Characterization and source identification of dry-weather metals and bacteria in Ballona Creek

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ABSTRACT - Dry-season urban runoff from watersheds in arid regions can contribute substantial concentrations and loads of bacteria and metals to downstream receiving waters. Identifying the relative contribution of different sources is an important step in managing dry-season runoff that has not been completed in most of southern California's urban watersheds. The goal of this study was to identify the relative contribution of various storm drain sources to the total dry-season loading of metals and bacteria in the Ballona Creek watershed. Approximately 40 actively flowing storm drains and 12 in-river sites were sampled three times during the spring and summer of 2003 for flow, total and dissolved metals, and bacteria. These data were analyzed in terms of mean concentration and load, temporal variability, and spatial distribution of substantial inputs to the creek. In general, Ballona Creek exhibited a bimodal distribution of elevated metals and bacteria, with the highest levels occurring between 3 km and 6 km immediately upstream of the tidal portion of the creek, and between 9 km and 12 km below the portion of the watershed where Ballona Creek daylights from an underground storm drain to an exposed channel. These two portions of Ballona Creek correspond to locations where storm drains with consistently high concentrations and loads discharge to the creek. Of the 40 drains sampled, 4 account for 85% of the daily storm drain volume. Between 91% and 93% of the total daily load for metals is contributed by eight drains. Nine drains consistently have the highest concentrations of metals and bacteria. Metals concentrations may vary by five-fold and bacteria concentrations may vary by up to five orders of magnitude on an intra- and inter-annual basis. However, despite this variability, managing a relatively small number of storm drain inputs has the potential to result in substantial improvement in water quality in Ballona Creek.

INTRODUCTION

Increased urbanization has been shown to result in increased runoff and pollutant loading to receiving waters (U.S. EPA 1995, Schueler and Holland 2000, Davis *et al.* 2001). The high amounts of impervious surfaces associated with urban landscapes result in increased magnitude and frequency of surface runoff during wet-season and dry-weather conditions (Roesner and Bledsoe 2003). The accumulation of toxic compounds, such as heavy and trace metals, from urban runoff can result in downstream bioaccumulation and toxicity (Schueler and Holland 2000). Similarly, bacterial loading to streams in urban areas has been well documented as one of the most common pollutants affecting aquatic systems (Porcella and Sorenson 1980, Simpson *et al.* 2002).

Over the past 10 years, management of urban runoff has focused primarily on the evaluation and control of stormwater. However, recent studies have shown that dry-season runoff can be a significant contributor to total annual load (Piechota and Bowland 2001, McPherson *et al.* 2002, Ackerman *et al.* 2003, Stein *et al.* 2003)—particularly in arid environments where dry season stream flow is comprised mainly of urban runoff and other effluent. The distinction between wet- and dry-season pollutant loading characteristics is important because management strategies differ for these two sources. For example, stormwater management typically focuses on retention or detention, whereas dry-season runoff control focuses on treatment, diversion, infiltration, and source control.

Management strategies for dry-weather pollutant loading such as diversion, treatment, and source control rely on an understanding of the specific sources or locations in the watershed that contribute the greatest proportional loading. Source identification can be particularly problematic in urban watersheds that are dominated by non-point source runoff. In contrast to watersheds where wastewater or industrial effluent comprises a significant source that can be managed, watersheds dominated by urban runoff have many sources of different sizes distributed throughout the watershed. Understanding the relative contribution of these sources to receiving water loading is critical to efficient allocation of source control strategies.

The Ballona Creek watershed in the greater Los Angeles, California, area provides an optimum environment for conducting a source identification study. The watershed is approximately 80% urbanized, and there are no permitted discharges of treated wastewater to the creek. Consequently, almost all the dry-season flow in Ballona Creek results from nuisance runoff from urban surfaces. Routine monitoring of dry-weather flow by the City of Los Angeles in 2001 and 2002 showed detectable levels of arsenic, cadmium, chromium, copper, nickel, zinc, and lead with concentrations of cadmium, copper, nickel, zinc, and lead exceeding State water quality criteria on at least an occasional basis. McPherson *et al.* (2002) characterized long-term wet and dry-weather flow and loading from the Ballona Creek Watershed and determined that between 10% and 30% of annual runoff volume and between 8% and 42% of the total annual load of trace metals occur during the dry season. This translates to between 100 and 500 kg/yr of dry-season loading for most metals. Suffet and Stenstrom (1999) also found elevated concentrations of certain volatile organic carbon (VOC) in dry-season runoff from Centinela Creek (a tributary to Ballona Creek). Although previous studies have documented dry-weather concentrations and loads within Ballona Creek, none have investigated contributions from storm drains draining various portions of the watershed.

The goal of this study was to investigate spatial patterns of dry-season metals and bacteria concentration and load in Ballona Creek and to link these patterns with storm drain inputs that contribute to in-river loads. The second goal of this project was to characterize the temporal variability in sources and in receiving water quality.

Methods

Study Area

Ballona Creek drains a watershed of about 329 square kilometers (km^2). The watershed boundary is shown in Figure 1 and includes the Santa Monica Mountains on the north and the cities of Baldwin Hills and Inglewood on the south. The western boundary is approximately 1.6 km inland from the Pacific Ocean and extends from the Santa Monica Mountains southward to Venice and eastward to Baldwin Hills. The eastern boundary extends from the crest of the Santa Monica Mountains southward and westward to the vicinity of central Los Angeles and then to Baldwin Hills. Tributaries of Ballona Creek include Centinela Creek, Sepulveda Canyon Channel, Benedict Canyon Channel, and numerous other storm drains.

Land use within the watershed consists of residential, commercial, industrial, public, and other urban usages. There are some areas of undeveloped land in the Santa Monica Mountains on the north side of the watershed and a section along the east side of Ballona Creek near the Pacific Ocean. All other areas are typically urbanized. There are no permitted wastewater or consistent industrial discharges to Ballona Creek (with the exception of discharges associated with construction, cleanup, and dewatering activities). All dry-season inputs consist of nuisance runoff from developed surfaces that are conveyed to Ballona Creek via storm drains and ultimately discharged to Santa Monica Bay, which is adjacent to Marina del Rey. Elevated levels of metals, bacteria, and organic pollutants in lower Ballona Creek and Marina del Rey have resulted in these water bodies being listed as impaired under Section 303(d) of the Clean Water Act, and subject to promulgation of Total Maximum Daily Loadings (TMDLs).

Sampling

Storm drain inputs and in-river waters were sampled along the entire 12.7 km of Ballona Creek. Sampling was conducted on May 17, July 16, and September 24, 2003. The last rain prior to the May 17 sampling occurred on May 3 (3.3 cm), and no measurable rain fell between the May and September sampling events. Each event sampled the same location and sampling was conducted in the morning to minimize the effects of diurnal variability.

Approximately 90 storm drains and 12 in-river sites were identified and located for potential sampling using a Garmin® handheld global positioning system (GPS). Of these, all 12 in-river sites and between 35 and 40 storm drains were sampled during each sampling event. The remaining drains lacked sufficient flow to sample or were inaccessi-

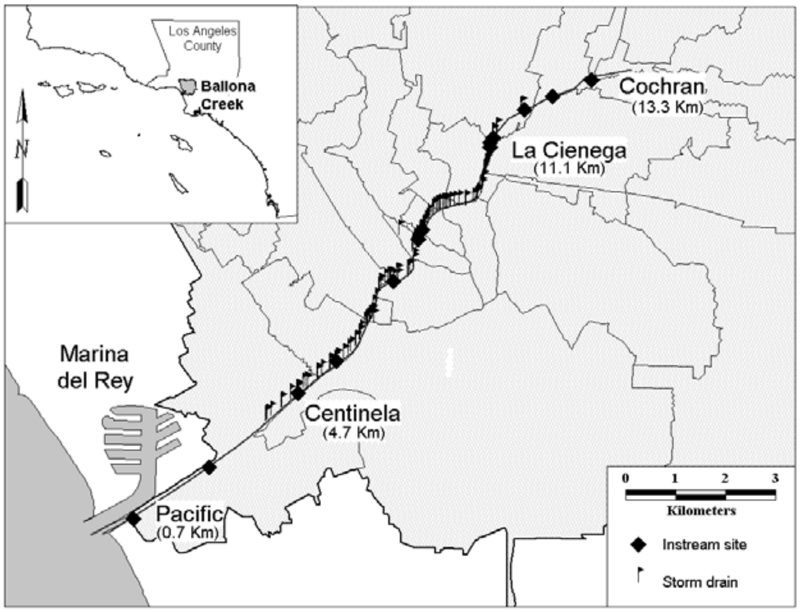

Figure 1. Map of the Ballona Creek watershed. Map showing storm drain and in-river sampling locations in Ballona Creek sampled during the 2003 dry season.

ble. The 35 to 40 drains sampled spanned the entire above-ground portion of Ballona Creek. At each storm drain sampled, flow was measured using a timed-volumetric or depth-velocity method. In-river flow was measured at each site using a Marsh-McBirney Model 2000® flow meter. Flow was measured at three points across the channel cross-section and integrated to estimate overall flow at each site.

Water quality samples were collected from storm drains and in-river sites, and immediately placed on ice for subsequent analysis. Storm drains samples were collected by directly filling a single bottle from each drain. At the in-river locations, three composite samples were collected at 20-min intervals. Each composite consisted of three grab samples collected at approximately equal intervals across the channel cross-section. Water samples were analyzed for metals (total and dissolved) and bacteria following protocols approved by the U.S. EPA (1983) and Standard Methods (APHA 2000). Metals were analyzed using inductively coupled plasma (ICP) methods and bacteria were analyzed using the Idexx QuantiTray® method using the detection limits shown in Table 1. Sampling locations are referenced by their distance in kilometers upstream of the mouth of Ballona Creek.

Data Analysis

Results of the flow and water quality sampling were analyzed for spatial and temporal patterns. Means and ranges of flow and concentration for storm drains and in-river sites were analyzed by individual sampling date and by combining the results of all three sampling dates. Constituent loads for storm drain and in-river sites were calculated by multiplying flow times concentration for each sample:

$$Load = \sum F_i C_i$$

where Fi was the flow at sampling location i and Ci was the constituent concentration at location i. When multiple samples were averaged, results are presented as means ±1 standard deviation. Differences between sampling events were investigated using a one-way analysis of variance (ANOVA), with $p<0.05$ significance level (Sokal and Rohlf, 1969). In all cases, non-detectable results were assigned a value of zero. For bacteria, results that were greater than the maximum quantifiable levels were assigned the maximum value for that test.

Results

Flow

Average in-stream flow in Ballona Creek was 0.34±0.17 cms during the May and September sampling event and 0.73±0.17 cms during the July sampling event. Flow generally increased from upstream to downstream until Centinela Boulvard, where tidal influence begins (approximately 5 km upstream from the mouth of the creek). Substantial tributary inflows occur at Sepulveda Channel (5.8 km) and upstream of Overland (7.7 km).

Preliminary surveys identified approximately 90 storm drains that potentially discharge into Ballona Creek. Of these, between 25 and 40 were actively flowing, and were sampled during each sampling event. Of the storm drains sampled, only 21% (9 drains) were flowing above 0.01 cms (Figure 2). Approximately 85% of the 54,000 m^3 /day discharged from flowing storm drains is attributable to the following storm drains: BC17 (Centinela

Table 1. Constituents analyzed.

Constituent	Min. Detection Limit (MDLs)	Units	Analytical Method
Metals (total and dissolved)			
Arsenic	0.4	ug/L	USEPA 200.7
Calcium	0.03	mg/L	
Magnesium	0.004	mg/L	
Cadmium	0.08	ug/L	USEPA 200.7
Chromium	0.7	ug/L	USEPA 200.7
Copper	1.5	ug/L	USEPA 200.7
Iron	24	ug/L	USEPA 200.7
Lead	3.0	ug/L	USEPA 200.7
Nickel	0.24	ug/L	USEPA 200.7
Selenium	1.4	ug/L	USEPA 200.7
Silver	0.26	ug/L	USEPA 200.7
Zinc	2.0	ug/L	USEPA 200.7
Mercury	0.022	ug/L	USEPA 200.7
Hardness		mg/L	SM 2340-B
TSS		mg/L	USEPA 160.2
Bacteria			
Total Coliforms		MPN/100 mL	Idexx QuantiTray
E. coli		MPN/100 mL	Idexx QuantiTray
Enterococcus		MPN/100 mL	Idexx QuantiTray

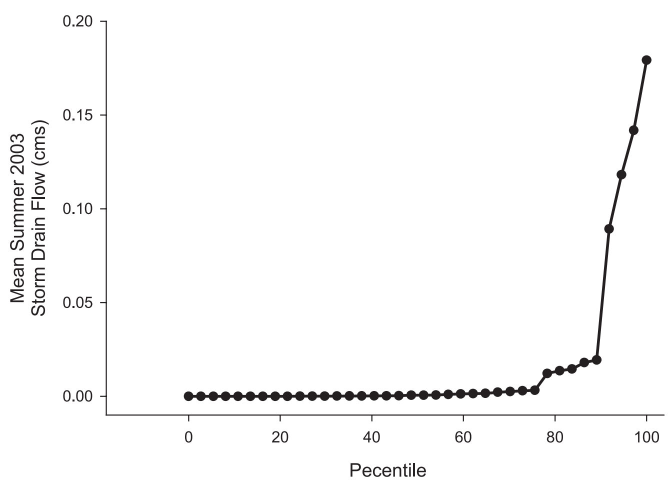

Figure 2. Cumulative distribution curve of mean storm drain flow (cms) in Ballona Creek. Percent of storm drains with mean summer 2003 flow (for all three sampling periods) below a given discharge.

Channel), BC60 (Sepulveda Channel), BC300, and BC310. Variability in storm drain flow, ponding effects, and drain obstructions precluded obtaining flow measurements in every drain during each sampling period.

Metals

Consistent detectable in-river concentrations of copper, iron, lead, nickel, and zinc were observed in Ballona Creek and in the storm drains during all three sampling events (Tables 2 and 3). With the exception of iron (which is primarily a natural earth element), subsequent results and discussion will focus on copper, lead, nickel, and zinc.

In-river metals concentrations varied considerably spatially and temporally. Results of the ANOVA between sampling times indicate that for copper, iron, lead, and zinc, in-river concentrations were significantly higher in July than during the other two sampling events. Results of the May sampling event were generally lower, but the differences between the May and September sampling events were only significant at approximately 30% of the sampling locations. Cadmium and chromium concentrations did not vary between the three sampling events (Table 2). Temporal variability in the storm drain samples was less pronounced than in the in-river samples. Although storm drain metals concentrations in July and May were consistently the highest and lowest, respectively, differences between sampling periods were less than significant.

Spatial patterns in metals concentrations were relatively similar between metals. The highest mean in-river concentrations of copper, zinc, and nickel were observed between 5 km and 6 km, immediately downstream of Sepulveda Channel, which drains a 42 km^2 portion of the watershed (Figure 3). For lead, this peak was obscured due to high concentrations at Pacific Avenue (1 km).

Table 2. Average concentrations of in-river metals for the three individual sampling events. Units are in ug/L. * = concentrations were significantly different that other sampling periods (p<0.05). For the month of May n=29, for July and September n=34.

	May		July		Sept	
Constituent	***Mean***	***SD***	***Mean***	***SD***	***Mean***	***SD***
Cadmium	0.09	0.08	0.02	0.07	0.06	0.18
Chromium	2.42	0.98	1.69	1.29	1.42	0.71
Copper	6.52	2.50	15.46*	9.67	10.07	4.14
Iron	417.28	586.57	1022.94*	1014.45	321.45	354.18
Lead	2.41	1.96	6.07*	3.94	3.47	5.12
Nickel	2.47	1.51	5.12*	4.13	3.90	1.82
Zinc	24.06	8.89	37.44*	18.44	28.05	11.02

Table 3. Average total metals concentrations for all storm drain samples for all sampling events. Units are in ug/L. In all cases n=103.

	Mean	SD	% Non Detects
Arsenic	3.72	2.81	16%
Cadmium	0.13	0.33	75%
Chromium	1.72	1.92	28%
Copper	19.85	28.98	3%
Iron	524.67	1129.41	1%
Lead	4.41	12.66	60%
Nickel	7.32	22.72	3%
Selenium	7.19	12.72	53%
Zinc	83.25	241.18	2%

The September lead concentrations at 1 km were more than double those observed during the other sampling events, resulting in a high mean concentration for this area. A smaller peak in in-river concentrations for copper, lead, nickel, and zinc was observed between 10 km and 11 km, downstream of a large storm drain, BC 250, which drains the eastern 60 km^2 of the watershed. This second peak was most pronounced for copper and zinc (Figure 3).

Of the 35 to 40 storm drains sampled, a relatively small number of drains had high metals concentrations; the locations of these drains roughly correspond to locations of high in-river concentrations. Five storm drains had mean concentrations that were significantly higher ($p<0.05$) than the other drains. Concentrations in all these drains exceeded twice the mean for all storm drains combined for at least one of the four metals of interest (Table 4). Four of these drains (BC 26, 31, 41, and 271) had consistently high concentrations for at least two of the four metals of interest. Three of these drains are located between 4 km and 5 km immediately downstream of the highest in-river metals concentrations, between Sepulveda Channel and Centinela Creek. The fourth drain (BC 271) is located at 11 km upstream of the location of the second in-river peak in metals concentration (Figure 3).

Spatial patterns of in-river metals loads were similar to those observed in the concentration data (Table 5 and Figure 4). Relatively high in-river metals loads were observed between 6 km and 8 km and between 11 and 13 km. In-river metals loads reflected the areas of highest storm drain loading. For all four metals analyzed, high storm drain loads occurred between 10 km and 13 km, at 5.5 km (Sepulveda Channel) and 3.5 km (Centinela Channel). Between 91% and 93% of the total daily storm drain load for each metal was accounted for by between 5 and 7 drains (Table 6). Overall, eight storm drains were responsible for the majority of daily load for all metals analyzed, and two drains (BC17 and BC60) accounted for between 48% and 77% of the total daily storm drain load.

Bacteria

Relatively high bacteria concentrations were observed throughout Ballona Creek and in all storm drains (Tables 7 and 8). Bacteria concentrations exhibited a wide range of variability, as indicated by the large standard deviations on all sample means. Although bacteria concentrations appeared to be slightly higher in July than during the other two sampling events, there were no statistically significant differences between sampling periods for bacteria (Table 8).

Spatial patterns in bacteria concentrations were similar to those observed for the metals. In-river *E. coli* concentrations were highest between 4 km and 5 km (between Sepulveda Channel and Centinela Creek) and between 9 km and 11 km (Figure 5). Enterococcus concentrations were highest between 10 km and 11 km, with a lower peak between 4 km

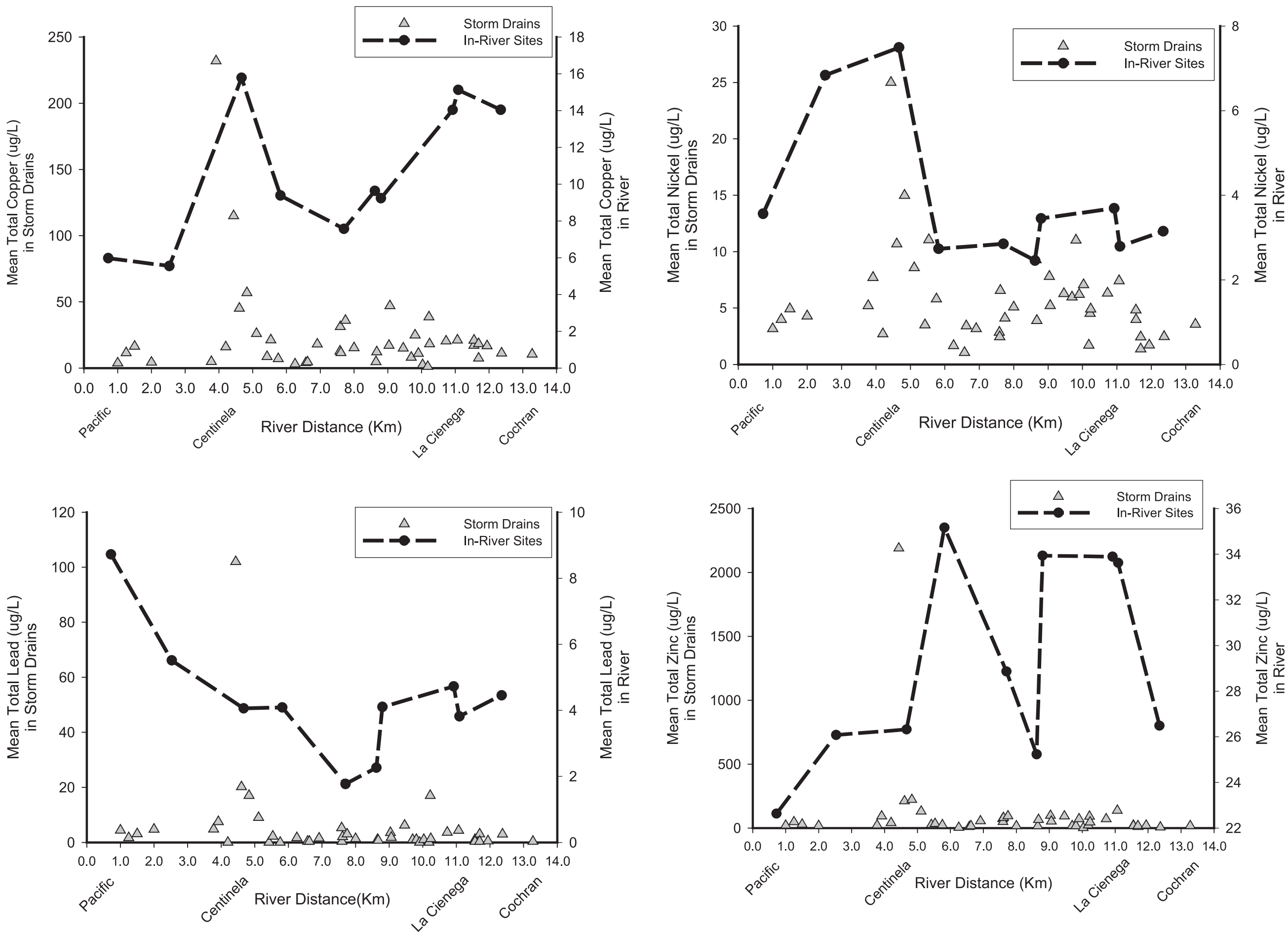

Figure 3. Mean in-river and storm drain metals concentrations. Concentrations of (a) total copper, (b) total lead, (c) total nickel, and (d) total zinc in Ballona Creek during the 2003 dry-season sampling period. Storm drain concentrations are shown on the left axis, in-river concentrations on the right axis.

Table 4. Storm drains with mean metals concentrations that were higher than other drains. + = mean storm drain concentration >= twice the overall mean for all storm drains. ++ = mean storm drain concentration >= five times the overall mean for all storm drains. (*) = concentration was significantly higher than other drains at p<0.05.

	Copper	Lead	Zinc	Nickel
BC 23	++(*)			
BC 26	++(*)	++(*)	++(*)	+(*)
BC 31	+	+(*)	+	
BC 41	+	+	+	+(*)
BC 271		++(*)	++(*)	
Mean ± SD	19.9± 29.0	4.4± 12.7	83.3± 421.2	7.3± 22.7

and 5 km. The spatial pattern of total coliforms concentrations was somewhat random; however, this is likely confounded by the high proportion of samples that exceeded the maximum detection limit, along with the ubiquitous nature of total coliforms.

Of the 35 to 40 storm drains sampled, 9 had consistently high concentrations for *E. coli* or enterococcus and 3 had high concentrations for both bacterial indicators (Table 9). Only 2 of these drains (BC 26 and BC 271) also had high metals concentrations. For *E. coli*, 2 of the drains with high concentrations were between 4 km and 5 km, while the other one was at 8 km (Figure 5). For enterococcus, the high storm drain concentrations were relatively evenly distributed between 4 km and 12 km and did not necessarily correspond to the peaks in the in-river concentrations.

Table 5. Average mass emissions of total metals during the entire sampling period. Units are in g/day.

StationID	River Distance from Mouth (Km)	N	Mass Emissions (g/day) Total Copper Mean	Total Copper Std. Dev.	Total Lead Mean	Total Lead Std. Dev.	Total Nickel Mean	Total Nickel Std. Dev.	Total Zinc Mean	Total Zinc Std. Dev.
Pacific	0.72	NF	NF	NF	NF	NF	NF	NF	NF	NF
Lincoln	2.53	NF	NF	NF	NF	NF	NF	NF	NF	NF
Centinela	4.67	6	27.0	31.7	16.1	7.0	13.7	12.2	63.9	54.6
Sepulveda Channel	5.82	6	477.8	86.7	251.8	108.3	183.6	79.6	1821.8	324.8
Overland	7.7	9	354.5	158.1	194.6	108.0	127.0	65.5	1506.9	432.1
Duquesne	8.62	9	386.4	258.8	184.9	57.7	111.3	74.6	1045.6	719.6
Higuera	8.8	NF	NF	NF	NF	NF	NF	NF	NF	NF
National	10.92	9	762.2	944.7	357.4	288.6	156.2	123.7	1921.0	2165.9
La Cienega	11.09	6	1144.2	970.6	529.0	278.9	196.4	152.6	2436.8	2135.1
Fairfax	11.94	8	494.5	698.3	250.8	410.3	84.6	93.9	902.5	1314.8
Thurman Overpass	12.5	2	0.5	0.6	0.0		0.1	0.1	0.6	0.7
Cochran	13.28	9	197.5	134.0	70.3	38.1	60.3	37.9	461.0	352.2

NF = No flow data.

Discussion

Results of the dry-season sampling conducted in Ballona Creek during the spring and summer of 2003 illustrated clear spatial patterns of load and concentration and identified some of the primary dry-weather sources of bacteria and metals. Ballona Creek appears to have a bimodal distribution of elevated loads and concentrations, with the highest levels of metals and bacteria occurring between 3 km and 6 km, immediately upstream of the tidal portion of the creek and between 9 km and 12 km, below the portion of the watershed where Ballona Creek daylights from an underground storm drain to an exposed channel.

Metals loading in Ballona Creek appears to be influenced mainly by less than 10 storm drains. The spatial pattern of metals load in Ballona Creek corresponds to the locations of eight storm drains that account for more than 90% of the metals loading to the creek. Two of these drains (Sepulveda and Centinela Channels; BC17 and BC60) contribute 50% of the daily storm drain volume and between 48% and 77% of the daily storm drain metals load. However, these drains discharge to the lower portion of Ballona Creek and are associated with only moderate increases to in-river load. Five drains that discharge to the upper portion of Ballona Creek (in the area where it transitions from an underground storm drain to an above-ground channel) appear to have the greatest effect on in-river metals load. These five drains (BC200, 210, 299, 300, and 310) account for between 16% and 40% of the total daily metals load; however, because they discharge to the upper portion of Ballona Creek, they have a proportionately larger effect on in-river load. Other factors undoubtedly contribute to increases in in-river concentrations and loads, such as the potential for tidal recirculation in

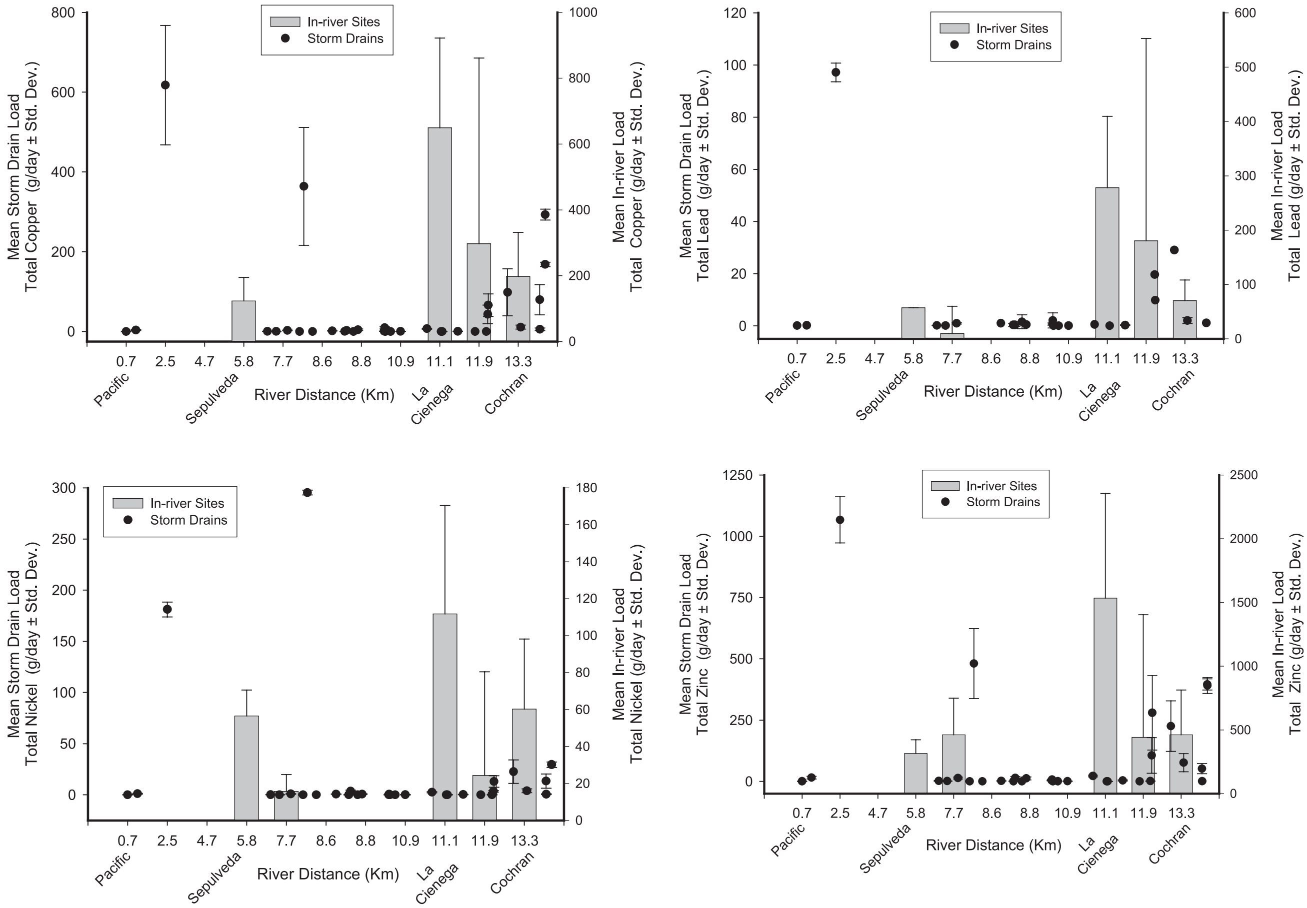

Figure 4. Change in mean in-river metals loads. Graph shows the change in mean in-river load (± standard deviation) between successive sampling locations in Ballona Creek for (a) total copper, (b) total lead, (c) total nickel (right y-axis). Left y-axis shows mean storm drain load (± standard deviation) by position along Ballona Creek.

Table 6. Storm drains contributing the greatest proportion of daily load. The percent of total mean daily load contributed by each of the listed drains. Drains listed account for a combined total of greater than 90% of the total daily storm drain load.

	Copper	Lead	Zinc	Nickel
BC17	33.5%	62.1%	32.9%	29.4%
BC60	19.8%		14.8%	47.9%
BC199		5.2%	3.3%	
BC200	3.6%	2.6%	8.6%	
BC210	5.3%	18.6%	7.0%	3.7%
BC299	4.3%			2.2
BC300	9.1%		12.2%	4.8%
BC310	15.9%	3.6%	12.0%	4.8%
Mean Daily Load +SD (g/day)	1841+126	156+17	3244+210	616+57
Percent of Total Daily Load due to Listed Drains	91.5%	92.1%	90.8%	92.8%

the lower reaches transporting constituents discharged from Centinela Channel back up into the lower reaches of Ballona Creek. Nevertheless, a relatively small number of storm drains contribute a disproportionate load to Ballona Creek. Investigation of these areas for management actions may be an efficient starting point for developing source control strategies.

Although consistent spatial patterns of bacteria and metals were observed between individual sampling events, the magnitude of concentration and load varied by more than five-fold over the course of a year, as well as between years. Some of the scatter in the storm drain and in-river metals concentrations is likely due to intra-annual variability in

Table 7. Geometric mean in-river concentrations of bacteria for the three individual sampling events. Units are in MPN/100 mL. For the month of May n=30, July n=34, and September n=35.

	May		July		September	
Constituent	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
E. coli	692.7	709.2	1902.1	7.5E+03	2400.1	8.3E+03
Enterococcus	726.6	1242.4	955.1	2172.7	758.1	1111.0
Total Coliforms	2.2E+04	1.6E+04	6.6E+04	5.7E+04	4.1E+04	3.1E+04

Table 8. Range and geometric mean concentrations of storm drain bacteria for all locations over all three sampling events combined. Units are MPN/100 mL. E. coli and Total Coliforms n=110. Enterococcus n=108.

Constituent	Min	Max	*Mean*	*SD*	Percent Exceeding Maximum Detection Limit
E. coli	<100	1.4E+05	4.7E+03	1.5E+04	4.5
Enterococcus	<10	>2.4E+04	5.9E+03	8.8E+03	12.0
Total Coliforms	<100	>2.4E+05	1.0E+05	9.6E+04	21.8

the system. Several potential sources of variability may result in a non-steady state conditions, such as illicit discharges, permitted periodic discharges of industrial or construction-related effluent, and inherent variability in storm drain discharges. Given this variability, the choice of a single sampling period for this study could have resulted in different conclusions (Figure 6). If samples were collected only in July, conclusions regarding average concentrations would have been higher than if samples were collected solely in May. Conversely, if data from the July sampling event were omitted, the mean in-river concentration would have been 8 ug/L instead of 11 ug/L. Metals concentrations may also vary up to five-fold from year to year. For example, measured copper concentrations at 2.5 km (Lincoln Boulevard) were 29 ug/L in 1999 (McPherson *et al.* 2002), "not-detected" in 2002 (City of Los Angeles 2002), and 6 ug/L in 2003 (this study). Therefore, it is important to account for this variability when assessing the condition of the creek and its compliance with water quality standards; and management decisions should not rely on measurements taken at a single point in time.

Bacteria concentrations typically also vary by up to five orders of magnitude on daily, seasonal, and inter-annual scales. The extreme variability in these indicators necessitates more frequent monitoring over longer time periods than for metals in order to make assessments of "typical" bacteria concentrations. Furthermore, between 5% and 22% of storm drain samples exceed the maximum detectable bacteria concentration (depending on the specific indicator). Therefore, mean concentrations reported from storm drains underestimate the actual bacteria levels being discharged to the creek. Regardless, bacteria concentrations from in-river and storm drain samples consistently and uniformly exceed water quality standards in almost all locations.

The manner in which samples with non-detectable levels of a particular metal are treated may also affect overall estimates of load. Non-detectable values may be assigned a value of zero, half the detection limit, or assumed to equal the detection limit. The degree to which this choice influences general conclusions about loading depends on the frequency of non-detectable values. For the four metals focused on in this study, only storm drain lead samples had a substantial fraction of non-detectable values (60%). In contrast, almost all the in-river samples contained detectable lead levels. If we had assumed that non-detectable values were equal to half the detection limit (instead of zero), our estimate of storm drain load would have increased by 43%; but our estimate of in-river load would have only increased by 16%. If we had assumed that non-detectable values were equal to the detection limit, our estimate of storm drain load would have increased by 100%, but our estimate of in-river load would have only increased by 29% (Figure 7). Therefore, for lead, the choice of values to assign to non-detectable results may affect conclusions regarding the spatial distribution of sources and compliance with water quality standards.

The concentrations and loads of metals and bacteria observed in Ballona Creek are comparable to those observed in the dry-weather flow of other urban watersheds, such as the Los Angeles River (Ackerman *et al.* 2003). For example, daily zinc load in the Los Angeles River (exclusive of publicly owned treatment work (POTW) discharges) was 2,300 g/day, compared to a mean zinc load of 1,442 g/day in Ballona Creek, upstream of the tidal area. Similarly, the daily copper load in the Los Angeles River was 1,036 g/day compared to 545 g/day in Ballona Creek. If the Los Angeles River loads are adjusted for differences in watershed size (834 km^2 vs. 329 km^2), the loads are even more similar: 920 g/day vs. 1,442 g/day for zinc and 414 g/day vs. 545 g/day for copper. Two possible interpretations may account for this similarity. Similar dry-weather metals concentrations could reflect natural background loadings from the two watersheds. Alternatively, similar sources (e.g., residential and commercial runoff, aerial deposition) could be contributing to watersheds. The lack of an undeveloped upper watershed in Ballona Creek, as exists in the Los Angeles River, favors the second explanation. However, further investigation of natural background loadings and aerial deposition will be necessary to answer this question.

Storm drain bacteria concentrations in Ballona Creek were 20% higher on average than those observed in the Los Angeles River. The mean *E.*

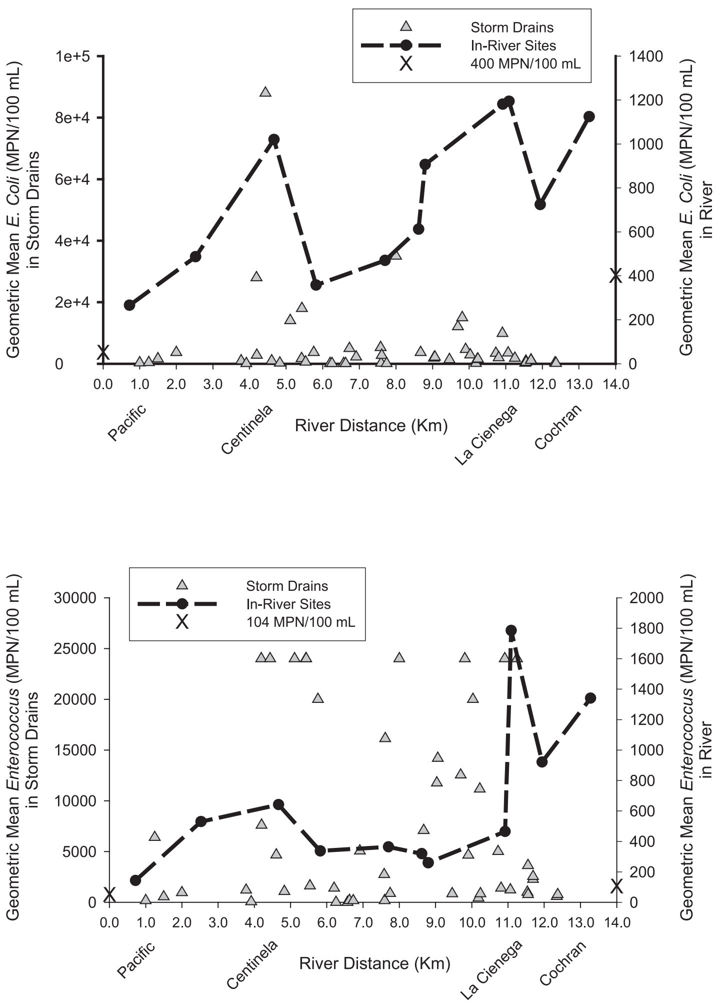

Figure 5. Mean in-river and storm drain bacteria concentrations. Concentrations of (a) E. Coli and (b) Enterococcus in storm drain and in-river sites in Ballona Creek during the 2003 dry-season study. Storm drain concentrations are shown on the left axis, in-river concentrations on the right axis. "X" on y-axis = AB411 water quality standard.

Table 9. Storm drains with mean bacteria concentrations greater than or equal to the mean concentration for all storm drains. (*) = concentration was significantly higher than other drains at p<0.05. Bolded rows indicate drains that also exhibited high metals concentrations.

	E. coli	Enterococcus
BC24	X	X
BC26	**X(*)**	**X(*)**
BC55		X
BC121		X
BC130	X	X(*)
BC160		X
BC185		X
BC214		X
BC271		**X**
Geometric Mean	3.0E+04	2.1E+04

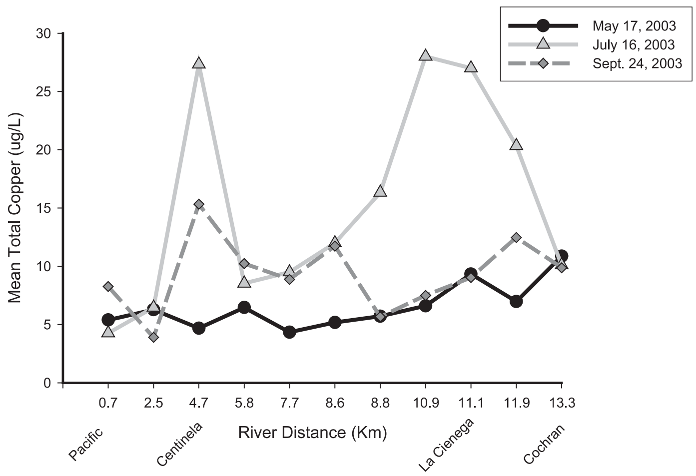

Figure 6. Intra-annual variability in copper concentration. Comparison of mean total copper concentrations in Ballona Creek in-river locations during each of the three summer 2003 dry-season sampling periods.

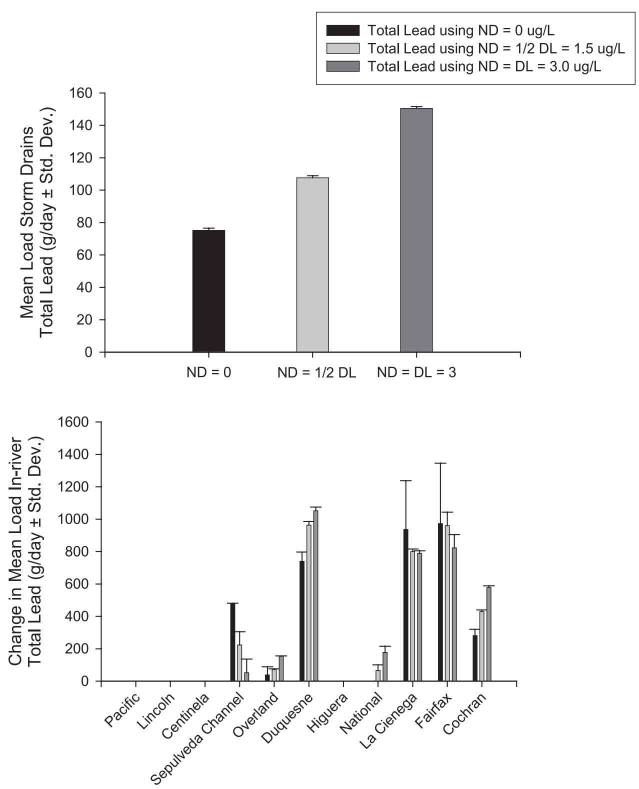

Figure 7. Effect on "non-detects" on mean mass emission estimates for total lead. Top graph (a) compares estimated mean storm drain load (± standard deviation) if non-detects are assumed to equal 0 ug/L, fi detection limit, or equal to detection limit (3ug/L). Bottom graph (b) compares change in mean in-river load (± standard deviation) between successive sampling in-river sites for various treatments of "non-detects."

coli concentration was 47,000 MPN/100 mL vs. 21,000 MPN/100 mL; and the mean total coliform concentration was 100,000 MPN/100 mL vs. 80,000 MPN/100 mL in Ballona Creek and the Los Angeles River, respectively. These differences are consistent with the uniformly high bacteria concentrations found in the highly urbanized Ballona Creek watershed.

Finally, as reported in previous studies (McPherson *et al.* 2002, Stein *et al.* 2003), dry-season metals load may constitute from a minor to an appreciable portion of total annual load in arid urban watersheds, depending on the amount of annual rainfall. Watersheds such as Ballona Creek experience storm flows approximately 15% of the time (based on 10 years of flow data). During the remainder of the year, dry-weather urban runoff is the predominant source of in-river flow. Comparing empirical data from this and other studies (McPherson *et al.* 2002, Stein *et al.* 2003, City of Los Angeles unpublished data) to estimates of stormwater loading (Ackerman *et al.* in preparation) shows that in years with low rainfall, such as 2001-2002, dry-season metals loading may comprise 10% to 25% of the total annual load. Similarly, modeling results show that the relative contribution of dry-season loading to total annual load varies from just over 10% during dry years to less than 1% during wet years, although up to 30% of the total annual volume discharged may occur during the dry season (Ackerman *et al.* in preparation). Furthermore, the role of dry-season metals load to overall toxicity may be amplified

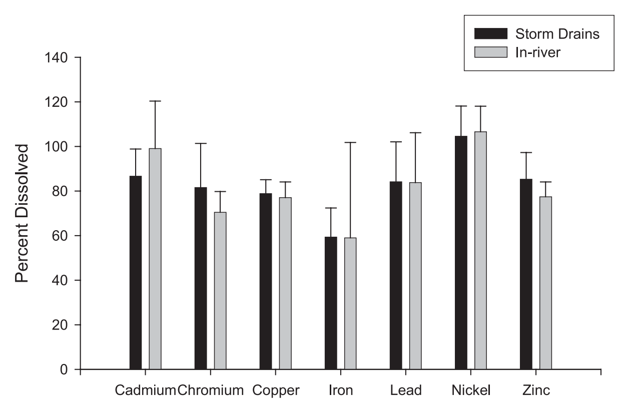

Figure 8. Comparison of percent dissolved metals. Percent of total metals as dissolved in storm drains and in-river sites in Ballona Creek during the 2003 dry season.

because, in contrast to stormwater runoff, dry-season metals occur predominantly in the dissolved phase (Figure 8), which is generally more bioavailable.

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Acknowledgements

The authors wish to thank the Los Angeles Regional Water Quality Control Board, U.S. Environmental Protection Agency Region IX, Los Angeles County Department of Public Works, City of Los Angeles Department of Sanitation, and Santa Monica Baykeeper for their support and guidance on the steering committee for this project. We also thank the volunteers who assisted in collecting storm drain samples and flow data. This project was partially funded by the City of Los Angeles.