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SPATIAL ANALYSIS OF METALS AND RELATIONSHIP TO INFAUNA IN MONTEREY BAY SEDIMENTS

A Thesis

Presented to

The Faculty of the Department of Environmental Studies

San Jose State University

In Partial Fulfillment

of the Requirement for the Degree

Master of Science

by

Anuraag Gill

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APPROVED FOR THE DEPARTMENT OF ENVIRONMENTAL STUDIES

Dr. Gary A. Klee, Committee Chair
Professor of Environmental Studies

Dr. Richard Taketa
Professor of Geography

Mr. Patrick Cotter
Environmental Scientist, Monterey Bay National Marine Sanctuary

Mr. Robert Lugo
Physical Scientist, U.S. Geological Survey

APPROVED FOR THE UNIVERSITY

ABSTRACT

SPATIAL ANALYSIS OF METAL AND RELATIONSHIP TO INFAUNA IN MONTEREY BAY SEDIMENTS

by Anuraag Gill

This thesis examines the spatial distribution of trace metals of concern in Monterey Bay sediment and their relationship to benthic infauna in the vicinity of municipal wastewater discharges. Geographic Information Systems were used to geo-reference monitoring data on trace metals and benthic infauna. Arsenic, nickel, and chromium were identified as metals of concern based on the sediment quality guidelines by MacDonald (1994). Possible sources for arsenic may include agricultural runoff. High concentration of nickel and chromium may be related to natural geologic sources.

High-nickel concentrations sites showed a significantly lower number of infauna species when compared to low-nickel concentration sites around the wastewater outfalls. Statistical analysis of chromium concentrations showed no apparent relationship to benthic infauna parameters.

Recommendations for regional monitoring were based on the above evaluation processes. This research shows a need for standardization in monitoring frequency, larger spatial coverage, coordination of monitoring methods, standard data format, and public and private agency cooperation in regional monitoring.

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LIST OF ABBREVIATIONS

AB	California Assembly Bill
Ag	Silver
AMBAG	Association of Monterey Bay Area Governments
ANOVA	Analysis of Variance
As	Arsenic
BEDS	Biological Effects Database for Sediments
BOD	Biochemical Oxygen Demand
BPTCP	Bay Protection and Toxic Cleanup Program
CA	California
Cal EPA	California Environmental Protection Agency
CCC	California Coastal Commission
CCJDC	Central Coast Joint Data Committee
CDFG	California Department of Fish and Game
Cd	Cadmium
Cr	Chromium
Cu	Copper
CWC	Clean Water Code
DLG	Digital Line Graph

EMAP	Environmental Monitoring and Assessment Program
ERL	Effects Range-Low
ERM	Effects Range-Median
ESI	Environmental Sensitivity Index
g	gram
GIS	Geographic Information Systems
gpd	gallons per day
GPS	Global Positioning Systems
Hg	Mercury
ICM	Integrated Coastal Management
kg	kilogram
km	kilometers
m	meters
mg	milligram
MBNMS	Monterey Bay National Marine Sanctuary
MGD	million gallons per day
MOA	Memorandum of Agreement
MPRSA	Marine Protection, Research, and Sanctuaries Act
MRWPCA	Monterey Regional Water Pollution Control Agency
Ni	Nickel
nmi	nautical miles
NOAA	National Oceanic and Atmospheric Administration

NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
NS & T	National Status and Trends Program
OCRM	Ocean and Coastal Resource Management
Pb	Lead
PEL	Probable Effects Level
PG & E	Pacific Gas and Electric Company
RWQCB	California Regional Water Quality Control Board, Central Coast Region
SFRWQCB	San Francisco Regional Water Quality Control Board
SQAGs	Sediment Quality Assessment Guidelines
SWOO	San Francisco's Southwest Ocean Outfall
SWRCB	California State Water Resources Control Board
TEL	Threshold Effects Level
TSS	Total Suspended Solids
ug	microgram
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WQPP	Water Quality Protection Program
ZID	Zone of Initial Dilution
Zn	Zinc

CHAPTER I

Introduction

Background

The need for resource protection and conservation, versus increased human development activity has led to many conflicting uses in coastal areas. The quality of coastal and marine waters may be degraded at various point sources (e.g., industrial, municipal, and vessel discharges), nonpoint sources (e.g., agricultural runoff, and urban runoff), and through water resource management (e.g., dams, diversions of water, overdrafting, and revetments) (NOAA 1994c).

This thesis focuses on an evaluation of the results from monitoring programs for trace metals and benthic infauna in the vicinity of major municipal discharges to Monterey Bay, California (CA). Geographic Information Systems (GIS) were used to determine the spatial distribution of trace metals. Comparisons of these data were used to make recommendations on regional monitoring.

The Monterey Bay study area is an integral part of the approximately 4,024 square nautical miles of estuarine, coastal, and ocean waters designated on September 18, 1992, as the Monterey Bay National Marine Sanctuary (MBNMS) (Figure 1). One of the highest priorities for management of the Sanctuary includes enhanced resource protection

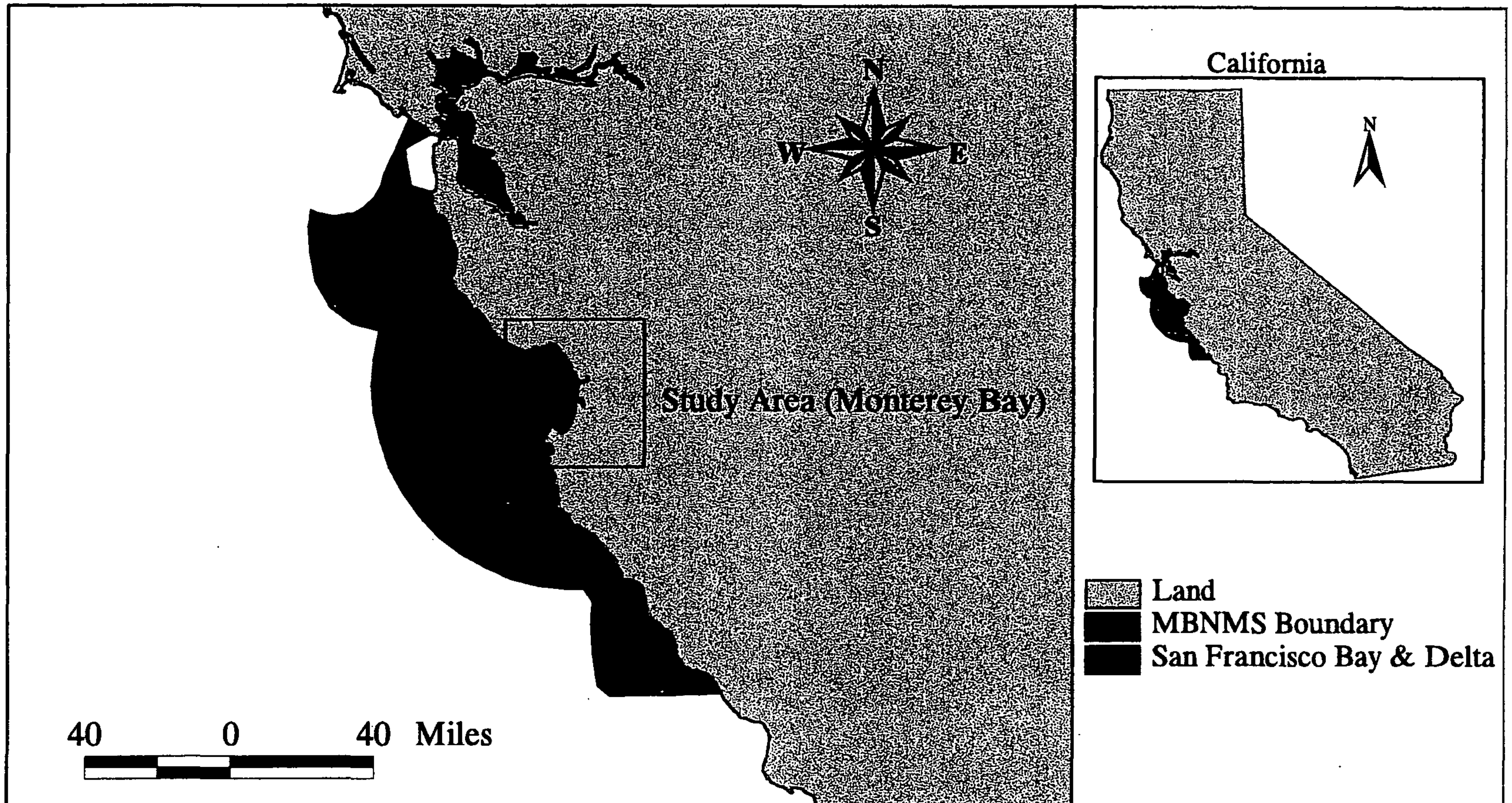

Figure 1: Monterey Bay National Marine Sanctuary, Monterey Bay, CA

Sources: Adapted from data sources: Hydrography (DLG data), U.S. Geological Survey (USGS 1993); Sanctuary Boundary, U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA 1992).

and conservation of the coastal and marine environment.

Among the significant threats to the water quality are the effluent from more than 50 permitted point source discharges in the drainage basins and coastal marine waters of the Sanctuary (Cotter 1997). Based on the maximum average daily flow, these point source discharges total more than 550 billion gallons of wastewater per year into the Sanctuary's waters. The larger municipal facilities alone discharge between 5 and 6 billion gallons of effluent per year (NOAA 1994c). Also the high population growth in the Monterey and Santa Cruz Counties, estimated at 2.4 percent per year, will put additional pressure on water allocation and existing wastewater treatment facilities (NOAA 1992).

Municipal and industrial effluents discharged into the Monterey Bay consist of pollutants such as heavy metals, oil and grease, and organic chemicals. Total suspended solids (TSS), biochemical oxygen demand (BOD), and fecal coliform bacteria are some of the major pollutant indicators measured in these discharges. These pollutants pose potential threats to the water quality and the benthic habitats of the Bay (NOAA 1994c).

Objectives

The primary objective of this thesis was to determine the spatial distribution of sediment trace metal concentrations and their relationship to benthic infauna in the vicinity of sewage and industrial discharges to Monterey Bay. To achieve this goal, the study was originally designed to develop a comprehensive regional database by integrating data from the five major sewage and industrial discharges released into Monterey Bay. These sewage and industrial discharges include:

1. Municipal wastewater effluent from the City of Santa Cruz
2. Municipal wastewater effluent from the City of Watsonville
3. Industrial cooling water discharge from Pacific Gas & Electric Company's power plant in Moss Landing
4. Industrial wastewater discharge from National Refractories and Minerals Corporation
5. Wastewater effluent discharges from Monterey Regional Water Pollution Control Agency's (MRWPCA) wastewater treatment plant north of Marina, CA

However, this study was unable to integrate monitoring data from the Pacific Gas & Electric Company (PG & E) and National Refractories and Minerals Corporation industrial discharges. PG & E has been exempt from monitoring its discharge to Monterey Bay since 1987 (Genz 1997). Before 1987, the monitoring protocol included bioaccumulation of heavy metals in fish or macro-invertebrate tissue (Seltenrich and White 1987). Bioaccumulation of pollutants in marine biota was not studied in this research project. National Refractories monitors only the receiving water quality and does not include the data on sediment quality and benthic parameters covered in this research project. Therefore, only three municipal wastewater monitoring programs were examined: the City of Santa Cruz, the City of Watsonville, and MRWPCA outfalls.

Additional data on sediment trace metal concentrations in Monterey Bay were integrated with the monitoring data from municipal sources to fill the gaps in data. These data included 20 additional sediment sampling sites in Monterey Bay designated under the 1995 Fort Ord study. The Fort Ord study was commissioned by the U.S. Army Corps of

Engineers to investigate possible contamination of sediments near the area offshore of Fort Ord. One of the primary objectives of the Fort Ord study was to determine the distribution of sediment contaminants in Monterey Bay (Stephenson et al. 1997).

This thesis project was specifically designed to identify trace metals of concern in the surface sediments of Monterey Bay and determine their spatial distribution. GIS were used for geo-referencing monitoring data on sediment quality and soft-bottom benthic biota at sampling stations surrounding the outfalls.

Trace metals examined include: arsenic (As); cadmium (Cd); total chromium (Cr); copper (Cu); lead (Pb); mercury (Hg); nickel (Ni); silver (Ag); and zinc (Zn). These metal concentrations were evaluated using the informal screening guidelines prepared by MacDonald (1994). The sediment data were categorized into low-metal concentration sites and high-metal concentration sites based on threshold effects level (TEL) and probable effects level (PEL) values for the metals of concern. The range of concentrations that could potentially be associated with adverse biological effects, is delineated by the TEL (lower limit) and PEL (upper limit) (MacDonald 1994). Monitoring data were analyzed statistically and spatially to help identify metals of concern, and the areas of potential adverse biological effects in Monterey Bay.

This study also examined the relationship of increasing trace metal concentrations to soft-bottom benthic infauna in the vicinity of the municipal outfalls to Monterey Bay. The benthic infauna parameters examined included average total abundance and average number of species. A t-test applied to the means of two independent samples was used to find a statistically significant difference in the means of the benthic parameters at low-metal concentration sites and high-metal concentration sites.

The monitoring program for each of the municipal discharges includes a reference station (farfield site) and several nearfield monitoring sites. The existing monitoring programs evaluated the impact on benthic community parameters by comparing the data collected at the reference station and the nearfield sampling stations. This study was designed to use one-way analysis of variance (ANOVA) to determine whether the average total abundance and number of infauna species differed among the stations. Statistically significant differences were evaluated to explain spatial patterns. *A priori* comparisons were applied to examine the differences in benthic infauna between the reference stations and the nearfield sampling stations around each of the three municipal outfalls.

Recommendations for the development of a comprehensive regional monitoring database were based on the conclusions from the above evaluation processes. This regional monitoring database was intended to enhance the existing management of marine monitoring programs by improving coordination, data sharing, data interpretation, and sampling strategies.

Limitations

This study focuses only on treated wastewater discharges into Monterey Bay. Therefore, this study does not account for other point and nonpoint sources of pollution affecting the coastal and marine environment of Monterey Bay. To have a complete understanding of the pollution problems and create options to resolve resource use conflicts, considering all sources of pollution is essential. These data can be added by interested agencies to regional GIS through networking and statistical modeling capabilities of an ARC/INFO software.

Scope of the Project

This thesis research project is based on improving wastewater management strategies through an integrated coastal management (ICM) approach. "ICM is an ecologically based, iterative process for identifying and implementing, at a regional scale, environmental objectives and cost-effective strategies for achieving them" (NRC 1993, 14). Although point sources can significantly contribute to coastal and marine pollution, little is known about the long-term regional impacts of municipal discharges on Monterey Bay's marine environment. GIS was used to develop a regional multifunctional spatial decision-support system by integration of long-term monitoring data on sediment quality and benthic infauna from three major municipal discharges into Monterey Bay. This contributes towards developing a regional monitoring program for the management and evaluation of point source pollution in the Monterey Bay region. Also, this will allow the development of regional strategies for enhancing the existing site-specific monitoring programs. Thus, this project will demonstrate the effectiveness of GIS as a tool for assisting in integrated coastal resource management, given the ability to incorporate a wide range of textual and spatial data, graphical displays, map overlays, and spatial statistics.

This thesis study will also help in determining relationships between increasing sediment trace metal concentrations and the effects on benthic infauna in Monterey Bay.

The spatial and temporal analysis of contamination and its effects on the biological communities will support a better understanding of the existing conditions in the Bay and the effects of municipal discharges on Monterey Bay's marine environments.

This research is unique because it is based on an integrative approach to water quality protection with regards to management and monitoring of point source discharges in Monterey Bay. The managers of various Federal, State, and local environmental programs for point source discharges that will likely benefit directly from this research include:

- Federal Agencies
    - Monterey Bay National Marine Sanctuary (MBNMS)
    - EPA, Region IX
- State Agencies
    - California Environmental Protection Agency (Cal EPA)
    - California Regional Water Quality Control Board (RWQCB)
    - California Coastal Commission (CCC)
    - California Department of Fish and Game (CDFG)
- Local Agencies
    - Association of Monterey Bay Area Governments (AMBAG)
    - Monterey County
        - Monterey Regional Water Pollution Control Board
    - Santa Cruz County
        - City of Santa Cruz

- City of Scotts Valley
- City of Watsonville

- Universities
  - San Jose State University (SJSU)
  - University of California Santa Cruz (UCSC)
  - Moss Landing Marine Laboratories (MLML)
  - California State University Monterey Bay (CSUMB)
  - Hopkins Marine Station (Stanford University)

Research conducted under this project will make GIS data layers available to the regulators, dischargers, scientists, and managers of Federal, State, and local agencies. This study will be a step towards enhancing management, planning, and policy decision making with regard to municipal discharges into Monterey Bay. Recommendations on the development of a regional monitoring database will help improve communication and coordination among various agencies involved in the monitoring and control of point sources of pollution to Monterey Bay. The research results will assist in analyzing the effectiveness of the current monitoring station locations around the three discharges into Monterey Bay, and the possible revision of sampling sites based on a regional perspective. This research project may be used as a model for developing spatial and temporal trends on a regional scale for marine environmental monitoring of point source pollution. Therefore, it will serve as a model for marine sanctuaries as they protect and conserve environmental quality despite the degradation caused by human activity.

Regulatory Background

Facilities that discharge to the waters of United States are required to obtain a National Pollutant Discharge Elimination System (NPDES) permit under section 402 of the Clean Water Act (CWA). Issuance of NPDES permits has been delegated to the California State Water Resource Control Board (SWRCB) and California Regional Water Quality Control Boards. These permits are generally issued for municipal wastewater treatment plants, power and industrial plants, and for other point source discharges (NOAA 1992).

All discharges into the MBNMS are subject to regulation under Title III of the Marine Protection, Research, and Sanctuaries Act (MPRSA) of 1972, Section 301 (b)(5), as amended, 16 U.S.C., Section 1431 (b)(5), to protect the Sanctuary's resources from discharges within the Sanctuary boundary [15 CFR, Section 922.49 (a-h)] as well as discharges outside the Sanctuary boundary that enter the Sanctuary and injure resources and qualities [15 CFR, Section 922.132 (2) (ii)] (NOAA 1992; U.S. Dept. of Commerce 1995).

The National Oceanic and Atmospheric Administration's Office of Ocean and Coastal Resources Management (NOAA/OCRM) is the primary agency responsible for the implementation of the Management Plan for the Sanctuary. As a part of the Management Plan for the Sanctuary, NOAA has entered a Memorandum of Agreement (MOA) to develop an ecosystem-based process and Water Quality Protection Program (WQPP) for the Sanctuary with the following Federal, State, and local agencies:

- National Oceanic and Atmospheric Administration (NOAA)
- Environmental Protection Agency, Region IX (USEPA)
- California Environmental Protection Agency (Cal EPA)
- State Water Resources Control Board (SWRCB)
- San Francisco Regional Water Quality Control Board (SFRWQCB)
- Central Coast Regional Water Quality Control Board (RWQCB)
- California Coastal Commission (CCC)
- Association of Monterey Bay Area Governments (AMBAG)

The Sanctuary has the authority to review and comment on NPDES permits under 15 CFR Section 922.134 (a). Under 15 CFR Section 922.134 (b), the MOA defines the existing NPDES permit certification process for the Sanctuary and the review process for new and revised (including renewal) permits. The MOA applies to permit administration within the State waters within the Sanctuary and the coordination process with the State permit program. The MOA also defines conflict resolution procedures if agreement on a permit cannot be reached (U.S. Dept. of Commerce 1995).

The MOA also addresses the integration and coordination of research, monitoring programs, and the development of a comprehensive WQPP for the Sanctuary. The WQPP is designed to recommend priority corrective actions and compliance schedules addressing point and nonpoint sources of pollution. The purpose of the program is to restore and maintain the chemical, physical, and biological integrity of the Sanctuary, including restoration and maintenance of its resources, qualities, and compatible uses (NOAA 1994b).

The Monterey Bay National Marine Sanctuary's Water Quality Protection Program held a workshop, "Issue Identification and Strategy Development," on January 25-27, 1994, in Monterey, California. The workshop was designed to: 1) identify and prioritize water quality problems, 2) identify sources and pollution associated with the problems, and 3) develop strategies to address those problems and enhance management of the natural resources of the Sanctuary (NOAA 1994c).

Participants at the workshop divided the Sanctuary into 11 watershed areas and 3 ocean segments based on the U.S. Geological Survey's (USGS) hydrological units and the California State Water Resources Control Board hydrologic maps. The most significant problems to marine and terrestrial environments of the watershed areas and ocean segments were identified. Eight problems were categorized as *biotic effects*, and 6 problems were categorized as *hydro-physical effects*. Biotic effects include problems where living organisms are the means of identifying the symptoms, such as coastal wetland alteration, fish population decline, habitat degradation, reproductive impairment, rare and endangered species impairment, impairment of sensitive biological areas, elevated tissue levels, and human health. Hydro-physical effects cover problems encountered primarily in the physical environment or water column. Priority problems of watershed areas and ocean segments include sedimentation, adverse levels of toxic pollutants, watershed disturbance, groundwater quality, low flows, and erosion (NOAA 1994c).

The Ocean Segment 2, which includes the Monterey Bay drainage basin, has between 9 and 10 priority problems, the highest number of any segment. The priority problems linked to the discharges of municipal wastewater include:

- Biotic effects: fish population decline, habitat degradation, rare and endangered species impairment, elevated tissue levels, and human health risks.
- Hydro-physical effects: sedimentation, and adverse levels of toxic pollutants.

The disposal of municipal wastewater was also linked with high to moderate levels of nutrients, oil and grease, heavy metals, and pathogens for all three ocean segments (NOAA 1994c).

Marine Environmental Monitoring

Marine monitoring programs produce information about three broad categories of problems:

> (1) compliance, to ensure that activities are carried out in accordance with regulation and permit requirements; (2) model verification, to check the validity of assumptions and predictions used as the basis for sampling design or permitting and evaluation of management alternatives; and (3) trend monitoring, to identify and quantify longer-term environmental changes anticipated (hypothesized) as possible consequences of human activities (NRC 1990, 8).

This research project focused mainly on the trend monitoring that is often conducted to assess conditions in the marine environment, detect changes in its environmental conditions, and warn against harmful effects of specific activities, such as wastewater discharges (NRC 1990).

The major goal of marine monitoring is protection of the environment, living resources, and human health. More than $133 million is spent annually on marine monitoring programs by Federal, State, and local agencies; public utilities; and private corporations (NRC 1990). This figure is modest (3 percent or less) as compared to the amount spent on water pollution abatement of point sources, estimated at $20.6 billion for the year 1985 (NRC 1990). Despite these considerable efforts and expenditures, the existing environmental monitoring programs fail to provide information needed to assess the overall health or the impact of human activities on the regional marine ecosystems (NRC 1990).

One of the major limitations of some current monitoring programs is the inability to develop spatial and temporal trend monitoring at a regional scale. In existing site-specific monitoring programs, NPDES permits are based on compliance monitoring. The permits are not coordinated with nearby discharges essential for measuring effects on larger spatial scales. Therefore, these programs are unable to provide adequate information on the overall health of the regional ecosystem, or public health and welfare. Also, site-specific programs often do not provide enough information to make effective environmental management decisions, resolve controversies related to specific waste discharges, or determine the effects of multiple impacts (NRC 1990).

The lack of communication and coordination among the various entities sponsoring or conducting monitoring and making environmental management decisions limits the usefulness of monitoring results. Also, monitoring data need to be converted into information that is useful, synthesized, and relevant to decision makers so they can directly address public concerns. Data interpretation, including spatial patterns and trend analysis of data such as contaminant concentration is essential for making more effective management decisions. These decisions include the protection or rehabilitation of the marine environment, its living resources, and other beneficial uses (NRC 1990).

Recent efforts to improve marine environmental monitoring have focused on developing regional and national monitoring programs. Development of a nationwide marine pollution research and monitoring program is being conducted under NOAA's National Status and Trends Program (NS&T) and U.S. EPA's National Estuary Program (NRC 1990). Regional monitoring programs may be developed by reallocation of compliance monitoring resources of the existing site-specific monitoring programs. The regional monitoring programs can then support and develop an effective national system of long-term regional monitoring. This research project will be a step towards developing a regional monitoring program by integrating monitoring data from three major point source discharges in the Monterey Bay region. This will allow the development of regional strategies for enhancing the existing site-specific monitoring programs.

Human Influence on Coastal Resources

Coastal regions are dynamic interface zones where atmosphere, land, and sea meet to form some of the world's most productive and diverse ecosystems. These areas provide a unique habitat for thousands of plant and animals species. Also, the abundance of natural resources, recreational aspects, and aesthetic and scenic elements make the coastal zone extremely attractive to urban development. The coastal areas of the world, including the United States, are facing increasing population growth rates. In the United States, nearly half of the country's population lives within 50 miles of a coastline (Beatley, Brower, and Schwab 1994). Population in coastal regions of the United States has nearly doubled from approximately 60 million in 1940 to almost 120 million in 1980. It is projected that the population will grow to about 127 million people by the year 2010 (Beatley, Brower, and Schwab 1994). Increasing human activities near high population growth areas exerts mounting pressures on natural resources, leading to detrimental impacts on the coastal environment. Human-induced disturbances have caused loss of habitat, interception of water and sediment, invasion of exotic species, increased pollution, and nutrient loading of the near-shore waters (Viles and Spencer 1995).

Increasing incidences of closed bathing beaches, restricted shellfishing beds, garbage washing up on shorelines, contaminated waters and sediments, oil spills, declining marine environmental quality, and ailing fisheries have been frequently reported from the Atlantic, Gulf of Mexico, and Pacific coasts of the United States (NRC 1990). Some of the major factors causing these perturbations in the coastal areas include municipal wastewater and stormwater discharges, combined sewer overflows, and direct industrial wastewater discharges (NRC 1993).

Among the major threats to the environment are the disposal of municipal and industrial wastewater to the coastal waters. Since the 1970's when the CWA was passed, efforts to minimize human impacts on the coastal ecosystem have focused on the control of point sources of pollution. Municipal discharges consist of pathogens, heavy metals, nutrients (nitrates and phosphates), synthetic organic compounds such as polychlorinated biphenyls (PCBs), pesticides such as dichlorodiphenyltrichloroethane (DDT), hexachlorocyclohexane (HCH), and particulate material which have significant impacts on human and marine life (Gay et al. 1991).

In the United States, at least 37 percent of the population resides in urban coastal areas. These coastal populations are serviced by more than 1,400 municipal wastewater treatment plants that discharge 10 billion gallons of treated effluent per day (NRC 1993). In addition to the municipal discharges, there are approximately 1,300 industrial facilities that are permitted to discharge about 11.3 billion gallons per day of treated industrial wastewater and spent cooling water to marine waters (NRC 1993).

The disposal of treated wastewater can lead to accumulation of heavy metals in bottom sediments near the outfalls. Depending on the chemical form and in high concentrations, heavy metals can be toxic to various marine organisms. Some metals can be extremely persistent and tend to bioaccumulate in organisms at lower trophic levels, such as benthic macrofauna. These organisms have the potential for transferring contaminants up the food chain to human consumers. Previous studies indicate that the high concentration of contaminants may affect the abundance of benthic communities. Also, the more tolerant species that become abundant near outfalls are common prey for fish and invertebrates consumed by humans (Steimle et al. 1994).

CHAPTER II

RELATED RESEARCH

Impacts of Waste Disposal on The Marine Environment

Coastal and marine environments face increasing conflicts between the need for environmental protection and conservation versus the impacts of growing pressures of human activities (Myers 1983; Ricketts, Mclver, and Butler 1989; Hilderbrand and Norrena 1992). The oceans have served as an *infinite sink* for receiving human-related waste discharges that would then be broken down by natural processes (Myers 1983). Recent evidence of adverse impacts of such activities on the marine ecosystems indicates that the capacity of the oceans to assimilate waste can no longer be considered infinite (Karau 1992). The impact of waste disposal on the coastal environment became apparent during the late 1960s, reached a high point in the 1970s, and has remained controversial since. There is also general agreement that land-based sources of marine pollution are inadequately addressed and the degradation of the marine environment will continue without coordinated action (Karau 1992).

The introduction of pollutants to coastal waters, from point and nonpoint sources, has posed problems for both humans and marine organisms. Numerous studies have been prompted by the growing concern over the potential impacts of municipal and industrial discharges on marine ecosystems, their long-term effectiveness and acceptability as marine treatment systems, and the risks to public health. Increasing evidence indicates that synergistic effects may exist between components of effluents from different ocean outfalls, and the cumulative effects of different components may be greater than the effects of the individual compounds in isolation.

Treated wastewater discharges consist of pathogens, trace chemicals of concern, organic enrichment and biochemical oxygen demand (BOD), and particulate material, which can have significant impacts on both marine organisms and human health. Major biotic communities such as demersal fish, benthic invertebrates, and attached algae are known to have undergone changes near municipal outfalls in the ocean (Cabelli, Levin, and Dufor 1983; Gay et al. 1991; Galasso 1993; Steimle et al. 1994; Scanes and Philip 1995; Otway 1995; Kellogg, Riege, and Navarret 1997; Clark and Taberski 1997; Robertson, Maurer and Haydock 1997; Fairy, Jacobi, and Roberts 1997).

Many heavy metals metal, such as As, Cd, Cu, Pb, Hg, Ni, Ag, and Zn, occur naturally at low concentrations in sea water and marine sediments. Anthropogenic sources may lead to high concentrations of these metals that can be toxic. Most metals absorb onto organic particulate material, leading to high concentrations in the organically rich sediment around the discharge sites. Heavy metals can also bioaccumulate in benthic macrofauna with the potential of transferring contaminants up the food chain to human consumers. Biomagnification of these contaminants can affect the health of resource species by causing behavioral changes and reduced egg viability (U.S. Congress OTA 1987;

Steimle et al. 1994). By the 1970s, severe pollution resulted from overloading of organic and inorganic substances, including metals such as mercury and lead, became apparent (Myers 1983). The case of mercury poisoning in Minimata Bay, Japan, is an example. It was not until 1953 that the first case of neurological disease was reported, approximately 15 years after the introduction of industrial wastewater, containing mercury to Minimata Bay. In 1959, mercury was finally associated with increasing neurological disorders, and it was not until 1963 that methyl-mercury chloride was identified as the specific active compound. Finally, in the early 1970s, Sweden, United States, and some other countries, made use of this instance and adopted upper allowable levels for mercury in edible fish (Myers 1983).

Municipal discharges consist of a range of particulates from coarse litter that escaped any screening process to fine suspended solids that are collectively referred to as TSS. Most of the larger sized particles are removed during the treatment process. The finer particles remaining in wastewater effluents may be associated with toxic organic chemicals, metals, and pathogens (NRC 1993). The introduction of low salinity effluents with high TSS mass loading leads to flocculation, precipitation, and sedimentation. This material is deposited on the seabed usually within 50 meters of the outfall, where physical smothering of the sediments may occur, reducing the penetration of oxygenated seawater into the sediment. This depletion of oxygen combined with high biochemical oxygen demand (BOD) can cause abnormal anoxic conditions in the sediment. For example, in July 1976 oxygen depletion (anoxia) in water of the middle Atlantic Bight (offshore

New Jersey) was attributed to both anthropogenic and natural stresses. This condition lasted for months and was characterized by low (less than 1 part per million) to zero dissolved oxygen that extended approximately over an ocean depth of about 150 to 60 km beneath the thermocline. This incident severely impacted the biological resources of the region (Myers 1983).

Solids that remain suspended in the water column, or are re-suspended, cause other harmful effects, such as clogging tentacles, fine filters, and gills of suspension feeders. This may also lead to the localized extinction of these suspension feeders within a few hundred meters from the point of discharge, depending on the dispersion achieved and pollutant loading. Further, an increase in the turbidity may cause reduction of light, affecting the rate of photosynthesis by macroalgae and phytoplankton. Larger solids, such as plastics if ingested by birds, can accumulate in the proventriculus and gizzards, impairing digestive efficiency, and may have acute and lethal effects (Gay et al. 1991).

Due to their relative lack of mobility and their trophic level, benthic communities are often used as biotic indicators of the existing conditions and quality of marine ecosystems. Benthic organisms are closely connected with the pelagic food web, forming a link for the transport of pollutants to higher trophic levels, such as fish and humans. These organisms can be used as indicators on various levels of biological organization, ranging from population distribution changes to genetic and physiological responses of individual to large-scale changes in ecosystems (Smith, Bernstein, and Cimberg 1988).

Many studies have established that waste disposal has resulted in the contamination of sediments by toxic chemicals and some alterations to the abundance, biomass and diversity of benthic communities (Luoma and Cloren 1982; Steimle 1985; U.S. Congress OTA 1987; Gay et al. 1991; Steimle et al. 1994; Robertson, Maurer, and Haydock 1997; Kellogg, Riege, and Navarret 1997; Fairy, Jacobi, and Roberts 1997).

Long-term studies are required to make an effective judgment of the temporal and spatial changes in the structure and composition that occur in response to changes in pollution from sewage and industrial discharges. Such long-term analysis can then eliminate any short-term pollution estimates that may be related to natural phenomena, rather than changes in effluent concentrations (Swartz et al. 1986; Ferraro et al. 1991). Long-term monitoring data has been analyzed to examine the temporal and spatial patterns in the benthos along a pollution gradient of known point sources. The important findings of these studies indicate:

1. Accumulation of particulate material in sediment significantly increases the concentration of chemical contaminants and organic matter in the vicinity of the outfalls.
2. The nutrient and metal loadings can alter the benthic community structures and composition considerably.
3. More opportunistic polychaetes, such as *Capitella* spp., are dominant at sites closer to the outfalls.
4. A related increase in biomass and abundance of more tolerant species is observed closer to the outfalls.
5. With increasing distance from the discharge point, there is a decline in the tolerant

species and an increase in the number of species, until normal levels are resumed (Orlob, ASCE, and O'Leary 1977; Moore 1978; Pearson and Rosenberg 1978; Swartz et al. 1986; Weston 1990; Ferraro et al. 1991; Zmarzly et al. 1994; Robertson, Maurer, and Haydock 1997; Kellogg, Riege and Navarret 1997; Fairy, Jacobi, and Roberts 1997).

Related Studies

Regional studies on the impacts of municipal discharges to Monterey Bay have not been conducted, although they have been for the San Francisco Bay, Southern California Bight, and the San Diego Bay in California. Under the San Francisco Ocean Monitoring Program, receiving water quality data has been collected from 1982 to present, spanning periods of pre-discharge of primary treated effluent and discharge of secondary treated effluent. This long-term monitoring data was analyzed using the before-after-control-impact (BACI) analysis technique to examine the shift in the benthic infauna community due to the impacts of discharges from the City and County of San Francisco's Southwest Ocean Outfall (SWOO). The BACI revealed a shift in the biota at the impact stations, but not at the reference station, during the period of primary effluent discharge. Since the initiation of secondary effluent discharge, the community structure shifted back to resemble the reference station again. Also, SWOO data was analyzed spatially to evaluate the field sampling design with respect to the information it provides to the management decision making process. The sampling design was found to be inadequate to answer a number of management questions relative to effluent discharge. A new sampling design proposed adding more stations, reducing sampling frequency to once per year, and reducing the number of station replicates. The new design allowed evaluation and modification as necessary. In addition, the proposed design was more regional in nature providing valuable information to the managers of the Gulf of Farallones National Marine Sanctuary, Cordell Bank, and MBNMS, as well as complementing studies inside the San Francisco Bay (Kellogg, Riege, and Navarret 1997).

In a study by the County Sanitation Districts of Orange County, California, selected data from a 10 year (1987 to 1996) ocean monitoring program were analyzed to study the impact of the treated wastewater discharges on the San Pedro Shelf, California (Robertson, Maurer, and Haydock 1997). Spatial and temporal trends of sediment contaminant concentrations and benthic infauna revealed decreasing effects of discharge over time and a declining magnitude of the observed changes. The contaminant-biological relationships were only weakly associated and were considered to be mainly coincidental (Robertson, Maurer, and Haydock 1997).

Another regional study was conducted to examine the chemistry, toxicity, and benthic community conditions in the sediment of bays and estuaries in the San Diego Bay region, California. San Diego Bay region has a long history of pollution from sewage and industrial discharges. The major objectives of this study were to determine the occurrence of spatial patterns and the spatial extent of toxicity in sediment and the relationship between chemical concentrations and biological communities in the San Diego Bay Region. Benthic analyses were performed at 75 stations to identify degraded habitats based on a benthic index of community parameters (e.g., diversity/evenness indices, abundance, indicator species). According to the benthic index 23 undegraded, 43 degraded, and 9 transitional communities were identified. All of the stations with elevated chemical summary quotients were found to have degraded benthic communities (Fairy, Jacobi, and Roberts 1997; SWRCB 1996).

In a regional effort towards the protection of California's bays and estuaries, the California Water Code established the Bay Protection and Toxic Cleanup Program (BPTCP). The BPTCP has four major goals:

(1) Protect beneficial uses of bays and estuaries;
(2) Identify and characterize toxic hot spots;
(3) Plan for the prevention and control of further pollution at toxic hot spots; and
(4) Develop plans for remedial action at existing toxic hot spots and prevent the creation of new hot spots (SWRCB 1997b, 1)

The SWRCB, NOAA, and EPA through the BPTCP conducted a cooperative research project to assess sediment contamination in selected bays and estuaries of California (Anderson et al. 1997). Measures of chemical contamination, toxicity, and benthic community were completed at 43 stations to determine relative degradation in selected Southern California bays, estuaries, and lagoons. The measurements were taken using a weight-of-evidence approach based on the Sediment Quality Triad (Long et al. 1995). Sediment quality guidelines developed by NOAA (Long et al. 1995) and the State of Florida (MacDonald 1994) were used to assess the degree of chemical contamination. Relative to these guidelines, DDT, chlordane, copper, mercury, and zinc were identified to be the chemicals or chemical groups of concern in Southern California. Sea urchin development was used as an indicator of toxicity. The results of sea urchin bioassays indicated 91%, 83%, and 51% of the randomly-sampled study area was found to be significantly toxic in 100%, 50%, and 25% concentrations of sediment interstitial water, respectively. The toxicity test results were found to have weak negative associations with some chemical compounds measured in solid phase samples. Benthic community structure was assessed based on a benthic index, calculated from measures of the total number of fauna, number of crustacean species, and number of positive and negative indicator species. The use of the index showed 15 of the 43 stations sampled (35%) to be significantly degraded, 10 of the 15 degraded stations were located in 4 of the coastal lagoons sampled. Benthic community degradation was weakly associated with measured solid phase chemicals (Anderson et al. 1997).

Regional Monitoring: An Integrated Coastal Management Approach

Degradation of the coastal and marine environments continues despite significant efforts being made to improve the nation's water quality in the past 20 years. Environmental management efforts have led to the establishment of numerous marine environmental monitoring programs. Although more than $133 million is spent annually on marine monitoring programs, most of these programs fail to provide the information needed to understand the status of the marine environment or to assess the effects of human activity on it (NRC 1990). The difficulty of providing useful information from monitoring programs can be attributed to poor design and inappropriate application of technology; inadequate resources (personnel and funds); and inability of converting data into useful information to develop broad public policy or to evaluate specific control strategies (NRC 1990).

The Marine Board of the National Research Council established a Systems Assessment of Marine Monitoring Committee to evaluate and make recommendations to improve the usefulness of monitoring programs. The committee reviewed current monitoring systems and technology, assessed marine monitoring as a component of sound environmental management, and identified required improvements in monitoring strategies and practices. Case studies were conducted on marine environmental monitoring of the Chesapeake Bay, monitoring of the Southern California Bight, and disposal of particulate wastes in the ocean. These case studies used the conceptual model for the design and implementation of monitoring programs and the role of monitoring in the marine environmental management, developed by the committee. The study concluded that marine monitoring can be made more effective by:

1. Strengthening the role of monitoring in marine environmental management;
2. Conducting more monitoring over regional and national scales; and
3. Improving monitoring program design and making information products more useful (NRC 1990, 90).

The NRC (1990) report concluded that comprehensive monitoring of regional and national trends was needed to assess the extent of pollution problems better and to address broader public concerns. A cooperative regional monitoring program is a critical component to coastal zone management. Regional monitoring allows for the development of better ways to address public health concerns, monitor the status of marine resources and nearshore habitats, and to assess the impacts of a variety of contaminant sources (Haydock et al. 1997).

Concern over the relative lack of progress in improving the quality of estuarine and coastal waters, the Water Science and Technology Board (WSTB) of the National Research Council formed a committee on Wastewater Management for Urban Coastal Areas (NRC 1993). This committee was appointed to examine issues relevant to wastewater management in urban coastal areas. Financial support was provided by U.S. EPA, the National Science Foundation, NOAA, the City of San Diego, the Freeman Fund of the Boston Society of Civil Engineers, and the National Academy of Engineering.

The committee proposed a framework called Integrated Coastal Management (ICM) for managing coastal resources, towards which coastal environmental quality management should evolve. The WSBT subcommittee recognized the concept of ICM as a starting point for achieving sustainable coastal development. The NRC (1993) stated that ICM has two general objectives:

1) To restore and maintain the ecological integrity of coastal ecosystems, and
2) To maintain important human values and uses associated with those resources (NRC 1993, 14).

Comprehensive monitoring programs focusing on processes or control measures and significant ecological, human health, and resource uses were recognized as essential to the ICM process. The NRC (1993) study acknowledges:

> ICM can only be accomplished if monitoring and other data for environmental systems are managed in a way that allows managers and other interested parties to appreciate and make decisions about the whole (NRC 1993, 85).

The study claimed that the success of a continuing iterative ICM program lies in strengthening the linkage between the planning process and research, monitoring, and data management activities (NRC 1993).

Following the release of the National Research Council's Report titled: *Managing Troubled Waters: The Role of Marine Environmental Monitoring*, the U. S. EPA began to implement a regional and national program called the Environmental Monitoring and Assessment Program (EMAP). EMAP is designed to provide a framework and a set of uniform data and quality objectives for regional programs. However, a need still exists for region-specific monitoring in many areas to examine identified issues, close data gaps found in the planning process, and monitor the performance of selected risk management strategies. In addition to recent work of the U.S. EPA, NOAA's National Status and Trends Program (NS&T) has produced national monitoring data since 1984. This significant marine monitoring program monitors for selected metal and organic compounds in sediment and benthic organisms at nearly 300 coastal locations in the United States. The primary objective of NS&T is to assess long-term trends in the concentrations of these toxic materials (NRC 1993).

Role of GIS in Regional Marine Monitoring

There are many different and sometimes conflicting uses of coastal and marine environments, such as fishing, aquaculture, waste disposal, recreation and tourism, habitation, transportation, hydrocarbon production and mining. A comprehensive knowledge of these diverse resources and their uses is essential. This information can then be used by decision-makers, scientists, and other information users to understand the functioning of marine ecosystems better. Unfortunately, such comprehensive information is seldom easily accessible to decision-makers and resource managers. Also, most often the bulk of the data collected under various Federal, State, or local government departments is designed to meet very specific purposes for particular agencies or organizations. Further, the data gathered is available in different formats varying in range from hard-copy to a range of electronic, satellite imagery, aerial photography, seismic profiles, and digital formats. Gaining access to easily understandable information is often difficult as data management, quality control, information storage, data presentation and distribution techniques vary from program to program (Ricketts, McIver, and Butler 1989; NOAA 1996).

A purely sectoral approach to the management of coastal and marine resources is inadequate to resolve growing conflicts among resource use and environmental degradation. These conflicts coupled with coastal development based on narrowly focused conservation and protection strategies indicate the need for a more integrated and well coordinated approach. A holistic ecosystem approach to monitoring and management must consider the environmental, natural resource, socio-economic, political, cultural, and geographic dimensions of the coastal and marine multi-sectoral framework (Hilderbrand and Norrena 1992).

A regional study boundary for strategic assessment and a planning framework for monitoring and resource management of marine environments must include:

1. Ecological boundaries using, for example, the ecological land or coastal classification system;
2. Temporal and spatial limits of primary and secondary resource development initiatives;
3. Administrative boundaries;
4. Political boundaries (Kelly et al. 1987, 224).

GIS has the potential for developing such a regional coastal management strategy, given that the bulk of coastal resource data is spatial in nature and that large amounts of data are now being collected in digital format. The advantages of using GIS in coastal and ocean management include:

1. Providing a repository for scattered data from diverse sources,
2. Improving the visualization of such data for land-use management,
3. Improving understanding of interactions between uses and relationships between ocean and land processes in coastal areas, and
4. Supporting statistical, modeling, and impact analysis,
5. Makes better use of remote-sensing data (Ricketts 1992, 82).

Managing pollutant discharges, monitoring receiving waters, and assessing long-term impacts of contaminants on the marine environment is a complex resource management problem. To deal with such complexities, a multidisciplinary approach on a regional level is required. GIS can be an effective tool for developing marine resource management strategies, given its capabilities for analytical modeling and manipulating large quantities of spatial-temporal data according to a defined set of objectives or constraints (Ji et al. 1993).

The necessity for such strategic assessments has led to the development of a number of regional GISs, encompassing large data sets covering bio-physical and socio-economic data for specifically defined areas or regions. Regional GISs have been developed around the globe to address a wide variety of coastal management issues, including integrated resource management, habitat conservation and preservation, coastal sensitivity mapping for oil spill contingency planning and response programs, ecological risk assessment, and the impact of agriculture and urban non-point source pollution on water quality. Some applications of regional GISs developed for coastal resource management include the United Kingdom Digital Atlas Project (UKDMAP) for the water around the British Isles, the REGIS system for the Great Barrier Reef in Australia, and the FMG (Fundy/Maine/Georges) InfoATLAS for the Gulf of Maine (Ricketts 1992). The FMG InfoATLAS was designed as an integrated spatial database linking maps, text and geo-referenced data on a variety of subjects such as bathymetry, geology, coastal physiology, physical, chemical, and biological oceanography, living marine resources, political and resource management boundaries, human use and population, and critical resource management issues. According to Ricketts, Mclver, and Butler (1989) and Ricketts (1992), the predicted benefits of the FMG approach include:

1. Managers of Federal, State, and local regulatory control programs such as those for ocean dumping and discharges, fish plant operation, aquaculture, and ocean mining will be able to negotiate knowledgeably and resolve potential resource use conflicts.
2. Resource use planning and strategic assessment will be facilitated through the incorporation of a holistic planning approach based on comprehensive data and information availability.
3. The management process will be enhanced as the bulk of the data will be displayed graphically.
4. Expanding and updating databases, and importing and exporting data within compatible formats will be possible.
5. Conflicts between resource use and environmental protection will be resolved in a

fair, effective, and economically efficient manner.

Similar applications for integrated coastal area management are involved in incorporating satellite remote sensing, LANDSAT Thematic Mapper, SPOT High Resolution Visible (HRV) satellite systems, global positioning systems (GPS), and GIS. The combined use of these technologies can significantly enhance resource mapping, and pollution monitoring and management plans. Environmental management using GIS tools can significantly improve environmental quality of the coastal and marine areas (Kam 1988; Omoregie and Babu 1994).

GIS is being used for management and monitoring of marine sanctuaries in the U.S. and other parts of the world. In the United States, GIS is being used for management and monitoring of marine habitats in the Florida Key National Marine Sanctuary. The project covers an area of 9,777 square kilometers. GIS is used to integrate aerial photography to identity and monitor benthic habitats in the Sanctuary (Clark and Rohmann 1994).

GIS has been in use since 1988 for Wadden Sea conservation along the west coast of Schleswig-Holstein, Germany. Land-use patterns surrounding the Wadden Sea are mapped and stored as separate data layers: landscape elements, coastal protection, recreation, agriculture, eco-potential, infrastructure, settlement, and legal status. Regions of conflict can be singled out by means of map overlays. The purpose is to allow coordination between planning bodies of different levels (municipality, district, federal, state, etc.) and encourage an integrated and "supra-regional" approach towards physical planning of the coastal region of Schleswig-Holstein (Schauser et al. 1992). Similarly in Belize, Central America, a planning process for marine protection areas adopted GIS technology to integrate data from a variety of sources. The proposed boundaries for the South Water Cay Marine Reserve management zones were demarcated using nine GIS data layers. Priority was placed in accommodating fishery activities, recreational activity, and habitat inventory (Mumby et al. 1995).

GIS capabilities in data processing, network computing, transactional database updating, and multimedia integration led to its use for Environmental Sensitivity Index (ESI). The traditional ESI was developed to rank the vulnerability of different geomorphic coastal segments to oil spills. Later modifications included biological considerations in ranking, based on persistence of oil in habitat, recovery time, and population size and density. ESI maps also include the identification of relevant socio-economic resources at risk and oil spill response considerations. Recent applications include the use of remote sensing analysis to identify some ESI types. The current prototype application of ARC/INFO based oil spill GIS focuses on contingency planning and response support. However, from a broader perspective, GIS is being structured for the monitoring and analysis of environmental data such as water quality samples, meteorological monitoring, compliance of oceanographic data, and species siting. The advantages of using GIS for resource mapping include efficient storage, retrieval, analysis, and display of resource information to support a variety of coastal and marine applications (Sorensen 1995).

GIS in Central California

In 1991, the California Legislature passed the Assembly Bill (AB) 2040, the Lempert-Keene-Seastrand Oil Spill Prevention and Response Act. This bill was passed to protect more than 1,100 miles of California's marine coastline against the enormous risk associated with the transportation and handling of petroleum products near areas with sensitive biological resources. The Office of Oil Spill Prevention and Response (OSPR) under the California Department of Fish and Game (CDFG) was established by AB 2040. The goal was to inventory and map the many sensitive biological, physical, and cultural resources at risk from marine oil spills and to use this information to plan for their protection. GIS technology became the foundation for this integrated solution where information about resource location was spatial or geographic in nature (Ellison and Veisze 1997).

The CDFG's most recent GIS feasibility study was a five year project to implement a CDFG-wide GIS starting in June of 1993. This triggered interest from other agencies interested in GIS. Resources Agency was interested in this technology for solving large area resource management problems and for tracking existing efforts in this regard. This interest led to the development of two projects associated with coastal and ocean resources. Following a request from the Resources Agency, the first project included the assemblage of data for Monterey Bay region. The second project was to conduct GIS operations of mutual interest to CDFG and SWRCB (Ellison and Veisze 1997). The goals specific to SWRCB involved:

1. Identification of the State's Hydrological Units and the federal Cataloging Units encompassing impaired water bodies.
2. Production of digital maps of impaired water bodies and source waters.
3. Compilation, documentation, and registration to the above maps related themes such as jurisdictional boundaries, wetlands, landfills, groundwater basins, point source discharges, roads, recreational areas, and marinas.
4. Coordination of GIS data acquisition with the US EPA, California Coastal Commission, and Teale Data Center.
5. Consulting with SWRCB and Regional Water Quality Control Boards for presentation and interpretation of GIS data (Ellison and Veisze 1997, 363-364).

Another GIS project in California involved the integration of aerial photograph images and water quality related data for a portion of the Elkhorn Slough and vicinity in north Monterey County. This project was undertaken by the California Coastal Commission (CCC) in an effort that would ultimately move the Central Coast Region towards ecosystem and watershed-based environmental management. This project is planned for installation in the CCC's Santa Cruz office, the CDFG office in Sacramento, the MBNMS office in Monterey, the AMBAG office in Marina, the Monterey County Planning Department's office in Salinas, and the SWRCB's Marine Laboratory in Moss Landing (Van Coops and Yap 1997).

The Central Coast Joint Data Committee (CCJDC) was formed in 1996 to facilitate the development of GIS for spatial data sharing among public and private agencies, from San Mateo County through San Luis Obispo counties, but focusing on the area of Santa Cruz, San Benito, and Monterey Counties in Central California. The purpose of this committee is:

> To facilitate the development and maintenance of an ongoing public-private partnership for sharing and expanding the use of spatial data to foster informed community decision making, innovative business development, environmental management and education in the Central Coast Region of California (AMBAG 1998, 1).

The original signatories for the CCJDC include: AMBAG, Cabrillo College, CCC, CDFG, California State University Monterey Bay, City of Monterey, City of Pacific Grove, Elkhorn Slough National Estuarine Research Reserve, Monterey County Water Resource Agency, Moss Landing Harbor District, Santa Cruz County, and University of California at Santa Cruz . The MBNMS and the U.S. Geological Survey are in the process of joining the CCJDC. Some of the major goals and objectives of the CCJDC include:

1. Exemplify the shared interests in geographic information and technology issues for organizations working with and using geographic information.
2. Identify, develop, and maintain a high-priority geographic database.
3. Promote cooperation and communication in issues related to the use and development of geographic information in the Central Coast Region.
4. Adopt, set, apply and adjust as required regional standards for spatial data.

The spatial data used in developing GIS consists of data pertaining to the geography of the region. This may include natural resource data, census data, Assessor's parcel records, streets and roads, etc. The CCJDC is committed to making spatial data mutually available to its members and providing free access to the public (AMBAG 1998).

CHAPTER III

Study Area

Background

This study focuses on Monterey Bay, located along the central California coast about 100 miles (160 km) south of San Francisco. Monterey Bay is an open embayment approximately 20 nautical miles (nmi) (36 km) long, extending north to south, and about 9 nmi (16 km) wide in an east-west direction. The surface area of the bay is approximately 160 square nautical miles (550 square km), making it the second largest bay in California (NOAA 1992).

A narrow continental shelf and slope, 4 or 5 miles wide, is bisected by Monterey Submarine Canyon, the deepest and largest submarine canyon along the west coast of North America. This geologic feature, combined with seasonal oceanographic conditions, leads to the upwelling of nutrient-rich bottom waters during the spring and summer months. The result is highly productive nearshore waters that provide a rich and varied habitat for a diversity of marine flora and fauna. Monterey Bay supports one of the world's most diverse populations of marine mammals, including the endangered California gray whale, finback whale, humpback whale, sperm whale, and California sea otter. The Monterey Bay area is also an important staging habitat for the migratory birds of Pacific

Flyway. The Bay waters support extensive fish populations and major commercial fishing industries along the west coast of United States (NOAA 1990).

Two large oceanic current systems dominate surface water circulation in Monterey Bay. The ocean currents change seasonally and are related to variable winds. From July to November the southerly-flowing California Current system dominates offshore water circulation. During November to February, when northwest winds weaken, the north-moving Davidson Current system surfaces and dominates the near shore transport of water. From March to July or August, winds from the north predominate. These north winds parallel the coast and move the water offshore, leading to the surfacing of the deeper and cooler bottom water (Griggs and Hein 1980). Physical oceanographers are learning more about the bottom currents in Monterey Bay. Wolf (1968, 1970) suggested that bottom currents generally flow parallel to the isobars in a southeast direction in northern Monterey Bay and to the northwest in southern Monterey Bay. Surface currents flow towards the equator in the outer part of the Monterey Bay, towards the pole in a narrow band nearshore, and are very sluggish in the middle of the Bay (Paduan and Rosenfeld 1996).

Ocean Outfall Discharge Monitoring Programs

This thesis project focuses on the three major municipal discharges to Monterey Bay, CA (Figure 2). These municipal discharges include:

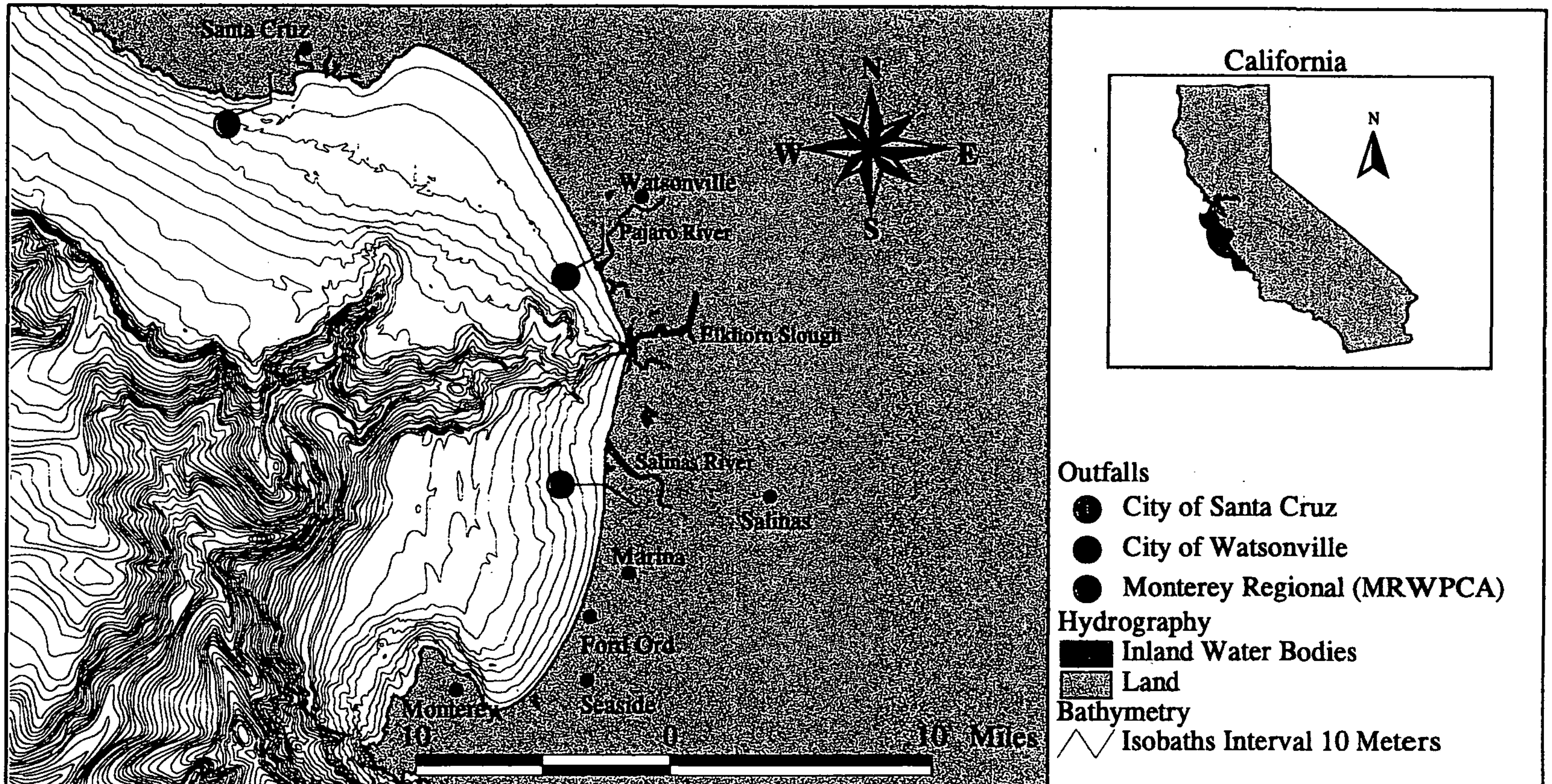

Figure 2: Municipal Wastewater Outfalls in Monterey Bay, CA

Sources: Adapted from data sources: Outfalls, National Pollution Discharge Elimination System (NPDES), Monterey Regional Permit No.CA0048551 (RWQCB 1992), City of Watsonville Permit No.CA0048216 (RWQCB 1993), City of Santa Cruz Permit No.CA0048194 (RWQCB 1994); Hydrography (DLG data), U.S. Geological Survey, National Mapping Division (USGS 1993); Bathymetry (digital data), U.S. Geological Survey, Marine and Coastal Geology (USGS 1990).

1. Municipal wastewater effluent from the City of Santa Cruz
2. Municipal wastewater effluent from the City of Watsonville
3. Wastewater effluent discharges from Monterey Regional Water Pollution Control Agency's (MRWPCA) plant north of Marina.

Periodic monitoring is conducted at fixed stations surrounding the zone of initial dilution (ZID) at each discharge point. The zone of initial dilution is defined in the California Ocean Plan as:

> Initial dilution is the process which results in the rapid and irreversible turbulent mixing of wastewater with ocean water around the point of discharge. For a submerged buoyant discharge, characteristic of most municipal and industrial wastes that are released from submarine outfalls, the momentum of the discharge and its initial buoyancy act together to produce turbulent mixing. Initial dilution in this case is completed when the diluting wastewater ceases to rise in the water column and first begins to spread horizontally (SWRCB 1997a, 20).

For each of the discharges, there are nearfield sampling sites located at the ZID boundary and stations beyond the ZID. In addition, a farfield site or reference station is located at a large distance from the centerpoint of the diffuser at the same depth. The station locations are plotted using a miniranger navigating system (precision ± 3 meters) and/or differential Global Positioning Systems (GPS) (precision ± 3 to 5 meters) (Kinney and Toal 1997a).

The U.S. EPA has adopted a conservative policy allowing a mixing zone of 30 meters on both sides of the diffuser for marine outfalls (Baumgartner, Frick, and Roberts 1993). Within this zone, the water quality criteria are permitted to exceed regulation standards (Baumgartner, Frick, and Roberts 1993). However, outside the ZID, water quality must comply with the 1997 California Ocean Plan Standards (SWRCB 1997a).

The State Water Resource Control Board (SWRCB) adopted the Water Quality Control Plan for Ocean Waters of California (Ocean Plan) in 1972. Subsequent amendments were made to the Ocean Plan 1978, 1983, 1988, 1990, and 1997. The SWRCB is responsible for reviewing, modifying, and adopting Ocean Plan water quality standards in accordance with Section 303 (c) (1) of the Federal Clean Water Act and Section 13170.2 of the California Water Code (CWC). The SWRCB specifies that protection of the quality of the ocean water for use and enjoyment by the people of the State requires control of the discharge of waste to ocean water in accordance with the provisions contained in the California Ocean Plan. The waste management systems that discharge to the ocean must be designed and operated in a manner that will maintain the indigenous marine life and a healthy and diverse marine community (SWRCB 1997a). According to the California Ocean Plan prepared by the SWRCB (1997a), general requirements for the management of waste discharge to the ocean include:

A. Waste management systems that discharge to the ocean must be designed and operated in a manner that will maintain the indigenous marine life and a healthy and diverse marine community.

B. Waste discharged to the ocean must be essentially free of:
   1. Material that is floatable or will become floatable upon discharge.
   2. Substances or settleable material that may form sediments which will degrade benthic communities or other aquatic life.
   3. Substances which will accumulate to toxic levels in marine waters, sediments or biota.
   4. Substances that significantly decrease the natural light to benthic communities and other marine life.
   5. Materials that result in aesthetically undesirable discoloration of the ocean surface.

C. Waste effluents shall be discharged in a manner which provides sufficient initial dilution to minimize the concentrations of substances not removed in the treatment.

D. Location of the discharges must be determined after a detailed assessment of the oceanographic characteristics and current patterns to assure that:
   1. Pathogenic organisms and viruses are not present in areas where shellfish are harvested for human consumption or in areas used for swimming or other body-contact sports.
   2. Natural water quality conditions are not altered in areas designated as being of special biological significance or areas that existing marine laboratories use as a source of seawater.
   3. Maximum protection is provided to the marine environment (SWRCB 1997a, 5).

City of Santa Cruz

The City of Santa Cruz outfall discharges secondary treated municipal wastewater to the Pacific Ocean through an ocean outfall structure 12,250 feet (3,734 m) in length, including a 2,000 foot (640 m) diffuser terminating approximately 1 mile offshore in about 110 feet (30.5 m) of water calibrated to mean lower low water (MLLW) (RWQCB 1994). This outfall's terminus is located at 36° 56' 2.94" N. Latitude and 122° 04' 23.05" W. Longitude (RWQCB 1994). The average dry weather effluent flow from this outfall is 17.0 million gallons per day (MGD) and the peak wet weather flow is 81.0 MGD (RWQCB 1994). The Monitoring and Reporting Program is designed to confirm compliance with conditions of NPDES Permit No. CA0048194. Monitoring has been conducted annually since the discharge began in 1988. Sediment quality monitoring is conducted at a fixed station within the ZID and 4 fixed stations at increasing distance from the outfall. The stations include: SC1 (30 m - WNW from the outfall), SC2 (200 m - ESE from the outfall), SC3 (300 m - WNW of the outfall), SC4 (1000 m - WNW from the outfall), and SC5 (3,650 m - WNW from the outfall) (Figure 3). Soft-bottom benthic

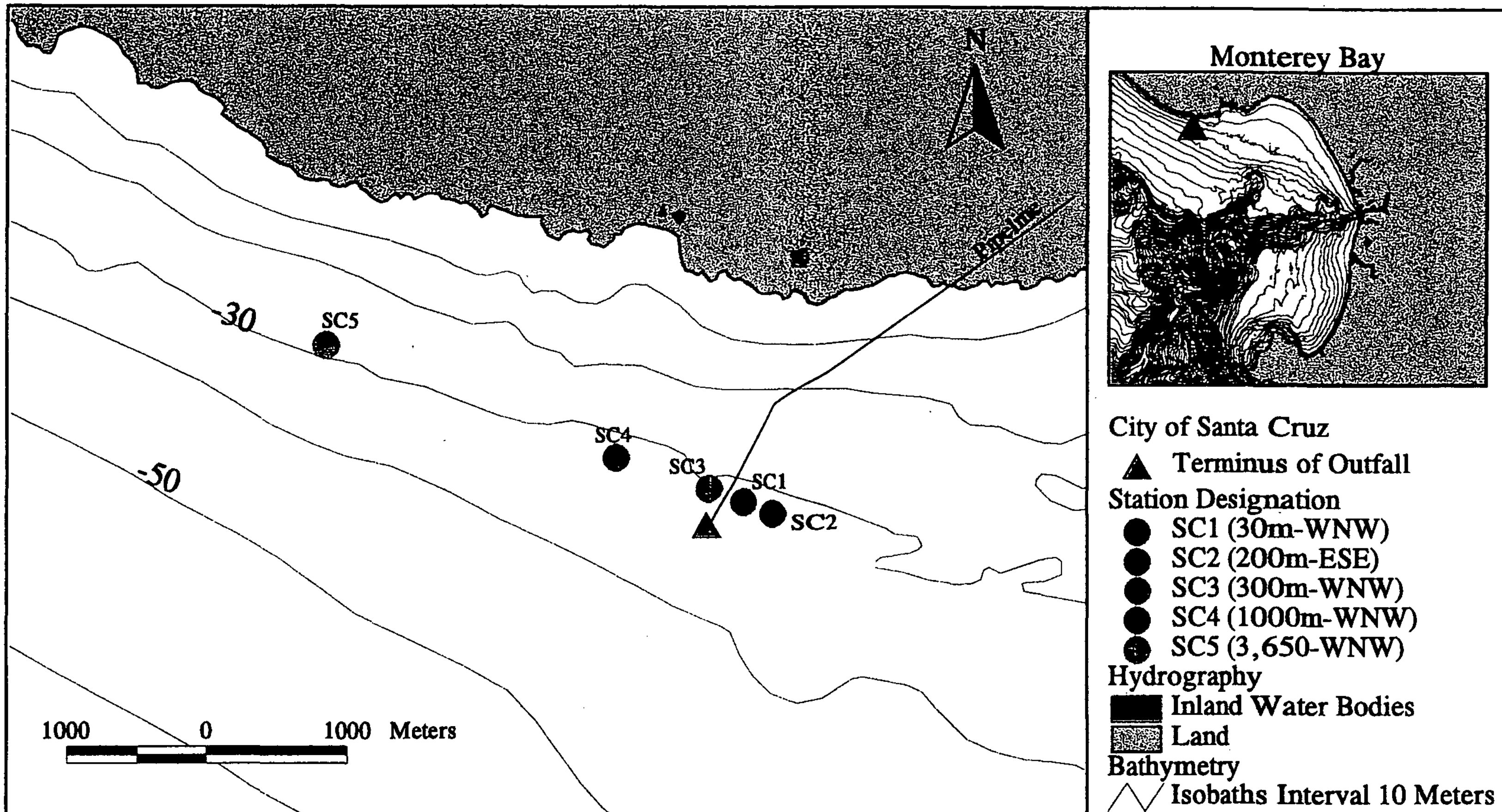

Figure 3: Sediment and Benthic Monitoring Stations around City of Santa Cruz Municipal Wastewater Outfall, Monterey Bay, CA

Sources: Adapted from data sources: Outfall, City of Santa Cruz Wastewater Treatment Facility, NPDES Permit No. CA0048194 (RWQCB 1994); Hydrography (DLG data), U.S. Geological Survey, National Mapping Division (USGS 1993); Bathymetry (digital data), U.S. Geological Survey, Marine and Coastal Geology (USGS 1990).

infauna, collected at 4 of the 5 stations (excluding SC5), are utilized for sediment quality monitoring.

City of Watsonville

The City of Watsonville's ocean outfall extends 7,350 feet (2,240 m) in length, including a 425 feet (129 m) diffuser terminating at the depth of about 64 feet (19.5m) in Monterey Bay. The terminus is located at 36° 50' 44" N. Latitude and 124° 49' 59" W. Longitude. The outfall discharges an average daily dry weather flow of 16.5 MGD of advanced primary and 12.0 MGD of secondary treated wastewater. The peak dry weather flow amount to 12.0 MGD and peak wet weather flow are estimated at 38.2 MGD of secondary treated wastewater (RWQCB 1998).

Biennial receiving water monitoring began in 1988 to document environmental conditions in the vicinity of the outfall and to assess the potential impacts to the environment associated with the wastewater discharge (Kinney and Toal 1997b). Sediment quality and benthic biota sampling station include a stations located at the boundary of the ZID (R1N) (19.5 m north of the outfall), the northerly nearfield station (R4) (170 m north of the outfall), the farfield station (R5) (1,000 m north of the outfall), and the reference station (R6) (3,000 m north of the outfall). Station R2 (170 m south) is a nearfield station which was added in 1994 to meet the requirement of the NPDES permit renewed in 1993 (Nigg and Stevenson 1995) (Figure 4).

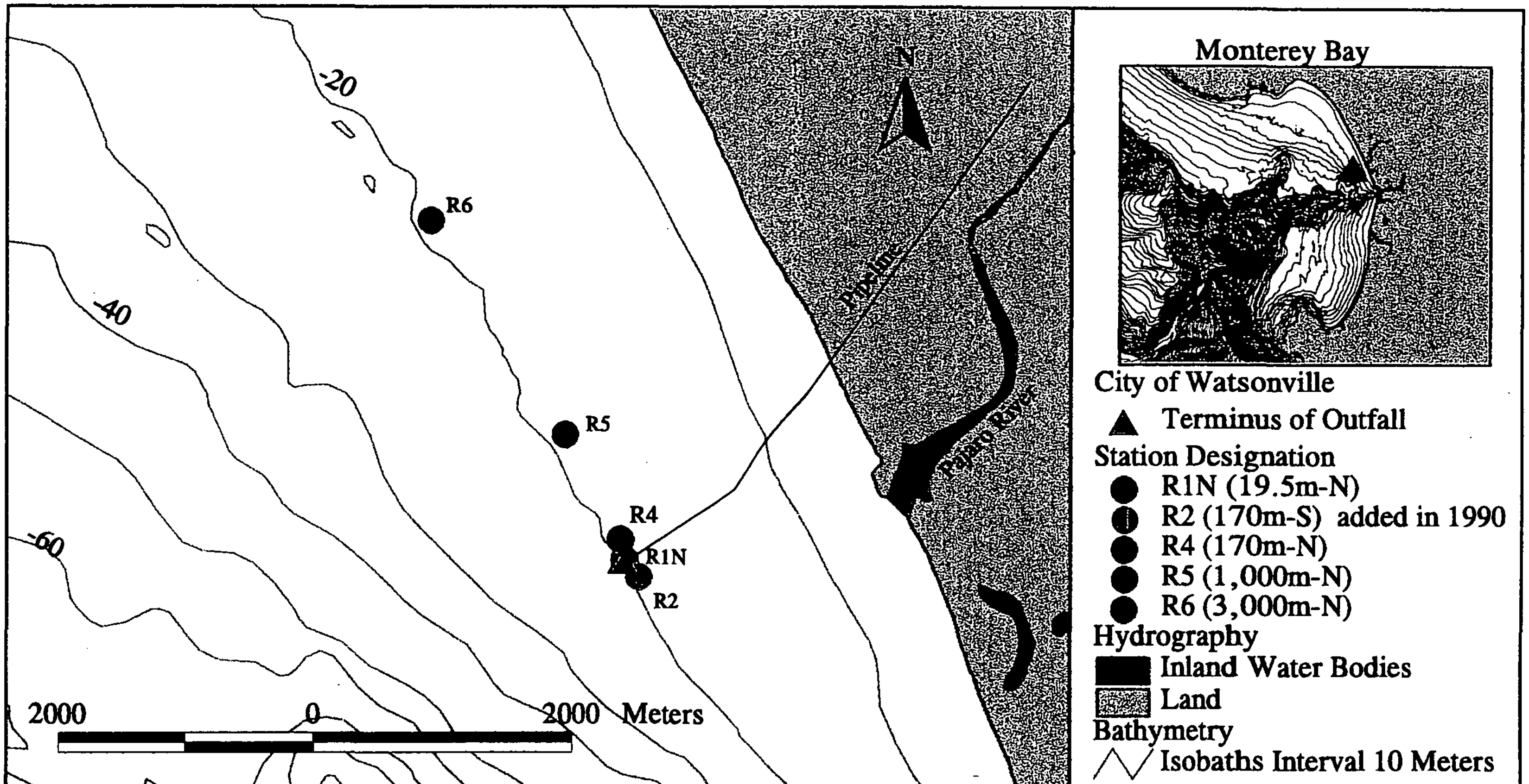

Figure 4: Sediment and Benthic Monitoring Stations around City of Watsonville Municipal Wastewater Outfall, Monterey Bay, CA

Sources: Adapted from data sources: Outfall, City of Watsonville, NPDES Permit No.CA0048216 (RWQCB 1998); Station Designation, 1996 Receiving Water Monitoring Study, Prepared for the City of Watsonville, Kinnetic Lab, Inc. (Kinney and Toal 1997b); Hydrography (DLG data), U.S. Geological Survey, National Mapping Division (USGS 1993); Bathymetry (digital data), U.S. Geological Survey, Marine and Coastal Geology (USGS 1990).

Monterey Regional Water Pollution Control Agency

Monterey Regional Water Pollution Control Agency (MRWPCA) manages a wastewater treatment system for the cities of Monterey, Pacific Grove, Seaside, Del Rey Oaks, Sand City, and Salinas, Marina County Water District, Boronda, Castroville, and Moss Landing County Sanitation Districts in northern Monterey County. The discharge consists of secondary and tertiary treated wastewater. Treated municipal wastewater is discharged to the Monterey Bay through a 11,260 foot (3,432 m) outfall/diffuser system. The treatment plant has the design capacity of peak dry weather flow of 29.6 MGD and peak wet weather flow of 81.2 MGD. The outfall terminates at the depth of approximately 97 ft (30 m) of water, at 36° 43' 40" N. Latitude and 121° 50'1 4" W. Longitude (RWQCB 1997).

The Monitoring and Reporting Program is designed to document compliance with the requirements of NPDES Permit No. CA0048551. Monitoring has been conducted every three years since 1985. To meet 1994 changes to the monitoring program, the sampling station locations were changed from the initial sites. During the monitoring years 1985, 1988, and 1991, the sediment quality sampling stations were located at 30 m south, 500 m north, 500 m south, and 2,000 m south of the outfall (Figure 5). Before 1994, the benthic biota sampling was conducted at station locations at 1 m south, 2 m south, 30 m south, 500 m north and south, and 2,000 m south of the outfall (Figure 5). In 1994 the station locations for sampling sediment quality and benthic biota were changed to 60 m north and south, 900 m north and south, and 3,000 m south (Figure 6). (ABA Consultants 1995).

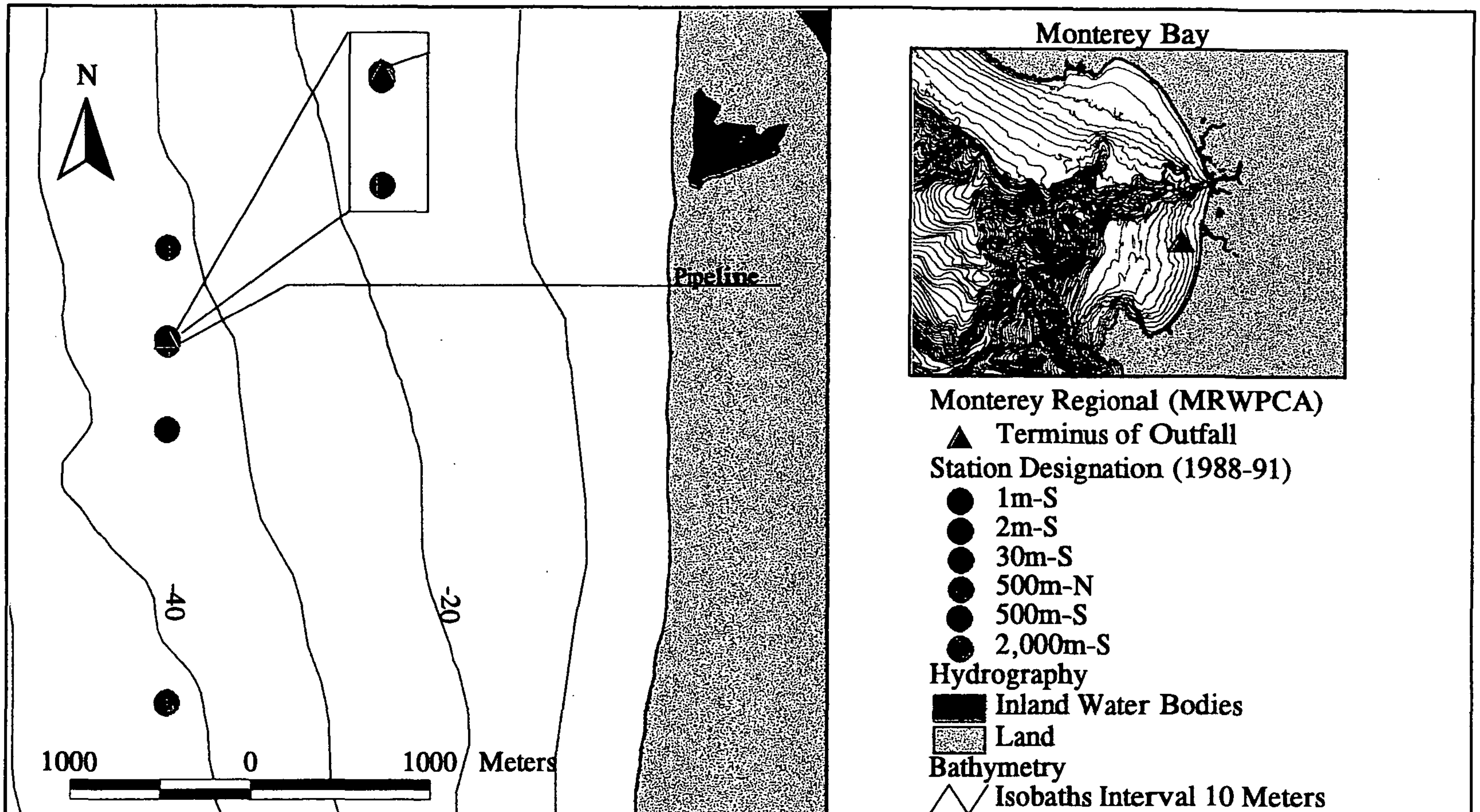

Figure 5: Sediment and Benthic Monitoring Stations around Monterey Regional Municipal Wastewater Outfall (1988-91), Monterey Bay, CA

Sources: Adapted from data sources: Outfall, Monterey Regional Water Pollution Control Agency (MRWPCA), NPDES No. CA0048551 (RWQCB 1997); Station Designation (1988-91), 1988-89 Marine Outfall Benthic Monitoring Report, prepared for MRWPCA, ABA Consultant (ABA Consultant 1989); Hydrography (DLG data), U.S. Geological Survey, National Mapping Division (USGS 1993); Bathymetry (digital data), U.S. Geological Survey, Marine and Coastal Geology (USGS 1990).

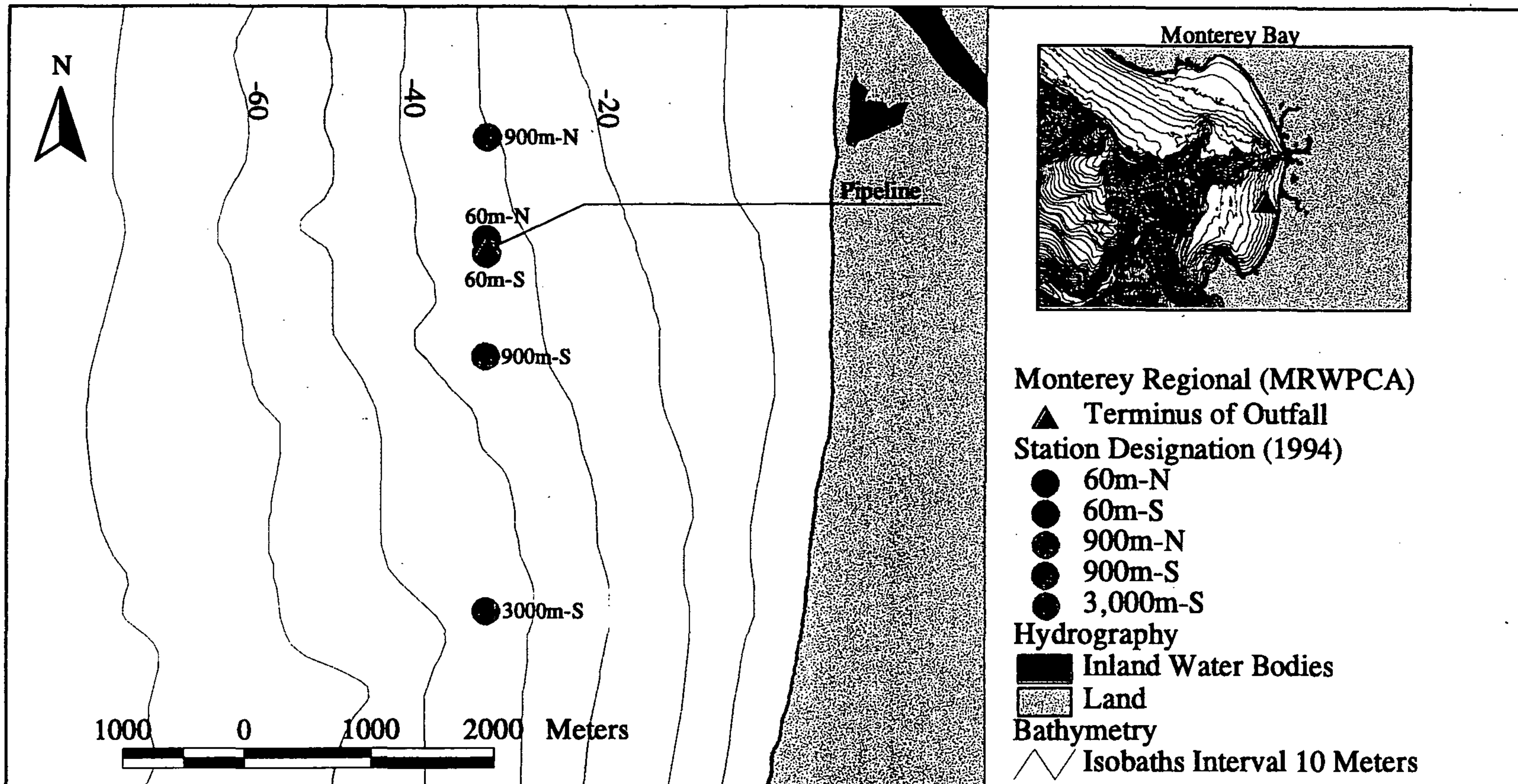

Figure 6: Sediment and Benthic Monitoring Stations around Monterey Regional Municipal Wastewater Outfall (1994), Monterey Bay, CA

Sources: Adapted from data sources: Outfall, Monterey Regional Water Pollution Control Agency (MRWPCA), NPDES Permit No. CA0048551 (RWQCB 1997); Station Designation (1994), 1994 Marine Outfall Benthic Monitoring Report, MRWPCA, ABA Consultants (ABA Consultant 1995); Hydrography (DLG data), U.S. Geological Survey, National Mapping Division (USGS 1993); Bathymetry (digital data), U.S. Geological Survey, Marine and Coastal Geology (USGS 1990).

Fort Ord Study Sites

A study was commissioned by the U.S. Army of Corp Engineers to investigate the presence or absence of contamination in sediments directly west of Fort Ord, California. During 1995, 20 sediment samples were collected from Monterey Bay for this assessment (Figure 7). Discharges from the army base through storm drains, firing range activities, or sewage disposal outfalls were among the sources of possible contamination. The major objectives of this study were to:

1. Determine the distribution of contaminants in the sediments of Monterey Bay.
2. Evaluate the distribution of contaminants to determine an association between contaminants and discharges from Fort Ord activities (Stephenson et al. 1997).

Contaminants analyzed during the study included the following metals: aluminum, arsenic, chromium, iron, manganese, nickel, silver, antimony, cadmium, copper, lead, mercury, selenium, tin, and zinc. Synthetic organic pesticides, polycyclic aromatic hydrocarbons (PAHs), tributylin, and polychlorinated biphenyls (PCBs) were among the trace organics analyzed.

The samples were collected during two cruises on the research vessels MCARTHUR and POINT SUR. The stations near Fort Ord were sampled in September 1995 (station numbers higher than B300) and the stations more distant from Ford Ord were sampled in April 1995 (station numbers less than B300). Stations were selected based on the following criteria: sediments had to be predominantly clay and silt (with the exception of a few stations near the beach at Fort Ord); many of the sediment samples were to be collected offshore of Fort Ord; sediments were to be collected both in the northern

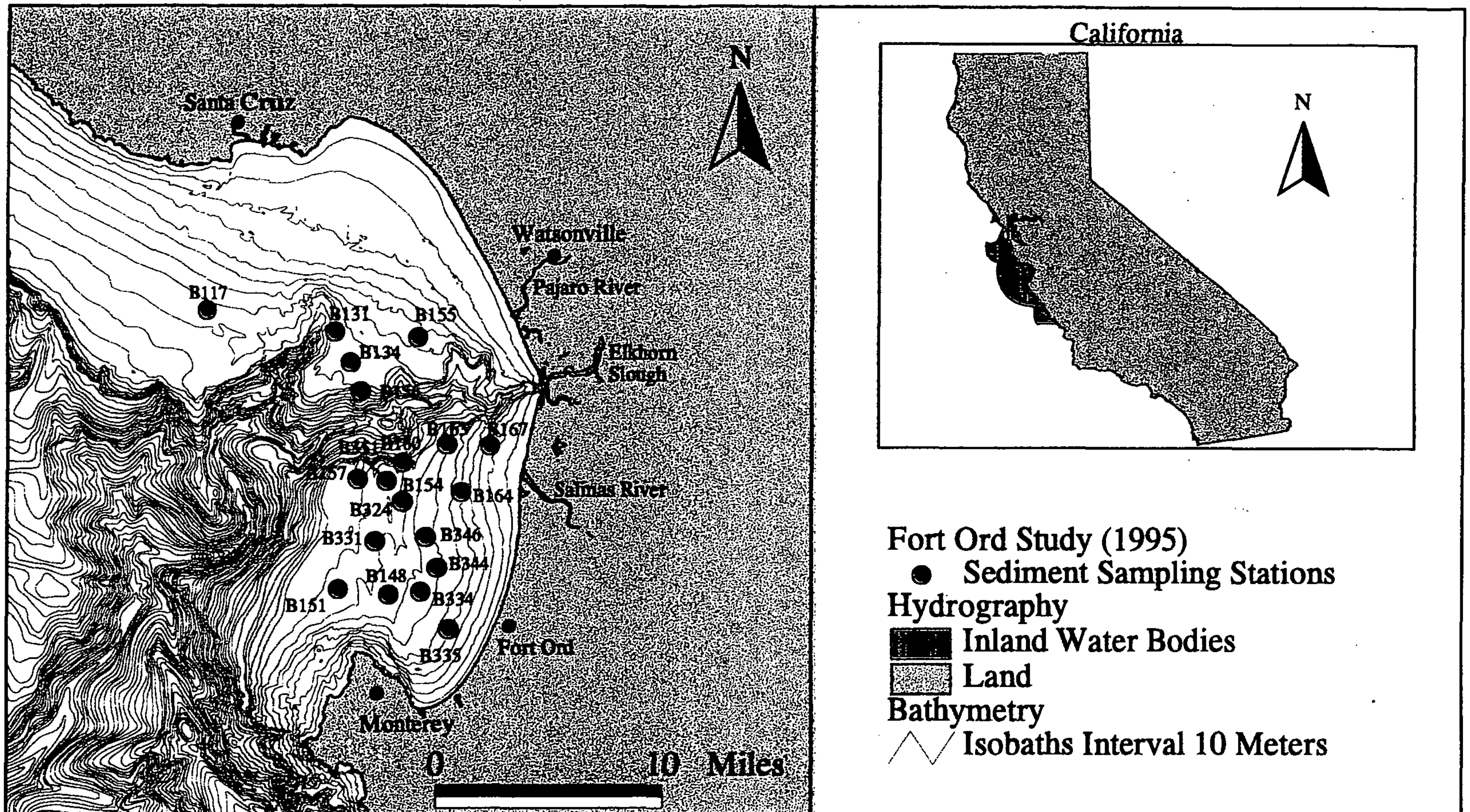

Figure 7: Fort Ord Study Sediment Sampling Stations for the Monterey Bay, CA

Sources: Adapted from data sources: Sediment Sampling Stations (1995), Distribution and Concentration of Selected Contaminants in Monterey Bay Sediments (Stephenson et al. 1997); Hydrography (DLG data), U.S. Geological Survey, National Mapping Division (USGS 1993); Bathymetry (digital file), U.S. Geological Survey, Marine and Coastal Geology (USGS 1990).

and southern part of Monterey Bay for reference; and sediments were to be collected near the mouth of the Salinas River because the river was thought to be a major source of pollutants. All sampling locations (latitude and longitude) were verified using differential GPS.

CHAPTER IV

METHODS

Data Collection

Base Maps

The base maps required for this study included bathymetry (isobath interval 10 meters) and hydrography (coastline data and inland water bodies) for the Monterey Bay area. Bathymetry in digital format was provided by the U.S. Geological Survey, Marine and Coastal Geology Division. Digital Line Graph (DLG) data on hydrography were made available by the U.S. Geological Survey, National Mapping Division.

Monitoring Data and Sampling Stations Locations

Monitoring data collected for this study included sediment quality and soft-bottom infaunal data. Sediment quality data were collected for the following trace metals: arsenic (As), cadmium (Cd), total chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), silver (Ag), and zinc (Zn). Soft-bottom benthic infaunal data included number of species and total abundance.

These data were collected under the Monitoring and Reporting Programs defined in the NPDES permits for each of the municipal wastewater dischargers. Sediment quality and soft-bottom benthic infauna data for the cities of Santa Cruz and Watsonville were provided by the respective municipal wastewater treatment facilities and in electronic format by Kinnetic Lab, Inc., Santa Cruz. Monitoring data for MRWPCA outfall was partially extracted from the monitoring reports and in part provided in electronic format by ABA Consultants, Capitola. The geographical locations (latitudes and longitudes) for the sediment and benthic sampling stations around each outfall were taken from the monitoring reports of the respective discharges. Latitudes and longitudes of the Fort Ord study sites were taken from the Fort Ord study report (Stephenson et al. 1997).

Digitizing Data

The geographical coordinates of the Fort Ord study sites, municipal outfalls and the associated sampling stations were projected into a point coverage data layer in the GIS. The Universal Transverse Mercator (UTM) coordinate system was used consistently for all the GIS data layers. Each data layer was stored as a separate coverage in the ARC/INFO GIS software program. Digital data were stored as the following coverages:

- Treated Wastewater Outfalls.
- Sediment Monitoring Stations for the Treated Wastewater Outfalls of City of Santa Cruz, City of Watsonville, and Monterey Regional (MRWPCA).
- Soft-bottom Benthic Monitoring Stations for the Outfalls of City of Santa Cruz, City of Watsonville, and Monterey Regional (MRWPCA).
- Fort Ord Sediment Sampling Sites.

- Bathmetric Map of the Monterey Bay (isobath interval of 10 meters).
- Hydrography including coastline, rivers and streams, and major water bodies in the Monterey Bay area.
- MBNMS boundary.

Monitoring data on trace metal concentration and benthic infauna community parameters were then geo-referenced with the respective sampling station location. This allowed the selection of any sampling station location in the Bay, and the ability to view and query associated monitoring data. Monitoring data associated with the stations were displayed as text in ARC/INFO, and as both text and in graphical form (histograms, bar and pie charts, plot, etc.) in ARCVIEW.

Methods for Evaluation of Trace Metals in Sediment

This study evaluated the trace metal concentrations in Monterey Bay sediments based on the sediment quality assessment guidelines (SQAGs) prepared by MacDonald (1994). Biological effects-based informal screening guidelines prepared for NOAA's National Status and Trends (NS&T) Program by Long and Morgan (1990), were chosen as the basis for developing SQAGs for Florida coastal waters (MacDonald 1994). This study was based on sediment and bioassay data from 200 sites nationwide which were analyzed to establish relationships between concentrations of sediment-associated contaminants and their potential for adverse biological effects (Long and Morgan 1990). MacDonald (1994) subsequently updated, expanded and refined the database used by Long and Morgan (1990). This was achieved by excluding data from freshwater studies and including additional data sites, biological test end points, and contaminants (MacDonald 1994). Among the kinds of adverse effects included were the measures of altered benthic communities (depressed species or total abundance), significantly or relatively elevated sediment toxicity, or histopathological disorders in demersal fish observed in field studies (Long et al. 1995).

The effects-based data distributions were determined using percentiles. The guideline values derived for each chemical include the threshold effects levels (TEL) and probable effects levels (PEL). The TEL is the range of sediment contaminant concentrations that are not likely to be associated with adverse biological effects on aquatic organisms (i.e., the minimal effects range). MacDonald (1994) states:

> The TEL represents the upper limit of the range of sediment contaminant concentrations dominated by no effects data entries (i.e., the minimal effects range). Within this range, concentrations of sediment-associated contaminants are not considered to represent significant hazards to aquatic organisms. The TEL was calculated as follows:
>
> $$TEL = \sqrt{EDS\text{-}L \times NEDS\text{-}M}$$
>
> where:
>
> TEL = Threshold effects level;
> EDS-L = 15^{th} percentile concentration on the effects data set; and,
>
> NEDS-M = 50^{th} percentile concentration in the no effects data set.
>
> (MacDonald 1994, 37)

The PEL represents the lower limit of the range of contaminant concentrations that are usually or always associated with adverse biological effects (i.e., the lower limit of the probable effects range). MacDonald (1994) states:

> Within the probable effects range, concentrations of sediment-associated contaminants are considered to represent significant and immediate hazards to aquatic

organisms. The PEL was calculated as follows:

$$PEL = \sqrt{EDS\text{-}M \times NEDS\text{-}H}$$

where:

PEL = Probable effect level;

EDS-M = 50th percentile concentration in the effects data set; and,

NEDS-H = 85th percentile concentration in the no effects data set.

The range of concentration that could, potentially, be associated with biological effects (i.e., the possible effects range) is delineated by the TEL (lower limit) and PEL (upper limit). Within this range of concentrations, adverse biological effects are possible; however, it is difficult to predict the occurrence, nature, and/or severity of these effects (MacDonald 1994, 40).

This thesis used the guidelines values, including TEL and PEL as defined by MacDonald (1994), to identify potential problem areas and the metals of concern in Monterey Bay sediments (Table 1). The spatial distribution was based on 3 categories of trace metal concentrations: 1) concentrations of metals < TEL; 2) concentration of metals ≥ TEL and < PEL, and 3) concentration of metals ≥ PEL. These guidelines may be used as an informal screening tool in environmental assessment. They do not represent official NOAA standards and are not intended for use in regulatory decisions (Long and Morgan 1990).

Table 1: Guideline Values for Trace Metals in Sediment
(parts per million (ppm), dry weight) (MacDonald 1994, 53)

	Sediment Guidelines	
Trace Metal	**Threshold Effects Level (TEL)**	**Probable Effects Level (PEL)**
Arsenic	7.2	41.6
Cadmium	0.6	4.2
Chromium, total	52.3	160.0
Copper	18.7	108.0
Lead	30.2	112.0
Mercury	0.13	0.69
Nickel	15.9	42.8
Silver	0.7	1.7
Zinc	124.0	271.0

Benthic Community Parameters: Relationship to Increasing Metal Concentrations

This thesis project compared increasing trace metal concentrations to the benthic community parameters (number of species and total abundance). For this purpose sediment monitoring stations around each of the treated wastewater outfalls were categorized into low-metal concentration sites and high-metal concentration sites for metals of concern in the Bay. The low-metal concentration sites included metal concentrations ≤ TEL guideline values for trace metals. High-metal concentration sites consisted of concentrations > TEL values for the trace metals in sediments. Sediment quality and benthic community parameters monitoring data collected from 1988 to 1996 were used for the analysis (See Appendix A through D).

A t-test applied to two independent sample means was performed comparing the means for the average number of species at sites with low-metal concentration and the average number of species at sites with high-metal concentration. Similarly, a two sample independent t-test was performed to compare the means of average total abundance between low-metal sites and high-metal sites. The following null hypotheses were tested by t-test applied to the means of two independent samples:

H_o1: There is no statistically significant difference between average number of species at low-metal concentration sites and high-metal concentrations sites.

H_o2: There is no statistically significant difference between average total abundance at low-metal concentration sites and high-metal concentrations sites.

The null hypothesis is rejected if the calculated t statistic, i.e.,

$$t = \frac{\text{Difference Between Means}}{\text{Pooled Standard Error}}$$

is greater than the *critical* t value at significance level (α) = 0.05 for $n_1 + n_2 - 2$ degrees of freedom (*df*), where n_1 and n_2 are the two sample sizes (Witte 1993).

Analysis of Benthic Control Stations

One-way analysis of variance (ANOVA) was used to compare and explain the spatial pattern of benthic parameters, total abundance, and number of species among stations surrounding the three treated wastewater outfalls. Data on total abundance and number of species was averaged for the replicate samples taken from 1988 to 1996 for each station surrounding the three municipal outfalls. The following null hypotheses were tested:

H_o3: There is no statistically significant difference in the mean number of species among stations.

H_o4: There is no statistically significant difference in the mean of total abundance among stations.

The null hypothesis was rejected if the calculated F value, where

$$F = \frac{\text{Between group variation}}{\text{Within group variation}}$$

exceeded the critical value of F obtained from table with k-1 and N-k degrees of freedom (*df*) at $\alpha = 0.05$. Where, k is equal to the number of groups, and N is equal to the number of scores (Witte 1993).

The benthic monitoring stations farthest from the outfalls are considered to be the reference stations, where the impacts from the effluent on the benthic infauna communities are minimal. One of the objectives of this thesis was to evaluate the suitability of the reference stations for the outfalls. If the null hypothesis is rejected the one way ANOVA concludes that the means among the stations are different. However, it is not possible to explain where the differences lie. Therefore, *a priori* comparisons were used to test if the benthic infauna community parameters differ among reference stations and the nearfield sampling stations. Comparisons involve placing factor levels into two groups. The following null hypotheses were tested:

H_o5: There is no statistically significant difference among means of average total abundance at the reference stations versus the nearfield sampling stations.

H_o6: There is no statistically significant difference among means of average number of species at the reference stations versus the nearfield sampling stations.

H_o is rejected if the p-value $< \alpha$, where $\alpha = 0.05$ and p-value is the degree of rarity of a test result, given the null hypothesis is true.

CHAPTER V

Results

Evaluation Results and Spatial Analysis of Trace Metal Concentrations

Concentrations of nine trace metals (As, Cd, Cr [total], Cu, Pb, Hg, Ni, Ag, and Zn) were evaluated using MacDonald (1994) TEL and PEL guideline values for trace metals in sediments. The monitoring data from 1988 through 1996 were screened for concentrations above the TEL and PEL for each trace metal. The data screened included both the monitoring data from municipal outfalls and the Fort Ord study sites. Arsenic, Cr (total), and Ni were identified as metals of concern in the Monterey Bay sediments since they were found to be above the screening levels (TEL and/or PEL).

The concentration for the metals of concern (As, Cr [total], and Ni) were mapped for the Fort Ord study sites [1995] and monitoring stations around the municipal discharges for the year 1994. Due to the different monitoring schedules for each of the municipal outfalls, the data for the year 1994 were selected for mapping as being the only recent year with data for all the three outfalls.

Arsenic

Arsenic was found to be above the TEL guideline value but below the PEL at 5 stations. None of the sampling stations had As concentrations above the PEL. Figure 8 shows that the sediment stations with levels over TEL are the sampling sites included in the Fort Ord Study, lying on north edge (stations B155 and B156) and south edge (B163 and B160) of the Monterey Bay Canyon. The station SC2 which lies 200 meters east-south-east of the City of Santa Cruz also has concentrations above the TEL but below PEL guideline value for As.

Chromium

The Cr (total) concentrations were found to be over guideline values of TEL and PEL in the Bay (Figure 9). The higher concentration levels, i.e. above PEL, were found at 6 stations on either side of the Monterey Bay Canyon. Concentrations above TEL but below PEL included 13 sampling sites under the Fort Ord study, nearfield sampling stations SC2 and SC3 for the City of Santa Cruz, and all five sampling stations around the City of Watsonville outfall. The City of Santa Cruz monitoring stations (SC1, SC4, and SC5), all 5 stations around MRWPCA outfall, and one station (B351) at the south edge of the Monterey Bay Canyon included the Ford Ord study, all had concentrations below TEL.

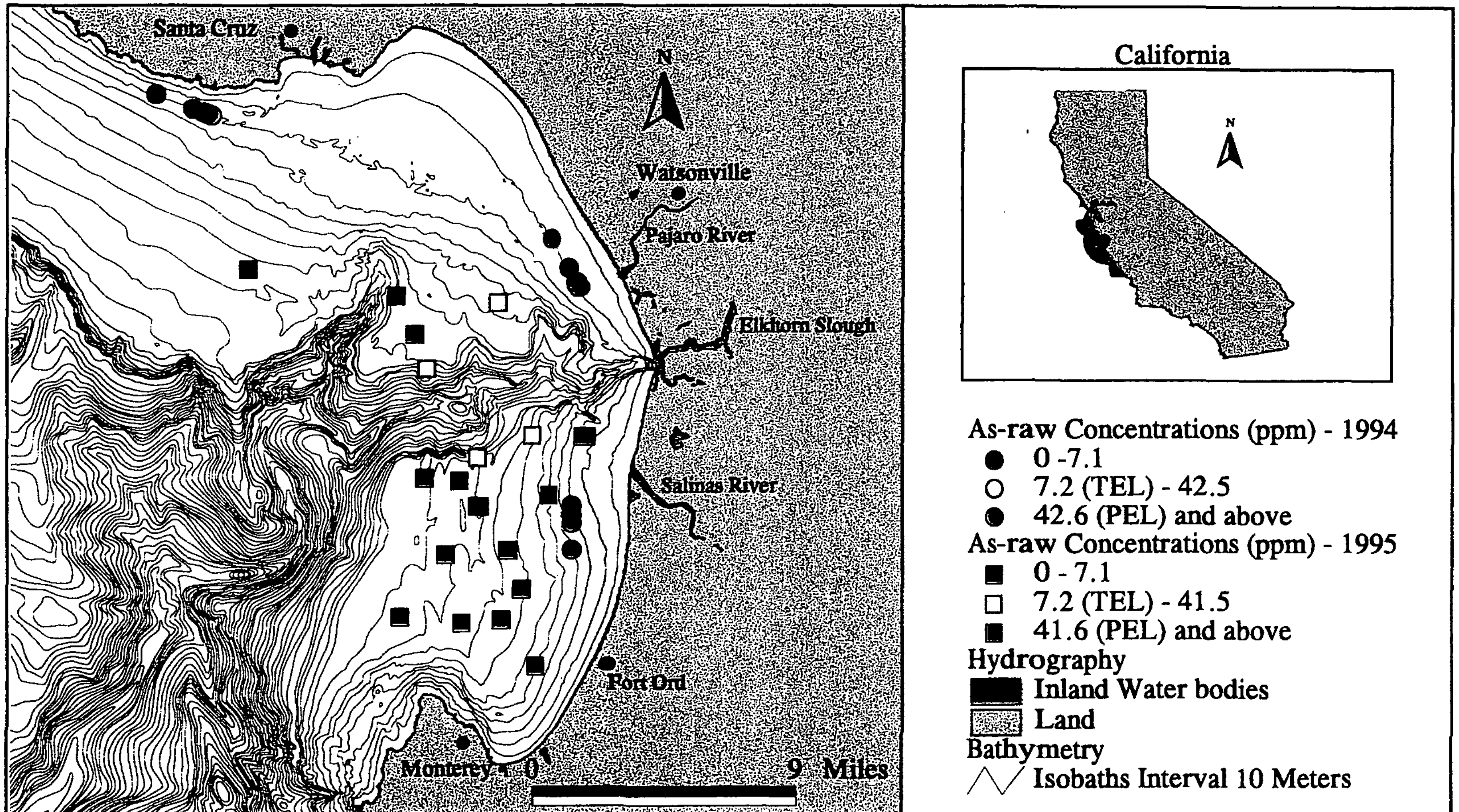

Figure 8: Spatial Analysis of Arsenic Concentrations in Monterey Bay Sediments

Sources: Adapted from data sources: As-raw (electronic data): (Kinnetic Lab 1995); (ABA Consultants 1995); As-raw (1995 data) (Stephenson et al. 1995); Hydrography (DLG data), U.S. Geological Survey, National Mapping Division (USGS 1993); Bathymetry (digital file), U.S. Geological Survey, Marine and Coastal Geology (USGS 1990).

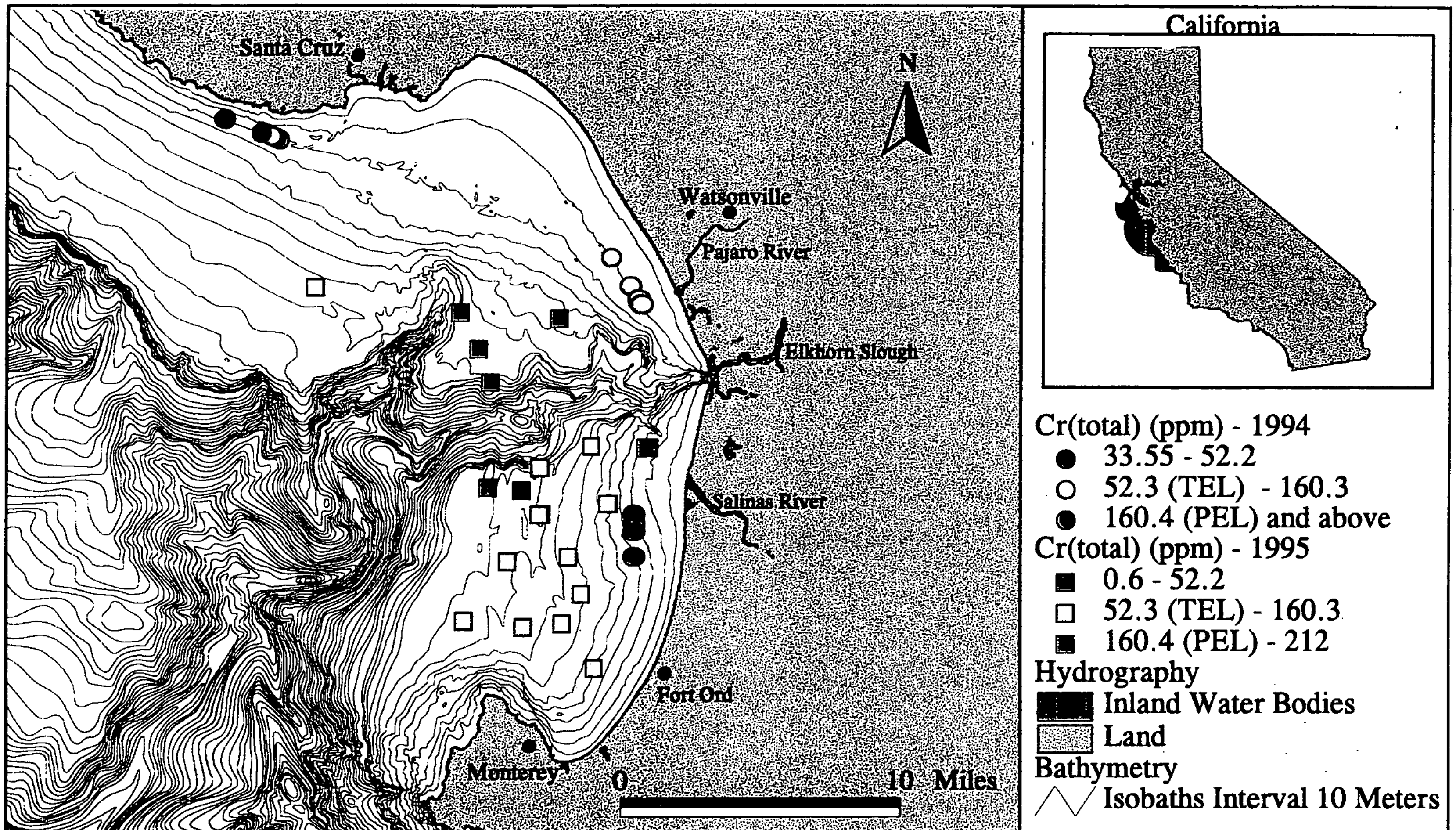

Figure 9: Spatial Analysis of Chromium (total) Concentrations in Monterey Bay Sediments

Sources: Adapted from data sources: Cr(total)-raw (1994 electronic data): (kinnetic Lab 1995); (ABA Consultants 1995); Cr(total)-raw (1995), Distribution and Concentration of Selected Contaminants in Monterey Bay Sediments (Stephenson et al. 1997); Hydrography (DLG data), U.S. Geological Survey, National Mapping Division (USGS 1993); Bathymetry (digital file), U.S. Geological Survey, Marine and Coastal Geology (USGS 1990).

Nickel

The concentration for Ni was found to be above both the screening values (TEL and PEL) in the Monterey Bay (Figure 10). Higher concentrations (above PEL) were found on either side of the Monterey Bay Canyon, including 12 Fort Ord study sites, monitoring stations R2, R4, and R5 around the City of Watsonville outfall, and monitoring station 500 meter south of the MRWPCA outfall. All 5 sampling stations around the City of Santa Cruz outfall, and the nearfield sampling station R1N around the City of Watsonville outfall had concentrations above TEL but below PEL. Monitoring stations (2,000m-S, 30m-S, and 500m-N) near the MRWPCA outfall had concentrations above the TEL but below PEL.

Benthic Community Parameters: Relationship to Increasing Metal Concentrations

The relationship of increasing metal concentrations to shifts in the benthic infauna community parameters were analyzed for Cr (total) and Ni around the three municipal outfalls. Association between increasing As concentrations and benthic communities was not analyzed as only one monitoring station had a concentration above the TEL screening level. Biological data was not available for the sampling sites included in the Fort Ord Study; therefore these sites were excluded from the benthic community analysis.

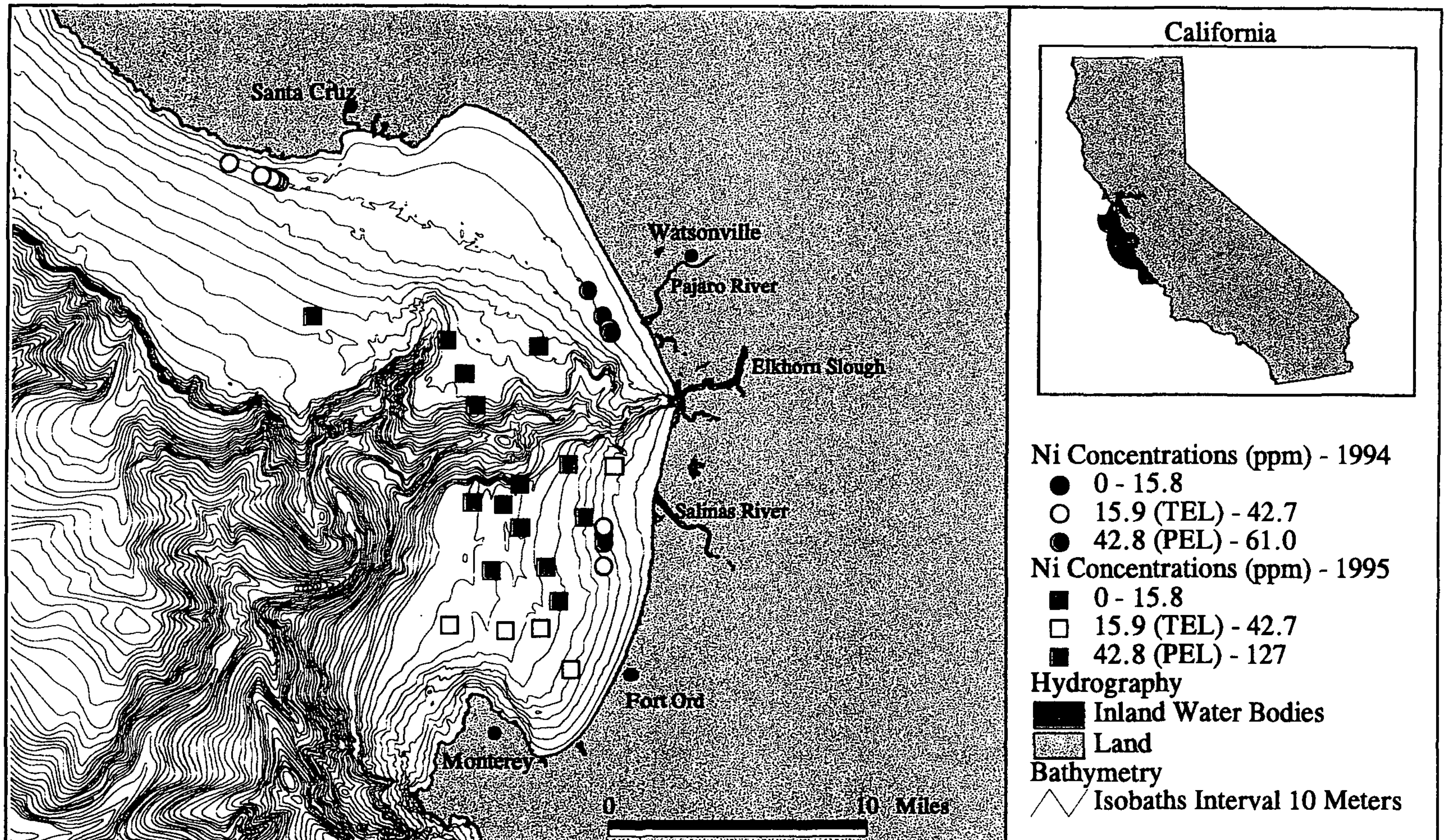

Figure 10: Spatial Analysis of Nickel Concentrations in Monterey Bay Sediments

Sources: Adapted from data: Ni-raw (1995 data), Distribution and Concentration of Selected Contaminants in Monterey Bay Sediments (Stephenson et al. 1997); Ni-raw (1994 electronic data), (Kinnetic Lab 1994), (ABA Consultants1995); Hydrography (DLG data), U.S. Geological Survey, National Mapping Division (USGS 1993); Bathymetry (digital file), U.S. Geological Survey, Marine and Coastal Geology (USGS 1990).

Chromium

The mean for the average number of species at low-Cr(total) concentration sites and the high-Cr(total) sites was 905.3 and 1,072.6 number of individuals per m^2 respectively. A t-test comparing these means shows no significant difference in the average number of species at low-Cr (total) concentration sites and the high-Cr(total) sites ($t = -1.36$; degrees of freedom (*df*) $= 50$; $p > 0.05$) (Table 2).

Table 2: A t-test Comparison Between the Means of Average Number of Species at Low-Cr (total) Concentration Sites and High-Cr (total) Concentration Sites.

t-test for Two Independent Samples	Mean for Average Number of Species	t statistics	*df*	p-value
Low-Cr (total) Concentration Sites (≤TEL)	905.3 n = 31; S.D. = 583.9	-1.36	50	p > 0.05
High-Cr (total) Concentration Sites (≥ TEL)	1072.6 n = 35; S.D. = 376.3			

The average total abundance had a mean of 10,617.5 number of individuals per m^2 for low-Cr(total) concentration sites and a mean of 10,298.57 number of individuals per m^2 at high-Cr(total) concentration sites. A t-test comparison of these means shows no statistically significant difference between the average total abundance at low-Cr(total) concentration sites and the high-Cr(total) sites ($t = 0.24$; *df* $= 63$; $p > 0.05$) (Table 3).

Table 3: t-test Comparison Between the Means of Average Total Abundance at Low-Cr (total) Concentration Sites and High-Cr (total) Concentration Sites.

t-test for Two Independent Samples	Mean for Average Total Abundance	t statistics	*df*	p-value
Low-Cr (total) Concentration Sites (≥ TEL < PEL)	10,617.5 n = 31; S.D. = 4672.1	0.24	63	$p > 0.05$
High-Cr (total) Concentration Sites (≥ TEL < PEL)	10,298.5 n = 35; S.D. = 6061.4			

Nickel

The mean for the average number of species at low-Ni concentration sites was 1,074.8 number of individuals per m^2 which is significantly higher that the mean of 719.1 number of individuals per m^2 for the average number of species at high-Ni concentration sites. A t-test comparing these means shows a significant difference in average number of species between low-Ni concentration sites and high-Ni concentrations sites ($t = 3.54$; $df = 44$; $p < 0.05$).

Table 4: A t-test Comparison Between the Means of Average Number of Species at Low-Nickel Concentration Sites and High-Nickel Concentration Sites.

t-test for Two Independent Samples	Mean for Average Number of Species	t statistics	*df*	p-value
Low-Ni Concentration Sites (≥ TEL < PEL)	1,074.8 n = 51; S.D. = 509.7	3.54	44	$p < 0.05$
High-Ni Concentration Sites (≥ PEL)	719.1 n = 15; S.D. = 273.1			

Similarly, the mean for average total abundance at low-Ni concentration sites was 11,010 individuals per m^2, and the mean of average total abundance at high-Ni concentration sites was 8,539 individuals per m^2. A t-test comparison of these means shows no significant difference between the average total abundance between low-Ni concentration sites and high-Ni concentrations sites ($t= 1.57$; $df = 64$; $p > 0.05$).

Table 5: A t-test Comparison Between the Means of Average Total Abundance at Low-Nickel Concentration Sites and High-Nickel Concentration Sites.

t-test for Two Independent Samples	**Mean for Average Total Abundance**	**t statistics**	***df***	**p-value**
Low-Ni Concentration Sites (≥ TEL < PEL)	11,010 n = 51; S.D. = 5168.0	1.57	64	p>0.05
High-Ni Concentration Sites (≥ TEL < PEL)	8,539 n = 15; S.D. = 5973.1			

Evaluation of Benthic Control Stations

Santa Cruz

One-way ANOVA was used to test the following null hypotheses:

H_o1: There is no statistically significant difference in the means of average number of species found among stations SC1, SC2, SC3, and SC4 surrounding the City of Santa Cruz outfall.

H_o2: There is no statistically significant difference in the means of average total abundance found among stations SC1, SC2, SC3, and SC4 surrounding the City of Santa Cruz outfall.

H_o1 was accepted, concluding that there is no difference between the means of average number of species among the monitoring stations surrounding the City of Santa Cruz ($F = 2.71$; F *critical* = 3.23; $df = 19$; $p > 0.05$). H_o2 was rejected, thus finding a significant difference in the means of average total abundance among stations ($F = 31.64$; F critical = 3.23; $df = 19$; $p < 0.05$). Table 6, summarizes the results of the *a priori* comparisons used to find which stations had different average total abundance.

Table 6: *A priori* Comparisons of Average Total Abundance (Infauna) for the Monitoring Stations Surrounding the City of Santa Cruz Outfall.

Levels of *a priori* comparisons	**p-value**	**Accept or Reject H_o**
H_o3: There is no statistically significant difference in the mean of average total abundance found at station SC4 versus stations SC1, SC2, and SC3, or SC4 = SC1, SC2, SC3, similarly,	$p < 0.05$	Reject
H_o4: SC3 = SC 1, SC2	$p > 0.05$	Accept
H_o5: SC1 = SC2	$p > 0.05$	Accept

The *a priori* comparisons revealed that there are differences in the average total abundance found at the reference station versus the nearfield sampling stations (SC1, SC2, and SC3).

Watsonville

The following null hypotheses were tested using a one-way ANOVA:

H_o1: There is no statistically significant difference in the means of average number of species found at stations R1N, R2, R4, R5, and R6 surrounding the City of Watsonville outfall.

H_o2: There is no statistically significant difference in the means of average total abundance found at stations R1N, R2, R4, R5, and R6 surrounding the City of Watsonville outfall.

H_o1 was rejected, concluding that there is a significant difference between the means of average number of species among stations ($F = 4.83$; F *critical* = 2.86; *df* = 24; $p < 0.05$). H_o2 was rejected, thus finding significant differences in the means of average total abundance among stations ($F = 4.71$; F *critical* = 2.86; *df* = 24; $p < 0.05$). *A priori* comparisons were used to find where the differences lie in the benthic parameters among the stations.

An *a priori* comparison found no significant difference in the means of number of species between the control station R6 versus the nearfield stations (R1N, R2, R4, and R5). *A priori* comparisons revealed that the average number of species at station R2, which lies south of the outfall, was significantly different from the other stations (Table 7). Therefore, stations lying north and south were also compared.

Table 7: *A priori* Comparisons of Average Number of Species (Infauna) for the Monitoring Stations Surrounding the City of Watsonville Outfall.

Levels of *a priori* comparisons	**p-value**	**Accept or Reject H_o**
H_o3: There is no statistically significant difference in the means of average number of species found at station R6 versus stations R1N, R2, R4, and R5, or, R6 = R1N, R2, R4, and R5, similarly,	$p > 0.05$	Accept
H_o4: R5 = R1N, R2, R4	$p > 0.05$	Accept
H_o5: R4 = R1N, R2	$p > 0.05$	Accept
H_o6: R2 = R1N	$p < 0.05$	Reject
H_o7: R2 = R6, R5, R4, R1N	$p < 0.05$	Reject

An *a priori* comparison was used to test the following null hypothesis:

H_o7: There is no statistically significant difference in the means of number of species found at the station R2 south of the outfall versus stations R1N, R4, R5, and R6 (north of the outfall).

The above hypothesis was rejected since $p < 0.05$.

Table 8, summarizes the results of the *a priori* comparisons used to find which stations had different average total abundance.

Table 8: *A priori* Comparisons of Average Total Abundance (Infauna) for the Monitoring Stations Surrounding the City of Watsonville Outfall.

Levels of *a priori* comparisons	**p-value**	**Accept or Reject H_o**
H_o8: There is no statistically significant difference in the means of average total abundance found at station R6 versus stations R1N, R2, R4, and R5, or, R6 = R1N, R2, R4, and R5, similarly,	$p > 0.05$	Accept
H_o9 R5 = R1N, R2, R4	$p > 0.05$	Accept
H_o10: R4 = R1N, R2	$p < 0.05$	Reject
H_o11: R2 = R1N	$p < 0.05$	Reject
H_o12: R2 = R6, R5, R4, R1N	$p < 0.05$	Reject

An *a priori* comparison found no significant difference in the means of average total abundance between the control station R6 versus the nearfield stations (R1N, R2,R4, and R5). An *a priori* comparison showed a significant difference in the means of average total abundance between station south of the outfall (R2), and stations north of the outfall (R1N, R4, R5, and R6).

MRWPCA

One-way ANOVA was used to test the following null hypotheses:

H_o1: There is no statistically significant difference among the means of number of species found at stations 60m-N, 60m-S, 900m-N, 900m-S, and 3,000m-S surrounding the MRWPCA outfall.

H_o2: There is no statistically significant difference among the means of total abundance found at stations 60m-N, 60m-S, 900m-N, 900m-S, and 3000m-S surrounding the MRWPCA outfall.

H_o1 was rejected, concluding that there is a significant difference between the means of number of species among the monitoring stations surrounding the MRWPCA outfall ($F = 3.52$; F *critical* = 2.87; $df = 24$; $p < 0.05$). H_o2 was accepted, thus finding no significant differences in the means of total abundance among stations ($F = 2.37$; F *critical* = 2.87; $df = 24$; $p > 0.05$). Table 9, summarizes the results of the *a priori* comparisons used to find which stations had different number of species.

Table 9: *A priori* Comparisons of Number of Species (Infauna) for the Monitoring Stations Surrounding the MRWPCA Outfall.

Levels of *a priori* comparisons	**p-value**	**Accept or Reject H_o**
H_o3: There is no statistically significant difference in the mean of number of species found at station 3000m-S versus stations 60m-N, 60m-S, 900m-N, 900m-S, or, 3000m-S = 60m-N, 60m-S, 900m-N, 900m-S, similarly,	$p > 0.05$	Accept
H_o4: 900m-S = 60m-N, 60n-S, 900m-N	$p > 0.05$	Accept
H_o5: 900m-N = 60m-N, 60m-S	$p < 0.05$	Reject
H_o6: 60m-S = 60m-N	$p < 0.05$	Reject

The *a priori* comparisons revealed that there was no difference in the average total abundance found at the control station (3000m-S) versus the nearfield sampling stations (60m-N, 60m-S, 900m-N, and 900m-S).

CHAPTER VI

Discussion of Results

Spatial Analysis of Metals of Concern

Arsenic

Arsenic concentrations were found to be above the TEL (7.2 ppm) screening levels at stations B155 and B156 on the north edge of the Monterey Bay Canyon and stations B163 and B160 on the southern edge of the Canyon. These stations were included in the Fort Ord Study. Station SC2, which lies 200 meters east-south-east of the City of Santa Cruz, also has concentrations above the TEL but below PEL (41.6 ppm) value for As. Historical monitoring data shows that the monitoring station SC2 had As concentrations above the TEL only during 1994 monitoring year (Figure 11).

Thus, As is observed to be of concern only in a small region along the northern and southern edge of the Monterey Bay Canyon (see Figure 8). The possible sources of As may include agricultural runoff (nonpoint source), since As is a constituent in pesticides and herbicides used in the cultivated fields in the Monterey Bay region (NOAA 1991b). The rivers and streams draining into the Bay may possibly be the sources bringing the agricultural runoff and arsenic to the Bay, which gets deposited in sediments along the Canyon.

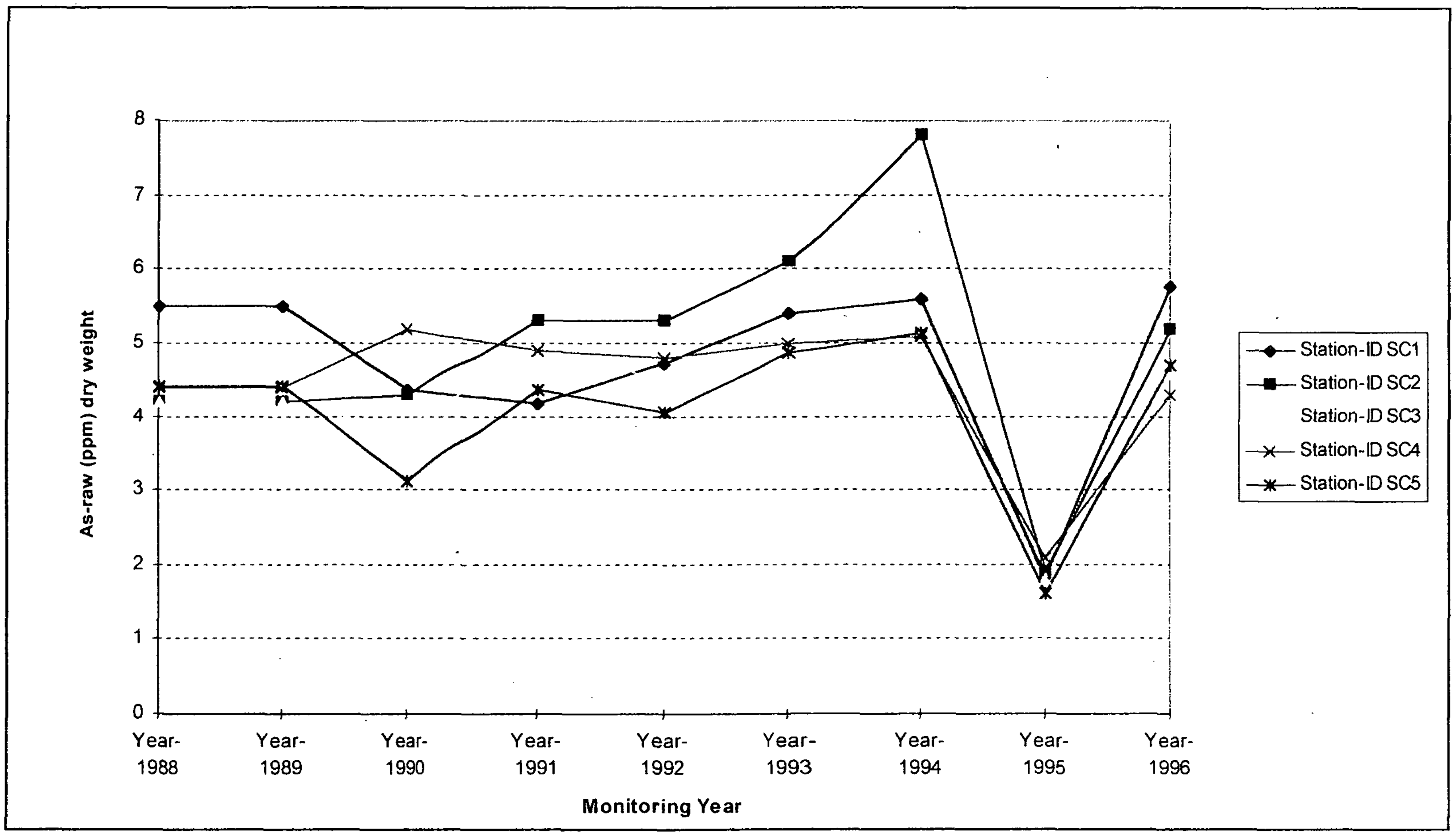

Figure 11: Arsenic Concentrations from 1988 to 1996 for the City of Santa Cruz Sediment Monitoring Stations (TEL = 7.2 ppm; PEL = 41.6 ppm)

Chromium

Chromium (total) was found in high concentrations, above TEL (52.3 ppm) screening levels, in sediments around the City of Santa Cruz and City of Watsonville outfalls. Historical monitoring data from 1988 to 1996, show that the Cr levels have been consistently above the TEL for most of the sampling stations around the City of Santa Cruz outfall (Figure 12). Fluctuations in the Cr concentrations are observed around the City of Watsonville outfall, as revealed by historical data for the years 1988 to 1996 (Figure 13). Historical monitoring data for sediment stations around the MRWPCA outfall shows Cr concentration to be below TEL (Figure 14). The Fort Ord Study sites show high Cr (total) concentration, above the PEL (160.4 ppm), observed along the edges of the Monterey Bay Canyon (see Figure 9) and most of the southern part of the Bay had concentrations above the TEL level.

Nickel

Nickel concentrations were observed to be high for the majority of the sediment sampling stations in Monterey Bay (see Figure 10). Historical data shows Ni concentrations to be above the TEL (15.9 ppm) through the majority of the monitoring year for the sediments around the City of Santa Cruz outfall (Figure 15). Monitoring year 1995 had concentrations ranging above the PEL (42.8 ppm) for Ni at two stations (SC2 and SC4) around the outfall.

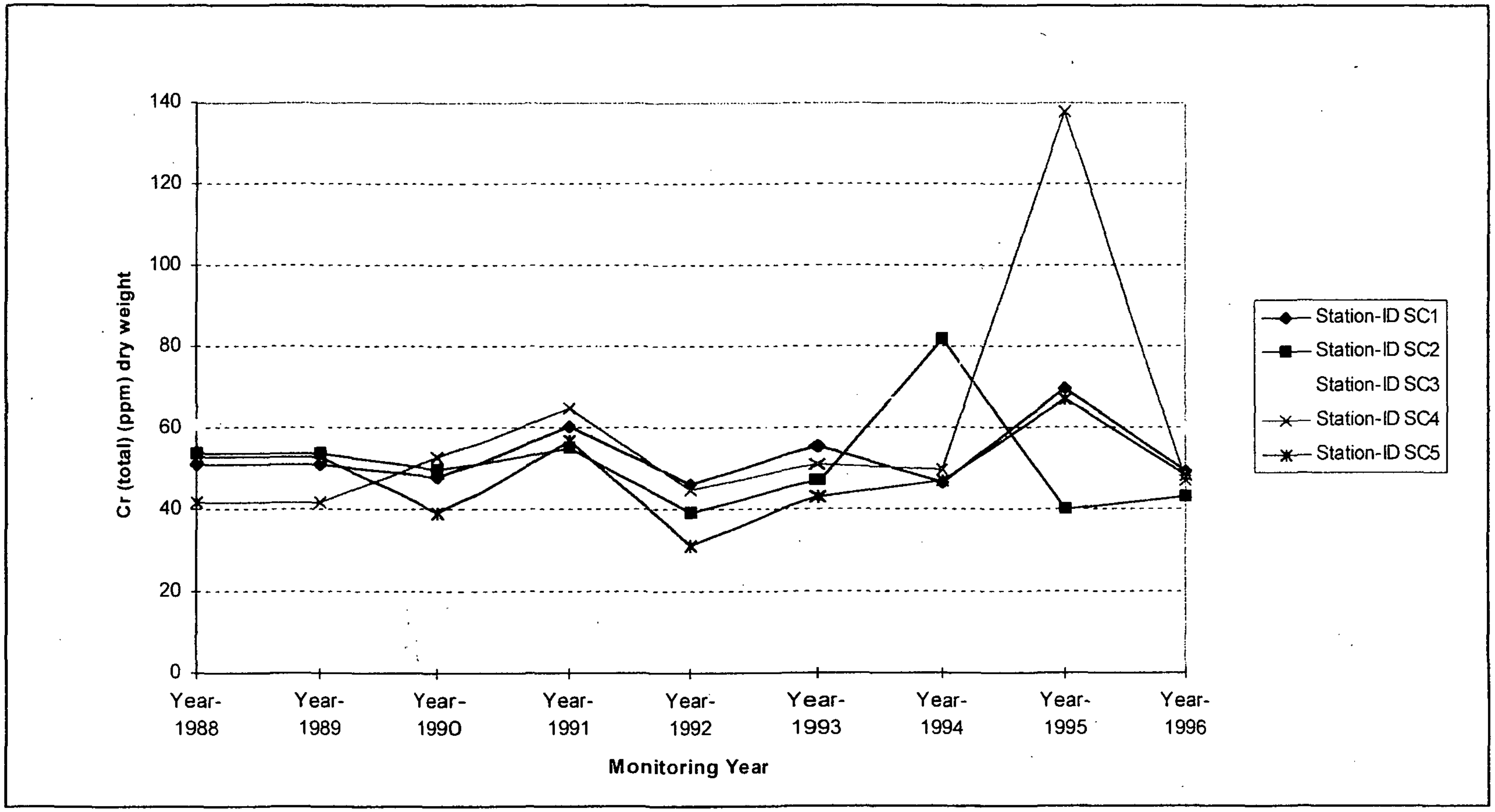

Figure 12: Chromium (total) Concentrations from 1988 to 1996 for the City of Santa Cruz Sediment Monitoring Stations (TEL = 52.3 ppm; PEL = 160.4 ppm)

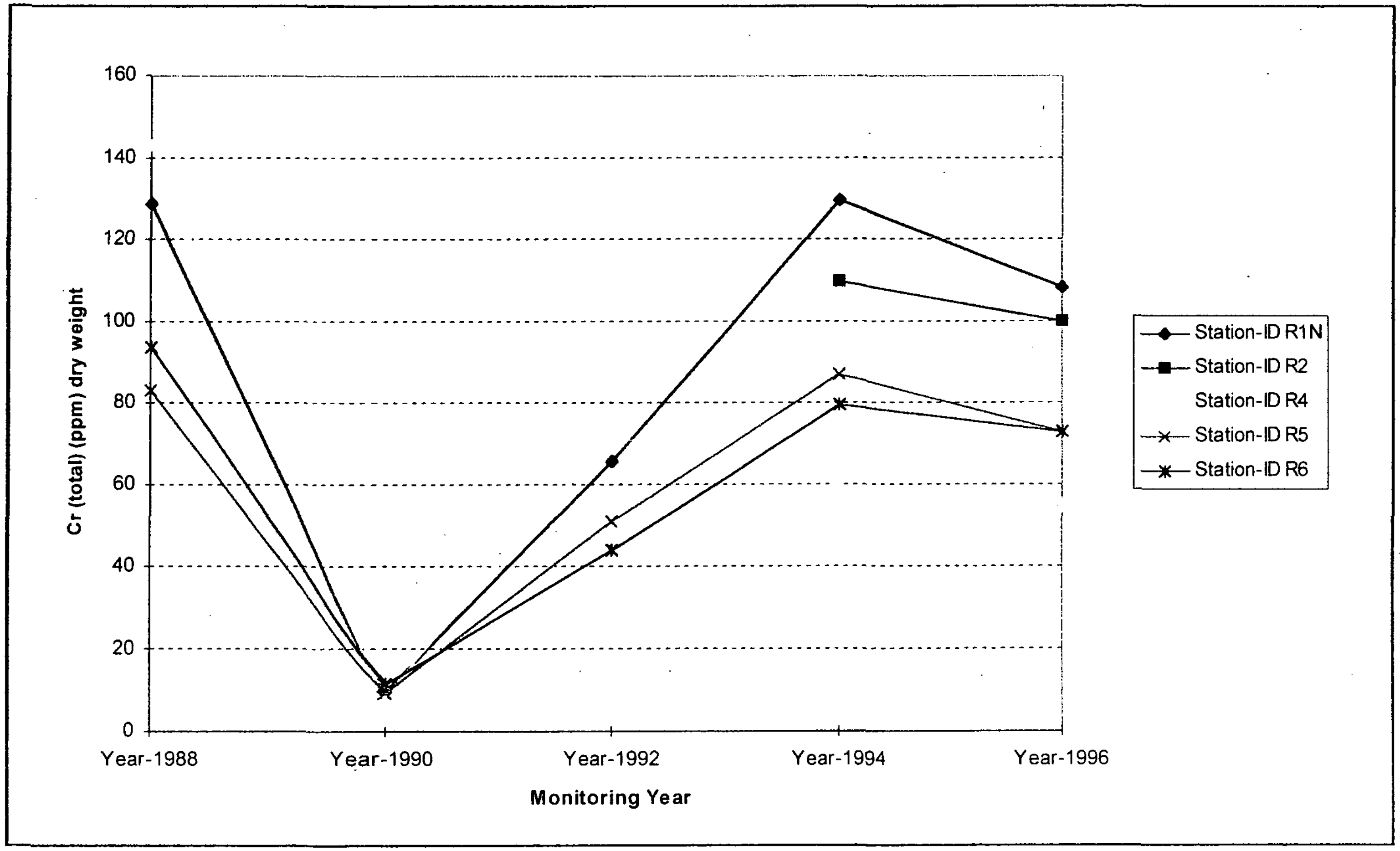

Figure 13: Chromium (total) Concentrations from 1988 to 1996 for the City of Watsonville Sediment Monitoring Stations (TEL = 52.3 ppm; PEL = 160.4 ppm)

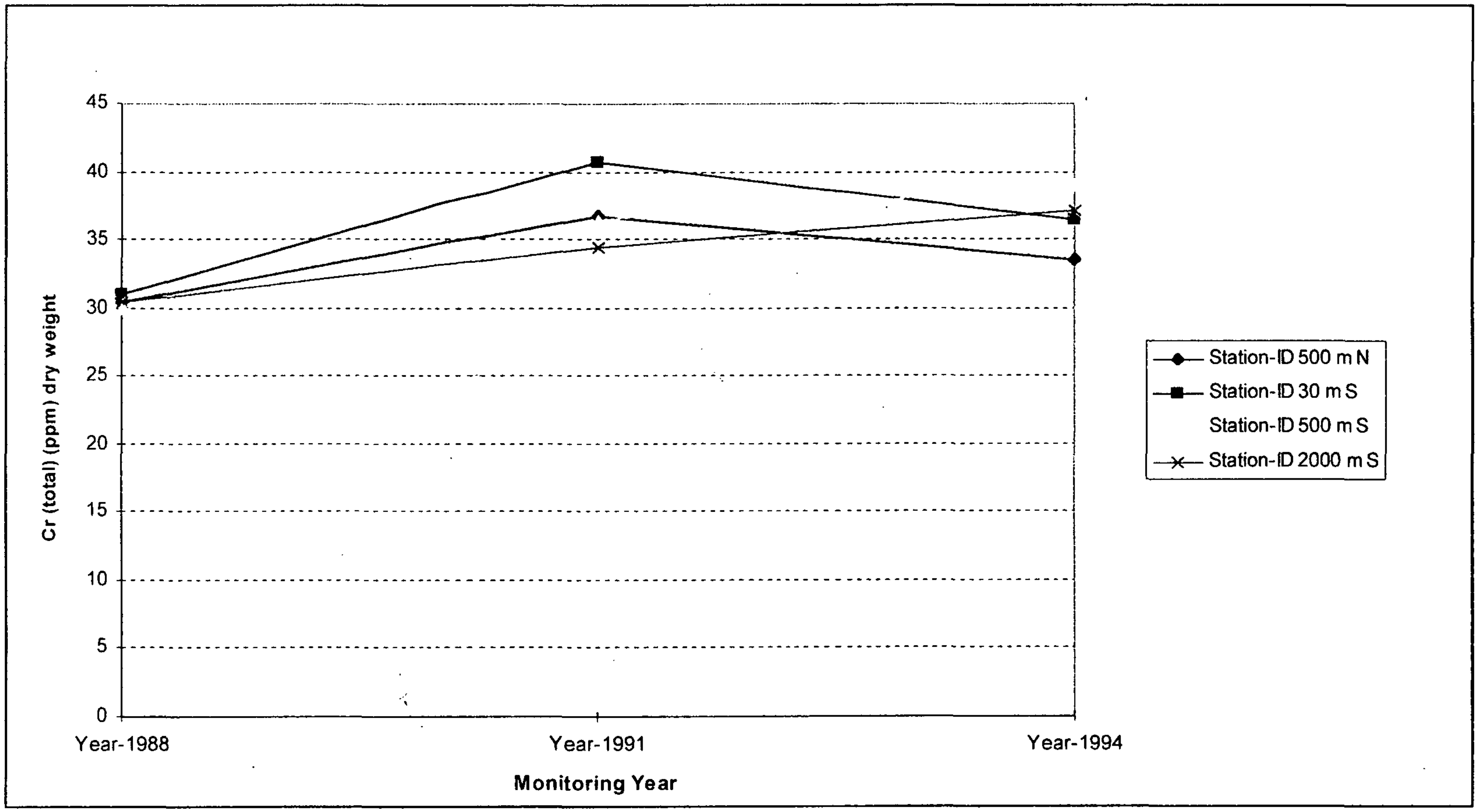

Figure 14: Chromium (total) Concentrations from 1988 to 1994 for the MRWPCA Outfall Sediment Monitoring Stations (TEL = 52.3 ppm; PEL = 160.4 ppm)

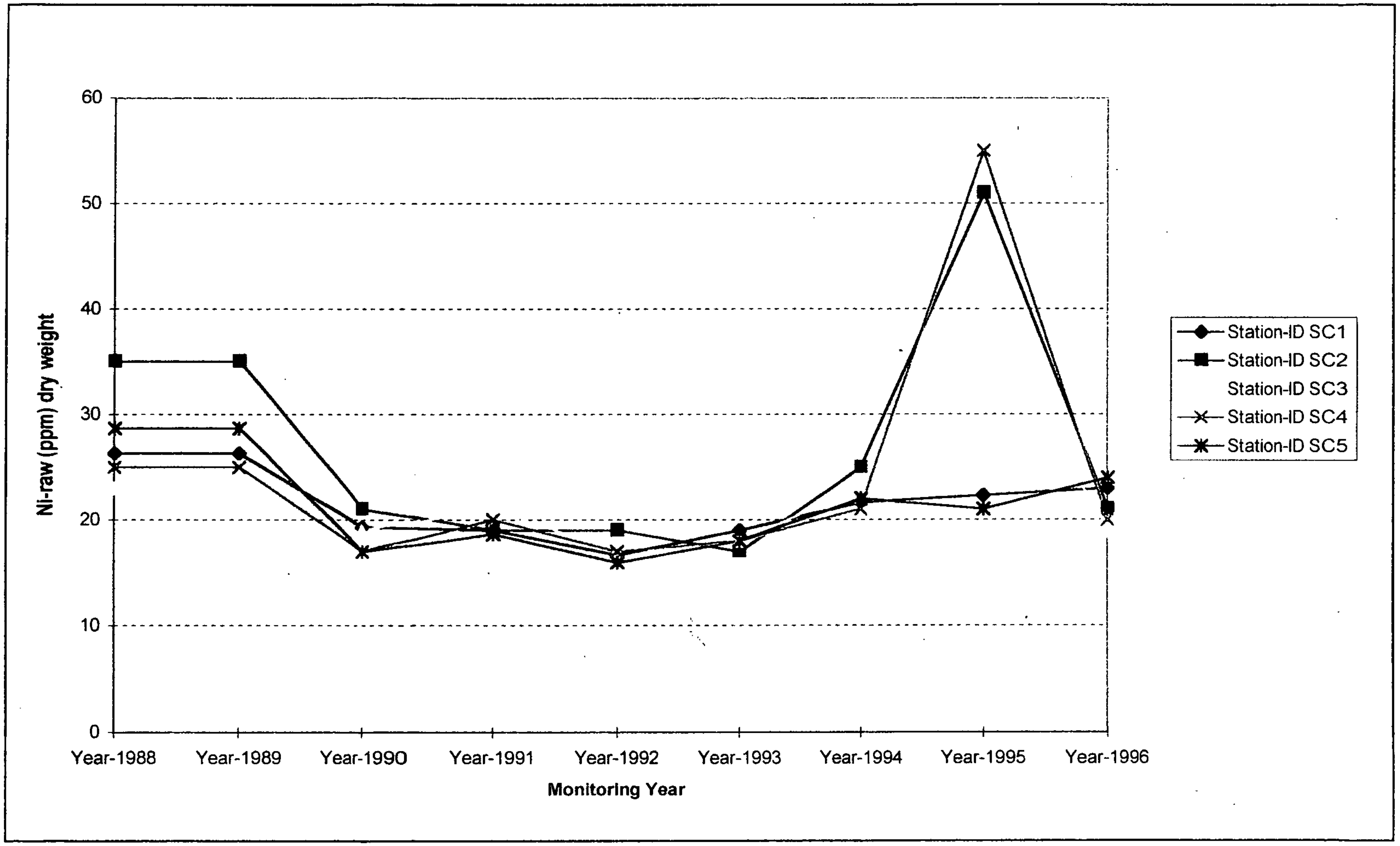

Figure 15: Nickel Concentrations from 1988 to 1996 for the City of Santa Cruz Sediment Monitoring Stations (TEL = 15.9 ppm; PEL = 42.8 ppm)

Figure 16 illustrates the sediment concentrations for Ni to be above TEL from 1988 through 1996 around the City of Watsonville outfall. High concentrations, i.e. above the PEL for Ni, were observed during the monitoring years 1988, 1994, and 1996 around the City of Watsonville outfall. During 1990 and 1992, Ni concentrations were found to be above TEL but below PEL.

Nickel concentrations in the sediment around the MRWPCA outfall were found to be above the TEL but below PEL during the monitoring years 1988, 1991, and 1994 (Figure 17). Sediment monitoring stations 30 m south of the outfall had concentration above PEL for Ni during 1991 and 1994. High Ni concentrations above PEL were also found at the sediment monitoring station 500 m south of the outfall.

Possible Explanation for High Chromium and Nickel Concentrations

Geologic sources may be the possible explanation for high concentration of Ni and Cr in Monterey Bay sediments. Ultramafic rocks, such as Serpentine, are known to be abundant in chromium and nickel. Serpentine deposits occur in many places in California, from Santa Barbara County to the Oregon border in the Coast Ranges and intermittently along the western foothills of the Sierra Nevada from Tulare to Plumas counties (Kruckeberg 1984). These metals have been found to be in high concentration in San Francisco Bay, Tomales Bay, and Humboldt Bay in Northern California and are thought to be natural in origin (Stephenson et al. 1997). In a study, sediment core samples dating from 1850 to present, showed high concentrations of Ni and Cr throughout the length of the cores from San Francisco Bay (Hornberger et al. 1998).

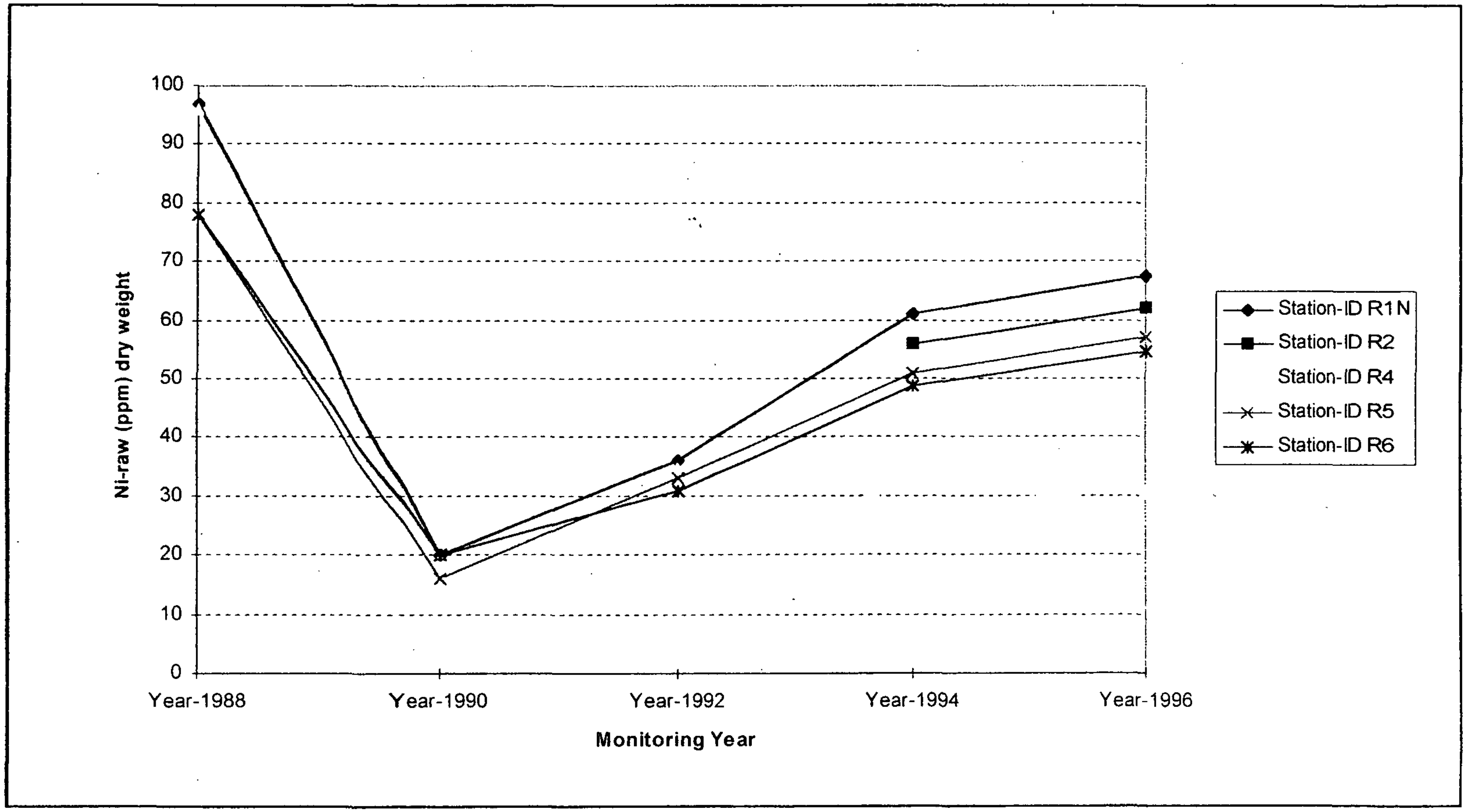

Figure 16: Nickel Concentrations from 1988 to 1996 for the City of Watsonville Sediment Monitoring Stations (TEL = 15.9 ppm; PEL = 42.8 ppm)

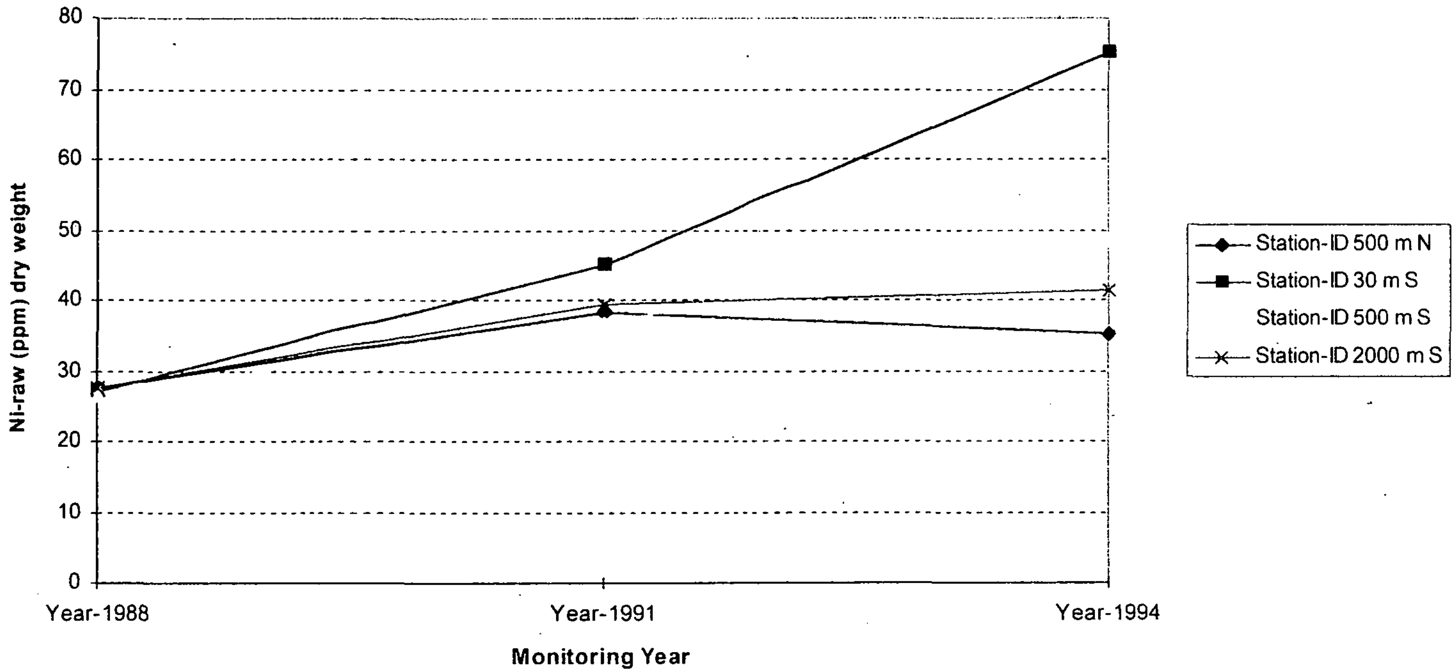

Figure 17: Nickel Concentrations from 1988 to 1994 for the MRWPCA Sediment Monitoring Stations (TEL = 15.9 ppm; PEL = 42.8 ppm)

These high concentrations of Ni and Cr in San Francisco Bay were found to be consistent with the surrounding watershed geology. Thus, the general landward to seaward declining gradient concentration of nickel and chromium was possibly related to geologic sources in San Francisco Bay (Hornberger et al. 1998). Nickel and chromium concentrations in Monterey Bay sediment are within the range of background levels found in other bays in Northern California (NOAA 1987; NOAA 1991a).

Temporal fluctuations in the concentrations of Ni and Cr around the three major municipal outfalls into Monterey Bay may be due to the methods used for trace metal extraction from sediment samples. The method of strong-acid digestion may produce greater amounts of metals by dissolving sediment particles into their mineral components, which presumably are not all bioavailable to marine organisms, whereas the weak-acid digestion method removes only the metals that are weakly absorbed to particle surfaces (Kinney and Toal 1997b). This component is alleged to be more readily available to the organisms. The weak acid digestion method was used to extract trace metals from sediment samples around the City of Watsonville outfall in 1990 and 1992 (Kinney and Toal 1997b). Monitoring data show a decline in the levels of Cr and Ni during these years. Chromium levels were below TEL, and Ni concentrations were below PEL. Also, the levels of Cr and Ni in the effluents from the municipal discharges have remained either constant or decreased over the years (Antosz 1998; Pierson 1998).

Relationship Between Increasing Metal Concentrations and Benthic Parameters

A t-test comparison of benthic infauna community parameters at low-Cr (total) concentration sites and high-Cr (total) sites showed no apparent relationship to the levels of Cr (total) in sediment around the three municipal outfalls (Table 10 and Table 11).

Table 10: A Summary of t-test Comparisons Between the Means of Average Number of Species (Infauna) at Low-Metals Concentration Sites and High-Metals Concentrations Sites.

t-test Comparison	p-value	Statistically Significant Difference
Low-Cr (total) Concentration Sites vs. High-Cr (total) Concentration Sites	$p > 0.05$	No
Low-Ni Concentration Sites vs. High-Ni Concentration Sites	$p < 0.05$	Yes

Table 11: A Summary of t-test Comparisons Between the Means of Average Total Abundance (Infauna) at Low-Metals Concentration Sites and High-Metals Concentrations Sites.

t-test Comparison	p-value	Statistically Significant Difference
Low-Cr (total) Concentration Sites vs. High-Cr (total) Concentration Sites	$p > 0.05$	No
Low-Ni Concentration Sites vs. High-Ni Concentration Sites	$p > 0.05$	No

Although, Cr (total) was found above the screening level (TEL) known to affect biotic communities, high Cr (total) concentrations do not show any impact on the benthic infauna (number of species and total abundance) in sediments around the three outfalls to Monterey Bay.

The t-test comparison of the benthic parameters at sites with low-Ni concentration and high-Ni concentration sites around the municipal outfalls to Monterey Bay shows a significant difference between the average number of species (Table 10). Monitoring stations with low-Ni concentrations show higher averages of number of species. High-Ni concentrations sites show a lower average number of species. Thus, a possible reason for the decrease in the number of species around the outfalls may include the increase in sediment concentrations of Ni in Monterey Bay. A t-test comparison of average total abundance at low-Ni concentration and high-Ni concentration sites show no apparent relationship to the levels of Ni in sediment around the municipal outfalls (Table 11).

Evaluation of Benthic Control Stations

The following tables (Table 12 and Table 13) give a summary of the analysis of variance (ANOVA) comparisons for the means of average number of species and average total abundance among the stations surrounding the three outfalls to Monterey Bay.

Table 12: A Summary of Analysis of Variance Comparisons of the Means of Average Number of Species (Infauna) Among Stations Surrounding the Municipal Outfalls to Monterey Bay.

ANOVA comparisons for Average Number of Species Among Stations Around the Outfall	**ANOVA p-value**	**ANOVA Statistically Significant Difference**	***A priori* Comparisons Between Reference Station vs. Nearfield Stations Around the Outfalls**	***A priori* Comparisons Between Stations North and South of the Outfalls**
City of Santa Cruz	$p > 0.05$	No	N.A.*	N.A.
City of Watsonville	$p < 0.05$	Yes	Not Significant	Significant
MRWPCA	$p < 0.05$	Yes	Not Significant	Significant

* N.A. = Not Analyzed

Table 13: A Summary of Analysis of Variance Comparisons of the Means of Average Total Abundance (Infauna) Among Stations Surrounding the Municipal Outfalls to Monterey Bay.

ANOVA for Average Total Abundance Among Stations Around the Outfall	**ANOVA p-value**	**ANOVA Statistically Significant Difference**	***A priori* Comparisons Between Reference Station vs. Nearfield Stations Around the Outfalls**	***A priori* Comparisons Between Stations North and South of the Outfalls**
City of Santa Cruz	$p < 0.05$	Yes	Significant	N.A.*
City of Watsonville	$p < 0.05$	Yes	Not Significant	Significant
MRWPCA	$p > 0.05$	No	N.A.	N.A.

* N.A. = Not Analyzed

Santa Cruz

One-way ANOVA showed no differences in the means of average number of species among stations surrounding the outfall (Table 12). ANOVA found significant differences in means of average total abundance among stations around the City of Santa Cruz outfall (Table 13). *A priori* comparisons revealed that the average total abundance was significantly different at control station (SC4) versus the nearfield sampling station in the vicinity of the City of Santa Cruz outfall. Figure 18 shows that the mean of average total abundance at the control station SC4 is significantly higher as compared to the nearfield stations (SC1, SC2, and SC3). Thus, the control station SC4 may be an appropriate reference site as it is removed from the impact of the effluent discharge.

Watsonville

One-way ANOVA found significant differences in the means of average number of species and average total abundance among stations in the vicinity of the City of Watsonville outfall (Table 12 and Table 13). *A priori* comparisons showed no difference in the benthic parameters between the reference station (R6) and the nearfield stations (R1N, R2, R4, and R5). The means of average number of species and total abundance were found to be significantly lower at the sampling station R2, which lies 200 m south of the outfall, versus stations north of the outfall (R1N, R4, R5, and R6). Figure 19 and Figure 20 show a decreasing trend in the mean average number of species and average total abundance with increasing distance from the outfall. Therefore, the reference site may not be removed from the impact of the effluent discharged. Additional data, such as

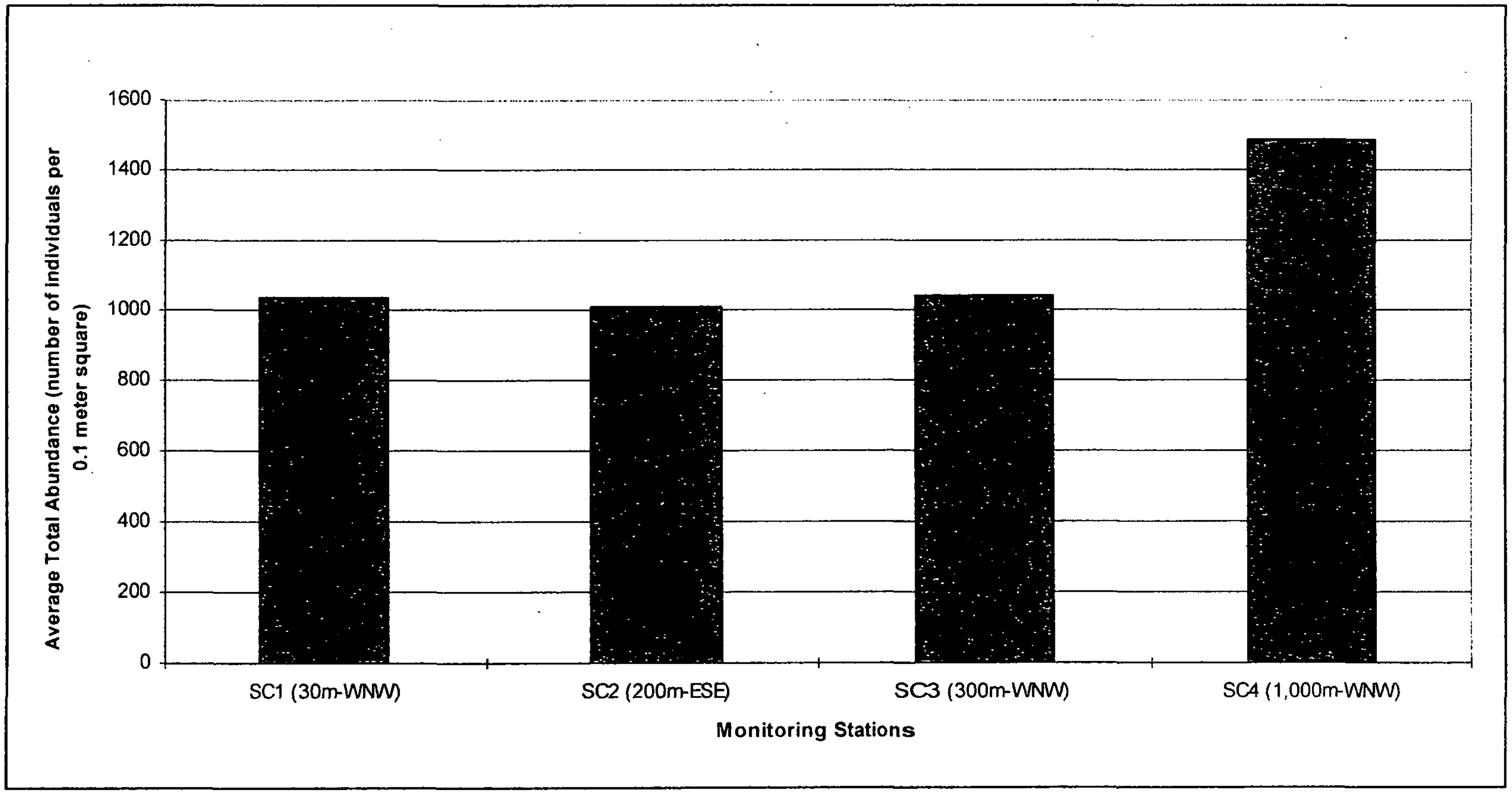

Figure 18: Average Total Abundance at Benthic Infauna Monitoring Stations around the City of Santa Cruz Outfall

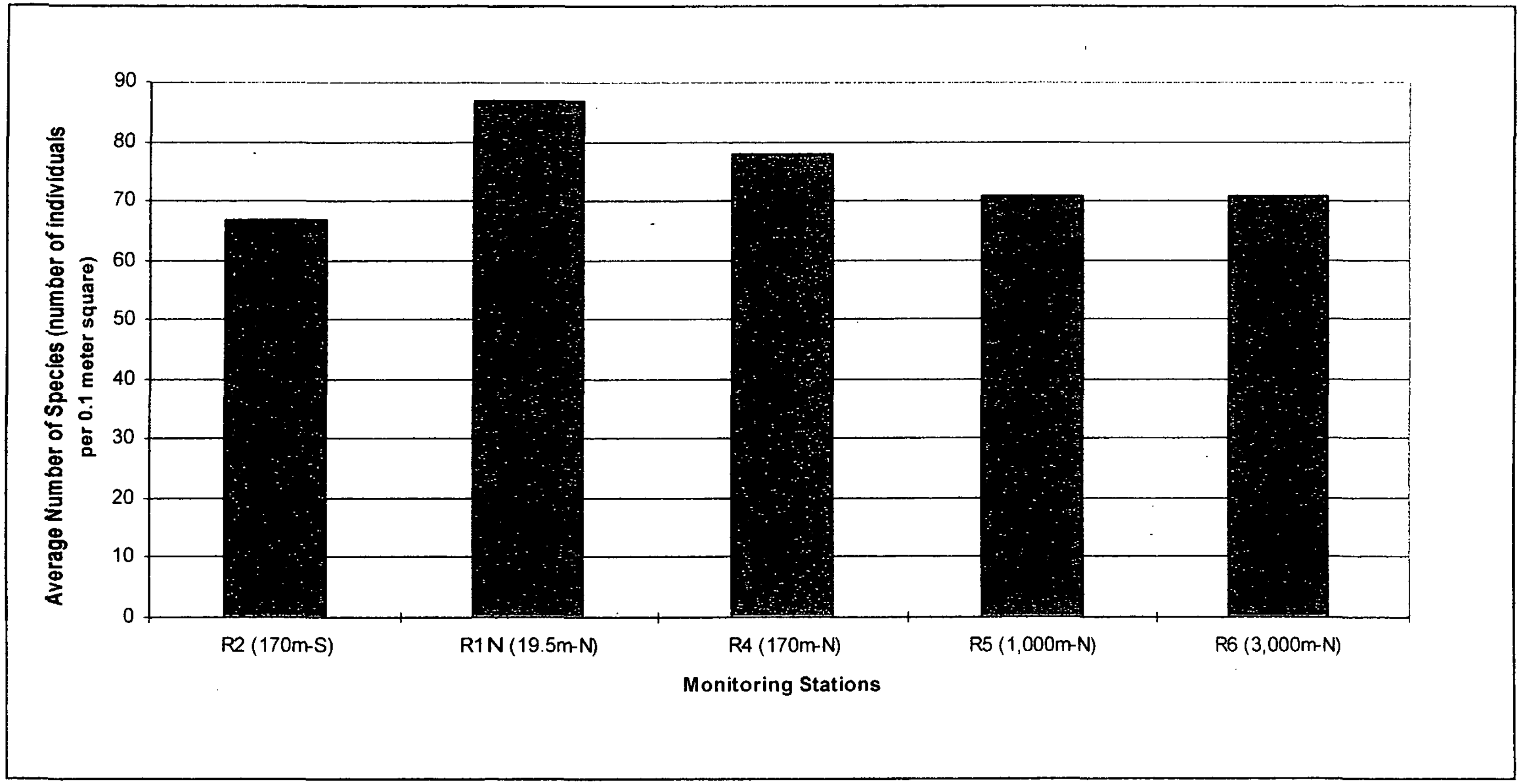

Figure 19: Average Number of Species at Benthic Infauna Monitoring Stations around the City of Watsonville Outfall

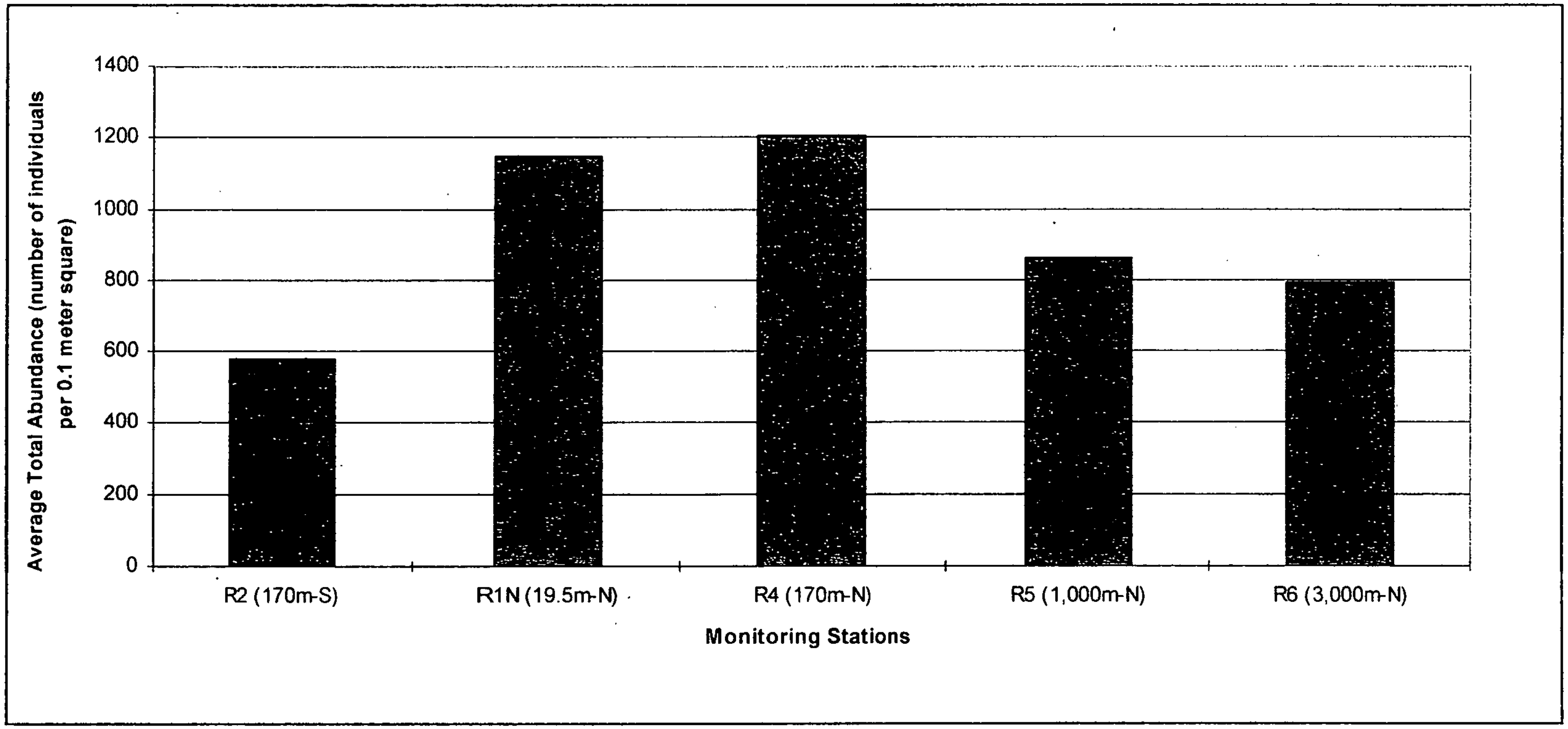

Figure 20: Average Total Abundance at Benthic Infauna Monitoring Stations around the City of Watsonville Outfall

species richness and evenness need to be considered for a complete analysis of the usefulness of the reference site.

MRWPCA

One-way ANOVA found a significant difference between the means of number of species among the monitoring stations surrounding the MRWPCA outfall. ANOVA showed no significant difference in the means of total abundance among the stations. *A priori* comparisons showed no difference in the means of number of species between the control station (3,000m-S) versus the nearfield stations (60m-N, 60m-S, 900m-N, and 900m-S). A significant difference was found among the mean number of species at stations 60-m N and 60m-S of the outfall. Figure 21, shows a decreasing trend in the number of species with increasing distance both north and south of the outfall. The reference station has a lower number of species as compared to the stations closer to the outfall. Thus, the above comparison raises concern over the possible inappropriate location of the reference site. For a complete evaluation of the reference site additional data, including species richness and evenness needs to be considered.

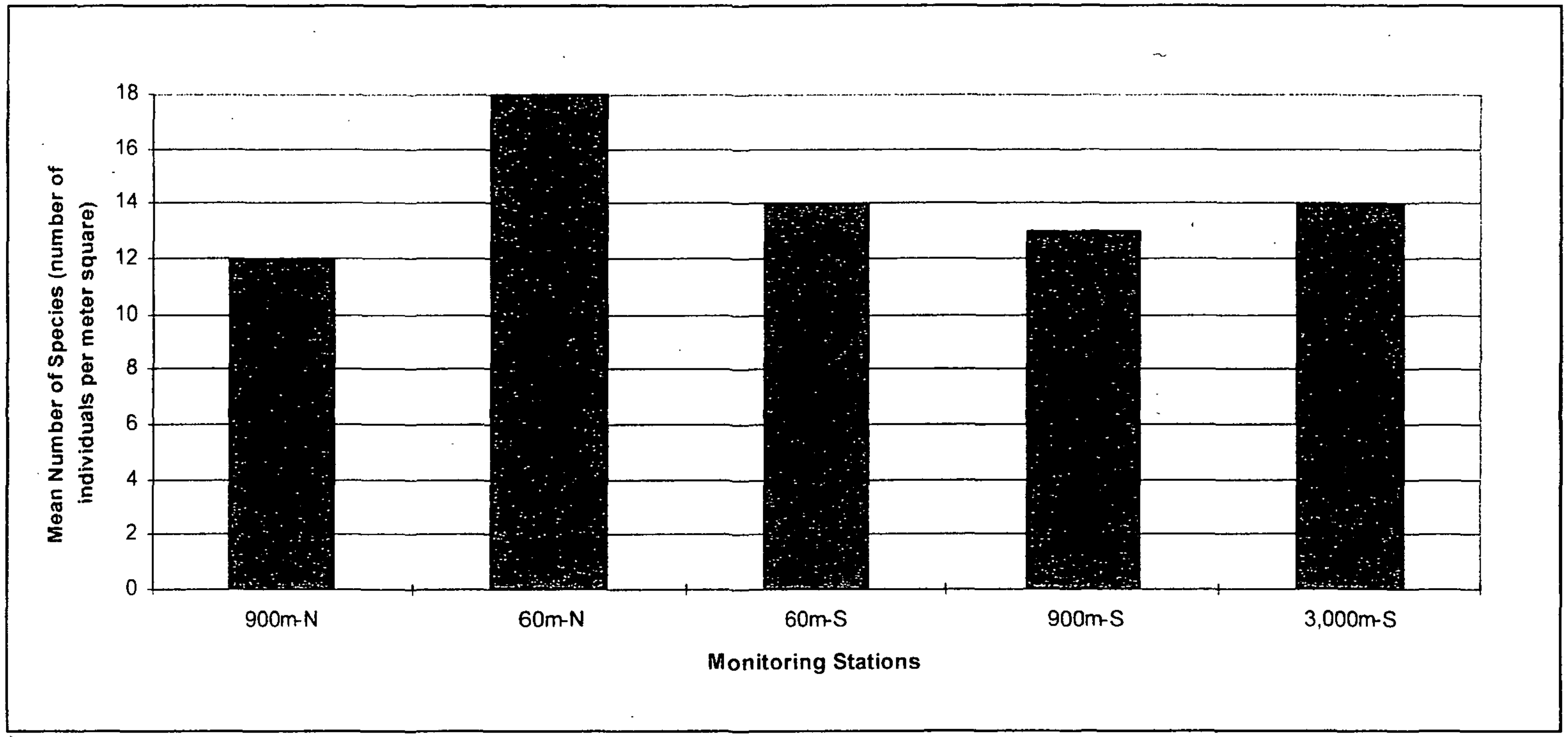

Figure 21: Mean Number of Species at Benthic Infauna Monitoring Stations around the MRWPCA Outfall

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

One of the primary objectives of this study was to identify and spatially analyze the trace metals of concern in Monterey Bay sediments. Arsenic, Cr (total), and Ni were identified as metals of concern in the Bay, based on informal screening guidelines prepared for NOAA as a part of the NS & T Program and updated by MacDonald (1994). The screening values used included the TEL and PEL for trace metals in sediments (MacDonald 1994; NOAA 1994a). These metals of concern were observed at concentrations that could potentially be associated with chronic or acute adverse biological effects.

Arsenic was found to be above TEL but below PEL at two stations along the north and south edges of the Monterey Bay Canyon. Possible sources for As may include agricultural runoff brought into Monterey Bay by the rivers. Since it is impossible to isolate sources related to contaminants in the marine environment, other possible sources may include various point and non-point source pollution activities in the Monterey Bay region.

Nickel and Chromium were found in high concentrations (above TEL and PEL) at many stations in Monterey Bay. Such concentrations of Ni and Cr (total) are not uncommon in northern California coastal sediments and may be related to the natural crustal abundance of these metals in sediments (Stephenson et al. 1997). Nickel and Chromium concentrations in Monterey Bay sediment are within the range of background levels found in other Northern California bays, such as San Francisco Bay, Tomales Bay, and Humboldt Bay (NOAA 1987; NOAA 1991a; Stephenson et al. 1997; Hornberger et al. 1998). Further research involving sediment core sample studies are needed to reveal the background levels for these metals in Monterey Bay sediments.

This study observed spatial and temporal fluctuations in the concentration levels of Cr and Ni around the three major municipal outfalls to Monterey Bay. The possible explanations of these variations may include:

1. Method of trace metal extraction from sediment samples, indicating greater or lesser amounts based on strong acid or weak acid digestion, respectively,
2. Terrestrial sources such as rivers bringing in metals loading,
3. Fluctuating inputs including effluent discharges mixing with more dilute marine waters,
4. Regional differences in serpentine deposits known to be abundant in Ni and Cr.

Spatial analysis of As, Cr (total), and Ni revealed that the higher level of contamination is generally observed around the north and south edges of the Monterey Bay Canyon. Contamination decreases towards the extreme north and south regions of the Bay. This spatial pattern may possibly be the result of the movement of contaminated sediments from the shallow depths to deeper depths along the Monterey Bay Canyon and in the deeper regions of the Bay (Kinoshita and Noble 1995).

Another major objective of this study was to study the relationship between the metals of concern and soft-bottom benthic biota in Monterey Bay. High levels of Ni in sediments were found to be related to lower numbers of species in the vicinity of the 3 major municipal outfalls into Monterey Bay. No apparent relationship was found between high Ni concentrations and total abundance. High Cr levels were found to have no association to shifts in the benthic community parameters.

This thesis also assessed the reference stations used for evaluating the impacts of discharges on benthic community in the vicinity of the three municipal outfalls. The benthic reference station associated with the City of Santa Cruz outfall showed significantly higher average total abundance but no difference in the average number of species when compared to the nearfield stations. Therefore, this control station may be an appropriate reference site based on the benthic infauna community characteristics.

The benthic parameters (total abundance and number of species) measured at the City of Watsonville and MRWPCA outfalls reference stations were found to be no different than the other nearfield monitoring stations. Therefore, these reference sites may not be removed from the impact of the effluent discharged. Additional data, such as species richness and evenness, need to be considered for a complete analysis of the usefulness of these reference sites. Significant differences in the benthic parameters were found among the stations north and south of the City of Watsonville and MRWPCA outfalls. Therefore, this study recommends that regulatory agencies consider designating more than one reference station for each discharge to evaluate the impact of effluent discharges on the benthic community.

This study was designed as an initial step towards developing a comprehensive regional monitoring database to enhance the existing management of marine monitoring programs. A regional monitoring database will improve coordination, data sharing, data interpretation, and sampling strategies. This thesis set out to integrate monitoring data from five major sewage and industrial discharges to Monterey Bay. This study was unable to integrate monitoring data from the industrial discharges including PG & E, and National Refractories and Minerals Corporation. These data could not be included since the sediment and benthic community parameters are not being monitored for the industrial discharges to Monterey Bay. Though these discharges are not required to monitor the discharge environment, the regulatory agencies may consider periodic monitoring at these sites as a part of the regional monitoring program.

Additional data on sediment trace metal concentrations for 20 sites in the Bay, designated under the Fort Ord study, were integrated with the monitoring data from the City of Santa Cruz, City of Watsonville, and MRWPCA municipal discharges. GIS software was used to integrate tabular and spatial data. Monitoring data between the years 1988 to 1996 on trace metal concentrations and benthic parameters were geo-referenced with the each sampling station location. This allows the selection of any sampling station location in the Bay and the ability to view and query sediment quality and benthic data associated with that location. GIS overlay of the hydrography (coastline and major rivers and streams), bathymetry, and sediment sampling location illustrates a regional spatial perspective of the outfall locations and the associated monitoring stations. Unlike the static paper map, this GIS is dynamic as data can be constantly added from various sources and updated. Thus, this GIS illustrates the ability to improve coordination, data sharing, data interpretation, and sampling strategies among the regulatory and regulated agencies. This study forwards the objective of CCJDC to enhance environmental management by developing a GIS to facilitate spatial data sharing among public and private agencies in Monterey Bay region. Thus, this project can be used as a model for developing a large scale regional database for monitoring and evaluation of point source pollution effects.

Recommendations

Comprehensive marine monitoring at regional and national scales is essential to understand the status of the marine environment and to assess the effects of human activity on it (NRC 1990). The following are some of the shortcomings of the current monitoring programs encountered during this research project. Subsequent recommendations are made to successfully develop a regional monitoring program for pollution control and protection of the marine environment.

Monitoring Frequency

The three municipal discharges under study were found to have different schedules for implementing the Monitoring and Reporting Programs. The City of Santa Cruz monitors annually, the City of Watsonville has a biennial monitoring program, and the MRWPCA outfall is monitored every three years. This creates spatial and temporal data gaps. This project found only one year of overlapping data for the period between 1988 to 1996 for all three discharges. This hinders studying regional long-term trends in sediment contamination and shifts in benthic community structures associated with the discharges. Therefore, it is essential to have consistency in monitoring frequency among different discharges.

Spatial Coverage

This study discovered many spatial gaps in the data. PG & E does not monitor its industrial discharge to the Bay, and the National Refractories and Minerals Corporation do not monitor sediment quality and soft-bottom benthic biota in the vicinity of its discharge to the Bay. The sampling locations for the municipal discharges are clustered around the outfalls, therefore providing localized impacts. A larger number of sampling stations covering the entire Monterey Bay is essential to evaluate regional trends in sediment contaminants concentrations and shifts in benthic infauna. Spatial and temporal data gaps may be filled by integrating data from different monitoring programs (Federal, State, and local), and extensions of existing programs.

Monitoring Coordination

Although marine monitoring in Monterey Bay has been conducted for more than 15 years, there is no overall coordination of monitoring programs. The lack of coordination reflects on the sectoral approach to marine monitoring involving different monitoring methods in use among programs. A good regional assessment of conditions is not possible due to inconsistent monitoring and reporting protocols. Therefore, the data collected by different monitoring programs cannot be easily integrated. The need for standardization of most commonly used marine monitoring methods is essential in developing comprehensive regional monitoring.

Such an effort was conducted for a regional survey of conditions on the mainland shelf of the Southern California Bight in 1994 (Allen 1997). The Southern California Bight Pilot Project consisted of 13 Federal, State, and local agencies and organization. The participating agencies were required to use standardized monitoring methods. This one-time standardization of methods is now evolving towards a permanent standardization of receiving-water quality monitoring methods. An effort to incorporate these methods into discharge permits is currently in progress.

Data Format

Regulatory agencies may consider requiring monitoring data to be delivered in electronic formats. Electronic data from various sources can be easily integrated into a regional GIS. This would support the ongoing effort of the CCJDC to develop regional GIS for spatial data sharing to enhance environmental management in the Central Coast region of California.

Cooperation in Regional Monitoring

Steps may be taken for developing a comprehensive regional marine monitoring program for the Monterey Bay region. Regional monitoring involves cooperative efforts among regulators, dischargers, and researchers. This study has been a step towards incorporating monitoring data from a few selected sources towards developing a regional monitoring program. Thus, it can be used as a model for developing a comprehensive regional monitoring program on larger scale to evaluate point source pollution, assess regional impacts of contaminants sources, and enhance marine environmental management.

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APPENDIX A

Sediment trace metal concentration (ug/g dry weight) for the sampling station designation under the Fort Ord Study, Monterey County, California.

Table 14: **Trace Metal Concentrations (ug/g dry weight) for the Fort Ord Study Sediment Sampling Stations.**

Station-ID	Date	Silver	Arsenic	Cadmium	Chromium	Copper	Mercury	Nickel	Lead	Zinc
B117	4/9/95	0.09	6.33	0.26	139	14.6	0.0959	67.6	8.65	50.2
B131	4/10/95	0.096	7.09	0.26	180	19.4	0.129	99.2	9.6	51.9
B131-D	4/10/95	0.1	7.33	0.28	160	17.9	0.0959	86.1	10.6	77.4
B134	4/10/95	0.089	6.74	0.25	165	17.8	0.107	96.2	8.88	56.2
B148	4/11/95	0.051	3.91	0.2	71.6	6.55	0.0402	34.1	11.3	43.6
B151	4/11/95	0.043	4.53	0.15	121	6.97	0.0311	36.5	10.6	44.9
B154	4/11/95	0.106	6.02	0.49	139	15.8	0.102	94.6	7.7	53.6
B155	4/12/95	0.1	8.35	0.37	171	20.8	0.122	94	7.73	75.9
B156	4/12/95	0.057	16.3	0.19	212	11.4	0.0789	64.6	9.12	61.2
B157	4/12/95	0.072	5.57	0.3	182	12.7	0.0739	64.4	9.48	51.9
B160	4/12/95	0.098	8.01	0.43	132	14	0.0878	78.4	12.7	69.9
B163	4/12/95	0.121	7.71	0.9	157	20.4	0.0986	127	12.4	80.8
B164	4/12/95	0.077	5.9	0.46	135	12.1	0.0419	83.7	10.5	52.5
B167	4/12/95	0.059	3.56	0.26	171	6.51	0.0214	37.5	9.46	39.6
B167-D	4/12/95	0.061	3.81	0.34	169	6.98	0.0236	46.8	11	41.9
B324	9/13/95	0.119	5.97	0.52	143	15.1	0.0835	103	11.4	71.1
B331	9/13/95	0.116	5.56	0.36	99.5	12.2	0.0907	64.4	7.34	76.8
B334	9/13/95	0.052	4.11	0.43	118	6.53	0.0391	36.3	13.3	36.2
B335	9/13/95	0.037	4.93	0.48	95.2	3.36	0.0278	17.7	13.4	25.3
B344	9/13/95	0.09	4.95	0.57	135	9.24	0.045	64.4	10.9	53.7
B346	9/13/95	0.094	5.85	0.59	141	14.4	0.117	93.1	8.7	46
B351	9/13/95	0.093	6	0.6	138	16.1	0.0677	83.9	10.5	70.5

APPENDIX B

Sediment trace metal concentrations (mg/kg dry weight) in the vicinity of City of Santa Cruz, City of Watsonville, and Monterey Regional (MRWPCA) outfalls into Monterey Bay, California.

Table 15: Trace Metal Concentrations (mg/kg dry weight) for Sediment Sampling Stations in Monterey Bay, CA.

Outfall	Station-ID	Date	Replicate	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Silver	Zinc
Santa Cruz	SC1	Oct-88	3	5.5	0	51	5.23	9.83	0.23	26.33	0.42	31.33
Santa Cruz	SC2	Oct-88	1	4.2	0	54	7.4	11.7	0.15	35	0.6	35
Santa Cruz	SC3	Oct-88	1	4.2	0	61	4.5	9.4	0.16	23	0.45	30
Santa Cruz	SC4	Oct-88	1	4.4	0.14	42	5.3	6.5	0.19	25	0.46	32
Santa Cruz	SC5	Oct-88	3	4.43	0	52.67	3.87	7.83	0.14	28.67	0.35	27.67
Watsonville	R1N	Oct-88	1	4.29	0	129	9.9	2	0.05	97	0.21	47
Watsonville	R4	Oct-88	1	3.57	0	143	9.3	1.04	0.05	96	0.14	39
Watsonville	R5	Oct-88	1	4.78	0	83	7.7	1.3	0.05	78	0.14	41
Watsonville	R6	Oct-88	1	4.93	0	94	7.8	3.28	0.05	78	0.14	46
MRWPCA	2000S	Oct-88	2	2.3	0.3	30.5	5	2.5	0.02	27.5	0.3	21.5
MRWPCA	30S	Oct-88	2	2.15	0.3	31	5	2.5	0.02	27.5	0.3	23
MRWPCA	500N	Oct-88	2	2.15	0.3	30.5	5.5	1	0.02	27.5	0.4	23
MRWPCA	500S	Oct-88	2	2.15	0.3	30	5.5	2	0.03	26.5	0.35	21.5
Santa Cruz	SC1	Oct-89	3	5.5	0	51	5.23	9.83	0.23	26.33	0.42	31.33
Santa Cruz	SC2	Oct-89	1	4.2	0	54	7.4	11.7	0.15	35	0.6	35
Santa Cruz	SC3	Oct-89	1	4.2	0	61	4.5	9.4	0.16	23	0.45	30
Santa Cruz	SC4	Oct-89	1	4.4	0.14	42	5.3	6.5	0.19	25	0.46	32
Santa Cruz	SC5	Oct-89	3	4.43	0	52.67	3.87	7.83	0.14	28.67	0.35	27.67
Santa Cruz	SC1	Oct-90	3	4.37	0.23	48	5.13	2.73	0.04	19.33	0.49	35.33
Santa Cruz	SC2	Oct-90	1	4.3	0.24	50	6.1	3.4	0.03	21	0.49	38
Santa Cruz	SC3	Oct-90	1	3.8	0.15	63	5.3	2	0.03	19	0.47	35
Santa Cruz	SC4	Oct-90	1	5.2	0.24	53	5	1.7	0.03	17	0.49	34
Santa Cruz	SC5	Oct-90	3	3.13	0.11	39.33	3.6	1.77	0.02	17	0.42	28.33
Watsonville	R1N	Oct-90	1	0.76	0	10	2	2.2	0.03	20	0	9.5
Watsonville	R2	Oct-90	1	0	0	0	0	0	0	0	0	0
Watsonville	R4	Oct-90	2	0.91	0	8.8	1.55	2.2	0.22	16	0	9.1
Watsonville	R5	Oct-90	1	1.3	0	9.2	1.6	1.4	0.03	16	0	10
Watsonville	R6	Oct-90	2	1.45	0	11.5	1.6	1.8	0.03	20	0	11.5

Table 15: Cont.

Outfall	Station-ID	Date	Replicate	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Silver	Zinc
Santa Cruz	SC1	Oct-91	3	4.17	0.13	60.33	4.9	4.93	0.04	19	0.46	26
Santa Cruz	SC2	Oct-91	1	5.3	0.15	55	5.1	5.1	0.02	19	0.51	28
Santa Cruz	SC3	Oct-91	1	5	0.2	89	5.9	4.9	0.03	21	0.53	33
Santa Cruz	SC4	Oct-91	1	4.9	0.2	65	5.8	5.4	0.05	20	0.48	32
Santa Cruz	SC5	Oct-91	3	4.37	0.12	57	4.17	4.53	0.03	18.67	0.43	23.33
MRWPCA	2000S	Oct-91	2	>63.9	0.64	34.5	4.9	4.05	0.1	39.35	1.3	29.5
MRWPCA	30S	Oct-91	2	>64.4	0.64	40.7	6.35	4.35	0.1	45	1.3	35.1
MRWPCA	500N	Oct-91	2	>63.7	0.64	36.75	5.4	3.8	0.1	38.45	1.3	30.15
MRWPCA	500S	Oct-91	2	>63.4	0.63	36.45	5.25	4.1	0.1	36.95	1.3	33.95
Santa Cruz	SC1	Oct-92	3	4.73	0.14	46.33	4.4	3.83	0.07	16.67	0	31.67
Santa Cruz	SC2	Oct-92	1	5.3	0.17	39	4.2	4.3	0.03	19	0	33
Santa Cruz	SC3	Oct-92	1	4.5	0.14	53	4.2	3.7	0.02	17	0	30
Santa Cruz	SC4	Oct-92	1	4.8	0.22	45	4.6	3.7	0.02	17	0	33
Santa Cruz	SC5	Oct-92	3	4.07	0.1	31	3.27	3.5	0	16	0	25.67
Watsonville	R1N	Oct-92	1	3.4	0.05	66	5.7	4	0.02	36	0	33
Watsonville	R2	Oct-92	1	0	0	0	0	0	0	0	0	0
Watsonville	R4	Oct-92	1	3.4	0.05	72	5.4	3.6	0.02	35	0	35
Watsonville	R5	Oct-92	1	4.3	0.05	51	4.7	3.7	0	33	0	31
Watsonville	R6	Oct-92	1	4.3	0.04	44	4.9	3.7	0.02	31	0	30
Santa Cruz	SC1	Oct-93	3	5.4	0.13	55.67	5.63	4.27	0.03	19	0	29
Santa Cruz	SC2	Oct-93	1	6.1	0.2	47	5.3	4.8	0.03	17	0	30
Santa Cruz	SC3	Oct-93	1	5.2	0.2	64	5.9	5.8	0.02	18	0	33
Santa Cruz	SC4	Oct-93	1	5	0.2	51	5.7	3.9	0.02	18	0	30
Santa Cruz	SC5	Oct-93	3	4.87	0.1	43	4.73	4.13	0	18	0	28.33
Santa Cruz	SC1	Oct-94	3	5.6	0.16	46.67	4.83	4.67	0.03	21.67	0	33.67
Santa Cruz	SC2	Oct-94	1	7.8	0.18	82	8	5.9	0.04	25	0	42
Santa Cruz	SC3	Oct-94	1	4.8	0.2	70	5.4	4.3	0.03	23	0	35
Santa Cruz	SC4	Oct-94	1	5.1	0.23	50	5	4	0.03	21	0	34
Santa Cruz	SC5	Oct-94	3	5.13	0.07	47	4.13	4.2	0.02	22	0	32.33

Table 15: Cont.

Outfall	Station-ID	Date	Replicate	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Silver	Zinc
Watsonville	R1N	Oct-94	3	3.47	0	130	7.3	4.23	0.16	61	0	39.67
Watsonville	R2	Oct-94	1	3.7	0	110	7.1	4.2	0.03	56	0	38
Watsonville	R4	Oct-94	2	1.65	0	60	3.4	2.2	0.02	29	0	19
Watsonville	R5	Oct-94	1	4.9	0	87	6.5	4.4	0.03	51	0	37
Watsonville	R6	Oct-94	3	4.9	0	79.67	6.57	4.6	0.04	48.67	0	37.67
MRWPCA	2000S	Oct-94	2	>25.1	0.5	37.15	6.35	3.45	0.1	41.35	1	34.35
MRWPCA	30S	Oct-94	2	>25.1	0.5	36.55	7.15	2.8	0.1	37.65	1	31.8
MRWPCA	500N	Oct-94	2	>25.1	0.5	33.55	5.65	2.9	0.1	35.25	1	29.25
MRWPCA	500S	Oct-94	2	>25.1	0.5	39.05	8.15	3.75	0.1	48.6	1	40.25
Santa Cruz	SC1	Oct-95	3	1.83	0.32	69.67	9.4	6.7	0	22.33	0	40.67
Santa Cruz	SC2	Oct-95	1	1.9	0.27	40	8.6	6.5	0	51	0	32
Santa Cruz	SC3	Oct-95	1	1.8	0.25	112	10	6.6	0	40	0	35
Santa Cruz	SC4	Oct-95	1	2.1	0.36	138	11	6.7	0	55	0	39
Santa Cruz	SC5	Oct-95	3	1.6	0.14	67.33	6.6	4.57	0	21	0	27.67
Santa Cruz	SC1	Oct-96	3	5.77	0.21	49.33	6.23	5.87	0.03	23	0	39.33
Santa Cruz	SC2	Oct-96	1	5.2	0.21	43	5.9	5.7	0.04	21	0	38
Santa Cruz	SC3	Oct-96	1	4.6	0.17	60	7.3	4.5	0.12	19	0	35
Santa Cruz	SC4	Oct-96	1	4.3	0.28	47	5.6	4.5	0.03	20	0	34
Santa Cruz	SC5	Oct-96	3	4.7	0.1	48.33	5.53	5.03	0.02	24	0	36.67
Watsonville	R1N	Oct-96	3	1.47	0	108.33	8	4.2	0.02	67.67	0	39
Watsonville	R2	Oct-96	1	1.9	0	100	7.5	4.2	0	62	0	38
Watsonville	R4	Oct-96	2	0.45	0	55	3.8	2.25	0.06	30.5	0	19.5
Watsonville	R5	Oct-96	1	2.6	0	73	6.9	4.5	0	57	0	39
Watsonville	R6	Oct-96	3	3.13	0	73	7.03	4.67	0.11	54.67	0	39.67

APPENDIX C

Benthic community parameters, including average number of species (number of individuals per 0.1 m^2) and total abundance (number of individuals per 0.1 m^2), measured at sampling stations around the City of Santa Cruz and City of Watsonville outfalls.

Table 16: Average Number of Species (Infauna) and Average Total Abundance (Infauna) for Sampling Stations in the Vicinity of Municipal Outfalls into Monterey Bay, CA.

Outfall	Station-ID	Date	Count	Average Number of Species	Average Total Abundance
City of Santa Cruz	SC1	10/30/88	5	140.2	1632.4
City of Santa Cruz	SC2	10/30/88	5	158.2	1657.2
City of Santa Cruz	SC3	10/30/88	5	146	1619
City of Santa Cruz	SC4	10/30/88	5	145.6	1718.6
City of Watsonville	R1N	11/7/88	5	87	1837
City of Watsonville	R4	11/7/88	5	86.6	2435
City of Watsonville	R5	11/7/88	5	71	1227.8
City of Watsonville	R6	11/7/88	5	80.6	1078.6
City of Santa Cruz	SC1	10/1/89	5	151.8	1091.2
City of Santa Cruz	SC2	10/1/89	5	144.8	1138
City of Santa Cruz	SC3	10/1/89	5	128.8	918.8
City of Santa Cruz	SC4	10/1/89	5	159	2132.2
City of Santa Cruz	SC1	10/5/90	5	158	1253.8
City of Santa Cruz	SC2	10/5/90	5	152.6	1181
City of Santa Cruz	SC3	10/5/90	5	146.2	1419
City of Santa Cruz	SC4	10/5/90	5	155.8	1885.6
City of Watsonville	R1N	10/9/90	5	104.4	1471.4
City of Watsonville	R4	10/9/90	5	85.6	1837.8
City of Watsonville	R5	10/9/90	5	82.6	1538
City of Watsonville	R6	10/9/90	5	71.8	1080
City of Santa Cruz	SC1	10/3/91	5	170.2	1862.4
City of Santa Cruz	SC2	10/3/91	5	158	1750.2
City of Santa Cruz	SC3	10/3/91	5	163.8	1580.6
City of Santa Cruz	SC4	10/3/91	5	169.8	2442.4
City of Santa Cruz	SC1	10/18/92	5	156.6	1445.4
City of Santa Cruz	SC2	10/18/92	5	136	1009.2
City of Santa Cruz	SC3	10/18/92	5	139.2	1351.2
City of Santa Cruz	SC4	10/18/92	5	147.2	1914.4
City of Watsonville	R1N	10/19/92	5	98	959.2
City of Watsonville	R4	10/19/92	5	84.6	740.6
City of Watsonville	R5	10/19/92	5	79.2	590
City of Watsonville	R6	10/19/92	5	85.8	734.4
City of Santa Cruz	SC1	10/21/93	5	124.8	712.8
City of Santa Cruz	SC2	10/21/93	5	139.6	774.8
City of Santa Cruz	SC3	10/21/93	5	124.8	682.6
City of Santa Cruz	SC4	10/21/93	5	134.2	1072
City of Santa Cruz	SC1	10/26/94	5	103.2	367
City of Santa Cruz	SC2	10/26/94	5	91	399.6
City of Santa Cruz	SC3	10/26/94	5	99.8	471.2
City of Santa Cruz	SC4	10/26/94	5	108.6	599.2

Table 16: Cont.

Outfall	Station-ID	Date	Count	Average Number of Species	Average Total Abundance
City of Watsonville	R1N	10/15/94	5	84.2	1084.8
City of Watsonville	R2	10/15/94	5	77	704.6
City of Watsonville	R4	10/15/94	5	82.6	670.2
City of Watsonville	R5	10/15/94	5	72	519.6
City of Watsonville	R6	10/15/94	5	66.8	457.4
City of Santa Cruz	SC1	10/19/95	5	116.4	535.8
City of Santa Cruz	SC2	10/19/95	5	110.6	573.2
City of Santa Cruz	SC3	10/19/95	5	120.4	614.2
City of Santa Cruz	SC4	10/19/95	5	118.2	711.6
City of Santa Cruz	SC1	10/8/96	5	89.4	433
City of Santa Cruz	SC2	10/8/96	5	119.8	616.2
City of Santa Cruz	SC3	10/8/96	5	113.4	588
City of Santa Cruz	SC4	10/8/96	5	125.8	934.2
City of Watsonville	R1N	10/9/96	5	63.8	393
City of Watsonville	R2	10/9/96	5	57.8	448.6
City of Watsonville	R4	10/9/96	5	51.2	357.6
City of Watsonville	R5	10/9/96	5	49.4	434.6
City of Watsonville	R6	10/9/96	5	51.8	356.2

APPENDIX D

Benthic community parameters, including average number of species (number of individuals per m^2) and total abundance (number of individuals per m^2), measured at sampling stations around the Monterey Regional (MRWPCA) outfalls.

Table 17: Average Number of Species (Infauna) and Average Total Abundance (Infauna) for Sampling Stations in the Vicinity of MRWPCA Outfall into Monterey Bay, CA.

Outfall	Station-ID	Date	Count	Average Number of Species	Average Total Abundance
MRWPCA	1m-S	10/16/88	6	40	66234
MRWPCA	2m-S	10/16/88	6	21	7116
MRWPCA	30m-S	10/16/88	6	29	12724
MRWPCA	500m-S	10/16/88	6	27	8623
MRWPCA	500m-N	10/16/88	6	25	10795
MRWPCA	2000m-S	10/16/88	6	29	10241
MRWPCA	1m-S	10/22/91	6	36	19782
MRWPCA	2m-S	10/22/91	6	19	4754
MRWPCA	30m-S	10/22/91	6	19	5465
MRWPCA	500m-S	10/22/91	6	19	5754
MRWPCA	500m-N	10/22/91	6	21	8553
MRWPCA	2000m-S	10/22/91	6	19	6998
MRWPCA	60m-N	11/94	5	18	6212
MRWPCA	60m-S	11/94	5	14	4319
MRWPCA	900m-N	11/94	5	12	4639
MRWPCA	900m-S	11/94	5	14	5412
MRWPCA	3000m-S	11/94	5	14	5679