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CHAPTER 116

Stormwater Runoff Effects on Santa Monica Bay: Toxicity, Sediment Quality, and Benthic Community Impacts

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ABSTRACT

Results from the initial year of a three year study of the effects of stormwater in Santa Monica Bay are described. Surface water and sediment samples were collected for analysis following four significantly-sized storm events in January through March, 1996. Toxicity was present in water samples offshore of Ballona Creek and was proportional to the concentration of runoff in the plume. Changes in sediment characteristics, such as grain size and TOC, were evident offshore of both Ballona and Malibu Creeks. Not only were the changes in sediment characteristics temporally stable (similar patterns observed after storms and during dry weather periods), but there was a gradient of change decreasing both upcoast and downcoast away from each creek mouth. Sediment contaminants, such as lead, total DDT, total PCB, and total PAH, were elevated at stations directly offshore Ballona Creek compared to sediments at similar depths offshore Malibu Creek. The first year's results have not detected significant stormwater-related changes in benthic infaunal community assemblages or sediment toxicity in the vicinity offshore the discharge of either creek.

INTRODUCTION

Urban runoff has been shown to discharge large quantities of contaminants (Schiff and Stevenson 1996; SCCWRP 1990, 1994a) 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

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enhancing in-channel measurements, yielding better information on characterization of wet weather inputs and 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.

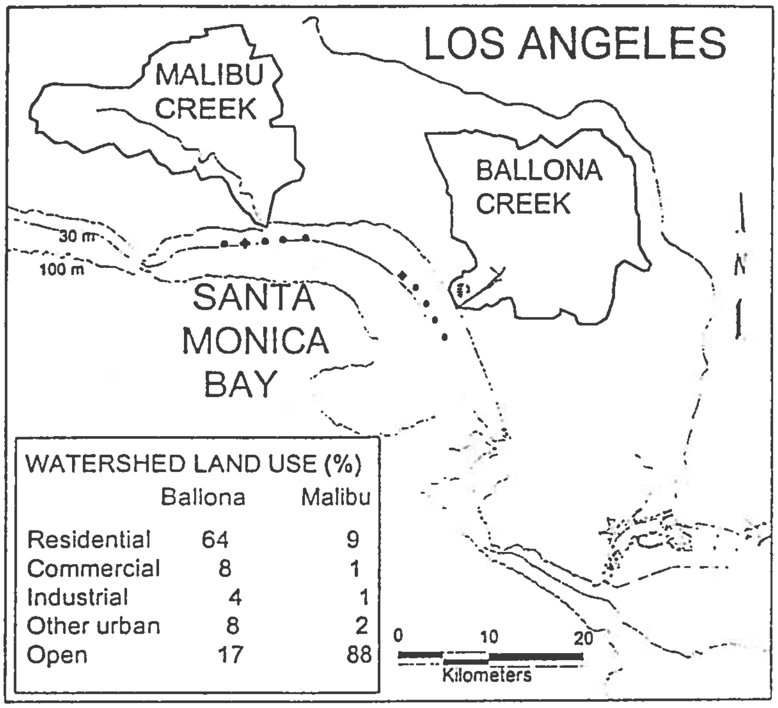
The fate and effects of contaminants on the receiving environment cannot be predicted from in-channel measurements alone. The mixing of the freshwater plume with ambient seawater alters the chemical state and solubility of some contaminants; particle aggregation and settling are also affected in complex ways. Furthermore, the nearshore environment is very dynamic with waves and currents having a strong influence on the deposition and distribution of stormwater contaminants. Moreover, much of what we know about the effects of contaminants in the benthic environment has been learned from studies of ocean wastewater outfalls. These systems differ greatly from stormwater discharges in terms of discharge composition and variability, mixing and dispersion, as well as the receiving environment characteristics. Therefore, directed studies of stormwater discharge are needed in order 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 linkage between stormwater discharge and environmental effects. This study, conducted in collaboration with the University of Southern California (USC), USC Sea Grant, and the University of California at Santa Barbara (UCSB), had three principal objectives. The first objective was to measure the dispersion and mixing of stormwater plumes in Santa Monica Bay; this work was conducted by our collaborators and is presented in an accompanying article. The second objective was 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 from measurements within the watershed. The final objective of this project was to measure the impacts to benthic communities in the immediate vicinity of the discharge. This article presents the results from the toxicity and benthic studies for the first wet season of sampling.

METHODS

The Ballona Creek and Malibu Creek watersheds were selected for evaluation in this study. Both watersheds are roughly similar in size (Figure 1), and 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 channel is almost entirely earthen. 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 type, we hope to distinguish between effects arising from urban and non-urban stormwater runoff.



WATERSHED LAND USE (%)

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

Figure 1. Watershed characteristics and sediment sampling sites for the two study locations. All stations were located along the 25 m isobath. Circles (•) indicate stations sampled after multiple storms for chemistry and infaunal community analyses. Sediment from all 10 stations were collected for toxicity tests following the February 1996 storm event.

Sampling and Sample Handling

Wet season sampling was accomplished after four 1996 storm events of variable magnitude: January 21 (1.52 cm rain at Los Angeles Civic Center), January 31 (0.51 cm), February 19-21 (10.16 cm), and March 4 (1.78 cm). Wet season sampling was coordinated with plume dispersion studies conducted by USC and UCSB. Water samples for toxicity were collected as soon as possible following a storm (8-48 hours), while sediment samples were collected up to 14 days following target storms in order to allow suspended particles to settle.

Surface water samples (upper meter) were collected during each of the four storm events. 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 amount of runoff found in the surface water. Water sampling methods varied because of the necessity to use different boats for some sampling. Surface water samples were either collected by dipping a glass jar attached to the end of an aluminum pole or from a submersible pump deployed from a boom amidships of the boat. Samples were stored under refrigeration at SCCWRP and tested within 48 hours.

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 containing no measurable runoff, located up to 6 km offshore.

Four stations offshore of each creek mouth were targeted for post-storm sediment chemistry, toxicity, and infauna measurements (Figure 1). All eight stations were located at roughly 25 m, a depth indicated by a pre-season spatial survey to show strong gradients of change across the area of stormwater influence (Bay and Schiff 1997). One additional sediment sample at each site was collected for sediment toxicity and chemistry following the February storm.

Sediments were collected using a 0.1 m^2 modified Van Veen grab. For contaminant analysis, only surficial sediments (top 2 cm) from undisturbed, representative grabs were collected. Sediment samples were placed in separate containers for grain size, TOC/TN, trace organics, and metals analyses. 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 1.0 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 minutes the sample was fixed with 10% borax buffered formalin and returned to the laboratory. After 24 hours, samples were rinsed with freshwater to remove formalin and preserved in 70% ethanol.

Analytical Chemistry

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

Total Organic Carbon, Total Nitrogen and Total Volatile Solids Analysis. Total organic carbon and total nitrogen (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 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. 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 (Thompson *et al.* 1993).

Metal Analysis. Samples were prepared for metal analysis (aluminum, antimony, arsenic, beryllium, cadmium, chromium, copper, iron, lead, mercury, nickel, selenium, silver, and zinc) in accordance with EPA Method 3051 (EPA 1996). Dried sediment samples were digested using a nitric acid:hydrochloric acid mixture. Metal concentrations 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 (PCB). Analytical methods for chlorinated pesticides and polychlorinated biphenyls followed EPA protocols (EPA 1986 or EPA 1983). Six DDT isomers and metabolites (o,p'-DDT, p,p'-DDT, o,p'-DDD, p,p'-DDD, o,p'-DDE, p,p'-DDE) 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, 209) were quantified. Samples were also examined for twelve 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 analyses can be found in SCCWRP (1994b) 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 sediment extraction by methylene chloride, the extracts 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 x 0.25 mm ID (0.25 μm film thickness) DB-5 fused silica capillary column and a ^{63}Ni electron capture detector (GC-ECD) for analyte measurement.

Polynuclear Aromatic Hydrocarbons (PAH). 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 x 0.25 mm ID x 0.25 μm film thickness) and a Hewlett Packard Model 5870 Mass Selective Detector in electron impact ionization mode.

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 resorted by another person to detect missed organisms. If sorting efficiency was less than 95%, then the entire sample was resorted. 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 Southern California Bight (SCAMIT 1996). Species level identifications were assigned by scientists who were experts in their 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 which is 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, 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 minutes. 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 tested 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 also at the end of the 10-day amphipod survival test. Electronic thermometers were used to measure water temperature continuously during 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 minute exposure of sperm to the samples at 15 °C. Eggs were then added and given 20 minutes 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.

Amphipod Survival. The toxicity of sediment samples was assessed by measuring the survival of amphipods following a 10 day exposure period. Test methods followed standard guidelines (ASTM 1991). A one liter sediment sample was removed from storage and homogenized with a 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 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 counted to determine the percent survival. Reburial success was not determined.

RESULTS

Surface Water Toxicity

Toxicity was present in surface water samples collected near the mouth of Ballona Creek during three of the four sampling events. No toxicity was detected in water samples collected one day following the January 21 storm. Water samples from this event contained less than 4% runoff, below the concentration range of Ballona Creek runoff (>6 %) shown to produce toxicity in related studies (Bay et al. 1997). The relatively small amount of runoff present in the January 22 samples may have been due to a delay in collection following the storm.

A map of the results for water samples collected following the January 31 and February 19-21 storms shows that toxicity was usually present near the mouth of Ballona Creek. Toxic water samples were restricted to a relatively small area (≤1 km offshore of Ballona Creek) following the January 31 (Figure 2) and March 4 storms (Bay and Schiff 1997). A greater area of toxicity appeared to be present on February 21, with toxic water present up to 4 km from the mouth of Ballona Creek. No toxicity was detected in water samples collected near the mouth of Malibu Lagoon in January and March. Toxicity was not expected in the Malibu samples, since all samples from the area contained less than 2% runoff. Too few samples were collected to examine the longshore distribution of toxic surface water.

The magnitude of toxicity was proportional to the amount of Ballona Creek runoff present in the sample (Figure 3). This relationship was also similar to the dose response pattern measured for Ballona Creek stormwater samples collected during the same storm (Figure 3).

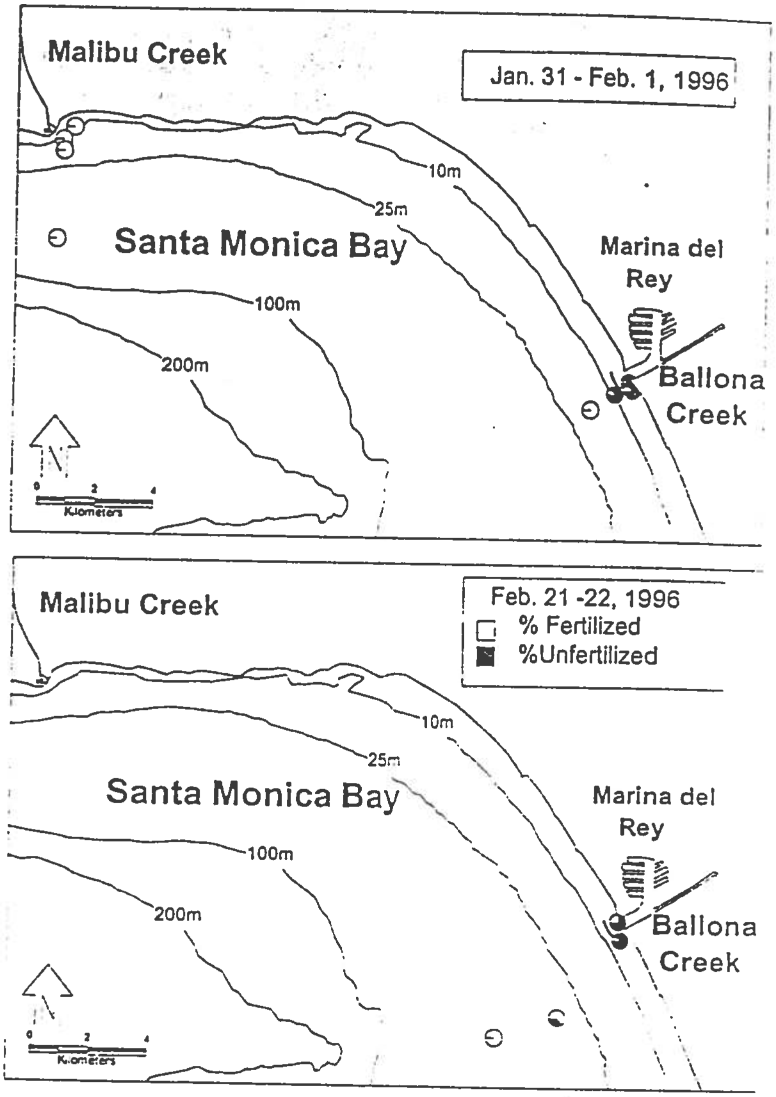


Figure 2. Surface water toxicity results for stations sampled after two storms. Pie diagrams show results of sea urchin fertilization test.

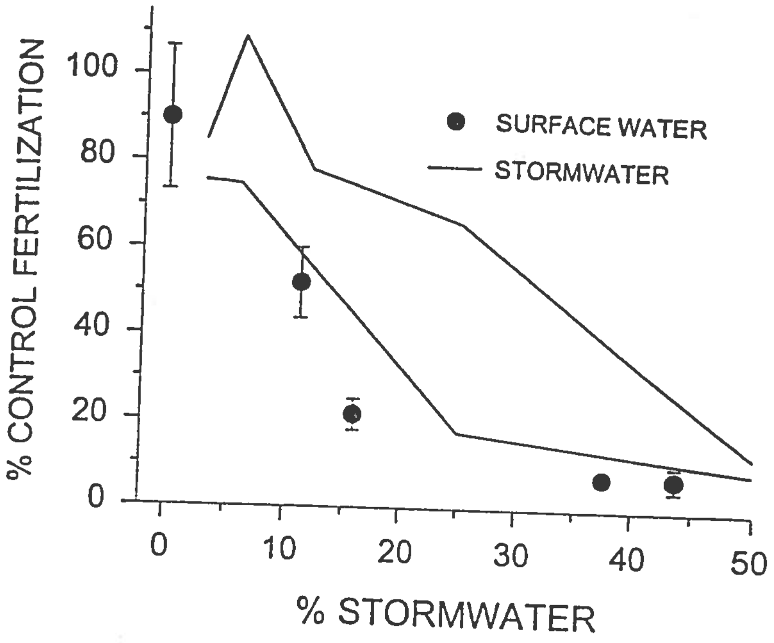


Figure 3. Comparison of sea urchin fertilization test results for February 21-22, 1996 samples of Ballona Creek stormwater (upstream) and nearby surface water (mean and standard deviation). Stormwater dose response lines are for two samples that represent the range of toxicity measured during the storm (Bay *et al.* 1997). All values have been normalized to the control response.

Effects on Sediment

Sediment Concentrations. The analytical results from the four sets of post-storm sediment samples were used to determine the wet season average concentrations of sediment characteristics and contaminants directly offshore the mouths of Ballona and Malibu Creeks. Sediments sampled at Malibu Creek contained twice the fines, 50% more TOC, and 25% greater TN than Ballona Creek (Table 1). Of the 14 different inorganic/metal constituents, seven were substantially greater in sediments offshore of Malibu Creek (Al, Be, Cd, Cr, Fe, Ni, Se), three were substantially greater in sediments offshore of Ballona Creek

(Pb, Hg, Ag), and the remaining three constituents were roughly similar in the sediments offshore of the two drainages (As, Cu, Zn). Ballona Creek was significantly greater in sediment concentrations of total DDT, total PCB, and total PAH than Malibu Creek.

Table 1. Mean (± 95% confidence intervals) sediment characteristics and pollutant concentrations offshore a highly urbanized (Ballona Ck) and less urbanized (Malibu Ck) watershed. Sediment samples were taken directly offshore each creek mouth at roughly 25 m depth following storm events.

	Ballona Creek (n=4)		Malibu Creek (n=3)	
	Mean	95% CI	Mean	95% CI
General Characteristics (% dry wt)				
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 (ug/dry g)				
Aluminum	14075	258	21500	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	15575	123	22933	2103
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

Gradients of Stormwater Influence. Sediment characteristics offshore of Ballona Creek followed a distinct pattern across the gradient of stormwater influence (Figure 4). The proportion of sedimentary fine-grained materials (silt + clay) was greatest directly offshore the creek mouth and declined both upcoast and downcoast. Grain size was significantly higher directly offshore Ballona Creek (31% fines) relative to sediments 4 km upcoast (19% fines). Similarly, a spatial pattern in sediment TOC and TN content was associated with Ballona Creek discharges. Sediment organic carbon content doubled directly offshore Ballona Creek (0.66% TOC) compared to sediments 4 km upcoast (0.30% TOC).

The spatial pattern in sediment characteristics offshore Malibu Creek was less distinct than at Ballona Creek, but was still discernible (Figure 4). Fine-grained sediments at 25 m depth directly offshore the creek mouth were 15% greater than in sediments collected at similar depths 4 km upcoast. In general, background conditions at Malibu Creek, as indicated by sediment characteristics such as grain size, were substantially different compared to background conditions offshore Ballona Creek.

Inorganic contaminants offshore of Ballona Creek followed a pattern across the gradient of stormwater influence which was similar to the pattern observed in sediment characteristics. Stormwater associated metals such as lead, copper, and zinc were significantly higher in sediments sampled directly offshore of the creek mouth and concentrations declined both 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 Ballona Creek mouth.

The pattern of inorganic sediment contamination across the gradient of stormwater influence offshore Malibu Creek was small or non-existent compared to the patterns observed offshore Ballona Creek (Figure 4). As with the sediment characteristics, where patterns did exist the magnitude of changes were smaller than at Ballona Creek. 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. Average metal concentrations were highest in sediments sampled 2 to 4 km downcoast from the Malibu Creek mouth.

Organic contaminants offshore of Ballona Creek followed a distinct pattern across the gradient of stormwater influence (Figure 4). Total DDT, total PCB, and total PAH were highest in sediments directly offshore of the creek mouth and concentrations declined both upcoast and downcoast. Wet season averages at distant stations 4 km upcoast were between 6% (for total PAH) and 41% (for total DDT) of average concentrations directly offshore of Ballona Creek mouth.

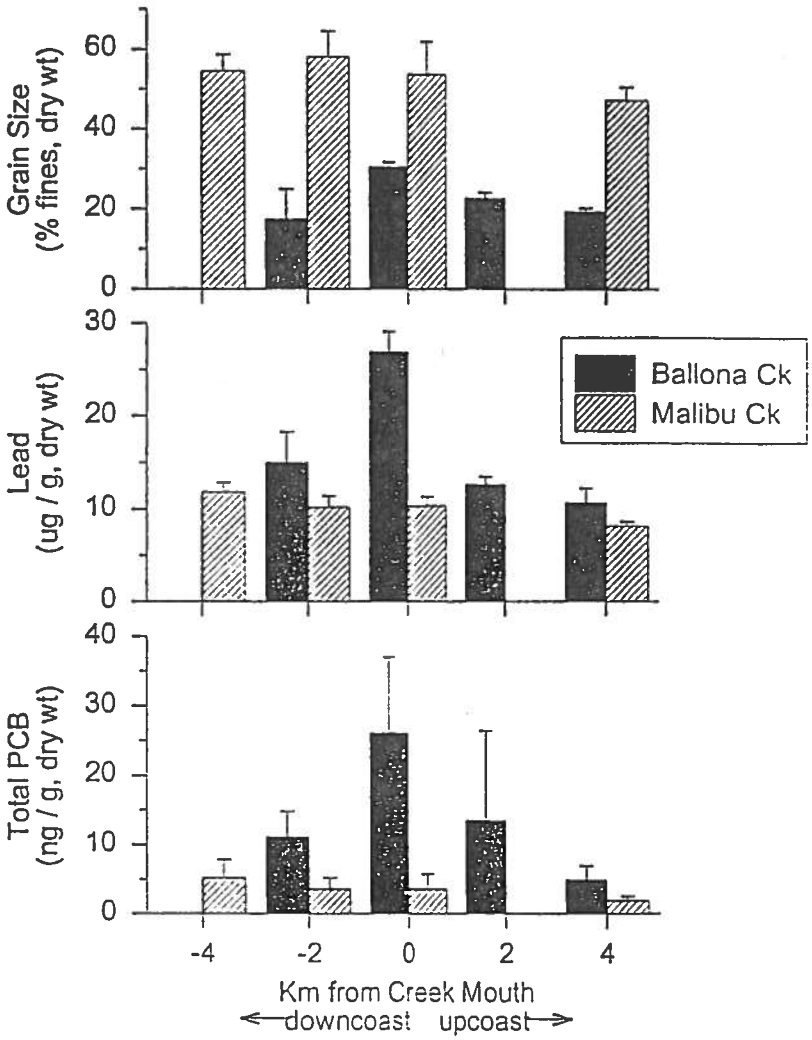


Figure 4. Grain size, lead, and total PCB concentrations in surficial sediments offshore of Ballona and Malibu Creeks. Values are mean (+95% CI) of 3-4 storms during the 1995-96 wet season. Distance from creek mouth refers to the upcoast (+) or downcoast (-) direction at a depth of 25 m.

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

Toxicity. Amphipod survival was high (89-98%) and indicative of no toxicity in all sediment samples (Table 2). 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 analyses. These ammonia concentrations were not toxic and were within the range typically found in sediment toxicity tests.

Interstitial water from nine of ten sediment samples was nontoxic to sea urchin sperm (Table 2). Only interstitial water from the Ballona Creek station located 6 km upcoast was toxic, reducing fertilization by about 60% (relative to the control).

Table 2. Summary of toxicity test results for whole sediment (amphipod survival) and interstitial water (sea urchin fertilization). Sediment samples were collected February 28, 1996. Distances refer to the upcoast (+) or downcoast (-) direction at a depth of 25 m.

	Amphipod survival		Sea urchin fertilization	
Distance from creek (km)	% Survival mean (SD)	Ammonia[a] (mg/L)	% 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

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 3). Abundance was slightly reduced offshore of Ballona Creek relative to Malibu Creek.

Table 3. Summary of infaunal results for the 1995-96 wet season. Distances refer to the upcoast (+) or downcoast (-) direction at a depth of 25 m.

Distance from creek mouth (km)	Mean (95% Confidence Interval)			
	Abundance [a]	Species Richness	Diversity [b]	Eveness [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

Examination of trends across the gradient of stormwater influence did not reveal any significant relationships to stormwater discharges (Table 3). Instead, mean abundance decreased moving upcoast offshore 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, but the station 2 km downcoast showed high variability. Diversity and eveness measures showed no strong trends between stations.

DISCUSSION

Results from the first year of this study, though preliminary, have already helped address several important questions regarding runoff effects in receiving waters. Stormwater runoff in Southern California is extremely variable between storms and years. We cannot be sure that the patterns or magnitudes of effects discussed below are representative without conducting similar measurements over a longer time span, as planned for the subsequent years of this study.

- **Do stormwater discharge plumes contain toxic materials?**

The results indicate that surface water toxicity in the Ballona Creek area may occur when discharge plumes contain greater than about 10% runoff. Malibu Creek discharge plumes did not contain toxic concentrations of runoff, primarily because of greater dilution. Differences in runoff concentrations in the surface water samples prevent a direct comparison of the results for Malibu and Ballona plumes. Less concentrated runoff plumes off Malibu are probably the result of several factors, including much lower flow rates (up to two orders of magnitude difference) due to the more permeable watershed and additional dispersion resulting from delays in obtaining samples from the Malibu area.

The surface water toxicity results are consistent with tests of stormwater (sampled upstream of the creek mouth) conducted as part of a project funded by the Santa Monica Bay Restoration Project (Bay *et al.* 1997). Toxicity of Malibu Creek stormwater is usually less than similar samples from Ballona Creek, with concentrations of $\geq 25\%$ usually needed to produce toxic effects. Extending these results to surface waters, it is likely that less toxicity will be present offshore of Malibu Creek.

- **Do stormwater discharges produce long-lasting alterations in Santa Monica Bay sediments?**

Discharges from Ballona and Malibu Creeks appeared to alter the general characteristics (e.g. grain size and organic content) of offshore sediments. The spatial pattern of altered sediment characteristics was persistent (present in dry weather) and could be observed at least 2 km distant. Some alterations in sediment characteristics were observed at depths of 40 m, but were not seen in depths of less than 10 m (Bay and Schiff 1997). These changes are not unexpected sine the combined loads of suspended solids from these two channels were estimated to be greater than 21 x 10^3 mt during the 1994-95 water year (LACDPW 1996). Moreover, these results are consistent with other studies which observed increases in sediment fines at distances ≥ 2 km offshore of the Santa Clara River following large winter storms (Kolpack and Drake 1985).

Runoff from urbanized watersheds appear to have some effect on the receiving water benthic environment. 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, compared to sediments offshore of the less urbanized Malibu Creek watershed. 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. Similarly, other researchers have shown that runoff from watersheds with as little as 15 to 25% urbanized land use(i.e. imperviouseness) have altered freshwater ecosystems (Yoder and Rankin 1996, Schueler 1994).

It is unlikely that the changes in sediment contaminants measured near Ballona and Malibu Creeks represent most of the many tons of contaminants entering Santa Monica Bay from stormwater each year. More research is needed to define the range of influence and eventual deposition of storm discharged particles in Santa Monica Bay. This work is continuing at SCCWRP, and is part of the effort being conducted with our collaborators at USC and UCSB.

- **Is sediment toxicity affected?**

Results from the sediment toxicity tests indicate that the altered sediment characteristics and increased contaminants resulting from stormwater discharge did not result in increased sediment toxicity. Amphipod survival was not reduced by exposure to sediment 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 10-200 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 always provide a highly sensitive measure of sediment toxicity. Recent amphipod survival tests on much more 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 day 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 Southern California sediments that did not affect amphipod survival (SCCWRP 1995b and 1996). The sea urchin fertilization test of interstitial water did detect toxicity in one sample at the northern end of the Ballona Creek study area. Sediment chemistry results indicate that this station is outside the area most influenced by the Creek (Figure 4). As interstitial water toxicity did not correspond to variations in sediment contamination, it is unlikely that the toxicity was related to Ballona Creek stormwater. 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. There were no indications of a strongly degraded environment. Differences in community composition between sites offshore of the two creeks were most likely a result of variations in sediment characteristics (e.g., grain size) rather than differences in sediment-associated contaminants.

Due to relatively small sample sizes (n ≤ 4), it is premature to reach conclusions regarding community disturbance at this time. However, these preliminary results are similar to previous surveys of reference areas which have reported 273-358 individuals and 78-91 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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