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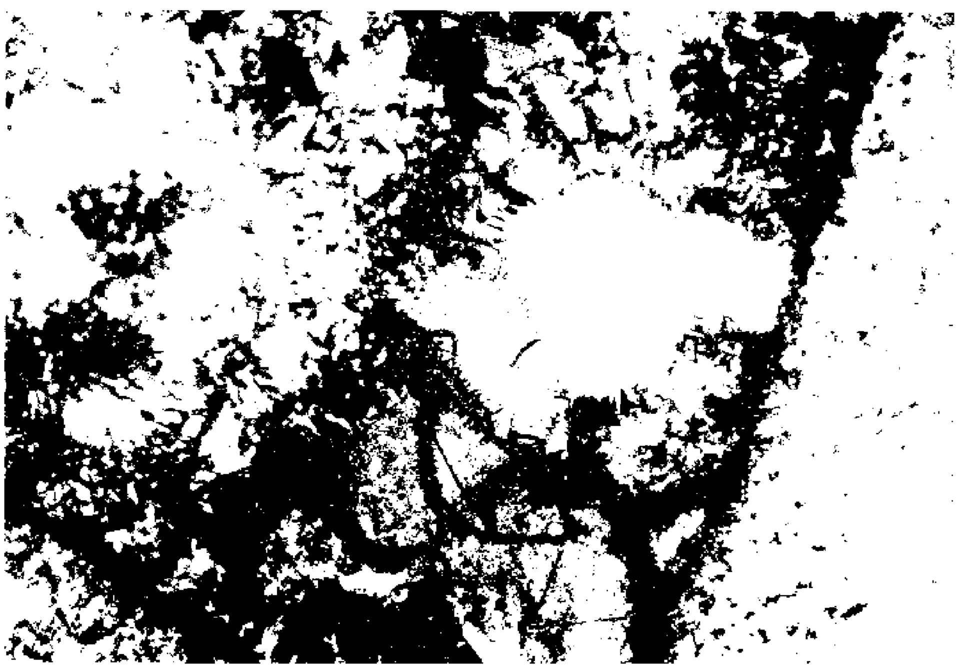

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Proceedings of a Special Symposium: Coastal Watersheds and their Effects on the Ocean Environment Sponsored by The Southern California Academy of Sciences May 5, 1995

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Preface

In the past century, the Southern California coastal zone, like many coastal zones in this country, has been changing from rural and agricultural uses to urban and industrial, dramatically altering the nature of our watersheds and adjacent coastal shelves. This process has altered hydrologic patterns and associated movement of sediments, and has contributed to increased loads of pollutants washing from watersheds to offshore marine environments. In addition, natural events such as fires and floods, especially those we endured during 1995, have their own unique effects.

Watershed management has become a topic of major public concern. Over the past several decades, we have seen significant progress in cleaning up point sources of pollution from sewage treatment and industrial plants. But a large problem remains with nonpoint sources of contaminants entering coastal systems from our urban storm drain systems and polluted waterways. Our goals as scientists should be to first identify and quantify the many problems associated with urban runoff, and to work with resource managers to develop, prioritize, and implement cost-effective solutions. This approach is the essence of the National Research Council's (NRC) framework for managing coastal resources contained in the report "Managing Wastewater in Coastal Urban Environments" (1993). Integrated Coastal Management (ICM) strategies are based on consideration of regional differences, multiple sources of perturbations, costs, and benefits. The NRC framework (1993: p. 14) stressed that implementation of ICM, among other things, needs to be based on the best scientific knowledge available about ecological functions, and that a trans-disciplinary perspective is critical in coastal problem solving.

A one-day symposium was held at the 1995 Annual Meeting of the Southern California Academy of Sciences entitled "Coastal Watersheds and their Effects on the Ocean Environment." The purpose of this symposium was to highlight the importance of the overall issue, to bring together local research from a variety of disciplines, and to identify gaps in our knowledge base. The morning session was concerned with water quality and pollutant loading, the effects of pollutants on marine life, improvements in monitoring technology, and changes in sediment delivery and erosion in the coastal zone. The afternoon session tackled coastal erosion and management, nutrient loading in estuaries and wetlands, and pollution sources in the urban watershed. We also included two student poster presentations, one on fecal indicators in L.A. coastal waters, and a second on transportation sources of pollution in the L.A. region. Full papers from five of these presentations are published herein. Others, which are in-press elsewhere, are published here in abstract form.

The breadth of subject matter covered in this symposium publication demonstrates the multifaceted nature of urban watersheds and complexity of the coastal management issues. In our first paper, Sibley examines an international problem of untreated sewage from Tijuana, Mexico flowing past the border to San Diego beaches. Schiff and Stevenson report on a newly instituted watershed-based approach to regional storm water monitoring in San Diego County, a study which attempts to characterize pollutant loading and potential toxicity in a major metropolitan region. Dalkey and Shisko give us a detailed picture of waste water field movement in Santa Monica Bay by measuring salinity anomalies derived from oceanographic measurements from electronic sensors. Bay et al. characterize levels of toxicity of dry weather flow using sensitive life stages of three marine organisms. They further attempt to identify the toxic components which were responsible for the observed toxicity. We proceed to a field study by Martin et al. showing the detrimental effects of freshwater inundation from street runoff on a species of intertidal sea anemone. In the final paper, Duke et al. looks at the transportation industry as a source of pollutants.

We wish to acknowledge the Southern California Academy of Sciences for sponsoring the original symposium as part of its annual meeting. A special thank-you to the authors for contributing papers to this symposium issue, to the reviewers for contributing their expertise in editing the papers, and finally to Southern California Sea Grant Program at the University of Southern California for providing financial support for this symposium issue of the Bulletin.

Susan E. Yoder, Ph.D.
John H. Dorsey, Ph.D.
February 1996

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The Border: Sharing a Problem and a Solution

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Abstract.—The Tijuana River flows through two countries. It passes through the poverty-stricken but growing community of Tijuana, Mexico and southern San Diego County where it empties into the Tijuana Estuary. Raw sewage from Tijuana and the surrounding watershed is dumped into the river as it flows to the Pacific Ocean. Littoral currents transport the waste north to beaches in San Diego County, creating health risks and forcing beach closures. Repeated attempts to remedy the situation have been made since 1930, however, successful sewage treatment has not been attained. Lack of money from Mexico and different standards for sewage treatment between the United States and Mexico have made this situation difficult to remedy.

Valuable opportunities are available to California because of its coastal location. However, careful management of marine resources is necessary to keep this asset viable for the future. Mexico and California share a river that has become an international issue because of poor management. The Tijuana River runs through some of the poorest areas of Tijuana, Mexico, picking up raw sewage and transporting it across the border through agricultural areas of southern San Diego County and finally discharging into the Tijuana Estuary on its way to the ocean. Littoral currents carry the waste north to beaches in San Diego County, creating health hazards and beach closures along several miles of coastline (Fig. 1). This is not a new phenomenon to this area, but has been happening since the 1930's.

In 1934 the Tijuana River was a concern to the International Boundary Commission because of sanitary conditions. The San Ysidro area, just north of the border, received run-off from the river and the sale of truck crops from that area was prohibited (Mydans 1990). A survey and study of the area was conducted, and in 1937, six and a half miles of sanitary sewer lines were constructed from near San Ysidro to the Pacific Ocean. The cost to the United States was $150,000, and was paid from emergency funds. The Mexican portion consisted of several miles of main lines and a sanitation plant in Mexico, near the border between the two countries (U.S. Bureau 1941).

Failure of the Sewage System

The population of Tijuana has grown considerably since the 1930's and the sewer system quickly became inadequate to handle the amount of sewage running into the small river. Nearly two million people live in Tijuana today, and less than half the population has plumbing. Recent industrial growth in the city and failure to enforce environmental laws contribute to the pollution of the river. The rapid population growth in Tijuana, especially after World War II, and the subsequent large amount of sewage dumping into the river caused the quarantine of

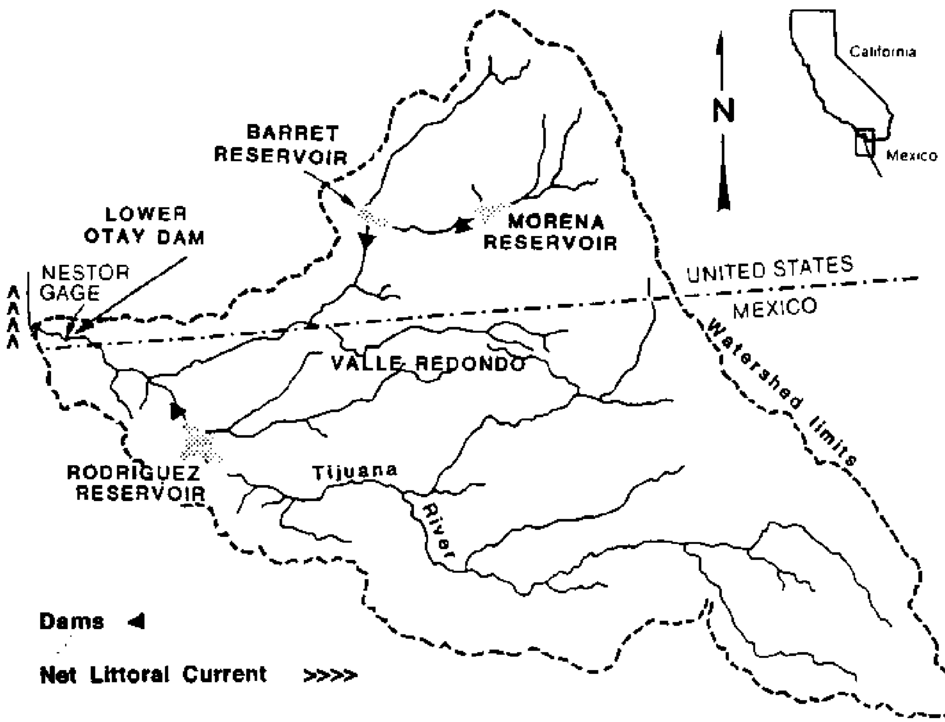

Fig. 1. Tijuana River Watershed.

Imperial Beach in San Diego County in 1959. The beach was re-opened in 1962 after Tijuana built another sewage system, but closed again in 1965 after the system repeatedly failed. To aid the situation, an emergency pipeline was constructed to carry up to 13 million gallons of sewage a day to the Point Loma Sewage Treatment Plant in San Diego. By 1980 this pipeline was at full capacity from population pressures on both sides of the border.

This arrangement is now renewed on a year-to-year basis. Yet, the combination of breaks in the Tijuana sewage plant and incessant dumping of raw sewage continue to pollute the river and the Pacific Ocean where it empties. In response, the International Boundary Water Commission (IBWC) was formed by the Mexican and U.S. governments to monitor the effects of 32 to 38 million gallons of sewage discharged each day (Boesch 1990).

Tijuana River Estuary

The Tijuana River and its tributaries drain a series of marine terraces and cross the border just north of Tijuana where it combines with water from the Pacific Ocean and exits at the Tijuana Estuary. The combination of these waters, the change in topography, and the consequence of tidal flow and streamflow provide a diverse habitat for a variety of birds plants, animals, fish, insects and organisms. The estuary is part of the Pacific Flyway and hosts thousands of waterfowl and shorebirds during winter migration. Several water-associated birds that are rare or endangered are often sighted there (Zedler et al. 1992).

The quality and quantity of water that drains into it is vital for the survival of plant life, fish, birds and other small animals. With three-fourths of the river's watershed in Mexico, it is difficult to control pollutants that flow into the river (Fig. 1). Furthermore, because watersheds from both countries create the estuary, it is internationally significant.

Water Sanitation Monitoring

Both the California Department of Health Services and the San Diego County Department of Health Services perform monitoring programs on the coast. Alarming results of water quality testing between 1977 and 1987 prompted more intensive monitoring (Boesch 1990). The data collected is shared with regional quality boards and other state and federal agencies. Volunteer work reflects San Diego residents' concern about their water quality and has also been effective in reporting physical evidence of sewage in the areas of recreational activity. Beaches have been closed when citizen reports have proven valid.

Waste Discharge to the Ocean

The Water Quality Control plan for ocean waters of California is set by the State of California State Water Resources Control Board. In Chapter III of the 1990 plan, the general requirements for management of waste discharge to the ocean is clearly stated. "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."

The Tijuana sewage plant now treats about 25 million gallons of sewage a day, but Mexican standards for sewage treatment are much lower than those in the United States and problems occur when ocean currents carry the discharge north to San Diego Harbor. Effective sewage treatment is expensive and Mexico has not provided the financial resources to properly treat the sewage. County Officials in San Diego can only post signs to alert people that the beaches are contaminated and unsafe for swimming even though the water may look safe (Mydans 1990). The sewage treatment plant in the U.S. is already processing sewage at capacity, but more problems occur with heavy storms, such as one in the winter of 1991. This storm was partially responsible for a break in a pipeline which carried sewage out to sea for dumping. The release of this partially treated sewage and the discharge of the Tijuana River raised bacteria readings from Point Loma and beaches two miles north to more than 400 times the legal limit. Now, after fifty years of requests for help a solution may be at hand.

A U.S. and Mexico environmental pact was signed in October 1989 which emphasizes United States–Mexican border environmental problems. This agreement includes cooperation from both governments in the construction of a San Diego based sewage treatment facility. The estimated cost of the sewage plant is $400 million, and requires both countries to share the financial responsibility as stated in the IBWC report of 1990. Because the water quality standards in the United States are more strict, the construction, operation and maintenance of deep ocean outfalls will be financed by the United States. Mexico agreed to repay the U.S. for any initial costs made on the construction of the sewage plant. However, the agreement also states that each country's financial obligation is subject to availability of funds (IBWC 1990). Combined efforts of the U.S. federal government, California, the IBWC and San Diego have allocated $339.7 million for the sewage plant, but Mexico has not designated any funding for the project yet (Woo 1995).

A projected completion date for the South Bay International Wastewater Treatment Plant is 1996, with the outfall to be completed in 1998/99. An Environmental Impact Statement has not been completed for the outfall yet, and during the interim period between plant completion and a functioning outfall, there is concern about where the treated sewage will go (Woo 1995). Release into the Tijuana River would have adverse effects on the estuary.

Conclusion

Sharing a border with a foreign country can be a delicate matter, especially when they have contrasting economies. A major pollution problem exists in the Tijuana River, where the course of its flow involves both the U.S. and Mexico. The U.S. has nothing to do with the origin of sewage in Mexico, but involvement cannot be avoided when it affects U.S. land and water. The remedy for the Tijuana River problem is costly, yet the alternative of doing nothing because of inequitable financial obligation is even more environmentally costly. Even if the pollution entering the ocean did not flow north to California beaches, the marine environment and the future of many valuable species in the estuary and surrounding coastal waters should be of concern to U.S. citizens. The Tijuana River contamination at the border may pale in comparison with larger global environmental issues, but it is a regional problem that needs to be addressed regardless of citizenship.

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San Diego Regional Storm Water Monitoring Program: Contaminant Inputs to Coastal Wetlands and Bays

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Abstract.—A watershed-based, Regional Monitoring Program was established by the City of San Diego, the County of San Diego, the San Diego Unified Port District, and 17 other incorporated cities within the county to evaluate the water quality of their wet weather runoff. Seventeen different locations were sampled between 1993 and 1995, and samples were analyzed for priority pollutants and toxicity. In general, measurable quantities of some metals and fecal indicator bacteria were found consistently while nearly all organic contaminants were below method detection limits. Results indicated that residential areas had similar event mean concentrations (EMC) of suspended solids, oil and grease, cadmium, chromium, nickel, and zinc compared to industrial or commercial areas. The EMC of copper and lead from residential areas were higher relative to commercial or industrial areas. However, even EMC from residential areas of San Diego were lower than the EMC from other urbanized watersheds measured from around the country as part of the Nationwide Urban Runoff Program. Potential receiving water effects included 7-day chronic toxicity of storm water effluents to *Ceriodaphnia.* Storm water was responsible for increased contamination of Mission Bay receiving waters by fecal indicator bacteria and exceedences in water quality objectives resulted in post-storm beach closures.

Over the past twenty years tremendous effort and resources have been used to measure contaminant inputs and effects of pollutant discharges to the coastal environment of southern California. An estimated $17 million is spent annually on pollution monitoring efforts (NRC 1990). The vast majority of these resources are used for monitoring point sources such as publicly owned sewage treatment plants. Non-point source discharges however, such as runoff from urban surfaces during storm events, has been shown to contribute more discharge volume and similar quantities of total pollutant mass loading as sewage treatment plants (Cross et al. 1990). Additionally, non-point source discharges enter the nearshore marine environment, often through estuaries or bays, wholly untreated. Sewage treatment plants often have the capability of either enhancing removal of pollutants and/or disinfection prior to discharge and effluents are typically released well offshore. Bays and estuaries are active ecological zones (Zedler and Nordby 1986), potential nursery grounds for fishes and invertebrates (Cross and Allen 1993), and have the largest potential for body contact recreation (Kinnetic Laboratories 1994a).

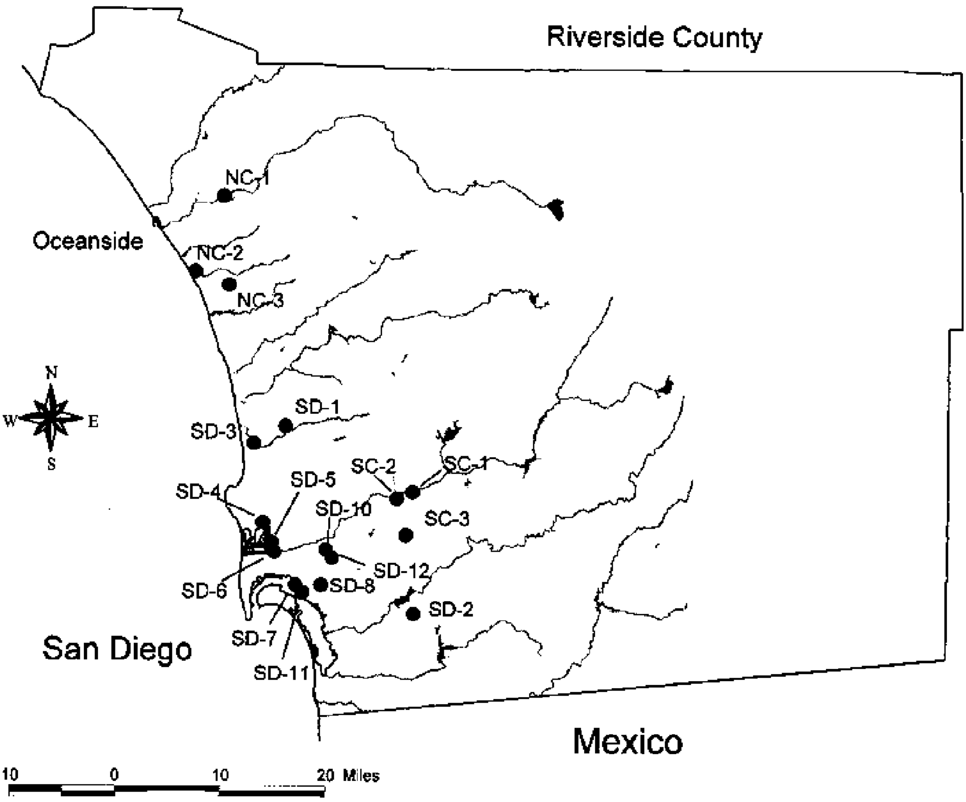

Fig. 1. Map of the major creeks and rivers which drain the urbanized areas of San Diego County. See Table 1 for a key to monitoring stations.

Part of the problem associated with the lack of measuring and/or treating non-point source discharges is the variability of rainfall and the inability to control exactly when and how much runoff is going to occur. Southern California receives between 12 and 14 storms per year. The wettest months of the year are January and February, but significant storms typically arrive from October through April and this time period contributes over 95% of the total annual rainfall (NOAA 1995).

In 1993, the Regional Water Quality Control Board, San Diego Region (RWQCB) instituted a wet weather monitoring program for the general discharge of urban storm waters in San Diego County. The wet weather monitoring program was mandated under the Code of Federal Regulations, Title 40, part 122.26 (d) (2) (iii) and the Clean Water Act, and is detailed in the National Pollutant Discharge Elimination System (NPDES) Permit Number 90-41. Figure 1 shows the 13 major streams and rivers which discharge to coastal marine waters in this region. It was apparent that many of these waterways cross numerous municipal boundaries. Therefore, a watershed-based approach, or "Regional Storm Water Monitoring", was adopted by the 20 jurisdictions which are listed in the NPDES Storm Water Discharge Permit including the City of San Diego, the County of San Diego, the incorporated cities within the County, and the San Diego Unified Port District.

The San Diego Regional Storm Water Monitoring Program was designed to; 1) directly measure pollutant concentrations and mass loading discharged from large urbanized watersheds during storm events, 2) characterize the water quality of runoff from small watersheds of homogeneous land use indicative of residential, commercial, and industrial areas within the region, and 3) investigate receiving water impacts through the use of toxicity tests and water quality objectives. Other objectives of the Regional Storm Water Monitoring Program, but outside the scope of this paper, were also addressed including modeling inputs of pollutants using computer algorithms or measuring sediment-associated pollutants and biological impacts at the mouth of an urbanized creek.

Materials and Methods

All storm water samples were collected using automatic, telemetering, flow-weighted compositing storm water monitoring stations. Automated stations were selected since first storms of the year and first flows during a storm were required for monitoring. A flow-weighted compositing strategy was a favorable approach since pollutant concentrations in storm waters can vary orders of magnitude depending upon flow and individual grab sampling can bias results. High resolution pressure transducers mounted in the bottom of creek beds or storm drain pipes were used to measure runoff stage (depth) at 30-second intervals. Customized software was then used to estimate instantaneous, 15-minute average, and 24-hourly flow characteristics, as well as cumulative runoff volume measurements. Non-contaminating peristaltic pumps fitted with Teflon tubing were used to collect water samples in pre-cleaned, large volume, borosilicate glass carboys. All flow and sampling data were logged by micro-computers installed in each monitoring station and relayed to storm personnel via modem communications. Field crews visited each station before, after, and periodically during each storm to calibrate equipment, verify operating status, and collect samples not amenable to a flow-compositing strategy (such as bacterial analysis which requires sterilized containers and very short holding times).

Two general types of watersheds were monitored for the San Diego Regional Storm Water Monitoring Program; 1) "mass loading" watersheds representing large areas (2500 to 108,000 acres) of mixed land uses typically located immediately prior to a receiving water body such as a wetland or bay, and 2) "land use" watersheds consisting of much smaller areas (32 to 422 acres) of a single homogeneous land use indicative of residential, commercial, or industrial land uses within the study area. Table 1 lists the sample sites, type of station, size, and land use. Altogether, 17 monitoring stations were installed and sampled between Fall 1993 and Spring 1995 (Fig. 1).

Each storm water sample was analyzed for 129 priority pollutants using established protocols (USEPA 1983a; APHA 1992; USEPA 1989) including suspended and dissolved solids (EPA Methods 160.1 and 130.2), oil and grease (EPA Method 413.2), volatile organic compounds (EPA Method 624), semi-volatile organic compounds (EPA Method 625), chlorinated pesticides (EPA Method 608), inorganic metals (EPA Method 200), nutrients (Standard Methods 4500, EPA Method 300), and fecal indicator bacteria (Standard Methods 9221 and 9230). Additionally, a subset of samples were subjected to 7-day survival and reproduction toxicity testing with the cladoceran *Ceriodaphnia* (EPA Method 1002.0).

Table 1. Watersheds sampled for the San Diego Regional Storm Water Monitoring Program.

Station code	Station name	Watershed type	Size (acres)	Percent land use: Residential	Percent land use: Commercial	Percent land use: Industrial	Percent land use: Open	Number of storms sampled
SD-3	Carroll Creek	Mass Loading	11,500	20	13	22	45	2
SD-4	Rose Creek	Mass Loading	23,000	16	15	8	60	3
SD-5	Tecolote Creek	Mass Loading	5,900	51	15	1	33	4
SD-6	San Diego River	Mass Loading	108,400	30	8	4	57	3
SD-7	Switzer Creek	Mass Loading	2,560	45	22	2	31	6
SD-8	Chollas Creek	Mass Loading	16,900	63	15	2	20	7
SC-1	Jeremy	Land Use Residential	169	90			10	5
NC-2	Park	Land Use Residential	422	83	14		3	5
SD-12	Landis	Land Use Residential	57	84	16			2
SC-3	Wal-Mart	Land Use Commercial	32		100			5
NC-1	Yuma	Land Use Commercial	32	6	94			6
SD-10	Bramson	Land Use Commercial	41	51	49			4
SC-2	Vernon	Land Use Industrial	56		18	82		5
NC-3	Yarrow	Land Use Industrial	308	1	20	66	13	7
SD-11	Crosby	Land Use Industrial	118	48	10	42		4
SD-1	Top Gun	Construction	31		100[a]			2
SD-2	Proctor Valley	Construction	40	100[a]				2

[a] Area under various phases of active construction.

Most pollutant concentrations in storm water runoff were expressed as the event mean concentration (EMC), a method determined to be of the most value by the USEPA (1983b). The EMC represents the total mass of pollutant divided by the total runoff volume for a given storm event which was measured directly using the automated, flow-weighted composite sampling stations. Since EMCs were distributed log-normally, geometric means are used for summarizing data.

Fecal indicator bacteria have been measured at 20 different stations around Mission Bay on a weekly basis since 1987 by the City of San Diego. Geometric means were summarized to describe temporal and spatial trends from runoff events. Fecal coliform results were stratified into wet and dry days. Wet days were defined as the day of recorded rainfall or the day after a recorded rainfall. Rainfall data from Lindbergh Field was supplied by the National Weather Service.

Results

A total of 14 storms were monitored from fall of 1993 through spring of 1995 which yielded 68 urban runoff samples for analysis of priority pollutants and 10 samples for toxicity. Cumulative rainfall during the 1993–94 wet weather season was near normal (9.86 inches) while the 1994–95 wet season was 60% greater than the long-term annual average (16.03 inches). Mean rainfall of monitored storm events ranged from 0.64 inches in 1993–94 to 0.77 inches in 1994–95. Mean storm duration during both years was approximately 15 hours.

Figure 2 depicts the mass emissions of selected constituents from six different watersheds for median-sized storm events during the 1993–94 water year. The

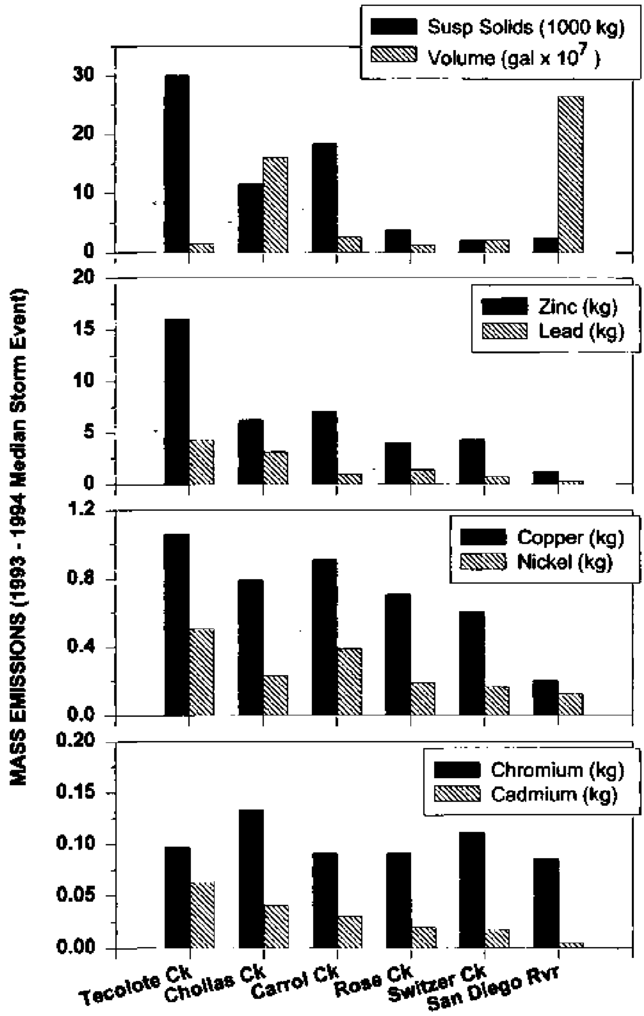

Fig. 2. Mass emissions of selected constituents discharged from six major San Diego drainages during median-sized storm events in the 1993–94 wet season.

San Diego River represented the channel with the largest runoff volume per event and also recorded highest peak flows. The San Diego River however, represented the channel with lowest mass emissions. In contrast, the other large watersheds recorded less runoff volume, but greater mass emissions of suspended solids and six different metals. Concentrations of pesticides, volatile, and semi-volatile organics were nearly always below the method detection limits and consequently, are not shown in Figure 2. Tecolote Creek recorded the greatest pollutant mass emissions of any watershed and drains to Mission Bay, a heavily used aquatic park. Chollas Creek discharged the second greatest measured mass emissions and drains to San Diego Bay, an impaired water body listed by the State of California. Carroll Creek had the third greatest reported mass emissions and drains to Pe-

Table 2. Geometric mean of event mean concentrations (EMC) by land use measured from the San Diego Regional Storm Water Monitoring Program 1993–95.

Constituent	Units	San Diego EMC Residential	Commercial	Industrial	NURP Range[a]
Sample Size		12	15	16	121
Suspended Solids	mg/l	112	89	128	141–224
Oil and Grease	mg/l	1.5	1.9	1.4	
Cadmium	μg/l	0.9	0.6	0.6	
Chromium	μg/l	4.6	2.9	4.4	
Copper	μg/l	25	12	18	38–48
Lead	μg/l	27	11	14	164–204[b]
Nickel	μg/l	6.0	8.3	5.5	
Zinc	μg/l	163	166	162	179–226

[a] Nationwide Urban Runoff Program (USEPA 1983); Range of mixed land uses.
[b] Contemporary lead values range from 6–54 μg/l (LWA 1990).

nasquitos Lagoon, a protected estuary and State Park. The Tijuana River, which receives raw, untreated sewage from regions within Mexico, was not sampled.

Table 2 represents the geometric mean EMC of suspended solids, oil and grease, and six metals for various land uses within urbanized San Diego County. Residential land uses equaled or exceeded the geometric mean EMC for these constituents at other land uses. Residential land use represents the vast majority of urbanized areas within San Diego County (Table 1) and likewise represents a large proportion of the mass emissions to the coastal environment (Kinnetic Laboratories 1994b, 1995). However, concentrations of suspended solids, copper, lead, and zinc in storm water from San Diego representative land use sites were lower than those reported by the Nationwide Urban Runoff Program (NURP) (Table 2). The NURP study measured 121 samples from 28 cities (not San Diego) across the country between 1981 and 1983 (USEPA 1983b). For lead, reductions in the use of leaded gasoline has been reflected in reduced concentrations in storm water (Cross et al. 1990). More contemporary values reported by others (Larry Walker Associates 1990) indicate lead in storm water to range from 5 to 64 μg/l. Differences in the EMC observed between San Diego and NURP results for constituents other than lead may reflect increased source control, better management practices, or reduced flows overall.

Chronic toxicity of runoff samples to *Ceriodaphnia* was observed during five separate storms captured at two different channels between November, 1994 and April, 1995 (Fig. 3). Chronic toxicity which ranged from 12.5 to 50% storm water was measured as the ability to produce offspring and was reported as the No Observed Effect Concentration (NOEC). From the three storms that were sampled simultaneously, Chollas Creek samples were more toxic than Tecolote Creek samples. A seasonal pattern in toxicity was evident from both channels. Early season storms (i.e. before January) exhibited greater toxicity compared to storms later in the season.

Runoff from Tecolote and Rose Creeks affected the temporal and spatial distribution of fecal indicator bacteria in Mission Bay (Fig. 4). There was a strong seasonal cycle in the density of enterococcus in Mission Bay that peaks in the

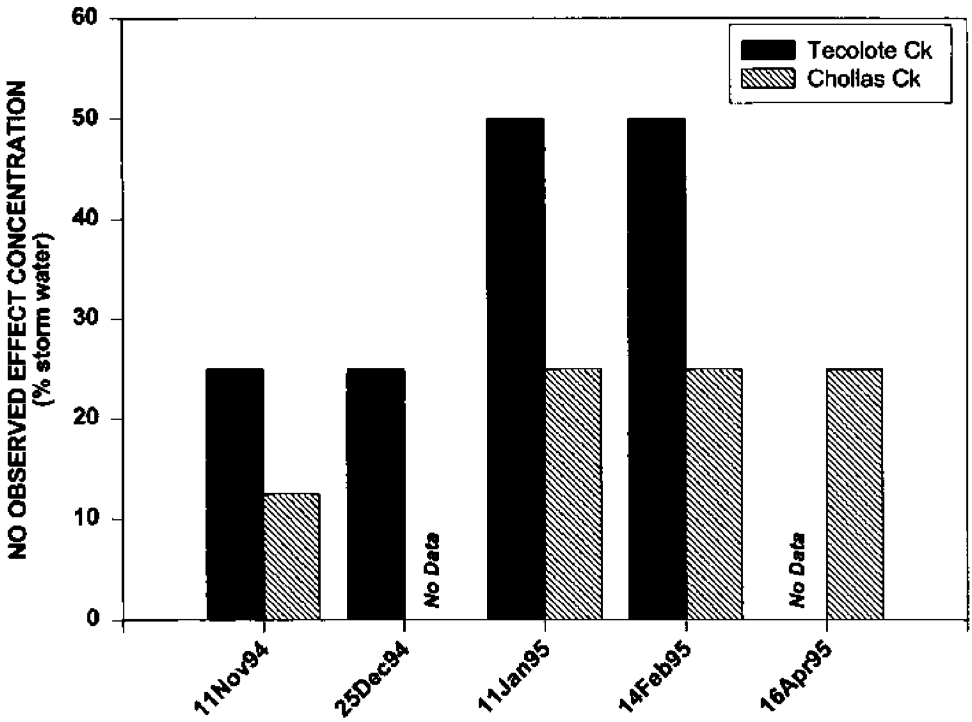

Fig. 3. Chronic toxicity of San Diego urban runoff samples to *Ceriodaphnia dubia* measured during the 1994–95 wet season.

winter when rainfall is greatest (Fig. 4A). In fact, there was a significant correlation of enterococcus density and rainfall quantity (Kinnetic Laboratories 1994a). Furthermore, enterococcus densities in east Mission Bay were higher than densities in west Mission Bay during the wet season, but were similar during the dry season. Figure 4B shows that wet days were always higher for fecal coliform than dry days throughout Mission Bay. Fecal coliform densities during wet days were highest at Station 3 and slowly decreased towards Station 10. Station 3 is located at the mouth of Tecolote Creek. Station 8 is located at the mouth of Rose Creek. In contrast, fecal coliform densities were variable during dry days with no consistent spatial trend.

Discussion

Contaminant concentrations in storm water and pollutant mass emissions discharged during storm events were greatest at Chollas and Tecolote Creeks. Relative to four other large urbanized watersheds in the study area, the loading of suspended solids and most metals during median-sized events were highest at these two channels. Although exact sources of contaminants within these watersheds are unclear, both have a low percentage of open lands relative to the other channels, amongst the highest proportions of residential and commercial land uses, and generate large flow rates which can mobilize pollutants. Tecolote and Chollas Creeks are currently the focus for continued wet weather monitoring.

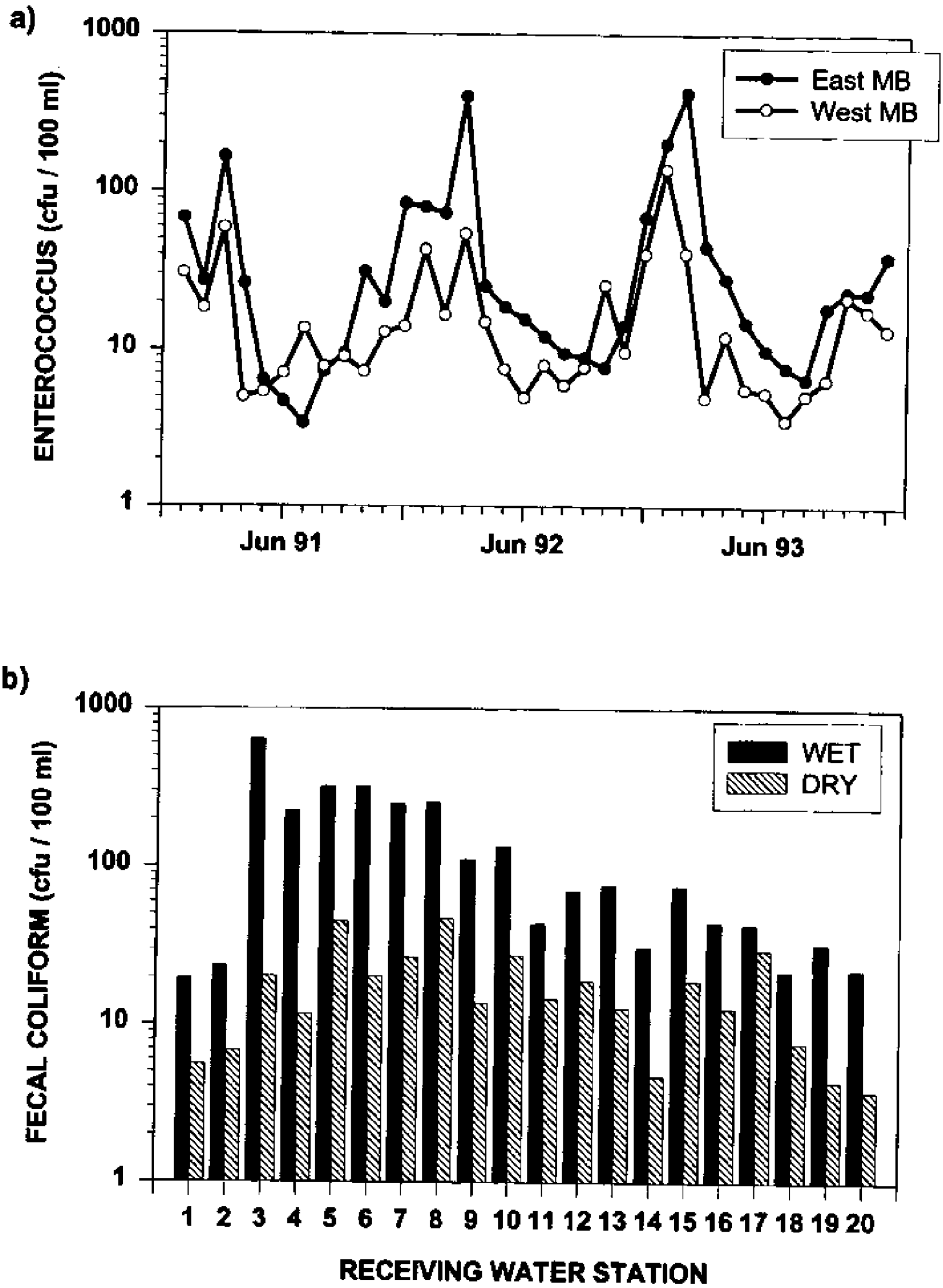

Fig. 4. Temporal (4a) and spatial (4b) distribution of the fecal indicator bacteria enterococcus and fecal coliform in Mission Bay.

Monitoring small watersheds of homogeneous land use revealed that residential areas in San Diego generated pollutant EMCs as high, or higher than, commercial or industrial areas within the county. Residential areas comprised the majority of urbanized land use within the study area. However, pollutant EMCs measured in storm water from residential areas were as low, or lower than, pollutant EMCs measured in storm water from mixed land uses measured from other cities around the Nation.

Although EMCs from urbanized areas within San Diego were lower than other areas nationwide, receiving water effects were observed. Significantly reduced reproduction was measured using *Ceriodaphnia* at concentrations greater than 12.5 to 25% storm water from Tecolote and Chollas Creeks. Other toxicity studies which have exposed aquatic organisms to San Diego storm water have measured impaired larval growth of the fish, *Pimephales* (Kinnetic Laboratories 1995), and significantly reduced hatching success and normal development of *Menidia* and *Medaka* fish embryos (Skinner et al. 1994). Although toxicity has been well documented, the mechanisms and source of toxicity in San Diego storm runoff are still unknown.

Storm water was responsible for increased contamination of Mission Bay receiving waters by fecal indicator bacteria such as total coliform, fecal coliform, and enterococcus. The increased contamination exceeded water quality objectives for these fecal indicators and resulted in beach closures for 99 days during 1993. Fecal indicator bacteria densities were significantly correlated with rainfall quantities and the highest densities were observed near runoff dominated creeks. Other studies measured fecal indicator bacteria in storm drain effluents which were consistently orders of magnitude greater than regulatory limits (Kinnetic Laboratories 1994a). The exact source of the bacterial contamination is still unknown.

A watershed-based approach was used to design a wet weather regional monitoring program in the San Diego area. This approach was successful due to three factors; 1) ability to integrate a study which could answer multiple hypotheses such as estimate total mass loading, generate data for computer based urban runoff models, and evaluate receiving water effects, 2) consistency in methodology of sampling, sample analysis, and storm capture which facilitated comparability for making inter- and intra-seasonal comparisons, and 3) reduced expenditure of resources from sponsoring agencies by not having to run multiple, but disjointed programs.

Acknowledgments

The authors are indebted to the many "storm troopers" that put their personal lives on hold for Mother Nature's gift of rain. Data from the Mission Bay Receiving Water Monitoring Program was supplied by the City of San Diego Environmental Monitoring and Technical Services Division. This work was funded by the City of San Diego and Co-permittees.

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Observations of Oceanic Processes and Water Quality following Seven Years of CTD Surveys in Santa Monica Bay, California

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Abstract.—The Environmental Monitoring Division conducted weekly CTD (conductivity-temperature-density) surveys in the Santa Monica Bay from September 1987 through June 1994 as part of a federal and state mandated ocean monitoring program for Los Angeles City's wastewater discharge. The data provide a unique opportunity to track the development and direction of movement of the discharged wastewater. Direction of wastewater field movement was highly variable whereas seasonal development followed general trends. Salinity anomaly, a measure of the deviation from mean salinity, was devised to more effectively detect the wastewater field and provided for estimation of effluent dilution in situ.

In September 1987, the EPA and California State Water Quality Resources Control Board jointly issued a National Pollutant Discharge Elimination System permit to City of Los Angeles for the Hyperion Treatment Plant which discharges approximately 350 MGD (1.3×10^9 l d^{-1}) of treated wastewater into Santa Monica Bay. The permit required that the City conduct an extensive marine monitoring program in the Bay including weekly water quality program of electronic CTD (conductivity-temperature-depth) profiles. The Environmental Monitoring Division conducted the weekly program from September 1987 through June 1994 until it was replaced with a monthly program following promulgation of a new permit in 1994. During nearly seven years of continuous monitoring under the 1987 permit, surveys were conducted under a variety of conditions including severe drought conditions in the late 1980's and an El Niño Southern Oscillation (ENSO) episode in 1991–92. The result of the program is an immensely comprehensive data set that provides the opportunity to investigate the movement of discharged wastewater in Santa Monica Bay on a weekly basis.

Seasonal oceanographic conditions, currents, and topographic features affect the dispersion and transport of wastewater in the ocean. Many theoretical studies addressing the behavior of wastewater in the ocean have been conducted using mathematical modeling and/or tank experiments. For example, through tank experiments Roberts et al. (1989a, 1989b) described the mixing process of the wastewater field as a two-part process in which rapid, turbulent mixing occurs initially in the near field region and is followed by slower mixing from ambient turbulence in the far field. Recent technological advancements that led to the development of continuous profiling instrument packages have enabled researchers to obtain more information on transport of wastewater through in situ research. Notably Wu et al. (1994) conducted intensive surveys using a suite of physical,

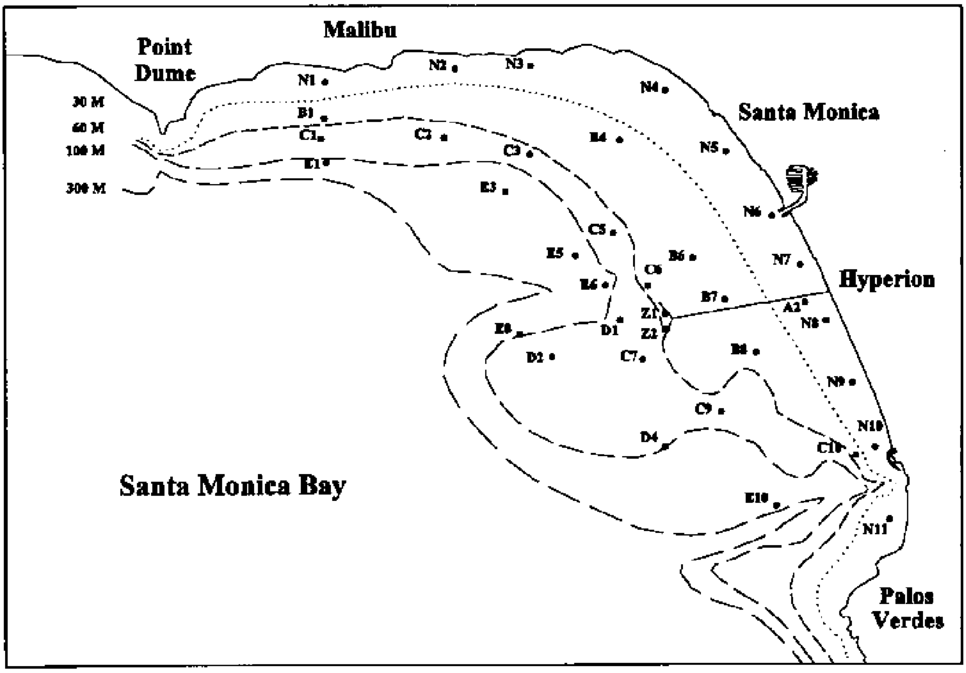


Fig. 1. Water quality stations in Santa Monica Bay.

bio-optical, and nutrient parameters over an eight month period to locate the wastewater field at the White's Point wastewater outfall located just south of Santa Monica Bay. The City of Los Angeles' program is the most comprehensive, resulting in a data set that provides a unique opportunity to thoroughly investigate oceanic processes and transport of wastewater in the ocean.

Materials and Methods

Field sampling.—Weekly CTD profiles were conducted at 36 sites throughout Santa Monica Bay (Fig. 1) beginning 22 September 1987 and continuing through 29 June 1994. Due to the large number of stations and distances between them, sampling was conducted over a two-day period. All nearshore stations and the northernmost and southernmost offshore stations were sampled on the first day and the remaining offshore stations were sampled on the second day. Weather observations for cloud cover, wind speed and direction, and occurrence of rain storms were recorded during the sampling program.

Profiles for salinity (psu), temperature (°C), transmissivity (%), density (kg/m^3), and dissolved oxygen (mg/L) were taken from surface to 2 m above the seabed using a Sea-Bird Electronics Inc. Model SBE-9 CTD system. Sensors for transmissivity and DO were calibrated weekly prior to each cruise, whereas temperature, conductivity, and density were calibrated semiannually by the manufacturer. The CTD unit was also equipped with a pH sensor, but we found that pH data provided little information that was useful for detecting the wastewater field and the sensor was subject to frequent electrode failure.

Data analysis.—Upon return from sea, data were inspected for outliers, and those data points differing by more than 10% from the preceding value were deleted. Mean Bay-wide temperature and salinity was calculated from all surface to bottom measurements taken at all 36 stations for each survey. The resulting means were plotted by fiscal year using SigmaPlot for Windows Version 1.02.

All data were plotted with a custom designed interpolative algorithm, developed by John F. Shisko. The resulting color graphics of CTD data were plotted vertically along depth transects. The shades of color used in these graphics illustrate the relative differences in the data between stations on a scale appropriate for each parameter. The graphics were examined for presence and depth of stratification and the presence/absence of any upwelling. Detailed notes were compiled for each parameter based on these observations of graphics from every CTD survey conducted. In addition, weather patterns were examined to determine the strength and direction of prevailing winds, and the presence/absence and duration of storms.

Color graphics were used primarily to detect the location of the wastewater field and presence/absence of density stratification and secondarily for detecting events such as upwelling. However, salinity is subject to temporal fluctuations that caused scaling problems in the plots that reduced our ability to detect the wastewater field. Therefore, the salinity anomaly was devised to eliminate temporal fluctuations. Salinity anomaly is a measurement of the deviation of salinity at a particular station and depth from the mean Bay-wide salinity as calculated using the following formula:

$$S_{A_i} = \left(\frac{S_{\bar{x}} - S_i}{S_{\bar{x}}}\right) 100$$

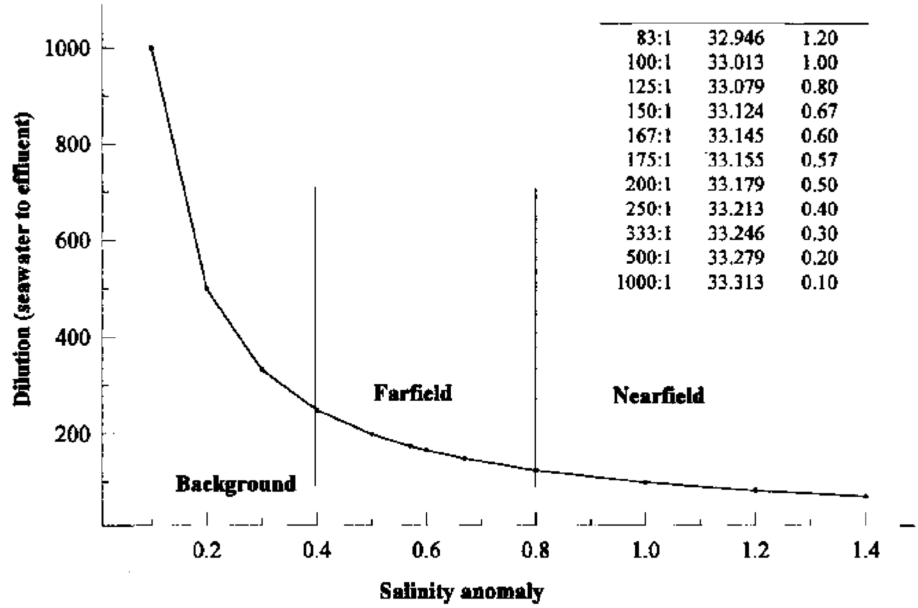
where S_{A_i} is the salinity anomaly at depth i, S_i is the salinity value from site and depth i, and $S_{\bar{x}}$ is the mean Santa Monica Bay salinity as calculated above for the particular survey week.

The relationship between salinity anomaly and wastewater dilution was developed by using theoretical S_A values computed for several wastewater dilutions ranging from 100:1 to 1000:1 (Fig. 2). A salinity value of 33.346 psu was arbitrarily selected as a typical mean Bay-wide salinity for the computations. Effluent salinity was assumed to be zero (effluent normally has an approximate salinity of 0.1 psu). As dilution increases from 100:1 to 1000:1, S_A decreases from 1.0 to 0.10 (Fig. 2).

The wastewater nearfield is defined in this report as water with a salinity anomaly greater than 0.80, with estimated dilutions of 125:1 or less. The wastewater farfield is defined as a lens of water located below the density cap having a salinity anomaly ranging from 0.40 to 0.80, with estimated dilutions ranging from 250:1 to 125:1.

Results

We found that salinity was best for detecting location of the wastewater field of the four directly measured CTD parameters. Our ability to detect the wastewater field was most effective during periods of density stratification but was diminished when stratification was absent. The wastewater field was most difficult to detect



Dilution	S(psu)	S_A
83:1	32.946	1.20
100:1	33.013	1.00
125:1	33.079	0.80
150:1	33.124	0.67
167:1	33.145	0.60
175:1	33.155	0.57
200:1	33.179	0.50
250:1	33.213	0.40
333:1	33.246	0.30
500:1	33.279	0.20
1000:1	33.313	0.10

Fig. 2. Calculated salinity anomaly (S_A) and computed salinities values for different dilutions based on a mean salinity of 33.346 psu.

when surface salinities decreased substantially during episodes of heavy rainfall and subsequent storm runoff. This effectively negated the effectiveness of salinity anomaly by decreasing Bay-wide mean salinity. In these instances, transmissivity, DO, and temperature provided useful information on the location of the wastewater field.

The size of the wastewater field in Santa Monica Bay followed seasonal trends relative to the development and duration of seasonal density stratification. The farfield was larger than the nearfield and could extend many kilometers beyond the nearfield. In early summer, the wastewater field was smaller and generally was detected at stations nearest the outfall, but became larger and more extensive as summer progressed. Usually the wastewater field reached the maximum size and concentration by October after eight months of stratified conditions. Within the nearfield, salinity was low and wastewater dilution, estimated from salinity anomaly, was below 125:1. In October the farfield was pervasive, clearly extending beyond the survey area boundaries more than 15 km from the outfall. Following maximum development, the wastewater field quickly reduced in size and moved deeper in the water column as density stratification deepened. Once stratification eroded, only the nearfield was detected either close to the outfall or as a surfacing plume. When stratification was reestablished, the wastewater field became easier to identify but was often confounded in spring by the presence of rain induced low surface salinities. Direction of movement was highly variable throughout the

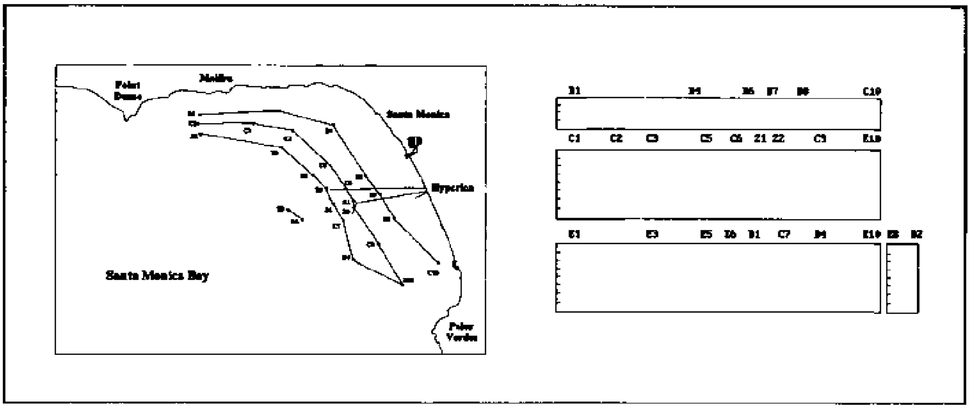


Fig. 3. Location of transects used for water quality plot contours with an example of an empty graphics box.

year and not related to any seasonal trend. The degree to which the location and size of the wastewater field varied from week to week was surprising.

To illustrate the weekly changes and the seasonal development of the wastewater field, salinity anomaly values were reconfigured in three shades of grey to represent the nearfield and farfield in this report. Three transects in the Bay were selected to provide a two-dimensional representation of the nearfield (depicted in black, $S_A > 0.80$), farfield (depicted in gray, S_A ranging from 0.40 to 0.80), and background (depicted in white, $S_A > 0.40$) (Fig. 3). Date notation indicates the respective survey year, month, and week; thus, 89Jul1 refers to the first weekly survey of July in 1989. Two years representing entirely different weather settings, a drought year, 1989–90, (Fig. 4a–d) and a wet year, 1991-92 (Fig. 5a–d) are presented to compare and contrast effects of rainfall on our ability to detect the wastewater field.

1989–90.—The sampling year began in July with summer conditions of shallow and strong density stratification overlying the submerged wastewater field. An example of the highly variable movement of the wastewater field in Santa Monica Bay is visible during the first four weeks of the year (Fig. 4a). Direction of movement was detected during the first week of the year as downcoast (C9) and offshore (D4) from the outfall, then shifted within two weeks to a centralized location over the outfall (Z1 and Z2) with a component of nearshore movement (B7). By the fourth week the wastewater field was detected upcoast and offshore (C5, E5, and E6) and a secondary field was present in the southern portion of the Bay (D4 and E10). This same variability in movement continued with the field contracting and enlarging in size throughout the ensuing weeks. The farfield generally followed the nearfield pattern but on a larger scale. A unique event occurred during the fourth week of September when the nearfield burst through density stratification to surface at the outfall stations (Z1 and Z2) and a nearshore station (B7).

In the next series of plots (Fig. 4b) the same variable wastewater field direction of movement continued with cooler surface temperatures, deeper stratification, and warmer bottom temperatures typical of fall. The fourth week of October provides an excellent example of a plume rising to neutral buoyancy as it is

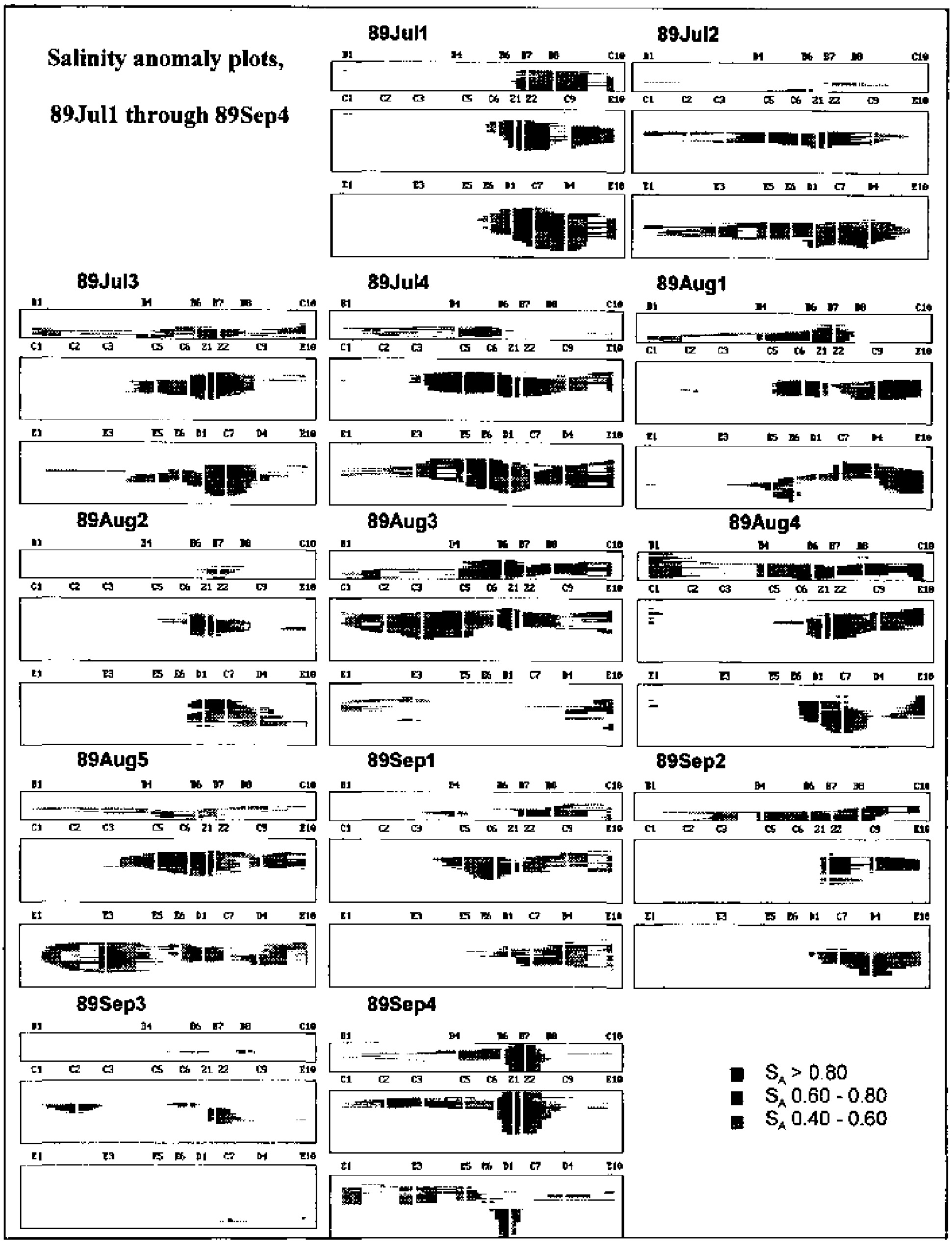


Fig. 4a. Salinity anomaly plots depicting nearfield (Black, $S_A > 0.80$) and farfield ($S_A = 0.40–0.80$) locations for surveys 89Jul1 through 89Sep4.

transported from the outfall. Beginning in mid-November (89Nov3), the wastewater field decreased in depth in response to the deepening density stratification. By the third week of December both the subsurface and a surfacing plume is visible as the nearfield was only partially submerged by weak stratification at 40–

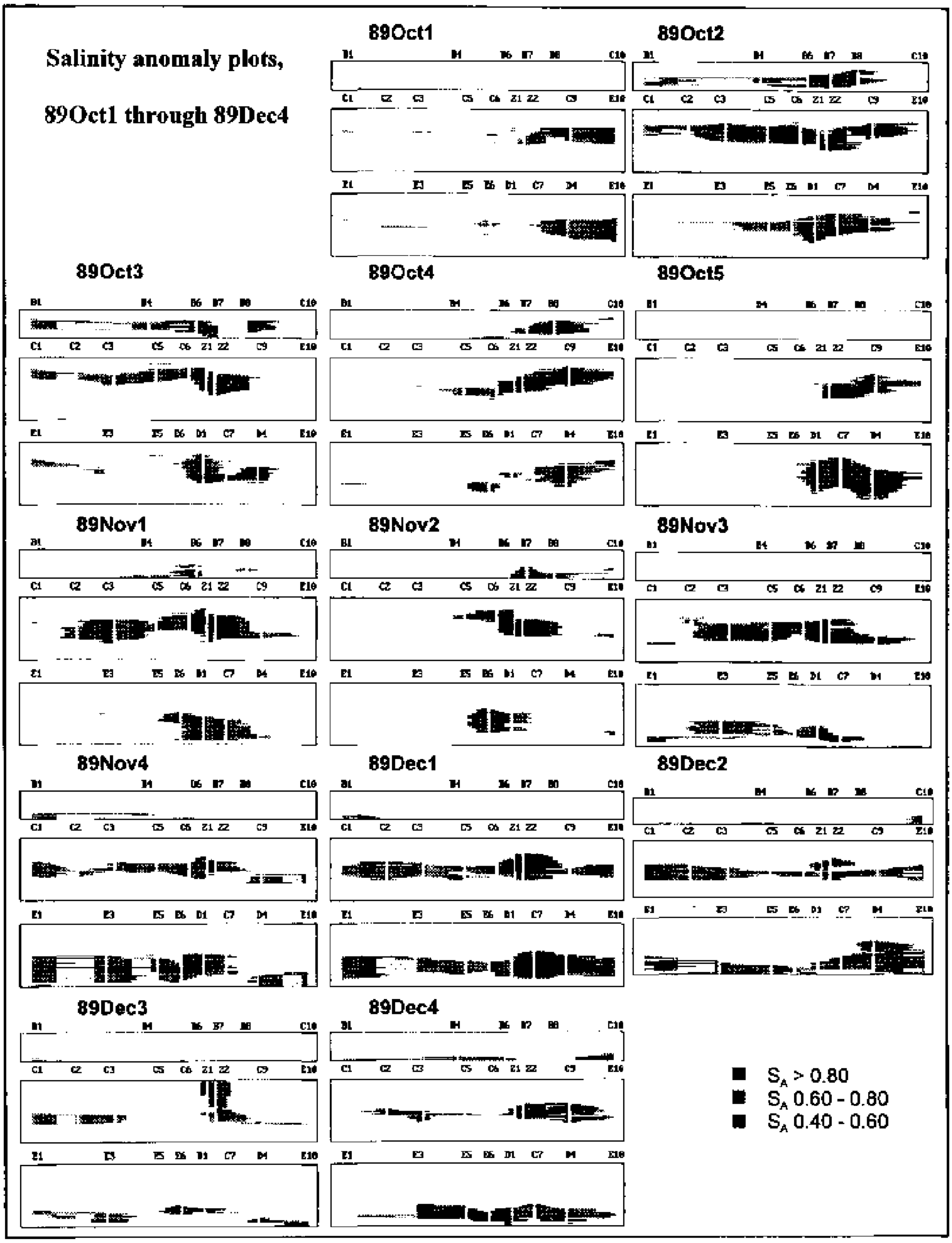


Fig. 4b. Salinity anomaly plots depicting nearfield (black, $S_A > 0.80$) and farfield (gray, $S_A = 0.40$–0.60) locations for surveys 89Oct1 through 89Dec4.

60 m. Weak stratification, characteristic of late fall, continued through most of January resulting in a submerged field that lasted until the last week of the month (Fig. 4c).

The winter season produced many cold fronts with associated strong winds but

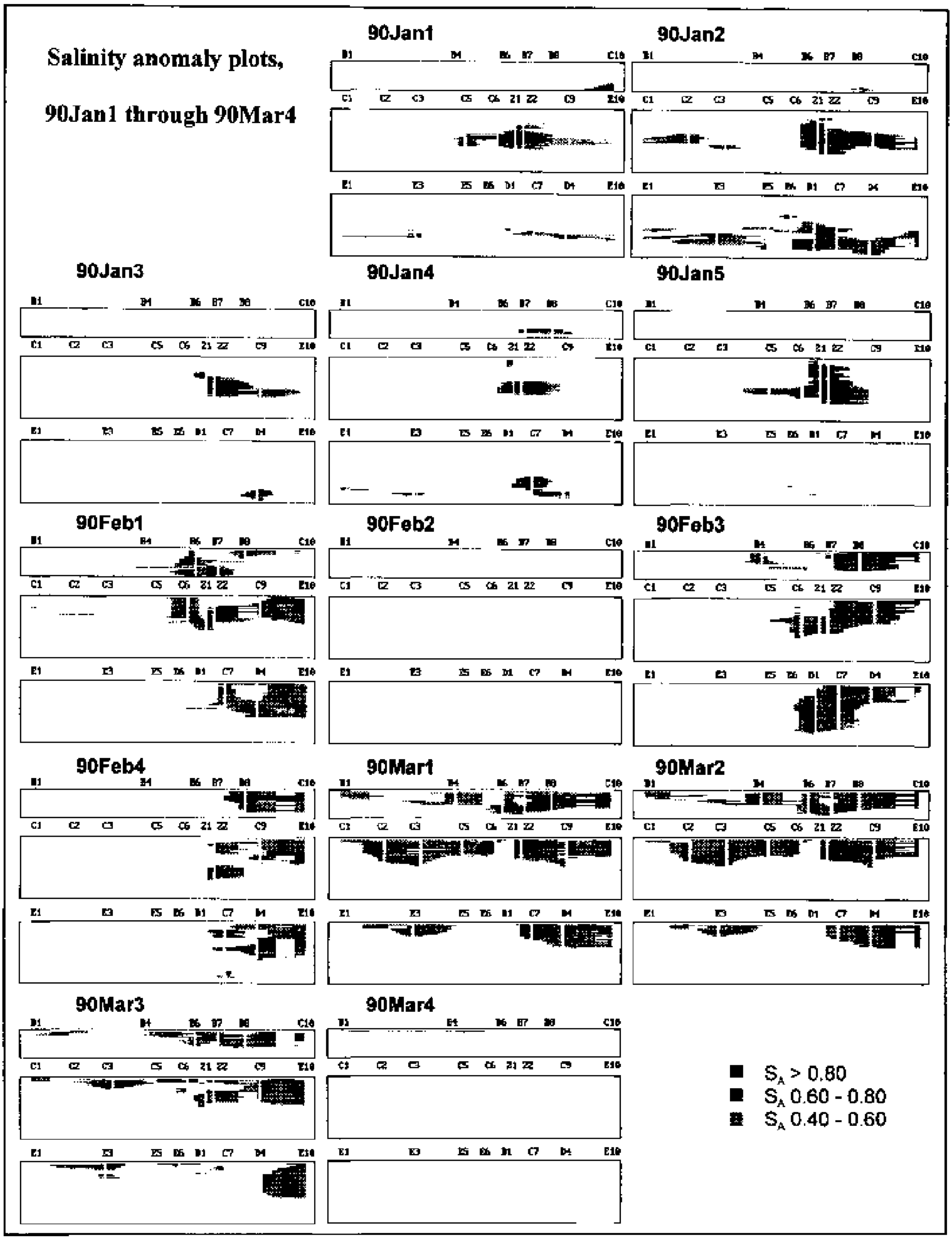


Fig. 4c. Salinity anomaly plots depicting nearfield (black, $S_A > 0.80$) and farfield (gray, $S_A = 0.40$–0.60) locations for surveys 90Jan1 through 90Mar4.

little rainfall. The total rainfall for the 1989–90 season was 18.7 cm, less than half of the normal 37.9 cm (Los Angeles Times). Unstratified conditions developed by the second week of February following two cold fronts resulting in a surfacing wastewater field in the latter part of February (Fig. 4c). The wastewater field was

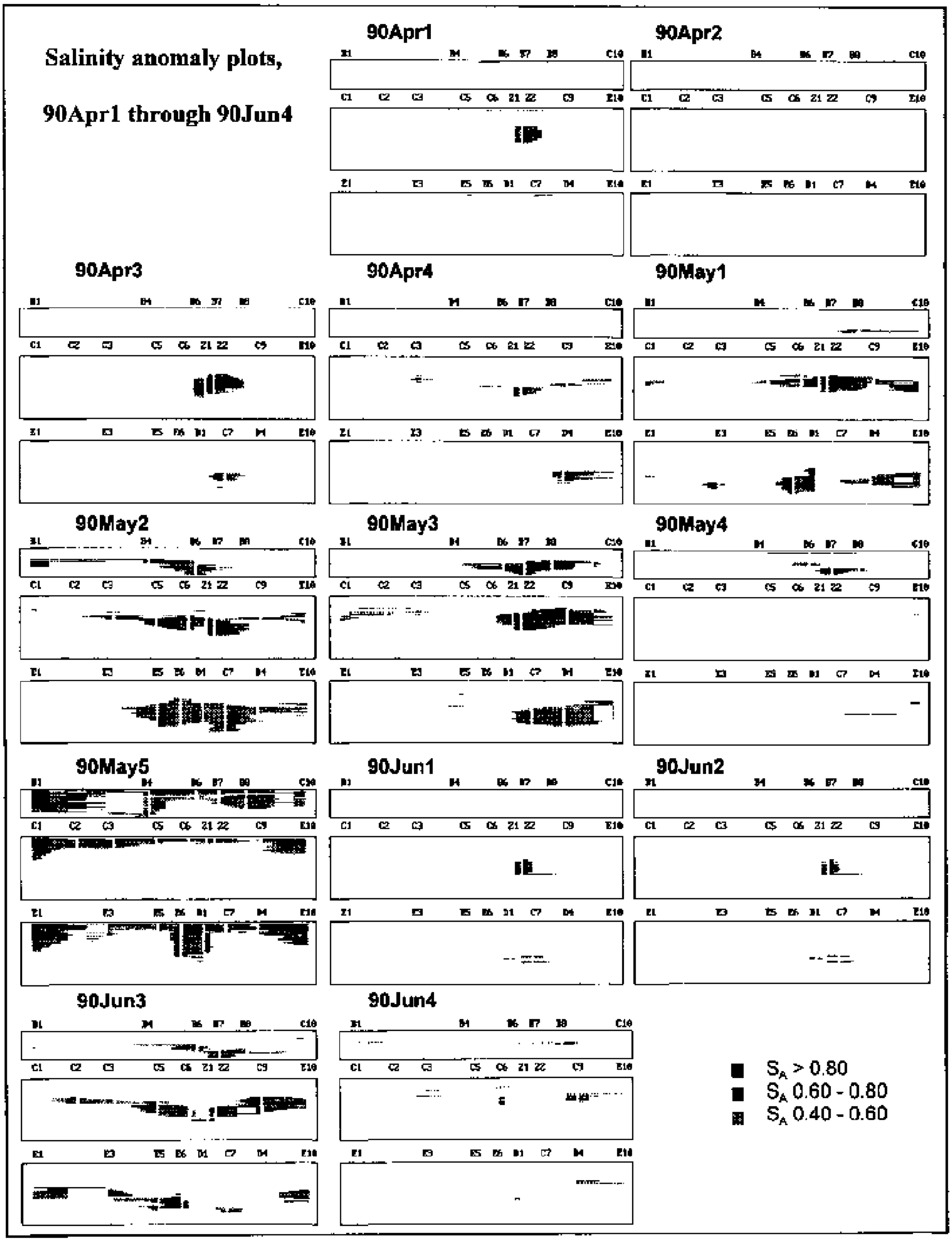


Fig. 4d. Salinity anomaly plots depicting nearfield (black, $S_A > 0.80$) and farfield (gray, $S_A = 0.40$–0.60) locations for surveys 90Apr1 through 90Jun4.

not detected during the first three weeks of March when low surface salinities developed following two rain producing fronts. The associated heavy winds resulted in continued unstratified conditions and an acute upwelling event as indicated by low temperatures and high salinity. Weak stratification developed during the last week of March, but was insufficient to prevent a surfacing wastewater field.

Spring conditions developed with re-establishment of density stratification and the wastewater field became more easily detectable. In early April, the submerged wastewater field remained small, situated mainly at the outfall stations (Z1 and Z2) (Fig. 4d). The wastewater field gradually increased in size as stratification remained in place and extended to stations beyond the outfall by May. Another apparent upwelling event occurred between the fourth and fifth week of May as indicated by low temperature and high salinity. Two weeks later, apparent downwelling occurred following tropical weather causing high temperature and low salinity. Daily afternoon onshore winds resumed and chronic upwelling took place as temperatures gradually decreased and salinity gradually increased for the remainder of the month.

1992–93.–Summer began with low surface salinities persisting from the 1991–92 rainfall. Density stratification during these surveys was well established and spring upwelling had ceased. The wastewater field was submerged, generally well defined, and, as during 1989–90, varied in direction of movement (Fig. 5a). The nearfield was detected most frequently at stations located along the discharge 60-m isobath (C5, C6, and C7) at distances up to 5.3 km from the outfall. September illustrates both the variability of the direction of movement plus variability in the size of the wastewater field. During the first three surveys, a fairly sizeable field changed direction of movement from onshore to upcoast to offshore, then diminished in size by the fourth survey and enlarged to a pervasive field throughout the Bay during the fifth survey of September.

The presence of a large wastewater field continued for the following six weeks, moving deeper in the water column as density stratification deepened with the onset of fall conditions (Fig. 5b). It reached maximum size by October and continued this way until November. During this time a large, subsurface lense of low salinity water, with salinity anomaly values indicating wastewater nearfield (0.4–0.6), covered large portions of the Bay. For example, during the first survey in October, the nearfield covered 12 stations in all directions from the outfall (Z1 and Z2); 17.4 km upcoast to C2; 2.2 km downcoast to C7; 2.7 km onshore to B7; and 7.5 km offshore to E6. The field became smaller in late November and early December as density stratification moved deeper in the water column and weakened.

The first winter storm occurred between the first and second surveys of December initiating an unusually wet winter that resulted in 69.5 cm of rainfall (Los Angeles Times). The water column became unstratified after the first winter storm, a condition that continued through March. During this time the wastewater field was rarely visible (Fig. 5c). Low surface salinities formed in the Bay in January following the heaviest rains and persisted through March. The deviation of salinity at the surface was sufficient to cause the signal for the nearfield to weaken and appear as a farfield (grey color in the plots). A wastewater field was identified only during the first survey of March as a small field positioned below the low surface salinity layer in the vicinity of the outfall. During this time, identification of the wastewater field was augmented by visual inspection of color plots for areas with lowered DO, transmissivity, and/or temperature.

Weak stratification was established by the fifth week of March, signalling the

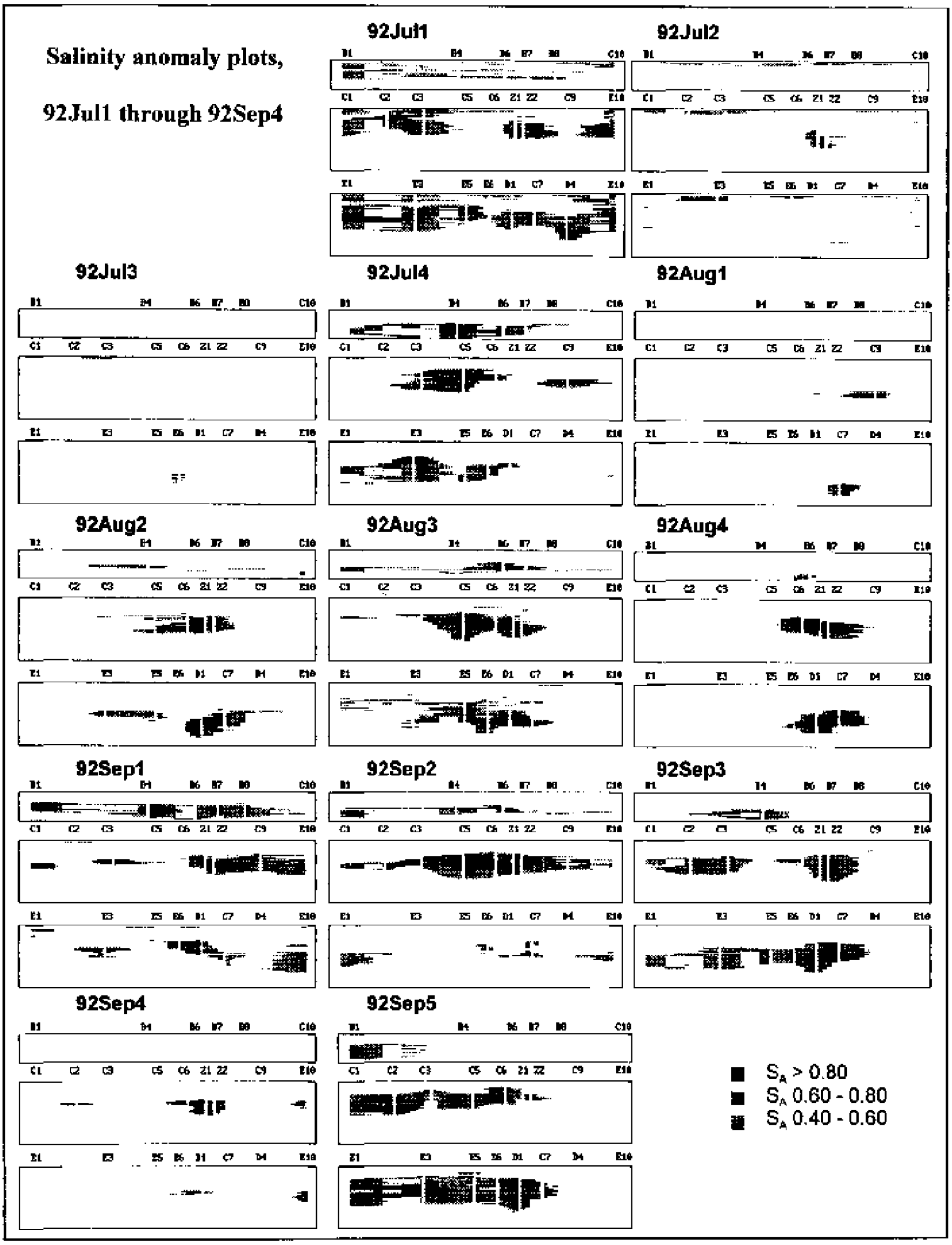


Fig. 5a. Salinity anomaly plots depicting nearfield (black, $S_A > 0.80$) and farfield (gray, $S_A = 0.40$–0.60) locations for surveys 92Jul1 through 92Sep5.

start of spring, but the wastewater field was not readily visible until April (Fig. 5d). Low surface salinity persisted through the end of the year but with diminishing intensity. The wastewater field was visible immediately after stratification reestablished. During this time it was localized at the outfall and was smaller than

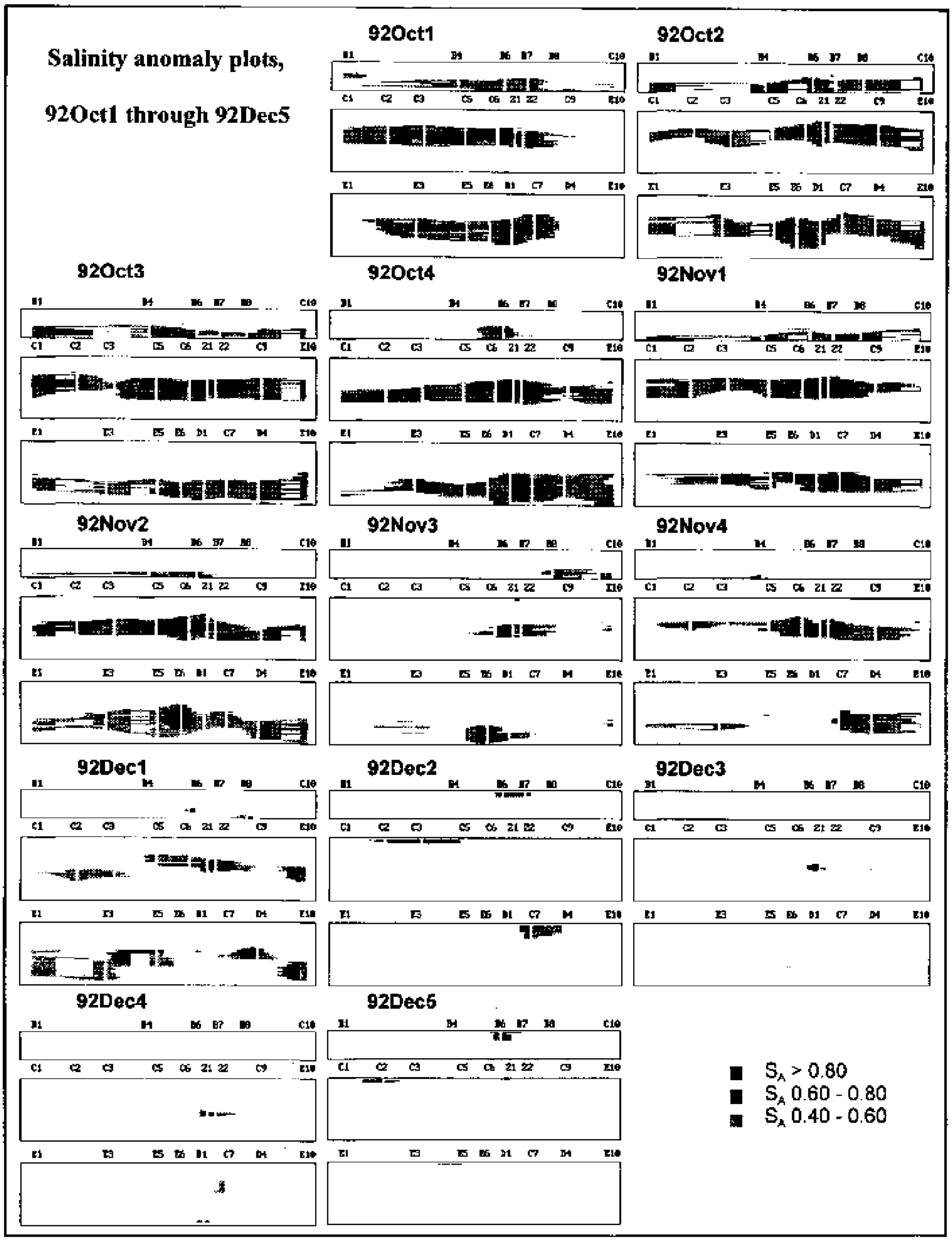


Fig. 5b. Salinity anomaly plots depicting nearfield (black, $S_A > 0.80$) and farfield (gray, $S_A = 0.40$–0.60) locations for surveys 92Oct1 through 92Dec5.

the nearfields surveyed during the previous summer and fall. Movement of the wastewater field was highly variable, similarly to summer and fall. An unusually late rainstorm occurred in early June resulting in a renewed appearance of low surface salinities that month.

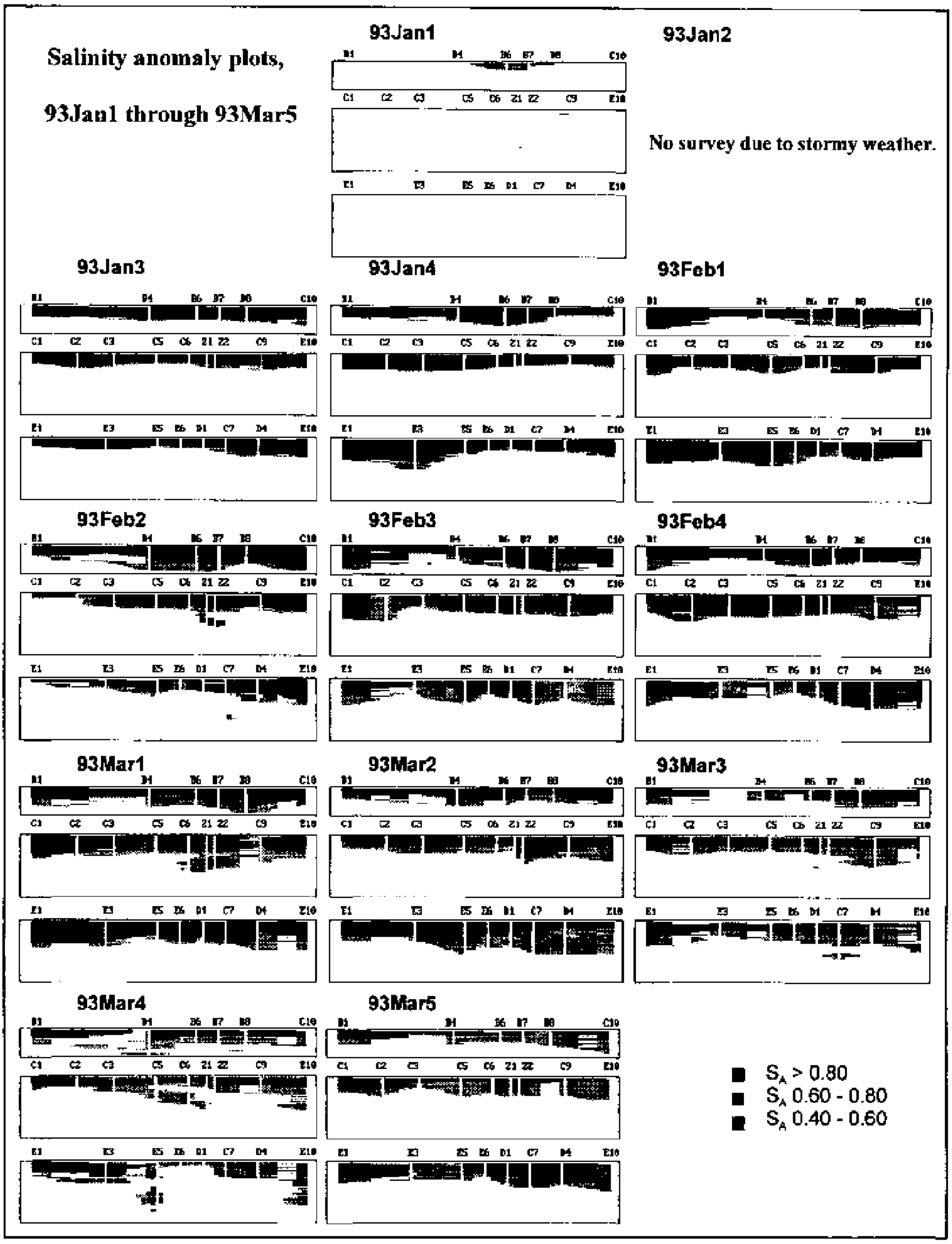


Fig. 5c. Salinity anomaly plots depicting nearfield (black, $S_A > 0.80$) and farfield (gray, $S_A = 0.40$–0.60) locations for surveys 93Jan1 through 93Mar5.

Discussion

We were able to effectively determine the location of the wastewater field and follow seasonal development of oceanographic processes over nearly seven years by employing fairly simple means for analyzing CTD data. In an earlier study,

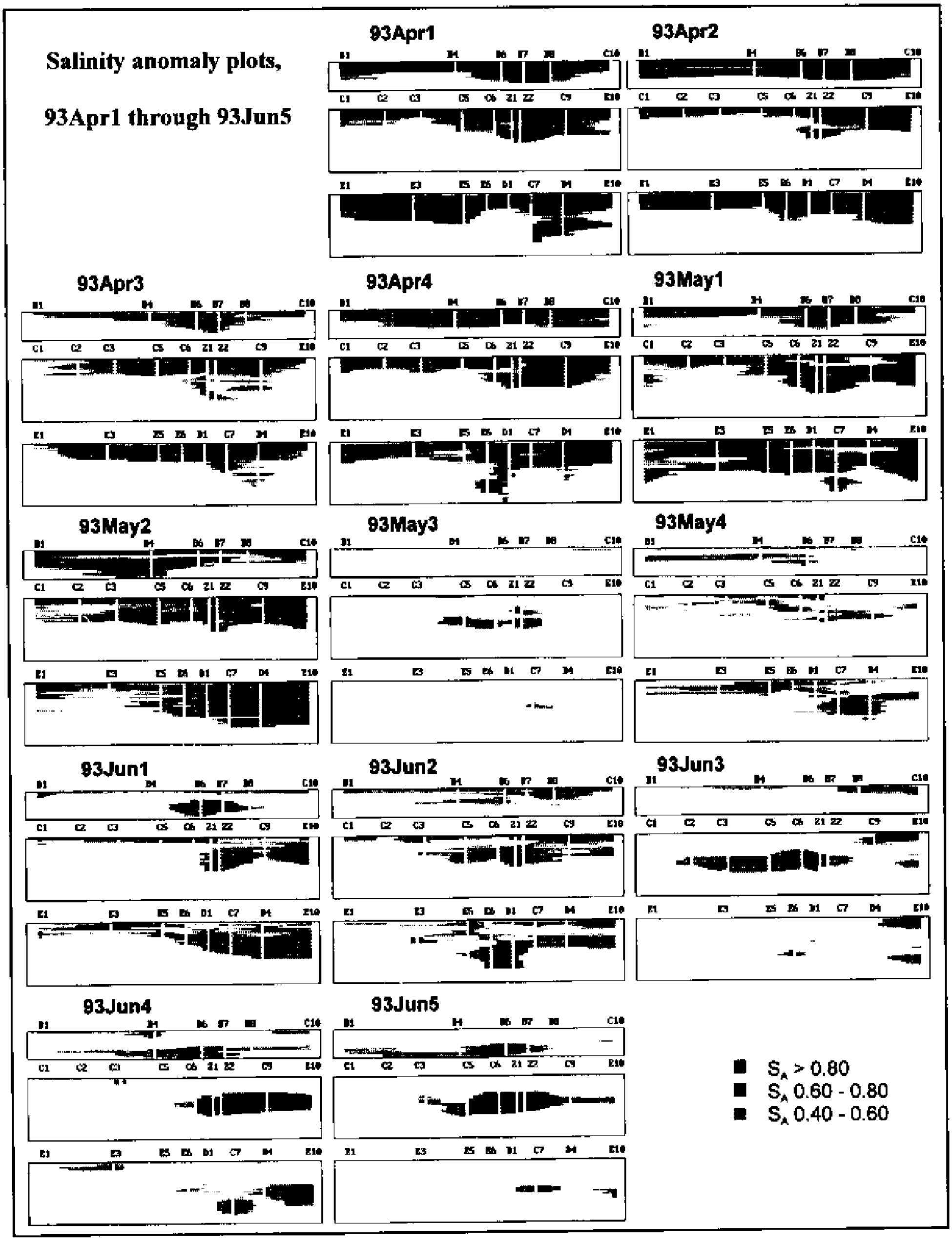


Fig. 5d. Salinity anomaly plots depicting nearfield (black, $S_A > 0.80$) and farfield (gray, $S_A = 0.40$–0.60) locations for surveys 93Apr1 through 93Jun5.

Wu et al. (1994) were able to unambiguously identify the location of the effluent field at White's Point by employing a quasi-objective procedure utilizing threshold criteria for combinations of salinity, turbidity, and chlorophyll fluorescence. Although our data set lacked chlorophyll fluorescence measurements that would enable us to employ similar methods, salinity measurements provided sufficient information for identifying the effluent field. Temperature, transmissivity, and dissolved oxygen augmented detection of the wastewater field, however, these parameters were not correlated with salinity anomaly at this time. Our long-range goals include utilizing multiple parameters in conjunction with salinity, in particular coliform and ammonia data, to better determine the location of the wastewater field.

Calculation of the salinity anomaly, initially devised to eliminate temporal fluctuations in salinity, enabled us to estimate dilutions of effluent in situ. Albeit sources of error such as variable background salinity were not included in the calculation, we believe that salinity anomaly works well to reveal patterns of wastewater field distribution. For example, the resulting estimated dilutions revealed that dilutions as low as 125:1, described as nearfield in this report, often occurred at stations 2 km from the outfall and less commonly at distances up to 8 km. These distances extend well beyond the zone of initial dilution (ZID) which is a theoretical 60-m boundary surrounding the outfall diffuser in which the turbulent mixing of initial dilution takes place. Outside this boundary the discharged effluent reaches neutral buoyancy with continued dilution of the wastewater field occurring from ambient turbulence at a much slower rate (Roberts et al. 1989a, 1989b). Surprisingly, salinity anomaly values measured in non-outfall nearfields often were higher than values at outfall stations indicating that a higher concentration of the wastewater field was present outside the ZID.

The presence of wastewater fields several kilometers from the outfall supports the concept that dispersion of the wastewater field following initial dilution is a much slower process. These wastewater fields were positioned higher in the water column than those of similar salinity characteristics at the outfall stations (Z1 and Z2) indicating that the initial turbulent mixing was complete and that neutral buoyancy had been achieved. Wu et al. (1994) also detected highly concentrated effluent several kilometers from the source of discharge. They noted that dilution of the effluent plume did not precisely follow that theorized by Roberts et al. (1989a) and attributed the effect to currents and the complicated three dimensional structure of effluent plumes. The fact that higher concentrations of the wastewater field have been detected outside the ZID illustrates the complexity of the dilution process and indicates that initial dilution may not be confined to within several hundred meters of the outfall as described by Roberts et al. (1989b).

The highly variable wastewater field movement demonstrates the complexity of currents that exist in the Bay as described by Tareah J. Hendricks of SCCWRP (personal communication) and Hickey (1992, 1994). Hendricks concluded that currents in the Bay were chaotic after conducting a survey in which he deployed current meters at various depths and locations in Santa Monica Bay. He provided us with a compilation of his data into graphical representations that show direction of movement and speed which we summarized by week for each mooring. When compared to CTD surveys conducted during the same time, a strikingly similar pattern between current patterns and distribution of the wastewater field appears. In the example provided in Table 1, two current meters were placed into service (6 September 1989) at the same time a CTD survey was conducted (6–7 September 1989). On that day, currents were measured as going upcoast at both depths, 35 m and the bottom, and the wastewater field was visible upcoast (Fig. 4a). In each

Table 1. Current direction as indicated by summarized results from a single mooring near the City's outfall compared to direction of wastewater movement detected by the CTD.

	Current meter data		CTD data	
	Current direction		Nearfield direction	
Date	35 m	Bottom	Sampling date	Stations
6 Sep 89	Upcoast	Upcoast	6–7 Sep 89	C6
13 Sep 89	Downcoast-onshore	Downcoast-onshore	12–13 Sep 89	Z2, C7–D4
20 Sep 89	Upcoast-onshore	Upcoast-onshore	19–20 Sep 89	C6, B6
27 Sep 89	Confused Double gyre	Confused Double gyre	26–27 Sep 89	C6–Z2, B7, D1

successive week, the nearfield was detected at stations located in the direction that currents were moving. During the last week of the survey, currents were very confused and the nearfield was detected in several directions; upcoast (C6), onshore (B7), and offshore (D1) (Fig. 4a).

In conclusion, nearly seven years of weekly CTD surveys enabled us to develop a detailed picture of anthropogenic and natural events in Santa Monica Bay that will serve as a benchmark for subsequent programs. Notably, the Hyperion outfall is functioning as a large underwater freshwater river that interacts with natural processes as it is transported erratically throughout the Bay. Additionally, the data support theories of wastewater plume behavior as described by Wu et al. (1994).

Acknowledgments

We appreciate the efforts of the many people have been involved in the City of Los Angeles' water quality program since its inception in 1987. We would like to extend special thanks to several of our co-workers: the crew of M/V La Mer and M/V Marine Surveyor; the Environmental Monitoring Division biology staff for field collections that began in 1987 and continue through the present; and Dr. Masahiro Dojiri for his stewardship as supervisor. Additional thanks go to Dr. Burton H. Jones, Dr. Libe Washburn, and Alex Steele for review comments.

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Toxicity of Dry Weather Flow from the Santa Monica Bay Watershed

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Abstract.—A significant source of contaminants to Santa Monica Bay is the daily discharge of 10–25 million gallons of urban runoff from approximately 70 storm drains. Research conducted in 1990–93 examined the toxicity of dry weather flow from Ballona Creek and three other drains discharging into Santa Monica Bay. Toxicity tests were conducted using sensitive life stages of purple sea urchins, red abalone, and giant kelp. Spatial and temporal variations in toxicity were observed. Sea urchin sperm and abalone embryos were more sensitive than kelp spores, with toxic effects produced by ≥5.6% dry weather flow. Preliminary toxicity identification evaluations indicated that the constituents causing toxicity in dry weather flow are variable.

Urban runoff consists of two major components: stormwater resulting from rainfall and dry weather flow. Dry weather flow occurs daily in some storm drains, with an estimated 40–90 million liters per day flowing into Santa Monica Bay through approximately 70 outlets that empty onto or across beaches (LAC, DPW 1985; SMBRP 1994). The contribution of dry weather flow to the total volume of runoff into Santa Monica Bay varies, depending upon rainfall patterns, accounting for about 30% of the total (NRC, COWT 1984). While the chemical composition and toxicity of sewage and industrial effluent discharges into the ocean are well characterized (SCCWRP 1990a, b) and subject to strict regulations (SWRCB 1990), studies of runoff are much more limited (SMBRP 1994; SCCWRP 1990c). A wide variety of chemical contaminants, including heavy metals, petroleum compounds, pesticides, and PCBs have been detected in samples of dry weather flow and stormwater (SCCWRP 1990c; Suffet et al. 1993; SMBRP 1994). It is estimated that runoff is responsible for about one-fourth of the current contaminant inputs to Santa Monica Bay (SMBRP 1994).

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Runoff usually enters the ocean at the beach, harbors, or bays, where the chances for interaction with sensitive environments (e.g., wetlands) or human contact are high. Though dry weather flow represents a chronic source of pollution to Santa Monica Bay's coastal environment, the biological effects are poorly known. This paper presents the results of recent toxicity studies of dry weather flow from several storm drains discharging into Santa Monica Bay. The objectives of this research were to measure the effects of dry weather flow on sensitive marine organisms, examine variability between sites or with time, and identify the toxic components.

Methods

Sampling Locations and Procedures

Samples were collected from four storm drains in the greater Los Angeles (Calif.) area (Fig. 1). Drainage area varied for each site, ranging from 25,952 ha for Ballona Creek to 1,123 ha for Ashland (unpublished UCLA data). Land use was primarily residential within each drainage (52–63% of total area). An additional criterion guiding station selection was the presence of dry weather flow in each drain.

Dry weather flow.—Samples of dry weather flow were collected during two separate research programs. In the first study, samples were collected in December 1990 and February 1991 from Ballona Creek only. In the second study, 1–6 samples were collected from the four drains between August 1992 and January 1993. Samples from Ballona Creek and Sepulveda Channel were obtained from the middle of the concrete drainage channels. At Pico-Kenter, samples were collected from a well installed to divert dry weather flow into the sanitary sewer. Samples from the Ashland drain were obtained from a sump near the beach. The Ashland site received seawater inputs at high tide, the other three sampling locations were above the tidal prism.

Samples were obtained by immersing a 1-L glass bottle (1990–91) or stainless steel bucket (1992–93) in the discharge. Water depth was generally shallow and it is likely that the surface microlayer was collected with the sample. Morning and afternoon samples were collected in 1992–93 and usually composited before toxicity testing. All samples were placed in coolers and stored at 4°C until further analysis.

Receiving water. Surface water from six locations within the area where Ballona Creek effluent mixes with receiving water from Santa Monica Bay (between end of concrete channel and Marina del Rey breakwater, Fig. 1) were collected in February 1991. Samples were obtained from the center of the channel by submerging a glass bottle approximately 0.2 m below the surface. Conductivity measurements were used to determine the percentage of runoff in each sample. The surface microlayer was not included in these samples.

Chemical Analysis

Samples collected in 1992–93 were analyzed for the following water quality parameters according to standard methods (APHA 1989): ammonia (method 4500-NH_3.F), total dissolved solids (TDS, method 2540.C), total suspended solids (TSS, 2540.D), chemical oxygen demand (COD, method 5220.B), dissolved or-

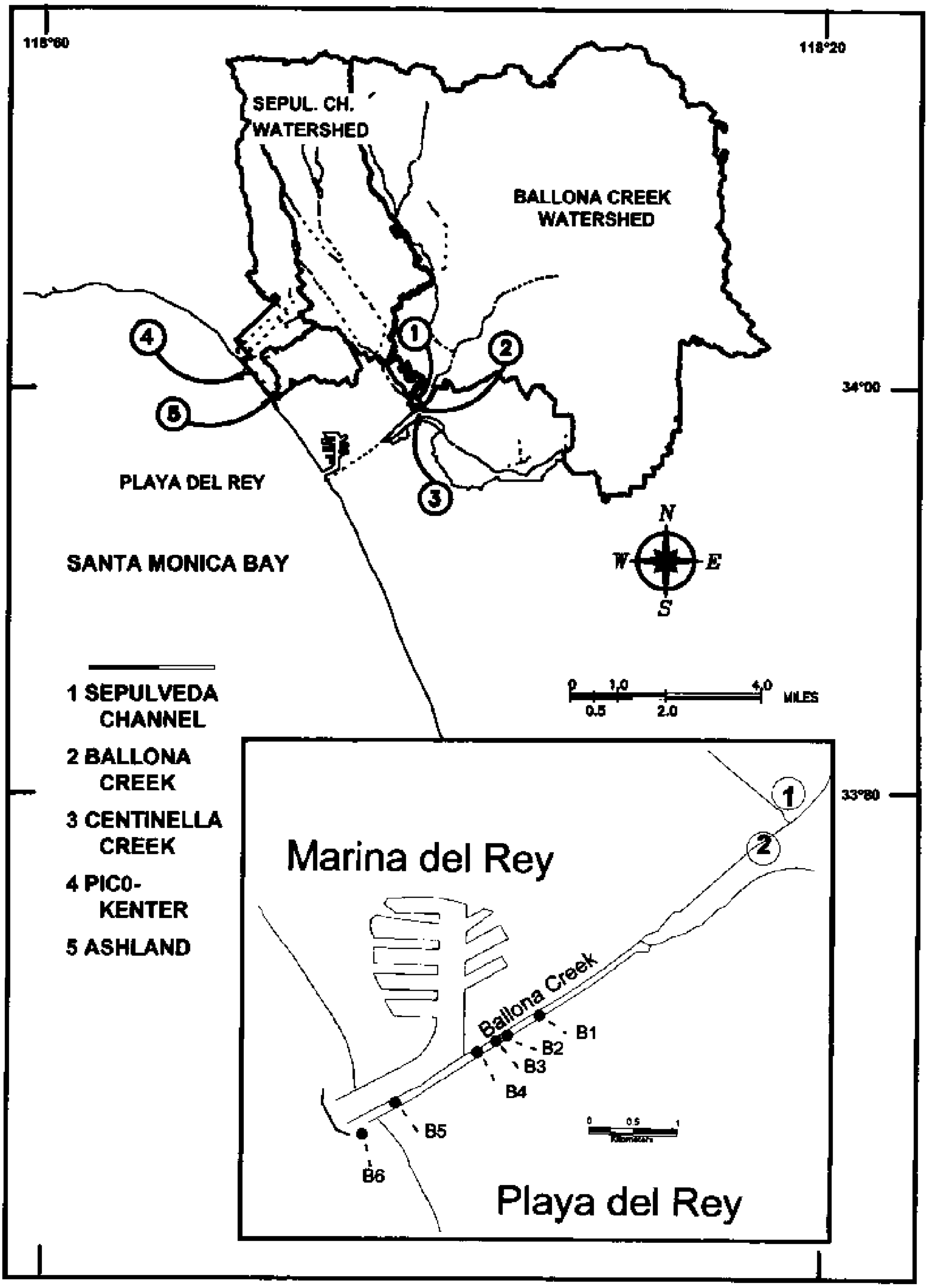

Fig. 1. Location of storm drain sampling sites and watershed boundaries (thick lines). Broken lines indicate larger storm drain channels. Inset shows locations of sampling sites for receiving water (B1–B6), Sepulveda Channel (1) and Ballona Creek (2).

ganic carbon (DOC, method 5310), turbidity (method 2130.B), and dissolved oxygen (method 4500-OG).

Toxicity Assessment

Samples collected in 1992–93 were passed through a 1.0 μm glass fiber (Whatman GF/B) and adjusted to a salinity of 34 g/kg by addition of brine before toxicity testing. Toxicity tests conducted in 1990–91 used unfiltered samples without salinity adjustment. Filtered natural seawater was added to all samples to produce four or five test concentrations ranging from 2–56% effluent. Three or four replicates of each concentration were tested. Toxicity tests were initiated within 24 hours of sample collection.

Short-term chronic toxicity tests using three species of marine organism (sea urchin, abalone, kelp) were used to evaluate the toxicity of dry weather flow samples. These methods are among those recommended in the State of California's Ocean Plan (SWRCB 1990) for measuring the toxicity of discharges into the marine environment. All tests were conducted at 15°C and a salinity of 34 g/kg. Concurrent reference toxicant tests using copper chloride or zinc sulfate were included to document temporal variations in test sensitivity. A summary of the toxicity test methods follows; additional method information is presented in Lau et al. (1994).

Sea urchin fertilization test.—All samples were tested for effects on the fertilization of sea urchin eggs using modifications of the method described by Dinnel et al. (1987). Sea urchins were induced to spawn through injection of KCl, sperm was collected dry (without addition of seawater), and stock solutions of sperm and eggs prepared. The test was conducted by adding sufficient sperm to 10 mL volumes of sample to produce a sperm : egg ratio of 200–400:1. Eggs were added after 60 minutes, given 20 minutes for fertilization, and preserved with formalin.

Abalone embryo development.—Embryos of the red abalone (*Haliotus rufescens*) were exposed to 1992–93 storm drain samples according to the method described by Anderson et al. (1990). Abalone spawning was induced by exposure to a hydrogen peroxide solution. Newly fertilized eggs were added to 200 mL of test sample and allowed to develop for 2 days. The resulting embryos were preserved with formalin and examined microscopically.

Giant kelp spore germination and growth.—Toxicity tests with giant kelp (*Macrocystis pyrifera*) spores were conducted according to procedures described by Anderson et al. (1990). Zoospore release was induced by desiccation of kelp blades containing reproductive spores (sporophyll). Spores were added to beakers containing 200 mL of sample and glass microscope slides. Slides were removed after 48 hours exposure under controlled light levels (50 $\mu Em^{-2}sec^{-1}$), preserved, and examined to assess spore germination rate and gametophyte length.

Toxicity Characterization

Two samples were collected from Ballona Creek for preliminary toxicity identification evaluation (TIE). Morning and afternoon grab samples were collected on December 14, 1992 and January 12, 1993. The sea urchin fertilization test was used to select the most toxic sample for each day. Phase I TIE manipulations were conducted the following day and consisted of C18 solid phase extraction (SPE), EDTA addition, and sodium thiosulfate addition following the recommendations of Norberg-King et al. (1992). All procedures were conducted at the

Table 1. Median effect (EC50) and no observed effect (NOEC) concentrations for dry weather flow samples collected from multiple sites in 1992. Toxicity was measured using abalone (*Haliotus rufescens*) embryo development, sea urchin (*Strongylocentrotus purpuratus*) fertilization, and giant kelp (*Macrocystis pyrifera*) spore germination/length tests.

		NOEC (% sample)				EC50 (% sample)			
Site	Date	Abalone	Kelp germination	Kelp length	Urchin	Abalone	Kelp germination	Kelp length	Urchin
Ashland	8/24/92	<5.6	18	18	10	6.8	32	>56	17
	9/29/92	nc[a]	nc	nc	5.6	nc	nc	nc	14
	10/12/92	5.6	5.6	5.6	<5.6	10	22	50	<5.6
Ballona	9/8/92	≥56	≥56	≥56	<5.6	>56	>56	>56	14
	9/29/92	nc	nc	nc	12[b]	nc	nc	nc	>56
	10/12/92	≥56	≥56	≥56	≥56	>56	>56	>56	>56
Pico-Kenter	8/24/92	18	≥56	≥56	≥56	42	>56	>56	>56
	9/29/92	nc	nc	nc	≥56	nc	nc	nc	>56
	10/12/92	12	≥56	25	25	21	>56	>56	41
Sepulveda	9/8/92	≥56	≥56	≥56	10	>56	>56	>56	nc

[a] Value could not be calculated due to poor test results or unusual dose-response curve.
[b] NOEC can also be stated as >56% since 56% concentration was not significantly different from brine control. A NOEC of 12% is felt to be more appropriate since the 56% brine control was toxic, making the accuracy of the results for 56% sample questionable.

ambient pH of the sample and are fully described by Lau et al. (1994). Toxicity of the treated samples, blanks, and untreated stored sample was measured the day after manipulation (approximately 48 hours after collection) using the sea urchin fertilization test.

Data Analysis

The no observed effect concentration (NOEC) was determined for each treatment by Dunnett's multiple comparison test (Zar 1984). Data for the sea urchin and abalone tests were arcsine transformed before statistical testing. The concentration producing a 50% toxic response (EC50) was calculated using probit analysis. Data from different experiments were normalized to the control response to facilitate comparisons between species. This was accomplished by expressing the result for a specific sample as a percentage of the average control response for the experiment.

Results

Toxicity Patterns

Results of the multiple site comparisons in 1992–93 show that toxicity was present in at least one sample from each of the four locations sampled (Table 1). There were differences in test response between locations and test species, however.

Species-specific patterns.—Examination of the dose-response plots for samples from Ballona Creek and Pico-Kenter show that each test species responded differently to some samples (Fig. 2). The sea urchin fertilization test was the only method to detect toxicity in the September 8, 1992 sample from Ballona Creek.

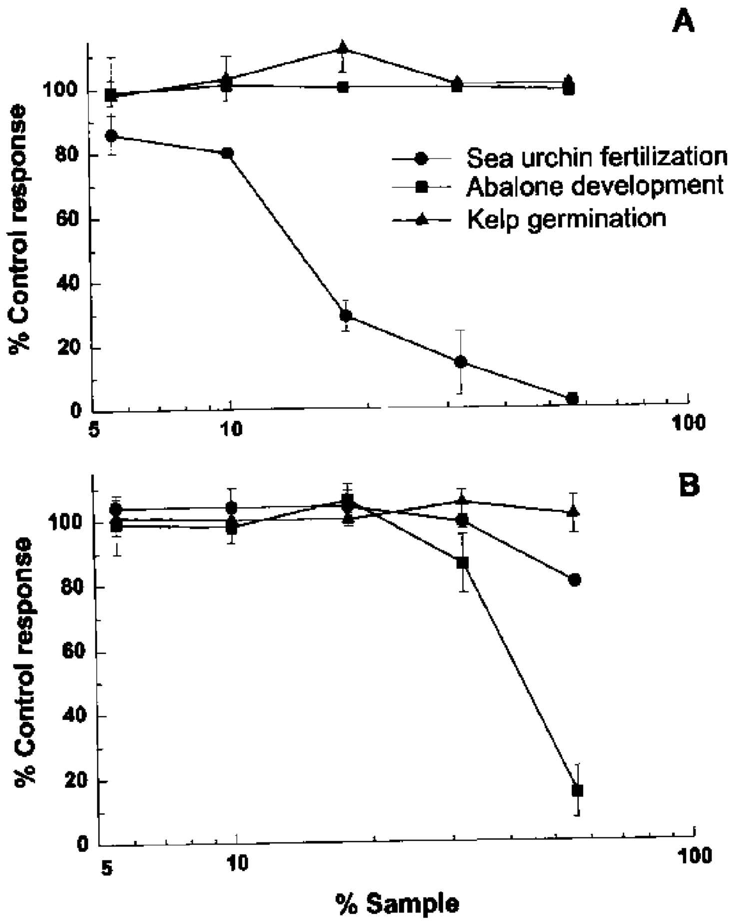

Fig. 2. Toxicity test responses to various concentrations of dry weather storm drain effluent. Test results (mean and standard deviation) have been normalized to the control response. A: Ballona Creek composite sample collected September 8, 1992. B: Pico-Kenter composite sample collected August 24, 1992.

For Pico-Kenter, abalone development was more sensitive than sea urchin fertilization or kelp germination/growth for both samples analyzed with multiple species. The kelp test was the least sensitive of the three test methods for all sites examined (Table 1).

Spatial variability.—The NOEC and EC50 data (Table 1) identify Ashland as consistently the most toxic site. Toxicity was detected by all three test methods for the Ashland samples.

Temporal variability.—The sea urchin fertilization test was used to evaluate the greatest number of samples and provides the best indication of temporal variability in toxicity. Toxicity units (TU, 100/EC50) were calculated in order to facilitate comparisons of relative toxicity between samples (Fig. 3). Substantial variations in toxicity were present between multiple samples from Ashland and Ballona Creek. Though the Ashland sample was consistently toxic, relative toxicity varied more than three-fold.

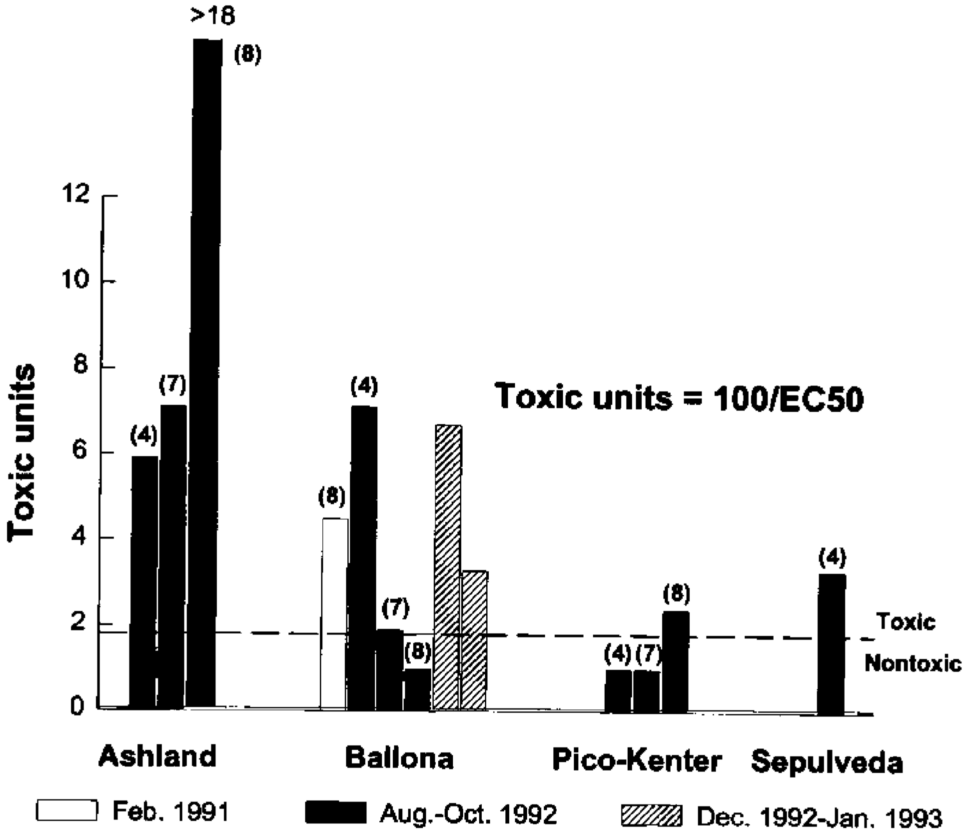

Fig. 3. Variability in sea urchin (*Strongylocentrotus purpuratus*) fertilization test results with time and storm drain location. Results of concurrent reference toxicant (copper) tests for each set of samples are shown in parentheses.

Even greater temporal variation was present between Ballona Creek samples. Three samples taken within the span of approximately one month ranged from strongly toxic (7 TU) to nontoxic (<2 TU). No long-term trends were evident at Ballona Creek; toxicity of a sample collected the previous year (February 1991) fell within the range measured in 1992–93 (Fig. 3). Results of reference toxicant (copper chloride) tests varied by about a factor of two, indicating that variations in fertilization test sensitivity, though present, were within acceptable limits. Variations in reference toxicant response did not correspond to the temporal or spatial variability in dry weather flow toxicity (Fig. 3).

General Constituents of Dry Weather Flow

Water quality measurements indicate variations in effluent composition between sites despite similar land use distributions (Table 2). Samples from Ashland usually had the poorest water quality. For example, Ashland had higher levels of suspended solids, chemical oxygen demand, dissolved organic carbon, turbidity, and ammonia than the other sites. Dissolved oxygen concentration was also low at Ashland and a sulfide odor was usually present. The ocean discharge pipe for

Table 2. Study site land use and physical/chemical characteristics of dry weather flow samples used in 1992–93 toxicity tests. Data are means and standard deviations. Ballona Creek means include data from two samples used for toxicity identification evaluations. See footnotes for sample collection dates.

Parameter	Ashland[a]	Ballona[b]	Pico-Kenter[a]	Sepulveda[c]
Land use (% of area)[d]				
Residential	55	63	52	58
Commercial	4	11	16	9
Light industrial	2	4	13	1
Public, open, or other	39	22	19	32
pH	7.6 ± 0.2	8.5 ± 0.4	7.6 ± 0.1	8.7
COD (mg/L)	252 ± 64	52 ± 24	88 ± 38	73
Dissolved oxygen (mg/L)	1.6 ± 0.3	>15	6.6 ± 0.8	>15
TDS (mg/L)	6,058 ± 4,045	1,903 ± 1,204	1,493 ± 841	4,071
TSS (mg/L)	299 ± 476	59 ± 75	103 ± 71	13
DOC (mg/L)	34 ± 14	9 ± 3	15 ± 1	16
Ammonia (mg/L as NH_3-N)	0.76 ± 0.46	0.22 ± 0.29	0.11 ± 0.10	0.06
Turbidity (NTU)	138 ± 209	42 ± 62	30 ± 14	4

[a] Samples collected on 8/24/92, 9/29/92, and 10/12/92.
[b] Samples collected on 9/8/92, 9/29/92, 10/12/92, 12/14/92, and 1/19/93.
[c] Sample collected on 9/8/92.
[d] Ashland, Ballona, and Pico-Kenter data from UCLA and WCC (1992). Sepulveda data from unpublished information.

Ashland was often blocked by sand, creating stagnant conditions that may have been responsible for the degraded water quality.

Both Ashland and Sepulveda Channel had relatively high levels of total dissolved solids (TDS), but for different reasons. Tidal intrusion of seawater influenced TDS levels at Ashland, while permitted discharges of ion exchange regeneration waters affected Sepulveda Channel TDS.

Dissolved oxygen (DO) and pH were unusually high at both Ballona Creek and Sepulveda Channel. Ballona Creek samples collected in 1990–91 had a high pH (10.1). Elevated pH and DO probably resulted from the metabolic activity of algal mats which lined the bottoms of these open channels.

Toxic Components

pH.—Variations in pH did not influence the toxicity results shown in Figure 3 because the pH was adjusted to typical seawater values (7.9–8.3) before testing. Ballona Creek samples collected in December 1990 and February 1991 were also tested without pH adjustment. The high pH of these samples (10.1) substantially elevated the pH of test concentrations containing ≥10% effluent (Fig. 4). Strong effects on sea urchin fertilization were observed for these samples; 1990 and 1991 Ballona Creek samples had EC50s of 10% & 6%, respectively. Toxicity of the 1991 Ballona Creek sample was greatly reduced, but not eliminated by pH adjustment (Fig. 4).

Salinity.—No adjustments for altered salinity were made on the 1990–91 test samples. Substantial reductions in salinity (>3 g/kg) were present in samples containing ≥10% effluent. The results of concurrent salinity controls (deionized water substituted for effluent) indicated toxic effects were produced when salinity

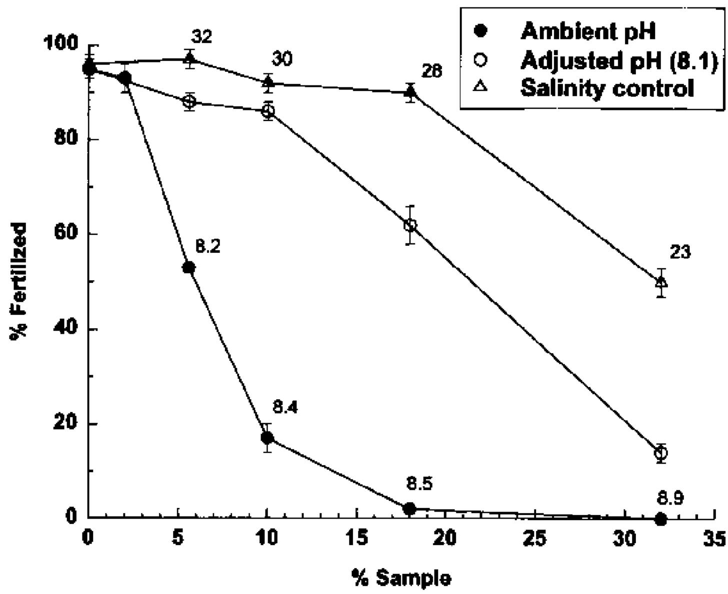

Fig. 4. Effects of reduced salinity and pH adjustment of a February 1991 Ballona Creek sample on sea urchin (*Strongylocentrotus purpuratus*) fertilization. Measured salinity and pH for selected treatments are indicated above the symbols.

fell below 28 g/kg (Fig. 4). The response of sea urchin sperm to pH adjusted Ballona Creek effluent was greater than that produced by salinity change alone.

Toxicity characterization.—Phase I TIE manipulations of two Ballona Creek samples produced variable results. Toxicity in the first sample (collected in December 1992), was partially removed by solid phase extraction and completely eliminated by thiosulfate addition (Table 3). Chelation by EDTA was not effective in reducing toxicity of the first sample. Solid phase extraction and thiosulfate

Table 3. Results of phase I TIE manipulations and water quality analyses of storm drain samples collected in December 1992 and January 1993 from Ballona Creek. The baseline sample represents stored effluent prior to TIE. Toxicity data are the mean of duplicates containing 56% storm drain effluent, water quality data represent single samples.

% fertilized after treatment			Water quality		
Treatment	12/92	1/93	Constituent	12/92	1/93
Baseline	15	16	pH	8.2	8.1
Chelation[a]	44	92	COD (mg/L)	70	37
Reduction[b]	99	10	TDS (mg/L)	3,810	829
Extraction[c]	76	20	TSS (mg/L)	174	97
			Ammonia (mg/L)	0.70	0.28
			Turbidity (NTU)	146	56

[a] Addition of 3 mg/L EDTA to sample.
[b] Addition of 10 mg/L sodium thiosulfate to sample.
[c] Solid phase extraction of 1 L sample using 1 g of C18 sorbent.

Table 4. Sea urchin (*Strongylocentrotus purpuratus*) fertilization toxicity test results for surface water samples from the mouth of Ballona Creek. Station locations are shown in Figure 1. Sample concentration was calculated from conductivity measurements.

	Station					
	B1	B2	B3	B4	B5	B6
Fertilization (%)	21	62	90	54	16	16
Dry weather flow concentration (%)	22	9	6	4	<1	<1

addition were ineffective when applied to the second sample (January 1993), while the toxicity was eliminated by EDTA.

Differences in TIE sample characteristics were also indicated by the water quality data. There were marked differences in water quality (e.g., TDS and turbidity) between the two TIE samples (Table 3).

Receiving Water Toxicity

Five of six receiving water samples from the mixing zone of Ballona Creek were toxic to sea urchin sperm (Table 4). The greatest toxicity was present in samples from both the upstream and downstream ends of the sampling area. Fertilization effects did not correspond to the amount of Ballona Creek effluent in the samples; the strongest toxicity was produced by water samples containing the highest (22%) and lowest (< 1%) concentrations of dry weather flow (Table 4).

Discussion

The results presented here are preliminary since they are based on a limited number of stations and samples. But they are sufficient to allow us to evaluate the following questions.

Is it toxic?—Dry weather flow often causes toxicity at concentrations above about 6%, as indicated by the data presented in Table 1. Toxicity to marine invertebrates was found in at least one sample from each of the four sites investigated and was evident in samples collected from Ballona Creek over a span of two years. Adult forms of the test organisms (sea urchins and abalone) are not found in the immediate vicinity of these storm drains, although it is likely that the larval forms of similar species are present in nearby waters. The test data indicate the relative toxicity of dry weather flow, but may not accurately predict effects on specific resident species.

Previous research has shown dry weather flow from two local drainages to be toxic to marine bacteria (SCCWRP 1989). In this study, toxicity of a dry weather flow sample was greater than the average toxicity of storm runoff samples in Ballona Creek. Toxicity of a dry weather flow sample from the Los Angeles River sample was lower, but within the range of stormwater samples from the same location.

Results from the 1992–93 samples demonstrate multiple sources of variability. Toxicity showed both spatial and temporal variations in magnitude, as well as species-specific differences. Reference toxicant results for both the sea urchin and abalone tests indicate that this variability is real, not the result of variations in toxicity test performance. Such complexity presents a challenge for designing an appropriate monitoring program to study dry weather flow. A year-round sampling program consisting of multiple times, locations, and species is needed to provide accurate information.

What are the toxic components?—Limited progress was made towards answering the second question. Toxicity in most Ballona Creek samples was not due solely to the pH and salinity changes (Fig. 4), indicating the presence of toxic chemical components. The first (December 1992) Ballona Creek sample examined using phase I TIE procedures contained toxicants with characteristics similar to non-polar organics and oxidants, while toxicants in the second sample were similar to metal ions.

Hydrogen sulfide or ammonia are potential contributors to the toxicity in the Ashland storm drain samples. A sulfide odor was detected in some samples and hydrogen sulfide concentrations as low as 0.02 mg/L cause reduced sea urchin fertilization (SCCWRP 1994). Quantitative measurements of sulfide concentration were not made in this study. Ammonia concentration was elevated in samples from Ashland and has been identified in TIE studies with other effluent types as a cause of toxicity. None of the dry weather flow samples contained sufficient ammonia to cause toxicity at the test concentrations of $\leq 50\%$. The ammonia NOEC for red abalone embryos is 0.98 mg/L NH_3-N (unpublished data).

A previous study of southern California stormwater runoff used correlation techniques in an attempt to identify contaminants associated with toxicity (SCCWRP 1989). Suspended volatile solids was the only component exhibiting a significant negative correlation with toxicity. No meaningful relationships were identified between toxicity and concentrations of trace metals or chlorinated organics (e.g., DDT and PCB).

The type of toxicant in dry weather flow may vary with time and multiple chemicals may be present at toxic concentrations in a single sample. More extensive TIE work is needed to confirm these findings, investigate different sites, and provide more specific results.

TIE techniques, which rely upon chemical manipulations to inactivate and separate specific chemical groups, offer a better chance of success in identifying specific toxicants in storm drain samples than do techniques that rely solely on chemical analysis (Bailey et al. 1995).

Are ecological effects likely?—The Ballona Creek data indicate that dry weather flow is unlikely to produce direct adverse effects on water column organisms in Santa Monica Bay. Dry weather flow was diluted more than 100× before entering Santa Monica Bay and toxicity is not expected to be present in samples containing <5% effluent (20× dilution). Toxicity resulting from other (smaller) dry weather flow discharges into Santa Monica Bay is even less likely, since a smaller volume is discharged into a highly dispersive environment (surfzone).

Variations in receiving water toxicity among some samples from the mouth of Ballona Creek did not correspond to the concentration of dry weather flow present. This observation indicates the presence of an additional source of toxicity to the nearshore environment, possibly the adjacent Marina Del Rey.

Water column toxicity represents just one potential adverse effect resulting from dry weather flow. Other effects that might arise include sediment toxicity and increased contaminant bioaccumulation caused by the deposition of contaminated particles in dry weather flow. These factors were not addressed in the present study and must be investigated before a more complete evaluation of the biological effects of dry weather flow is possible.

Conclusions

- Dry weather flow samples from urbanized regions of Santa Monica Bay often contain unidentified chemicals at levels toxic to marine organisms.
- The composition and toxicity of dry weather flow is variable with time and between storm drains.
- The discharge of dry weather flow is unlikely to cause water column toxicity in Santa Monica Bay, but potential impacts on sediment quality, contaminant bioaccumulation by marine life, and human health have not been adequately studied.

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Adverse Effects of Hyposalinity from Stormwater Runoff on the Aggregating Anemone, *Anthopleura elegantissima*, in the Marine Intertidal Zone

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Abstract.—Coastal watersheds strongly impact the near-shore marine environment with freshwater inundation and runoff from the land. At Leo Carillo State Beach in Malibu, California, we have noticed marked effects of stormwater runoff on the local marine fauna. The aggregating sea anemone expels symbiotic algae under the influence of hyposaline stress, causing bleaching. The number and distribution of bleached sea anemones have increased dramatically from 1992 to 1995 at Leo Carillo State Beach under the influence of increased rainfall and the artificial broadening of the arroyo channel at its mouth.

On a gently sloping beach, many horizontal meters of marine habitat may be exposed to air during low tides. The area on rocks between the lowest low tide and the highest high tide, the rocky intertidal zone, is among the most productive habitats on earth, similar to a tropical rainforest or a coral reef (Leigh et al. 1987). Invertebrate animals living in the marine intertidal zone are hardy, generally well-adapted for the changing conditions of temperature, pH, oxygen, and carbon dioxide during tidal excursions (Truchot and Duhamel-Jouve 1980). However, because they are at the interface between the ocean and the land, they are more directly exposed to runoff than other marine organisms. If harmful conditions occur during low tides, any mitigating effects of dilution are not present and these organisms bear the full brunt of the exposure.

The intertidal sea anemone *Anthopleura elegantissima* normally maintains a symbiotic relationship with microscopic single-celled algae that live within its tissues. The dinoflagellate algae, or zooxanthellae, photosynthesize and provide a substantial fraction of the host anemone's nutritional needs (Fitt et al. 1982). Sea anemones have millions of zooxanthellae for each gram of tissue. *A. elegantissima* is very tolerant, surviving coverage by sand, exposure to air, and starvation for extended periods. However, when exposed to prolonged darkness, high temperatures, cold shock, or excessive time in bright sunlight, some sea anemones react by expelling some of their zooxanthellae (Muscatine et al. 1991). This expulsion causes a reduction in the green-brown color of the anemone and is therefore called bleaching. Bleaching by expulsion of zooxanthellae is seen in many species of reef-building corals, and is considered a sign of stress (Jokiel and Coles 1990). Without their symbionts, anemones and corals have much less energy available for growth and reproduction, and they may die. The presence or absence of symbiotic zooxanthellae provides a simple and fairly reliable indicator of health of these hardy and adaptable intertidal animals, although some of their color may

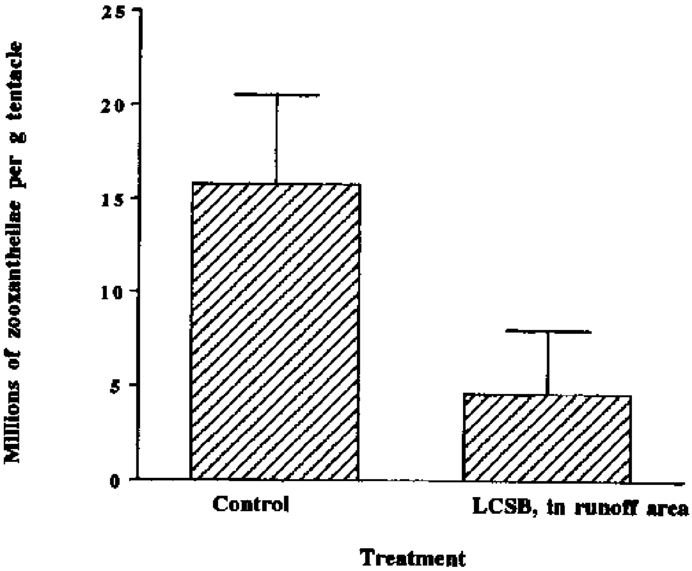

Fig. 1. Zooxanthellae were counted from tentacles of *A. elegantissima* from a control site and from the freshwater influx area of LCSB. The numbers of zooxanthellae per gram of tissue were significantly lower in the LCSB anemones. Shown are means ± standard errors.

come from endogenous pigments (Buchsbaum 1968). We suggest that they may be used as an indicator species for hyposalinity of seawater in rocky intertidal zone.

Leo Carillo State Beach (LCSB) in Los Angeles County, California, has extensive rocky substrate and a gently sloping face that provides an excellent potential habitat for rocky intertidal animals and plants. During the drought of the late 1980's, the intertidal fauna here was lush and diverse, and the area was frequented by members of the public, school classes, and park rangers for educational and interpretive lessons. However, following the heavy rains of 1991–1992, we observed a drastic decrease in the numbers and diversity of the intertidal organisms. Of those animals still remaining, the sessile *A. elegantissima* appeared much paler than before, indicating that bleaching had occurred (Engebretson and Martin 1994).

We did a series of laboratory experiments that indicated that the loss of color in *A. elegantissima* in the field was the result of loss of zooxanthellae (Engebretson and Martin 1994). Bleached anemones taken from LCSB had significantly reduced numbers of zooxanthellae (Fig. 1). We hypothesized that the bleaching was caused by excessive exposure to freshwater runoff. Healthy anemones from another site were placed into several different dilutions of seawater for time periods ranging from several days to several weeks. These *A. elegantissima* lost their symbiotic zooxanthellae and bleached rapidly, proportional to the strength and duration of the hyposaline exposure (Fig. 2). The anemones remained closed and did not feed while in hyposaline water.

A line transect to measure the number of bleached *A. elegantissima* at LCSB was done parallel to shore at a tidal height of −0.15 m over a distance of 120 m

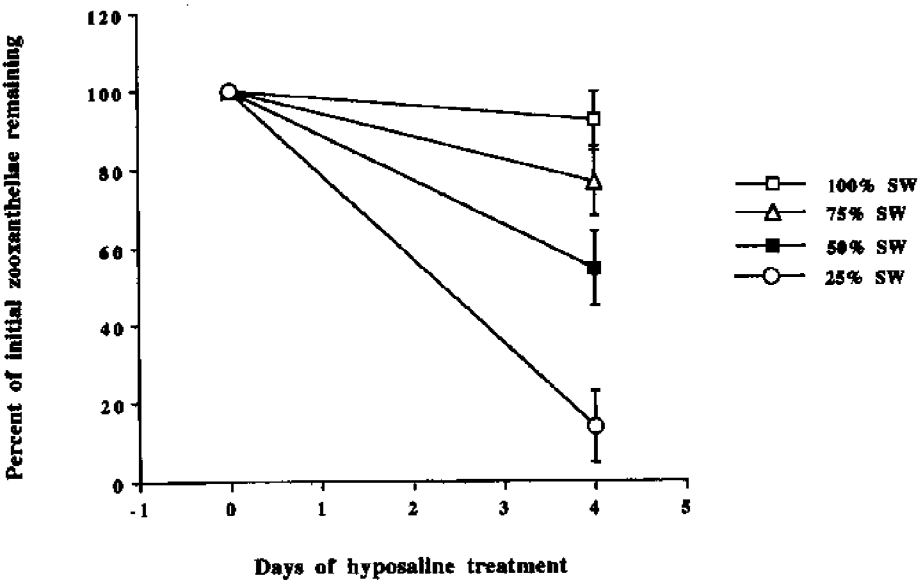

Fig. 2. *A. elegantissima* expelled zooxanthellae in response to constant exposure to hyposaline water, at the levels stated (100% = 32 ppt, 75% = 24 ppt, 50% = 16 ppt, and 25% = 8 ppt). After 4 days, all treatments except the control (100% SW) showed significant losses of zooxanthellae. Shown are means ± standard errors.

in 1992 (Engebretson and Martin 1994). At that time the anemones that were bleached were located within a limited area of freshwater runoff, resulting from discharge of the Arroyo Sequit (Fig. 3). Anemones located at the same tidal height but on either side of this freshwater runoff area were apparently not affected. We returned to this site in 1995 and ran line transects at four different tidal heights, −0.3 m, −0.24 m, −0.15 m, and −0.07 m, again parallel to shore over a distance of 132 m. These transect lines were separated by 3 m or more of horizontal distance. Line transects in 1995 indicated that anemones were bleached over a much greater area of the habitat, and at lower tidal heights, than in the previous transect (Fig. 4). We observed far less of the biological diversity that was so prevalent intertidally during the drought years in the intertidal zone at this site; all the sea urchins, snails, crabs, octopus, chitons, tidepool fish, and other marine organisms have apparently either died or moved into deeper water.

When anemones are exposed to short duration pulses of hyposaline water, similar to tidal exposure in tidepools during freshwater runoff, bleaching was even more pronounced and more rapid than bleaching in response to constant, long-term exposure to hyposaline conditions (Fig. 5). Thus, the field conditions of stormwater runoff during low tides over several days is potentially extremely detrimental and probably has caused the widespread bleaching of *A. elegantissima* seen in the transects at LCSB in 1995 (Lawson and Martin, unpublished), in addition to the profound loss of biodiversity in this habitat. Being sessile, *A. elegantissima* do not move away from harsh conditions. The hyposaline stress is likely to cause osmotic influx into cells and damage by rupture (Engebretson and Martin 1994; Gates et al. 1992).

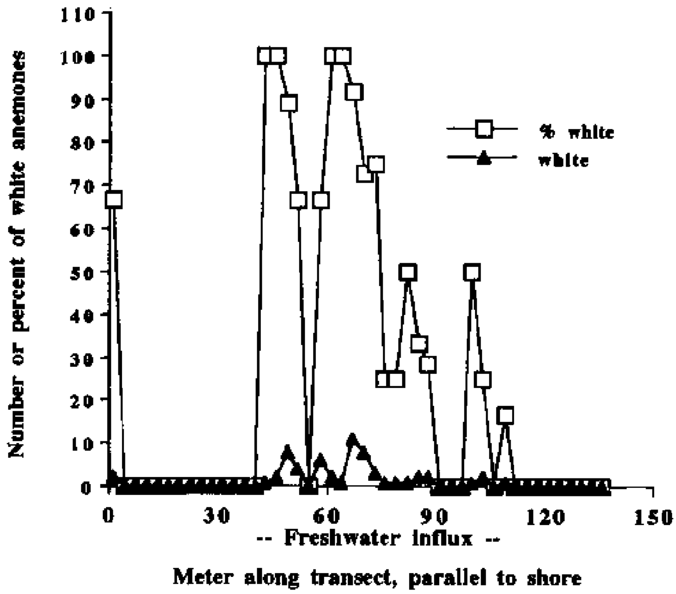

Fig. 3. Line transect data from 1992, showing bleaching within the freshwater influx area. Very little bleaching is shown outside of the channel for runoff. Transects were taken at −0.15 m tidal height.

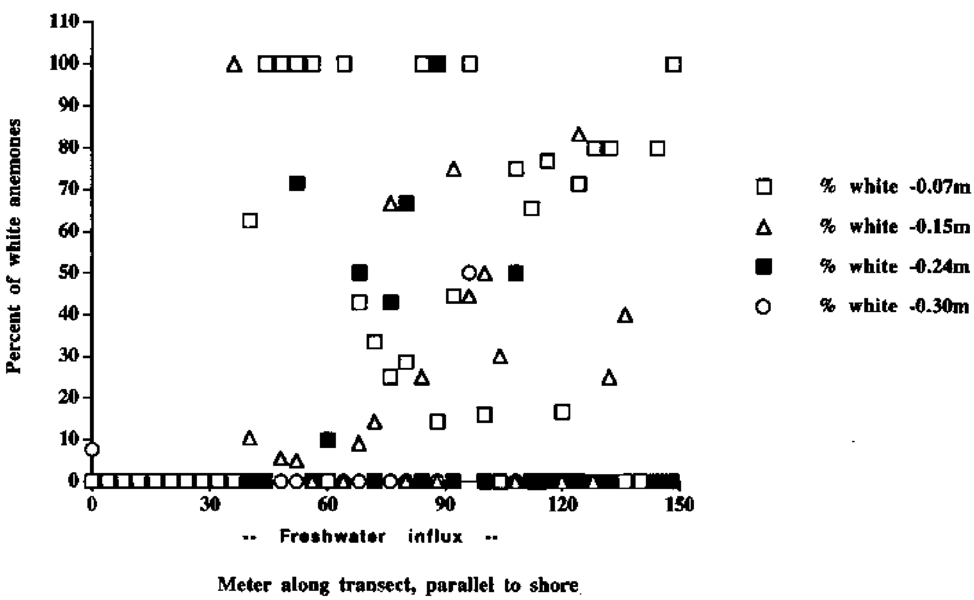

Fig. 4. Line transect data from 1995, showing increased influence of freshwater runoff over a larger area of the beach. Transects were taken at four tidal heights, −0.07 m, −0.15 m, −0.24 m, and −0.3 m.

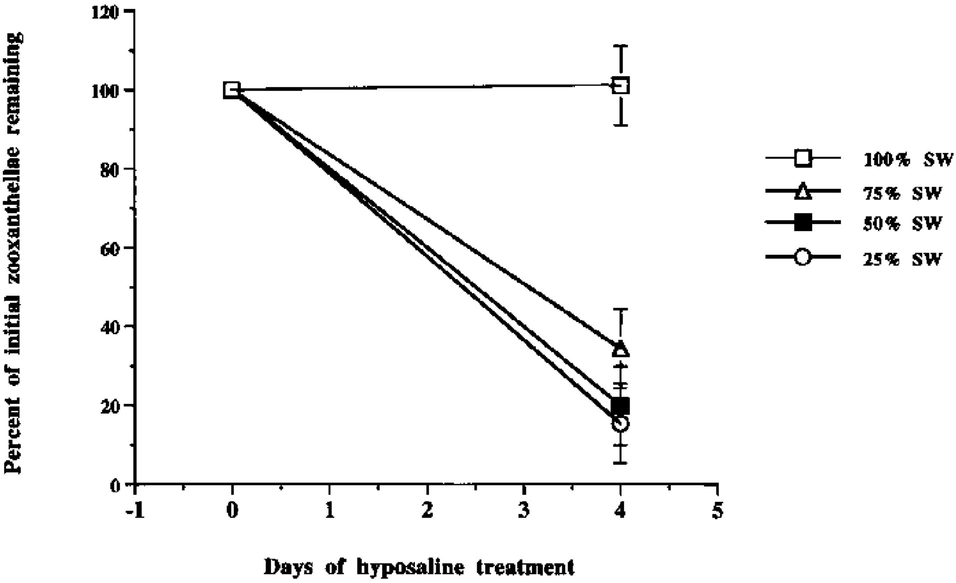

Fig. 5. Percent of initial numbers of zooxanthellae remaining following 4 days of treatments in which anemones were held in 100% seawater except for one 3 h pulse of hyposalinity per day (100% = 32 ppt, 75% = 24 ppt, 50% = 16 ppt, and 25% = 8 ppt). Shown are means ± standard errors.

Over the summer of 1995 we observed freshwater runoff from the arroyo on several occasions, covering a much greater area of the expanse of rocky intertidal habitat than the natural runoff channel. Heavy equipment had been used to bulldoze sand in order to direct the stormwater runoff much more broadly, rather than allowing it to continue to run in its natural, narrow channel. In addition, fresh water seeped farther across the beach by flow under the sand when the water was deep in the arroyo channel. From these studies it is not clear whether some other factors, such as pollutants, could also have contributed to the bleaching seen in the field. However, in the laboratory distilled water was used for all dilutions of artificial seawater in the experiments, and no contaminants were present. The hyposaline dilution alone is sufficient to cause the bleaching.

The increased area of LCSB containing bleached anemones in 1995 is cause for concern. Freshwater inundation is episodic but frequent at this site, and it is channeled artificially in a manner that causes direct effects in this near-shore marine environment. Particularly during low and minus tides, seawater dilution of stormwater runoff does not occur. We measured salinity in the field as low as 0 ppt, or freshwater, in the intertidal zone during a minus tide that occurred a few hours after a light rainfall. We are concerned that efforts to increase the speed and efficiency of stormwater runoff have taken precedence over efforts to preserve an important biological habitat that educates and is enjoyed by many people of the Los Angeles area.

Acknowledgments

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Abstract: Storm Water Pollution Regulatory Compliance in the Los Angeles Region Transportation Industry

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Pollutants in storm water discharges are an important source of surface water quality impairment in densely developed urban regions, and are targeted as one of the key sources of impaired water quality in Santa Monica Bay (SMBRP 1994). Stormwater pollutants are the target of multiple regulatory controls promulgated at the federal, state, regional, and local levels during the 1990s. The industrial sector conducts one set of urban activities where storm water pollutants originate, and is subject to a permit under the National Pollutant Discharge Elimination System of the U.S. Clean Water Act (U.S. EPA 1992). This research investigates the effectiveness of stormwater regulations in the Los Angeles region by facilities of one selected industrial segment, the transportation industry.

This abstract summarizes three presentations at the May 1995 Coastal Watershed Symposium in Fullerton, California, which include research that is more fully presented elsewhere. This research analyzed facilities of the transportation industry in the Los Angeles region to characterize their compliance to date with the 1992 California General Industrial Activities Storm Water Permit (the General Industrial Permit) (California State Water Resources Control Board 1992).

First, the researchers visited transportation facilities to develop an understanding of the kinds of industrial activities conducted, the potential sources of pollutants in storm water runoff that typically originate with those activities, and the forms of stormwater pollution control practices typically implemented by such facilities. The authors conducted site investigations at five facilities of the transportation industry within the Los Angeles region (Duke and Chung 1996). The five facilities were: a municipal bus maintenance facility; a small school bus maintenance yard; a municipal "corporate yard," operated to maintain and fuel municipal trucks, buses, and equipment; a small facility to maintain trucks for local and interstate hauling; and a large facility for maintenance, fueling, and loading of trucks for package shipping and delivery.

At these five facilities, the industrial activities where BMPs appear to have least successfully eliminated the possible stormwater pollutants fall into three categories: vehicle fueling; vehicle and equipment storage; and materials handling and storage. For these activities, the kind of BMPs that can be readily implemented at existing facilities without great financial burden do not appear to completely prevent discharge of pollutants in storm water runoff. Pollution control measures

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included covering activities with a roof, grading and berming to direct stromwater flow, spill prevention and control procedures, and dry clean-up procedures. Control measures identified are fully described elsewhere, but some general observations are possible. Some facilities had chosen to discontinue certain activities by contracting for services from offsite facilities. A large proportion of the storm water pollution prevention activities reported by these facilities are not new or specifically tailored for storm water regulatory compliance, but instead are originally designed to improve compliance with regulations addressing other fields such as hazardous waste, spill prevention, worker safety, and water use reduction. Relatively few new pollutant controls appear to have been implemented expressly for the purpose of compliance with new storm water regulations.

Second, the researchers conducted a telephone survey addressed to all facilities of the selected industrial sector within a selected portion of the Los Angeles region, the Santa Monica Bay watershed (Duke and Beswick 1996). The purpose of this step was to estimate the proportion of facilities conducting business in this industry which also conduct industrial activities, and therefore are required to comply with the General Industrial Permit. Researchers developed a structured questionnaire, designed to determine whether a transportation-industry facility conducts industrial activities and therefore is required to comply with the General Industrial Permit. The questionnaire was administered by telephone to personnel of 48 facilities, a large proportion of the 68 facilities in the Santa Monica Bay watershed that appear in industrial directories with one or more SICs of the motor vehicle-related transportation industry (Dun and Bradstreet Corp. 1994; Database Publishing Co. 1994) and which are confirmed to be active as of November 1994. Responses were solicited equally from all 68 facilities, but 20 declined to participate.

One or more industrial activities were reported to be conducted at 56% of the facilities where a representative responded to the questionnaire (27 of 48 surveyed). Results show that industrial activities are conducted at a higher proportion of facilities in three trucking-related industries (4-digit SICs 4212, 4213, and 4214) than for other motor-vehicle transportation facilities (the eight other 4-digit SICs). Seventy-eight per cent of facilities in the trucking industry reported conducting industrial activities, compared to 43% of other motor-vehicle transportation facilities.

For the third segment of this research, the researchers reviewed files of the California Regional Water Quality Control Board, Los Angeles Region (RWQCB) to determine how many of those same facilities' operators have notified RWQCB of their intent to comply. The researchers searched for compliance documents filed by the same facilities identified as active in the Santa Monica Bay watershed. Facilities are required to file a Notice of Intent (NOI) with RWQCB if they conduct industrial activities, as the initial action signifying their compliance with the General Industrial Permit. Duke and Beswick (1996) include statistics for NOIs filed by the 48 facilities of the Santa Monica Bay population. Of the 27 facilities surveyed which conducted industrial activities, fewer than one-third (8 of 27) had filed the Notice of Intent to comply with the General Permit. The trucking industries again show different behavior: the compliance rate in this small sample of the trucking industry is zero per cent (none of the 14 identified trucking facilities required to comply had filed an NOI within 24 months after the due date), compared to 62% in facilities of all other transportation SICs, where 8 of 13 facilities determined to be required to comply had filed an NOI.

The researchers reviewed a representative sample of compliance documents submitted to RWQCB by facilities of the same industry segment, for the entire Los Angeles region, to characterize the continuing compliance efforts of regulated facilities. A total of 430 NOIs listing one or more motor-vehicle transportation SICs had been filed for facilities in the Los Angeles region as of December 31, 1994. Duke and Beswick (1996) summarize data from the annual reports and monitoring results submitted by a representative sample of 140 of those 430 facilities. Slightly more than half of the facilities in the sample (73 of 140 reviewed) submitted an annual report one year after filing the NOI; and just over one-third (53 of 140) submitted the required annual report two years after filing the NOI. Of 120 facilities in the sample required to submit monitoring results, 22% (27 of 120 facilities) submitted results for the first year required; and 31% (37 of 120) submitted results for the second year. These data do not fully describe facilities' compliance because the review does not include group monitoring reports, and facilities which applied to be part of a monitoring group may not have filed individual annual reports.

Acknowledgments

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ABSTRACTS

FIRST LINE DEFENSES AGAINST TOXINS. *D. Epel* and *B. Holland Toomey.* Hopkins Marine Station of Stanford University, Pacific Grove, CA 93950.

Estuarine organisms live in a chemical smorgasbord, where the sediments absorb and retain potentially toxic metabolites and defense molecules, as well as man-introduced toxins. What defense systems do these organisms possess? Are they unique to estuarine forms or do estuarine forms simply have a higher titer of a general detoxification mechanism? Most research on this question has focused on how the toxins are handled once they have entered the cell. We describe a novel mechanism in the echiuroid *Urechis caupo* and mollusk *Mytilus galloprovincialis,* which acts as a transport barrier to keep toxins out of the cell, so that the cell avoids the problem of ever having to modify the chemical to make it less toxic. The mechanism is the utilization of a non-specific transporter, the multixenobiotic transporter, which is a relative of the multidrug transport family and uses ATP to efflux a variety of moderately hydrophobic compounds out of the cell. Therefore, the toxins are only briefly in the cytoplasm where damage can occur. We consider the nature of this mechanism, its adaptive significance and evidence that it is involved in protecting estuarine forms.

EVALUATION OF CHARGED MICRO POROUS FILTERS FOR RECOVERY OF ENTEROVIRUSES FROM SEA WATER. *M. T. Yahya, C. E. Reed* and *C. D. McGee.* Environmental Science Laboratory, County Sanitation District of Orange County, Fountain Valley, CA 92728.

Positively charged filters have been recommended for the concentration of enteroviruses from groundwater and drinking water for higher virus recovery. Cellulose filters (1MDS) and cellulose/glass fiber filters (MK with graded density) were evaluated for recovery of poliovirus type 1 from seawater. As a comparison, electronegative virus adsorbent filters (epoxy fiberglass, Balston and Filterite filters with K27 as a prefilter) were tested. To determine the percent of the recovery of the seeded virus, cell associated poliovirus type 1 was added to 30 to 100 L of seawater for an initial concentration of 10^3 pfu/L. Viruses were eluted using 1.5 to 3% beef extract with glycine (pH 9.5 for MDS, MK and Filtrite, pH 7.0 for Balston), reconcentrated by organic flocculation, detoxified and tested for the formation of plaques on confluent monolayer of Buffalo Green Monkey kidney cells. Results indicate that with 1MDS filters, less numbers of poliovirus were recovered compared to the Balston or Filterite/K27 filter combination. Recovery ranged from 10 to 30 with 1MDS, 3.5 to 6.0% with Balston/K27, 1 to 10% with MK and 30 to 59% with Filtrite filters. Positively charged filters eliminated to need to condition the water the aluminum chloride and hydrochloric acid which may cause filter clogging during concentration.

EFFECTS OF COASTAL AND WATERSHED DEVELOPMENT ON SHORELINE POSITION AND SEDIMENTATION AT MUGU LAGOON, CALIFORNIA. *James L. Sadd.* Geology Department, Occidental College, Los Angeles, CA 90041.

Digital mapping of the mean high water shoreline and topographic profiles were used to monitor shoreline position and sediment volume at Mugu Lagoon from 1857–1989. The barrier was in dynamic equilibrium until 1901 when rates of shoreline migration increased. Dredging updrift at Port Hueneme in 1940 increased sand supply briefly, then formed a littoral barrier which initiated rapid net erosion on the Mugu barrier. Beach renourishment updrift of Mugu in 1961 reversed this trend, but since 1972 the shoreline segment updrift of the inlet has eroded more rapidly than at any time since 1857. This pattern is consistent with observations of more frequent westerly storms and storm wave hindcast modeling. Interior Mugu lagoon shorelines showed little net change until 1901, when the central and eastern lagoon began infilling at higher rates of net deposition. Infilling accelerated significantly during mid-century. The pattern and timing of infilling parallels landuse changes in the upland watershed. Between 1945 and 1990, agricultural acreage in the upland watershed was reduced by about one third, largely due to rapid expansion of urban and residential land cover. The U.S. Soil Conservation Service has documented measured increased sediment yield triggered by changing landuse in this watershed. Time series analysis of precipitation and stream hydrograph data show a sudden increase in total annual discharge on streams which deliver sediment to Mugu Lagoon beginning about 1970. Between 1945 and 1970, considerable interior shoreline change also resulted from military facility construction and maintenance, but since 1970 lagoon filling has primarily resulted from watershed-scale effects.

POST-FIRE SEDIMENT MOVEMENT IN MALIBU LAGOON WITH A POST-1995-FLOOD POST SCRIPT. *J. Wolcott*[1] and *J. Shulmeister*[2]. [1]University of Southern California, Department of Geography, Los Angeles, CA 90089-0255 and [2]Victoria University, Wellington, New Zealand.

Within six weeks of the Malibu fire of November 1–2, 1993, a 6 month pilot study was begun to monitor the effects of the expected sudden influx of sediment into Malibu Lagoon. Eight transects spaced 20 meters apart were established in the main lagoon with stations located every 20 meters along the transects. An additional 30 stations were located in the back bays. Five transects were established at approximately 100 meter spacings upstream of the lagoon on Malibu Creek. Elevation measurements were taken at weekly intervals in the main lagoon and back bays and bi-weekly on the creek.

Most of the stations in the back bays showed little change, although the most western back bay was very active within the first 100 meters closest to the ocean. The main channel in the lagoon also was more active than anticipated, often eroding vertically while adjacent areas were aggrading.

The model of levee development, in this case sub aqueous, is beautifully displayed, as well as general flood plane accretion and subsequent channel incision. Sediment storage occurred in part by oversteepening the main channel banks thereby facilitating removal by much lower flows.

AN ANALYSIS OF HISTORICAL PROFILE CHANGES IN THE ORANGE COUNTY COASTAL ZONE. *Ernesto A. Tabarez*[1] and *Kwan M. Chan*[2]. [1]Department of Civil Engineering, California State University, Long Beach, CA 90840, [2]Department of Geology, California State University, Long Beach, CA 90840.

This study concentrates on the sedimentation processes along a 30 mile stretch south of the Long Beach Harbor. Analyses of data gathered by different local and federal agencies were utilized. The results should be helpful in determining long term effects of any contaminates in the sediment brought forth by sewage disposal and toxic waste spills. There were three types of data analyzed: bathymetric data, synoptic meteorological marine observation wave data, and research of current literature. The data was used to establish the effects of wave motion and sediment transport over a historical period. Based on the results, various sections of the coastal zone were characterized according to different degrees of stability or instability. From onshore to as far as 9000 ft. from the benchmarks, the numerical analyses of the data provided a detailed picture of the historical changes. (Primary source of information from U.S. Army Corps of Engineers, Los Angeles District and Orange County Department of Beaches and Harbors.)

REDUCING NATURAL ROUGHNESS: FIRST SAN DIEGO RIVER IMPROVEMENT PROJECT, SAN DIEGO, SAN DIEGO COUNTY, CALIFORNIA. *Pablo O. Grabiel.* University of California, Los Angeles, CA 90024 and California State University, Fullerton.

Rivers flowing through urban areas pose a variety of hazards to the community. These hazards need to be addressed by municipal leaders and planners. Storm floods, vector control, dangers inherent by the attractive nuisance posed by a river all must be considered by government authorities. Concomitantly, the measures intended to alleviate such hazards posed by a riparian system tend to negatively impact the sensitive riparian environment itself. The reduction of natural roughness at the riparian-terrestrial habitat boundary is one such consequence. The First San Diego River Improvement Project attempts many objectives: maintaining a thriving riparian ecosystem, providing for recreation, and sustaining natural riparian functions. This project's impact is studied over time to assess the consequences of these changes upon the river's natural environment.

NITROGEN ADDITIONS TO ESTUARIES FROM COASTAL WATERSHEDS: HOW CAN SCIENTISTS AND MANAGERS DEAL WITH UNCERTAIN INFORMATION? *G. Collins* and *J. N. Kremer.* University of Southern California, CA 90089.

After a four-year study of the impacts of watershed development on estuaries (the Waquoit Bay Land-Margin Ecosystem Research Project, Cape Cod, MA), there are still gaps in our understanding of how nitrogen travels from watersheds to coastal waters. Because of these gaps, predictions of anthropogenic nutrient loading rates from watersheds are uncertain, as are predictions of responses of coastal ecosystems to these nutrients. This uncertainty presents problems to scientists trying to understand how nutrient loading forces changes in coastal ecosystems, and to planners trying to prevent or remediate such changes by managing watershed development. We have quantified uncertainty in calculations of nitrogen loading for Waquoit Bay (the standard deviation is about 40% of the loading rate), and have identified two parts of the loading calculation that contribute the most to that uncertainty: denitrification in groundwater during travel to the sea, and the efficiency with which septic systems remove nitrogen from sewage. Further investigations of these processes are necessary to increase the certainty in loading calculations. Managers, however, cannot wait for this information, and so must make decisions about development in the coastal zone with uncertain information. Uncertainty estimates may be used to help make conservative decision and assess "worst case scenarios," but it may be necessary to turn to other criteria (economic, aesthetic, etc.) in the management process.

FATE OF FERTILIZER-DERIVED NITROGEN ENTERING A SALT MARSH IN GROUND WATER: CLUES FROM STABLE NITROGEN ISOTOPE RATIO ANALYSIS. *H. M. Page.* Marine Science Institute, U.C. Santa Barbara, CA 93106.

To investigate the fate of anthropogenic nitrogen in ground water within a salt marsh ecotone and the effects of ground water inputs on marsh vegetation, I measured the natural abundance of ^{15}N in pore water NO_3–N and NH_4–N, and in the salt marsh halophyte, *Salicornia virginica,* along an environmental gradient from agricultural land into a salt marsh. The increase in $\delta^{15}NNO_3$ ($\sim +40‰$), accompanied by the decrease in NO_3–N (and total dissolved inorganic N, DIN) concentration along the gradient, suggested that the salt marsh ecotone is a site of transformation, most likely through denitrification, of inorganic nitrogen in ground water. *S. virginica* (and the parasitic herb, *Cuscuta salina*), were enriched in ^{15}N along the tidal marsh boundary ($\delta^{15}N = \sim 16‰$), relative to high and middle marsh locations ($\delta^{15}N = \sim 8‰$), indicating that ground water nitrogen is also retained as vegetative biomass. Ground water inputs enhanced the standing crop, above ground productivity, and nitrogen content of *S. virginica* but the relative effects of pore water salinity and DIN concentration on these parameters were not determined. ^{15}N enrichment of marsh plants by ground water DIN inputs could prove useful in tracing these inputs in the marsh.

INSTRUCTIONS FOR AUTHORS

The BULLETIN is published three times each year (April, August, and December) and includes articles in English in any field of science with **an emphasis on the southern California area**. Manuscripts submitted for publication should contain results of original research, embrace sound principles of scientific investigation, and present data in a clear and concise manner. The current AIBS *Style Manual for Biological Journals* is recommended as a guide for contributors. Consult also recent issues of the BULLETIN.

MANUSCRIPT PREPARATION

The author should submit *at least two additional copies with the original,* on 8½ × 11 opaque, nonerasable paper, double spacing the entire manuscript. ***Do not break words at right-hand margin anywhere in the manuscript.*** Footnotes should be avoided. **Manuscripts which do not conform to the style of the BULLETIN will be returned to the author.**

An abstract summarizing in concise terms the methods, findings, and implications discussed in the paper *must* accompany a *feature article. Abstract should not exceed 100 words.*

A feature article comprises approximately five to thirty typewritten pages. Papers should usually be divided into the following sections: abstract, introduction, methods, results, discussion and conclusions, acknowledgments, literature cited, tables, figure legend page, and figures. Avoid using more than two levels of subheadings.

A research note is usually one to six typewritten pages and rarely utilizes subheadings. Consult a recent issue of the BULLETIN for the format of *notes.* Abstracts are not used for notes.

Abbreviations: Use of abbreviations and symbols can be determined by inspection of a recent issue of the BULLETIN. **Omit periods after standard abbreviations:** 1.2 mm, 2 km, 30 cm, but Figs. 1–2. Use numerals *before* units of measurements: 5 ml, but nine spines (10 or numbers above, such as 13 spines). The metric system of weights and measurements should be used wherever possible.

Taxonomic procedures: Authors are advised to adhere to the taxonomic procedures as outlined in the International Code of Botanical Nomenclature (Lawjouw et al. 1956), the International Code of Nomenclature of Bacteria and Viruses (Buchanan et al. 1958), and the International Code of Zoological Nomenclature (Ride et al. 1985). Special attention should be given to the description of new taxa, designation of holotype, etc. Reference to new taxa in titles and abstracts should be avoided.

The literature cited: Entries for books and articles should take these forms.

McWilliams, K. L. 1970. Insect mimicry. Academic Press, vii + 326 pp.

Holmes, T. Jr., and S. Speak. 1971. Reproductive biology of *Myotis lucifugus.* J. Mamm., 54:452–458.

Brattstrom, B. H. 1969. The Condor in California. Pp. 369–382 *in* Vertebrates of California. (S. E. Payne, ed.), Univ. California Press, xii + 635 pp.

Tables should not repeat data in figures *(line drawings, graphs, or black and white photographs) or contained in the text.* The author must provide numbers and short legends for tables and figures and place reference to each of them in the text. Each table with legend must be on a separate sheet of paper. All figure legends should be placed together on a separate sheet. **Illustrations and lettering thereon should be of sufficient size and clarity to permit reduction to standard page size;** *ordinarily they* **should not exceed 8½ by 11 inches** in size and after final reduction lettering must equal or exceed the size of the typeset. All half-tone illustrations will have light screen (grey) backgrounds. Special handling such as dropout half-tones, special screens, etc., must be requested by and will be charged to authors. **As changes may be required after review, the authors should retain the original figures in their files until acceptance of the manuscript for publication.**

Assemble the manuscript as follows: cover page (with title, authors' names and addresses), abstract, introduction, methods, results, discussion, acknowledgements, literature cited, appendices, tables, figure legends, and figures.

A cover illustration pertaining to an article in the issue or one of general scientific interest will be printed on the cover of each issue. Such illustrations along with a brief caption should be sent to the Editor for review.

PROCEDURE

All manuscripts should be submitted to the Editor, Daniel A. Guthrie, W. M. Keck Science Center, 925 North Mills Avenue, Claremont, CA 91711. **Authors are requested to submit the names, addresses and specialities of three persons who are capable of reviewing the manuscript. Evaluation of a paper** submitted to the BULLETIN begins with a critical reading by the Editor; several referees also check the paper for scientific content, originality, and clarity of presentation. Judgments as to the acceptability of the paper and suggestions for enhancing it are sent to the author at which time he or she may be requested to rework portions of the paper considering these recommendations. The paper then is resubmitted and may be re-evaluated before final acceptance.

Proof: The galley proof and manuscript, as well as reprint order blanks, will be sent to the author. He or she should **promptly** and **carefully read** the proof sheets for errors and omissions in text, tables, illustrations, legends, and bibliographical references. He or she marks corrections on the galley (copy editing and proof procedures in *Style Manual*) and **promptly returns both galley and manuscript** to the Editor. Manuscripts and original illustrations will not be returned unless requested at this time. **All changes in galley proof attributable to the author (misspellings, inconsistent abbreviations, deviations from style, etc.) will be charged to the author. Reprint orders are placed with the printer, not the *Editor.***

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COVER: Bleached specimen of Aggregating Anemone, *Anthopleura elegantissima* at Leo Carillo State Beach. Photo by K. Martin.