Characterization of Dry Weather Metals and Bacteria in Ballona Creek

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ABSTRACT

Runoff from the highly urbanized Ballona Creek Watershed typically contains bacteria and metals that have the potential to affect human and ecological health, both in the watershed and in downstream receiving waters. Previous studies have documented that dry season urban runoff can contribute a substantial proportion of total annual load of metals, but questions remain regarding the spatial distribution of sources of dry season metals and bacteria in the Ballona Creek Watershed. The goal of this study was to characterize dry weather concentrations of metals and bacteria and to identify the relative contribution of various portions of the watershed to total dry season loading of metals and bacteria. To address these questions, 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. Metals concentrations in Ballona Creek were below chronic criteria under the California Toxics Rule (CTR) between 96% and 100% of the in-river samples. In contrast, bacteria concentrations at the majority of storm drains and in-river sites were consistently above AB411 water quality standards. In general, Ballona Creek exhibits a bimodal distribution of elevated metals and bacteria, with the highest levels occurring between km 3 and 6, immediately upstream of the tidal portion of the creek and between km 9 and 12, 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, four 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 5-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.

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TABLE OF CONTENTS

INTRODUCTION

Increased urbanization has been shown to result in increased runoff and pollutant loading to receiving waters (USEPA 1995, Schueler and Holland 2000, Davis et al. 2001). Higher amounts of impervious surfaces associated with urban landscapes result in increased magnitude and frequency of surface runoff during both wet and dry weather conditions (Roesner and Bledsoe 2003). This urban runoff results in accumulation of toxic compounds, such as heavy and trace metals, which 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 ten years management of urban runoff has focused primarily on evaluation and control of storm water. However, recently, there has been more recognition that dry season runoff can be a significant contributor to total annual load (Piechota and Bowland 2001, Ackerman et al. 2003, Stein et al. 2003). This is especially true for urban watersheds in arid areas where stream flow is comprised entirely of urban runoff and other effluent for the majority of the year. The distinction between wet and dry season pollutant loading characteristics is important because management strategies differ for these two sources. For example, storm water management typically focuses on retention or detention, whereas dry season runoff control focuses on treatment, diversion, infiltration, and source control.

The Ballona Creek watershed in the greater Los Angeles, California area is an ideal place to study dry season runoff issues. The 329 km^2 watershed is approximately 80% urbanized, land use is a relatively homogenous mix of residential, commercial, and industrial uses, and there are no permitted discharges of treated wastewater to Ballona Creek. Consequently, almost all the dry season flow in Ballona Creek results from nuisance runoff from urban surfaces. Ballona Creek is a concrete lined channel that conveys urban runoff from the central and western portion of Los Angeles 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). In addition, sediment contamination in Marina del Rey has hindered maintenance dredging of the small craft harbor since 1981 (USACOE 2002). The combination of economic and biologic concerns have prompted investigation of contaminant sources to Marina del Rey and identification of source control strategies as a key element of long-term management of sediment contamination in the estuary and harbor.

Most of the contamination to Marina del Rey is assumed to result from runoff from the watershed into Ballona Creek and subsequently into Marina del Rey (USACOE 2002). Comprehensive sediment sampling and testing conducted on behalf of the Corps of Engineers indicate that the highest levels of trace metals in Marina del Rey are near the mouth of Ballona Creek. Moffatt and Nichol (1994) analyzed the data on Marina del Rey Harbor water quality and concluded that storm water runoff appears to be the largest source of contamination in Marina del Rey Harbor.

Although storm water runoff is the primary source of pollutant loading to Ballona Creek, dry season runoff can constitute an important contribution to total annual loading, especially during dry years. 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[1] 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). Furthermore, because dry weather loads are predominantly in the dissolved phase, they may be more bioavailable to organisms that reside in the estuary and harbor.

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. Previous studies have documented dry weather concentrations and loads within Ballona Creek (McPherson et al., 2002), but have not investigated contributions from storm drains draining various portions of the watershed. Similarly, previous studies have focused on constituents associated with sediment contamination in Marina del Rey (e.g. metals and organics), and not on bacteria, which is one of the sources of impairment in Ballona Creek. Like metals, bacterial loading may vary spatially within a watershed depending on site-specific land use practices.

This study addressed these information gaps by conducting three comprehensive surveys of storm drain discharge into Ballona Creek in order to characterize the spatial distribution of metals and bacteria loading to Ballona Creek. The goal of this study was to identify the relative contribution of various portions of the watershed to total dry season loading of metals and bacteria so that local agencies can more effectively target source control, treatment or other management strategies.

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[1] Concentrations were compared to the freshwater chronic criteria under the California Toxics Rule (CTR)

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 usage. 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, conveyed to Ballona Creek via storm drains.

Sampling

Water quality sampling consisted of sampling both storm drain inputs and in-river samples along the entire 12.7 km of Ballona Creek using a combination of agency staff and citizen volunteers. Replicate sampling for flow and water quality was conducted on May 17, July 16, and September 24, 2003. The last rain prior to the May sampling occurred on May 3rd (3.3 cm), and no measurable rain fell between the May and September sampling events. Given that there were 14 antecedent dry days prior to the first sampling, these three samples should be representative of dry season conditions. The same locations were sampled during each sampling event, and sampling occurred in the morning to minimize 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) unit. Of these, all 12 in-river sites and between 35 and 40 storm drains were sampled during each sampling event. The remaining drains either lacked sufficient flow to sample or were inaccessible. The 35-40 drains sampled spanned the entire portion of Ballona Creek that is above ground. At each storm drain sampled, flow was measured using either 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 both storm drains and in-river sites, and immediately placed on ice for subsequent analysis. Storm drains samples were collected by direct-filling a single bottle from each drain. At the in-river locations, three composite samples were collected at 20-minute intervals. Each composite consisted of three grab samples collected at approximately even intervals across the channel cross-section. Water samples were analyzed for metals (total and dissolved) and bacteria following protocols approved by the USEPA (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 (km) upstream of the mouth of Ballona Creek.

Analysis

Results of the flow and water quality sampling were analyzed for spatial and temporal patterns. Means and ranges of flow and concentration for both 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[2] (Sokal and Rohlf, 1969). In all cases non-detects 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. Biological significance of observed concentrations was investigated by comparing metals concentrations to the California Toxics Rule standards and bacteria to the AB411 water quality standards.

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[2] a significance level of 0.05 indicates that there is a 95% probability that a conclusion that two means are different is correct.

RESULTS

Flow

Average in-stream flow in Ballona Creek was 0.34±0.17 cms (12±6 cfs) during the May and September sampling and 0.73±0.17 cms (26±6 cfs) during the July sampling. Flow generally increased from upstream to downstream until Centinela Blvd., where tidal influence begins (approximately 5 km upstream from the mouth of the creek; Figure 2). Substantial tributary inflows occur at Sepulveda Channel (km 5.8) and upstream of Overland (km 7.7).

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 (0.4 cfs; Figure 3). Approximately 85% of the 54,000 m^3 /day (14 million gallons/day) discharged from the flowing storm drains, results from four storm drains: BC17 (Centinela Channel), BC60 (Sepulveda Channel), BC300, and BC310 (Figures 2 and 3). Variability in storm drain flow, ponding effects, and obstructions in some of the drains 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 all three sampling events (Table 2). Similarly, copper, iron, nickel, and zinc were consistently detectable in storm drain samples (Table 3). However, storm drain metals concentrations were generally higher than those observed in Ballona Creek itself, and peak concentrations were typically an order of magnitude greater in the storm drains than in the creek. Metals occurred predominantly in the dissolved phase, although the dissolved fraction varied by metal (Figure 4). With the exception of iron (which is primarily a natural earth element), subsequent results and discussion will focus on copper, lead, nickel, and zinc. Mean metals concentrations for each storm drain and in-river sampling location are provided in Appendix A.

In-river metals concentrations varied considerably both 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 were generally lower, but the differences between the May and September sampling were only significant at approximately 30% of the sampling locations. Cadmium and chromium concentrations did not vary between the three sampling events (Table 4). 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 km 5 and 6, immediately downstream of Sepulveda Channel, which drains a 42 km^2 portion of the watershed (Figure 5). For lead, this peak was obscured due to high concentrations at Pacific Avenue (km

1). The September lead concentrations at km 1 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 concentration for copper, lead, nickel, and zinc was observed between km 10 and 11, 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 5).

Of the 35-40 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 5). 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 km 4 and 5, between Sepulveda Channel and Centinela Creek, immediately downstream of the highest in-river metals concentrations. The fourth drain (BC 271) is located at km 11, upstream of the location of the second in-river peak in metals concentration (Figure 5).

Spatial patterns of in-river metals loads were similar to those observed in the concentration data (Table 6 and Figure 6). Relatively high in-river metals loads were observed between km 6 and 8 and between km 11 and 13. In-river metals loads reflect the areas of highest storm drain loading. For all four metals analyzed, high storm drain loads occur between km 10 and 13, at km 5.5 (Sepulveda Channel) and km 3.5 (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 7). 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 (Table 7).

Concentrations of copper, lead, and zinc in Ballona Creek were generally below the freshwater and saltwater chronic toxicity standards established under the California Toxics Rule (Figures 7-9). Of the 97 individual in-river samples for each metal, four lead samples, two copper samples, and no zinc samples exceeded the CTR standards. Although the CTR standards are typically not enforced for storm drain discharges, comparison of storm drain samples to standards can be instructive in estimating the likelihood that inherent variability of in-river concentrations may result in periodic exceedances. Storm drain copper concentrations exceeded CTR standards in 21.5% and 26.2% of the drains in the freshwater and tidal portions of the creek, respectively. In contrast, only 9.5% of storm drains in the freshwater portion of the creek exceeded CTR standards for lead. In the tidal portion of the creek, 35% of the storm drains exceeded CTR standards for lead. No storm drain samples exceeded the CTR standards for zinc.

Bacteria

Relatively high bacteria concentrations were observed throughout both Ballona Creek and the storm drains draining to the creek (Tables 8 and 9). Mean storm drain concentrations were typically one to two orders of magnitude greater than those observed in the in-river samples. However, actual mean storm drain concentrations may have been underestimated, due to the relatively high proportion of samples that exceeded maximum detection limits, especially in the case of total coliforms. Mean bacteria concentrations for each storm drain and in-river sampling locations are provided in Appendix B.

Bacteria concentrations exhibited a wide range of variability, as indicated by the large standard deviations on all sample means. In general, concentrations were higher in July than during the other two sampling events; however unlike the metals, differences between sampling periods were not significant for bacteria (Table 10).

Spatial patterns in bacteria concentrations were similar to those observed for the metals. In-river *E. Coli* concentrations were highest between km 4 and 5 (between Sepulveda Channel and Centinela Creek) and between km 9 and 11 (Figure 10). Enterococcus concentrations were highest between km 10 and 11, with a lower peak between km 4 and 5 (Figure 10). The spatial pattern of total coliforms concentrations were 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 35-40 storm drains sampled, nine had consistently high concentrations for either *E. Coli* or Enterococcus and three had high concentrations for both bacterial indicators (Table 11). Only two of these drains (BC 26 and BC 271) also had high metals concentrations. For *E. Coli*, two of the drains with high concentrations were between km 4 and 5, while the other one was at km 8 (Figure 10). For Enterococcus, the high storm drain concentrations were relatively evenly distributed between km 4 and 12 and did not necessarily correspond to the peaks in the in-river concentrations (Figure 10).

The majority of storm drain and in-river bacteria concentrations exceeded the AB411 freshwater standards for bacteria (Figures 10 and 11). Storm drain concentrations exceeded water quality standards at 87% of the drains for total coliforms, 95% of the drains for Enterococcus, and 72% of the drains for E.Coli (Figure 11). Exceedences of AB411 standards occurred along the entire length of Ballona Creek.

DISCUSSION

Results of the dry season sampling conducted in Ballona Creek during the spring and summer of 2003 build upon previous studies by the City of Los Angeles (2001 and 2002) and McPherson et. al (2002) by illustrating clear spatial patterns of load and concentration and identifying 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 km 3 and 6, immediately upstream of the tidal portion of the creek and between km 9 and 12, below the portion of the watershed where Ballona Creek daylights from an underground storm drain to an exposed channel.

The two portions of Ballona Creek that exhibit high concentrations of metals and bacteria correspond to locations where storm drains with consistently high concentrations discharge to the creek. Four drains in the lower portion of the creek and five drains in the upper portion of the creek appear to be substantial contributors to high in-river concentrations. In particular drain BC 26 at km 4.4 and drain BC 271 at km 11 had high concentrations for both metals and bacteria.

Metals loading in Ballona Creek appears to be mainly influenced by less than ten 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. There are undoubtedly other contributing factors to increases in in-river concentrations and loads, such as the potential for tidal recirculation in 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.

Several metals occur in appreciable concentrations in dry weather flow, particularly copper and lead. Although most of the in-river metals samples were below CTR standards, elevated storm drain concentrations and the inherent variability in the system make it reasonable to assume that concentrations may exceed standards at some points in time. In contrast, most of the in-river and storm drain bacteria concentrations exceeded water quality standards.

Although we observed consistent patterns of bacteria and metals, there are several sources of variability that may affect concentration and load. In-river metals concentrations may vary by more than 5-fold over the course of a year, as well as between years. Given this variability, the choice of a single sampling period for this study could have resulted in different conclusions

(Figure 12). If samples were only collected in July, conclusions regarding average concentrations and CTR exceedences would have been higher than if samples were collected solely in May. Conversely, if data from the July sampling were omitted, the mean in-river concentration would have been 8 ug/l instead of 11 ug/l. Similarly, the percent of storm drain concentrations that exceeded CTR standards varied from 7% to 30% depending on the sampling period. Many of the storm drains whose mean concentrations were near or above CTR standards were in the same location as in-river sampling sites that were at or immediately below the CTR standards. Therefore, it is important to account for this variability when assessing the condition of the creek and its compliance with water quality standards.

The manner in which samples with "non-detectable" levels of a particular metal are treated may also affect overall estimates of load. "Non-detect" values may be assigned a value of zero, ½ 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-detect values. For the four metals focused on in this study, only storm drain lead samples had a substantial fraction of non-detect values (60%). In contrast, almost all the in-river samples contained detectable lead levels. If we had assumed that "non-detects" were equal to ½ 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-detects" 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 13). Therefore, for lead, the choice of values to assign to "non-detects" may affect conclusions regarding compliance with water quality standards.

Estimates of metals loadings may also vary due to variations in both in-river concentration and flow. In this study, in-river flows varied by 2-3 fold between sampling periods. Field observations and measurements showed several large storm drains discharging only in July, and not during other sampling periods. The combination of higher flow and higher concentrations resulted in large differences in loading estimates depending on when samples were collected. For example at km 10.9 (National Blvd) July 2003 flows were 2.5 times higher than those observed in May 2003, while copper concentrations were 5 times higher in July than in May. Consequently, estimates of in-river load varied by more than 12 fold between these two sampling periods.

Metals concentrations may also vary up to 5-fold from year to year. For example, measured copper concentrations at km 2.5 (Lincoln Blvd.) 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). Similar patterns can be observed throughout Ballona Creek for copper and lead (Figure 14). Many in-river samples collected in 2002 by the City of Los Angeles showed non-detectable levels of these metals. However, samples collected at the same locations and dates in 2003 showed appreciable concentrations of both copper and lead (Figure 14).

Bacteria concentrations typically 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 both in-river and storm drain samples consistently and uniformly exceed water quality standards in almost all locations.

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 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, 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. Storm drain bacteria concentrations in Ballona Creek were on-average 20% higher than those observed in the Los Angeles River: Mean *E. Coli* concentration in Ballona Creek of 47,000 MPN/100mL vs. 21,000 MPN/100mL in Los Angeles River; mean total coliform concentrations in Ballona Creek of 100,000 MPN/ 100mL vs. 80,000 MPN/100mL in Los Angeles River. These differences are consistent with the uniformly high bacteria concentrations 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 an appreciable portion of total annual load in arid urban watersheds. 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, urban runoff is the predominant source of in-river flow. In years with low rainfall, such as 2001-2002 dry season metals loading may comprise 25%-35% of the total annual load. The role of dry season metals load to overall toxicity may be amplified because, in contrast to storm water runoff, dry season metals occur predominantly in the dissolved phase (Figure 4), which is generally more bioavailable.

This work builds on previous investigations of dry season loading in Ballona Creek by providing insight into the magnitude and spatial distribution of metals and bacteria concentrations and loads. The results of this study illustrate that evaluation of concentration and loading at a single location along a creek (typically at the lowest reach) is insufficient to characterize the entire watershed. Furthermore, as illustrated by this study, synoptic investigations can help identify priority areas for investigating source control or other management strategies. Given the concentrations and relative contribution of dry season runoff to overall metals and bacteria loading, more work should be done to characterize the intra and inter annual variability in these systems.

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Table 1. Constituents analyzed.

Constituent	MDL	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/100mL	Idexx Quantitray
E. coli		MPN/100mL	Idexx Quantitray
Enterococcus		MPN/100mL	Idexx Quantitray

Table 2. Range and average concentration of in-river total metals for all locations and all three sampling events combined. Units are in ug/l. In all cases n=97. ND = non detect.

Constituent	Min	Max	Mean	SD
Cadmium	ND	0.81	0.06	0.12
Chromium	ND	4.92	1.82	1.09
Copper	1.00	28.00	10.90	7.32
Iron	56.46	4100.00	598.84	776.08
Lead	0.00	19.00	4.06	4.22
Nickel	0.24	12.43	3.90	2.98
Zinc	3.5	85.00	30.24	14.73

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	% ND
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%

Table 4. 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 both 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 5. 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

Table 6. 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		Total Lead		Total Nickel		Total Zinc	
			Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	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

Table 7. 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%

Table 8. Range and geometric mean concentration of in-river bacteria for all locations and all three sampling events combined. Units are in MPN/100 mL. In all cases n=98

Constituent	Min	Max	*Mean*	*SD*	% Exceeding Max DL
E. Coli	<100	4.4E+04	1.2E+03	4.4E+03	1.0
Enterococcus	<10	1.3E+04	816.8	1580.5	0.0
Total Coliforms	630	2.0E+05	4.4E+04	4.3E+04	0.0

Table 9. 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*	% Exceeding Max DL
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

Table 10. 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 11. 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. Shaded 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 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.

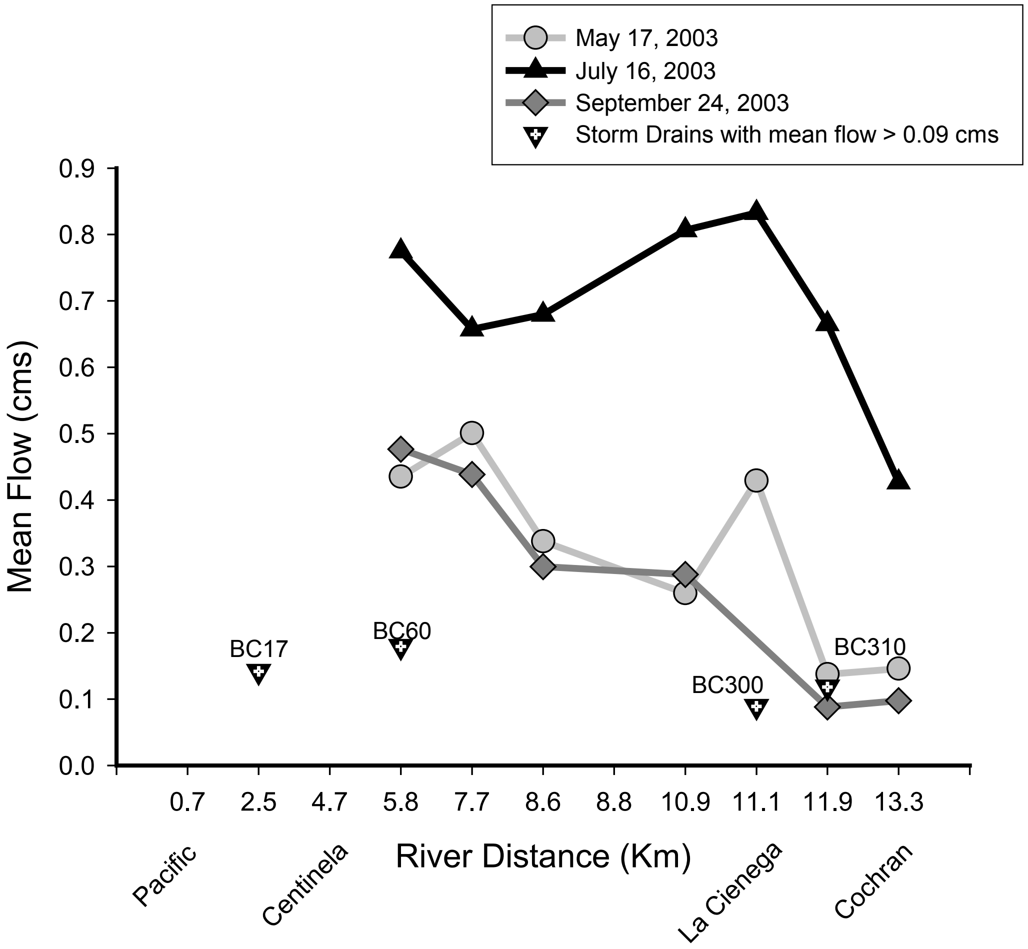

Figure 2. Comparison of flow (cms) in Ballona Creek during May, July and September, 2003. The black triangles with crosses represents the four storm drains with the greatest mean flow (each greater than 0.09 cms.). The four storm drains indicated account for approximately 85% of the daily storm drain discharge.

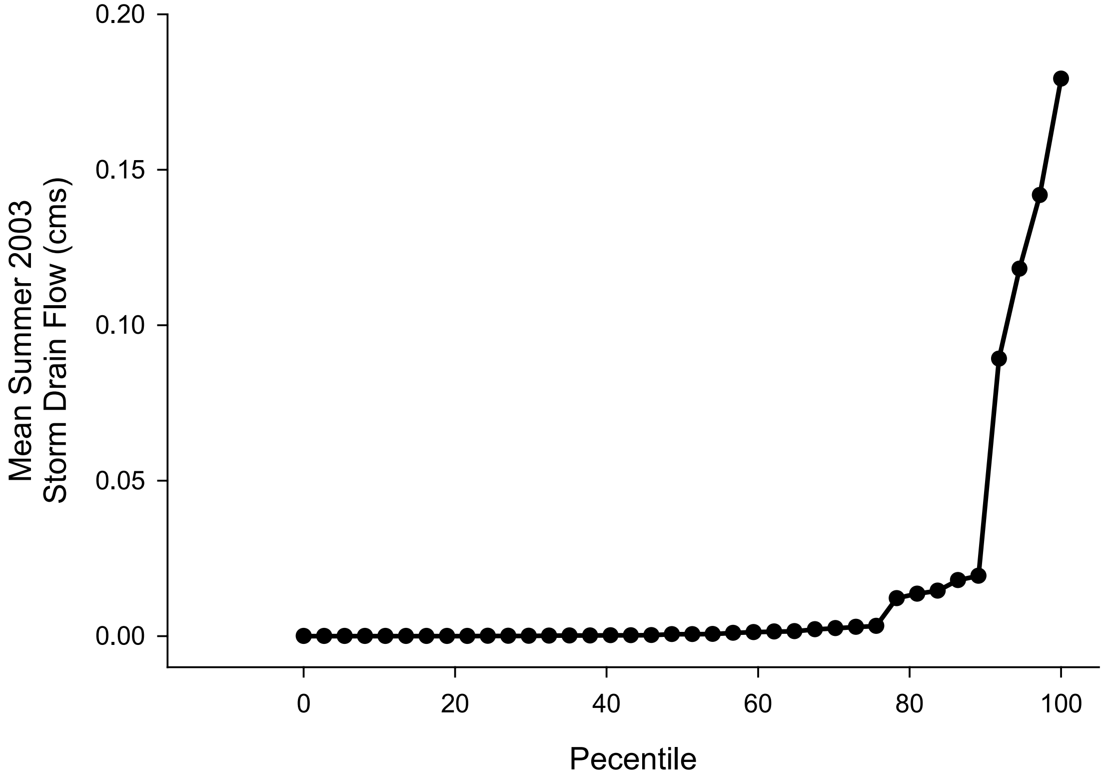

Figure 3. Cumulative distribution curve of mean storm drain flow (cfs) in Ballona Creek. Percent of storm drains with mean summer 2003 flow (for all three sampling periods) below a given discharge.

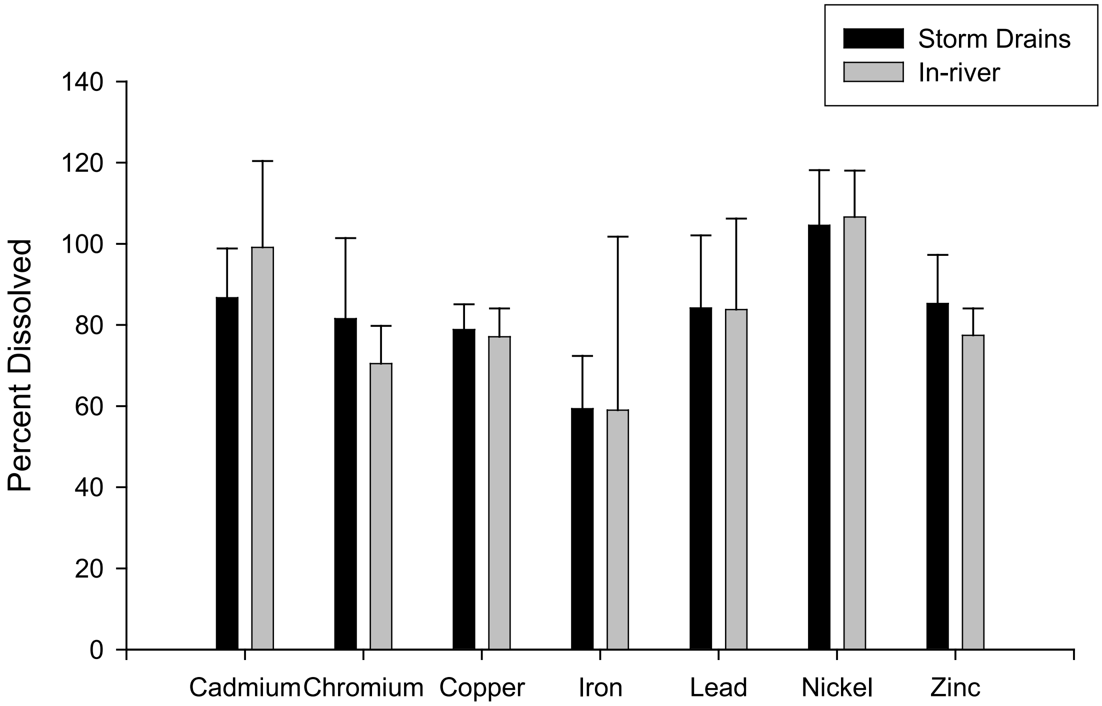

Figure 4. Comparison of percent dissolved metals. Percent of total metals as dissolved in storm drains and in-river sites in Ballona Creek during the 2003 dry season.

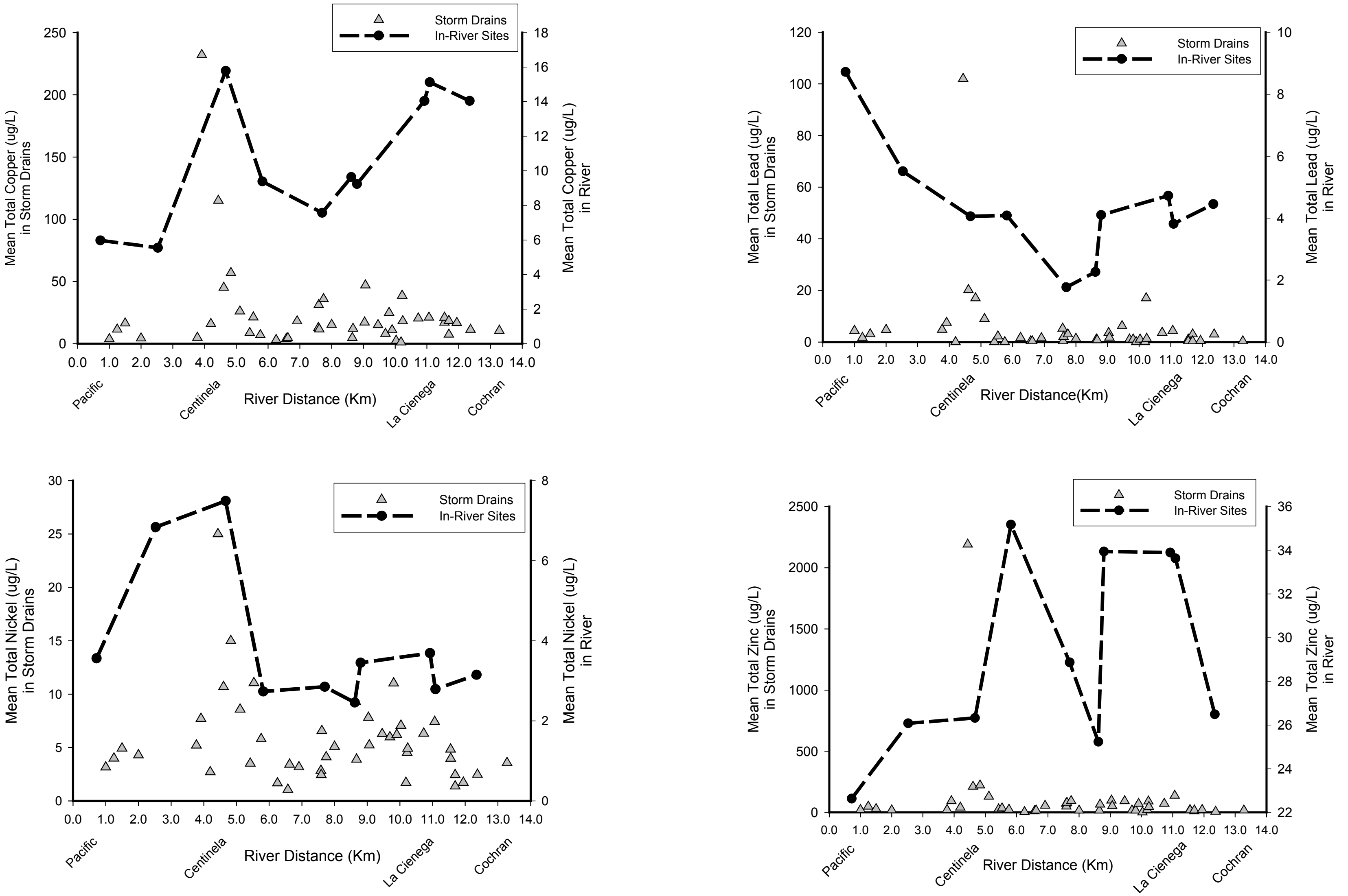

Figure 5. Mean in-river and storm drain metals concentrations. Concentrations of (a) total copper, (b) total lead, (c) total nickel, and (d) total zinc in Ballona Creek during the 2003 dry season sampling period. Storm drain concentrations are shown on the left axis, in-river concentrations on the right axis.

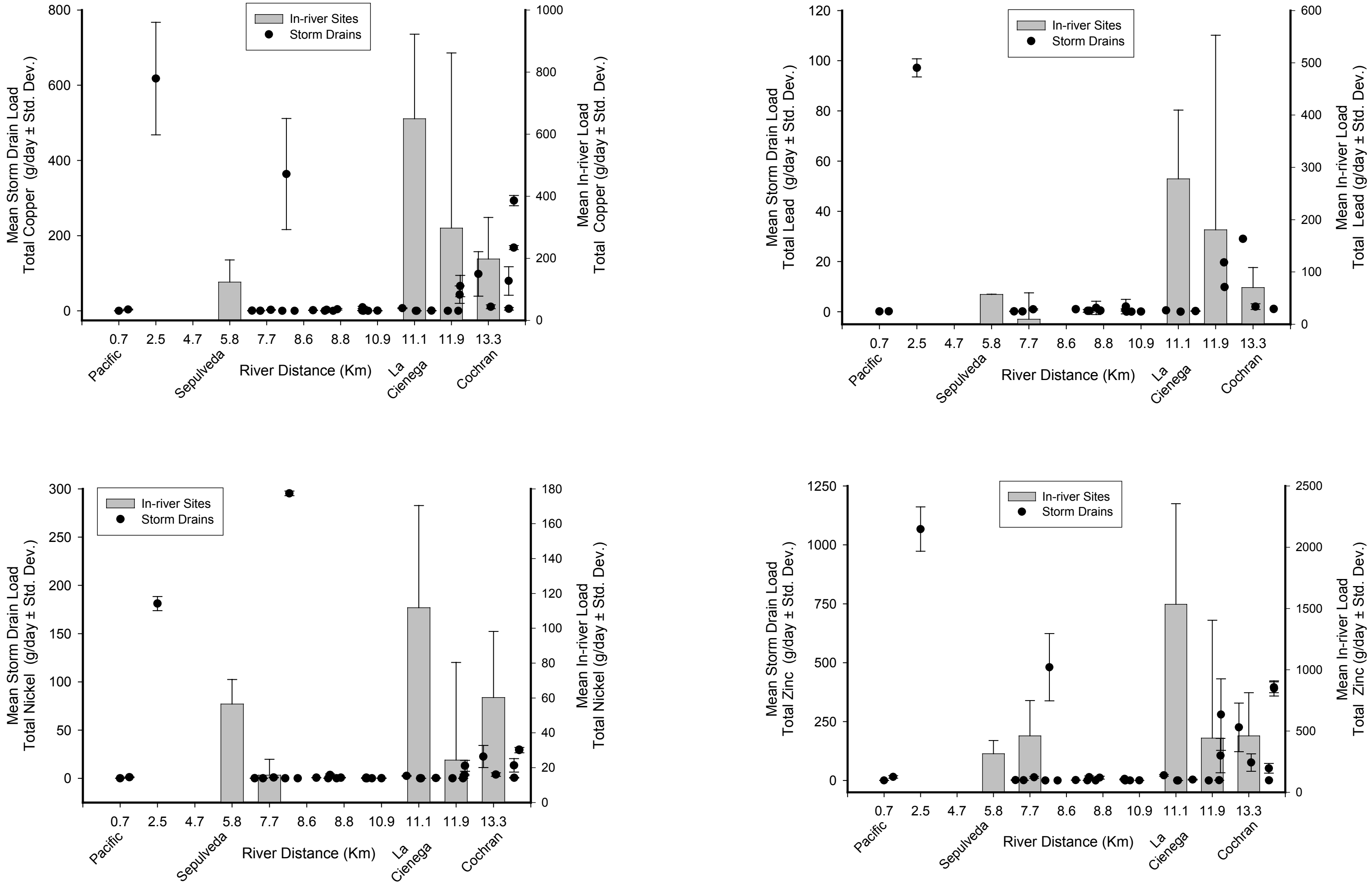

Figure 6. Change in mean in-river metals loads. Graph shows the change in mean in-river load (± standard deviation) between successive sampling locations in Ballona Creek for (a) total copper, (b) total lead, (c) total nickel (right y-axis). Left y-axis shows mean storm drain load (± standard deviation) by position along Ballona Creek.

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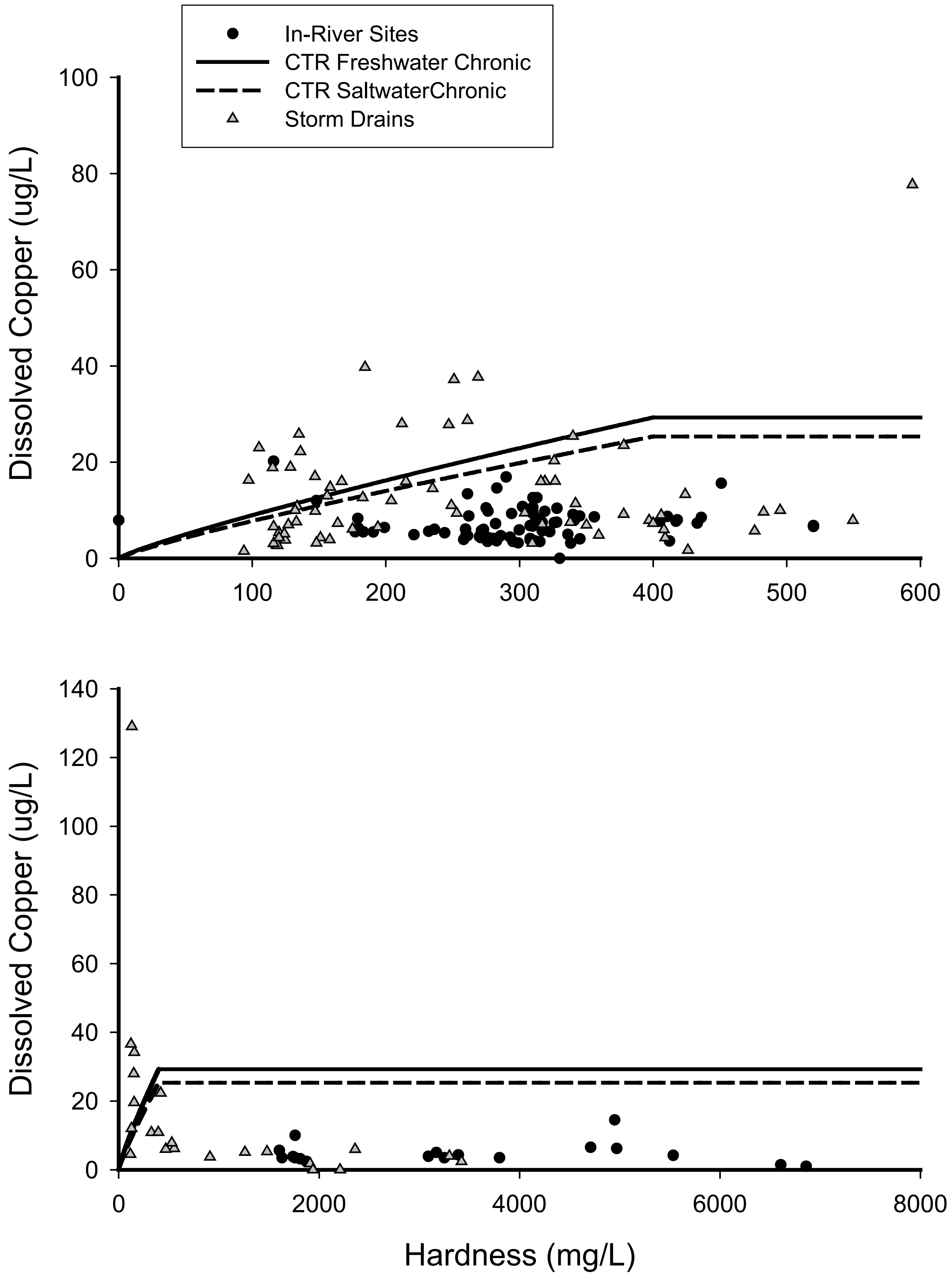

Figure 7. Comparison of storm drain and in-river dissolved copper concentrations to the California Toxics Rule (CTR). Concentrations relative to CTR standards for both (a) upstream/freshwater and (b) downstream/tidal portion of Ballona Creek.

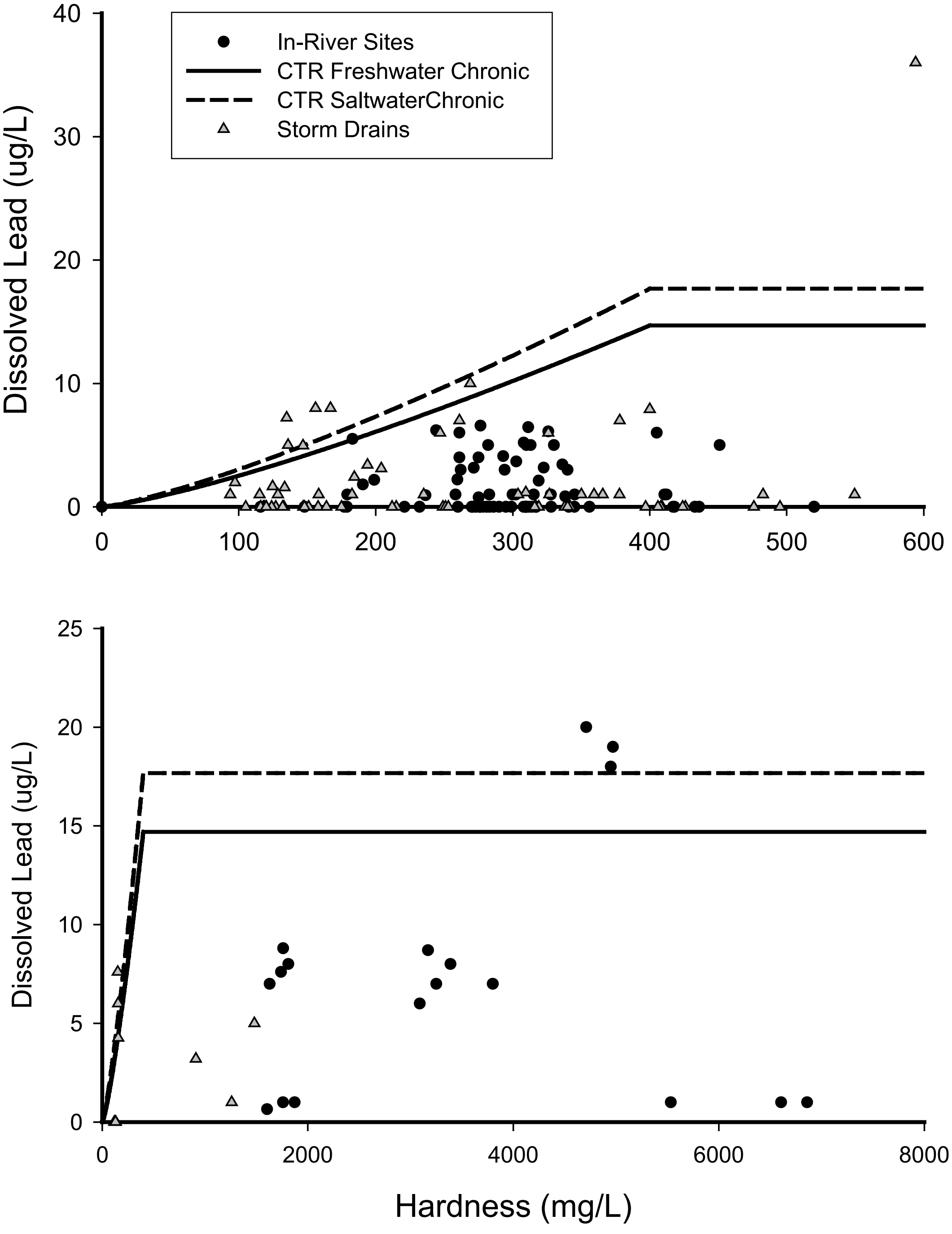

Figure 8. Comparison of storm drain and in-river dissolved lead concentrations to the California Toxics Rule (CTR). Concentrations relative to CTR standards for both (a) upstream/freshwater and (b) downstream/tidal portion of Ballona Creek.

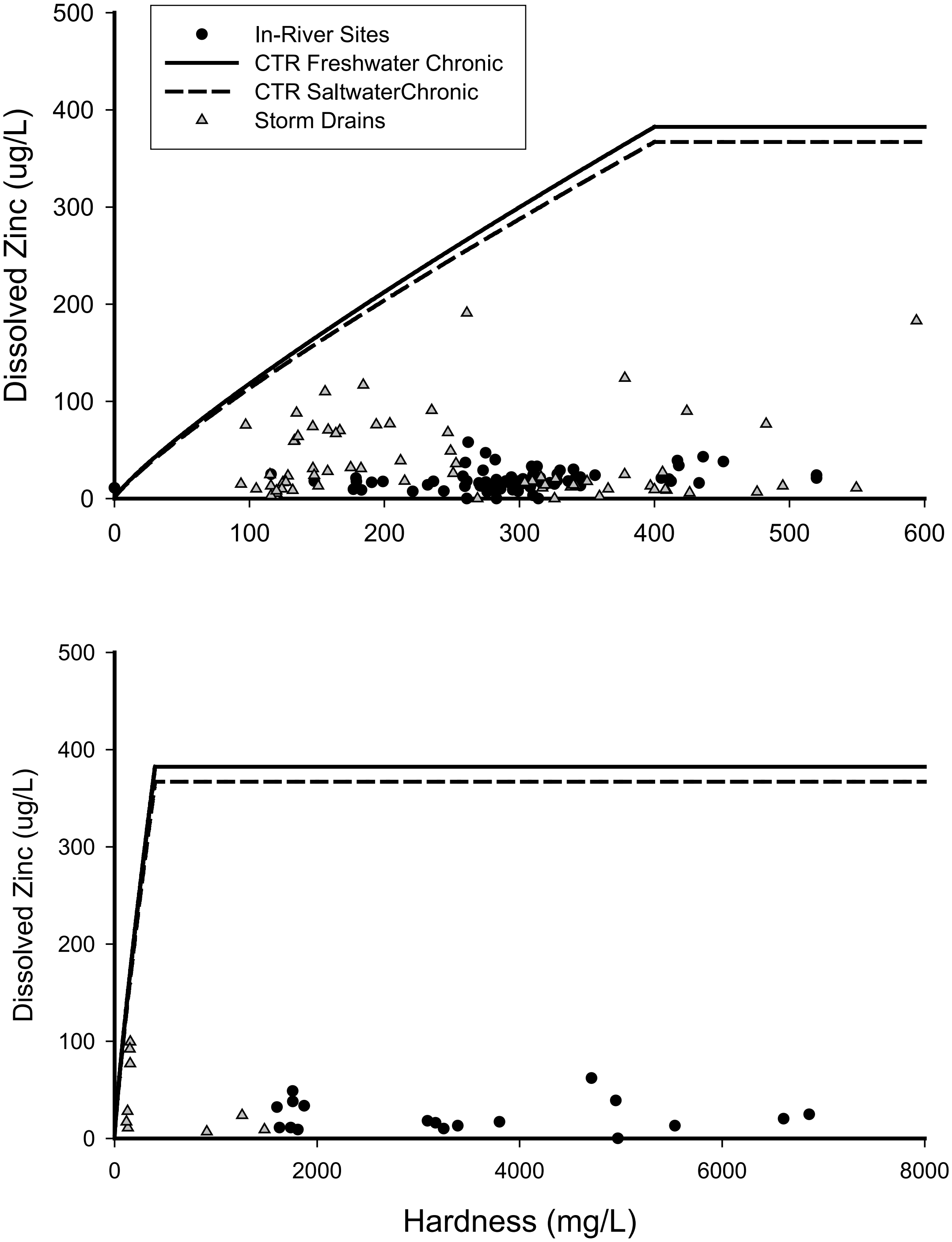

Figure 9. Comparison of storm drain and in-river dissolved zinc concentrations to the California Toxics Rule (CTR). Concentrations relative to CTR standards for both (a) upstream/freshwater and (b) downstream/tidal portion of Ballona Creek.

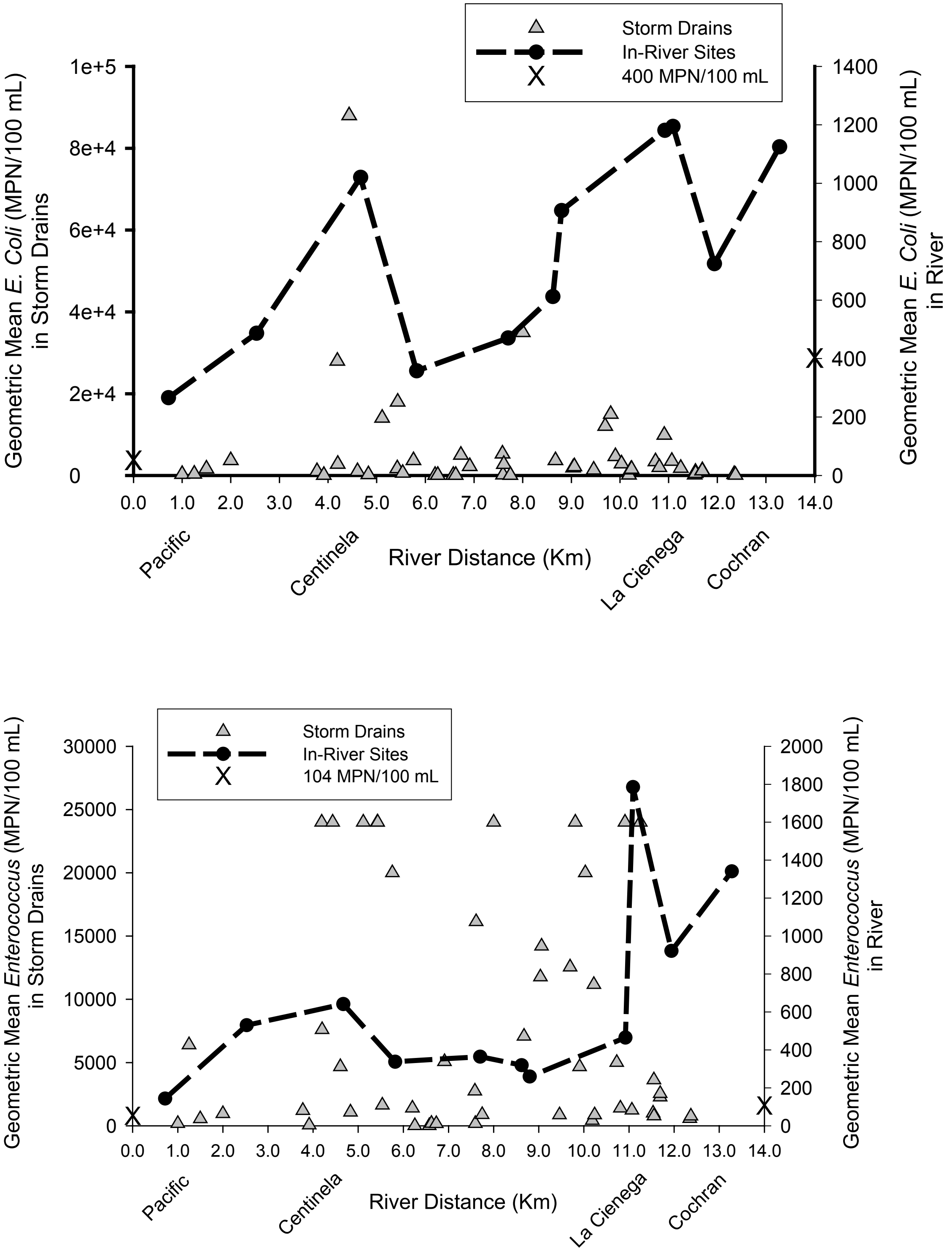

Figure 10. Mean in-river and storm drain bacteria concentrations. Concentrations of (a) *E. Coli* and (b) *Enterococcus* in storm drain and in-river sites in Ballona Creek during the 2003 dry season study. Storm drain concentrations are shown on the left axis, in-river concentrations on the right axis. X on y-axis = AB411 water quality standard.

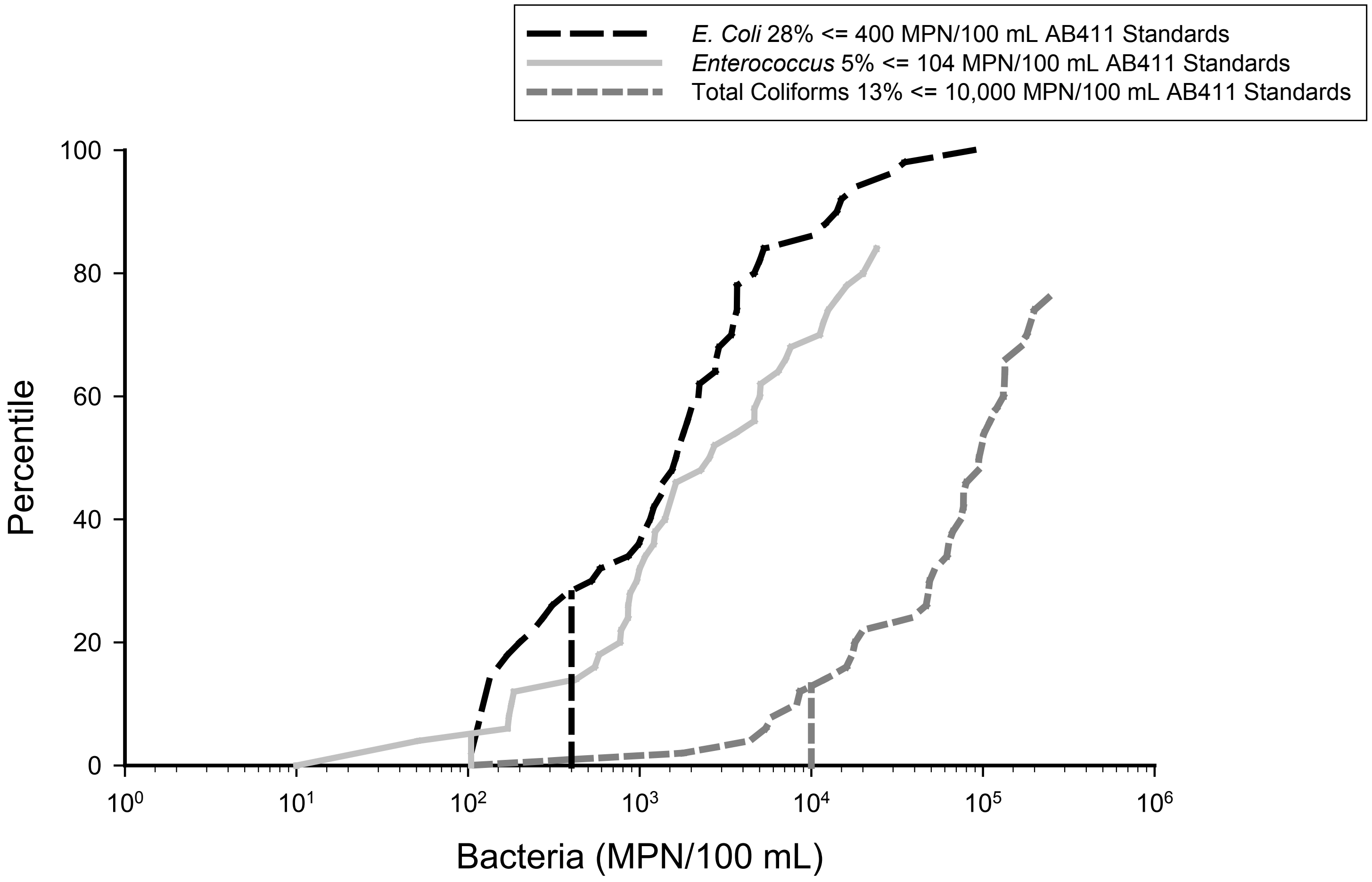

Figure 11. Cumulative frequency distribution of storm drain concentrations. Percent of storm drains discharging to Ballona Creek with specific concentrations of total coliforms, *Enterococcus* and *E. Coli*. during the 2003 dry season study. Vertical lines to each graph show AB411 water quality standard for that bacterial indicator.

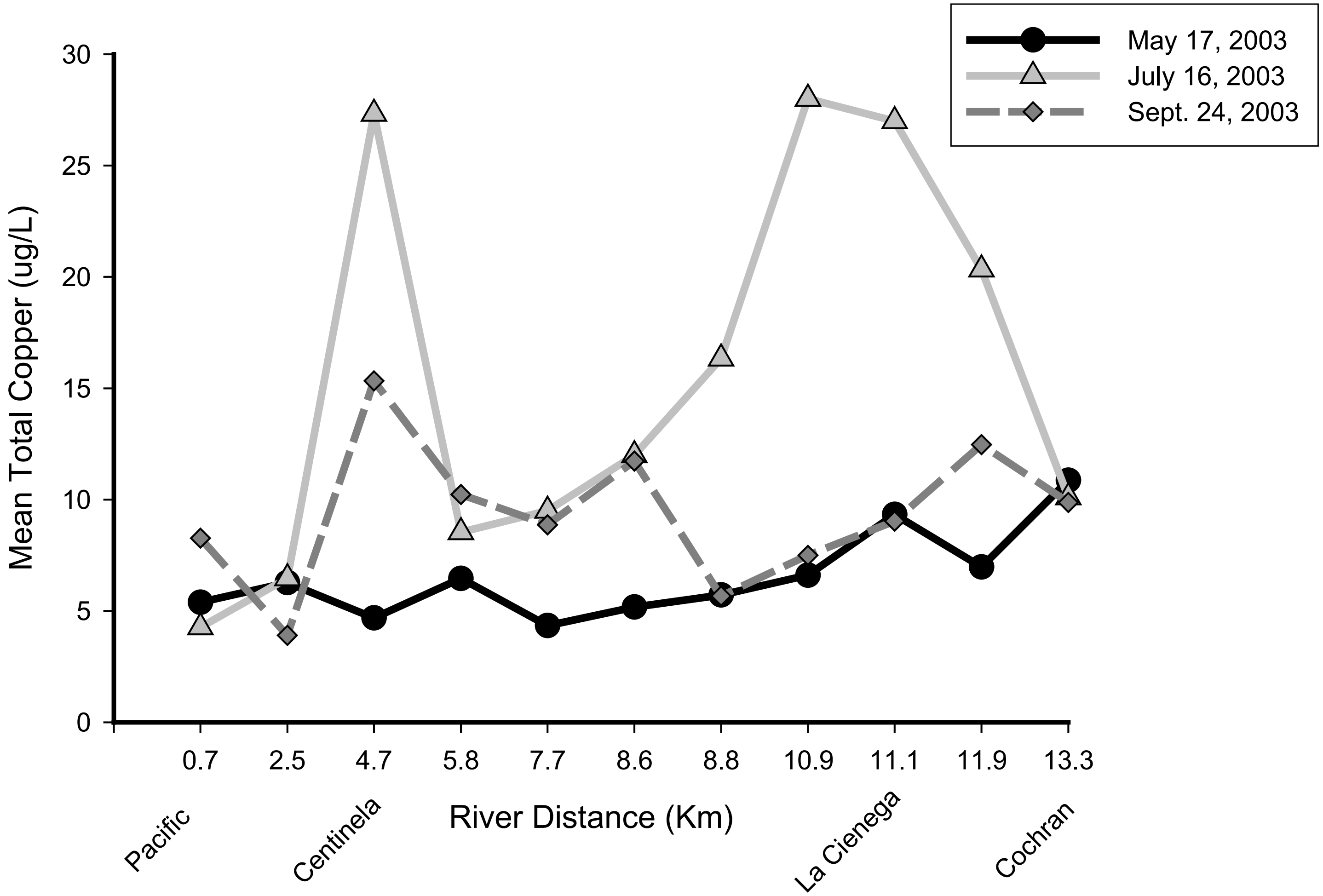

Figure 12. Intra-annual variability in copper concentration. Comparison of mean total copper concentrations in Ballona Creek in-river locations during each of the three summer 2003 dry season sampling periods.

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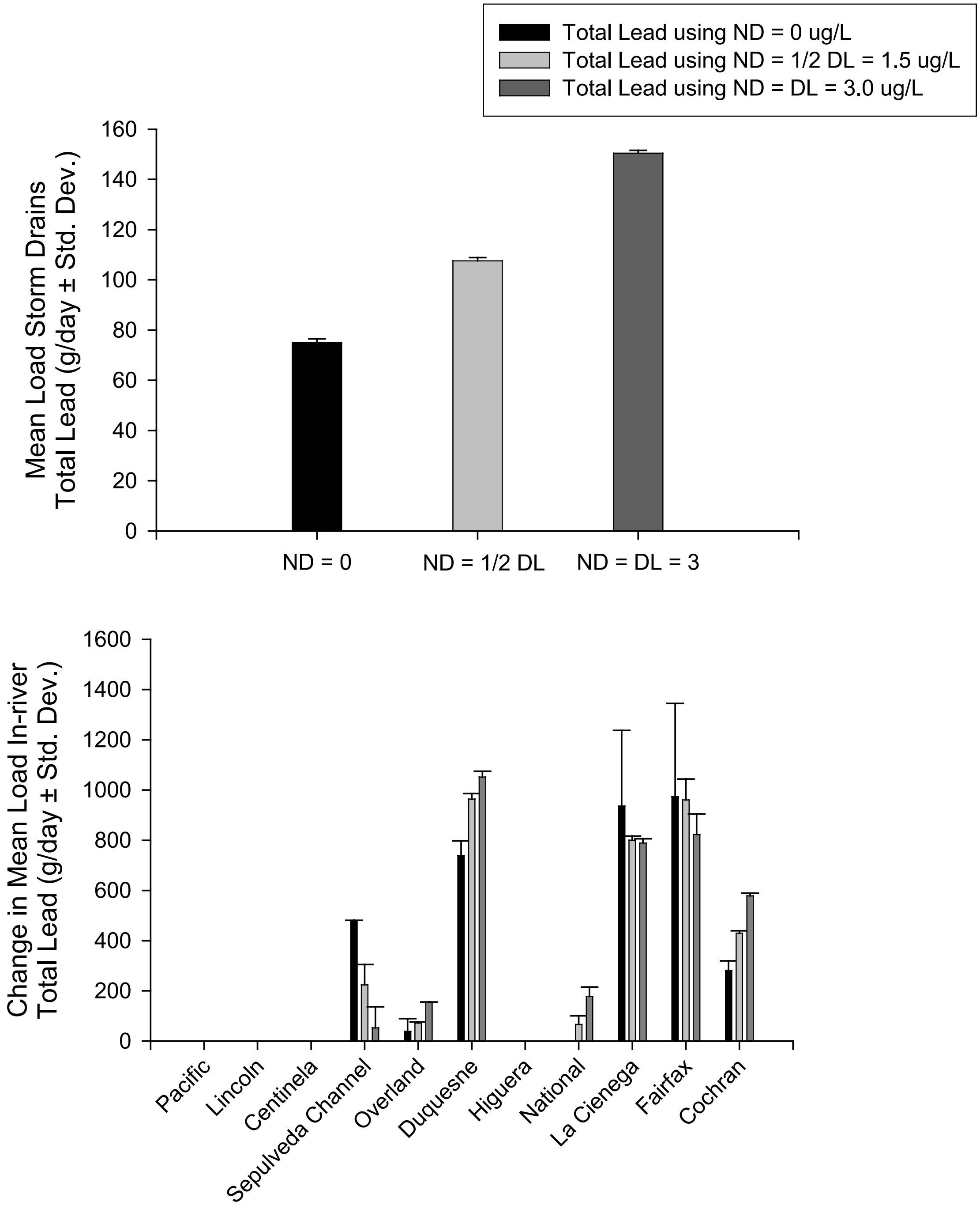

Figure 13. Effect on "non-detects" on mean mass emission estimates for total lead. Top graph (a) compares estimated mean storm drain load (± standard deviation) if non-detects are assumed to equal 0 ug/L, ½ detection limit, or equal to detection limit (3ug/L). Bottom graph (b) compares change in mean in-river load (± standard deviation) between successive sampling in-river sites for various treatments of "non-detects".

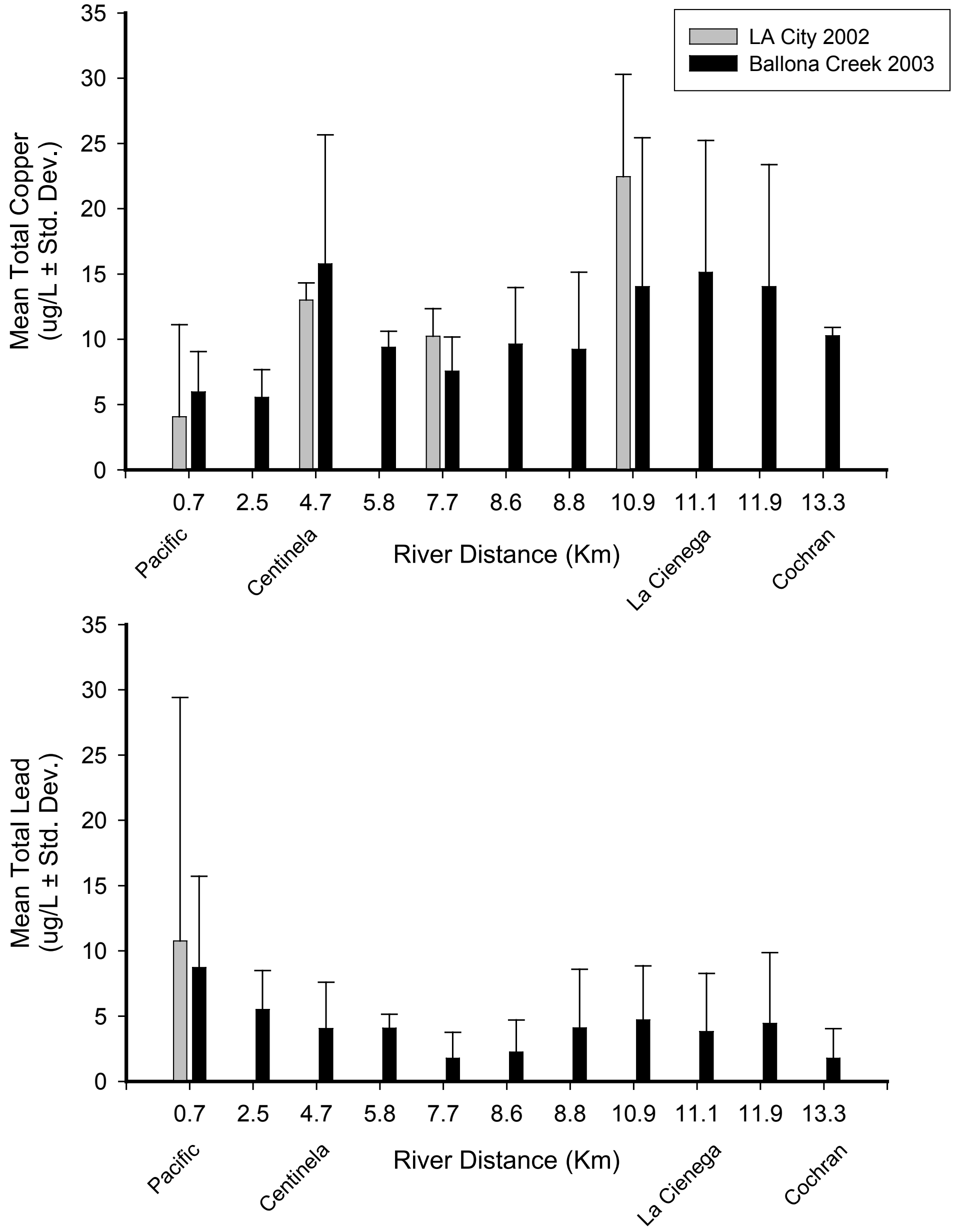

Figure 14. Inter-annual variability in copper and lead concentration. Comparison of in-river (a) total copper and (b) total lead concentrations collected in Ballona Creek in 2002 by the City of Los Angeles to concentrations collected in 2003 during this study. Means (± standard deviation) are reported. Detection limits for total copper and total lead were comparable between the two studies; 1.5 ug/L and 3 ug/L, respectively..

APPENDIX A

Trace Metals Concentrations for In-River and Storm Drain Sampling Locations

Appendix A1. Mean total and dissolved metal concentrations (ug/L ± 1 Std. Dev.) for storm drains located in Ballona Creek during the summer of 2003. Bolded values indicate higher dissolved concentrations compared to the total.

	River		Concentration (ug/L)											
	Distance from		Dissolved Cadmium		Total Cadmium		Dissolved Chromium		Total Chromium		Dissolved Copper		Total Copper	
StationID	Mouth (Km)	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
BC13	2.65	3	0.3	0.6	0.4	0.6	0.3	0.5	0.3	0.6	2.1	2.0	3.8	1.5
BC16	3.28	3	0.4	0.6	0.4	0.6	1.5	0.4	1.6	0.1	9.3	2.8	11.5	2.5
BC17	3.49	3	0.4	0.6	0.4	0.5	0.8	1.3	0.3	0.6	12.1	8.9	16.4	10.9
BC18	3.28	3	0.5	0.5	0.3	0.6	1.7	3.0	1.8	2.3	2.6	3.1	4.3	4.1
BC20	3.77	3	0.4	0.5	0.3	0.6	0.6	1.1	1.2	2.0	4.7	0.9	4.8	4.2
BC23	3.91	1	0.0		0.2		0.0		3.3		129.0		232.0	
BC25	4.20	1	0.0		0.1		0.7		1.0		4.5		16.0	
BC26	4.43	1	0.0		2.4		0.0		11.0		12.0		115.0	
BC31	4.60	3	0.5	0.2	0.6	0.2	0.7	0.6	2.2	2.5	27.3	7.3	45.1	25.4
BC41	4.83	2	0.3	0.4	0.6	0.1	0.5	0.7	4.7	5.2	16.5	0.7	56.9	52.5
BC50	5.11	2	0.0		0.3	0.4	0.8		2.7	0.8	6.5		26.0	18.4
BC54	5.42	1	0.0		0.0		0.0		0.0		7.0		8.6	
BC55	5.43	1	0.4		0.2		0.0		0.0		3.9		10.8	
BC60	5.53	3	0.4	0.5	0.4	0.5	0.4	0.7	1.5	1.6	8.8	2.3	21.2	18.5
BC63	5.76	1	0.0		0.0		0.0		0.0		4.3		7.0	
BC71	6.26	3	0.4	0.6	0.4	0.5	0.3	0.6	0.3	0.6	3.2	0.5	3.1	0.3
BC88	6.57	3	0.4	0.5	0.4	0.5	0.3	0.6	0.3	0.6	3.6	2.7	4.0	2.6
BC90	6.62	3	0.3	0.3	0.2	0.3	0.3	0.6	0.5	0.8	3.4	1.9	4.6	2.2
BC93	6.73	1	0.0		0.0		0.0		1.3		3.2		4.6	
BC100	6.91	3	0.2	0.3	0.2	0.4	0.5	0.5	1.3	0.5	16.4	20.2	18.0	18.0
BC110	7.58	3	0.3	0.6	0.3	0.6	0.6	0.5	1.7	1.8	8.3	7.3	31.2	4.7
BC120	7.60	3	0.3	0.6	0.3	0.6	0.3	0.6	0.9	0.8	21.3	2.2	12.6	8.4
BC121	7.61	2	0.0	0.0	0.1	0.1	0.0	0.0	1.3	0.8	8.6	1.8	11.6	2.0

Appendix A1 continued.

StationID	River Distance from Mouth (Km)	N	Concentration (ug/L)											
			Dissolved Cadmium		Total Cadmium		Dissolved Chromium		Total Chromium		Dissolved Copper		Total Copper	
			Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
BC124	7.75	1	0.0		0.0		0.0		0.0		28.0		36.0	
BC130	8.00	2	0.5	0.7	0.5	0.7	0.5	0.7	0.5	0.7	13.1	4.4	15.3	1.8
BC140	8.65	1	1.0		1.0		2.9		3.4		5.1		4.6	
BC150	8.67	3	0.3	0.6	0.3	0.6	1.2	1.1	2.8	1.3	9.5	3.8	12.1	2.9
BC160	9.04	2	0.0	0.0	0.0	0.0	0.0	0.0	2.8	3.0	15.7	11.0	17.1	13.0
BC161	9.06	2	0.5	0.7	0.5	0.7	0.5	0.7	2.0	0.7	31.5	8.1	46.9	19.3
BC175	9.46	2	0.6	0.6	0.6	0.6	0.6	0.8	0.8	0.1	11.9	1.6	15.0	1.4
BC185	9.69	1	1.0		1.0		1.7		1.4		7.9		8.1	
BC189	9.81	1	1.0		1.0		2.5		2.7		23.6		24.8	
BC190	9.90	1	0.0		0.0		0.0		0.0		6.1		11.0	
BC191	10.03	1	0.8		0.9		3.0		3.8		2.0		2.4	
BC195	10.19	2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	1.9	0.4	1.1	1.6
BC199	10.22	3	0.3	0.6	0.3	0.6	2.1	1.9	3.8	4.0	29.4	41.8	38.6	57.5
BC200	10.24	3	0.3	0.6	0.3	0.6	0.4	0.8	1.3	1.6	12.7	3.3	18.2	5.2
BC210	10.73	3	0.2	0.3	0.4	0.5	1.6	0.7	1.5	0.7	17.8	8.9	20.3	9.7
BC250	11.06	3	0.8	0.8	0.8	0.8	3.0	3.7	1.5	1.8	18.5	8.9	21.1	9.0
BC271	11.25	1	0.0		0.0		1.1		1.6		36.6		40.5	
BC298	11.54	1	1.0		1.0		**1.6**		-0.1		19.0		17.1	
BC299A	11.55	3	0.3	0.6	0.3	0.6	2.3	0.8	3.9	1.9	17.2	7.8	21.0	7.7
BC299B	11.56	3	0.3	0.6	0.3	0.6	0.8	0.9	0.8	0.8	18.1	17.0	18.3	17.7
BC300	11.69	3	0.3	0.6	0.3	0.6	2.1	0.6	1.9	0.2	7.6	2.8	7.4	0.9
BC310	11.69	2	0.5	0.7	0.5	0.7	2.3	0.8	2.6	0.2	15.0	11.4	16.7	9.6
BC350	12.35	3	0.3	0.6	0.3	0.6	2.4	1.2	2.6	0.7	10.9	8.3	11.2	6.8
BC360	12.37	3	0.3	0.6	0.3	0.6	**3.0**	1.0	2.8	0.6	8.9	6.1	10.4	6.4

Appendix A1 continued.

	River Distance from		Concentration (ug/L)											
			Dissolved Lead		Total Lead		Dissolved Nickel		Total Nickel		Dissolved Zinc		Total Zinc	
StationID	Mouth (Km)	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
BC13	2.65	3	**4.9**	3.6	4.4	2.9	3.0	1.0	3.2	1.0	16.8	5.7	21.4	10.8
BC16	3.28	3	0.3	0.6	1.7	2.1	4.4	1.4	4.0	1.4	37.7	26.1	48.2	17.1
BC17	3.49	3	2.0	2.6	3.1	1.8	5.2	0.7	4.9	0.3	18.1	9.8	28.9	7.0
BC18	3.28	3	4.5	2.0	4.7	2.7	5.4	2.0	4.3	0.1	11.8	6.9	18.4	5.6
BC20	3.77	3	3.1	2.0	4.8	2.0	4.1	1.0	5.2	0.6	13.1	9.1	21.9	7.8
BC23	3.91	1	0.0		7.5		5.1		7.7		11.0		93.0	
BC25	4.20	1	0.0		0.0		2.4		2.7		17.0		41.0	
BC26	4.43	1	0.0		102.0		4.9		25.0		28.0		2190.0	
BC31	4.60	3	6.0	1.7	20.2	25.9	8.1	0.7	10.7	4.7	89.4	11.3	210.7	172.6
BC41	4.83	2	2.5	3.5	17.0	22.6	8.7	0.9	15.0	12.7	46.0	39.6	221.5	210.0
BC50	5.11	2	3.4		9.0	4.2	9.5		8.6	4.9	76.0		130.5	68.6
BC54	5.42	1	0.0		0.0		3.1		3.5		17.0		26.0	
BC55	5.43	1	0.0		0.0		9.4		9.7		28.0		30.0	
BC60	5.53	3	0.3	0.6	2.2	3.0	8.4	2.6	11.0	2.9	11.6	1.2	34.9	34.9
BC63	5.76	1	0.0		0.0		5.4		5.8		13.0		24.0	
BC71	6.26	3	0.5	0.9	1.7	2.1	1.2	0.5	1.7	0.9	7.2	7.9	3.6	1.2
BC88	6.57	3	0.3	0.6	0.3	0.6	1.6	1.1	1.0	0.6	10.2	6.6	10.7	5.5
BC90	6.62	3	0.4	0.7	0.3	0.6	2.8	1.8	3.4	2.6	9.8	7.0	16.4	13.1
BC93	6.73	1	0.0		0.0		3.4		3.7		24.0		62.0	
BC100	6.91	3	0.8	1.4	1.5	2.7	4.5	4.7	3.2	2.3	44.9	62.2	55.5	49.5
BC110	7.58	3	3.0	4.4	5.3	0.6	2.9	1.3	2.4	0.9	48.7	28.0	48.7	50.5
BC120	7.60	3	**2.0**	2.6	0.3	6.1	3.5	1.4	2.8	2.2	32.9	27.9	71.8	50.5
BC121	7.61	2	0.0	0.0	2.0	2.9	6.3	0.5	6.5	1.3	49.0	25.5	80.5	53.0

Appendix A1 continued.

	River		Concentration (ug/L)											
	Distance from		Dissolved Lead		Total Lead		Dissolved Nickel		Total Nickel		Dissolved Zinc		Total Zinc	
StationID	Mouth (Km)	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
BC124	7.75	1	0.0		3.0		4.1		4.1		39.0		94.0	
BC130	8.00	2	1.0	1.4	1.3	1.9	2.8	0.9	5.1	2.4	42.0	47.5	16.4	6.2
BC140	8.65	1	**1.7**		1.0		8.6		9.3		12.2		15.9	
BC150	8.67	3	0.3	0.6	0.7	1.3	3.1	0.5	3.9	0.3	57.8	44.7	65.4	75.4
BC160	9.04	2	3.5	4.9	3.5	4.9	7.1	0.3	7.8	1.3	68.5	78.5	98.6	126.5
BC161	9.06	2	**3.6**	5.1	1.8	2.5	4.2	1.6	5.2	0.5	56.9	43.8	52.6	13.2
BC175	9.46	2	4.8	4.6	6.2	2.6	6.0	4.9	6.3	5.0	84.8	35.7	93.0	52.3
BC185	9.69	1	1.0		1.0		**6.7**		6.0		14.1		17.5	
BC189	9.81	1	1.0		1.0		8.1		11.0		10.9		16.8	
BC190	9.90	1	0.0		0.0		6.0		6.2		32.0		71.0	
BC191	10.03	1	1.0		1.0		6.2		7.1		1.0		1.0	
BC195	10.19	2	**2.0**	2.8	0.0	0.0	2.2	0.3	1.7	1.0	10.8	3.0	21.8	18.6
BC199	10.22	3	12.3	20.5	17.0	28.6	3.5	2.4	4.5	2.2	63.9	103.1	91.3	151.4
BC200	10.24	3	0.3	0.6	1.3	1.5	3.8	1.9	4.9	2.1	27.0	11.5	46.4	31.5
BC210	10.73	3	2.3	3.2	3.7	5.5	5.5	1.7	6.3	1.2	69.2	20.9	71.4	16.4
BC250	11.06	3	3.7	3.0	4.4	2.9	8.3	3.5	7.4	3.5	112.9	67.7	137.3	77.9
BC271	11.25	1	**25.0**		24.0		5.8		5.9		**1040.0**		987.0	
BC298	11.54	1	1.0		1.0		**5.6**		4.8		23.2		20.5	
BC299A	11.55	3	0.3	0.6	0.3	0.6	2.4	2.9	4.0	1.6	15.8	4.0	18.0	5.0
BC299B	11.56	3	**3.7**	5.5	3.0	4.4	**4.2**	2.2	2.4	1.5	12.3	12.4	9.5	9.0
BC300	11.69	3	0.3	0.6	0.3	0.6	1.8	1.6	1.4	1.6	17.4	9.2	17.8	5.7
BC310	11.69	2	**2.0**	1.4	0.5	0.7	1.1	0.6	1.7	1.1	25.3	10.9	20.9	7.2
BC350	12.35	3	**5.0**	3.6	3.0	4.3	**2.6**	1.9	2.5	1.9	6.4	5.6	6.6	6.1
BC360	12.37	3	0.3	0.6	0.3	0.6	3.5	1.8	3.6	2.2	11.3	10.0	17.7	9.1

Appendix A2. Mean total metal concentrations (ug/L ± 1 Std. Dev.) for in-river sites located in Ballona Creek during the summer of 2003. Bolded values indicate higher dissolved concentrations compared to the total.

	River		Concentration (ug/L)											
	Distance from		Dissolved Cadmium		Total Cadmium		Dissolved Chromium		Total Chromium		Dissolved Copper		Total Copper	
StationID	Mouth (Km)	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Pacific	0.72	9	0.5	0.4	0.5	0.5	0.6	0.6	1.3	1.7	5.2	4.0	6.0	3.1
Lincoln	2.53	9	0.3	0.5	0.3	0.5	0.7	1.1	0.7	1.1	4.4	2.3	5.5	2.1
Centinela	4.67	9	0.3	0.5	0.3	0.5	1.2	0.6	2.0	0.8	8.6	4.8	15.8	9.9
Sepulveda Channel	5.82	6	0.0	0.0	0.0	0.0	1.5	0.3	1.8	0.3	6.8	3.0	9.4	1.2
Overland	7.7	9	0.4	0.5	0.3	0.5	1.2	0.8	1.8	0.4	5.4	1.8	7.6	2.6
Duquesne	8.62	9	0.4	0.5	0.4	0.5	1.3	0.9	1.9	0.5	6.4	4.5	9.6	4.3
Higuera	8.8	9	0.3	0.5	0.3	0.5	1.3	0.9	2.2	0.8	5.8	2.9	9.2	5.9
National	10.92	9	0.3	0.5	0.4	0.5	1.4	0.9	2.5	1.0	5.9	2.0	14.0	11.4
La Cienega	11.09	9	0.3	0.5	0.4	0.5	1.2	1.1	2.0	0.9	7.6	1.9	15.1	10.1
Fairfax	11.94	8	0.3	0.5	0.3	0.5	1.2	0.8	2.0	1.2	8.9	3.0	14.0	9.3
Thurman Overpass	12.5	2	0.0	0.0	0.0	0.0	0.9	1.3	0.6	0.8	16.1	5.8	19.8	5.4
Cochran	13.28	9	0.3	0.5	0.3	0.4	1.1	0.9	2.0	1.6	7.5	2.0	10.3	0.6

Appendix A2 continued.

StationID	River Distance from Mouth (Km)	N	Concentration (ug/L) Dissolved Lead Mean	Dissolved Lead Std. Dev.	Total Lead Mean	Total Lead Std. Dev.	Dissolved Nickel Mean	Dissolved Nickel Std. Dev.	Total Nickel Mean	Total Nickel Std. Dev.	Dissolved Zinc Mean	Dissolved Zinc Std. Dev.	Total Zinc Mean	Total Zinc Std. Dev.
Pacific	0.72	9	**9.3**	7.9	8.7	7.0	3.4	2.1	3.6	2.0	22.0	18.5	22.6	15.3
Lincoln	2.53	9	5.2	3.3	5.5	3.0	**7.0**	6.4	6.8	6.5	24.2	14.2	26.1	15.7
Centinela	4.67	9	2.2	2.7	4.1	3.5	6.7	3.0	7.5	3.6	15.3	11.4	26.3	20.9
Sepulveda Channel	5.82	6	3.2	1.8	4.1	1.1	2.3	1.2	2.7	1.4	29.2	19.6	35.2	8.6
Overland	7.7	9	1.6	2.0	1.8	2.0	**3.2**	1.1	2.8	1.0	20.5	12.7	28.9	14.1
Duquesne	8.62	9	1.6	2.7	2.3	2.5	**2.9**	1.2	2.5	0.9	19.7	10.0	25.2	7.3
Higuera	8.8	9	1.3	1.8	4.1	4.5	**3.7**	2.3	3.4	2.3	22.4	11.9	33.9	11.3
National	10.92	9	1.3	2.3	4.7	4.1	2.5	0.9	3.7	1.1	14.8	5.3	33.9	24.0
La Cienega	11.09	9	1.3	2.2	3.8	4.5	**2.9**	1.4	2.8	1.4	17.0	6.1	33.6	21.4
Fairfax	11.94	8	2.2	2.5	4.5	5.4	3.5	1.5	3.1	1.3	16.5	9.5	26.5	19.3
Thurman Overpass	12.5	2	0.0	0.0	1.8	2.5	3.8	0.9	4.0	1.1	21.5	4.9	37.0	9.9
Cochran	13.28	9	0.9	1.2	1.8	2.3	2.7	0.6	3.3	0.6	20.2	5.1	26.7	2.8

APPENDIX B

Bacteria Concentrations for In-River and Storm Drain Sampling Locations

Appendix B1. Mean bacteria concentrations (MPN/100 mL ± 1 Std. Dev.) for storm drains located in Ballona Creek during the summer of 2003.

	River		Concentration (MPN/100 mL)					
	Distance from		*E. Coli*		*Enterococcus*		Total Coliforms	
StationID	Mouth (Km)	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
BC13	2.65	3	310.0	281.6	178.7	124.4	6.7E+04	5.3E+04
BC16	3.28	3	376.7	162.6	6400.0	3252.7	1.3E+05	6.0E+04
BC17	3.49	3	1626.7	660.4	546.7	566.2	1.7E+05	1.3E+05
BC18	3.28	3	3683.3	5480.0	960.0	1084.3	1.1E+05	1.2E+05
BC20	3.77	3	986.7	554.7	1206.7	769.5	1.3E+05	1.1E+05
BC23	3.91	1	100.0		51.0		8.6E+03	
BC24	4.19	2	28000.0		>24000		>240000	
BC25	4.20	1	2800.0		7600.0		>240000	
BC26	4.43	1	88000.0	73539.1	>24000		>240000	
BC31	4.60	3	986.7	956.3	4666.7	4105.3	1.3E+05	1.0E+05
BC41	4.83	3	240.0	242.5	1078.3	1579.3	1.7E+04	1.5E+04
BC50	5.11	2	14050.0	18314.1	24000.0		>240000	
BC54	5.42	1	1700.0		24000.0		>240000	
BC55	5.43	1	18000.0		>24000		>240000	
BC60	5.53	2	590.0	551.5	1630.0	2078.9	5.3E+04	6.4E+04
BC63	5.76	1	3700.0		20000.0		>240000	
BC70	6.20	1	<100		1400.0		1.2E+05	
BC71	6.26	3	<100		<10		<100	
BC88	6.57	3	<100		<10	5.8	4.4E+03	7.4E+03
BC90	6.62	2	<100		185.0	247.5	8.3E+03	8.1E+03
BC93	6.73	1	5000.0		170.0		7.7E+04	
BC100	6.91	3	2233.3	2554.1	5066.7	6870.5	9.5E+04	9.1E+04
BC110	7.58	3	5300.0	6090.2	2731.7	2436.5	9.8E+04	8.5E+04
BC120	7.60	3	170.0	121.2	173.3333	282.9016	5.4E+03	9.2E+03
BC121	7.61	3	2760.0	2186.0	16126.67	13637.01	1.8E+05	7.2E+04
BC124	7.75	1	<100		880.0		4.9E+04	
BC130	8.00	2	35000.0	32526.9	>24000	0	>240000	
BC150	8.67	3	3683.3	5384.1	7076.7	11192.9	8.0E+04	1.0E+05
BC160	9.04	3	1900.0	1800.0	11766.7	10896.9	1.8E+05	5.3E+04
BC161	9.06	2	2200.0		14200.0	13859.3	>240000	
BC175	9.46	3	1336.7	923.6	856.7	372.9	7.4E+04	4.7E+04
BC185	9.69	2	12050.0	16899.9	12550.0	16192.7	1.4E+05	1.5E+05
BC189	9.81	1	15000.0		>24000		>240000	
BC190	9.90	2	4650.0	3889.1	4660.0	5713.4	>240000	
BC191	10.03	1	2900.0		20000.0		1.8E+04	
BC195	10.19	2	150.0	70.7	425.0	586.9	1.8E+03	4.2E+02

Appendix B1 continued.

	River		Concentration (MPN/100 mL)					
	Distance from		*E. Coli*		*Enterococcus*		Total Coliforms	
StationID	Mouth (Km)	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
BC199	10.22	3	1370.0	832.9	11166.7	11320.0	1.0E+05	1.2E+05
BC200	10.24	3	1540.0	1158.8	853.3	626.3	6.2E+04	6.3E+04
BC210	10.73	3	3420.0	5106.4	5003.3	7793.3	9.4E+04	1.3E+05
BC212	10.81	1	2000.0		1400.0		2.0E+05	
BC214	10.91	1	9900.0		>24000		>240000	
BC250	11.06	3	3533.3	3265.5	1232.7	987.7	6.3E+04	9.3E+04
BC271	11.25	1	1800.0		>24000		>240000	
BC298	11.54	1	200.0		1000.0		1.2E+04	
BC299A	11.55	2	855.0	770.7	3625.0	4631.5	4.8E+04	2.4E+04
BC299B	11.56	3	523.3	369.5	780.0	620.0	7.7E+04	1.1E+05
BC300	11.69	3	1210.0	585.1	2266.7	1514.4	4.7E+04	1.1E+04
BC310	11.69	2	1150.0	70.7	2550.0	70.7	3.9E+04	2.3E+04
BC350	12.35	3	273.3	219.4	580.0	226.1	1.6E+04	1.0E+03
BC360	12.37	3	133.3	57.7	766.7	167.7	2.0E+04	6.0E+03
BC672	?	1	100.0		1400.0		6.0E+03	

Appendix B2. Mean bacteria concentrations (MPN/100 mL ± 1 Std. Dev.) for in-river sites located in Ballona Creek during the summer of 2003.

	River		Concentration (MPN/100 mL)					
	Distance from		*E. Coli*		*Enterococcus*		Total Coliforms (x 10^4)	
StationID	Mouth (Km)	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Pacific	0.72	9	265.6	283.0	146.0	122.8	6.6	9.4
Lincoln	2.53	9	486.7	441.2	530.0	406.1	6.8	6.7
Centinela	4.67	9	1020.0	640.9	640.8	675.9	5.2	4.5
Sepulveda Channel	5.82	6	358.3	171.0	337.2	238.1	2.4	1.4
Overland	7.7	9	470.0	390.7	363.4	448.1	2.0	1.5
Duquesne	8.62	9	612.2	419.2	318.9	295.4	2.7	1.0
Higuera	8.8	9	906.7	740.7	259.1	172.0	3.2	0.6
National	10.92	9	1181.1	962.6	464.4	167.3	3.4	1.1
La Cienega	11.09	9	1194.4	922.2	1784.2	2014.7	4.2	2.3
Fairfax	11.94	9	724.4	614.8	922.4	823.0	3.6	2.7
Thurman Overpass	12.5	2	23100.0	29557.1	8550.0	6293.3	8.6	3.5
Cochran	13.28	9	1124.4	657.2	1340.0	1205.1	6.2	3.6