IV

Quality of Urban Runoff in the Tijuana River Watershed

Richard M. Gersberg, Chris Brown, V ctor Zambrano,
Karilyn Worthington, and Daniel Weis

ABSTRACT

A sampling program was conducted to assess the quality of runoff associated with a variety of land uses in the Tijuana River watershed, a binational river basin on the U.S. Mexican border. Generally, metal concentrations in samples collected during the first two to four hours of runoff (early storm) were higher than those in samples collected 24 36 hours into the rain event (late storm). A notable exception to this pattern was observed for the site on Tecate Creek, where levels of cadmium, chromium, copper, and nickel were higher in the late-storm sample. This is possibly due to the point source discharge of wastewater effluent from the Tecate Municipal Wastewater Treatment Plant just one mile upstream. At the industrial site, concentrations of lead and zinc in samples of early-storm runoff fell in the 85th percentile range (80th percentile for copper) of a U.S. industrial runoff dataset (Line et al. 1997). Other urban land-use sites (including residential and commercial) were generally comparable to the 90th percentile values for wet-weather runoff in an urban watershed of Los Angeles County. The resulting data suggest that nonpoint source pollution arising from a variety of land uses in the Tijuana River watershed will continue to enter the Tijuana Estuary and near-shore ocean during wet weather, arguing for basin-wide wastewater and stormwater management in this urban watershed.

INTRODUCTION

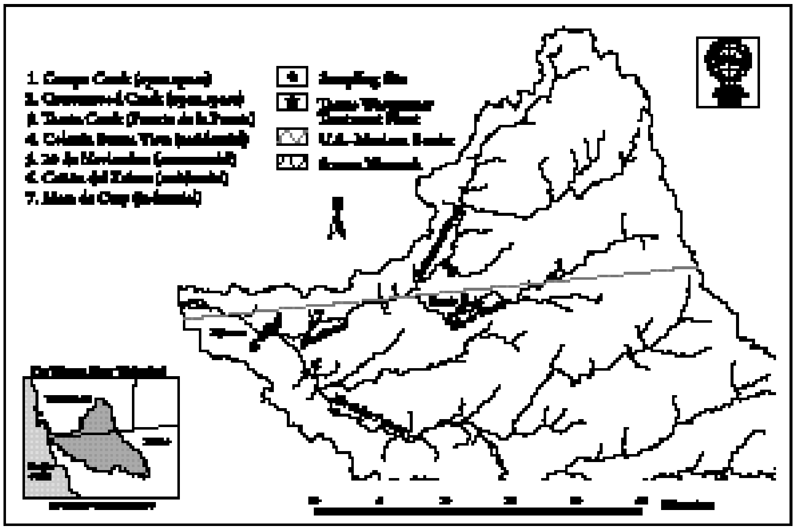
For decades, raw sewage from the city of Tijuana, Mexico, has flowed into the Tijuana River and across the international border into the Tijuana Estuary. This problem has worsened in recent years with the substantial growth of Tijuana s population, along with the intensive industrial development associated with the maquiladora program (in-bond manufacturing and assembly plants) in Mexico. Although discharges from the Tijuana River watershed account for only a small percentage of total gauged runoff to the Southern California coastal ocean, it contains the highest concentrations of suspended solids, Cd, Cu, Ni, Pb, Zn, and PCBs among the eight largest creeks and rivers in Southern California (SCCWRP 1992).

Many of the water quality problems in the Tijuana River watershed are due to diffuse, nonpoint sources of pollution and, as such, may be addressed more effectively along watershed lines. Managing natural resources on a watershed basis offers a geographic context within which the interactions of land, water, and human activity can be monitored, assessed, and understood. Nonpoint pollution processes, such as stormwater runoff, are inherently difficult to model due to the temporal and spatial complexity of pollutant loading and hydrological processes. Such modeling generally requires organizing and processing large amounts of spatially referenced data. To accomplish this, a geographic information system (GIS) may be linked with a hydrological urban runoff model and land-use-specific water quality data to estimate the mass emission of selected anthropogenic pollutants into the Tijuana Estuary. Unfortunately, no data currently exist on the water quality characteristics of runoff in the Tijuana River watershed. The objective of this study was to generate such land-use-specific water quality data for the Mexican portion of the Tijuana River watershed, including industrial, residential, commercial, and open-land sites, as well as Tecate Creek. In addition, we compare the water quality at these sites to that in the main river during rain events, and to stormwater quality of similar land-use sites in the United States.

METHODOLOGY

Seven sites were sampled in the Tijuana River watershed: two in the United States (Campo and Cottonwood Creeks), and the remaining sites in Mexico (Figure 1). The specific geographical coordinates for these sites were determined with a global positioning system (GPS) receiver, and were then incorporated into a GIS for further analysis.

Figure 1: Water Quality Sampling Sites



Determination of Land-Use Types within Each Contributing Subbasin

To delineate which land-use types were present within the subbasins upstream from the sampling points, we used modeling algorithms in our GIS software, a digital elevation model (DEM), and the locational data of the sampling sites to generate boundaries of the subbasins. Specifically, the GRID module of the Arc/Info GIS was used to examine a DEM for the Tijuana River basin to model the direction and accumulation of surface water flows for each grid cell. The resulting flow direction and accumulation data formed the basis for a stream network map for the entire basin. Then, each sampling point s location was placed exactly on the stream network and a further series of algorithms was run that incorporated the accumulation data in order to generate the specific boundaries of the contributing subbasins above each of the sampling points. These subbasin boundaries were then overlaid with land-use data for the larger watershed to determine the composition of the land use within each subbasin. The locations of these sites in the watershed are shown in Figure 1 and are described below.

Open-Space Sites

Two sites, which drained mostly rural and undeveloped subbasins, were sampled to characterize this land use. The first site, Campo

Creek in the United States, is just upstream of the city of Tecate, Mexico, and is 88% undeveloped. This reach of the river runs through a sparsely populated, predominantly agricultural rural area and flows into Tecate Creek, a main tributary of the Tijuana River. The other site, on Cottonwood Creek, is located directly under the State Highway 94 bridge and drains a region that is mostly undeveloped (92%), with limited agricultural activities.

Residential Sites

Two sites were sampled to characterize this type of land use. The first, Colonia Buena Vista, lies in an arroyo that drains a fairly large residential area of Tijuana near Otay Mesa. This site is nearly 100% residential land use. The Colonia Buena Vista extends along the length of the channelized Tijuana River and is comprised of two settlements of low-income families. The second site, located in Caæ n del Zaines, is an arroyo that drains a large residential area of southwestern Tijuana, and then empties into the R o de las Palmas branch of the river. Residential land use comprises about 30% of the developed land-use area of this urbanizing subbasin.

Industrial Site

This site lies at the foot of Otay Mesa, and drains a rather small subbasin (Otay Mesa) that is almost entirely developed (98.5%) with maquiladoras industrial facilities comprised mostly of assembly and manufacturing plants. Maquiladora plants are foreign-owned facilities that had initially used lower-priced Mexican labor to assemble goods from imported components, however, currently, NAFTA has allowed many of these plants to be full-scale production facilities. Industries located at this site include Nypro, Matsushita, Hitachi, Tabuchi Electr nica, Tocabi, Sanyo, Santomi, and Energy Labs.

Commercial Site

This site is on a large stormwater channel that drains a main commercial center close to the Tijuana River. The site is located on Avenida 20 de Noviembre in the colonia (neighborhood) of the same name, at the intersection of several important transit routes: Blvd. D az Ordaz, Blvd. Ben tez, Blvd. Agua Caliente, Paseo de los HØroes, and Calle F. C. Sonora. Of the developed land-use area at this site, commercial use accounts for about 40% of the total.

Tecate Creek Site

Tecate Creek lies just below the urban area of Tecate, Mexico, (a city of 90,000 inhabitants) and is a major tributary of the Tijuana River.

Tecate has marginal sewage treatment and disposal infrastructure. This site is located approximately one mile downstream from the Tecate Municipal Wastewater Treatment Plant. It drains a very large subbasin of 39,660 hectares, which is 81.5% nondeveloped. The two major land-use categories are agriculture and residential, comprising 9.5% and 3.8%, respectively, of the total land-use area of this subbasin.

Chemical and Biological Analyses

A total of seven storm events were sampled at Lindbergh Field, San Diego, with the dates of each storm and the total amount of precipitation given below. Three events were sampled during the 1996 1997 rainy season: 21 23 November 1996 (4.3 cm), 15 17 January 1997 (0.53 cm), and 10 12 March 1997 (< 0.25 cm). During the 1997 1998 rainy season, four storm events were sampled: 24 25 September 1997 (2.0 cm), 26 27 November 1997 (1.0 cm), 9 10 January 1998 (2.9 cm), and 14 15 February 1998 (2.9 cm).

Surface water grab samples were taken twice during each storm event once within the first two to four hours of the storm s inception (early-storm samples), and once again at an interval of 24 36 hours after the first sample was taken (late-storm samples). An exception to this regime was the commercial site (September 1997 and November 1997 events) and light industrial site (January 1998 and February 1998 events), which were sampled on four occasions during the above rain events.

All samples were handled, preserved, and analyzed according to the Standard Methods for the Examination of Water and Wastewater (APHA, AW WA, WPCF 1989). Stormwater samples were filtered (for dissolved metal analysis), and the filter was then digested for total metal analysis. Both particulate and dissolved metal concentrations were analyzed by graphite furnace atomic absorption (GFAA) using a Perkin-Elmer SIMAA 6000 A A with Zeeman corrector. The exception was for the analysis of Zn, where flame atomic absorption spectrophotometry (Perkin-Elmer Model 2380) was used because of the relatively high levels of this metal. Quality assurance/quality control (QA/QC) for metals analysis included duplicate analyses, blanks, and standard additions to stormwater samples consisting of both dissolved metal spikes, and particulate metal spikes (in the form of a soil standard addition). Statistical analyses comparing metal levels among land-use sites and for early- versus late-storm samples were done using the Student s T-test.

Figure 2: Cd Concentrations for Early- and Late-Storm Events

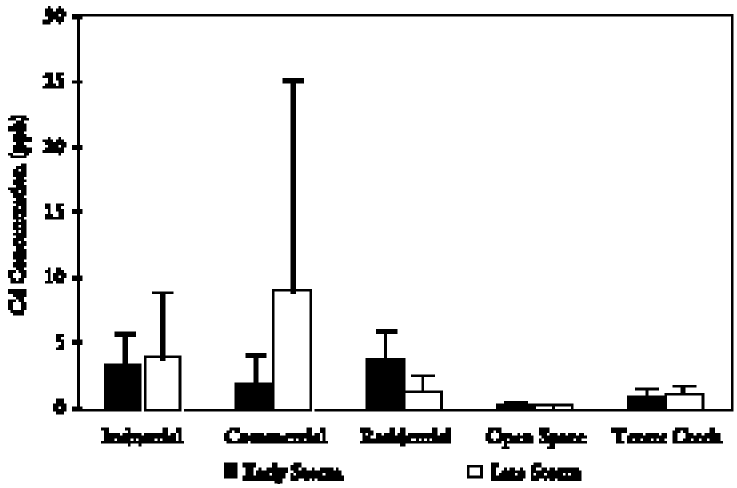
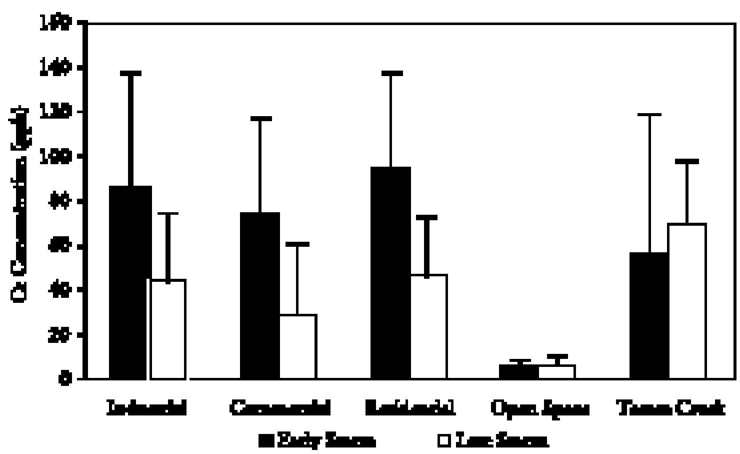


Figure 3: Cr Concentrations for Early- and Late-Storm Events



RESULTS AND DISCUSSION

This study was conducted to characterize the metal levels in stormwater runoff from a variety of land-use sites in the Tijuana River watershed. During the 1996 1997 rainy season, precipitation was relatively light, with only 17.5 cm recorded at Lindbergh Field, San Diego, from 1 October 1996 through 31 May 1997. From 1 October 1997 through 31 May 1998, precipitation was relatively high, with 42.7 cm recorded. The precipitation for each storm event sampled is

Figure 4: Cu Concentrations for Early- and Late-Storm Events

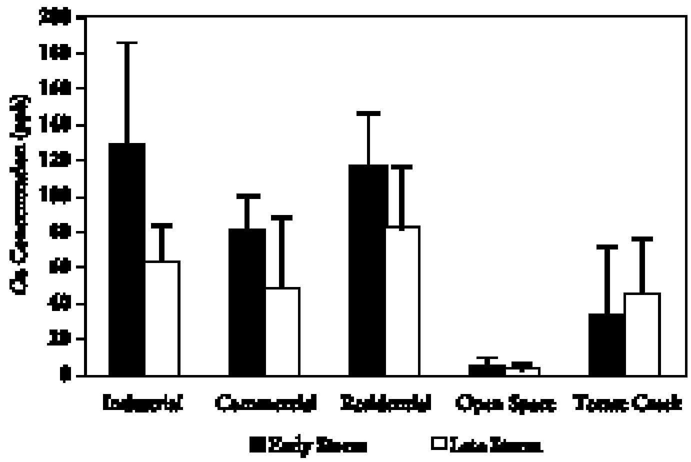
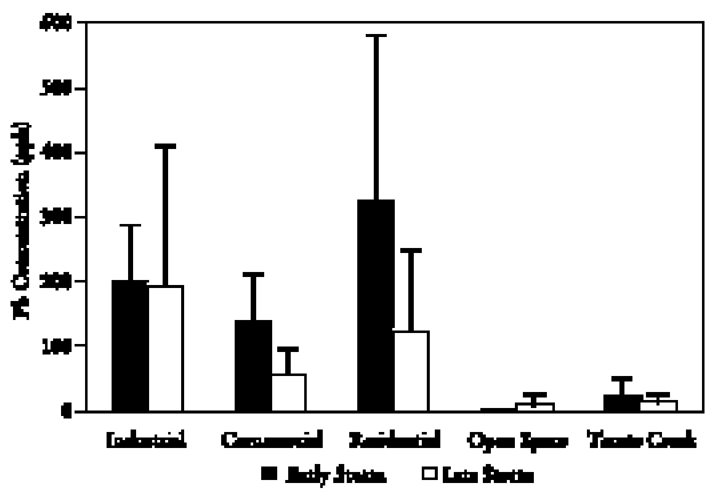


Figure 5: Pb Concentrations for Early- and Late-Storm Events



given in the methodology section. Due to logistical constraints associated with sampling in Mexico, there were no measurements made of stream flow volume when samples were taken.

Mean concentrations (n = 7 for industrial and residential sites, and n = 5 for residential and open-space sites) of total metals for early- and late-storm events are shown in Figures 2 7. Metal concentrations in stormwaters of the Mexican portion of the Tijuana River watershed vary considerably among the following circumstances: during the course of a storm event, from event to event at a given

Figure 6: Ni Concentrations for Early- and Late-Storm Events

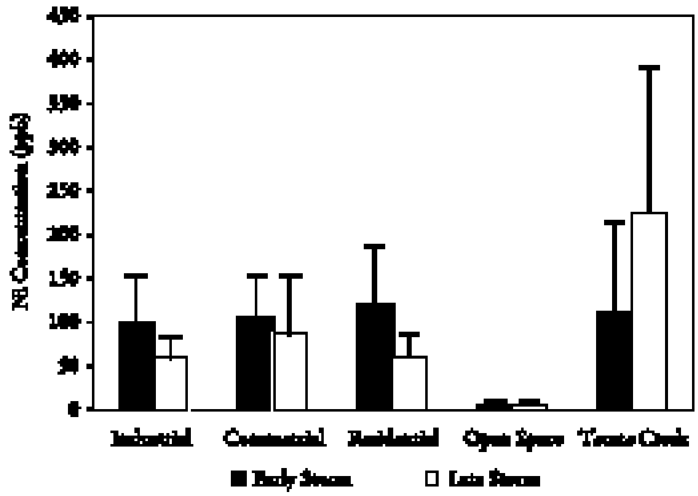
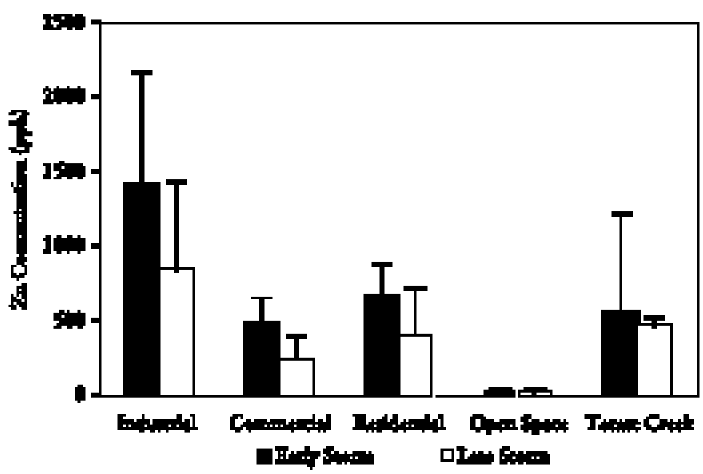


Figure 7: Zn Concentrations for Early- and Late-Storm Events



site, and from site to site depending on land use. Such differences in concentrations are a result of variations in rainfall characteristics, differing watershed features that affect runoff quantity and quality, and variability in urban activities. Generally, the early-storm metal concentrations for the sites in the Tijuana River watershed were higher than the late-storm values, this pattern reflecting what is generally termed the first-flush phenomenon. Levels of Cd, Cr, and Ni found in the residential sites were significantly higher ($p < 0.05$) in early-storm samples as opposed to late-storm samples. Additionally, for the industrial site, levels of Cu in the early-storm samples were significantly higher ($p < 0.05$) than in the late-storm samples. However, due to the relatively small number of samples (and the high variation of metal levels within a given storm event), other temporal differences were not found to be statistically significant.

The term first flush was coined to describe the phenomenon whereby high pollutant concentrations are observed during the initial stages of a runoff event, decreasing as the event progresses. The variation in quality during an event can be explained by relating it to the transport capacity of the runoff flow. The potential capacity to transport pollutants is significantly reduced once the hydrograph peak is reached. The result is that a significant fraction of the mass load of an insoluble pollutant can be removed by a relatively small fraction of the total runoff volume (Griffin et al. 1980). A notable exception to this

Table 1: Toxic Heavy Metal Concentrations (mg/L) for Nationwide Urban Runoff Program and Tijuana River Watershed

Land Use	NURP*			Tijuana River		
	Total Cu	Total Pb	Total Zn	Total Cu	Total Pb	Total Zn
Industrial	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.150
Residential	[illegible]	[illegible]	[illegible]	[illegible]	0.231	[illegible]
Commercial	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Open Space	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

*NURP values are 90th percentile event mean concentrations (U.S. EPA 1983).

first-flush pattern was observed for Tecate Creek, where total levels of Cd, Cu, Cr, and Ni in our late-storm samples were higher than for the early-storm samples. For Ni, the late-storm sample on Tecate Creek showed the highest value (226 ppb) among all of the sites (Figure 6). The presence of continuously elevated levels of these toxic heavy metals in Tecate Creek, a major tributary of the Tijuana River, is surprising due to the rather undeveloped nature of the watershed, but is probably due to the point source discharge from the Tecate Municipal Wastewater Treatment Plant just upstream of our sampling point. This fact, coupled with our finding of rather continuous loading of metals at this site (with no observable first-flush effect) suggests that Tecate Creek is a significant contributor to metal loading in the Lower Tijuana River watershed and estuary. In addition, the site on Tecate Creek consistently showed the highest level of total dissolved solids (TDS) among all of the sites tested, with a mean TDS concentration of 1300 mg/L as compared to 782 mg/L, 752 mg/L, and 297 mg/L for open-space, residential, and industrial sites, respectively. Unfortunately, major anions and cations were not measured in this study.

To the best of our knowledge, the present study represents the first time that data have been published on the quality of stormwaters in the Mexican portion of the Tijuana River watershed. The EPA s Nationwide Urban Runoff Program (NURP) identified toxic metals as the most prevalent priority pollutants found in urban runoff in the United States (U.S. EPA 1983). The toxic metals lead, copper, and zinc were identified in 91% of the samples. Other inorganic pollutants detected were arsenic, chromium, cadmium, and nickel (U.S. EPA 1983). For the toxic heavy metals Pb, Zn, and Cu, the 90th percentile concentrations of the NURP data for specific land-use categories are shown in Table 1.

The mean levels of each metal for each land use in the TijuanaRiver watershed, obtained by averaging the early- and late-storm values for all of the rain events, are also shown in Table 1. While storm event sampling is not entirely equivalent to the event mean concentrations (EMC) given by the NURP data, it does provide a useful benchmark for comparison purposes. When mean values for our early-storm and late-storm events (Table 1) are compared to the 90th percentile NURP values, there was a general agreement (within a factor of 2.5) among all land uses except open space.

Comparing metal levels between land-use types, the industrial land-use site showed the highest level for Zn only, with a mean level

Table 2: Percentage of Total Metals in Stormwater Runoff
Associated with Filterable Particulate Matter

Metal	Industrial		Commercial		Residential		Open Space	
	Early	Late	Early	Late	Early	Late	Early	Late
Cadmium	47.9	71.1	43.1	55.9	[illegible]	[illegible]	[illegible]	[illegible]
Chromium	95.9	94.2	[illegible]	[illegible]	95.8	95.1	91.1	94.0
Copper	73.5	64.1	69.9	57.7	88.5	63.5	[illegible]	96.9
Lead	85.9	81.3	82.5	82.6	95.7	96.4	39.6	98.3
Nickel	86.3	81.6	[illegible]	[illegible]	67.5	91.4	51.2	76.8
Zinc	81.6	73.9	82.5	88.6	84.4	89.2	42.7	67.9

of 1150 ppb. Zn levels at the industrial site were significantly higher ($p < 0.05$) than at any of the other sites tested. However, for Cr, Cu, and Pb, the residential land use showed the highest levels, with mean levels of 73 ppb, 101 ppb, and 231 ppb, respectively. This is somewhat surprising since there are a number of electronics firms at the industrial site that might be expected to be significant sources of metals such as copper. When metal levels were statistically compared among the land-use sites, only open space was significantly different ($p < 0.05$) from all other land-use sites, for all metals tested. For the open-space sites, the levels of Pb and Zn in the Tijuana River watershed were less than 5% (< 10% for Cu) of the 90th percentile NURP values. The reason for this significant discrepancy is unknown, but it does suggest that the relative contribution to the loading of metals from the nonurbanized area of Tijuana is probably even less than one might surmise from NURP data alone.

In order to lend additional perspective to the data, in an attempt to assess the degree to which the lack of an industrial pretreatment program in Mexico influences the quality of stormwaters, we can compare these data to that of Line et al. (1997), which measured the water quality of first-flush runoff from 20 industrial sites in the United States. These authors found mean levels of Pb, Zn, and Cu were 82 ppb, 593 ppb, and 116 ppb, respectively. Corresponding levels of these same metals in our early-storm runoff samples for the industrial land-use site in Mexico were 199 ppb, 1412 ppb, and 129 ppb, and all were in the 80th percentile (or above) of the U.S. industrial runoff dataset.

Table 2 shows the percent of heavy metals associated with the filterable particulate fraction of the stormwater runoff for industrial, urban, and open-space land uses. It can be seen that the values for the particulate-associated fraction are rather high for all the metals at most of the sites. Only at the open-space site does the percentage of particulate-associated metals fall below 50% for Pb and Zn. For Cd, the early-storm value for the commercial land use is also below 50%. The high percentage of particulate-associated metals implies that management strategies that involve erosion control in the upper watershed may also function to reduce metal contamination of the downstream estuary.

Placchi (1998) measured metal levels under base flow conditions during dry weather from 30 April 1997 through 25 June 1997 in the Upper Tijuana River watershed. The open-space and industrial sites investigated in Placchi s study were identical to the wet-weather sampling sites of the present study. Placchi found concentrations of Cu, Pb, and Zn were 0.015 mg/L, 0.009 mg/L, and 0.082 mg/L, respectively, at the open-space sites during base flow conditions. In contrast, our wet-weather values (Table 1) were markedly lower, particularly for Cu (0.004 mg/L) and Zn (0.016 mg/L). This pattern was attributed to rather constant, low-level sources of these pollutants in these subbasins, which were then diluted by runoff during rain events. A similar pattern was shown by Cu at the industrial site, where the concentration during dry weather flow was 50% higher than during a rain event. However, at the same site, both Pb and Zn levels were significantly elevated for wet-weather as opposed to dry-weather flows (30-fold for Pb and 7-fold for Zn).

Figure 8: Storm Event, 7 8 December 1997

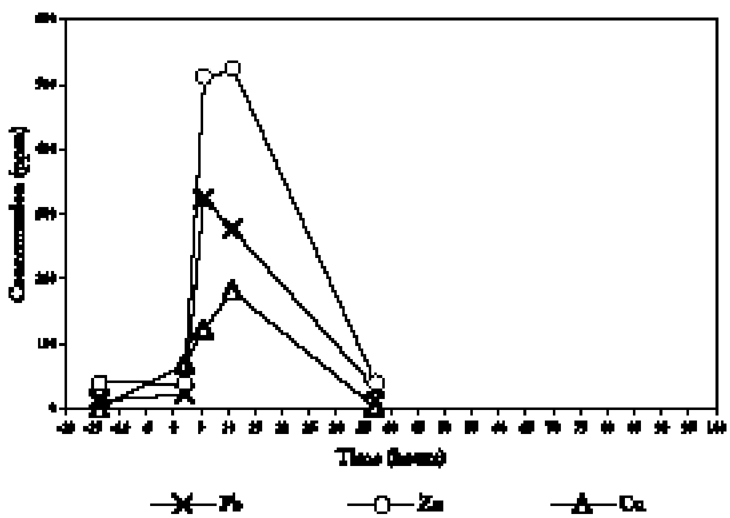


Figure 9: Storm Event, 24 27 March 1998

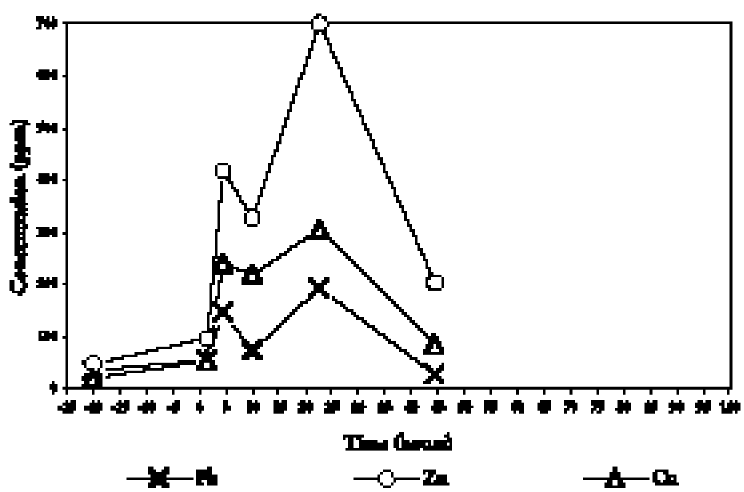
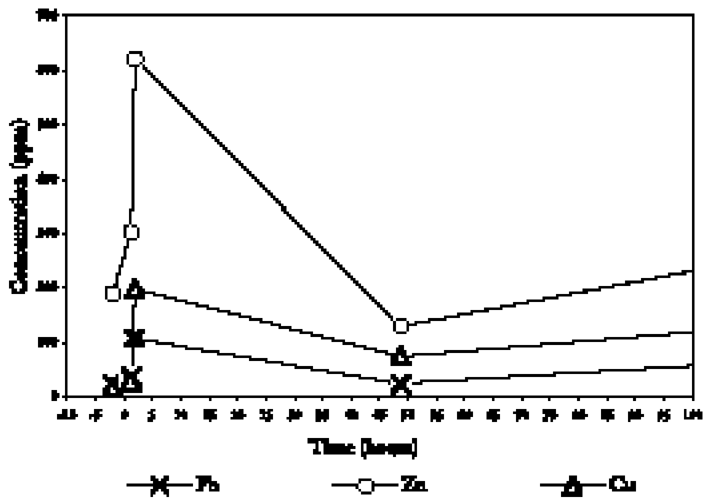


Figure 10: Storm Event, 11 15 April 1998



In order to estimate metal loadings to the downstream estuary, a land-use runoff model was developed using a GIS database for the Tijuana River watershed, coupled with an empirical runoff model. Several assumptions were made for this modeling effort. First, since water quality data were only available for four land-use classifications in the Mexican portion of the watershed, the land-use database was reclassified with all land-use types (and areas) being assigned to either open-space, residential, commercial, or industrial designations. Second, since annual precipitation was not available for the Mexican portion of the watershed, we used the annual precipitation values for Lindbergh Field in San Diego for our regional estimate. Third, since much of the runoff in the Tijuana River watershed is impounded by reservoirs, only four subbasins were considered as contributing to the downstream flow of the estuary. These subbasins are the R o Tijuana (24,708 ha, encompassing much of the urban city of Tijuana), Lower Cottonwood Creek (35,147 ha), Campo Creek (43,159 ha), and El Florido (28,343 ha). Using land-use specific runoff coefficients (Driscoll et al. 1990), we could then calculate the volume of runoff from each land-use area of each of these four subbasins, which, when multiplied by our mean land-use-specific metal concentration, yielded an estimate of the metal loading from the watershed on an annual basis.

The results of this analysis for the two years from October 1996 through May 1998 (mean annual precipitation of 30.1 cm) yields modeled values for annual metal loading of 6,660 kg/yr for Pb, 3,140 kg/yr for Cu, and 22,740 kg/yr for Zn. From September 1986 through August 1988 (mean annual precipitation of 39.6 cm) the Southern California Coastal Water Research Project measured the metal loading from the Tijuana River (SCCWRP 1992). They found that annual loads of Pb, Cu, and Zn were 24,867 kg/yr, 10,468 kg/yr, and 28,964 kg/yr, respectively. Comparison of our modeled estimates with their measured data shows that while both estimates of annual loading for Zn are relatively similar (within about 20%), in the case of Pb and Cu our model underpredicts SCCWRP s measured loading values by nearly 70%. For Pb, this discrepancy may be rather easily explained by the phase-out of leaded gasoline that occurred in the United States in the early 1980s and was subsequently initiated in Mexico in 1991. Apparently, concentrations of Pb in runoff have declined markedly since the late 1980s when SCCWRP did their study. Indeed, the mean Pb levels for all of the urban land uses that we investigated were in the range of 0.98 0.231 mg/L, while SCCWRP s flow-weighted mean lead concentration was 0.988 mg/L for the Tijuana River.

In order to assess the nature of the temporal variations in water quality, sampling was conducted at Dairy Mart Road during three storm events: 7 8 December 1997, 24 27 March 1998, and 11 15 April 1998. This process determined how the levels of total metals varied as a function of flow throughout the storm events. Figures 8 10 show the pattern of change throughout the three storm events for Pb, Zn, and Cu. For all the metals tested, there is a pronounced first-flush phenomenon (paralleling what we observed at most of the individual land-use sites), with metal levels typically increasing markedly (compared to base flow level) after the onset of the rain event to some peak level, and then decreasing thereafter to near the original baseline level.

Since the Tijuana River watershed is a semiarid environment, it is useful to compare our results to those of similar coastal chaparral basins of Southern California. A study on water quality under wet-weather conditions at three sites in Ballona Creek (which drains into Santa Monica Bay) showed that the 90th percentile values for Pb, Zn, and Cu were 1,329 ppb, 2,055 ppb, and 247 ppb, respectively (Stenstrom and Strecker 1993). With a minor exception (Cu during storm two), these values for Ballona Creek were higher than levels we measured for the Tijuana River. The fact that these values for an urban environment in coastal Los Angeles County generally exceeded those for our sites in the Tijuana River watershed suggests that stormwater contamination is ubiquitous in urban environments, even where industrial pretreatment and stormwater permitting regulations are in place.

CONCLUSIONS

This study represents the first published data on the quality of stormwater in the Mexican portion of the Tijuana River watershed. Results show that levels of Cu, Pb, and Zn at both industrial and urban land-use sites in the Tijuana watershed were generally comparable to the 90th percentile NURP values. Levels in the main Tijuana River were not significantly elevated above those in urban wet-weather flows in Ballona Creek in Los Angeles County. The data document the effect of the discharge from the Tecate Municipal Wastewater Treatment Plant on metal levels in Tecate Creek, and suggest that this major tributary to the Tijuana River is a significant source of pollutants in the watershed. Nonpoint source pollution arising from a variety of land uses in the watershed will continue to contaminate the Tijuana Estuary and near-shore coastal ocean during wet weather and, therefore, highlights the need for comprehensive wastewater and stormwater management in the urbanized portions of the watershed.

ACKNOWLEDGEMENTS

This study was funded by the Southwest Center for Environmental Research and Policy under Cooperative Agreement No. CX 824924-01-0 with the U.S. Environmental Protection Agency. The authors greatly appreciate the help of Paul Ganster, Richard Wright, and Walter Hayhow.

REFERENCES

American Public Health Association (APHA), American Water Works Association (AWWA), and Water Pollution Control Federation (WPCF). 1989. Standard methods for the examination of water and wastewater, 17th ed. New York: Prepared and published jointly by the APHA, AWWA, and WPCF.

Driscoll, Eugene D., Phillip E. Shelley, and Eric W. Strecker. 1990. Analytical investigation and research report. Vol 3, Pollutant loadings and impacts from highway stormwater runoff. Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Griffin, D. Morris Jr., Clifford Randall, and Thomas J. Grizzard. 1980.