PREDICTIVE MODELING OF THE INTERACTIONS BETWEEN LAND USE AND STORM WATER QUALITY IN THE TIJUANA RIVER WATERSHED

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NARRATIVE SUMMARY

INTRODUCTION

The Tijuana River Watershed (TRW) is a binational watershed on the westernmost portion of the United States-Mexican border, encompassing parts of Tijuana, Mexico, and the City and County of San Diego. The basin presents special transboundary and cross-cultural water resource management challenges. Inadequate infrastructure for the collection, treatment, and disposal of wastewater originating in Tijuana has long plagued the region, as wastewater flows have chronically outpaced the ability of infrastructure to handle them. The "fate of topography" places Tijuana at a higher elevation than the rest of the region. Gravity has allowed transboundary surface water pollution to negatively impact the lower reaches of the watershed, posing risks to human and environmental health on both sides of the border.

For decades, raw sewage from the City of Tijuana 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. The *maquiladora* industry, fueled primarily by foreign investment, has grown faster than the capability of the municipality to deliver services to them. Moreover, the lack of pollution prevention measures for industry and other businesses in Tijuana, coupled with a deficiency in proper enforcement of existing regulations, has generated non-point source pollution that contaminates the Tijuana River.

Water quality in the Tijuana River has long been an issue affecting both residents of Tijuana and southwestern San Diego County. As the river flows through the urban areas of Tecate and Tijuana toward the City of Imperial Beach, it acquires large amounts of contaminants, including sewage and industrial wastes. In fact, during dry weather, the flow of the Tijuana River is comprised almost entirely of untreated domestic and industrial wastewater (Public Citizen 1996) causing storm water quality during heavy rain events to have a major impact on regional water quality. Previous research has documented that urban storm water runoff presents a serious risk of both heavy metal and organic contamination of surface waters. The manner by which pollutants can be transported by overland flow from non-point sources to water bodies during storm events depends upon the soils, land cover, land use, and topography of an area. For these reasons, analysis of storm water for heavy metals contamination was the focus of this study in which information was sought about the effects of various land uses on nearby surface waters. Previous studies conducted in the Tijuana River have shown that surface water quality is in jeopardy and poses a health hazard to those coming in contact with it (Lewis and Kaltofen 1991; Conway and Salgado 1990). These studies, however, have focused primarily on the lower reaches of the river that flow through the urban core of Tijuana and across the border into the United States.

RESEARCH OBJECTIVES

1. Generate land use specific water quality data for the Mexican portion of the Tijuana River Watershed, including industrial, residential, commercial, and open land use sites, as well as Tecate Creek. Additionally, compare the water quality at these sites to that in the main Tijuana River during rain events and to storm water quality of similar land use sites in the United States.

2. In light of the rapid increase in industrial development of the Tijuana region over the past decade, an additional objective of the present study was to evaluate the toxicity of both wet and dry weather runoff from the Tijuana River using the standard test organism *Ceriodaphnia*. Toxicity identification evaluations (TIE) were also performed in order to determine the general category of chemicals that caused such toxicity.

3. Employ a GIS-based water quality analysis in order to examine metal loading from the reaches of the Tijuana River that flow through the eastern portion of Tijuana and the urban area of Tecate, as well as less urbanized reaches that lie upstream in the United States. In this study, the author examined the relationships between different configurations of land use/land cover, surface topography, surface water hydrology, precipitation events, and surface water quality. The following questions were then asked:

- How does water quality (i.e., concentrations of specific pollutants) vary spatially across different land uses, precipitation events, and sub-basins in the study area?
- What utility can existing GIS software provide in a binational basin using data with a wide range of quality, scale, and granularity? Specifically, how can these GIS tools aid in delineating contributing sub-basins above the sampling points and integrating land use, topographic, hydrologic, soils, and precipitation data?
- What are storm event loadings of different pollutant parameters across sub-basins with different land use configurations and precipitation levels?

RESEARCH METHODOLOGY/APPROACHES

The sampling program at different sites assessed the quality of runoff associated with a variety of land uses in the Tijuana River Watershed.

OPEN

Two sites, which drained mostly rural and undeveloped sub-basins, were sampled to characterize this land use. The first site, Campo Creek, is located in the United States, upstream from 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. The other site on Cottonwood Creek is located directly under the State Highway 94 bridge and drains a region that is mostly undeveloped, with limited agricultural activities.

RESIDENTIAL

Two sites were sampled to characterize this land use. The first site, Colonia Buena Vista, lies in an arroyo that drains a fairly large residential area of Tijuana near Otay Mesa. Colonia Buena Vista extends along the length of the canal and is comprised of two settlements of low-income families. The second site, located in Cañón del Zaines, is an arroyo that drains a large residential area of southwestern Tijuana and empties into the Río de las Palmas branch of the river.

INDUSTRIAL

This site lies at the foot of Otay Mesa and drains into a basin that contains one of the largest *maquiladora* parks in Tijuana. *Maquiladora* plants are foreign-owned facilities that initially assembled 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.

SCHLAGE INDUSTRIAL

This site lies on a small tributary of the Río de Tecate in western Tecate, Mexico. This site is influenced by a variety of land uses (undeveloped, residential, commercial, agricultural, and industrial). Schlage Lock Maquiladora lies immediately adjacent to this tributary. This company moved to Tecate, Mexico, in 1988 from Rocky Mount, North Carolina, leaving behind a Superfund site (Held 1993).

COMMERCIAL

This site is on a large storm water 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. Díaz Ordaz, Blvd. Benítez, Blvd. Agua Caliente, Paseo de los Héroes, and Calle F.C. Sonora.

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 one mile downstream from the Tecate Municipal Wastewater Treatment Plant.

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. 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 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. Levels of fecal indicator bacteria at both the commercial site (in the City of Tijuana) and the Tecate Creek site were as high as those found in raw sewage, with densities of 10^{7} to 10^{8} most probable number (MPN)/100ml for total coliform (TC) and fecal coliform (FC). The data suggest that non-point source pollution arising from a variety of land uses in the Tijuana River Watershed will continue to enter the Tijuana River Estuary and nearshore ocean during wet weather, arguing for basin-wide wastewater and storm water management in this urban watershed.

In this research, a geographic information system (GIS) was also used to study the interactions of land use and storm water quality in the TRW. Surface water samples were collected during storm events for the last two rainy seasons. These samples were analyzed for a wide range of physical, chemical, and biological parameters (including toxicity), and these data were integrated into the hydrological modeling component of a commercial GIS (Arc/Info). With this modeling component, regional topography, precipitation, soil type, and land use data were incorporated to estimate runoff. Additionally, land use and land cover data were linked with point water quality data to estimate mass loadings of various surface water pollutants within sub-basins of the larger watershed.

Toxicity tests of water samples from the Tijuana River were performed during both dry and wet weather. Grab samples were taken from the Tijuana River at Via San Ysidro approximately 200 yards past the international border at the same location each time along the north bank of the river by submerging a four liter glass amber bottle into the water. Samples were transported in the sealed amber bottles in coolers on ice and promptly stored at 4"C. Two dry weather samples were collected on March 14, 1997, and April 22, 1997, and acute and chronic toxicity tests were carried out. Two wet weather samples were collected on February 28, 1997, and April 2, 1997, and acute and chronic toxicity tests, as well as toxicity identification evaluations were performed on these.

The toxicity test method used in this study was the *Ceriodaphnia dubia* survival and reproduction test. This measures the chronic toxicity of whole effluents and receiving water to *C. dubia*, during a three-brood seven-day static renewal exposure. The methods used for culturing, feeding, and testing are based on the U.S. EPA manual, "Short Methods for Estimating the Chronic Toxicity of Effluents and the Receiving Waters to Freshwater Organisms" (U.S. EPA 1989). Dry weather flows of the Tijuana River had very low toxicity, with values of 1.0 and 1.25 toxicity units (TUs). However, wet weather runoff was extremely toxic with values of four and 10 TUs. Phase I Toxicity Identification Evaluation (TIE) procedures using *C. dubia* indicated that this toxicity was largely due to non-polar organics rather than heavy metals or volatile organics.

RESEARCH FINDINGS

These data also documented 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. Non-point source pollution arising from a variety of land uses in the watershed will continue to contaminate the Tijuana Estuary and nearshore coastal ocean during wet weather and therefore highlights the need for comprehensive wastewater and storm water management in the urbanized portions of the watershed.

CONCLUSIONS

Through the watershed approach that has been pursued in this research, the authors have examined the interaction of land use, topography, soils, and surface water hydrology to model storm water quality variations in sub-basins of the Tijuana River Basin that are currently of considerable regional interest. This research has demonstrated the utility of the approach taken for performing hydrologic modeling in a data poor environment and lent insight into the spatio-temporal variability of storm water quality and pollutant loadings in the study sub-basins.