Bull. Southern California Acad. Sci.
95(1), 1996, pp. 7–16

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).

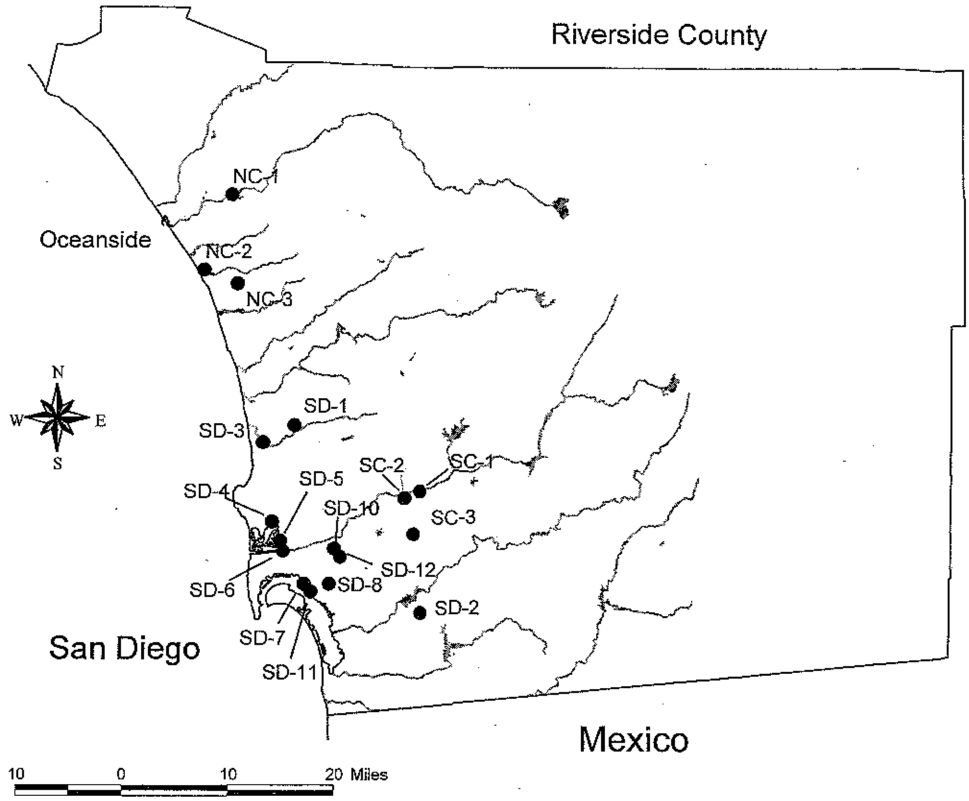

Fig. 1. Map of the major creeks and rivers which drain the urbanized areas of San Diego County. See Table 1 for a key to monitoring stations.

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				Number of storms sampled
				Residential	Commercial	Industrial	Open	
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

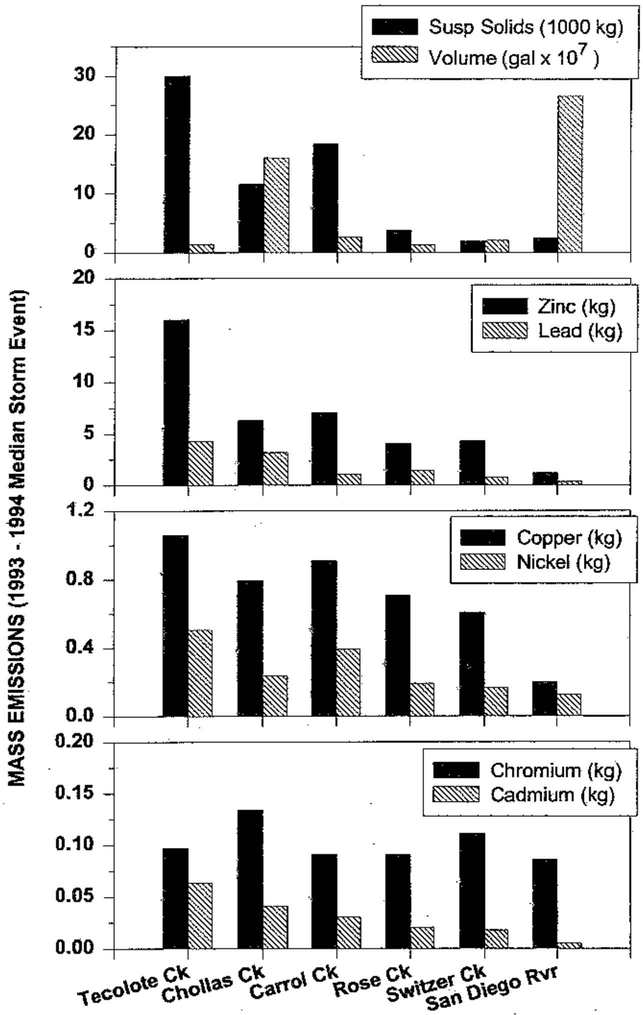

Fig. 2. Mass emissions of selected constituents discharged from six major San Diego drainages during median-sized storm events in the 1993–94 wet season.

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.

		San Diego EMC			
Constituent	Units	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

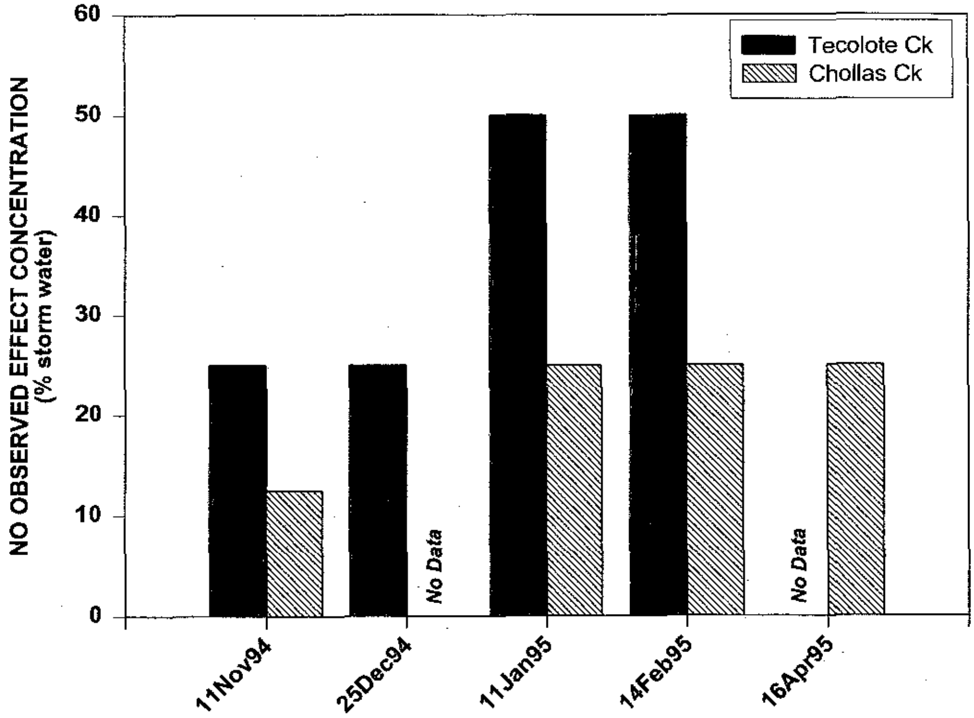

Fig. 3. Chronic toxicity of San Diego urban runoff samples to *Ceriodaphnia dubia* measured during the 1994–95 wet season.

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.

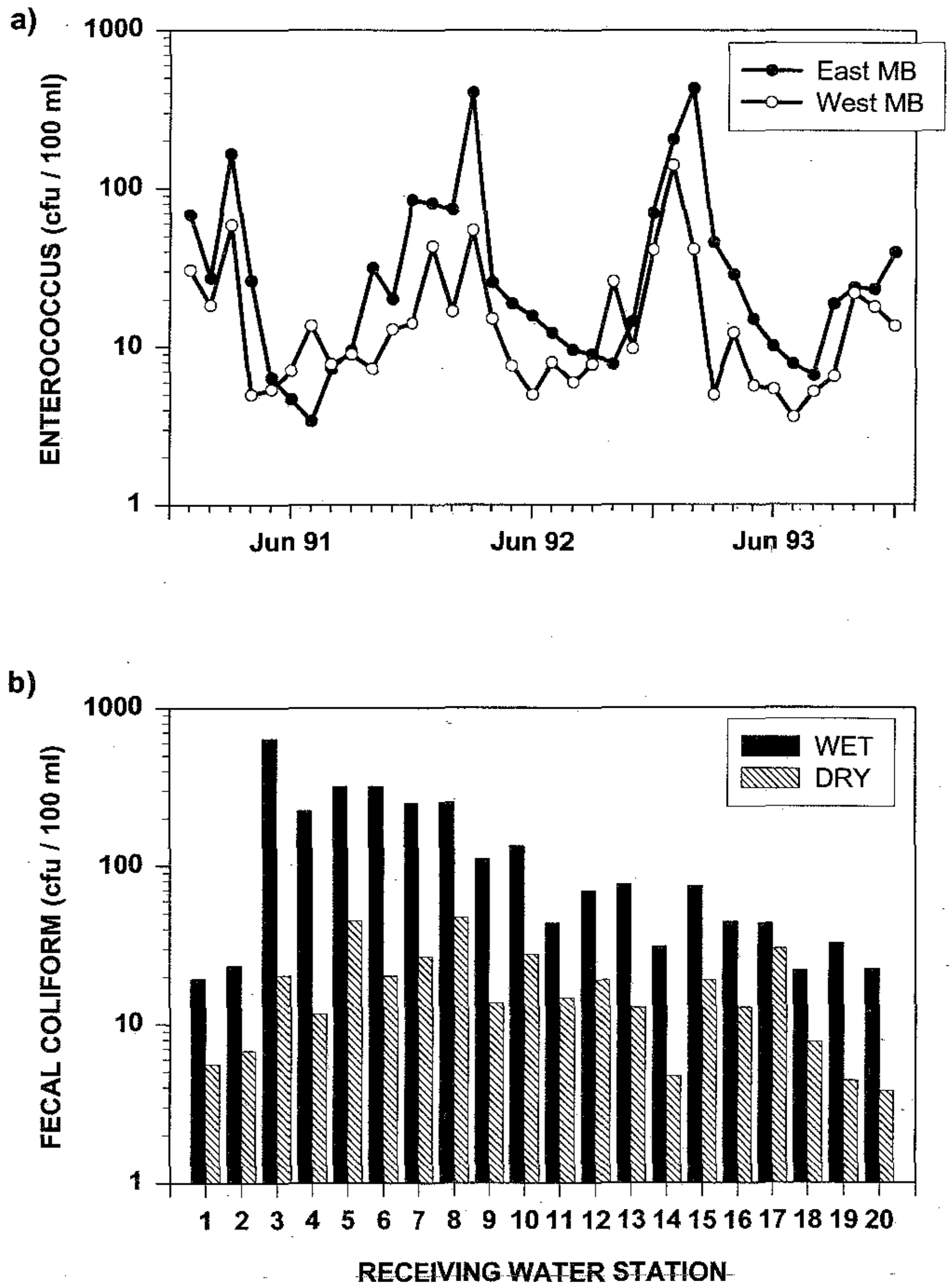

Fig. 4. Temporal (4a) and spatial (4b) distribution of the fecal indicator bacteria enterococcus and fecal coliform in Mission Bay.

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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