Impacts of Stormwater Discharges on the Nearshore Environment of Santa Monica Bay

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ABSTRACT

This report describes the first-year results of a three-year study to investigate the receiving water effects of stormwater discharges from Ballona and Malibu Creeks. Surface water and sediment samples were collected for analysis following four storm events in January and February, 1996. Surface water toxicity was present offshore of Ballona Creek and was proportional to the concentration of runoff in the plume. Deposition of runoff particulates offshore of both Ballona and Malibu Creeks was indicated by spatial changes in sediment characteristics, such as grain size and total organic carbon (TOC). Similar spatial patterns were present in samples collected after storms and during dry weather, indicating that the changes were persistent. Sediment contaminants, such as lead, total polychlorinated biphenyl (PCB), and total polycyclic aromatic hydrocarbon (PAH), were elevated at stations located nearest the mouth of Ballona Creek. Sediment contamination was less offshore of Malibu Creek and did not show a pattern related to stormwater discharge. The first-year results have not detected stormwater-related changes in benthic infaunal community assemblages or sediment toxicity near the discharges.

INTRODUCTION

Urban runoff has been shown to discharge large quantities of contaminants (Schiff and Stevenson 1996; SCCWRP 1990, 1993a) and can be toxic to marine organisms (Bay *et al.* 1996). Unlike municipal wastewater, stormwater runoff enters the nearshore marine environment, often through estuaries or wetlands, wholly untreated. New regulations and increased monitoring efficiency are enhancing in-channel measurements, more accurately characterizing wet weather inputs and the effectiveness of best management practices (LACDPW 1996). However, virtually no information exists on contaminant fates and their biological effects once wet weather discharges enter the marine environment.

The fates and effects of contaminants on the receiving environment cannot be predicted from in-channel measurements alone. The mixing of the freshwater plume with seawater alters the chemical state and solubility of some contaminants; particle aggregation and settling are also affected in complex ways. The nearshore environment is very dynamic, with waves and currents having strong influences on the deposition and distribution of stormwater contaminants. Much of what is known about the benthic effects of contaminants has been learned from studies of offshore ocean wastewater outfalls. These systems differ markedly from stormwater discharges in terms of discharge composition, variability, and receiving environment characteristics. Directed studies of stormwater discharge are needed to identify the contaminants of concern and their biological effects.

The research described in this report represents the initial results of a three-year program to investigate the correlation between stormwater discharge and environmental effects. This study, conducted in collaboration with the University of Southern California (USC), USC/SeaGrant, and the University of California at Santa Barbara (UCSB), has three principal objectives. The first objective is to measure the dispersion and mixing of stormwater plumes in Santa Monica Bay (this work was conducted by our collaborators and is not presented herein). The second objective is to examine the magnitude and characteristics of water column and sediment toxicity near stormwater discharges. This work element examines potential contaminant effects and provides an important link with similar data obtained from upstream measurements. The final objective of this project is to measure the impacts to benthic communities in the immediate vicinity of the discharge. This report presents the results of toxicity and benthic impact testing during the first wet season of sampling. Upon completion of the three-year study, an integration of these results with data obtained from our joint investigators will appear in a future issue of the Southern California Coastal Water Research Project (SCCWRP) Annual Report.

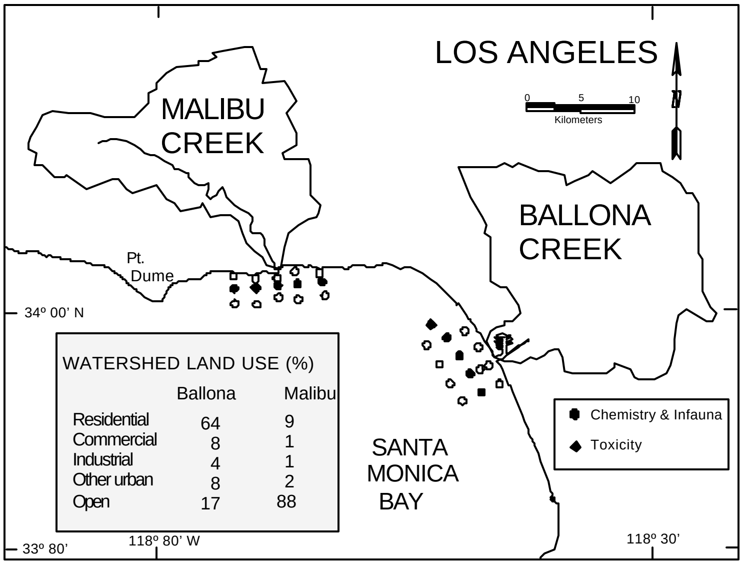
MATERIALS AND METHODS

The Ballona Creek and Malibu Creek watersheds were selected for evaluation in this study. Both watersheds are approximately the same size (Figure 1). Together, they encompass over half of the entire Santa Monica Bay drainage area (Stenstrom and Strecker 1993). The Ballona Creek drainage basin is highly urbanized; 83% of the watershed is developed and comprised of predominantly residential land use. Almost the entire channel is concrete-lined. Conversely, Malibu Creek is predominantly undeveloped; 88% of the watershed is open land and the creek is in a natural state. These differences in watershed characteristics, combined with localized diversity in rainfall, lead to large variations in flow and pollutant loading to the ocean, even for the same storm event (LACDPW 1996). By comparing impacts associated with each watershed, we hope to distinguish between effects arising from urban and nonurban stormwater runoff.

Sampling and Sample Handling

The sampling program consisted of two phases. In the first phase, sediment samples were collected in November 1995 and January 1996 (Table 1) to examine the spatial extent of runoff-affected sediment offshore of each creek. These data were used to select sediment sampling stations for the second phase, consisting of sediment and water sampling during or soon after storms (wet season sampling). Wet season sampling was also coordinated with plume dispersion studies conducted by USC and UCSB. Sample dates (Table 1) and methods varied throughout the study because of the unpredictable nature of storm events, the limitations of ship availability, and the objectives of different study components. Water samples for toxicity were collected as soon as possible following a storm (8 to 48 h), while sediment samples were collected 7 to 12 d following target storms in order to allow suspended particles to settle.

FIGURE 1. Watershed characteristics and sediment sampling sites for the two study locations. All stations except for the toxicity station near Ballona Creek were sampled during the spatial survey. Stations along the 25 m isobath, indicated by closed symbols (·), were also sampled for post-storm toxicity, chemistry, and infaunal community analyses.



WATERSHED LAND USE (%)

	Ballona	Malibu
Residential	64	9
Commercial	8	1
Industrial	4	1
Other urban	8	2
Open	17	88

The spatial survey consisted of two grids (13 to 15 stations each) surrounding the mouths of Ballona and Malibu Creeks (Figure 1). Stations were separated by approximately 2 km and extended 2 to 4 km upcoast or downcoast from each creek mouth. Sampling depths were approximately 10, 25, and 40 m. The spatial survey was completed prior to significant flow from either creek during the 1995 to 1996 wet season.

Wet season sampling was accomplished after four storm events during the 1995 to 1996 wet season (Table 1). Based upon the results of the spatial survey, four stations offshore of each creek mouth were targeted for post-storm sediment chemistry and infaunal sampling (Figure 1). Samples were taken at approximately 25 m at all eight stations to reduce any depth-related bias. One additional sediment sample was collected at each site on February 28 for sediment toxicity and chemistry testing. Continuous profiles of water column temperature, salinity, dissolved oxygen, and transmissivity were also taken at each sediment collection station (these data are not presented in this report).

Sediments were collected using a 0.1 m^2 modified Van Veen grab from either the R/V LaMer or R/V Sea World. For contaminant analysis, only surficial sediments (the top 2 cm) from undisturbed grabs were collected. Sediment samples were placed in separate containers for grain size, TOC/total nitrogen (TN), trace organics, and trace metals analysis. These samples were taken from the same grab but were not homogenized prior to splitting. Samples were either stored under refrigeration (grain size) or frozen until analyzed. Samples for sediment toxicity tests were taken from replicate grabs and stored under refrigeration.

For benthic invertebrate community (infaunal) analysis, entire sediment grab samples were gently washed through a

TABLE 1. Summary of sampling dates and activities. Spatial survey samples were collected offshore of Ballona Creek (B) on November 15 and offshore of Malibu Creek (M) on January 22 and 30; all other samples were collected to examine conditions following stormwater runoff.

Sampling	Rainfall[a]		Water	Sediment	Sediment	Sediment	Biological
Date	(days)	(in)	Toxicity	Toxicity	Characteristics	Contamination	Communities
15-Nov-95	15				B		
22-Jan-96	1	0.6	B,M		M		
30-Jan-96	3	0.6			B,M	B	B
31-Jan-96	0	0.2	B				
1-Feb-96			M				
12-Feb-96	9	0.2			B,M	B,M	B,M
21-Feb-96	0	4.0	B				
28-Feb-96	1	0.4		B,M	B,M	B,M	B,M
5-Mar-96	0	0.7	B, M				
13-Mar-96	1	1.4			B,M	B,M	B,M

[a] Number of days since most recent rainfall and amount as recorded at the Los Angeles Civic Center.

1 mm mesh stainless steel screen on the boat. The organisms retained on the screen were “relaxed” using $MgSO_4$ (Epsom salts) in seawater. After 30 min, the sample was fixed with 10% borax-buffered formalin and returned to the laboratory. After 24 h, samples were rinsed with freshwater to remove formalin and preserved in 70% ethanol.

Surface water samples (upper meter) were collected during each of the four storm events (Table 1). Five water samples were obtained from the Ballona Creek area during each event. Fewer samples were collected off Malibu Creek, due to difficulties in accessing the study area and the relatively small volume of runoff found in the surface water. Water sampling methods varied because of the necessity to use different boats for sampling operations. Surface water samples for January 31 and February 1 were collected by dipping into the water a glass jar attached to the end of an aluminum pole. Water samples for other storms were obtained with a submersible pump deployed off the side of the boat. Both sampling techniques may have captured portions of the sea surface microlayer, but no special effort was made to sample this portion of the water column. Samples were stored under refrigeration at SCCWRP and tested within 48 h.

Locations of the water sampling stations were determined during each cruise and varied between events. Salinity measurements were used to select locations that represented a gradient of runoff concentration, usually aligned along a transect running between the creek mouth and a reference station (no apparent runoff) located up to 6 km offshore. Deviations from the general sampling plan occurred in response to available ship time, weather conditions, and the extent of the runoff plume.

Analytical Chemistry

Grain Size Analysis

Sediment grain size was measured using a Horiba Model LA-900 laser-scattering particle size distribution analyzer. The sediment sample was first homogenized, then a representative aliquot was passed through the instrument and the particle sizes were determined by detection of scattered (refracted and reflected) laser light.

Total Organic Carbon, Total Nitrogen and Total Volatile Solids Analysis

The TOC/TN measurements were conducted using a Carlo Erba 1108 CHN elemental analyzer, according to methods developed by SCCWRP (1993b). Sediment samples were homogenized, dried, and then digested with acid to remove inorganic carbon. Samples were then oxidized by combustion in the analyzer, and the evolved carbon and nitrogen were quantified using a thermal conductivity detector.

Total volatile solids (TVS) was measured using a Thermolyne Model 62700 muffle furnace. Sediments were dried at 60 °C overnight, combusted at 500°C, and then weighed after cooling. The TVS was determined from the net loss in weight after combustion. While not as specific a measure as TOC, TVS has been shown to be significantly correlated with TOC measurements in reference areas of the Southern California Bight (SCB) (Thompson *et al*. 1993).

Metals Analysis

Samples were prepared for metals analysis in accordance with Environmental Protection Agency (EPA) Method 3051 (EPA 1996). Dried sediment samples were digested using a nitric acid:hydrochloric acid mixture. Concentrations of aluminum, arsenic, beryllium, cadmium, chromium, copper, iron, lead, mercury, nickel, selenium, silver, and zinc were determined using a Hewlett Packard Model 4500 inductively coupled plasma-mass spectrometer (ICP-MS) according to EPA Method 200.8 (EPA 1991).

Pesticides and Polychlorinated Biphenyls

Analytical methods for chlorinated pesticides (DDTs) and PCBs followed EPA protocols (EPA 1986 or EPA 1983). Six DDT isomers and metabolites (o,p'-DDT, p,p'-DDT, o,p'-DDE, p,p'-DDE, o,p'-DDD, p,p'-DDD) and 27 individual PCB congeners (Congeners 8, 18, 28, 29, 44, 50, 52, 66, 77, 87, 101, 104, 105, 118, 126, 128, 138, 153, 154, 170, 180, 187, 188, 195, 201, 206, and 209) were quantified. Samples were also examined for 12 additional chlorinated pesticides (isomers of chlordane and lindane, hexachlorobenzene, and derivatives of endosulfan), but none of these compounds were detected for any sample in this study.

Specific methodological details for the sediment analyses can be found in SCCWRP (1994) or Zeng and Khan (1995), but a general description of the procedure follows. Samples for DDT and PCB analysis were homogenized and then centrifuged to remove pore water. Following extraction by methylene chloride, samples were cleaned of interfering compounds using activated copper addition and preparative columns of alumina and silica. Extracts were concentrated to 1 mL and injected into a Hewlett Packard Model 5890 II gas chromatograph equipped with a 60m by 0.25 mm in diameter (0.25 µm film thickness) DB-5 fused silica capillary column and a 63Ni electron capture detector (GC-ECD) for analyte measurement.

Polycyclic Aromatic Hydrocarbons

The PAH analyses were conducted using EPA protocols (EPA 1986 or EPA 1983), which quantify 28 different PAHs. Specific methodological details can be found in Zeng and Khan (1995) or SCCWRP (1995a). Analysis was accomplished by injecting a portion of the same solvent extract used for the chlorinated hydrocarbon measurements into a Hewlett Packard Model 5890 II gas chromatograph equipped with a DB-5 column (60m by 0.25 mm in diameter by 0.25 µm film thickness) and a Hewlett Packard Model 5870 mass selective detector in electron impact ionization mode.

Quality Assurance

Each batch of samples for metals or organics analysis included blanks, spiked samples, and standard reference materials to monitor method performance and recovery. Instrument calibration was verified prior to analyzing each batch of samples, and internal standards were added to each solvent extract to correct for variations in instrument performance.

Infaunal Community Analysis

Each infaunal sample was sorted into six different taxonomic groups: annelids, molluscs, arthropods, ophiuroids, miscellaneous echinoderms, and "other phyla." A minimum of 10% of each sample was re-sorted by another person to detect missed organisms. If sorting efficiency was less than 95%, then the entire sample was re-sorted. Biomass measurements were obtained by weighing each group of organisms to the nearest 0.01 g (wet weight).

Each organism was identified to the lowest taxon possible, using standardized nomenclature developed for the SCB (SCAMIT 1996). Species-level identifications were assigned by scientists who were experts in their respective taxonomic group and were active members of the Southern California Association of Marine Invertebrate Taxonomists (an interagency quality assurance group). Ten percent of all samples were re-identified and enumerated by a second taxonomist for quality assurance. All new species encountered were maintained in a voucher collection located at SCCWRP.

Toxicity Measurement

Three types of environmental samples were tested for toxicity: surface water, sediment interstitial water, and whole sediment. Surface water samples were not filtered or centrifuged before testing. Brine (prepared by the partial freezing of seawater) was added to samples with a salinity below 30 g/kg to adjust the salinity to 34 g/kg. Each water sample was tested at a single concentration; i.e., 100% sample or the maximum concentration after salinity adjustment. Four replicates of each sample were tested. The percentage of runoff present in each toxicity test sample was calculated from the initial salinity value and included dilution resulting from salinity adjustment. This calculation assumed that the percent of runoff present in the original sample was inversely proportional to the relative salinity, expressed as a percentage of the background value (outside of plume).

Interstitial water was extracted from the sediment samples by centrifugation twice at 3,000 x g for 30 min. Laboratory seawater was added to the samples to produce three test concentrations containing 100, 50, and 25% interstitial water. Three replicates of each concentration were tested.

Water quality measurements conducted during each toxicity test consisted of salinity, dissolved oxygen, pH, and total ammonia content. Measurements were made using electrodes that were calibrated daily. Measurements were made at the start of each test and at the end of the 10-d amphipod survival test. Electronic thermometers were used to measure water temperature continuously throughout the duration of each experiment.

Sea Urchin Fertilization

All samples of surface water and interstitial water were tested for toxicity using a sea urchin fertilization test (Chapman *et al.* 1995). The test consisted of a 20-min exposure of sperm to the samples at 15 °C. Eggs were then added and given 20 min for fertilization to occur. The eggs were preserved and examined later with a microscope to assess the percent fertilized. Toxic effects are expressed as a reduction in fertilization percentage.

Purple sea urchins (*Strongylocentrotus purpuratus*) used in the tests were collected from intertidal areas in northern Santa Monica Bay. The tests were conducted in glass vials containing 10 mL of solution.

A negative control (0.45 µm and activated carbon filtered natural seawater from Redondo Beach) and a brine control (distilled water containing 50% brine) were included in each test series for quality assurance purposes. A reference toxicant test (copper in seawater) was conducted with each batch of samples to document sea urchin health.

Amphipod Survival

The toxicity of sediment samples was assessed by measuring the survival of amphipods following a 10-d exposure period. Test methods followed standard guidelines (ASTM 1991). A one-liter sediment sample was removed from storage and manually homogenized with a large plastic spoon. A 2 cm layer of sediment was added to five replicate one-quart glass canning jars for each station. Approximately 750 mL of lab seawater, adjusted to a salinity of 30 g/kg, was added to each jar. The jars were fitted with aeration tubes and allowed to equilibrate overnight before the addition of the amphipods.

Twenty amphipods (*Rhepoxynius abronius*) were added to each jar. The test animals were collected from Puget Sound, Washington. A sample of collection site sediment was also included in the test, as a negative control. The test was conducted at 15°C, under constant illumination. Surviving animals were removed from the sediment at the end of the exposure by sieving and were counted to determine the percent survival. Reburial success was not determined. A concurrent reference toxicant test consisting of a four-d exposure to cadmium in seawater was conducted to document amphipod health.

Data Analysis

The sea urchin fertilization test results were normalized to the control (lab seawater) response in order to compensate for variations in response between experiments. Normalization was accomplished by dividing the mean fertilization for each sample by the control fertilization percentage, then expressing the resulting fraction as a percentage.

Sediment characteristics and infaunal community parameters at the 25 m stations were summarized by calculating the mean and 95% confidence interval of all wet weather samples for each station (n = 3 or 4 for Malibu or Ballona, respectively).

RESULTS

Surface Water Effects

Toxicity

Toxicity was present in surface water samples collected near the mouth of Ballona Creek during three of the four sampling events (Table 2). No toxicity was detected in water samples collected on January 22. Samples from this event contained little runoff (<4%), whereas water samples from later storm events contained up to 44% runoff (Table 2). Toxicity was always detected in water samples containing greater than 10% runoff, with samples containing the most runoff having the greatest toxicity (Table 2). The relatively small volume of runoff present in the January 22 samples was probably due to a delay in collection following the storm.

Toxicity was usually present in water samples collected nearest the mouth of Ballona Creek (Figure 2). Toxic water samples were restricted to a relatively small zone (<2 km offshore of Ballona Creek) on January 31 and March 5. A greater area of toxicity was present on February 21, with toxic water present up to 4 km from the mouth of Ballona Creek. Too few samples were collected to examine the longshore distribution of toxic surface water.

No toxicity was detected in water samples collected near the mouth of Malibu Lagoon during three storm events. Toxicity was not expected to be found in the Malibu samples, since they contained less than 2% runoff (Table 2).

Sediment Effects

Spatial Patterns

Sediments from the spatial survey were analyzed for indicators of grain size (percent fines) and organic material (percent TVS). These parameters were examined to identify deviations in general sediment characteristics caused by stormwater particle deposition near each creek. Since most runoff contaminants associate with stormwater

TABLE 2. Sea urchin fertilization test results for surface water samples. Shaded regions indicate samples from reference areas located relatively far from the creek mouth.

Date	Location	Salinity[a]	Percent Flow[b]	Percent Fertilized[c]
1/22/96				
	Ballona	32.4	3.3	98
	Ballona	33.1	1.2	100
	Ballona	33.4	0.3	99
	Ballona	33.5	0.0	99
	Ballona	33.5	0.0	99
	Malibu	33.5	0.0	96
1/31-2/1/96				
	Ballona	15.4	38.3	4
	Ballona	15.2	38.7	4
	Ballona	21.2	28.5	8
	Ballona	28.8	12.4	13
	Ballona	33.2	0.6	107
	Malibu	32.8	1.8	107
	Malibu	32.8	1.8	107
	Malibu	33.2	0.6	101
	Malibu	33.4	0.0	107
2/21/96				
	Ballona	15.5	37.6	8
	Ballona	11.1	43.7	8
	Ballona	26.8	15.9	22
	Ballona[d]	28.8	11.2	52
	Ballona	32.9	0.0	90
3/5/96				
	Ballona	24.4	21.6	20
	Ballona	26.6	16.7	27
	Ballona	29.9	8.6	95
	Ballona	32.2	2.4	99
	Ballona	33.0	0.0	99
	Malibu	32.8	0.6	98
	Malibu	32.7	0.9	99

[a] Initial value; salinity adjusted to 33 to 34 g/kg for toxicity test.

[b] Estimated amount of runoff in water sample during toxicity test; calculated from salinity and sample test concentration.

[c] Percent of control (laboratory seawater or brine control) fertilization.

[d] Sample from Marina del Rey Channel.

organic material or silt/clay particles, stations having elevated sediment fines or TVS (relative to nearby areas) were assumed to represent locations most likely to contain the highest concentrations of stormwater-derived contaminants.

At 25 m depth, sediments directly offshore of the mouth of Ballona Creek showed a distinct increase in percent of fine-grained material, relative to sediments collected at similar depths to the north or south (Figure 3). The proportion of sediment fines doubled offshore of Ballona Creek (40%) relative to the fines measured in sediments 4 km upcoast (22% fines, Table 3). Although less pronounced, this longshore spatial pattern also reached to 40 m depth, but was not evident at a depth of 10 m. Similarly, a spatial pattern in the sediment TVS content was associated with Ballona Creek discharges. At 25 m depth, TVS was approximately 75% greater in sediments sampled directly offshore of the creek (2.5%) compared to sediments 4 km upcoast (1.4%, Figure 3).

The spatial pattern in grain size or TVS at Malibu Creek was less distinct than at Ballona Creek. Background levels of TVS and fines in the Malibu study site were higher than off Ballona Creek, potentially obscuring patterns of sediment deposition from Malibu Creek. TVS provided the strongest indication of a spatial pattern produced by Malibu Creek discharges; TVS at 25 and 40 m depth directly offshore of the creek mouth was greater than in sediments collected at similar depths to the east or west (Table 3). The spatial pattern extended 2 to 4 km upcoast and downcoast. Similar to the Ballona Creek site, data for the 10 m samples showed little evidence of discharge-related changes.

Since the spatial patterns in sediment characteristics (TVS or fine-grained sediment) were greatest at a depth of 25 m offshore of Ballona Creek, benthic sampling stations were established at this depth for the wet season (Figure 1). All stations, including Malibu Creek sites, were established at the same depth to eliminate any depth-related bias among or between creek sites.

Sediment Concentrations

Ballona and Malibu Creeks

The analytical results for the four sets of post-storm sediment samples were used to determine the wet season average concentrations of sediment characteristics and contaminants directly offshore of the mouths of Ballona and Malibu Creeks. Sediments sampled at Malibu Creek contained twice the fines, 50% more TOC, and 25% more TN than Ballona Creek (Table 4). Of the 14 different inorganic/metal constituents, 7 were substantially greater in sediments offshore of Malibu Creek (Al, Be, Cd, Cr, Fe, Ni, Se); 3 constituents were substantially greater in sediments offshore of Ballona Creek (Pb, Hg, Ag); and the remaining 3 constituents were roughly similar in the sediments offshore of the two

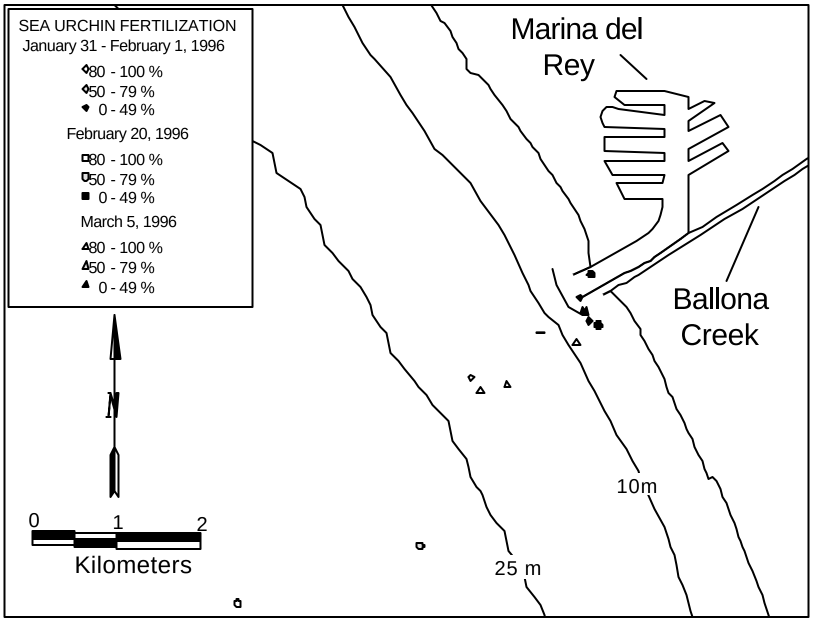
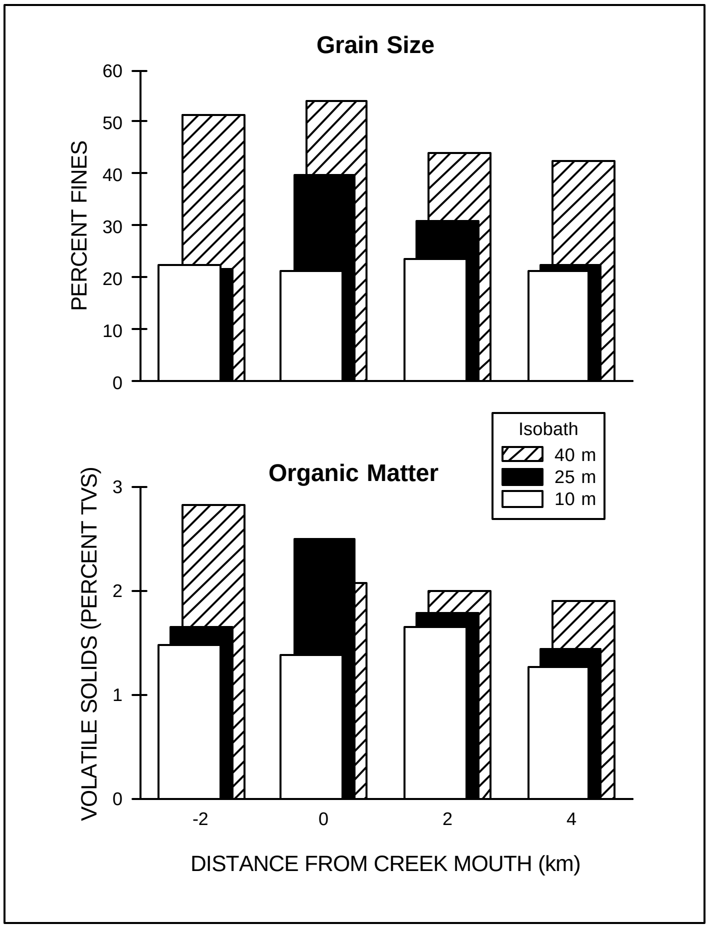


FIGURE 2. Summary of sea urchin fertilization test results for surface water samples near the mouth of Ballona Creek during three storm events in 1996. Differences in symbol size and shading indicate the magnitude of toxicity. Note that multiple samples were collected near the mouth of Ballona Creek during each storm; these samples had similar toxicity and are shown as overlapping symbols. Water samples were collected near the mouth of Malibu Creek, but no toxicity was present.

FIGURE 3. Sediment characteristics of samples collected during the dry season spatial survey for Ballona Creek. Station locations are shown in Figure 1. Distance refers to the upcoast (positive values) or downcoast (negative) direction, relative to the creek mouth.



drainages (As, Cu, Zn). Ballona Creek had significantly higher sediment concentrations of total DDT, total PCB, and total PAH than Malibu Creek.

The differences in general sediment characteristics between the two drainage areas is of fundamental importance. The sediments offshore of Malibu Creek were significantly finer than sediments offshore of Ballona Creek. Concentrations of common marine inorganic constituents such as aluminum and iron were also highest offshore of Malibu Creek. Concentrations of these metals are typically high (in the percentage range) and are related to the degree of geological mineralization (e.g., alumina-silicate silts and clays).

Inorganic contaminants offshore of Ballona Creek followed a pattern across the gradient of stormwater influence that was similar to the pattern observed in the spatial survey. Concentrations of stormwater-associated metals such as lead, copper, and zinc were significantly higher in sediments sampled directly offshore of the creek mouth, and decreased upcoast and downcoast (Figure 4). Wet season averages at distant stations 4 km upcoast were between 41% (for copper) and 70% (for zinc) of average concentrations directly offshore of the Ballona Creek mouth.

Organic contaminants offshore of Ballona Creek also followed a similar pattern across the gradient of stormwater influence (Figure 4). Total DDT, total PCB, and total PAH were highest in sediments sampled directly offshore of the creek mouth and concentrations decreased upcoast and downcoast. Wet season averages at distant stations 4 km

TABLE 3. Results of dry weather spatial survey. Distance refers to the upcoast (positive values) or downcoast (negative) direction, relative to the creek mouth.

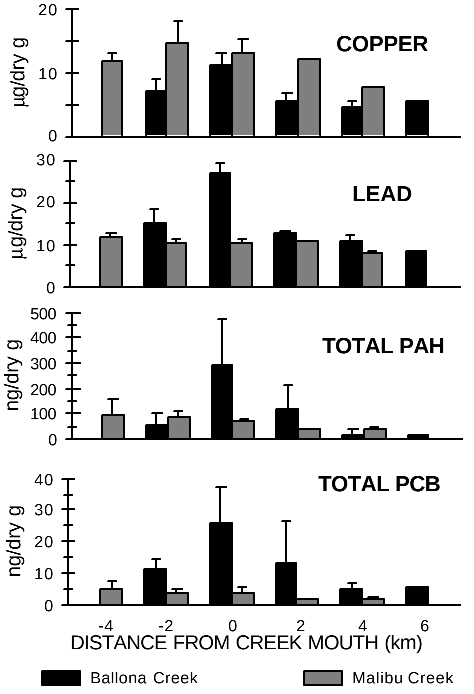
Distance from Creek (km)	Depth (m)	Ballona Creek Percent TVS	Ballona Creek Percent Fines	Malibu Creek Percent TVS	Malibu Creek Percent Fines
-4	10	NS[a]	NS	1.95	32.2
-2	10	1.48	22.6	1.86	44.0
0	10	1.39	21.5	1.67	9.8
2	10	1.66	23.5	1.40	29.5
4	10	1.28	21.5	1.49	15.6
-4	25	NS	NS	2.56	61.9
-2	25	1.65	21.8	4.14	68.6
0	25	2.50	39.9	3.29	63.3
2	25	1.79	30.8	3.81	63.0
4	25	1.44	22.5	2.31	67.4
-4	40	NS	NS	3.36	87.8
-2	40	2.83	51.2	4.14	92.3
0	40	2.08	54.0	5.16	90.1
2	40	2.00	44.1	4.34	88.5
4	40	1.91	42.6	3.75	85.9

[a]NS = Location not sampled in survey.

TABLE 4. Summary of sediment characteristics and pollutant concentrations in sediments offshore of the creek mouths. Values are the mean of 3 to 4 sediment samples taken directly offshore of each creek (at a depth of 25 m) following storm events.

	Ballona Creek (4 Storms) Mean	Ballona Creek (4 Storms) 95% CI	Malibu Creek (3 Storms) Mean	Malibu Creek (3 Storms) 95% CI
General Characteristics (% dry weight)				
Fines	30.5	1.2	53.6	8.2
TOC	0.662	0.263	0.912	0.106
TN	0.064	0.012	0.080	0.008
Inorganic Contaminants (µg/dry g)				
Aluminum	14,075	258	21,500	898
Arsenic	4.9	0.7	5.0	1.3
Beryllium	0.39	0.03	0.57	0.10
Cadmium	0.45	0.07	0.68	0.15
Chromium	41.8	3.1	57.5	13.7
Copper	11.2	2.0	13.0	2.6
Iron	15,575	123	22,933	2,103
Lead	26.8	2.2	10.3	1.2
Mercury	0.17	0.02	0.10	0.01
Nickel	14	1	29	4
Selenium	0.49	0.05	0.69	0.04
Silver	0.93	0.13	0.31	0.05
Zinc	56	3	58	7
Organic Contaminants (ng/dry g)				
Total DDT	26.5	6.7	17.5	3.3
Total PCB	26.0	11.0	3.6	2.1
Total PAH	289.3	185.3	73.5	2.2

FIGURE 4. Mean (± 95% CI) concentrations of surface sediment metals and organic contaminants offshore of Ballona and Malibu Creeks during the 1995-1996 wet season. N=3-4 except for the Ballona 6 km and Malibu 2 km stations, which represent a single sample.



upcoast were between 6% (for total PAH) and 41% (for total DDT) of average concentrations directly offshore of the Ballona Creek mouth.

Inorganic contaminants offshore of Malibu Creek followed a pattern across the gradient of stormwater influence similar to the pattern described for general sediment characteristics. Figure 4 shows the pattern for copper and lead. Wet season averages at distant stations 4 km upcoast were between 58% (for copper) and 80% (for zinc) of values measured directly offshore of the Malibu Creek mouth. Except for lead, metals were highest in sediments sampled 2 km downcoast from the Malibu Creek mouth. For lead, sediment concentrations were similar between stations within 2 km of the Malibu Creek mouth. The distribution of sediment contaminants offshore of Malibu Creek was less clear than at Ballona Creek.

Organic contaminants offshore of Malibu Creek generally did not follow a pattern across the gradient of stormwater influence (Figure 4). No consistent trend was established for the data, and organic contaminant concentrations were very low overall. The highest wet season concentrations of total PCB and total PAH were not found directly offshore of Malibu Creek, but 4 km downcoast. However, the lowest values for all three organic compound classes were regularly observed 4 km upcoast from the Malibu Creek mouth.

Identification of Enriched Contaminants

Unlike synthetic organic pollutants such as DDT or PCB, which are strictly anthropogenic in origin, trace metals are naturally occurring elements that are part of the earth's crustal matrix. Most metals, including prominent stormwater constituents like copper, lead, and zinc, have native concentrations within the detectable range of measurements for this project. Natural variations in sediment metal concentrations must be accounted for before anthropogenic enrichment can be identified. To compensate for these naturally occurring concentrations, iron was used as a reference element to establish baseline conditions and to evaluate anthropogenic enrichment of sediments (see *Iron as a Reference Element for Determining Trace Metal Enrichment in California Coastal Shelf Sediments,* this report). When the 1995 to 1996 wet season lead data were normalized to iron, many Ballona Creek samples contained higher-than-expected concentrations (Figure 5), indicating enrichment. Interestingly, the most enriched concentrations (between 24 and 30 µg/dry g) all occurred at the site directly offshore of the Ballona Creek mouth. All lead concentrations in Malibu Creek samples fell within the expected relationship with iron, indicating that these values were probably due to natural variations in sediment composition. Copper and zinc concentrations for Malibu Creek and Ballona Creek offshore sediments fell within the

FIGURE 5. Iron normalization technique applied to sediment lead data for Ballona and Malibu Creek samples. Baseline relationship was derived using data from shallow water reference sediments throughout the Southern California Bight (see *Iron as a Reference Element for Determining Trace Metal Enrichment in California Coastal Shelf Sediments,* this report). Samples plotted above the baseline prediction interval (95% confidence limit) are enriched in lead content.

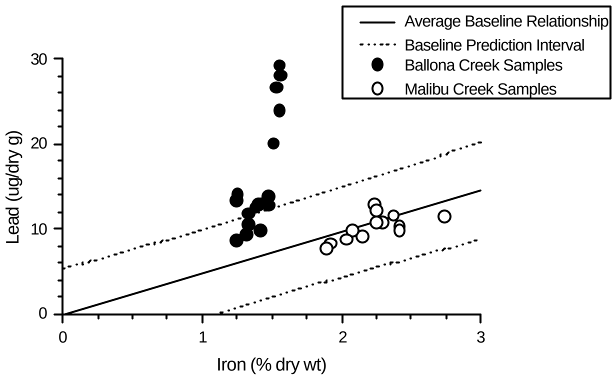


TABLE 5. Summary of toxicity test results for whole sediment (amphipod survival) and interstitial water (sea urchin fertilization). Sediment samples were collected February 28, 1996. Distance refers to the upcoast (positive values) or downcoast (negative values) direction, relative to the creek mouth.

		Amphipod Survival Test		Sea Urchin Fertilization Test	
	Distance from Creek (km)	Percent Survival Mean (SD)	Ammonia[a] (mg/L)	Percent Fertilized Mean (SD)	Ammonia[b] (mg/L)
Ballona Creek	-2	93 (4)	2.0	98 (2)	4.2
	0	95 (6)	3.1	98 (2)	6.2
	2	89 (11)	2.6	95 (4)	4.1
	4	97 (4)	1.5	96 (1)	3.4
	6	98 (3)	1.7	42 (5)	9.8
Malibu Creek	-4	93 (6)	1.1	98 (1)	2.1
	-2	91 (8)	1.6	99 (1)	2.0
	0	90 (7)	2.8	95 (1)	2.7
	2	93 (6)	2.0	99 (1)	1.5
	4	89 (10)	0.6	99 (2)	1.7

[a] Total ammonia concentration in overlying water at start of experiment.
[b] Total ammonia concentration in interstitial water.

baseline relationship (data not shown), indicating that anthropogenic enrichment of these metals was not present.

Toxicity

Amphipod survival was high (89 to 98%). which indicated an absence of toxicity in all sediment samples (Table 5). The concentration of ammonia in the water overlying the sediment was slightly higher for stations within 2 km of either creek, possibly reflecting the organic enrichment identified by chemical analysis. These ammonia concentrations were not toxic and were within the range typically found in sediment toxicity tests.

Interstitial water from 9 of 10 sediment samples was nontoxic to sea urchin sperm (Table 5). Only interstitial water sampled from one station (6 km) upcoast of Ballona Creek was toxic, reducing fertilization by about 60% (relative to the control sample).

Infaunal Community Structure

A total of 30 samples were sieved, sorted, weighed, and identified for infaunal community structure analysis. A total of 8,531 individuals were identified, comprising 389 different taxa. About 90% of the total abundance at each creek represented species common to both sites. The dominant species recorded at each creek site included the polychaetes, *Spiophanes missionensis* and *Paraprionospio pinnata*; the mollusc, *Tellina modesta*; and the amphipods, *Amphideutopus oculatus* and *Ampelisca brevisimulata*. Interestingly, the Malibu Creek site also contained some organisms (e.g., *Amphiodia urtica*), which are typical of fine-grained habitats common in deeper water (Bergen 1995).

For the entire wet season, stations directly offshore of Ballona Creek and Malibu Creek at 25 m depth had similar diversity (Shannon-Wiener H'), evenness (Pielou's J), and species richness (Table 6). Abundance was slightly reduced offshore of Ballona Creek compared to Malibu Creek.

Examination of trends across the gradient of stormwater influence did not reveal any significant relationships to stormwater discharges (Table 6). Instead, mean abundance decreased moving upcoast of both creeks. Similarly, species richness was highest downcoast and lowest upcoast of the Ballona Creek mouth. Species richness was fairly constant across the gradient of stormwater influence at Malibu Creek; however, the station 2 km downcoast showed high variability. Diversity and evenness measures showed no strong trends between stations.

DISCUSSION

Results from the first year of this study, though preliminary, provide sufficient data to address several important questions regarding runoff effects in receiving waters.

Do stormwater discharge plumes contain toxic materials?

Study results indicate that surface water toxicity in the Ballona Creek area is present when runoff concentrations are greater than 10%. This finding correlates well with the level of toxicity measured in samples of Ballona Creek

TABLE 6. Summary of infaunal results for the 1995 to 96 wet season. Distance refers to the upcoast (positive) or downcoast (negative) direction, at a depth of 25 m. Values are the mean of 3 to 4 samples.

Distance from	Mean (95% Confidence Interval)			
Creek Mouth (km)	Abundance[a]	Species Richness	Diversity [b]	Evenness [c]
Ballona Creek (n=4)				
-2	324 (46)	94.5 (12.4)	1.73 (0.08)	0.88 (0.03)
0	244 (18)	80.0 (4.4)	1.70 (0.04)	0.89 (0.01)
2	216 (33)	66.5 (4.4)	1.60 (0.05)	0.88 (0.02)
4	145 (47)	67.3 (13.1)	1.68 (0.08)	0.93 (0.02)
Malibu Creek (n=3)				
-4	374 (66)	94.0 (10.4)	1.70 (0.10)	0.86 (0.03)
-2	378 (325)	85.3 (57.1)	1.60 (0.30)	0.90 (0.08)
0	333 (38)	95.7 (9.1)	1.74 (0.02)	0.88 (0.02)
4	303 (52)	91.3 (10.4)	1.71 (0.08)	0.87 (0.04)

[a] Number of individuals/0.1 m^2.
[b] Shannon-Wiener H'.
[c] Pielou's J.

stormwater collected during the same storms (see *Toxicity of Stormwater from Ballona and Malibu Creeks*, this report). The average EC50 (concentration causing 50% reduction in fertilization) of Ballona Creek stormwater samples was 16%. Stormwater composition is highly variable, however, so future results may modify estimates of in-channel and receiving water toxicity.

The area offshore of Ballona Creek receives contaminant inputs from other sources (e.g., industrial and municipal effluents, marinas, and aerial fallout) that could contribute to water column toxicity in the area. However, the spatial pattern and magnitude of toxicity between the two sites, are consistent with Ballona Creek being the dominant source of toxicity. A further correlation between receiving water and Ballona Creek stormwater toxicity has been provided by studies conducted to characterize the toxicants. Preliminary toxicity identification studies indicate that the primary toxicants in both types of samples are similar (possibly divalent trace metals).

We were unable to obtain surface water samples from the Malibu area with runoff concentrations similar to those measured near Ballona Creek. Consequently, a direct comparison of the results between study areas cannot be accomplished at this time. It is not known whether the low runoff concentrations measured are representative of the area or reflect a deficiency in sampling methodology(e.g., delays in reaching the study site after a storm). It is anticipated that this issue will be clarified during the second year of sampling. Malibu Creek stormwater appears to be less toxic that Ballona Creek stormwater, with concentrations of ≥ 25% usually needed to produce toxic effects (see *Toxicity of Stormwater Runoff from Ballona and Malibu Creeks,* this report). Extending these results to surface waters, it is likely that less toxicity will be present offshore of Malibu Creek.

Does stormwater discharge produce long-lasting alterations in Santa Monica Bay sediment characteristics?

Discharges from Ballona Creek appeared to alter offshore sediment characteristics, as shown by spatial patterns in grain size and TVS. This pattern was persistent (present in dry weather) and could be observed at least 2 km upcoast and at 40 m depth. The spatial patterns at Malibu Creek were more complicated than at Ballona Creek, probably due to differences in oceanographic processes that modify particle fate, additional sources of fine-grained and organic-rich particles, and differences in background conditions.

Enhanced local deposition of silt/clay particles may be a common feature of stormwater discharges. Increases in sediment fines were observed at distances ≥ 2 km offshore of the Santa Clara River following large winter storms (Kolpack and Drake 1985). More research is underway at SCCWRP, USC, and UCSB to define the range of influence and deposition of storm discharged particles in Santa Monica Bay.

Are sediment contaminants elevated?

Sediments offshore of Ballona Creek were higher in concentrations of organic contaminants such as total DDT, total PCB, and total PAH as well as lead, a stormwater-associated metal. This contamination covaried with sediment characteristics across the gradient of Ballona Creek stormwater influence. Sediment concentrations of organic and inorganic pollutants were highest offshore of the Ballona Creek mouth and then decreased upcoast and downcoast.

Sediments offshore of the mouth of Malibu Creek were finer, contained more organic carbon and nitrogen, and had higher concentrations of some naturally occurring inorganic constituents. No evidence was found of enrichment of inorganic or organic contaminants from Malibu Creek stormwater.

Is sediment toxicity affected by stormwater runoff?

The results available to date show no evidence of sediment or interstitial water toxicity that can be attributed to discharges from Ballona or Malibu Creeks.

Amphipod survival was not reduced by exposure to sediments from any station. These results are similar to sediment toxicity data from the Southern California Bight Pilot Project (SCBPP), a regional study of coastal sediment quality conducted in 1994 (SCCWRP 1996). Sediment from 72 stations in southern California (in depths of 10 to 200 meters), including 13 sites in Santa Monica Bay, were collected and tested for toxicity using a similar amphipod survival test. No significant amphipod mortality was found at any of the SCBPP stations.

Amphipod survival tests do not provide a sensitive measure of sediment toxicity. Recent amphipod survival tests on highly contaminated sediments located near southern California wastewater outfalls failed to detect toxicity in samples that caused sublethal effects on other toxicity test species (SCCWRP 1995b) or contained altered benthic communities (SCCWRP 1993c). The 10-d amphipod survival test was used in this program because it is a reliable method commonly used in sediment quality studies, and toxic effects observed with this test are often associated with adverse benthic community changes.

Interstitial water toxicity measurements were included in this program to provide a more sensitive measure of sediment quality. Previous studies have detected interstitial water toxicity in sediments from southern California. Sea urchin fertilization was reduced in interstitial water samples from the Palos Verdes Shelf, with the magnitude of effects corresponding to sediment contamination level (SCCWRP 1995b). Toxic effects on sea urchin embryo development was produced by interstitial water from 15 of 72 samples tested during the SCBPP (SCCWRP 1996). The sea urchin embryo development test is usually more sensitive than the fertilization test when applied to interstitial water (Carr and Chapman 1995).

The sea urchin fertilization test of interstitial water did detect toxicity in one sample off Ballona Creek. This station was located 6 km upcoast of Ballona Creek (Figure 1), and the sediment chemistry data indicate this station is outside the area most influenced by the Creek (Figure 4). As increased interstitial water toxicity did not directly correspond to variations in sediment contamination, it is unlikely that the toxicity at this station is directly related to stormwater from Ballona Creek. All measured interstitial water quality parameters for this station (pH, dissolved oxygen, hydrogen sulfide, salinity, and ammonia) were within nontoxic ranges, although total ammonia concentration was higher than all other samples.

A cause for the interstitial water toxicity cannot yet be identified. This toxicity may indicate the presence of unidentified contaminants from an unknown source, or it may reflect temporary variations in sediment quality caused by natural factors or sediment storage. Additional research is needed to clarify the significance of the results. Additional toxicity tests of sediments from the Ballona Creek study area are in progress to assess the sublethal effects and bioavailability of the sediment-associated contaminants.

Are infaunal communities impaired?

No dramatic biological effects in the benthic community structure were evident from the first wet season of sampling. No indications of a strongly degraded environment were found. Differences in community composition between sites offshore of the two creeks most likely resulted from variations in sediment characteristics (e.g., grain size) rather than differences in sediment-associated contaminants.

Due to relatively small sample sizes ($n \leq 4$), it is premature to reach conclusions regarding community disturbance at this time. However, these preliminary results are similar to previous reference surveys, which reported 273 to 358 individuals and 78 to 91 species per grab at depths of 30 m during the summer months (Thompson *et al.* 1987, 1993). Completion of the second year of infaunal analysis will provide a greater ability to detect subtle differences in communities across gradients of stormwater influence and determine whether the results are consistent over time.

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