MONITORING AND MODELING OF WATER QUALITY IN THE TIJUANA RIVER WATERSHED (Project WQ PP96II-10)

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INTRODUCTION

The Tijuana River Watershed (TRW) is a binational watershed on the westernmost portion of the US - Mexico border, encompassing much of the City of Tijuana in Mexico and portions of the City and County of San Diego in the US (Figure 1). The basin contains three surface water reservoirs, various flood control works, and a National Estuarine Sanctuary which is home to several endangered species and is protected by the US federal government. 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 intensive industrial development associated with the maquiladora (in-bond manufacturing and assembly plants) program in Mexico. Unfortunately, due to many factors, an industrial pretreatment program similar to one implemented in the United States, has not been initiated in Mexico. Moreover, in Mexico there is no program equivalent to the U.S. EPA's National Pollutant Discharge Elimination System (NPDES) stormwater permitting program, so the threat of chemical contamination of the Tijuana Estuary is pronounced. Additionally, inadequate infrastructure for the collection, treatment, and disposal of sewage originating in Tijuana has long plagued the watershed, as wastewater flows have chronically outpaced the ability of the infrastructure to handle them. These elements yield transboundary and cross-cultural water quality management challenges.

Although discharges from the Tijuana River 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 PCB,s among the eight largest creeks and rivers in Southern California (SCCWRP, 1992). Using flow weighted mean concentrations, SCCRWP (1992) estimated that the mass emission of metals from the Tijuana River for the year 1987-1988 was 7,385 kg for Cr, 16,706 kg for Cu, 39,684 kg for Pb, 46,221 kg for Zn, and 205 kg for Cd. Obviously, significant loading of these toxic heavy metals to the Tijuana Estuary is occurring. To date, however, there has been no data published on the quality of urban stormwater in Mexico.

The purpose of this study was to determine the concentration of heavy metals and fecal indicator bacteria in stormwater associated with a variety of land uses in the Tijuana River Watershed. This research was the initial phase of a larger effort to use GIS-based modeling in a predictive fashion to estimate mass loading of stormwater pollutants to the Estuary under a variety of border development scenarios.

METHODOLOGY

Seven sites were sampled in the Tijuana River watershed; two in the US (Campo Creek and Cottonwood Creek), and the remaining sites in Mexico. The specific geographical coordinates for these sites were determined with a global positioning system (GPS) receiver, and were then incorporated into a geographical information system (GIS) for further analysis. The locations of these sites in the watershed are shown in Figure 2 and described below:

Rural

The Campo Creek in the US is just upstream of the city of Tecate, Mexico. This reach of the river runs through a relatively undeveloped and sparsely populated rural area of predominantly agricultural usage and flows into Tecate Creek, a main tributary of the Tijuana River.

Urban

This is a recently urbanized site in a canyon (Cañón del Zaines) that drains a fairly large residential area of southwestern Tijuana, then empties into the Rio de las Palmas branch of the Tijuana river. This site lies approximately 1 mile from the river and 3 miles downstream from La Presa Rodriquez , a reservoir from which Tijuana obtains part of its drinking water supply.

Industrial

This site lies at the foot of Otay Mesa, and drains a basin that contains one of the largest maquiladora park in Tijuana. Maquiladora plants are foreign-owned facilities that initially used lower priced Mexican labor to assemble goods from imported components, but presently the North American Free Trade Agreement (NAFTA) has allowed many of these plants to be full-scale production facilities.

Cottonwood Creek

This site is located directly under the State Highway 94 bridge that runs over the Cottonwood Creek branch of the river. It lies in a small sub-valley of the river that is mostly undeveloped, with limited agricultural activities, yet is proximal to a small mobile home park. We have selected this as a more representative site for our undeveloped sub-basin.

Cañon del Padre Bridge

This site also lies on this stem of the river, approximately 20 miles downstream from selected as an undeveloped site and to explore the hypothesis that the waste assimilative capacity of the upstream reach of the river may improve water quality at this site. Tecate and just above the eastern edge of the urban area of Tijuana. Considerable controversy exists as to whether water quality degradation on this reach of the river is caused by wastewater flows from Tijuana, Tecate, or both. By examining the assimilative capacity of the river, we will provide insight into this controversy. Schlage/Ingersoll Rand industrial site in Tecate

This site sits on a very small arroyo that drains the Ingersoll Rand industrial complex in southwestern Tecate. Runoff in this arroyo flows directly from the site into the main channel of the Rio Tecate . The arroyo experiences intermittent and low flows except during heavy rain events when it flows freely; hence, this site yields stormwater runoff that is representative of wet weather industrial runoff.

Tecate Creek

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 1 mile downstream from the Tecate Municipal Wastewater Treatment Plant.

CHEMICAL AND BIOLOGICAL ANALYSES

Three storm events during the 1996-1997 rainy season were sampled. Sampling dates were November 21-23, 1996, January 15-17, 1997, and March 10-12, 1997. Precipitation at La Presa Rodriguez reservoir (in the southern part of the city of Tijuana) was 12.0 mm, 11.4 mm, and <2.5 mm, respectively for the three storm events. The lack of measurable precipitation for the last event, does not imply that there was no rainfall in other parts of the watershed. Indeed, in this latter storm precipitation was observed (and runoff was sampled) at our sampling sites in the urban part of Tijuana and in the US portion of the watershed.

Samples were taken as surface water grab samples twice during each storm event- once within the first 2-4 hours of the storm's inception (referred to as early -storm samples), and once again at an interval of 24-36 hours after the first sample was taken (referred to as late-storm). During the March 10-12, 1997 rain event, late-storm runoff at the industrial and urban sites in Tijuana was very low and precluded sampling.

All samples were handled, preserved, and analyzed according to Standard Methods (AWWA, APHA, WEF, 1989). Stormwater samples were filtered (for dissolved metal analysis), and the filter than digested for total metal analysis (total = particulate metal plus dissolved metal. Both particulate and dissolved metal concentrations were analyzed by graphite furnace atomic absorption (GFAA) using a Perkin-Elmer SIMAA 6000 AA 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. 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).

Total coliform and fecal coliform bacteria were determined for stormwater samples using the Most Probable Number (MPN) procedure given in Standard Methods (AWWA, APHA, WEF, 1989). Enterococci was determined using a membrane filter (MF) procedure using ME agar and EI (esculin iron) agar as per Standard Methods (AWWA, APHA, WEF, 1989). Nutrients in stormwater were analyzed by colorimetry , using the phenate method for ammonia, the cadmium reduction and diazotization method for nitrate, and the ascorbic acid method for phosphorus (Standard Methods, 1989).

DETERMINATION OF LAND USE TYPES WITHIN EACH CONTRIBUTING SUB-BASIN

To delineate which land use types were present within the sub-basins upstream from our points of sampling, we used modeling algorithms in our GIS software, a digital elevation model (DEM), and the locational data for the sampling sites to generate boundaries of the sub-basins. Specifically, we used the GRID module of the Arc/Info GIS 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. We then placed each sampling point's location exactly on the stream network and ran a further series of algorithms that incorporated the accumulation data to generate the specific boundaries of the contributing sub-basins above each of the sample points. These sub-basin boundaries were then overlayed with land use data for the larger watershed to determine the composition of the land use within each sub-basin.

RESULTS

Table 1 shows the type and percentage of each land use type within each sub-basin sampled. The industrial site drains a rather small sub-basin (Otay Mesa) which is almost entirely developed (98.5%) with maqiladoras, these industrial facilities comprised mostly of assembly and manufacturing plants. The urban site is in the southern part of the City of Tijuana and drains a basin that is presently 63% undeveloped, but is subject to increasing urbanization as the city expands. The two major categories of developed land uses at this site are disturbed/ under construction and residential, comprising 14% and 11%, respectively of the total land area. The rural site at Campo Creek (which drains into Tecate Creek) lies in the United States, just above the city of Tecate, Mexico,. This sub-basin is in a rural area, which is 88%

non-developed. The two major land use categories are agriculture and dispersed residential, comprising 6.5% and 3.1%, respectively of the total land area. Tecate Creek site is a major tributary of the Tijuana River. It drains a very large sub-basin of 39,660 hectares, which is 81.5% non-developed. The two major land use categories are agriculture and residential, comprising 9.5% and 3.8%, respectively of the total land area of this sub-basin. It is important to underscore the fact that although this sub-basin is predominantly undeveloped, Tecate Creek receives the effluent discharge from both the city of Tecate Municipal Sewage Treatment Plant and the Tecate Brewery, both located just a few miles upstream of our sampling point.

Figures 3-8 show the mean total metal levels for each metal analyzed for three storm events for each of four land use designations, including industrial, urban, rural, and the mixed-use subbasin of Tecate Creek. For the metals Cr, Cu, and Zn, the industrial land use showed the highest early-storm metal concentrations, with mean values of 102 ppb for Cd, 158 ppb for Cu, and 1,473 ppb for Zn. In the case of Pb, however, the urban land use showed the highest level, with a mean level of 372 ppb.

Table 2 shows the percent of heavy metals associated with the filterable particulate fraction of the stormwater runoff for industrial, urban, and undeveloped (rural) landuses. It can be seen that the values for the particulate-associated fraction are rather high for all the metals at most of the sites. Indeed, for both early and late-storm samples, the values are greater than 50% for all the metals at the industrial and urban sites. Only at the rural site, do the percentage of particulate-associated metals fall below 50%, for Ni, Pb, and Zn. The high percentage of particulate-associated metals implies that strategies, which involve erosion control in the upper watershed, may reduce metal contamination of the downstream estuary.

Figures 9-11 show the mean bacterial indicator levels (including total and fecal coliforms and enterococci) for the three storm events sampled for each land use category. Levels of the indicators at Tecate Creek were as high as those found in raw sewage in the U.S. , with densities of 10^7-10^8 MPN/100ml for TC and FC and 10^6-10^7 MPN/100ml for enterococci. The next highest levels measured were for the urban land use site, but even the industrial site showed elevated densities as compared to the rural site on Campo Creek..

Figures 12-13 show the level of the inorganic nutrients, ammonia-N, nitrate-N+ nitrite- N, and phosphate-P at the four sites for the early and late-storm events, respectively. Levels of ammonia-N are relatively low at all of the sites, but levels of nitrate-N+nitrite-N are elevated particularly for the early storm events at both the industrial and urban sites. For phosphate-P, the levels at all sites except the rural (mostly undeveloped) site are elevated.

DISCUSSION

Metal concentrations in stormwaters of the Mexican portion of the Tijuana River watershed vary considerably, both during the course of a storm event, from event to event at a given site, and from site to site depending on land use (Figs. 3-8). Such variability is 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 our sites in the Tijuana River watershed were higher than the late storm values, this pattern reflecting what is generally termed the "first-flush" phenomenon. A notable exception to this pattern was observed for Tecate Creek, where total levels of Cd, Cu, Cr, Ni in our late-storm samples were higher than for the early storm samples.

For Ni, the site on Tecate Creek showed the highest value (226 ppb) among all of the sites. At this site, water quality standards for freshwaters promulgated by the U.S. EPA for toxic pollutants were exceeded for Cu, Pb (criterion continuous concentration only) and for Zn. The presence of elevated levels of these toxic heavy metals in Tecate Creek, a major tributary to the Tijuana River, is surprising due to the rather undeveloped nature of the watershed (Table 1), but is probably due to the point source discharge from the Municipal Treatment Plant of Tecate just upstream of our sampling point. This fact, coupled with our finding of rather continuous loading of metals (with no observable first-flush effect) at this site, suggests that Tecate Creek is a significant contributor to metal loading in the lower Tijuana River Watershed and Estuary.

To the best of our knowledge, the present study represents the first time data has been published on the quality of stormwaters in the Mexican portion of the Tijuana River watershed. The U.S. EPA's National Urban Runoff Program (NURP)(U.S. EPA , 1992) identified toxic metals as the most prevalent priority pollutants found in urban runoff in the U.S.. 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, 1992). For the toxic heavy metals lead (Pb), zinc (Zn), and copper (Cu), the 90^{th} percentile concentrations were 465 ppb for lead, 540 ppb for Zn, and 120 ppb for Cu. While our storm event sampling was not entirely equivalent to the event mean concentrations (EMC) given by the NURP data, they do provide a useful benchmark for comparison purposes. Using average values for our early-storm and late-storm events, total metal concentrations for the industrial land use site in the Tijuana watershed for Cu and Zn (128 ppb and 1353 ppb, respectively) exceeded both of the 90^{th} percentile NURP values, while the urban site exceeded the same NURP value for zinc only (620 ppb).

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 our data to that of Line et al. (1997) who measured the water quality of first flush runoff from 20 industrial sites in the U.S. These authors found mean levels of Pb, Zn, and

Cu were 82 ppb, 593 ppb, and 116 ppb, respectively. The levels of these same metals in our early-storm runoff samples for our industrial land use site in Mexico fell in the 80^{th} percentile range of this U.S industrial runoff dataset

Since the Tijuana River watershed is a semi-arid 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 (tributary to Santa Monica Bay) showed that the 90 percentile values for Pb, Zn and Cu were 1329 ppb, 2055 ppb, and 247 ppb, respectively (Stenstrom and Stecker, 1993). 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 that stormwater contamination is ubiquitous in urban environments, even where industrial pretreatment and stormwater permitting regulations are in place.

Our data clearly showed that the sparsely- developed, rural site (Campo Creek) showed relatively low levels of both heavy metals and bacterial indicators, and indicate that fecal contamination is not necessarily ubiquitous in the watershed, but is associated with development and human habitation. It is also of interest to note, that for these fecal indicators, no significant first-flush effect seems to exist, as the late- storm indicator densities are often as high or higher than are the early storm values (Figs. 9-11). This suggests a rather continuous contaminant loading source in these sub-basins (e.g sewer overflows and pump station failures). Gersberg et al. (1994) found that dry weather (baseline) flows in the Tijuana River were generally low and in the same range as indicator levels in dry weather runoff in southern California stormdrains. However, during wet weather, the densities of TC, FC in stormwaters of the Tijuana River generally exceeded the levels in surface runoff in an urban portion of the Santa Monica Bay watershed in southern California (Stenstrom and Stecker, 1993) by one to two orders of magnitude, this most probably due to the inadequate sewage collection infrastructure in the City of Tijuana

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 copper and zinc at both industrial and urban land use sites in the Tijuana watershed exceeded the 90^{th} percentile NURP values, but levels were not significantly elevated above those in urban wet weather flows in Los Angeles County. Our data document the effect of the discharge from the Tecate Municipal Treatment Plant on both metal and fecal indicator levels in Tecate Creek, and suggests that this major tributary to the Tijuana River is a significant source of pollutants to 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.

CREDITS

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Table 1- Area of major land uses and percent of total area (in parentheses) for each of the sub-basins sampled in the Tijuana River watershed.

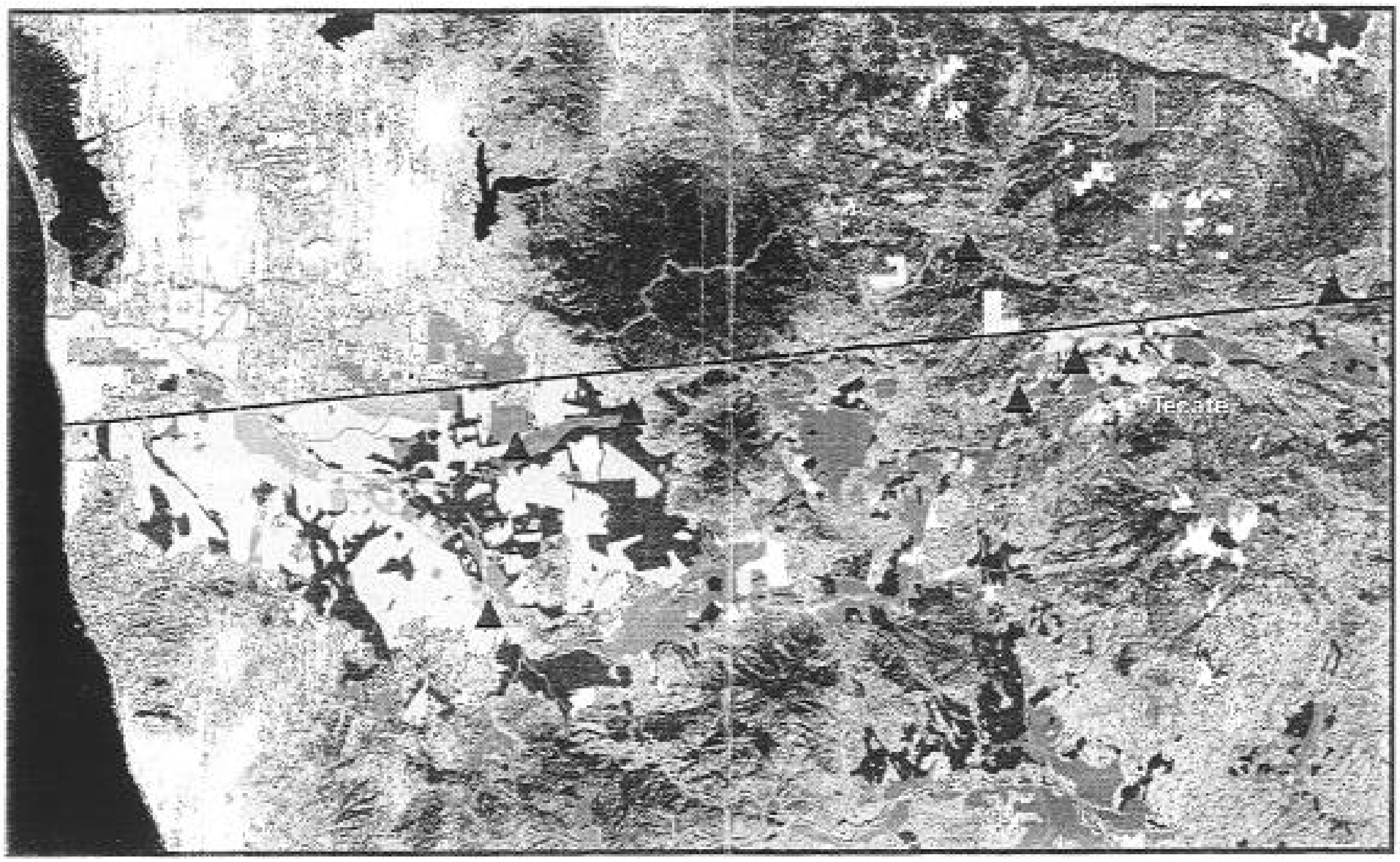
Site name and total basin area in hectares (ha)	Rural site Campo Creek (21810.6 ha)	Industrial Site Otay Mesa (101.3 ha)	Tecate Creek Site (39660.9 ha)	Urban Site Cañon del Zaines (1655.3 ha)
hectares industrial	n/a	99.8 (98.5%)	153.2 (0.38%)	n/a
hectares commercial	5.6 (0.03%)	n/a	152.3 (0.38%)	10.9 (0.66%)
hectares residential	665.8 (3.1%)	.05 (0.05%)	1516.5 (3.8%)	187.0 (11.3%)
hectares agricultural	1408.7 (6.5%)	n/a	3775.6 (9.5%)	152.4 (9.2%)
hectares non-developed	19162.9 (87.9%)	.04 (0.04%)	32317.7 (81.5%)	1042.8 (63%)
hectares disturbed/under construction	29.6 (0.14%)	1.4 (1.4%)	858.4 (2.2%)	235.8 (14.2%)

Table 2—Percent of total stormwater runoff of heavy metals associated with filterable particulates

METAL	INDUST. EARLY	INDUST. LATE	URBAN EARLY	URBAN LATE	RURALEARLY	RURAL LATE	MEAN
Cd	61	71	65	73	50	50	62
Cr	91	92	88	85	98	92	91
Cu	65	57	71	52	94	90	72
Ni	76	61	73	57	47	55	62
Pb	67	78	75	88	29	37	62
Zn	80	76	66	51	51	37	60

Urban Land Use and Hydrology in the Tijuana River Watershed

Tijuana / Tecate Region



Land Use and Hydrological Features

- Residential
- Dispersed Residential
- Commercial
- Industrial
- Extractive Industry
- Institutional
- Transportation
- Landfills/Junkyards
- Recreation
- Agriculture
- Water Bodies
- Disturbed/Under Construction
- US-Mexico Border
- Derived Stream Network
- Watershed Boundary
- Sampling Sites

10 0 10 20 30 40

Kilometers

Compilation: C. Placchi, R. Miles, and C. Brown

Scale = 1:1,000,000

Water Quality Sampling Sites
Major Subbasins, Tijuana River Watershed

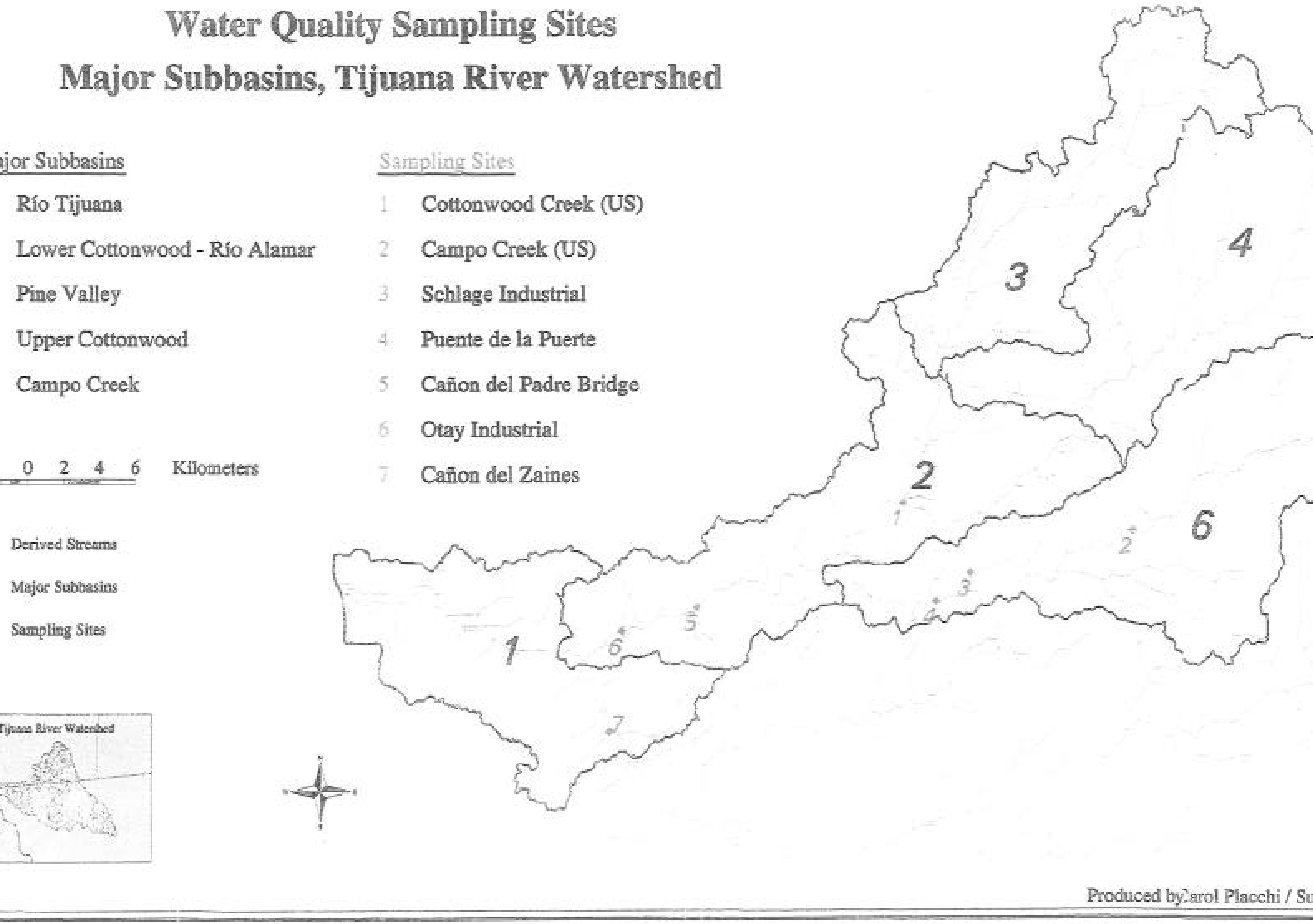
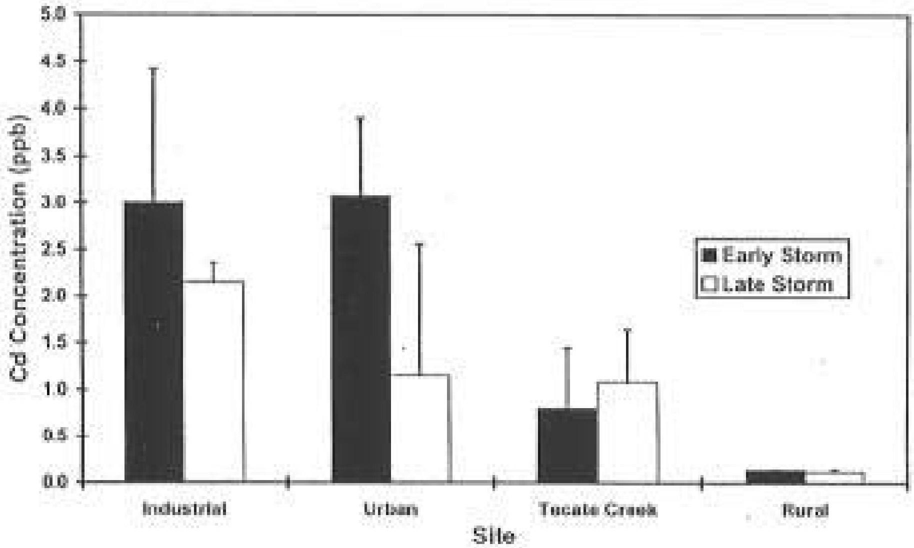


FIGURE 3



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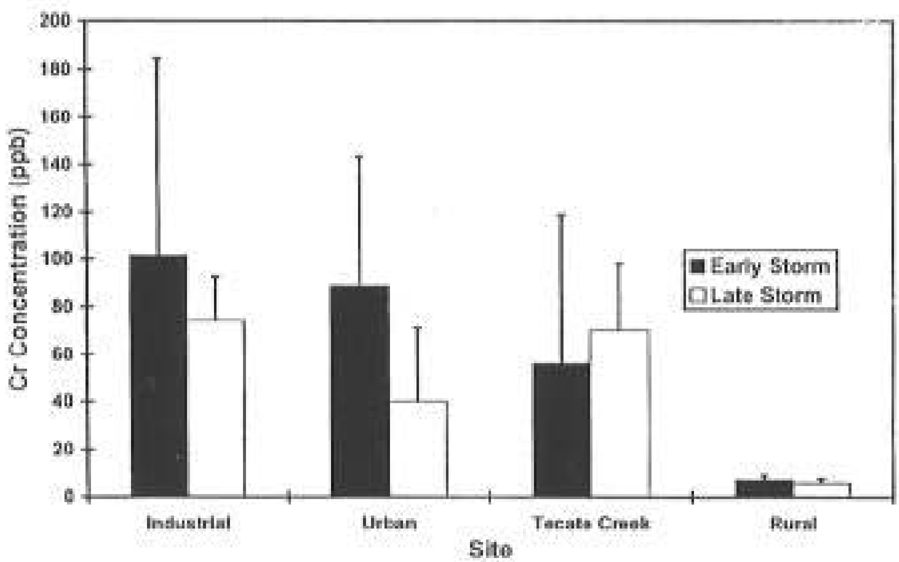

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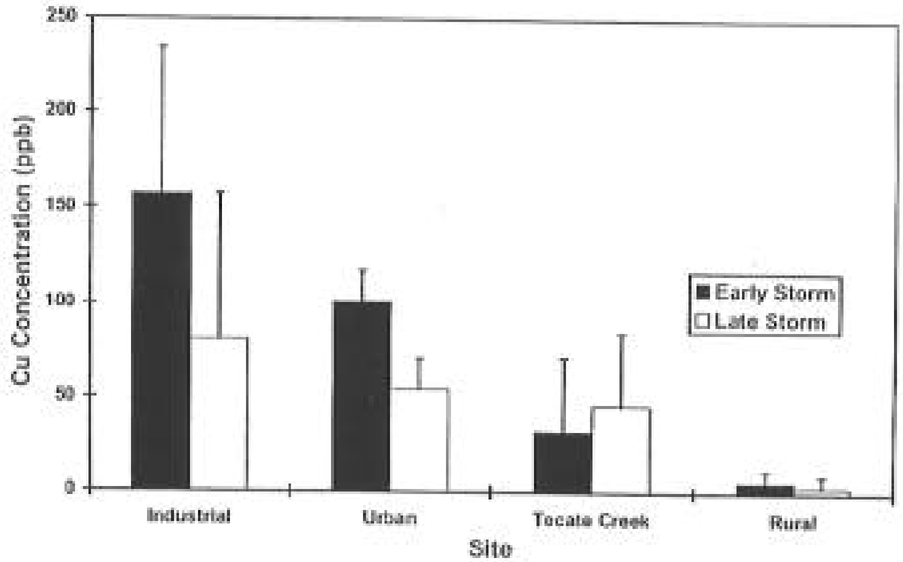
250
200
150
100
50
0
Cu Concentration (ppb)
Early Storm
Late Storm
Industrial
Urban
Tecate Creek
Rural
Site

[illegible]

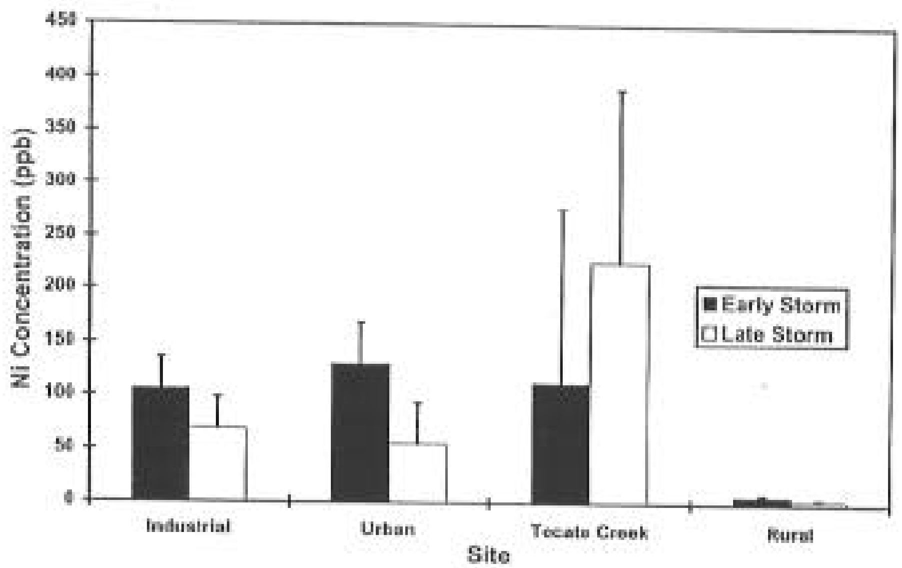
450
400
350
300
250
200
150
100
50
0
Ni Concentration (ppb)
Early Storm
Late Storm
Industrial
Urban
Tecate Creek
Rural
Site

FIGURE 7

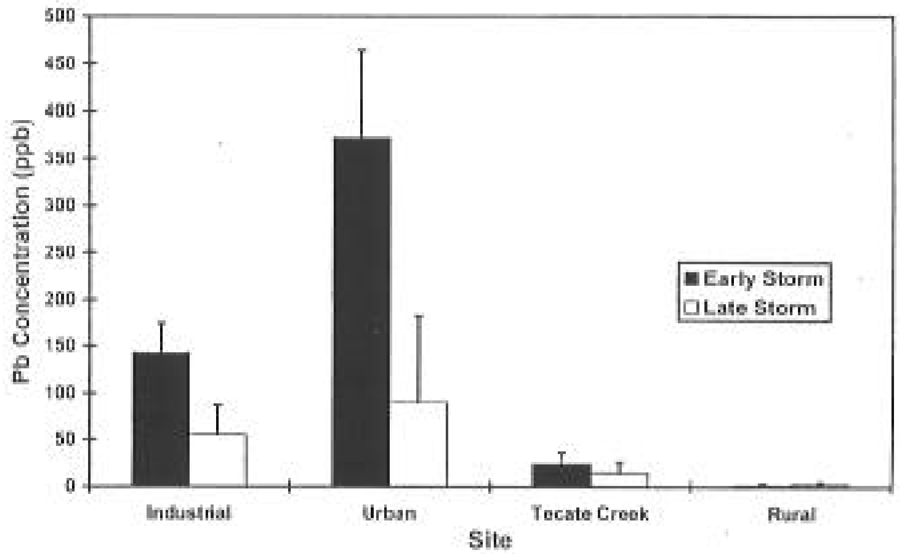

FIGURE 8

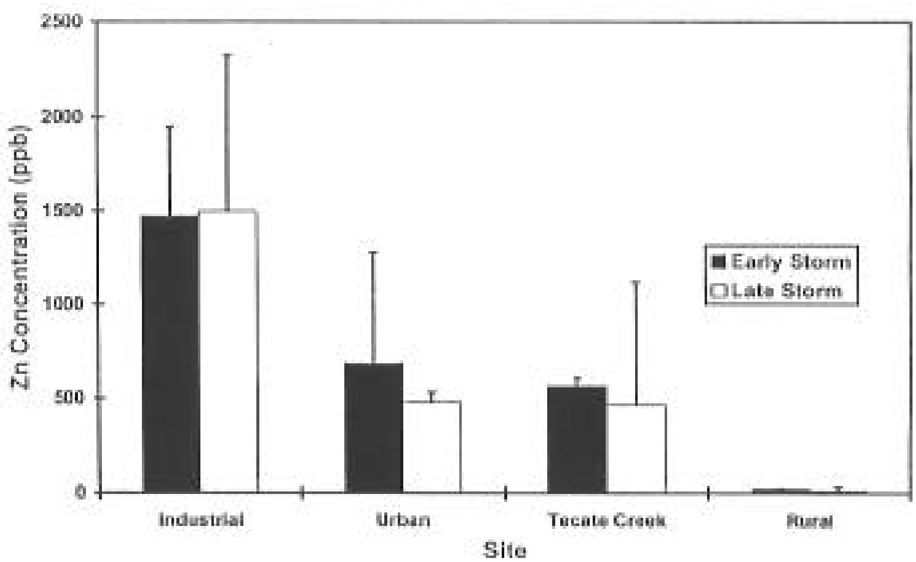

FIGURE 9

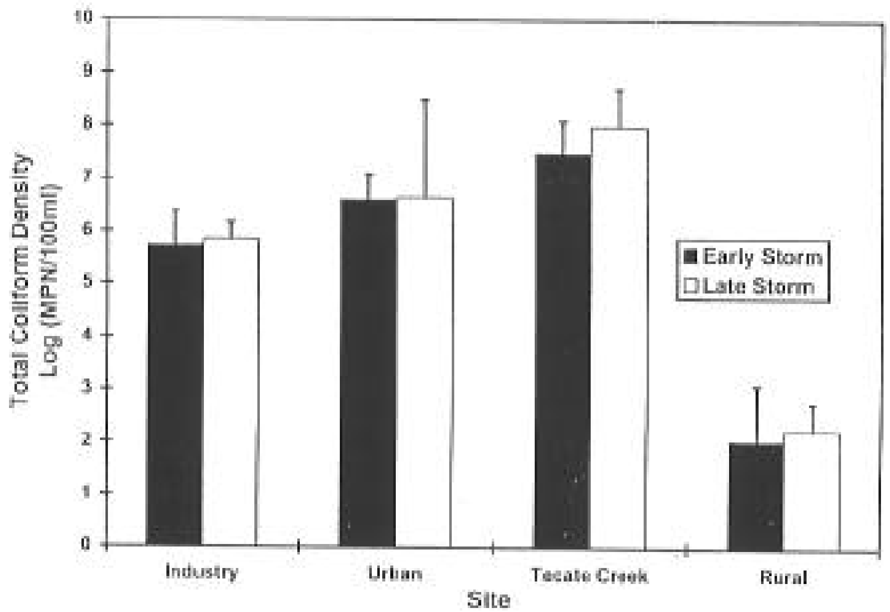

FIGURE 10

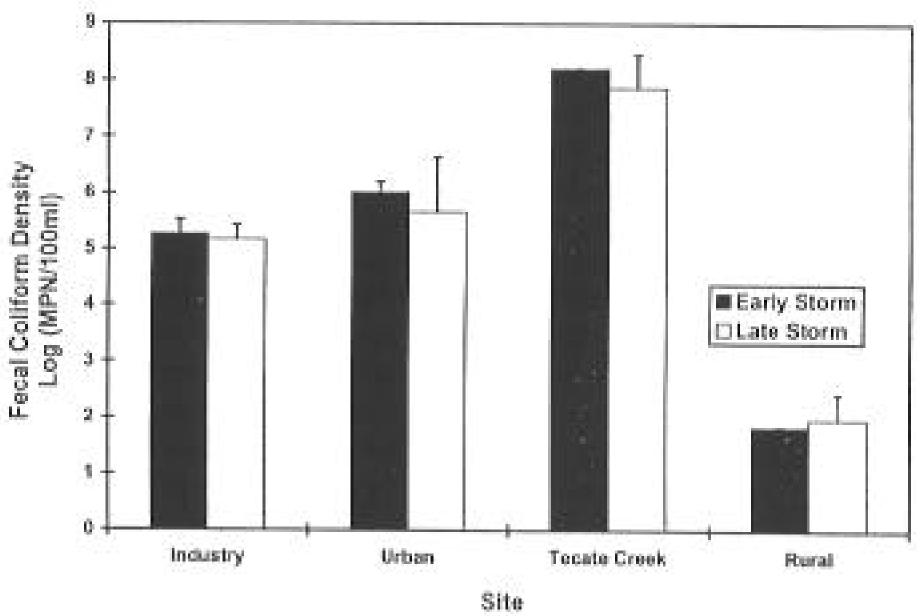

FIGURE 11

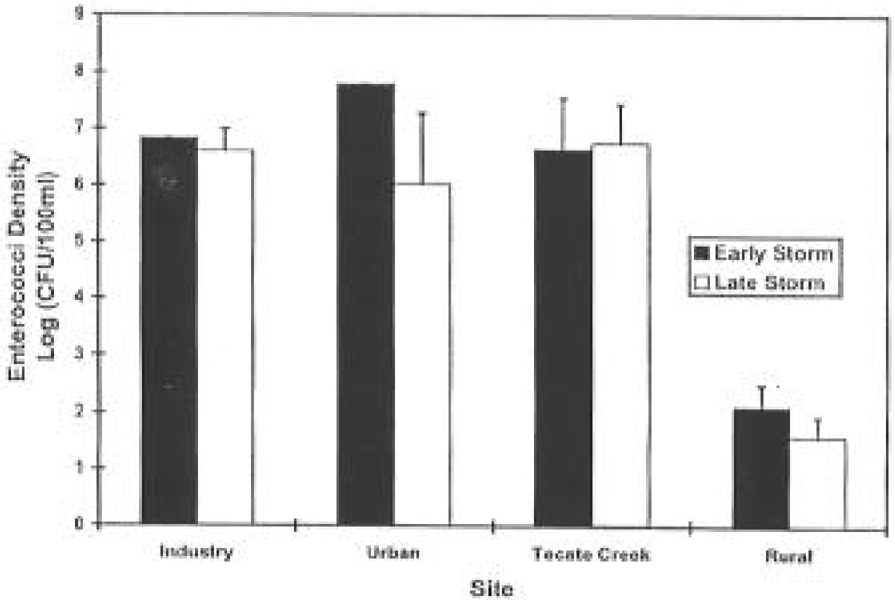

FIGURE 12

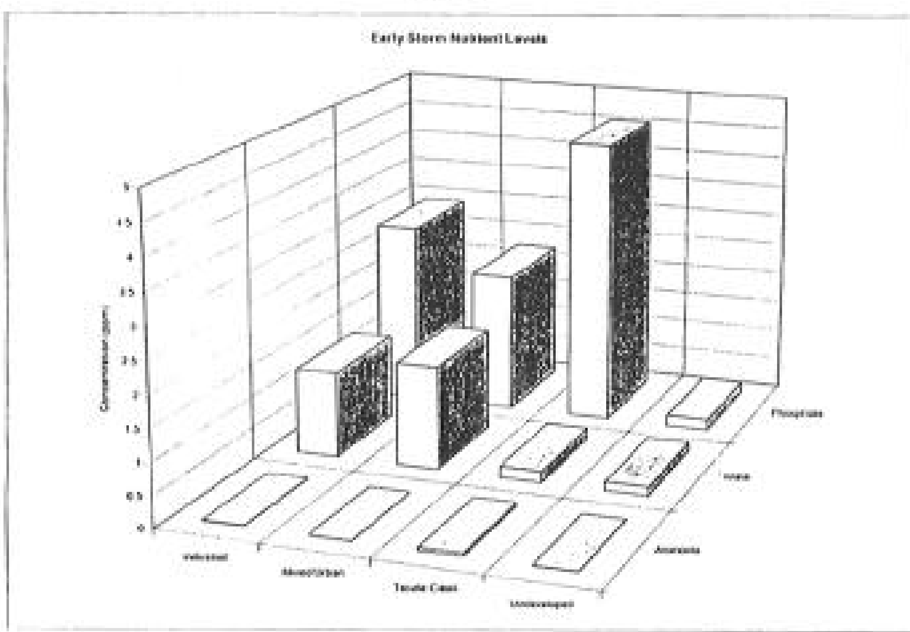

FIGURE 13