d. As expected from the June monthly average reported in Table 2.2, the 30-day moving average, shown with black fill, briefly extended above the permit's 70-mg/L 30-day limit. However, the lower 95% confidence bound,¹ shown with grey fill, was well below the limit at that time, suggesting that the exceedance was weakly determined. In fact, throughout the period of weekly TSS sampling, the actual 30-day average could reasonably be expected to range 25 mg/L below the reported level. In contrast, at the historical sampling frequency, the span of the lower confidence interval is only about 7 mg/L.

Regardless of uncertainty in the reported June TSS effluent concentration, its 8.5% excursion above the 30-day permit limit in June is of little environmental or regulatory consequence. The "technology-based" limits on TSS were established based on the capability of various levels of treatment to remove BOD and suspended solids from the wastestream. Thus, in contrast to concentration limits on toxic chemicals, which are determined by their potential for actual environmental impacts, technology-based limits do not reflect the degree of measurable harm within receiving waters. This is particularly true for open-ocean discharges where energetic turbulent processes quickly dissipate solids loads within a large capacity receiving-water volume. As a result, improvements in treatment level, from primary to secondary for example, has not been found to perceptibly change the seawater or sediment quality within marine environment surrounding marine discharges (Diener and Fuller 1995). In fact, Section 301(h) was added to the Clean Water Act because scientific evidence challenged the efficacy of imposing purely technology-based limits on open-ocean dischargers (Isaacs 1978).

In their compliance enforcement policy, the SWRCB (2017) recognizes the distinction between potential impacts from excursions in technology-based (Group 1) concentrations and exceedances associated with toxic chemicals (Group 2). Group 1 pollutants, such as TSS, require an enforcement action if their concentrations exceed an effluent limitation by more than 40%. For the MBCSD monthly TSS limit of 70 mg/L, that enforcement threshold would be 98 mg/L. Thus, the reported June TSS concentration would need to be 22 mg/L higher to be of regulatory concern.

Effluent turbidity is a related measure of solids loading. Not surprisingly then, effluent turbidity also exhibited an increase in its 7-day and 30-day running averages in conjunction with the June reduction in RAS flow (Table 2.2 and Figure 2.7ab on the following page). In contrast to TSS, however, none of the permitted turbidity limits was exceeded in 2017. For the most part, turbidity levels measured within individual daily grab samples were low (Figure 2.7c), and reflect levels too low to have a perceptible impact on receiving seawater clarity after discharge. Accordingly, Chapter 3 of this report presents analysis of transmissivity measurements collected offshore that demonstrate that turbidity associated with effluent discharge dissipates rapidly upon discharge. Perceptible changes in water clarity associated with effluent particulate loading are only found extremely close to discharge ports near the seafloor where little ambient light penetrates. The general absence of perceptible turbidity impacts on receiving-water clarity is visually apparent in the diffuse cloud emanating from the diffuser shown in Figure 2.2 on Page 2-5. In fact, some of the distortion apparent in the photograph is an artifact of differences in the refractive index at the seawater-wastewater interface rather than particulate loading.

¹ Although confidence intervals are useful for quantifying the relative influence of different sampling frequencies, they are not, strictly speaking, suitable for a rigorous statistical hypothesis test. Because they are applied to points in a time series, which are often serially correlated, the statistical construct's assumption that the points are independent is violated.

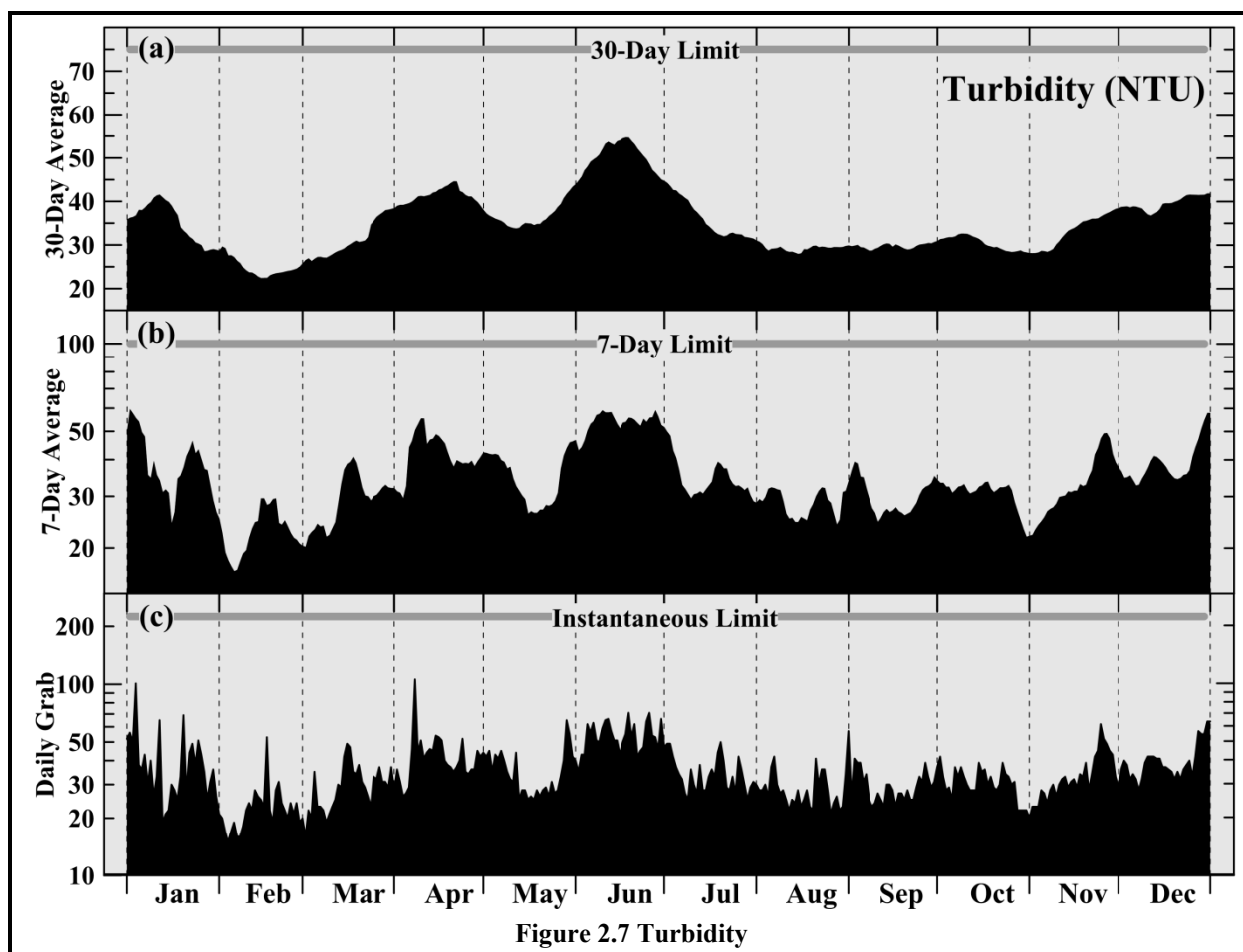


Figure 2.7 Turbidity

Settleable solids concentrations, which are the only remaining solids-related measure of effluent quality, echo the above findings that overall particulate loads of all types were low during 2017. Specifically, the monthly averages not only remained well below the permit limits, but were also below the 0.1-ml/L detection limit (Table 2.2). None of the 365 daily effluent samples contained a detectable amount of settleable solids.

Thus, during 2017 as in prior years, all measures of effluent solids demonstrated that the treatment process exceeded performance expectations by regularly removing a greater amount of solids from the influent stream, and by discharging a small fraction of the maximum anticipated load to the marine environment. The consistently low monthly averages for effluent TSS, turbidity, and settleable solids attest to the overall effectiveness of the treatment plant’s screening, grit removal, sedimentation, filtration, and clarifying processes (Table 2.2).

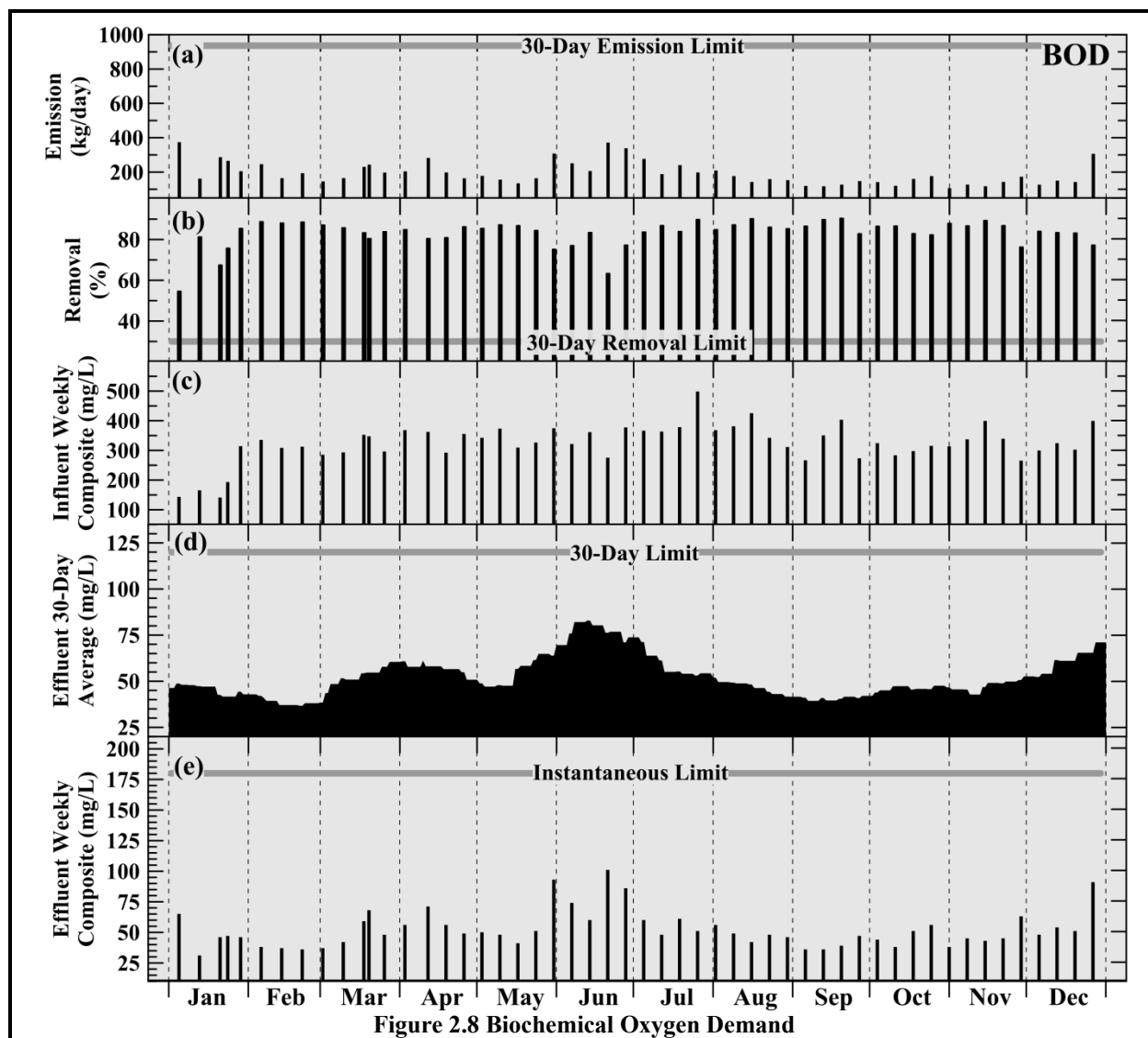
2.2.3 Biochemical Oxygen Demand

In combination with solids removal, a primary function of the treatment process is to reduce organic material within the wastewater stream. The effectiveness of the organic removal process is closely linked to solids removal because the majority of organic constituents are associated with wastewater particulates. However, the measure of organic loading, namely BOD, differs from the direct physicochemical measurements of turbidity and solids concentrations. Instead, BOD indirectly measures organic loading

within the wastewater stream by determining 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 fundamentally differ from the highly oxygenated open-coastal marine environment of Estero Bay. In fact, because of the ocean's higher oxygen-replenishment capabilities, an evaluation by the National Academy of Sciences (1993) questioned the environmental benefits of imposing a technology-based BOD limit on open-ocean dischargers, namely, requiring secondary-treatment standards for BOD.

Nevertheless, the NPDES discharge permit sets limits on the discharge of BOD, and independent of potential environmental influence, BOD constitutes an important measure of the overall performance of

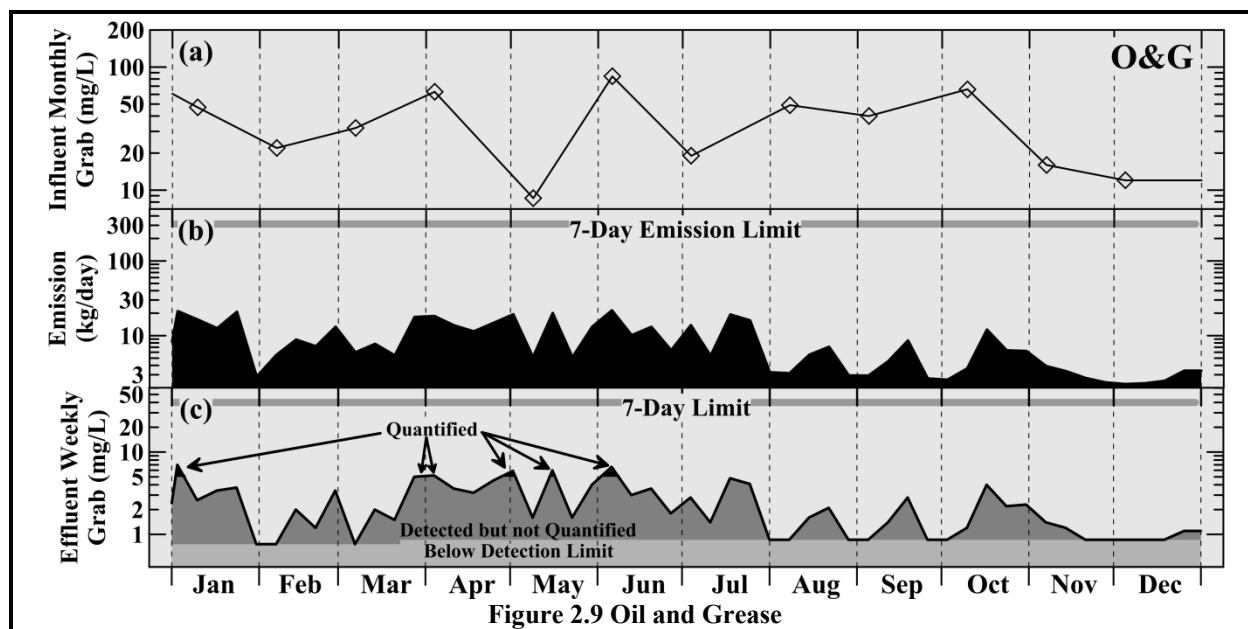


the treatment process. However, because of the complexity and duration of BOD determinations, its evaluation is only required on a weekly basis (Figure 2.8 on the prior page). In combination with the high overall performance of the solids removal process during 2017, BOD removal was also exceptionally high. Annually, the WWTP reduced influent organics by more than 83.8%, as determined by the average of weekly composite samples analyzed for BOD (Table 2.2). Thus, the WWTP removed organic material at a rate nearly three times greater than the 30% removal rate required by the NPDES discharge permit (Figure 2.8b). The monthly removal rate even exceeded the 85% removal rate established for secondary treatment in five months of the year, and the removal approached secondary treatment in most other months by exceeding 81% all but two months.

BOD concentrations within individual effluent samples were consistently low throughout the year, and all were far below the instantaneous permit limit (Figure 2.8e). As a result, the running 30-day average remained well below the limit that applies to averages over calendar months (Figure 2.8d). This includes the period during June when TSS removal in the secondary process was affected by a decline in the RAS process. Even so, as with TSS, the overall low BOD concentrations combined with the low overall flow in 2017 resulted in a low annual BOD emission of 70 MT, which was only 20% of the 342 MT allowed by the discharge permit (Figure 2.8a).

2.2.4 Oil and Grease

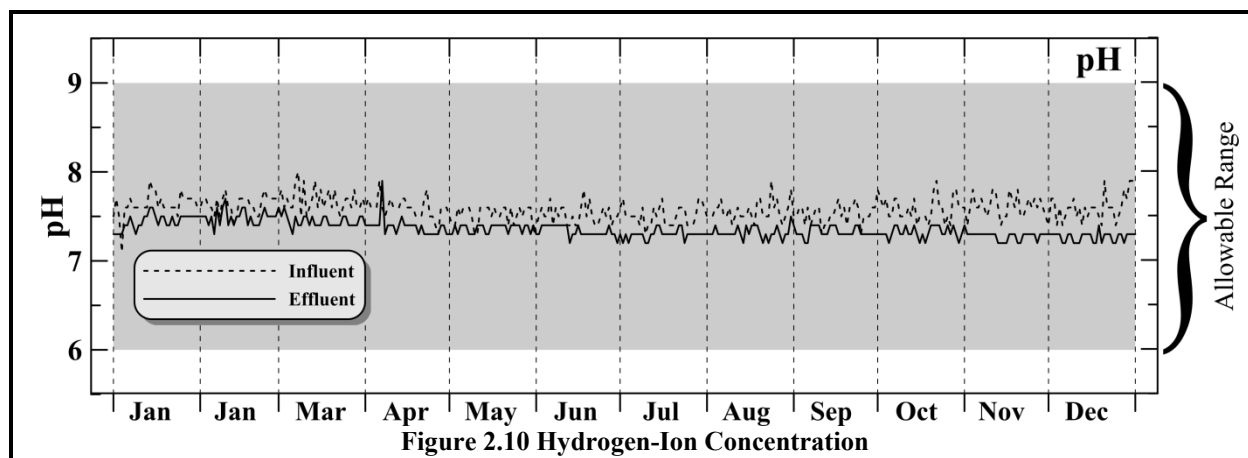
During 2017, the treatment process reduced average O&G concentrations within the influent stream by at least 21-fold (Table 2.2). The actual amount of the reduction cannot be precisely determined because O&G concentrations within all but six of the 52 weekly effluent samples were too low to be quantified. The six quantifiable concentrations were randomly distributed, occurring in January, March, April, May and June, and only marginally exceeded the 5.0-mg/L PQL specified for the O&G analysis method (black shading in Figure 2.9c). Although the presence of O&G was detected within most of the remaining 46 samples, fourteen of the samples had concentrations too low to be detected even with the sensitive analysis method (light gray shading in the Figure).



The long series of consistently low O&G concentrations measured in effluent samples collected during 2017, and in recent prior years, were unusual in the three-decade-long database. The annual median effluent concentration during 2017 (<1.8 mg/L) was among the lowest measured in the database, and may reflect the low influent concentrations measured during the year (Figure 2.9a). When combined with the low overall flow, the 2017 weekly O&G emissions were an order of magnitude below the allowed emission (note the logarithmic scale in Figure 2.9b).

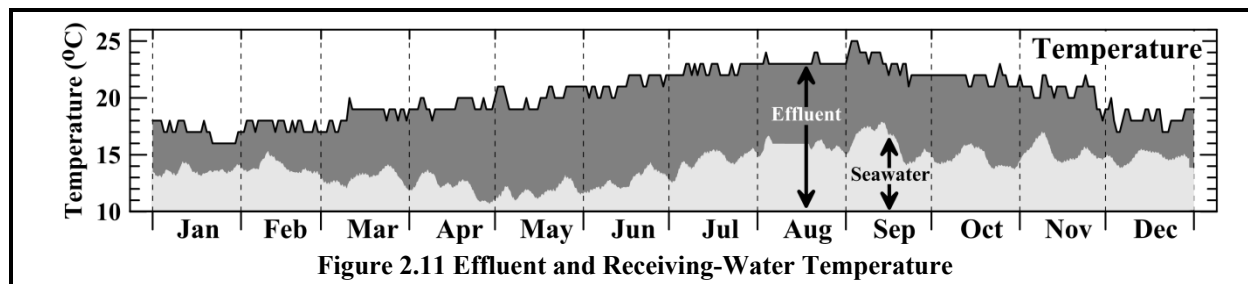
2.2.5 pH

The MBCSD discharge permit requires that hydrogen-ion concentrations (pH) within effluent samples remain between 6 and 9 at all times. Although Section 301(h) of the Clean Water Act allows an NPDES permit to be issued that exceeds these pH limits, the MBCSD discharge permit does not allow this exception. The general absence of heavy-industrial input into the collection system creates an influent stream with a nominal pH that routinely meets the discharge requirement even without treatment. Thus, because influent pH (dashed line in Figure 2.10) remained within the discharge limits (shaded area) throughout 2017, 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, and slightly reduced its pH. Average annual effluent pH (7.36) was slightly less alkaline than the influent (7.58) and substantially less alkaline than the receiving seawater (8.0).



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 upper time series in Figure 2.11, exhibits a distinct semiannual cycle that tracks seasonal insolation, in a manner similar to air-temperature fluctuations. Typically, effluent temperatures begin gradually increasing in late-winter (March), peak in late summer (September), decline slightly through November, and then drop relatively quickly during late fall (mid-November through mid-December).

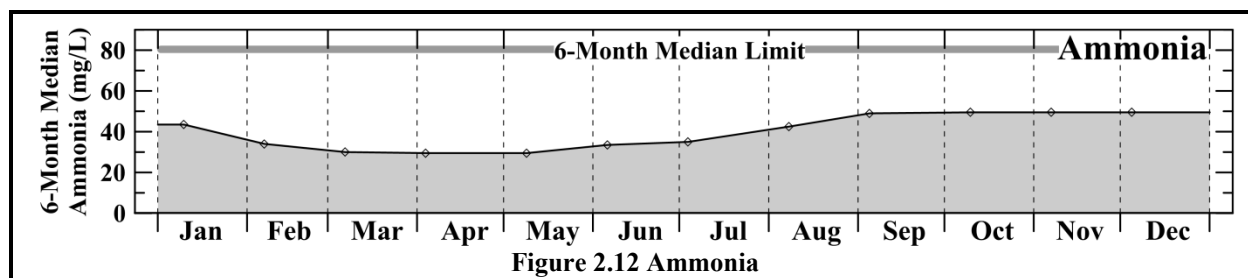


Because of the strong and sustained influence of upwelling during 2017, seawater temperatures, shown by the light shading, did not track the seasonal-insolation trend seen in effluent temperature. In response to the onset of intense southeastward winds in April, cool deep seawater was brought to the sea surface near the discharge location. Upwelling counteracted the warming effects of solar insolation throughout spring and into early summer (see Sections 3.2.3 and 3.2.4), and seawater temperatures were actually lower than winter temperatures during this period.

The difference in timing of insolation and upwelling produced a period of large thermal contrast, which persisted from April through October (dark shading in the Figure). Effluent temperatures were at least 6°C higher throughout most of this period. However, during May and June, the thermal contrast was much larger. It regularly exceeded 9°C as onshore surface waters continued to warm while seawater temperature was suppressed by upwelling. This large thermal contrast would normally enhance buoyancy-induced dispersion of the effluent plume significantly. However, upwelling also causes water-column stratification, which can limit vertical movement of the plume and offset the buoyancy-enhanced turbulence to some extent. The strength of upwelling winds began to decline after mid-June and sea-surface temperatures began a slow increase that extended through mid-September. Thus, buoyancy-induced vertical mixing of the discharge plume was greatest during the early summer of 2017 when thermal contrasts were still large and water-column stratification had decreased.

2.2.7 Ammonia

The concentration of ammonia as nitrogen ($\text{NH}_3\text{-N}$) was uniformly low throughout 2017, as has been the case in prior years. Median concentrations, computed over a 180-day period, were consistently close to 50 mg/L, which is a little more than half of the long-term permit limit (Figure 2.12). Individual grab samples analyzed for ammonia on a monthly basis during 2017 had concentrations at or below 66 mg/L, which is one-fifth of the 322-mg/L daily-maximum permit limit, and one-twelfth of the instantaneous maximum (804 mg/L) established to protect marine aquatic life.



2.2.8 Residual Chlorine

Total residual chlorine (TRC) quantifies the amount of chlorine remaining in effluent grab samples that are collected after disinfection with sodium hypochlorite and subsequent dechlorination, or buffering, with sodium bisulfite. Effluent grab samples are collected when flow reaches its daily maximum, and concentrations of effluent constituents, as well as hypochlorite and bisulfite dosage, are expected to be at their highest levels. However, TRC concentrations were below the 0.05-mg/L detection limit in all but one of the 365 daily grab samples collected during 2017.

The only measureable amount of TRC was recorded on 5 January, when extraordinarily high flow was processed through the WWTP. It occurred shortly after the first and most intense rainstorm impinged on the collection system. At 0.65 mg/L, the reported TRC concentration was below the 1.07 mg/L daily limit and well below the instantaneous limit of 8.04 mg/L. Because it was an isolated detectable-concentration event, it did not contribute to the 6-month median, which remained below the 0.05-mg/L detection limit, and well below the maximum allowable median concentration of 0.27 mg/L.

The general absence of detectable TRC concentrations during 2017 resulted from a careful balancing of the complex chlorination and dechlorination processes to obtain adequate disinfection (coliform reduction) without dosing the marine environment with excess chlorine. The complexity arises because chlorine demand is constantly changing due to continuous variations in flow and organic loading within the wastestream. Hypochlorite and bisulfite dose is normally controlled by both total-chlorine-residual and flow-paced pumps that automatically inject precisely measured amounts of these chemicals into the wastestream. However, the disinfection process occasionally requires direct operator intervention on short notice. An auto-dialing alarm system is linked to the process to notify operators by phone immediately upon an unusual excursion in TRC at any time day or night. A narrow range on the alarm points facilitate a quick response, but at the expense of numerous false alarms.

2.2.9 Coliform Bacteria

The efficacy of the disinfection process is tracked by regular measurements of coliform populations within effluent samples. As part of the NPDES permit provisions, samples collected on five consecutive days each week were analyzed for the most probable number of total coliform organisms per 100 ml (MPN/100 ml). Figure 2.13b on the following page shows that when there are detectable coliform populations, their densities vary widely among individual measurements. WWTP personnel strive to maintain densities close to the detection limit of 2 MPN/100 ml, and during 2017, over half of the 284 measurements were at or below this detection level (see the inset in Figure 2.13b). Accordingly, the median coliform density for the year was also below the detection threshold and an order-of-magnitude below the 23-MPN/100 ml monthly permit limit (Table 2.2).

However, due to the complexities of the disinfection process, elevated density is occasionally observed within individual samples. The greatest population density (500 MPN/100 ml) was measured on January 20th in conjunction with high plant flow following two intense rainstorms. Nevertheless, this isolated maximum measurement was still an order of magnitude lower than the permit limit on instantaneous coliform density (Figure 2.13b¹).

¹ Note the logarithmic density scale in Figure 2.13b.

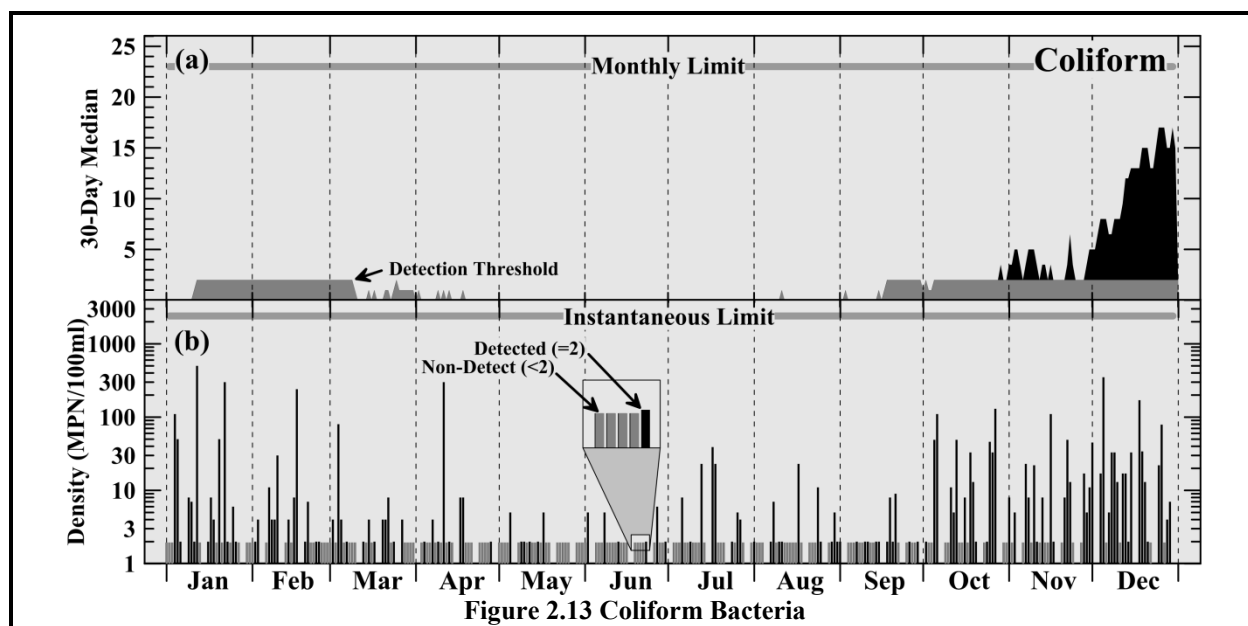


Figure 2.13 Coliform Bacteria

Clusters of measurable coliform density continued into March in conjunction with the increased I&I plant throughput during this particularly active rainy period. As a result, the 30-day moving median maintained a detectable level of coliform over a two-month period (grey shading between mid-January and mid-March in Figure 2.13a, and two detectable monthly medians in Table 2.2). The longer-term trends shown in Figure 2.13a are based on a running median computed over a 30-day look-back period of the individual measurements shown in Figure 2.13b. As with the individual effluent samples, long-term coliform density remained at, or below detectable levels for six months of the year.

However, in the 30 days prior to mid-September, the detection frequency of individual coliform measurements increased slightly and detectable coliform density began to be regularly reported in the long-term median (grey shading from mid-September through October in Figure 2.13a). As the window advanced into November, the amplitude of the detectable densities within the 30-day median increased slightly (scattered black spikes in Figure 2.13a), resulting in a 5 MPN/100 ml reported for November (Table 2.2). Throughout December, the frequency of measurable densities above 5 MPN/100 ml steadily increased, culminating in a 15 MPN/100 ml median reported for that month. Because compliance with the monthly permit limit is based on a 30-day look-back period for each calendar month, only the November and December month-end medians of 5 and 15 MPN/100 ml ranged above the detection limit and therefore, were appropriate for comparison to the 23-MPN/100 ml permit limit on the 30-day median coliform density (Table 2.2). Both of those densities were well within the compliance threshold, as were the ten other months when reported monthly coliform densities were at or below the detection limit.

2.2.10 Toxicity

In 2017, effluent was tested semiannually, in January and July, for toxicity using chronic bioassays¹ of composite effluent samples (Table 2.3). The chronic bioassays found consistently low effluent toxicity, with levels much less than the discharge permit limit.

¹ Acute bioassay testing requirements were eliminated in the current MBCSD discharge permit, in accordance with prior updates to the 2005 COP.

Table 2.3 Comparison of Measured Toxicity Levels with Permit Limits

Sample Date	Bioassay Test	End Point (%)	Concentration (TU)	Limit (TU)
17 January	Red Abalone (<i>Haliotis rufescens</i>) Larval Development	5.6	17.9	134
19 July	Red Abalone (<i>Haliotis rufescens</i>) Larval Development	5.6	17.9	134

Chronic bioassays have historically been conducted using giant kelp zoospores (*Macrocystis pyrifera*). Toxicity 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 following 17 years, MBCSD bioassays repeatedly demonstrated that giant kelp zoospores were 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 effluent samples collected in July 2009 and January 2010. Those screening assays assessed the effluent's effect on the development of larval red abalone (*Haliotis rufescens*) in addition to that of giant kelp. These screening bioassays indicated that larval abalone were slightly more sensitive to MBCSD effluent than kelp zoospores; therefore, all subsequent bioassays have been conducted using larval abalone.

The chronic toxicity tests conducted in January and July 2017 measured growth response in larval red abalone after exposure to a range of effluent dilutions.¹ The results of the 2017 abalone bioassays confirmed that the effluent continued to exhibit low marine toxicity. Both chronic-toxicity endpoints were less than one-seventh of the applicable permit limit 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 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 monoculture blooms of particular species that are harmful to humans or other life. In addition to harm caused through the production of toxins by these species, large phytoplankton blooms can negatively affect the marine ecosystem simply from their accumulated biomass.

Historically, processes such as coastal upwelling and river runoff have been implicated as the primary factors that create physical and chemical conditions (e.g., high nutrient concentrations) conducive to the development of phytoplankton blooms (Trainer et al. 2002, Kudela et al. 2004). In particular, upwelling conditions, which are discussed in Chapter 3 of this report, have been chiefly implicated in the generation of HABs along the central California coastline (Trainer et al. 2000, Kudela et al. 2005).

However, over the last decade, the extent and duration of phytoplankton blooms have been increasing within the upwelling zones along central and southern California coastlines (Nezlin et al. 2012). Additionally, upwelling alone cannot account for the recent observed distributions, suggesting that

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 2017ab).

anthropogenic nutrient input could be a contributing factor in the stimulation of phytoplankton biomass that promote HABs. Within highly localized nearshore areas adjacent to large wastewater dischargers offshore southern California, nutrient loads within the discharges are comparable to the nutrient flux associated with upwelling (Howard et al. 2014).

Because increased human activity and pollution are now thought to be contributing factors to the recently observed increase in the frequency and intensity of HABs, the USEPA proposed a conservation measure for “*Regular monitoring of nutrient loading from the [MBCSD] facility’s ocean outfall*” in their biological evaluation. 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) 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].

These particular compounds were selected because they represent limiting macronutrients for phytoplankton growth within the euphotic zone of the ocean, 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 current permit requirement, nutrient assays of MBCSD effluent were conducted on grab samples collected in January and July 2017. The results were consistent with those of prior years, and demonstrate that nutrient concentrations within the MBCSD effluent, and their mass loading to the marine environment from discharge, are small compared to: i) other central- and southern-California coastal dischargers, ii) the contribution from regional streams and rivers, and iii) the nitrogen flux from localized upwelling (Table 2.4). Although concentrations of urea within MBCSD effluent (≤ 0.091 mg/L) were comparable to those of the three large central-coast WWTP’s to the north (≤ 0.110 mg/L), the concentrations of nitrate, phosphate, and silica within MBCSD effluent were substantially lower than those of the other dischargers. The MBCSD nitrate levels, in particular, were two orders of magnitude lower than those of the other WWTP’s within the central-coast region. Nitrate and silica concentrations within MBCSD effluent were also less than the average concentrations found within central-coast rivers and streams; although, urea and phosphate concentrations were higher, as was the case for the other central-coast WWTP’s.

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	<0.07	0.084	1.6	17.0				
MBCSD July	<0.07	0.091	2.8	13.0	<99.	124.	3020.	22,000.
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.
Localized Upwelling ²	9.53	—	2.0	—	1,818,000.	—	377,000.	—

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)

² McLaughlin et al. 2017 found that the nitrate volume discharged by the Orange County Sanitation District was comparable to the nitrogen flux from localized upwelling.

Notwithstanding the effluent nutrient concentrations within effluent, potential marine bio-stimulatory effects from nutrient discharge are dictated by the total mass nutrient emission contributed by the various sources (right side of Table 2.4). After accounting for the relatively small volume of wastewater discharged by the MBCSD, its total nutrient loading¹ to the marine environment during 2017 was 24-times smaller than any of the three large WWTP's, all of which discharge into the waters of the Monterey Bay National Marine Sanctuary. Similarly, total nutrient loading from the MBCSD discharge was three orders-of-magnitude smaller than the contribution from runoff within the central-coast region. Lastly, and most relevant for evaluating the potential impacts on HAB stimulation, the nitrogen flux from the MBCSD outfall was four orders of magnitude smaller than the flux from the Orange County discharge, which was found to be comparable to that of localized upwelling (last line in Table 2.4).

2.2.12 Chemical Compounds

In addition to the effluent properties and bioassay results described above, 78 chemical contaminants are regulated by the COP, and have their effluent concentrations limited in the discharge permit. Effluent composite samples were analyzed in January and July 2017 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 (Table 2.5 on the following page). The COP regulates the discharge of these compounds for the protection of marine life and human health from exposure to both carcinogenic and noncarcinogenic substances.

As has been the case in the historical record of 3,966 chemical assays spanning 25 years of MBCSD effluent monitoring, the 2017 analyses detected concentrations of only a few ubiquitous compounds at levels well below the regulatory limits. Those 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 2017ab).

The chemical assays found only five of the 78 regulated chemical compounds present in quantifiable amounts within the 2017 effluent samples.² The measured concentrations for all five compounds were significantly less than the permitted limits. Annual mass emissions of these compounds also met the goals identified in the discharge permit's reporting provisions. The compounds with quantifiable concentrations included three trace metals (copper, lead, and zinc), selenium, and radionuclides.

The analyses also detected the presence of seven additional compounds in the semiannual effluent samples, but at concentrations that were too low for reliable quantification. Specifically, the concentrations of these compounds were higher than the method detection limit (MDL)³ but less than the minimum reporting level (ML).⁴ Reporting of these detected-but-not-quantified concentrations is required

¹ Sum of the emissions from the four nutrient compounds listed on the right side of the Table

² Quantifiable concentrations are listed in bold typeface in Table 2.5.

³ 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.

⁴ The Minimum Level (ML) for individual chemical compounds are as specified in the 2005 Ocean Plan, and represent the method-specific minimum concentration of a substance that can be reliably measured in a sample given the current analytical performance level achieved by most certified laboratories within California.

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.	≈1.7 ¹	≈1.1	17.	≈2.04
Chromium VI ²	270.	<1.2 ³	≈1.4	93.	<1.83
Copper	140.	16.	21.	690.	25.8
Lead	270.	1.3	1.3	465.	1.84
Mercury	5.29	<0.030	≈0.032	1.4	<0.04
Nickel	670.	≈5.5	≈5.4	142.	≈7.74
Selenium	2,010.	3.1	2.6	65.	4.08
Zinc	1,620.	52.	68.	244.	84.
Radionuclides (pCi/L) α	15.	— ⁴	0.003	—	—
Radionuclides (pCi/L) β	50.	—	15.	—	—
Protection of Human Health (Non-Carcinogens)					
Chromium III ²	25,500,000.	—	≈1.4	—	—
Toluene	11,400,000.	—	≈0.3	4.	≈0.43
Protection of Human Health (Carcinogens)					
Chloroform	17,400.	—	≈1.2 ⁵	5.	≈0.93
Dioxin (pg/L)	0.52	—	≈0.0431	1.48 mg	≈0.078 mg

under the current NPDES discharge permit; although they are not compared to effluent limits for compliance determinations.

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, including the marine sediments within Estero Bay. Accordingly, 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 at most one-sixth of levels deemed deleterious to marine organisms, and the highest metal mass emission was one-third of the emission goal recommended in the discharge permit.

These three metals have been detected at quantifiable levels in more than half of the effluent samples collected during the last 25 years; therefore, they do not represent a new or increased source of

¹ The “approximation” symbol (≈) indicates that the detected concentration, designated with an “as estimated” qualifier, was too low to be reliably quantified, namely, it was below the prescribed Minimum concentration Level (ML). Accurately quantified “as measured” concentrations are indicated by bold typeface.

² The total chromium concentration is reported instead of the trivalent or hexavalent oxidation states alone.

³ The “less-than” symbol (<) indicates that the substance was not detected at a concentration above the 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.

⁵ The reported concentration was above the PQL and accordingly, was not identified “as estimated” by the chemistry laboratory. However, in accordance with the guidance from the COP and the NPDES permit, the reported value is listed here as an estimated concentration because the measured value was below the 2.0-µg/L chloroform ML.

contaminants entering the collection system. Moreover, statistical analyses of the long monitoring history unequivocally demonstrate that there is no reasonable potential for these effluent metal concentrations to exceed discharge permit limits in the future.

Selenium

Selenium, a naturally occurring metalloid within the mineralogy of the central California coast, was also detected within the 2017 effluent samples. Selenium concentrations have been found to increase slightly within MBCSD effluent samples when these naturally occurring compounds are mobilized within surficial soils following rainstorms. Rainwater inflow into the collection system from the storms that preceded the effluent sample collection on 18 January (refer to Figure 2.5 on Page 2-19) may account for the increased presence of quantifiable concentrations found in that sample. Conversely, the absence of measureable rainfall prior to the July sampling event resulted in a lower selenium concentration. Regardless of its source, the selenium concentrations found in the 2017 effluent samples were two orders of magnitude below levels deemed deleterious to marine organisms, which are encapsulated in its permit limit.

Radionuclides

As with the trace metals and metalloids described above, the presence of measurable alpha (α) and beta (β) radioactivity within the MBCSD effluent samples is commonplace. The regular detection of radionuclides within MBCSD effluent samples arises 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. As such, they incorporate 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 2017 effluent sample were well within drinking-water standards.

The low decay levels measured within the July 2017 effluent samples were typical of most prior effluent samples and of naturally occurring sediments of the region. Alpha particle activity arises from natural mineral deposits that enter the collection system through erosion. Beta particle activity arises from radioactive decay in both natural and man-made materials.

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, a complete description of sludge production and disposal activities covering 2017 was submitted by the MBCSD to the USEPA, RWQCB, and SLO EHS (MBCSD 2018). That letter-report and its eight attachments are incorporated in this annual monitoring report by reference. The disposition of the 161 dry metric tons of biosolids generated by the WWTP during 2017 is briefly summarized in this Section. This Section also discusses the major chemical compounds that were found within the biosolids produced by the plant, because they lend insight into the performance of the WWTP and because they determine the suitability of biosolids for composting and land application (MRS 2017c).

2.3.1 Solids Treatment Process

Solids removed by the clarifiers (Figure 2.3 on Page 2-12) are processed as shown in the schematic of Figure 2.14. Sludge is stabilized within two mixed-primary digesters that heat the sludge to temperatures between 95°F and 98°F (35°C to 37°C). Heated sludge is transferred to a secondary digester with heat exchange from the primary digesters. Solids settle in the secondary digester and the supernate is returned to the wastewater treatment process. The sludge is transferred to solar drying beds. The primary digesters' capacities are 170,544 gallons and 191,500 gallons, and the secondary digester's capacity is 166,056 gallons, giving a total capacity of 528,100 gallons (2 megaL).

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 has an under-drain and decanting system that recirculates runoff through the treatment process. 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 removed from the WWTP. Biosolids storage times are generally less than one year.

On October 9, and 13 through 16, all 161.2 tons of biosolids in storage the WWTP were hauled to the Liberty Composting Facility, which operates under Solid Waste Information System Permit No. 15-AA-0287. The biosolids transferred to the Liberty Composting Facility were used for soil amendment after composting was completed at the facility. Prior to shipping, the MBCSD provided a Title 22 Certification for Non-hazardous Materials and a Class-B biosolid certification statement based in part on chemical analyses described below.

2.3.2 Chemical Compounds

In compliance with the Monitoring and Reporting Program, chemical analyses were conducted on a composite of biosolid samples collected from the drying beds on 23 August 2017. Those beds contained all 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 (2017c). They are compared with regulatory limits in Table 2.6 on the following page.

The data in the table show that biosolid contaminant concentrations were significantly less than regulatory thresholds that would designate them as hazardous, or that would 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. Dry-weight concentrations for all detected metals in the biosolid

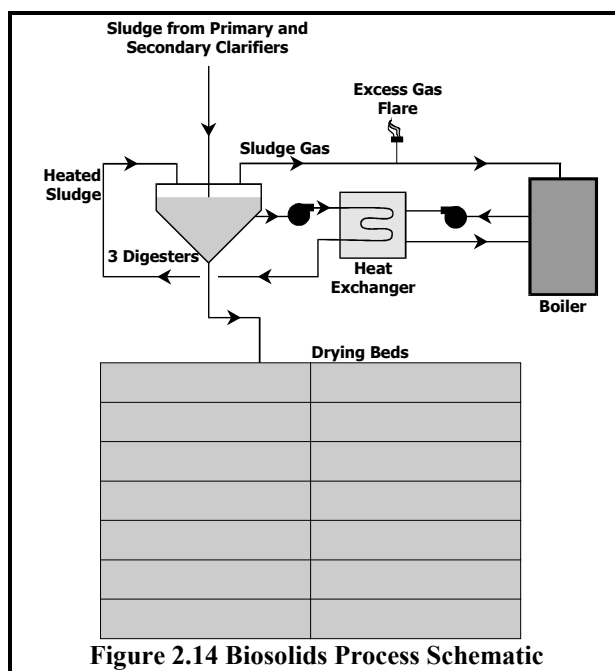


Figure 2.14 Biosolids Process Schematic

sample were well below the federally-mandated thresholds, including the monthly limit for materials suitable for agricultural land application (as represented in the three right-most columns of Table 2.6). The other compounds listed in Table 2.6 further characterize the biosolids, as mandated in the waste discharge requirements. Additionally, a modified WET test (STLC) for Hexavalent chromium and total dissolved solids was conducted in response to a request from the composter.

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	%	84.4	— ⁶	—	—	—	—	—
Cyanide	ppm	2.0	—	—	—	2.4	—	—
Antimony	ppm	≈1.3 ⁷	—	15.	500.	≈1.5	—	—
Arsenic	ppm	1.4	—	5.	500.	1.7	41.	75.
Barium	ppm	210.	—	100.	10,000.	250.	—	—
Beryllium	ppm	≈0.13	—	0.75	75.	≈0.16	—	—
Boron	ppm	10.	—	—	—	12.	—	—
Cadmium	ppm	0.97	—	1.	100.	1.2	39.	85.
Chromium (Total)	ppm	27.	—	560.	2,500.	32.	1,200.	3,000.
Chromium (Hexavalent)	ppm	≈2.8	ND	5.	500.	≈3.3	—	—
Cobalt	ppm	≈2.3	—	80.	8,000.	≈2.7	—	—
Copper	ppm	160.	2.9	25.	2,500.	190.	1,500.	4,300.
Lead	ppm	12.	—	5.	1,000.	15.	300.	840.
Mercury	ppm	0.33	—	0.2	20.	0.39	17.	57.
Molybdenum	ppm	7.5	—	350.	3,500.	8.9	18.	75.
Nickel	ppm	17	—	20.	2,000.	20.	420.	420.
Selenium	ppm	4.0	—	1.	100.	4.8	36.	100.
Silver	ppm	1.0	—	5.	500.	1.2	—	—
Thallium	ppm	ND	—	7.	700.	ND	—	—
Vanadium	ppm	13.	—	24.	2,400.	15.	—	—
Zinc	ppm	460.	—	250.	5,000.	540.	2,800.	7,500.
Hydrogen-Ion	pH	6.48	—	—	—	—	—	—
Phosphate	ppm	44,000.	—	—	—	52,000.	—	—
Ammonia	ppm	2,800.	—	—	—	3,300.	—	—
TKN	ppm	14,000.	—	—	—	16,000.	—	—
Organic Nitrogen	ppm	11,200.	—	—	—	12,700.	—	—
Nitrate as NO ₃	ppm	1,400.	—	—	—	1,600.	—	—
Oil & Grease	ppm	16,000.	—	—	—	20,000.	—	—
Total Dissolve Solids	ppm	—	3,100.	—	—	—	—	—

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 10 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).

3.0 RECEIVING WATER QUALITY

This chapter describes environmental conditions within the ocean waters immediately adjacent to the MBCSD wastewater discharge during 2017. 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. It addresses how plume dispersion is influenced by the hydraulic design of the outfall and by the 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 during 2017 (MRS 2017defg) 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 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 2017 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 that the observed perturbations were small compared to the natural variability in seawater properties observed along this portion of the central California coast. Based on the high initial-dilution levels measured during the surveys, maximum end-of-pipe contaminant concentrations allowed by the NPDES permit would be expected to achieve the receiving-water objectives of the COP with a large margin of safety. 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 2017, and for the past three decades, the receiving-water monitoring program has included requirements for quarterly offshore surveys conducted near the wastewater discharge within northern Estero Bay, and 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 and potential aesthetic impacts.

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 highly 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 embodied in the COP. These objectives, summarized in Table 3.1 on the following page, ensure the reasonable protection of beneficial uses and prevention of nuisances. 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 can cause the density of the effluent plume to approach that of ambient seawater (neutral buoyancy) at some point in the water column. Depending on the degree of water-column stratification at the time of discharge, the plume either can reach the surface or can 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 diluted 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 a previous NPDES permit was issued in 1999 (RWQCB–USEPA 1998b). Prior to 1999, the effluent plume was rarely observed in the instrumental measurements and when it was, its lateral extent was largely indeterminate. This was partially due to the widely spaced water-sampling stations that, at the time, coincided with the benthic sampling pattern. Additionally, the earlier NPDES 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 76 surveys conducted since the beginning of 1999.

Further improvements to 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 navigational precision permitted accurate delineation of the plume's spatial extent, which is important for assessing compliance with water-quality objectives because they only apply to that portion of the plume that lies beyond the ZID. With that in mind, the receiving-water monitoring program in the current NPDES 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 instrument package, commonly referred to as a CTD,¹ was used to collect precise *in situ* measurements of seawater properties during each of the four quarterly receiving-water surveys of 2017. Measured seawater parameters consisted of temperature, salinity, dissolved oxygen (DO),

¹ Conductivity, temperature, and depth (CTD)

acidity/alkalinity (pH), and light transmittance (transmissivity or water clarity). Qualitative visual observations made during the offshore surveys provided ancillary 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 state, were also noted.

In addition to the quarterly sampling used to delineate the discharge plume offshore, regular monitoring of the adjacent surfzone along Atascadero State Beach has historically been conducted to assess aesthetic conditions conducive to the site-specific beneficial uses described in Section 2.1.3. 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). Therefore, the current NPDES permit no longer requires regular monitoring of surfzone bacteria, but triggers monitoring at eight surfzone locations along Atascadero State Beach only 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 2017, as in prior years, no instances of elevated effluent coliform triggered the requirement for surfzone sampling.

Table 3.2 Target Locations of Surfzone Sampling Stations

Station	Description	Along-Shore Distance ¹ (m)	Latitude ²	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 designated for this coastal area include fishing and non-water-contact recreation, consisting of beachcombing, boating, and picnicking. These uses were addressed by visual observations of aesthetic conditions, which were documented during the offshore surveys conducted in 2017. Other 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.

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

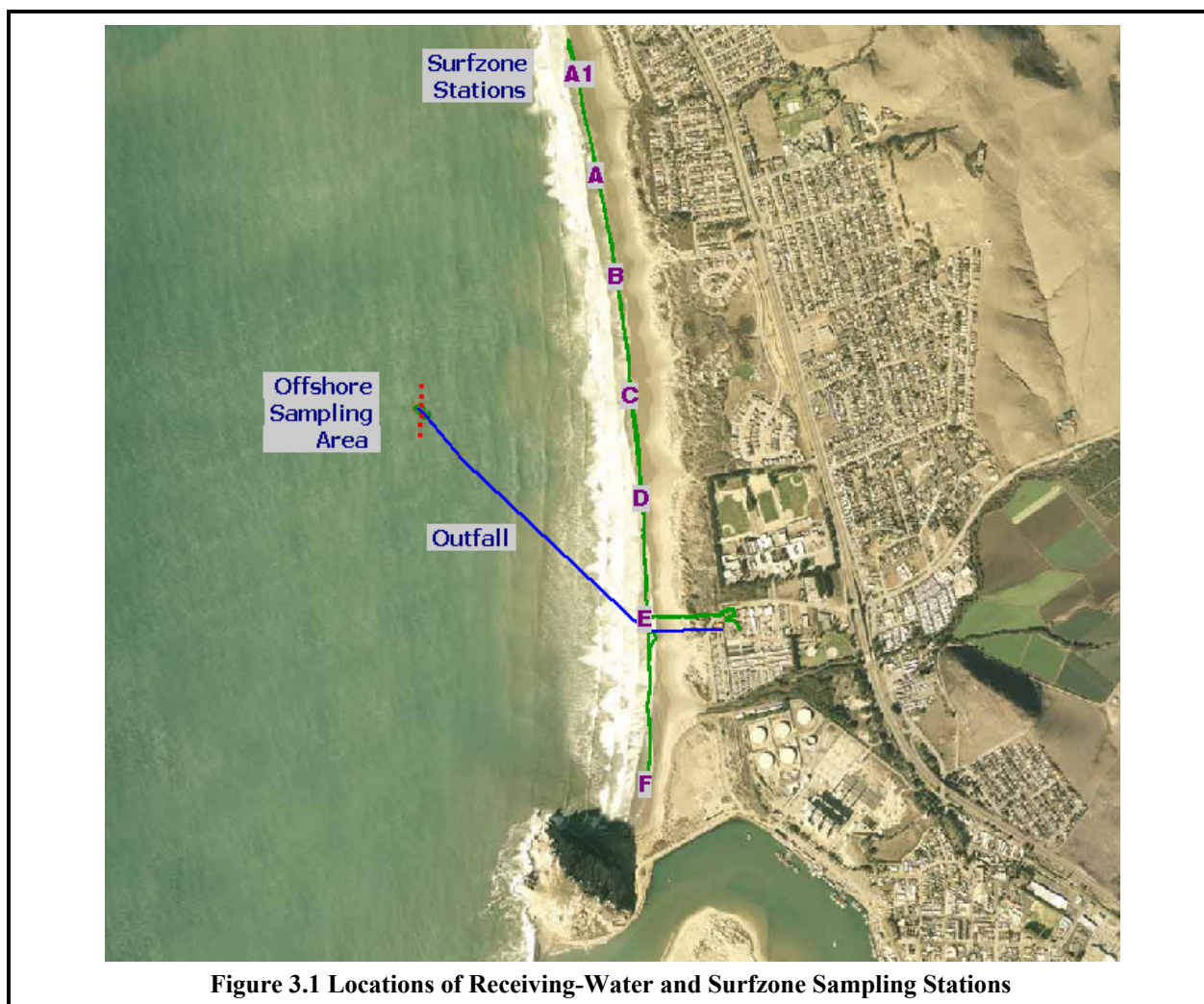


Figure 3.1 Locations of Receiving-Water and Surfzone Sampling Stations

3.1.3 Sampling Station Design

Offshore receiving-water sampling focuses on the water column close to the discharge location (Figure 3.1). The beginning 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.

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 dilute effluent rapidly within the receiving seawater immediately upon discharge. Most of this turbulent mixing occurs within a zone of initial dilution (ZID), which by regulatory assertion alone, 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 implausible. 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 2017, vertical seawater measurements were recorded at six offshore stations situated at three gradient distances upcoast and downcoast from the ZID (Figure 3.2). The sampling pattern was designed to evaluate the discharge's region of influence during each quarterly water-quality survey. 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. 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 inappropriate to design a nearfield sampling pattern based solely on center-point distances rather than closest-approach distances.

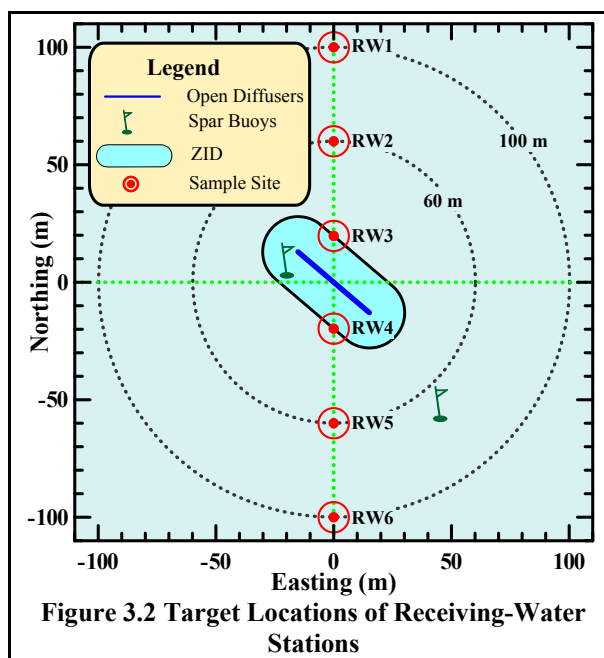


Figure 3.2 Target Locations of Receiving-Water Stations

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

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

¹ Distance from the closest open diffuser port

² Distance to the center of the open diffuser section

diffuser ports (Table 3.3). Stations RW2 and RW5 were located at nearfield distances (60 m) from the diffuser center point, which positioned them 49.4 m from the closest diffuser port. 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 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 diametric stations quantify discharge-induced 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 improved markedly with the advent of Differential Global Positioning Systems (DGPS). DGPS, with typical position errors of less than 2 m, significantly enhances the accuracy of traditional GPS navigation systems, which have position errors as large as ± 15 m, a span equaling 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 accurately 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 seastates, drift is induced by residual vessel momentum remaining after station approach. Prior to the use of DGPS, these offsets could not be reliably resolved by the available navigation, but, during the 2017 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 2017 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 distances 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 slightly beyond the ZID boundary, namely, at distances

Table 3.4 Station Proximity to the Discharge

Station	Description	Closest-Approach Distance ¹ (m)				
		Target	March	May	September	October
RW3	Upcoast ZID	15.0	9.5²	14.7	16.6	24.6
RW4	Downcoast ZID	15.0	14.5	12.1	12.1	12.8
RW2	Upcoast Nearfield	49.4	51.3	50.8	47.1	46.5
RW5	Downcoast Nearfield	49.4	55.3	53.9	48.6	48.4
RW1	Upcoast Midfield	88.4	88.3	87	85.8	93.9
RW6	Downcoast Midfield	88.4	91.1	94.6	90.9	88.7

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

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

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 thus lend timely insight into the dispersive capabilities of the outfall. These close-in measurements have demonstrated that the MBCSD discharge routinely meets the COP receiving-water objectives within the ZID and well before completion of the initial dilution process.

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 2017. Douglas Coats of Marine Research Specialists (MRS) supervised scientific operations as Chief Scientist, and provided data-acquisition and navigational support during all the surveys. He also assisted with the deployment and recovery of the CTD and drifter, and collected meteorological measurements at each station. Crewmember William Skok managed deck operations and collected Secchi Depth measurements at each station.

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 handheld Holdpeak 866B Digital Thermo-Anemometer.

Auxiliary Measurements

After collection of vertical CTD profiles, each station was re-occupied and 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 sea-surface observations described above, were ancillary to the digital measurements of seawater parameters collected by the CTD throughout the water column.

At the beginning of each survey, a drifter was deployed near 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 to aid in the interpretation of seawater property distributions.

Instrumental Measurements

A Sea Bird Electronics SBE-19plusV2 CTD instrument package was used during all four of the 2017 surveys. It was deployed in both a vertical water-profiling mode, as well as a horizontal-tow configuration. It collected measurements of conductivity, temperature, light transmittance, dissolved oxygen (DO), pH, and pressure at a sampling rate of 4 Hz (0.25-second intervals). Submersible pumps on the CTD continuously flushed water through the conductivity cell and oxygen plenum at a constant rate, independent of the CTD's motion through the water.

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

Component	Depth ¹	Units	Range	Accuracy	Resolution
Housing (19p-1a; Acetron Plastic)	680	m	0 to 680	—	—
Pump (SBE 5P)	3400	—	—	—	—
Pressure (19p-2h; Strain-Gauge)	680	dBar	0 to 680	±1.7	± 0.10
Conductivity	3400	Siemens/m	0 to 9.0	± 0.0005	± 0.00005
Salinity	3400	‰	0 to 58	± 0.004	± 0.0004
Temperature	3400	° C	-5 to 35	± 0.005	± 0.0001
Transmissivity (WETLabs C-Star) ²	2000	%	0 to 91.3 ³	± 0.3	± 0.03
Oxygen (SBE 43)	200	%Saturation	0 to 120	± 2	—
pH (SBE 18)	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 tow phase of the surveys. Additionally, during the vertical-profiling phase, they quantified layering, or vertical stratification and stability of the water column, which affects 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 SBE-19plusV2 CTD system was placed into service in mid-2011 and offers many advantages over the other CTD in the MRS equipment inventory, an SBE-19 Seacat. That unit was successfully used for two decades in previous MBCSD surveys. 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. The probes and sensors on the current CTD also have a much faster response time, further enhancing the spatial resolution of seawater properties. Finally, the probes and sensors on the current CTD unit are more stable and exhibit negligible long-term drift. As a result, and in accordance with the manufacturer's recommendations, the current CTD package does not require regular recalibration of the sensors prior to each field survey. However, these instrumental improvements and operational differences did not materially affect the temporal compatibility among datasets collected before and after the new CTD was commissioned and placed into service.

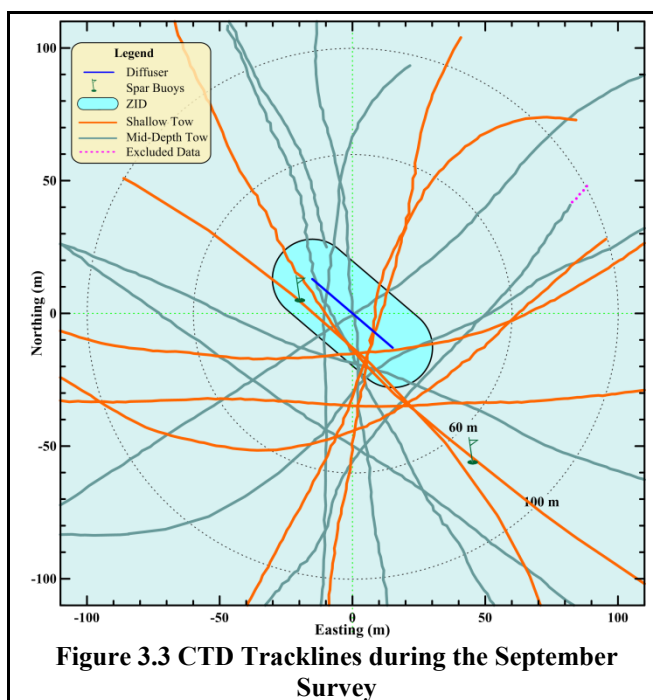
¹ Maximum depth limit in meters

² 25-cm path length of red (660 nm) light

³ The transmissometer was calibrated to yield 100% transmission in air, and the maximum transmission of 660nm light in pure water is 91.3%.

After the drifter was deployed during the 2017 surveys, the CTD was held below the sea surface for several minutes for equilibration as the survey vessel was positioned for the first mid-depth tow transect. Prior to deployment, the CTD package had been configured for horizontal towing with forward-looking probes. The protective cage around the CTD was fitted with a horizontal stabilizer wing and a depth-suppression weight was added to the towline to achieve near constant-depth tows. During this first deployment, the CTD was 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. Monitoring of real-time sensor output was used to evaluate the CTD's progress and adjust the tow depth, which was accomplished by small adjustments to vessel speed.

An example of the tow pattern, from the third-quarter survey, is shown in Figure 3.3. During each of the four surveys in 2017, eight-to-nine transects of mid-depth were collected at a speed near 2 m/s over the span of approximately 40 minutes (blue-green lines in Figure 3.3). Subsequently, eight-to-nine additional passes were made with the CTD at a shallower depth (orange lines). At the observed towing speeds and the 4 Hz sampling rate, at least two CTD measurements were collected for each meter traversed. This complies with the NPDES discharge permit requirement for minimum horizontal resolution of at least one sample per meter during at least five passes around and across the ZID at two separate depths, one within the surface mixed layer and one at mid-depth within the thermocline. Contemporaneous navigation fixes recorded onboard the survey vessel were adjusted for CTD setback and aligned with time stamps on the internally recorded CTD data. The resulting data for the six seawater properties were then processed to produce high-resolution horizontal maps within the upper mixed-layer and sub-thermocline portions of the water column.



Following completion of the last shallow transect, the CTD package was brought aboard the survey vessel and reconfigured for vertical profiling. The CTD was then redeployed and held again beneath the surface to equilibrate while the vessel was repositioned for the first vertical profile. The CTD was then raised to within 0.5 m of the sea surface and profiling commenced. The CTD was lowered at a continuous rate of speed to the seafloor. Measurements at all six stations were collected during a single deployment of the CTD package by towing it below the ocean surface while transiting between adjacent stations. Upon retrieval of the CTD, 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 2017defg) and digitally archived within the USEPA STORET database using their Water Quality Exchange (WQX) framework.

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 seawater properties. However, a complex suite of physical oceanographic processes induces wide variation within the ambient seawater properties near the outfall. This variability makes detection of the relatively minor discharge-related changes challenging. Because of this, the significance of potential discharge-related impacts is evaluated by comparing the amplitude of excursions caused by the presence of dilute wastewater constituents against the inherent variability in ambient seawater properties. Statistically speaking, if the amplitude of the effluent anomaly is small compared to the expected range in ambient seawater properties, then the water-quality impact caused by the discharge 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 upon discharge from the diffuser structure.

The final two subsections describe oceanographic processes that affect ambient seawater properties within northern Estero Bay and how those properties vary as a result of changes in the oceanographic processes. Quantitative measures of natural-variability are used to establish thresholds for determining whether discharge-induced changes are large enough to impact the beneficial uses of the receiving waters significantly. Regional processes induce major fluctuations in the character of the receiving waters near 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.

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 This flow rate applies when 34 ports are open, with a total flow of 0.340 m³/s (7.76 MGD) through the diffuser structure. The outfall design capacity is 0.358 m³/s (8.17 MGD).

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 with light-blue shading in Figure 3.2 on Page 3-6. 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. Based on these dimensions, the ZID covers an ocean surface area of approximately 3000 m² and contains 12 million gallons of seawater. At the nominal discharge rate of 1 MGD, it would take twelve days for the wastewater discharge to fill a volume equal to the ZID.

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 currents carry the effluent plume well beyond the boundaries of the idealized ZID, long before it achieves buoyant equilibrium and well before initial mixing is complete. Nevertheless, because wastewater is rapidly diluted upon discharge, the water-quality objectives of the COP are consistently met, almost immediately upon discharge and well within the boundary of the ZID.

3.2.2 Critical Initial Dilution Ratio

During the first few minutes after discharge, wastewater dilution is determined by the physical characteristics of the diffuser system and stratification within the receiving waters. This initial rapid mixing occurs within the ZID, and close to the diffuser structure. There, the turbulent processes associated with the high-velocity discharge jets emanating from each diffuser port, and the buoyant rise of the effluent plume through the water column, entrain seawater and 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 worst-case 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. Applying this in 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 within wastewater is restricted to 1.34 mg/L, or 134 times the seawater objective of 0.01 mg/L. Specifically, 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 COP receiving-water objective will be met. This demonstrates how the maximum effluent (end-of-pipe) limit on cadmium concentrations (1.34 mg/L) was established in the NPDES discharge permit granted to the MBCSD.

The foregoing calculation also reveals how strongly the assumed initial dilution influences the wastewater limitations that are specified in the NPDES discharge permit. Because an unusually low value was specified for the critical initial dilution (133:1), conservative wastewater limitations were established for the MBCSD discharge. As discussed in Section 3.3.1, however, direct observations recorded close to the diffuser indicate that dilutions much higher than 133:1 were achieved well within the ZID and below the 6.4-m plume-trapping depth identified in the dilution model. 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 ejection velocity and the associated turbulent mixing rate achieved by individual diffuser ports.

Additionally, the model assumed that the receiving waters at the point of discharge were unrealistically stratified. The stringent vertical stratification profile used in the modeling is not representative of the receiving-water conditions 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 excessively stratified due to the influence of the thermal discharge from the Morro Bay power plant.¹ 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 3-5).

Because this southernmost 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 an artificially stratified profile from this station. The model predicted that the receiving waters would trap the effluent plume 6.4 m below the sea surface, which is unnaturally deep because of the unrealistic density profile used in the model. Accordingly, more recent dilution modeling demonstrates that with weaker vertical stratification representative the water column near the diffuser, a critical initial dilution of approximately 200:1 with a plume trapping depth of 1.4 m best characterizes the worst-case outfall performance (Lindstrom 1998). These recent dilution modeling results are consistent

¹ The plant has not operated for several years and is now permanently closed by its current owner, Dynegy Corporation. However, at the time the original initial dilution modeling was performed, it was discharging a large volume of heated seawater north of Morro Rock.

with the observations collected in field surveys conducted since the inception of the MBCSD offshore monitoring program, including the results described in this report.

Nevertheless, even with dilutions of only 133:1, the highly sensitive instruments on the CTD have a difficult time detecting the direct influence of the dilute wastewater constituents, 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.

These large-scale, along-shore current flows are 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 along the central California coast.

These open-ocean flow processes heavily influence the character of, and variability in sea-surface water 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 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 California coast undergoes less seasonal variation than surface waters at similar latitudes along the eastern seaboard.

The northward flowing Davidson countercurrent lies along the continental slope and shelf immediately shoreward of the California Current. It carries more saline and less oxygenated seawater from the Southern California Bight. The Davidson Current exhibits marked seasonal variability in its flow depth

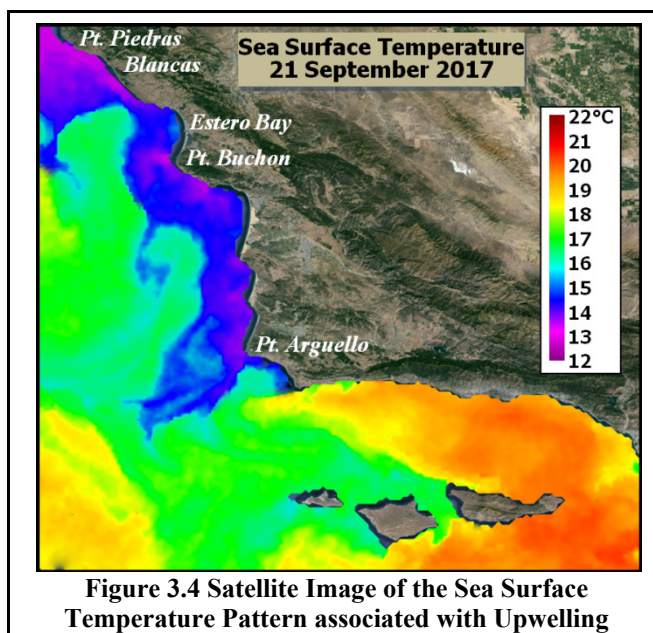
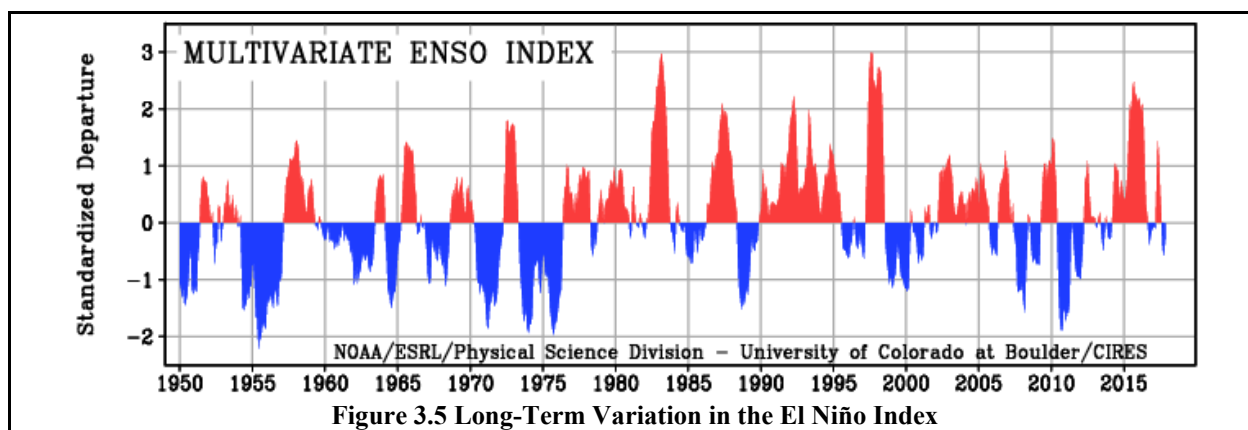


Figure 3.4 Satellite Image of the Sea Surface Temperature Pattern associated with Upwelling

and intensity that is driven by 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 winds cause upwelling along the coastline, which produces the distinctive surface cooling shown in satellite imagery (dark blue and purple shading in Figure 3.4). During these periods, the northward flowing Davidson Current remains at depth, and forms an undercurrent. When the northwesterly winds relax, usually between December and February, the Davidson Current strengthens and can extend to the sea surface.

The spring transition back to strong southwestward winds typically occurs rapidly between March and May, and relegates the Davidson current to the deep offshore waters. Despite reversals observed elsewhere along the California Coast, the Davidson current maintains a sustained subsurface northward flow in the waters offshore Estero Bay (Coats et al. 1991). During the upwelling season, when strong northwesterly winds cause widespread upwelling along the central California coast, warm surface seawater near the coast is transported offshore by the prevailing winds. At these times, upwelling draws the deep Davidson seawater shoreward along the seafloor, and its distinct properties are often observed in the lower water column within in the MBCSD survey area. The Davidson watermass consists of cold, saline, low-DO, and nutrient-rich seawater that is brought northward from the southern California bight with the undercurrent.

On longer time scales, significant inter-annual fluctuations in oceanographic properties and marine fauna have also occurred along the central California coast, and have strongly influenced the waters of Estero Bay. The sequence and magnitude of these long-term events over the last half-century are captured in Figure 3.5. The warm-seawater fluctuation is called 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. The red excursions in Figure 3.5 reflect times when El Niño conditions prevail, while La Niña conditions are shown in blue.



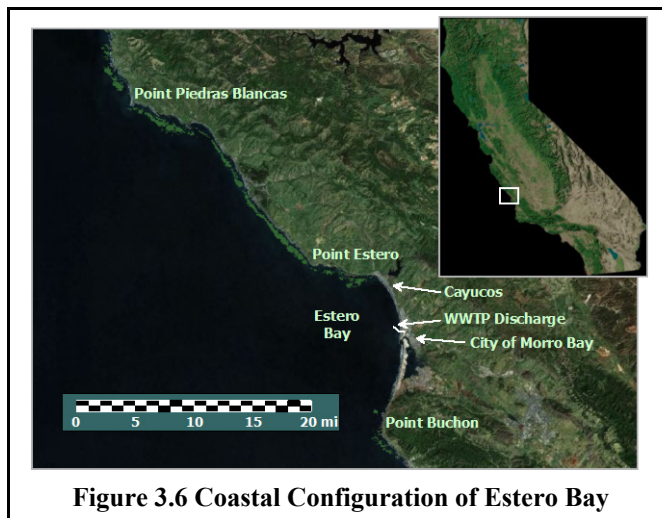
The El Niño event that was occurring in the year before the 2017 survey (rightmost red region in the Figure) ranks among the top three events of the last half-century. During strong El Niño periods, basin-wide changes in the dynamic balance of wind-driven currents result in modified flow patterns along 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.

Conversely, 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 North America, Peru, and Ecuador to intensify, and causing a reduction in sea surface temperatures throughout the Eastern Pacific Ocean, 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. However, the rainfall pattern does not always correlate with the long-term ENSO index. The exceptionally large rainfall amount experienced within southern California at the beginning of 2017 coincided with the onset of a La Niña event, while the intense El Niño event in the years prior to that time, coincided with a prolonged drought in California.

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. Some of these cross-shore turbulent features are evident in the complex surface-flow pattern depicted in satellite images. For example, in Figure 3.4, upwelling-induced reductions in coastal sea-surface temperature, delineated in shades of dark blue and purple, stretch southward along the coast. South of Pt. Piedras Blancas, Pt. Buchon, and Pt. Arguello, offshore-directed jets carried the cool water offshore. These types of cross-shore flow features are capable of transporting significant quantities of coastal heat, nutrients, and pollutants to offshore waters (Savoie et al. 1991). As these features extend offshore, they are entrained within eddies and swirls that bend the jets in various directions.

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 and result in water-level changes that are a significant fraction of the 15.2 m MLLW depth at the outfall location. Typically, however, the tidal range near the outfall site is approximately 1 m between mean high and low water. Even so, variation in tidal levels among surveys account for noticeable differences in the number of 0.5-m depth bins reported for the standardized vertical datasets.

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 distant North Pacific storms generate episodic swell events that can travel great distances. 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 3.6). When shoaling waves are large, this wave-generated littoral cell can extend well offshore into Estero Bay, and encompass the MBCSD discharge location.



Four primary meteorological sources generate waves along the south-central California coastline: 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 within northern Estero Bay, while the last two generate swells from the south, which are diminished near the outfall site by the sheltering effects of Point Buchon (Figure 3.6).

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 eastward 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 3-3), 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 NPDES 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 more sophisticated comparison between field measurements and numerical thresholds that reflect the natural variation in transmissivity, DO, and pH within the receiving waters surrounding the outfall. The 30-year record of quarterly receiving-water surveys conducted as part of the MBCSD monitoring program provides the necessary insight to rigorously establish compliance thresholds based on natural temporal and spatial variation in ambient seawater properties close to the outfall.

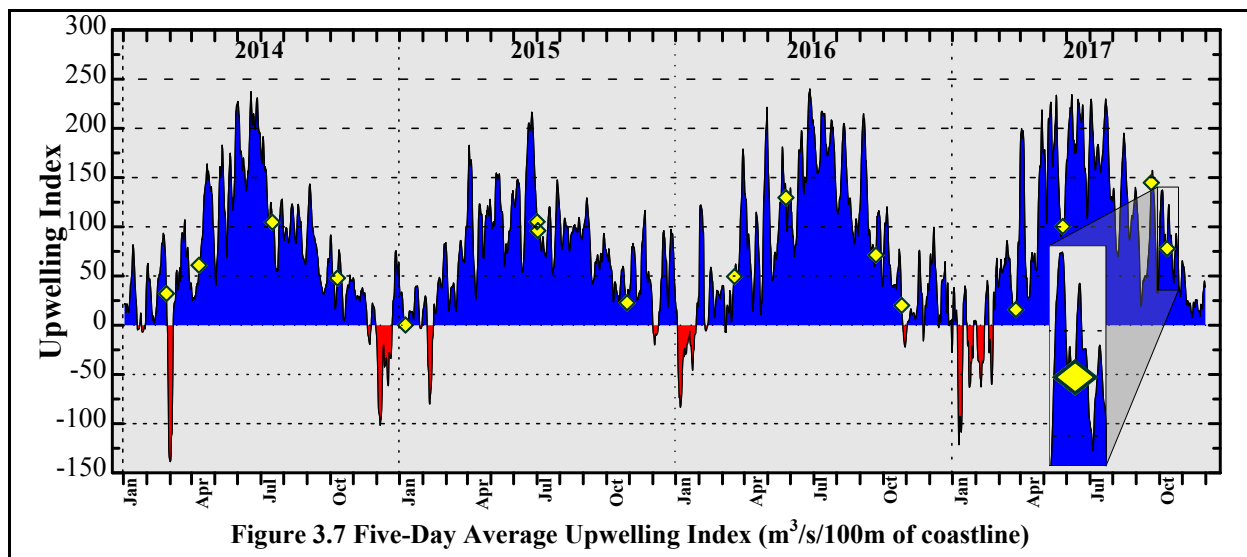
Natural variation in seawater properties is driven by a varying combination of the oceanographic processes described in the previous section. These processes determine the range in ambient seawater properties caused by spatial variation within the survey region at a given time (e.g., vertical stratification), 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 thus are subject to the compliance evaluation, from changes that arise because of the upward transport 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 can create a 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 2017 (Table 3.8). The Table shows that the upwelling intensity that prevailed at the time of each survey tended to influence the strength of the stratification.

Table 3.8 Oceanographic Conditions during the Quarterly Receiving-Water Surveys

Conditions	March (winter)	May (spring)	September (summer)	October (fall)
Tide	Ebb	Flood	Flood	Slack – Flood
Wave Height (from)	3-4 NW	2-3 NW	3-4 NW	1-2 NW
Flow Direction (toward)	SSE	N	SSE	NNE
Flow Speed (cm/s)	8.9	6.6	10.5	0.5 – 3.4
ZID Residence Time (min)	2.9	3.9	2.3	7 – 53
Stratification	Moderate	Strong	Strong	Limited
Water Clarity	High	Moderate	High	Low
Upwelling	Weak	Intense	Intense	Weak
Plume Visible	No	No	No	No
Plume Signature	Yes	Yes	Yes	Yes

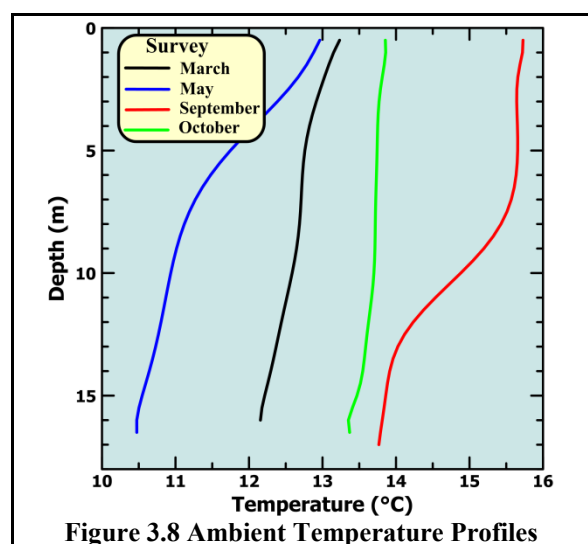
All four of the 2017 surveys were conducted when some degree of upwelling and water-column stratification was present. Blue shaded areas in Figure 3.7 represent times when northwesterly winds prevailed near Estero Bay, driving surface waters offshore, and inducing upwelling near the coast. The yellow diamonds identify the upwelling intensity at the specific time of the individual receiving water surveys. As seen in the figure, receiving-water surveys over the last several years have generally been



conducted during periods of moderate upwelling. During 2017, however, both the March and October surveys were conducted when upwelling winds relaxed shortly after an intense wind event.

During late fall and winter, upwelling is typically weak, and occasionally downwelling events, indicated by the negative (red shaded) indices in Figure 3.7, occur when passing storms temporarily reverse the normal wind pattern and drive surface waters shoreward. As the surface waters approach the coastline, they downwell, producing nearly uniform seawater properties throughout the water column. An unusual series of severe winter storms at the beginning of 2017 produced multiple downwelling events (refer to the red downward excursions in the upwelling index during January and February 2017). Downwelling displaces deep watermasses offshore, where they no longer provide a nearshore vertical contrast with surface seawater properties, and a uniform (unstratified) water column is produced within the survey area.

The degree of stratification during each of the quarterly surveys in 2017 is reflected by the four ambient temperature profiles shown in Figure 3.8. The profiles are averages of data measured at locations unaffected by the discharge plume. During the March and October surveys (black and green lines), when upwelling was minimal, seawater temperature was nearly uniform throughout most of the water column. In contrast, vertical temperature differences exceeding 1.9°C were present within the water column during the May and September profiles (blue and red). Over half of the 2.5°C temperature change during the September survey occurred across only 4 m of depth change. This sharp thermocline separated the warmer seawater within the surface mixed layer above 8 m from a deep cold watermass below 12 m. This colder watermass was transported shoreward from deep offshore by intense upwelling that prevailed at the time of the survey. The resulting temperature profile is typical of intense upwelling conditions when north-westerly winds along the central California coast



drive surface waters offshore, allowing cooler, denser, saltier, and oxygen-poor water at depth to migrate shoreward along the seafloor to replace it.

Although upwelling is recognized as the primary driver behind the productive fisheries of the central California coast, its persistence can also result in depleted oxygen levels within the bottom waters of Estero Bay. Within the euphotic zone in the upper water column, upwelling conditions facilitate phytoplankton blooms that produce oxygen and consume carbon dioxide. However, as phytoplankton die and fall to the seafloor, their decomposition consumes oxygen within deep offshore water masses. Over a period of time, DO levels within the submerged seawater can become depleted due to the absence of recent atmospheric equilibration. When upwelling processes transport this deep watermass shoreward and into the survey area, markedly reduced DO concentrations are occasionally observed near the seafloor. During the May survey, DO levels measured in ambient seawater at depth dropped to as low as 5.4 mg/L, and approached the Basin Plan limit of 5 mg/L. In prior years, DO concentrations within ambient seawater at depth fell well below the Basin Plan limit (MRS 2011).

3.3 COMPLIANCE EVALUATION

This section evaluates the significance of potential receiving-water impacts from MBCSD effluent discharged in 2017 through a comparison 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 NPDES 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 in seawater properties. 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.

These analyses of data collected during 2017 demonstrate that the MBCSD discharge complied with the NPDES discharge permit, as has been the case for the prior quarter century of high-resolution monitoring. Moreover, although observations within the ZID are not subject to compliance evaluations, they often meet the prescribed limits because dilution levels routinely exceed the conservative design specifications assumed in the NPDES 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 2017.

3.3.1 Screening for Applicability

Evaluating whether any of the 46,364 receiving-water measurements collected during 2017 exceeded a permit limit can be a complex process. For example, apparently significant excursions in an individual seawater property are usually unrelated to the presence of wastewater constituents, and instead are 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).

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?	5,567	40,797	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?	40,258	539	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?	539	0	Temperature
		539	0	Transmissivity
		539	0	DO
		539	0	pH

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 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 2017 dataset eliminated 5,567 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 NPDES discharge permit also 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 to anomalies that arise from the movement of ambient seawater that becomes entrained in the rising effluent plume. Analyses of high-quality 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

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

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, low 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 being diluted to levels substantially greater than the 133-fold critical initial dilution assumed in the NPDES 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 associated salinity reduction. By rearranging Equation 3.1, the dilution ratio (D) can be computed from the salinity anomaly ($A = C_o - C_s$) as follows:

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

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 salinity of the effluent-seawater mixture (C_o). After dilution, C_o is nearly constant and close to that of ambient salinity (C_s). Consequently, its variation can be neglected in the equation and, to a close approximation; dilution levels are directly proportional to the inverse of the salinity anomaly itself (A). Thus, reduced effluent dilution at a given location within receiving waters is directly reflected by a larger-amplitude salinity anomaly.

The smallest reduction in salinity that can be reliably detected within receiving waters is 0.062‰, which reflects a dilution level of 542-fold when substituted into Equation 3.2. This plume-detection threshold was determined from a statistical analysis of the naturally occurring 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 40,797 observations that were measured outside the ZID during 2017 surveys determined that only 539 measurements were associated with 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, 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 2017 (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	May	September	October
Temperature (°C)	>13.94	>13.75	>16.58	>14.59
Transmissivity (%)	<58.0	<64.9	<64.4	<64.1
DO (mg/L)	<5.90	<4.11	<4.79	<6.16
pH (minimum)	<7.885	<7.743	<7.900	<7.968
pH (maximum)	>8.149	>8.258	>8.276	>8.218

The thresholds of natural variation for each water property were established using a two-step procedure analogous to the guidance in 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 individual survey during 2017, 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 when fluctuations could be deemed a significant departure from natural conditions 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 only on potentially significant anomalies caused by the presence of wastewater constituents themselves.

Application of these thresholds to the temperature, pH, and DO concentrations associated with the 539 remaining measurements of potential compliance interest were all well within their respective ranges of natural variability (Table 3.9, Question 3). As such, the screening procedure unequivocally eliminated those measurements from further consideration.

Because of the high performance of the treatment process and diffuser system, the screening procedure described above usually eliminates all the measurements collected in a given survey from further consideration in the compliance analysis. This is often the case, regardless of whether samples were collected within the ZID or were associated with low salinity anomalies. Among the 46,364 samples collected during the four 2017 surveys, none of the seawater properties exceeded the natural variability thresholds listed in Table 3.10. Consequently, the same outcome would have been achieved had the screening procedure consisted of the third Screening Question in Table 3.9 alone. This was the case even though 1,389 of the observations were unequivocally found to contain dilute wastewater as indicated by a salinity reduction that ranged significantly beyond salinity fluctuations associated with ambient seawater. As noted in Table 3.9, 539 of these statistically significant salinity reductions were located beyond the ZID boundary.

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. These provisions are derived from three regulatory documents: the Central Coast Basin Plan, the COP, and by reference, the California Thermal Plan. An additional quasi-quantitative threshold on Secchi depth measurements can be developed from 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 adding the COP allowances to the thresholds of natural variability listed in Table 3.10. After applying these allowances, the permitted range in wastewater-induced excursions in DO and pH encompass a slightly broader range (*cf.*, bottom three rows of Table 3.10 and Table 3.11). However, because none of the 539 DO and pH measurements that were left after applying the first two screening questions in Table 3.9 exceeded the natural variability thresholds, all of these measurements were also in compliance with the less-restrictive COP receiving-water objectives. In fact, none of the 46,364 receiving-water measurements of DO and pH collected during 2017 exceeded each survey’s respective natural variability threshold, much less the less-stringent numerical limits listed in Table 3.11.

Table 3.11 COP Limits on Discharge-Related Changes to Seawater

Water Property	March	May	September	October
Temperature (°C)	>16.14	>15.94	>18.78	>16.79
Transmissivity (%)*	<58.0	<64.9	<64.4	<64.1
*Applicable Depth (m)	0-8	0-8	0-8	0-6
DO (mg/L)	<5.31	<3.69	<4.31	<5.55
pH (minimum)	<7.685	<7.543	<7.700	<7.768
pH (maximum)	>8.349	>8.548	>8.476	>8.418

Although the COP remains silent regarding allowable thermal change, it incorporates the California Thermal Plan (SWRCB 1972) requirements by reference (COP Introduction §C.3). The Thermal Plan restricts temperature increases caused by new discharges to coastal water to be less than 2.2°C (4°F). As with DO and pH, a quantitative permit limit on temperature increases can be established for each survey (Table 3.11) by combining the Thermal Plan allowance with the natural variability thresholds listed in the first row of Table 3.10. As with DO and pH, none of the 46,364 receiving-water temperature measurements collected during 2017 exceeded each survey's respective natural variability threshold, and thus, all of the measurements also easily complied with the Thermal Plan's limits. In fact, maximum temperatures measured within the rising effluent plume were uniformly below that of the surrounding seawater because cooler seawater near the seafloor had been entrained in the plume shortly after discharge. Consequently, any potential thermal impact resulting from the discharge of warm wastewater was almost immediately eliminated upon discharge because the effluent entrained much colder seawater.

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 (second row of Table 3.11) match the lower bound of the natural transmissivity range applicable to each survey (second row of Table 3.10). However, the transmissivity limits only pertain to a portion of the water column. Specifically, the penetration of ambient sunlight is largely restricted to the euphotic zone, which extends to twice the Secchi depth. Thus, the quantitative limits on transmissivity reductions only apply within the depth range of the euphotic-zone listed after the asterisk in Table 3.11.

For example, a turbid benthic nepheloid layer (BNL) sometimes forms immediately above the seafloor during upwelling events. Such was the case during the May 2017 survey (MRS 2017e) when localized reductions in water clarity arose from naturally occurring surficial sediments and light flocs of detritus that were suspended within a 2-m thick BNL. When it occurs, the BNL is widespread, and is a natural phenomenon unrelated to the particulate discharge from the diffuser structure. Regardless, because the transmissivity decrease within the May-2017 BNL was located below 14.5 m, it had no effect on the transmission of natural light that only penetrated to a depth of 8 m at the time of the survey (Table 3.11).

In addition to determining the extent of the euphotic zone, Secchi depth measurements provide an independent assessment of potential discharge-related impacts to natural light penetration. However, the Secchi depth's measure of light transmission is far less precise than the instrumentally recorded transmissivities used in the screening procedure. Secchi depths are determined visually, by lowering a standard-sized disk into the water column, and noting the depth at which it disappears. Because of the somewhat subjective nature of the measurement, Secchi depths are generally only reported to the nearest 0.25 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 inside or outside of the survey vessel's shadow.

Nevertheless, statistical hypothesis tests can be applied to the measurements to determine whether there are potentially significant reductions in average Secchi depths measured close to the diffuser structure (Table 3.12). For each of the four surveys, the tests found that any perceived reduction in the transmission of natural light was too small to be of statistical significance at the 95% confidence level. Although the 4.0-m average nearfield Secchi depth was slightly less than the 4.4-m reference-station average during the September survey (Table 3.12), the differences was too small to be resolved given the inherent measurement error in the Secchi depth measurements and the few number of observations (degrees of freedom).

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

Survey	Nearfield ¹	Reference
March	4.0	4.0
May	4.0	4.0
September	4.0	4.4
October	3.8	3.5

Specifically, a one-tailed two-sample t-test assuming equal variances found no statistically significant reduction in the nearfield mean depths at the 95% confidence level ($p > 0.08$).² More importantly, the 0.4 m reduction found among mid-field stations during the September survey arose because high-speed currents carried the rising discharge plume to mid-field Stations RW5 and RW6, where the plume's water clarity was higher than the surrounding seawater within the upper water column (MRS 2017f). Because the plume had entrained less-turbid seawater near the seafloor and transported it into the upper water column, Secchi depths measured at those stations were actually increased by the presence of the plume.

Basin Plan Limits

The COP limits, which are benchmarked to “*that which occurs naturally*,” allow adaption to seasonal and interannual changes in the ambient marine environment surrounding the outfall. In contrast, 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 may result in excursions in ambient seawater that range well beyond those limits.

Although none of the 2017 receiving-water observations ranged beyond the Basin Plan limits on DO and pH, the lowest measured DO of 5.4 approached the Plan's 5-mg/L lower-bound limit, and the highest measured pH of 8.2 approached the Plan's 8.3 upper-bound limit. Both of these extrema were measured within ambient seawater and well away from the influence of the discharge. These, and other past DO and pH measurements of ambient seawater within the survey area call into question the applicability of the fixed Basin Plan limits to ocean waters. In fact, published range-acceptability criteria that are used to assess the validity of CTD data in this and other California regional monitoring programs characterize seawater with DO concentrations as low 3 mg/L and with pH as high as 8.5 as being reasonable along the California mainland shelf.³ Not surprisingly, DO and pH concentrations measured within ambient seawater during past MBCSD surveys, have ranged well beyond the Basin-Plan limits.

For example, some or all of the measurements collected during the March and April 2010 surveys, the August 2011 survey, and the May 2013 survey significantly exceeded the Basin Plan's upper bound pH threshold of 8.3 units (MRS 2011, 2012, and 2013). In those cases, perfunctory application of the Basin Plan's pH threshold could have led to the incorrect conclusion that the discharge had caused an

¹ within 24 m of the diffuser structure

² As defined in the acronym list at the beginning of this report, the “*p*-value” determines the significance of any perceived difference in mean Secchi depths by testing it against a null hypothesis of no difference in means. It quantifies the probability that a perceived difference in mean depths 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.

³ Table 3 in the field operations manual for the Southern California Bight Study (SCBFMC 2002)

unacceptable increase in pH. In reality, the pH levels were the result of regional phenomena that were not particularly unusual within ambient seawater along the California coast.

As with pH, DO concentrations within ambient seawater surrounding the outfall also occasionally fall outside the boundaries considered acceptable by the Basin Plan. Such was the case during the May 2014 survey when 266 observations ranged below the minimum Basin Plan limit of 5 mg/l (MRS 2015). As with the pH measurements, these DO observations were well within the range considered typical of ambient waters at the time of that survey, and therefore complied with the COP portion of the NPDES permit provisions. The low DO concentrations arose because the deep watermass that was transported shoreward and into the survey area by upwelling was naturally depleted in oxygen. DO concentrations below 5 mg/L have been observed in a number of past water-quality surveys in conjunction with prolonged upwelling events (MRS 2011, 2012, 2013, and 2014). On a statistical basis, natural variability in DO concentrations during May and September 2017 surveys could be expected to range as low as 4.11 mg/L (Table 3.10), which is well below the 5 mg/L Basin Plan limit. Nevertheless, those levels would be considered perfectly acceptable under the COP regulations, which would have allowed DO levels as low as 3.69 mg/L during the May 2017 Survey (MRS 2017e).

Clearly, DO and pH variations beyond their respective fixed limits were simply not envisioned for coastal ocean waters when the Basin Plan was promulgated in 1972. The fixed Basin Plan limits were largely designed for discharges to onshore surface waters (e.g. streams and lakes), where little natural variation in DO and pH is expected. 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 redundant but also inappropriate. For these reasons, this annual report as well as past monitoring reports (MRS 2011, 2012, 2013, 2014, 2015, 2016, and 2017a) have recommended removal of the Basin Plan limits from future MBCSD discharge permits (see the recommendation in Section 5.4).

The Basin Plan also limits temperature excursions to those that will not adversely affect beneficial uses (P3 in Table 3.7). As documented by the response to Question 3 in Table 3.9, however, the presence of dilute wastewater particulates beyond the ZID exerted no perceptible thermal influence during 2017 and thus, could not have affected any of the beneficial uses designated for the receiving waters surrounding the outfall.

3.3.3 Other Lines of Evidence

The screening procedure 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, all of the 2017 observations were summarily eliminated from further compliance consideration. However, within the eliminated measurements lies a body of additional evidence that further substantiates the finding that the receiving-water measurements recorded during the 2017 surveys complied with the limitations specified in the NPDES discharge permit. Three of these major other lines of evidence are described below: the high mixing performance of the outfall, the low discharge volume, and the high quality of the effluent that was discharged.

Abductive inference (Suter 2007) is a procedure for analyzing these varied lines of evidence. 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). Application of this “*best explanation*” approach to the water quality dataset 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 NPDES permit during 2017. In particular, it supports the finding that the localized presence of dilute wastewater constituents had no tangible effect on the ocean environment surrounding the outfall.

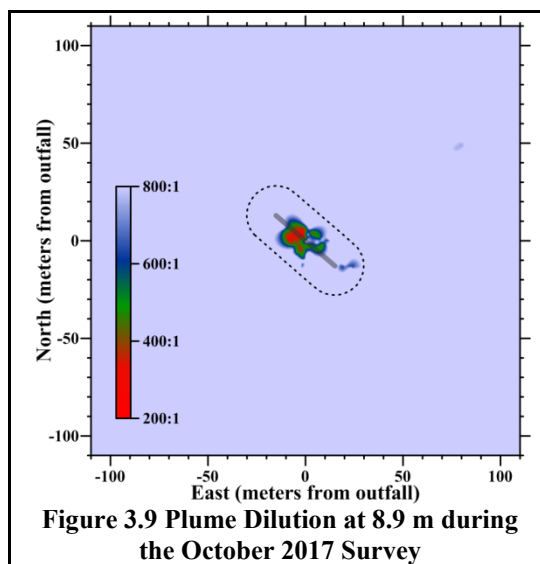
Mixing Performance

The high-spatial-resolution tow measurements recorded during 2017 demonstrated that even well within the ZID, wastewater was being diluted to levels far higher than expected from the dilution modeling. Although the screening procedure eliminates observations within the ZID because the permit limits do not apply there, these close-in observations foretell whether the outfall is capable of routinely meeting the 133-fold dilution necessary to achieve COP objectives that apply after completion of the initial dilution process.

Some of the lowest dilutions encountered during 2017 were recorded during the October survey at a location almost directly over the center of the diffuser structure (red shading Figure 3.9). The highly localized column of buoyant dilute wastewater was rising rapidly through an unstratified water column shortly after discharge. Salinity measurements collected after the plume had only risen 7.1 m documented the presence of wastewater that had been diluted 280-fold shortly after discharge and long before the initial dilution process was complete (MRS 2017g). Nevertheless, the measured dilution was double the 133:1 critical initial dilution used to establish limits on contaminant concentrations in MBCSD wastewater.

In addition, this minimum dilution was measured well within the ZID, near a diffuser port, and at a depth of 8.9 m, which was 2.5 m deeper than the 6.4-m trapping depth identified in the modeling that established the 133:1 critical initial dilution ratio. Based on its location, the initial dilution process had only just begun and, according to the conservative modeling results, dilution levels would be expected to be substantially less than 133:1 at that depth level. Instead, the measured dilution demonstrated that the diffuser structure was dispersing the effluent far more efficiently than predicted by the conservative initial-dilution model.

These measurements, and the large number of other measurements collected close to the diffuser structure during 2017, demonstrate that the COP receiving-water objectives were being routinely met by the limits on chemical concentrations within discharged wastewater that are promulgated by the NPDES discharge permit issued to the MBCSD. This includes measurements collected well within the ZID and before completion of initial mixing. All dilution levels measured throughout the year easily exceeded the 133:1 critical initial dilution used to establish end-of-pipe permit limitations on contaminant concentrations within wastewater discharged from the MBCSD treatment plant.



In addition, only slight salinity and density anomalies showed any indication of the presence of dilute wastewater constituents within the survey area during 2017. The absence of wastewater-induced signatures in other seawater properties was the direct result of the high dilution achieved within a few meters of a diffuser port, and the low contrast between effluent and seawater properties other than salinity. This supports the conclusion that changes to receiving-water quality caused by the discharge of MBCSD effluent was imperceptible against the backdrop of natural variation in temperature, transmissivity, DO, and pH.

Limited Discharge Volume

In addition to high dilution, the small volume of wastewater discharge further clarifies why wastewater constituents do not exhibit a perceptible influence on seawater properties, even shortly after discharge. As such, the limited discharge volume provides another line of evidence supporting the conclusion that the MBCSD discharge complied with permit limits designed to protect the beneficial uses of receiving waters.

Largely because of the small discharge volume, plume signatures observed during receiving-water surveys have been of limited lateral extent, and tended to be highly localized within the ZID surrounding the diffuser structure (dotted line in Figure 3.9). As discussed in Section 3.2.1, the reason for the small discharge footprint can be appreciated when the low MBCSD discharge rate is evaluated relative to the volume of seawater encompassed within ZID. At the 1 MGD average discharge rate in 2017, an entire day of discharge would only displace 8% of the seawater within the ZID, and it would take 14 days to fill the entire ZID volume. The MBCSD discharge's tiny fraction of the receiving-water volume pales in comparison to that of the vast majority of other municipal discharges to US coastal waters, some of which have discharge rates 200-times larger than that of the MBCSD WWTP.

In addition, because of the combined effect of low discharge rate and rapid dilution, plume measurements within the MBCSD survey area are almost always exclusively delineated by reductions in salinity alone. Excursions in other water properties caused by the presence of dilute wastewater constituents have never been observed except extremely close to the diffuser structure and within the ejection jet from an individual diffuser port. Although 5,567 CTD measurements were collected within the ZID during 2017, none was close enough to a diffuser port to discern the influence of wastewater constituents, other than by a reduction in salinity. Although anomalies in some seawater properties were apparent in the upper water column in conjunction with the plume's low salinity, they arose from the entrainment and upward displacement of ambient seawater rather than from the presence of wastewater constituents.

However, in 2015 (MRS 2016), a set of CTD measurements were collected within an ejection jet and provided a rare glimpse into the direct influence of wastewater constituents on water-property measurements. Small but perceptible increases in temperature, and reductions density, DO, pH, and transmissivity were captured as the CTD passed within 22 cm of a diffuser port. These coincided with the largest-amplitude salinity anomaly ever encountered in the MBCSD receiving-water quality database, and the associated 48:1 dilution was far lower than any previously encountered. These measurements demonstrated that the influence wastewater constituents on receiving-water properties, other than salinity, begins to disappear at a dilution close to 48-fold, and at a distance of less than 0.5 m from each diffuser port. Thus, the perceptible influence of the comparatively low-volume MBCSD discharge is restricted to a small region around each diffuser port, and does not materially comele with the discharge from adjacent ports, as is often the case with larger volume dischargers.

Effluent Quality

The consistently high quality of the MBCSD effluent provides another independent line of evidence that demonstrates why significant water-quality impacts would not be expected from the MBCSD discharge. Specifically, the high treatment level achieved by the MBCSD WWTP results in the removal of nearly all (90.0%) of the suspended solids and oxygen-demanding material (82.9%) from the wastestream prior to discharge (Table 2.2). The small residual amount of remaining material is then easily dispersed by the high-efficiency diffuser structure that discharges into the particularly well flushed, open-ocean environment within Estero Bay. As a result, the discharge would not be expected to contribute materially to turbidity within the dilute effluent plume; or to excursions in DO, pH, and temperature.

For example, oxygen-demanding material discharged by the MBCSD WWTP does not accumulate within seafloor sediments because the dispersive capacity of the energetic open-ocean environment of Estero Bay prevents wastewater particulates from settling near the outfall. Within the water column, organic-decay modeling demonstrates that the DO demand (BOD) within the MBCSD effluent would be less than 3 mg/L upon discharge (Page II-8 of MRS 2003a). After mixing 133-fold, the dilute BOD loading would induce a minuscule DO depression of no more than 0.022 mg/L. Because similar levels of BOD loading are typical of most ocean dischargers, the National Academy of Sciences (Page 9; 1993) determined that 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 1993).

The low potential for water-quality impacts from the MBCSD suspended-solids discharge can be demonstrated in a similar manner. As with DO, wastewater-induced turbidity is imperceptible except within a diffuser’s ejection jet. This is the case because of a combination of three factors, the low suspended-solid concentrations within the MBCSD effluent, the high dilution levels achieved shortly after discharge, and the large natural variability in the transmissivity of ambient seawater. This can be demonstrated quantitatively for each survey by projecting the transmissivity decrease that would result from the discharge of effluent with a TSS concentration equal to that measured onshore on the day of the survey (Table 3.13). After completion of the initial dilution process, the projected reduction in measured transmissivity due to effluent solids loading is projected to be 1.3% or less. This potential influence on receiving-water turbidity measurements is small compared to the observed range in ambient transmissivity, which, during the 2017 surveys, was at least six-times greater.

Table 3.13 Projected Transmissivity Reduction caused by Wastewater Particulates and the Background Transmissivity Range

Parameter	March	May	September	October
Initial Dilution	732	300	437	410
Effluent TSS (mg/L)	32	58	30	31
Transmissivity (%)				
Projected Reduction	0.3	1.3	0.5	0.5
Natural Range ¹	29.6	8.5	20.8	13.5

¹ Observed difference between the most extreme transmissivity measurements collected beyond the influence of the discharge

3.3.4 Visual Observations

Two remaining permit provisions (P1 and P2 in Table 3.7) 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 2017. These permit provisions are instead addressed by visual observations made during each of the surveys. The visual observations documented during the 2017 surveys found no evidence of these discharge-related impacts to the ocean surface.

3.4 BENEFICIAL USE

Additional visual observations compiled from the 2017 receiving-water surveys demonstrated that the coastal waters near the outfall and along adjacent shoreline continued to be beneficially used 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 pedestrians, equestrians, sailboats, 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*).

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 incorporates 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 larger outfalls serving more industrialized communities (Stull et al. 1986a); however, no such impacts have been found after more than three decades of intensive benthic monitoring around the MBCSD outfall. This includes the October 2017 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 11 October 2017. Physical properties of sediments are tabulated in Appendix C and laboratory chemistry results from the survey are provided 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 2017.

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 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 11 October 2017, 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 three decades 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.

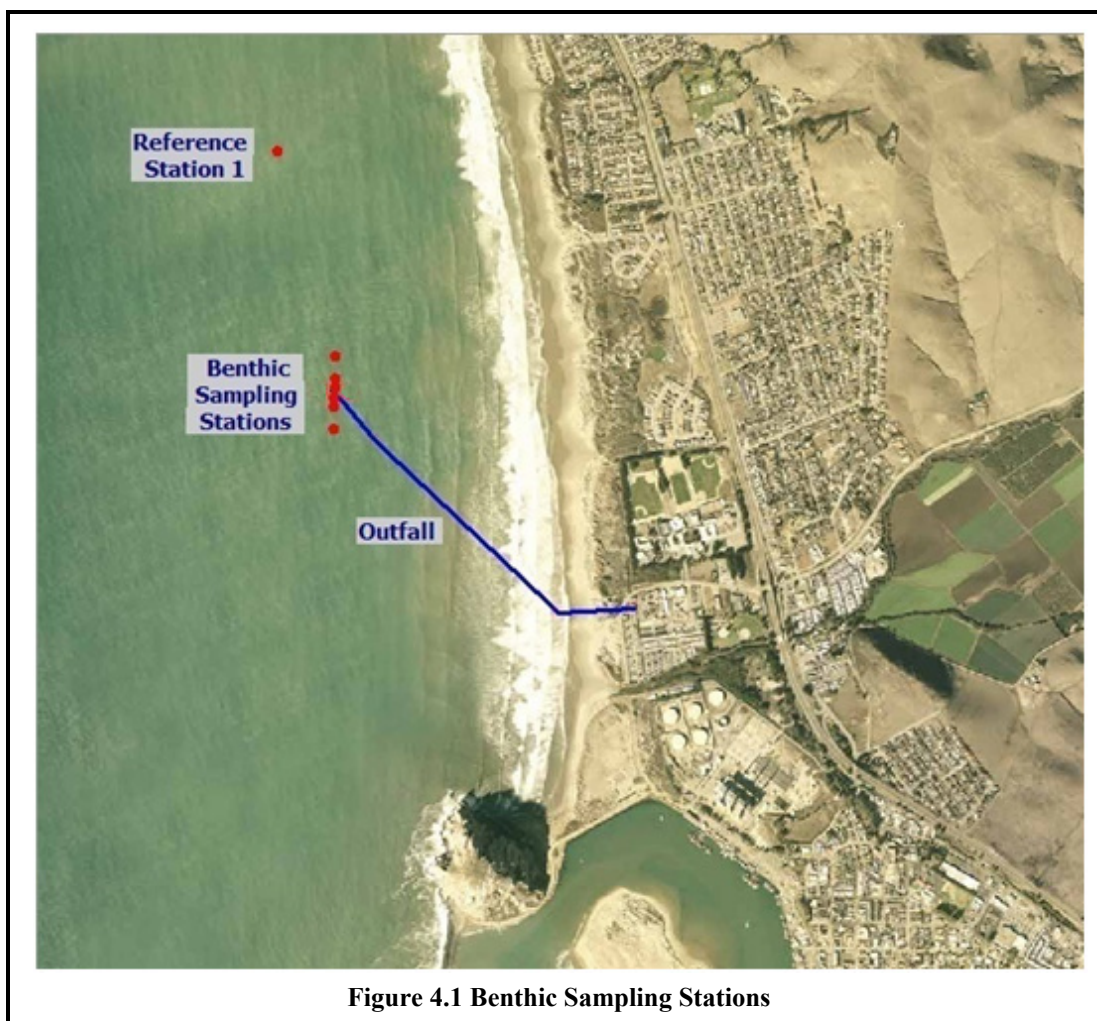


Figure 4.1 Benthic Sampling Stations

The discharge permit that was reissued in 1993 (RWQCB-USEPA 1993ab) also changed laboratory protocols. It required separate chemical analysis of each of the three replicate samples collected at the five Stations. Statistical analysis of the scatter in chemical concentrations measured within the replicate samples at each individual station quantified the within-station variability and quantified the power of the monitoring program to detect spatial differences among stations. In particular, this chapter's analysis uses 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 statistically 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 reissued 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 prior 23 years of benthic data, the current permit (RWQCB-EPA 2009), adopted in January 2009, also instituted several substantive 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 were homogenized into a single composite sample prior to analysis. This approach was found to mitigate 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 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. Irrespective of its lack of value in compliance evaluation, 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 at work within Estero Bay as a whole. Therefore, sampling for sediment parameters at Station B1 has been voluntarily continued for its scientific value alone.

4.1.2 Sampling Station Design

Benthic sampling during 2017 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 specified in the current NPDES permit 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). The locations of these two stations coincide with those of the receiving-water Stations RW3 and RW4 (Figure 3.2 in Chapter 3). Two additional stations (B3 and B6) are located at nearfield distances (60 m) from the center of the diffuser structure, and coincide with Stations RW2 and RW5. Finally, the midfield stations (B2 and B7) are

Table 4.1 Target Locations of Benthic-Sediment Sampling Stations

Station	Description	Latitude	Longitude	Distance (m)	
				Closest¹	Center²
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

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.

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 two nearfield stations (B3 and B6) were incorporated into the program in 1999, and improved the program's ability to resolve potential benthic impacts at intermediate distances (49 m) from closest point of effluent discharge.

The upcoast reference station (B1), midfield stations (B2 and B7), and ZID stations (B4 and B5) have all been regularly sampled throughout the 32 years of benthic monitoring. The extraordinarily long record of infauna, grain size, and trace metals collected at these five stations has provided valuable insights into previously unknown regional trends in benthic conditions. As mentioned above, 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. Although the regional trends are unrelated to the MBCSD discharge, their lengthy 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 those 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 Mark M. Tognazzini of Morro Bay, provided vessel support during the offshore survey. Dr. Douglas Coats of Marine Research Specialists (MRS) logged navigation fixes, and collected sediment subsamples for chemical assay. Cletis England, a biologist with MRS, sieved and processed infaunal samples. Dean Dusette, a compliance-monitor also with MRS assisted in benthic grab deployment and retrieval, in conjunction with Vessel Marine-Equipment Technician William Skok, who was responsible for overall deck 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 (Appendix 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 seafloor 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 the seafloor at each of the 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 Table E.1.

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

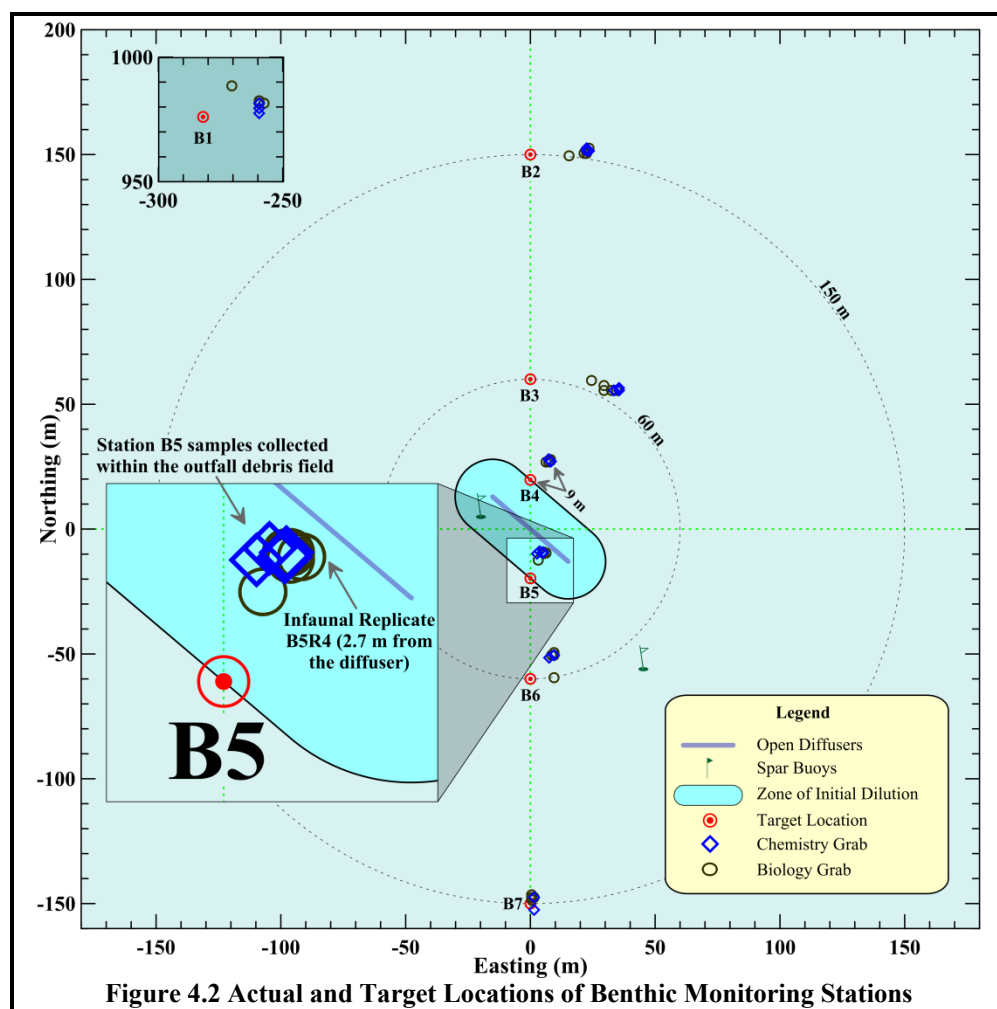
In addition to samples collected for sediment chemistry, five replicate grab samples were collected at each of seven benthic-monitoring stations for infaunal analyses. Upon retrieval of the grab, each sample was inspected for acceptability. Acceptance criteria are based on penetration depth, surface 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.

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

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 32-year benthic-monitoring program. The voucher collections contain specimens representative of each species 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 diamond) and infaunal (green circle) grabs, relative to each target location (red target shape) that were recorded during the October survey. As described in Chapter 3, a combination of factors often induces an offset in the actual grab locations relative to the target locations listed in Table 4.1. However, as opposed to the receiving-water stations, which are live-boated, the vessel is anchored during sediment grab sampling. As a result, the offsets in benthic sampling and target positions arise because the vessel swings about the anchor location along a scope of approximately 20 m. The ultimate vessel 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 some movement from anchor drag prior to dig-in.



The within-station position changes during the October 2017 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. In contrast to most prior surveys, metocean conditions were relatively consistent during the sampling at each individual station. As a result, all but the first of the eight grab-trip locations were extraordinarily tightly spaced, with an average offset of only 1.5 m from one another. The much larger offset (up to 12 m) in the first grab sample at Stations B1, B2, B3, and B6 (green-circles offset from each station group in Figure 4.2) arose because the sample was collected when the vessel had yet to settle into the initial anchor set.

As with the receiving-water data collection, regulatory and historical benthic sampling locations are only reported at a single position. In that spirit, Table 4.3 lists the average position of the eight grabs collected at each station. Although it is not possible to collect samples at the precise target locations, knowledge of the actual location where samples were collected allows the spatial offsets to be factored into the gradient analysis. Without the benefit of differential GPS navigation, most of these spatial offsets would never have been resolved. The enhanced resolution provided by differential GPS even lends insight into minute spatial differences between individual grab samples that would 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° 23.730' N	120° 52.676' W	999	1016	22
B2	Upcoast Midfield	35° 23.281' N	120° 52.490' W	143	153	22
B3	Upcoast Nearfield	35° 23.229' N	120° 52.483' W	64	65	32
B4	Upcoast ZID	35° 23.214' N	120° 52.499' W	26	28	11
B5	Downcoast ZID	35° 23.194' N	120° 52.501' W	4	11	11
B6	Downcoast Nearfield	35° 23.171' N	120° 52.498' W	39	52	12
B7	Downcoast Midfield	35° 23.119' N	120° 52.503' W	136	148	2

As with receiving-water-quality data, detailed knowledge concerning the actual grab locations collected at the two ZID stations is especially important. Benthic samples collected well within the ZID, such as those at Station B5 (see the inset in Figure 4.2), are not explicitly germane to an evaluation of the discharge's compliance with sediment-quality limitations promulgated in the COP. However, in contrast to seawater-quality stations that are collected within the ZID and close to the diffuser structure, benthic sampling near the outfall is complicated by the potential for diffuser damage from the anchor and chain, or from the grab sampler itself. During any given survey, an anchor set on one of the target ZID locations (e.g., Station B5) can result in grab samples collected uncomfortably close (<7 m) to the diffuser structure, while grab samples at the other ZID station are located well outside (>9 m) the ZID boundary (Station B4 sampling locations in Figure 4.2). At the other stations that are more-distant from the diffuser structure, fidelity to the target locations is less important, as are concerns about damage to the outfall from the grab sampler. Because of these concerns, and because the intensity of metocean conditions were expected to increase as the 2017 survey progressed, Stations B4 and B5 were sampled first to optimize grab-sample positioning near the diffuser structure.⁴

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

⁴ Grab trip times are listed in Table C.1 of Appendix C.

Nevertheless, during the 2017 Benthic Survey, both the infaunal and chemical replicate samples collected at Station B5 were located well within the ZID and immediately adjacent to the open section of the diffuser structure (see inset in Figure 4.2). All but two of the 12 grab attempts had trip locations within 4 m of the edge of the diffuser where a debris field immediately surrounding seafloor structures is typically encountered. The outfall's debris field was also encountered at Station B5 during surveys conducted in 2000 and 2010 (MRS 2001 and 2011), and the 2010 annual report contained a detailed characterization of the biology of the debris field at varying distances from the outfall structure. That analysis demonstrated that the debris field was comprised of organic material and shell hash that had accumulated within the seafloor sediments as epifaunal organisms sloughed from the structure or were purposely dislodged by divers during periodic cleaning. The spatial analysis demonstrated that the degree of sediment alteration was limited to a highly localized 4-m-wide corridor immediately surrounding the outfall and increased rapidly with outfall proximity within that corridor.

The Station-B5 samples collected very close to the diffuser structure during the 2017 survey reconfirmed the highly localized nature of the greatly altered sediments within debris field. As described in the rest of this chapter, samples collected within about 3 m of the structure exhibited substantial differences in their physicochemistry and biology. For example, slightly higher biochemical oxygen demand (BOD) and total volatile solid (TVS) concentrations indicated the presence of increased sub-surface organic material associated with decaying epifauna (see Section 4.2.2 on Page 4-24). In response to the disturbed nature of the sediments, the Station-B5 infaunal community was also measurably different from that of other stations, and contained sub-surface detritus feeders typical of degraded seafloor conditions found in hypoxic environments (see Section 4.3.5 on Page 4-56). In particular, however, the fourth successful infaunal grab sample (B5R4) was collected only slightly closer to the outfall (2.7 m in the inset of Figure 4.2). It contained a suite of infauna that perceptibly departed from that of the all the other 2017 replicate samples, including the other Station B5 replicate samples.

4.1.4 Benthic Analysis

A wide variety of physical, chemical, and biological parameters was determined from the 57 sediment samples collected during the October 2017 survey.¹ This chapter 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 2017 survey were analyzed for moisture content, grain size, organic properties, and eleven trace metals. The organic-loading parameters, oil and grease (O&G), TVS, total Kjeldahl nitrogen (TKN), and 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.

¹ Fifty seven instead of the normal 56 samples were collected during the 2017 benthic survey. As noted in Table C.1 of Appendix C, an extra, fourth chemistry grab sample was collected at Station B5 because it was needed to fill the chemistry sample container. The presence of numerous large sand dollars within the grabs limited the volume of sediment available for collection and processing. This was especially true at Station B5 because the samples were collected very close to the diffuser structure.

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

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, such as drifting kelp, has resulted in erroneously high levels at some stations in previous surveys. Specifically, Station B9 in 2000, and various stations prior to 1995 (Figure 4.9b on Page 4-28) 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 also 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) concentration, below which toxic effects are not expected, and an effects-range median (ERM), above which adverse biological effects are anticipated. 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 (e.g. 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, mud concentrations have 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 within 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. Therefore, 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 within 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. In addition, 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 32 years of MBCSD benthic monitoring, 266,000 specimens representing 392 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 (Hurlbert 1971, 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 ZID proximity, which are evaluated using standard statistical hypothesis tests, must be interpreted carefully. Table 4.4 lists the infaunal indices computed in this chapter. The associated algorithms and guidance on how to interpret them are presented in Appendix B.1.

Table 4.4 Infaunal Parameters Evaluated in the Monitoring Program

• 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)
--	---

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 those 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 an indication of deleterious impacts to seafloor sediments resulting from the MBCSD discharge, including during 2017. 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 (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 2017 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 during 2017 bore no consistent relationship to outfall proximity. Third, sediment concentrations do not exhibit long-term trends that suggest a buildup of contaminants along the ZID boundary.

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 32 years of continuous benthic monitoring, there has never been an indication of discharge-related degradation of marine organisms within Estero Bay. In large part, this is due to the consistently low chemical concentrations within the discharged effluent (Chapter 2), and the rapid dispersion effluent experiences shortly after discharge (Chapter 3). 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 by benthic contaminant levels that are well below concentrations measured in the majority of 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 chapter to evaluate sediment chemical concentrations measured during 2017. 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 chapter to determine the potential for marine biological impacts from all but one of the chemical concentrations that were measured within Estero Bay during 2017. 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 their concentrations are regularly 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, including synthetic compounds.

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 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. In addition, 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 within 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 (>98%; Table 4.5; Appendix Table C.3), iron- and aluminum-normalized concentrations are assessed instead.

Table 4.5 Grain-Size Distribution (%) within Sea-floor Sediment Samples Collected on 11 October 2017

	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	0.71	1.12	97.74	0.14	0.15	0.15
Station B2	0.44	0.90	98.51	0.14	0.01	0.00
Station B3	0.45	0.88	98.47	0.17	0.02	0.00
Station B4	0.58	0.83	98.41	0.13	0.02	0.02
Station B4 ¹	0.61	0.95	98.30	0.11	0.03	0.00
Station B5	0.59	0.85	98.31	0.11	0.03	0.10
Station B5 ¹	0.65	0.92	98.28	0.13	0.01	0.01
Station B6	0.65	1.06	98.06	0.15	0.05	0.04
Station B7	0.50	0.77	98.35	0.22	0.10	0.06
Mean ²	0.57	0.92	98.28	0.14	0.04	0.02

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. Additionally, the overall character of the grain-size distribution reflects the dynamics within a particular benthic environment. For example, 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, the predominance of sand-sized particulates in the grain-size distributions within the 2017 sediment samples reflects the high-energy environment near the outfall.

The sediment samples collected during October 2017 consisted of very-well-sorted³ fine sands with a distribution skewed slightly toward the finer fractions⁴ (Appendix Table C.4). During 2017, mean particle diameters ranged from 143 (Station B1) to 162 μ m (Station B5), 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 ($0.323 < \sigma < 0.385$). 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

¹ Duplicate analysis of sediment sample

² Mean computed after arc-sine transformation

³ With an average standard deviation [σ (ϕ)] of 0.348, the sediments were very close to the very-well-sorted end of the well-sorted range between 0.5 (moderately sorted) and 0.35 (very well sorted)

⁴ Positive skewness ranging between 0.15 to 0.19 except at Station B1, where the much larger skewness (0.23) indicates a more significant fine-fraction weighting

fractions ($\leq 1\phi$) represented less than 0.25% of the total sample weight, except within the samples collected at Stations B1 and B5, which contained more surficial shell hash in the gravel size range, and at Station B7, which contained a slightly greater amount of coarse sand (Table 4.5). At most stations, the largest fractions consisted mainly of fragments of shell hash and the remains of sand dollars that were randomly distributed on the surface of sediments throughout the region. As described below, the presence of surficial shell hash and coarser sediments is characteristic of scour pits around seafloor structures. This accounts for the greater amount (0.1 %) of gravel found in samples collected immediately adjacent to the outfall at Station B5, as well as their higher median grain size.

Undetected and Nontoxic Metals

During 2017, most trace-metal concentrations within sediment samples were either not detected or were below levels that are considered 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. The presence of cadmium and silver was not detected in any of the seven 2017 sediment samples, although they have been detected occasionally in prior monitoring surveys but at concentrations too low to be reliably quantified. Thus, the maximum potential concentrations for cadmium and silver (0.069 and 0.07 mg/Kg) were well below their respective lowest toxic-effects levels (ERLs of 1.2, and 1.0 mg/Kg) where biological effects can first become apparent, and far below the median effects levels (ERMs) where biological impacts are expected. Thus, even if cadmium and silver were present in Estero Bay sediments in concentrations consistently near quantifiable levels, they would be unlikely to affect marine organisms.

Table 4.6 Metal Concentrations (mg/Kg-dry) within Seafloor Sediment Samples Collected on 11 October 2017

Station	Aluminum	Arsenic	Cadmium	Chromium	Copper	Iron	Lead	Mercury	Nickel	Silver	Zinc
B1	6,900	3.0	<0.067 ¹	71	3.3	9,900	2.3	0.218	42	<0.07	17
B2	5,600	3.6	<0.069	45	3.3	8,500	2.3	≈0.056 ²	45	<0.07	15
B3	6,000	3.9	<0.066	44	3.7	9,000	2.3	≈0.033	51	<0.06	15
B4	6,200	3.9	<0.069	46	4.0	9,600	2.4	≈0.040	53	<0.07	16
B5	6,000	3.6	<0.068	44	4.0	9,200	2.2	≈0.027	57	<0.07	17
B6	5,300	3.9	<0.067	43	3.2	8,200	2.3	≈0.058	48	<0.07	14
B7	5,500	3.4	<0.068	43	3.0	8,500	2.0	≈0.055	44	<0.07	14
Mean³	5,900	3.6	<0.067	47	3.5	9,000	2.2	≈0.054	48	<0.07	15
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	—	6.0	0.2	26	11.1	—	9.9	—	28	0.2	42

¹ The “less-than” symbol (<) indicates that the substance was not detected at a concentration above the dry-weight-adjusted method detection limit (MDL), which is listed after the “<” symbol.

² The “approximation” symbol (≈) indicates that the reported concentration was too low to be reliably quantified; namely, 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)

Mercury also normally remains below detection levels, but was found within all of the 2017 sediment samples. While mercury concentrations were too low to be quantified at six stations, the unusually high concentration (0.218 mg/Kg) found at Station B1 was well above the quantification limit. Not only was this the first instance of a quantifiable mercury concentration within the monitoring database, it was four times higher than the quantification limit. More importantly, the measured concentration was well above mercury's ERL (0.15 mg/Kg) where biological impacts are possible but not expected. However, because the quantifiable mercury concentration was only found in a sediment sample collected at the distant reference Station B1, its occurrence was unrelated to the effluent discharge located 1 km to the south. Nevertheless, the sudden presence of elevated mercury concentrations within the normally pristine sediments of Estero Bay at levels of potential biological significance may be of concern for the wellbeing of regional benthic environment.

Two of the remaining eight metals, 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 the 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 regularly 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 throughout the central California coastal region. During 2017, as in previous years, five of these six metals had concentrations well below the ERL where biological effects can begin to become apparent (Table 4.6). Only the mean nickel concentration was above the ERL. Each of the six detected metals is described below.

Arsenic

Although present in measurable amounts (≤ 3.9 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. In comparison, approximately 75% of the area within the Southern California Bight (SCB) has arsenic concentrations exceeding the mean level measured in Estero Bay during 2017 (Schiff and Gossett 1998). After adjustment for the mean iron concentration, average arsenic levels would have to be 2.4 mg/Kg higher to be considered enriched relative to background concentrations in marine sediments to the south (SCB = 6.0 mg/Kg in Table 4.6).

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 of the entire south central-coast region, including within Estero Bay sediments. This enrichment is reflected in the 47-mg/Kg mean chromium concentration collected in samples surrounding the outfall during 2017, which is nearly double the 26-mg/Kg that would be considered impaired for sediments within the SCB (Table 4.6). However, chromium concentrations within all the 2017 sediment samples remained below the lowest toxicity benchmark where biological effects might first be observed. The highest concentration (71 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 one-eighth 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 also 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 analyses were 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).

The presence of higher chromium concentrations within central-coast sediments often leads to misinterpretation by regulators and scientists unfamiliar with the local mineralogy. For example, only around 25% of the SCB has sediments with chromium concentrations higher than those of Estero Bay. Most of this area of higher chromium concentrations lies within Santa Monica Bay, where a high mass-emission of contaminants from publicly owned treatment works occurred prior to 1988. However, elevated chromium levels were also observed within the Santa Barbara Basin in the northern reaches of the SCB. The SBC study speculated that those sediments were impaired as well, when the increased chromium concentrations were actually related to naturally occurring chromite ore within the same geologic formation that extended southward from the south-central California coastal region (Chow and Earl 1978). Their erroneous characterization of an impaired condition in the northern SCB was further invalidated by the 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. However, this assertion is 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 was observed in the decade prior to 2000. During that time, increases in chromium, arsenic, copper, and nickel that were unrelated to the MBCSD discharge (MRS 2010a) were documented throughout the Estero Bay region. 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 increases in marine sediment concentrations that were observed in the MBCSD monitoring program suggest that the erosion of these mineral deposits was accelerated by human activities, such as mining. As described by MRS (2000b, 2001), sediment samples collected in conjunction with a supplementary environmental project indicated that erosion around abandoned chromite mines was the likely cause for increasing 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 3.5-mg/Kg average copper concentration within marine sediments collected at the seven benthic-monitoring stations during 2017 is well below the 11.1-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 2017 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 (4.0 mg/Kg) was 67-times lower than the ERM level where adverse effects become probable.

Lead and Zinc

Lead and zinc concentrations within 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 is the only metal whose concentration within Estero Bay sediments consistently exceeds its ERL level (Table 4.6). In fact, none of the 282 samples collected during the more than three decades of benthic monitoring has contained nickel in concentrations less than the ERL of 20.9 mg/Kg. Additionally, twenty-three of the samples have had concentrations exceeding the nickel ERM of 51.6 mg/Kg where biological impacts to marine organisms would normally be expected to occur, including two samples collected during 2017. However, 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 the surfaces of fine-grained sediments, it is much more likely to affect organisms that ingest or come into contact with the sediments. Conversely, nickel that is bound into the mineralogy of larger sand grains, as is the case within MBCSD benthic monitoring area, has little influence on marine organisms.

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 persisted 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 incorrect 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 within the northern SCB to anthropogenic contamination.

Organic Loading

Organic-loading parameters including moisture content, mud fraction, BOD, and O&G measured in the sediment samples collected during 2017 (Table 4.7) were comparable to levels measured in most MBCSD benthic surveys. Although TVS concentrations measured within Estero Bay sediments after 2013 were perceptibly higher than in previous years, this may be an artifact of the large number of adult large sand dollars that were present during that time. In contrast to trace-metal concentrations, it is difficult to gauge the ecological significance of the organic-constituent concentrations measured during 2017, and in prior years, because there are no well-established biological effects levels for any of these parameters.

Table 4.7 Non-metal Concentrations (mg/Kg-dry)¹ within Seafloor Sediment Samples Collected on 11 October 2017

Station	Moisture (%)	BOD	Oil & Grease	TKN	Volatile Solids (%)
B1	22.1	54	— ²	180	1.99
B2	25.0	56	≈31	133	2.35
B3	21.3	52	≈27	165	2.26
B4	24.7	58	<28	173	2.35
B5	23.0	70	≈58	169	2.45
B6	22.7	61	≈27	181	2.23
B7	23.4	52	<27	144	2.26
Mean ³	23.2	57	<33	163	2.27

4.2.2 Spatial Distribution Unrelated to ZID Proximity

During 2017, as in previous years, the spatial distribution of sediment chemicals did not exhibit a pattern indicative of a benthic environment impaired by the MBCSD wastewater discharge. Specifically, there was no consistent evidence that chemical concentrations within sediment samples collected near the ZID boundary were elevated relative to those of distant sites. A gradient of steadily increasing contaminant concentrations with increasing ZID 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.

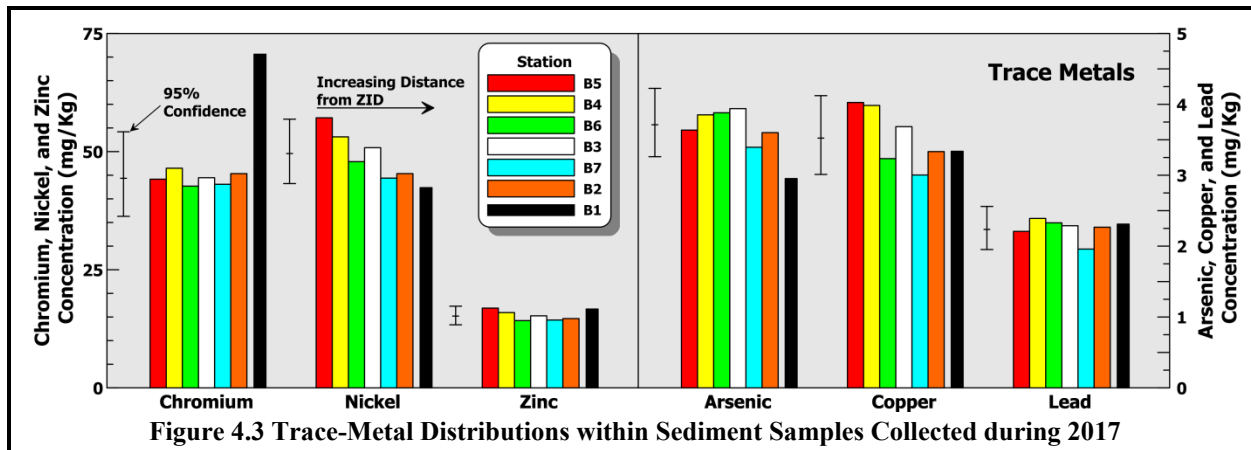
The bar charts in Figure 4.3 on Page 4-20 show trace-metal concentrations ranked by distance from the diffuser. Potential outfall-related impacts would appear as bar heights steadily decreasing from left to right in most, if not all of the trace metals. However, concentrations measured at the geographically distant Station B1, shown by the thinner, separate black bars in Figure 4.3, can be disregarded. As

¹ Unless otherwise indicated as “%”

² Sample not analyzed for O&G

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

described in the last paragraph of Section 4.1.1 on Page 4-3, sediment samples collected at Station B1 are considered irrelevant for compliance purposes because its benthic environment has been found to be materially different from that of the permit-required survey area surrounding the outfall.



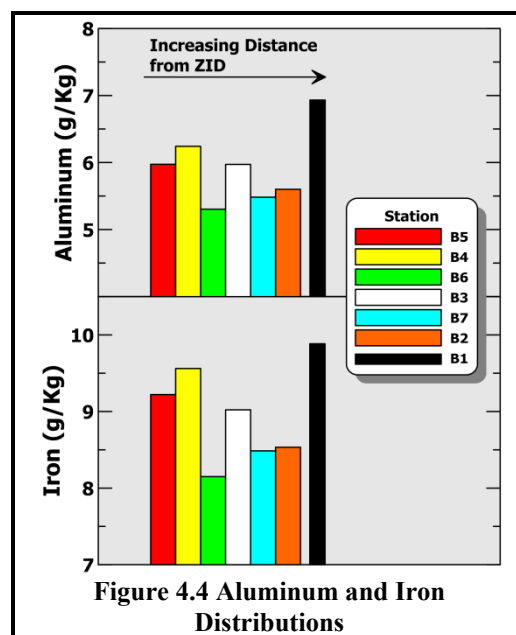
Visual inspection of the concentration sequences at the remaining sites shown in Figure 4.3 do not readily exhibit an enrichment gradient potentially related to outfall proximity, except for perhaps nickel, and possibly zinc and copper. Although concentrations for these and other metal concentrations may visually appear to generally decrease with increasing distance from the diffuser structure (left to right in the Figure), the gradients are so slight that the actual spatial differences among the stations were encompassed within the uncertainty in concentrations measured at individual stations. This uncertainty is quantified by the 95% confidence intervals shown to the left of each bar chart.¹ When all the measured concentrations for a specific metal lie within the 95% confidence interval associated with that metal, then any observed differences in concentrations among stations can be ascribed to inherent sampling variability, rather than to actual spatial changes in chemical concentrations within the sediments. Figure 4.3 shows that, during 2017, all of the individual metal concentrations measured within the survey area² were encompassed within their respective confidence interval.

Inherent sampling variability aside, some of the scatter in the raw metal concentrations may have also resulted from natural processes unrelated to the outfall discharge. As described in the last paragraph of the *Trace Metals* subsection within Section 4.1.4 on Page 4-9, the influence of natural processes on the distribution of sediment-metal concentrations are often reflected in the aluminum and iron distributions (Figure 4.4 on Page 4-21). Human activities have little influence on aluminum and iron concentrations within seafloor sediments and normalization by these concentrations is common practice in impact-assessment studies because it can reveal anthropogenic patterns that are otherwise masked by variability in background trace-metal concentrations. Similarly, they can eliminate spatial differences that may appear to be related to a discharge impact, when they are in fact due to natural variability.

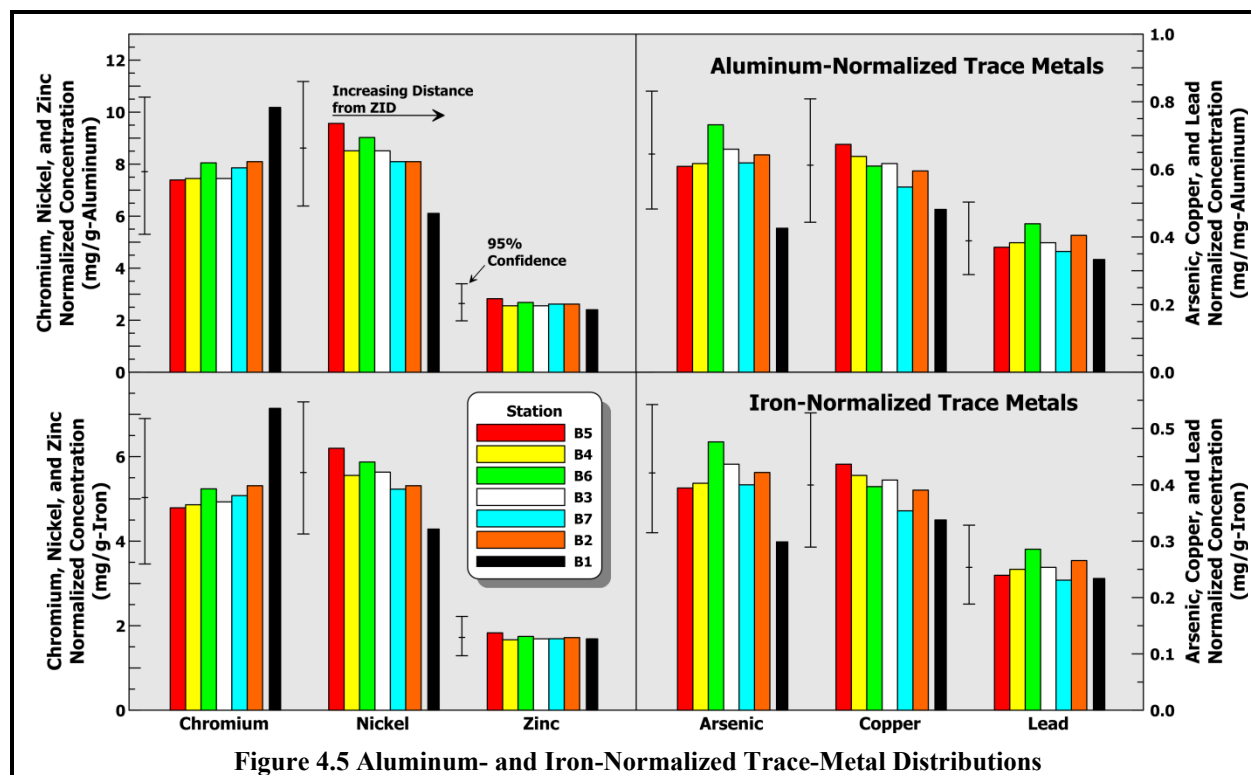
¹ The 95% confidence intervals reflect the inherent sampling uncertainty at any given station and were determined from the variability in concentrations found among three individual replicate samples collected and separately analyzed at each station during 1993 and 1994.

² As described previously, Station B1 is located far beyond the boundary of the survey area in a location where the benthic environment is measurably different. Not surprisingly then, metal concentrations measured in sediment samples collected at Station B1 regularly depart significantly from the average of the concentrations within the survey area. Depending on the metal, the Station B1 concentration can be well above (chromium) or slightly below (nickel and arsenic) the survey-area average.

The aluminum and iron spatial patterns shown in Figure 4.4 exhibit similarities to the distributions in Figure 4.3, namely elevated concentrations at Stations B5, B4, and B3 (red, yellow and white bars) compared to Stations B6, B7, and B2 (green blue and orange bars). As a result, normalization (Figure 4.5) tempers the variability in all of the metals relative to their respective confidence intervals. For example, the obvious Station-B1 outlier in raw chromium concentration (black bar in the left group of Figure 4.3) is well above its respective confidence interval, but after normalization by both aluminum and iron, its excursion is significantly moderated (Figure 4.5). Clearly, the much higher concentrations of both aluminum and iron at that station (Figure 4.4) suggest that trace metals would be expected to have naturally higher concentrations as compared to the outfall survey area.



Although spatially ranked bar charts provide a useful visualization of potential gradients, statistical hypothesis tests provide a more rigorous, quantitative method for assessing the significance of potential spatial gradients such as the subtle gradient in raw nickel concentrations. Specifically, these tests establish whether the MBCSD discharge could be causing an increase in metal concentrations close to the outfall compared to the more distant stations. Two types of



spatial tests were performed on the data collected during 2017 (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 concentrations consistently decrease with distance, then the negative slope of the line will be statistically significant and possibly indicative of outfall-related impacts.

Table 4.8 Tests for 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)	-0.023	0.34	5.83	5.68	0.46	0.34	[0.23]	NA
Arsenic	-0.011	0.63	3.79	3.64	0.85	0.24	0.44	0.40
Chromium	-0.002	0.89	44.4	44.3	0.10	0.46	[0.24]	[0.29]
Copper	-0.070	0.08	3.73	3.33	1.23	0.15	0.10	0.07
Iron (g/Kg)	-0.025	0.27	9.0	8.7	0.61	0.30	NA	0.24
Lead	-0.017	0.56	2.31	2.17	1.15	0.18	0.33	0.29
Nickel	-0.069	0.01	52.6	46.8	1.76	0.09	0.06	0.07
Zinc	-0.043	0.04	15.6	14.8	1.10	0.19	0.21	0.19
BOD	-0.077	0.02	62.9	53.4	2.72	0.06		
TKN	-0.061	0.15	174	147	2.58	0.06		
TVS (%)	-0.007	0.14	2.34	2.29	0.74	0.27		
Mud (%)	-0.013	0.25	1.56	1.31	3.57	0.04		

The second statistical test evaluated whether mean concentrations at the three close-in stations (B4, B5, and B6) where samples were collected within 40 m of the discharge differed significantly from the average of the three distant stations (Stations B2, B3, and B7), that are located more than 63 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 higher than that of distant stations, which would again be indicative of outfall-related impacts.

The “*p*-value” determines the significance of any perceived spatial gradient by testing it against a null hypothesis of no gradient. 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

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-tailed” *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 B4, B5, and B6, which lie within 35 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 B2, B3, and B7, which lie more than 65 m from a diffuser port.

⁵ *t*-value computed from the difference between 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.

exhibit an anomalous concentration at one or more stations that results in a spatial gradient that appears to be related to outfall proximity, for example, when 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.

Within the 2017 database, three sediment properties exhibited a statistically significant linear gradient in their raw concentrations (first two data columns of Table 4.8). Among the metals, the lowest *p*-value of 0.01 (bold value in the second data column) was determined for the visually obvious spatial trend seen in the raw nickel concentrations of Figure 4.3. Its gradient, as measured by a linear slope of -0.069 (first data column), was large enough and consistent enough to be statistically significant, namely, with a *p*-value less than or equal to 0.05. Zinc also exhibited significant negative slope, where concentrations steadily decrease with outfall distance, although with a *p*-value of 0.04, its significance was marginal.

Additionally, for both these metals, the statistical significance of the perceived spatial trend arose because a maximal concentration happened to be measured unusually close (4 m) to the diffuser structure at Station B5 (first red bar in Figure 4.3). Because that measurement was located at the extreme of the distance range, it weighed much more heavily in the spatial regression analysis as compared to the other measurements. Additionally, because the Station B5 samples were collected well within the ZID, their relevance to the discharge’s compliance analysis is questionable. This is particularly true because the Station-B5 samples were collected within the highly localized debris field immediately surrounding the outfall structure. As described in the *Sampling Location Offsets* subsection on Page 4-6 and elsewhere in this chapter, sediments within the debris field have been physically, chemically, and biologically altered by the accumulation of material sloughed from the outfall’s exterior over decades. Thus, the differences in benthic sediments did not arise from effluent discharge, but instead, from the physical presence of the seafloor structure itself. The spatial trend among the remaining stations was much weaker after excluding concentrations measured at Station B5. Specifically, the resulting nickel and zinc *p*-values of 0.07 and 0.34 demonstrate that the spatial trends in raw concentrations beyond the ZID boundary were not statistically significant.

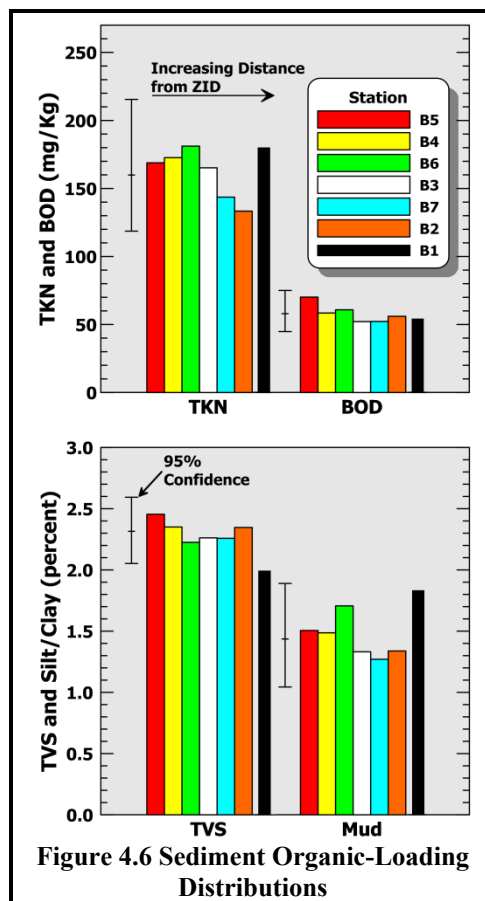
The results for the other type of test, for significant differences between near and distant average concentrations, are shown in the remaining columns of Table 4.8. The statistical test for a difference in means is more robust than the regression test because data points at the extreme ends of the spatial range do not unduly influence test. In the test for differences in group averages, the average mud fraction at the three close-in stations (1.56%) was the only property found to be significantly higher than that of the three distant stations (1.31%). Because the associated *p*-value (0.04) was less than the significance threshold (0.05), it is highlighted in bold in the Table. The significance of the difference is not surprising given that all three of the close-in stations (red, yellow, and green bars in the bottom-right frame of Figure 4.6 on Page 4-24) had greater mud fractions than the three distant stations (white, blue, and orange bars). Regardless of the marginal significance associated with the difference in average mud content, all of the mud-content determinations remained well within the overall uncertainty associated with those determinations. This is evident from the 95% confidence interval shown to the left of the mud bar chart, which encompasses all of the measurements, including the mud fraction determined at the distant reference station (black bar).

The same two spatial tests that were applied to the distributions of the three remaining organic loading parameters (Figure 4.6) revealed a statistically significant linear trend in BOD ($p=0.02$ in Table 4.8; upper right bar chart in the Figure). However, the spatial trend was largely driven by an elevated BOD that was measured in very close proximity to the diffuser structure (Station B5; solid red bar in the upper right bar chart), rather than by a steadily declining concentration at the other stations (other bars in the graph). Accordingly, the difference between the average BOD concentrations located near the diffuser (62.9 mg/L in Table 4.8) and at a distance (53.4 mg/L) was slightly too small to be deemed statistically significant ($p=0.06$).

Nevertheless, the fact that perceptibly higher concentrations in both BOD and TVS were measured in samples collected at Station B5 indicates that the sediments within the debris field surrounding the outfall structure contained more organic material (see the discussion in the *Sampling Location Offsets* subsection of Section 4.1.3 on Page 4-6). 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 is accidentally dislodged by collisions by the grab during sample collection. Like the shell mounds below offshore platforms, the accumulation of organic debris can be quite large but is localized very close to the structure. As discussed later in this chapter, this debris field was also found to support a unique community of benthic organisms with an affinity for higher subsurface concentrations of organic material.

It is unlikely that the elevated organic content at Station B5 was caused by organic content within the effluent discharge itself, rather than by the physical presence of the outfall structure. Instead, as described in Chapters 2 and 3, the low organic particulate load within effluent is rapidly dissipated upon discharge by the energetic receiving waters, and would not be expected to accumulate within seafloor sediments. If measurable deposition of wastewater particulates were occurring, all the metals commonly found in effluent, namely, copper, lead, and zinc, would also be significantly elevated in the Station-B5 sediment samples. Instead, both raw (Figure 4.3) and normalized (Figure 4.5) concentrations measured at Station B5 fall within the confidence bounds surrounding station averages.

Moreover, the potential increase in sediment organic content was highly localized around the outfall, and did not extend beyond the ZID where measurements are normally subject to permit-compliance evaluations. This is visually apparent in the BOD and TVS bar charts of Figure 4.6. Distance-ranked concentrations at the other stations surrounding the outfall, shown in yellow, green, white, blue, and orange bars, do not exhibit steadily decreasing concentrations from left to right. Accordingly, no significant linear spatial trends were found in the BOD and TVS concentrations beyond the ZID ($p \geq 0.24$).



4.2.3 No Buildup over Time Related to Wastewater Discharge

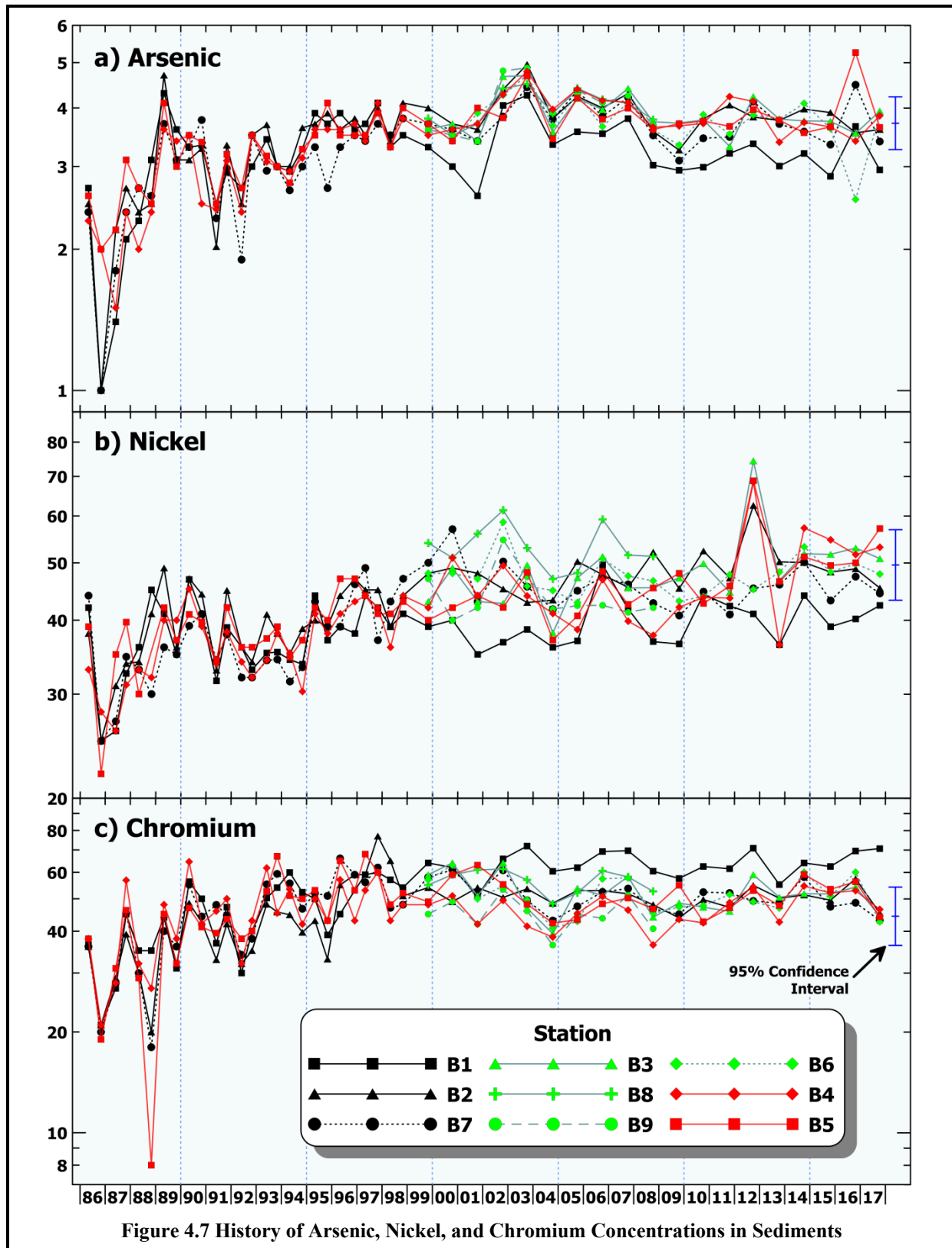
The previous section examined the spatial distribution of sediment constituents at a single point in time, namely, during the October 2017 survey. However, the characteristics of ambient sediments at individual stations can be inherently different because of slight differences in their water depth, or because of differences in the depositional characteristics of their geographic location. These factors complicate the interpretation of any perceived spatial gradients with respect to 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 gradients in contaminant concentrations over time can reveal discharge-related trends that may be masked in a spatial analysis applied to a single survey.

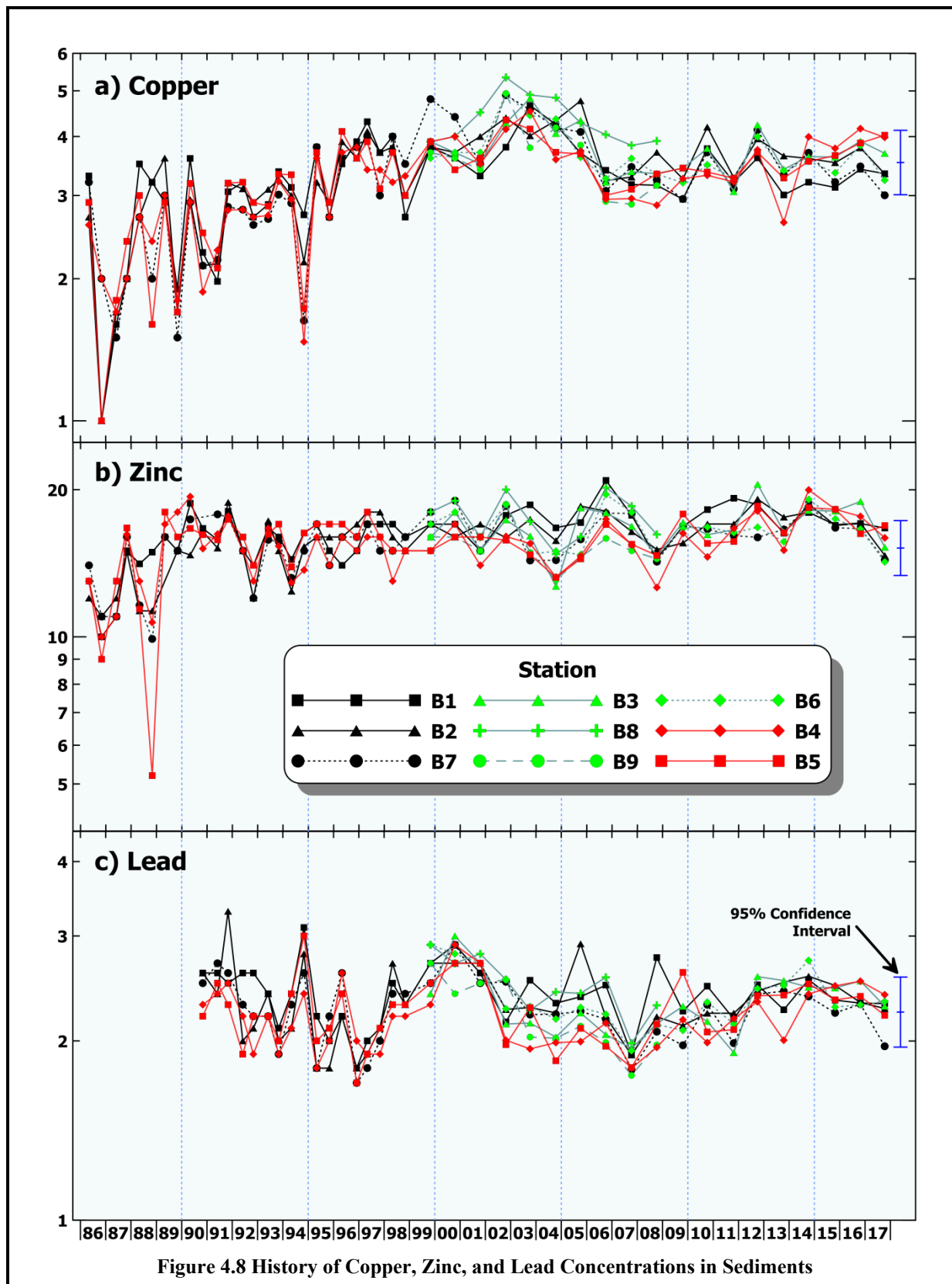
However, perceived temporal trends in contaminant concentrations must be interpreted carefully because natural and anthropogenic processes unrelated to the effluent discharge can also cause large and widespread changes in chemical concentrations within sediments. These regional influences are apparent in the time series of sediment chemical concentrations shown in Figure 4.7, Figure 4.8, and Figure 4.9 on the following pages. Specifically, the large-amplitude fluctuations that occur over periods of a few years reflect widespread seasonal and interannual changes in the sedimentary environment. Similarly, the general increase in the concentrations of five sediment constituents that are apparent in the decade-and-a-half prior to 2000 are in response to even longer-term influences within northern Estero Bay (Figure 4.7abc, Figure 4.8a, and Figure 4.9c).

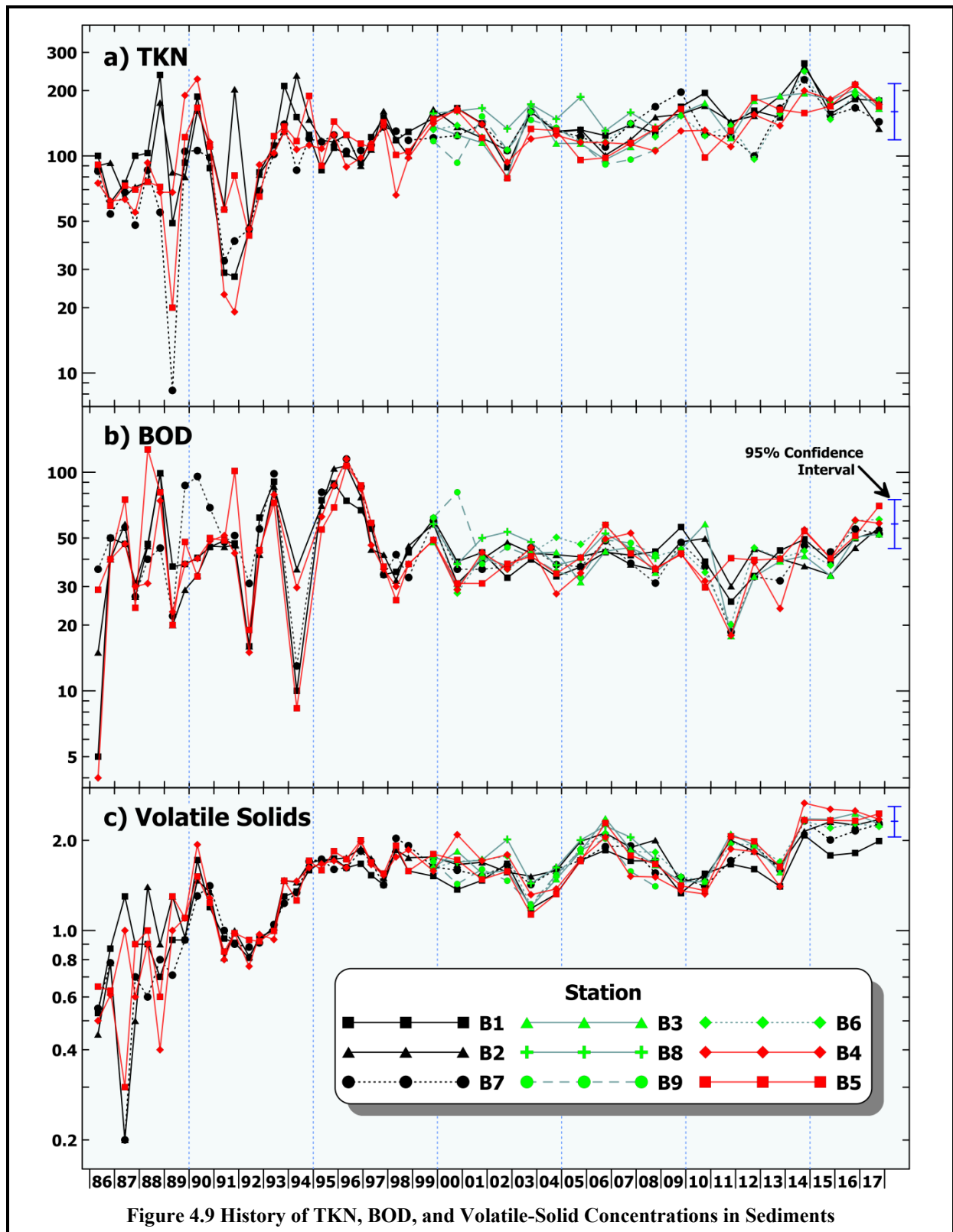
Nevertheless, these large interannual fluctuations and long-term trends tend to occur in unison at all stations, so the spatial differences among samples collected at a given time (i.e., within a given survey) are comparatively small. In other words, the fluctuations in concentrations at the group of monitoring stations generally track one another through time. This indicates that changes in sediment concentrations that arise from regional influences throughout Estero Bay are far larger than those induced by any localized effect. 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), which 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 temporal trends are large enough to be reliably quantified in the presence of sampling uncertainty. Moreover, these large temporal changes can mask subtle spatiotemporal trends in sediment chemical composition that may be related to the MBCSD discharge. The parallelism technique applied in this section is best suited for revealing relevant spatiotemporal relationships that would otherwise be difficult to discern in the presence of these large-amplitude regional excursions in sediment chemistry.

The pre-2000 long-term increase in the sediment concentrations of a number of metals, predominately arsenic, chromium, nickel, and copper, was the subject of intensive investigation in prior annual reports (MBCSD 1999b, 2000a, 2001 – 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 metals emission was far too small to account for the widespread increase, and 3) the discharge remained unchanged while the temporal trend in average concentrations leveled out after 2000.







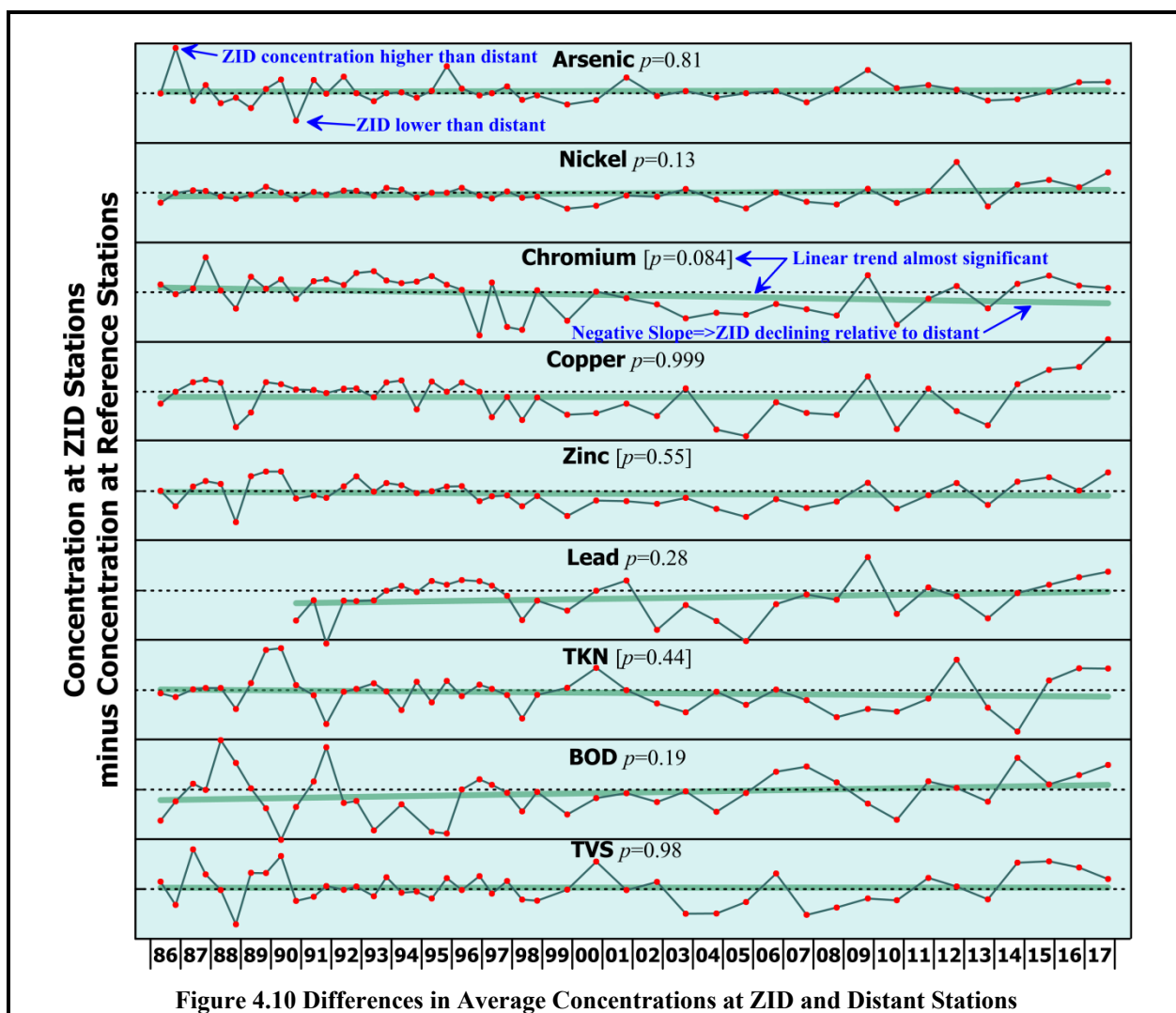
Instead, the steady increase in sediment metal concentrations prior to 2000 was ascribed to accelerated erosion of contaminated mine tailings at abandoned chromite mines within the adjacent watershed. After 2000, sediment concentrations appear to have reached equilibrium with the metal loading from the watershed's runoff into Estero Bay.

Discerning subtle localized impacts within the backdrop of large interannual fluctuations and long-term temporal trends is aided by a special statistical technique that tests for the presence of parallel time histories. A parallelism test overcomes limitations associated with purely spatial or purely temporal approaches to impact evaluation (Coats et al. 1999, Skalski et al. 2001). This 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 concentrations 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. 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 on Page 4-30. If contaminants discharged by the MBCSD discharge were accumulating in sediments near the outfall, then concentrations at stations nearest the outfall (B4 and B5) would slowly increase relative to distant stations (B2 and B7). These increases would appear as positive slopes in the difference in averages 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.

Six compounds exhibited slightly positive slopes, suggesting the possibility of a buildup of wastewater contaminants close to the discharge compared to distant stations. Because this trend may be of compliance interest, their *p*-values were not enclosed in brackets in the difference series of Figure 4.10. Similar to the other statistical tests in this report, the *p*-values measure confidence in the slope of the line, by comparing the slope magnitude with the variability resulting from the presence of scatter among individual data points. When the slope is small or the scatter is large, the spatiotemporal trend cannot be considered statistically significant. This was the case for all six compounds with positive slopes because the tests indicated that all of these spatiotemporal trends were far too small to be reliably determined in the presence of year-to-year fluctuations ($p \geq 0.13$).



The remaining three chemicals exhibited negative slopes in Figure 4.10, indicating that ZID concentrations were possibly decreasing over time relative to the reference stations. 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 in Figure 4.10. Additionally, the spatiotemporal trends in two of these compounds were very poorly resolved ($p \geq 0.44$), as was the case for the six compounds with positive slopes.

The slope of one chemical, however, was nearly large enough to be resolved (third plot from the top in Figure 4.10). Specifically, the hypothesis of a long-term trend in relative chromium concentrations was only marginally rejected at the 95% confidence level ($p=0.084$). In fact, prior to the last two data points that were added in 2016 and 2017, which showed a slightly higher concentrations at the ZID stations, chromium exhibited a strong case for rejecting parallelism ($p=0.031$), and accepting the alternative hypothesis that chromium concentrations are actually decreasing near the outfall compared to distant stations. Before the four positive differences were added in the last four years, the spatiotemporal trend through 2013 was strikingly well established ($p=0.003$).

This negative chromium slope could be indicative of large-scale changes within the sediments of Estero Bay that may warrant attention even though they are unrelated to the MBCSD discharge. The parallelism tests in Figure 4.10 included four stations within the survey area immediately surrounding the outfall¹ and thus, only represented a small portion of northern Estero Bay region. As a result, the separation of chromium concentrations among these stations was too subtle to discern from an inspection of the time series shown in Figure 4.7c on Page 4-26. However, chromium concentrations at the northernmost Station B1, shown by the black trace with square data points, exhibit an obvious temporal separation that is consistent with the parallelism tests. In the first half of the record, chromium concentrations were comparable to those of other monitoring stations. In the latter half of the record, however, chromium concentrations at Station B1 diverge from rest of the group. Specifically, in each of the last fifteen years, concentrations of chromium have been higher at Station B1 than at any of the other stations. This overall spatiotemporal trend in chromium concentrations may be a manifestation of ongoing erosion of mine tailings that caused the widespread increase in some metal concentrations prior to 2000. The slightly higher chromium concentrations at Station B1 may reflect more localized effects due to its proximity to the mouth of Toro Creek, whose watershed encompasses a relict chromite mine.

4.3 BENTHIC INFAUNAL COMMUNITY

The infauna living within the surficial sediments of northern Estero Bay provide additional insights into the wellbeing of its seafloor environment. They are also particularly effective for compliance determinations that assess the presence of a BIP surrounding the outfall. They act as sentinels that are responsive to 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 widely, making it impossible to determine where contaminant exposure may have occurred.

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 source of potential pollution. Additionally, individual infaunal species vary in their sensitivity to pollutant stressors. As such, changes in the 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 provide food 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. As such, infaunal monitoring addresses the COP requirement that the discharge not degrade indigenous marine biota (see Objective E.1 in Table 3.1 on Page 3-3 in Chapter 3). The benthic monitoring has now amassed more than three decades of infaunal data. During that time, 266,000 specimens representing 392 individual taxa have been collected, identified, and enumerated. Throughout the monitoring program, there has never been an 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, and no evidence of spatial changes in the infaunal assemblages beyond the ZID. During the last

¹ As with the other statistical tests performed on sediment constituents in this chapter, Station B1, which lies well north of the survey area, was excluded because its benthic environment is not representative of the area around the discharge. The parallelism tests in Figure 4.10 compared average concentrations at ZID Stations B4 and B5, shown in red in Figures 4.7 through 4.9, with midfield Stations B2 and B7, shown by the black traces with round and triangular data points.

three years, however, all measures of infaunal health declined precipitously throughout northern Estero Bay as a massive increase in sand-dollar density displaced most of the surficial sediment normally occupied by infauna.

Observations regarding the lack of discharge impacts, however, 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 the benthic environment of northern Estero Bay on at least four occasions during the last three decades of MBCSD monitoring (NOAA 2018). All coincided with major sand-dollar recruitment events within northern Estero Bay (refer to the population history in Figure 4.12 on Page 4-34 later in this chapter). 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 that occurred in 1991 had a perceptible impact within Estero Bay.

However, the event with the largest influence on benthic fauna within MBCSD survey area occurred in 2009 when the faunal density was 100-times higher than historical average due to a huge explosion in the sand-dollar population. The effects of that initial population boom continued to be apparent through 2017 as the original 2009 cohort matured, grew in size, and began to experience senescence. As described in the 2015 and 2016 annual reports (MRS 2016 2017h), that sand dollar cohort began to profoundly impact the entire infaunal community when numerous large sand dollars (*Dendraster excentricus*) dramatically altered the benthic environment and displaced a large fraction of the sediment that is normally collected within each grab. As described in this chapter, their ongoing presence during 2017 continued to overwhelmingly affect the infaunal community. Beginning in 2016, sand-dollar senescence began to affect the resident infauna in subtly different ways that were also apparent within the 2017 database.

A total of 3,429 individual infaunal organisms were enumerated in the 35 sediment samples that were collected for biological analysis during the October 2017 benthic survey. A compendium of the taxonomic identifications and enumerations that were performed on the year-2017 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 community indices that were computed from infaunal data, as required by the NPDES monitoring and reporting program. This chapter of the annual report combines these data with biological data collected over the prior three decades to determine whether there have been discharge-related impacts to the benthic biota.

Three quantitative analyses were conducted to evaluate whether there have been deleterious impacts to benthic organisms as a result of the discharge. First, the organisms that inhabit the sediments around the outfall were evaluated to determine whether they indicative of an indigenous community. Throughout most of the monitoring program, indigenous infauna were dominated by filter-feeding organisms that thrive only in clean sediments, but during 2015, the entire benthic community underwent a major transformation to one more typical of dense sand-dollar beds. Second, infaunal data collected during 2017 were assessed for evidence of spatial gradients indicative of biotic degradation attributable to effluent discharge. Third, the variations in time histories of community parameters were examined for long-term spatiotemporal trends indicative of an increasingly degraded benthic environment around the outfall. The historical record shows that infauna at individual stations respond in unison to large interannual and seasonal influences on the infaunal community. As a result, infaunal differences among stations during a

given survey tend to be negligible compared to naturally occurring temporal variations. To date, the indigenous benthic community remains healthy, with no perceptible influence from ambient contaminant levels, including the previously discussed long-term temporal trends in some trace-metal concentrations that occurred throughout Estero Bay prior to 2000.

4.3.1 Excluded Organisms

In the past, fluctuations in the population of two organisms, *Diopatra ornata* and *D. exentricus*, have had a profound effect on the MBCSD infaunal database. However, these organisms and their attached taxa are not particularly diagnostic of 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.

Tube Worms

Since 2000, the parchment tubes of the Ornate Tubeworm (*D. ornata*) have routinely been separated in the field prior to sieving of the infauna. The “Ornate” portion of the tubeworm’s common name refers to 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 epibionts reside on the microhabitats created by these tube casings, including small crabs and other crustaceans, particularly Gammarid amphipods. Inclusion of these epibionts in the infaunal database can dramatically skew the enumeration of marine infaunal organisms in samples where they are randomly present. Removal of large *D. ornata* parchment tubes in the field, prior to sieving, limits sample contamination by the epibionts associated with these tubes. 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 2017 survey, several small- to medium-sized *D. ornata* tube casings were separated from four of the sediment samples.¹ Some of the casings contained adult worms that were included in the infaunal enumerations, while other tubes were empty. The small size and limited occurrence of the tube casings found during the October 2017 survey departed from the more numerous larger specimens found in recent surveys prior to 2015. During 2015, however, no *D. ornata* tube casings were found within the infaunal sediment grab samples, and that general population decline extended into 2017. The decline may be related to the dense bed of mature sand dollars (*D. exentricus*) that disturbed surficial sediment and associated infauna within all the grab samples collected mainly during the last three surveys. In prior surveys, removal of the parchment tubes prior to sieving helped limit the introduction of associated epibionts, but some of these organisms also reside in sediment immediately surrounding the tubes (Wooden 1978), and as a result, their influence was still partially evident in the historical infaunal record. Thus, even though the tubes were removed immediately upon retrieval of the sediment grab samples,

¹ Refer to the comments in the Sediment-Grab-Sample Collection Record in Table C.1 in Appendix C.

those samples were found to contain fauna that were distinct from the communities in all the other replicate samples (MRS 2013–2015).

Sand Dollars

Statistical analyses performed on the 2017 benthic samples also excluded enumerations of Pacific sand dollars (*D. excentricus*). Although sand dollars can be sensitive to pollution, they are excluded 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. Additionally, because they tend to reside on the sediment surface, they are not, strictly speaking, infauna, and because their mature size represents a significant fraction of the dimensions of the grab sampler, there is a greater risk of undersampling sand dollar populations as compared to most infauna, which are far smaller. Lastly, because their populations can be extremely patchy, surveys prior to 2016 have found that even closely spaced replicate grab samples contain vastly different abundances, confounding the determination of spatial trends in their distribution across the survey area.

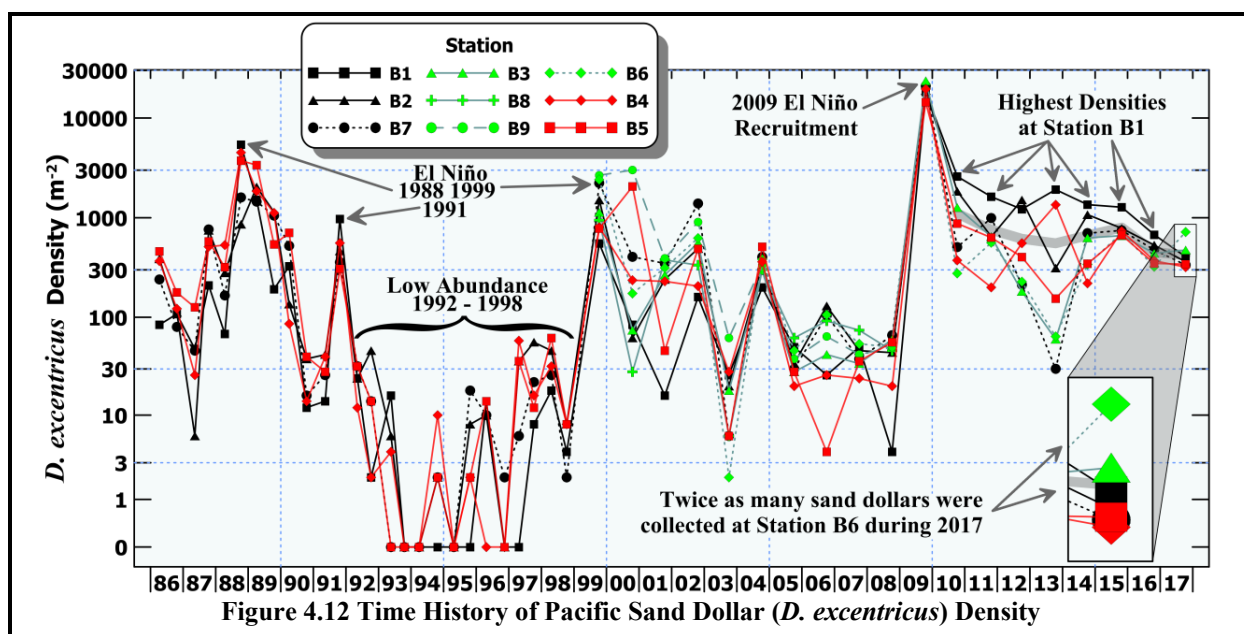


Figure 4.12 Time History of Pacific Sand Dollar (*D. excentricus*) Density

Sand Dollar Biology

Sand dollars normally form dense beds just seaward of the wave break. At that location, predation is limited because predators, consisting mainly of 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, frequently associated with El Niño events, may reduce predation, permitting enhanced recruitment of juvenile sand dollars. Specifically, the increased sand-dollar recruitment that occurred in late 1988, 1991, 1999, and 2009 may have been related to El Niño events that occurred around the same times (Figure 4.12).

Sand-dollar beds are often dominated by a single age cohort, indicating that recruitment is episodic and only occasionally successful (Cameron 1980, Oliver et al. 1980, Morin et al. 1985, Cameron and Rumrill 1982). During low-population years, the exclusion of *D. excentricus* specimen counts from the database

had little impact on the statistical analyses of benthic populations. This was the case between 1992 and 1998, when average sand dollar densities were less than 50 m^{-2} (Figure 4.12). However, because their numbers overwhelmingly dominate the population statistics during and following high-recruitment years, inclusion of sand-dollar enumerations has the potential to mask any influence of the discharge on less-dominant taxa. The populations of taxa that may be sensitive to potential discharge impacts are normally stable over the long-term. As a result, slight changes in their populations arising from localized anthropogenic impacts can be more easily discerned when the large and variable sand-dollar counts are excluded from the numerical analyses.

2009 Sand Dollar Recruitment

The extremely successful recruitment event that took place in 2009 resulted in the collection of more than 67,000 individual sand dollars, while only 4,289 other infaunal specimens were collected during the same survey (MRS 2010). In the presence of such an extreme sand-dollar population, consistent year-to-year evaluation of infaunal community structure could only be achieved by excluding the sand dollar counts when computing the diversity indices. Although these juveniles incurred a high mortality rate ($>90\%$) over the following year, the cohort of sand dollars originating from this recruitment event steadily increased in size as they matured (Figure 4.13abcd).

Another much-smaller recruitment event occurred in 2013 and resulted in the presence of two distinct cohorts in that database, one consisting of small, first-year juveniles, and the other consisting of large, mature sand dollars from the 2009 recruitment. However, the second juvenile cohort did not survive and after the 2013 survey, the sand dollar population was again comprised solely of adult specimens from the original 2009 cohort.

Sand dollars maintained a substantial numerical superiority over all other infaunal taxa in every survey since the original recruitment event in 2009, although their abundance varied widely among stations from 2011 through 2015. Nevertheless, average sand-dollar density remained relatively stable with approximately 700 individuals collected within each square meter of seafloor (shaded line in the rightmost portion of Figure 4.12). However, during the two most-recent surveys in 2016 and 2017, spatial variability moderated and their average survey densities steadily declined¹ to below 460 m^{-2} . Even so, far more sand dollars were collected than the next most populous benthic organism during that period.



Figure 4.13 Comparison of the Sand Dollar cohort in a) 2009, b) 2010, c) 2011, and d) 2012

¹ The overall decline in sand dollar counts during 2016 and 2017 is more dramatic than that exhibited in Figure 4.12 because of its logarithmic vertical axis.

For example, twice as many sand dollars were collected during the 2017 survey as compared to the infaunal organism with second highest abundance.¹ Because of their comparatively large numbers, sand-dollar counts still heavily influenced population statistics, potentially masking important variations in community structure among other infaunal taxa. In particular, many community indices computed with the inclusion of the 2017 *D. excentricus* population (Table B.9 on Page B-12) were noticeably different from indices computed without their inclusion (Table B.10 on the following page). Indices, such as dominance and diversity, measure the uniformity in abundance among species. When sand dollars were included, the survey-wide diversity indices decreased by 17% and dominance increased by 25%. The infaunal trophic index (*ITI*) was unaffected by the exclusion of sand dollars because they are not members of the feeding guilds² quantified by that index. For most community indices, however, exclusion of the sand-dollar population clearly enhanced the impact evaluation by allowing other less abundant, but potentially more pollution-sensitive taxa to participate.

Moreover, the sand-dollar time history does not exhibit a visually apparent relationship to ZID proximity over time. As such, compliance assessments that exclude sand-dollar counts are not hampered by their absence. As with the chemical constituent time histories, any trend in the spatial distribution of sand-dollar populations that might be related to ZID proximity would be evident in the sand-dollar population history (Figure 4.12 on Page 4-34) as a gradual color 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, large fluctuations in the overall record of sand-dollar abundance tend to occur equally at all stations. However, one notable exception was the spatial distribution of 2009 cohort's abundance, which was consistently higher at Upcoast Reference Station B1 in seven of the eight years following the recruitment event (black squares on the right of Figure 4.12). For the many other reasons presented elsewhere in this chapter, that station was excluded from the compliance analyses of the benthic infauna presented in this section.

Other Sand Dollar Influences

As described above, the overwhelming influence of sand dollar variability on infaunal population indices is easily eliminated by simply excluding their counts prior to the analyses. However, the presence of numerous sand dollars can also strikingly affect the benthic infaunal analysis in two other ways. In contrast to the influence of high numbers on population statistics, these two other influences cannot be mitigated, and the overwhelming physical presence of the numerous large sand dollars in the seven surveys conducted after 2010 severely compromised the ability compare those infaunal analyses with prior non-*Dendroaster* analyses, even after their counts were excluded. This was particularly true during the last three years, when the sand dollars were much larger.

First, the presence of numerous large sand dollars within grab samples markedly reduced the sediment volume remaining within the grab samples. Second, their presence altered the infaunal community by introducing parasitic and opportunistic taxa capable of coexisting with them, and by eliminating taxa that normally reside in a less-disturbed benthic environment. The burrowing activity of sand dollars reworks surficial sediments and eliminates delicate suspension-feeding taxa that are considered sensitive to pollution because their populations decline upon contaminant exposure in undisturbed benthic environments. However, these taxa are also highly sensitive to mechanical disturbance of surficial sediments that is unrelated to contaminant content. Conversely, the overwhelming presence of sand dollars also allows the incursion of a few opportunistic taxa that can coexist with sand dollars, and that

¹ Compare the Survey Total of 1,480 *D. excentricus* specimens with the 746 *Balcis rutila* specimens in the first two rows at the top of Table B.1 in Appendix B.

² A "Guild" is a group of taxa that exploit the same class of resources (in this case food) in a similar way.

under other circumstances, would be considered pollution tolerant (Chia 1969; Rhoads and Young 1971; Woodin 1978; Merrill and Hobson 1970; and Smith 1981).

Reduced Sediment Volume after 2010

The sand dollar population record shown in Figure 4.12 on Page 4-34 does not lend any insight into the other two sand-dollar influences that affected infaunal analyses of population data collected during surveys conducted from 2011 through 2017. The shaded line in the Figure shows that average sand dollar density has been relatively constant for the eight surveys following the initial recruitment of vast numbers tiny specimens during the 2009 El Niño event (note the uniformly small size in the photograph of the sieve offshore in Figure 4.13a on Page 4-35). While the number of sand dollars collected since that survey remained relatively constant, their size increased dramatically from 2009 through 2010 (Figure 4.13abc). The associated increase in sand-dollar volume successively displaced greater amounts of sediment within the grab sampler. Thus, the amount of sediment actually processed for infaunal organisms steadily decreased with each successive survey. Upon approaching maturity in 2012 (Figure 4.13d), the presence of numerous, very large, sand dollars left little sediment in the grab available for sieving offshore. As a result of the much smaller sediment volumes, infaunal numbers were markedly reduced in the last seven years; this dramatically affected every aspect of infaunal community evaluation, and made comparison with data collected in prior years untenable.

However, the reduced sediment volume that resulted from the presence of large sand dollars was only problematic after the 2009 recruitment event, when much older and larger individual sand dollars became prevalent as a result of that cohort's longer tenure. Population increases associated with past sand dollar recruitments, during the 1988, 1991, and 1999 El Niño events (Figure 4.12 on Page 4-34), were transient and generally dissipated within a year or two following the initial recruitment. Thus the sand-dollar cohort never fully matured.

In addition to other possible factors,¹ the rapid decline in sand dollar populations observed after previous recruitment events probably resulted from predation by sea stars. Surveys conducted in the year immediately following past recruitment events encountered increased numbers of predatory sea stars, usually ochre stars (*Pisaster ochraceus*). Those encounters were noteworthy because these large stars occasionally got stuck in the jaws of the grab and prevented it from fully closing, resulting in the loss of the sample. In contrast, no sea stars were encountered in any of the seven benthic surveys conducted after the 2009 sand dollar recruitment. The absence of sea-star predation undoubtedly contributed to the observed longevity of the latest sand-dollar cohort. Ochre stars are the archetypical definition of a keystone species (Paine 1969), which are organisms that are disproportionately influential in maintaining local biodiversity through predation, which controls the populations of other species (e.g., sand dollars) that would otherwise dominate the community. The recent sea-star demise resulted from an outbreak of the sea-star wasting syndrome that has decimated their population along much of the North American Pacific coast (Hewson *et al.* 2014).

Additionally, the initial sand-dollar population explosion in 2009 was much larger than the increases seen in prior events, and it produced a populous cohort of surviving individuals that have remained in the survey area for the following eight years. Not only was their abundance relatively constant during this eight-year post-recruitment period, but the population was much denser than most prior recruitments. In the two years immediately following the 2009 recruitment, the large number of maturing sand dollars grew in size and began to occupy increasingly larger portions of the grab samples collected in each

¹ The observed rapid declines in sand dollar populations after previous recruitment events may have also resulted from the cross-shore movement of the sand dollar bed out of the survey area in response to changes in wave climatology from year to year (Merrill and Hobson 1970).

successive survey. Nevertheless, because of the smaller size of the juvenile sand dollars, adequate sediment volumes were collected during the 2010 survey, and to a lesser extent, the 2011 survey.

However, beginning with the 2012 survey, seafloor sediment occupied only a small fraction of the grab samples and as a result, the infaunal population was undersampled, which compromised the accurate characterization of that community, thus precluding reliable comparison with the historical database. Although sand dollars collected during the 2016 and 2017 surveys were still uniformly large, their numbers declined enough to allow slightly more-representative sediment sample-volumes to be collected within all the grabs. Thus, the sediment sample-volume artifacts seen in the prior two surveys were not quite as apparent in the population statistics described in this chapter.

Taxonomic Influence

While the slight decline in sand-dollar counts during the 2016 and 2017 surveys ameliorated the some of the issues associated with insufficient sediment-sample volume, the ongoing presence of numerous large sand dollars still exerted a profound taxonomic influence on the resident infaunal community. In addition to their impact on sample volume, the presence of a large swath of mature sand dollars within the survey area directly affected infaunal community composition by introducing opportunistic taxa that are capable of coexisting with sand dollars, and by eliminating suspension feeders that normally reside on the surface of an undisturbed benthos. Specifically, sand dollar predation on small crustaceans, such as amphipods and isopods, virtually eliminated some of these normally prevalent taxa from the database. Other impacts on the infaunal community arose indirectly through enhanced competition for food and space. Sand dollars can be both deposit and suspension feeders, and when little sediment is available, or has low organic content, they survive by suspension feeding (Timko 1976). Most other infauna do not have the same trophic flexibility and losses due to competition with the fully mature cohort of sand dollars, certainly contributed to the observed declines in species richness and diversity within the remaining infaunal community, as well as anomalies in other community properties described below (e.g. *ITI*).

4.3.2 Indigenous Infaunal Community

The type and abundance of benthic organisms directly reflects 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 organic-particulate loads such as those that can be discharged from low-performance treatment works. Historically, the widespread presence of suspension feeders around the MBCSD outfall indicated that the discharge was 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 of Chapter 2). Their presence is indicative of the benign nature of the suspended sediments discharged by the treatment plant.

In this and past reports, the overall health of the benthic community within Estero Bay is characterized by the principal population parameters computed from samples collected at each station over the duration of the monitoring program. The community parameters provide a succinct description of the abundance, diversity, richness, and trophic (feeding) structure of benthic biota. Figure 4.14 on Page 4-40 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 during 2017. Each major category of community parameter is discussed in the sections that follow.

Abundance

Population density, shown in Figure 4.14a, measures the total abundance, or number of organisms, within a 1-m² area of the seafloor. For the reasons described above, infaunal density and the other infaunal community parameters analyzed here exclude sand-dollar counts. Although population density is the most basic single measure of a community of organisms, it 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 high numbers of opportunistic species repopulate the degraded environment.

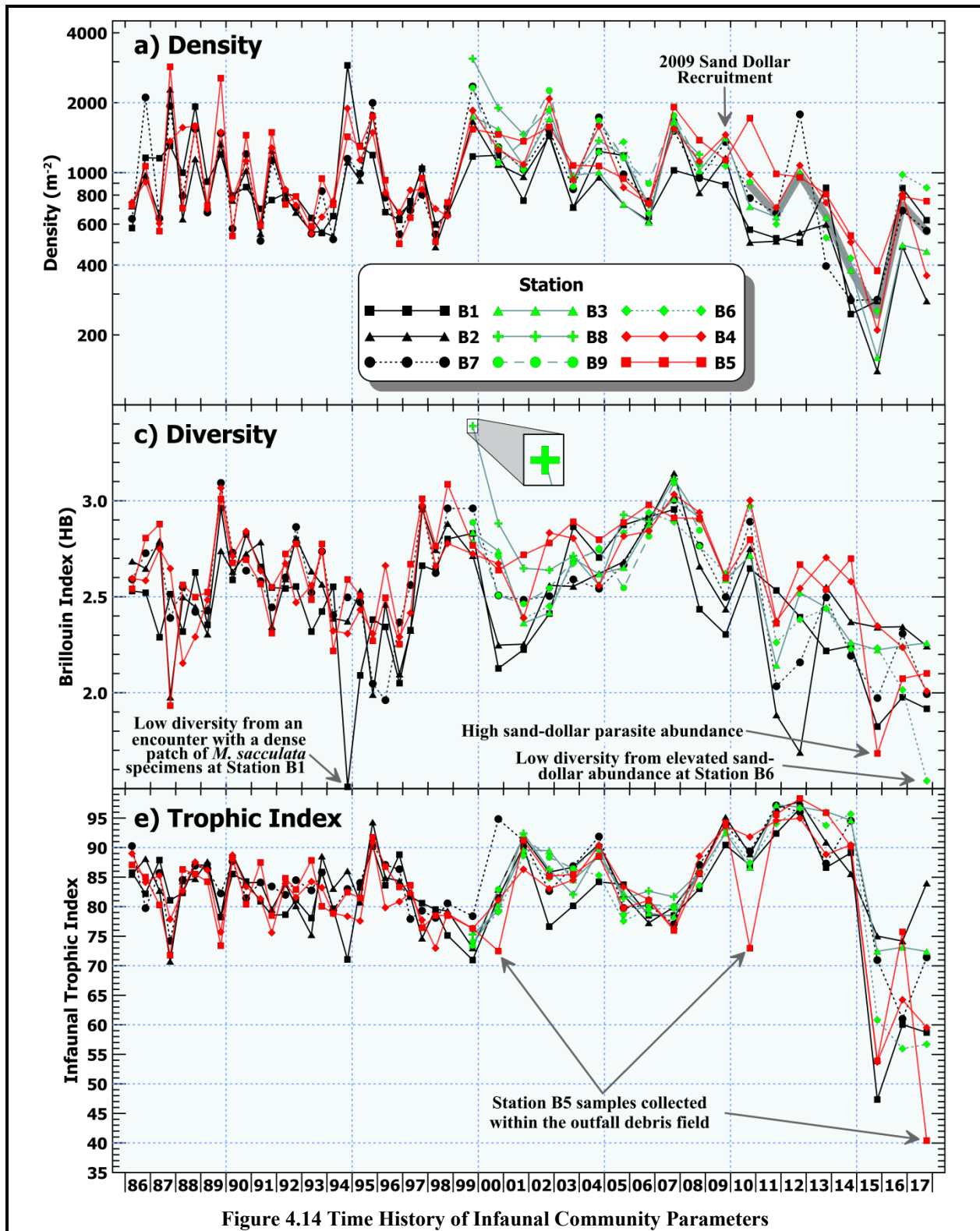
Throughout the monitoring program history, the number of organisms collected at each station has fluctuated enormously. Although the range in abundance covers an order of magnitude, differences in abundance among individual stations within any given survey were generally smaller. Namely, all the stations tend to track the temporal fluctuations as a group, and spatial differences among stations within a given survey are generally no larger than the wide temporal fluctuations between surveys. The relatively large temporal fluctuation places perceived spatial differences within a given survey into context; namely, if an ecosystem is able to accommodate seasonal and interannual population fluctuations with amplitudes far exceeding spatial gradients, then the spatial differences observed during a given survey are probably not environmentally significant.

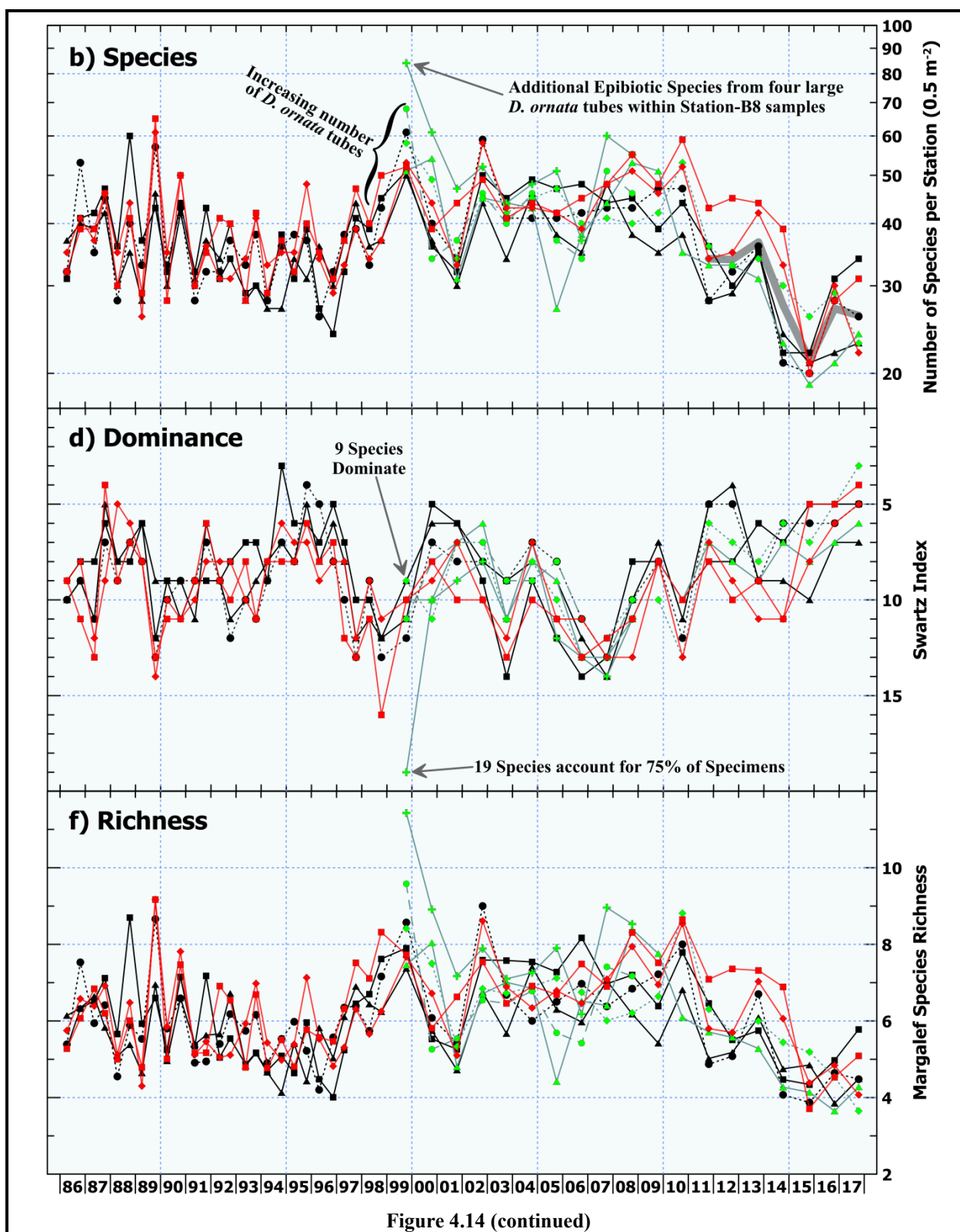
In that regard, prior to 1999 when seasonal survey data were available, the largest population changes occurred on a seasonal basis. Post-summer specimen counts (those sampled during the October survey) were generally three times higher than that of the post-winter populations. The reduced winter population, which was only measured prior to 1999, reflects 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 uniformly higher densities that are visually apparent in Figure 4.14a for most of the last half of the monitoring record, at least until the 2009 sand-dollar recruitment.

Prior to 2009, small spatial gradients that may be apparent in density within a given survey tend to be obscured by the large temporal fluctuations. In particular, infaunal abundance at stations near the outfall (shown in red) were not consistently lower than the density at distant stations (shown in black), and this lack of spatial distinction has remained constant throughout the monitoring program. It demonstrates that any potential accumulation of sediment chemicals from the effluent discharge over the last three decades has had no discernible impact on infaunal abundance, particularly when compared to large seasonal and interannual population fluctuations.

2009 Sand Dollar Recruitment

Following the major sand-dollar recruitment in 2009, average survey density (excluding sand dollars) declined to levels below 1000 m⁻² (shaded line in the rightmost portion of Figure 4.14a), and density differences among stations within a given survey increased perceptibly. In the four years following the recruitment event, average infaunal density was lower than post-summer densities, which regularly exceeded 1000 m⁻², and remained at levels comparable to those of the post-winter surveys conducted prior to 1999. As the sand dollars matured during this time, the slightly lower average infaunal abundance was probably a response to increased competition for food and space, and to predation by the large population of sand dollars.





However, in addition to the sand dollar's biological influence, sediment sample size undoubtedly factored into the observed decline in average infaunal abundance after this initial post-recruitment period. Specifically, during 2014 and 2015, as sand dollars approached their adult size, average infaunal density declined precipitously and reached the lowest densities ($<400 \text{ m}^{-2}$) recorded in the 32-year database. This brief dramatic decline in infaunal abundance cannot be easily ascribed to sand-dollar predation or competition for resources, particularly considering that average numbers of sand dollars in 2014 and 2015 were comparable to prior post-recruitment years (Figure 4.12 on Page 4-34).

Instead, as previously discussed, the sharp decline in infaunal populations was partially an artifact of undersampling caused by the physical presence of the numerous mature sand dollars within the grab samples. The sheer volume of sand dollars displaced the sediment normally collected within grab samples. Consistent sediment-sample volumes are necessary for accurate intercomparison of infaunal abundances determined from the enumeration of taxa within individual grab samples. For that reason, infaunal sampling protocols require a grab penetration depth¹ of at least 7 cm to ensure that a sufficient amount of sediment is collected to assess the indigenous community adequately and consistently. Nevertheless, when large sand dollars occupy most of the grab volume, infaunal populations within the remaining sediment are undersampled, leading to an under-reported density.

In 2016 and 2017, infaunal densities rebounded to levels comparable to other post-recruitment years as sand-dollar abundance declined slightly and allowed an increased amount of sediment to be collected. Nevertheless, infaunal density remained below 1000 m^{-2} , indicating the ongoing biological and sediment-volume influences of the large sand-dollar population on infaunal density.

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 that sample, i.e., it is inherently related to infaunal abundance. Because rare species are generally undersampled, the number of species automatically increases in samples that contain more organisms because they are more likely to encounter rare species. 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, however, reductions in species counts could suggest a decline in diversity resulting from degradation of the marine environment.

Nevertheless, because of their interrelationship with population density, temporal fluctuations in species counts (Figure 4.14b) tend to track the fluctuations in abundance (Figure 4.14a). Accordingly, at least some of the variability in the numbers of species at individual stations within the MBCSD database is an artifact of changes in the sample size (abundance) rather than purely an increase in species richness or diversity. As with the density time histories, species counts in post-winter surveys, which were conducted prior to 1999, were generally lower than post-summer counts. Additionally, in conjunction with density, the survey-wide numbers of species encountered in samples collected during the last seven years were perceptibly lower than those of the prior decade (shaded line in the rightmost portion of Figure 4.14b), and were markedly lower in 2015 when only about 20 species were encountered at each station.

In general, however, there is no obvious long-term spatial gradient in numbers of species suggesting that sedimentary conditions near the outfall have been preferentially degraded. Specifically, there is no obvious divergence in the colors over time, where species counts at stations near the outfall, shown in red,

¹ Refer to the *Penetration Depth* measurements for the 2017 samples in Table C.1 in Appendix C.

steadily decline relative to stations far from the outfall (black). As with abundance, spatial differences in among the 2017 species counts itself were limited, and comparable to seasonal and interannual fluctuations of past surveys, even though the overall number of species was among the lowest on record.

Beginning in 1996, there was a brief three-year increase in the overall number of species encountered in the MBCSD samples. This trend culminated in 1999, when 84 species were collected at Station B8 alone (green line with the green cross). 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 epibionts associated with their tube casings contributed to the steady increase in species counts, culminating in the unusually large number of species recorded in 1999.

Reduced Sediment Volume after 2010

As with density, the historically low survey-average numbers of species reported after 2010, and particularly in 2014 and 2015, could have resulted from the reduced sediment volume caused by the presence of numerous large sand dollars (shaded line in the rightmost portion of Figure 4.14b). Based on rarefaction analysis,¹ the observed decrease from 40 to 20 species would have resulted from a five-fold reduction in sediment volume. Based on anecdotal visual observations of the grab samples collected during the 2015 survey, sand dollars typically filled about 80% of the grab volume prior to sieving. Thus, their displacement of benthic sediments could easily account for the observed decrease in both infaunal density and average species. Other field studies that quantitatively accounted for differences in sediment volume within sand dollar beds also found decreases in diversity and numbers of infaunal species that were directly related to the reduced sediment volumes in benthic samples collected within the beds (Smith 1981).

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, within the MBCSD database, temporal trends in diversity do not exhibit any evidence of a deteriorating benthic environment near the outfall; namely, a steadily decreasing diversity at ZID stations relative to distant stations. On the contrary, the highest diversity has often been observed at one of the two stations located closest to the outfall (shown in red).

Nevertheless, because of the aforementioned taxonomic and sediment-volume influences from numerous large sand dollars after 2010, diversity measures have been of questionable value for assessing potential impacts from the discharge over the following six years. During that time, diversity dropped below 2.5 at most stations and, with a within-survey range near 0.5, the diversity index exhibited much higher variability among stations than seen in prior years. Furthermore, the wide excursions seen at individual stations during recent years could not be readily ascribed to other aspects of the samples collected those

¹ Rarefaction (Hurlbert 1971) provides an estimate of species counts as a function of sample size.

stations, such as grab-penetration depth or the presence of ornate tubeworms. Instead, the large observed diversity fluctuations were probably in response to varying levels of competition with sand dollars for space and food.

During and prior to the 2009 sand-dollar recruitment, and in the year immediately afterward, diversity measured at individual stations within a given survey were fairly similar, and when isolated large excursions were observed at a particular station, their cause could be easily identified. For example, the two most prominent outliers occurred during the 1994 and 1999 surveys. The markedly high diversity (3.39) that was measured at nearfield Station B8 in 1999 was an artifact of the enumeration of additional epibionts residing on the casings of ornate tubeworms. As discussed previously, the presence of large numbers of epibiont species substantially increased both the overall abundance, and number of species counted at this station during the 1999 survey (Figure 4.14ab). Not surprisingly, the diversity reported at that station was also markedly elevated (green cross + in the inset of Figure 4.14c)

The second unusual outlier is the very low diversity ($H_B=1.51$) 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 of this clustering worm were collected at Station B1 during the October 1994 survey. Because of the numeric dominance of this one taxon, the computed diversity at this station was the lowest measured in the 32-year database.

However, a diversity index nearly as low ($H_B=1.54$) was measured at Station B6 during the 2017 survey (green diamond ♦ in the lower right of Figure 4.14c). In this case, the low diversity resulted from the taxonomic influence of the much larger sand dollar population at that station. Nearly twice as many sand dollars were collected at that station during 2017 (see the inset in Figure 4.12). While the increased presence of large sand dollars at that station undoubtedly reduced sediment volume and contributed to the low diversity, the markedly low diversity was primarily due to an isolated increase in the population of a sand-dollar parasite commonly found within sand-dollar beds. It was the most populous non-Dendroaster taxon collected during 2017, and one third of all those specimens were collected at Station B6 (see the second row in Table B.1 in Appendix B). This marine snail (*Balcis rutila*¹), is a well-known sand-dollar parasite (Lovell 2003, Morin et al. 1985). Another isolated increase its abundance occurred at Station B5 in 2015, and resulted in a diversity index nearly as low ($H_B=1.68$; red square ■ in Figure 4.14c) as the 2017 outlier.

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 (see Appendix B.1). The index 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.² 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

¹ For consistency in the MBCSD database, the historical name, *B. rutila*, is used in this report even though the name has been revised to *Melanella rutila*, which is synonymous with *Polygireulima rutila* (Lovell 2003).

² Note that the vertical axis of the Swartz index plot in Figure 4.14d is inverted so that values that are located higher in the plot represent increased dominance.

differences in dominance among stations from a given survey were generally comparable to, or smaller than temporal fluctuations, at least prior to 2011.

After that, however, the dominance among individual stations from individual surveys ranged widely. Again, this reflects the varying taxonomic influence of the large sand dollar populations on the infaunal populations within individual replicate grab samples. At the stations with the highest dominance, only three-to-six species shared numerical superiority, which is among the highest measured in the 32-year database. However, the wide excursions in dominance that occurred after 2010 are unrelated to the environmental quality within individual benthic samples. A potentially degraded environment at a particular location would be reflected in a time history where that one station's dominance is consistently higher than that of the other stations. Instead, the station with the highest dominance varied randomly from year-to-year.

This level of variability was not the case prior to 2010, when outliers were easily ascribed to conditions within individual samples. For example, as discussed above in reference to the very high specie-count outlier, the very low Station-B8 dominance in 1999 (green line with the green cross) contained numerous epibionts from multiple ornate tubeworms. The presence of the tubeworms resulted in the lowest historical dominance by far, and allowed quantification of the actual number species that the tubeworm casings added to the samples. Within the Station-B8 samples, nineteen species accounted for 75% of the specimens collected, while other stations sampled during the 1999 survey had as few as nine species. Thus, up to 10 of the 19 dominant species that were found at Station B8 during 1999 were epibionts associated with the presence of ornate tubeworms. The exclusion of these tubeworms from subsequent surveys resulted in more stable and representative values of the Swartz index, at least until 2011.

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 individual feeding guilds, as reflected by a change in the Trophic Index, can be indicative of a benthic environment degraded by excess 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 is assumed to result when sediments are rich in the organic material that acts as a food source for these types of infaunal organisms.

As with the Swartz dominance index described above, the *ITI* differs fundamentally from the other interrelated community indices and as a result, its time series (Figure 4.14e) does not closely track the excursions in other indices (Figure 4.14abcf). Its emphasis on feeding behavior provides a somewhat independent assessment of the health of the infaunal community. The *ITI* has been exceptionally high throughout the MBCSD monitoring program prior to 2015; often exceeding 80, and after 2008, exceeding 90 (Figure 4.14e). These very high indices reflect a community almost entirely dominated by suspension-feeding organisms, with few organisms that depend on organic material within the substrate to survive. Prior to 2015, 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 enriched benthic conditions are believed to be potentially responsible for the composition of the infaunal community. In fact, trophic indices never dropped below 70 at any of the MBCSD benthic stations sampled during the 29 years prior to 2015, confirming the consistent dominance of suspension and surface-detritus feeders within the exceptionally pristine 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. Increasing effluent-related degradation due to the deposition of organic particulates around the outfall 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 an increasingly higher *ITI* at nearfield stations, shown in green, with distant stations, shown in black, eventually having the highest *ITIs*. Instead, as with the other community indices, and as with chemical concentrations measured within benthic sediments, there is no consistent pattern of color separation over time. Even after the 2014 survey, when the *ITI* declined precipitously, no spatially consistent color separation is visually evident that would indicate the decline was preferentially greater at the ZID stations.

Outfall Debris Field

Before addressing the striking overall *ITI* decline after 2014, three outliers warrant discussion because their low *ITI* departed markedly from the *ITIs* at the rest of the stations at the time of each survey. All were associated with a markedly lower *ITI* at ZID Station B5 that stood-out from the other *ITIs* reported in the same year at other stations (red squares ■ in 2000, 2010, and 2017 in Figure 4.14e). Although the first two *ITIs* were not particularly low compared to *ITIs* reported in other years, in the absence of other influences, they could indicate localized short-term habitat degradation from the discharge of organic particulates within wastewater.

Because of this, Section 4.4 of the 2010 Annual report (MRS 2011) conducted a detailed analysis that 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 organic loading was found to be 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 during both the 2000 and 2010 surveys. 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 slightly farther from the diffuser at other stations during those surveys (refer to the residue photograph in Figure 4.23a on Page 4-63 at the end of this Chapter).

Significant amounts of organic and other 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 when the grab unintentionally collides with the structure (as it did during the 2010 survey). Like the shell mounds below offshore platforms, the accumulation of structural debris can be quite large but is restricted to the seafloor immediately adjacent to the structure. Consequently, the outfall structure's debris field is rarely encountered except when grab samples are collected within a few meters of the outfall. In addition to the organic enrichment, these structural debris fields contain highly disturbed sediments that support a unique community of opportunistic benthic organisms that also happen to have an affinity for high concentrations of organic material, which weighs heavily in the reduction of the *ITI*.

ITI Decline after 2014

As discussed in the *Sampling Location Offsets* subsection on Page 4-6, sampling within the outfall's debris field was again responsible for the extraordinarily low *ITI* at Station B5 during the 2017 survey. However, in the case of the 2017 survey, and in all the surveys after 2014, the *ITI* was already far lower at all stations than in surveys conducted in years prior to 2015. The presence of a seafloor environment dominated by numerous large sand dollars dramatically altered the sparse infaunal community that remained within the small amount of sediment not occupied by the sand dollars. The resulting overall transition in feeding guilds from suspension feeders to subsurface deposit feeders was further

compounded by the increased subsurface organics present in the outfall's debris field. This led to the historical low *ITI* of 40.4 measured at Station B5 during the 2017 survey.

As with the two anomalously low *ITIs* described above, the abrupt *ITI* decrease observed at all stations after 2014 cannot be ascribed to the discharge of organic particulates within wastewater. Within the highly variable *ITI* values measured after 2014, there was no evidence a consistent gradient of decreasing *ITI* with increasing ZID proximity; namely, lower *ITIs* shown in red versus those shown in black. As with the other community indices, which are somewhat independent of the *ITI*, the *ITIs* determined in the three years since 2014 were highly variable among replicate samples collected at each individual station. As a result, the associated station *ITIs* spanned a remarkably wide range of 45 compared to prior years, which were typically 10 (Figure 4.14e).

More importantly, the unmistakable overall *ITI* decline after 2014 was not solely due to a marked increase in the populations of subsurface detritus feeders (Group IV), which would suggest an influx of opportunistic organisms. Instead, the decline mainly resulted from a large reduction in the population of suspension-feeding organisms. The lowest *ITIs* measured during this period contrasted sharply with the *ITIs* measured in surveys conducted just a few years before in 2011 and 2012, when the *ITIs* were the highest ever observed in the entire 32-year benthic monitoring program (Figure 4.14e). With *ITIs* as high as 98, the infaunal community at that time consisted almost entirely of suspension feeders (Group I) residing in sediments largely devoid of any organic content whatsoever.

If the MBCSD discharge had caused a brief, highly accelerated accumulation of organic effluent particulates around the outfall during the short period between the 2014 and 2015 surveys, the *ITI* reduction would have definitely been more apparent at the ZID stations during at least the first year (2015). Considering the large magnitude of the overall *ITI* decline, the profound transition from an infaunal community of effectively all suspension feeders to exclusively deposit and detritus feeders would have been initially more evident at the ZID stations. On the contrary, the lowest *ITIs* measured during some of these years, including the first year (2015), were regularly measured at the distant reference Station B1, indicating that organic enrichment was occurring regionally, and was not due to an inhospitable benthic environment created by a sudden increase in sediment organic content near the outfall. Additionally, such a localized buildup of organic materials would have been evident in the time series of all three of the organic loading constituents (Figure 4.9c on Page 4-28). The localized buildup would have been apparent as a statistically significant concentration increase at the ZID stations relative to prior measurements, and relative to measurements at distant stations.

As previously discussed, the increased sand-dollar size may have been responsible for some of the change within the infaunal communities observed during the last three years. Their physical size probably resulted in an attendant reduction in the amount of surficial sediment collected within the grab samples after 2014. Undersampling causes a disproportionate reduction in the most populous organisms collected from grab samples, which for past MBCSD benthic surveys has been the assemblage of active suspension-feeding Gammarid amphipods. These organisms are small shrimp-like crustaceans (Figure 4.15). Specifically, *Foxiphalus xiximeus*, *Majoxiphalus major*, *Rhepoxynius abronius*, and *Rhepoxynius menziesi* have dominated the infaunal populations collected in the MBCSD monitoring program as a whole, and because

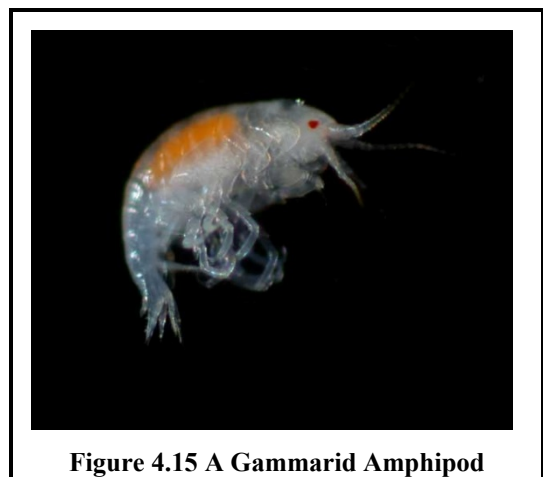


Figure 4.15 A Gammarid Amphipod

they are all members of Trophic Group I, their near elimination after 2014 weighed heavily on the observed decline in the *ITI*. For example, in 2012, 156 *F. xiximeus* and *M. major* specimens were collected, while in 2015, only eight of these organisms were found. Similarly, the number of *R. menziesi* declined by an order of magnitude in 2015, and *R. abronius* disappeared entirely.

However, undersampling alone, cannot account for the sand-dollar-induced decline in these gammarid populations. These amphipods are known to be extremely sensitive to pollution (Pearson and Rosenberg, 1978) and because of this, are routinely used in bioassay testing of marine sediments (ASTM, 1991; USEPA-USACOE, 1991, 1993). However, as described in Section 4.2, there was no material change in sediment quality after 2014, there was no change in MBCSD effluent quality, and there was no new source of pollution within Estero Bay. Instead, the extraordinary decline in the amphipod population was probably also related to habitat disturbance, competition for space and food, and predation by the numerous large sand dollars that overwhelmingly occupied seafloor sediments after 2014.

While sensitive to sediment pollution, gammarid amphipods are also sensitive to bioturbation caused by burrowing sand dollars, which can result in changes in surficial grain size and moisture content that cause amphipod mortality (DeWitt et al. 1988). In contrast to prior years, when, except for a few sand dollars, a generally smooth sediment surface was observed within grab samples, the surface of grab samples collected after 2014 consisted almost entirely of large sand dollars with little or no surficial sediment visible. The high rugosity of the seafloor during those years mechanistically limits the mobility of organisms that normally forage for particulate material on or near the sediment surface.

In addition to direct competition for space on the sediment surface, the sand dollars increasingly compete for food with suspension feeders as their density increases (Fodrie et al. 2007). At low density, sand dollars are predominately deposit-feeders. Thus, in prior years, the physically smaller sand dollars occupied a lower volume of the seafloor sediments, and in their deposit-feeding mode, preferentially competed with Group II and IV detritus-feeding organisms rather than suspension feeders. At least in part, this competition was responsible for the lower population of subsurface detritus feeders that were observed during, and in the five years following the 2009 sand-dollar recruitment event. The lower numbers of detritus feeders rather than an increase in suspension-feeding population resulted in the exceptionally high *ITI* (>90) observed between 2009 and 2014.

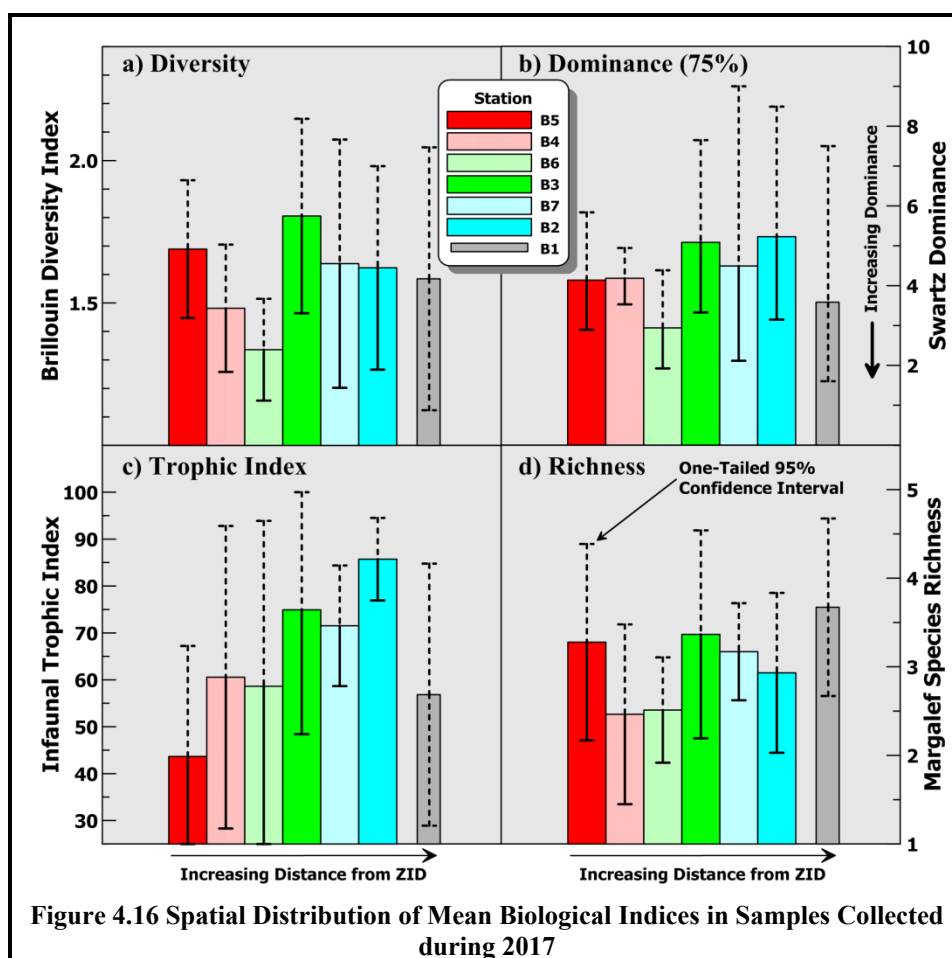
However, with the marked increase in the density of sand dollars after 2014, suspension feeding became the sand dollar's preferred feeding mode. Reduced competition with detritus feeders resulted in the small observed increase in numbers that brought Group II and IV populations closer to historical levels, when sand dollars were less prevalent. In contrast, increased competition with Group I suspension feeders contributed to their near elimination in sediment samples collected after 2014. Thus, the combined effect of a near-normal deposit feeding population and a severe reduction in suspension feeders caused the *ITIs* to drop to historic lows after 2014.

In addition to competition for food, small crustaceans, such as gammarid amphipods, comprise the majority of sand dollar prey when the sand dollars are in their deposit-feeding mode (Timko 1976). Thus, the population of gammarid amphipods, which are highly influential in the determination of the *ITI*, could have been further reduced because of predation by adult sand dollars. While it is unclear what combination of these potential interactions between infauna and the sand dollar bed was responsible for the observed *ITI* decline after 2014, it is clear that the presence of numerous large sand dollars was directly responsible for the low *ITI*, rather than some new pollutant source within Estero Bay sediments, particularly one related to the MBCSD effluent discharge.

4.3.3 Infaunal Diversity Unrelated to ZID Proximity

The previous section documented the overall health of the infaunal community surrounding the outfall using a 32-year record of infaunal community indices. It analyzed long-term trends in community parameters and explored the causes of isolated outliers that were evident at a few stations during individual surveys. In contrast, this section examines the 2017 infaunal database alone to determine whether average population parameters near the outfall were significantly lower than those of distant stations, which could indicate potential discharge-related degradation of the infaunal community surrounding the ZID over the short term.

As described in Appendix B.1, four of the biological indices are more independent and informative than the other indices. They include the Brillouin Diversity Index, the Swartz Dominance Index, the Margalef Richness Index, and the *ITI*. The spatial ranking of average values for these four indices is shown in Figure 4.16.¹ The bars are arranged in order of increasing distance from the diffuser structure. The red-colored bars on the far left are associated with the ZID stations located closest to the diffuser and within



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 shown in the bar chart of Figure 4.16. The confidence bounds surrounding the average station values reflect the within-station variability among the five replicate samples collected at each individual station during 2017.

27 m of a diffuser port.¹ The two green bars in the middle represent the nearfield stations that lie between 37 m and 65 m from the diffuser structure. The two blue bars represent the two mid-field stations that are between 134 m and 135 m from the diffuser. The thinner and separate grey bar on the far right represents the distant reference Station B1, which lies 1 km from the discharge. As with the benthic chemistry samples collected at this distant station, its infaunal community is unrepresentative of the community found within the survey area surrounding the outfall. Because its community parameters are unsuitable for comparison with those of other stations, its bar is separated from the rest of the bar chart to emphasize its exclusion from the discussion of benthic conditions within the area of interest.

The height of the bars in Figure 4.16 reflects the average community parameter determined from the five replicate samples collected at each station. Potential impacts to infaunal communities from the discharge would be revealed as significant declines in average diversity, *ITI*, and richness as the source of the discharge is approached, which would appear as a sequence of shorter bars from right to left (Figure 4.16acd). In contrast, dominance (Figure 4.16b) would be expected to increase with outfall proximity, so the axis of its chart is inverted so that the same pattern of decreasing bar heights from right to left would also indicate possible benthic impairment near the outfall.

Confidence intervals surrounding each station's average value reflect the degree of scatter among the five replicate samples collected at that station. As such, the intervals measure the inherent uncertainty in the average station value. Thus, the significance of any perceived reduction in the height of a bar on the left, relative to bars located farther right, can be visually determined by comparing its average value with the lower confidence bound at the more distant station.² Increasing infaunal health with outfall proximity would not be expected from an effluent-discharge impact, so the upper confidence bounds are shown with dashed lines to highlight their irrelevance in the compliance assessment.

Visual inspection of the distance-ranked averages of diversity, dominance, and richness (Figure 4.16abd) does not reveal a consistent spatial pattern indicative of infaunal impairment related to the discharge, namely, progressively lower bar heights from right to left. Instead the bar height appear to be somewhat randomly distributed. Moreover, most of the pairwise differences between station averages (bar heights) are encompassed within the lower confidence bound of the more-distant station (to the right). This indicates any perceived decline in the closer-in station's average is not statistically significant at the 95% confidence level. Only at the downcoast nearfield station (B6), shown by the light green bar (third from left), appears to have an infaunal community that is of measurably lower diversity and richness, and higher dominance than the communities at many of the other stations, including the more-distant stations with bars farther right.³

As described in the prior section, during 2017, this station supported a sand dollar community that was twice as populous as at other stations. There was an associated large increase in the presence of a sand-dollar parasite (*B. rutila*) and a reduced abundance of other infaunal taxa within the smaller sediment

¹ Recall, however, that the Station B5 replicate samples (solid red bars) were collected well within the ZID at distances of as little as 2.7 m from the diffuser; while the Station B4 replicate samples (shaded light red bars) were collected well beyond the ZID, at distances ranging between 24 m and 27 m from the diffuser centerline.

² Each pairwise comparison of bar height is equivalent to an unpaired two-sample Student *t*-test of the null hypothesis that there is no decrease in mean values between the two stations at the 95% confidence level assuming unequal variances and a one-tailed distribution. A Bonferroni correction was incorporated into the confidence bounds to account for the five pairwise comparisons available for each index (excluding Station B1).

³ Average diversity (Figure 4.16a) at Station B6 is significantly lower than that of Stations B5 and B3. Average dominance (Figure 4.16b) at Station B6 is significantly higher (lower bar height) than that of Stations B5, B4, B3, and B2. Average richness (Figure 4.16d) at Station B6 is significantly lower than that of Station B7. Among the many other pairwise comparisons for these three community parameters, only one other station (B4, light red bar second from left in Figure 4.16d) has a significantly lower bar height as compared to that of another station (B7, light blue bar fifth in distance ranking).

volume left within grab as result of the denser sand-dollar bed. The resulting marked increase in the relative dominance of that parasite led to a concomitant decrease in diversity and richness within the Station-B6 infaunal assemblage. The quantitative analysis of variance displayed by Figure 4.16abd demonstrates that the impact of the denser sand-dollar population on Station-B6's infaunal community during 2017 was large enough to cause a statistically significant reduction in these common measures of diversity, even in the presence of large within-station variability among replicates collected at individual stations. The multivariate analyses described later in Section 4.3.5 provides a more rigorous and comprehensive analysis of the relationships among individual replicate samples that reveals more specifics about the unique infaunal assemblage associated with increased sand dollar abundance. It reveals that the differences are actually distributed along a north-south gradient, in contrast to one that is isolated at Station B6, or one that is related to outfall proximity.

In contrast to the diversity indices described above, the *ITI* is based upon trophic (feeding) strategy. As such, the distribution of distance-ranked trophic measures in Figure 4.16c differs noticeably from that of the other population-based indices described above. At least visually, the average *ITI* ranking exhibits a relatively consistent spatial pattern indicative of decreased infaunal wellbeing with increasing proximity to the effluent discharge (declining bar heights from right to left). In historical benthic studies surrounding large wastewater discharges, this kind of striking *ITI* spatial pattern resulted from a buildup of organic wastewater constituents in sediments surrounding the outfalls. However, the pattern of declining *ITI* with outfall proximity seen in the Figure 4.16c did not arise from a sudden decline in sediment quality related to the MBCSD discharge.

As described in the previous section, Station *ITIs* measured after 2014 have been highly variable and uniformly low compared to the prior 29-year record (Figure 4.14e on Page 4-40). As with the other indices measured at individual stations during 2017, the *ITIs* among replicate samples were highly variable, thereby increasing the uncertainty in average *ITIs* determined for most stations. This variability is reflected in the broad confidence-bound range that encompasses the average *ITIs* at many of the other stations. As with the diversity-related indices, few of the differences in the *ITI* averages shown in the bar chart of Figure 4.16c were statistically significant, suggesting that at least some of the perceived spatial trend was happenstance. Specifically, because of their wide confidence bounds, none of the differences between station averages reported for the four intermediate-distance stations (B4, B6, B3, and B7; second through fifth bars) were significantly different from one another at the 95% confidence level. Their lower confidence bounds encompassed one another's average *ITI*.

In contrast, hypothesis tests of station pairs that include the most distant station (B2, sixth solid darker-blue bar on the right of the survey-area group), found its average *ITI* was significantly elevated compared to that of all the closer-in stations shown in the bars to the left (i.e., the Station B2 lower confidence bound was above all the other station's averages). Additionally, the average *ITI* measured at Station B5 (first bar in solid red) was significantly lower than the averages at the three most distant stations (B7 in solid green, B2 in light blue, and B2 in solid blue).

Regardless of its significance, the visually apparent *ITI* trend seen in the bar chart of Figure 4.16c was unrelated to the discharge of organic constituents within effluent. As discussed in Section 4.2.2 on Page 4-24, subsurface organic enrichment within the outfall structure's debris field was responsible for the remarkably lower *ITI* observed very close to the outfall at Station B5 during 2017 (first bar in solid red in Figure 4.16c), as well as for the anomalously low *ITIs* measured at that station during the 2000 and 2010 surveys (see Figure 4.14e on Page 4-40). During the 2017 survey, the debris field's increased organic content was confirmed by the BOD and TVS concentrations measured at Station B5, which were the highest found during the 2017 survey (see the solid red bar on the left of the upper right and lower left bar charts in Figure 4.6 on Page 4-24). However, as documented elsewhere in this chapter, the increased

organic content within the outfall structure's debris field arose from epifauna that sloughed from the outfall structure itself, and not from organic material discharged within effluent.

In contrast to the debris field, the significantly higher *ITI* found at Station B2 was an artifact of slight variations in the phenomenally dense sand-dollar bed that was present during the 2017 survey, and during the two previous surveys. As described above, the population of numerous mature sand dollars exerted both a taxonomic and sample-size influence on the infaunal community measured during the three most-recent surveys. From a sample-size standpoint, the sheer volume of sand dollars collected within the grab samples displaced much of the sediment that was normally collected in other surveys. As a result, fewer infauna were collected overall and as a result, changes in a single taxon that happens to have an affinity for sand dollar beds controlled the determination of the *ITI*.

Other benthic studies that successfully employed *ITIs* to discern discharge impacts, measured *ITI* in samples that contained multiple taxa within all four trophic groups included in *ITI* computation. In contrast, the *ITIs* computed from the 2017 MBCSD sediment samples were based on very few specimens contained within the limited sediment volume recovered from the dense sand-dollar beds. Because of this, the *ITI* determination was almost entirely controlled by the abundance of single taxon, the lugworm *Armandia bioculata*. This taxon has a strong affinity for sand dollar beds (Smith 1981), and because of the reduced sediment volume, few infaunal specimens were collected overall, including ones in other feeding guilds. As a result, this taxon was the third most abundant non-Dendraster taxon collected during 2017. Because it is also included in Group IV subsurface detritus feeders, its increased abundance is three-times more influential in reducing the *ITI* than the more commonplace Group II surface detritus feeders (see the *ITI* equation in Section B.1.4 in Appendix B).

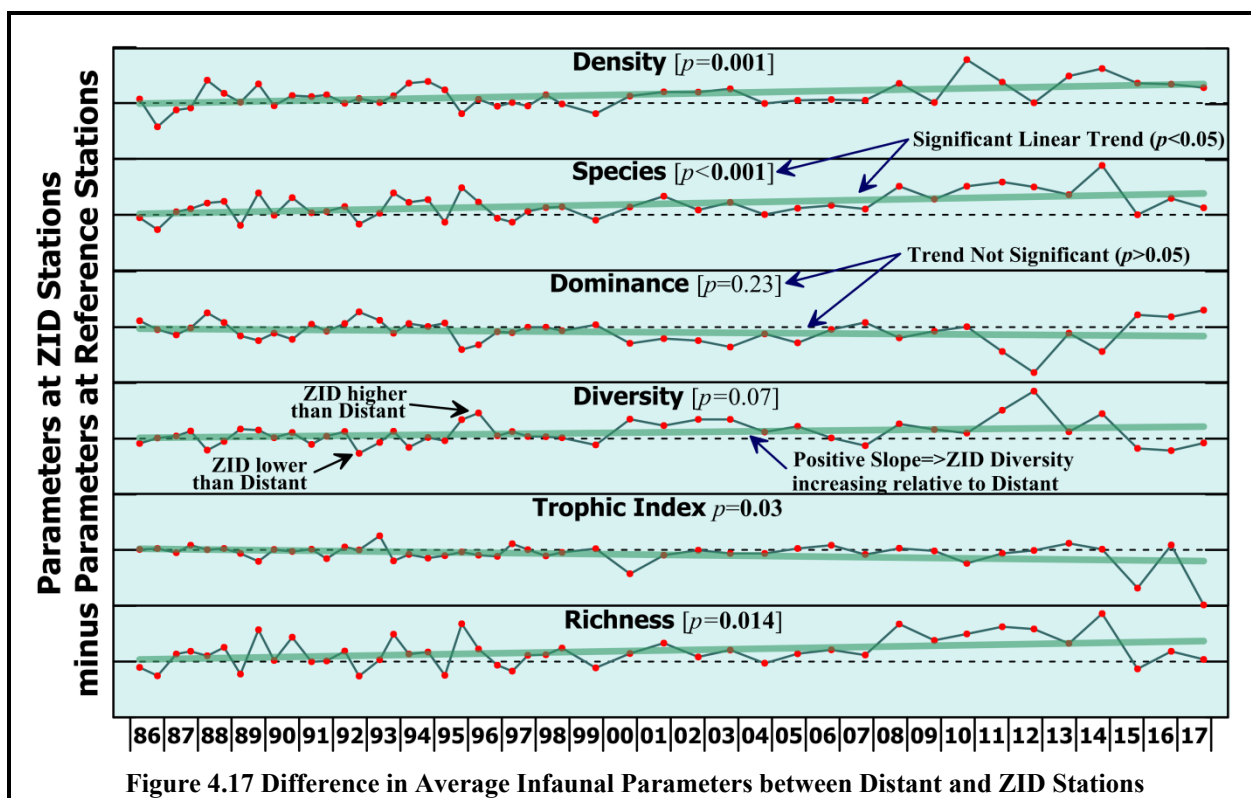
Accordingly, the significantly higher *ITI* observed at Station B2 (solid-blue sixth bar in Figure 4.16c) arose because the fewest (only three) *A. bioculata* specimens were collected there (see the fourth row of Table B.1). Similarly, the markedly lower *ITI* at Station B5 (solid red first bar) was a direct consequence of the 110 specimens collected there. This particular Opheliid lugworm is known to thrive in high numbers within sand dollar beds irrespective of their organic content. Field studies have consistently found significantly higher numbers of *A. bioculata* within sand dollar beds than within adjacent sediments with identical concentrations of organic material (Smith 1981). Thus, the *ITI* spatial variation observed during the 2017 survey was not related to degradation in sediment quality from the deposition of organic material within the MBCSD effluent. Instead it resulted from the enhanced influence of a particular lugworm that happens to have natural affinity for sand dollar beds.

4.3.4 Spatiotemporal Infaunal Trends Unrelated to ZID proximity

As with the chemical constituents within northern Estero Bay sediments, subtle spatiotemporal trends in the infaunal community can be difficult to discern by visual inspection of the station time series shown in Figure 4.14 on Page 4-40. The parameters exhibit wide fluctuations between seasons and among 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.¹ This temporal coherence indicates that changes within infaunal communities that arise from regional influences throughout Estero Bay are far more influential than those induced by any localized effects. Therefore, within a given survey, spatial differences among infaunal parameters can be difficult to differentiate, and are likely to be confounded by larger natural differences in the sedimentary environment, as well as other zoogeographic influences.

¹ Except for the *ITIs* in Figure 4.14e after 2014, which were confounded by the presence of a mature sand dollar bed

The limitations associated with purely spatial or purely temporal approaches to impact evaluation are largely eliminated through application 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 fluctuate widely 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 indices may be present but not visually apparent in that kind of presentation. Taking the difference in average values at sites distant and proximal to the outfall removes the coherent 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, which presented in Figure 4.17, eliminate these coherent fluctuations and can reveal potentially significant influences of the effluent discharge.



If the MBCSD discharge were negatively impacting the benthic community over time, the infaunal community indices at stations near the outfall (B4 and B5) would slowly diverge from those of the more distant stations (B2 and B7). This would appear as a trend or slope in the difference of average indices shown in Figure 4.17. 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 32-year time series found slight, but statistically significant trends in all the indices except the dominance ($p=0.23$) and diversity ($p=0.07$). The significant, positive linear trends in density, number of species, and richness demonstrate that the time histories at the ZID and reference stations were not parallel. However, because their slopes were all positive, the trends in those indices document a steadily increase in index values at the ZID stations, as compared to those of distant reference stations. Those type of temporal trends are opposite of those that would occur if the MBCSD effluent discharge were having a long-term deleterious impact on the benthos near the outfall. Increasingly greater abundance, species counts, and richness at stations close to the outfall reflect an increasingly healthier infaunal community compared to the distant reference stations.

Because the observed trends are opposite of what would be expected from a community that was being negatively impacted by the MBCSD discharge, the parallelism tests are irrelevant to the impact assessment even though parallelism was rejected for these three indices. Accordingly, their p -values are enclosed in brackets in Figure 4.17 to reflect their inapplicability. This was the case for all of the infaunal community indices except for the statistically significant negative trend in *ITI* ($p = 0.03$). However, its negative trend was solely the result of anomalously low *ITI* values reported in 2015, and especially in 2017 when samples were inadvertently collected within the outfall's debris field. Prior to 2015, *ITI* differences were negligible, as indicated by values near the centerline in Figure 4.17. Because the anomalously low differences happened to be measured near the end of the time series, they weighed more heavily in the regression analysis because they were located near the end of the time series.

The reasons for the significantly positive spatiotemporal trends in the other indices are less clear. However, in contrast to the analyses in previous sections, the parallelism tests presented in Figure 4.17 are much more robust and have a higher degree of confidence. The tests for steady long-term increases in infaunal density and numbers of species near the discharge, for example, indicates that a spatiotemporal trend of the observed magnitude would occur by chance only one-in-a-thousand times. Even so, causality cannot be easily ascribed to an observed relationship where infaunal health is steadily improving in samples collected close to outfall. In fact, it is probably related to long-term zoogeographic changes throughout northern Estero Bay as a whole.

4.3.5 Infaunal Community Structure

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.

In addition, decades of analysis has demonstrated that benthic pollution affects marine ecosystems by changing the infaunal community structure in well-defined ways, namely, changes in the number and type of benthic organisms found within the sediments. However, evaluating the wellbeing 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 determination challenging because it is difficult to summarize 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 population-based indices, without having a single species in common. One sample may consist entirely of opportunistic pollution-tolerant taxa, and the other sample could contain high numbers of pollution-sensitive taxa, but that important distinction would be completely missed by an analysis of the infaunal diversity indices alone.

Despite the univariate indices' 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 (i.e. within an individual replicate grab sample) at a particular time (α -diversity). In contrast, pollution and other stresses tend to induce changes in community composition wherein completely different (pollution-tolerant) taxa begin to inhabit an impacted area. This produces assemblages that differ substantially among the samples collected through time at widely separated locations. This 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 2017 infaunal dataset. Compositional differences among the 35 samples collected during 2017 were moderately large, as demonstrated by a Whittaker (1972) β -diversity of 2.7.¹ This elevated level of β -diversity suggests that the summary univariate indices may be incapable of differentiating subtle trends in community structure among the samples.

Multivariate techniques are much better suited to the evaluation of datasets with moderate to high β -diversity. The 2017 dataset used in this multivariate analysis consisted of a matrix of counts for 66 taxa² in 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 large numbers of species, but because many pairs of samples have few species in common. In response to these challenges, landscape ecologists have, over the last 70 years, developed specialized multivariate analysis tools. These techniques are designed to efficiently extract dominant patterns within a complex species-sample database. They accomplish this by exploiting redundancies (correlations) in the abundance of individual species among the samples, thereby compressing the data into the most meaningful patterns.

Inherent Sampling Uncertainty

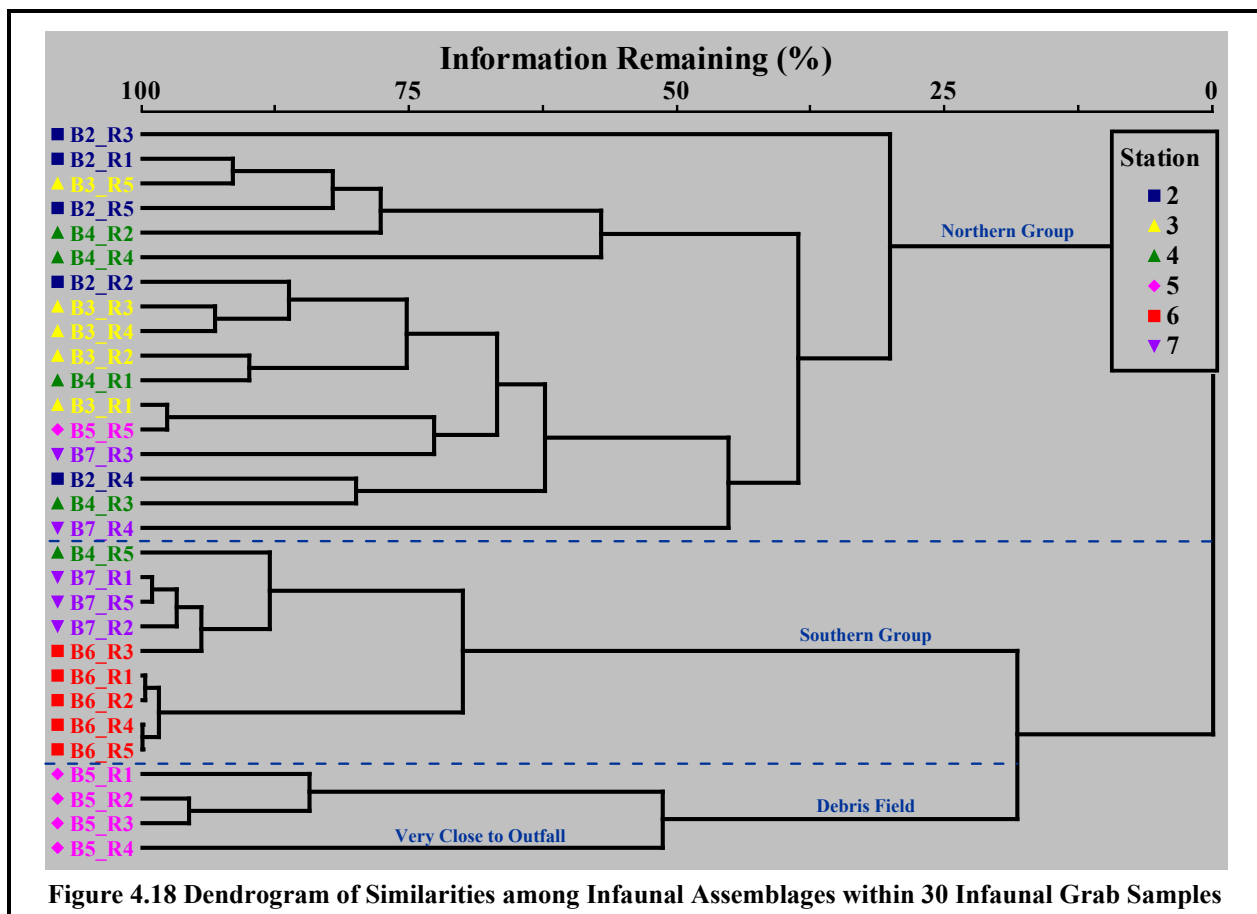
As with other field measurements that are collected to assess potential discharge impacts, it is crucial to determine the inherent uncertainty associated with characterizing an infaunal community at a given station. Specifically, the variability among repeated replicate grab samples collected from an individual station at a particular time lends insight into the confidence in average values reported for each station.

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 all the species. $\beta_w=2.7$ indicates that the entire 2017 database had four distinct communities, with almost four-times as many species (48) as the average individual grab sample (12.9).

² Because the multivariate analysis examines 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.

Thus, accurate determination of this within-station variability is essential 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 two stations, then the spatial difference cannot be considered significant. As described below, the multivariate analyses of spatial trends in the 2017 database demonstrate that infaunal communities within only a few stations could be readily distinguished from that of adjacent stations. Conversely, infaunal assemblages within the large group of stations located north of the outfall were not found to be perceptibly different from one another.

A dendrogram (branching tree diagram) produced from the multivariate taxonomic database provides a convenient graphical means for assessing the relative importance of within-station and between-station infaunal variability among the samples (Figure 4.18). It shows how similar the infaunal assemblage within a given sample is to that of all the other grab samples collected during 2017. If that assemblage is more similar to the other four replicates collected at the same station, rather than replicates from other stations, then the infaunal community at that station can be readily distinguished from that of other stations. Specifically, if differences among replicates collected at a station are smaller than the differences between the stations, spatial differences are large enough to be reliably resolved, even in the presence of inherent sampling uncertainty associated with characterizing a station's discrete community.



The relative similarity in the infaunal assemblages among samples, or groups of samples, is graphically displayed using branches in the dendrogram. 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, the short, almost non-existent branch connecting the fourth and fifth replicate samples at Station B6 in Figure 4.18¹ shows that the infaunal assemblages within those samples were nearly identical, and considering them as a single combined assemblage results in a negligible (<0.1%) 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.

A multivariate analysis of variance (MANOVA) applied to the dendrogram quantifies the clustering tendency as a whole. It determined that the within-station similarity among replicate samples was far greater than expected by chance ($p < 0.0002$). The p -value cited here is the probability that the observed station-clustering tendency 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 among replicate samples is large compared to the differences between average station communities, then the station difference is more likely to be an artifact of chance alone, rather than a real spatial difference.

As with the hypothesis tests throughout this report, differences are considered statistically significant when p -values are less than 0.05, which corresponds to a 5% (1-in-20) probability that the difference would have occurred by chance alone. Thus, the observed infaunal differences among the six survey-area stations² during 2017 were very unlikely (0.02% chance) to have been entirely due to random sampling uncertainty. Although, the 57-by-30 species-sample matrix contains discernible information about spatial differences in the infaunal communities, this does not mean that the communities within each pair of stations were perfectly distinct from one another. Instead, it only implies that the within-station fidelity among all 30 replicate samples was definitely greater than if the replicate samples were randomly assigned to stations.

In fact, none of the stations supported an infaunal community that was sufficiently unique to produce replicate samples with perfect within-station fidelity. Even the replicates collected within the outfall's debris field at Station B5, shown by "Debris Field" branch in the lower portion of the dendrogram, did not cluster first with the fifth replicate (B5R5) from that station. Instead, that replicate contained an infaunal assemblage that was more comparable to the survey area north of the diffuser structure, shown in the "Northern Group" branch within the top half of the dendrogram. As discussed below, the difference in Replicate B5R5's infauna arose because the sample was collected just beyond the debris field, where benthic conditions were more like most of the other stations.

As documented in the 2010 Annual Report (MRS 2011) and in the *Sampling Location Offsets* Subsection on Page 4-6 of this chapter, the outfall's debris field is limited to a very narrow corridor immediately surrounding the structure. Within that narrow corridor, the character of the sediments, and the infauna that reside within them, change rapidly as the structure is approached. This is apparent from the distinct suite of the infauna within Replicate B5R4 that was located only slightly closer to the outfall than the other replicates at that station (see the inset of Figure 4.2 on Page 4-6). The unique character of its infauna is

¹ The straight line on the far left of the diagram connecting ■ B6_R4 and ■ B6_R5

² Excluding Station B1

encapsulated in the “*Very Close to Outfall*” branch at the bottom of the dendrogram. That branch did not coalesce with the other debris-field samples until only half of the information (variability) in the species-sample matrix remained, and all but two other samples (B2R3 and B7R4 at the top and bottom of the Northern Group) had combined into groups of similar samples.

A MANOVA conducted on station pairs demonstrated that only Stations B5 and B6 had distinct communities that could be reliably be distinguished from that of all the other stations ($p \leq 0.024$). This finding is visually evident in the dendrogram because the replicates from those stations, shown at the bottom of the dendrogram, tend to cluster first with replicates from the same station. In contrast, station-fidelity among most replicate samples collected north of the diffuser structure, shown in the upper Northern Group was particularly low. Nearly all of those replicates tend to coalesce first with replicates from other stations, or with branches that contain replicates from other stations.

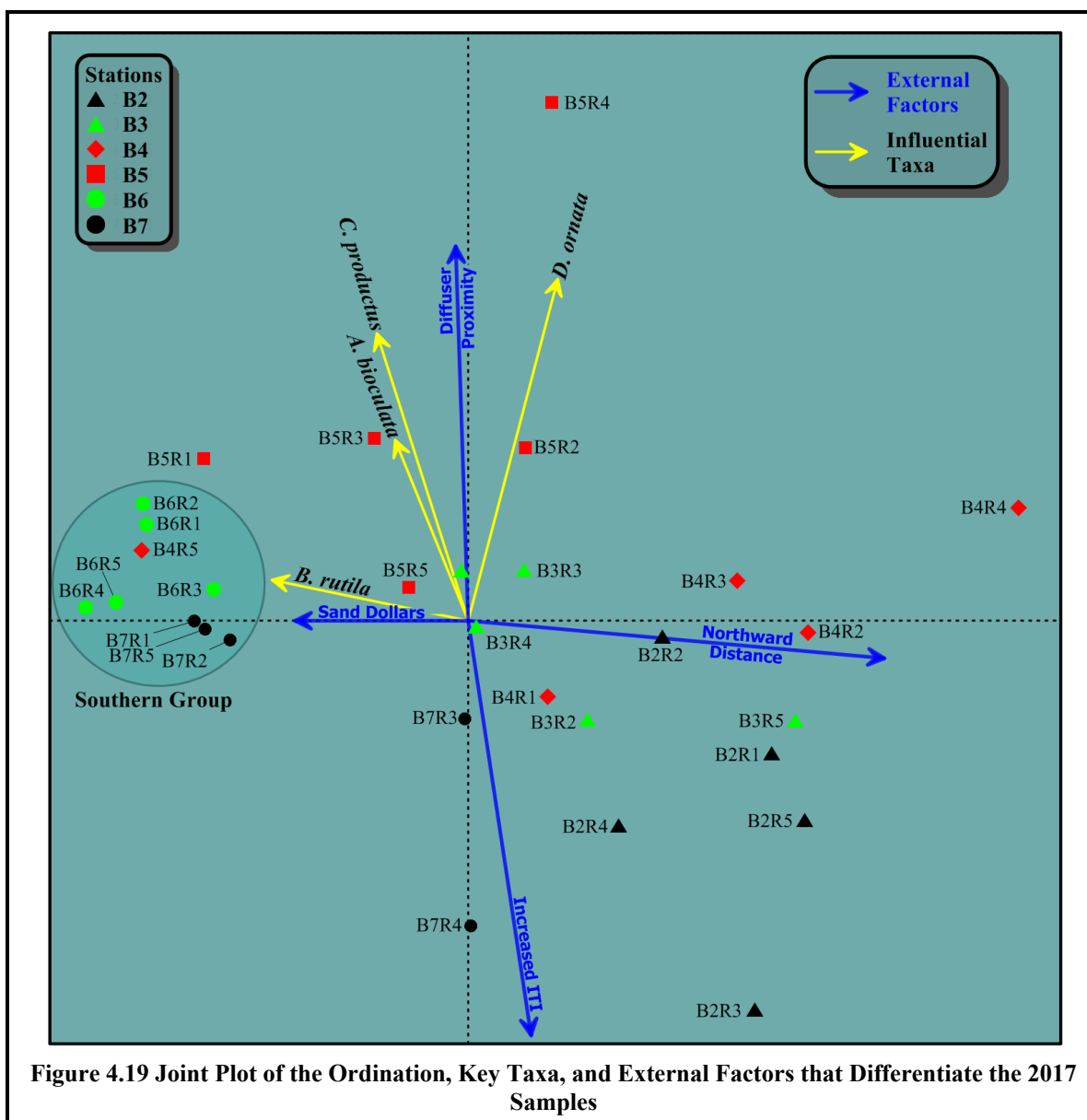
Despite the low within-station fidelity among the samples collected north of the diffuser structure, as a group, their infaunal assemblage differed significantly from that of the two southernmost Stations B6 and B7 ($p = 0.00007$). This was the case even though this Northern Group included replicates from the “*Southern Group*,” and one (B5R5) from the Debris Field Group. However, separation of the Northern Group only became fully apparent after many replicate samples were combined and only 30.1% of the information (variability) in the species-sample matrix remained. In contrast, there was no statistically significant spatial pattern in the 2017 database that was related to outfall proximity ($p = 0.07$), at least beyond the ZID (i.e., excluding the debris-field Station B5).

Spatial Variability

The two major branches in the dendrogram of Figure 4.18 demonstrate that most replicate samples collected at stations north of the diffuser structure (Stations B2, B3, and B4 in the upper branch), contained an infaunal community that differed from that of the group of stations downcoast of the diffuser structure (Stations B5, B6, and B7 in the lower branch). This north-south trend suggests a naturally occurring zoogeographic spatial pattern of along-shore change rather than a pattern indicative of seafloor impairment surrounding the ZID, which would be reflected by groupings related to outfall proximity. However, the influence of external influences on community composition can be better explored using another related multivariate analysis technique, known as ordination analysis.

The resulting two-dimensional ordination¹ diagram provides a visual interpretation of the differences in the infaunal communities found among the 30 samples remaining after exclusion of Station-B1 data (individual color-coded sample points in Figure 4.19). The diagram distills the major infaunal differences among samples as a separation between sample points in the multivariate 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 grab samples. The distance between a pair of points quantifies difference in species compositions contained within those samples. Widely separated points, such as B4R4♦, at the extreme end of the positive X-axis, and B6R4●, on the opposite extreme of the X-axis, have dissimilar infaunal assemblages. Namely, they have few species in common, and large differences in the abundance of any species that are common to

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 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. The method is unconstrained by the external factors, but the influence of those factors was evaluated by superimposing them on the ordination diagram.



both samples. In contrast, points that lie close to one another have assemblages with many common species and similar abundances among those common species (e.g., B6R4● and B6R5● within the Southern Group at the negative extreme of the X-axis).

In addition, separation between sample points along the horizontal axis of the ordination plot characterizes a variation in species composition that is fundamentally different (uncorrelated) from the variation in community composition along the vertical axis. In past surveys, changes along the major (horizontal) axis often reflected a large-scale zoogeographic difference while the secondary vertical axis usually coincided with a local environmental gradient in the samples, such as water depth or mud content. However, the vertical distribution of sample points within the 2017 ordination diagram did not exhibit a strong association with these external influences that were commonly observed in surveys prior to 2015.

Alongshore Location and Sand-Dollar Density

The diagram (Figure 4.19) resulting from an ordination of the 2017 database echoes some of the findings discussed above in conjunction with the dendrogram (Figure 4.18), and in conjunction with the univariate infaunal community parameters (Section 4.3.3). Specifically, nine of the replicate samples collected within the southern extent of the survey area contained a consistent infaunal assemblage that was distinct from the other samples; it was designated the Southern Group. Accordingly, all of its samples were located in comparatively close proximity along the negative X-axis of the ordination diagram in Figure 4.19.

A much larger group of 17 samples were collected north of the diffuser structure, and although they exhibited much less within-station and within-group fidelity in the dendrogram, their infauna as a whole, were measurably different from those found in the Southern Group. Accordingly, these 17 samples are widely dispersed in the ordination diagram. Nevertheless, most are located in the right hemisphere of the ordination diagram, and all are located to the right of the Southern Group.

This horizontal distribution of sample points within the ordination diagram confirms that differences in the 2017 the infaunal assemblages beyond the ZID were related to alongshore location, rather than proximity to the effluent discharge. If MBCSD effluent discharge were perceptibly influencing the infaunal community beyond the ZID, the sample-point distribution would visually exhibit a distinctly different sample-point pattern. Specifically, the ZID stations (in red) would form a cluster that is distinct from that of the near-field stations (green), and from that of the mid-field and reference stations (black). No such consistent grouping or steady progression of colors is apparent in the ordination diagram.

Another advantage to the ordination analysis is that it provides a means for evaluating various external environmental factors that influenced the distribution of samples points, and by extension, that caused differences in infaunal assemblages within the replicate samples. For the 2017 database, the most influential of these factors are jointly displayed on the ordination diagram of Figure 4.19 as blue arrows radiating from the center of the diagram. The angle and length the arrows reflect the direction and strength of the relationship between each external factor and the infaunal community within individual samples displayed as points in the ordination diagram. Other external factors were also examined but did not exhibit a significant relationship to the sample distribution, and consequently, their arrows were much shorter than those shown in the ordination joint plot.

As discussed previously, much of the variation in the infaunal community among samples collected during 2017 was related to their alongshore location. In particular, as indicated by the length of the “*Northward Distance*” arrow along the positive X-axis, alongshore location strongly determined the type of infauna found within most individual replicate samples ($p < 0.001$). The ordination also demonstrated that sand-dollar density, as shown by the “*Sand Dollars*” arrow, which covaried with alongshore distance may be the underlying external factor responsible for the observed zoogeographic trend. Specifically, the markedly increased density of large live sand dollars found to the south introduced higher numbers of parasites into the infaunal community. The spatial difference in sand dollar abundance was readily apparent during their enumeration after the survey (Figure 4.20 on Page 4-61). Samples collected to the south at Stations B6 and B7 were more numerous (Figure 4.20a) than those collected at other locations (Figure 4.20b).

Debris Field and Reduced ITI

Independent of the alongshore changes in the infaunal composition shown by the sample distribution along the X-axis of the ordination plot, marked differences were also observed in the Station B5 samples, which were collected very close to the outfall and within the structure's debris field. Because the difference in their infauna departed from the alongshore changes in seen in infauna from all the other stations, their sample points separate along the perpendicular Y-axis in the ordination diagram. Specifically, all five of the replicates collected at Station B5 (shown by the red squares ■) were located in the upper hemisphere of the ordination plot (i.e. they had positive Y-axis values). Four of the five replicates were located well above other sample points, indicating that some aspects of their infaunal composition were distinct from the infauna collected at all other stations during the 2017 survey. The other replicate sample from that station (B5R5), however, was located near the origin of the plot, indicating its infauna were close to the survey's overall average composition. As described above, that replicate (B5R5) was probably collected slightly beyond the outfall's debris field.

Also, as described previously, one of the other replicate samples (B5R4) was collected slightly closer to the outfall structure and had a markedly different infaunal composition from all other sample collected during the 2017 survey. The strength of its infaunal difference is reflected in the ordination diagram by a large positive Y-axis separation from all the other samples. Two external variables strongly correlate with the sample distribution along the Y-axis. Because Station B5 samples were collected much closer to the outfall structure, the *Outfall Proximity* arrow is long and closely aligned with the positive Y-axis. Similarly, because the *ITI* was much lower in the Station B5 samples, the *Increased ITI* arrow points away from the Station B5 samples, and along the negative Y-axis. This is because few taxa other than the Group IV subsurface detritus feeder *A. bioculata*, were collected in the B5R4 replicate sample, and as a result, its computed *ITI* (23) was far below the next lowest *ITI* (37).

Key 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 2017 infaunal database, which is listed in Table B.1. Although perusal of the table may reveal patterns for specific taxa, it is challenging 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

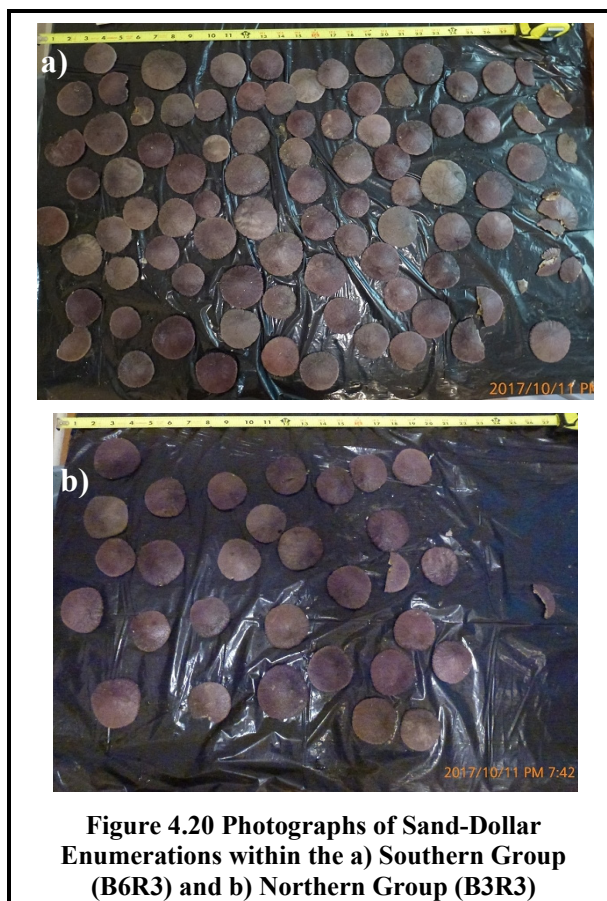


Figure 4.20 Photographs of Sand-Dollar Enumerations within the a) Southern Group (B6R3) and b) Northern Group (B3R3)

samples. As described previously, multivariate community analysis was designed to distill this complex set of information quantitatively, to eliminate redundant or marginal patterns, and to produce most important information concerning how the communities within individual samples relate to one another. In that regard, the ordination methodology also identifies which taxa primarily influence the community differences among replicate samples, namely, the distribution of sample points in the ordination diagram. Those influential taxa often have life-history information, such as a tolerance or sensitivity to pollution and organic loading, that 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 in yellow on the joint plot of Figure 4.19. As with the external environmental factors, the level of influence each individual key taxon had on the overall distribution of the samples is represented by the yellow arrows superimposed on the ordination plot. 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 ordination identified the parasitic marine snail *B. rutila* (Figure 4.21) as a primary species responsible for separating samples along the horizontal axis of the ordination. Its numbers were particularly elevated within the Southern Group samples where sand dollars were more populous. This is not surprising given that sand dollars are a well-known host for these parasites (Lovell 2003, Morin et al. 1985). Its distribution was also found to co-occur with increased sand-dollar density during the 2015 survey, when it was instrumental in differentiating Station B5 samples (MRS 2016). During the 2017 survey, however, it was the most populous non-Dendraster taxon, and its 746 specimens constituted 38% of the infauna collected (Table B.1 in Appendix B). Nearly half were collected at Station B5 and B6, where their populations were uniformly distributed among the replicate samples. Replicate B4R4, on the other hand, only contained three specimens, which accounts for its sample-point location on the far right of the horizontal axis. That sample also contained comparatively few (15) sand dollars.

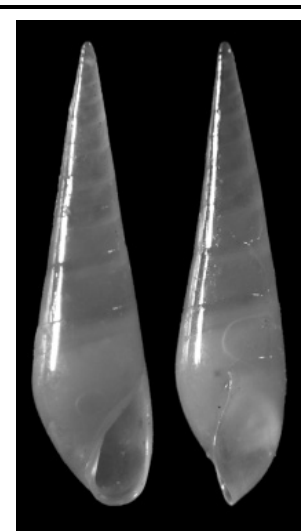


Figure 4.21 *B. rutila*

As described previously, the outfall debris-field samples contained elevated numbers of the Opheliid lugworm *A. bioculata* (Figure 4.22), so it is not surprising that it played a pivotal role in determining the distribution of sample points along the vertical ordination axis. Because sand dollars were present throughout the survey area, that lugworm was found in all but six of the 35 infaunal grab samples (Table B.1 in Appendix B). It was the third most abundant non-Dendraster taxon. However, nearly half (103) of the 225 specimens collected during the survey were found within the four debris-field samples. The other Station-B5 sample (B5R5) only contained four specimens, which accounts for its location near the center of the ordination diagram. In contrast, the sample collected closest to the diffuser structure (B5R4) contained by far the most specimens (40), which accounts for its location at the extreme top of the ordination diagram where it was well-separated from even the other Station-B5 replicate samples.



Figure 4.22 *A. bioculata*

That organism is part of a group of opportunistic detritus-feeding organisms that are considered diagnostic of organically polluted sediments. Because of this, its increased presence at Station B5

weighed heavily in reducing the *ITI*. Thus, the *Increased ITI* arrow points along the negative Y-axis, in the opposite direction of the *A. bioculata* arrow. However, in this case, the *ITI* is unrepresentative of sediment pollution because *A. bioculata* is also capable of rapid population growth in highly disturbed habitats, such as the scour zone immediately surrounding seafloor structures (viz., the outfall). Replicate sample B5R4 was widely separated along the positive Y-axis of the ordination largely because it was collected slightly closer to the diffuser structure as compared to the other replicates at the same station.

At that location, it was well within the scour zone where seafloor sediments are the most highly disturbed, and where sediments contain the highest fraction of structural debris, such as shell hash. This was immediately evident during the sample-sorting effort after the survey. Its residue, shown in Figure 4.23a, was of a much larger volume and contained far more debris than all the other samples (Figure 4.23b).

Two other taxa were also more prevalent within the debris field, the red rock crab (*Cancer productus*) and the ornate tube worm (*D. ornata*). Based on their life histories, both would reasonably be expected to be prevalent in the vicinity of a seafloor structure such as the outfall. All three of the rock-crab specimens were collected within the debris-field samples, and four of the six tube worms were found within the close-in outfall sample B5R4. As described in Section 4.3.1 on Page 4-33, large ornate tubeworms are normally separated from the sample in the field, but small specimens are not always found. Tubeworms congregate in higher densities close to both natural reefs and manmade structures, such as outfalls (Davis et al. 1982). Red rock crabs were first observed within the MBCSD infaunal database only as recently as the 2016 survey, although it is prevalent near rocky substrates throughout the central coast region.



Figure 4.23 Photographs of Sorting Residue from Grab Samples collected within a) the outlier replicate (B5R4), and b) a typical replicate (B3R4)

Overall, the multivariate ordination demonstrates that the differences among the infaunal communities collected at various sampling locations were largely controlled by the increased sand-dollar density found to the south of the diffuser structure. In addition to this alongshore distribution, samples collected very close to the diffuser structure and within its debris field contained a suite of infaunal taxa that were materially different from the rest of the samples collected during 2017. Overall, the multivariate results were consistent with the findings from the analyses of infaunal community indices and sediment chemistry. Together, the weight of quantitative evidence demonstrates that, even within sediments immediately adjacent to the outfall structure, there was no evidence of a buildup of organic particulates from the MBCSD wastewater discharge. Moreover, although the indigenous infaunal population that resides throughout northern Estero Bay changed dramatically after sand-dollars began dominating the benthos in 2015, the new BIP extends throughout the region, including the survey area surrounding the MBCSD effluent discharge.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The MBCSD monitoring program was designed to appraise the performance of the wastewater treatment plant, to monitor the quality of effluent discharged to the ocean, and to assess potential impacts within receiving waters and seafloor environment. This annual report evaluated compliance with the NPDES discharge permit and documented the potential for discharge impacts through quantitative analyses of an extensive data set of effluent constituents, receiving-water measurements, sediment chemistry concentrations, and marine biological enumerations. Of the thousands of measurements collected as part of the monitoring program during 2017, only one exceeded a discharge limitation and then, only by a marginal amount.

As discussed in Section 2.2.2, the 76-mg/L average effluent Total Suspended Solids (TSS) concentration reported for June slightly exceeded the 70-mg/L permitted monthly maximum concentration. However, the average concentration was determined from only four measurements and consequently, the reported value had a low degree of confidence. Normally, monthly TSS averages are determined from 20 or more daily measurements, so the reported averages are determined with a high level of confidence. Although few in number, some of the June effluent TSS measurements were unusual, and resulted from an actual temporary decline in the plant's suspended-solids removal process. Specifically, they arose from a reduction in return activated sludge (RAS) from the secondary clarifier. Effluent TSS concentrations quickly returned to normal after accumulated solids were cleared from the RAS piping, and the entire RAS system was later rehabilitated to prevent future accumulations. Although the TSS exceedance was slight, its occurrence was highly unusual in a near-perfect 15-year record of compliance with the solids limitations in the discharge permit.

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 2017 marking the 32nd year of consistently high performance by this treatment facility. In fact, many of the best measures of treatment performance have been achieved during the past decade of operation (Table 5.1). For example, the low average effluent TSS concentration during 2017 (38 mg/L) was the direct result of the treatment process's exceptional efficiency, which removed over 88% of the influent solids. As a result, the solids discharge was only 26% of that allowed under the NPDES permit.

Removal of oil and grease (O&G) and biochemical oxygen demanding (BOD) materials from the wastewater stream also attest to the plant's overall high standard of performance during 2017. As with TSS, the discharge of these materials was only a fraction of that allowed, and was lower than the emissions averaged over all years of operation. Although the 2017 removal rates were comparable to the overall operational average, the lower flow during 2017 helped reduce the annual emission of these substances.

5.1.1 Overall Performance

Measurements of wastewater characteristics acquired throughout 2017 demonstrate that the treatment process exceeded expectations based on the original plant design, the NPDES discharge permit, and federal regulatory standards. For example, during 2017, the plant removed 13% more suspended solids than required, and the annual BOD removal rate was more than two-and-a-half times greater than the minimum permitted rate of 30%.

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
2012	1.10	379	27.1	92.5	41	322	49.9	83.5	77
2013	0.96	351	29.9	90.4	39	327	55.7	82.6	74
2014	0.94	377	29.2	91.3	37	352	51.4	85.3	66
2015	0.93	389	30.8	91.5	39	370	48.9	86.5	63
2016	0.84	358	37.1	90.0	42	384	63.7	82.9	74
2017	1.02	357	37.7	88.1	52	324	52.3	83.8	70
Average	1.30	342	32.1	89.9	58	293	51.2	81.7	91
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	94.6	≈7	26	7.6	13.95	27
2012	91	5.0	94.5	8	26	7.6	13.95	33
2013	115	≈4.5	96.1	≈6	25	7.5	24.55	40
2014	81	≈4.0	95.1	≈5	28	7.5	17.90	50
2015	81	<1.7	97.9	<2.7	29	7.5	17.90	45
2016	79	≈3.2	95.9	≈4	39	7.5	17.90	44
2017	38	<1.8	95.3	<2.5	35	7.4	17.90	41
Average	59	5.2	89.7	10	35	7.5	10.15	28
Limitation		25.0			75	6-9	134.00	80.4

¹ Screening bioassay of three marine species

² Screening bioassay of two marine species

Moreover, the plant routinely achieved treatment levels that exceeded the removal requirements applicable to full secondary treatment. For example, monthly solids-removal rates substantially surpassed the 85% full secondary criterion in ten months, while BOD removal rates achieved full secondary levels during five months of the year. Other effluent constituents were also correspondingly low during 2017. The discharge of settleable solids was imperceptible, and monthly averages of effluent turbidity, pH, ammonia, and coliform density remained well within the applicable permit limitations.

The continued high overall performance of the treatment process during 2017 was the direct result of vigilant control by plant personnel, a proactive program of preventative maintenance, and the successful completion of numerous MMRP projects. Plant personnel actively sought out and corrected potential mechanical problems with plant components before they occurred, and responded quickly to the occasional unforeseen failure. During 2017, and in recent prior years, their constant attention to the idiosyncratic disinfection process undoubtedly prevented excursions beyond allowable discharge limits.

The benefits of current and 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. These efforts account for the marked decline in plant throughput during 2002, when average daily flow dropped below 1.3 MGD and remained at or below 1.25 MGD for the last decade-and-a-half. In all fifteen years prior to that time, annual reported flow remained above 1.25 MGD.

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 during 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 30-year record would be closer to 1.15 MGD rather than the reported 1.33 MGD. Because of overestimated flow prior to 2002, the annual mass emissions were also overestimated. Consequently, the average emissions over the entire plant history, shown in bold at the bottom of Table 5.1, are slightly inflated. Specifically, over the operational history of the WWTP, the reported average TSS emission of 58 MT was actually closer to 51 MT. Similarly, the average BOD emission reported at 91 MT was, in reality, closer to 81 MT, and the reported 10 MT of O&G discharged was closer to 8 MT. Even after adjusting for past overtotalization in the historical averages, the 2017 emissions of BOD, and O&G (70 and <2.5 MT) were still well below those of the overall operational record (81, and 8 MT).

During 2002, overtotalization was largely eliminated after the more accurate influent flow meter was commissioned, and flow began to be reported based on its measurements. In contrast to the existing turbine flow meter that was located within the effluent-discharge stream from the plant, the new meter determined flow from water level within a metering flume located within the influent stream. However, on occasion, the new meter still overtotalizes flow, for example, when the influent flume becomes temporarily surcharged after water backs up into the influent channel behind the plant headworks. Nevertheless, judicious use of corrected effluent flow totals in place of these obviously aberrant influent flow-meter reports effectively eliminated significant flow overtotalization after 2002. Highly accurate annual flow totals are now regularly achieved by reporting a downward-adjusted effluent-meter flow on those rare occasions that the influent flow data is compromised. The effluent-flow adjustment factor is updated at least annually as described in the recommendation presented in Section 5.4 below.

Irrespective of these past flow-measurement improvements and I&I reductions, the marked decrease in plant flow over the last five years was largely due to another factor, water conservation. At ≤ 1.02 MGD, the reported flows were the lowest on record, with 2017 being slightly higher than the previous four years due to increased I&I. Some of this recent flow decrease can be attributed to reduced groundwater

infiltration into the collection system due to a lowering of the water table during the prolonged drought. However, much of the decrease was undoubtedly related to the successful water-conservation measures implemented by the citizens of Cayucos and Morro Bay. For example, the City of Morro Bay reduced water usage during 2015 by 13.5%, significantly surpassing the 12% mandatory water-restriction goal imposed by statewide limits that went into effect in April of that year.

5.1.3 Effluent Constituents

The treatment process was designed to remove organic particulates from the wastewater stream and disinfect effluent. As with most municipal treatment plants, the MBCSD WWTP was not designed to eliminate chemical contaminants that may be present within the wastewater entering the plant. Instead, a vigorous pollution-prevention program is in place, which aims to limit the introduction of chemical contaminants at the source, before they enter the collection system. The multifaceted pollution-prevention program includes public education efforts, an onsite hazardous waste collection facility, source identification, and inspections of commercial and 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. In the absence of 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 2017. Of the 78 chemical compounds tested for in the 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.

Quantifiable compounds within the effluent included three commonly occurring trace metals (copper, lead, and zinc), selenium, and radionuclides. The three trace metals all occur naturally within the mineralogy of sediments along the central California coast. These metals also enter the collection system through internal corrosion of household plumbing systems. The metalloid selenium, also occurs naturally within the natural mineralogy of the region, but is less likely to arise within plumbing systems. Lastly, 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.

Bioassays conducted over the past two decades have repeatedly demonstrated the MBCSD effluent's low toxicity to marine organisms. The chronic bioassays conducted during 2017 again confirmed the benign nature of MBCSD effluent. Average toxicity levels during 2017 were seven-times lower than the permitted limit.

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 15 constituents with quantifiable concentrations consisted of ubiquitous metals, metalloids, and cyanide. 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 during 2017. Precision navigation, in combination with high-resolution data on light transmittance, density, temperature, salinity, pH, and dissolved oxygen delineated 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. Many of these plume measurements captured the signature of wastewater deep within the water column while it was undergoing rapid initial mixing and rose toward the sea surface. Dilution rates determined from these deep measurements were compared with expected critical initial dilution ratios based on modeling used to design the outfall. They demonstrated that the diffuser structure was dispersing 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 measurements of dilute wastewater shortly after discharge 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 during the 2017 surveys confirmed that the diffuser was operating efficiently and that wastewater was diluted 280-fold shortly after discharge from the diffuser ports and well before the completion of the initial-dilution process.

5.3 SEAFLOOR SEDIMENTS

The monitoring program has evaluated the physical, chemical, and biological conditions within benthic sediments around the MBCSD outfall for more than three decades. Those evaluations provide strong empirical evidence that the quality of the sediments surrounding the outfall have not been perceptibly impacted by the discharge, and that a balanced indigenous population of marine organisms inhabits the benthos throughout the region, including locations along the ZID boundary.

As one component of the benthic assessment, spatiotemporal analyses were applied to the entire physicochemical dataset, which now spans 32 years since benthic monitoring began in 1986. Those analyses demonstrated that there has been no buildup of sediment contaminants surrounding the outfall. In addition, trace-metal and organic concentrations collected both near and far from the outfall during 2017 were tested for consistent spatial trends related to ZID proximity, and none were found. As in prior years, sediment concentrations throughout the survey area remained below thresholds considered harmful to marine biota. In fact, most 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 within northern Estero Bay. Nickel and chromium are the only trace metals that have comparatively elevated concentrations within Estero Bay sediments. However, the concentrations of these particular metals are also naturally elevated in the chromite mineral ores found

throughout the region. Thus, the Estero Bay sediment metal concentrations are comparable to those found in nearby benthic environments, such as Port San Luis (NOAA 1991a), and the Morro Bay Estuary (Tenera and Marine Research Specialists 1997).

To test for discharge-related biological effects, a large number of population indices and parameters were computed from an enumeration of the 266,000 specimens collected over past 32 years of benthic infaunal 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 along the ZID boundary. Not only were spatial differences within individual surveys small compared to inherent sampling variability, but the differences were also generally much smaller than the long-term changes in community structure that arise from natural environmental fluctuations. Specifically, changes in the seafloor biology within the survey area correlate with widespread natural oscillations, the largest of which occur on seasonal and interannual time scales.

The most notable faunal variations within the survey area involve interannual population fluxes of the Pacific sand dollar (*Dendraster excentricus*). Specifically, marked increases in the abundance of juvenile sand dollars were documented in 1989, 1991, 1999, and 2009 in conjunction with major El Niño global climate fluctuations. During, and shortly after these episodic recruitment events, high numbers of juvenile sand dollars dominated infaunal population statistics, but because of their small size, their increased presence did not significantly alter the taxonomic composition of the infaunal community. Because these discrete population changes were related to widespread oceanographic fluctuations, they affected all of the benthic monitoring stations, including the distant reference site, and therefore, were demonstrably unrelated to the MBCSD effluent discharge.

During the first three events, residual sand-dollar populations from the initial successful sand-dollar recruitment only persisted for a year or two following the event due to predation by ochre sea stars. These sea stars are considered a keystone species, which are organisms that are disproportionately influential in maintaining local biodiversity. Specifically, their predation has been found to be the key to controlling the populations of other species, such as sand dollars, that would otherwise dominate the resident community. However, in recent years, sea-star populations along the Pacific coast of North America suffered widespread losses from an outbreak of the sea-star wasting syndrome. The resulting absence of sea stars within the MBCSD survey area allowed the initial 2009 sand-dollar population to grow unchecked.

As a result, during the 2017 benthic survey, and in the prior two annual surveys, numerous large sand dollars displaced nearly all of the sediment normally collected within grab samples, and the resident infauna that are normally collected with it. Thus, the overwhelming presence of mature sand dollars within the MBCSD survey area not only dominated infaunal population statistics, as they had briefly after prior El Niño events, but the taxonomic makeup of the infaunal community had now changed dramatically. During the 29 years prior to the 2015 survey, the diverse infaunal community consisted almost exclusively of assemblages of delicate suspension feeding organisms and surface detritus feeders, whose presence is considered indicative of an extremely pristine undisturbed seafloor habitat. In contrast, after 2014, few infaunal specimens were found within the small amount of available sediment surrounding the many large sand dollars collected in each grab sample. This new low-diversity infaunal community consisted almost entirely of a marine snail, which is a sand-dollar parasite, and an opportunistic lugworm that thrives in disturbed seafloor habitats. This particular lugworm, *A. bioculata*, happens to have a well-known strong affinity for sand-dollar beds.

The enormous taxonomic change associated with the mature sand dollar bed resulted in an abrupt decline in every measure of infaunal community health after 2014, including infaunal density, diversity, species counts, and richness. However, a far more dramatic decline was observed in the infaunal trophic index

(*ITI*), which estimates the wellbeing of the infaunal community from the relative abundance of suspension-feeding infauna, which typically reside in clean sediments, and the pollution-tolerant detritus-feeding organisms, which opportunistically occupy organically contaminated seafloor habitats. Prior to improvements in wastewater treatment during the 1980s, marked *ITI* declines were observed within seafloor sediments immediately surrounding large ocean discharges from low-performance treatment works. However, the sharp *ITI* decline measured within the MBCSD survey area was unrelated to organic loading from effluent discharge. The concentrations of organic constituents measured within both effluent and benthic sediments over the last three years were comparable to those of the prior 29 years. Moreover, the *ITI* declines were clearly unrelated to the MBCSD discharge because they occurred uniformly throughout the survey area, with no evidence of a spatial gradient related to outfall proximity.

Instead of sediment-quality degradation resulting from organic material within MBCSD effluent, the dramatic *ITI* decline after 2014 was an artifact of the sharply increased presence of the *A. bioculata* lugworm within the sand-dollar community. Because this lugworm is a subsurface detritus feeder, it has an inordinately large influence on the *ITI* computation. However, irrespective of its feeding style, this particular Opheliid lugworm is known to thrive within sand dollar beds irrespective of their organic content. Other field studies have consistently found significantly higher numbers of *A. bioculata* within sand dollar beds than in adjacent sediments with identical concentrations of organic material (Smith 1981).

5.4 RECOMMENDATIONS

The 32 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 affected 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 2017.

Past adjustments to the monitoring program were largely based on recommendations for improving its ability to detect impacts and assess compliance. Few recommendations have dealt with changes to the treatment plant or its process, largely because of the consistently high performance of the plant and outfall system. Most of the recommendations for revisions to the monitoring program that were provided in recent prior annual reports have now been adopted in the new NPDES issued to the MBCSD in December 2017. The only remaining relevant recommendation deals with ongoing updates to flow-meter correction factor, as described below.

Recommendation: Apply a revised correction formula when reporting daily flow using effluent flow-meter measurements: Daily plant throughput is normally determined by totaling individual readings from the influent flow meter. The influent flow-meter readings are used because they measure the volume of wastewater processed by the treatment plant more accurately than the effluent flow meter. On rare occasions, however, the influent flow meter reports 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 during periods when inflow at the headworks is intentionally reduced to facilitate equipment repair. On those occasions, the original, potentially erroneous daily flow should still be reported on the monitoring form using measurements from the influent flow meter. However, when plant staff suspect, or have direct knowledge that the influent flow reading is inaccurate or compromised, they should note that in the narrative of the monthly monitoring

form and provide an estimate of the actual flow based upon effluent flow readings adjusted downward to account for that meter's overttotalization.

Historically, the effluent flow meter has been found to overttotalize the actual flow by approximately 25% [MRS 2003b]. A comparison of daily flow totals reported by the influent and effluent meters during 2017 (Figure 5.1), however, provides an updated formula for adjusting the effluent flow-meter readings that is more representative of current conditions:

$$A = 0.75 \times E - 0.07 \quad \text{Equation 5.1}$$

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

Equation 5.1 was determined from a linear regression on 339 pairs of daily flow observations that were measured by the influent and effluent meters throughout 2017 (blue dots in Figure 5.1). Missing or anomalous influent measurements associated with surcharging in the trunk line were excluded in the regression analysis.

The relationship between influent and effluent readings changes slowly over time due to inherent drift in the meters, or sporadically when either meter is recalibrated, serviced, or replaced. Nevertheless, while updating the adjustment equation annually is useful, the actual interannual changes are small compared to the overall adjustment for overttotalization of the effluent meter. Specifically, the red line in Figure 5.1 displays the relationship between the influent and effluent meters that would be expected in the absence of overttotalization by the effluent meter, namely, exactly the same readings from each meter. That relationship departs significantly from the scatter among the cloud of dark-blue points surrounding the green regression line in the Figure, which represent actual measurements made by each meter during 2017.

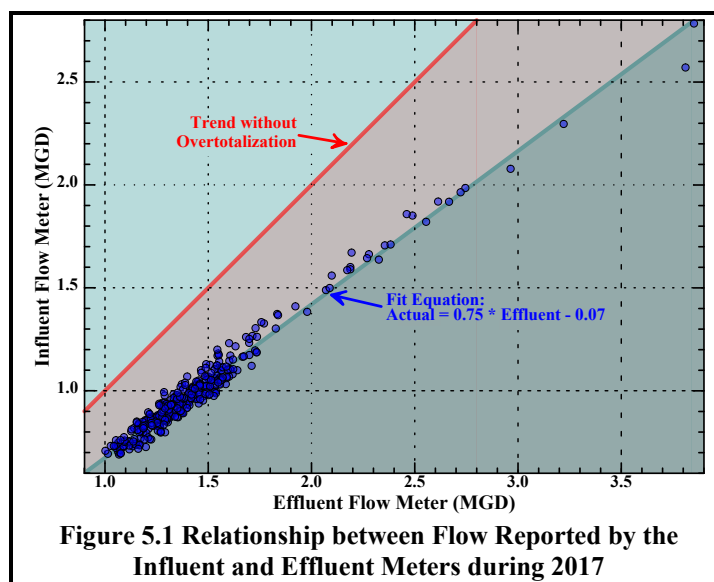
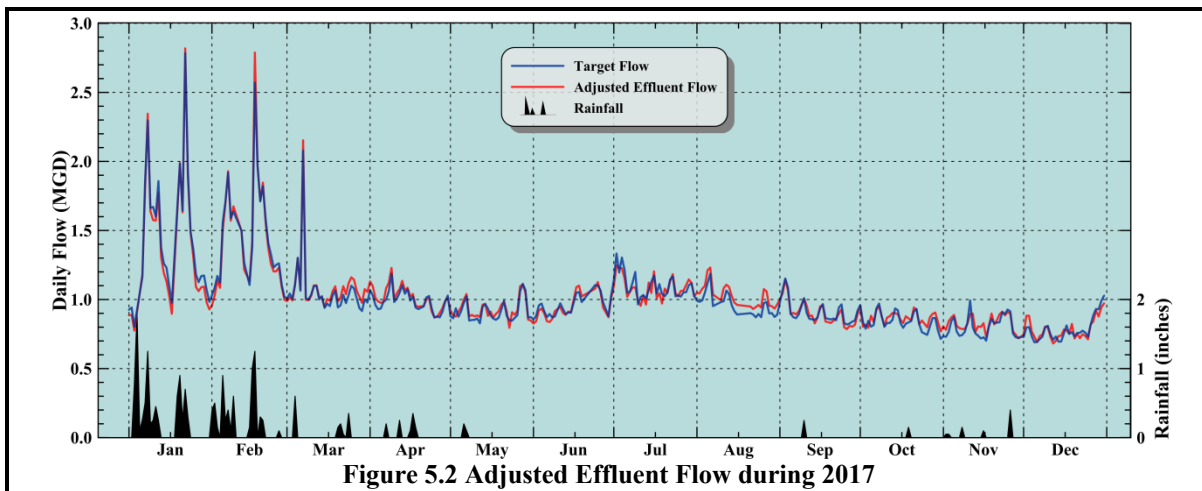


Figure 5.1 Relationship between Flow Reported by the Influent and Effluent Meters during 2017

Occasionally, providing an adjusted effluent-meter reading is warranted so that a continuous time series of reliable flow data can be later established. Daily flow predicted by adjusting the effluent flow-meter data using Equation 5.1 (red time series in Figure 5.2) shows excellent agreement with influent data (blue time series) throughout 2017, and lends confidence in its use when the influent meter becomes surcharged. Normally, the influent measurements, which are based on precision water-level measurements, provide a more reliable determination of flow than the impeller-based effluent meter. However, when readings from the influent meter are obviously compromised, including both the erroneous daily flow value and an adjusted effluent reading allows a credible estimate of the actual flow to be later determined.



The availability of precise and closely matching measurements from both the influent meter and the adjusted effluent meter provides valuable redundancy in the event that one of the meters is taken offline for repairs or calibration. However, 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 at least annually, or when major modifications are made to the meters or flow system.

6.0 LITERATURE CITED

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Table A.1 WWTP Specifications

Parameter	Quantity	Parameter	Quantity
Waste Loading		Tank 2	2.74
Flow (MGD)		Surface loading rate PSDWF (10 ³ L/m ² /day)	29.74
Average dry-weather flow	2.06	Detention time at PWWF (hr.)	2.2
PSDWF	2.36	Total Treatment	
Peak dry-weather flow	6.64	Overall treatment efficiencies (%)	
PWWF	6.60	BOD ₅	57
Strength		Suspended solids	75
BOD ₅ (mg/L)	280	Expected effluent quality (mg/L)	
Suspended solids (mg/L)	280	BOD ₅	120
Grit (ft ³ /mg)	10	Suspended solids	70
Waste quantities at PSDWF		Solids stabilization	
BOD ₅ (mt/day)	2.5	Anaerobic digester loading (mt/day)	
Suspended Solids (mt/day)	2.5	Primary solids	1.6
Grit (ft ³ /day)	23.6	Secondary solids	0.4
Preliminary Treatment		Assumed sludge volatile content (%)	
Mechanically Cleaned Bar Screen		Primary solids	70
Number	1	Secondary solids	82
Capacity (MGD)	8.2	Sludge volume (m ³ /day)	50.7
Channel Monster		Digester 1 (existing, fixed cover)	
Number	1	Diameter (m)	12.2
Capacity (MGD)	7.0	Side water depth (m)	4.9
Influent Pumps (variable speed)		Volume (m ³)	629
Number	3	Digester 2 (existing, fixed cover)	
Capacity each (MGD)	3.3	Diameter (m)	12.2
Total head (m)	9.6	Side water depth (m)	5.8
Aerated Grit-Removal Tanks		Volume (m ³)	725
Number	1	Digester 3 (new, floating cover)	
Length (m)	9.1	Diameter (m)	10.7
Width (m)	4.9	Side water depth (m)	6.9
Depth (m)	2.4	Volume (m ³)	646
Detention time at PWWF (min)	6.3	Hydraulic detention time based on net volume of digesters 2 and 3 (days)	23
Grit Pumps		Assumed volatile solids reduction (%)	55
Number	2	Expected sludge gas production (m ³ /day)	804
Capacity (gpm)	250	Sludge Drying Beds	
Primary Treatment		Number	12
Sedimentation Tanks		Length each (m)	49.4
Number	2	Width each (m)	9.8
Diameter (m)		Solids Loadings (kg ft ⁻¹ yr ⁻¹)	78.3
Tank 1	15.2		
Tank 2	12.2		
Average side water depth (m)			
Tank 1	2.74		

Parameter	Quantity
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
Stand-by (2-speed)	
Capacity (gpm)	960
	1660
Total head (m)	3.4
	4.4

Parameter	Quantity
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

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 at least 75% of all individual organisms collected in a sample. In this dominance measure, species are first ranked by the number of individual organisms before summing the number of species that represent a cumulative percent equal to, or first 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 2017

Taxonomic Group	Taxon	Station							Survey Total	Percent of Total	Cumulative %
		B1	B2	B3	B4	B5	B6	B7			
Echinodermata	<i>Dendraster excentricus</i>	203	181	237	160	171	360	168	1480	—	—
Mollusca	<i>Balcis rutila</i>	159	24	48	66	89	242	118	746	38.28	38.28
Crustacea	<i>Rhepoxynius menziesi</i>	26	38	51	26	55	39	28	263	13.49	51.77
Annelida	<i>Armandia bioculata</i>	23	3	22	21	110	37	9	225	11.54	63.31
Bivalvia	<i>Tellina bodegensis</i>	11	10	20	14	24	30	33	142	7.29	70.60
Crustacea	<i>Americhilidium shoemakeri</i>	5	3	12	8	5	21	8	62	3.18	73.78
Annelida	<i>Nephtys caecoides</i>	1	8	2	4	5	8	10	38	1.95	75.73
Bivalvia	<i>Tellina modesta</i>	9	3	7	4	4	3	3	33	1.69	77.42
Crustacea	<i>Rhepoxynius abronius</i>	—	9	11	3	2	6	2	33	1.69	79.12
Annelida	<i>Sigalion spinosa</i>	9	4	4	2	4	4	3	30	1.54	80.66
Bivalvia	<i>Rochefortia tumida</i>	1	2	6	4	8	2	4	27	1.39	82.04
Bivalvia	<i>Chione</i>	1	2	6	1	2	7	7	26	1.33	83.38
Annelida	<i>Scoloplos armiger</i>	5	8	3	2	—	—	7	25	1.28	84.66
Annelida	<i>Apoprionospio pygmaea</i>	7	2	3	1	1	1	8	23	1.18	85.84
Nemertea	<i>Carinoma mutabilis</i>	8	2	2	3	3	2	2	22	1.13	86.97
Annelida	<i>Chaetozone setosa</i>	2	2	5	—	3	4	5	21	1.08	88.05
Annelida	<i>Eumida</i>	4	1	1	1	6	5	2	20	1.03	89.07
Bivalvia	<i>Cooperella subdiaphana</i>	5	5	—	—	9	—	1	20	1.03	90.10
Annelida	<i>Glycinde armigera</i>	5	2	4	3	1	1	2	18	0.92	91.02
Annelida	<i>Glycera convoluta</i>	2	2	3	—	6	—	2	15	0.77	91.79
Annelida	<i>Magelona sacculata</i>	1	2	1	1	2	—	7	14	0.72	92.51
Nemertea	<i>Carinomella lactea</i>	—	—	2	5	—	1	4	12	0.62	93.12
Nemertea	<i>Cerebratulus californiensis</i>	3	1	1	1	2	1	1	10	0.51	93.64
Bivalvia	<i>Macoma acolasta</i>	—	—	2	2	5	1	—	10	0.51	94.15
Crustacea	Cumacea	1	1	2	1	—	1	1	7	0.36	94.51
Annelida	<i>Diopatra ornata</i>	—	1	1	—	4	—	—	6	0.31	94.82
Annelida	<i>Lumbrineris</i>	—	—	—	1	3	1	1	6	0.31	95.13
Annelida	<i>Lumbrineris californiensis</i>	2	—	—	—	1	2	1	6	0.31	95.43
Annelida	<i>Notomastus lineatus</i>	1	—	—	—	3	—	1	5	0.26	95.69
Annelida	<i>Sthenelais verruculosa</i>	1	—	—	—	—	3	1	5	0.26	95.95
Nemertea	<i>Paranemertes sp. A</i>	2	—	—	1	2	—	—	5	0.26	96.20
Bivalvia	<i>Clinocardium nuttallii</i>	—	—	1	—	2	2	—	5	0.26	96.46
Bivalvia	<i>Siliqua lucida</i>	—	—	3	—	—	—	2	5	0.26	96.72
Annelida	Syllidae	1	2	—	—	—	1	—	4	0.21	96.92
Crustacea	<i>Cancer productus</i>	1	—	—	—	3	—	—	4	0.21	97.13
Annelida	<i>Chone mollis</i>	1	1	—	1	—	—	—	3	0.15	97.28
Mollusca	<i>Nassarius perpinguis</i>	—	1	—	—	—	1	1	3	0.15	97.43
Bivalvia	Bivalvia	—	—	2	1	—	—	—	3	0.15	97.59
Crustacea	<i>Lepidopa californica</i>	—	—	—	1	1	—	1	3	0.15	97.74
Mollusca	<i>Alvania</i>	—	—	—	—	2	—	1	3	0.15	97.90
Annelida	<i>Phyllodoce</i>	—	—	—	—	2	—	1	3	0.15	98.05
Annelida	<i>Prionospio cirrifera</i>	—	—	—	—	3	—	—	3	0.15	98.20
Bivalvia	<i>Rochefortia grippi</i>	1	—	1	—	—	—	—	2	0.10	98.31
Annelida	<i>Capitella capitata</i>	1	—	—	1	—	—	—	2	0.10	98.41
Crustacea	<i>Foxiphalus xiximeus</i>	1	—	—	—	1	—	—	2	0.10	98.51

Table B.1 Station Abundance by Taxa during October 2017

Taxonomic Group	Taxon	Station							Survey Total	Percent of Total	Cumulative %
		B1	B2	B3	B4	B5	B6	B7			
Annelida	<i>Nephtys cornuta franciscana</i>	1	–	–	–	–	1	–	2	0.10	98.61
Crustacea	<i>Cancer gracilis</i>	2	–	–	–	–	–	–	2	0.10	98.72
Annelida	<i>Gyptis brevipalpa</i>	2	–	–	–	–	–	–	2	0.10	98.82
Crustacea	<i>Photis brevipes</i>	2	–	–	–	–	–	–	2	0.10	98.92
Echinodermata	<i>Leptosynapta</i>	–	–	1	–	–	1	–	2	0.10	99.03
Mollusca	<i>Epitonium sawinae</i>	–	–	–	–	2	–	–	2	0.10	99.13
Crustacea	Hippolytidae	–	–	–	–	–	2	–	2	0.10	99.23
Bivalvia	<i>Macoma</i>	–	–	–	–	–	–	2	2	0.10	99.33
Annelida	<i>Harmothoe</i>	1	–	–	–	–	–	–	1	0.05	99.38
Nemertea	<i>Lineus bilineatus</i>	1	–	–	–	–	–	–	1	0.05	99.44
Annelida	<i>Ampharete labrops</i>	1	–	–	–	–	–	–	1	0.05	99.49
Annelida	<i>Dispio uncinata</i>	1	–	–	–	–	–	–	1	0.05	99.54
Annelida	Cirratulidae	1	–	–	–	–	–	–	1	0.05	99.59
Annelida	<i>Goniada maculata</i>	–	1	–	–	–	–	–	1	0.05	99.64
Crustacea	<i>Ischyrocerus</i>	–	–	1	–	–	–	–	1	0.05	99.69
Crustacea	Amphipoda	–	–	1	–	–	–	–	1	0.05	99.74
Crustacea	<i>Crangon</i>	–	–	–	1	–	–	–	1	0.05	99.79
Annelida	<i>Platynereis bicanaliculata</i>	–	–	–	–	1	–	–	1	0.05	99.85
Annelida	<i>Drilonereis falcata</i>	–	–	–	–	1	–	–	1	0.05	99.90
Echinodermata	<i>Amphiodia</i>	–	–	–	–	–	–	1	1	0.05	99.95
Mollusca	Gastropoda	–	–	–	–	–	–	1	1	0.05	100.00
Total Number of Individuals		515	321	466	340	548	790	449	3429		
Total Number of Individuals Excluding <i>D. Excentricus</i>		312	140	229	180	377	430	281	1949		

Table B.2 Replicate Sample Abundance by Taxa at Station B1 during October 2017

Taxonomic Group	Taxon	Replicate					Station Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Echinodermata	<i>Dendraster excentricus</i>	31	59	50	1	62	203	–	–
Mollusca	<i>Balcis rutila</i>	42	24	17	16	60	159	50.96	50.96
Crustacea	<i>Rhepoxynius menziesi</i>	6	2	10	3	5	26	8.33	59.29
Annelida	<i>Armandia bioculata</i>	7	5	1	2	8	23	7.37	66.67
Bivalvia	<i>Tellina bodegensis</i>	3	1	3	–	4	11	3.53	70.19
Annelida	<i>Sigalion spinosa</i>	1	3	1	2	2	9	2.88	73.08
Bivalvia	<i>Tellina modesta</i>	2	1	2	3	1	9	2.88	75.96
Nemertea	<i>Carinoma mutabilis</i>	2	4	1	1	–	8	2.56	78.53
Annelida	<i>Apoprionospio pygmaea</i>	–	–	–	6	1	7	2.24	80.77
Crustacea	<i>Americhilidium shoemakeri</i>	1	1	3	–	–	5	1.60	82.37
Bivalvia	<i>Cooperella subdiaphana</i>	1	2	–	1	1	5	1.60	83.97
Annelida	<i>Scoloplos armiger</i>	2	1	1	1	–	5	1.60	85.58
Annelida	<i>Glycinde armigera</i>	–	1	1	1	2	5	1.60	87.18
Annelida	<i>Eumida</i>	–	1	–	2	1	4	1.28	88.46
Nemertea	<i>Cerebratulus californiensis</i>	1	1	1	–	–	3	0.96	89.42

Table B.2 Replicate Sample Abundance by Taxa at Station B1 during October 2017

Taxonomic Group	Taxon	Replicate					Station Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Annelida	<i>Lumbrineris californiensis</i>	1	1	–	0	–	2	0.64	90.06
Annelida	<i>Glycera convolute</i>	1	1	–	–	–	2	0.64	90.71
Crustacea	<i>Cancer gracilis</i>	1	–	–	–	1	2	0.64	91.35
Crustacea	<i>Photis brevipes</i>	2	–	–	–	–	2	0.64	91.99
Annelida	<i>Chaetozone setosa</i>	–	–	1	1	–	2	0.64	92.63
Nemertea	<i>Paranemertes sp. A</i>	–	–	–	1	1	2	0.64	93.27
Annelida	<i>Gyptis brevipalpa</i>	–	–	–	2	–	2	0.64	93.91
Crustacea	<i>Cancer productus</i>	1	–	–	–	–	1	0.32	94.23
Annelida	<i>Ampharete labrops</i>	1	–	–	–	–	1	0.32	94.55
Annelida	<i>Chone mollis</i>	1	–	–	–	–	1	0.32	94.87
Annelida	<i>Harmothoe</i>	–	1	–	–	–	1	0.32	95.19
Bivalvia	<i>Rochefortia grippi</i>	–	1	–	–	–	1	0.32	95.51
Crustacea	<i>Foxiphalus xiximeus</i>	–	–	1	–	–	1	0.32	95.83
Annelida	<i>Capitella capitata</i>	–	–	1	–	–	1	0.32	96.15
Annelida	<i>Nephtys cornuta franciscana</i>	–	–	1	–	–	1	0.32	96.47
Annelida	<i>Dispio uncinata</i>	–	–	1	–	–	1	0.32	96.79
Bivalvia	<i>Chione</i>	–	–	–	1	–	1	0.32	97.12
Bivalvia	<i>Rochefortia tumida</i>	–	–	–	1	–	1	0.32	97.44
Annelida	<i>Nephtys caecoides</i>	–	–	–	1	–	1	0.32	97.76
Nemertea	<i>Lineus bilineatus</i>	–	–	–	1	–	1	0.32	98.08
Crustacea	Cumacea	–	–	–	1	–	1	0.32	98.40
Annelida	<i>Notomastus lineatus</i>	–	–	–	1	–	1	0.32	98.72
Annelida	Cirratulidae	–	–	–	1	–	1	0.32	99.04
Annelida	<i>Magelona sacculata</i>	–	–	–	–	1	1	0.32	99.36
Annelida	<i>Sthenelais verruculosa</i>	–	–	–	–	1	1	0.32	99.68
Annelida	Syllidae	–	–	–	–	1	1	0.32	100.00
Total Number of Individuals		107	110	96	50	152	515		
Total Number of Individuals Excluding <i>D. Excentricus</i>		76	51	46	49	90	312		

Table B.3 Replicate Sample Abundance by Taxa at Station B2 during October 2017

Taxonomic Group	Taxon	Replicate					Station Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Echinodermata	<i>Dendraster excentricus</i>	32	27	42	62	18	181	–	–
Crustacea	<i>Rhepoxynius menziesi</i>	5	11	8	10	4	38	27.14	27.14
Mollusca	<i>Balcis rutila</i>	5	8	1	5	5	24	17.14	44.29
Bivalvia	<i>Tellina bodegensis</i>	2	2	–	4	2	10	7.14	51.43
Crustacea	<i>Rhepoxynius abronius</i>	–	2	2	1	4	9	6.43	57.86

Table B.3 Replicate Sample Abundance by Taxa at Station B2 during October 2017

Taxonomic Group	Taxon	Replicate					Station Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Annelida	<i>Nephtys caecoides</i>	1	–	4	2	1	8	5.71	63.57
Annelida	<i>Scoloplos armiger</i>	–	4	–	2	2	8	5.71	69.29
Bivalvia	<i>Cooperella subdiaphana</i>	2	2	–	–	1	5	3.57	72.86
Annelida	<i>Sigalion spinosa</i>	1	2	1	–	–	4	2.86	75.71
Bivalvia	<i>Tellina modesta</i>	1	1	1	–	–	3	2.14	77.86
Crustacea	<i>Americhilidium shoemakeri</i>	2	–	–	–	1	3	2.14	80.00
Annelida	<i>Armandia bioculata</i>	–	3	–	–	–	3	2.14	82.14
Annelida	<i>Glycera convoluta</i>	1	1	–	–	–	2	1.43	83.57
Annelida	<i>Glycinde armigera</i>	1	–	–	1	–	2	1.43	85.00
Bivalvia	<i>Chione</i>	1	–	–	–	1	2	1.43	86.43
Annelida	<i>Chaetozone setosa</i>	–	1	1	–	–	2	1.43	87.86
Annelida	<i>Magelona sacculata</i>	–	1	–	–	1	2	1.43	89.29
Nemertea	<i>Carinoma mutabilis</i>	–	2	–	–	–	2	1.43	90.71
Annelida	<i>Apoprionospio pygmaea</i>	–	2	–	–	–	2	1.43	92.14
Bivalvia	<i>Rochefortia tumida</i>	–	–	–	2	–	2	1.43	93.57
Annelida	Syllidae	–	–	–	2	–	2	1.43	95.00
Nemertea	<i>Cerebratulus californiensis</i>	1	–	–	–	–	1	0.71	95.71
Annelida	<i>Eumida</i>	1	–	–	–	–	1	0.71	96.43
Annelida	<i>Diopatra ornata</i>	–	1	–	–	–	1	0.71	97.14
Mollusca	<i>Nassarius perpinguis</i>	–	–	1	–	–	1	0.71	97.86
Annelida	<i>Chone mollis</i>	–	–	1	–	–	1	0.71	98.57
Crustacea	Cumacea	–	–	–	1	–	1	0.71	99.29
Annelida	<i>Goniada maculata</i>	–	–	–	1	–	1	0.71	100.00
Total Number of Individuals		56	70	62	93	40	321		
Total Number of Individuals Excluding <i>D. Excentricus</i>		24	43	20	31	22	140		

Table B.4 Replicate Sample Abundance by Taxa at Station B3 during October 2017

Taxonomic Group	Taxon	Replicate					Station Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Echinodermata	<i>Dendraster excentricus</i>	44	29	50	46	68	237	–	–
Crustacea	<i>Rhepoxynius menziesi</i>	9	10	13	14	5	51	22.27	22.27
Mollusca	<i>Balcis rutila</i>	12	7	10	12	7	48	20.96	43.23
Annelida	<i>Armandia bioculata</i>	10	1	7	4	–	22	9.61	52.84
Bivalvia	<i>Tellina bodegensis</i>	4	3	7	3	3	20	8.73	61.57
Crustacea	<i>Americhilidium shoemakeri</i>	3	1	1	6	1	12	5.24	66.81
Crustacea	<i>Rhepoxynius abronius</i>	–	3	4	2	2	11	4.80	71.62
Bivalvia	<i>Tellina modesta</i>	2	1	2	1	1	7	3.06	74.67
Bivalvia	<i>Chione</i>	3	1	1	1	–	6	2.62	77.29

Table B.4 Replicate Sample Abundance by Taxa at Station B3 during October 2017

Taxonomic Group	Taxon	Replicate					Station Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Bivalvia	<i>Rocheportia tumida</i>	–	4	–	2	–	6	2.62	79.91
Annelida	<i>Chaetozone setosa</i>	1	1	2	1	–	5	2.18	82.10
Annelida	<i>Sigalion spinosa</i>	1	1	1	1	–	4	1.75	83.84
Annelida	<i>Glycinde armigera</i>	–	2	–	2	–	4	1.75	85.59
Annelida	<i>Apoprionospio pygmaea</i>	1	1	1	–	–	3	1.31	86.90
Annelida	<i>Scoloplos armiger</i>	–	1	1	1	–	3	1.31	88.21
Bivalvia	<i>Siliqua lucida</i>	–	1	–	2	–	3	1.31	89.52
Annelida	<i>Glycera convoluta</i>	–	–	2	–	1	3	1.31	90.83
Annelida	<i>Nephtys caecoides</i>	1	1	–	–	–	2	0.87	91.70
Nemertea	<i>Carinomella lactea</i>	1	1	–	–	–	2	0.87	92.58
Nemertea	<i>Carinoma mutabilis</i>	–	1	1	–	–	2	0.87	93.45
Bivalvia	<i>Macoma acolasta</i>	–	–	1	1	–	2	0.87	94.32
Bivalvia	Bivalvia	–	–	1	1	–	2	0.87	95.20
Crustacea	Cumacea	–	–	–	1	1	2	0.87	96.07
Crustacea	<i>Ischyrocerus</i>	1	–	–	–	–	1	0.44	96.51
Bivalvia	<i>Rocheportia grippi</i>	1	–	–	–	–	1	0.44	96.94
Echinodermata	<i>Leptosynapta</i>	–	1	–	–	–	1	0.44	97.38
Annelida	<i>Magelona sacculata</i>	–	–	–	1	–	1	0.44	97.82
Annelida	<i>Diopatra ornata</i>	–	–	–	1	–	1	0.44	98.25
Annelida	<i>Eumida</i>	–	–	–	1	–	1	0.44	98.69
Nemertea	<i>Cerebratulus californiensis</i>	–	–	–	–	1	1	0.44	99.13
Bivalvia	<i>Clinocardium nuttallii</i>	–	–	–	–	1	1	0.44	99.56
Crustacea	Amphipoda	–	–	–	–	1	1	0.44	100.00
Total Number of Individuals		94	71	105	104	92	466		
Total Number of Individuals Excluding <i>D. Excentricus</i>		50	42	55	58	24	229		

Table B.5 Replicate Sample Abundance by Taxa at Station B4 during October 2017

Taxonomic Group	Taxon	Replicate					Station Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Echinodermata	<i>Dendraster excentricus</i>	28	44	30	16	42	160	–	–
Mollusca	<i>Balcis rutila</i>	12	8	4	3	39	66	36.67	36.67
Crustacea	<i>Rhepoxynius menziesi</i>	7	4	7	3	5	26	14.44	51.11
Annelida	<i>Armandia bioculata</i>	1	2	5	5	8	21	11.67	62.78
Bivalvia	<i>Tellina bodegensis</i>	3	2	5	2	2	14	7.78	70.56
Crustacea	<i>Americhilidium shoemakeri</i>	–	1	–	–	7	8	4.44	75.00
Nemertea	<i>Carinomella lactea</i>	–	–	–	3	2	5	2.78	77.78
Bivalvia	<i>Tellina modesta</i>	1	–	1	–	2	4	2.22	80.00
Annelida	<i>Nephtys caecoides</i>	1	–	–	–	3	4	2.22	82.22
Bivalvia	<i>Rocheportia tumida</i>	–	–	2	–	2	4	2.22	84.44

Table B.5 Replicate Sample Abundance by Taxa at Station B4 during October 2017

Taxonomic Group	Taxon	Replicate					Station Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Annelida	<i>Glycinde armigera</i>	1	–	–	–	2	3	1.67	86.11
Crustacea	<i>Rhepoxynius abronius</i>	3	–	–	–	–	3	1.67	87.78
Nemertea	<i>Carinoma mutabilis</i>	–	1	–	1	1	3	1.67	89.44
Annelida	<i>Sigalion spinosa</i>	–	1	1	–	–	2	1.11	90.56
Annelida	<i>Scoloplos armiger</i>	–	–	–	–	2	2	1.11	91.67
Bivalvia	<i>Macoma acolasta</i>	–	–	–	–	2	2	1.11	92.78
Nemertea	<i>Cerebratulus californiensis</i>	1	–	–	–	–	1	0.56	93.33
Bivalvia	<i>Chione</i>	1	–	–	–	–	1	0.56	93.89
Nemertea	<i>Paranemertes sp. A</i>	1	–	–	–	–	1	0.56	94.44
Crustacea	<i>Crangon</i>	1	–	–	–	–	1	0.56	95.00
Annelida	<i>Magelona sacculata</i>	–	1	–	–	–	1	0.56	95.56
Crustacea	<i>Lepidopa californica</i>	–	–	–	1	–	1	0.56	96.11
Annelida	<i>Lumbrineris</i>	–	–	–	–	1	1	0.56	96.67
Annelida	<i>Eumida</i>	–	–	–	–	1	1	0.56	97.22
Annelida	<i>Apoprionospio pygmaea</i>	–	–	–	–	1	1	0.56	97.78
Annelida	<i>Capitella capitata</i>	–	–	–	–	1	1	0.56	98.33
Crustacea	Cumacea	–	–	–	–	1	1	0.56	98.89
Bivalvia	Bivalvia	–	–	–	–	1	1	0.56	99.44
Annelida	<i>Chone mollis</i>	–	–	–	–	1	1	0.56	100.00
Total Number of Individuals		61	64	55	34	126	340		
Total Number of Individuals Excluding <i>D. Excentricus</i>		33	20	25	18	84	180		

Table B.6 Replicate Sample Abundance by Taxa at Station B5 during October 2017

Taxonomic Group	Taxon	Replicate					Station Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Echinodermata	<i>Dendraster excentricus</i>	37	60	54	1	19	171	–	–
Annelida	<i>Armandia bioculata</i>	25	16	22	40	7	110	29.18	29.18
Mollusca	<i>Balcis rutila</i>	37	9	17	7	19	89	23.61	52.79
Crustacea	<i>Rhepoxynius menziesi</i>	13	15	17	1	9	55	14.59	67.37
Bivalvia	<i>Tellina bodegensis</i>	7	5	7	–	5	24	6.37	73.74
Bivalvia	<i>Cooperella subdiaphana</i>	5	–	–	3	1	9	2.39	76.13
Bivalvia	<i>Rochefortia tumida</i>	1	–	1	6	–	8	2.12	78.25
Annelida	<i>Eumida</i>	2	1	–	2	1	6	1.59	79.84
Annelida	<i>Glycera convoluta</i>	–	4	1	1	–	6	1.59	81.43
Annelida	<i>Nephtys caecoides</i>	1	1	1	1	1	5	1.33	82.76
Crustacea	<i>Americhilidium shoemakeri</i>	2	–	2	–	1	5	1.33	84.08
Bivalvia	<i>Macoma acolasta</i>	–	2	2	1	–	5	1.33	85.41
Annelida	<i>Sigalion spinosa</i>	2	2	–	–	–	4	1.06	86.47
Bivalvia	<i>Tellina modesta</i>	–	1	1	–	2	4	1.06	87.53
Annelida	<i>Diopatra ornata</i>	–	–	–	4	–	4	1.06	88.59

Table B.6 Replicate Sample Abundance by Taxa at Station B5 during October 2017

Taxonomic Group	Taxon	Replicate					Station Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Crustacea	<i>Cancer productus</i>	1	–	1	1	–	3	0.80	89.39
Annelida	<i>Notomastus lineatus</i>	–	1	1	1	–	3	0.80	90.19
Annelida	<i>Chaetozone setosa</i>	–	–	1	1	1	3	0.80	90.98
Annelida	<i>Prionospio cirrifera</i>	–	–	1	2	–	3	0.80	91.78
Nemertea	<i>Carinoma mutabilis</i>	–	–	–	3	–	3	0.80	92.57
Annelida	<i>Lumbrineris</i>	–	–	–	3	–	3	0.80	93.37
Nemertea	<i>Cerebratulus californiensis</i>	1	1	–	–	–	2	0.53	93.90
Annelida	<i>Magelona sacculata</i>	1	1	–	–	–	2	0.53	94.43
Crustacea	<i>Rhepoxynius abronius</i>	–	1	1	–	–	2	0.53	94.96
Bivalvia	<i>Clinocardium nuttallii</i>	–	1	–	1	–	2	0.53	95.49
Bivalvia	<i>Chione</i>	–	1	–	–	1	2	0.53	96.02
Mollusca	<i>Alvania</i>	–	2	–	–	–	2	0.53	96.55
Nemertea	<i>Paranemertes sp. A</i>	–	–	1	–	1	2	0.53	97.08
Annelida	<i>Phyllodoce</i>	–	–	–	2	–	2	0.53	97.61
Mollusca	<i>Epitonium sawinae</i>	–	–	–	2	–	2	0.53	98.14
Annelida	<i>Glycinde armigera</i>	1	–	–	–	–	1	0.27	98.41
Crustacea	<i>Lepidopa californica</i>	1	–	–	–	–	1	0.27	98.67
Crustacea	<i>Foxiphalus xiximeus</i>	–	1	–	–	–	1	0.27	98.94
Annelida	<i>Lumbrineris californiensis</i>	–	1	–	–	–	1	0.27	99.20
Annelida	<i>Platynereis bicanaliculata</i>	–	–	1	–	–	1	0.27	99.47
Annelida	<i>Apoprionospio pygmaea</i>	–	–	–	1	–	1	0.27	99.73
Annelida	<i>Drilonereis falcata</i>	–	–	–	1	–	1	0.27	100.00
Total Number of Individuals		137	126	132	85	68	548		
Total Number of Individuals Excluding <i>D. Excentricus</i>		100	66	78	84	49	377		

Table B.7 Replicate Sample Abundance by Taxa at Station B6 during October 2017

Taxonomic Group	Taxon	Replicate					Station Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Echinodermata	<i>Dendraster excentricus</i>	58	70	85	76	71	360	–	–
Mollusca	<i>Balcis rutila</i>	55	52	30	52	53	242	56.28	56.28
Crustacea	<i>Rhepoxynius menziesi</i>	8	7	3	10	11	39	9.07	65.35
Annelida	<i>Armandia bioculata</i>	11	17	4	3	2	37	8.60	73.95
Bivalvia	<i>Tellina bodegensis</i>	7	5	5	8	5	30	6.98	80.93
Crustacea	<i>Americhilidium shoemakeri</i>	3	3	3	8	4	21	4.88	85.81
Annelida	<i>Nephtys caecoides</i>	2	1	1	2	2	8	1.86	87.67
Bivalvia	<i>Chione</i>	1	1	–	4	1	7	1.63	89.30
Crustacea	<i>Rhepoxynius abronius</i>	–	1	–	3	2	6	1.40	90.70
Annelida	<i>Eumida</i>	2	1	–	–	2	5	1.16	91.86

Table B.7 Replicate Sample Abundance by Taxa at Station B6 during October 2017

Taxonomic Group	Taxon	Replicate					Station Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Annelida	<i>Sigalion spinosa</i>	1	–	1	1	1	4	0.93	92.79
Annelida	<i>Chaetozone setosa</i>	2	1	1	–	–	4	0.93	93.72
Bivalvia	<i>Tellina modesta</i>	1	1	1	–	–	3	0.70	94.42
Annelida	<i>Sthenelais verruculosa</i>	1	–	1	1	–	3	0.70	95.12
Bivalvia	<i>Rocheportia tumida</i>	1	1	–	–	–	2	0.47	95.58
Nemertea	<i>Carinoma mutabilis</i>	2	–	–	–	–	2	0.47	96.05
Bivalvia	<i>Clinocardium nuttallii</i>	–	1	–	1	–	2	0.47	96.51
Annelida	<i>Lumbrineris californiensis</i>	–	2	–	–	–	2	0.47	96.98
Crustacea	Hippolytidae	–	–	2	–	–	2	0.47	97.44
Nemertea	<i>Cerebratulus californiensis</i>	–	–	–	1	–	1	0.23	97.67
Annelida	Syllidae	1	–	–	–	–	1	0.23	97.91
Annelida	<i>Glycinde armigera</i>	–	1	–	–	–	1	0.23	98.14
Crustacea	Cumacea	–	1	–	–	–	1	0.23	98.37
Echinodermata	<i>Leptosynapta</i>	–	–	1	–	–	1	0.23	98.60
Annelida	<i>Lumbrineris</i>	–	–	1	–	–	1	0.23	98.84
Mollusca	<i>Nassarius perpinguis</i>	–	–	1	–	–	1	0.23	99.07
Nemertea	<i>Carinomella lactea</i>	–	–	1	–	–	1	0.23	99.30
Annelida	<i>Nephtys cornuta franciscana</i>	–	–	–	1	–	1	0.23	99.53
Annelida	<i>Apoprionospio pygmaea</i>	–	–	–	–	1	1	0.23	99.77
Bivalvia	<i>Macoma acolasta</i>	–	–	–	–	1	1	0.23	100.00
Total Number of Individuals		156	166	141	171	156	790		
Total Number of Individuals Excluding <i>D. Excentricus</i>		98	96	56	95	85	430		

Table B.8 Replicate Sample Abundance by Taxa at Station B7 during October 2017

Taxonomic Group	Taxon	Replicate					Station Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Echinodermata	<i>Dendraster excentricus</i>	34	39	62	2	31	168	–	–
Mollusca	<i>Balcis rutila</i>	36	31	12	5	34	118	41.99	41.99
Bivalvia	<i>Tellina bodegensis</i>	6	10	4	8	5	33	11.74	53.74
Crustacea	<i>Rhepoxynius menziesi</i>	6	7	3	4	8	28	9.96	63.70
Annelida	<i>Nephtys caecoides</i>	2	2	3	3	–	10	3.56	67.26
Annelida	<i>Armandia bioculata</i>	2	2	4	–	1	9	3.20	70.46
Annelida	<i>Apoprionospio pygmaea</i>	1	1	1	3	1	7	2.49	72.95
Crustacea	<i>Americhilidium shoemakeri</i>	1	3	3	–	1	8	2.85	75.80
Annelida	<i>Scoloplos armiger</i>	1	2	–	3	2	8	2.85	78.65
Annelida	<i>Magelona sacculata</i>	1	1	2	3	–	7	2.49	81.14
Bivalvia	<i>Chione</i>	2	1	–	1	3	7	2.49	83.63
Annelida	<i>Chaetozone setosa</i>	1	2	–	1	–	4	1.42	85.05
Nemertea	<i>Carinomella lactea</i>	–	3	1	1	–	5	1.78	86.83
Bivalvia	<i>Rocheportia tumida</i>	1	–	–	–	2	3	1.07	87.90
Bivalvia	<i>Tellina modesta</i>	–	1	–	–	3	4	1.42	89.32

Table B.8 Replicate Sample Abundance by Taxa at Station B7 during October 2017

Taxonomic Group	Taxon	Replicate					Station Total	Percent of Total	Cumulative Percent
		1	2	3	4	5			
Annelida	<i>Sigalion spinosa</i>	–	2	1	–	–	3	1.07	90.39
Annelida	<i>Glycinde armigera</i>	1	–	1	–	–	2	0.71	91.10
Nemertea	<i>Carinoma mutabilis</i>	2	–	–	–	–	2	0.71	91.81
Annelida	<i>Eumida</i>	–	–	1	1	–	2	0.71	92.53
Bivalvia	<i>Siliqua lucida</i>	–	1	1	–	–	2	0.71	93.24
Bivalvia	<i>Macoma</i>	–	–	1	1	–	2	0.71	93.95
Crustacea	<i>Rhepoxynius abronius</i>	–	–	2	–	–	2	0.71	94.66
Annelida	<i>Glycera convoluta</i>	–	–	–	1	1	2	0.71	95.37
Annelida	<i>Lumbrineris californiensis</i>	1	–	–	–	–	1	0.36	95.73
Annelida	<i>Lumbrineris</i>	1	–	–	–	–	1	0.36	96.09
Mollusca	Gastropoda	1	–	–	–	–	1	0.36	96.44
Crustacea	<i>Lepidopa californica</i>	–	1	–	–	–	1	0.36	96.80
Crustacea	Cumacea	–	–	1	–	–	1	0.36	97.15
Mollusca	<i>Nassarius perpinguis</i>	–	–	1	–	–	1	0.36	97.51
Bivalvia	<i>Cooperella subdiaphana</i>	–	–	–	1	–	1	0.36	97.86
Mollusca	<i>Alvania</i>	–	–	–	1	–	1	0.36	98.22
Annelida	<i>Phyllodoce</i>	–	–	–	1	–	1	0.36	98.58
Annelida	<i>Sthenelais verruculosa</i>	–	–	–	1	–	1	0.36	98.93
Nemertea	<i>Cerebratulus californiensis</i>	–	–	–	–	1	1	0.36	99.29
Echinodermata	<i>Amphiodia</i>	–	–	–	–	1	1	0.36	99.64
Annelida	<i>Notomastus lineatus</i>	–	–	–	–	1	1	0.36	100.00
Total Number of Individuals		100	109	104	41	95	449		
Total Number of Individuals Excluding <i>D. Excentricus</i>		66	70	42	39	64	281		

Table B.9 Infaunal Indices in Sediment Samples Collected in October 2017

Parameter		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	107	107	19	6	1.90	1.69	0.25	4	3.85	0.65	57
	Replicate 2	110	108	16	7	1.57	1.39	0.35	2	3.20	0.57	40
	Replicate 3	96	96	17	6	1.70	1.50	0.32	3	3.51	0.60	80
	Replicate 4	50	45	18	3	2.34	1.92	0.16	7	4.47	0.81	65
	Replicate 5	152	150	14	11	1.45	1.33	0.34	2	2.59	0.55	42
Station B2	Replicate 1	56	54	12	5	1.56	1.32	0.37	3	2.76	0.63	90
	Replicate 2	70	70	16	4	2.12	1.84	0.20	5	3.53	0.76	77
	Replicate 3	62	62	10	6	1.22	1.04	0.48	2	2.18	0.53	86
	Replicate 4	93	90	10	9	1.20	1.07	0.49	2	2.00	0.52	86
	Replicate 5	40	39	10	4	1.77	1.48	0.26	4	2.46	0.77	89
Station B3	Replicate 1	94	90	13	7	1.73	1.55	0.28	4	2.67	0.67	51
	Replicate 2	71	69	18	4	2.09	1.80	0.22	5	4.02	0.72	83
	Replicate 3	105	103	15	7	1.83	1.64	0.27	4	3.02	0.68	70
	Replicate 4	104	100	17	6	1.93	1.71	0.25	4	3.47	0.68	78
	Replicate 5	92	90	10	9	1.02	0.89	0.58	1	2.00	0.44	93
Station B4	Replicate 1	61	59	11	5	1.65	1.43	0.29	3	2.45	0.69	89
	Replicate 2	64	64	9	7	1.17	1.01	0.50	2	1.92	0.53	67
	Replicate 3	55	55	8	7	1.49	1.30	0.34	3	1.75	0.72	60
	Replicate 4	34	34	8	4	1.65	1.38	0.27	4	1.99	0.80	38
	Replicate 5	126	122	17	7	1.93	1.74	0.23	4	3.33	0.68	50
Station B5	Replicate 1	137	135	15	9	1.90	1.75	0.20	4	2.85	0.70	37
	Replicate 2	126	122	17	7	1.80	1.62	0.28	4	3.33	0.63	54
	Replicate 3	132	132	18	7	1.88	1.71	0.23	4	3.48	0.65	47
	Replicate 4	85	78	19	4	1.96	1.68	0.29	5	4.13	0.67	23
	Replicate 5	68	66	11	6	1.85	1.64	0.20	4	2.39	0.77	57
Station B6	Replicate 1	156	152	13	12	1.60	1.49	0.29	3	2.39	0.63	47
	Replicate 2	166	163	14	12	1.55	1.44	0.30	3	2.55	0.59	37
	Replicate 3	141	139	14	10	1.33	1.21	0.42	2	2.63	0.50	47
	Replicate 4	171	167	13	13	1.53	1.43	0.31	2	2.34	0.60	79
	Replicate 5	156	153	11	14	1.39	1.29	0.34	2	1.99	0.58	83
Station B7	Replicate 1	100	96	15	6	1.70	1.52	0.28	3	3.07	0.63	72
	Replicate 2	109	107	15	7	1.87	1.69	0.23	4	3.00	0.69	72
	Replicate 3	104	101	15	7	1.55	1.37	0.40	3	3.03	0.57	59
	Replicate 4	41	37	14	3	2.40	1.97	0.11	7	3.60	0.91	74
	Replicate 5	95	91	13	7	1.69	1.51	0.27	3	2.66	0.66	80
Mean	Station B1	103	101	16.8	6.2	1.79	1.57	0.28	3.6	3.52	0.63	57
	Station B2	64	63	11.6	5.6	1.57	1.35	0.36	3.2	2.59	0.64	86
	Station B3	93	90	14.6	6.5	1.72	1.52	0.32	3.6	3.04	0.64	75
	Station B4	68	67	10.6	6.2	1.58	1.37	0.33	3.2	2.29	0.68	61
	Station B5	110	107	16.0	6.7	1.88	1.68	0.24	4.2	3.24	0.68	44
	Station B6	158	155	13.0	12.0	1.48	1.37	0.33	2.4	2.38	0.58	59
	Station B7	90	86	14.4	6.0	1.84	1.61	0.26	4.0	3.07	0.69	72
Standard Deviation	Station B1	36	38	1.9	3.0	0.35	0.24	0.08	2.1	0.70	0.11	16.7
	Station B2	19	19	2.6	2.1	0.39	0.33	0.13	1.3	0.60	0.12	5.2
	Station B3	14	13	3.2	1.9	0.41	0.36	0.15	1.5	0.77	0.11	15.8
	Station B4	34	33	3.8	1.3	0.28	0.26	0.10	0.8	0.64	0.10	19.2
	Station B5	31	32	3.2	1.8	0.06	0.05	0.04	0.4	0.66	0.05	14.1
	Station B6	12	11	1.2	1.5	0.12	0.12	0.05	0.5	0.25	0.05	21.0
	Station B7	28	28	0.9	1.9	0.33	0.23	0.10	1.7	0.34	0.13	7.7

Table B.9 Infaunal Indices in Sediment Samples Collected in October 2017

Parameter		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	515	506	35	14	1.91	1.82	0.27	3	5.46	0.54	59
	Station B2	321	315	24	13	1.74	1.63	0.36	3	4.00	0.55	84
	Station B3	466	452	25	18	1.85	1.76	0.31	4	3.93	0.57	72
	Station B4	340	334	23	15	1.83	1.73	0.28	3	3.79	0.58	60
	Station B5	548	533	32	17	2.14	2.05	0.19	4	4.94	0.62	40
	Station B6	790	774	24	32	1.56	1.51	0.32	2	3.46	0.49	57
	Station B7	449	432	27	16	1.98	1.88	0.24	4	4.28	0.60	71
Survey	Total	3429	3346	49	68	1.96	1.94	0.26	4	5.91	0.51	60

Table B.10 Infaunal Indices excluding *D. excentricus* in Sediment Samples Collected in October 2017

Parameter		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	76	76	18	4.22	1.83	1.56	0.33	4	3.93	0.63	57
	Replicate 2	51	49	15	3.27	1.93	1.61	0.27	5	3.60	0.71	40
	Replicate 3	46	46	16	2.88	2.11	1.74	0.20	5	3.92	0.76	80
	Replicate 4	49	44	17	2.59	2.29	1.87	0.17	7	4.23	0.81	65
	Replicate 5	90	88	13	6.77	1.31	1.14	0.48	2	2.68	0.51	42
Station B2	Replicate 1	24	22	11	2.00	2.17	1.67	0.14	6	3.24	0.91	90
	Replicate 2	43	43	15	2.87	2.36	1.96	0.13	8	3.72	0.87	77
	Replicate 3	20	20	9	2.22	1.82	1.39	0.23	4	2.67	0.83	86
	Replicate 4	31	28	9	3.11	1.88	1.53	0.20	4	2.40	0.85	86
	Replicate 5	22	21	9	2.33	2.00	1.56	0.16	5	2.63	0.91	89
Station B3	Replicate 1	50	46	12	3.83	2.03	1.73	0.17	4	2.87	0.82	51
	Replicate 2	42	40	17	2.35	2.44	1.98	0.12	7	4.34	0.86	83
	Replicate 3	55	53	14	3.79	2.21	1.89	0.14	5	3.27	0.84	70
	Replicate 4	58	54	16	3.38	2.29	1.94	0.15	6	3.76	0.83	78
	Replicate 5	24	22	9	2.44	1.89	1.49	0.19	4	2.59	0.86	93
Station B4	Replicate 1	33	31	10	3.10	1.82	1.48	0.23	4	2.62	0.79	89
	Replicate 2	20	20	8	2.50	1.75	1.36	0.23	4	2.34	0.84	67
	Replicate 3	25	25	7	3.57	1.75	1.44	0.19	4	1.86	0.90	60
	Replicate 4	18	18	7	2.57	1.82	1.42	0.18	4	2.08	0.93	38
	Replicate 5	84	80	16	5.00	1.96	1.71	0.27	5	3.42	0.71	50
Station B5	Replicate 1	100	98	14	7.00	1.81	1.63	0.23	3	2.84	0.69	37
	Replicate 2	66	62	16	3.88	2.17	1.87	0.16	5	3.63	0.78	54
	Replicate 3	78	78	17	4.59	2.04	1.79	0.19	4	3.67	0.72	47
	Replicate 4	84	77	18	4.28	1.92	1.65	0.29	5	3.91	0.66	23
	Replicate 5	49	47	10	4.70	1.75	1.50	0.24	4	2.34	0.76	57
Station B6	Replicate 1	98	94	12	7.83	1.52	1.36	0.37	3	2.42	0.61	47
	Replicate 2	96	93	13	7.15	1.52	1.36	0.36	3	2.65	0.59	37
	Replicate 3	56	54	13	4.15	1.70	1.43	0.33	4	3.01	0.66	47
	Replicate 4	95	91	12	7.58	1.55	1.38	0.36	3	2.44	0.62	79
	Replicate 5	85	82	10	8.20	1.30	1.15	0.44	2	2.04	0.57	83
Station B7	Replicate 1	66	62	14	4.43	1.63	1.39	0.36	3	3.15	0.62	72
	Replicate 2	70	68	14	4.86	1.92	1.66	0.25	4	3.08	0.73	72
	Replicate 3	42	39	14	2.79	2.29	1.89	0.14	7	3.55	0.87	59
	Replicate 4	39	35	13	2.69	2.32	1.90	0.12	7	3.38	0.90	74
	Replicate 5	64	60	12	5.00	1.58	1.36	0.35	3	2.69	0.64	80

Table B.10 Infaunal Indices excluding *D. excentricus* in Sediment Samples Collected in October 2017

	Parameter	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	62	61	15.8	3.9	1.89	1.59	0.29	4.6	3.67	0.69	57
	Station B2	28	27	10.6	2.5	2.05	1.62	0.17	5.4	2.93	0.87	86
	Station B3	46	43	13.6	3.2	2.17	1.81	0.15	5.2	3.37	0.84	75
	Station B4	36	35	9.6	3.3	1.82	1.48	0.22	4.2	2.46	0.83	61
	Station B5	75	72	15.0	4.9	1.94	1.69	0.22	4.2	3.28	0.72	44
	Station B6	86	83	12.0	7.0	1.52	1.34	0.37	3.0	2.51	0.61	59
	Station B7	56	53	13.4	4.0	1.95	1.64	0.25	5.0	3.17	0.75	72
Standard Deviation	Station B1	20	20	1.9	1.69	0.37	0.28	0.12	1.8	0.60	0.12	16.7
	Station B2	9	10	2.6	0.47	0.22	0.21	0.04	1.7	0.54	0.04	5.2
	Station B3	14	13	3.2	0.72	0.21	0.20	0.03	1.3	0.70	0.02	15.8
	Station B4	27	26	3.8	1.02	0.08	0.13	0.03	0.4	0.61	0.09	19.2
	Station B5	19	19	3.2	1.22	0.17	0.14	0.05	0.8	0.66	0.05	14.1
	Station B6	18	17	1.2	1.63	0.14	0.11	0.04	0.7	0.35	0.04	21.0
	Station B7	15	15	0.9	1.13	0.35	0.26	0.11	2.0	0.33	0.13	7.7
Station Total	Station B1	312	303	34	8.91	2.07	1.92	0.29	5	5.78	0.59	59
	Station B2	140	134	23	5.83	2.48	2.24	0.14	7	4.49	0.79	84
	Station B3	229	215	24	8.96	2.43	2.26	0.14	6	4.28	0.76	72
	Station B4	180	174	22	7.91	2.19	2.01	0.19	5	4.07	0.71	60
	Station B5	377	362	31	11.68	2.23	2.10	0.18	4	5.09	0.65	40
	Station B6	430	414	23	18.00	1.62	1.54	0.37	3	3.65	0.52	57
	Station B7	281	264	26	10.15	2.14	1.99	0.23	5	4.48	0.66	71
Survey	Total	1949	1866	48	38.88	2.29	2.24	0.20	5	6.24	0.59	60

SUSAN J. WILLIAMS

11100 Telegraph Rd #81

Ventura, CA 93004

(805) 659-7274

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.

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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.

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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..

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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.

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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.

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Kropp, R.K. and R.B. Manning. 1987. The Atlantic gall crabs, family Cryptochiridae (Crustacea: Decapoda: Brachyura). *Smithsonian Contributions to Zoology* 462:1-21.

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APPENDIX C

Properties of Sediment Samples Collected during the October 2017 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	10/11/2017	10:16:43	9.0	35° 23.7365' N	120° 52.6688' W	Sand	Lt. Brown	Many worm tubes ³
	Bio 2	10/11/2017	10:19:59	9.0	35° 23.7331' N	120° 52.6616' W	Sand	Lt. Brown	1 <i>D. ornata</i> tube
	Bio 3	10/11/2017	10:21:53	8.0	35° 23.7326' N	120° 52.6616' W	Sand	Lt. Brown	
	Bio 4	10/11/2017	10:29:55	7.0	35° 23.7326' N	120° 52.6603' W	Sand	Lt. Brown	
	Bio 5	10/11/2017	10:31:49	9.0	35° 23.7326' N	120° 52.6616' W	Sand	Lt. Brown	
	Chem 1	10/11/2017	10:23:41	N/A	35° 23.7315' N	120° 52.6616' W	Sand	Lt. Brown	
	Chem 2	10/11/2017	10:27:16	N/A	35° 23.7304' N	120° 52.6617' W	Sand	Lt. Brown	
	Chem 3	10/11/2017	10:33:45	N/A	35° 23.7326' N	120° 52.6616' W	Sand	Lt. Brown	
2	Bio 1	10/11/2017	9:48:15	7.0	35° 23.2796' N	120° 52.4918' W	Sand	Lt. Brown	
	Bio 2	10/11/2017	9:49:59	8.5	35° 23.2811' N	120° 52.4865' W	Sand	Lt. Brown	Intact brittle star
	Bio 3	10/11/2017	9:51:38	7.5	35° 23.2806' N	120° 52.4872' W	Sand	Lt. Brown	
	Bio 4	10/11/2017	9:53:18	10.	35° 23.2800' N	120° 52.4872' W	Sand	Lt. Brown	
	Bio 5	10/11/2017	9:58:33	7.0	35° 23.2801' N	120° 52.4879' W	Sand	Lt. Brown	
	Chem 1	10/11/2017	9:55:06	N/A	35° 23.2806' N	120° 52.4865' W	Sand	Lt. Brown	
	Chem 2	10/11/2017	10:00:49	N/A	35° 23.2811' N	120° 52.4872' W	Sand	Lt. Brown	
	Chem 3	10/11/2017	10:03:33	N/A	35° 23.2806' N	120° 52.4872' W	Sand	Lt. Brown	
3	Bio 1	10/11/2017	9:15:22	7.5	35° 23.2308' N	120° 52.4872' W	Sand	Lt. Brown	
	Bio 2	10/11/2017	9:17:01	7.0	35° 23.2297' N	120° 52.4839' W	Sand	Lt. Brown	
	Bio 3	10/11/2017	9:19:03	7.0	35° 23.2286' N	120° 52.4839' W	Sand	Lt. Brown	
	Bio 4	10/11/2017	9:22:44	7.0	35° 23.2286' N	120° 52.4819' W	Sand	Lt. Brown	1 <i>D. ornata</i> tube
	Bio 5	10/11/2017	9:28:57	7.0	35° 23.2285' N	120° 52.4806' W	Sand	Lt. Brown	
	Chem 1	10/11/2017	9:24:36	N/A	35° 23.2286' N	120° 52.4813' W	Sand	Black	Mixed w/ Organics
	Chem 2	10/11/2017	9:30:50	N/A	35° 23.2285' N	120° 52.4800' W	Sand	Lt. Brown	
	Chem 3	10/11/2017	9:33:59	N/A	35° 23.2291' N	120° 52.4799' W	Sand	Lt. Brown	
4	Bio 1	10/11/2017	7:50:47	7.5	35° 23.2134' N	120° 52.4997' W	Sand	Lt. Brown	
	Bio 2	10/11/2017	8:04:54	7.0	35° 23.2134' N	120° 52.4990' W	Sand	Lt. Brown	
	Bio 3	10/11/2017	8:06:45	7.0	35° 23.2139' N	120° 52.4985' W	Sand	Lt. Brown	
	Bio 4	10/11/2017	8:08:35	7.0	35° 23.2136' N	120° 52.4985' W	Sand	Lt. Brown	
	Bio 5	10/11/2017	8:10:31	8.0	35° 23.2134' N	120° 52.4997' W	Sand	Lt. Brown	Barnacles ⁴
	Chem 1	10/11/2017	7:52:43	N/A	35° 23.2140' N	120° 52.4990' W	Sand	Lt. Brown	
	Chem 2	10/11/2017	7:56:46	N/A	35° 23.2135' N	120° 52.4984' W	Sand	Lt. Brown	
	Chem 3	10/11/2017	7:59:50	N/A	35° 23.2135' N	120° 52.4986' 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

³ Also, a pebble with anemones attached

⁴ Attached to pebble

Table C.1 Sediment Grab-Sample Collection Record

Station	Sample	Date	Time ¹	Penetration Depth (cm)	Latitude	Longitude	Sediment Type	Sediment ² Color	Comment
5	Bio 1	10/11/2017	7:04:20	7.0	35° 23.1922' N	120° 52.5023' W	Sand	Lt. Brown	Small decayed sticks
	Bio 2	10/11/2017	7:06:39	7.5	35° 23.1939' N	120° 52.5008' W	Sand	Lt. Brown	
	Bio 3	10/11/2017	7:13:21	7.0	35° 23.1936' N	120° 52.5008' W	Sand	Lt. Brown	
	Bio 4	10/11/2017	7:24:41	7.5	35° 23.1937' N	120° 52.5002' W	Sand	Lt. Brown	4 <i>D. ornata</i> tubes ¹ Heavy Residue ¹
	Bio 5	10/11/2017	7:29:09	7.0	35° 23.1939' N	120° 52.5010' W	Sand	Lt. Brown	
	Chem 1	10/11/2017	7:17:19	N/A	35° 23.1937' N	120° 52.5011' W	Sand	Lt. Brown	
	Chem 2	10/11/2017	7:32:32	N/A	35° 23.1939' N	120° 52.5010' W	Sand	Lt. Brown	
	Chem 3	10/11/2017	7:36:20	N/A	35° 23.1941' N	120° 52.5019' W	Sand	Lt. Brown	
	Chem 4	10/11/2017	7:39:37	N/A	35° 23.1936' N	120° 52.5026' W	Sand	Lt. Brown	Added to get volume
6	Bio 1	10/11/2017	8:19:36	7.5	35° 23.1667' N	120° 52.4988' W	Sand	Lt. Brown	
	Bio 2	10/11/2017	8:21:23	7.0	35° 23.1715' N	120° 52.4986' W	Sand	Lt. Brown	
	Bio 3	10/11/2017	8:23:13	7.5	35° 23.1715' N	120° 52.4993' W	Sand	Lt. Brown	
	Bio 4	10/11/2017	8:25:03	8.0	35° 23.1721' N	120° 52.4986' W	Sand	Lt. Brown	
	Bio 5	10/11/2017	8:26:55	7.0	35° 23.1715' N	120° 52.4986' W	Sand	Lt. Brown	
	Chem 1	10/11/2017	8:28:38	N/A	35° 23.1715' N	120° 52.4986' W	Sand	Lt. Brown	
	Chem 2	10/11/2017	8:32:13	N/A	35° 23.1715' N	120° 52.4986' W	Sand	Lt. Brown	
	Chem 3	10/11/2017	8:35:12	N/A	35° 23.1710' N	120° 52.5000' W	Sand	Lt. Brown	
7	Bio 1	10/11/2017	8:51:39	7.0	35° 23.1192' N	120° 52.5053' W	Sand	Lt. Brown	
	Bio 2	10/11/2017	8:53:44	7.0	35° 23.1192' N	120° 52.5059' W	Sand	Lt. Brown	
	Bio 3	10/11/2017	8:59:19	8.0	35° 23.1186' N	120° 52.5060' W	Sand	Lt. Brown	
	Bio 4	10/11/2017	9:01:09	9.0	35° 23.1197' N	120° 52.5059' W	Sand	Lt. Brown	
	Bio 5	10/11/2017	9:03:16	8.5	35° 23.1192' N	120° 52.5059' W	Sand	Lt. Brown	Intact brittle star
	Chem 1	10/11/2017	8:45:24	N/A	35° 23.1165' N	120° 52.5054' W	Sand	Lt. Brown	
	Chem 2	10/11/2017	8:48:54	N/A	35° 23.1192' N	120° 52.5053' W	Sand	Lt. Brown	
	Chem 3	10/11/2017	8:55:48	N/A	35° 23.1192' N	120° 52.5059' W	Sand	Lt. Brown	

Table C.2 Grain-Size Class Distribution

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	0.146%	0.150%	0.138%	0.608%	73.378%	23.751%	1.115%	0.714%
Station 2	0.000%	0.010%	0.140%	1.139%	79.620%	17.753%	0.901%	0.437%
Station 3	0.000%	0.023%	0.175%	1.481%	83.313%	13.678%	0.879%	0.453%
Station 4	0.018%	0.023%	0.130%	1.647%	82.685%	14.082%	0.833%	0.581%
Station 4(d)	0.000%	0.031%	0.115%	1.653%	82.097%	14.546%	0.952%	0.607%
Station 5	0.102%	0.032%	0.112%	1.822%	86.165%	10.327%	0.846%	0.594%
Station 5(d)	0.007%	0.013%	0.133%	1.776%	85.869%	10.632%	0.916%	0.654%
Station 6	0.039%	0.046%	0.148%	1.126%	82.413%	14.522%	1.060%	0.646%
Station 7	0.064%	0.098%	0.222%	1.495%	81.822%	15.028%	0.773%	0.497%

¹ High residue volume consisting of numerous dead sand-dollar fragments; pebbles; sheets of black tar-like material; and decaying leaves and sticks

Table C.3 Grain-Size Weight Distribution

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	112.657	2.099	114.756	0.146%	98.025%	1.829%
Station 2	113.920	1.545	115.465	0.000%	98.662%	1.338%
Station 3	112.284	1.515	113.799	0.000%	98.669%	1.331%
Station 4	113.601	1.629	115.230	0.018%	98.568%	1.414%
Station 4(d)	111.690	1.769	113.459	0.000%	98.441%	1.559%
Station 5	111.800	1.634	113.434	0.102%	98.457%	1.440%
Station 5(d)	111.779	1.783	113.562	0.007%	98.423%	1.570%
Station 6	111.300	1.932	113.232	0.039%	98.255%	1.706%
Station 7	112.392	1.446	113.838	0.064%	98.666%	1.270%

Table C.4 Grain-Size Statistics

Station	Percent Coarser than Listed Diameter (µm)								
	Mean (φ)	σ (φ)	Skewness (φ)	Mean (µm)	5%	16%	50%	84%	95%
B1	2.81	0.385	0.23	143	206	180	147	110	80
B2	2.73	0.352	0.19	151	212	186	153	120	88
B3	2.68	0.336	0.17	156	218	191	158	127	92
B4	2.68	0.346	0.17	156	220	192	158	126	91
B4(d)	2.68	0.352	0.18	156	220	192	158	125	89
B5	2.63	0.323	0.15	162	223	196	163	132	97
B5(d)	2.64	0.327	0.16	160	222	195	162	132	95
B6	2.70	0.343	0.19	154	214	188	156	124	88
B7	2.69	0.347	0.16	155	219	191	157	124	91

OUTFALL/DIFFUSOR ANNUAL REPORT

NAME OF DISCHARGER MBCSD
NPDES PERMIT # _____

NAME OF DIVER/INSPECTOR Craig Porter
FIRM & ADDRESS Porter Diving
15730 Morro road Atascadero CA 93442
TELEPHONE # (805) 674-6702

OUTFALL LENGTH 5160 FT. DEPTH OF WATER 50' FT.

DESIGN OF DIFFUSOR (physical dimesions, shape, include sketch)

OF PORTS 34 # PORTS OPEN 28 DIFFUSOR LEVEL? 4"-5"

END OF DIFUSSOR OPEN? _____ CLOSED? ☒

OUTFALL MARKED BY BOUYS? YES ☒ NO _____ TYPE SPAR (2)

DIFFUSORS OPERATING AS DESIGNED? YES ☒ NO _____

BREAKS IN OUTFALL LINE NOTED? YES _____ NO ☒ IF YES, DESCRIBE

DESCRIBE PROBLEMS NOTED NONE

CORRECTIVE ACTION NEEDED NONE

PHYSICAL DESCRIPTION OF ENVIRONMENT AROUND OUTFALL (ie. fish noted, debris, sediments, etc.) Sand Dollars, Anemones, crabs, Small Fish

DIRECTION OF PLUME IN RELATIONSHIP TO SHORELINE NO Noticeable plume at surface.

PICTURES TAKEN? YES ☒ video NO _____ (INCLUDE COPIES IF TAKEN)

SIGNATURE OF DIVER/INSPECTOR

12/7/2017
DATE

[Signature]
SIGNATURE OF DISCHARGER

Supervisor / CPO
TITLE

RHS/DIFF. DISC C

**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.
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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.

Date of Report: 10/27/2017

Doug Coats

Marine Research Specialists

4744 Telephone Rd

Ste 3-315

Suite A

Ventura, CA 93003-3238

Client Project: MBCSD 2017

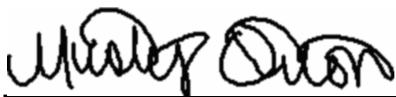
BCL Project: Annual Benthic Sediment Sampling for MBTP

BCL Work Order: 1729080

Invoice ID: B283607

Enclosed are the results of analyses for samples received by the laboratory on 10/11/2017. If you have any questions concerning this report, please feel free to contact me.

Sincerely,



Contact Person: Misty Orton
Client Service Rep



Authorized Signature

Certifications: CA ELAP #1186; NV #CA00014; OR ELAP #4032-001; AK UST101

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report must be reproduced in its entirety.
All results listed in this report are for the exclusive use of the submitting party. BC Laboratories, Inc. assumes no responsibility for report alteration, separation, detachment or third party interpretation.

4100 Atlas Court Bakersfield, CA 93308 (661) 327-4911 FAX (661) 327-1918 www.bclabs.com

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Laboratories, Inc.

Environmental Testing Laboratory Since 1949.

Chain of Custody Form

17-29080

Report To: Client: Marine Research Specialists		Project #:		Analysis Requested													
Attn: Douglas A Coats		Project Name: MBCSD Benthic 2017															
Street Address: 4744 TELEPHONE RD STE 3 PMB 315		Global ID #:		Comments: PRIOR TO ANALYSIS: HOMOGENIZE EACH SAMPLE IN LAB and remove macrofauna and remnants larger than 0.25 inches. Report dry weights and see additional instructions attached on Page 2													
City, State, Zip: Ventura, CA 93003		Sampler(s):															
Phone: 805.218.3662																	
Email Address: Marine@Rain.org																	
Work Order#				Sample Matrix Are there any tests with holding times less than or equal to 48 hours? ☒ Yes ☐ No													
Sample #	Description	Date Sampled	Time Sampled	Moisture 160.3, SM-2540G, or BC	Total Volatile Solids 160.4 or 2540G	BOD 405.1 or SM17-5210B	Total Kjeldahl Nitrogen 351.2	Oil and Grease 413.2 or 1664/HEM	Al, Fe, As, Cd, Cr (total), Cu, Pb, Hg, Ni, Ag, Zn	Soil	Sludge	Drinking Water	Ground Water	Waste Water	Other	Notes	
1	Station B1 -1	10/11/17	10:29	X	X	X	X	X	X	X	X	X	X	X	X	No O&G at Station B1	
2	Station B2 -1 -2		10:01	X	X	X	X	X	X	X	X	X	X	X	X		
3	Station B3 -2 -3		9:34	X	X	X	X	X	X	X	X	X	X	X	X		
4	Station B4 -3 -4		7:59	X	X	X	X	X	X	X	X	X	X	X	X		
5	Station B5 -4 -5		7:40	X	X	X	X	X	X	X	X	X	X	X	X		
6	Station B6 -5 -6		8:32	X	X	X	X	X	X	X	X	X	X	X	X		
7	Station B7 -6 -3		8:51	X	X	X	X	X	X	X	X	X	X	X	X		
		CHK BY: <i>[Signature]</i>		DISTRIBUTION		SUB OUT		SHORT HOLDING TIME		Cr ⁶⁺		NO ₂		NO ₃		UP SS	
										DC		Cl ₂		BOD		MBAS COT	
Billing		☒ Same as above		EDF Required?		☐ Yes ☒ No		Sample Disposal		☐ Return to Client ☒ Disposal by lab ☐ Archive Months		Special Reporting		☒ QC ☐ EDF ☐ Raw Data			
Client:				Send Copy to State of CA?		☐ Yes ☒ No		1. Relinquished By: <i>Douglas A. Coats</i> Date: <i>10/11/17</i> Time: <i>12:00</i>		1. Relinquished By: <i>Jay Mosen</i> Date: <i>10-11-17</i> Time: <i>12:00</i>							
Address:								2. Relinquished By: <i>Jay</i> Date: <i>10/11/17</i> Time: <i>2:00</i>		2. Relinquished By: <i>Jay Mosen</i> Date: <i>10/11/17</i> Time: <i>2:00</i>							
City: State Zip								3. Relinquished By: _____ Date: _____ Time: _____		3. Relinquished By: _____ Date: _____ Time: _____							
Attn:																	
PO#:																	

BC Laboratories, Inc. - 4100 Atlas Court Bakersfield, Ca. 93308 661.327-4911 Fax: 661.327-1918

Page 1 of 2

marine research specialists

4744 Telephone Rd., Suite 3 PMB 315 • Ventura, CA 93003 • 805-644-1180

17-29080

Attachment (Page 2 of 2) to Chain of Custody Form Morro Bay Benthic Sediment Sampling at 7 Stations during October 2017

The following analyses should be conducted on the **composited** soil matrix using procedures and a QC Level similar to the analyses conducted in 2016 on BC Laboratory Sample Number **16-29997**. Any questions can be directed to Doug Coats of Marine Research Specialists at (805) 218-3662.

NOTES:

1. **Prior to analysis** -macrofauna and large remnants greater than 0.25 inches should be removed, taking care to avoid contamination.
2. **Prior to analysis** -the composite samples should be **homogenized** the in the laboratory to ensure uniform distribution of multiple subsamples within the sample container(s).
3. **Reporting** - 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 or m6020sm
Cadmium	7	SW-6010
Total Chromium	7	SW-6010
Copper	7	SW-6010
Lead	7	SW-7421 or m6020sm
Mercury	7	SW-7471
Nickel	7	SW-6010
Silver	7	EPA-272.2 or m6020sm
Zinc	7	SW-6010



BC Laboratories, Inc.

Environmental Testing Laboratory Since 1949

Chain of Custody and Cooler Receipt Form for 1729080 Page 3 of 3

BC LABORATORIES INC.		COOLER RECEIPT FORM		Page 1 Of 1							
Submission #: 17-29080											
SHIPPING INFORMATION Fed Ex ☐ UPS ☐ Ontrac ☐ Hand Delivery ☐ BC Lab Field Service ☒ Other ☐ (Specify) _____		SHIPPING CONTAINER Ice Chest ☒ None ☐ Box ☐ Other ☐ (Specify) _____		FREE LIQUID YES ☐ NO ☐ W / S							
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: CR Glass Thermometer ID: Q08 Temperature: (A) 1.2 °C / (C) 0.9 °C		Date/Time: 10/11/2020 Analyst Init: [Signature]							
SAMPLE CONTAINERS		SAMPLE NUMBERS									
		1	2	3	4	5	6	7	8	9	10
QT PE UNPRES											
4oz / 8oz / 16oz PE UNPRES											
2oz Cr ⁶											
QT INORGANIC CHEMICAL METALS											
INORGANIC CHEMICAL METALS 4oz / 8oz / 16oz											
PT CYANIDE											
PT NITROGEN FORMS											
PT TOTAL SULFIDE											
2oz NITRATE / NITRITE											
PT TOTAL ORGANIC CARBON											
PT CHEMICAL OXYGEN DEMAND											
PIA PHENOLICS											
40ml VOA VIAL TRAVEL BLANK											
40ml VOA VIAL											
QT EPA 1664											
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											
40ml EPA 547											
40ml EPA 531.1											
8oz EPA 548											
QT EPA 549											
QT EPA 8015M											
QT EPA 8270											
8oz / 16oz / 32oz AMBER											
8oz / 16oz / 32oz CLEAR											
SOIL SLEEVE											
PCB VIAL											
PLASTIC BAG											
TEDLAR BAG											
FERROUS IRON											
ENCORE											
SMART KIT											
SUMMA CANISTER											
Comments: _____											
Sample Numbering Completed By: [Signature] Date/Time: 10/5/2010 10:12 PM Rev 21 05/23/2016											
= Actual / C = Corrected [S:\WPDoc\WordPerfect\LAB_DOCS\FORMS\SAMRECrev 20]											

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report must be reproduced in its entirety. All results listed in this report are for the exclusive use of the submitting party. BC Laboratories, Inc. assumes no responsibility for report alteration, separation, detachment or third party interpretation.

4100 Atlas Court Bakersfield, CA 93308 (661) 327-4911 FAX (661) 327-1918 www.bclabs.com

Marine Research Specialists
4744 Telephone Rd
Ste 3-315
Suite A
Ventura, CA 93003-3238

Reported: 10/27/2017 10:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: MBCSD 2017
Project Manager: Doug Coats

Laboratory / Client Sample Cross Reference

Laboratory	Client Sample Information			
1729080-01	COC Number:	---	Receive Date:	10/11/2017 20:20
	Project Number:	---	Sampling Date:	10/11/2017 10:29
	Sampling Location:	---	Sample Depth:	---
	Sampling Point:	Station B1	Lab Matrix:	Solids
	Sampled By:	---	Sample Type:	Soil
1729080-02	COC Number:	---	Receive Date:	10/11/2017 20:20
	Project Number:	---	Sampling Date:	10/11/2017 10:01
	Sampling Location:	---	Sample Depth:	---
	Sampling Point:	Station B2	Lab Matrix:	Solids
	Sampled By:	---	Sample Type:	Soil
1729080-03	COC Number:	---	Receive Date:	10/11/2017 20:20
	Project Number:	---	Sampling Date:	10/11/2017 09:34
	Sampling Location:	---	Sample Depth:	---
	Sampling Point:	Station B3	Lab Matrix:	Solids
	Sampled By:	---	Sample Type:	Soil
1729080-04	COC Number:	---	Receive Date:	10/11/2017 20:20
	Project Number:	---	Sampling Date:	10/11/2017 07:59
	Sampling Location:	---	Sample Depth:	---
	Sampling Point:	Station B4	Lab Matrix:	Solids
	Sampled By:	---	Sample Type:	Soil
1729080-05	COC Number:	---	Receive Date:	10/11/2017 20:20
	Project Number:	---	Sampling Date:	10/11/2017 07:40
	Sampling Location:	---	Sample Depth:	---
	Sampling Point:	Station B5	Lab Matrix:	Solids
	Sampled By:	---	Sample Type:	Soil
1729080-06	COC Number:	---	Receive Date:	10/11/2017 20:20
	Project Number:	---	Sampling Date:	10/11/2017 08:32
	Sampling Location:	---	Sample Depth:	---
	Sampling Point:	Station B6	Lab Matrix:	Solids
	Sampled By:	---	Sample Type:	Soil
1729080-07	COC Number:	---	Receive Date:	10/11/2017 20:20
	Project Number:	---	Sampling Date:	10/11/2017 08:51
	Sampling Location:	---	Sample Depth:	---
	Sampling Point:	Station B7	Lab Matrix:	Solids
	Sampled By:	---	Sample Type:	Soil

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Ste 3-315
Suite A
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Reported: 10/27/2017 10:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: MBCSD 2017
Project Manager: Doug Coats

Chemical Analysis

BCL Sample ID:	1729080-01	Client Sample Name:	Station B1, 10/11/2017 10:29:00AM						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Moisture	0	22.1	%	0.05	0.05	Calc	ND		1
Total Kjeldahl Nitrogen	180	140	mg/kg	40	16	EPA-351.2	ND		2
Volatile Solids	1.99	1.55	%	0.200	0.200	SM-2540G	ND		3
Biochemical Oxygen Demand	54	42	mg/kg	10	10	SM17-5210B			4
Solids	100	77.9	%	0.05	0.05	SM-2540G			5

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	Calc	10/15/17	10/25/17 21:01	AMM	Calc	1	B[J]1521
2	EPA-351.2	10/23/17	10/24/17 15:34	JMH	SC-1	1	B[J]2394
3	SM-2540G	10/18/17	10/18/17 12:00	CAD	MANUAL	1	B[J]1846
4	SM17-5210B	10/12/17	10/12/17 07:10	HPR	YSIPRO	0.333	B[J]1825
5	SM-2540G	10/20/17	10/21/17 14:55	PG1	MANUAL	1	B[J]2209

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Ste 3-315
Suite A
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Reported: 10/27/2017 10:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: MBCSD 2017
Project Manager: Doug Coats

Total Concentrations (TTLC)

BCL Sample ID: 1729080-01		Client Sample Name: Station B1, 10/11/2017 10:29:00AM							
Constituent	Dry Basis Result	As Recvd Result	Units	As Received		Method	MB Bias	Lab Quals	Run #
Arsenic	3.0	2.3	mg/kg	0.50	0.17	EPA-6020	ND		1
Cadmium	ND	ND	mg/kg	0.50	0.052	EPA-6010B	ND		2
Chromium	71	55	mg/kg	0.50	0.050	EPA-6010B	ND		2
Copper	3.3	2.6	mg/kg	1.0	0.050	EPA-6010B	ND		2
Lead	2.3	1.8	mg/kg	0.25	0.12	EPA-6020	ND		1
Mercury	0.22	0.17	mg/kg	0.16	0.019	EPA-7471A	ND		3
Nickel	43	33	mg/kg	0.50	0.15	EPA-6010B	ND		2
Silver	ND	ND	mg/kg	0.25	0.051	EPA-6020	ND		1
Zinc	17	13	mg/kg	2.5	0.087	EPA-6010B	0.18		2
Aluminum	6900	5400	mg/kg	5.0	1.2	EPA-6010B	ND		2
Iron	9800	7700	mg/kg	5.0	1.7	EPA-6010B	ND		2

Run #	Method	Prep Date	Run		Analyst	Instrument	Dilution	QC
			Date/Time					Batch ID
1	EPA-6020	10/25/17	10/25/17 23:30		ARD	PE-EL2	0.952	B[J]2624
2	EPA-6010B	10/25/17	10/25/17 16:08		JCC	PE-OP3	0.980	B[J]2631
3	EPA-7471A	10/17/17	10/17/17 15:35		MEV	CETAC2	1.025	B[J]1682

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Reported: 10/27/2017 10:35
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Project Number: MBCSD 2017
Project Manager: Doug Coats

EPA Method 1664

BCL Sample ID:	1729080-02	Client Sample Name:	Station B2, 10/11/2017 10:01:00AM						
Constituent	Dry Basis Result	As Recvd Result	Units	As Received PQL	MDL	Method	MB Bias	Lab Quals	Run #
Oil and Grease	30	23	mg/kg	50	21	EPA-1664A HEM	ND	J	1

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-1664A HEM	10/13/17	10/13/17 13:30	MAM	MAN-SV	0.994	BJ1475

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Reported: 10/27/2017 10:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: MBCSD 2017
Project Manager: Doug Coats

Chemical Analysis

BCL Sample ID:	1729080-02	Client Sample Name:	Station B2, 10/11/2017 10:01:00AM						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Moisture	0	25.0	%	0.05	0.05	Calc	ND		1
Total Kjeldahl Nitrogen	140	100	mg/kg	40	16	EPA-351.2	ND		2
Volatile Solids	2.35	1.76	%	0.200	0.200	SM-2540G	ND		3
Biochemical Oxygen Demand	55	42	mg/kg	10	10	SM17-5210B			4
Solids	100	75.0	%	0.05	0.05	SM-2540G			5

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	Calc	10/15/17	10/25/17 21:01	AMM	Calc	1	B[J]1521
2	EPA-351.2	10/23/17	10/24/17 15:38	JMH	SC-1	1	B[J]2394
3	SM-2540G	10/18/17	10/18/17 12:00	CAD	MANUAL	1	B[J]1846
4	SM17-5210B	10/12/17	10/12/17 07:10	HPR	YSIPRO	0.333	B[J]1825
5	SM-2540G	10/20/17	10/21/17 14:55	PG1	MANUAL	1	B[J]2209

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Reported: 10/27/2017 10:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: MBCSD 2017
Project Manager: Doug Coats

Total Concentrations (TTLC)

BCL Sample ID: 1729080-02		Client Sample Name: Station B2, 10/11/2017 10:01:00AM							
Constituent	Dry Basis Result	As Recvd Result	Units	As Received		Method	MB Bias	Lab Quals	Run #
Arsenic	3.6	2.7	mg/kg	0.50	0.17	EPA-6020	ND		1
Cadmium	ND	ND	mg/kg	0.50	0.052	EPA-6010B	ND		2
Chromium	45	34	mg/kg	0.50	0.050	EPA-6010B	ND		2
Copper	3.4	2.5	mg/kg	1.0	0.050	EPA-6010B	ND		2
Lead	2.2	1.7	mg/kg	0.25	0.12	EPA-6020	ND		1
Mercury	0.055	0.042	mg/kg	0.16	0.019	EPA-7471A	ND	J	3
Nickel	46	34	mg/kg	0.50	0.15	EPA-6010B	ND		2
Silver	ND	ND	mg/kg	0.25	0.051	EPA-6020	ND		1
Zinc	15	11	mg/kg	2.5	0.087	EPA-6010B	0.17		2
Aluminum	5600	4200	mg/kg	5.0	1.2	EPA-6010B	ND		2
Iron	8600	6400	mg/kg	5.0	1.7	EPA-6010B	ND		2

Run #	Method	Prep Date	Run		Analyst	Instrument	Dilution	QC
			Date/Time					Batch ID
1	EPA-6020	10/25/17	10/25/17 23:33		ARD	PE-EL2	0.980	BJJ2624
2	EPA-6010B	10/25/17	10/25/17 16:11		JCC	PE-OP3	0.926	BJJ2631
3	EPA-7471A	10/17/17	10/17/17 15:37		MEV	CETAC2	1.008	BJJ1682

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Ste 3-315
Suite A
Ventura, CA 93003-3238

Reported: 10/27/2017 10:35
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Project Number: MBCSD 2017
Project Manager: Doug Coats

EPA Method 1664

BCL Sample ID:	1729080-03	Client Sample Name:	Station B3, 10/11/2017 9:34:00AM						
Constituent	Dry Basis Result	As Recvd Result	Units	As Received PQL	MDL	Method	MB Bias	Lab Quals	Run #
Oil and Grease	26	21	mg/kg	50	21	EPA-1664A HEM	ND	J	1

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-1664A HEM	10/13/17	10/13/17 13:30	MAM	MAN-SV	0.990	BJ1475

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Reported: 10/27/2017 10:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: MBCSD 2017
Project Manager: Doug Coats

Chemical Analysis

BCL Sample ID:	1729080-03	Client Sample Name:	Station B3, 10/11/2017 9:34:00AM						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Moisture	0	21.3	%	0.05	0.05	Calc	ND		1
Total Kjeldahl Nitrogen	160	130	mg/kg	40	16	EPA-351.2	ND		2
Volatile Solids	2.26	1.78	%	0.200	0.200	SM-2540G	ND		3
Biochemical Oxygen Demand	52	41	mg/kg	10	10	SM17-5210B			4
Solids	100	78.7	%	0.05	0.05	SM-2540G			5

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	Calc	10/15/17	10/25/17 21:01	AMM	Calc	1	B[J]1521
2	EPA-351.2	10/23/17	10/24/17 15:39	JMH	SC-1	1	B[J]2394
3	SM-2540G	10/18/17	10/18/17 12:00	CAD	MANUAL	1	B[J]1846
4	SM17-5210B	10/12/17	10/12/17 07:10	HPR	YSIPRO	0.333	B[J]1825
5	SM-2540G	10/20/17	10/21/17 14:55	PG1	MANUAL	1	B[J]2209

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Ste 3-315
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Reported: 10/27/2017 10:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: MBCSD 2017
Project Manager: Doug Coats

Total Concentrations (TTLC)

BCL Sample ID:	1729080-03	Client Sample Name:	Station B3, 10/11/2017 9:34:00AM						
Constituent	Dry Basis Result	As Recvd Result	Units	As Received		Method	MB Bias	Lab Quals	Run #
Arsenic	4.0	3.1	mg/kg	0.50	0.17	EPA-6020	ND		1
Cadmium	ND	ND	mg/kg	0.50	0.052	EPA-6010B	ND		2
Chromium	45	35	mg/kg	0.50	0.050	EPA-6010B	ND		2
Copper	3.6	2.9	mg/kg	1.0	0.050	EPA-6010B	ND		2
Lead	2.3	1.8	mg/kg	0.25	0.12	EPA-6020	ND		1
Mercury	0.033	0.026	mg/kg	0.16	0.019	EPA-7471A	ND	J	3
Nickel	51	40	mg/kg	0.50	0.15	EPA-6010B	ND		2
Silver	ND	ND	mg/kg	0.25	0.051	EPA-6020	ND		1
Zinc	16	12	mg/kg	2.5	0.087	EPA-6010B	0.18		2
Aluminum	6000	4700	mg/kg	5.0	1.2	EPA-6010B	ND		2
Iron	9100	7100	mg/kg	5.0	1.7	EPA-6010B	ND		2

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-6020	10/25/17	10/25/17 23:37	ARD	PE-EL2	0.952	BJJ2624
2	EPA-6010B	10/25/17	10/25/17 16:13	JCC	PE-OP3	0.962	BJJ2631
3	EPA-7471A	10/17/17	10/17/17 15:44	MEV	CETAC2	1.008	BJJ1682

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Ste 3-315
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Ventura, CA 93003-3238

Reported: 10/27/2017 10:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: MBCSD 2017
Project Manager: Doug Coats

EPA Method 1664

BCL Sample ID:	1729080-04	Client Sample Name:	Station B4, 10/11/2017 7:59:00AM						
Constituent	Dry Basis Result	As Recvd Result	Units	As Received PQL	MDL	Method	MB Bias	Lab Quals	Run #
Oil and Grease	ND	ND	mg/kg	50	21	EPA-1664A HEM	ND		1

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-1664A HEM	10/13/17	10/13/17 13:30	MAM	MAN-SV	1	BJ1475

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Reported: 10/27/2017 10:35
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Project Number: MBCSD 2017
Project Manager: Doug Coats

Chemical Analysis

BCL Sample ID:	1729080-04	Client Sample Name:	Station B4, 10/11/2017 7:59:00AM						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Moisture	0	24.7	%	0.05	0.05	Calc	ND		1
Total Kjeldahl Nitrogen	180	130	mg/kg	40	16	EPA-351.2	ND		2
Volatile Solids	2.35	1.77	%	0.200	0.200	SM-2540G	ND		3
Biochemical Oxygen Demand	58	44	mg/kg	7.5	7.5	SM17-5210B			4
Solids	100	75.3	%	0.05	0.05	SM-2540G			5

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	Calc	10/15/17	10/25/17 21:01	AMM	Calc	1	B[J]1521
2	EPA-351.2	10/23/17	10/24/17 15:40	JMH	SC-1	1	B[J]2394
3	SM-2540G	10/18/17	10/18/17 12:00	CAD	MANUAL	1	B[J]1846
4	SM17-5210B	10/12/17	10/12/17 07:10	HPR	YSIPRO	0.250	B[J]1825
5	SM-2540G	10/20/17	10/21/17 14:55	PG1	MANUAL	1	B[J]2209

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Reported: 10/27/2017 10:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: MBCSD 2017
Project Manager: Doug Coats

Total Concentrations (TTLC)

BCL Sample ID:	1729080-04	Client Sample Name:	Station B4, 10/11/2017 7:59:00AM						
Constituent	Dry Basis Result	As Recvd Result	Units	As Received		Method	MB Bias	Lab Quals	Run #
Arsenic	3.9	2.9	mg/kg	0.50	0.17	EPA-6020	ND		1
Cadmium	ND	ND	mg/kg	0.50	0.052	EPA-6010B	ND		2
Chromium	47	35	mg/kg	0.50	0.050	EPA-6010B	ND		2
Copper	3.9	3.0	mg/kg	1.0	0.050	EPA-6010B	ND		2
Lead	2.3	1.8	mg/kg	0.25	0.12	EPA-6020	ND		1
Mercury	0.040	0.030	mg/kg	0.16	0.019	EPA-7471A	ND	J	3
Nickel	53	40	mg/kg	0.50	0.15	EPA-6010B	ND		2
Silver	ND	ND	mg/kg	0.25	0.051	EPA-6020	ND		1
Zinc	16	12	mg/kg	2.5	0.087	EPA-6010B	0.18		2
Aluminum	6200	4700	mg/kg	5.0	1.2	EPA-6010B	ND		2
Iron	9500	7200	mg/kg	5.0	1.7	EPA-6010B	ND		2

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-6020	10/25/17	10/25/17 23:40	ARD	PE-EL2	0.962	BJJ2624
2	EPA-6010B	10/25/17	10/25/17 16:15	JCC	PE-OP3	1	BJJ2631
3	EPA-7471A	10/17/17	10/17/17 15:46	MEV	CETAC2	0.977	BJJ1682

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Reported: 10/27/2017 10:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: MBCSD 2017
Project Manager: Doug Coats

EPA Method 1664

BCL Sample ID:	1729080-05	Client Sample Name:	Station B5, 10/11/2017 7:40:00AM						
Constituent	Dry Basis Result	As Recvd Result	Units	As Received PQL	MDL	Method	MB Bias	Lab Quals	Run #
Oil and Grease	58	45	mg/kg	50	21	EPA-1664A HEM	ND	J	1

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-1664A HEM	10/13/17	10/13/17 13:30	MAM	MAN-SV	0.998	BJ1475

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Project Number: MBCSD 2017
Project Manager: Doug Coats

Chemical Analysis

BCL Sample ID:	1729080-05	Client Sample Name:	Station B5, 10/11/2017 7:40:00AM						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Moisture	0	23.0	%	0.05	0.05	Calc	ND		1
Total Kjeldahl Nitrogen	160	130	mg/kg	40	16	EPA-351.2	ND		2
Volatile Solids	2.46	1.89	%	0.200	0.200	SM-2540G	ND		3
Biochemical Oxygen Demand	70	54	mg/kg	10	10	SM17-5210B			4
Solids	100	77.0	%	0.05	0.05	SM-2540G			5

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	Calc	10/15/17	10/25/17 21:01	AMM	Calc	1	B[J]1521
2	EPA-351.2	10/23/17	10/24/17 15:41	JMH	SC-1	1	B[J]2394
3	SM-2540G	10/18/17	10/18/17 12:00	CAD	MANUAL	1	B[J]1846
4	SM17-5210B	10/12/17	10/12/17 07:10	HPR	YSIPRO	0.333	B[J]1825
5	SM-2540G	10/20/17	10/21/17 14:55	PG1	MANUAL	1	B[J]2209

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Reported: 10/27/2017 10:35
Project: Annual Benthic Sediment Sampling for MBTP
Project Number: MBCSD 2017
Project Manager: Doug Coats

Total Concentrations (TTLC)

BCL Sample ID:	1729080-05	Client Sample Name:	Station B5, 10/11/2017 7:40:00AM						
Constituent	Dry Basis Result	As Recvd Result	Units	As Received		Method	MB Bias	Lab Quals	Run #
Arsenic	3.7	2.8	mg/kg	0.50	0.17	EPA-6020	ND		1
Cadmium	ND	ND	mg/kg	0.50	0.052	EPA-6010B	ND		2
Chromium	44	34	mg/kg	0.50	0.050	EPA-6010B	ND		2
Copper	4.0	3.1	mg/kg	1.0	0.050	EPA-6010B	ND		2
Lead	2.2	1.7	mg/kg	0.25	0.12	EPA-6020	ND		1
Mercury	0.028	0.021	mg/kg	0.16	0.019	EPA-7471A	ND	J	3
Nickel	57	44	mg/kg	0.50	0.15	EPA-6010B	ND		2
Silver	ND	ND	mg/kg	0.25	0.051	EPA-6020	ND		1
Zinc	17	13	mg/kg	2.5	0.087	EPA-6010B	0.17		2
Aluminum	5900	4600	mg/kg	5.0	1.2	EPA-6010B	ND		2
Iron	9200	7100	mg/kg	5.0	1.7	EPA-6010B	ND		2

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-6020	10/25/17	10/25/17 23:44	ARD	PE-EL2	0.952	BJJ2624
2	EPA-6010B	10/25/17	10/25/17 16:17	JCC	PE-OP3	0.935	BJJ2631
3	EPA-7471A	10/17/17	10/17/17 15:48	MEV	CETAC2	0.992	BJJ1682

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Project Number: MBCSD 2017
Project Manager: Doug Coats

EPA Method 1664

BCL Sample ID:	1729080-06	Client Sample Name:	Station B6, 10/11/2017 8:32:00AM						
Constituent	Dry Basis Result	As Recvd Result	Units	As Received PQL	MDL	Method	MB Bias	Lab Quals	Run #
Oil and Grease	27	21	mg/kg	50	21	EPA-1664A HEM	ND	J	1

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-1664A HEM	10/13/17	10/13/17 13:30	MAM	MAN-SV	0.990	BJ1475

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Project Number: MBCSD 2017
Project Manager: Doug Coats

Chemical Analysis

BCL Sample ID:	1729080-06	Client Sample Name:	Station B6, 10/11/2017 8:32:00AM						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Moisture	0	22.7	%	0.05	0.05	Calc	ND		1
Total Kjeldahl Nitrogen	180	140	mg/kg	40	16	EPA-351.2	ND		2
Volatile Solids	2.23	1.72	%	0.200	0.200	SM-2540G	ND		3
Biochemical Oxygen Demand	61	47	mg/kg	10	10	SM17-5210B			4
Solids	100	77.3	%	0.05	0.05	SM-2540G			5

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	Calc	10/15/17	10/25/17 21:01	AMM	Calc	1	B[J]1521
2	EPA-351.2	10/23/17	10/24/17 15:43	JMH	SC-1	1	B[J]2394
3	SM-2540G	10/18/17	10/18/17 12:00	CAD	MANUAL	1	B[J]1846
4	SM17-5210B	10/12/17	10/12/17 07:10	HPR	YSIPRO	0.333	B[J]1825
5	SM-2540G	10/20/17	10/21/17 14:55	PG1	MANUAL	1	B[J]2209

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Project Number: MBCSD 2017
Project Manager: Doug Coats

Total Concentrations (TTLC)

BCL Sample ID:	1729080-06	Client Sample Name:	Station B6, 10/11/2017 8:32:00AM						
Constituent	Dry Basis Result	As Recvd Result	Units	As Received		Method	MB Bias	Lab Quals	Run #
Arsenic	3.9	3.0	mg/kg	0.50	0.17	EPA-6020	ND		1
Cadmium	ND	ND	mg/kg	0.50	0.052	EPA-6010B	ND		2
Chromium	43	33	mg/kg	0.50	0.050	EPA-6010B	ND		2
Copper	3.2	2.5	mg/kg	1.0	0.050	EPA-6010B	ND		2
Lead	2.3	1.8	mg/kg	0.25	0.12	EPA-6020	ND		1
Mercury	0.058	0.045	mg/kg	0.16	0.019	EPA-7471A	ND	J	3
Nickel	48	37	mg/kg	0.50	0.15	EPA-6010B	ND		2
Silver	ND	ND	mg/kg	0.25	0.051	EPA-6020	ND		1
Zinc	14	11	mg/kg	2.5	0.087	EPA-6010B	0.17		2
Aluminum	5300	4100	mg/kg	5.0	1.2	EPA-6010B	ND		2
Iron	8200	6300	mg/kg	5.0	1.7	EPA-6010B	ND		2

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-6020	10/25/17	10/25/17 23:47	ARD	PE-EL2	0.990	B[J]2624
2	EPA-6010B	10/25/17	10/25/17 16:18	JCC	PE-OP3	0.935	B[J]2631
3	EPA-7471A	10/17/17	10/17/17 15:50	MEV	CETAC2	0.977	B[J]1682

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EPA Method 1664

BCL Sample ID:	1729080-07	Client Sample Name:	Station B7, 10/11/2017 8:51:00AM						
Constituent	Dry Basis Result	As Recvd Result	Units	PQL	MDL	Method	MB Bias	Lab Quals	Run #
Oil and Grease	ND	ND	mg/kg	50	21	EPA-1664A HEM	ND		1

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-1664A HEM	10/13/17	10/13/17 13:30	MAM	MAN-SV	0.998	BJ1475

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Project Number: MBCSD 2017
Project Manager: Doug Coats

Chemical Analysis

BCL Sample ID:	1729080-07	Client Sample Name:	Station B7, 10/11/2017 8:51:00AM						
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	150	110	mg/kg	40	16	EPA-351.2	ND		2
Volatile Solids	2.26	1.73	%	0.200	0.200	SM-2540G	ND		3
Biochemical Oxygen Demand	53	40	mg/kg	10	10	SM17-5210B			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	10/15/17	10/25/17 21:01	AMM	Calc	1	B[J]1521
2	EPA-351.2	10/23/17	10/24/17 15:45	JMH	SC-1	1	B[J]2394
3	SM-2540G	10/18/17	10/18/17 12:00	CAD	MANUAL	1	B[J]1846
4	SM17-5210B	10/12/17	10/12/17 07:10	HPR	YSIPRO	0.333	B[J]1825
5	SM-2540G	10/20/17	10/21/17 14:55	PG1	MANUAL	1	B[J]2209

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Project Number: MBCSD 2017
Project Manager: Doug Coats

Total Concentrations (TTLC)

BCL Sample ID:	1729080-07	Client Sample Name:	Station B7, 10/11/2017 8:51:00AM						
Constituent	Dry Basis Result	As Recvd Result	Units	As Received		Method	MB Bias	Lab Quals	Run #
Arsenic	3.4	2.6	mg/kg	0.50	0.17	EPA-6020	ND		1
Cadmium	ND	ND	mg/kg	0.50	0.052	EPA-6010B	ND		2
Chromium	43	33	mg/kg	0.50	0.050	EPA-6010B	ND		2
Copper	3.0	2.3	mg/kg	1.0	0.050	EPA-6010B	ND		2
Lead	1.9	1.5	mg/kg	0.25	0.12	EPA-6020	ND		1
Mercury	0.055	0.042	mg/kg	0.16	0.019	EPA-7471A	ND	J	3
Nickel	44	34	mg/kg	0.50	0.15	EPA-6010B	ND		2
Silver	ND	ND	mg/kg	0.25	0.051	EPA-6020	ND		1
Zinc	14	11	mg/kg	2.5	0.087	EPA-6010B	0.18		2
Aluminum	5500	4200	mg/kg	5.0	1.2	EPA-6010B	ND		2
Iron	8500	6500	mg/kg	5.0	1.7	EPA-6010B	ND		2

Run #	Method	Prep Date	Run Date/Time	Analyst	Instrument	Dilution	QC Batch ID
1	EPA-6020	10/25/17	10/25/17 23:51	ARD	PE-EL2	0.990	BJJ2624
2	EPA-6010B	10/25/17	10/25/17 16:20	JCC	PE-OP3	1	BJJ2631
3	EPA-7471A	10/17/17	10/17/17 15:53	MEV	CETAC2	1.025	BJJ1682

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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: B[J1475						
Oil and Grease	B[J1475-BLK1	ND	mg/kg	50	21	

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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: B[J1475									
	B[J1475-BS1	LCS	778.88	816.73	mg/kg	95.4		59 - 117		

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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: B[J1475		Used client sample: N									
Oil and Grease	DUP	1724840-55	ND	ND		mg/kg			30		
	MS	1724840-55	ND	779.44	818.36	mg/kg		95.2		56 - 111	
	MSD	1724840-55	ND	787.13	811.88	mg/kg	1.0	97.0	30	56 - 111	

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Chemical Analysis

Quality Control Report - Method Blank Analysis

Constituent	QC Sample ID	MB Result	Units	PQL	MDL	Lab Quals
QC Batch ID: B[J1521]						
Moisture	B[J1521-BLK1	ND	%	0.05	0.05	
QC Batch ID: B[J1825]						
Biochemical Oxygen Demand	B[J1825-BLK1	ND	mg/kg	0.98	0.98	
QC Batch ID: B[J1846]						
Volatile Solids	B[J1846-BLK1	ND	%	0.133	0.133	
QC Batch ID: B[J2394]						
Total Kjeldahl Nitrogen	B[J2394-BLK1	ND	mg/kg	40	16	

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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: B[J1825										
Biochemical Oxygen Demand	B[J1825-BS1	LCS	199.16	198.00	mg/kg	101		85 - 115		
QC Batch ID: B[J2394										
Total Kjeldahl Nitrogen	B[J2394-BS1	LCS	374.72	400.00	mg/kg	93.7		90 - 110		

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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: B[J1825]		Used client sample: Y - Description: Station B1, 10/11/2017 10:29									
Biochemical Oxygen Demand	DUP	1729080-01	42.090	31.415		mg/kg	29.0		20		Q01
QC Batch ID: B[J1846]		Used client sample: Y - Description: Station B1, 10/11/2017 10:29									
Volatile Solids	DUP	1729080-01	1.5520	1.4676		%	5.6		20		
QC Batch ID: B[J2209]		Used client sample: N									
Solids	DUP	1728980-13	96.750	96.520		%	0.2		20		
QC Batch ID: B[J2394]		Used client sample: Y - Description: Station B1, 10/11/2017 10:29									
Total Kjeldahl Nitrogen	DUP	1729080-01	136.48	128.84		mg/kg	5.8		20		
	MS	1729080-01	136.48	544.58	400.00	mg/kg		102		90 - 110	
	MSD	1729080-01	136.48	512.00	400.00	mg/kg	6.2	93.9	20	90 - 110	

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Total Concentrations (TTLC)

Quality Control Report - Method Blank Analysis

Constituent	QC Sample ID	MB Result	Units	PQL	MDL	Lab Quals
QC Batch ID: B[J1682]						
Mercury	B[J1682-BLK1	ND	mg/kg	0.16	0.019	
QC Batch ID: B[J2624]						
Arsenic	B[J2624-BLK1	ND	mg/kg	0.50	0.17	
Lead	B[J2624-BLK1	ND	mg/kg	0.25	0.12	
Silver	B[J2624-BLK1	ND	mg/kg	0.25	0.051	
QC Batch ID: B[J2631]						
Cadmium	B[J2631-BLK1	ND	mg/kg	0.50	0.052	
Chromium	B[J2631-BLK1	ND	mg/kg	0.50	0.050	
Copper	B[J2631-BLK1	ND	mg/kg	1.0	0.050	
Nickel	B[J2631-BLK1	ND	mg/kg	0.50	0.15	
Zinc	B[J2631-BLK1	0.18380	mg/kg	2.5	0.087	J
Aluminum	B[J2631-BLK1	ND	mg/kg	5.0	1.2	
Iron	B[J2631-BLK1	ND	mg/kg	5.0	1.7	

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Total Concentrations (TTLC)

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
QC Batch ID: B[J1682										
Mercury	B[J1682-BS1	LCS	0.85360	0.80000	mg/kg	107		80 - 120		
QC Batch ID: B[J2624										
Arsenic	B[J2624-BS1	LCS	25.589	25.000	mg/kg	102		75 - 125		
Lead	B[J2624-BS1	LCS	26.404	25.000	mg/kg	106		75 - 125		
Silver	B[J2624-BS1	LCS	10.244	10.000	mg/kg	102		75 - 125		
QC Batch ID: B[J2631										
Cadmium	B[J2631-BS1	LCS	10.038	10.000	mg/kg	100		75 - 125		
Chromium	B[J2631-BS1	LCS	106.61	100.00	mg/kg	107		75 - 125		
Copper	B[J2631-BS1	LCS	99.639	100.00	mg/kg	99.6		75 - 125		
Nickel	B[J2631-BS1	LCS	110.88	100.00	mg/kg	111		75 - 125		
Zinc	B[J2631-BS1	LCS	103.37	100.00	mg/kg	103		75 - 125		
Aluminum	B[J2631-BS1	LCS	504.92	500.00	mg/kg	101		75 - 125		
Iron	B[J2631-BS1	LCS	498.84	500.00	mg/kg	99.8		75 - 125		

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Total Concentrations (TTLC)

Quality Control Report - Precision & Accuracy

Control Limits											
Constituent	Type	Source Sample ID	Source Result	Result	Spike Added	Units	RPD	Percent Recovery	Percent RPD	Percent Recovery	Lab Quals
QC Batch ID: B[J1682]		Used client sample: N									
Mercury	DUP	1729294-04	ND	ND		mg/kg			20		
	MS	1729294-04	ND	0.83516	0.80645	mg/kg		104		80 - 120	
	MSD	1729294-04	ND	0.86823	0.80645	mg/kg	3.9	108	20	80 - 120	
QC Batch ID: B[J2624]		Used client sample: N									
Arsenic	DUP	1730122-09	3.4562	3.7500		mg/kg	8.2		20		
	MS	1730122-09	3.4562	52.454	50.000	mg/kg		98.0		75 - 125	
	MSD	1730122-09	3.4562	50.800	50.000	mg/kg	3.2	94.7	20	75 - 125	
Lead	DUP	1730122-09	3.7125	3.9738		mg/kg	6.8		20		
	MS	1730122-09	3.7125	53.014	50.000	mg/kg		98.6		75 - 125	
	MSD	1730122-09	3.7125	51.739	50.000	mg/kg	2.4	96.1	20	75 - 125	
Silver	DUP	1730122-09	ND	ND		mg/kg			20		
	MS	1730122-09	ND	20.084	20.000	mg/kg		100		75 - 125	
	MSD	1730122-09	ND	19.435	20.000	mg/kg	3.3	97.2	20	75 - 125	
QC Batch ID: B[J2631]		Used client sample: N									
Cadmium	DUP	1728980-01	0.14983	0.14127		mg/kg	5.9		20		J
	MS	1728980-01	0.14983	8.7088	10.000	mg/kg		85.6		75 - 125	
	MSD	1728980-01	0.14983	8.5254	10.000	mg/kg	2.1	83.8	20	75 - 125	
Chromium	DUP	1728980-01	28.413	26.746		mg/kg	6.0		20		
	MS	1728980-01	28.413	116.62	100.00	mg/kg		88.2		75 - 125	
	MSD	1728980-01	28.413	112.49	100.00	mg/kg	3.6	84.1	20	75 - 125	
Copper	DUP	1728980-01	16.418	15.715		mg/kg	4.4		20		
	MS	1728980-01	16.418	108.04	100.00	mg/kg		91.6		75 - 125	
	MSD	1728980-01	16.418	106.07	100.00	mg/kg	1.8	89.7	20	75 - 125	
Nickel	DUP	1728980-01	30.056	27.922		mg/kg	7.4		20		
	MS	1728980-01	30.056	115.13	100.00	mg/kg		85.1		75 - 125	
	MSD	1728980-01	30.056	112.79	100.00	mg/kg	2.1	82.7	20	75 - 125	
Zinc	DUP	1728980-01	33.561	31.381		mg/kg	6.7		20		
	MS	1728980-01	33.561	116.41	100.00	mg/kg		82.9		75 - 125	
	MSD	1728980-01	33.561	112.42	100.00	mg/kg	3.5	78.9	20	75 - 125	
Aluminum	DUP	1728980-01	11285	10760		mg/kg	4.8		20		
	MS	1728980-01	11285	11418	500.00	mg/kg		26.6		75 - 125	A03
	MSD	1728980-01	11285	11062	500.00	mg/kg	3.2	-44.7	20	75 - 125	A03
Iron	DUP	1728980-01	14554	13988		mg/kg	4.0		20		
	MS	1728980-01	14554	13799	500.00	mg/kg		-151		75 - 125	A03
	MSD	1728980-01	14554	13455	500.00	mg/kg	2.5	-220	20	75 - 125	A03

Marine Research Specialists
4744 Telephone Rd
Ste 3-315
Suite A
Ventura, CA 93003-3238

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Project: Annual Benthic Sediment Sampling for MBTP
Project Number: MBCSD 2017
Project Manager: Doug Coats

Notes And Definitions

J	Estimated Value (CLP Flag)
MDL	Method Detection Limit
ND	Analyte Not Detected
PQL	Practical Quantitation Limit
A03	The sample concentration is more than 4 times the spike level.
Q01	Sample precision is not within the control limits.