Bull. Southern California Acad. Sci.
95(1), 1996, pp. 33–45

Toxicity of Dry Weather Flow from the Santa Monica Bay Watershed

Steven M. Bay*, Darrin J. Greenstein

Southern California Coastal Water Research Project, 7171 Fenwick Lane, Westminster, CA 92683

Sim-Lin Lau, Michael K. Stenstrom

Department of Civil and Environmental Engineering, University of California, Los Angeles, CA 90024

Carolyn G. Kelley

Department of Biology, University of California, San Diego, La Jolla, CA. 92093-0364

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

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

---

* Author to whom correspondence should be addressed.

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

Methods

Sampling Locations and Procedures

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

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

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

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

Chemical Analysis

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

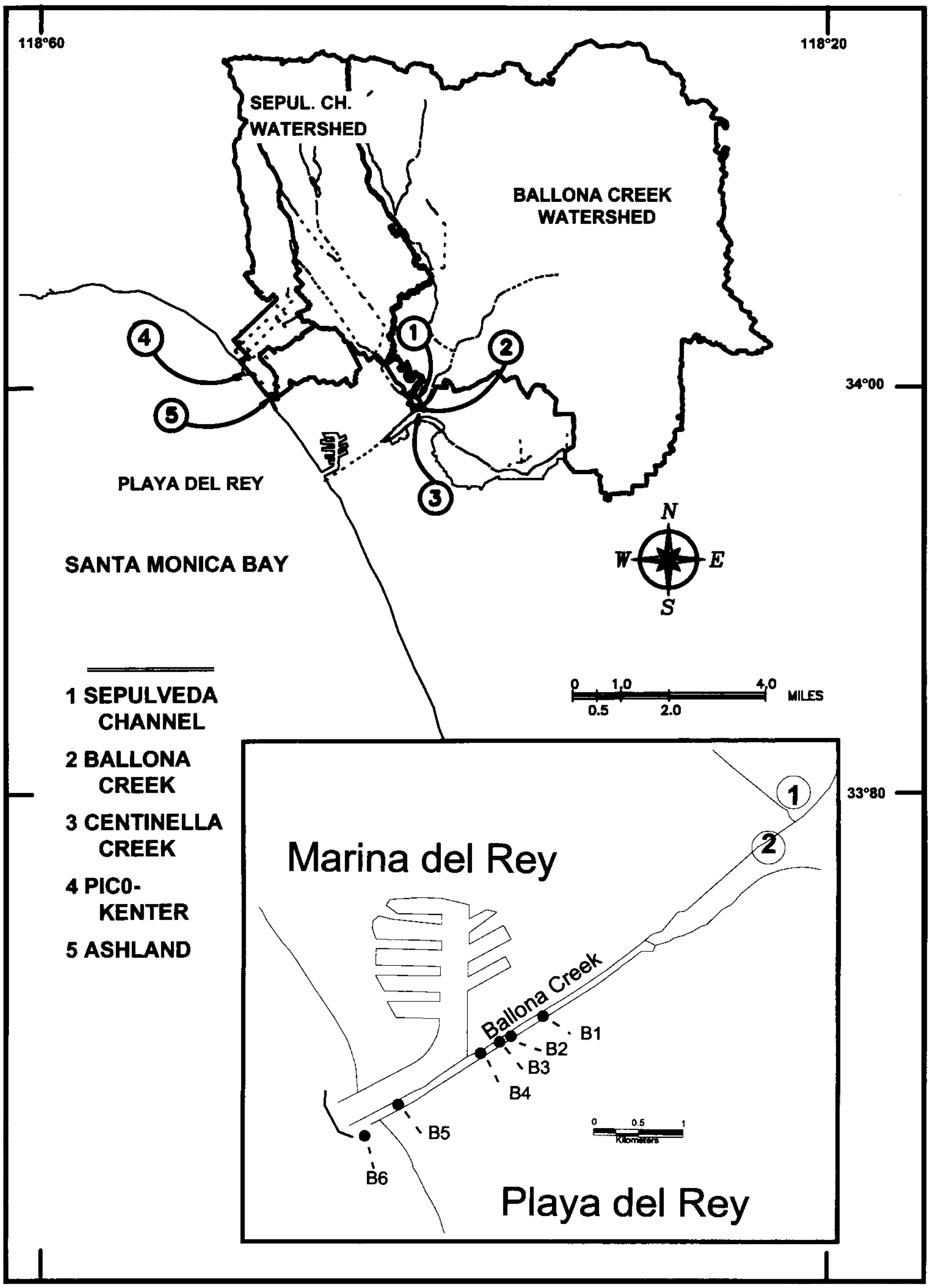

Fig. 1. Location of storm drain sampling sites and watershed boundaries (thick lines). Broken lines indicate larger storm drain channels. Inset shows locations of sampling sites for receiving water (B1–B6), Sepulveda Channel (1) and Ballona Creek (2).

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

Toxicity Assessment

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

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

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

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

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

Toxicity Characterization

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

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

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

[a] Value could not be calculated due to poor test results or unusual dose-response curve.

[b] NOEC can also be stated as >56% since 56% concentration was not significantly different from brine control. A NOEC of 12% is felt to be more appropriate since the 56% brine control was toxic, making the accuracy of the results for 56% sample questionable.

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

Data Analysis

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

Results

Toxicity Patterns

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

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

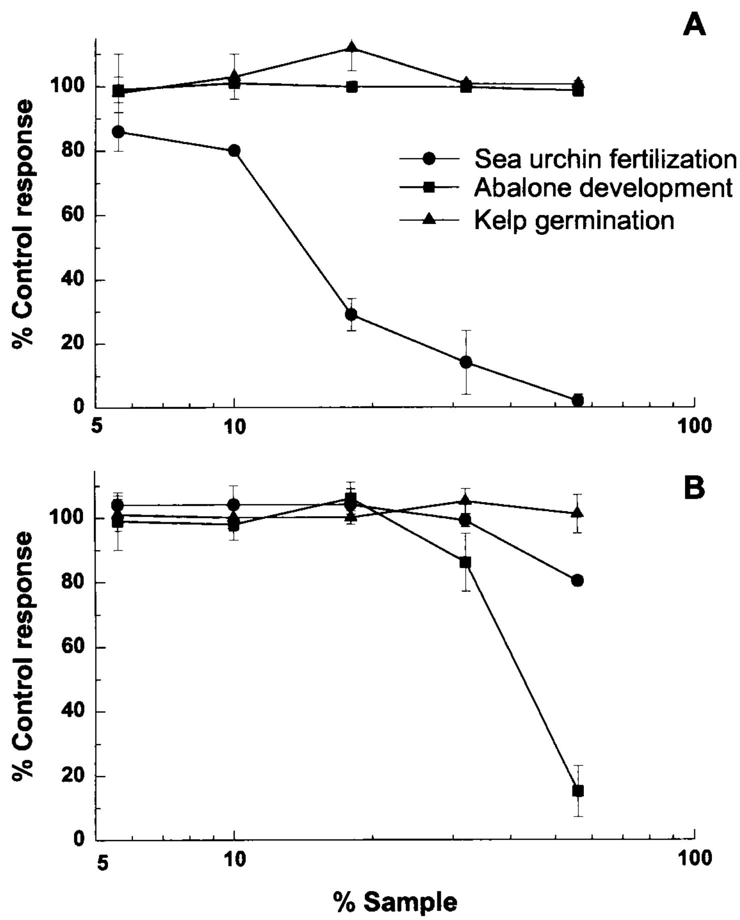

Fig. 2. Toxicity test responses to various concentrations of dry weather storm drain effluent. Test results (mean and standard deviation) have been normalized to the control response. A: Ballona Creek composite sample collected September 8, 1992. B: Pico-Kenter composite sample collected August 24, 1992.

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

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

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

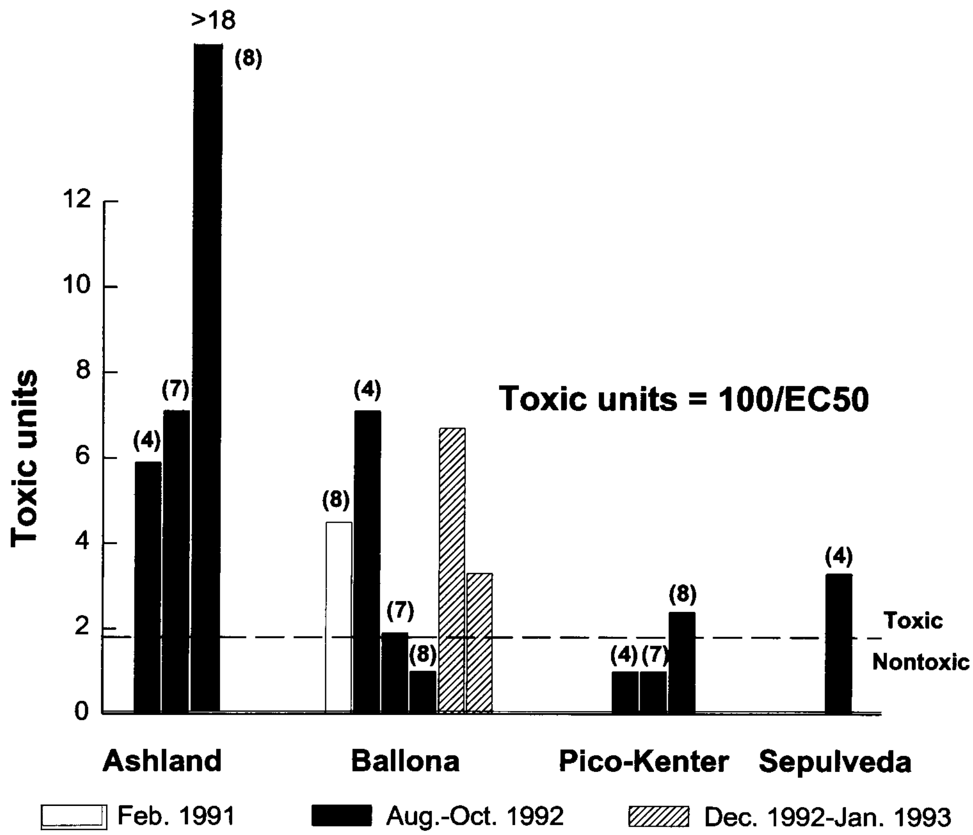

Fig. 3. Variability in sea urchin (*Strongylocentrotus purpuratus*) fertilization test results with time and storm drain location. Results of concurrent reference toxicant (copper) tests for each set of samples are shown in parentheses.

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

General Constituents of Dry Weather Flow

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

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

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

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

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

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

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

Toxic Components

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

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

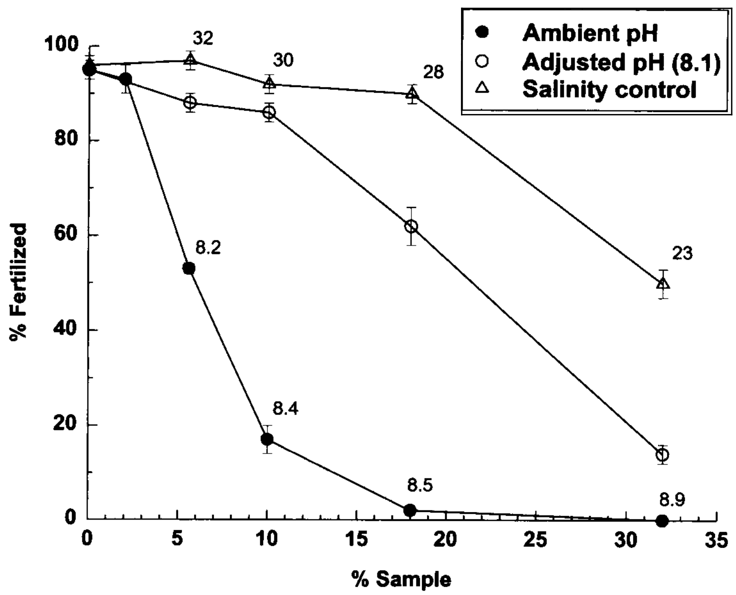

Fig. 4. Effects of reduced salinity and pH adjustment of a February 1991 Ballona Creek sample on sea urchin (*Strongylocentrotus purpuratus*) fertilization. Measured salinity and pH for selected treatments are indicated above the symbols.

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

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

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

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

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

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

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

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

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

Receiving Water Toxicity

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

Discussion

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

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

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

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

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

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

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

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

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

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

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

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

Conclusions

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

Acknowledgments

The authors are grateful to the staffs of the Santa Monica Bay Restoration Project and Los Angeles Regional Water Quality Control Board, especially Dr. Guang-yu Wang, Ms. Catherine Tyrell, Dr. Rainer Hoeinke, and Mr. Xavier Swamikannu, for their assistance. The Los Angeles County Department of Public Works and the City of Santa Monica were helpful in permitting the sampling. The authors also wish to thank Jeff Brown, Andrew Jirik, and Valerie Raco of SCCWRP for assistance with toxicity tests. Portions of this research were funded by grants from the Santa Monica Bay Restoration Project and the National Science Foundation Young Scholars Program.

Literature Cited

American Public Health Association. 1989. Standard methods for the examination of water and wastewater, 17th edition. American Public Health Association, Washington, D.C.

Anderson, B. S., J. W. Hunt, S. L. Turpen, A. R. Coulon, M. Martin, D. L. McKeown, and F. L. Palmer. 1990. Procedures manual for conducting toxicity tests developed by the Marine Bioassay Project. California State Water Resources Control Board Report No. 90-10WQ.

APHA see American Public Health Association.

Bailey, H. C., J. L. Miller, M. J. Miller, and B. S. Dhaliwal. 1995. Application of toxicity identification procedures to the echinoderm fertilization assay to identify toxicity in a municipal effluent. Environ. Toxicol. Chem., 14:2181–2186.

Dinnel, P. A., J. M. Link, and Q. J. Stober. 1987. Improved methodology for a sea urchin sperm cell bioassay for marine waters. Arch. Environ. Contam. Toxicol., 16:23–32.

LAC see Los Angeles County.

Lau, S.-L., M. K. Stenstrom, and S. Bay. 1994. Assessment of storm drain sources of contaminants to Santa Monica Bay, volume V: Toxicity of dry weather urban runoff. Department of Civil and Environmental Engineering, University of California, Los Angeles, CA.

Los Angeles County, Department of Public Works. 1985. Plan for Flood Control and Water Conservation, maps 2, 3, 7, 16, and 17. LAC, DPW, Los Angeles, CA.

National Research Council, Committee on Ocean Waste Transportation. 1984. Wastewater characteristics. Chapter 2 *in* Ocean disposal systems for sewage sludge and effluent. Natl. Acad. Press.

Norberg-King, T. J., D. I. Mount, J. R. Amato, D. A. Jensen, and J. A. Thompson. 1992. Toxicity Identification Evaluation: Characterization of Chronically Toxic Effluents, Phase I. EPA/600/6-91/005F. Office of Research and Development, U.S. Environmental Protection Agency, Duluth, MN.

NRC see National Research Council.

Santa Monica Bay Restoration Project. 1994. Characterization Study of the Santa Monica Bay Restoration Plan. Santa Monica Bay Restoration Project, Monterey Park, CA.

SCCWRP see Southern California Coastal Water Research Project.

SMBRP see Santa Monica Bay Restoration Project.

Southern California Coastal Water Research Project. 1989. Toxicity of stormwater runoff in Los Angeles County. Pp. 66–71 *in* Southern California Coastal Water Research Project Annual Report 1988–89. SCCWRP, Long Beach, CA.

———. 1990a. Characteristics of effluents from large municipal wastewater treatment plants in 1989. Pp. 8–15 *in* Southern California Coastal Water Research Project Annual Report 1989–90. SCCWRP, Long Beach, CA.

———. 1990b. Characteristics of effluents from small municipal wastewater treatment plants, electrical generating stations, and industrial facilities in 1989. Pp. 16–24 *in* Southern California Coastal Water Research Project Annual Report 1989–90. SCCWRP, Long Beach, CA.

———. 1990c. Mass emission estimates for selected constituents from the Los Angeles River. Pp. 25–34 *in* Southern California Coastal Water Research Project Annual Report 1989–90. SCCWRP, Long Beach, CA.

———. 1994. Toxicity of sediments on the Palos Verdes Shelf. Pp. 79–90 *in* Southern California Coastal Water Research Project Annual Report 1993–94. SCCWRP, Westminster, CA.

State Water Resources Control Board. 1990. Water Quality Control Plan, Ocean Waters of California. State Water Resources Control Board, Sacramento, CA.

Suffet, I. H., J. Froines, E. Ruth, L. Schweitzer, and M. Capangpangan. 1993. Chemical Contaminant Release Into the Santa Monica Bay: A Pilot Study. School of Public Health, University of California, Los Angeles, CA.

SWRCB see State Water Resources Control Board.

UCLA see University of California, Los Angeles.

University of California, Los Angeles and Woodward-Clyde Consultants. 1992. Annual pollutant loadings to Santa Monica Bay from storm water runoff. Prepared for Santa Monica Bay Restoration Project., Monterey Park, CA, by UCLA, Los Angeles, CA. 109 pp.

Zar, J. H. 1984. Biostatistical analysis, second edition. Prentice Hall, Inc.